NORWEGIAN REFUGEE COUNCIL

Rainwater Harvesting for Irrigation and Groundwater Recharge through Ponds and Small Dams

Review Study

Situation Report
April 2021

Water Resource Associates

DOCUMENT CONTROL

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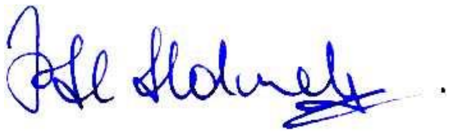
This is Document v7 of the Situation Report
Signed on behalf of Water Resource Associates:



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Cover photographs: flowing wadi Sinjar with mixed livestock and cropping in Mar-2021, karez5, ploughed field, Kwlat sink 2.

Summary

Introduction

Sinjar and Baaj Districts were historically an important farming region of Iraq, but recent conflict resulted in damaged infrastructure, social deprivation and an exodus of people who are now slowly returning to their homes. NRC is implementing a three-year project called Activating Market-based Agricultural Livelihood [AMAL] to help reinstate the vital role that agriculture plays in providing economic security for local communities.

The region is a focus of national and international efforts to bring life back to normal: potential use of water harvesting as a means of increasing water availability for people, livestock and agriculture, required investigation to see if it is feasible and what methods would offer durable solutions for this water scarce environment.

Mean annual rainfall in Sinjar is only 378 mm, so agriculture focused traditionally on rain-fed wheat and barley crops. Besides rainfall, water is available in the form of springs at the foot of Sinjar Mountain, wadi runoff and groundwater. Groundwater was widely exploited using karez, dug-wells and boreholes, for domestic supply, supplemental irrigation and large-scale agri-business. Salinity generally increases with distance from mountain and with depth of exploitation, and in recent years, large-scale unmanaged abstraction has resulted in increased groundwater salinity, with the use of reverse osmosis for public water supply. The national strategy has been to use groundwater for drinking water with development of other sources for livestock and agriculture, so infrastructure rehabilitation focuses on domestic supply.

Climate change projections suggest that rainfall in Sinjar may halve and become more erratic during the remainder of the century which will place pressure on water supply and agriculture, making water resource management essential.

The potential role of water harvesting in post-conflict reconstruction has been recognised in research and publications, especially when coupled with improved agronomy. This report aims to summarise published information, and provide an overview of climate and water resources constraints, highlighting requirements for effective management and water resource assessment, and practical water harvesting measures for the Sinjar and Baaj Districts.

Key Project Objectives

This report forms part of NRC's three-year AMAL project to promote the resilience of rural Iraqi communities through restoration of agricultural production, markets and associated livelihoods, in a region historically renowned for dry-farmed wheat production.

The desk-based review of available information focuses on rainwater harvesting for livestock watering, agricultural irrigation and aquifer recharge in Sinjar and Baaj Districts in Nineveh Governorate. The report provides a review of information on water harvesting in the project area, and identifies gaps in the existing data and knowledge so that guidance may be provided on future project implementation and scale. It includes a review of available climatological and hydrological data for the region and the use to date of remote sensing for planning of water harvesting initiatives.

Given the difficulties of working in the region and lack of data, remote sensing has been used herein to provide an interpretation of water, soil and land-use features, which are not available in the literature.

Climate and Hydrological Data

Data Availability

There are some five climatological stations in or near the project area: Baaj, Sinjar, Tel-Afer, Tel-Abtah and Rabiah. Sinjar and Tel-Afer have the longest records, starting in 1935and 1939 respectively. MOWR provided files containing monthly and daily climatological data gathered from other government agencies such as the Ministries of Transport and Agriculture. Monthly records provided by MOWR end in December 2013. Annual rainfall totals are available for some stations to 2020. There are no records of spring and wadi discharge, or groundwater levels and groundwater quality.

Rainfall and Evaporation

Mean annual rainfall at Sinjar was calculated as 378 mm for the period, 1941-2010. The TRMM-GPM value of 239 mm for the period 1998-2019 compares well with the Sinjar station value of 267 mm for a similar period. Mean annual evaporation was estimated at 40-50% of annual precipitation, so 50-60% of precipitation is available for soil moisture storage, groundwater recharge and runoff.

Although rainfall intensity in the region is usually less than 10 mm/h, higher intensities of 20 mm/h can occur during storm durations up to 20 hours. Occasionally, severe storms exceeding 20 mm/h and of short duration occur. Rainfall intensity is an important criterion for water harvesting as it largely controls the generation of runoff.

Climate Change

Observed trends in rainfall and temperature at Mosul indicate a decreasing trend in both annual rainfall and the number of rainy days between the early 1940s and 2009. Downscaling, processing and analysis of HADCM3 global climate model for Sinjar District indicates a decline in rainfall of 30 to 100 mm over the period 2020-2100.

Groundwater

Project Focus

The focus of the NRC project is on the northern part of the Al Jazira plains formed by Sinjar and the northern part of Baaj Districts, where agriculture is possible covering an area of the order of 3,850 km^2. In southern Baaj, soils and groundwater become too saline for practical use without treatment, and the region is dominated saline lakes, brackish wells and salt marsh.

Hydrogeology

The project area is dominated by an asymmetric anticline of older rocks forming Sinjar Mountain, and flatter syncline to the south, which contains water-bearing sedimentary rocks divided into three main groups of strata: Quaternary, Upper Fars and Lower Fars Formations. The mountain wadis have built alluvial fans out on to the plain at the mountain edge, and the north side of the anticline is steeper and eroding more significantly than the southern perimeter. The Upper Fars outcrops in the wadi valleys to the south where the Quaternary covered has been eroded. Both Upper and Lower Fars consist of multiple layers of water-bearing strata, not necessarily with vertical or lateral continuity.

Fresh groundwater occurs both as karst springs at the edge of the mountainous area along the contact of the Serikagni and Jeribe Limestones, and in the upper layers of sediments which fill the syncline, fed primarily by mountain runoff, karst sink-holes, spring discharge and direct rainfall. There are seven groups of groundwater resurgence along the southern edge of Sinjar Mountain, draining a mountain catchment of 350 km^2: Sinjar, Gizil, Gabare, Jaddala, Sakiniya, Kharabet Ikheder and Umm Al-Diban. The Jaddala and Kani Kedri springs are perennial and discharge up to 0.3 and 1.4 m^3/s respectively.

Groundwater Exploitation

The principal problem with groundwater is salinity. Dug-wells and boreholes historically exploited freshwater in the Quaternary and Upper Fars aquifers characterised by a TDS of 0.5 to 1.0 g/l. The best quality water is close to the source of recharge in Sinjar Mountain, notably in the area up to 15 to 25 km south of Sinjar village, beyond which TDS increases to 1 to 3 g/l. The Upper Fars has a higher incidence of sandstone and many wells have been excavated or drilled in the Upper Fars. There is little or no groundwater information on the plains north of Sinjar Mountain.

MOWR provided a well inventory which shows that there were 5,698 dug-wells and boreholes in the project area in 2014, of which the majority are boreholes exceeding 45 m depth, and maximum borehole depth is 300 m. There are significant well concentrations and severe water shortage occurs in a 15 km wide west-east belt through Baaj.

Although a large number of karez existed in the area north-east of Baaj, they are no longer operational, as groundwater levels have most likely fallen below the structure invert. Satellite imagery shows five karez along the edge of Sinjar Mountain between Wardiya and Sinjar town., some of which have water and might be reinstated. Current groundwater levels are not known.

Prior to 2004, 5 to 25 new boreholes were drilled each year, but since then, over 500 boreholes per year have been built, with an average well yield of 0.1 to 32 l/s. If the data are accurate, it would imply that excessive damage has been done to the aquifers since 2004, but there are no monitoring data in this region. Construction of boreholes may have connected shallow water-bearing strata with the deeper poorer quality water.

Water Resource Assessment

The groundwater research reviewed for this report generally refers to other parts of Iraq. No work would appear to have been carried out by the Iraqi government to analyse and interpret historical and current data on groundwater resources in the project area. MoWR only gives the general guidance that new water resources development in the project area should not have an adverse impact on flows in the Tigris River.

There are no references or data describing long-term change in groundwater level or quality, except for a surface geo-electrical survey, which compared groundwater level in 2012 with an identical survey done in the 1980s. This concluded that there had been an average drawdown of 1 to 3 m over the 30-year period.

In 1977, it was considered that average annual rainfall was enough to replenish aquifers, at the level of exploitation existing at the time. In the absence of research and reports, a crude appraisal of available resources was made for the area south of Sinjar Mountain, as a function of rainfall. This shows that the level of abstraction by 2,660 wells in the Al Ajeej catchment amounts to 207 Mm^3, which grossly exceeds estimated recharge of 89 Mm^3 assuming water is pumped for three months of the year at an average of 10 l/s per well. A sustainable level of abstraction would need to more than half the number of existing wells or the irrigation period might be reduced, or used only for livestock and fodder.

Given the probable damage to the main aquifers in the Quaternary and Upper Fars Formations, which will require concerted effort and management to reverse the probable trends, the project might focus use of groundwater recharge on the area of Quaternary deposits immediately south and north of Sinjar Mountain, where a spring source or karez might be enhanced. However, use of such water for recharge would compete with other direct uses for domestic and horticultural requirements. It was confirmed during the rapid rural appraisal that springs at Sinjar and Kani Kedri were being used for irrigation of vegetables by gravity and some impoundment.

Recharge Options

There are a number of options for injection of clean water into the aquifers and the approach depends on whether the source of water is clean or dirty: wadi runoff or rainwater.

It will not be worthwhile enhancing aquifer recharge, unless the deeper saline boreholes are sealed permanently. Once this is carried out, it is likely that recharge could focus on the shallow water-bearing strata. Recharge by sinkhole, pond, roof runoff or recharge dam could then be considered.

The simplest form of recharge system that could be considered in a pilot scheme is the collection of rainwater from roofs connected to a recharge borehole. In the project area, a target village or town could be selected and pipework laid to centralise roof runoff and carry the water to a newly-drilled borehole.

Spring discharge could be increased if certain wadi courses were captured and diverted to new karst sinkholes.

The capture and diversion of wadi runoff is more controversial and would depend whether the flow is being used by farmers downstream.

Groundwater recharge by wadi dams in Baaj District would be located too far south to be of local use and water would have to be pumped back up to the higher elevations of the Al Jazira plains.

The recharge water would need to be clean and free from sediment, so wadis, ponds and recharge dams would require some form of sedimentation. The usual process at recharge dams is to release water through a draw-off tower to allow infiltration of the water in the wadi bed downstream which can be enhanced by using underground infiltration galleries.

Rainwater Harvesting

Small-scale Water Harvesting

There are no reports of small-scale water harvesting schemes in the project area, so recourse was made to interpretation of satellite imagery. It was confirmed that supplementary water is used from wells and springs for vegetable and/ fruit production and small plots of maize. There is historical evidence of irrigation using boreholes and central pivot schemes, exclusive to richer farmers.

Small-scale water harvesting techniques suited to the area include variations of:

- Rooftop and compound harvesting.
- Bunds encircling fields to capture and hold overland flow
- Contour ridges to harvest small amounts of water at regular intervals
- Renovation of the hexagonal lattice systems of contour ploughing, practiced historically in Sinjar District.
- Stone bunds and terraces
- open, excavated water pans for livestock watering

It is pointed out that the project area has traditionally relied on rainfed wheat production, although this may become riskier as drought years become more common with climate change.

There are several studies that show that the benefits of supplemental irrigation from water harvesting sources are considerable. Because such irrigation can be applied at stages of crop growth which are particularly sensitive to drought, the overall water use efficiency can be increased: a recommendation is that a general target should be to ensure that half of the crop water requirement is met, up to 300 mm on wheat in dry years. The “water harvesting paradox” is the inescapable fact that when the crop demand is greatest, the runoff to be harvested is the least.

There are no documents on important aspects of water harvesting that examine the environment for successful water harvesting, such as farm seed supplies, machinery and effective social organisation.

While livestock watering is clearly specified as one of the NRC aims of water harvesting, there is only anecdotal information about the requirements, type of livestock and regime. It is important to know whether the main demand is for livestock in and around the household or for livestock owned by pastoralists covering a wide area of grazing and browsing land. Watering points can be a crucial element of grazing strategies, allowing on the one hand access to dry season grazing, and on the other hand deliberately limiting overgrazing in other zones.

Satellite imagery shows that micro-scale water harvesting existed in the form of hexagonal contour ploughing of fields and diversion of wadi flow. A rapid rural survey by NRC suggests that such ploughing and diversion is no longer practiced.

A small pond approximately 10 m in diameter has been constructed at Kani Kedri spring, some 5 km east of Sinjar town. The pond temporarily retains spring flow and allows farmers to pump or divert water to nearby fields.

Household rain-water harvesting for domestic and household garden use was proposed by Relief International in a 2016 WASH assessment report.

Large-scale Water Harvesting

Large-scale harvesting involves earth embankments and dams not exceeding 15 m height and storage not exceeding 3 Mm^3.

One study describes the construction of the Bistana water harvesting pond near Erbil in 2019, with a volume of 12,000 m^3. The pond is part of a plan by the Ministry of Agriculture and Water Resources in Erbil Governorate to combat drought. The plan includes construction of 25 large ponds and 49 smaller ponds, of which 18 have been built. Potential use includes groundwater recharge, irrigation, livestock, wildlife conservation, tourism and drinking water.

In the Badia region of Jordan, concrete-lined water harvesting ponds up to 10,000 m^3 capacity have been used in villages since the mid-1960s, to store water diverted in channels from small wadis. Small tanks are used to trap sediment prior to discharge to the pond. A programme of larger earth ponds up to 50,000 m^3 capacity excavated adjacent to wadis was commenced in the mid-1990s, and they have been found to be efficient in storing and providing water over many years and successfully used for irrigation, animal watering and washing.

Several studies in the project area have been reviewed involving construction of large dams on Wadi Al-Jeej and Wadi Al-Tharthar up to 20 m high and capacity 96 Mm^3, which are not considered to be relevant to the scale of the current project. The studies relied on theoretical calculations only.

A number of literature sources reviewed show that there is a basic misunderstanding of how recharge dams are intended to operate in arid and semi-arid regions. Recharge dams are very different to storage dams. Small dams will inevitably allow fine sediment to accumulate in the reservoir basin. While periodic removal of sediment is to be encouraged, the goal here is to maintain storage volume, not direct recharge through the reservoir basin floor. Recharge dams should be operated so that they capture runoff, but then release it quickly to promote recharge through the wadi bed or through infiltration galleries downstream. The objective is to minimise standing time of the water in the reservoir basin.

Remote Sensing

Remote sensing has been used in the literature to analyse potential sites in in the project area, without giving details which would allow accuracy to be determined. In several papers, it appeared that the spatial resolution was inadequate to accurately define dam and reservoir characteristics: a spatial resolution providing horizontal accuracy of 1-2 m and vertical accuracy of 0.5 m is usually necessary by using combined photogrammetric satellite analysis and ground-survey.

Hydrology Conclusions

Limitations and Gaps

- Basic information on the climatological network is missing, and climatological studies use incomplete data sets with no standardised period.
- Basic analysis of rainfall at Sinjar and Baaj, has not been carried out, and there are no recording rain-gauges to produce sub-daily data.
- Spatial distribution of rainfall and other variables has not been mapped, with consideration of orography.
- Snow is not identified in the literature, so precipitation measured is rainfall.
- Complete absence of routine monitoring of wadi and spring discharge, and analysis of runoff in relation to rainfall.
- Al Sawaf offers the only detailed reference on groundwater resources in Sinjar and Baaj Districts.
- No research papers or government reports on the overall status of groundwater resources in the region.
- No long-term data-sets on groundwater levels and hydrochemistry in Sinjar and Baaj.
- No routine measurements of spring discharge or well abstraction in Sinjar and Baaj.
- No well construction details in the well inventory showing aquifer depths exploited.

Recommendations

- Iraqi 1:25,000 topographic and geological mapping should be acquired for the project area.
- Obtain complete listings of the climatological network of stations in the project and neighbouring areas.
- Obtain complete listings of climatological variables measured at each station and their periods of record and gaps.
- If required, obtain complete climatological data-sets for analysis, planning and design.
- If required, consider installation of automatic weather stations or project rain-gauges in the pilot area.
- If required, consider setting up a wadi gauging station in the pilot area.
- Install pressure transducers to start monitoring groundwater levels in selected boreholes in three target aquifers.
- Install V-notch weirs at three selected springs and equip with water level monitoring equipment.
- Improve the well inventory in the pilot area, to show water well use, yield, water level and total depth, taking a sample from each and dipping the water level.
- Surveys of karez should be undertaken to establish their condition, use and need for rehabilitation.

Water Harvesting Conclusions

Limitations and Gaps

- All studies in Sinjar District have been academic and theoretical in nature.
- Estimation of water resources at dam sites has not benefitted from local measurements of wadi flow.
- Estimation of irrigable areas has not taken account of field experience of irrigation practices and real-world losses in irrigation systems.
- DEMs presented in literature to select dam sites use inappropriate low-resolution imagery.
- Studies have not considered technical, social and economic aspects of dam feasibility.
- No access to government feasibility studies of water harvesting if they exist.
- No studies of micro-water harvesting in the project area.
- No information on project requirements: target area, population to be served, livestock numbers.
- No reports on agricultural demand by the population or priority: whether supplemental irrigation for extensive cropping of wheat and barley, or for more intensive production of fruit and vegetables, or for livestock watering.

Recommendations

- Enquiries should be made to obtain government reports on water harvesting schemes in or near the project area.
- Enquiries should be made regarding the existence of design reports on Bistana pond and other planned ponds, and hydrological and other studies that support the designs.
- Enquiries should be made to Relief International and other organisations regarding their activities involving water harvesting to confirm whether they have been active in Sinjar District since 2016 and to obtain any relevant reports.

There are many different options available for water harvesting in Sinjar-Baaj, but they are all contingent on carrying out further studies, due to the scarcity of existing information of the project area.

Current thoughts include the following:

- Rainfed production of wheat and barley might be best / most quickly/ most cheaply helped by looking at other limiting factors, including input [seed, machinery] availability and timeliness. Early planting is in fact, de facto "water harvesting".
- Forms of water harvesting that are likely to be feasible in the project area, and which should be explored, include:

– Rooftop/ compound harvesting.
– Renovation of the hexagonal lattice systems observed by this study as a form of contour ploughing used in the recent past.
– Earth bunds surrounding plots to capture overland flow [as with the "Teras" system used in eastern Sudan that has been documented in publications by W.R.S. Critchley]. Here, water storage and utilisation take place in the same location and it is easier to be equitable.
– Haffir tanks for livestock watering, possibly including cultivation of vegetables downstream of the spillway.
– Wadi spate harvesting using mini-diversion structures.

Glossary of Units, Terms and Abbreviations

m	metres
mm	millimetres
km^2	square kilometres
Mm^3	million cubic metres
m^3/s	cubic metres per second
m aMSL	metres above Mean Sea Level
m bgl	metres below ground level
Ha	hectare
mm/min	millimetres per minute
l/s	litres per second
g/l	grams per litre
m/d	metres per day
max	maximum
min	minimum
ALOS	Advanced Land Observing Satellite
AMAL	Activating Market-based Agricultural Livelihood
catchment	area drained by a river
DEM	Digital elevation model
DTM	Digital terrain model
Elev	elevation
ICOLD	International Commission on Large Dams
JAXA	Japanese Aerospace Exploration Agency
LiDAR	Laser imaging, detection, and ranging
MOWR	Ministry of Water Resources, Iraq Government
NRC	Norwegian Refugee Council
P	Precipitation
PR	Percentage runoff
river gauging	point on the river where the rate of discharge is measured
SCS CN	Soil Conservation Service curve number
SRTM	Shuttle radar topography mission
SWL	static water level
TDS	total dissolved solids
USBR	United States Bureau of Reclamation
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation

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1 Introduction

1-1 Context

Sinjar and Baaj Districts in Nineveh Governorate, considered to be part of the granary of Iraq, have recently suffered from violent conflict. These districts are now the focus of national and international efforts to revive the local agricultural economy and encourage return of the local population displaced by the conflict. This report contributes to these efforts by assessing the potential for water harvesting as a means of increasing the availability of water for people, livestock and agriculture.

Agriculture in Sinjar and Baaj Districts, mainly extensive rain-fed wheat and barley cultivation, is under constant threat due to variable rainfall and drought. Rain falls between October and May, on average ranging from around 240 to 270 mm per year in the north of Sinjar District to about 150 mm in the south of Baaj District and varying greatly from year to year. Surface water is rare, occurring as a few permanent springs at the foot of Sinjar Mountain or as occasional short-lived flash floods. While groundwater is ubiquitous throughout the area, its salinity increases generally with distance from Sinjar Mountain, the main source of recharge, and with depth of exploitation. Nevertheless, groundwater is widely exploited. Historically this has been for domestic supply via shallow wells, but in the last two decades brackish or saline groundwater has been increasingly pumped by agri-businesses for relatively large-scale irrigation via centre pivots and lateral sprinklers. Salinization of soils thus irrigated is probably occurring.

Climate change projections suggest that rainfall will decline over the 21st Century, possibly by 50%. In Sinjar and Baaj Districts, this will have significant implications for agriculture, and careful management of available water resources is essential. Water harvesting is a potential means of increasing the availability of water for domestic, agricultural and livestock use, and for recharge of groundwater resources, and potentially has a critical role in post-conflict reconstruction in Sinjar and Baaj. This has long been recognised, as the literature shows in the present report, although most studies to date have been academic and theoretical in nature. Improved agronomy will also mean that the water would be used more efficiently.

In this context, this report provides an initial contribution to the development of practical water harvesting and guidelines for water resources management in the Sinjar and Baaj Districts.

1-2 Background

This report forms part of NRC's three-year project [2020-2022] called Activating Market-based Agricultural Livelihoods [AMAL] in Nineveh and Kirkuk governorates. The overall objective of AMAL is to promote the resilience of rural Iraqi communities through the restoration of agricultural production, markets and associated livelihoods. The terms of reference are included for reference in Appendix A.

The study has involved a desk-based review of available documentation on the rainwater harvesting potential of Sinjar and Baaj Districts in the Nineveh Province of Iraq, as a means of improving water resources availability for livestock and agricultural irrigation. Rainwater harvesting measures include aquifer recharge and surface storage schemes, appropriate for local communities to become re-established in a water-scarce environment.

Two decades of research and interest in the recharge and storage approach produced a large number of reports and publications by international and national bodies and consulting firms. NRC collated a package of electronic documents for the project, which was supplemented by WRA's own research and information provided by MOWR.

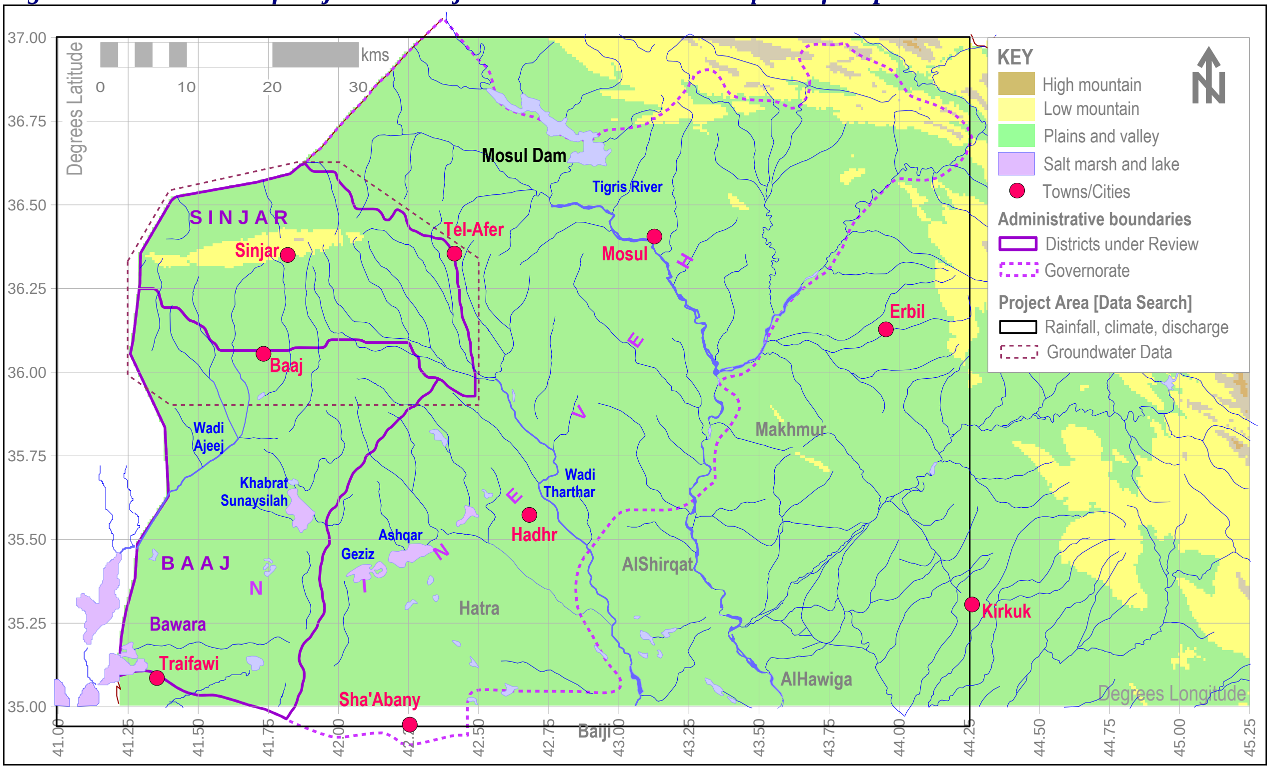
The documentation has been examined to develop an appreciation of the use of water harvesting in the project area, and to identify gaps in the existing data and knowledge, so that guidance may be provided on AMAL project implementation and scale.

The study area of Sinjar and Baaj Districts is shown in Figure 1-1. It is usual for a project of this nature to consider two "project areas", a wider region for acquiring relevant hydrological data and a local zone of interest for agricultural and water resource development.

In the present case, the two areas have been defined as follows:

- AREA 1 [black rectangle] for rainfall, climatological parameters and wadi/spring discharge.
- AREA 2 [dashed magenta] for groundwater [water level and water chemistry] and agricultural data.

Figure 1-1 Location of Sinjar and Baaj Districts on Northern Iraq Relief Map



Source: DIVA database, developed by Robert Hijmans [co-developers Edwin Rojas, Mariana Cruz, Rachel O'Brien, Israel Barrantes]

1-3 Report Structure

The Terms of Reference refer to the following three subject areas:

D1. Existing rainwater harvesting schemes, ponds and small dams.
D2. Groundwater and options to increase recharge in the Al-Jazira aquifer.
D3. Regional and local climate, and baseline hydrological data.

The Interim Report summarises the results of reviewing reports and research papers related to these three topics, highlighting gaps and limitations in information and data, and identifying the main points for discussion, to be taken to the next stage.

The literature collated for the assignment has been grouped into four main themes:

- CL Climate change and climatological/hydrological data [including remote sensing].
- GW Groundwater.
- WH Water harvesting.
- WS Water supply.

Each document has been searched to determine origins and expertise of the authors, whether peer review was undertaken as part of the international publishing process, whether completed by government departments, consultants or universities. The results of the research have also been compared, to the extent possible, with international work in other similar conditions and with global data-sets.

The published work and reports have been summarised in tabular form in Appendix B, considering world standing of the publishing entity, authorship, peer review and value/relevance to the project, in forming the following classification: ■ Poor, ■ Fair and ■ Good.

1-4 Hydrological Mapping of the Region

Given the difficulties of working in the region caused by war, remote sensing has been used to provide an interpretation of water, soil and land-use features, which are not available in the literature.

An important component of baseline work for water harvesting is topographic data. For the purposes of this review, recourse has been made to USGS SRTM and JAXA ALOS data to derive a DTM of the project area, and to Tactical Pilot Charts [TPC] and Joint Operations Graphic [JOG] 1:250,000 mapping. The TPC mapping is shown in Figure 1-2, depicting the area considered to be the detailed study area which is the whole of Sinjar District and the northern part of Baaj District.

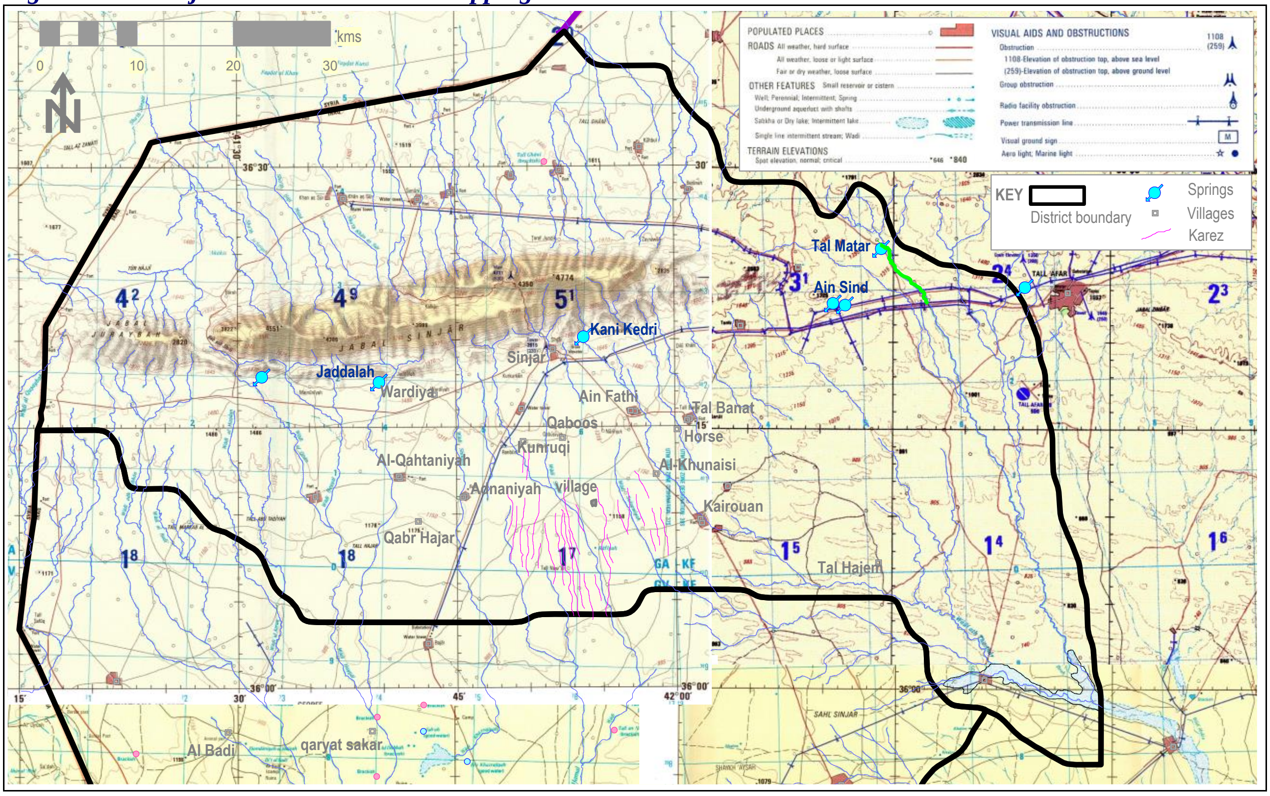
Use could also be made of old soviet military mapping if required.

It is reported that Iraq has at least 1:25,000 topographic and geologic mapping of the project area, which would be very useful in building up the knowledge base of the district in order to adequately recommend the correct course of action. This scale of mapping is particularly important for small dams and water harvesting solutions beyond the micro-scale, and for developing possible groundwater recharge enhancement schemes along the edge of the mountain.

The DTM relief and extracts of mapping used during the review are included in Appendix C.

If up-to-date satellite imagery cannot be obtained in-country for future work, high resolution imagery can be purchased from global suppliers like Airbus and Digital Globe to better enable the feasibility stage and pilot project. Alternatively, for very small areas, topographic data can be obtained by flying drone surveys

Figure 1-2 Sinjar District Historical Mapping



Source: Joint Operations Graphic: sheets NJ37-16, NJ3818, NI37-4, NI38-1. Prepared and published by the US Defense Mapping Agency Aerospace Center, St Louis, Missouri; compiled January 1991.

2 Climatological and Hydrological Data

2-1 Introduction

This section refers to **Deliverable 3** of the Terms of Reference [Appendix A]:

"3. Review available research papers and studies on regional and district level rainfall and climate data, summarize, identify gaps, limitations and provide recommendations".

2-2 Area of Interest

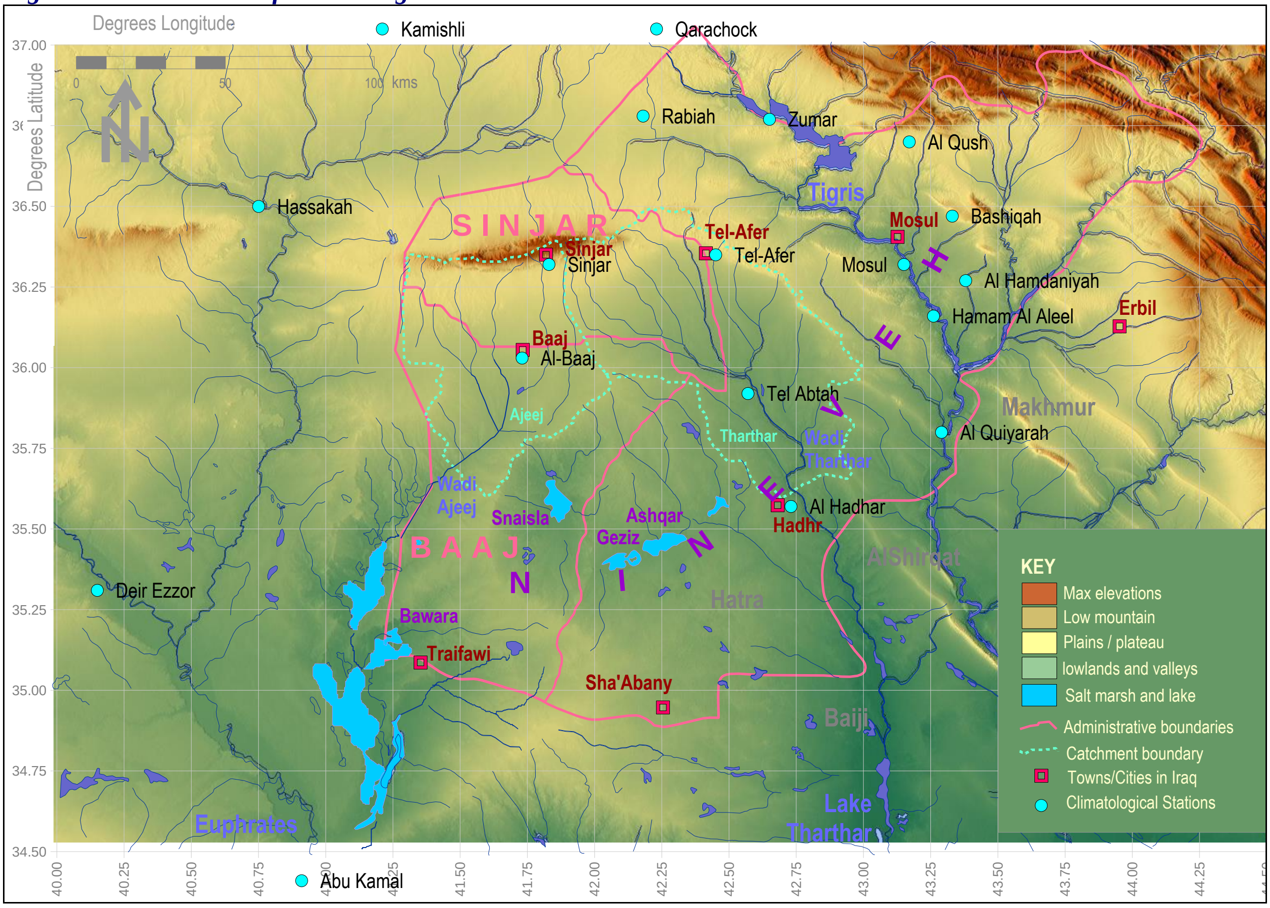
The area of interest for climatological and hydrological data is Sinjar, Baaj, surrounding districts in Nineveh Governorate, and neighbouring areas of Syria. The River Tigris is a major river which is unrepresentative of hydrological conditions in Sinjar and Baaj districts. The river was therefore excluded from information searches.

The surface hydrology of the project area is dominated by the drainage of two wadi systems southwards, Wadis Ajeej and Tharthar, while the north side of Sinjar Mountain drains through alluvial fans to dissipate across the Syrian border.

2-3 Climatological and Hydrological Stations

Figure 2-1 shows climatological stations in northern Iraq and neighbouring areas of Syria. Of these, the stations in Iraq at Sinjar, Baaj, Rabiah, Tel-Afer and Tel-Abtah are of particular relevance to this project, as they likely represent climatological conditions across the project area. Table 2-1 summarises the location, height and available record at those sites.

Figure 2-1 Location of Climatological Stations and Catchments



Sources: Ministry of Water Resources, Baghdad [climatological stations], SRTM colour render. Relief data based on SRTM, rivers from DIVA database.

2-4 Climatological and Hydrological Records

Table 2-2 provides information on climatological records at the stations in Table 2-1 as far as they are known at the present time.

Table 2-1 Summary of Climatological Records in the Project Area

Station ID	Station name	Latitude Dec.°N [1]	Longitude Dec.°E [1]	Elevation [maMSL]	Year Opened	Year Closed	Record [years]
	Baaj	36.03	41.73	312	1939	n/a	17
	Rabiah	36.78	42.18	385	1975	n/a	38
364419	Sinjar	36.32	41.83	502	1935	n/a	63
364425	Tel-Afer	36.35	42.45	345	1939	n/a	64
	Tel-Abtah	35.92	42.57	211	1969	n/a	n/a

Source: Ministry of Water Resources, Baghdad. Notes: n/a: not available [possibly still operating]. Geographical coordinates of station sites to be confirmed by GPS and other information by the Directorate General of Meteorology and Seismology [Ministry of Transportation, Mosul].

Table 2-2 Summary of Climatological Records Available for Sinjar and Neighbouring Stations

STATION			Baaj		Sinjar		Tel-Afer		Tel-Abtah		Rabiah	
Parameter	**Unit**	**Timebase**	**From**	**To**	**From**	**To**	**From**	**To**	**From**	**To**	**From**	**To**
Precipitation	mm	Monthly	Dec 1980	Dec 2013	Oct 1935	Dec 2013	Jan 1939	Dec 2013	Oct 1969	Dec 2013	Jan 1975	Dec 2013
Precipitation	mm	Daily	Oct 2003	Dec 2013	Oct 2003	Dec 2013	-	-	Oct 2003	Dec 2013	Oct 2011	Dec 2010
Evaporation	mm	Monthly	Feb 1991	Dec 2008	Nov 1968	May 2006	Jul 1974	Oct 2002	Feb 1992	Jan 2006	Jun 1980	Dec 2002
Humidity	%	Monthly	Feb 1991	Dec 1999	Jan 1971	Mar 2001	Sep 1981	Dec 2000	Feb 1992	Dec 1999	Feb 1975	Dec 2000
Humidity	%	Daily	-	-	-	-	-	-	Jul 2011	Apr 2012	-	-
Temperature [max]	°C	Monthly	Feb 1991	Dec 2008	Jan 1970	Dec 2008	Sep 1981	Dec 2010	Jan 1992	Apr 2012	Jan 1975	May 2010
Temperature [max]	°C	Daily	Jan 2000	Dec 2010	Jan 2000	Dec 2010	Jan 2000	Dec 2010	Jan 2000	Apr 2012	Jan 2000	May 2010
Temperature [min]	°C	Monthly	Mar 1992	Dec 2008	Jan 1962	Dec 2008	Sep 1981	Dec 2010	Feb 1992	Apr 2012	Jan 1975	May 2010
Temperature [min]	°C	Daily	Jan 2000	Dec 2010	Jan 2000	Dec 2010	Jan 2000	Dec 2010	-	-	Jan 2000	May 2010
Temperature [mean]	°C	Monthly	Feb 1991	Dec 2008	Jan 1962	Dec 2008	Sep 1981	Dec 2008	Feb 1992	Dec 2008	Jan 1975	Dec 2008
Sunshine duration	hours	Monthly	Jan 1991	Nov 1999	Dec 1974	Feb 2001	Feb 1982	Sep 2000	Jan 1992	Nov 1999	Sep 1977	Nov 2000
Solar radiation	n/a	Daily	-	-	-	-	-	-	Jul 2011	Apr 2012	-	-
Windspeed	m/s	Monthly	Jan 1991	Nov 1999	Jan 1970	Feb 2001	Dec 1981	Nov 2000	Jan 1992	Nov 1999	Jan 1975	Nov 2000
Windspeed	m/s	Daily	-	-	-	-	-	-	Jul 2011	Apr 2012	-	-

Source: Records held in the HEC-DSS[1] database provided by the Ministry of Water Resources, Baghdad. The Ministry of Water Resources has also provided a table of total annual rainfall for the period 2010-2020 for these stations. Total annual rainfall has been recorded at Baaj, Tel-Afer and Rabiah during 2010-2020, although 2015-2017 are missing. Annual rainfall totals at Sinjar extend only to 2014.

[1] U.S. Army Corps of Engineers' Hydrologic Engineering Centre Data Storage System

Sinjar and Tel-Afer have the longest records, apparently starting in 1935 and 1939 respectively. Notably, apart from precipitation, the most recent data sets are December 2013, after which date there are no further climatological records in this part of Iraq.

The absence of hydrological gauging records of wadi flow in the project area is a significant gap in the available information.

2-5 Evaluation of Available Documentation

A comprehensive description and details of the climatological station network are not available among the literature reviewed. A number of academic publications have been reviewed which study particular aspects of the climatic environment, and data from these are presented below where it is believed that the information may be of interest or use. However, the periods of record for the statistics presented vary, making comparison of values given in different tables difficult. The Ministry of Water Resources has provided HEC-DSS files containing monthly and daily meteorological data for stations in the project area. However, the records [Table 2-2] are believed to only represent information that the Ministry of Water Resources holds.

No record of a rain gauge existing on Sinjar Mountain has been seen. Precipitation on the mountain would be expected to be higher than on the plain due to orographic effects, and would be important to know if a comprehensive water resources assessment was required. The absence of a rain gauge and rainfall record on the mountain is not necessarily a gap in terms of the project's objectives, but the lack of knowledge of precipitation on the mountain does constrain estimation of groundwater recharge at elevation.

We have not seen a basic map of average annual rainfall isohyets [the spatial distribution of rainfall] for the project area or northern Iraq. We consider such a map to be a gap in the available information.

2-6 Climatological Data and Statistics

2-6-1 Precipitation

In this section, an extract is shown of statistical tables found in the literature reviewed that may be useful to the project. The climate in the project area may be described as arid with cool to mild winters and warm to very warm summers. Precipitation can fall as snow in winter, although no data have been seen to indicate the frequency of occurrence, measurement or the proportion of annual precipitation that falls as snow.

Table 2-3 presents the most comprehensive statistics found on annual precipitation and its variation. Mean annual rainfall for the period 1941-2010 at Sinjar is shown as **378 mm**. Table 2-4 presents average monthly precipitation and temperature at Sinjar and Baaj stations. The rainy season extends from October to May.

Table 2-3 Annual Rainfall and Dry Periods at Sinjar and Baaj Stations

Station	Record	Length of record [years]	Mean Annual Rainfall [mm]	Annual Standard Deviation [mm]	Minimum Annual Rainfall [mm]	Maximum Annual Rainfall [mm]	Dry period		Months of dryness
							From	To	
Sinjar	1941-2010	70	378	138	164	670	July 2006	Jan 2010	43
Tel-Afer	1941-2010	70	321	108	134	614	July 2006	Jan 2010	43

Source: Kalyana and Awchi [2015], CL8

Table 2-4 Average Monthly Precipitation and Temperature at Sinjar and Baaj Stations, 1960-2002

Stn	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Precipitation in mm													
Sinjar	67.7	63.4	64.7	45.3	23.1	0.7	0	0	0.5	12.2	37.1	67.6	382.3
Baaj	57.8	44.5	47.6	24.0	21.1	2.5	0	0	0.2	10.8	37.9	65.2	311.6
Temperature ^{o}C													
Sinjar	6.5	8.4	12.0	17.1	23.7	29.8	33.5	33.1	29.2	22.6	14.7	8.5	19.9
Baaj	5.9	7.2	11.1	17.5	22.2	28.8	32.2	31.7	28.3	23.0	12.5	10.0	19.2

Sources. Rainfall: Al-Taiee and Rasheed [2011], WH1; Al-Daghastani [2010]. Temperature: Al-Daghastani [2010], WH4.

Drought is a frequent occurrence in the project area. Table 2-5 presents statistics on dry months in the project area.

Table 2-5 Dry Period Characteristics in Sinjar and Tel-Afer Stations, 1941-2010

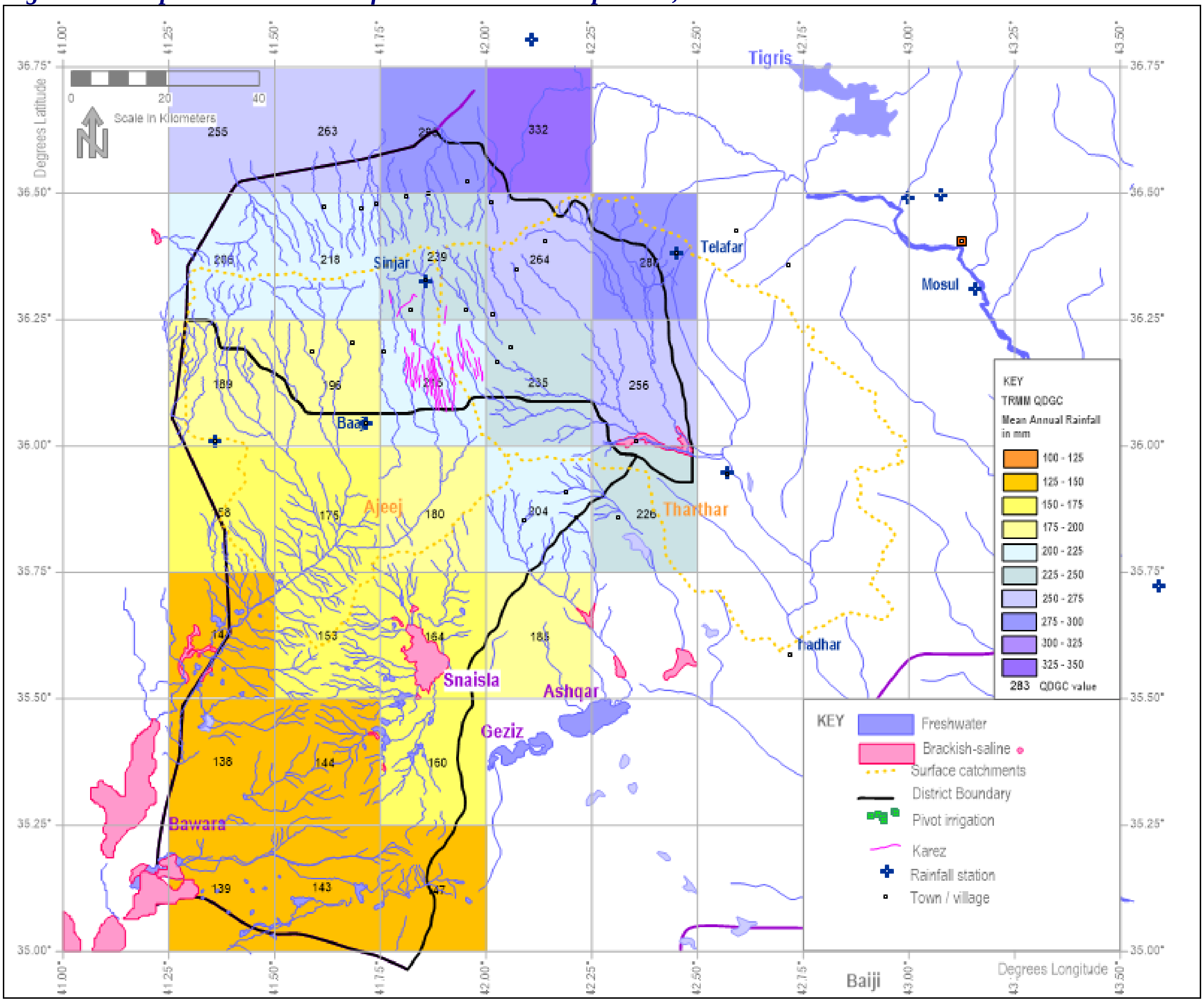
Station	Record length Months	No of Dry Months	% of Dry Months	No of dry periods	Average Length of Dry Periods Months	No of Long Dry Periods in Record	Average Length of Long Dry Spells Months	Long-Term Accumulated Deficiency Rate mm	Deficiency Rate for Long Periods mm/month
Sinjar	838	491	58.6%	57	8.6	9	22.3	241	10.8
Tel-Afer	838	499	59.6%	58	8.6	10	20.4	191	9.4

Source: Kalyana and Awchi [2015], CL8; Record length 1941-2010.

2-6-2 Comparison with Global Gridded Data

WRA's TRMM-GPM[2] database and software have been used to extract gridded data for the project area. TRMM-GPM grid cells are 0.25^0 x 0.25^0 in size and precipitation values are spatial averages across them. Figure 2-2 shows the distribution of TRMM-GPM precipitation across the project area.

Figure 2-2 Spatial Distribution of Mean Annual Precipitation, 1998-2019



Source: TRMM-GPM cell mean 1998-2019.

2 TRMM – Tropical Rainfall Monitoring Mission. GPM – Global Precipitation Measurement Mission. https://earthdata.nasa.gov/learn/articles/tools-and-technology-articles/trmm-to-gpm

The general south-west to north east increase in precipitation is evident. The grid cell size is too coarse to pick up the impact of orographic enhancement of rainfall caused by Sinjar Mountain and the possible rain shadow effect which this mountain may have on rainfall distribution. This effect would be more readily visible using the CHIRPS data-set[3]. Table 2-6 suggests that there is quite good agreement between TRMM-GPM and observed mean annual rainfall at Sinjar and Baaj, although there are some years missing from the observed records.

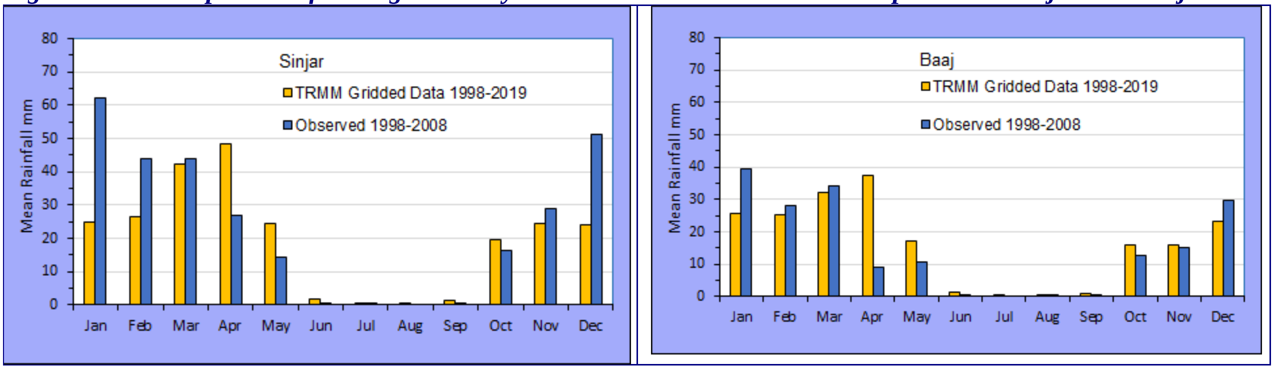
Table 2-6 Comparison of Mean Annual TRMM-GPM Data with Ground Data, 1998-2019

Station	TRMM-GPM [mm]	Observed [mm][1]	Missing years
Sinjar	239	267	2008, 2009, 2015-2019
Baaj	196	179	2003, 2009, 2015-2017

Sources: [1] Ministry of Transport rainfall records held in HEC-DSSVue by Ministry of Water Resources.

Figure 2-3 compares TRMM-GPM average monthly rainfall with observed average monthly rainfall. Direct comparison is made difficult by the mismatch in the periods of available record. However, December and January values are underestimated by TRMM-GPM. The role of snow in this is not known. The over-estimation of April precipitation could be due to the relatively short observed records being unrepresentative.

Figure 2-3 Comparison of Average Monthly TRMM-GPM and Observed Precipitation at Sinjar and Baaj



Overall, there is reasonable agreement between TRMM-GPM and the observed records at Sinjar and Baaj stations. This gives confidence that the data sets are comparable. TRMM-GPM data are useful for infilling missing data in observed data records or for providing a rainfall record in an area with no rain gauges.

2-6-3 Evaporation

Table 2-7 presents elements of the water balance for stations in the project area computed using the Thornthwaite method. The Thornthwaite method allows potential evapotranspiration and actual evapotranspiration to be estimated. Subtraction of actual evaporation from precipitation yields an estimate of the surplus water, here 50%-60% of mean annual precipitation, available for soil moisture storage, groundwater recharge and runoff.

Table 2-7 Elements of the Water Balance for Selected Climatological Stations in the Project Area

Station	Record [1] years	Temp. [2] °C	Precip. [3] mm	PET [4] mm	AET [5] mm	Surplus [6] mm	Surplus %
Baaj	17	20.5	229.0	1,361.5	112.3	116.7	51.0
Rabiah	31	18.5	367.1	1,122.7	160.1	207.0	56.4
Sinjar	28	20.6	389.3	1,399.5	153.8	235.5	60.5
Tel-Afer	25	21.0	322.8	1,464.7	139.8	183.0	56.7

Source: Al-Sudani [2020], CL1. 1. Available record length [up to 2015]. 2. Mean annual temperature. 3. Mean annual precipitation. 4. Potential evapotranspiration. 5. Mean annual actual evapotranspiration. 6. Mean annual precipitation minus mean annual actual evapotranspiration

[3] The Climate Hazards Group InfraRed Precipitation with Station data

Table 2-8 presents climate data used to calculate reference crop evapotranspiration [ETo] for the South Jazira Irrigation Project [SJIP] using the FAO Penman-Monteith equation. The SJIP is located mostly in Tel-Afer and eastern Sinjar districts. The data are said to represent 15 years of not necessarily consecutive data recorded at Tel-Afer station in the period 1981-2010.

Table 2-8 Climate Data and Reference Crop Evapotranspiration for the South Jazira Irrigation Project

Month	Rainfall mm	T_{max} °C	T_{min} °C	RH %	WS_{2m} m/s	Sunshine n hours	ETo mm
Jan	53	12.5	3.1	77	1.3	4.9	30
Feb	41	15.2	4.4	69	1.4	6.5	44
Mar	44	20.1	7.8	59	1.6	7.3	83
Apr	21	25.7	12.3	53	2.0	8.3	125
May	8	33.3	18.0	36	2.3	9.7	201
Jun	0	39.5	23.0	25	2.4	11.3	253
Jul	0	42.8	26.4	23	2.5	12.0	290
Aug	0	42.3	25.8	24	2.3	11.6	267
Sep	0	37.6	21.3	26	2.0	10.3	199
Oct	12	30.4	15.7	39	1.6	8.4	127
Nov	30	21.2	8.3	58	1.3	6.6	61
Dec	44	14.7	4.2	75	1.3	5.1	33
Annual	**256**	**27.9**	**14.2**	**47**	**1.8**	**8.5**	**1 714**

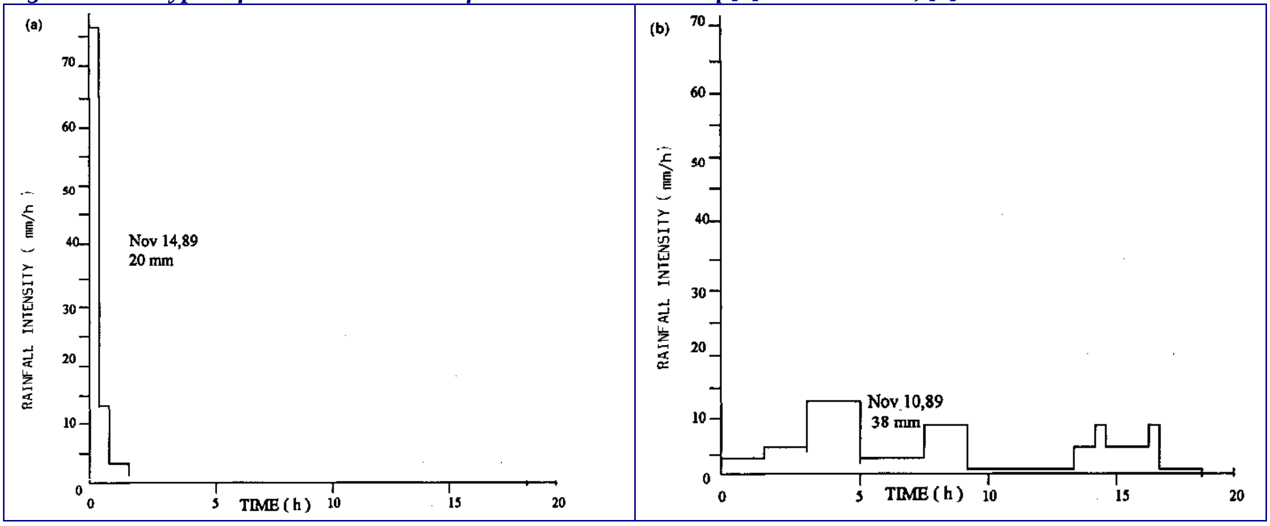
Source: Studio Galli Ingegneria SpA, MED Ingegneria Srl, El Concorde Construction LLC [2014]. Notes: Tmax and Tmin - maximum and minimum temperatures respectively; RH - relative humidity; WS2m - windspeed at 2m height; n - sunshine hours; ETo – FAO Penman-Monteith reference crop evapotranspiration.

Note: It should be emphasized that South Jazira lies outside the AMAL project area.

2-6-4 Rainfall Intensity and Runoff

Northern Iraq is described as being characterised by low intensity rainfall. Rainfall intensities in the region are usually less than 10 mm/h, but occasionally high intensity storms occur [Awad & Abdul-Jabbar [1994, CL10]. Hussein [1996, CL12] classifies storms as 'normal' and 'severe'. Normal storms have maximum intensities of about 20 mm/h and are of relatively long duration, perhaps up to 20 hours. Severe storms have rainfall intensities well in excess of 20 mm/h and are typically of short duration [Figure 2-4]. As far as is known, there are no recording rain gauges in the project area that record rainfall intensity.

Figure 2-4 Types of Storm Distribution found in Northern Iraq [a] Severe Storm, [b] Normal Storm



Source: Hussein [1996, CL12]

Typically, low rainfall intensities do not give rise to runoff because the rainfall rate is lower than the soil infiltration rate. In a study of rainfall, runoff and soil losses from natural runoff plots [of size 30 m x 3 m] at the University of Mosul's College of Agriculture and Forestry experimental farm at Hamam Al-Aleel, less than half of rainfall events were runoff producing, while one or two severe storms contributed 50% of the seasonal runoff [Hussein, 1996, CL12]. This points to the importance of rainfall intensity as a key factor controlling the generation of runoff for water harvesting.

At high rainfall intensities, raindrop impact on the soil surface mobilises fine soil particles and causes the sealing of the soil surface during the storm and/or the saturation of the soil profile. This reduces the soil infiltration rate below that of the rainfall rate and results in runoff, usually as shallow sheet flow owing to the very flat topography. Sheet flow becomes concentrated where it encounters gullies and channels, resulting in flash floods which flow down the wadi channel network. However, runoff rates [on the plain] may be assumed to be relatively low owing to low slopes and relatively deep soils.

Unfortunately, the absence of wadi gauging records and [likely] absence of rainfall intensity data does not presently permit the relationship between rainfall intensity and runoff at the catchment level to be studied, although such data do exist at the runoff plot scale at the University of Mosul [Hussein, 1996, CL12].

The more intense rainfall events not only generate runoff, they are also responsible for impoverishing soils by causing most soil erosion [by rain drop impact and running water as sheet flow] and loss of nutrients such as Phosphorous [P] and Nitrogen [N] in soluble form and chemically bound to soil particles [Hussein et al [1999, CL11]. Results of studies show that eroded sediment is always rich in available P and inorganic N compared to the original soil.

2-6-5 Observed Climatological Trends

According to the Ministry of Foreign Affairs of The Netherlands [2018, CL3], Iraq has been experiencing an overall decrease in rainfall ranging from 1.3 to 6.2 mm/year, particularly during recent years and this has resulted in a decrease in water resources.

Table 2-9 presents information provided in Iraq's Initial National Communication to the UNFCCC[4] on observed trends in rainfall and temperature at Mosul over the given periods. The negative regression coefficients indicate a decreasing trend. Positive coefficients indicate an increasing trend. The data presented indicate a decreasing trend in both annual rainfall and the number of rainy days between the early 1940s and 2009. Average annual temperature is shown to have increased slightly over the same period. These trends are consistent with the climate change narrative of rising temperatures and declining precipitation. Similar information is not available yet for stations in Sinjar/Baaj.

Table 2-9 Historical Trends in Climatic Variables at Mosul

Variable	Period	Regression coefficient
Annual rainfall	1938-2009	-1.36
Rainy days	1941-2009	-0.5
Average annual temperature	1941-2009	0.01

Source: Ministry of Health and Environment [2016], CL6

2-6-6 Climate Projections

Figure 2-5 shows trends in projected rainfall for Sinjar District for the period 2020-2100. This projection is based on downscaling, processing and analysis of HADCM3 global climate model[5] data to identify the trend in rainfall in Sinjar District during the 21st Century for the A2 and B2 emissions scenarios.[6]

In summary for Sinjar District, the available rainfall data suggest that mean annual rainfall of about 350-360 mm/year over the period 1941-2010 [Table 2-3] has decreased by 130 mm to an average of about 220-230 mm in 1998-2019 [Table 2-6]. A similar trend is recorded in rainfall in countries on the other side of the

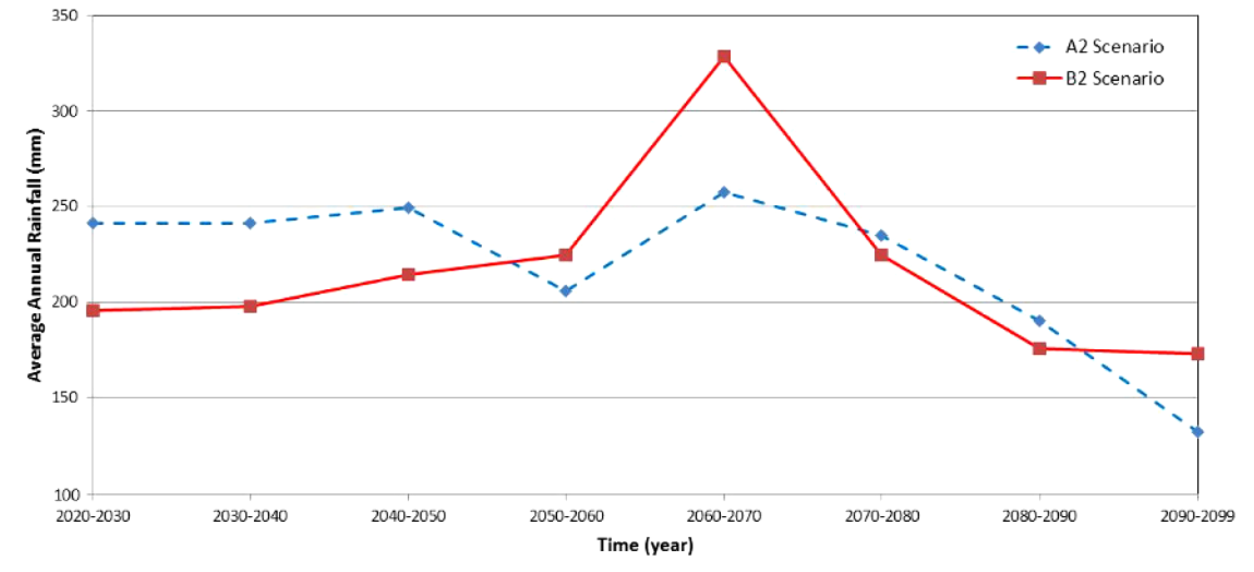
4 United Nations Framework Convention on Climate Change

5 The HADCM3 global climate model was developed by the Hadley Centre in the UK Met Office.

6 The A2 emissions scenario assumes that economic development is regionally oriented and economic development and per capita economic growth is slower and more fragmented than for other scenarios. The B2 scenario assumes a slower global population growth rate and the development of local solutions to economic, social and environmental sustainability.

Gulf like Bahrain and UAE, but here it is recognised that the post-2000 lower rainfall may simply be part of a longer-term fluctuation.

Figure 2-5 Trends in Projected Rainfall for Sinjar District for A2 and B2 Emissions Scenarios



Source: Al-Ansari et al [2014], CL2

Climate change modelling predicts a further decline in mean annual rainfall of the order of 75 mm to around an average of 150 mm/year to be reached by the end of the 21st Century [Figure 2-5]. Clearly, a process of drying may be underway which will severely constrain agriculture without the use of techniques such as water harvesting to sustainably maximise the availability of water resources.

This long-term picture of declining rainfall has been pieced together from the results of disparate studies. For this reason, values of rainfall presented in Table 2-3, Table 2-6 and Figure 2-5 do not link together precisely, but do suggest an overall trend. Hence the 2020-30 values are also different.

2-7 Wadi and Spring Discharge

No recent references have been found describing the existence of gauging stations in the project area that measure wadi or spring discharge.

The discharge of six springs at Kani Kedri were measured by v-notch in 1979-83, recording flows of 0.4 to 1.4 m^3/s. [GW10, Jawad S B & Hussien K A, 1986, Contribution to the study of temporal variations in the chemistry of spring water in karstified carbonate rocks].

Reference has been found to the recording of three flood hydrographs in a 53.8 km^2 catchment in Erbil Governorate in the winter of 1991-92. These three flood records have been used in several theoretical studies of water harvesting dam sites in Sinjar District, discussed in Section 4. Reference has also been found to continuous gauging in Wadis Amij and Awij of several flood events in the winters of 1975-76 and 1978-79 by the Ministry of Agriculture. Wadis Amij and Awij are right bank tributaries of the River Euphrates located some 200 km south of Sinjar in the Western Desert.

Wadi flow records are fundamental to both water resources assessment generally and to estimation of water volumes available for harvesting by wadi diversion or storage. The Ministry of Water Resources has confirmed that there have never been any recording sites in Sinjar and Baaj and there are no plans to fill this obvious gap. The Ministry of Agriculture has not been consulted.

2-8 Groundwater Monitoring

After correspondence with the Ministry of Water Resources, it was confirmed that there have never been any observation boreholes or monitoring wells in Nineveh, which would record long-term groundwater level and chemistry.

The absence of research papers or government reports on the overall status of groundwater resources in the Nineveh region is also indicative that there are no data-sets on long-term groundwater level and chemistry that might be analysed. The condition of the aquifers is therefore largely unknown and information is reliant only on anecdotal evidence and well construction data from the inventory of 5,698 wells in Sinjar and Baaj Districts, covering the period 1940-2012, with well depths of reaching 335 m.

The absence of groundwater monitoring leaves the AMAL project “blind” with respect to how groundwater resources might be improved or exploited.

2-9 Limitations and Gaps

The literature reviewed is considered to have the following limitations:

- The meteorological studies reviewed cannot be said to be definitive since complete data sets have not been used or a standardised period adopted.
- Some basic hydrological analysis, such as probability studies of rainfall at Sinjar and Baaj, do not appear to have been reported.
- The spatial distribution of rainfall isohyets and other variables has not been mapped across the project area, taking into account variations in altitude [rainfall stations are at low altitude].
- The occurrence of snow has not been discussed in the literature reviewed, so precipitation measured is actually rainfall.

The following are presently considered to be gaps in relation to the objectives of the AMAL project:

- Basic information on the climatological network of stations in the project and neighbouring areas, including dates of opening/closing of stations.
- Listings of all meteorological variables measured at each station and their complete periods of record [and data gaps].
- Complete absence of routine monitoring of wadi and spring discharge, and analysis of runoff in relation to rainfall.

2-10 Recommendations

The following recommendations are made:

- Obtain complete listings of the climatological network of stations in the project and neighbouring areas from the Ministry of Transport.
- Obtain complete listings of all meteorological variables measured at each station and their complete periods of record [and data gaps].
- If required, consider obtaining complete meteorological data records for analysis, planning and design.
- If required, consider installation of meteorological and/or hydrological monitoring facilities [wadi gauging station] as required.

3 Groundwater

3-1 Evaluation of Available Documentation

This section refers to **Deliverable 2** of the Terms of Reference:

"2. Review available research papers and studies on the Ray-Jazira aquifer, summarize, identify gaps, limitations and provide recommendations".

3-2 Topography and Geology

3-2-1 Topography and Catchments

While Al Jazira refers to the area between the Rivers Euphrates and Tigris, the focus of the NRC project is on Sinjar District and the northern part of Baaj District, where agriculture is possible. This region was one of the best-known agricultural areas in Iraq for dry-farmed wheat production.

In southern Baaj, soils and groundwater become too saline for practical use without treatment, and the region is dominated by the internal drainage system of Khabrat Sunaysilah [playa lake]. These saline lakes and salt marsh were shown in Figure 2-1, and south of a clear east-west line, salt encrustation of soils becomes clearly visible in satellite imagery. In contrast, Lake Thartar in the south-east remains comparatively fresh. There are therefore four main hydrographic basins in the project area:

- Wadi Al-Ajeej, 1,495 .... 3,670 km^2
- Sunaisala playa lake basin .... 1,480 km^2
- Wadi Al Tharthar, limits defined by Lower Fars anticlines .... 5,490 km^2
- Alluvial fans and plain north of Sinjar Mountain .... 1,495 km^2

There are as many as seven groups of groundwater resurgence along the southern edge of Sinjar Mountain which drain a mountain catchment of 350 km^2.

3-2-2 Geology and Groundwater Occurrence

Information on geology and groundwater occurrence has been obtained principally from Al Sawaf [1977]. The project area is dominated by an asymmetric anticline of older rocks forming Sinjar Mountain, and flatter syncline to the south which rises in a more gentle fold to give higher ground just north of the Euphrates valley.

The sedimentary rocks filling the syncline can be divided into two main groups of strata: the Upper Fars [Injana] and Lower Fars [Fatha] Formations, with a maximum thickness of 350 and 460 m thick respectively. A thick veneer of Quaternary sediment covers the solid geology across the whole district, which gives rise to the good quality of soils for agriculture. The mountain wadis have built alluvial fans out on to the plain at the mountain edge, and the north side of the anticline is steeper and eroding more significantly than the southern perimeter. This erosion has resulted in an elongated valley on the northern limb of the anticline, which was home to livestock-rearing communities, and the wadi discharges on to the northern plain. The Upper Fars only outcrops in the deeper wadi valleys due to the extensive cover of Quaternary deposits of variable sands, silts and clays. The basic geological structure is sketched in the generic North-South schematic shown in Figure 3-1.

Fresh groundwater occurs both as karst springs at the edge of the mountainous area along the contact of the Serikagni and Jeribe Limestones, and in the upper layers of sediments which fill the syncline, fed primarily by mountain runoff and direct rainfall. The following springs and their catchment are mentioned: Sinjar village 40 km^2, Gizil 22 km^2, Gabare 12 km^2, Jaddala 46 km^2, Sakiniya 23 km^2, Kharabet Ikheder 23 km^2, Umm Al-Diban [ام الديبان] 73 km^2 [disappears into sinkholes]. The Jaddala spring is perennial and 330 l/s was measured by v-notch in 1977.

Both Upper and Lower Fars consist of multiple layers of water-bearing strata, sometimes with little vertical connectivity or lateral continuity. The strata repeat monotonously but can be broadly classified into the principal lithologies shown in Table 3-1. The principal aquifers are the Quaternary, Upper Fars and Jeribe Limestone.

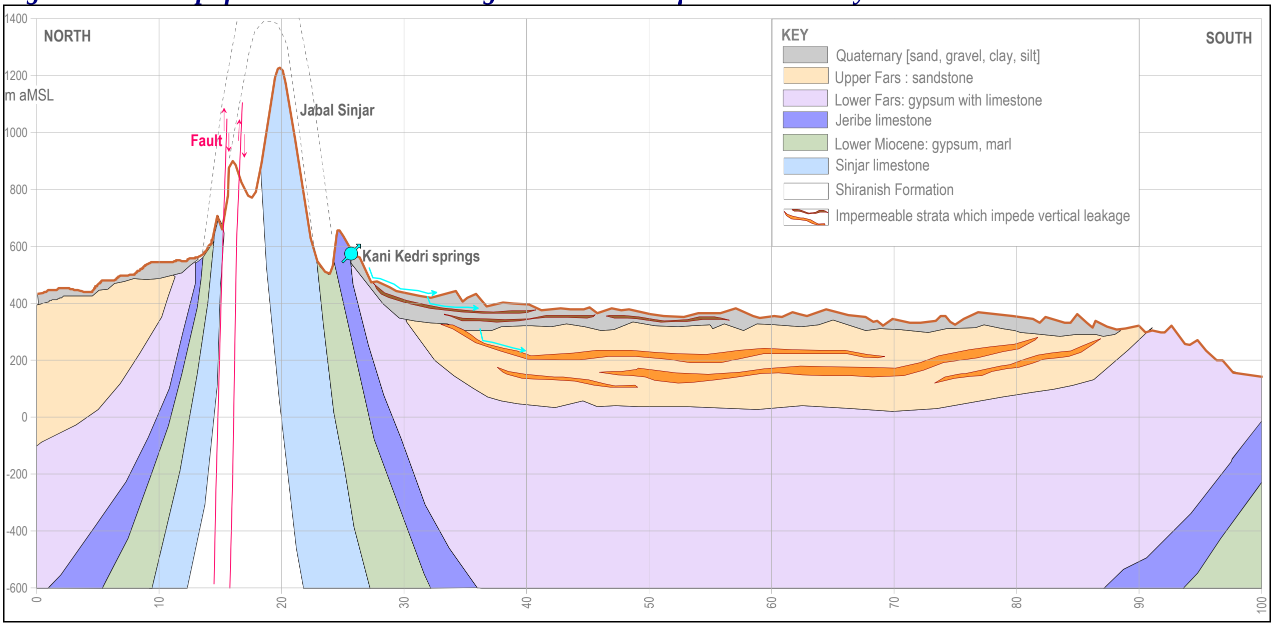
Because of the faulting and asymmetric nature of the Sinjar anticline, the springs which appear on the southern side of the mountain do not issue from the Jeribe limestone on the north side.

Table 3-1 Stratigraphy and Lithology of the Al Jazira Syncline

Age	Formation name	Dominant rock	Lithology range
Quaternary		unconsolidated	aeolian and alluvial fan, valley alluvium [sand, gravel, silt, clay]
Pliocene	Lower Bakhtiari		
Upper Miocene	Upper Fars [Injana]	sandstone	Coarse-grained Sandstone, siltstone, claystone
Middle Miocene	Lower Fars [Fatha]	Gypsum	Gypsum interbedded with limestone in the upper part and green marlstones
	Jeribe Limestone	l/st	Dolomitic Limestone, with chalky limestone
Lower Miocene	Dhiban Anhydrite	Gypsum	Gypsum with marly limestone
	Serikagni	marly limestone	Limestone with marly limestone and marlstone
Upper-Lower Eocene	Avanah limestone	marly limestone	Limestone alternating with marly limestone
	Jaddalah	Clay/marl	Chalky limestone interbedded with marly limestone
Lower Eocene to Upper Palaeocene	Sinjar Limestone	limestone	Massive crystalline limestone
Upper Cretaceous	Shiranish	marl	Shelly marls and marly limestone

Blue shading indicates important water-bearing strata.

Figure 3-1 Simplified North-South Geological Schematic of the Al Jazira Syncline



Source based on Al Sawaf, 1977.

3-2-3 Aquifer Hydraulics and Water Quality

In addition to structure and lithology, the permeability will vary depending on the degree of fissuring and porosity of the formation. Hydrogeological assessments require spatial estimates of these variables which are usually derived from aquifer pumping tests carried out in boreholes in the target aquifers. No evidence of such field operations was found in the literature or analysis of pumping data, except for the Al Sawaf thesis [1977]: one paper provided theoretical values derived from geoelectric survey. Selected analysis from Al Sawaf has been reproduced here in Appendix C, in particular groundwater quality types and the spatial variation of transmissivity. This shows corridors or fans of higher transmissivity possibly related to coarser sediment in the core of alluvial fans, and such information could be used to focus future aquifer reinstatement, as the yield of wells would normally be higher and recharge faster in these zones.

3-3 Groundwater Exploitation

3-3-1 Wells

Dug-wells and boreholes traditionally exploited freshwater in the Quaternary and Upper Fars aquifers characterised by a TDS of 0.5 to 1.0 g/l. The best quality water is close to the source of recharge in Sinjar Mountain, in particular the area up to 12 km south of Sinjar village, roughly as far as Baaj, and in a broad west-east arc, where TDS is reported to lie in the 1 to 3 g/l range. Beyond this, groundwater is too mineralised for drinking purposes, and use for agriculture depends on the degree of salt-tolerance of the crop and low intensity use to ensure salt accumulation does not occur in the soil. The lowest salinity is water in the alluvial fan at Sinjar town where superficial deposits are recharged by limestone springs.

The Upper Fars has a higher incidence of sandstone and many wells have been excavated or drilled in the Upper Fars. There is likely to occur calcrete and gypcrete strata at certain depths which are impermeable and prevent vertical infiltration. Soils a little way south of Baaj start to become saline with most shallow wells brackish and soils showing a white salt encrustation evident on the surface. Groundwater would logically move towards Khabrat Sunaysilah [playa lake] which forms the lowest point in the synclinal basin.

The principal problem with groundwater in the area is salinity, which becomes steadily worse towards the south and generally with greater depth in the aquifers: this is to be expected as rainfall becomes lower and distance from the source of recharge increases, with intercalated impermeable layers at depth which prevent recharge by leakage through the shallower horizons.

For reasons of runoff, groundwater position, water quality, historical infrastructure and agricultural practice, it is likely that the area between the town of Baaj and Sinjar Mountain will be the focus for the AMAL project. There is little or no groundwater information on the plains north of Sinjar Mountain.

MOWR provided a well inventory as an Excel spreadsheet which has been processed to reveal some general statistics in Table 3-2. In 2014, there were a total of 5,698 dug-wells and boreholes in the project area, of which the majority are boreholes exceeding 45 m depth, and 17 groundwater springs. The maximum depth of recorded construction details is 300 m. Their spatial distribution and data on water scarcity are shown in Figure 3-2. There are clear focal points of well concentration and problems of water shortage.

Table 3-2 Inventory of Springs, Wells and Boreholes in the Project Area

District	Springs	Total No	Dug-well	Bore holes	Min depth mbgl	Max depth mbgl	Min SWL mbgl	Max SWL mbgl	Min Elev m aMSL	Max Elev m aMSL	Construction Year	
											Earliest	Latest
Sinjar	11	4371	113	4258	4	300	3	91	201	937	1945	2014
Baaj	6	1327	53	1214	5	300	3	82	241	627	1940	2012

Some errors were found in the inventory with contradictory classifications and no information was given on the target aquifer at each site, usually recorded by the position of the well screen: the information is therefore only considered indicative and needs to be updated to show how many of the wells are actually being used.

3-3-2 Karez

It is reported [Al-Sawaf, 1977] that a large number of karez had been built in the area east of Baaj, but they are no longer visible in satellite imagery. A brief interpretation of imagery found five karez along the edge of the mountain between Wardiya and Sinjar town. Due to the extent of groundwater exploitation in recent decades, groundwater levels may have fallen below the invert level of these structures in some cases, and some canals might be blocked by debris which has fallen into the construction shafts. Current groundwater levels are not known. There are examples of dug-wells with elaborate staircases down to depths of 25 m.

A schematic section through the Wardiya karez is shown in Figure 3-3, and this shows how the underground gallery has been excavated upstream to intercept the groundwater circulation at the geological discontinuity between the Quaternary and basement sedimentary rock [probably Jeribe Limestone or Lower Fars].

This section can also be used for conceptualisation of other karez, which would originally have been built to operate in a similar manner. Faced with declining water levels, increasing lengths of the karez are left dry.

Figure 3-2 Distribution of Springs, Wells and Boreholes in the Project Area

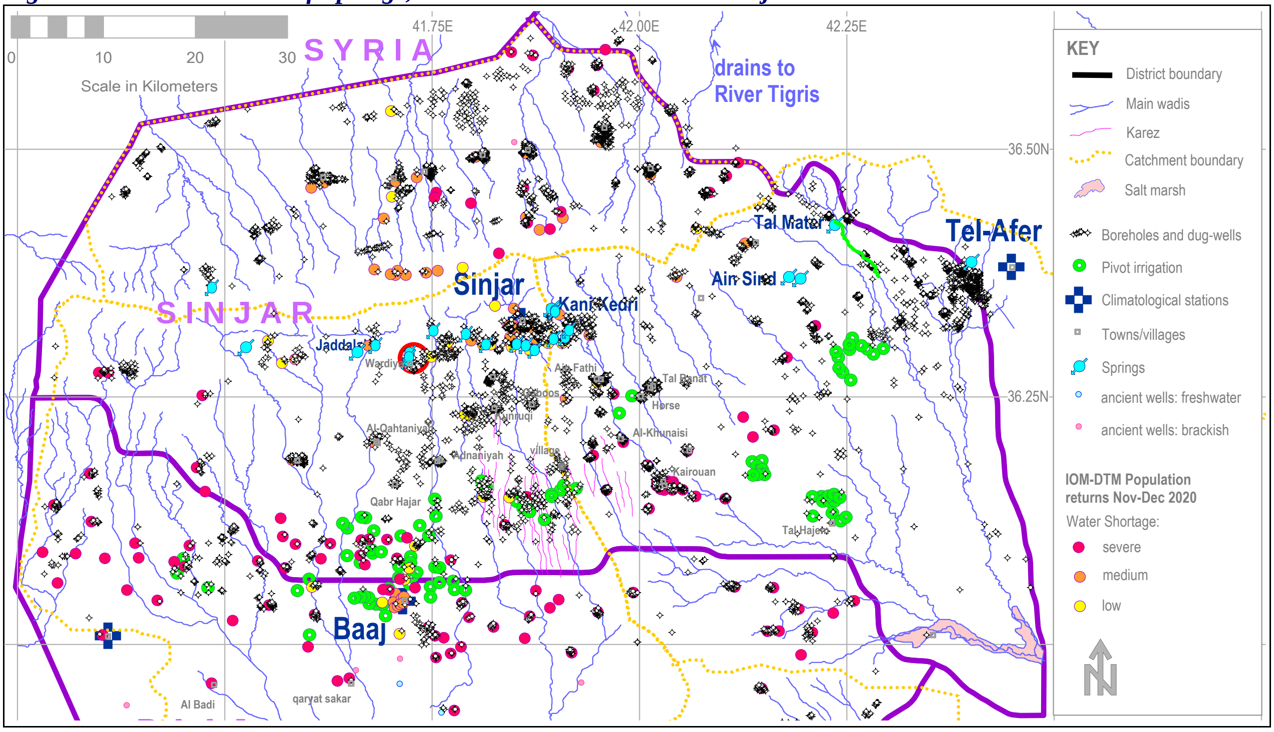
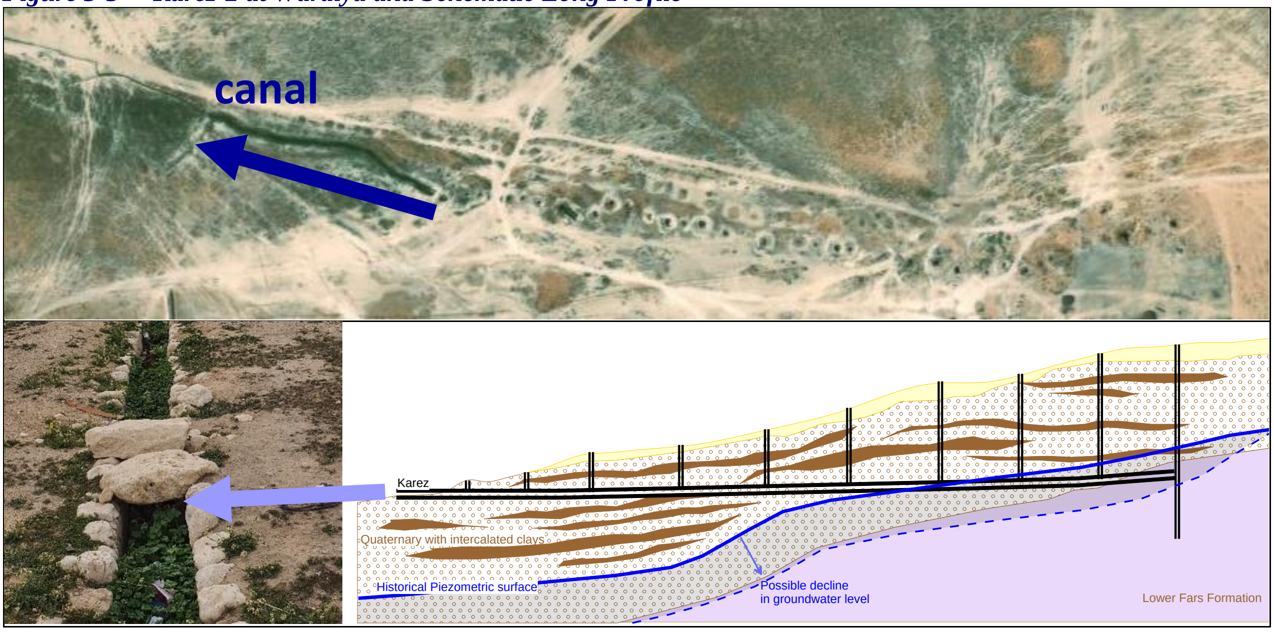


Figure 3-3 Karez-2 at Wardiya and Schematic Long Profile



Source: Water Resource Associates, Bing satellite imagery, RRA photograph

A number of karez were visited by NRC during a Rapid Rural Appraisal [RRA], 15-18 March 2021. Several have become blocked or have fallen into disrepair, while others remain operational. Further surveys of the karez should be undertaken to establish their condition, use and potential for reinstatement.

The southern foothills of Sinjar Mountain and Jeribe Limestone benefit from erosion of a west-east valley. This will enhance recharge along the north side of the limestone outcrop, leaving only significant storms to overflow through break-through points in the limestone ridge. This can be seen in the 10 m contouring of the map in Appendix C-3, developed from the SRTM DTM.

Mean annual production in a karez could amount to 0.4 to 0.8 Mm^3, based on a mean groundwater catchment of 11.4 km^2, and mean annual rainfall of 350 mm, that is an average rate of groundwater capture by the karez of 10 to 15%.

These values are useful in showing the potential yield of karez systems: even if enhanced, they capture a comparatively small amount of the resource at the the edge of the Sinjar plain, so are most likely to be of use for limited supplemental irrigation of vegetables and similar crops in the vicinity of villages.

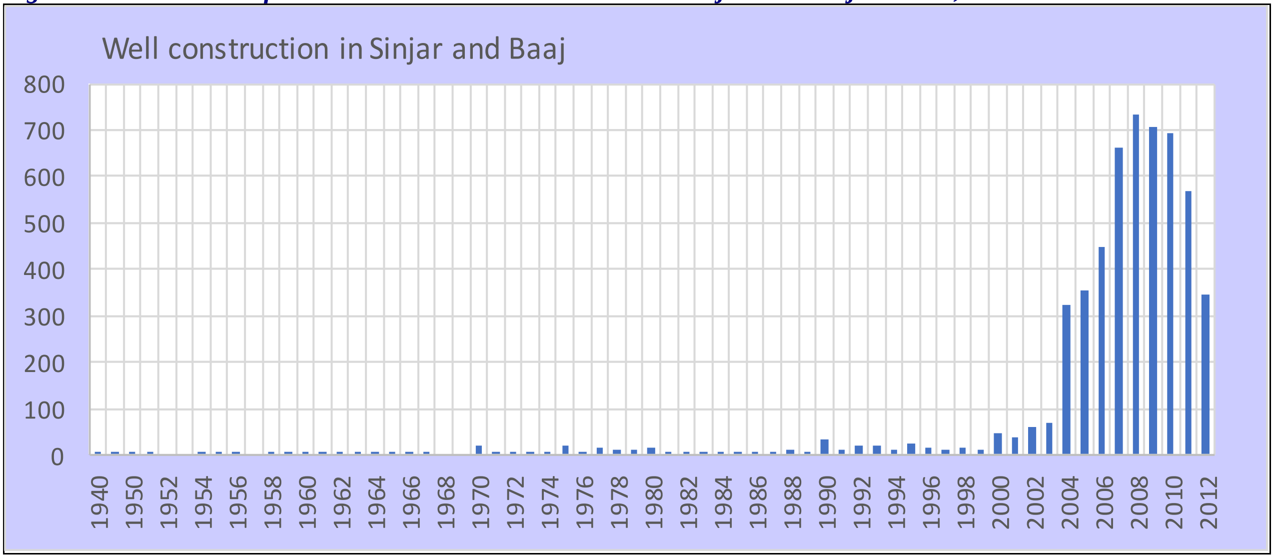
3-4 Present Groundwater Conditions

Documentation specifically on Sinjar and Baaj Districts is sparse. The groundwater research reviewed for this report generally refers to other parts of Iraq or is not up to date, and contains many temporal and spatial gaps, which makes strategic planning, monitoring and providing groundwater development advice difficult. No work would appear to have been carried out by the Iraqi government to analyse and interpret historical and current data on groundwater resources in the project area. Instead, the government has been involved in strategic planning at national level which has included the development of a groundwater model of the whole country. Such work is of no real relevance to the task in hand, apart from reinforcing the general guidance that water resources development in Sinjar and Baaj should not have an adverse impact on flows in the Tigris River.

In the absence of studies and documentation, the MOWR representative assigned to the NRC project provided an inventory carried out in 2012 of groundwater sources in Sinjar and Baaj Districts and an extract from the South Jazira confidential monograph entitled Strategy for Water and Land Resources in Iraq, prepared for the Ministry of Water Resources in 2014.

The well inventory was analysed and it was found that the annual rate of borehole drilling since 2004 has been staggering, as shown in Figure 3-4. Up until 1989, an average of 4 to 5 boreholes were built in the area each year, but this then jumped to 27 per year for the 1990-2003 period, and then since 2004, an estimated 538 boreholes per year. To put this in context, and if correctly designed and constructed, it would be usual to expect to drill 250 boreholes per year using 3 to 4 drilling rigs reaching depths of 100 to 150 m in sedimentary formations at diameters up to 300 mm. Clearly, this implies having up to 8 rigs drilling non-stop every day of the year since 2004. Although the data are questionable, this intense activity presumably stopped in 2014. Average well yield appears to lie in the range, 0.1 to 32 l/s for Sinjar and 0.1 to 16 l/s for Baaj District.

Figure 3-4 Number of Wells and Boreholes Constructed in Sinjar and Baaj Districts, 1940-2012



If the data are accurate, it would imply that excessive damage has been done to the aquifers since 2004, and there are no monitoring data in the districts under study, although boreholes are concentrated in certain areas, as shown in Figure 3-2. It was confirmed that the State Groundwater Commission in Baghdad has no observation boreholes in the project area.

There are no references or data describing long-term change in groundwater level or quality, except for a surface geo-electrical survey, carried out by Al Ridha N A et al [2013], which compared groundwater level in 2012 with an identical survey done in the 1980s. The survey covered a large area of 7,920 km^2 containing different groundwater types and different lithologies down to the Lower Fars Formation, which would make interpretation challenging. They concluded that there had been an average drawdown of 1 to 3 m over the 30-year period. No information was given on the construction details of the six calibration wells: given the multiple level aquifers in the area and known difference between groundwater quality at different depths and locations, the results should be treated with caution.

3-5 Water Resource Availability

Although there appears to have been a general lack of hydrological data and water resources analysis for the project area, it was considered in 1977 that average annual rainfall of 200 to 400 mm was enough to replenish aquifers, at the level of exploitation existing at the time.

Without taking the different geologies into account, a crude assessment of available resources in the area south of Sinjar Mountain as a function of rainfall has been made in Table 3-3. This shows that the level of abstraction by 2,660 wells in the Al Ajeej catchment amounts to 207 Mm^3, which grossly exceeds an estimated recharge of 89 Mm^3 [33 mm] assuming irrigation of crops for three months of the year and an average of 10 l/s per well. A sustainable level of abstraction would need to more than half the number of existing wells to 1,150 [if indeed they are all used, not known], or the irrigation period might be reduced.

It is reported that cooperative farms at Kirkubat and Irfai [Mazraat Al Anwar] used to use deep boreholes for both irrigation and livestock watering, so an option might be to use groundwater only for livestock and fodder.

Table 3-3 Water Budget for the Aquifers South of Sinjar Mountain

Catchment	Area	Rainfall	Rainfall volume	Evaporation	Runoff	Deep Loss	Recharge	wells	Actual abstraction
Unit	km^2	mm	Mm^3	Mm^3	Mm^3	Mm^3	Mm^3	No	Mm^3
Al-Ajeej	2,700	330	891.00	623.70	133.65	44.55	89.10	2660	206.88
Al Tharthar	1,157	330	381.81	267.27	57.27	19.09	38.18	1140	88.65

Source: modified from Al Sawaf, 1977

The practicality of reversing the yield and salinity problems in the aquifer depends on reducing the present level of abstraction rather than enhancing recharge. If a sustainable source was found for recharge, one well might introduce 0.2 Mm^3 per year. These rough values help to put the general problem into perspective.

Given the probable damage to the main aquifers in the Quaternary and Upper Fars Formations, which will require concerted effort and management to reverse the probable trends, the project might focus use of groundwater recharge on the area of Quaternary deposits immediately south and north of Sinjar Mountain, where a spring source or karez might be enhanced. However, use of such water for recharge would compete with other direct uses for domestic and horticultural requirements. It was confirmed during the rapid rural appraisal that springs at Sinjar and Kani Kedri were being used for irrigation of vegetables by gravity and some impoundment.

A similar water budget calculation can be done for each spring and associated irrigation area. The budget for Sinjar spring was calculated by Sawaf [1977], summarised in Table 3-4, and he found that 30 to 35% of rainfall resurged at the spring and 3% of the other groundwater recharged downstream aquifers.

Table 3-4 Water Budget for Sinjar Spring

Catchment	Area	Rainfall	Rain vol	Evap	Discharge	Losses
Unit	km^2	mm	Mm^3	Mm^3	Mm^3	Mm^3
Sinjar Spring	40	430	17.2	10.32	6.36	0.52

3-6 Recharge options

There are a number of options that might improve the groundwater potential of the region. The terms of reference refer to "borehole recharge": this implies injection by pumping or gravity of clean water into the aquifer at an injection or recharge well and implies having a source of water of sufficient quantity to justify the expense of setting up such schemes. The water source in Sinjar will be wadi runoff or rainwater.

A key problem of the districts is that aquifers may have been damaged irreparably by the intense rate of construction of boreholes over an eight-year period, 2004-2012, which may have unfortunately connected shallow water-bearing strata with the deeper poorer quality water.

It will not be worthwhile enhancing aquifer recharge, unless the deeper saline boreholes are sealed permanently. At District level, there are so many boreholes that this would require a carefully-managed initiative by an appropriate government agency, after providing clear explanation to the communities in the region that it is being done for their benefit. The actual operation is fairly simple and consists of pumping a bentonite-cement grout using a tremie-pipe into each borehole so that the screen and annular filter pack are infiltrated and all water-bearing layers are sealed off. At the surface the casing would be removed and hole backfilled.

If this was carried out, it is likely then that recharge could focus on the shallow water-bearing strata. It is considered that drilling boreholes deeper than 120 m in the area immediately south of Sinjar Mountain is counter-productive.

Recharge by sinkhole, pond, roof runoff or recharge dam could then be considered. The recharge water would need to be clean and free from sediment, so wadis, ponds and recharge dams would require some form of sedimentation. The usual process at recharge dams is to release water through a draw-off tower to allow infiltration of the water in the wadi bed downstream which can be enhanced by using underground infiltration galleries.

The simplest form of recharge system that could be considered in a pilot scheme is the collection of rainwater from roofs and then connection to a soakaway borehole. These systems are becoming increasingly common in Europe and go under the name of SuDS [Sustainable drainage systems]. Although the idea in higher rainfall areas is to reduce runoff and prevent flooding, the same soakaway borehole concept can be used in water scarce areas to create a groundwater mound in the area. In recent years, WRA has designed and built such systems. In Sinjar, a target village or town could be selected and pipework laid to centralise roof runoff and carry the water to a newly-drilled borehole. An observation borehole would also be required to monitor the performance of the scheme.

Spring discharge could be increased or turned into a perennial flow if certain wadi courses were captured and diverted to a recharge system which might be a combination of crates and boreholes. Study of 1:25,000 geological and topographic mapping would be required to identify the best locations, supplemented by a DTM derived from satellite imagery.

The capture and diversion of wadi runoff is more controversial and would depend whether the flow is being used by farmers downstream. Some wadis such as the Sinjar and Kani Kedri wadis are known to flow a considerable distance south before being absorbed by local terrain or farm diversions.

Groundwater recharge by wadi dams in Baaj District would be located too far south to be of local use and water would have to be pumped back up to the higher elevations of the Al Jazira plains. Such schemes are therefore concerned with reservoir storage for large-scale irrigation rather than water harvesting, and they are described in Section 4.

There may be some scope for small dams or weirs closer to the foothills of Sinjar Mountain, and here recharge would be correctly positioned for increasing groundwater in the shallow Quaternary aquifers.

3-7 Limitations and Gaps

The literature review has picked up the following limitations:

- There is only one reference which refers to groundwater resources in Sinjar and Baaj Districts; several research papers focus on very narrow fields of science in geology and geophysics, while others cover the whole of Iraq and are therefore too general to be of help.
- There are no long-term data-sets on groundwater levels and hydrochemistry.
- There are no routine measurements of spring discharge or well abstraction.
- There are no well construction details in the well inventory showing aquifer depths exploited.

Given the general absence of studies and documentation, historical satellite imagery was reviewed and an MOWR well inventory analysed to obtain some insight into the possible conditions on the ground.

3-8 Recommendations

The following recommendations are made:

- The NRC staff on the ground have reported through conversation with local communities that the recent winter has been drier than average. It is important to quantify this, so immediate access to a rain-gauge would allow this. Project rain gauges should be established at the sites of pilot schemes.
- To support project planning and monitoring, three boreholes in appropriate locations should be equipped with pressure transducers to start monitoring groundwater levels long-term, in each of three target aquifers [Jeribe Limestone, Quaternary deposits and Upper Fars].
- To support project planning and monitoring, V-notch thin plate weirs should be built at three selected springs and equipped with water level monitoring equipment.
- The accuracy of the well inventory should be improved by bringing it up-to-date, to show its current use, yield, water level and depth, taking a sample from each and dipping the water level. The difference between static water level in the inventory and current dipped water level may be indicative of the long-term change.

4 Water Harvesting

4-1 Deliverable 1

This section refers to **Deliverable 1** of the Terms of Reference: "review existing rainwater harvesting and small dams research papers in Sinjar district, summarize, identify gaps, limitations and provide recommendations".

4-2 Small-Scale Water Harvesting

4-2-1 Small-Scale Water Harvesting

There are no reports of small-scale water harvesting schemes other than the interpretation given to satellite imagery described under Section 4-3-2 which may suggest impounding of waters from flash flooding of neighbouring wadis. Other use of supplementary water is reported [and has been testified to in discussions with NRC staff and colleagues] as micro-irrigation from wells and springs which is used for vegetable/ fruit production and small plots of maize. The only other evidence of irrigation, observed on satellite imagery, is the existence of central pivot schemes, using boreholes as sources of water. This is not reported in the literature, and is almost certainly exclusive to richer farmers.

There are many sources of potentially applicable water harvesting techniques, suited to the area, that could be characterised as small-scale [i.e. other than dams supplying a source of supplemental water for large areas]. Thus, attention is drawn to compilations of technology descriptions: inter alia, Oweis et al [2012, WH23], Mekdaschi-Studer et al [2013, WH 24] and Critchley and Siegert [1991, WH12]. Techniques, both indigenous and improved, include variations of:

- Rooftop and compound harvesting [corrugated iron rooftops are excellent sources of clean water which can be captured and held in tanks of various sizes and materials. Household compounds are generally compacted and have high runoff coefficients. Runoff can be channelled into kitchen gardens carrying organic matter that has accumulated around the house. [WH24 covers design criteria].
- Bunds encircling fields to capture and hold overland flow [WH12, page 80 illustrates the "teras" system from Sudan, storage and utilisation can take place in the same location and it is easier to be equitable].
- Contour ridges to harvest small amounts of water at regular intervals [e.g. for trees] [WH23 describes these]
- Renovation of the hexagonal lattice systems of contour ploughing, practiced historically in Sinjar District.
- Stone bunds and terraces [see WH23].
- Haffirs [open, excavated water pans] for livestock watering [potentially combined with vegetable gardens below their spillways] [see WH23].

4-2-2 End-Use of Water Harvested

With respect to end-use of harvested water, there is a cluster of studies that report the benefits of supplemental irrigation [Oweis et al, 1999, WH21; Adary et al, 2002, WH18; Zakaria et al, 2013, WH10]. These studies are closely related in terms of authorship, and there is considerable cross-referencing. It is pointed out that the project area has traditionally relied [for the most part at least] on rainfed wheat production [both bread and durum wheat], although this may become riskier as drought years become more common with climate change. The potential benefits of supplemental irrigation from water harvesting sources are very considerable. Because such irrigation can be applied at stages of crop growth which are particularly sensitive to drought [establishment, flowering and grain-fill] the overall water use efficiency [grain per unit water consumed] can be increased. A recommendation from the literature is that a general target should be to ensure that 50% of the crop water requirement/ irrigation demand is met [including rainfall]. This translates very broadly into supplying up to 300 mm on wheat in the driest of years. Calculations are required to establish what extra water needs to be [or can be] harvested to meet what this demand may be – and clearly the design must build in the level of risk that is tolerable. The "water harvesting paradox" that makes these calculations so difficult is the inescapable fact that when the crop demand is greatest, the runoff to be harvested is the least.

It must be noted that the literature is silent on various important aspects of water harvesting that constitute an enabling environment for successful water harvesting: after all, water harvesting is not simply about provision of water. Thus, [1] soil fertility is crucial as it can quickly limit the efficiency of extra water; [2] supplies of farm inputs are crucial as lack of machinery or seed are also potential limiting factors; [3] effective social organisation is an absolutely necessary condition when establishing community works that need management, sharing and equity.

While livestock watering is clearly specified as one of the aims of water harvesting implementation – corroborated by discussion with NRC personnel - there is only anecdotal information about the requirements. The NRC agronomist confirmed that some land users have flocks of up to 200 small stock, though other, poorer, households may have just a few. Cattle are apparently not numerous. In the case of small stock, consumption may reach 5 litres per day per head; dairy cows need up to 150 litres per head. However, hard data are lacking. There needs to be more precision, for planning purposes, about what types of livestock are managed in the area or under what regimes. It is important to know whether the main demand is for livestock in and around the household [for example, a limited number of small-stock and/or dairy cows] or rather [as indicated in discussions] for livestock owned by pastoralists covering a wide area of grazing and browsing land. In the latter case, water points can be a crucial element of grazing strategies, allowing on the one hand access to dry season grazing, and on the other hand deliberately limiting overgrazing in other zones. At least indicative information and data are vital.

4-3 Large-scale Water Harvesting

4-3-1 Definition of a Small Dam

The focus of this water harvesting section is on schemes comprising earth embankment excavations and small dams, generally considered to refer to structures which do not exceed the following criteria:

- Height above foundations 15 m.
- Maximum reservoir storage 3 Mm^3.

The classification varies from country to country but international best practice is promoted by ICOLD [International Commission on Large Dams] and dam classification can be traced back to a much-used source of reference, Design of Small Dams, [US Bureau of Reclamation, 3rd ed 1987].

A small dam will still be a significant structure with associated design and impact considerations, and certainly more influential than a pond. There is therefore a crossing over from micro-scale to macro-scale in passing from pond-scale to the scale of small dams.

4-3-2 Existing Schemes

At the time of writing, no documentation has been found or reviewed on historical or modern water harvesting schemes implemented in the project area. However, inspection of high-resolution satellite imagery probably taken around 2010 [https://www.bing.com/maps/] suggests ploughing patterns in fields and diversion of flow from local small wadis that would act as micro-scale water harvesting schemes [Figure 4-1]. Preliminary enquiries on the ground by NRC [March 2021] suggest that such ploughing may no longer be practiced and no evidence of flow diversion was found, although the reconnaissance was limited in extent. Further enquiries and field inspections are necessary to confirm these observations.

A small pond approximately 10 m in diameter has been constructed at Kani Kedri spring, some 5 km east of Sinjar town [Appendix D1-1]. The pond temporarily retains spring flow and allows farmers to pump the water to nearby fields.

Household water harvesting for domestic and household garden use was proposed by NGO Relief International in a 2016 WASH assessment report [WS01]. Enquiries should be made to Relief International regarding their activities involving water harvesting to confirm whether they have been active in Sinjar District since 2016 and to obtain any relevant reports for review.

In Erbil Governorate, an anonymous undated report [WH5] documents the construction of the “Bistana” water harvesting pond near Bistana village in April-June 2019 at a cost of U$55,000. Co-financed by UNICEF-Erbil, the pond has volume of 12,000 m^3 and is part of a strategic plan by the Ministry of

Agriculture and Water Resources in Erbil Governorate to combat drought. The plan includes the construction of 25 large scale ponds and 49 smaller ponds. Eighteen of the smaller ponds have been constructed, one of which is the Bistana pond. Potential uses of the Bistana pond include recharge of groundwater, irrigation of 550 ha of agricultural land, watering of 5,000 trees, 5,000 livestock, local wildlife conservation, tourism and provision of drinking water if the water is treated [Bistana village has a population of 10,000]. The pond is hailed as an example of UNICEF-Erbil stepping away from humanitarian assistance and getting involved in development assistance. The report calls for clear site selection criteria for future ponds that include community vulnerability. Enquiries should be made regarding the existence of design reports on Bistana pond and other planned ponds, and hydrological and other studies that support the designs.

Figure 4-1 Ploughing Patterns Suggest Water Harvesting

Location: North side of Highway 47: 36.377718°, 42.337353° **Hex4**

Further away, in the Badia region of Jordan, Alkhadder [2003, WH3] reports the use of ponds for water harvesting. In villages, small ponds of about 10,000 m^3 capacity, lined with concrete to prevent infiltration losses, store water diverted in channels from local small wadis with catchment areas of a few hectares. Small concrete tanks of 50 m^3 capacity act as sediment traps prior to discharge into the main tank. Simple maintenance is required comprising removal of sediment and repair of cracks in the concrete linings. The ponds have been in use since the mid-1960s. A programme of larger earth ponds was commenced in the mid-1990s by Jordan's Badia Research and Development Programme in cooperation with the Ministry of Water and the US Army Corps of Engineers. Earth ponds, up to 100 m wide, 4-5 m deep and over 50,000 m^3 in capacity, were excavated using bulldozers adjacent to major wadis where soils are softer and less permeable. Water is diverted from the wadi. The earth ponds have been found to be efficient in storing and providing water over many years, and have been successfully used for irrigation, animal watering and washing. Pond water quality is an issue. Pathogenic organisms from human activities or animals are washed into ponds in runoff. Pond water is not fit for human consumption without filtration and chlorination, a strict water quality monitoring programme and public education.

4-3-3 Small Dams Research Literature

A number of academic studies of water harvesting in the project area have been reviewed which have involved 'macro' water harvesting [small and large dams with earth embankments of 3-20 m in height and reservoirs of up to 96 Mm^3 in volume irrigating theoretical areas up to 49,000 ha]. These studies have generally aimed to calculate the theoretical area of land that can be irrigated from small dams under a number of assumptions involving rainfall and the degree to which crop water requirements are satisfied by supplemental [deficit] irrigation.[7] Two institutions have been particularly active in this research: The

[7] Deficit irrigation aims to partially fulfil crop water requirements

University of Mosul's Department of Dams and Water Resources Engineering, and the University of Lulea's Department of Civil Engineering, Environmental and Resource Engineering, Sweden.

Most studies selected dam sites on relatively major wadis such as Wadi Al-Jeej and Wadi Al-Tharthar using topographic mapping and DEMs[8]. No field surveys of dam sites were reported in the literature reviewed. Only on occasion is the location of a dam site specified. Sites are usually shown on small-scale maps, inhibiting identification of the precise location. All studies reviewed use the US Soil Conservation Service [SCS][9] runoff curve number [CN] method to estimate inflows to the dams. In several cases, however, studies calibrated the CN model to three observed wadi runoff hydrographs for three single storms which were recorded in the 1991-92 rainy season on a 53.8 km^2 catchment in Erbil Governorate [**Rafik, 1993, not available**][10]. That most studies use the same historical data again and again to calibrate the CN model reflects the lack of hydrological observations of wadi flow in the region. Examples of the academic studies follow.

Al-Taiee and Rasheed [2011, WH1] describe hydrological calculations for an earth dam on Wadi Al-Ajeej at approximately 35.766^{0}N 41.6^{0}E. The dam is said to be 12.5 m high, 1,277 m long and has a reservoir length of 7.1 km and a normal capacity of 38.8 Mm^3. The catchment area is approximately 3,043 km^2. The proposed dam had no specific reported purpose, although it was recognised in principle that the water could be used for public water supply, supplemental irrigation and groundwater recharge. Annual runoff volumes for the period 1994-2006 were estimated to range 8.5-137 Mm^3, with a mean of 53.1 Mm^3. Runoff was estimated to be approximately 6% of mean annual rainfall. No consideration was given to geotechnical or social feasibility.

Al-Ansari et al [2013, WH2], Zakaria et al [2012, WH16] and **Zakaria et al [2012, WH17]** studied multiple dam sites in southern, northern and eastern Sinjar respectively. The three papers publish the results of Zakaria's PhD thesis at Lulea University [**WH20**]. In each area, the dam sites were selected to minimise the volume of earthmoving required and to minimise evaporation [reservoirs that have relatively high volume:width ratios], but details of the dam sites are not presented. In each case, linear programming[11] is used to estimate the irrigable area under various assumptions of full supplemental irrigation [satisfying crop water requirements] and deficit irrigation to 50% and 25% of crop water requirements. The studies all conclude that meeting 50% of the crop water requirements results in the greatest benefits, although there is a cost to crop yield per unit area. Details of agronomic and economic aspects of the studies are not given in the papers.

Ezz-Aldeen et al [2016, WH6] estimated the lifespan of the reservoirs in south Sinjar studied by **Al-Ansari et al [2013, WH2]**. A soil erosion model called the Modified Universal Soil Loss Equation [MUSLE] and sediment transport theory were used to predict the accumulation of sediment in the reservoirs over the period 1990-2009. Estimated annual sediment yields ranged 9.5-20 ton/km^2 and reservoir lives were estimated to exceed 100 years. The MUSLE model was calibrated using field studies of sedimentation in the existing Duhok Reservoir in Duhok Governorate reported in **Mohammad et al [2016, WH7]**.

The above studies consider water harvesting on a relatively large scale; relatively large structures on relatively large catchment areas with relatively large irrigated areas. Such projects, if realised, would be relatively expensive and would imply the participation of multiple farmers and the authorities working in a coordinated manner. One academic study, **Hachum and Mohammad [undated, WH11],** considered a 'farm-scale' pond with a catchment area of just 10 ha. A linear programming model was developed to optimise the size of the pond [cost] and irrigated area [benefit] assuming supplemental irrigation of barley. The model was applied using rainfall and evapotranspiration data from Al-Hader. The CN method was used to estimate runoff. The volume of irrigation water applied to cropped area was reduced from 100% to 62.5% of crop water requirements to study the effect on irrigated area, and reservoir volume. The optimum irrigable

[8] Digital elevation models

[9] Now called the Natural Resources Conservation Service, an agency of the US Department of Agriculture.

[10] Rafik HR [1993] Recharging of ground water in Sinjar region. Final Report, Dams & Wat Resour Res Centre, Mosul Univ, Iraq.

[11] A mathematical optimisation technique.

area was found to be 3 ha and optimum reservoir volume to be 111 m^3/ha or 1,110 m^3. A pond shape of an inverted truncated pyramid with base dimensions of 12.5 m x 12.5 m was proposed. This size of pond would appear to be implementable by one or a small number of farmers. [Note: it is believed this study has a flaw in the modelling and results may not be reliable].

A gap in the available literature is government reports on water harvesting in the project and neighbouring areas. Enquiries should be made for government reports on water harvesting schemes in or near the project area.

4-3-4 Correct Approach to Recharge Basins

A number of literature sources reviewed show that there is a basic misunderstanding of how recharge dams are intended to operate in arid and semi-arid regions. Recharge dams are very different to storage dams.

Both storage dams [for water supply] and recharge dams will inevitably experience the accumulation of fine sediment in the reservoir basin. The sediment will have the effect of sealing the reservoir floor and reducing infiltration losses. While periodic removal of sediment is to be encouraged, the goal for storage dams is to maintain storage volume for supply, not direct recharge through the reservoir basin floor.

Recharge dams, on the other hand, should be operated so that they capture runoff, but then release it quickly through the draw-off tower to promote recharge through the natural gravels of the wadi downstream or through use of infiltration galleries downstream. The objective is to minimise time in the reservoir basin and encourage the water to enter the ground as quickly as possible. Water standing around in a reservoir basin for weeks will simply promote evaporation losses.

4-4 Remote Sensing

Remote sensing has been used extensively in the studies reviewed. However, details of which satellites, which imagery, and if and how the imagery was processed are often not given. DEMs are used by several studies to assist in the location of dam sites. However, details of their spatial resolution are not given. If derived from publically available digital databases such as SRTM [90 m pixel][12], the spatial resolution is unlikely to be sufficient for accurately defining dam characteristics. Ideally, a spatial resolution providing an accuracy of ±1-2 m in the X-Y direction and an accuracy of ±0.5 m in the vertical direction, is necessary for siting of small dams. These accuracies are obtained through photogrammetric mapping techniques provided by specialist companies, such as Photosat [www.photosat.ca].

Examples of the use of remote sensing in water harvesting studies in Sinjar follow.

Al-Daghastani [2010, WH4] describes the mapping of geomorphic landforms, land use/land cover and geological lineaments in Nineveh Governorate using Landsat 7 multispectral imagery for use in the search for sites for water harvesting dams and channels. Five dam sites in Wadi Al-Jeej and three sites in Wadi Al-Tharthar were located, notably using topographic maps, and compared on the basis of dam dimensions and reservoir volume [Landsat data do not provide a DEM]. A single preferred site was identified in each catchment, but coordinates of the dam sites are not given, though they are indicated [unnumbered] on maps which do not appear to be the final remote sensing maps. The main contribution of this work is to have generated [hardcopy] maps which show land use patterns in the mid-late 2000s. The maps are likely to be held in the University of Mosul.

Al-Ansari et al [2013, WH2], Zakaria et al [2012, WH16] and **Zakaria et al [2012, WH17]** report using DEMs and topographic mapping for selecting dam sites in south, north and east Sinjar respectively. However, details of the satellite and the DEMs and their spatial resolution are not provided.

Bilal et al [2019, WH27] report using satellite images, digital maps, and a DEM to select water harvesting dam sites in Wadi Al-Murr close to the River Tigris. Again, no details are given. However, inspection of their diagrams of the topography at the dam sites suggests that a DEM with a spatial resolution of approximately 90 m was used.

12 Shuttle radar topography mission. Available at: https://srtm.csi.cgiar.org/srtmdata/

More generally, the use of GIS to assist in the identification of potential sites for harvesting rain water is currently an active area of research. **Adham et al [2018, WH25]** present an approach to identifying sites for rainwater harvesting dams using a "site suitability model" created using ModelBuilder in ArcGIS 10.2. The approach is applied to a watershed in the Iraqi Western Desert and maps of suitability for water harvesting were generated. The model combines digital maps of physical factors: slope [from a 30m resolution DEM], runoff depth [estimated using the US SCS CN method for each 30 m pixel], land use [based on classification of a Landsat 8 image with 30 m resolution], soil texture [method unclear but may involve estimation of soil type based on clay content as deduced from Landsat 8 digital image processing] and stream order [based on mapping of stream junctions]. Each map layer is divided into classes whose limits are defined by numerical criteria. Scores are allocated to each class of each physical factor which reflect its water harvesting potential. Scoring is subjective and requires expert input. The maps are digitally superimposed and the resulting overall suitability map, which itself is divided into five classes of suitability, is said to allow planners to identify areas with the highest water harvesting potential. Actual dam sites are identified by visual interpretation of large-scale topographic cartography and satellite imagery. A suitable site for a dam is defined as “a place where a wide valley with high walls leads to a narrow canyon with tenacious walls” [Sayl et al, 2016]. SRTM data [90 m resolution] is said to be useful in assessing valley width.

Adham et al [2016, WH27] review technical methods for identifying sites suitable for water harvesting published in 48 publications dating from the 1970s with the aim of defining a general method for use in arid and semi-arid regions. The technical methods reviewed involve GIS with or without hydrological modelling [HM] and with or without multi-criteria analysis [MCA]. The paper notes that biophysical criteria [rainfall, slope, land use/cover and soil type] determine technical suitability but do not guarantee success [adoption and replication by farmers]. Failure has often been due to other, socio-economic, reasons, which are often case-specific. Selecting the most relevant socio-economic criteria requires good insight into the local situation and stakeholders involved. There is no consensus on the socio-economic criteria to use. Reference is made to FAO [2003] guidelines which suggest population density, people’s priorities, experience with water harvesting and land tenure should be considered. It is concluded the most suitable method for identifying sites for water harvesting depends on the objectives and needs of the project and on the quality of data available.

4-5 Limitations and Gaps

The literature reviewed is considered to have the following limitations:

- All studies in Sinjar District have been academic and theoretical in nature.
- Estimation of water resources at dam sites has not benefitted from local measurements of wadi flow in relation to rainfall, but have been dependent on just three flood hydrographs recorded in Erbil Governorate for model calibration. Detailed information on the Erbil catchments is not presently available.
- Estimation of irrigable areas has not [apparently] taken account of field experience of irrigation practices and real-world losses in irrigation systems.
- The reported use of DEMs [remote sensing] to select dam sites seems to imply use of low-resolution data [possibly 90 m SRTM data] for selecting dam sites. Such DEMs are not able to provide the resolution necessary for accurate estimation of dam characteristics.

The following are presently considered to be gaps and limitations in knowledge of water harvesting relation to the objectives of the AMAL project:

- Studies undertaken have not considered geotechnical aspects of dam feasibility, nor social or economic [cost/benefit] analysis of macro-water harvesting [other than estimating irrigable areas].
- No reports have been seen of government feasibility studies of water harvesting in the project area.
- No studies have considered the feasibility of micro-water harvesting in the project area.
- Practical details of remote sensing techniques in water harvesting are not reported in the literature reviewed.
- There is an absence of information on project requirements: what area is targeted: how many people and how many livestock.

- No reports are available that examine expressed demand by the population: for example, is their priority supplemental irrigation for extensive cropping of wheat and barley, or for more intensive production of fruit and vegetables, or for livestock watering.

4-6 Recommendations

The following recommendations are made:

- Enquiries should be made to obtain government reports on water harvesting schemes in or near the project area.
- Further surveys of the Karez should be undertaken to establish their condition and use and need for rehabilitation.
- Enquiries should be made regarding the existence of design reports on Bistana pond and other planned ponds, and hydrological and other studies that support the designs.
- Enquiries should be made to Relief International and other organisations regarding their activities involving water harvesting to confirm whether they have been active in Sinjar District since 2016 and to obtain any relevant reports for review.
- Iraqi government topographic and geological mapping should be acquired at the available scale of 1:25,000 for the project area, or processed from high resolution satellite imagery [either option will require government approval]

There are many different options available for water harvesting in Sinjar-Baaj, but they are all contingent on carrying out further studies, due to the scarcity of existing information on the project area. Current thoughts include the following:

- Rainfed production of wheat and barley might be best / most quickly/ most cheaply helped by looking at other limiting factors, including input [seed, machinery] availability and timeliness. Early planting is in fact, de facto "water harvesting".
- Forms of water harvesting that are likely to be feasible in the project area, and which should be explored, include:
    - Rooftop/ compound harvesting.
    - Renovation of the hexagonal lattice systems observed by this study as a form of contour ploughing used in the recent past.
    - Earth bunds surrounding plots to capture overland flow [as in Eastern Sudan with the "teras" system that has been documented in publications by W.R.S. Critchley]. Here, water storage and utilisation areas are in the same location and it is easier to be equitable.
    - Haffir tanks for livestock watering, possibly including the cultivation of vegetables downstream of the spillway.
    - Wadi spate harvesting by mini-diversion structures.

5 References

5-1 Arrangement

This section is arranged under the main report headings

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Appendix A Terms of Reference

1. The AMAL Project

1.1 Background information

Revitalizing the agriculture sector is critical for Iraq's recovery from years of armed conflict. Although agriculture has long been the primary source of livelihoods in the targeted areas, years of conflict and related developments, such as violence, displacement and the loss of productive assets have caused large-scale and systemic degradation of this vital sector. This, in turn, has had wide-ranging ramifications, negatively affecting the socio-economic status particularly of the most vulnerable households in the targeted areas. In this context, NRC seeks to address structural barriers to the comprehensive rehabilitation of the agricultural sector – and its vital role in providing economic security for local communities. These structural barriers include damaged infrastructure; loss of productive assets; lack of access to finance and inputs; explosive hazard contamination of farm land; resource constraints limiting innovation; subdued markets and weak demand for agricultural products; and inadequate service provision for agro-businesses. As such, NRC is implementing three years [2020-2022] Agricultural livelihoods project called **Activating Market-based Agricultural Livelihood - AMAL** in Ninawa and Kirkuk governorates targeting three districts [Sinjar, Baaj and Hawija] with funding support from Federal Republic of Germany through German Development Bank [KFW].

AMAL Project Components

The overall aim of the AMAL project is to promote the resilience of conflict-affected rural Iraqi communities through the restoration of agricultural production, markets and associated livelihoods. The project is divided into three outcomes areas.

Outcome 1 – Agricultural productive capacity of farmers within the targeted areas is increased

The disruption of agricultural productive capacity in the targeted locations has severely affected the social-economic status of the rural population and poses a major barrier to independent recovery. Activities under this component of the project are therefore geared towards restoring various aspects of that capacity. As such, they range from infrastructure rehabilitation to provision of inputs and from training activities to facilitating safe and sustainable access to farm land.

Outcome 2 – Revitalization of markets within the agricultural value chain provides for increased employment opportunities in the targeted areas

For the agricultural sector to truly restore its role as driver of economic resilience, enhancing productive capacity is not enough. For this, the wider agricultural value chain needs to be revitalised, driving up demand for produce, strengthening market linkages and – in the process – boosting employment. To this end, this component will help strengthen small, micro and medium sized non-farm agro-businesses – both through direct support [in the form of business grants and relevant training] and by building the capacity of relevant public and private providers of Business Development Services [BDS]. This in turn, will help create jobs and other economic opportunities in targeted areas. To meet the demand for labour, and ensure the programme's intended beneficiaries can successfully capitalise on such opportunities, the program will deliver technical training with a particular focus on skills that agro-businesses require to realise growth.

Outcome Area 3 – Targeted communities enhance their resilience to future shocks

This component is primarily designed to ensure that the proposed intervention is inclusive [i.e. that it benefits vulnerable groups who otherwise may be at risk of losing out on newly created economic opportunities] and contributes to resilience and social cohesion in the targeted communities. It will help identify community priorities and allocate resources accordingly. It will also help vulnerable households enhance their economic resilience and strengthen their social support networks.

1.2 North West Nineveh context

Sinjar and Ba'aj, locally known as Al-Jazirah [the area bounded by the Tigris and Euphrates Rivers north of Tharthar Lake], is a water scarce district, with an underground aquifer being the primary source of water for domestic purposes, by extraction through deep boreholes. There is no suitable alternative water source for drinking water, other than boreholes or water trucking from municipal infrastructure, which is expensive. Extraction is high, with little to no monitoring of the aquifer or understanding of its recharge rate. This issue is compounded by no law enforcement to prevent over extraction or illegal drilling, or having any effective approach to water resource governance. The health of the aquifer can be judged by the increasing requests for Reverse Osmosis units by the Directorate of Water, to be installed on boreholes due to increasing salinity of the aquifer. This would suggest that the aquifer has a higher extraction rate than replenishment rate, as the salinity is increasing. Furthermore, after significant impact due to conflict and lack of O&M funding, water infrastructure requires rehabilitation, which has been ongoing for the past 2 years. As a result, drinking water is the primary need in the area, in competition with livestock and agricultural use. This was previously recognized by the Government of Iraq through planning and construction of a major water network from the Tigris river to the district, but has since been on hold as a result of the conflict. Given that the scale and scope of this project requires significant investment, it cannot be considered a solution in the near future.

Within this water scarce environment, there are significant competing demands between water for domestic use and water for agriculture and livestock. As most agricultural production in the district is rain fed, and given the priority for domestic water use from existing infrastructure, there is limited opportunity to rehabilitate boreholes for irrigation purposes. Furthermore, it is not recommended to use this aquifer for crop irrigation given the poor health of the water source, which will only increase demand. As emphasized by recent assessments, any infrastructure rehabilitation projects are requested to focus on water for domestic supply.

In Iraq, service provision is typically centralised through large scale, municipality level, infrastructure solutions. In the case of water supply, this is typically through boreholes, water treatment plants and river fed irrigation canals. However, given the previously stated challenges, these are not feasible for Sinjar or Baaj.

2. Purpose of the review study

2.1 Overarching purpose of the study

Given the contextual constraints outlined in section 1, and the objective of the project, rainwater harvesting for livestock & agricultural irrigation, including aquifer recharge, is a proposed method to support durable solutions for populations residing in a water scarce environment.

Throughout the past two decades, further consideration has been given to this approach, through the publication of a number of remote, desk-based modelling studies and papers. Although some of these have been undertaken by international institutions, and others by academic bodies in Iraq, there is currently no summary of these investigations, nor an overview of the climatic nor aquifer involvement in these. Furthermore, although some current data exists, it is not clear what is lacking in terms of monitoring and evaluation of the natural resources in the district.

The aim of this study is to initially review the existing national and international literature on rainwater harvesting potential in Sinjar district. It will summarise previous research with limitations and recommendations on review of small-scale rainwater harvesting for agricultural practices, identify gaps in data collection and monitoring, and provide guidance on how to implement such projects, and to what scale for the Sinjar District. This will include review of current and historic available data on groundwater and rainfall in the district.

In addition, it will compare with previously implemented projects in catchments with similar characteristics in other countries, highlighting the failures and successes where relevant.

3. Methodology

Inception

A week allowance has been made for mobilisation, arrangement of an inception meeting with the client to establish protocol and kick off verbal liaison with the local support team. This week will also allow time to carry out some basic mapping and remote sensing interpretation using GIS which may be poorly represented in the reports and publications. This will also help the D1-3 reporting.

Review of Existing Studies

The second week of the assignment will be devoted to collating, reviewing and analysing work carried out in the last two decades. Three main subject areas have been selected by NRC for review by the consultant:

- Rainwater harvesting and the use of small dams and ponds
- Groundwater and options to increase recharge in the Al-Jazira aquifer
- Analysis of precipitation and climate data for the project area and northern Iraq

In addition, it will be important to assess the extent to which remote sensing has been applied to provide high resolution DTM mapping of topography, contouring, water features, geology, land-cover, soil. It will be important to review the general availability of meteorological and hydrometric monitoring sites in the area and their periods of record, and to verify reported results against historical and global gridded data. It is understood that Iraq has been using HEC-DSS1 software to archive meteorological and hydrological data, which will facilitate the evaluation of data availability and gaps in data quality and period of record. Data summaries for the study area would be requested from the relevant Ministry.

The main objectives of the systematic review are to categorise the existing research works into themes, identify gaps, limitations, and draw conclusions. The review, analysis and evaluation of the local research effort will likely focus on the period between 2000 and 2020, but reference would also be made where appropriate to other material.

The results of the work will be compared with other national and international studies on the same subject areas drawing on the consultant's extensive practical knowledge in this field both in the Middle East, Asia and Africa. The work will include guidance on the potential use of remote sensing and satellite-derived data such as CHIRPS and TRMM-GPM, for which the consultancy holds global databases which are continuously being updated.

The review of existing studies would be written up in an Interim Report [Deliverables 1-3] for discussion with the client and stakeholders.

Research Evaluation Framework

The package of literature provided by NRC and obtained for the assignment will be grouped into the four main related themes: water harvesting, groundwater, hydrological data, remote sensing.

Each document will be searched to determine origins and expertise of the authors, whether peer review was undertaken as part of the international publishing process, whether completed by government departments, consultants or universities. The results of the existing research will be compared, to the extent possible, with international work in other similar conditions and with global data-sets.

The work will be summarised in tabular form using a traffic-light system, used by the consultancy in other similar peer review and auditing work, using three or more classifications such as Poor, Fair and Good, using the criteria indicated above.

During the course of the evaluation, researchers in the Department of Water Resources at Kirkuk University would also be consulted who have a good knowledge and experience of small dam construction in the southern and western parts of the project area.

Workshop

The review of work and possible options will be discussed with the client and stakeholders during a workshop to be arranged remotely using Ms-Teams, Zoom, Google-hangouts or equivalent, and facilitated by presentation of a summary of the findings using Ms-Powerpoint. If there is extensive discussion and debate, a follow-up meeting would be organised. A PDF of the presentation would be translated into Arabic.

Final Report

Once the review of existing work and historical data has been discussed in the workshop, further thought will be given to the practical options available for resolving water scarcity as a barrier to achieving the goal of bringing back sustainable agriculture in Sinjar and Baaj districts. This optioneering will identify the next steps and potential further research to fill data gaps and identify appropriate water harvesting measures and groundwater conservation.

The subject of hydrological monitoring will also be addressed in order to assess the need to invest in new monitoring sites to infill gaps in data where necessary.

During the final assessment and to provide recommendations, particular attention will be paid to Wadi Ajeej runoff and the plateaus which feed the Snaisla and Bawara salt marshes. The Ajeej valley is shared with Syria, and a number of recent studies have assessed Ajeej wadi runoff and possible flow retention in the main valley with objectives of providing water for agricultural activities and groundwater recharge. Clearly, this may have environmental concerns which will be evaluated, as the wadi system is shared with neighbouring Syria and is already characterised by extensive salt marsh.

It is important that the AMAL measures be considered in the light of the existing social framework and environmental conservation objectives which have been identified. For this reason, an allowance has been made to test the feasibility of water harvesting solutions against social and ecological impacts using local specialists in these fields.

4. Deliverables and reporting deadlines

The consultant will deliver, based on an agreed-upon work plan:

1. Review existing rainwater harvesting and small dams research papers in Sinjar district, summarize, identify gaps, limitations and provide recommendations.
2. Review available research papers and studies on the Ray-Jazira aquifer, summarize, identify gaps, limitations and provide recommendations.
3. Review available research papers and studies on regional and district level rainfall and climate data, summarize, identify gaps, limitations and provide recommendations.
4. Presentation of key findings workshop to NRC, review and next steps.
5. Provide an overall summary, recommendations and next steps, towards the implementation of small-scale rainwater harvesting for agricultural practices at community level in Sinjar and Baaj districts for supplementary or deficit irrigation.
6. Provide considerations, actual or otherwise, for social and environmental impacts of implementing the recommended approach.
7. Translation of key documents [1, 2, 3, 5] into Arabic.

Appendix B Literature Summaries

This appendix provides brief notes on each document reviewed, where necessary identifying gaps or poorly interpreted data, to contribute to the review of the literature in the main report. The international standard, degree of accuracy and project relevance is then shown in the final table in Section B-6, considering world standing of the publishing entity, authorship, peer review and value/relevance to the project, using the following classification: ■ Poor, ■ Fair and ■ Good.

The sections have been organised in logical sequence of baseline data and hydrology, followed by water harvesting and water supply.

B-1 Climate and Hydrology

ID	Authors	Year	Title	Name of Publication	Publisher	Collation
CL1	Al-Sudani H I Z	2020	Calculation of meteorological water balance in Iraq	Resources Environment and Information Engineering	SyncSci Publishing	2[1]: 84-89, DOI: 10.25082/ REIE.2020.01.004
CL2	Al-Ansari N, Abdellatif M, Ali SS, Knutsson S	2014	Long term effect of climate change on rainfall in northwest Iraq	Central Europoean Journal of Engineering	Versita sp. z o.o.	Vol 4[3], 250-263. DOI: 10.2478/ s13521-013-0151-4
CL3	Ministry of Foreign Affairs of the Netherlands	2018	Climate change profile, Iraq		Ministry of Foreign Affairs of the Netherlands	18p.
CL4	Yenigun K, Ibrahim WA	2019	Investigation of drought in the northern Iraq region	Meteorological Applications	Royal Meteorological Society	Vol 26, 490-499.
CL5	Abdulla FA, Amayreh JA, Hossain AH	2002	Single event watershed model for simulating runoff hydrograph in desert regions	Water Resources Management	Kluwer Academic Publishers	Vol 16, 221-238.
CL6	Ministry of Health and Environment	2016	Iraq’s Initial National Communication to the UNFCCC		Ministry of Health and Environment, Iraq	240p.
CL7	Al-Sudani H I Z	2019	Rainfall returns periods in Iraq	Journal of University of Babylon for Engineering Sciences	University of Babylon	9p.
CL8	Kalyana MM, Awchi TA	2015	Investigating the meteorological drought in northern Iraq using deciles method	Al-Rafidain Engineering	Ministry of Higher Education & Scientific Research of Iraq	Vol 23[3], 12-21.
CL9	Hussein MH, Othman AK	1988	Soil and water losses in a low intensity rainfall region in Iraq	Hydrological Sciences Journal	Taylor & Francis for International Association of Scientific Hydrology	Vol 33[3], 257-267

ID	Authors	Year	Title	Name of Publication	Publisher	Collation
CL10	Hussein MH, Awad MM, Abdul-Jabbar AS	1994	Predicting rainfall-runoff erosivity for single storms in northern Iraq.	Hydrological Sciences Journal	Taylor & Francis for International Association of Scientific Hydrology	Vol 39[5], 535-547.
CL11	Hussein MH, Hussein AJ, Awad MM	1999	Phosphorous and nitrogen losses associated with runoff and erosion on an Aridisol in northern Iraq.	Hydrological Sciences Journal	Taylor & Francis for International Association of Scientific Hydrology	Vol 44[5], 657-664.
CL12	Hussein MH	1996	An analysis of rainfall, runoff and erosion in the low rainfall zone of northern Iraq.	Journal of Hydrology	Elsevier	Vol 181, 105-126.
CL13	HEC-DSS Files		Summary of records in MOWR HEC Database for Nineveh and Syria	not published	Ministry of Water Resources, Baghdad	
CL14	Saleh, D.K	2010	Stream gage descriptions and streamflow statistics for sites in the Tigris River and Euphrates River Basins, Iraq:	Data Series 540	US Geological Survey	146 p.

Classification is provided at the end of the Appendix

CL1. Al-Sudani H I Z [2020] Calculation of meteorological water balance in Iraq. *Resources Environment and Information Engineering*, Vol 2[1]: 84-89 DOI: 10.25082/REIE.2020.01.004

Al-Sudani [2020] describes a nationwide study of the balance between precipitation and evaporation. Using the Thornthwaite method of estimation of potential and actual evapotranspiration, the study presents the spatial distribution of the surplus of precipitation over actual evaporation across Iraq. Table B1-1 presents mean annual climatic data for stations in the project area extracted from tables in the article. Surpluses of 50%-60% of mean annual precipitation are indicated which are available for groundwater recharge and runoff.

Table B1-1 Elements of the Water Balance for Selected Climatological Stations in the Project Area

Station	Record [1] years	Temp. [2] °C	Precip. [3] mm	PET [4] mm	AET [5] mm	Surplus [6] mm	Surplus %
Baaj	17	20.5	229.0	1,361.5	112.3	116.7	51.0
Rabiah	31	18.5	367.1	1,122.7	160.1	207.0	56.4
Sinjar	28	20.6	389.3	1,399.5	153.8	235.5	60.5
Tel-Afer	25	21.0	322.8	1,464.7	139.8	183.0	56.7

Source: Al-Sudani [2020], CL1. 1. Available record length [up to 2015]. 2. Mean annual temperature. 3. Mean annual precipitation. 4. Potential evapotranspiration. 5. Mean annual actual evapotranspiration. 6. Mean annual precipitation minus mean annual actual evapotranspiration

CL2. Al-Ansari N, Abdellatif M, Ali SS, Knutsson S [2014] Long term effect of climate change on rainfall in northwest Iraq. *Central European Journal of Engineering*, Vol 4[3], 250-263.

Al-Ansari et al [2014] analysed daily rainfall records for Sinjar station for the period 1961-2001 and noted that average annual rainfall is 303 mm. The rainy season extends from November to May. Maximum evaporation usually occurs in July and minimum in December. Soils in the area are sandy loam, silty loam and silty clay loam. Land use consists of cultivated land, pasture and rock. Cultivated land represents very good farming conditions and the main crops are wheat and barley.

Al-Ansari et al [2014] report the downscaling, processing and analysis of HADCM3 global climate model[13] data to identify the trend in rainfall in Sinjar District during the 21st Century for the A2 and B2 emissions scenarios.[14] Results suggest for both emission scenarios that seasonal, monthly, daily rainfall, rainfall variability and extreme storm rainfall are all projected to decline during the 21st Century and that average annual rainfall will decrease by about 30%. Projections suggest 83% of years will have less than 300 mm of rainfall. The availability of water is therefore likely to decline, requiring water management strategies to overcome or mitigate the shortage.

CL3. Ministry of Foreign Affairs of the Netherlands [2018] Climate Change Profile, Iraq. 18p.

From the Summary:

"Lying in a water stressed region with little water resources of its own, Iraq is…experiencing significant and interconnected political, economic, environmental and security challenges. The effects of climate change…will exacerbate those challenges…."

"The overall decrease of rainfall in Iraq [ranging from 1.3 to 6.2 mm/ year] particularly during recent years…has resulted in a decrease in water resources".

Importantly, under the table summarising CC adaptation action, water use efficiency in distribution networks, irrigation methodology, and the planting of drought resistant crops should be tools to be used [amongst other actions]. The document further states that a national strategy for climate change will be developed – and water resources will constitute one of the most important sectors.

CL4. Yenigun K, Ibrahim W A [2019] Investigation of drought in the northern Iraq region. *Meteorological Applications*, Vol 26, 490-499.

Yenigun and Inbrahim [2019] investigated drought in northern Iraq over the period 1979-2013 using monthly rainfall records from 15 meteorological stations including Sinjar and Tel-Afer. The longest period of drought recorded by Sinjar station as defined by negative values of Standardised Precipitation Index was 86 months. The timing of historical drought periods in Sinjar was not shown. Effects of drought on agricultural economies such as Sinjar include reduced crop yields, production, employment, income and increased food prices, and food insecurity, especially for small farmers and landless workers.

CL5. Abdulla FA, Amayreh JA, Hossain AH [2002] Single event watershed model for simulating runoff hydrograph in desert regions. Water Resources Management, Vol 16, 221-238.

Abdulla et al [2002] report the calibration of a conceptual single event watershed model to two wadi catchments in an area of the Western Desert of Iraq on which extensive field hydrological investigations were conducted [Ministry of Agriculture, 1977]. Wadis Amij and Awij [3,210 km^2 and 1,293 km^2 respectively] are situated some 200 km south of Sinjar District. The average annual rainfall in the area is about 120 mm. Hourly climatological and hydrological data for events in the rainy seasons of 1975-76 and 1978-79 were used for this publication. Pan evaporation data from Rutba station were used [Delsi, 1975]. Data from the catchments were subsequently used by Kadim [1983] and Mohammed [1989]. It looks like this paper is publishing the work of Kadim and Mohammed.

Delsi M [1975] A simplified method for estimation of evaporation, evapotranspiration and water requirements based on the temperature dependence of Penman's Equation. Ministry of Agriculture Publ. No.5, Baghdad.

Kadim SM [1983] A mathematical model of watershed hydrology. MSc Thesis, College of Engineering, University of Baghdad, Iraq.

13 The HADCM3 model was developed by the Hadley Centre in the UK Met Office

14 The A2 emissions -scenario assumes that economic development is regionally oriented and economic development and per capita economic growth is slower and more fragmented than for other scenarios. The B2 scenario assumes a slower global population growth rate and the development of local solutions to economic, social and environmental sustainability.

Ministry of Agriculture [1977] Hydrogeological explorations and hydrotechnical works. Vol. 1: Climatology and Hydrology; Vol. 5 'Hydrogeology', Iraqi Western Desert Block 7, Directorate of Western Desert Development Projects, Baghdad.

Mohammed RJ [1989] Development of a mathematical model from Wadi Horan catchment. MSc Thesis, College of Engineering, University of Baghdad, Iraq.

CL6. Ministry of Health and Environment [2016] Iraq's Initial National Communication to the UNFCCC. Ministry of Health and Environment, Iraq. 240p.

Reports historical trends in climate recorded at Mosul. Rainfall and the number of rainy days have declined on average since the late 1930s/early 1940s. Average annual temperature is increased slightly since the early 1940s [Table B1-3].

Table B1-3 Historical trends in climatic variables at Mosul

Variable	Period	Regression coefficient
Annual rainfall	1938-2009	-1.36
Rainy days	1941-2009	-0.5
Average annual temperature	1941-2009	0.01

Source: Ministry of Health and Environment [2016]

Detailed climate change studies for the country had not been undertaken at the time of this report, but it is expected that average annual temperatures will rise and rainfall will decline. Dust and sand storms are expected to increase in frequency.

Reports studies that show that crop water requirements of wheat will increase by 2.8%, 6.0%, 13.0% and 17.2% in response to increases in mean annual temperature of 1^{0}C, 2^{0}C, 3^{0}C and 5^{0}C. It is expected that average annual temperatures will increase over the 21st Century, putting pressure on water resources. A decrease in the cropped area is expected to result from the increased water requirements of crops. This would mean reduced food production in the face of a growing need for food. The expected decline in rainfall will reduce the viability of rain-fed crop yields and put pressure on natural pastures.

Adaptation actions required include:

- Improved management of rain-fed agriculture by digging water wells and applying complementary irrigation.
- Dig water wells for drinking and livestock grazing in desert areas…
- Apply water harvesting techniques and expand them in desert areas to take advantage of rain floods."

CL7. Al-Sudani H I Z [2019] Rainfall returns periods in Iraq. *Journal of University of Babylon for Engineering Sciences*, Vol 27[2], 1-9.

Al-Sudani [2019] undertook a frequency analysis of annual rainfall totals in Iraq. All annual rainfall totals from 32 meteorological stations across the country were combined into a single sample, sorted, ranked and the return period was calculated for the ranked data. A graph is presented relating annual precipitation to return period. This analysis is flawed in that the type of analysis described is normally carried out at each station as each station samples the climate local to it.

The study provides the data shown in Table B1-4 for climatological stations in the AMAL project area.

Table B1-4 Summary of Climatological Records in the Project Area

Station ID	Station	UTM Easting	UTM Northing	Record [years]	Mean annual rainfall [mm]
	Baaj	744675	3991979	17	229.0
	Rabiah	240543	4077402	38	367.1
364419	Sinjar	756491	4023370	63	389.3
364425	Tel-Afer	267050	4027270	64	322.8

The climate of Iraq is described as continental and subtropical semi-arid. The mountainous regions along the border with Iran are described as having a Mediterranean climate.

CL8. Kalyana MM, Awchi TA [2015] Investigating the meteorological drought in northern Iraq using deciles method. *Al-Rafidain Engineering*, Vol 23[3], 12-21.

Kalyana and Awchi [2015] report a study of drought frequency in northern Iraq using rainfall deciles. Monthly rainfall from 9 met stations including Sinjar and Tel-Afer for the period 1937-2010 were used. The analysis showed that drought has reoccurred every decade. The most severe droughts in northern Iraq were in 1997-2001 and 2007-2010.

CL9. Hussein MH, Othman AK [1988] Soil and water losses in a low intensity rainfall region in Iraq. *Hydrological Sciences Journal*, Vol 33[3], 257-267.

Hussein and Othman [1988] report the establishment of two erosion plots in the Hirjan basin along the road between Erbil and Shaqlawa. Mean annual rainfall is about 900 mm. The plots were established in 1980 and are 20 m x 4 m in size and on a Mollisol soil and a uniform slope of 17%. Data are used to calculate soil erodibility for tilled and untilled conditions. Sheet or inter-rill erosion is the dominant erosion type on the plots.

Hussein and Othman describe this part of northern Iraq as being characterised by low rainfall intensity. To illustrate this, Figure 1 shows a 14-hour storm with hourly intensities varying up to 8 mm/hr. Occasional snow showers occur in winter.

Al-Taie FH, Sys C, Stoops G [1969] Soil groups of Iraq: Their classification and characterization. Pédologie Vol XiX, 65-148.

CL10. Hussein MH, Awad MM, Abdul-Jabbar AS1994, Predicting rainfall-runoff erosivity for single storms in northern Iraq, *Hydrological Sciences Journal*, Vol 39[5], 535-547.

Water erosion in northern Iraq varies greatly between storms. Hussein et al [1994] argue that event-based rainfall-runoff erosivity factors are needed to accurately predict erosion and sediment yield in the region. This study derived rainfall-runoff erosivity factors for northern Iraq based on the basic theory of water erosion and tested them with available soil loss data collected from natural runoff plots at 3 sites in the region.

One of the sites is Hammam, located in NW Iraq. Mean annual rainfall is about 340 mm. Runoff and sediment yield data were collected from 1988 to 1992. Soil is an aridisol, 6% slope, 1.5% organic matter, 20% sand, 44% silt, 36% clay.

Rainfall intensity in the region is usually less than 10 mm/h, but occasionally high intensity storms occur.

For the Hammam site, both runoff depth and peak discharge are important variables for accurately describing the rainfall-runoff erosivity factor.

Observations showed a near absence of rilling, due to the normal rainfall intensity being less than the soil infiltration capacity for most soils in the region.

Runoff normally occurs as sheet flow due to surface sealing due to raindrop impact and/or soil profile saturation [Awad, Hussein, Abdul-Jabber [1992] Mesopot. J. Agric, 24, 31-36]. Runoff rates are low and depths of flow are low. Detachment by raindrop impact is the dominant form of soil detachment. Sediment is transported in sheet flow as bedload.

In addition to deriving erosivity factors, Hussein et al tested a number of other erosivity factors, including the EI_{30} index, used in the USLE Universal Soil Loss Equation. The derived factor [above] was found to be superior to the EI_{30} factor.

CL11. Hussein MH, Hussein AJ, Awad MM, 1999, Phosphorous and nitrogen losses associated with runoff and erosion on an Aridisol in northern Iraq. *Hydrological Sciences Journal*, Vol 44[5], 657-664.

At the University of Mosul's Hammam Al Aleel natural runoff plot on an Aridisol [Calciorthid] in NW Iraq, Hussein et al [1999] report recording sediment-bound P and N losses along with eroded sediment and runoff and soluble P and N for three rainfall seasons. Results show that eroded sediment is always rich in available P and inorganic N compared to the original soil. Concentrations of soluble P and N were variable between storms and between seasons. Sediment-bound P and soluble P were significantly correlated with the runoff ratio.

Soil erosion by rainfall and runoff is a major problem in northern Iraq. Rainfall-runoff events cause nutrient losses. Soluble nutrients are transported in surface runoff. Insoluble forms of nutrients and nutrients adsorbed to sediment particles are transported in eroding sediment. Nutrient leaching by percolating water to groundwater is of minor importance due to low seasonal recharge and relatively deep groundwater.

This paper briefly assesses the impact of erosion on soil productivity and surface water quality.

CL12. Hussein MH [1996] An analysis of rainfall, runoff and erosion in the low rainfall zone of northern Iraq. *Journal of Hydrology*, Vol 181, 105-126.

Hussein [1996] analysed rainfall, runoff and soil loss measured at six natural runoff plots [30m and 10m long and 3m wide] at the University of Mosul's College of Agriculture and Forestry's experimental farm at Hamam Al-Aleel. The soil is described as fine, mixed, thermic, calcareous, Xerolithic Calciorthids. The soil was tilled and smoothed and kept free of weeds during the four rainy seasons over which measurements took place. Normally, the soil surface is covered with stones and other non-erodible materials, so soil losses could be maximised.

Erosion on the plots is caused by raindrop impact and running water. Rilling was absent, probably due to the low intensity rain characteristic of the region. Characteristics of storms and runoff were noted as follows:

- Storms were classified as 'normal' or 'severe'. Normal storms had maximum intensities of about 20 mm/h. Storms of higher intensity [and lower duration] were classified as severe.
- 1 or 2 severe storms contributed 50% of the seasonal runoff.
- Less than half of rainfall events were runoff producing.
- In a dry rainy season, runoff is 4-8% of total seasonal rainfall on large and small plots.
- In a wet rainy season, runoff is 25-33% of total seasonal rainfall on large and small plots.
- Runoff prediction for design purposes may be better based on maximum runoff events rather than on seasonal values.

Two widely used models were tested using the plot data: the US SCS curve number method for runoff prediction and the universal soil loss equation for soil loss prediction. USLE was designed to predict long term average annual soil loss from sheet and rill erosion.

For normal storms, the SCS method over predicts runoff. For severe storms, the SCS method underpredicts runoff. This may have implications for the studies that have used SCS to predict runoff volumes at dam sites.

The USLE was found to over predict soil loss. Many storms used to calculate the erosivity index are in fact non- or only slightly erosive. Using a threshold storm depth to calculate the erosivity index gave satisfactory results.

CL13. Summary of Climatological Records available for Sinjar and Neighbouring Districts, provided to NRC by MOWR, Baghdad.

A station inventory was provided by the Ministry of Water Resources in spreadsheet format, exported from the HEC-DSS database held in Baghdad. Notably, the most recent data-sets are Dec 2013, after which date there are no further hydrological records in this part of Iraq, and Sinjar has the longest record starting in 1935.

A summary of the available records is given in Table 2-2 in the main text.

CL14. Saleh, D.K, 2010, Stream gage descriptions and streamflow statistics for sites in the Tigris River and Euphrates River Basins, Iraq: [Data Series 540 US Geological Survey] 146 p.

This publication presents summaries of streamflow gauging stations and statistical summaries for all long-term streamflow gauging stations in the Tigris and Euphrates River basins. There are no streamflow gauging stations reported in the project area or neighbouring areas. The nearest stations are located on the main Tigris and Euphrates Rivers which are of no interest to the project.

B-2 Groundwater

ID	Authors	Year	Title	Name of Publication	Publisher	Collation
GW1	Stevanovic Z & Iurkiewicz A	2009	Groundwater management in northern Iraq	Hydrogeology Journal	IAH, Springer	Vol 17 [2], pp367-378.
GW2	Al-Sawaf, FDS	1977	Hydrogeology of South Sinjar Plain Northwest Iraq.		UCL Provost and Vice Provost Offices	377pp
GW3	Lightfoot, D R	2009	Survey of infiltration karez in northern Iraq: history and current status of underground aqueducts	UNESCO	Oklahoma State University - Stillwater	Book 57pp
GW4	Sissakian VK et al	2015	Origin and evolution of Wadi Al-Ajeej, Al-Jazira vicinity, NW Iraq	Jl Earth Sci and Geotech Eng	Scienpress Ltd	Vol 5 [14], pp69-83
GW5	Kareem I R	2013	Artificial groundwater recharge in Iraq through rainwater harvesting [case study]	Eng Tech Journal	Min Higher Education & Scientific Research	Vol 31, part A No 6
GW6	Hasan A A & Rasheed A M M	2006	Using computer systems to predict the changes in groundwater elevations due to recharge from rainwater harvesting	Symp Proceedings IAHS Brasil, Apr 2005: Sustainability of groundwater and its indicators	IAHS Press, Institute of Hydrology, Wallingford	Vol 302, Book, 205pp
GW7	Alridha N A, AlYasi AI & AlKhafaji WMS	2013	Role of geoelectric and hydrogeologic parameters in the evaluation of groundwater reservoir at South of Jabal Sinjar area	Iraqi Jl of Science	Min Higher Education & Scientific Research	Vol 54, No 3, pp628-637
GW8	AlYasi AI, Alridha N A & Shakir W M	2013	Exploitation of Dar-Zarrouk Parameters to differentiate between fresh and saline groundwater aquifers of Sinjar Plain area	Iraqi Jl of Science	Min Higher Education & Scientific Research	Vol 54, No 2, pp358-367
GW9	Saleh S A, Al Ansari N & Abdullah T	2020	Groundwater hydrology in Iraq	Jl Eart Sci & Geotech Eng	Scientific Press Int Ltd	Vol 10, No 1, pp155-197
GW10	Jawad S B & Hussien K A	1986	Contribution to the study of temporal variations in the chemistry of spring water in karstified carbonate rocks	Hydrol Sci Jl	Taylor & Francis	Vol 31, No 4, pp529-541
GW11	Jawad S B & Hussien K A	1988	Groundwater monitoring network rationalisation using statistical analyses of piezometric fluctuation	Hydrol Sci Jl	Taylor & Francis	Vol 33, No 2, pp181-191
GW12	Al Ansari N, Saleh S A et al	2021	Quality of Surface water and groundwater in Iraq	Jl Eart Sci & Geotech Eng	Scientific Press Int Ltd	Vol 11, No 2, pp161-199
GW13	Sissakian V K, AlAnsari N, Abdullah L H	2020	Neotectonic activity using geomorphological features in Iraqi Kurdistan region	Geotech & Geol Eng Jl	Springer	Vol 38 No 4, pp4889–4904
GW14	McDermid C	2013	Ancient aqueducts give Iraq a trickle of hope	Al Jazira online	Al Jazira online	

ID	Authors	Year	Title	Name of Publication	Publisher	Collation
GW15	Abdul Qader U N	2009	Mapping groundwater quality of Injana aquifer south of Sinjar anticline	Iraqi Jl earth Sci		
GW16	Al Daghastani	2013	Impact of tectonics on alluvial fan landforms in Sinjar mountain using remote sensing	ARSGISO Jl of remote sensing and GIS		Vol1, No 2, pp15-20
GW17						
GW18	Sissakian VK	2011	Geology of Iraq			
GW19	Sissakian VK & Fouad S F A	2015	Geological map of Iraq, 1:1million 4th edition 2012	Iraqi Bulletin of geology & Mining		Vol 11, No 1, 2015, pp9-16
GW20	Burungh P	1957	Exploratory Soil map of Iraq 1:1,000,000, accompanied by memoir Soils and soil conditions in Iraq 1960	Div of Soils & Agric chemistry	Ministry of Agriculture, Baghdad	

Classification is provided at the end of the Appendix

GW1 Stevanovic Z & Iurkiewicz A, 2009, Groundwater management in northern Iraq, *Hydrogeology Journal* Vol 17 [2], pp367-378.

Although well written and researched, the article is devoted to groundwater on the north-east side of the Tigris River, focusing on Dohuk, Erbil and Sulaimani. In the final section, it discusses more generally groundwater management, and some recharge schemes are cited such as an injection well on the Erbil Plain. The author discusses injection wells and sub-surface dams, as well as rehabilitation of wells and groundwater spring development.

GW2, Al-Sawaf, FDS, 1977, Hydrogeology of South Sinjar Plain Northwest Iraq. PhD Thesis, UCL.

The thesis opens with a poignant acknowledgement: "Dedicated to the thirsty desert dwellers". Al-Sawaf opens with a basic description of the topography, climate, geology and hydrology and discusses how groundwater conditions have deteriorated with lowering of water levels and increase in mineralisation. Aquifer characteristics are plotted and water resources assessment made with recommendations for future management. The thesis presents an un-necessarily complicated computer program for analysing water chemistry, which distracts from the results summarised in the main text.

There are many useful diagrams and maps, although a large number have been removed "due to third party copyright".

GW3 Lightfoot, D R 2009 Survey of infiltration karez in northern Iraq: history and current status of underground aqueducts. UNESCO. 57p.

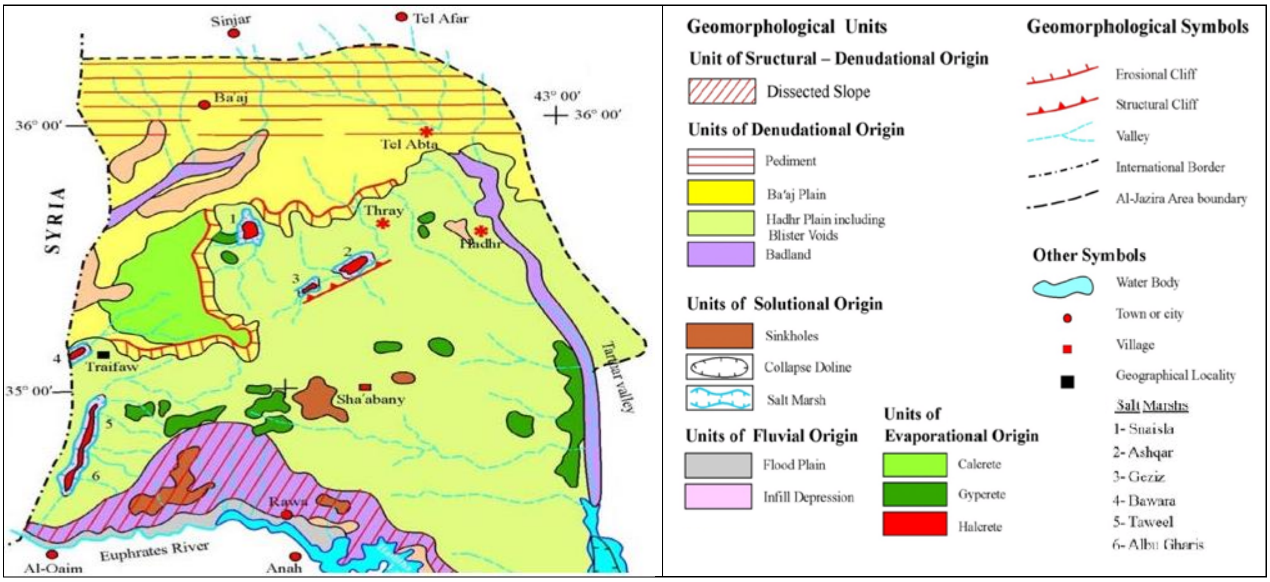
The reference reports only a small number of karez found in Sinjar and Baaj Districts, but there are important comments about the need to meet certain criteria before rehabilitation is considered.

GW4 Sissakian VK et al 2015 Origin and evolution of Wadi Al-Ajeej, Al-Jazira vicinity, NW Iraq *Journal Earth Sci and Geotech Eng.* Vol 5 [14], pp69-83

Focuses on the origin and original course of Wadi Al Ajeej along River JaghJagh in Syria.
Relevance: formation of river terraces / superficial groundwater. Identifies and describes the following stratigraphic sequence:

- Quaternary [terrace deposits, alluvial fans]
- Late Miocene [Injana Formation] red-brown grey sandstone, siltstone, claystone
- Middle Miocene [Fatha Formation] marl, red claystone, limestone, gypsum

Figure B2-1 Geomorphological Map of the Al Jazira Basin



Source: Sissakian et al [2015, GW4]

GW5. Kareem I R 2013 Artificial groundwater recharge in Iraq through rainwater harvesting [case study], *Eng Tech Journal Min Higher Education & Sci Research*, Vol 31, part A No 6

Studies the 400 km^2 Jolak Basin north of Kirkuk in Sulamania District, producing 10.8 Mm^3 of annual runoff from 360 mm rainfall. Outside the project area. Rainwater collected in lined and covered ponds then injected using recharge wells. Uses 3-5m deep ponds storing 540 m^3. Would require 97 ponds. T 2000 m^2/d 76 injection wells. Used GMS program to simulate theoretical impact of recharge. Poorly-written with no proof-reading, of little relevance to the Sinjar project.

GW6. Hasan A A and Rasheed A M M 2006 Using computer systems to predict the changes in groundwater elevations due to recharge from rainwater harvesting: in "*Sustainability of groundwater and its indicators" Symp Proceedings IAHS Brasil, Apr 2005* IAHS Press, Institute of Hydrology, Wallingford Vol 302, Book, 205pp

Presents study of a Bashiqa gravel plain NE of Mosul, an area used for fruit and olive cultivation and characterised by historical decline in groundwater levels, caused by borehole abstraction from Upper Fars aquifers, under the remit of Bashiqa Agriculture Office, Nineveh Irrigation Office.

The article does not make clear if artificial recharge has been practiced or is being considered, as it says that use of small dams at point of exit from mountains was selected for research.

Geology the same as the Sinjar Plain: Pilaspi [dolomitic limestone], Fatha [marl, limestone, gypsum], Injana sandstone, siltstone, mudstones] Formations: most wells drilled in Injana. Previous studies indicate GWL decline of 0.7-0.8m /yr. Used WMS program [Aquaveo] for 8 sub-basins total area 40.5 km^2. Figure showing location of small dams missing. GMS used for groundwater modelling [also Aquaveo], also MODFLOW. Exploit permeable gypsum outcrop for infiltration. Supposedly overseen by Bruce Webb at the Univ of Exeter, but poorly developed article: no model calibration or long-term water levels shown. Also erroneously suggest modelling replaces the need for fieldwork and hydrometric records [should have used pre-war data].

GW7 Alridha N A, AlYasi AI & AlKhafaji WMS 2013 Role of geoelectric and hydrogeologic parameters in the evaluation of groundwater reservoir at South of Jabal Sinjar area Iraqi. *Jl of Science Min Higher Education & Scientific Research,* Vol 54, No 3, pp628-637

Compares groundwater level change using VES survey done in 1980s with a new survey in 2012, based on six calibration wells over an area of 7,920 km^2. Confirms the geology as Quaternary alluvial/aeolian deposits and terrace deposits, overlying Miqdadiyah [sandstone, siltstone, claystone], Injana [Upper Fars, coarse-grained sandstone, claystone], and Fatha [Lower Fars, green marlstones, red claystones, anhydrite, thin limestones, gypsum].

Concludes a 1-3m drawdown over the 30 yr period. No information given on the construction details of the 6 calibration wells: given the multiple level aquifers in the area and known difference between shallow and deep groundwater, the value of the results cannot be established.

GW8 AlYasi AI, Alridha N A & Shakir W M 2013 Exploitation of Dar-Zarrouk Parameters to differentiate between fresh and saline groundwater aquifers of Sinjar Plain area Iraqi. *Jl of Science Min Higher Education & Scientific Research*, Vol 54, No 2, pp358-367

Further work related to GW7, confirming existing knowledge of higher salinity groundwater to the south and freshwater in the broad arc south of Sinjar Mountain. Of little use for the project.

GW9 Saleh S A, Al Ansari N & Abdullah T 2020 Groundwater hydrology in Iraq. *Jl Eart Sci & Geotech Eng, Vol 10, No 1, pp155-197*

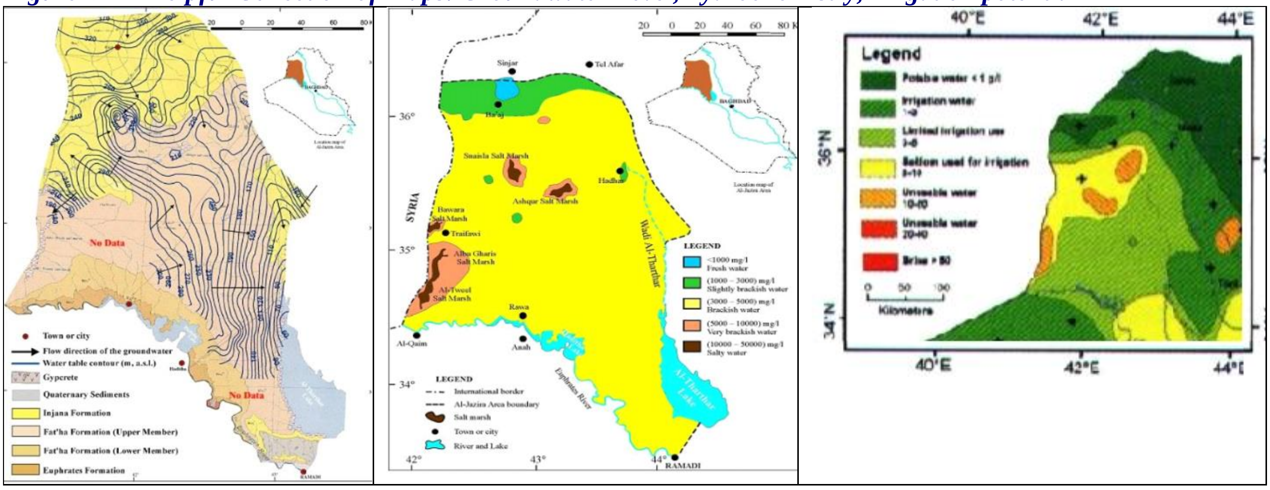
Refers to declining water resources without providing evidence. Summarises the problem well: "research studies are not up to date, and contain many temporal and spatial gaps, which make planning, monitoring and exploitation difficult. Coordination between government agencies is poor, making it difficult to carry out a comprehensive and integrated evaluation. There is a real need to collate historical and current data on groundwater resources in Iraq in a single integrated database, especially traditional survey methods and groundwater extent".

Broad overview of mean annual climatological parameters and groundwater levels across the whole of Iraq. Includes GWL in Al Jazira indicating depths are 40m immediately south of Sinjar Mountain and in the range 20-30 m bgl further south. Includes some useful maps showing spatial variation in salinity and water use, although does not discriminate between shallow and deep aquifers.

Paper by AlJiburi 2009, geology of al Jazira, hydrogeology IBGM special issue No 3, pp71-84 [could not be downloaded from IBGM website].

Suggests that there is an abstraction licensing system, but it is not enforced, and farmers are unaware of the danger of penetrating more saline deeper water. Classifies the whole of Al Jazira as poor quality for agriculture, and recommends investigation of salt-tolerant crops.

Figure B2-2 Helpful Collection of Maps: Groundwater Level, hydrochemistry, irrigation potential



Source: Saleh et al [2020, GW9]

GW10 Jawad S B & Hussien K A 1986 Contribution to the study of temporal variations in the chemistry of spring water in karstified carbonate rocks. *Hydrological Sciences Journal* , Vol 31, No 4, pp529-541

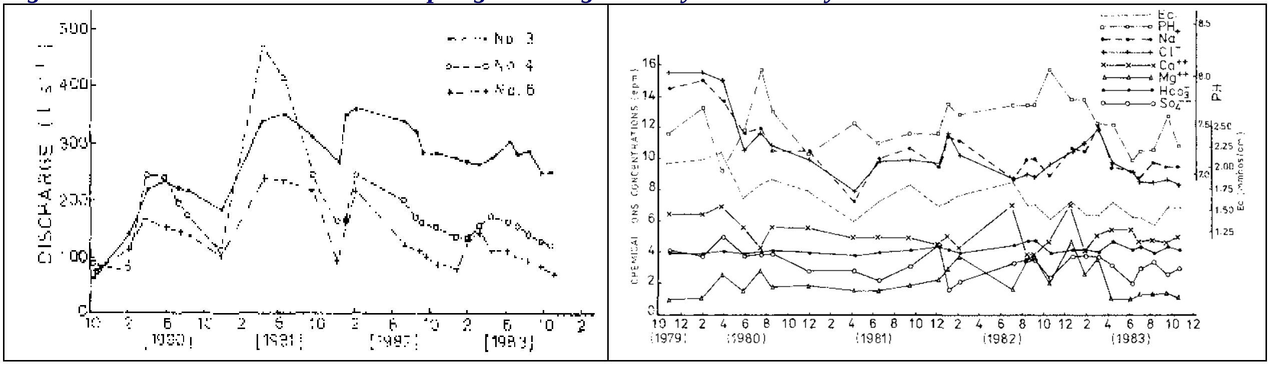
After broad introduction about impact of porosity vs permeability and how it affects degree of carbonate saturation and passage time through limestone/chalk, discusses Kani Kedra springs 5km east of Sinjar.

Springs appear at junction of Serikagni limestone and Jeribe limestone overlain by Lower Fars.

Discharge measurement 1979-83: hydrographs presented for each spring. Suggests some contamination with Dhiban anhydrite, low flow / high EC.

The discharge of six springs at Kani kedri shown to vary 0.4 to 1.4 m^3/s, emerging at the contact of the Serikagni and Jeribe Limestones.

Figure B2-3 Variation in Kani Kedri Spring Discharge and Hydrochemistry



Source: Jawad & Hussein [1986, GW10]

GW11 Jawad S B & Hussien K A 1988 Groundwater monitoring network rationalisation using statistical analyses of piezometric fluctuation *Hydrological Sciences Journal*, Vol 33, No 2, pp181-191

Study of groundwater around Erbil and rationalising groundwater monitoring. Not really relevant.

GW12 Al Ansari N, Saleh S A et al 2021 Quality of Surface water and groundwater in Iraq *Jl Eart Sci & Geotech Eng,* Vol 11, No 2, pp161-199

Broader review of the water status in Iraq, repeating information in GW9.

GW13 Sissakian V K, AlAnsari N, Abdullah L H 2020 Neotectonic activity using geomorphological features in Iraqi Kurdistan region *Geotech & Geol Eng Jl,* Vol 38 No 4, pp4889–4904

Useful general structural geology setting, includes section on faults affecting formations in Sinjar Plain.

GW14 McDermid C 2013 Ancient aqueducts give Iraq a trickle of hope Al Jazira online Al Jazira online

Good collection of photographs of karez.

GW15. Abdul Qader U N, 2009, Mapping groundwater quality of Injana aquifer south of Sinjar anticline, *Iraqi Jl earth Sci*

Restricted to 10-15 km south of Sinjar Mountain: focus on drinking water quality.

GW16. Al Daghastani, 2013, Impact of tectonics on alluvial fan landforms in Sinjar mountain using remote sensing *ARSGISO Jl of remote sensing and GIS*, Vol1, No 2, pp15-20

Alluvial fan mapping, mainly north of Sinjar Mountain.

GW17. Sissakian VK, 2011, Geology of Iraq

Relevant small-scale map.

GW18. Sissakian VK & Fouad S F A, 2015, Geological map of Iraq, 1:1million, 4th edition 2012 *Iraqi Bulletin of Geology & Mining*, Vol 11, No 1, 2015, pp9-16

Relevant small-scale map.

GW19. Burungh P, 1957, Exploratory Soil map of Iraq 1:1,000,000, accompanied by memoir Soils and Soil Conditions in Iraq 1960 Div of Soils & Agric chemistry, Ministry of Agriculture, Baghdad

Although dated, useful map which is cited in more recent references, and shows important different zones in Sinjar Plain.

B-3 Water Harvesting and Agriculture

ID	Authors	Year	Title	Name of Publication	Publisher	Collation
WH1	Al-Taiee TM & Rasheed AMM	2011	Hydro engineering feasibility study of surface runoff water harvesting in Al-Ajeej basin, north west Iraq	Tikrit Journal of Eng. Sciences	Tikrit University, Iraq	Vol 18[1], 15-28
WH2	Al-Ansari N, Ezz-Aldeen M, Knutsson S and Zakaria S	2013	Water harvesting and reservoir optimization in selected areas of south Sinjar Mountain, Iraq	Journal of Hydrologic Engineering	American Society of Civil Engineers [ASCE]	Vol 18: 1607-1616
WH3	Alkhadder R	2003	Water harvesting in Jordan using earth ponds	Waterlines	ITDG Publishing [Practical Action Publishing]	Vol 22[2], 19-21
WH4	Al-Daghastani H S	2010	Water harvesting search in Ninevah Governorate using remote sensing data	Iraqi Journal of Desert Studies	Ministry of Higher Education & Scientific Research of Iraq	Vol 2[1]
WH5	Anonymous	undated	Design and construction of "Bistana" water catchment pond, Erbil Governorate: A pilot project between UNICEF and Directorate of Irrigation, Erbil Governorate	-	-	-
WH6	EzzAldeen M, AlAnsari N &Knutsson S	2016	Estimating the life span of rainwater harvesting reservoirs in Sinjar area, Iraq	Journal of Environmental Hydrology	International Association of Environmental Hydrology	Vol 24, Paper 9, 1-10
WH7	Mohammad E, Al-Ansari N, Knutsson S	2016	Annual runoff and sediment in Duhok reservoir watershed using SWAT and WEPP models	Engineering	SciRes	8, 412-422
WH8	FAO	2018	Iraq: Restoration of agriculture and water systems sub-programme 2018-2020		FAO, Rome	Book 110pp
WH9	Adil Al-Khafaji. ICARDA, Syria	2004	Indigenous WH Systems in Iraq	Indigenous WH Systems in West and North Africa	ICARDA	Book 173pp
WH10	Zakaria, S et al	2013	Wheat yield scenarios for RWH at Northern Sinjar Mountain, Iraq		Natural Science Journal	Paper 12pp
WH11	Hachum AY, Mohammad ME	undated	Optimal reservoir sizing for small scale water harvesting system at Al-Hader in northern Iraq	Unpublished?		19p.
WH12	Critchley W and Siegert K, FAO	1991	Water Harvesting: a manual for the design and construction of water	FAO Publications	FAO, Rome	133pp

ID	Authors	Year	Title	Name of Publication	Publisher	Collation
			harvesting schemes for plant production			
WH13	CritchleyW and Gowing J.	2012	Water Harvesting in Sub-Saharan Africa	Earthscan	Earthscan	201pp
WH14	Steenberger F van et al	2010	Guidelines on Spate Irrigation	FAO Publications	Fao, Rome	233pp
WH15	Baquhaizel, S. A. et al	1996	Traditional Irrigation Systems and Methods of Water Harvesting in Yemen	MetaMeta	MetaMeta Netherlands	93+94
WH16	Zakaria S, Al-Ansari N, Knutsson S, Ezz-Aldeen M	2012	Rain water harvesting and supplemental irrigation at northern Sinjar Mountain, Iraq	Journal of Purity, Utility Reaction and Environment	Design for Scientific Rennaissance	Vol 1[3], 121-141
WH17	Zakaria S, Al-Ansari N, Ezz-Aldeen M, Knutsson S	2012	Rain water harvesting at eastern Sinjar Mountain, Iraq	Geoscience Research	BioInfo Publications	Vol 3[2], 100-108
WH18	Adary A, Hachim A, Oweis T and Pala M	2002	Wheat Productivity under Supplemental Irrigation in North Iraq	ICARDA Research Paper	ICARDA	Research Report Series No 2
WH19	FAO	2016	Iraq Agriculture and Livelihoods Needs Assessment in the newly liberated areas of Kirkuk, Ninewa and Salahadin	FAO Publications	FAO, Rome	
WH20	Zakaria S	2012	Rain water harvesting and supplemental irrigation at Sinjar District in north west Iraq	Licentiate Thesis	Lulea University of Technology, Sweden	141p.
WH21	Oweis T, Hachum A and Kijne J	1999	WH and Supplemental Irrigation for Improved Water Use Efficiency in Dry Areas	IMWI Overview	IMWI. Sri Lanka	
WH22	Regional Land Management Unit [RELMA: in ICRAF]	2005	Water from Ponds, Pans and Dams: A manual on planning, design, construction and maintenance	RELMA/ICRAF	World Agroforestry Centre. Nairobi, Kenya	119pp.
WH23	Oweis T, Prinz D and Hachum AY	2012	Water Harvesting for Agriculture in the Dry Areas	CRC Press	CRC Press. London, New York, Leiden	235pp.

ID	Authors	Year	Title	Name of Publication	Publisher	Collation
WH24	Mekdeschi-Studer R and Liniger HP [technical editor Critchley W]	2013	Water Harvesting: Guidelines to Good Practice	Uni Bern/ Rainwater Harvesting Implementation Network/ MetaMeta/ IFAD	Uni Bern/ Rainwater Harvesting Implementation Network/ MetaMeta/ IFAD	186pp.
WH25	Adham A, Sayl KN, Abed R, Abdeladhim MA, Wesseling JG, Riksen M, Fleskens L, Karim U, Ritsema CJ	2018	A GIS-based approach for identifying potential sites for harvesting rainwater in the Western Desert of Iraq	International Soil and Water Conservation Research	International Research and Training Center on Erosion and Sedimentation and China Water and Power Press. Hosting by Elsevier.	Vol 6, 297-304.
WH26	Adham A, Riksen M, Ouessar M, Ritsema C	2016	Identification of suitable sites for rainwater harvesting structures in arid and semi-arid regions: A review	International Soil and Water Conservation Research	International Research and Training Center on Erosion and Sedimentation and China Water and Power Press. Hosting by Elsevier.	Vol 4, 108-120.
WH27	Bilal AA, Abdulbaqi YT, Al-Shakraji BM	2019	Rain water harvesting for Al-Murr Valley, Ninava Governorate, North Iraq	Iraqi Journal of Desert Studies	Ministry of Higher Education & Scientific Research of Iraq	Vol 9[1], 72-85
WH28	Studio Galli Ingegneria SpA, MED Ingegneria Srl, El Concorde Construction LLC	2014	Appendix D/G, Report D.1 & G.5 Monography of Ips. South Jazira. Project ID 039. Final Report		National Center for Water Resources Management, Ministry of Water Resources, Republic of Iraq	Rev000_ 20141027.
WH29	Forzieri G, Gardenti M, Caparrini F, Castelli F	2007	A methodology for the pre-selection of suitable sites for surface and underground small dams in arid areas: A case study in the region of Kidal, Mali.	Physics and Chemistry of the Earth	Elsevier	Vol 33, 74-85.
WH30	Nasri S, Albergel J, Cudennec C, Berndtsson R	2004	Hydrological processes in macrocatchment water harvesting in the arid region of Tunisia: the traditional system of tabias	Hydrological Sciences Journal	Taylor and Francis on behalf of the International Association of Hydrological Sciences	Vol 49[2], 261-272.

Classification is provided at the end of the Appendix

WH1. Al-Taiee TM and Rasheed AMM [2011] Hydro engineering feasibility study of surface runoff water harvesting in Al-Ajeej basin, north west Iraq. *Tikrit Journal of Eng. Sciences* 18[1], 15-28.

Al-Taiee and Rasheed [2011] describe the hydrological calculations for an earth dam on Wadi Al-Ajeej 12.5 m high, 1,277 m long and with a reservoir length of 7.1 km and a normal capacity of 38.8 Mm3. The dam site is located at approximately 35.766^{0}N 41.6^{0}E and has a catchment area of approximately 3,043 km^2. The proposed dam had no specific purpose, although it was recognised in principle that the water could be used for public water supply, supplemental irrigation and groundwater recharge. Of interest were the hydrological calculations to estimate catchment yield. Using the US Soil Conservation Service Curve Number method [a Curve Number of 82], annual runoff volumes for the period 1994-2006 were estimated to range 8.5-137 Mm^3 and mean annual runoff [53.1 Mm^3] was estimated to be approximately 6% of mean annual rainfall. The soils were described as calcareous and gypsiferous. No further consideration was given to geotechnical aspects. It is anticipated that dams and reservoirs of the size considered in this paper are outside the range being considered by NRC.

WH2. Al-Ansari N, Ezz-Aldeen M, Knutsson S and Zakaria S [2013] Water harvesting and reservoir optimization in selected areas of south Sinjar Mountain, Iraq. *Journal of Hydrologic Engineering, ASCE*, 18:1607-1616.

Al-Ansari et al [2013] developed a linear programming technique to maximise the area irrigated by water harvesting dams. Four dam sites were selected in the Al-Ajeej catchment and three in the neighbouring Al-Tharthar catchment to the east that provided a dam length of 0.6-1.8 km and sufficient capacity that can store the expected runoff. The dam sites were selected using a DEM where valley width [construction material for building the dam] was minimised and the ratio of surface area to storage volume [evaporation losses] was minimised. Catchment areas at the dam sites ranged 378-4,108 km^2. Storage capacities ranged from 7.6 Mm^3 to 96 Mm^3 and averaged 29 Mm^3. No site investigations or other feasibility studies were undertaken.

Runoff was estimated using the Watershed Modelling System [WMS] which utilises the US SCS CN method of runoff estimation. The model was calibrated using three observed flood events on a 53.8 km^2 catchment recorded in the winter of 1991-92 [Rafik, 1993]. All three hydrographs resulted from rainfall depths of 23-25 mm. Land use and soil type, identified using Landsat 7 remote sensing imagery [**Al-Daghastani, 2010, WH4**] were used to identify the CN for each catchment. Using the standard US SCS approach, the catchment CN was assumed to apply to average antecedent moisture conditions. Using standard equations, the average CN value was modified for each storm to a CN for dry or wet conditions depending on antecedent precipitation in the preceding 5 days. The calibrated WMS model was used in predictive mode to estimate the runoff volume for each storm event in the study area [recorded at Sinjar, Baaj and Tel-Afer stations] in the period 1990-2009 [except for the war years 2002-2003] in order to estimate the total annual runoff at the dam sites.

Supplemental irrigation water requirements were calculated for winter wheat and barley for each day of the growing season, the available rainfall depth and soil moisture content. The available soil water storage was identified based on soil type based on information from the Ministry of Agriculture, Fisheries and Food, Canada. Soils are described as sandy loam, silty loam and silty-clay loam. Limestone is reported to wholly cover the area. Land use is described as seasonal winter rainfed crops [mainly wheat and barley], mixed rainfed crops and seasonal pasture.

A linear programming optimization technique [using MATLAB software] was developed to determine the maximum planting area that could be supplied from stored runoff in a selected reservoir site, or alternatively, the reservoir size required to satisfy the water requirements.

Irrigated areas were calculated for two operational scenarios: Scenario I in which each reservoir served its own command area, with excess water spilling to the next reservoir downstream, and Scenario II in which all reservoirs in each catchment were operated as a single system with upstream reservoirs operating as temporary storage reservoirs which released water gradually to the downstream-most reservoir which served a single command area. For Scenario I, average irrigated areas per reservoir ranged from 1,300 ha to 7,860 ha, and maximum irrigated areas [in wet years] ranged 4,709 ha to 49,554 ha. For Scenario II, average irrigation areas per system increased by 4.4%-11%, and maximum irrigation areas increased by 28%-59%, indicating the benefit of operating a series of reservoirs as a single system. However, such a system would require good management.

It was shown that the resulting irrigation areas depend not only on reservoir size [storage volume], but also on watershed area, and evaporation losses which depend on reservoir area, and the temporal distribution of runoff over the rainy season in relation to the reservoir volume.

WH3. Alkhadder R [2003] Water harvesting in Jordan using earth ponds. *Waterlines*, Vol. 22[2], 19-21.

Alkhadder [2003] describes two water harvesting programmes in the Badia area, north west Jordan. Since the 1960s, the Badia has seen a big expansion in permanent settlement and cultivation of land. Water harvesting was used all over the Badia some 6,000 years ago to provide water for settlements ranging in size from permanent settlements such as the ancient city of Jawa, 30 km north west of Safawi, to small villages. To provide water for livestock and domestic uses [though not drinking] in the Badia, the Government of Jordan has undertaken programmes of water harvesting comprising the construction of two types of ponds.

Starting in the 1960s, relatively small ponds of about 10,000 m^3 in capacity have been constructed in villages. The ponds are lined with concrete to prevent infiltration losses. A channel diverts water from one or more small wadis with catchments a few hectares in area. The channel carries surface runoff into one or more small concrete tanks of up to 50 m^3 capacity which act as sedimentation tanks. Water is then conveyed into the main storage tank which is equipped with a spillway to drain excess volumes. The ponds have been in use since their completion in the mid-1960s. Simple maintenance is required comprising removal of sediments from the sediment traps and the main pond and repair of cracks in the concrete linings.

A programme of larger earth ponds was commenced in the mid-1990s by Jordan's Badia Research and Development Programme in cooperation with the Ministry of Water and the US Army Corps of Engineers. Earth ponds, up to 100 m wide, 4-5 m deep and over 50,000 m^3 in capacity, were excavated using bulldozers adjacent to major wadis where soils are softer and less permeable. Smaller ponds were also excavated to act as sediment traps. A channel diverts water from the wadi and conveys water into the sediment traps and thence into the main pond. The ponds are fenced to prevent unauthorised access by livestock and children. Infiltration losses into underlying soils decline with time as fine sediments collect on the bottom of ponds. Depending on the rainfall, some ponds dry up, requiring people and livestock to find alternative sources of the water. The earth ponds have been found to be efficient in storing and providing water over many years and have been successfully used for irrigation, animal watering and washing.

Pond water quality is an issue. Pathogenic organisms from human activities or animals into the ponds are washed into ponds in runoff. Pond water is not fit for human consumption without filtration and chlorination, a strict water quality monitoring programme and public education.

WH4. Al-Daghastani H S [2010] Water harvesting search in Ninevah Governorate using remote sensing data. *Iraqi Journal of Desert Studies*, Vol 2[1].

Al-Daghastani [2010] describes the mapping of geomorphic landforms, land use/land cover and geological lineaments in Ninevah Governorate using Landsat 7 multispectral imagery [possibly principally Bands 453 in RGB] for use in the search for sites for water harvesting dams and channels. Five dam sites in Wadi Al-Jeej and three sites in Wadi Al-Tharthar were located using topographic maps and compared on the basis of dam dimensions and reservoir volume. A single preferred site was identified in each catchment. The coordinates of the dam sites are not given, though they are indicated [un-numbered] on maps which do not appear to be the final remote sensing maps. How the remote sensing maps contributed to site selection is not discussed. Ditches are proposed for diverting runoff and conveying it to the saline playas of Sinaisla [in Wadi Al-Jeej catchment] and Ashqar [in Wadi Al-Tharthar catchment] for the purpose of lowering the salinity of these basins. As the playas are closed basins, diversion of runoff is unlikely to be effective. Ditches are also proposed on alluvial fans on the northern and southern flanks of Sinjar Mountain for recharge of local aquifers near villages. However, these proposals are unclear. The main contribution of this work is to have generated [hardcopy] maps which show land use patterns in the mid-late 2000s. These should be updated and used in planning of water harvesting projects.

WH5. Anonymous [undated] Design and construction of "Bistana" water catchment pond, Erbil Governorate: A pilot project between UNICEF and Directorate of Irrigation, Erbil Governorate. File report.

This brief Word document reports the construction of a 12,000 m^3 water harvesting pond at Bistana village, Erbil Governorate. The pond was part of a strategic plan by the Ministry of Agriculture and Water Resources in Erbil Governorate to combat drought. The plan includes the construction of 25 large scale ponds and 49 smaller ponds. Eighteen of the smaller ponds have been constructed, one of which is Bistana. The pond was constructed over an 8-week period in April-June 2019 at a cost of U$55,000. Potential uses of Bistana pond include: recharge of groundwater, irrigation of 550 ha of agricultural land, watering of 5,000 trees, 5,000 livestock, local wildlife conservation, tourism and provision of drinking water if the water is treated [Bistana village has a population of 10,000]. The pond is hailed as an example of UNICEF-Erbil stepping away from humanitarian assistance and getting involved in development assistance. The report calls for clear site selection criteria for future ponds that include community vulnerability.

WH6. Ezz-Aldeen M, Al-Ansari N, Knutsson S [2016] Estimating lifespan of rainwater harvesting reservoirs in Sinjar area, Iraq. Journal of Environmental Hydrology, Vol 24, Paper 9, 1-10.

Aldeen et al [2016] describe the estimation of annual sediment loads trapped in the seven hypothetical reservoirs studied in **Al-Ansari et al [2013, WH2]** and the estimation of the life of these reservoirs. The study utilises the SWAT model, which utilises the US SCS Curve Number method for runoff estimation, the Modified Universal Soil Loss Equation [MUSLE] for estimating sediment yield and Bagnold's [1977] theory of channel sediment load transport for estimation of sedimentation in the reservoirs. **Al-Ansari et al [2013, WH2]** reported the calibration of the runoff model. The sediment model was calibrated based on field measurements in a catchment in northern Iraq with a similar geology to the study catchments reported in **Mohammad et al [2016, WH7]**. The SWAT model was run for the period 1990-2009. Estimated annual sediment yields, which decrease with catchment area, ranged 9.5-20 ton/km^2. Estimated trap efficiencies ranged 96.5-100% due the high reservoir capacities. Resultant reservoir lives exceeded 100 years.

WH7. Mohammad ME, Al-Ansari N, Knutsson S [2016] Annual runoff and sediment in Duhok Reservoir watershed using SWAT and WEPP models. *Engineering*, Vol 8, 410-422. http://dx.doi.org/10.4236/eng.2016.87038

Mohammad et al [2016] describe the estimation of annual sediment yields to the existing Duhok Reservoir, near Duhok city, Erbil Governorate, over the period 1998-2011. Duhok earth fill dam, constructed in 1988, is 64 m high and 613 m long. The total as built storage capacity of 52 Mm3 comprised 47.51 Mm3 live storage and 4.39 Mm^3 dead storage. The reservoir irrigates 4,300 ha, supplies water to Duhok city and provides a recreation amenity. The catchment area is about 130 km^2. Catchment soils are described as sandy clay loam, silty clay loam, clay loam and loam. Catchment geology is not reported. Duhok dam is important because it provides probably the only case study in northern Iraq where measurements were made [during 2008-2009] of runoff and runoff turbidity and, using a relationship established between turbidity and sediment concentration, the estimation of actual annual sediment input to Duhok Reservoir. For 2008-2009 this was 4,082 tons [3,703 tonnes]]. The field studies are described in:

Sulaiman A [2010] Estimating of annual sediments of Duhok Dam by using river turbidity water samples. Journal of Duhok University Agricultural and Veterinary Science, 13, 82-89.

Mohammed R [2020] The impact of man activity in Duhok Dam watershed on the future of Duhok Dam lake North-Iraq. 1st International Applied Geological Congress, Department of Geology, Islamic Azad University-Mashad Branch, Iran, 26-28 April 2010.

Mohammad et al [2016] calibrated the SWAT and WEPP models manually and validated both against to the field data presented in **Mohammed R [2010, not reviewed]** before using both models to estimate annual sediment yields and the total accumulated volume of sediment over the 24-year period 1988-2011. Land use and land cover, based on Landsat 7 imagery analysis, were described as forest [23.8%], open land [16.7%], grass land [13.6%], open land with trees [13.4%], waste land rock [10.8%], cultivated land [10.8%] and rock land [8.4%]. Both models gave comparable estimates. Average annual sediment yield was estimated to be about 120,000 tons. Total sediment accumulation [1988-2011] was estimated to be about 2.9 Mt or 2.4 Mm^3 [assuming a dry density of limestone] sediment of 1.2 t/m^3] or 66% of dead storage.

WH 08. FAO's Component of: Restoration of Agriculture and Water Systems 2018-2020

Executive Summary: "There is a strong imperative to rebuild Iraq's agricultural sector".

Page 4: re Food Security "Of the 8.3 million people in need of humanitarian assistance across Iraq, 2 million are estimated to be food insecure".

Page 12: from the National Development Plan 2018-2022 "Achieving high yields of cereals, especially wheat, as well as for fruit and vegetables was estimated to have the largest effects on economic growth and household income.

Before "the crisis" 65% of farmers had access to irrigation [whole country], now reduced to 20%.

WH 09. Adil Al-Khafaji. 2004. Indigenous Water Harvesting Systems in Iraq. Chapter Seven in: *Indigenous Water Harvesting Systems in West and North Africa*. Eds Oweis et al. 2004. ICARDA.

Introduces the "long history of water inception, collection and storage" in Iraq. However, notes that this has had limited impact in the country as a whole because of irrigation on the Mesopotamian plain where irrigation from the two great rivers has been practised. Nevertheless, WH has had local importance in the more remote areas, and "is gaining more support, enthusiasm and popularity". A map pinpoints the location of specific types of WH systems. There is a precipitation map also. Nine indigenous systems are described/ illustrated, though with superficial detail. In summary these are:

1. Sahārīj: diverted runoff stored in caves. Typically amounts of around 300m3
2. **Kahariz**: a synonym for Karez [see Lightfoot, 2009, GW3]
3. Faydah: ponds constructed alongside wadis
4. Khabrāt: ponds for livestock drinking
5. **Faydah** Agriculture: flood retreat planting
6. Sudūd: small dams intercepting floodwater
7. **Kharījah**: bottle shaped pit dug by hand in high water-table areas
8. Jilban: shallow well in the bed of a wadi
9. Hassy: a well through sand to reach water stored over a hard pan

Note: numbers 2, 5, 7 and 8 are those likely to be found in the study area.

WH 10. Zakaria et al, 2013. Wheat Yield Scenarios for Rainwater Harvesting in Northern Sinjar Mountain, Iraq. *Natural Science Journal*, 12p.

Six basins with rainfed production of wheat were selected to investigate the potential of water harvesting through modelling. Water harvesting was based on collection of runoff in reservoirs. The study looked at production of wheat [bread wheat and durum] under rainfall alone, compared with supplementary irrigation providing 100% of water requirements, 75% of requirements and 50% of requirements. Four years were selected from the recent past. The model assumed a linear increase in production with water supply [total of rainfall and irrigation] up to 450 mm then yield increases tailing off. In summary, to meet the full irrigation demand for bread wheat, between 356 mm and 661 mm of irrigation would have been required [in the highest and lowest rainfall years] while to meet 50% of the irrigation requirement the supplementary water would have been 104 mm and 294 mm respectively. One of the most important conclusions was that supplementary irrigation meeting 50% of crop water requirements was a good compromise between yield and water saving.

While this research is not entirely robust in its assumptions, discussion or conclusions, it does provide an important rule of thumb: that aiming to provide a maximum of 300 mm extra water will ensure that a wheat crop will receive at least 50% of its crop water requirement and yields of around 4-6 tonnes per hectare should be achievable.

WH11. Hachum AY, Mohammad ME [undated] Optimal reservoir sizing for small scale water harvesting system at Al-Hader in northern Iraq. Unpublished paper, 19p.

Hachum and Mohammad [undated] developed a linear programming model to optimise the size of a water harvesting reservoir for supplemental irrigation. The model was applied using rainfall and evapotranspiration data from the Al-Hader area in Ninevah Governorate [Al-Hader is south west of Sinjar].

The soils of the study area are silty clay loam. A barley crop with a 6-month growing season between November and April [thirty six 5-day periods] was assumed over which the mean annual rainfall [1982-1992] is 142 mm [mean 12-month rainfall is 150 mm]. Supplemental irrigation is assumed to take place when the available water in the root zone is 50% of field capacity. The US SCS Curve Number method [CN used is not specified] and 5-day rainfall of 50% probability was used to generate a 5-day runoff record. A reservoir shape comprising an inverted truncated pyramid with a square base and side slopes of 1V:1.5H was assumed. A catchment area of 10 ha was assumed. The objective of the linear programming model was optimisation of benefits vs costs. The volume of irrigation water applied to the cropped area was reduced from 100% to 62.5% of the crop water requirement to study the effect on irrigated area, reservoir volume and objective function value. The optimal benefit was obtained for an irrigation rate of 87.5% of the crop water requirements. The optimum ratio of catchment area to irrigation area was found to be 3, implying an irrigation area of about 3 ha. The optimum reservoir volume was found tobe 1 110 m3for the catchment area of 10 ha or 111 m^3/ha. The dimensions of the square base of the reservoir were given as 12.5 m x 12. 5 m, but the maximum water depth was not given.

Uncertainties [questions] include:

1.The maximum depth of water in the reservoir.

2.The record of 5-day rainfalls with 50% probability may not have been correctly calculated because the total rainfall over the growing season used in the model is 324.5mm and is said to represent an average year.

3.How does application of irrigation water at rates of 100% down to 62.5% of crop water requirements square with irrigating only when the available water in the root zone is 50% of field capacity?

WH12. Critchley W and Siegert K, FAO 1991, Water Harvesting: a manual for the design and construction of water harvesting schemes for plant production, FAO Publications, FAO, Rome, 133pp.

The first overview of water harvesting for FAO – based on a study carried out for the World Bank. The focus is on sub-Saharan Africa but many of the systems reported are more widely appropriate. The booklet provides a classification of water harvesting systems, covers crop water requirements, as well as describing various systems based on case studies. It does not directly address ponded water/ supplemental irrigation however.

WH13. Critchley W and Gowing J., 2012, Water Harvesting in Sub-Saharan Africa, Earthscan, 201pp.

An edited book which is based on an update of experience documented by the World Bank's "Sub-Saharan Water Harvesting Study" some 20 years before. Particularly relevant to this assignment is the Chapter on Sudan.

WH14. van Steenberger F et al 2010, Guidelines on Spate Irrigation, FAO Publications, Rome, 233pp.

The authoritative text on spate irrigation: covers all aspects of different types of systems. Technical considerations as well as agronomic and social. North Africa/ the Horn of Africa, Yemen and Pakistan are the key areas of attention.

WH15. Baquhaizel, S. A. et al, 1996, Traditional Irrigation Systems and Methods of Water Harvesting in Yemen, MetaMeta, Netherlands 93+94.

Well-illustrated but light on detail. Nevertheless, a useful overview and has English and Arabic sections.

WH16. Zakaria S, Al-Ansari N, Knutsson S, Ezz-Aldeen M [2012] Rain water harvesting and supplemental irrigation at northern Sinjar Mountain, Iraq. *Journal of Purity, Utility Reaction and Environment*, Vol 1[3], 121-141.

A paper by the same team as [WH2 and WH7]. Six dam sites were selected in six catchments on the northern flank of Sinjar Mountain, ranging in area 43.4 km^2-197.7 km^2. Dam heights ranged 3.5-5.7 m and reservoir capacity ranged 0.256-2.359 Mm^3, smaller than those reported in WH2. How the dam sites were selected is not described. The US SCS runoff curve method [within the WMS modelling package] was calibrated to three observed hydrographs, as described in **Al-Ansari et al [2011, WH2]** and used to synthesise a daily runoff record for each basin from the daily rainfall record. Soils in northern Sinjar are reported as sandy loam, silty loam and silty clay loam with low organic content [Rasheed, 1994]. Supplemental irrigation water requirements were estimated for each day of the growing season. A linear programming model was used to optimise irrigated area by supplemental irrigation [100% crop water requirement-cwr] and deficit irrigation [50% and 25% of crop water requirements] depending on the storage in the reservoir. For the 100% cwr satisfaction, irrigable areas ranged 0.3-1,928 ha, 50% cwr –33-39,827 ha, and 25% cwr –20-7,314 ha. The lower area for 25% cwr is not explained. Deficit irrigation allows larger areas to be irrigated, but there is a cost to crop yield per unit area. Benefits were maximised by a deficit irrigation of 50% of cwr, but these were not well explained. Water spilled from reservoirs may be used for groundwater recharge, but how was not explained. The paper doesn't cover economic aspects of the study.

The authors state that mean annual rainfall in northern Sinjar was 286.7 mm over the period 1990-2009 [a mean of Sinjar, Tel-Afer and Rabiah stations]. Maximum and minimum annual rainfall in this period was 478.1 mm [1995-96] and 110.1 mm [1998-99]. Maximum monthly evaporation [pan evaporation?] is usually recorded in July and reaches 563.4 mm, dropping to 57.4 mm in December.

WH17. Zakaria S, Al-Ansari N, Ezz-Aldeen M, Knutsson S [2012] Rain water harvesting at eastern Sinjar Mountain, Iraq. *Geoscience Research*, ISSN: 0976-9846 & E-ISSN: 0976-9854, Vol 3[2], 100-108.

Another paper with the aims and content of **Zakaria et al [2012, WH16]** and **Al-Ansari et al [2013, WH2]**, but reporting studies of four dams in eastern Sinjar District. Catchment areas ranged 63.32-154.25 km^2. Dam height ranged 2.5-6 m, length 636-904 m and capacity 0.265-0.872 Mm^3. Two soils from the soils map of Iraq are represented in the area: Type 35 is a silty clay and silt clay loam, with a depth >2m, pH>7 and 1-2% organic matter. Secondly, soil type 31 is a lithosolic soil in sandstone and gypsum and covers the hills and upland areas. Land use comprises cultivated land, pasture of poor to good condition, and rock. The dam sites were selected in order to minimise the volume of earthmoving required and minimise evaporation [high volume:width ratio]. The catchments are located north of Tel-Afer. Methods and findings were similar to **WH16**. Deficit irrigation of 50% of crop water requirements was found to be most beneficial, no explanation given.

WH18. Adary A, Hachum A, Oweis T and Pala M [2002]. Wheat Productivity under Supplementary Irrigation in Northern Iraq. ICARDA Research Report Series.

Iraq had a significant deficit in wheat production vs consumption even in 2002. In Nineveh Governate, all wheat was produced under rainfed conditions before 1990 - except around springs [and Karez outlets presumably]. Rainfall ranges from 350-500 mm p.a. and rainfed wheat yields average 0.5 tonnes/ha. Supplemental irrigation [SI] is a powerful tool in improving [increasing and stabilising] yields, and importantly it increases water use efficiency [water use : yield ratio] when applied at times of deficit/ critical stages of wheat growth [March-April in particular at flowering and grainfill stages]. Relatively small amounts of supplemental irrigation can "substantially enhance wheat production". This was established on the basis of a replicated trial at Rabiah Research Station, some 80 km NW of Mosul, where annual average rainfall is 391 mm. Results confirmed ICARDA's findings from Syria.

WH19. FAO [2016] Iraq Agriculture and Livelihoods Needs Assessment in the "newly liberated areas of Kirkuk, Ninewa and Salahadin"

The impacts of the previous decade's problems have been significant on crops, livestock, fisheries and livelihoods. Recommendations for "resilient livelihood recovery" with respect to crops include crop insurance, early warning systems, expansion of irrigation, rehabilitation of destroyed irrigation infrastructure and payment of fees for water use.

WH20. Zakaria S [2012] Rainwater harvesting and supplemental irrigation at Sinjar District in north west Iraq. Licentiate Thesis, Lulea University, Sweden, 141p.

The PhD thesis that underpins and provides material for papers **WH2** and **WH16**. Paper **WH17** is an extension of the approach taken in Paper **WH16** to eastern Sinjar with similar findings

WH21. Oweis T, Hachum A and Kijne J [1999] Water Harvesting and Supplemental Irrigation for Improved Water Use Efficiency in Dry Areas. IWMI. Sri Lanka.

A state-of-the-art overview of water harvesting and supplemental irrigation in the WANA region. With respect to supplemental irrigation this overview stresses that the water productivity of rainfall + supplemental irrigation exceeds that of either alone. Figure 12 shows yield response to water. The paper quotes Critchley and Siegert [1991: Water Harvesting, FAO]: “It is sad but true that often the people simply do not understand what a project is trying to achieve, or even what the meaning of the various structures is.”

WH22. RELMA/ World Agroforestry Centre [2005] Water from Ponds, Pans and Dams. Nairobi, Kenya.

This practical manual goes through all stages of planning and implementation of small water holding structures. While aimed at Kenya is particular, most of the information is applicable and relevant elsewhere. Topics/ chapter cover “Community Participation”, “Feasibility and Planning”, “Design and Construction”, “Operation” and “Tools”. There are excellent, simple, diagrams and tables of quantities, etc.

WH23. Oweis T, Prinz D and Hachum AY, 2012 Water Harvesting for Agriculture in the Dry Areas, CRC Press. London, New York, Leiden, 235pp.

A must-have for the project. This booklet has many similarities to other guidelines listed here, but is focussed on the region covered by ICARDA [MENA]. Covers micro-catchment systems as well as macro-catchment and floodwater harvesting. Water harvesting for livestock included.

WH24. Mekdeschi-Studer R and Liniger HP [technical editor Critchley W], 2013, Water Harvesting: Guidelines to Good Practice, University of Bern/ Rainwater Harvesting Implementation Network/ MetaMeta/ IFAD, 186pp.

An excellent overall guideline – this and **WH23** have considerable overlap though this is better laid out and illustrated. Particularly good on rooftop and compound water harvesting.

WH25.Adham A, Sayl KN, Abed R, Abdeladhim MA, Wesseling JG, Riksen M, Fleskens L, Karim U, Ritsema CJ [2018] A GIS-based approach for identifying potential sites for harvesting rainwater in the Western Desert of Iraq. *International Soil and Water Conservation Research*, Vol 6, 297-304.

Adham et al [2018] present an approach to identifying sites for rainwater harvesting dams using a "site suitability model" created using ModelBuilder in ArcGIS 10.2. The model combines digital maps of physical factors: slope [from a 30m resolution DEM], runoff depth [estimated using the US SCS CN method for each 30 m pixel], land use [based on classification of a Landsat 8 image with 30 m resolution], soil texture [method unclear but may involve estimation of soil type based on clay content as deduced from Landsat 8 digital image processing] and stream order [based on mapping of stream junctions]. Each map layer is divided into classes whose limits are defined by numerical criteria. Scores are allocated to each class of each physical factor which reflect its water harvesting potential. Scoring is subjective and requires expert input. The maps are superimposed and the resulting overall suitability map, which itself is divided into five classes of suitability, is said to allow planners to identify areas with the highest water harvesting potential. Actual dam sites are identified by visual interpretation of large-scale topographic cartography and satellite imagery. A suitable site for a dam is defined as “a place where a wide valley with high walls leads to a narrow canyon with tenacious walls” [Sayl et al, 2016, not reviewed]. SRTM data is said to be useful in assessing valley width. Adham et al [2018] recommend that the valley behind the dam should have a slope of 1.5-4.5% and clay and silty clay soils that have a high water-holding capacity [low permeability]. Each potential dam site is then investigated further by calculating elevation-volume-area [EVA] curves. Volumes and heights of dams are calculated and plans should be developed showing the inundated area at different water levels. Sites should be selected for development which minimise construction costs and evaporation. Adham et al [2018] also recognise the importance of how well sites fit with stakeholders’ social and economic context and indicators such as proximity to roads, distance to settlements, land ownership and even family size and education in the final selection of sites for development. The method as far as plotting EVA curves for three potential dam sites is demonstrated on the 13,370 km^2 Wadi Horan catchment to the south of Nineveh Governorate.

WH26. Adham A, Riksen M, Ouessar M, Ritsema C [2016] Identification of suitable sites for rainwater harvesting structures in arid and semi-arid regions: A review. *International Soil and Water Conservation Research*, Vol 4, 108-120.

Adham et al [2016] review methods for identifying sites suitable for water harvesting published in 48 publications dating from the 1970s. Methods and criteria are compared with the aim of defining a general method for use in arid and semi-arid regions. Biophysical criteria [rainfall, slope, land use/cover and soil type] determine technical suitability but do not guarantee success [adoption and replication by farmers]. Failure has often been due to other, socio-economic, reasons, which are often case-specific. Selecting the most relevant socio-economic criteria requires good insight into the local situation and stakeholders involved. There is no consensus on the socio-economic criteria to use. Reference is made to FAO [2003] guidelines which suggest population density, people's priorities, experience with water harvesting and land tenure should be considered.

The technical methods of selecting suitable sites are GIS methods with or without hydrological modelling and with or without multi-criteria analysis [MCA]. GIS combined with MCA is suggested to provide the most rational, objective and unbiased method, and is said to be compatible with indigenous knowledge of the farmers [presumably incorporated in the MCA]. They conclude the most suitable method depends on the objectives and needs of the project and on the quality of data available.

WH27. Bilal AA, Abdulbaqi YT, Al-Shakraji BM, [2019]. Rainwater harvesting for Al-Murr valley, Nineveh Governorate, North Iraq. *Iraqi Journal of Desert Studies*, Vol 9[1],72-85.

Bilal et al [2019] estimate the volumes of water generated in Wadi Al-Murr [exact location unknown] for water years 2003-04 to 2011-12 using the US SCS CN method and daily rainfall data from Rabiah station. The Wadi Al-Murr drains 2,469 km^2 and flows into the River Tigris downstream of Mosul dam. The catchment lies outside NRC's study area. Satellite images, digital maps, a DEM and the WMS modelling system were used to select dam sites and estimate flow data. Dams were proposed in two sub-basins with heights of 5m. Mean rainfall for the period 2003-2012 was 297 mm. Runoff ranged 2.17-46.2 mm. No runoff was generated in the rainy seasons of 2007-08 and 2011-12.

WH28. Studio Galli Ingegneria SpA, MED Ingegneria Srl, El Concorde Construction LLC [2014] Appendix D/G, Report D.1 & G.5 Monography of Ips. South Jazira. Project ID 039. Final Report Rev000_20141027. Report to National Center for Water Resources Management, Ministry of Water Resources, Republic of Iraq.

This 2014 report presents the status of planning for the South Jazira Irrigation Project. The SJIP is located mostly in Tel-Afer District, but partly in Sinjar District. The report presents much information of interest to the review.

The southern boundary of the SJIP is marked by a zone of unfavourable topography and shallow soils [badlands] in an east-west zone roughly along a line drawn between Baaj and Al-Abtah.

Three types of land tenure exist in Ninawa Governorate: i] privately owned land [dominant], ii] land rented from government or individuals, iii] sharecropped land. The average land holding is 26 ha [104.8 du].

Page 11. In terms of calcium sulphate [$CaSO_4$], surface water salinity hazard is classified as 'high' to 'very high'. But in terms of sodium hazard, surface water quality is classified as 'low' to 'medium'. However, surface water in Wadi Tharthar is sodium rich.

Groundwater is discounted as a potential source of water for SJIP. Recharge is far too low in comparison with the maximum irrigation water requirement [125 m^3/s].

Soils are described as gypsiferous. During a rapid assessment survey, soils were observed to have a fine texture, depth greater than 0.6 m, salinity ranging 0.65-3.41 dS/m and averaging 1.22 dS/m, pH ranging 7.74-8.20 and averaging 7.93.

WRT to land suitability for irrigation, the SJIP area is classed as <u>moderately suitable</u> for irrigation. Limiting factors are soil depth [16% of soils are shallower than 1 m, the moderately high soil $CaCO_3$ and heavy to medium soil textures. Soils are reported to be not saline.

WRT to land capability, the soils are more or less suitable for cultivation, but have severe limitations which restrict the choice of crops. The main limitations are: fertility, moderately high soil $CaCO_3$, soil texture and risk of erosion. Soils are reported to be not saline.

Most of the project area is covered by rainfed cropland and marginal agriculture. Wheat and barley are considered 'strategic' and are purchased by Iraqi Government at a subsidised price [700 ID/kg]. Rainfed crop yields vary from zero in a dry year to 0.5-0.8 ton/du[15] [2.0-3.2 ton/ha] in a good year.

In scattered areas, wheat is irrigated using centre pivots or lateral moving sprinklers. Is it supplemental irrigation, or full irrigation? Groundwater is abstracted using shallow and deep [>100 m] boreholes. "All of the shallow and deep wells are saline." Three observations of groundwater salinity gave 5.95, 5.20 and 5.84 dS/m, which is classified as 'unsuitable' for irrigation. Fruit and vegetables are not grown. Continued use of groundwater for irrigation is unsustainable; the resource will be depleted due to the imbalance of abstraction and recharge, groundwater is saline and irrigated soils will be salinized. The average depth to groundwater table in the SJIP area is reported to be 6.23 m, shallower than average in ACZ3.

Salinity classification of water suitability is shown as follows:

- Unsuitable >3.0 dS/m
- Doubtful 2.0-3.0 dS/m
- Permissible 0.75-2.0 dS/m
- Good 0.75 dS/m
- Excellent 0.25 dS/m
- Cost per dunam of wheat [irrigated?] is 250,000 ID [Iraqi Dinars]
- Income per dunam of wheat if irrigated by sprinkler: 350,000 ID.

The report presents climate data from Sinjar meteorological station, but whether the data are averages for a particular period or monthly data for 1982 is unclear.

The project area is located in agro-climatic zone ACZ3 and is characterised as arid climate, cool to mild winter, warm to very warm summer.

Table B3-1 presents the meteorological data used to calculate reference evapotranspiration [ETo] using the FAO Penman-Monteith equation. The data are said to represent 15 years of not necessarily consecutive data in the period 1981-2010.

Table B3-1 Climate data for the South Jazira Irrigation Project

Month	Rainfall [mm]	T_{max} [°C]	T_{min} [°C]	RH [%]	WS_{2m} [m/s]	n [hours]	ETo [mm]
Jan	53	12.5	3.1	77	1.3	4.9	30
Feb	41	15.2	4.4	69	1.4	6.5	44
Mar	44	20.1	7.8	59	1.6	7.3	83
Apr	21	25.7	12.3	53	2.0	8.3	125
May	8	33.3	18.0	36	2.3	9.7	201
Jun	0	39.5	23.0	25	2.4	11.3	253
Jul	0	42.8	26.4	23	2.5	12.0	290
Aug	0	42.3	25.8	24	2.3	11.6	267
Sep	0	37.6	21.3	26	2.0	10.3	199
Oct	12	30.4	15.7	39	1.6	8.4	127
Nov	30	21.2	8.3	58	1.3	6.6	61
Dec	44	14.7	4.2	75	1.3	5.1	33
Annual	**256**	**27.9**	**14.2**	**47**	**1.8**	**8.5**	**1 714**

Notes: T T max and Tmin - maximum and minimum temperatures respectively; RH - relative humidity; WS2m - windspeed at 2 m height; n - sunshine hours; ETo – FAO Penman-Monteith reference crop evapotranspiration.

[15] In Iraq, 1 dunam = 0.25 ha [2,500 sq. metres]. 1 ha = 4 dunams

WH29. Forzieri G, Gardenti M, Caparrini F, Castelli F [2007] A methodology for the pre-selection of suitable sites for surface and underground small dams in arid areas: A case study in the region of Kidal, Mali. *Physics and Chemistry of the Earth*, Vol 33, 74-85.

Forzieri et al [2007] present a screening procedure for assessing the suitability of sites for small surface [sand] and sub-surface dams. Both types of dam aim to retain water in sediment upstream of the structure for abstraction by shallow wells. Neither type of dam aims to recharge groundwater in the sense that is proposed by NRC/WRA. Both types of dam must be founded on impermeable strata and form impermeable barriers to horizontal groundwater flow in order to function as planned. In contrast, 'our' dams merely aim to maximise infiltration of surface flow in a localised area, for subsequent abstraction downgradient, or within the 'reservoir area'.

Forzieri et al [2007] proposed to evaluate sites based on two coefficients: Alpha = {Vs[eff] / V}; and Beta = {Alpha. P}.

where:

- alpha reflects the morphology of the dam site
- Vs[eff] is the estimated volume of water held in the sand reservoir upstream
- V is the volume of the dam structure [in effect a benefit/cost ratio].
- Beta is a coefficient reflecting the overall morphological and hydrological suitability of a dam site.
- P is the probability of exceeding a depth of rain that will generate sufficient runoff to fill the available storage. [The estimation of P is not explained in the paper.]

Forzieri et al [2007] proposed a three-stage screening procedure:

1. Identification of potential dam sites based on:
    a. cartography [available in Mali at 1:200 000] and estimation of the length L of the dam.
    b. Estimation of the 'reservoir basin' area A'.
    c. Estimation of the stream channel length within the reservoir basin.
    d. Estimation of the catchment area A.
    e. Identification of faults using available geological mapping and Landsat 7 TM imagery.
    f. Estimation of bedrock depth and porosity of the sediments in the reservoir basin. Forzieri et al had surface geophysical data and sediment samples available.
2. Qualitative selection of sites based on:
    a. Impermeable stratum for dam foundations
    b. Absence of faulting
    c. Porous sediments
    d. Proximity to villages
    e. Proximity to roads
3. Site classification based on the coefficients Alpha and Beta. Calculation of Alpha involves calculation of:
    a. Volume of the structure
    b. Volume of the sand reservoir
    c. Volume of water stored based on porosity of the sediment.

Forzieri et al's [2007] approach is not necessarily useful in the context of Sinjar.

Any [NRC] recharge dam should be founded on firm bedrock, but it should not be impermeable, but allow recharge of the local groundwater system. Sediment should not be allowed to build up within a recharge dam, but should be periodically removed in order to allow water to be retained behind the dam to promote infiltration.

This is generally the wrong approach to recharge basins as the reservoir area will always seal over with fine silty-clay materials and become impermeable.

WH30. Nasri S, Albergel J, Cudennec C, Berndtsson R [2004] Hydrological processes in macrocatchment water harvesting in the arid region of Tunisia: the traditional system of tabias. *Hydrological Sciences Journal*, Vol 49[2], 261-272.

Tabias are a traditional system of long slope or macrocatchment water harvesting practised in Tunisia. This paper presents the results of four years of rainfall, runoff and infiltration measurements in a tabia with the aim of showing how the tabia influences the water balance and to improve understanding how the system changes the hydrology of an arid catchment. The efficiency of the water collection system is established.

The monitored Bou Hedma catchment is gently sloping [8-12%]. The geology consists of Pleistocene alluvial deposits overlying calcareous [limestone] bedrock. Soils are fairly deep sandy clay or sandy silt with a gypsiferous limestone crust at 1 m depth. The climate is characterised by cool rainy winters and hot, dry summers with transitional periods in spring and autumn. Average annual rainfall [1935-1996] is 141 mm with a standard deviation of 58.9 mm.

A tabia is a cropped strip of land that is enclosed on three sides by 1.5 m high soil banks. A traditional stone weir discharges excess water to the next tabia downslope. The stone weirs on four tabias were converted into thin plate weirs for flow measurement. Rainfall and runoff were measured continuously and soil water content at 10, 20, 40 and 80 cm depth were measured at weekly intervals in run-on areas. The water level-volume relationship for each tabia was measured and a water balance calculated for each tabia.

Conclusions reached:

- System captures hillslope runoff very efficiently and significantly reduces flood risk downgradient [no excess runoff from the total catchment].
- The cultivated area is about 5% of the catchment area. On average, the system supplies seven times the actual rainfall amount for events exceeding 20 [15] mm [is this the threshold for runoff generation]
- Runoff stored behind tabias infiltrates in 2-3 days and recharges soil water storage, allowing farmers to grow vegetables. Fruit trees are grown in areas of deeper soil. Farmers can choose different crops depending on sub-catchment size.
- Presently unknown is the maximum rainfall event that can be harvested by the system without loss.

B-4 Water Resources and Water Supply

ID	Authors	Year published	Title		Publisher	Collation
WS1	Relief International	2019	Situation report on WASH in Sinjar District	Report to Nadia's Initiative	Nadia's Initiative	42p.
WS2	IOM Iraq	2012	Water scarcity	Special Report	IOM Iraq	22p.
WS3	Engicon	2016	Environmental management drought plan guidelines for Iraq		UNICEF	207p.
WS4	World Bank	2017	Beyond scarcity – Water security in the Middle East and North Africa [MENA]		World Bank Group	199p.
WS5	Tinti A	2017	Water resources management in the Kurdistan Region of Iraq: A policy report	Institute of Regional and International Studies	American University of Iraq, Sulaimani	11p.

Classification is provided at the end of the Appendix

WS1. Relief International [2019] Situation report on WASH in Sinjar District. Report to Nadia's Initiative, April 2019, 42p.

Lack of access to water and sanitation is said to be the single greatest challenge faced by returning Yazidis. International NGO Relief International herein reports the WASH situation and needs assessment in 10 communities in Sinjar District in 2016, covering water sources, water distribution systems, wastewater collection and treatment, rainwater drainage and solid waste. The report focuses on villages and does not cover agricultural land outside villages.

Issues reported include the competition between agriculture [assumed within or immediately around the villages] and domestic needs for borehole water, water sharing between communities has been unsuccessful [conflicts], absence of policy on allocation of water resources, unregulated leaking connections, bottomless septic tanks, open greywater disposal, insufficient solid waste collection.

The report outlines three possible programs of projects to run in tandem, all of which aim to balance the struggle for limited water resources between competing domestic and agricultural needs. The programs are [i] Immediate response [fast track WASH response projects], [ii] Rehabilitation [larger projects to bring WASH back to previous conditions], and [iii] Transformational [innovative new projects that will lead to stronger water resiliency]. Program [iii] specifically identifies water conservation measures.

Water harvesting initiatives are included in the programs in the following ways:

- Immediate program: Provision of training and materials to build household rainwater harvesting systems and enable household agriculture
- Rehabilitation program: Rehabilitation of irrigation networks [disconnect irrigation systems from household networks and provide separate supply for irrigation if necessary]. [It is assumed that the irrigation is taking place immediately within or around villages]
- Rehabilitation of existing rainwater drainage systems. [These could be directed to irrigation areas if the topography allows]
- Transformation program: A borehole tracking program and installation of improved water distribution systems and rainwater drainage systems.

The report recommends inter alia the following policy and advocacy campaigns:

- Extending the work of the Advanced Survey of Hydrogeological Resources in Iraq Phase II to north of Sinjar Mountain.
- Develop alternative water sources [rainwater harvesting]
- Develop a water resource management plan for Sinjar to determine seasonal groundwater fluctuations, establish sustainable groundwater abstraction rates and develop a system of water resource allocation and management.

NRC should consider collaboration and cooperation with Relief International if IR has decided to support WASH in Sinjar District.

WS2. IOM Iraq [2012] Water scarcity. IOM Iraq Special Report, 22p.

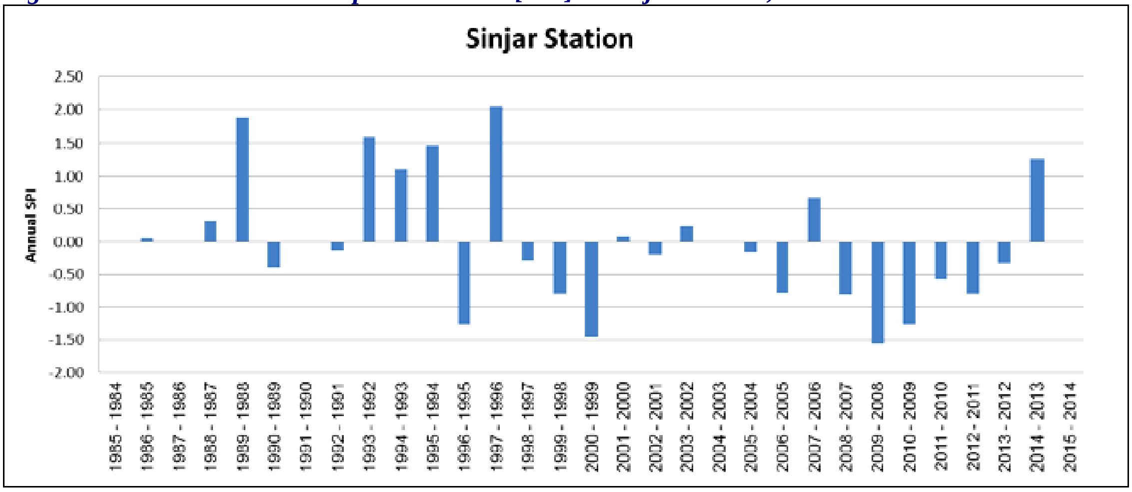
Reports a nationwide survey during 2011-2012 to measure the effect of water scarcity caused by lack of water, high salinity and poor water quality on the lives of vulnerable families. Recognises the use of groundwater and flood irrigation techniques in northern Governorates. Reports IOM's involvement in rehabilitation of Karez [not in Ninewa]. Does not mention water harvesting, but recommends continuation of a trend towards less water intensive crops and irrigation methods [p.12].

Very general and self-evident: recommendations about dealing with water scarcity. Highlights the importance of awareness raising campaigns. Discusses the importance of targeted rehabilitation of irrigation infrastructure as well as restoration of “Karez” well networks.

WS3. Engicon [2016] Environmental management drought plan guidelines for Iraq. UNICEF, September 2016, 207p.

Engicon [2016] aims to provide comprehensive guidelines for drought planning. Drought threatens sustainable development in Iraq. The most vulnerable sectors are water and health. The study is in two parts: firstly, baseline conditions are assessed in terms of existing resources and drought risk. Secondly, guidelines for drought management are developed. Droughts are cyclical in Iraq. Between 1984-2014 Kurdistan suffered four serious and three moderate drought events, as demonstrated by the Standardized Precipitation Index [SPI] and Reconnaissance Drought Index [RDI]. The report provides high level existing and future estimated water supply and demand figures. Looks at coverage of water supply and sanitation and estimates growth in unserved populations if nothing is done and population growth continues. Estimates investment required to provide full coverage with water supply and sanitation. The proposed drought management plan comprises 3 components: [i] preparedness, [ii] Drought responses, and [iii] Recovery. The formation of a National Drought Committee and a Drought Monitoring Centre are proposed. Responses include augmenting water supplies, managing demand [proposes reducing daily per capita usage from 400 l to 120 l] and minimising impacts by, inter alia, awareness programs related to water use efficiency and improved sanitation. Agricultural water consumption should be reduced by improving irrigation efficiency. Lists of immediate actions and partners were proposed. Benefits and costs of investment in water and sanitation were estimated between 2016 and 2050. The B/C ratio is about 2 for the period 2016-2020 rising to about 6 between 2046-2050.

Figure B4-1 Standardised Precipitation Index [SPI] at Sinjar stations, 1983-2016



Source: Engicon [2016, WS3]

WS4. World Bank [2017] Beyond scarcity – Water security in the Middle East and North Africa. World Bank Group.

More than 60% Iraq's population lives in areas with high/ very high water-stress. There is "erosion of water resources" continuing to take place. Great care must be taken with groundwater because of the danger of further depletion. Paramount is the sustainability of investments. Where applicable, more use should/ could be made of treated wastewater for irrigation.

Page 18. SDG Goal 6.A: By 2030, expand international cooperation and capacity building support to developing countries in water and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, recycling and re-use technologies.

Page 52. Storm water harvesting and spate irrigation are well established measures that have been used for centuries to address water scarcity in the MENA region.

Decentralised systems for rainwater harvesting using water tanks and cisterns provide important supply sources.

In the face of population growth and ongoing urbanisation, urban rainwater harvesting will become increasingly important [Lange et al 2012, Hydrology and Earth System Science, Vol 16, 715-724

Spate irrigation systems, although technically complex and often uneconomic at scale, are still a valid development option for rural populations in hyper-arid areas of the Middle East [Van Steenbergen 2010, no reference given].

WS5. Tinti A [2017] Water resources management in the Kurdistan Region of Iraq: A policy report. Institute of Regional and International Studies, The American University of Iraq, Sulaimani, 11p.

Kurdistan includes most of Sinjar District. See map at https://en.wikipedia.org/wiki/Kurdistan

Reports that there are three governorates under KRG administration [Nineveh, Erbil and Dohuk]. This is no longer the case. Since most of Kurdistan is in NE Iraq, this document focuses on NE Iraq. The extent to which it also covers NW Iraq [Sinjar] is unclear.

Groundwater levels are reported to have dropped by 30-40 m over the last 10 years. Factors responsible include unauthorized drilling of wells and traditional irrigation methods. Does this apply to Sinjar too?

Iraq has suffered from recurring droughts since 2007.

Tinti [2017] presents the main challenges to water planning and management in the Kurdistan Region of Iraq [KRI], and summarises policy measures and best practices based on a functional needs assessment of the Kurdistan regional Government [KRG] to address these challenges.

Traditionally, farmers use groundwater and flood irrigation methods. The use of groundwater continues to increase unregulated. Tinti [2017] states "Among the MoAWR's several missions is the protection of groundwater resources and the development of surface water supplies for irrigation and water harvesting projects."

Policy recommendations include:

- Investment in small-scale decentralised projects [ponds, micro and subsurface dams, water recycling plants which are seen as cost-effective and high reward alternatives that can be undertaken even in times of austerity] to increase water supply and recharge groundwater.
- Incentivise the adoption of water-saving measures and advanced irrigation systems.

WS7. Water Resources in Iraq. Fanack Water

Iraq's annual active groundwater recharge is not fully understood. It is currently under study with UNESCO. Groundwater is very sensitive to the consumption and availability of surface water. "If surface flow from upstream riparian neighbours is reduced as much as forecasted, there will be also be a significant impact on groundwater systems.

B-5 Classification

ID	Authors	Year published	Title	Name of Publication	Publisher	Collation	Edition	Material type	Language	Main topic	Notes / version	Nature of contents	ISSN	ISBN	author nationality	author expertise	peer review	classification	value to project
CL1	Al-Sudani H I Z	2020	Calculation of meteorological water balance in Iraq	Resources Environment and Information Engineering	SyncSci Publishing	2(1): 84-89	DOI: 10.25082/REIE.2020.01.004	Technical journal	English	Rainfall, evaporation, water balance	Electronic version only	Technical paper			Iraqi	Hydrology	No?		Provides estimates at Sinjar, Baaj and other meteorological stations of mean annual rainfall, potential and actual evapotranspiration using the Thornthwaite method, and of water surplus available for groundwater recharge and runoff.
CL2	Al-Ansari N, Abdellatif M, Ali SS, Knutsson S	2014	Long term effect of climate change on rainfall in northwest Iraq	Central Europoean Journal of Engineering	Versita sp. z o.o.	Vol 4(3), 250-263.	DOI: 10.2478/s13521-013-0151-4	Technical journal	English	Climate change	Electronic version only	Technical paper			Iraqi	Climate science	Yes?		Projects a decline in rainfall and therefore water resources in Sinjar District over the 21st Century based on downscaling of HADCM3 global climate model data for the A2 and B2 emissions scenarios. Suggests that prudent water management practices should be adopted to overcome or mitigate the expected severe water shortages projected.
CL3	Ministry of Foreign Affairs of the Netherlands	2018	Climate change profile, Iraq		Ministry of Foreign Affairs of the Netherlands	18p.		Government report	English	Climate change	Electronic version only	Summary for policy makers			International	Climate change	Yes?		A high level summary of Iraq's vulnerability to climate change and policy choices facing Iraq, with information on climate finance aimed at policy makers .
CL4	Yenigun K, Ibrahim WA	2019	Investigation of drought in the northern Iraq region	Meteorological Applications	Royal Meteorological Society	Vol 26, 490-499.		Technical journal	English	Climate change	Electronic version only	Technical paper			Iraqi	Climate science	Yes		Not a terribly useful investigation of drought in northern Iraq. Although Sinjar station was one of the stations used, little information is given on drought in Sinjar District.
CL5	Abdulla FA, Amayreh JA, Hossain AH	2002	Single event watershed model for simulating runoff hydrograph in desert regions	Water Resources Management	Kluwer Academic Publishers	Vol 16, 221-238.		Technical journal	English	Hydrological modelling	Electronic version only	Technical paper			Jordanian	Hydrology	Yes		Reports field hydrological investigations took place in the mid-1970s in two catchments in the Western Desert some 200 km south of Sinjar District. Hourly rainfall and wadi flow data are (were) available from the Ministry of Agriculture Directorate of Western Desert Development Projects.
CL6	Ministry of Health and Environment	2016	Iraq's Initial National Communication to the UNFCCC		Ministry of Health and Environment, Iraq	240p.		Government report	English	National circumstances and contribution to global greenhouse gas emissions	Electronic version only	National report			Iraqi	Multi-disciplinary	Yes?		Reports historical trends in climate variables at a number of stations including Mosul. Outlines national adaptation strategies to address expected future increasing temperatures and decreasing rainfall, including water harvesting and groundwater-based irrigation!
CL7	Al-Sudani H I Z	2019	Rainfall returns periods in Iraq	Journal of University of Babylon for Engineering Sciences	University of Babylon	9p.		Technical journal	English	Hydrology	Electronic version only	Technical paper			Iraqi	Hydrology	No?		The study provides some details of the met stations in the project area. Otherwise the study is flawed in its analysis.
CL8	Kalyana MM, Awchi TA	2015	Investigating the meteorological drought in northern Iraq using deciles method	Al-Rafidain Engineering	Ministry of Higher Education & Scientific Research of Iraq	Vol 23(3), 12-21.		Technical journal	Arabic (English abstract)	Meteorological drought	Electronic version only	Technical paper			Iraqi	Climate	Yes?		Reports that droughts have reoccured in northern Iraq about every decade. The most severe droughts in northern Iraq were in 1997-2001 and 2007-2010.
CL9	Hussein MH, Othman AK	1988	Soil and water losses in a low intensity rainfall region in Iraq	Hydrological Sciences Journal	Taylor & Francis for International Association of Scientific Hydrology	Vol 33(3), 257-267		Technical journal	English	Hydrology, Soil erosion	Electronic version only	Technical paper			Iraqi	Soil science	Yes		Describes experiments using instrumented erosion plots 20mx4m in area for the estimation of relationship between rainfall and soil erosion. The plots are located between Erbil and Shawqala in an area receiving 900 mm rainfall per year
CL10	Hussein MH, Awad MM, Abdul-Jabbar AS	1994	Predicting rainfall-runoff erosivity for single storms in northern Iraq.	Hydrological Sciences Journal	Taylor & Francis for International Association of Scientific Hydrology	Vol 39(5), 535-547.		Technical journal	English	Hydrology, Soil erosion	Electronic version only	Technical paper			Iraqi	Soil science	Yes		Derives and tests erosivity factors with erosion plot data. One of the plots is in NE Iraq at Hammam al-Alil (adjacent to River Tigris). Provides insight into runoff and erosion processes in NE Iraq.
CL11	Hussein MH, Hussein AJ, Awad MM	1999	Phosphorous and nitrogen losses associated with runoff and erosion on an Aridisol in northern Iraq.	Hydrological Sciences Journal	Taylor & Francis for International Association of Scientific Hydrology	Vol 44(5), 657-664.		Technical journal	English	Hydrology, Soil erosion, soil chemistry	Electronic version only	Technical paper			Iraqi	Soil science	Yes		Provides insight into the impact of soil erosion on soil productivity and water quality.
CL12	Hussein MH	1996	An analysis of rainfall, runoff and erosion in the low rainfall zone of northern Iraq.	Journal of Hydrology	Elsevier	Vol 181, 105-126.		Technical journal	English	Hydrology, Soil erosion	Electronic version only	Technical paper			Iraqi	Hydrology, Soil science	Yes		Provides useful insight into runoff and soil loss generating processes in the region, albeit at the runoff plot scale. Showed that the US SCS and USLE do not give accurate results (at the plot scale) without modification for the type of rainfall in the region.
CL13	HEC-DSS Files		Summary of records in MoWR HEC Database for Nineveh and Syria	not published	Ministry of Water Resources, Baghdad						Electronic version only	Excel			Iraqi				
CL14	Saleh, D.K	2010	Stream gage descriptions and streamflow statistics for sites in the Tigris River and Euphrates River Basins, Iraq:	Data Series 540	US Geological Survey	146 p.				Hydrol Data	Electronic version only				USA	Geology, Hydrology	Yes		

ID	Authors	Year published	Title	Name of Publication	Publisher	Collation	Edition	Material type	Language	Main topic	Notes / version	Nature of contents	ISSN	ISBN	author nationality	author expertise	peer review	classification	value to project
GW1	Stevanovic Z & Iurkiewicz A	2009	Groundwater management in northern Iraq	Hydrogeology Journal	IAH, Springer	Vol 17 (2), pp367-378.	v1	Technical journal	English	Groundwater	Electronic version only	Technical paper	1431-2174						
GW2	Al-Sawaf, FDS	1977	Hydrogeology of South Sinjar Plain Northwest Iraq.		UCL Provost and Vice Provost Offices	Vol1, 171pp, Vol2 206pp	scan	Thesis (Doctoral)	English	Groundwater	digitised by British Library EThOS	PhD Thesis		UCL No 1349178	Iraqi	not known	UCL board		Good historical baseline knowledge of the area
GW3	Lightfoot, D R	2009	Survey of infiltration karez in northern Iraq: history and current status of underground aqueducts	UNESCO	Oklahoma State University - Stillwater	Book 57pp	research gate	Report	English	Groundwater			IQ/2009/SC/RP/1						Small number in Sinjar but important comments about need to meet criteria before rehabilitation
GW4	Sissakian VK et al	2015	Origin and evolution of Wadi Al-Ajeej, Al-Jazira vicinity, NW Iraq	Jl Earth Sci and Geotech Eng	Scienpress Ltd	Vol 5 (14), pp69-83	research gate	Technical journal	English	Groundwater	univ Kurdistan, Erbil		1792-9660						Well presented evidence of Al Ajeej terrace deposits with some good diagrams
GW5	Kareem I R	2013	Artificial groundwater recharge in Iraq throuh rainwater harvesting [case study]	Eng Tech Journal	Min Higher Education & Scientific Research	Vol 31, part A No 6		IASJ Journal	English	Groundwater	univ Technology, Baghdad	Technical paper	2412-0758				national academic		Poorly written, of little relevance to project area; no proof-reading
GW6	Hasan A A & Rasheed A M M	2006	Using computer systems to predict the changes in groundwater elevations due to recharge from rainwater harvesting	Symp Proceedings IAHS Brasil, Apr 2005: Sustainability of groundwater and its indicators	IAHS Press, Institute of Hydrology, Wallingford	Vol 302, Book, 205pp		Intl public Book	English	Groundwater				1901502430			international, Bruce Webb [Exeter]		bashiqa region: small dam construction at mountain edge to reverse decline in groundwater levels. Could be useful but no model calibration or long-term water levels shown. Wrongly suggest model replaces the need for fieldwork and hydrometric records [should have used pre-war data].
GW7	Alridha N A, AlYasi AI & AlKhafaji WMS	2013	Role of geoelectric and hydrogeologic parameters in the evaluation of groundwater reservoir at South of Jabal Sinjar area	Iraqi Jl of Science	Min Higher Education & Scientific Research	Vol 54, No 3, pp628-637			English	geophysical mapping	univ of Baghdad	Technical paper							Conclude a 1-3m drawdown 1982-2012. No information on 6 calibration wells: multiple level aquifers and difference between shallow and deep groundwater, the value of the results cannot be established
GW8	AlYasi AI, Alridha N A & Shakir W M	2013	Exploitation of Dar-Zarrouk Parameters to differentiate between fresh and saline groundwater aquifers of Sinjar Plain area	Iraqi Jl of Science	Min Higher Education & Scientific Research	Vol 54, No 2, pp358-367				geophysical mapping	univ of Baghdad	Technical paper							Further work related to GW7, confirming existing knowledge. Of little value for the project
GW9	Saleh S A, Al Ansari N & Abdullah T	2020	Groundwater hydrology in Iraq	Jl Eart Sci & Geotech Eng	Scientific Press Int Ltd	Vol 10, No 1, pp155-197		Int Technical journal					online 1792-9660. print 1792-9040						Summarises the problem: “research studies are not up to date, and contain many temporal and spatial gaps, which make planning, monitoring and exploitation difficult. Coordination between government agencies is poor, making it difficult to carry out a comprehensive and integrated evaluation. There is a real need to collate historical and current data on groundwater resources in Iraq in a single integrated database, especially traditional survey methods and groundwater extent”. Gives a broad overview of mean annual parameters and groundwater levels across the whole of Iraq. Includes some useful maps showing spatial variation in salinity and water use, although does not discriminate between shallow and deep aquifers. Paper by AlJiburi 2009, geology of al Jazira, hydrogeology IBGM special issue No 3, pp71-84 [could not be downloaded from IBGM website]. Suggests that there is an abstraction licensing system, bit it is not enforced, and farmers are unaware of the danger of penetrating more saline deeper water. Classifies the whole of Al Jazira as poor quality for agriculture, and to investigate salt-tolerant crops. Refers to declining water resources without providing evidence.
GW10	Jawad S B & Hussien K A	1986	Contribution to the study of temporal variations in the chemistry of spring water in karstified carbonate rocks	Hydrol Sci Jl	Taylor & Francis	Vol 31, No 4, pp529-541		Int Technical journal		hydro-geochemistry			online 2150-3435. print 0262-6667		Agr & Wat Resour Res Centre				Discusses Kani Kedri springs, resurging at junction of Serikagni and Jeribe limestone. Discharge measurement 1979-83: 0.4 to 1.4 m3/s, hydrographs and WQ monitoring: low flow / high EC.
GW11	Jawad S B & Hussien K A	1988	Groundwater monitoring network rationalisation using statistical analyses of piezometric fluctuation	Hydrol Sci Jl	Taylor & Francis	Vol 33, No 2, pp181-191		Int Technical journal		Groundwater			online 2150-3435. print 0262-6667				open to discussion for 6 mths		Study of groundwater around Erbil and rationalising groundwater monitoring. Not really relevant
GW12	Al Ansari N, Saleh S A et al	2021	Quality of Surface water and groundwater in Iraq	Jl Eart Sci & Geotech Eng	Scientific Press Int Ltd	Vol 11, No 2, pp161-199		Int Technical journal					online 1792-9660. print 1792-9040						Broader review of the water status in Iraq, repeating information in GW9
GW13	Sissakian V K, AlAnsari N, Abdullah L H	2020	Neotectonic activity using geomorphological features in Iraqi Kurdistan region	Geotech & Geol Eng Jl	Springer	Vol 38 No 4, pp4889–4904		Int Technical journal					online .... print ...						Useful general structural geology setting, includes section on faults affecting formations in Sinjar Plain.
GW14	McDermid C	2013	Ancient aqueducts give Iraq a trickle of hope	Al Jazeera online	Al Jazeera online														
GW15	Abdul Qader U N	2009	Mapping groundwater quality of Injana aquifer south of Sinjar anticline	Iraqi Jl earth Sci															Very general and self-evident - recommendations about dealing with water scarcity. Highlights the importance of awareness raising campaigns. Discusses the importance of targeted rehabilitation of irrigation infrastructure as well as restoration of “Karez” well networks
GW16	Al Daghastani	2013	Impact of tectonics on alluvial fan landforms in Sin jar mountain using remote sensing	ARSGISO Jl of remote sensing and GIS		Vol1, No 2, pp15-20							online 2052-5583						restricted to 10-15 km south of Jabal Sinjar: focus on drinking water quality
GW17	Sissakian VK	2011	geology of Iraq																
GW18	Sissakian VK & Fouad S F A	2015	Geological map of Iraq, 1:1million 4th edition 2012	Iraqi Bulletin of geology & Mining		Vol 11, No 1, 2015, pp9-16													
GW19	Burungh P	1957	Exploratory Soil map of Iraq 1:1,000,000, accompanied by memoir Soils and soil conditions in Iraq 1960	Div of Soils & Agric chemistry	Ministry of Agriculture, Baghdad			map											

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WH1	Al-Taiee TM & Rasheed AMM	2011	Hydro engineering feasibility study of surface runoff water harvesting in Al-Ajeej basin, north west Iraq	Tikrit Journal of Eng. Sciences	Tikrit University, Iraq	Vol 18(1), 15-28		Technical journal	English	Macro water harvesting	Electronic version only	Technical paper			Iraqi	Hydrology	Yes?		Focuses on hydrological asessment of one particular dam site on Wadi Al-Jeej, Sinjar District.
WH2	Al-Ansari N, Ezz-Aldeen M, Knutsson S and Zakaria S	2013	Water harvesting and reservoir optimization in selected areas of south Sinjar Mountain, Iraq	Journal of Hydrologic Engineering	American Society of Civil Engineers (ASCE)	Vol 18:1607-1616		Technical journal	English	Macro water harvesting	Electronic version only	Technical paper			Iraqi, Swedish	Hydrology, Modelling	Yes		A theoretical study illustrating the areas of wheat that may be irrigated from seven relatively large hypothetical water harvesting dams in the Wadi Al-Jeej and Al-Tharthar drainages operated singly and as a system.
WH3	Alkhadder R	2003	Water harvesting in Jordan using earth ponds	Waterlines	ITDG Publishing (now Practical Action Publishing)	Vol 22(2), 19-21		Technical journal	English	Macro water harvesting	Paper copy	Technical paper			Jordanian	Water engineering	Yes		Overview of simple, low cost Jordanian water harvesting programmes in the Badia region, NE Jordan.
WH4	Al-Daghastani H S	2010	Water harvesting search in Ninevah Governorate using remote sensing data	Iraqi Journal of Desert Studies	Ministry of Higher Education & Scientific Research of Iraq	Vol 2(1)		Technical journal	English	Macro water harvesting	Electronic version only	Technical paper	ISSN: 1994-7801		Iraqi	Remote sensing	Yes?		Documents the production by the University of Mosul Remote Sensing Centre of three thematic maps of Ninevah Governorate using Landsat7 multispectral satellite imagery (hydromorphology, land use/land cover, lineaments).
WH5	Anonymous	undated	Design and construction of "Bistana" water catchment pond, Erbil Governorate: A pilot project between UNICEF and Directorate of Irrigation, Erbil Governorate	-	-	-		Unfinished informal report	English	Macro water harvesting	Electronic version only	Informal report							Documents the construction in 2019 of a 12,000 m3 pond at Bistana village, Erbil Governorate.
WH6	EzzAldeen M, AlAnsari N &Knutsson S	2016	Estimating the life span of rainwater harvesting reservoirs in Sinjar area, Iraq	Journal of Environmental Hydrology	International Association of Environmental Hydrology	Vol 24, Paper 9, 1-10		Technical journal	English	Macro water harvesting	Electronic version only	Technical paper			Iraqi, Swedish	Hydrology, Modelling	Yes?		Estimates sediment yields and reservoir lives for the seven hypothetical reservoirs studied in WH2. The SWAT sediment model was calibrated using sediment data from a reservoired catchment in northern Iraq of similar geology (WH7).
WH7	Mohammad E, Al-Ansari N, Knutsson S	2016	Annual runoff and sediment in Duhok reservoir watershed using SWAT and WEPP models	Engineering	SciRes	8, 412-422		Technical journal	English	Macro water harvesting	Electronic version only	Technical paper			Iraqi, Swedish	Hydrology, Modelling	Yes?		Reports the validation of SWAT and WEPP sediment yield models using observed sediment data at Dukok Reservoir collected in 2008-2009. The observed sediment data are themselves reported in two articles: Sulaiman A [2010] Estimating of annual sediments of Duhok Dam by using river turbidity water samples. Journal of Duhok University Agricultural and Veterinary Science, 13, 82-89. Mohammed R [2020] The impact of man activity in Duhok Dam watershed on the future of Duhok Dam lake North-Iraq. 1st International Applied Geological Congress, Department of Geology, Islamic Azad University-Mashad Branch, Iran, 26-28 April 2010.
WH8	FAO	2018	Iraq: Restoration of agriculture and water systems sub-programme 2018-2020		FAO, Rome	Book 110pp	1	Int publication	English	Agriculture, water	Licence CC BY-NC-SA 3.0 IGO	recovery & resilience prog			UN	Agriculture	yes?		General overview of agrilcuture and irrigation in Iraq in context of rehabilitation efforts. Useful overview statements and data.
WH9	Adil Al-Khafaji. ICARDA, Syria	2004	Indigenous WH Systems in Iraq	Indigenous WH Systems in West and North Africa	ICARDA	Book 173pp		int publication	English	Water Harvesting - Indigenous	Personal hard copy	Technical paper			Iraqi	agriculture	Yes?		Overview of nine indigenous WH systems in Iraq. But only two or three relevant in project area and superficial detail only.
WH10	Zakaria, S et al	2013	Wheat yield scenarios for RWH at Northern Sinjar Mountain, Iraq		Natural Science Journal	Paper 12pp		int publication	English	Agriculture, water		Technical paper			Iraqi, Swedish	Agricultural engineering	Yes		Useful modelling of different levels of irrigation water (from RWH ponds) on wheat in project area. Recommends target of meeting 50% total requirement for economy of water use/ optimal yield
WH11	Hachum AY, Mohammad ME	undated	Optimal reservoir sizing for small scale water harvesting system at Al-Hader in northern Iraq	Unpublished?		19p.		Unpublished paper	English	Macro water harvesting	Electronic version only	Technical paper			Iraqi		No?		An (unpublished?) linear programming study to optimise the size of a farm-scale reservoir (pond) for supplemental irrigation of winter barley in the Al-Hader area, SW of Sinjar. The optimum pond volume was found to be 1110 m3 for a catchment area of 10 ha or 111 m3/ha. Area irrigated is about 3ha. However, there may be an error in the modelling, possibly negating the results.
WH12	Critchley W and Siegert K, FAO	1991	Water Harvesting: a manual for the design and construction of water harvesting schemes for plant production	FAO Publications	FAO, Rome	133pp		Technical report	English	Water harvesting design (micro)	FAO website	Technical paper			British/ German	Agriculture	Yes		The first FAO publication on WH with useful detail on calculations of crop water requirements. Most systems described are microcatchments systems without ponded water.
WH13	CritchleyW and Gowing J.	2012	Water Harvesting in Sub-Saharan Africa	Earthscan	Earthscan	201pp		Edited book	English	Water harvesting - Indigenous and Improved	Earthscan for purchase	Book			British +	Multiple	Yes		Overview chapter/ review of literature and glossary especially useful.
WH14	Steenberger F van et al	2010	Guidelines on Spate Irrigation	FAO Publications	Fao, Rome	233pp		Report	English	Spate (floodwater harvesting) irrigation	FAO website	Report			International	Engineering	Yes		Very useful - for situation where spate irrigation/ wadi agriculture/ floodwater harvesting is relevant. Focus on Pakistan/ Yemen/ Somalia/ Sudan.
WH15	Baquhaizel, S. A. et al	1996	Traditional Irrigation Systems and Methods of Water Harvesting in Yemen	MetaMeta	MetaMeta Netherlands	93+94		Report	Arabic/ English	Water Harvesting	MetaMeta	Report			Yemeni	Engineering	?		Wide-ranging and practical discussion of indigenous WH in Yemen with many similarities to Iraq. Half the book in Arabic makes it widely relevant in Iraq.

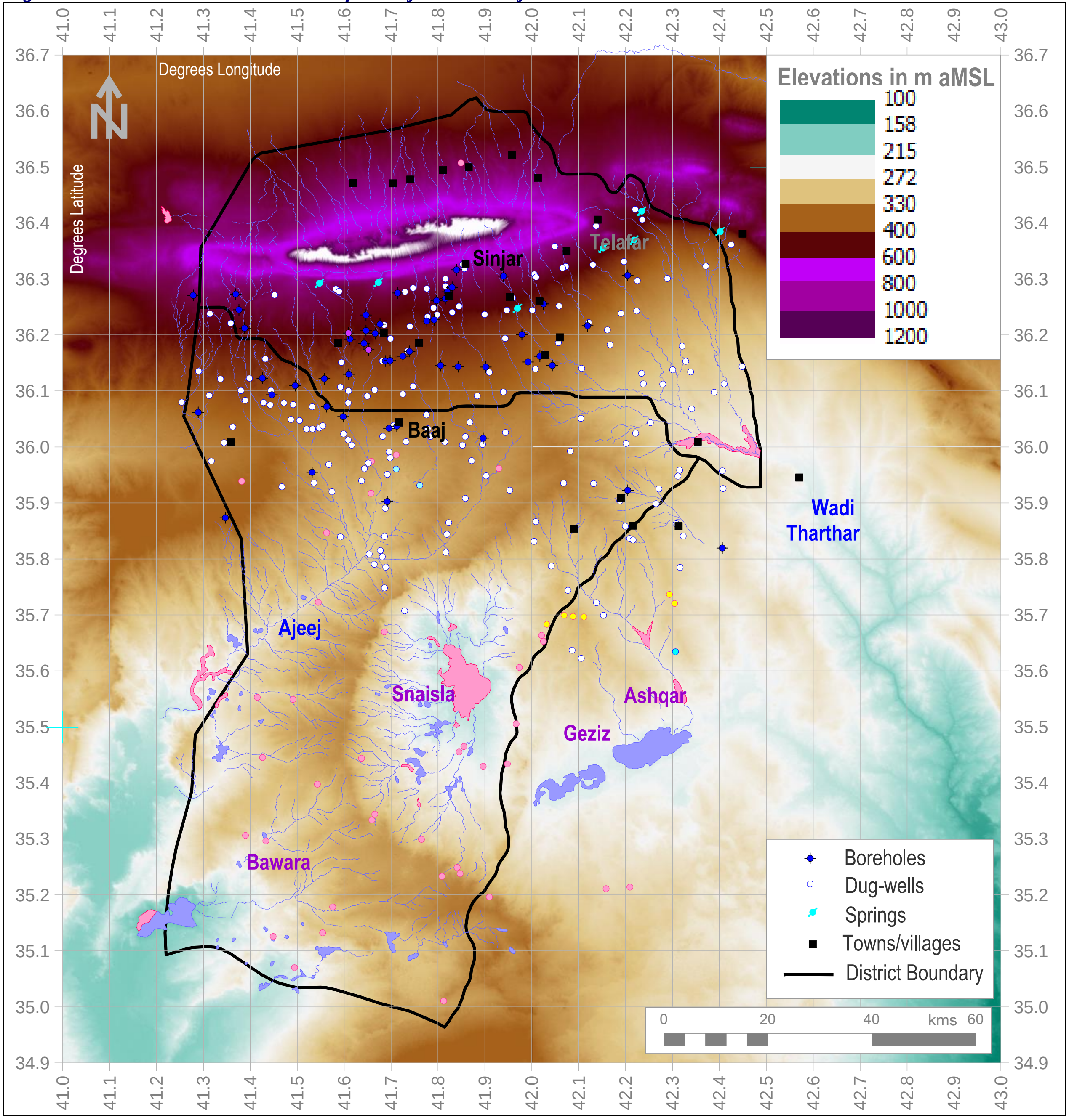
ID	Authors	Year published	Title	Name of Publication	Publisher	Collation	Edition	Material type	Language	Main topic	Notes / version	Nature of contents	ISSN	ISBN	author nationality	author expertise	peer review	classification	value to project
WH16	Zakaria S, Al-Ansari N, Knutsson S, Ezz-Aldeen M	2012	Rain water harvesting and supplemental irrigation at northern Sinjar Mountain, Iraq	Journal of Purity, Utility Reaction and Environment	Design for Scientific Rennaissance	Vol 1(3), 121-141		Technical journal	English	Macro water harvesting	Electronic version only	Technical paper	ISSN: 2232-1179		Iraqi, Swedish	Hydrology, Modelling	Yes?		Another theoretical study similar in scope to [WH2], illustrating the areas of barley that may be irrigated from six relatively large hypothetical water harvesting dams on the northern side of Sinjar Mountain. Deficit irrigation of 50% of crop water requirements was found to be most beneficial, no details given.
WH17	Zakaria S, Al-Ansari N, Ezz-Aldeen M, Knutsson S	2012	Rain water harvesting at eastern Sinjar Mountain, Iraq	Geoscience Research	BioInfo Publications	Vol 3(2), 100-108		Technical journal	English	Macro water harvesting	Electronic version only	Technical paper	ISSN: 0976-9846 E-ISSN: 0976-9854		Iraqi, Swedish	Hydrology, Modelling	Yes?		Another theoretical linear programming study very similar in scope and finding to [WH2 and WH16]. Four dams north of Tel-Afer in eastern Sinjar District. Dam sites chosen as before to minimise earthmoving and evaporation (high capacity/width ratios). Deficit irrigation of 50% of crop water requirements was found to be most beneficial, no explanation given.
WH18	Adary A, Hachim A, Oweis T and Pala M	2002	Wheat Productivity under Supplemental Irrigation in North Iraq	ICARDA Research Paper	ICARDA	Research Report Series No 2		Report	English	Supplemental Irrigation					International	Irrigation, Replicated trial	Yes		An excellent overview of wheat production in Ninerva Governate and the potential benefits obtainable through supplemental irrigation. Recommends aiming at 50% of total irrigation need above rainfall
WH19	FAO	2016	Iraq Agriculture and Livelihoods Needs Assessment in the newly liberated areas of Kirkuk, Ninewa and Salahadin	FAO Publications	FAO, Rome			Report	English	General: Agriculture and Livelihoods		Report			International	Agriculture: Workshop			Very general and superficial/ general but supports concepts of expanding/ improving irrigation and rehabilitating irrigation infrastructure
WH20	Zakaria S	2012	Rain water harvesting and supplemental irrigation at Sinjar District in north west Iraq	Licentiate Thesis	Lulea University of Technology, Sweden	141p.		Licentiate Thesis	English	Macro water harvesting	Electronic version only	Licentiate Thesis	ISSN: 1402-1757	ISBN: 978-91-7439-446-7	Iraqi	Hydrology, Modelling	Yes		The PhD thesis that underpins and provides material for papers WH2 and WH16. Paper WH17 is an extension of the approach taken in Paper WH16 to eastern Sinjar.
WH21	Oweis T, Hachum A and Kijne J	1999	WH and Supplemental Irrigation for Improved Water Use Efficiency in Dry Areas	SWIM No. 7	IWMI. Sri Lanka			Report	English	WH and Supplemental Irrigation		Report			International	Water Harvesting and Supplement	Yes		A very useful overview of the potential of WH and Supplemental Irrigation in dry areas of WANA. Highlights the water productivity benefits (ratio of yield to water consumed) of SI when used at critical crop stage.
WH22	Regional Land Management Unit (RELMA: in ICRAF)	2005	Water from Ponds, Pans and Dams: A manual on planning, design, construction and maintenance	RELMA/ICRAF	World Agroforestry Centre. Nairobi, Kenya	119pp.		Technical Handbook	English	as title		Handbook			International	as title	Yes		A user-friendly guide to design and construction of water bodies for supplemental irrigation/ domestic use/ livestock. East Africa = target but widely useful
WH23	Oweis T, Prinz D and Hachum AY	2012	Water Harvesting for Agriculture in the Dry Areas	CRC Press	CRC Press. London, New York, Leiden	235pp.		Book	English	as title		Book			International	as title	Yes		Comprehensive practitioners overview of WH and its applicability in the WANA region with design criteria for catchment: cropped area ratios, storage structures as well as socio-economic issues (etc).
WH24	Mekdeschi-Studer R and Liniger HP (technical editor Critchley W)	2013	Water Harvesting: Guidelines to Good Practice	Uni Bern/ Rainwater Harvesting Implementation Network/ MetaMeta/	Uni Bern/ Rainwater Harvesting Implementation Network/ MetaMeta/	186pp.		Book	English	as title		Book			International	as title	Yes		Well witten and lavishly illustrated compendium. Global with some cases from WANA (but mainly North Africa). Very well referenced.
WH25	Adham A, Sayl KN, Abed R, Abdeladhim MA, Wesseling JG, Riksen M, Fleskens L, Karim U, Ritsema CJ	2018	A GIS-based approach for identifying potential sites for harvesting rainwater in the Western Desert of Iraq	International Soil and Water Conservation Research	International Research and Training Center on Erosion and Sedimentation and China Water and Power Press. Hosting by Elsevier.	Vol 6, 297-304.		Technical journal	English	Macro water harvesting	Electronic version only	Technical paper			Iraqi, International	GIS	No?		Presents an example of a GIS-based approach to identifying areas suitable for rainwater harvesting dams in Iraq. Potential dam sites are chosen using large-scale topographic maps and satellite imagery. Soil type and channel/floodplain slope are also factors to be considered. Potential dam sites are assessed by drawing EVA curves. Socio-economic criteria are very important in final selection of sites to develop. The method is demonstrated on the 13370 km2 Wadi Horan catchment to the south of Nineveh Governorate.
WH26	Adham A, Riksen M, Ouessar M, Ritsema C	2016	Identification of suitable sites for rainwater harvesting structures in arid and semi-arid regions: A review	International Soil and Water Conservation Research	International Research and Training Center on Erosion and Sedimentation and China Water and Power Press. Hosting by Elsevier.	Vol 4, 108-120.		Technical journal	English	Macro water harvesting	Electronic version only	Review paper			Iraqi, International	GIS	Yes		Reviews technical criteria and GIS-based methods used to select areas ("sites") for water harvesting, but warns that satisfaction of technical criteria does not guarantee success (farmer uptake), and suggests that socio-economic criteria are critical, but likely to be case-specific. Refers to FAO (2003) guidelines for suggestions on socio-economic criteria.
WH27	Bilal AA, Abdulbaqi YT, Al-Shakraji BM	2019	Rain water harvesting for Al-Murr Valley, Ninava Governorate, North Iraq	Iraqi Journal of Desert Studies	Ministry of Higher Education & Scientific Research of Iraq	Vol 9(1),72-85		Technical journal	English	Macro water harvesting	Electronic version only	Technical paper			Iraqi	Hydrology, modelling	Yes?		Presents another example of the estimation of water volumes harvestable by relatively large dams. Studies the 15 sub-basins of the Wadi Al-Murr catchment which drain into the Tigris River downstream of Mosul dam (outside the study area).
WH28	Studio Galli Ingegneria SpA, MED Ingegneria Srl, El Concorde Construction LLC	2014	Appendix D/G, Report D.1 & G.5 Monography of Ips. South Jazeera. Project ID 039. Final Report		National Center for Water Resources Management, Ministry of Water Resources, Republic of Iraq	Rev000_2014 1027.		Consultant report	English	South Jazeera Irrigation Project	Electronic version only	Summary of status of project planning			International	Irrigation planning	Yes?		Provides information on climate, soils, land suitability and capability and existing rainfed and irrigated agriculture and groundwater (in 2014) in the South Jazeera Irrigation Project area which spans Tel-Afer and eastern Sinjar districts. General information may be extrapolated westwards across the southern part of Sinjar District.
WH29	Forzieri G, Gardenti M, Caparrini F, Castelli F	2007	A methodology for the pre-selection of suitable sites for surface and underground small dams in arid areas: A case study in the region of Kidal, Mali.	Physics and Chemistry of the Earth	Elsevier	Vol 33, 74-85.		Technical journal	English	Macro water harvesting	Electronic version only	Technical paper			International	Hydrology, small dams	Yes		Presents a screening procedure for assessing the suitability of sites for small surface (sand) and sub-surface dams. The procedure is applied in an area of Mali.
WH30	Nasri S, Albergel J, Cudennec C, Berndtsson R	2004	Hydrological processes in macrocatchment water harvesting in the arid region of Tunisia: the traditional system of tabias	Hydrological Sciences Journal	Taylor and Francis on behalf of the International Association of Hydrological Sciences	Vol 49(2), 261-272.		Technical journal	English	Macro water harvesting	Electronic version only	Technical paper			Tunisian, International	Hydrology	Yes		Tabias are a traditional system of long slope or macrocatchment water harvesting practised in Tunisia. This paper presents the results of four years of rainfall, runoff and infiltration measurements in a tabia with the aim of showing how the tabia influences the water balance and to improve understanding how the system changes the hydrology of an arid catchment. The efficiency of the water collection system is established.

ID	Authors	Year published	Title	Name of Publication	Publisher	Collation	Edition	Material type	Language	Main topic	Notes / version	Nature of contents	ISSN	ISBN	author nationality	author expertise	peer review	classification	value to project
WS1	Relief International	2019	Situation report on WASH in Sinjar District	Report to Nadia's Initiative	Nadia's Initiative	42p.		Report	English	Water, sanitation, hygiene		Situation Report			US	Water supply and sanitation	Yes?		Assesses WASH needs in 10 communities around Sinjar Mountain. Outlines three programmes of projects: (i) immediate response, (ii) rehabilitation of WASH, and (ii) transformational projects. Water resource problems are recognised and household water harvesting measures in the villages form part of the response. The report makes recommendations on water harvesting and water resource planning. NRC could consider collaboration with RI.
WS2	IOM Iraq	2012	Water scarcity	Special Report	IOM Iraq	22p.		Report	English	water supply		Situation Report			International	Water development planning	Yes?		Reports a nationwide survey during 2011-2012 to measure the effect of water scarcity caused by lack of water, high salinity and poor water quality on the lives of vulnerable families. Recognises the use of groundwater and flood irrigation techniques in northern Governorates. Reports IOM's involvement in rehabilitation of Karez (not in Ninewa). Does not mention water harvesting, but recommends continuation of a trend towards less water intensive crops and irrigation methods (p.12).
WS3	Engicon	2016	Environmental management drought plan guidelines for Iraq		UNICEF	207p.		Report	English	Drought management		National drought management plan			International	Water development planning	No?		Provides description of SPI and RDI as drought indices and plots graphs for met stations including Sinjar. Provides approaches to drought planning at national level - augmenting water supplies, managing demand (proposes reducing daily per capita usage from 400 l to 120 l) and minimising impacts by , inter alia, awareness programs related to water use efficiency and improved sanitation. Agricultural water consumption should be reduced by improving irrigation efficiency. Doesn't mention water harvesting per se.
WS4	World Bank	2017	Beyond scarcity – Water security in the Middle East and North Africa [MENA]		World Bank Group	199p.		Report	English	Water security		Situation report			International	Water planning	Yes		Provides a very high level review of approaches to water security in MENA region. In the face of population growth and ongoing urbanisation, urban rainwater harvesting will become increasingly important.
WS5	Tinti A	2017	Water resources management in the Kurdistan Region of Iraq: A policy report	Institute of Regional and International Studies	American University of Iraq, Sulaimani	11p.		Report	English	Policy		Policy report			International	Water resources, Policy	Yes?		Provides policy recommendations on behalf of the Kurdistan Regional Government on small-scale decentralised projects involving water harvesting and groundwater recharge.

Appendix C Mapping

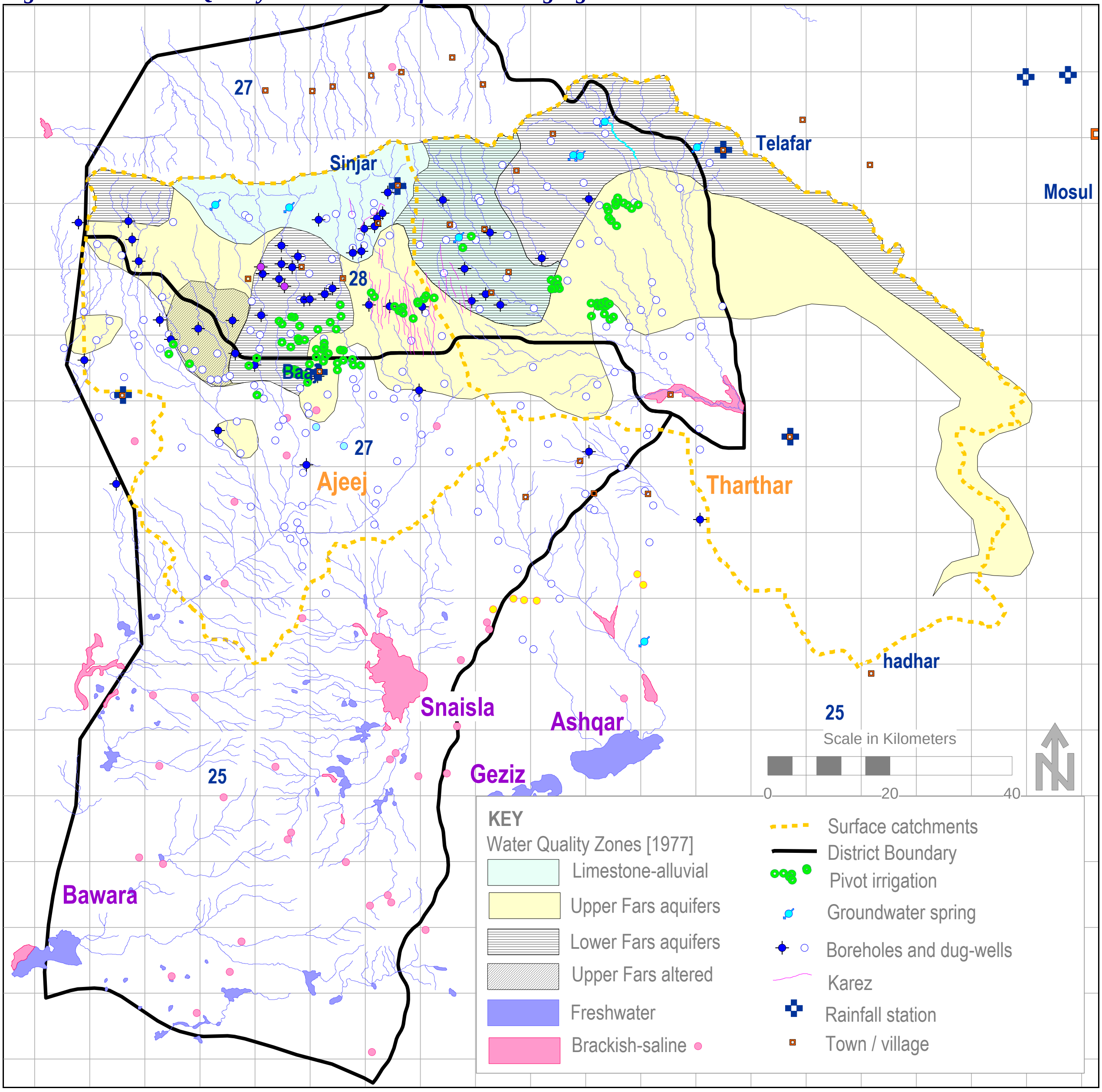
This appendix contains extracts of mapping developed and used during the review study.

Figure C-1 Colour-rendered DTM for Sinjar and Baaj Districts



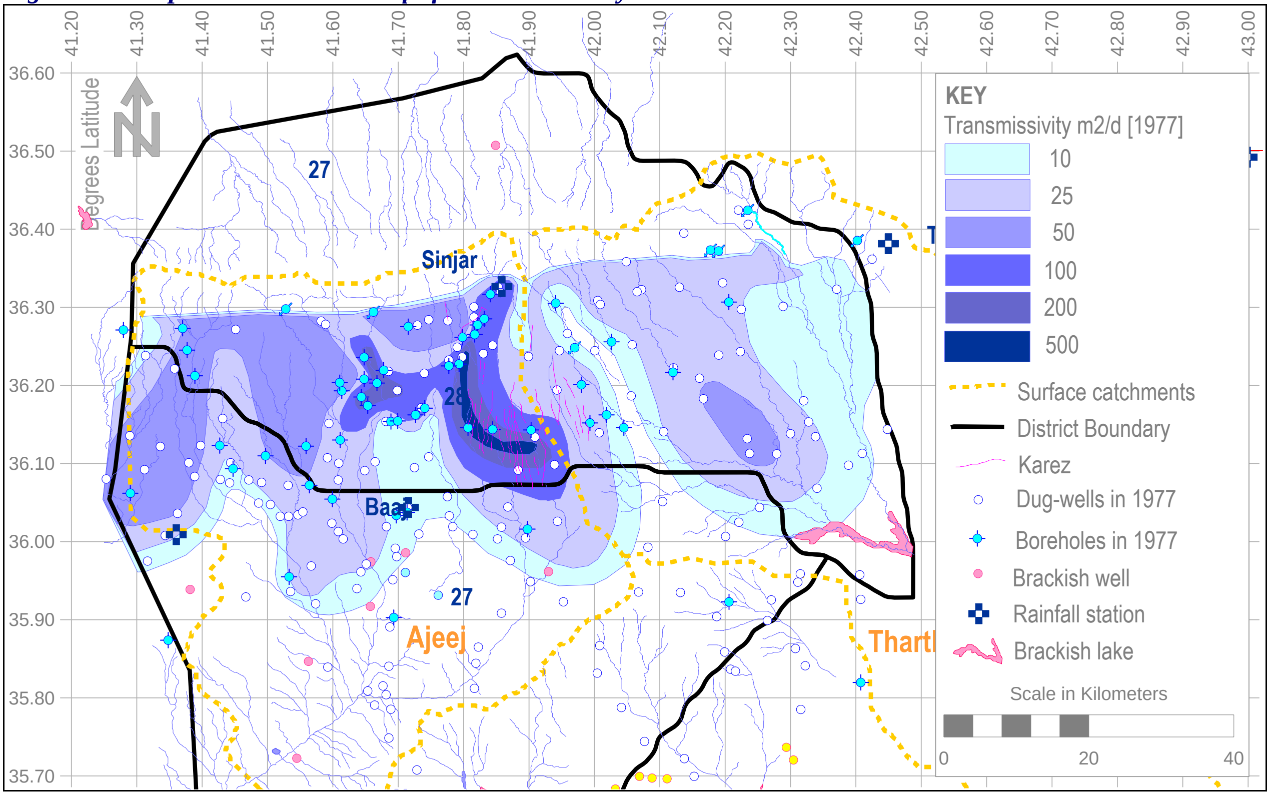
Data source: NASA SRTM and Al Sawaf [1977]

Figure C-2 Water Quality and Presence of Water-Using Agriculture



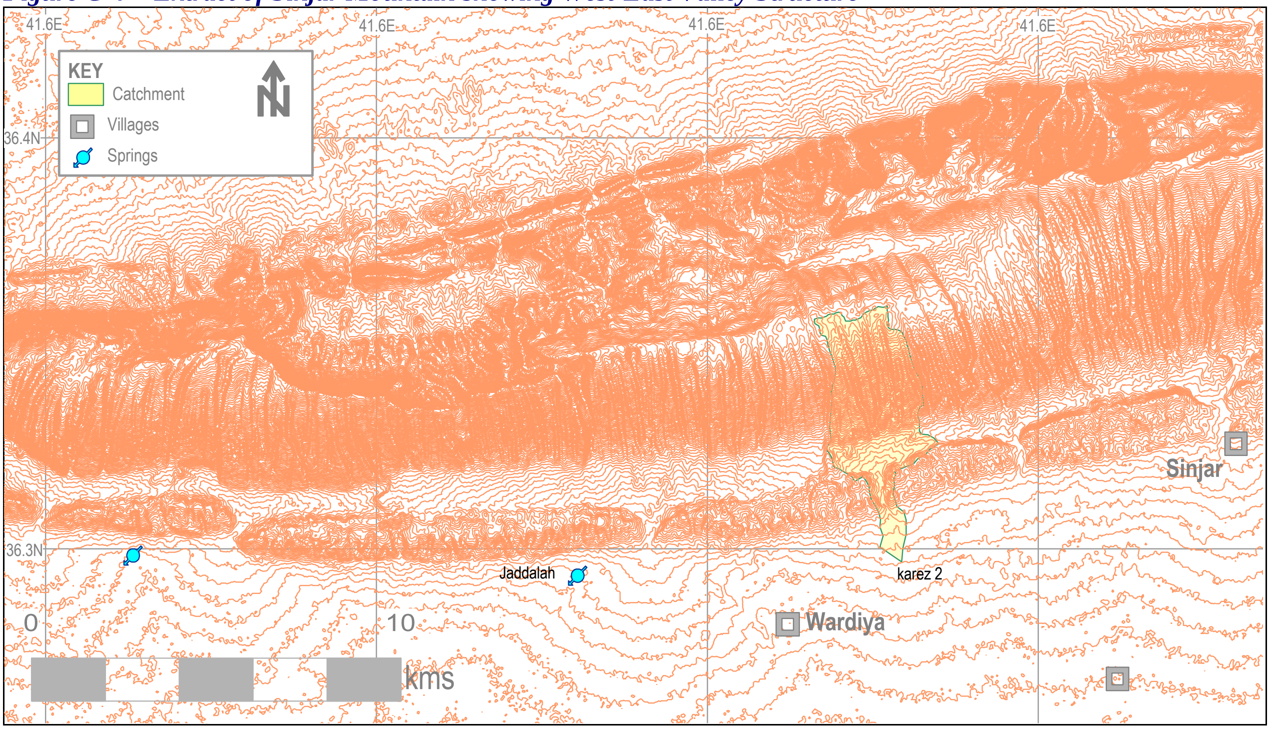
Source: Groundwater data from Al Sawaf [1977], surface water features from Joint Operations Graphic

Figure C-3 Spatial Variation in Aquifer Transmissivity



Source: Groundwater data from Al Sawaf [1977], wadis from Joint Operations Graphic

Figure C-4 Extract of Sinjar Mountain showing West-East Valley Structure



Data source: NASA SRTM, 10 m contour interval, shows break-out points from valley north of the Jeribe Limestone on to the Southern Sinjar Plain

Appendix D Field Reconnaissance

This appendix contains a selection of photographs taken during a Rapid Rural Appraisal by Ali Dawood during the week, 15-18 March 2021.

D-1 Springs

D1-1 Pond on one of the Kani Kedri springs

D1-2 Irrigation canal leaving one of Kani Kedri springs

D1-3 Herd of sheep south of Sinjar Spring

D1-4 irrigation using water from Sinjar Spring

D-2 Karez

D2-1 Karez No 5 access shaft

D2-2 Karez No 2 with water

D2-3 Karez No 2 shaft

D2-4 Irrigation canal at the end of Karez 2, Wardiya

D-3 Karst Sink-holes

D3-1 Kwlat limestone sink, herd of sheep and gang of shepherds

D3-2 Another Sink-hole in the Kwlat valley

D3-3 Large doline north of Wardiya

D-4 Solagh Spring


D4-1 Eastern spring and irrigation canal


D4-2 Pumping well


D4-3 Weir on the west spring for diversion water


D4-4 Irrigation canal

Appendix E Satellite Imagery

Microsoft Bing Maps collection of historical imagery, used to interpret water and land features, and to plan field reconnaissance for NRC's Rapid Rural Appraisal by Ali Dawood during the week, 15-18 March 2021.

Figure E-1 Regular Hexagonal Lattice Water Harvesting in Fields NE of Baaj

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Figure E-2 Another Variant of Water Harvesting in Fields NE of Baaj

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Dark green areas are assumed to be land at lower elevation which retains moisture for longer or to greater soil depth. The hexagonal shapes are created by ploughing along the contour with a tractor and then turning a 90 degree bend at the four corner vertices of the geometric shape.

Figure E-3 Kani Kedri Springs and Three Irrigation Canals, 5 km East of Sinjar Town

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Figure E-4 Pivot Irrigation 12 km NE of Baaj

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Close-up in next image

Figure E-5 Close-up of Pivot Irrigation cell and Line of over 50 Lorries queuing into the Haulage Centre

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Figure E-6 Limestone Sinks north of Wurdiya, 30 km West of Sinjar Town

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