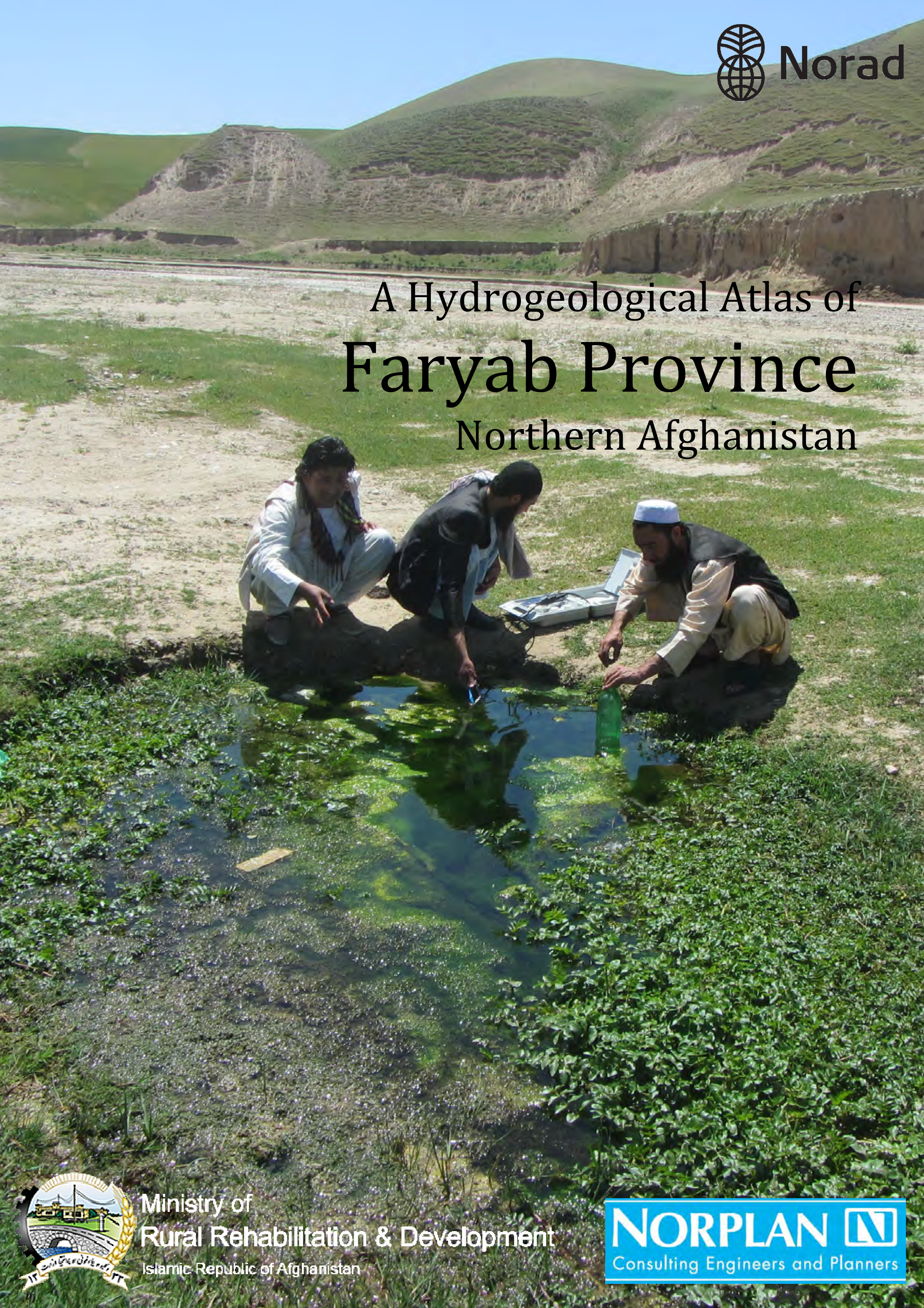
Norad

A Hydrogeological Atlas of Faryab Province Northern Afghanistan



Ministry of Rural Rehabilitation & Development
Islamic Republic of Afghanistan

NORPLAN
Consulting Engineers and Planners

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1. Faryab Province: A History of Water Resources

Faryab Province straddles several steep topographic, meteorological and geological gradients. The southern portion of the Province is dominated by the high topography of the Safed Koh / Band-e Turkestan mountains of the Hindu Kush: temperatures are modest and winter snow and rain provide adequate supplies of fresh water.

Towards the north, the lowland semi-desert plains of Oxiana predominate, underlain by the molasse-like and alluvial erosional deposits of the Hindu Kush uplift. The climate becomes more severe, with high evapotranspiration and limited rainfall. Water resources become scarcer and what water can be found is brackish. The northern portion of Faryab has thus been a marginal environment for human habitation during recent centuries.

Faryab not only occupies a physiographical and climatic divide, it also represents a cultural and political transition, between the Afghan and Persian heartlands to the south and the plains of Central Asia to the north. The semi-desert area north of the mountains and around the Amu Darya River (or Oxos) has often been referred to as Oxiana or Turkestan.

Maimana had been a prominent city since the early Islamic era, when it had been known in Arabic as *al-Yahudiyya* (city of the Jews - Lee 1987). It was destroyed during the Mongolian invasions of Turkestan and subsequently became a khanate that was a bone of contention between the Persians and Afghans to the south and the Turkic powers (such as the Emirate of Bokhara) to the north. From 1893 onwards, Maimana became a province of Afghanistan, with an Afghan governor.

Today, Faryab has an area of 20,293 km^2 a population of around 948,000, of which 114,000 are classified as "urban" and 834,000 are "rural" (CSO 2013). The Province is subdivided into 14 districts, as follows:

Table 1.1. The Districts of Faryab Province (as of 2013)

District	Population (CSO 2013)	Area (km^2) (Wikipedia)
Qaysar	138,400	2,502
Almar	68,300	1,525
Kohistan	53,100	2,254
Gurziwan	73,700	1,875
Pashtun Kot	183,500	4,000
Khwaja Sabz Posh	49,400	800
Bilchiragh	50,700	1,189
Maimana	78,500	133**
Shirin Tagab	79,100	3,500
Dowlatabad	47,200	2,598
Qaramqol	19,100	2,192
Qurgan	45,800	797
Andkhoi	38,700	381
Khani Chahar Bagh	22,500	1,056
Ghormach	52,566*	2,083

** Ghormach has been included in this Atlas, as there has been some recent discussion as to whether to transfer this district from Badghis to Faryab. The district's population was 52,566 in 2003, according to http://en.wikipedia.org/wiki/Ghormach_District*

*** Calculated in Google Earth*

A large proportion of the population, especially in rural districts, are from Uzbek or Turkmen linguistic groups, with significant numbers of Tajiks and Pashtuns, and a minority of Hazaras.

1.1 Vámbéry's (1865) Travels in Central Asia

When Arminius Vámbéry described his 1863 travels to the area in his *Reise in Mittelasien*, Maimana was a somewhat precarious khanate loyal to Turkestan. Indeed, Maimana was regarded as offering a first line of defence to any attempt on Bokhara from the south.

Vámbéry he entered Faryab from the north. He described the country between Zeid and Andkhoi as "*one dry barren plain, only occasionally producing a sort of thistle, the favourite fodder of the camels". *Vámbéry encamped at Khani Chahar Bagh and remarked of Andkhoi that "*it is astonishing what a quantity of fruit, corn and rice is raised in this desert-like neighbourhood, only scantily watered by a little salt stream* (the Shirin Tagab) *flowing hither from Maymene. In summer, a stranger finds the water - to the execrable taste of which the inhabitants are accustomed - quite undrinkable...it is said to produce many other evil consequences".* Vámbéry cites an old Persian verse:

Andkhuy has bitter salt water, scorching sand, venomous flies and even scorpions;
Vaunt it not, for it is the picture of a real hell.

In 1865, Vámbéry notes that a mere 30 years previously, Andkhoi had been a thriving city of 50,000 souls, with a widespread export of sheepskins and camels. Andkhoi, then a khanate in its own right, had subsequently been subsumed by Bokhara and forced to resist incursions by Afghans from the south. Caught between the jaws of Maimana, Bokhara and the Afghans, it had diminished to a ruinous town of 2000 houses and maybe 3000 tents in the surrounding area, with a total population of some 15,000.

Vámbéry progressed south via Khairabad, Bad Qaq and Akkale towards Maimana, strategically located at the boundary between plains and mountains (Figure 1.1). Vámbéry found Maimana to be a fortified town of some 1500 dwellings, inhabited by Afghans, Uzbeks, Tadjiks, Heratis, Jews and Hindus, with markets trading in horses, carpets, raisins, aniseed and pistachio. His journey continued via Almar, Nahrin, Qaysar, Chechaktu and on across the mountains to the valley of Bala (Upper) Murghab

1.2 Byron's (1937) Road to Oxiana

In 1933, some 70 years after Vámbéry, the irascible Robert Byron journeyed through Persia and Afghanistan to Oxiana. He entered Faryab via Bala Murghab, Karez (which he regarded as the beginning of "Turkestan"), Bukhara Qala and Maimana. He compared Maimana to the Wiltshire uplands of England, with strings of villages along a meandering river, flanked by mulberry and apricot trees. For Byron, the transition to semi-desert seemed to take place around Faizabad, where the landscape became lower, barren and sandy. The Governor of Maimana at that time described the ground as "*cooked*" between Faizabad and Mazar-e-Sharif, until one reached the fertile banks of the Amu Darya.

Like Vámbéry, Byron described Andkhoi as the centre of the lambskin (karakul and arabi) trade. Beyond (NE of) Andkhoi, Byron found the Oxianian landscape "*colourless and suburban*", turning progressively from "*leaden*" to the colour of aluminium.

1.3 Irrigation

In recent times, the situation has not changed so much. The main use of water in Faryab Province is for irrigation - much of this comes from the main rivers themselves.

Anecdotally, ever greater "takes" of water for irrigation have led to less and less water reaching Andkhoi in the summer months. Indeed, at Araba, a major irrigation channel takes the majority of the Shirin Tagab river's flow, leading it north to the Dowlatabad area, leaving the natural watercourse almost dry at some times of year (Figure 1.2).

Groundwater from springs and wells is also used in lesser quantities for irrigation and, historically, *karezes* (also called *qanats* or *aflaaj* in Arabia) were used to provide irrigation in many parts of Afghanistan. These karezes are horizontal adits, skimming groundwater from just below the water table in foothill areas and leading it several hundred metres, or even kilometres, to a point of use. In the last two decades, these karezes have fallen into disuse (Shobair & Alim 2004), as a result of:

- damage or lack of maintenance during the many years of civil war,
- disruption of social customs and management systems for irrigation usage, often traditionally coordinated by a village *mirab* (Thomas & Ahmad 2009), and
- in some cases, natural drought periods or the exploitation of deeper, pumped boreholes lowering the water table and drying up shallow karezes or dug wells (Banks 2001, Banks & Soldal 2002).

The economy of Faryab is based partly on livestock (cattle, sheep, goats, donkeys, occasionally camels), but largely on irrigated agriculture. Crops include wheat, barley, maize, potatoes and flax in fields, with fruit, nuts, vegetables, alfalfa, clover and (especially in Qaysar) grapes being cultivated in garden plots. Cotton, sesame and (in Almar, Qaysar and Gurziwan) tobacco are also produced as commodities. There was also a small (4% of rural population) opium poppy activity reported in 2005 (MRRD 2007).

Of the Shirin Tagab catchment area, around 40% is classified as rangeland, 36% is amenable to rain-fed agriculture while some 7.2% is irrigated (Ibrekk et al. 2006). Of the rural population of Faryab, around 81% had access to rain-fed land in 2005, with 37% having access to irrigated land (MRRD 2007). In the 1980s, Lee (1987) was able to write that "*There is still much semi-sedentary farming in the outlying areas, and during the summer many villages in Gurziwan are empty except for older men and the sick, the rest of the community have moved to the summer pastures and* lalmi *or non-irrigated lands where they grow their summer wheat and pitch their yurts and tents near a convenient source of water*."

Although Qureshi (2002) cites data suggesting that karezes have previously been a significant source of irrigation water in Faryab, his graphic materials suggest that canals are responsible for by far the largest area of irrigated land. During the NORPLAN surveys of 2013, no operational karezes were registered in Faryab (although the survey did not cover all areas or districts).

Table 1.2. Land cover in the catchments of the Murghab River in Afghanistan and the Shirin Tagab, after Favre & Kamal (2004).

Land cover	% of Murghab catchment	% of Shirin Tagab catchment
Rangeland (grass / low shrubs)	84.1	40.4
Rain-fed crops	12.9	35.8
Irrigated (intermittent)	1.4	4.7
Irrigated (intensive, 1 crop/year)	1.1	2.6
Irrigated (intensive, 2 crops/year)	0.01	-
Sand (semi desert)	-	15.5
Fruit trees	0.00	0.5

1.4 Potable Water Supply

There are three areas in the Province where saline groundwater has been a major issue:

1. the **Shor Darya Valley** (See Section), where both the Shor Darya river itself and the adjacent groundwaters are highly saline (>6000 µS/cm in the Shor Darya River). The main sources of potable water in this area (from which water is distributed by donkey or camel) are:

- the large Ateh Khan Khwaja spring, at the confluence of the Maimana and Qaysar Rivers, with a discharge of some 25 L/s and an electrical conductivity of only some 2660 µS/cm (Hassan Saffi 2010b).
- the Shirin Tagab river itself, with an electrical conductivity of <1000 µS/cm, but highly vulnerable to faecal microbial contamination (Hassan Saffi 2010b).

2. the **Astana Valley**, where both the Astana river itself (> 45,000 µS/cm) and the adjacent groundwaters are highly saline. The main sources of potable water in this area are:

- springs at Moghaito, on the southern flanks of a Cretaceous / Palaeozoic limestone/sandstone inlier, with discharges of around 3 L/s and an electrical conductivity of only some 3400-4500 µS/cm (Hassan Saffi 2010a).
- the Shirin Tagab river itself.

3. the area north of Faisabad and, in particular, the city of **Andkhoi** and surrounding urban areas. The groundwater is typically brackish in this area, and the surface water in the Shirin Tagab and its distributary irrigation canals is also brackish, contaminated and scarce, especially in the summer months. Alternative sources of potable water in this area include:

- a few wells or boreholes (typically located near irrigation ditches) where somewhat less brackish groundwater can be got (it is surmised that these may be recharged from irrigation canal infiltration).
- desalination (by electrically-powered reverse osmosis) of saline groundwater from dug wells. The NGO *Norwegian Church Aid* has been especially active in piloting such plants, although some question marks hang over the long-term technical and economic sustainability of such a strategy.
- collection and transport of water from distant sources, such as Shirin Tagab district, which is the northernmost district where relatively fresh groundwater can be got. A water trade, based on transport and sale of water collected from fresh sources, is in operation.

In recent years, a major engineering project was contracted by the Government for the construction of a major pipeline, carrying fresh groundwater from a well-field on the southern bank of the Amu Darya river, located a short distance NW of Kelif, across the desert to Andkhoi (MUMTAZ 2007). Several of these wells yielded relatively fresh calcium bicarbonate water of total dissolved solids <1000 mg/L, and in some cases <500 mg/L. This project appears to have been unsuccessful, allegedly due to issues with pipeline materials' quality and interference with the pipeline.

It is possibly worth noting that such large scale import of water to an urban area such as Andkhoi is fraught with difficulty unless an adequate disposal route can be identified. The import of water would likely lead to increased infiltration to the ground, via pit latrines, pipe leakages and irrigation. It would thus potentially lead to a rise in water table and further salinisation of groundwater, as salts are leached out of the unsaturated zone by the rising groundwater. It could even lead to problems with groundwater

inundation if allowed to continue unchecked. Such a scenario is recorded from many areas of the world where water has been imported to arid city environments, most notably in Riyadh, Saudi Arabia (Kreibich & Thieken 2008).

Figure 1.1. Irrigation pumps on the River Shirin Tagab at Char Shengo, Dowlatabad District. Photo taken by DACAAR on 12th May2013.

Figure 1.2. Irrigation channel, fed by water drawn from the River Shirin Tagab, near Araba, Dowlatabad District. Photo taken by DACAAR on 12th May2013.

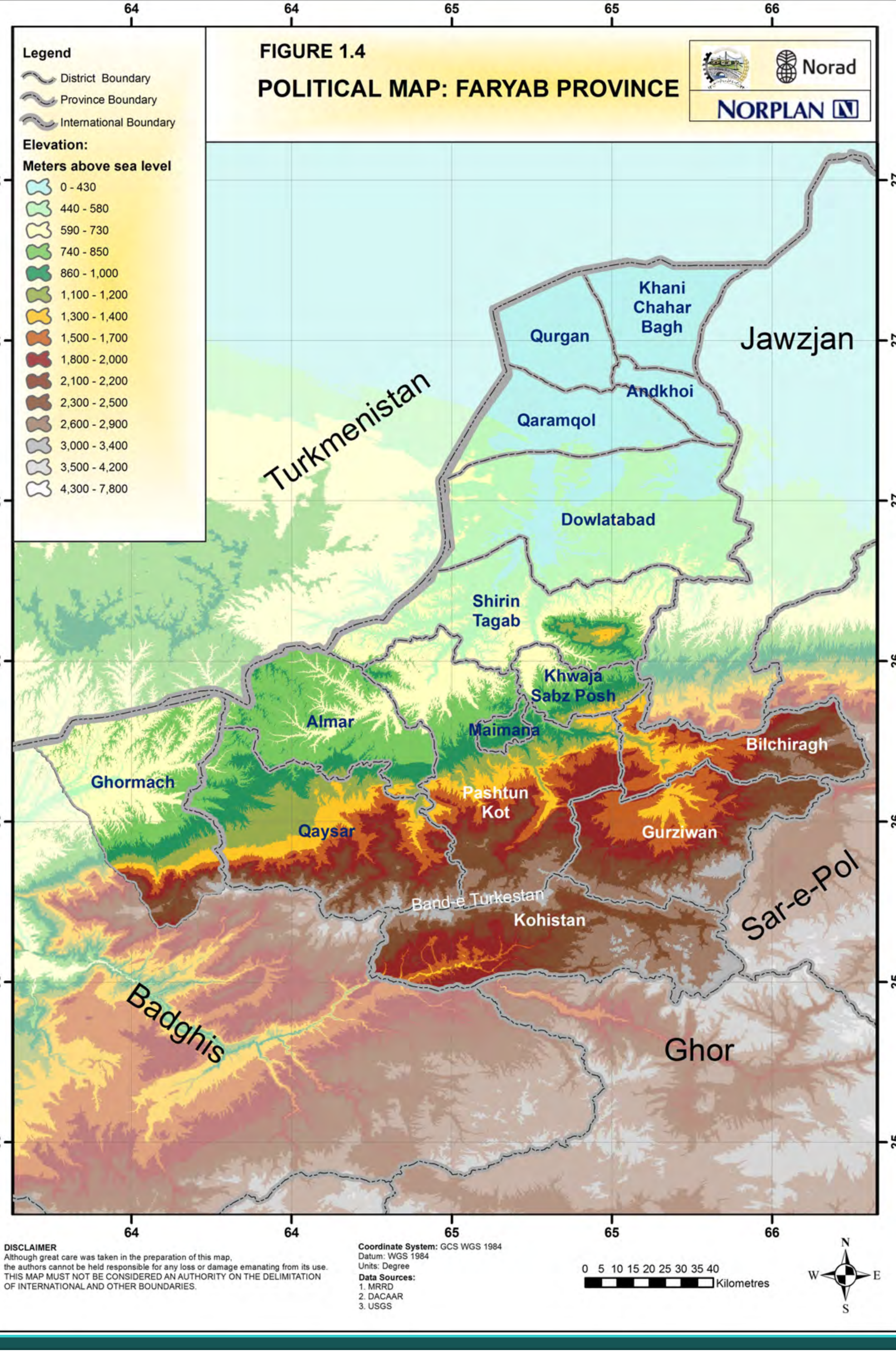
Of Etymological Interest

The name ***Faryab*** is believed to mean *irrigated land.*

Figure 1.3. The channel of the River Shirin Tagab at Araba (Dowlatabad District), heavily depleted by the upstream offtake of irrigation water (Figure 1.3). Photo taken by DACAAR on 12th May2013.

FIGURE 1.4

POLITICAL MAP: FARYAB PROVINCE



DISCLAIMER
Although great care was taken in the preparation of this map, the authors cannot be held responsible for any loss or damage emanating from its use. THIS MAP MUST NOT BE CONSIDERED AN AUTHORITY ON THE DELIMITATION OF INTERNATIONAL AND OTHER BOUNDARIES.

Coordinate System: GCS WGS 1984
Datum: WGS 1984
Units: Degree

Data Sources:
1. MRRD
2. DACAAR
3. USGS

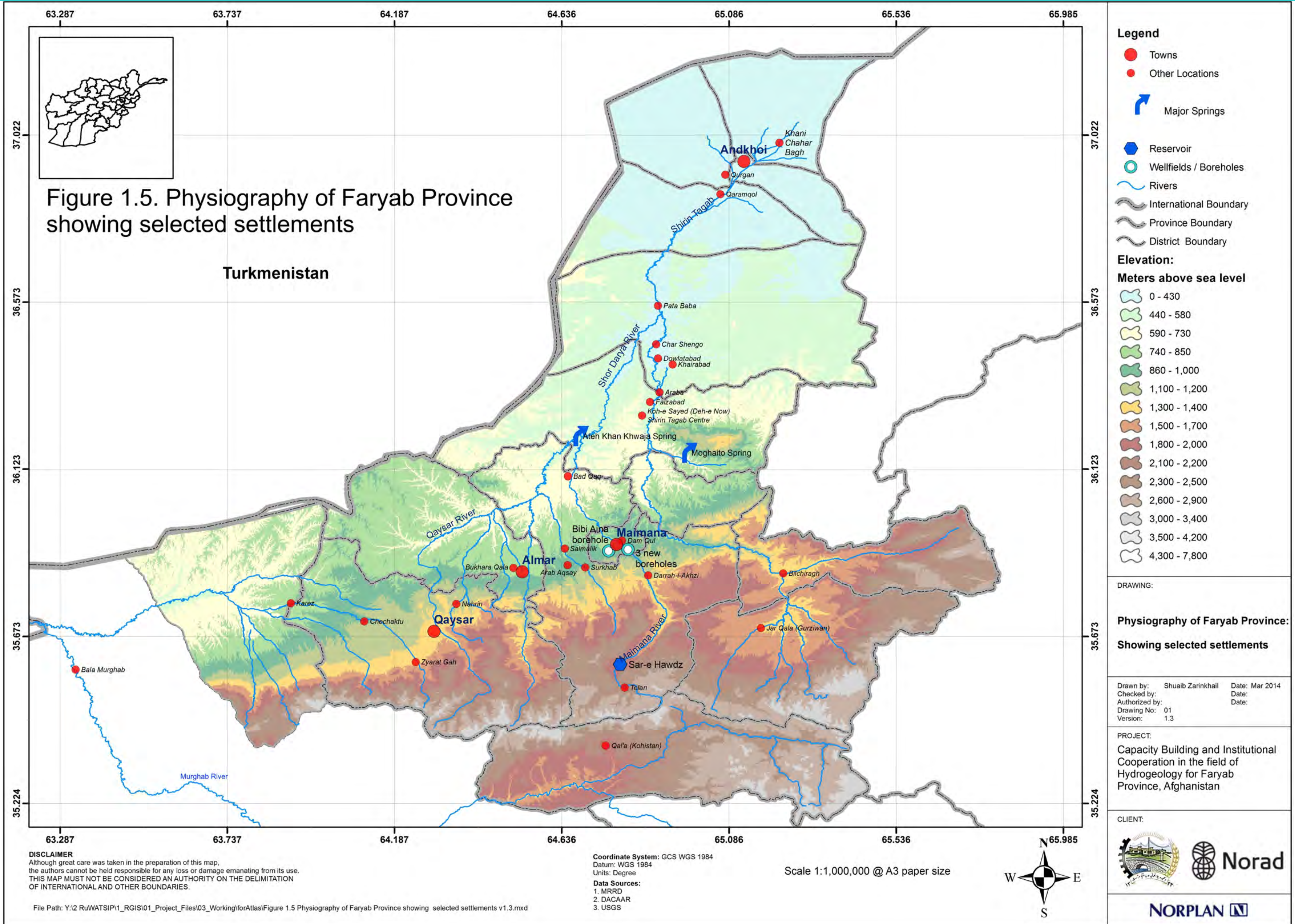


Figure 1.5. Physiography of Faryab Province showing selected settlements

2. Faryab: Location, Topography and Climate

2.1 Location

Faryab Province lies in the north of Afghanistan, with a northern border to the former Soviet republic of Turkmenistan. Faryab is bordered in the west by Badghis Province, to the east by Jawzjan and Sar-e-Pol and to the south by the mountainous province of Ghor.

2.2 Topography

At the core of Faryab province lies the Band-e-Turkestan, an east-west ridge of mountains. This is the westernmost spur of the Hindu Kush massif, which is in turn the Afghan portion of the great Himalayan orogenic belt.

The Band-e-Turkestan range is formed by a horst-like inlier of older lithified Permian and Triassic sedimentary rocks penetrating through the surrounding Cretaceous-Palaeogene limestones and clastic sedimentary rocks. Erosion in Miocene times has restricted the elevation of the summits of the Band-e-Turkestan to 3200-3500 m asl (Encyclopaedia Iranica 2013).

The Band-e-Turkestan forms a major watershed, separating the Shirin Tagab catchment to the north from the Murghab catchment to the south.

The terrain to the south of the Band-e-Turkestan (Kohistan district, in Faryab) is largely underlain by Cretaceous-Palaeogene limestones and is relatively elevated, much of it being at an altitude in excess of 1800 m asl. The terrain is deeply incised by the River Murghab and its tributaries, which form deep ravines. Limestone-fed springs are abundant.

To the north of the Band-e-Turkestan, the land falls away to the plains of the Dasht-e Shortepe (the salty desert), which stretch between Faizabad and the Amu Darya. Cretaceous and Palaeogene sedimentary rocks predominate until an elevation below c. 1500 m, below which the topography is dominated by foothills comprised of the erosional deposits from the Himalaya / Hindu Kush mountain building episode - namely Neogene molasse and alluvial fan deposits. These are often overlain by silty Quaternary wind-blown loess.

The main rivers (e.g. Maimana and Shirin Tagab) have flat valley floors, infilled with recent alluvium, and it is on these that much of the irrigated agriculture takes place.

Below Faizabad (c. 500 m asl) the terrain opens out into the flat semi-desert of Dasht-e Shortepe which is formed by Quaternary alluvial and wind-blown deposits. The terrain continues to fall gently northwards past Andkhoi (c. 310 m asl) and the Turkmenistan Border at Kolodets Imam Nazar (260 m asl), towards the Zeid depression (240 m asl, now occupied by a large Turkmen reservoir) and the Amu Darya itself at c. 245 m asl.

2.3 Climate: Temperature, Sunshine and Humidity

According to historic maps published by AIMS, many of which are reproduced in Favre & Kamal (2004), Faryab experiences between 2600 and 3000 sunshine hours per year, inversely depending on altitude.

The average temperature of the hottest month varies from >30°C in the northern semi-desert to <15°C in the Bund-e-Turkestan mountains.

The average temperature of the coldest month varies from <5°C in the northern semi-desert to below 0°C just south of Maimana and <-10°C in the Bund-e-Turkestan mountains. Figure 2.1 indicates that the average temperature in Maimana varies from

around 2°C in January to over 27°C in July, with a long term average of 14.7°C (Favre & Kamal 2004 cite an annual average temperature of 14.4°C).

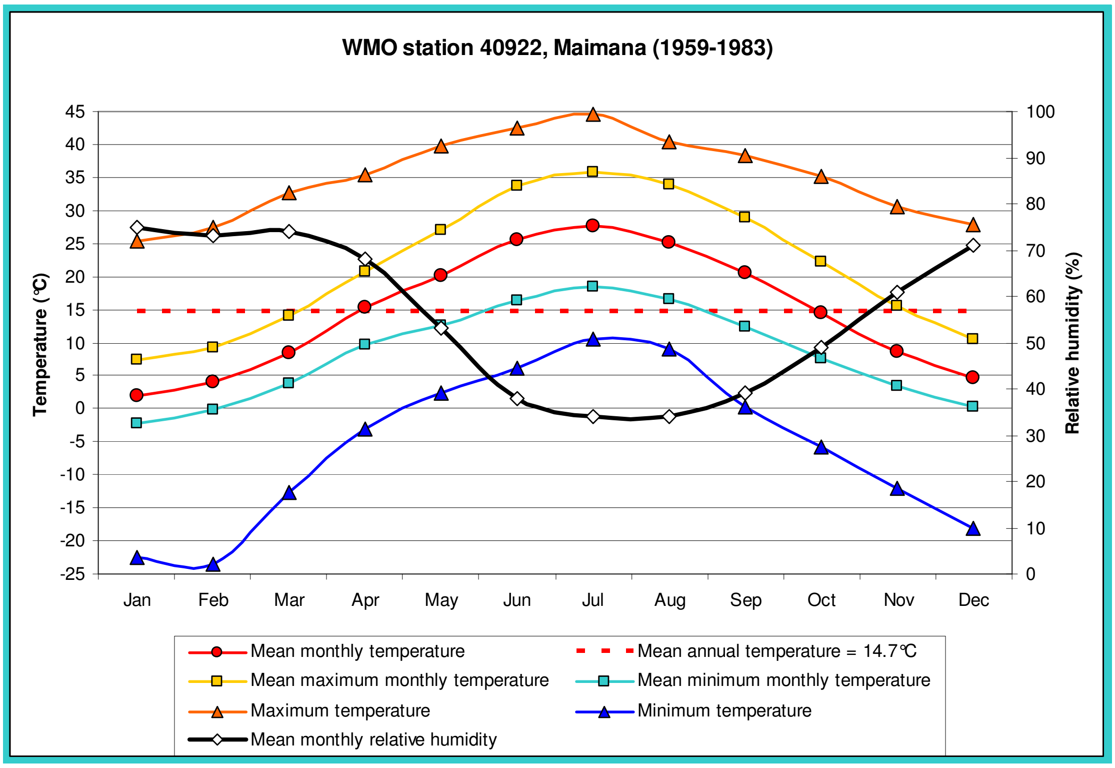


Figure 2.1. Long term dry-bulb air temperature data for WMO meteorological station Maimana (station 40922) in period 1959-83 (minimum temperature and relative humidity based on 1964-1983. Data derived from the NOAA website: ftp://dossier.ogp.noaa.gov/GCOS/WMO-Normals/RA-II/AH/40922.TXT

Arguably, the best regional sources of meteorological data for temperature are found at the NOAA website http://www.esrl.noaa.gov/psd/data/gridded/data.ghcncams.html. For air temperature, the following file has been used to calculate (Figure 2.2) long-term gridded monthly means, based on data from 1981-2010, on a 0.5 degree latitude x 0.5 degree longitude global grid (360x720):

- ftp://ftp.cdc.noaa.gov/Datasets/ghcncams/Derived/air.mon.1981-2010.ltm.nc.

These data are derived from the GHCN_CAMS Gridded 2m Temperature (Land) data set (Fan & Van den Dool 2008). Figure 2.3 compares the temperatures recorded at Maimana, with those in the calculated grid squares containing Andkhoi and mountainous Kohistan regions.

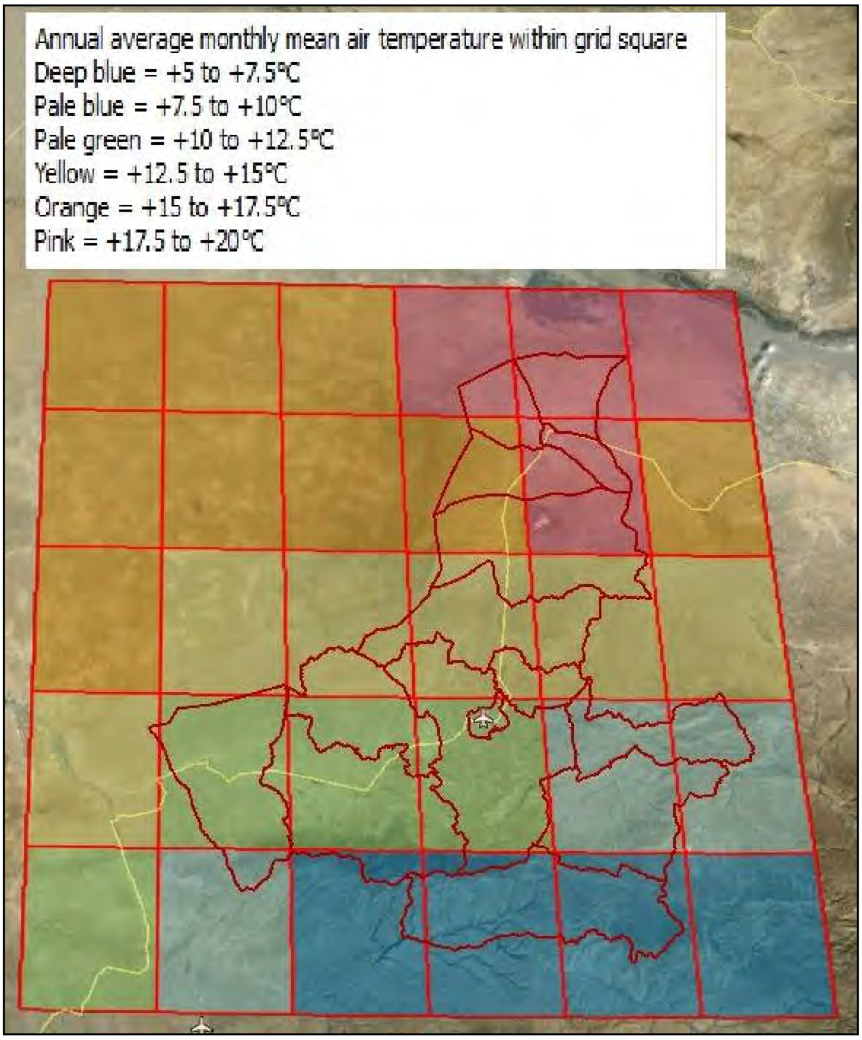


Figure 2.2. Average monthly mean air temperature within 0.5° grid squares, based on 1981-2010 data, after Fan & Van den Dool (2008).

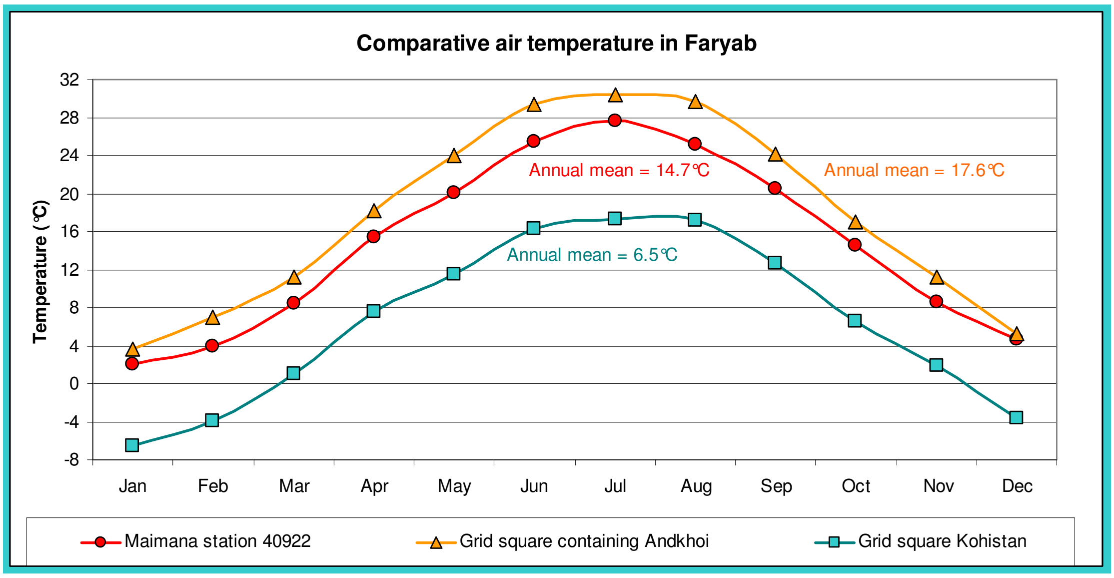


Figure 2.3. Long term annual mean air temperatures at Maimana (WMO station 40922) and in the grid squares containing Andkhoi and western Kohistan (from the NOAA dataset described in Fan & Van den Dool 2008).

2.4 Climate: Precipitation and Evaporation

According to historic maps published by AIMS, many of which are reproduced in Favre & Kamal (2004), average precipitation in Faryab ranges from 600-800 mm/a in the mountains, down to <300 mm/a in the semi-deserts of the north of the province.

Figure 2.4 shows that the bulk of precipitation in Faryab falls between November and May, with very little occurring between June and September.

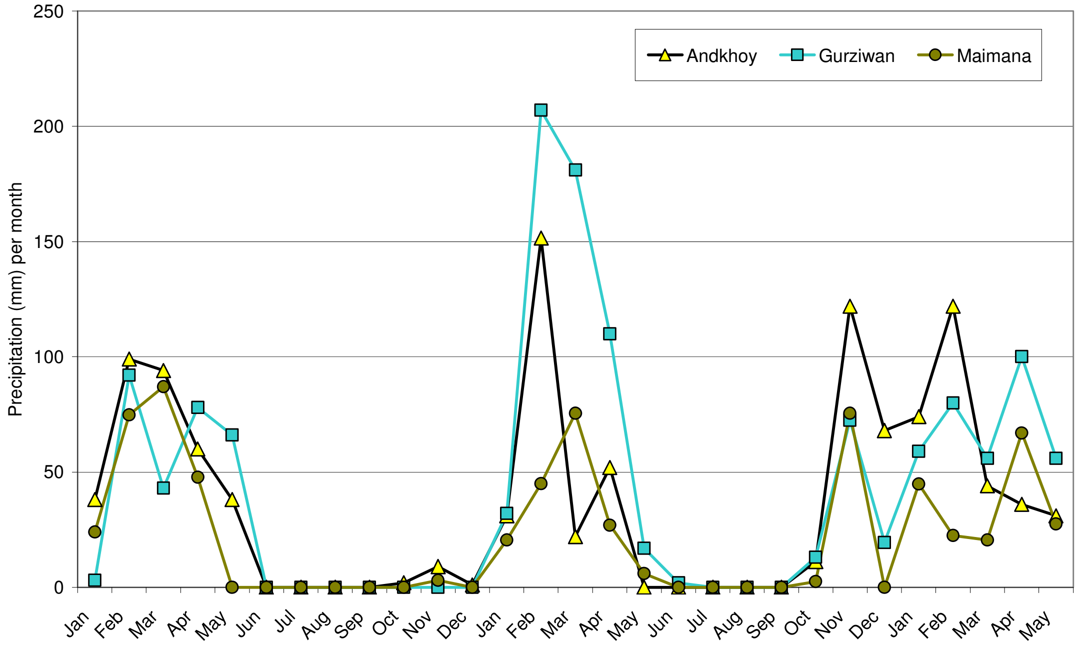


Figure 2.4. Monthly precipitation measured at Agromet stations in Maimana, Gurziwan and Andkhoi from January 2010 to May 2012, provided by the Afghan Ministry of Agriculture, Irrigation and Livestock (MAIL).

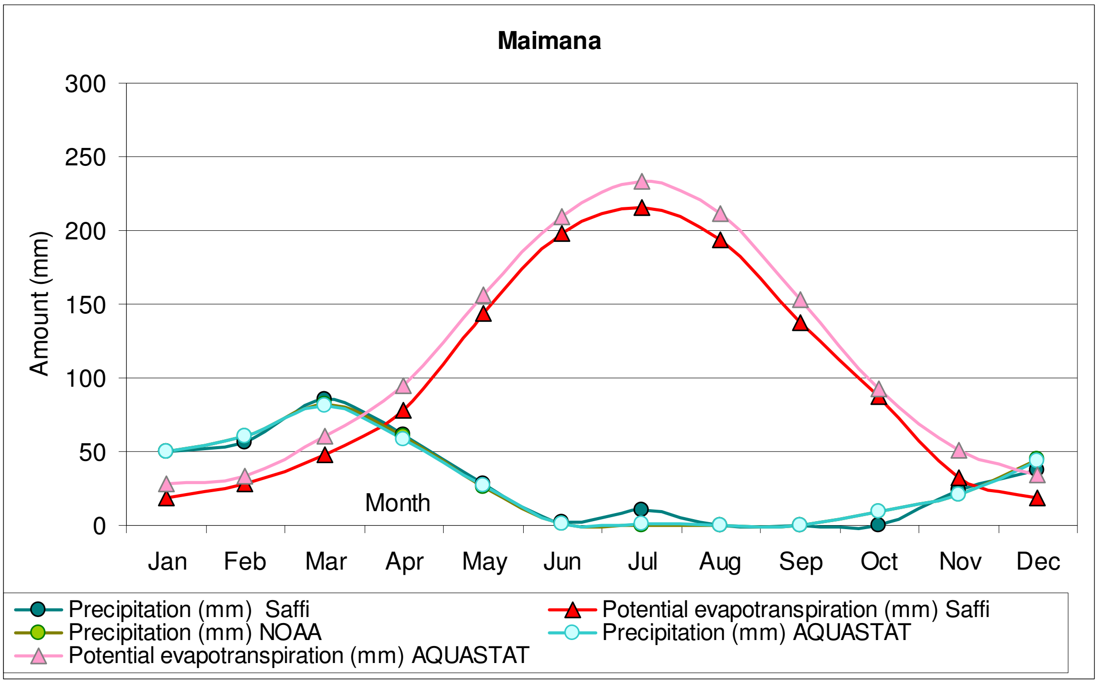
Station	Mazar-e-Sharif	Maimana	Lal-o-Sarjangal
Annual average precipitation	189 mm/a	354 mm/a	227 mm/a
Annual average potential evapotranspiration	1376 mm/a	1202 mm/a	695 mm/a
Monthly average potential evapotranspiration (coolest month)	0.6 mm/d	0.6 mm/d	0.2 mm/d
Monthly average potential evapotranspiration (hottest month)	8.5 mm/d	7.2 mm/d	4.3 mm/d

Table 2.1. Comparison of long-term precipitation and potential evapotranspiration data for Maimana with a semi-desert location (Mazar-e-Sharif) and a highland location (Lal-o-Sarjangal) - after Favre & Kamal (2004)

Figure 2.5 compares the precipitation and potential evapotranspiration in Maimana, with that at Andkhoi. It will be noted that, throughout Faryab, potential evapotranspiration greatly exceeds precipitation on an annual basis. In Maimana, precipitation typically only exceeds potential evapotranspiration in the window December to March. In Andkhoi, excess precipitation only marginally occurs in January, implying that opportunities for infiltration of excess rainfall as groundwater recharge will be very limited in the north of the Province.

The Watershed Atlas of Favre & Kamal (2004) indicates that the “normal” annual precipitation at Maimana is 354 mm, with a range from 200 mm to 582 mm. The annual

average potential evapotranspiration is cited as a massive 1202 mm/a (equivalent to 3.34 mm/d), with monthly means ranging from 0.6 to 7.2 mm/d. Table 2.1 compares these data with Mazar-e-Sharif (which would not be dissimilar to Andkhoi) and Lal-o-Sarjangal in Ghor Province (not dissimilar to the mountainous portions of Faryab).



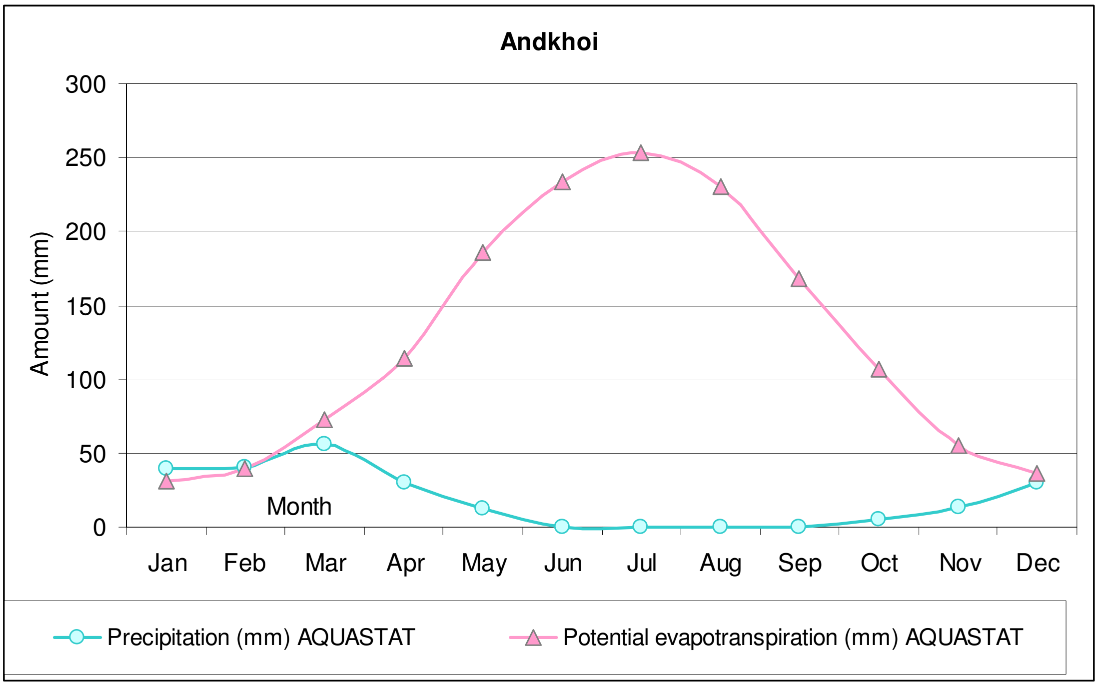


Figure 2.5. Monthly mean precipitation and evapotranspiration data for Maimana and Andkhoi. The data marked *Saffi* are long-term averages (annual mean total precipitation - 354 mm and potential evapotranspiration 1202 mm) from the Maimana meteorological station (1958-1978) cited by Hassan Saffi (2010a,b). *AQUASTAT* refers to data from the FAO Aquastat tool at http://www.fao.org/nr/water/aquastat/gis/index3.stm. *NOAA* refers to long-term averages (annual mean total precipitation - 356 mm) from the WMO station 40922 (1964-83) at Maimana, from ftp://dossier.ogp.noaa.gov/GCOS/WMO-Normals/RA-II/AH/40922.TXT. The *AQUASTAT* and *NOAA* data are almost identical.

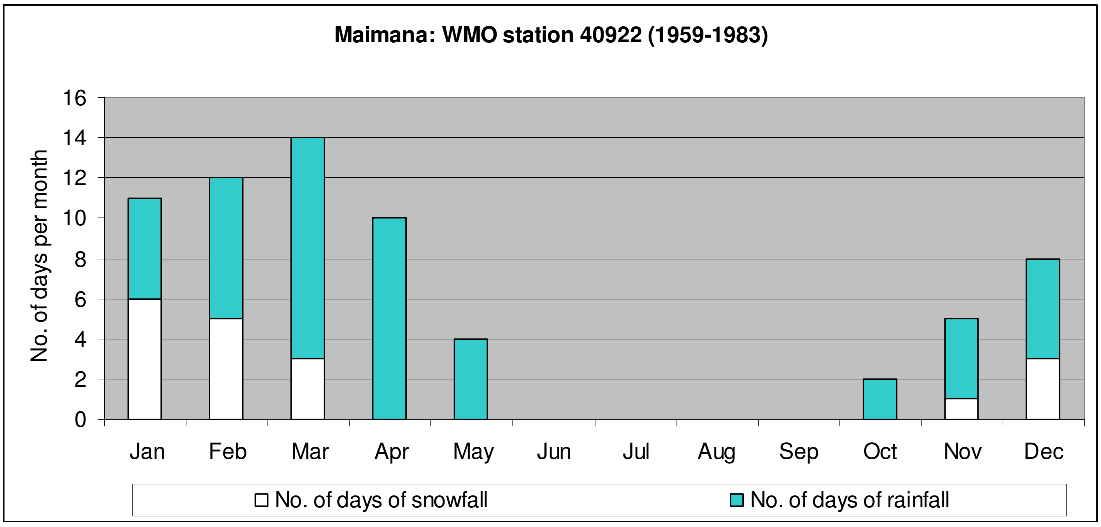


Figure 2.6. Average number of days of snowfall and rainfall recorded at WMO station 40922 Maimana for the period 1959-1983, according to data download from ftp://dossier.ogp.noaa.gov/GCOS/WMO-Normals/RA-II/AH/40922.TXT

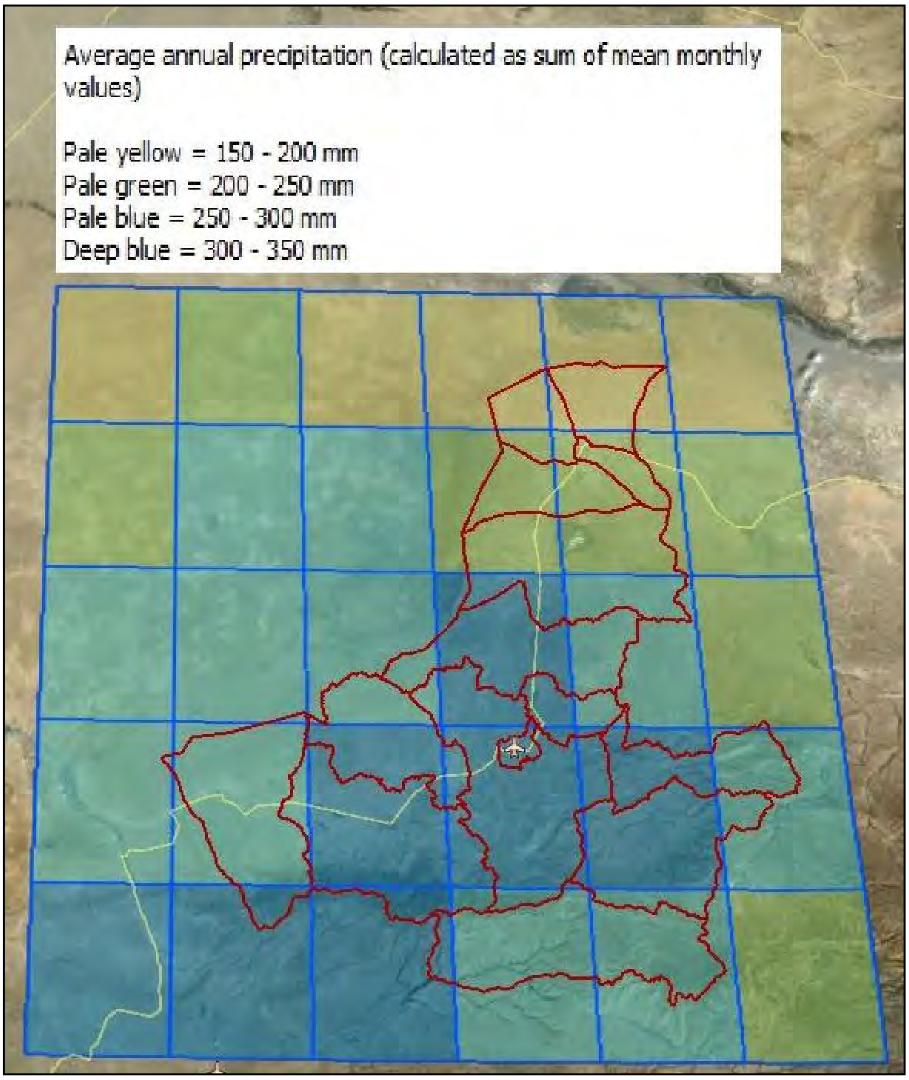


Figure 2.7. Average annual precipitation within 0.5° grid squares, based on 1981-2010 data, after Schneider et al. (2011).

Arguably, the best regional sources of meteorological data for precipitation are found at the NOAA website http://www.esrl.noaa.gov/psd/data/gridded/data.gpcc.html. For precipitation, the following file has been used to calculate long-term gridded (Figure 2.7) monthly means, based on data from 1981-2010, on a 0.5 degree latitude x 0.5 degree longitude global grid (180x720)

- ftp://ftp.cdc.noaa.gov/Datasets/gpcc/full_v6/precip.mon.1981-2010.ltm.v6.nc.

These data are derived from the GPCC Global Precipitation Climatology Centre data set (Schneider et al. 2011):

2.5 Chemical and Isotopic composition of precipitation

During winter 2013 and spring 2014, samples of rainfall and snowfall were collected at the premises of the Agricultural Departments in Maimana, Andkhoi and Gurziwan (near Jar Qala). These were couriered to the United Kingdom and analysed at the laboratories of the British Geological Survey (BGS) at Keyworth for a wide range of elements by ICP-MS techniques, anions by ion chromatography and stable O and H isotopes by mass spectrometry at the NERC isotope facility at Keyworth. The results are shown in Table 2.2.

It should be noted that, to avoid risk of contamination, the samples were *not* filtered in the field and might thus possibly contain traces of dust or other airborne materials. This effect could have resulted in elevated concentrations in, for example, the snow sample from Andkhoi.

In general, however, the samples have chloride concentrations of 1-2 mg/L at Andkhoi, 0.1 to 1.7 mg/L at Maimana and c. 0.6 mg/L at Gurziwan. The highest concentrations at Andkhoi presumably reflect evapo-concentration of salts during residence in the atmosphere. While precipitation in European maritime climates (e.g. Norway and the UK) is usually dominated by marine salts (e.g. NaCl) and atmospheric industrial contaminants (sulphate, nitrate from so-called "acid rain"), the precipitation in Faryab is characterised by calcium is the dominant cation and sulphate as the dominant anion, followed by chloride and nitrate. Thus may reflect a greater contribution from wind-blown dust (containing calcite and gypsum, and possibly halite). Sodium approximately balances chloride in the analyses, suggesting a derivation from halite in wind-blown dust, or possibly from distal marine salts.

As regards isotopic composition, the snowfall signatures are by far the isotopically lightest, with the signatures becoming "heavier" throughout spring. The heaviest isotopic rainfall signatures typically come from Andkhoi, as one would expect, due to greater isotopic fractionation by evaporation during its passage through the atmosphere.

Of Etymological Interest

The Faryab District of ***Kohistan*** means *mountainous land*.

Safed Koh means *White Mountains*, while ***Band-e-Turkestan*** refers to this range forming the *boundary wall to Turkestan*.

Dasht-e Shortepe: the ***dasht*** refers to a desert, while ***tepe*** probably derives from a Turkic word for hill, and ***shor*** means salty. Thus, *desert of salty hills* might be a rough translation.

Badghis means *Home of the wind.*

Table 2.2. Chemical and isotopic (VSMOW2) composition of rainfall sampled in Faryab in Winter 2012-13 and Spring 2013.

NORPLAN sample no. BGS sample number	Location Elevation	Type Date	Ca mg/L	Mg mg/L	Na mg/L	K mg/L	Sr µg/L	B µg/L	Cl^- mg/L	SO_4^{2-} mg/L	NO_3^- mg/L	$\delta^{18}O$ ‰	δ^2H ‰
Method			Inductively coupled plasma mass spectrometry						Ion chromatography			Mass spectrometry	
NOR-AND-SNW-03 13131-0003	Andkhoi c. 293 m asl	Snow 28/12/12	19.3	2.43	11.3	6.5	231	16	15.6	25.1	16.4	-18.01	-129.8
NOR-AND-RAIN-01 13131-0022	Andkhoi c. 293 m asl	Rain 15/3/13	15.0	1.38	2.5	0.6	57	12	2.0	6.9	6.8	-5.82	-35.3
NOR-AND-RAIN-02 13131-0023	Andkhoi c. 293 m asl	Rain 1/4/13	3.7	0.58	2.0	0.4	33	<10	1.4	3.9	1.0	-6.32	-32.9
NOR-GW-SNW-01 13088-0002	Gurziwan (Jar Qala) c. 1390 m asl	Snow 28/12/12	2.9	0.27	0.5	0.6	13	<10	0.60	0.75	0.38	-18.4	-122
NOR-GW-RAIN-01 13131-0001	Gurziwan (Jar Qala) c. 1390 m asl	Rain 26/2/13	5.3	0.33	0.5	0.8	19	<10	0.56	0.88	0.49	-12.24	-81.3
NOR-MAY-SNW-01 13088-0001	Maimana c. 847 m asl	Snow 28/12/12	5.2	0.14	<0.2	0.1	17	<10	0.10	0.58	0.46	-23.0	-165
NOR-MAY-RAIN-01 13131-0002	Maimana c. 847 m asl	Rain 26/2/13	2.5	0.18	0.5	0.4	13	<10	0.48	3.2	1.7	-8.64	-48.6
NOR-MAY-RAIN-02 13131-0021	Maimana c. 847 m asl	Rain 1/4/13	2.5	0.72	2.1	0.3	46	11	1.74	2.5	0.64	-5.32	-25.6

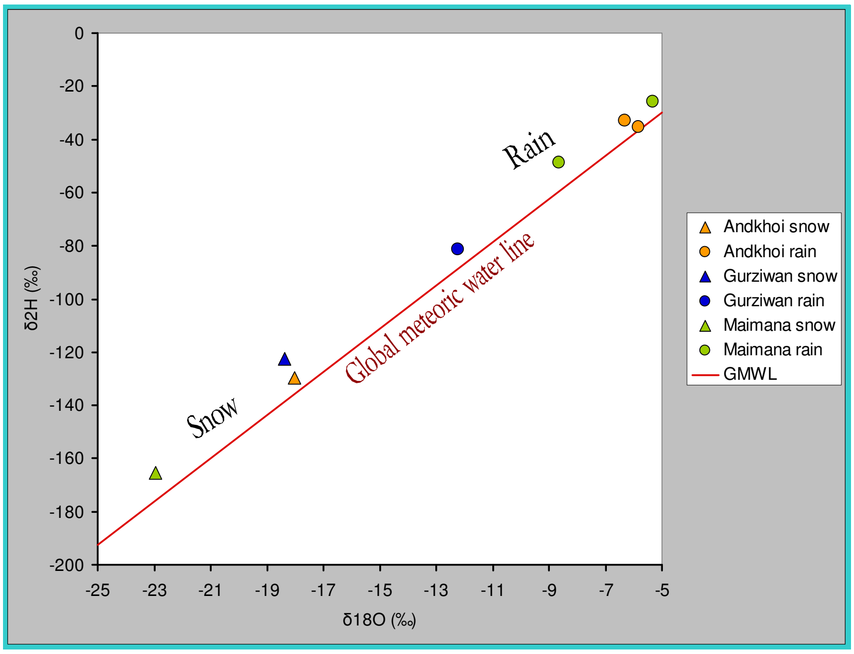


Figure 2.8. Stable isotope diagram comparing the isotopic composition of precipitation samples from Table 2.2. The GMWL is taken as $\delta^2H = (8.13 \times \delta^{18}O) + 10.8$ (Clark & Fritz 1997).

3. Faryab: Rivers and Surface Waters

3.1 The Amu Darya (Oxus)

The Amu Darya (or Oxos / Oxus, as it was called by the ancient Greeks) is the main watercourse running through northern Afghanistan, and forming the border with Turkmenistan. It is an "trans-boundary" watercourse and its use has been the subject of considerable international controversy. Usage of water from the Amu Darya has also been controversial as it is one of the two large watercourses (the Syr Darya being the other), which feeds the inland Aral Sea. As has been widely reported, the volume of water entering the Aral Sea has dramatically reduced over recent decades, leading to a catastrophic shrinking of the area of the sea, and desertification of the adjacent area (Zavialov 2005).

One of the main abstractions of water from the Amu Darya is the quantity drawn off by the Lenin (now renamed the Niyazov) Karakum Canal near the town of Khatab, in Turkmenistan, close to the northern extremity of Jawzjan Province.

The Karakum Canal traverses the Turkmen desert north of Faryab, via the Mary (Merv) inland delta (where it connects with the Murghab) and Gökdepe (near Ashgabat) to Bereket (Gazandjyk) only some 130 km short of the Caspian Sea. It was constructed by the Soviet Union between 1954 and 1988, with the objective of irrigating the Karakum desert, primarily for cotton production, but also supplying the city of Ashgabat with water. The canal is 1375 km long, is partly navigable and conveys some 13 km^3/a of water (an average of 412 m^3/s). A large proportion of the water is reported to be lost via seepage to the ground. Soil and groundwater salinisation is reportedly promoted by canal leakage, causing rises in groundwater level and dissolution of salts from the unsaturated zone, and evaporative accumulation of salts in irrigation water (Kharin 2002; Esenov 2014; Zonn 2014; http://en.wikipedia.org/wiki/Karakum_Canal). The Zeid Reservoir at the head of the canal, in the Lebap region of the Turkmen desert, has a reported capacity of 3.5 km^3, and the maximum off-take from the Amu Darya to the Karakum Canal is reported by Glantz (1999) as 580 m^3/s.

The salinity of the Amu Darya at Kelif gauging station is reported as around 0.5 g/L (Gapparov et al. 2011), while the annual flow is reported as 55.3 km^3 (1752 m^3/s; INTAS 2006). At Kerki gauging station, a short distance downstream from the Karakum Canal offtake, the annual flow is reported as 1696 m^3/s (period 1932-1989).

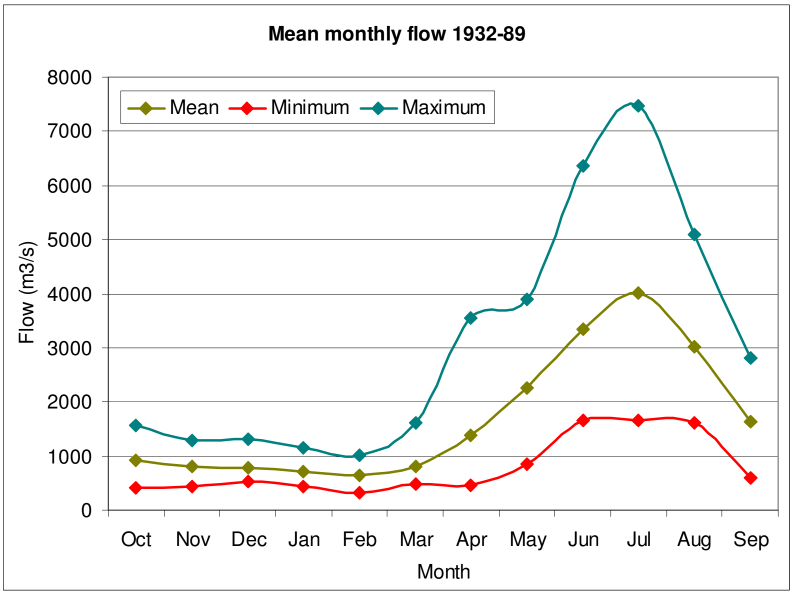


Figure 3.1. Mean monthly flows in the River Amu Darya at Kerki in Turkmenistan. *Source: UNH/GRDC from http://grdc.sr.unh.edu/html/Polygons/P2917110.html.*

Like the Balkh, Sar-e-Pol and Murghab Rivers, the Shirin Tagab system does not reach to the Amu Darya, but disperses within an inland delta system of distributary channels. There is no evidence that the Shirin Tagab ever discharged into the Amu Darya during historical or even recent geological (Holocene) times. The Amu Darya and Zeid depression does, however, form the base level towards which groundwater in the aquifers of northern Faryab drains.

3.2 The Murghab

The Murghab River flows westward through Afghanistan between the Band-e-Turkestan range to the north and the Safed Koh mountains to the south. Leaving Faryab, it passes through Badghis Province (and the town of Bala Murghab. It then enters Turkmenistan, before running out in the distributary channels of the inland delta in the desert around the town of Mary (historic *Merv*).

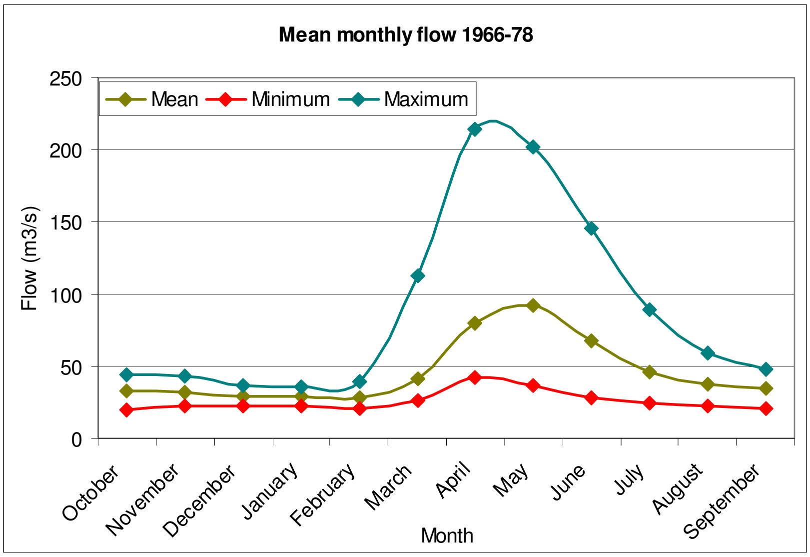


Figure 3.2. Mean monthly flows in the River Murghab at Qala-e-Niazkhan (station 40) in Badghis Province.
Source:

1966-1978 data from the USGS suggest that the flow is strongly seasonal, with the greatest flows (exceeding 50,000 L/s at Qala-e-Niazkhan) between March and June, and being related to snowmelt. The river baseflow is likely to be substantially supported by groundwater discharge, especially from the large areas of Palaeogene-Cretaceous limestone aquifer outcrop that it traverses.

The long-term annual average flow at Qala-e-Niazkhan is 46,800 L/s, for an upstream catchment area of 13,805 km^2. This equates to an average run-off of 3.4 L/s/km^2 or 107 mm/a.

3.3 The Chechaktu (or Western Qaisar or Ghormach) River

The Chechaktu River (also referred to as the Western Qaisar river, the Ghormach River or the Karawal Kana) rises in the Ban-e-Turkestan mountains and exits the mountains onto the alluvial outwash plain at Zyarat Gah. The river has small tributary channel that rise very close to Qaisar town, within "spitting distance" of the true Qaisar River.

As the Chechaktu leaves Faryab and enters Ghormach district, it is joined by other tributaries flowing down from the Bund-e-Turkestan, notably the Shakh and Ghormach Rivers. The Chechaktu joins the larger Murghab River just downstream of Bala Murghab.

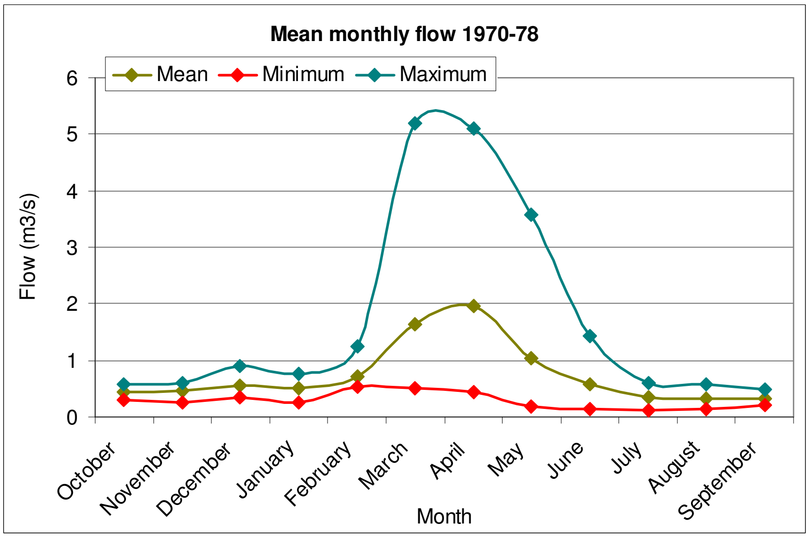


Figure 3.3. Mean monthly flows in the River Chechaktu at Chechaktu (station 44) in Qaisar District. Source:

1970-1978 data from the USGS suggest that the flow is strongly seasonal, with the greatest flows (exceeding 2,000 L/s at Chechaktu) between March and May, and being related to snowmelt.

The long-term annual average flow at Chechaktu is 760 L/s, for an upstream catchment area of 415 km^2. This equates to an average run-off of 1.8 L/s/km^2 or 58 mm/a.

3.4 The Shirin Tagab

According to Ahmad & Wasiq (2004) the Shirin Tagab has a total catchment area of 13,600 km^2. The annual run-off is estimated as between 100 and 132 Mm^3.

A major tributary joins the Shirin Tagab river near Pata Baba in Dowlatabad district. This is the Shor Darya, which carries the combined flow deriving from the Almar, Qaysar and Maimana Rivers. They are fed by snowmelt, rainfall and groundwater base-flow, especially baseflow from the productive Palaeogene-Cretaceous limestone aquifers up the mountains.

All these rivers rise in the northern slopes of the Band-e-Turkestan mountains. It has been argued that the Qaysar / Shirin Tagab river system may be the River *Ochus* referred to by writers of antiquity (Rawlinson 1879, Olbrycht 2010).

The rivers flow north down on the Neogene molasse and Quaternary loess plains, where they deposit their eroded sediment load and often form poorly defined braided river channels. They also change from a gaining (spring-fed) regime, to a losing regime, where flow temporarily or permanently infiltrates into the alluvial outwash sediments and starts to be lost to evaporation and irrigation take-off.

The Shirin Tagab is a so-called "blind" river system, which dissipates due to evaporation, irrigation off-take and infiltration to the ground, without ever reaching the Amu Darya. The River dissipates in an "inland delta" area, today comprising a network of irrigation channels around the city of Andkhoi.

The Shirin Tagab

The Shirin Tagab proper rises in the eastern part of Bilchiragh Province, although near Bilchiragh town, it is joined by the Chashma-i Khwab river, flowing out of a spectacular

gorge. The Chashma-i Khwab is, in turn, is fed by the streams of five valleys flowing out of Gurziwan: the Khwaja Ghar, the Shakh, the Zang, the Takhra and the Rabat (Favre & Kamal 2004)

There are three historic gauging stations on the course of the Shirin Tagab. In descending order these are:

1. At Khisht Pul, in Pashtun Kot district, shortly after the river has emerged from the pre-Neogene terrain onto the Neogene proluvial outwash deposits.
2. At Dawlatabad, prior to the confluence with the Shor Darya.
3. At Pata Baba, downstream of the confluence with the Shor Darya.

In the Shirin Tagab we can see that elevated flows are observed during the rainier months from October-November through to February. In March-May there is a strong snow-melt peak, and then the flow drops quickly to summer levels.

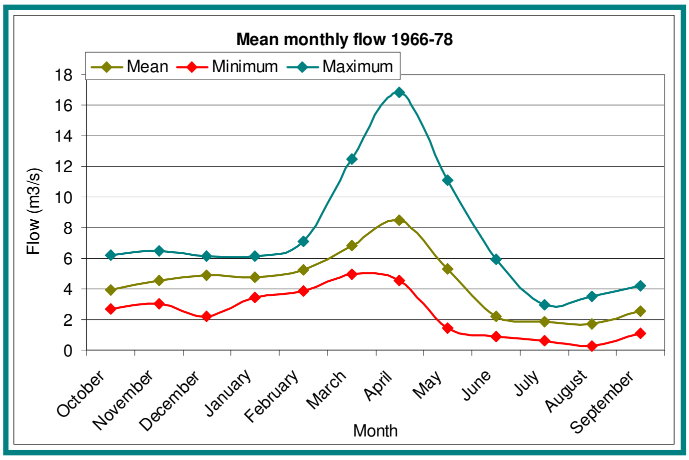


Figure 3.4. Mean monthly flows in the Shirin Tagab at Khisht Pul (station 48) in Pashtun Kot District. Source:

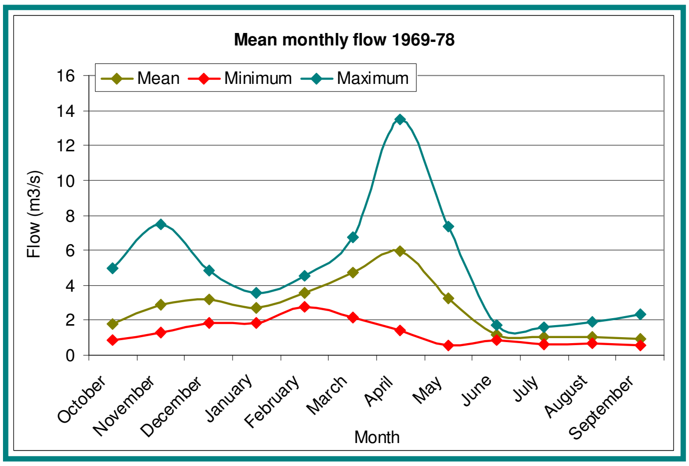


Figure 3.5. Mean monthly flows in the Shirin Tagab at Dawlatabad (station 47). Source:

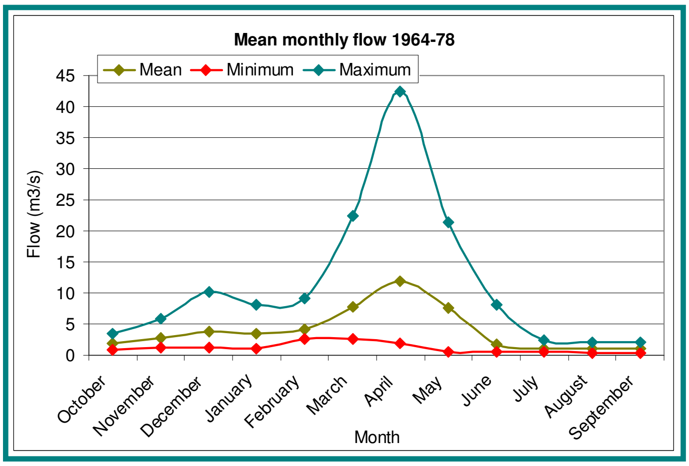


Figure 3.6. Mean monthly flows in the Shirin Tagab at Pata Baba (station 46,), Dawlatabad District. Source:

It is also important to note that the flows decrease downstream from Khisht Pul to Dowlatabad, by almost 50% on an annual average basis. As yet it is not clear whether this can be ascribed to:

- infiltration losses to groundwater
- abstraction for irrigation (and thereafter loss to evapotranspiration or infiltration to groundwater)
- evapotranspirative losses

or (as would be likely, a combination of all three).

The total flow at Pata Baba is, on average 1640 L/s greater than at Dowlatabad, presumably due to the confluence with the Shor Darya (average 2440 L/s, see below), but the specific areally distributed run-off rate decreases consistently downstream.

Table 3.1.

Gauging station	Long term annual mean discharge	Upstream catchment area	Areally distributed long term run-off
Khisht Pul (station 48)	4,450 L/s	3,280 km^2	1.4 L/s/km^2 43 mm/a
Dowlatabad (station 47)	2,340 L/s	4,645 km^2	0.50 L/s/km^2 16 mm/a
Pata Baba (station 46)	3,980 L/s	11,775 km^2	0.34 L/s/km^2 11 mm/a

<u>The Astana River</u>

The Astana is an east-bank tributary of the Shirin Tagab. It is unique in not rising on the pre-Neogene terrain of the Band-e-Turkestan, but rather, within the Neogene molasse sediments of Shirin Tagab District. The River itself is known to be extremely salty, due to the highly saline nature of the groundwaters in the Neogene aquifer, which feed it. A sample from Chel Quduq, taken in October 2005, has an electrical conductivity of 45,000 μS/cm.

The salinity of the ground and surface waters in the Astana Valley may be ascribed to (i) the very high rates of evaporation in the area, leading to up-concentration of precipitation derived salts in the soil and (ii) possibly, the suspected content of halite and gypsum in the Neogene soils.

To the north of the Astana River is a small inlier of Cretaceous and Palaeogene sedimentary rocks around Qara Qol. Somewhat fresher springs of groundwater drain from the southern flanks of this inlier (e.g. Moghaito, which has a reported discharge of up to 3 L/s and an electrical conductivity of 3400 μS/cm), but these have largely been captured for public water supply purposes.

3.5 The Qaisar / Maimana / Shor Darya Rivers

The Qaisar, Maimana and Almar Rivers all rise on the northern flank of the Band-e-Turkestan mountains.

<u>The Maimana River</u>

The Maimana is presumed to gain baseflow from groundwater discharge of the Cretaceous / Palaeozic limestone aquifers of its upper reaches. Shortly before arriving at Maimana, it crosses onto Neogene molasse deposits.

The Qaysar River

The Qaisar River also traverses onto Neogene / Quaternary deposits shortly upstream of Qaisar town.

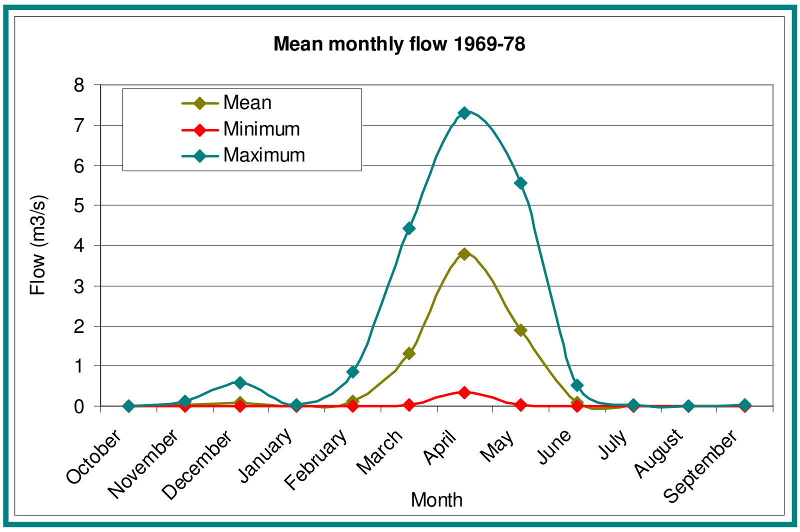


Figure 3.7. Mean monthly flows in the Qaisar River at Qaisar (station 49). Source:

1969-1978 data from the USGS suggest that the Qaisar River's flow is very strongly seasonal, with the greatest flows (typically up to 4,000 L/s at Qaisar town) between March and May, and being related to snowmelt. The river often effectively dries up at Qaisar between July and February, suggesting a lack of groundwater baseflow to the upper sections.

The long-term annual average flow of the Qaisar at Qaisar town is 540 L/s, for an upstream catchment area of 425 km^2. This equates to an average run-off of 1.3 L/s/km^2 or 40 mm/a.

The Almar and Aqsay Rivers

Several south bank tributaries join the Qaisar, of which the most important are the Almar River(s) and the Aqsay, all arising on the pre-Neogene rocks on the northern flanks of the Band-e-Turkestan mountains. In particular, the Almar River emerges from the pre-Neogene bedrock terrain through a canyon near Yaka Khana and immediately forms a wide alluvial fan and takes on a very diffuse, braided nature around Almar.

The Shor Darya

The Shor Darya is the name given to the combined flow of the Qaysar and Maimana Rivers, downstream of their confluence near Ateh Khan Khwaja. The Shor Darya section is known to be saline and this is belived to be due to discharge of saline or brackish groundwaters in the area.

At Ateh Khan Khwaja, there is a major spring (some 15- 35 L/s reported by DACAAR, varying seasonally) discharging to the Shor Darya. It represents some of the freshest water in the area, with an electrical conductivity of 2660 µS/cm (Hassan Saffi 2010b).

In May 2007, the Shor Darya was sampled at Ateh Khan Khwaja, where the electrical conductivity was found to be 6000 µS/cm. It was also sampled at Chokazi, near Jalair, and the electrical conductivity was found to be 8730 µS/cm (Hassan Saffi 2010b).

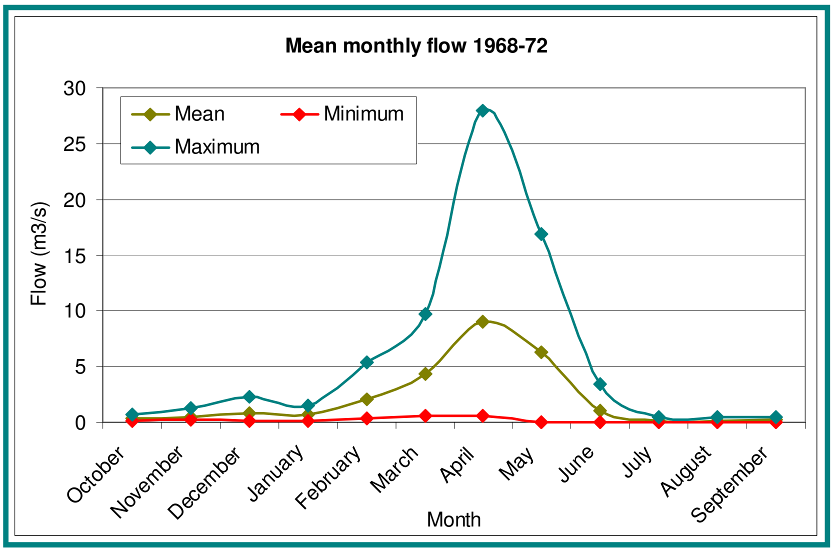


Figure 3.8. Mean monthly flows in the Shor Darya near Pata Baba (station 50,), Dawlatabad District. Source

1968-1972 data from the USGS suggest that the Shor Darya's flow is seasonal, with the greatest flows (typically up to 9,000 L/s near Pata Baba) between February and May. Flows are extremely low from July to November, suggesting a lack of groundwater baseflow.

The long-term annual average flow of the Shor Darya, prior to its confluence with the Shirin Tagab at Pata Baba 2440 L/s, for an upstream catchment area of 6685 km². This equates to an average run-off of 0.36 L/s/km² or only 12 mm/a.

The total flow in the Shirin Tagab at Pata Baba is, on average 1640 L/s greater than at Dowlatabad, presumably due to the confluence with the Shor Darya (av, but the specific areally distributed run-off rate decreases consistently downstream.

From these Figures and those from Table xx.xx we can calculate the accretion of flow:

(a) on the Qaisar / Shor Darya, between Qaysar and Pata Baba, as

(2440 - 540) L/s / (6685-425) km² = 1900 / 6260 km² = 0.30 L/s/km² = 10 mm/a

(b) on the Shirin Tagab, between Khisht Pul and Dowlatabad, as

(2340-4450) L/s / (4645-3280) km² = -2110 / 1365 km² = 1.5 L/s/km² = -49 mm/a

(c) on the joint system, between Shor Darya / Dowlatabad and Pata Baba, as

(3980-2440-2340) L/s / (11775-6685-4645) km²

= -800 / 445 km² = -1.8 L/s/km² = -57 mm/a

3.6 *The 2013 Maimana River Survey*

On 1st May 2013, a stretch of the Maimana River was surveyed between Koh-e Khana, on the northern outskirts of Maimana, and Badghisy, representing a linear distance of almost 19 km and a river distance of just over 25 km. Flow, electrical conductivity, pH and temperature were taken at 5 stations along thos length (Figure 3.9), while chemical and isotopic samples, filtered at 0.45 µm, were taken at 3 stations and sent to the British Geological Survey, Keyworth, UK for analysis (see NORPLAN 2014 for methods).

The river temperature increased from 14.1 to 18.5°C downstream over the course of the survey, the electrical conductivity increased from 545 to 690 µS/cm, while the field pH was relatively constant at 8.4.

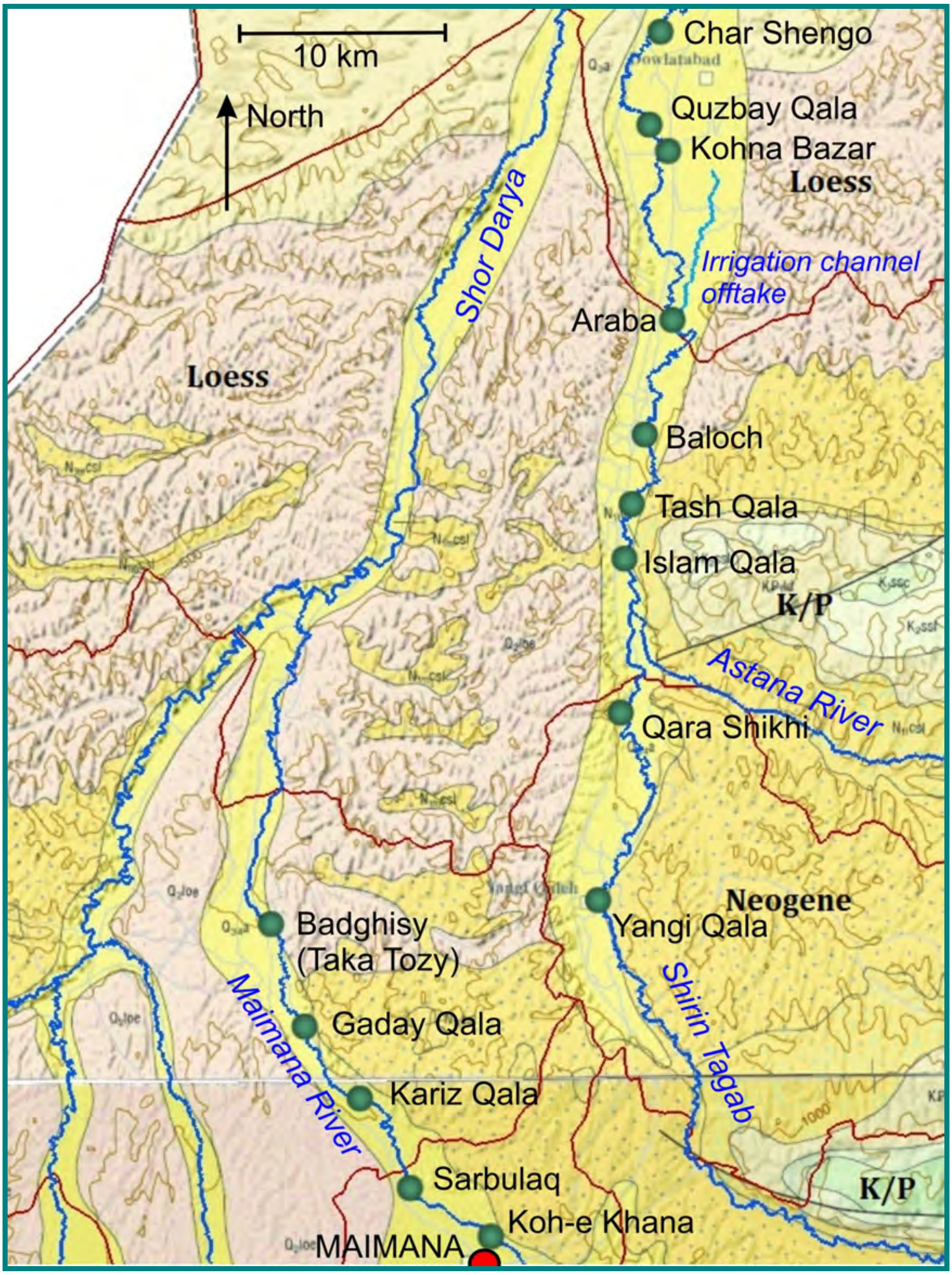


Figure 3.9. The locations for gauging and sampling during the 2013 survey of the Shirin Tagab and Maimana Rivers. The rivers are superimposed on the published 1:200,000 AGS/USGS geological maps (McKinney & Sawyer 2005; Wahl 2005), on which pink colours generally denote Quaternary loess, orange Neogene proluvial/molasse deposits, yellow Quaternary alluvium and green/brown Cretaceous / Palaeogene sedimentary rocks (K/P). These maps are believed to be public domain products.

At Koh-e Khana, the river contained around 8 mg/L nitrate (as NO_3^-) and <0.01 mg/L total phosphorus. The water chemistry was dominated by calcium and bicarbonate, with subsidiary sulphate.

Along the surveyed length, the flow rate (as estimated by impeller profile gauging) dropped from 2.1 m^3/s to 1 m^3/s, while the electrical conductivity rose by a factor of 1.27.

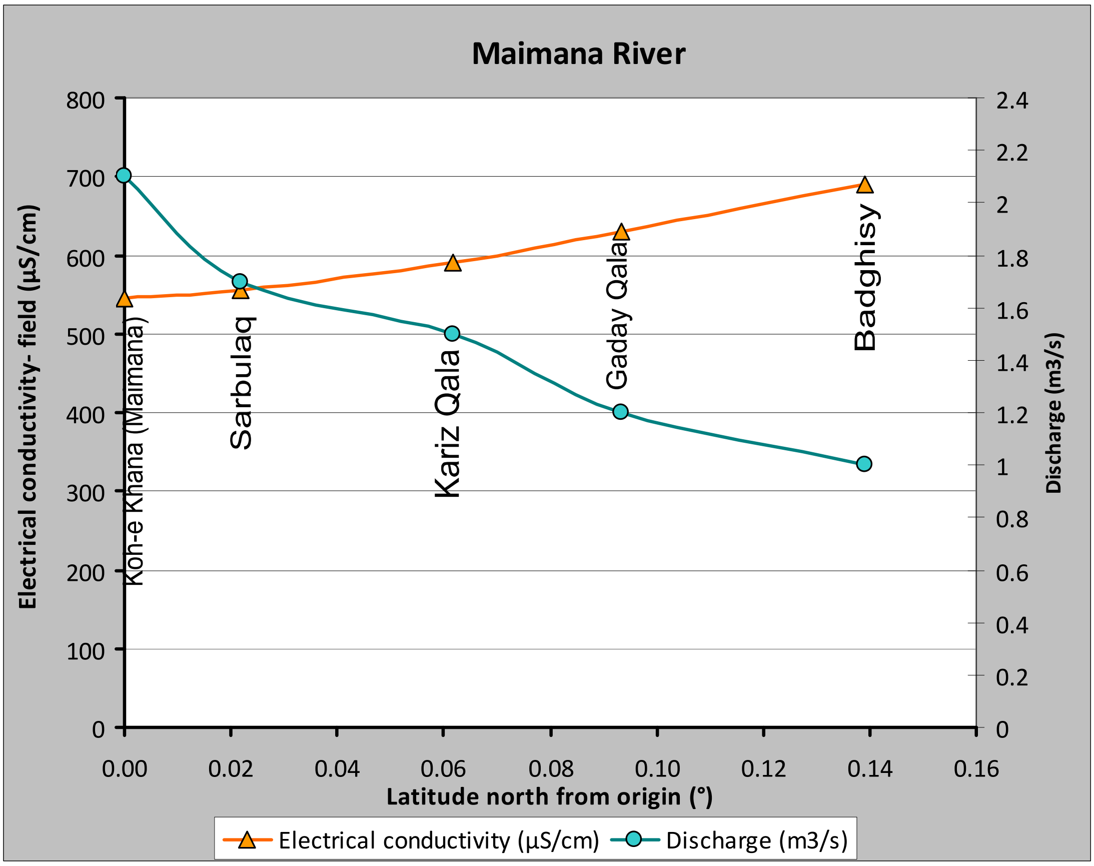


Figure 3.10a. Change in electrical conductivity and flow rate along the surveyed length of the Maimana River on 1st May 2013.

Different solutes were concentrated downstream at different rates, however, with calcium and bicarbonate accumulating relatively slowly, and solutes such as chloride, (followed by arsenic and potassium), which can be regarded as relatively conservative, accumulating by a factor of some 1.7.

The fact that the maximum solute upconcentration factor is only a little less than the flow loss factor (2.1) suggests that evaporation is a main driving force for loss of flow (abstraction and infiltration may also be factors in flow depletion).

If the channel is on average 6 m wide and 25 km long, the river stretch has a surface area of at least 150,000 m^2 (and probably more, given that narrow, straight sections were specifically chosen for gauging). The total flow loss over this section was 1.1 m^3/s = 3960 m^3/hr, implying the loss of 26 mm/hr from the open surface area.

From Chapter 2, we see that potential evapotranspiration in early May is around 140 mm per month; we could thus suppose that daytime evapotranspiration is approximately 0.375 mm/hr. Thus, we can conclude that direct evaporation from the river surface is unlikely to be adequate to account for the flow loss over the surveyed distance.

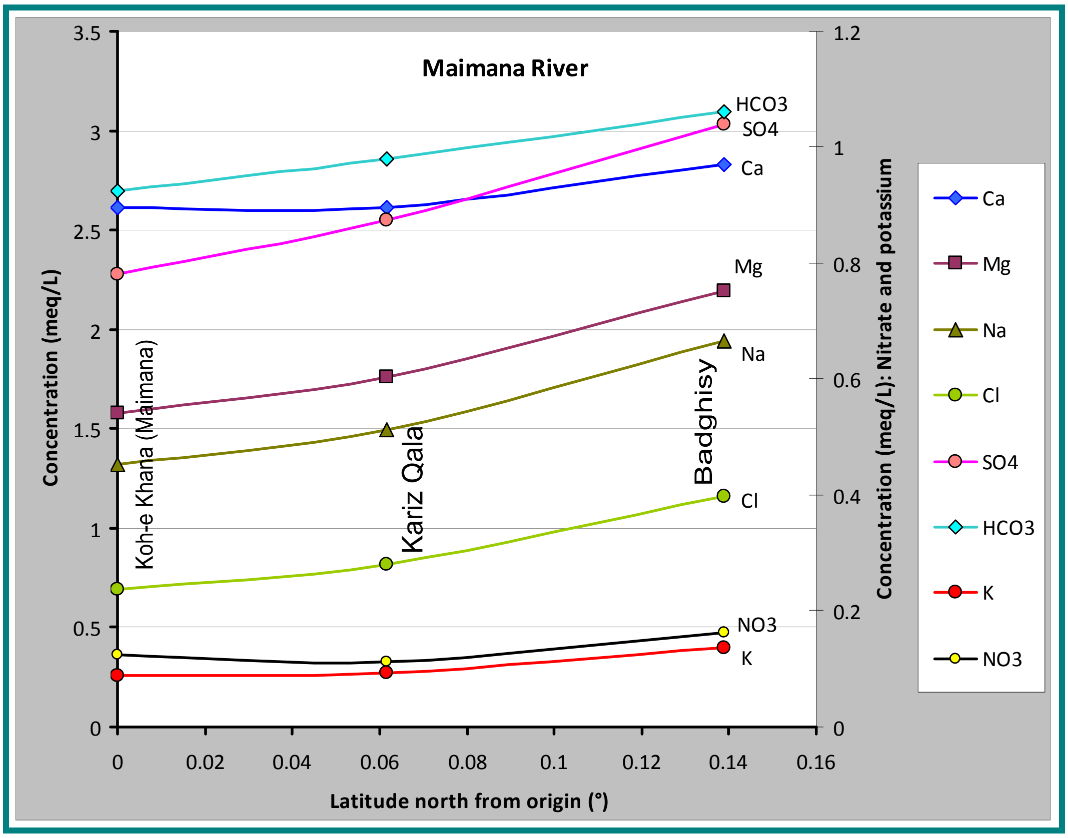


Figure 3.10b. Change in major ion concentrations (meq/L) along the surveyed length of the Maimana River on 1st May 2013. Samples analysed at British Geological Survey, Keyworth, UK.

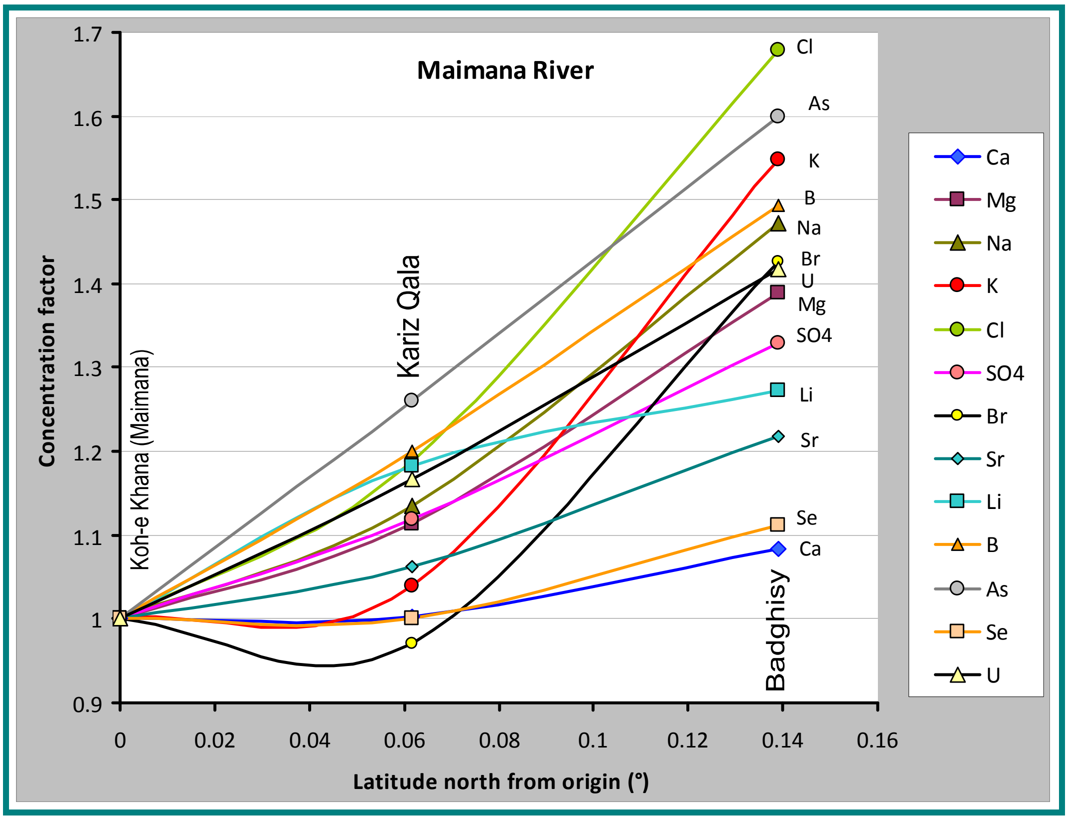


Figure 3.10c. Upconcentration of selected solutes (relative to Koh-e Khana) along the surveyed length of the Maimana River on 1st May 2013.

Stable isotopes of oxygen and hydrogen were also analysed at the NERC facility at the British Geological Survey and they show (Figure 3.10d) a steady enrichment in heavier isotopes downstream, indicative of evaporative fractionation. The isotopic values plot in the same area as rainfall in Figure 2.8.

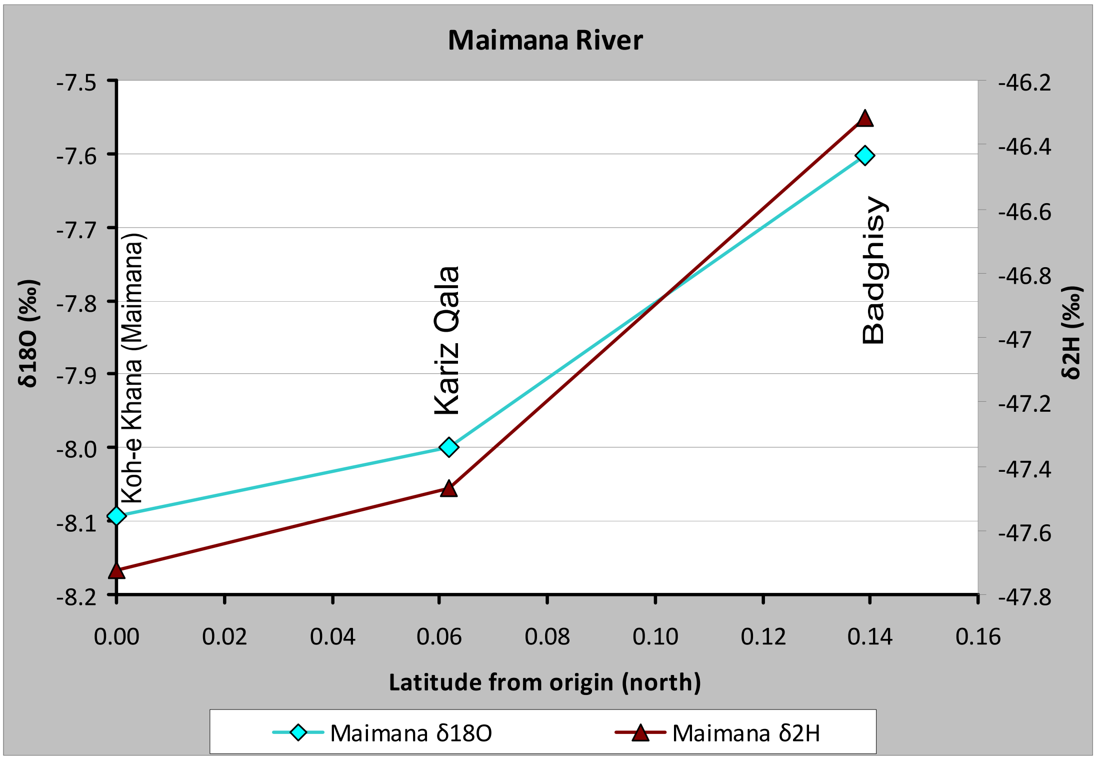


Figure 3.10d. Change in stable isotopic signature along the surveyed length of the Maimana River on 1st May 2013. Samples analysed at the NERC isotope facility at the British Geological Survey, Keyworth, UK.

3.7 The 2013 Shirin Tagab River Survey

On 11th-12th May 2013, a stretch of the Shirin Tagab River was surveyed between Yangi Qala and Char Shengo, representing a linear distance of c. 43 km and a river distance of c. 70 km. Flow, electrical conductivity, pH and temperature were taken at 9 stations along this length (Figure 3.9), while chemical and isotopic samples, filtered at 0.45 µm, were taken at 5 stations and sent to the British Geological Survey, Keyworth, UK for analysis (see NORPLAN 2014 for methods).

The river temperature varied between 16 and 18°C over the course of the survey, with 17°C being typical. The field pH was relatively constant at 8.4-8.5 upstream of Araba, and 8.1 to 8.2 downstream of Araba.

Along the surveyed stretch, the highly saline Astana River enters the Shirin Tagab just upstream of Islam Qala: it has no significant mitigating effect on the loss of flow in the Shirin Tagab, but *may* contribute to the step up in electrical conductivity at Islam Qala (Figure 3.11a).

Along the surveyed length, the flow rate (as estimated by impeller profile gauging) dropped from 1.9 L/s to 1 L/s between Yangi Qala and Baloch, while the electrical conductivity rose by a factor of 2.3 from 697 top 1605 µS/cm. The fact that the salinity increase exceeds the flow loss factor could be due to the saline input from the Astana area.

Just upstream of Araba, almost the entire flow of the Shirin Tagab is taken off into a major irrigation channel, leaving the natural channel of the Shirin Tagab effectively dry. The chemical and isotopic signature dips at Araba.

Downstream of Araba, the flow in the Shirin Tagab re-accretes: it is speculated that this is due to infiltration of irrigation water (i.e. the water taken off upstream of Araba) to the ground and thence discharging to the river. The flow rate does not reach its pre-Araba rate, however, with only 0.5 m^3/s being recorded at Kohna Bazar.

Salinity is re-acquired (irrigation water having been evapoconcentrated in the soil zone, and possibly also having picked up solutes from minerals in the unsaturated zone and aquifer), exceeding 2000 µS/cm in the lowermost stretches of the surveyed section

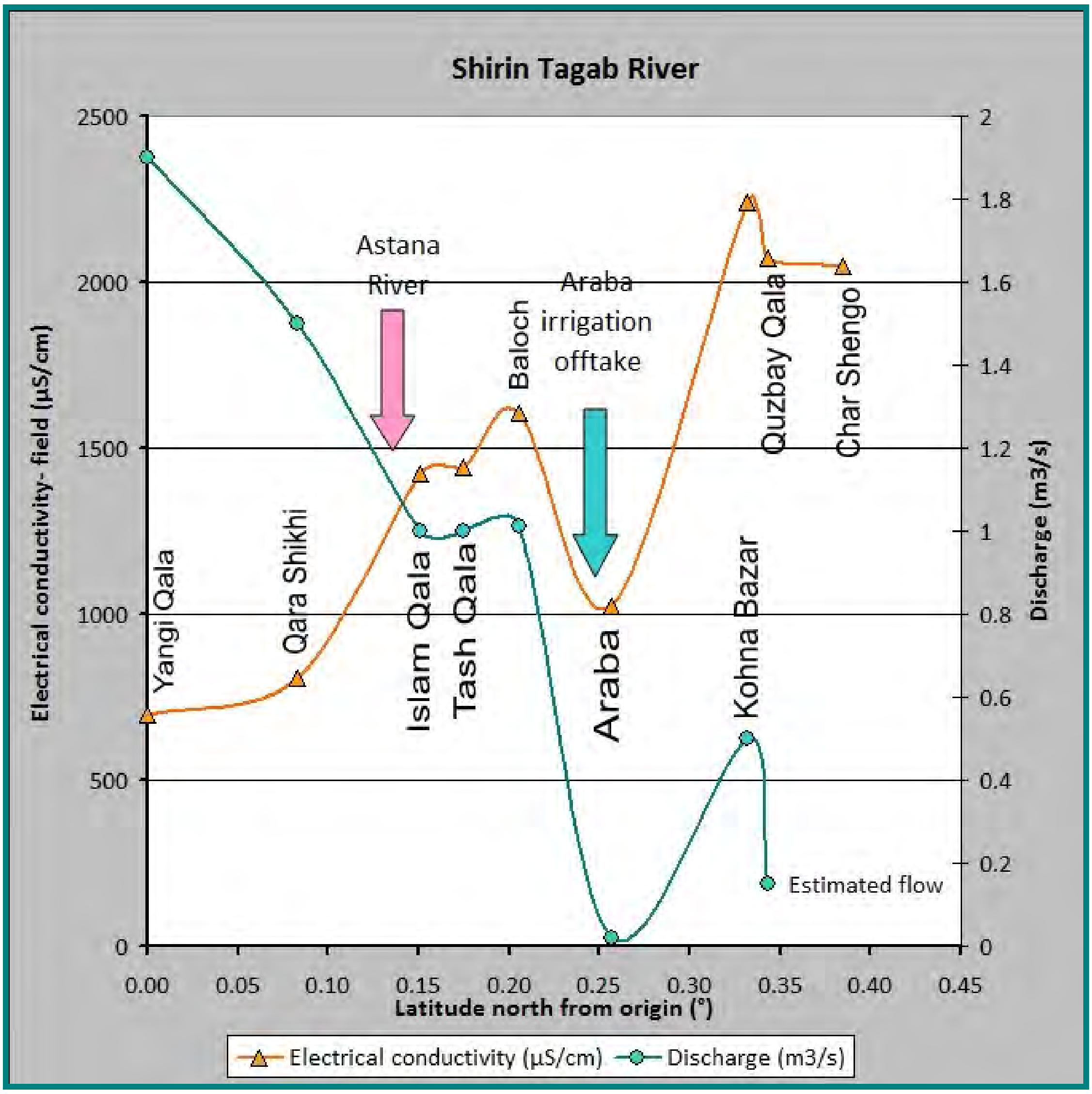


Figure 3.11a. Change in electrical conductivity and flow rate along the surveyed length of the Shirin Tagab River on 11th-12th May 2013.

At Yangi Khana, the river contained around 8.7 mg/L nitrate (as NO_3^-) which increases to c. 20 mg/L by Islam Qala and downstream. Total phosphorus is <0.01 mg/L along the entire surveyed length.

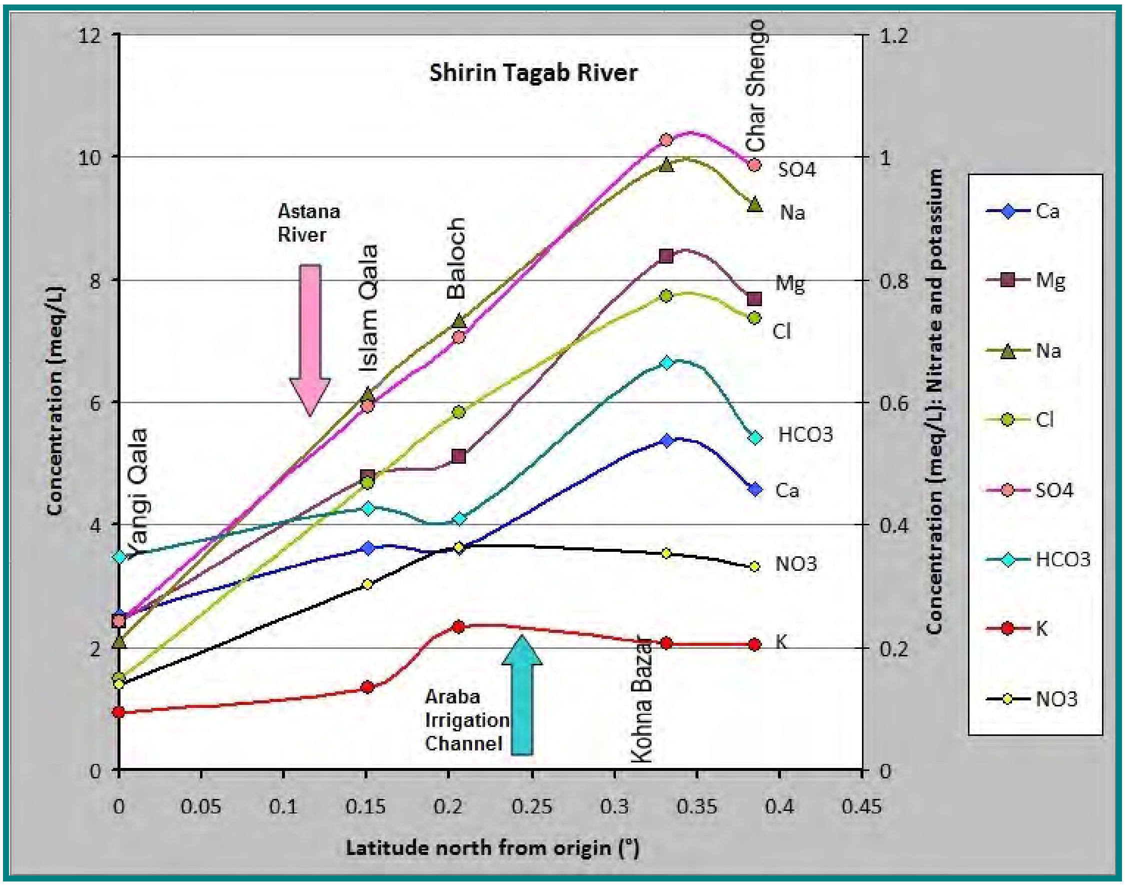


Figure 3.11b. Change in major ion concentrations (meq/L) along the surveyed length of the Maimana River on 11th-12th May 2013. Samples analysed at British Geological Survey, Keyworth, UK.

At Yangi Qala, the water chemistry is dominated by a Ca-(Na)-HCO_3^- composition. Downstream, concentrations of $SO_4^=$, Na, Mg and Cl^- increase rapidly and in parallel, whereas concentrations of Ca and HCO_3^- increase relatively slowly. Downstream, therefore, the water rapidly becomes dominated by Na and $SO_4^=$, with subsidiary Mg and Cl^-. It should be noted that this increase cannot be ascribed to simple dissolution of gypsum and halite, otherwise one would expect similar concentrations of Na and Cl and the increases in the ions would be unlikely to parallel each other. The parallel increases in soluble ion concentrations bear the signature of evaporative concentration, with increases in calcium and bicarbonate possibly being suppressed by calcite saturation.

Different solutes were concentrated downstream at different rates, however, with calcium and bicarbonate accumulating relatively slowly, and solutes such as chloride, (followed by sodium, bromide and sulphate), which can be regarded as relatively conservative, accumulating by a factor of some 3-4 by Baloch and 4-5 by K.ohna Bazar and Char Shengo (Figure 3.11c).

The fact that the maximum solute up-concentration factor is similar, though slightly greater than, the flow loss factor (1.9 to Baloch, c. 4 to Kohna Bazar) suggests that evaporation is a significant driving force for loss of flow (abstraction and infiltration may also be factors in flow depletion).

If the channel is on average 4 m wide and 34.1 km long between Yangi Qala and Baloch, the river stretch has a surface area of at least 136,400 m^2 (and probably more, given that narrow, straight sections were specifically chosen for gauging). The total flow loss over the Yangi Qala - Charshengo section was 0.9 m^3/s = 3240 m^3/hr, implying the loss of 23.8 mm/hr from the open surface area.

From Chapter 2, we see that average potential evapotranspiration in early May is around 150 mm per month at Maimana and 180 mm in Andkhoi; we could thus suppose that daytime evapotranspiration is approximately 0.44 mm/hr in the Shirin Tagab area. Thus, we can conclude that direct evaporation from the river surface is unlikely to be adequate to account for the flow loss over the surveyed distance.

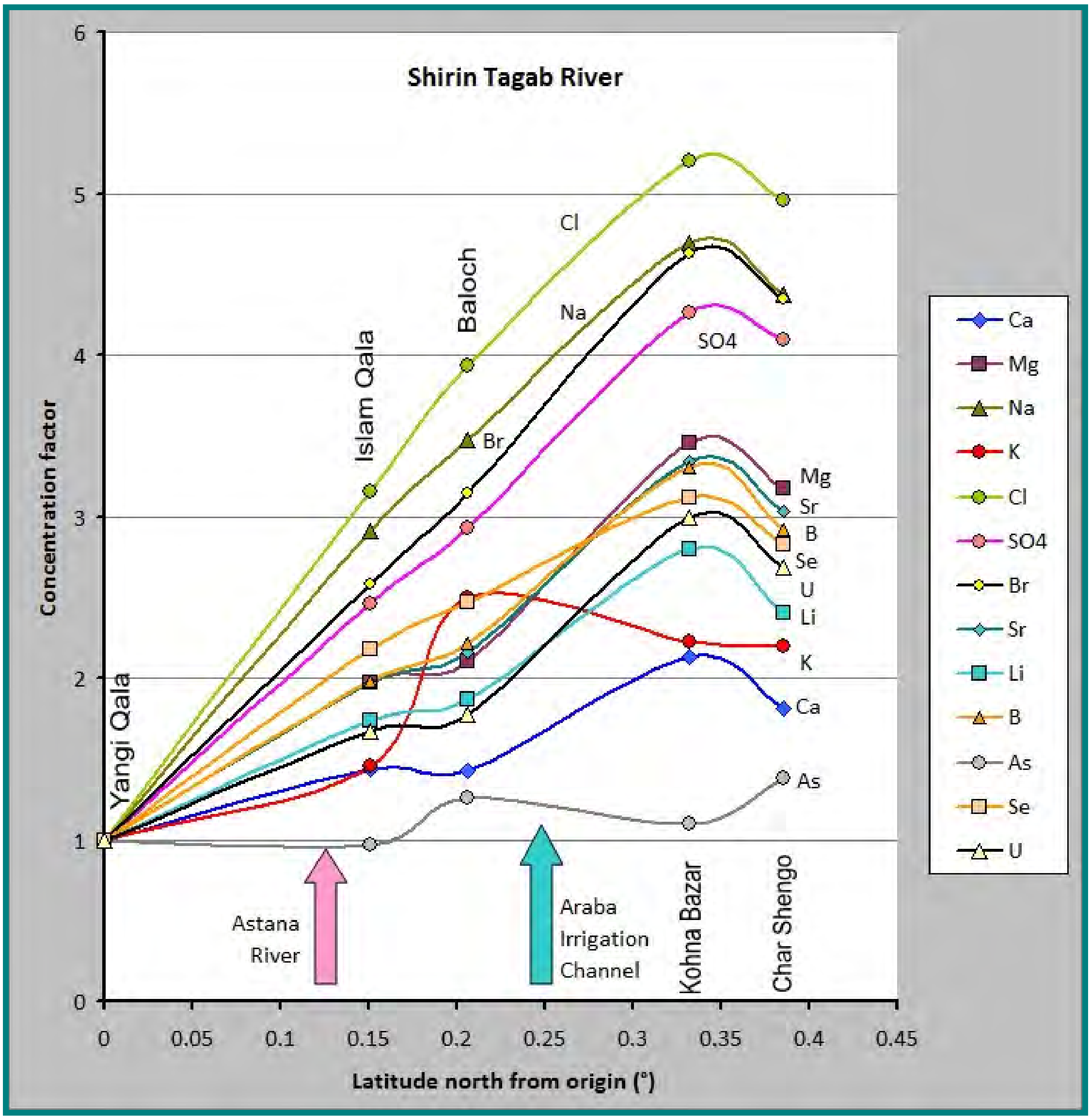


Figure 3.11c. Up-concentration of selected solutes (relative to Yangi Qala) along the surveyed length of the Maimana River on 11th-12th May 2013.

Stable isotopes of oxygen and hydrogen were also analysed at the NERC facility at the British Geological Survey. The isotopic values plot in the same area as rainfall in Figure 2.8. The isotopic values show (Figure 3.11d) a steady enrichment in heavier isotopes downstream in the reaches of flow depletion, from Yangi Qala to Baloch and from Kohna Bazar to Char Shengo, indicative of evaporative fractionation. In the zone of flow accretion, however, from Araba to Kohna Bazar, the isotopic values fall: this is presumably due to the river being fed with groundwater baseflow with a lighter isotopic signature. The reason that such groundwater has a lighter signature may be that it was recharged to the ground in upstream reaches of the river, during times of snowmelt (lighter signature, see Figure 2.8).

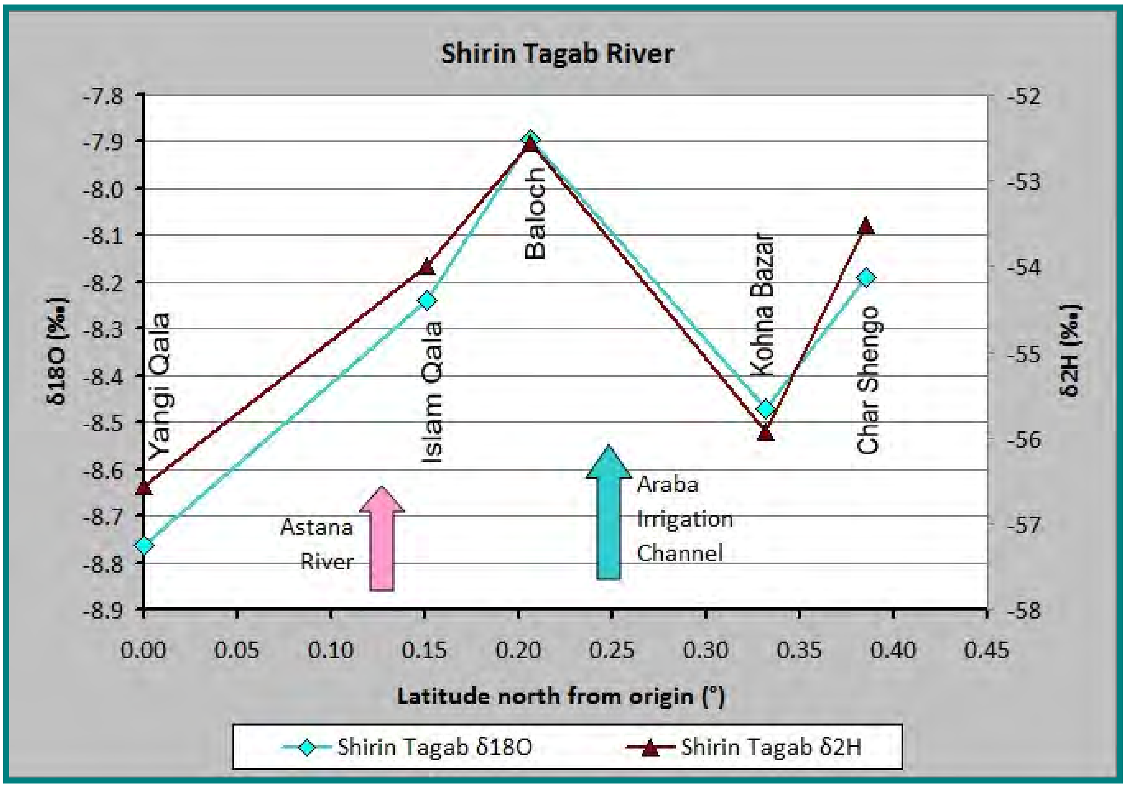


Figure 3.11d. Change in stable isotopic signature along the surveyed length of the Maimana River on 11th-12th May 2013. Samples analysed at the NERC isotope facility at the British Geological Survey, Keyworth, UK.

3.8 Summary: 2103 River Survey

The two River Surveys of 2013 reveal that, along the surveyed reaches, flows typically decrease downstream, with concentrations of solutes increasing. The fact that the solute up-concentration factors approximately mirror the flow loss factors strongly suggests that evapotranspiration is a major driving factor in this process. The steady enrichment of river waters in heavy stable isotopes is also strongly indicative of evaporative processes.

However, it would appear that direct evaporation from the river surface is inadequate to explain the flow loss. In fact, for both the Shirin Tagab and Maimana sections, around 50 times more surface area than appears to be available, would be required to result in the observed losses in flow due to open water evaporation. Even allowing for the fact that river widths measured at gauging stations may under-represent the average river width (as narrow, straight sections were preferentially chosen for gauging), we need to acknowledge that:

(i) abstraction and use for irrigation, and

(ii) river bed infiltration to groundwater

probably also contribute to loss in flow.

However, mechanism (i) could, in some circumstances be regarded as an evapotranspirative up-concentration mechanism. Water abstracted from the river is used to irrigate riparian crops: plants and soils efficiently lose water via evapotranspiration, but most non-nutrient solutes remain in the residual water, which either infiltrates to the soil. We will see in Chapter that, along these river reaches, the alluvial sand and gravel aquifer beneath the river valleys is effectively separated from the surafce via a layer of silty clay. This, infiltrating irrigation water may not reach the

deeper sand and gravel aquifer, but may discharge as shallow groundwater or interflow, back to the rivers, via natural seepages, field drains or ditches. The net result is loss of river discharge (abstraction and evapotranspiration), proportionate up-concentration of solutes and an effectively increased (additional areas of riparian irrigated land) for evaporative processes.

In the Shirin Tagab , just upstream of Araba, almost the entire flow of the Shirin Tagab is led off into an irrigation channel to water the land SE of Dawlatabad. We assume that the same evapo-concentrative processes occur in this irrigated land on a much larger scale. Eventually, the residual infiltrating water from the fields returns to the Shirin Tagab River and flow re-accretes (but never to pre-Araba levels) and with an increased load of solutes.

3.9 The Kelif Uzboy and the ancient course of the Amu Darya

The existence of enormous fresh groundwater resources in the Nubian sandstones below the Sahara Desert has drawn hydrogeologists' attention to the possibility that groundwater recharge could have taken place many thousands of years ago (during pluvial periods in the Pleistocene or early Holocene), bequeathing usable groundwater resources, even in terrains that are arid or brackish according to today's standards.

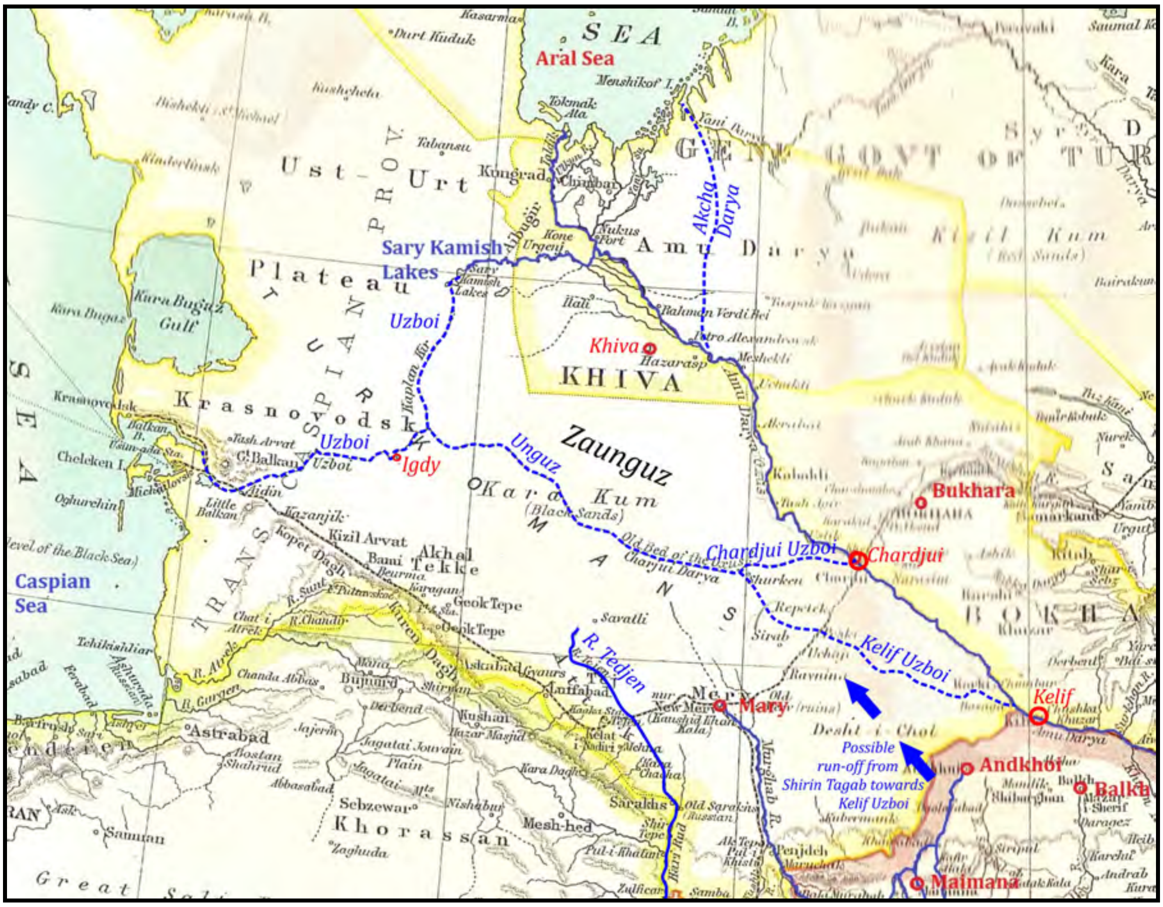


Figure 3.12. A map of Central Asia, showing the supposed former course of the Amu Darya (the Kelif Uzboi) and the borders of the Russian imperial territories of Khiva, Bukhara and Kokand around the time of 1902-1903. Source: http://en.wikipedia.org/wiki/Emirate_of_Bukhara. Believed to be public domain.

If we allow that, during such pluvial episodes, the river discharge in Faryab would have been greater and river water quality fresher, it seems reasonable that recharge of fresh groundwater resources might also have been greater, either by direct recharge

mechanisms or by increased infiltration of fresh river water in valleys, including river channels that are dry today.

The Aral Sea, the Sary Kamysh and the Unguz and the Uzbois

The Amu Darya, together with the Syr Darya, feeds the current inland Aral Sea. In large part, due to over-abstraction of the two rivers, the flows reaching the Aral Sea have decreased dramatically in recent decades, leading to a catastrophic desiccation of the Aral Sea (Zavialov 2005).

The palaeogeography of the Aral / Amu Darya system has long been a source of tremendous interest and controversy, because the system is associated with a number of apparent palaeochannels, which are largely inactive today. Amongst these are (Figure 3.12):

- The **Akcha Darya** channel: a minor palaeochannel system of the Amu Darya, by which water entered the Aral Sea slightly to the east of the recent main course.
- The **Sary Kamysh lakes**. These are a string of saline lakes to the south-west of the Aral Sea and have historically been fed by waters from the Amu Darya in a number of episodes. Up to the 15th-16th centuries AD, some of the Amu Darya's flow continued to the Sary Kamysh saline lakes and, at times of high flow, overspilled into the Western Uzboi and thence towards the Caspian (Aladin et al. 2005, Pravilova 2008). Even after, the 16th century some of the channels between the Amu Darya and the Sary Kamysh lakes were maintained as irrigation channels. Breckle & Geldyeva (2012) note that the Sary Kamysh Lakes and the Aral Sea represent two terminal receptors for the Amu Darya flow and that, in historical times, the Amu Darya rather often changed its outflow between the two. The reasons for this alternation may have been natural, but many authors have suggested that irrigation / damming projects by the Central Asian civilizations may also have been important in determining flow distributions.
- The (**Western) Uzboi,** a (now largely dry) palaeochannel running from Sary Kamysh, through the desert town of Igdy, to the Caspian Sea (Aladin et al. 2005, Létolle et al. 2007, Zonn et al. 2010). This channel was historically regarded as a major, and partly navigable, watercourse, carrying excess water (ultimately from the Amu Darya) from the Sary Kamysh depression. It thus provided an outlet for the Amu Darya's waters to the Caspian sea.
- The **Unguz** has the appearance of a palaeochannel crossing the Karakum towards the Caspian Sea, meeting the Western Uzboi just upstream of Igdy. It appears that it may have been linked to other apparent palaeochannels (the **Kelif Uzboi** or **Chardjui Uzboi**) further east. It has been widely speculated that these channels represent a former southern course of the Amu Darya, departing the current course near the towns of Kelif or Chardjui (respectively) and conveying the flow of the Amu Darya directly to the Caspian Sea.

The Unguz / Kelif Uzboi

Within various literature sources, it is widely (but, by no means, universally - see Boroffka 2010) claimed that the Amu Darya formerly left its current channel near Kelif (or possibly Chardjui), to cross the Karakum desert in a desiccated valley (supposed palaeochannel), referred to as the **Kelif Uzboi** (or Chardjui Uzboi) or **Unguz**, which joined the Western Uzboi upstream of Igdy and discharged to the Caspian Sea.

Fyedorovich (1979) states that the central and southern Karakum desert is composed of the alluvial deposits of the ancient Amu Darya and those of the deltas of the Murghab

and Tedzhen. The **Unguz** *consists of a chain of hollows up to 15 km long and 1–4 km wide, with flat bottoms of solonchak or takyr (*Great Soviet Encyclopedia 1979 - entry for Unguz), running along the northern margin of the central Karakum, at the foot of the scarp (40-80 m high) of the elevated Zaunguz Karakum plateau to the north. [Fyedorovich suggests that the northern Zaunguz plateau itself is composed of Miocene and Pliocene sedimentary rocks, laid down by an earlier palaeo-Amu Darya]. The Great Soviet Encyclopedia (1979) believes that the Unguz is a palaeochannel of the former Amu Darya, and that some of its hollows are filled in sands from the river and later *deformed by tectonic movements and subjected to denudation.*

It is thus widely accepted that the palaeo-Amu Darya traversed the central Karakum in Neogene and Pleistocene times. However, the "myth" of the Kelif Uzboi as a more recent channel for the Amu Darya seems remarkably tenacious. The rumour of the Amu Darya discharging into the Caspian seems to have its route in some very hazy Greek geography by Herodotus, Strabo and Patrocles (Tarn 1901), which not only appears to confuse the Aral with the Caspian, but also introduces the nebulous River *Ochus* (easily confused with the *Oxus* - Olbrycht 2010), which might plausibly be construed an alternative southern course of the Amu Darya to the Caspian (Rawlinson 1879). Such rumours persisted for many centuries. Indeed, on the wall of the Doge's Palace in Venice, there is a 17th Century map showing the Amu Darya discharging to the Caspian rather than the Aral Sea. The ideas were kept alive by Russian and English adventurers and geographers such as Baron Aleksander V. Kaulbars, Arthur Conolly, General Mikhail N. Annenkoff and Sir Henry Creswicke Rawlinson (1879).

In 1714, Peter the Great was taken with the idea of turning the Amu Darya from its course to the Aral into its former (Sary Kamysh - Western Uzboi) course to the Caspian, and ordered an expedition to investigate this possibility (thus creating a waterway from Moscow to India). Eventually, the Russians convinced themselves that the Amu Darya had been deliberately diverted away from its old course via the Sary Kamysh lakes by the Turkmen nations (Zonn et al. 2010). In 1879, the Grand Duke Nikolaj Konstantinovich organized an expedition to survey the entire Amu Darya basin. By summer of that year, a group had arrived at the (then Bokhara-controlled) fortress on the Amu Darya at Kelif (just north of Faryab). A Turkmen guide (one Geldygog) informed the party that, close by, near the Afghan village of Aladat, a former channel of the Amu Darya (termed the "Shor") branched off the left bank of the Amu Darya and continued across the desert towards the Caspian Sea. Thus grew the myth of the **Kelif Uzboi** or **Chardjui Uzboi** as a recent southern course of the Amu Darya - possibly with a basis Pleistocene geological reality, but partly wishful thinking on the part of Russian adventurers!

The Recent Geological History of the Amu Darya / Aral Sea

The complex early Quaternary history of the Aral Sea is documented by Breckle & Geldyeva (2012) and its later history by Boomer et al. (2009) and Boroffka (2010). Boomer et al. (2000) probably provide the best overall overview of the evolution of the system, upon which the following is largely based:

- the Aral / Sary Kamysh depression was formed in the late Neogene, some 3 million years ago (Boomer et al. 2000). The Aral Sea may first have become water-filled by overflow from the Caspian Sea some 2-3 million years ago.
- During the latest Neogene (Pliocene) and early Pleistocene, the Amu Darya probably traversed the area known as the **Zaunguz Karakum** (between its modern course and the Unguz) towards the Caspian Sea, laying down broad expanses of sandy / clayey sediments. It is these sediments which, today, underlie the Zaunguz plateau (see above, and Fyedorovich 1979).

- Somewhere in the middle of the early Pleistocene, the Amu Darya's course shifted south to the *Nizmenie (Lower) Karakum*, i.e. to the area occupied by the apparent Kelif Uzboi / Unguz palaeochannel. The Amu Darya thus flowed towards the Caspian Sea and laid down the geological sequence of sediments known to Soviet geologists as the Karakumskaya Suite (sand, clay and carbonate muds). In this period, the Murghab and Tedjen Rivers would have been left-bank tributaries of the Amu Darya.
- Sometime during the late Pleistocene, the course of the Amu Darya began to migrate northwards towards its current channel, possibly in response to a gradual uplift and doming of the Karakum (Lyberis & Mering 2000). It may also have been in response to an increase in the flow and erosive power of the River (related to changes in climate or uplift patterns in the Pamir). The Unguz may thus have been one of the most recent Pleistocene palaeochannels in the area.
- During large parts of the Pleistocene, the Aral would likely have been dry for protracted periods.
- At the end of the late Pleistocene, or early Holocene, the course of the Amu Darya turned north and began to fill the Sary Kamysh depression and the Aral Sea. Fyedorovich (1979) suggests that the Amu Darya left the Karakum depression (the Unguz) some 20-30,000 years BP. Other authors place the filling of the Aral Sea at a later date (17,000 to 9,000 years BP; Zavialov 2005). Boomer et al. (2000) place the final diversion of the Amu Darya away from the Caspian towards the Aral / Sarykamysh / Khorezm Basin (the so-called "Great Aral Sea") at the onset of the Lavlakansky Pluvial period around 9000 years BP.
- During the warmer climate of 5000-7000 years BP, the Amu Darya's increased flow passed both into the Aral Sea (possibly via the Akcha Darya channel) and via the Sary Kamysh and Western Uzboi to the Caspian Sea. Fyedorovich (1979), Zavialov (2005) and Breckle & Geldyeva (2012) concur that the Amu Darya began to overflow from the Sary Kamysh lakes to the Caspian via the Western Uzboi in the early to mid Holocene (Fyedorovich suggests somewhere in the 5th-2nd millennia BC). Boroffka (2010) suggests that the Sary Kamysh / Western Uzboi route may have been active earlier than this, however.
- Up to the 15th-16th centuries AD, some of the Amu Darya flow continued to the Sary Kamysh lakes and, at times of high flow, overspilled into the Western Uzboi and thence towards the Caspian (Aladin et al. 2005, Pravilova 2008). During this period, the flow of the river was partially managed by the Khorezm civilization for irrigation. In 1558, an English merchant, Anthony Jenkins, observed that:

  > *`..the water that serveth all the country is drawn by ditches out of the river Oxus unto the great destruction of the said river, for which it falleth not into the Caspian Sea as it hath done in times past, and in short time all that land is like to be destroyed, and to become a wilderness for want of water, when the river Oxus shall fail."* (cited in Boomer et al. 2000).

- Even after, the 16th century some of the channels between the Amu Darya and the Sary Kamysh lakes were maintained as irrigation channels. In 1878, a major flood on the Amu Darya broke through to the Sary Kamysh, and re-filled the lakes.

<u>So: What is the Kelif Uzboi / Unguz ?</u>

Although many authors regard the Unguz as a former channel of the Amu Darya in the Pleistocene and even late Neogene (e.g. Lyberis & Mering 2000), there is not a complete consensus. Aladin et al. (2005) state that there is no trace of any flow of the Amu Darya

along the Kelif or Chardjui "Daryas" during the past five centuries. Furthermore, their assessment of the Unguz suggests that the "channel" shows no obvious traces of fluvatile activity and may be a wind-erosional feature.

According to Pravilova (2009) and Zonn (2014), the Kelif Uzboi was not (at least in the recent past) a southern channel for the Amu Darya, but rather an intermittent channel accepting discharge from the northern Afghan Rivers (such as the Balkh, Shirin Tagab and Sar-e Pol) at times of excessive flow. Indeed, Berg (1950) records that, in 1907, water from the rivers of northern Afghanistan penetrated into the Kelif Uzboy.

Of Etymological Interest

The name ***Shirin Tagab*** means *sweet water*.

Murghab means *River of the Birds*. In Greek it is believed to have been *Margiana*.

Amu Darya means the *River of Amul* (the city of Amul is the modern city of Türkmenabat, in Turkmenistan). In Greek the river was called the *Oxos* (Latin *Oxus*; Sanskrit *Vaksu*) and the plain between it and the mountains (including northern Faryab) was called *Oxiana*.

Shor Darya means *salty river* - a very apt description.

The Turkic name ***Unguz*** is believed to refer to an *old dry river bed* - see http://en.wikipedia.org/wiki/User:Yeniler/Hazar.

The ***Kelif Uzboi*** was believed to be the former channel of the River Amu Darya that diverged from the current channel near the town of Kelif and followed the initial line of the Lenin Canal, through Zeid and the Unguz towards the Caspian Sea. There is no evidence that the Amu Darya followed this course in historic times, and is based on a misunderstanding (see text).

Safed Koh means *White Mountains*, while ***Band-e-Turkestan*** refers to this range forming the *boundary wall to Turkestan*.

Figure 3.13. Surface water hydrology; Faryab Province

4

4. Faryab: Geology

4.1 Tectonic Overview

The geology of Afghanistan is dominated by the Mesozoic (Cimmeride) and Tertiary (Himalayan - Alpine) orogenic episodes that have given the nation its mountainous core and which have controlled recent sedimentary deposition in the adjacent areas.

During the late Permian, a number of tectonic plate fragments (micro-plates) broke away from the southern "super-continent" of Gondwanaland (Figure 4.1). One of these, the Afghan micro-plate, collided with the Eurasian continental plate in the Mesozoic. This "Cimmeride" (also loosely referred to as "Hercynian") orogenic episode commenced around the late Triassic and was complete by the Jurassic / Early Cretaceous (200-150 million years ago). The Cimmeride orogeny created the Paropamisus / Band-e Turkestan mountains, to the south of Faryab (Whitney 2006)

Around the Early Cretaceous, the Indian plate disengaged from Gondwanaland and subsequently collided with the Eurasian plate in the Palaeogene (late Palaeocene, early Eocene) resulting in further orogenesis, crustal thickening and crustal displacement (broadly referred to as the so-called Himalayan orogenic episode). South of the Harirud fault, the remnant of the Afghan micro-plate (the Afghan Block) has been (and is still being) squeezed south-westward at rates in excess of 1 cm/year by this crustal shortening (Whitney 2006).

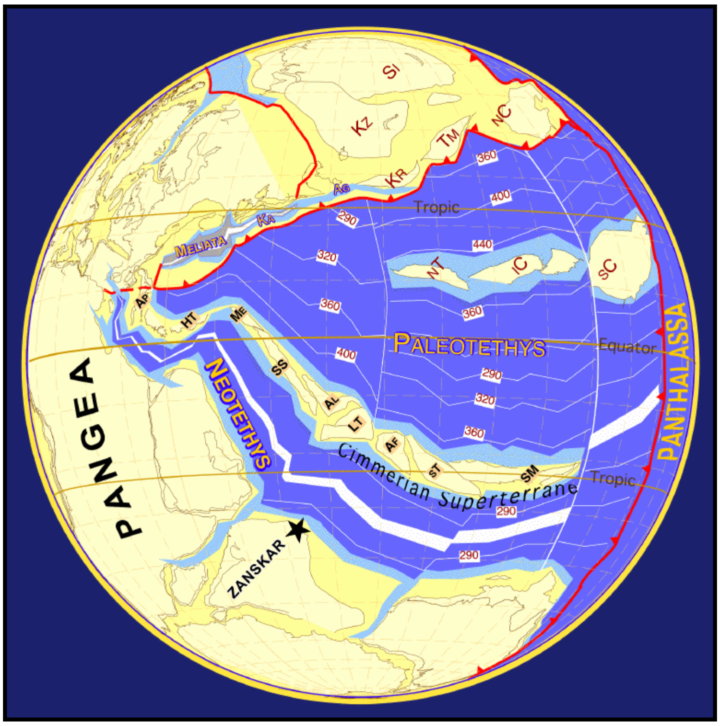


Figure 4.1. Plate tectonic reconstruction of the Himalayan region at 249 million years ago (late Permian / early Triassic). The Cimmerian superterrane, including the Afghanistan micro-plate (AF) is seen approaching Eurasia across the closing Palaeotethys Ocean. After Dèzes (1999); Available at http://en.wikipedia.org/wiki/Cimmerian_Orogeny.

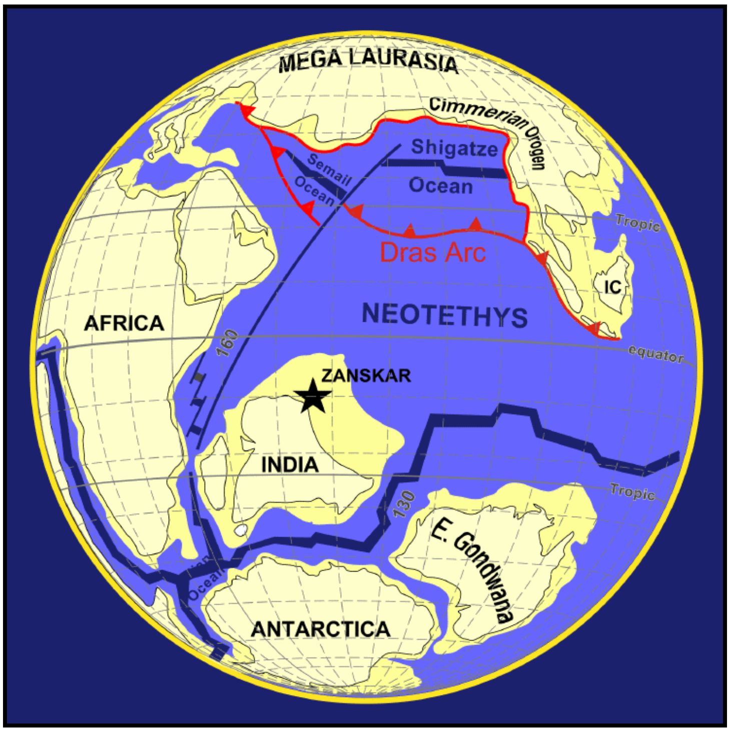


Figure 4.2. Plate tectonic reconstruction of the Himalayan region at 100 million years ago. The area of the Cimmeride orogen (now complete) is seen, as is the approaching Indian plate across the closing Neotethys Ocean. After Dèzes (1999); Available at http://en.wikipedia.org/wiki/Cimmerian_Orogeny.

The North Afghanistan Platform, on which Faryab is located, is thus an area of Cimmeride (pre-Jurassic) deformation. The Cretaceous and Palaeogene rocks are generally marine limestone and clastic sequences deposited in shallow basins. These uplifted during the Alpine / Himalayan orogenic episode. The huge thicknesses of Neogene and Quaternary sediments in the northern part of Faryab are the erosional result of the most recent (Himalayan) episode of uplift and mountain-building.

4.2 The North Afghanistan Platform

Faryab sits upon the *North Afghanistan platform* - an area including and to the north of the Band-e Turkestan mountain chain. The platform thus represents the extreme southern edge of the former Eurasian plate.

Tectonic Structure

The Platform is typically divided into two distinct areas:

- the southern Paropamisus-Band-e Turkestan ***Uplift*** area
- the northern Murghab-Upper Amu Darya ***Basin***, which is the main, subsiding sedimentary basin accumulating Neogene and Quaternary deposits.

These two features seem to have acquired their tectonic character (uplift and subsidence, respectively) during and after the Himalayan-Alpine orogeny, although it is acknowledged as possible that they may have evolved as uplifted or down-warped structures during Jurassic-Palaeogene times.

The Paropamisus-Band-e Turkestan Uplift area is subdivided into three distinct fault blocks, stepping down towards the north into the Murghab-Upper Amu Darya Basin. These are:

- The Qala-e Naw Fault Block

- The Maimana fault block and
- The Shebergan fault block.

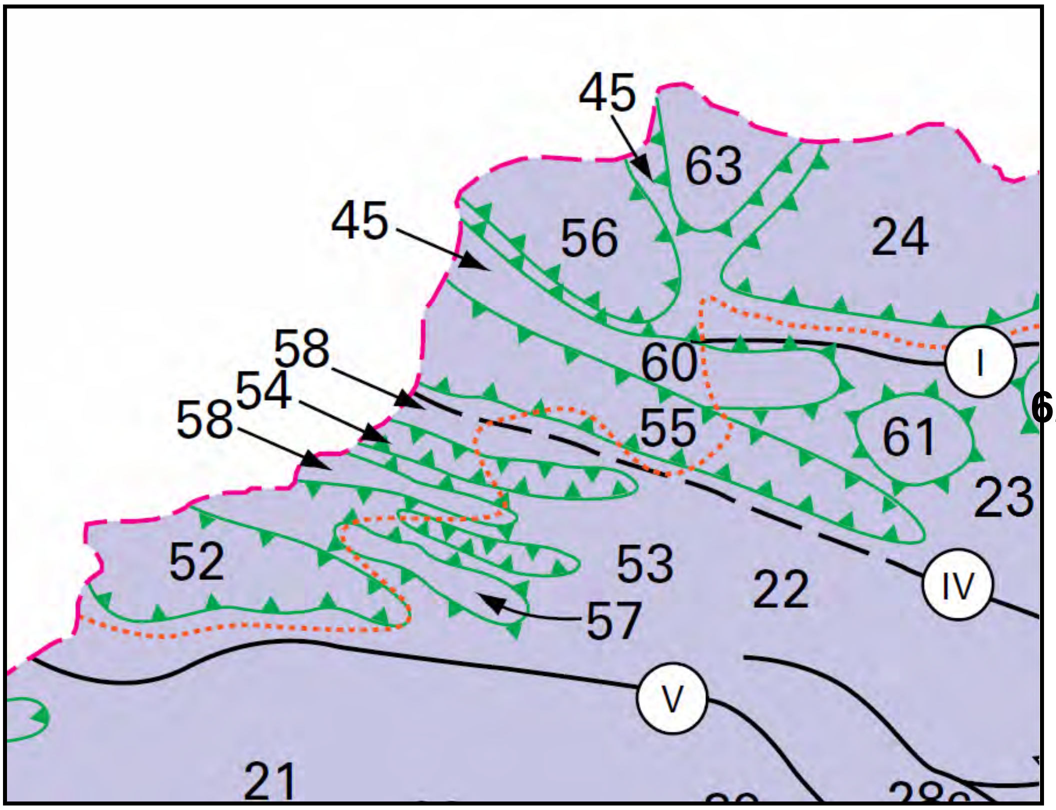


Figure 4.3. Tectonic map of the North Afghanistan Platform in the region of Faryab, after Abdullah & Chmyriov (2008), not believed to be copyrighted. The red dashed line shows the edges of the Murghab - Upper Amu-Darya Neogene-Quaternary basin. The green lines show areas of Alpine uplift or subsidence within the Cimmeride platform area.
Paropamisus-Band-e Turkestan Uplift: *21 - Qala-i Naw fault block; 22 - Maimana fault block; 23- Shebergan fault block; 61 - Sheram arch; 62 - Shadian arch.*
Afghanistan-South Turkmenistan Basin. *24 - Surkhan (Mazar-e Sharif) megasyncline.* Troughs: *52-Qala-i-Mor-Kaisar troughs, 53-Almar trough, 54- Ortepin trough, 55- North Karabil - Dawlatabad trough, 56- Obruchev trough.* Ramparts: *57 - Jekdalek, 58 - Khwaja Qol, 59 - Qara-Qol, 60 - Andkhoi, 63- Pericline of South-West Gissar.*
Neogene-Quaternary Basins: *45-Murghab - Upper Amu Darya*
Major Faults: *I - Alburz-Mormul; IV - Andarab-Mirza Wolang; V - Band-e Turkestan.* The *Band e-Turkestan Fault is approximately vertical and about 400 km long, separating the Qala-i Naw and Maimana fault blocks. It appears to be a right- lateral fault.*

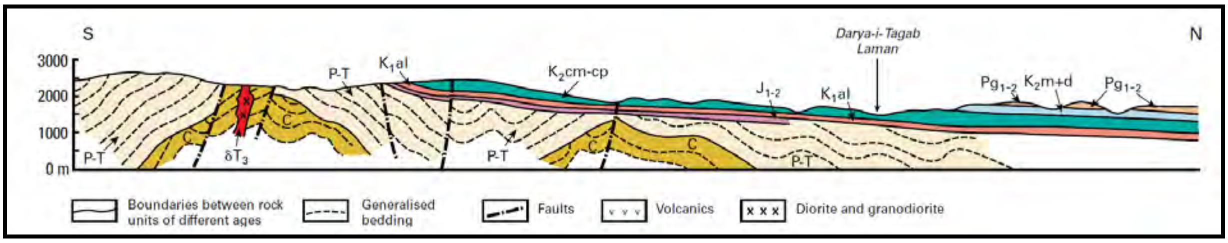


Figure 4.4. North-south cross section through the southern North Afghanistan Platform along the Darya-e Tagab Laman River, near Qala-e Naw, Badghis, after Abdullah & Chmyriov (2008a), not believed to be copyrighted. Note the relatively flat-lying Jurassic-Palaeogene sedimentary rocks sitting upon the folded Cimmeride basement.

Summary of Stratigraphy

According to Brookfield & Hashmat (2001), the stratigraphy of the North Afghanistan Platform can be roughly divided into three:

- Pre-Jurassic (pre-Cimmeride) folded basement of Palaeozoic to Triassic age.
- A post-Cimmeride, Jurassic to Palaeogene sequence of sedimentary rocks and some volcanic rocks, unconformably overlying the basement. These sedimentary rocks are relatively flat-lying, but show large scale flexure and deformation related to the Himalayan-Alpine orogeny.
- A syn- and post-Himalayan orogenic, Neogene to Quaternary continental clastic sequence.

The Jurassic-Palaeogene can be subdivided into four units:

1. A Late Triassic to Middle Jurassic rift succession, dominated by coarse, continental, coal-bearing clastics, laid down by braided and meandering streams in linear, rifting-related grabens.
2. Mid-Upper Jurassic mixed continental-marine clastic and carbonates, overlain by a regressive Upper Kimmeridgian–Tithonian evaporite-bearing sequence.
3. Lower Cretaceous red-beds and evaporites (unconformably overlying the Jurassic), succeeded by a transgressive sequence of Cenomanian to Maastrichtian shallow marine limestones.
4. Palaeocene to Eocene marine limestones with gypsum, succeeded by thin conglomerates and brackish-marine Upper Oligocene / Lower Miocene shales.

Information Sources

The most recent geological maps of Faryab are those provided by the Afghan Geological Survey, assisted by the U.S. Geological Survey, although these are largely based on the mapping of earlier Afghan and Soviet geologists. The sheets covering Faryab are published by:

- McKinney & Sawyer (2005), covering the southern part of Faryab: Maimana, the Band-e Turkestan, Kohistan, Almar, Qaysar and Gurziwan.
- McKinney & Lidke (2005), covering the extreme east of he study area, including Ghormach.
- Wahl (2005), covering the northern part of Faryab, including Shirin Tagab, Dawlatabad and Andkhoi.

The British Geological Survey has also re-published the two volumes of the Geology of Afghanistan by Abdullah & Chmyriov (2008a,b). Originally written in Russian and published by Nedra in Moscow, the volumes reflect the Soviet unwillingness to fully embrace modern plate tectonic theory, but nevertheless remain an extremely comprehensive and systematic source work.

The following is largely derived from the sources mentioned above (and especially Dronov's 2008b overview).

4.3 Pre-Cimmerian Rocks in Faryab and the North Afghanistan Platform

At depth, the North Afghanistan Platform comprises a folded Palaeozoic-Triassic basement that was intruded by granites (not exposed in Faryab) during the last stages of the subduction of the Palaeotethys Ocean (BGS 2014). In Faryab, the Cimmerian

basement is most prominently exposed in the fault-bounded, horst-like Band-e Turkestan range. The units mapped in Faryab include:

C_2ls Late Carboniferous: dominated by limestones, with subordinate clastic sedimentary rocks (slates, sandstones, conglomerates, siltstones) and volcanic rocks (andesites, basalts).

Pssl Permian: dominated by red and variegated sandstones and siltstones, with subordinate conglomerates and mudstones.

T_1ssc Early Triassic: dominated by variegated marine sandstones and conglomerates, with subordinate chert and volcanic rocks (rhyolite, basalt).

T_{23}ssl Middle-Late Triassic sedimentary complex: dominated by marine sandstones and siltstones, with subordinate carbonaceous shales, mudstones, limestones, marls conglomerates, acidic and mafic volcanics. The late Triassic terrigenous deposits have been described as flysch.

4.4 Jurassic-Palaeogene Rocks in Faryab and the North Afghanistan Platform

The Cimmeride orogeny was largely complete in the Faryab area by the Jurassic. Following the orogeny, the mountain chain was eroded and peneplained. The northern part of the North Afghanistan Platform thus started subsiding and accumulating sediments.

Jurassic

Early to Middle Jurassic: Initially, erosion of the Cimmeride mountain chain produced a sequence of Jurassic clastic sediments on the new Cimmeride basement. The early-mid Jurassic clastic sequence contains some coal lenses and layers and is known to reach 100-1450 m in thickness, known as the **Sayghan Series.**

Middle to Upper Jurassic: Towards the end of the Middle Jurassic (167 Ma BP), conditions changed in the northern part of the platform, with marine carbonate sequences becoming predominant (Bathonian - Oxfordian). The carbonates are an important hydrocarbon reservoir rock and are referred to as the **Kugitang** or **Gissar Formation.**

Upper Jurassic: In the Upper Jurassic (Kimmeridgian-Tithonian), terrigenous red-bed (conglomerate, sandstone, siltstone) and evaporites again became predominant. One especially thick evaporite sequence forms the cap rock for the Middle-Upper Jurassic hydrocarbon reservoirs and is referred to as the **Gaurdak Salt Formation** (includes anhydrite, halite and some sylvite, Ulmishek 2004)**.** The Gaurdak salt generally increases in thickness to the north and pinches out to the south of Andkhoi (Figure 4.7).

The Jurassic strata are not exposed to any extent in Faryab, but are known at depth from drilled boreholes and are known to produce significant quantities of geothermal groundwater.

Cretaceous

Late Jurassic terrigenous clastic deposition continued into the Cretaceous.

K_1ssc Early Cretaceous: In Faryab, the early Cretaceous is represented largely by red sandstones and conglomerates, with less abundant siltstones, gypsum evaporites and clays. Near the Paropamisus-Band-e Turkestan Uplift in the south, the deposits are coarser-grained and of a terrestrial nature. To the north, in the Murghab-Upper Amu Darya Depression, the sediments are finer, with some marine layers and lenses within the terrigenous sequence. The deposits can reach 1000 m in thickness.

The Hauterivian (Lower Cretaceous) sandstones of the Qezeltash Formation are an important hydrocarbon reservoir rock. Figure 4.5 shows structural contours on the top of the Qezeltash sandstone formation in Faryab.

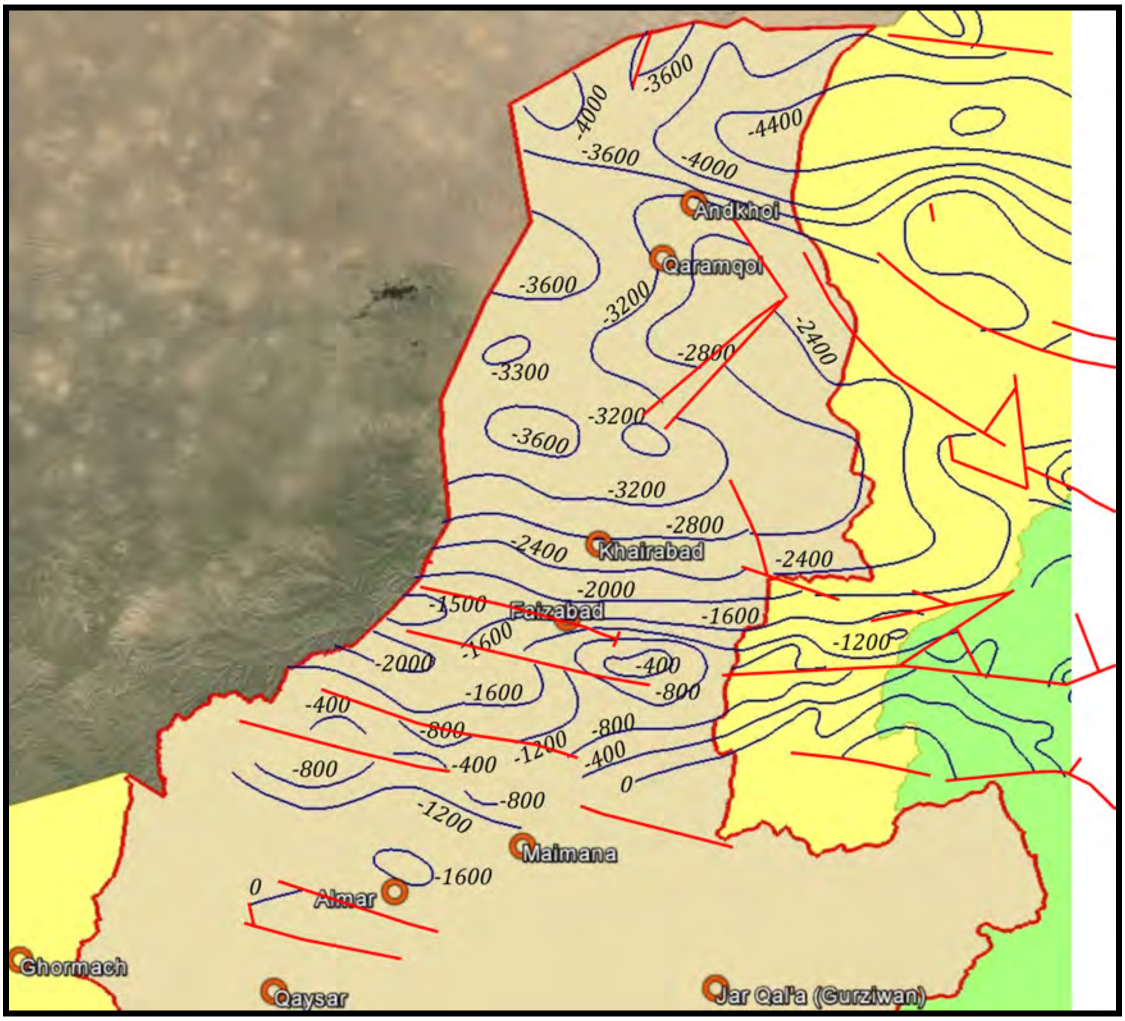


Figure 4.5. Structure contours on the top of the Hauterivian Qezeltash sandstone formation in m relative to sea level in Faryab. Based on data of Steinshouer et al. (2006). See also http://pubs.usgs.gov/of/2006/1179/metadata/qezeldpafg.htm. Red lines show faults transposed from Ghory Formation map of Klett et al. (2006).

Towards the end of the Early Cretaceous, marine conditions started transgressing from the north, with a finer grained, mainly clastic sequence accumulating in shallow marine basins, with the sediment supply coming from the Paropamisus-Band-e Turkestan Uplift.

K_2ssl Late Cretaceous clastic facies: In Faryab, the late Cretaceous is represented largely by shallow marine sandstones and siltstones, with less abundant clays, limestones, marls, conglomerates and gypsum evaporites.

From the start of the Cenomanian (start of the Late Cretaceous) onwards, marine carbonate facies start appearing, especially in the north and south-east of the area. By the end of the Cretaceous (Campanian-Maastrichtian), the marine transgression of the North Afghanistan Platform is almost complete, and marine platform deposits of limestone/dolomite sediments predominate. This deposition continued until the Palaeogene. The Maastrichtian-Palaeocene in the southern (Paropamisus-Band-e Turkestan) part of the platform is dominated by a carbonate reef facies, which can reach

up to 777 m thick. In the north, in the Murghab-Upper Amu Darya Depression, the deposits are more terrigenous in nature, with no reef facies and up to 600 m thick.

KP_1ld Late Cretaceous and Palaeocene carbonate facies (often referred to as the Ghory Formation): Deposits of marine limestones, marls and dolomites, with less abundant sandstones, clays, siltstones, gypsum, and conglomerates. The Ghory formation is some 150-170 m thick on the Maimana Step (Klett et al. 2006).

The Ghory Formation is a hydrocarbon reservoir rock in some areas, capped by Eocene mudstones. Figure 4.6 shows structural contours on the top of the Upper Campanian to Palaeocene Ghory formation in Faryab.

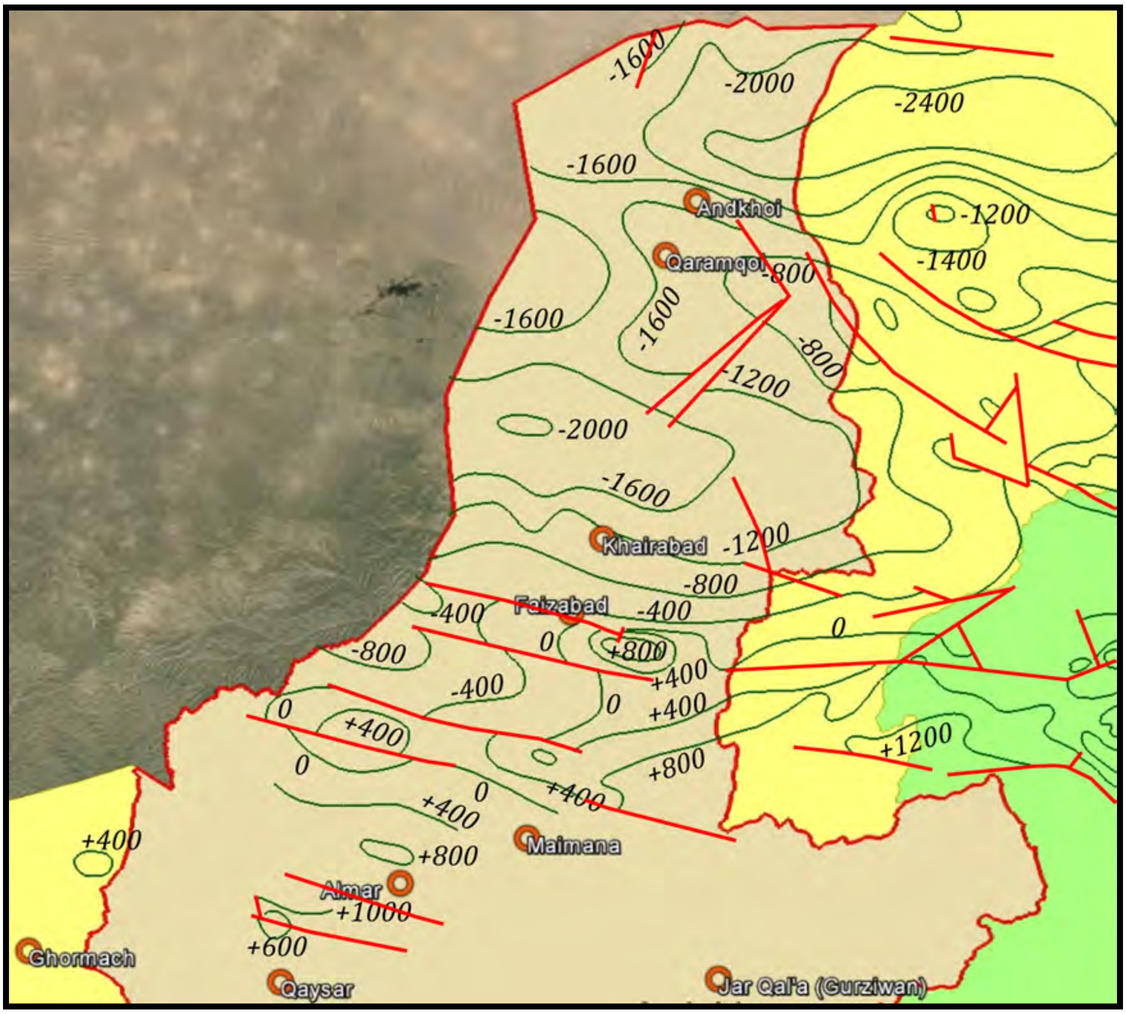


Figure 4.6. Structure contours on the top of the Campanian-Palaeocene Ghory carbonate formation in m relative to sea level in Faryab. Based Steinshouer et al. (2006). See also http://pubs.usgs.gov/of/2006/1179/metadata/ghorydpafg.htm. Red lines show faults (after Klett et al. 2006).

Palaeogene

KP_1ld Late Cretaceous and Palaeocene: see above.

During the Eocene, sedimentation was more dominated by terrigenous, fine clastic material, up to 800 m thick, in a marine basin.

P_2csh Eocene: In Faryab, Eocene deposits of clay, shale and siltstone are observed, with less abundant sandstone, limestone, marl, gypsum and conglomerate.

In the Eocene and Oligocene, some volcanic deposits are recorded from the North Afghanistan Platform, although these are not specifically mapped in Faryab.

4.5 Neogene and Quaternary Rocks in Faryab and the North Afghanistan Platform

The final stages of subduction of the Neotethys Ocean, as the Indian plate converged on the Afghan plate, took place in the Cretaceous and Tertiary, with volcanic activity further south and some intrusion of Oligocene/Miocene granites as far north as north-eastern Afghanistan. The Himalayan - Alpine orogenesis culminated in the late Palaeogene, early Neogene.

The focus of the Himalayan - Alpine orogeny was further south in Afghanistan than Faryab: nevertheless, the effects were felt in the North Afghanistan Platform area as an uplift of the southern part of the platform, commencing towards the end of the Eocene. Thus, Oligocene deposits are essentially absent in outcrop. Some Eocene-Oligocene shallow and partly fresh water sediments were deposited in the northern Murghab-Upper Amu Darya Depression.

The Uplift was coupled with dramatic erosion and deposition of Neogene and Quaternary proluvial and alluvial sediments in sedimentary basins to in the northern part of the North Afghanistan Platform, collectively referred to as the Afghanistan-South Turkmenistan Basin (or, in Faryab, as the Murghab-Upper Amu Darya basin).

Neogene

At the culmination of the Himalayan-Alpine orogeny, the Murghab-Upper Amu Darya Depression started subsiding very rapidly relative to the uplifted Paropamisus-Band-e Turkestan area and thus started accumulating vast thicknesses (up to 14,000 m) of predominantly terrigenous sediments. The upper Oligocene to Quaternary succession is probably no greater than 1.5 km thick in the Murghab depression (Figure 4.7) and adjacent areas (Ulmishek 2004, Klett et al. 2006). Within the southern uplifted area, minor, local sedimentary basin structures also developed (see Figure 4.3). The deposits commenced with finer material and coarsened as uplift continued. Adjacent to the main uplifted mountain areas, one might describe these deposits as “molasse”-type proluvial deposits, “dumped” in huge poorly-sorted alluvial fan structures washing out of the uplifted mountain areas.

The main stratal divisions mapped at outcrop in the AGS/USGS maps are:

N_1dig Miocene: in eastern Kohistan, a few small igneous intrusions of diorites, granodiorites and associated igneous rocks are noted.

N_{1l}csl Early Miocene: Predominant red clays and siltstones, with less abundant sandstones, conglomerates and limestones.

N_{1m}csl Middle Miocene: Predominant brown clay and siltstone, with less abundant sandstones, conglomerates and limestones.

Note that the AGS/USGS maps show the outcropping Neogene deposits in Faryab as Miocene, while the description of Abdullah & Chmyriov (2008a) implies that the Quaternary further north may be underlain by a thick Pliocene sequence, overlying the Miocene.

The AGS/USGS maps suggest that the outcropping Neogene deposits of Faryab are predominantly fine grained siltstones and clays. This is likely because the mapped outcrops represent only the **Lower Miocene Shafay Formation** and **Middle Miocene Kashtangi Formation**, both of which are dominated by red-brown finer grained clastics.

Other sources (Table 4.1 and Dronov & Chmyriov 2008) suggest that in large portions of the Neogene sequence, coarser sandstones and conglomerates may predominate. For example, in the **Upper Miocene Rustak Formation**, the **Lower Pliocene Kokcha Formation** and the **Upper Pliocene Keshm Formation**, coarser grained sandstones and conglomerates are more dominant (Dronov 2008a).

The lower Neogene sediments typically contain gypsiferous clays and siltstones and it is anecdotally reported that halite also occurs.

Quaternary

During the Quaternary, the northern Murghab-Upper Amu Darya Depression continued subsiding rapidly relative to the uplifted Paropamisus-Band-e Turkestan area, and alluvial sedimentation continued. As the tectonic situation began to stabilise intermittently, discrete “terrace” levels of alluvial sedimentation could be identified. The thickness of Quaternary sediments can reach several km in the deepest basins of the North Afghanistan Platform.

Q_1a Early Pleistocene alluvium: Predominantly gravels and sands (sometimes lithified), with silts and clays.

Q_2a Middle Pleistocene alluvium: Predominantly gravels and sands (sometimes lithified), with silts and clays. Occurs at high elevations in south of Faryab as a cover deposit overlying Cretaceous / Palaeogene and Neogene deposits. Some GIS data sets map this as late Pleistocene / Holocene Q_{34}t glacial till.

Q_2loe Middle Pleistocene loess: loess (silt) with some sand and clay. Wind-blown loess results from aeolian erosion of the vast alluvial plains during periglacial episodes of the Pleistocene. From published geological maps we must deduce that these can reach several tens of metres thickness.

Q_3a Late Pleistocene alluvium: Predominantly gravels and sands (sometimes lithified), with silts and clays.

Q_{34}e Late Pleistocene / Holocene aeolian sands: Occurs as cover deposits over alluvial plains in the semi-desert area in the north of the region.

Q_{34}a Late Pleistocene / Holocene alluvium: Predominantly gravels and sands (sometimes lithified), with silts and clays. Occurs mainly along modern river channels.

Q_4sm Recent Quaternary salt marsh deposits: Mud, silt, and clay, with some sand, limestone, gypsum and salt. The main salt basins (intermittent saline lakes) in Faryab are the **Khwaja Mod** (gypsum and halite), c. 20 km NNE of Khairabad, and the **Chakan** on the eastern border of Dawlatabad district. As of 1995, halite was being mined for table salt from the Khwaja Mod deposit on a small scale (Orris & Bliss 2002). The northern semi-desert area and the Karakum of Turkmenistan also contain takyrs or solonchaks.

The entire Neogene / Quaternary sequence of the northern Faryab plains and the Karakum of Turkmenistan can be regarded as the ancient proluvial / alluvial / lacustrine deposits of the precursors to the Shirin Tagab, Murghab and palaeo-Amu Darya rivers (see Chapter 3.9 and Fyedorovich 1979).

4.6 Oil and Gas deposits of the North Afghanistan Platform

Oil and gas resources are located in the huge Mesozoic-Tertiary sedimentary basin of northern Afghanistan, which can broadly be subdivided (Klett et al. 2006) into an eastern **Afghan-Tajik Basin** and a western **Murghab-Amu Darya basin**, separated by the **Gissar Mega-anticline** (Figure 4.7). According to Brookfield & Hashmat (2001), the oil and gas traps of the North Afghanistan platform are mainly associated with:

- Upper Jurassic carbonates, sealed by cap rocks of Upper Jurassic evaporite salt (Gaurdak salt formation). The Gaurdak salt generally increases in thickness to the north and pinches out to the south of Andkhoi (Figure 4.7). These evaporites occur at depths of c. 3 to 3.6 km in the North Karabil-Dawlatabad trough and at 4 to 5 km in the Obruchev trough (Klett et al. 2006).
- Lower Cretaceous sandstones, sealed by Aptian–Albian shales and siltstones.
- To a lesser extent, Upper Cretaceous / Palaeocene carbonates, sealed by cap rocks of Palaeogene shales.

The structural traps are typically anticlinal structures related to Neogene wrench faulting, and the hydrocarbon sources are mainly in the Jurassic, mostly the Lower-Middle Jurassic coal-bearing strata.

Tectonic Cycle	Structural Formation Complex	QALA-I-NAW FAULT BLOCK AND WEST MAYMANA FAULT BLOCK	SHEBERGHAN FAULT BLOCK	AFGHANISTAN - SOUTH TADJIKISTAN DEPRESSION
		Formations	Formations	
		Sedimentary and sedimentary-volcanogenic rocks	Sedimentary and sedimentary-volcanogenic rocks	Sedimentary and sedimentary-volcanogenic rocks
Orogenic	Quaternary	Q Grey, terrigenous, terrestrial	Q Grey, terrigenous, terrestrial	Q Grey, terrigenous, terrestrial
	Pliocene	N_2 Variegated to grey, terrigenous, terrestrial 50 - 250m	N_2 ?	N_2 Variegated to grey, terrigenous, terrestrial 9,000m
	Miocene	N_1 Variegated to red, terrigenous, terrestrial 300 - 800m	N_1 Variegated to red, terrigenous, terrestrial 1,100 - 1,550m	N_1 Variegated to red, terrigenous, terrestrial 1,100 - 5,750m
	Eocene - Oligocene	$Pg_{2\text{-}3}$ Terrestrial volcanogenic (porphyry) 250 - 1,400m	$Pg_{2\text{-}3}$?	$Pg_{2\text{-}3}$?
Cratonic	Jurassic - Eocene	Pg_2 Terrigenous 250 - 700m	Pg_2 Terrigenous 400m	Pg_2 Terrigenous 400 - 620m
		$K_2m\text{-}Pg_1$ Carbonate 150 - 1,150m	$K_2m\text{-}Pg_1$ Carbonate 200 - 600m	K_2 Terrigenous-carbonate 150 - 1,700m
		K_2 Carbonate-terrigenous 250 - 500m	K_2 Carbonate-terrigenous 300 - 1,700m	
		K_1 Carbonate-terrigenous 90 - 130m	K_1 Green to variegated (marine in the upper portion, terrestrial in the lower portion) 550 - 850m	K_1 Carbonate-terrigenous (marine in the upper portion, terrestrial in the lower portion) 170 - 850m
		J_3 Terrigenous 800m	J_3 Terrigenous-carbonate and evaporite 700 - 1,150m	J_3 Terrigenous-carbonate and evaporite 250 - 1,150m
		$J_{1\text{-}2}$ Terrigenous (coal-bearing) 60 - 100m	$J_{1\text{-}2}$?	$J_{1\text{-}2}$ Terrigenous (coal-bearing) 1,250 - 1,450m
In superimposed troughs	Triassic	T_3r ?	T_3r ?	T_3r Terrigenous, terrestrial 350m
		$T_{2\text{-}3}$ Dark-coloured, terrigenous, marine 2,200 - 4,000m	$T_{2\text{-}3}$ Dark-coloured, terrigenous, marine 1,100m	$T_{2\text{-}3}$?
		T_1 Variegated volcanogenic-terrigenous, marine 150 - 2,000m	T_1 ?	T_1 ?

Table 4.1. Summary stratigraphic table of the sedimentary sequences on the North Afghanistan Platform. Modified after Annex 15 of Abdullah & Chmyriov (2008a). Not believed to be subject to copyright.

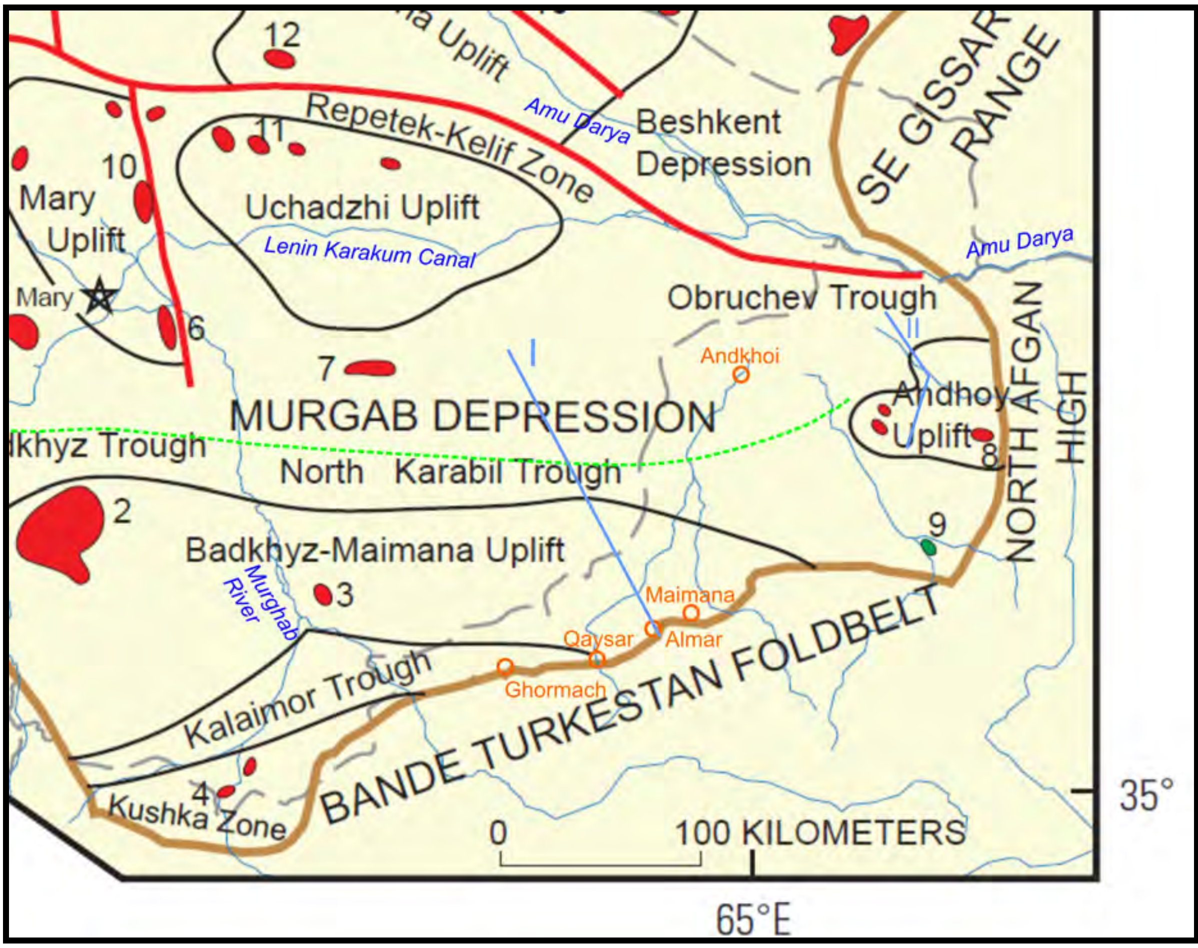


Figure 4.7. Structural map of northern Afghanistan and the Amu Darya basin, showing gas (red) and oil (green) reserves. The boundary of the Murghab-Amu Darya basin is shown as a thick brown line (note that many of the main towns of Faryab - orange circles - lie on the transition from the Band-e Turkestan uplift to the Murghab-Amu Darya depression). 8 = Hodja Gugerdag gas fields, 9 = Angot oil field. The dashed green line shows the pinch-out to the south of the Jurassic Gaurdak Salt Formation. The blueish lines marked I and II show the approximate positions of Figures 4.8 and 4.9. After Ulmishek (2004). *Not believed to be subject to copyright (public domain USGS report).*

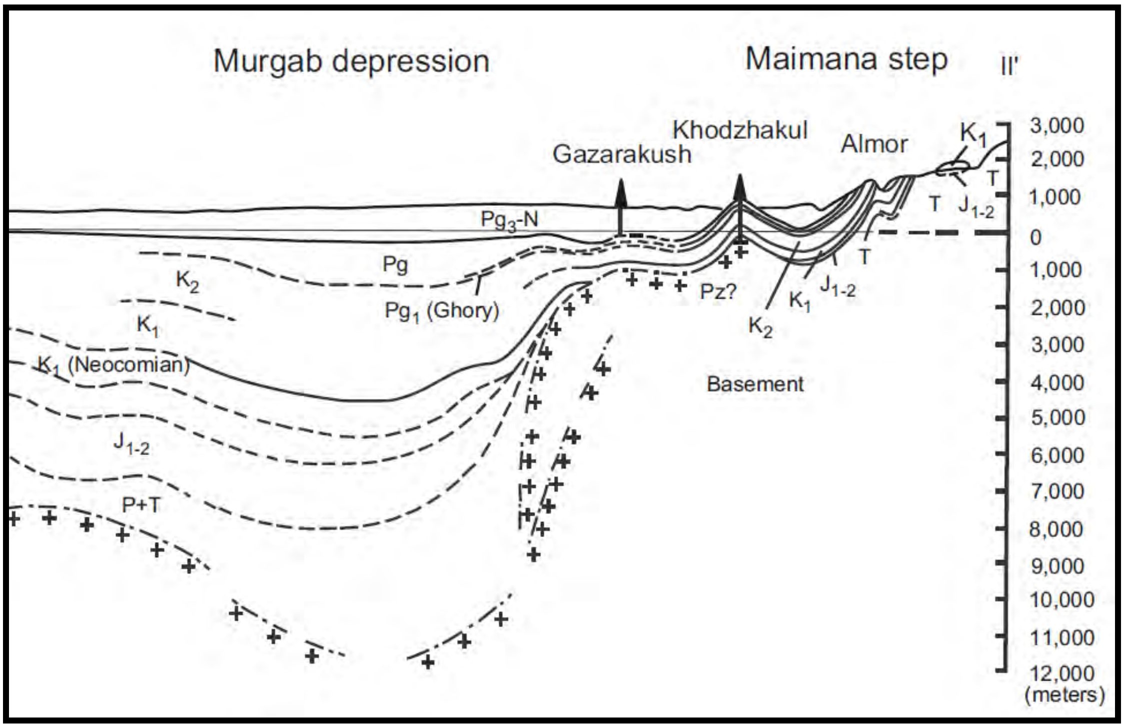


Figure 4.8. Cross-section north-west from Almar (south-east, right) into Turkmenistan (north-west, left). Approximate line of cross-section shown as I on Figure 4.7. After Klett et al. (2006). USGS Public domain report, not believed to be subject to copyright.

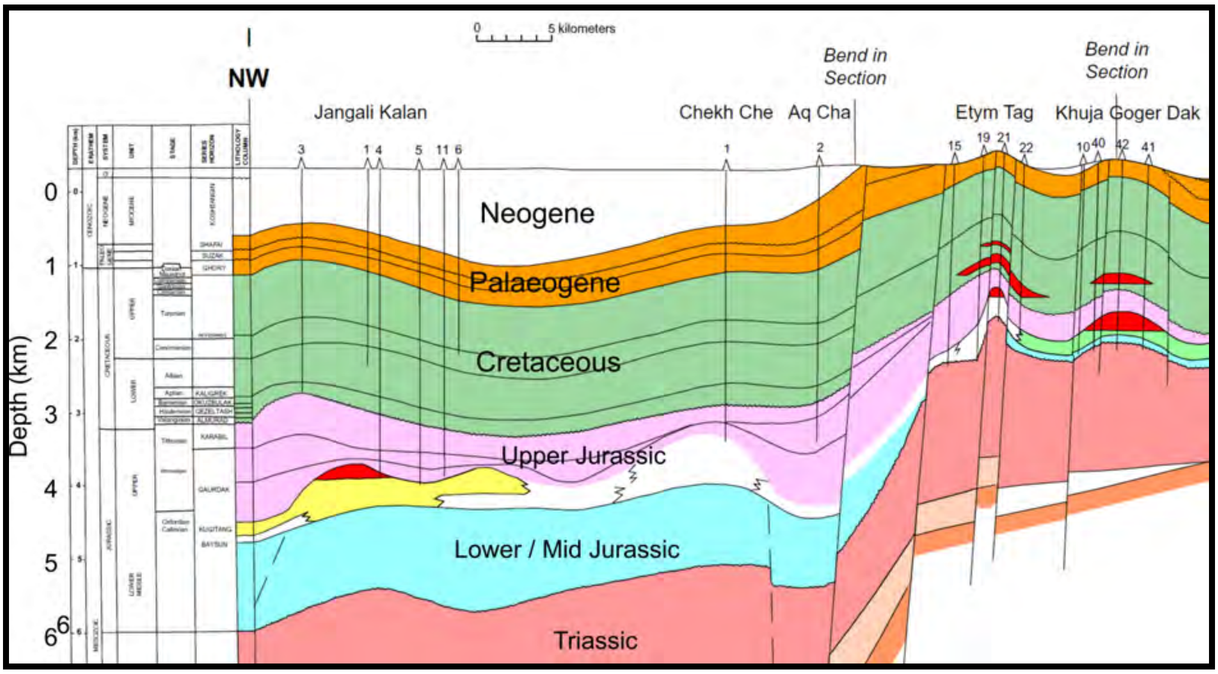


Figure 4.9. Cross-section over the Andkhoi uplift in Jawzjan Province from NW (left) to south (right). Approximate line of cross-section shown as II on Figure 4.7. Modified after Klett et al. (2006). Gas deposits are shown in red. USGS Public domain report, not believed to be subject to copyright.

Of Etymological Interest

The name **Band-e Turkestan** means *Boundary wall of Turkestan*. It is the main mountain range of southern Faryab and runs in a west-east direction for 200 km. According to Iranica Online (2014), the summit level (3,200-3,300 m; highest point 3,481 m) probably represents a pre-Miocene erosional, peneplained surface, which was subsequently uplifted during the Himalayan-Alpine orogeny.

The **Paropamisus** refers to the western part of the Hindu Kush range in Afghanistan (including the Siah Koh, Safed Koh, Chalap Dalan, and Malmand ranges). One possible derivation of the name is that it is from the Sanskrit "Para-Vami" - *the excellent and pure city of Vami (Bamyan).*

Flysch - marine clastic sediments, typically deposited as turbidites in a foreland basin of an incipient continental collision. These are often deformed during orogenesis by thrusting.

Molasse - typically coarser sands, conglomerates and shales eroded from a rapidly-rising mountain chain and deposited in the foreland basin. The molasse deposits thus succeed, and may be deposited on top of, flysch. Molasse is typically terrestrial proluvial, alluvial and occasionally lacustrine or shallow marine in nature.

Proluvium - a Soviet geological term used to describe alluvial fan deposits forming as outwash from mountain massifs. "*Proluvium forms alluvial fans and, where they merge, proluvial trains. The texture of the detrital material changes from pebbles and gravel with fanglomerates at the top of the fan to finer, more highly sorted sediments, frequently loess-like loams and sandy loams (proluvial loesses), at the bottom. Proluvium is most fully developed in the foothills of arid and semiarid regions where aleurite-clay sediments (frequently gypsumized and salinized) from flash floods sometimes form on the periphery of the area of proluvium distribution*". The Great Soviet Encyclopaedia (1978).

Takyr - is a shallow depression in a semi-desert area, with a clayey base, that fills with water when it rains. As the accumulated water evaporates, the clayey surface desiccates and fractured crust is formed, often containing filamentous cyanobacteria. Salinisation may develop at or below the surface, typically of gypsum and halite, as accumulated salts are leached out of the soil and concentrated. A saline takyr is often referred to as a **solonchak** (Berg 1950).

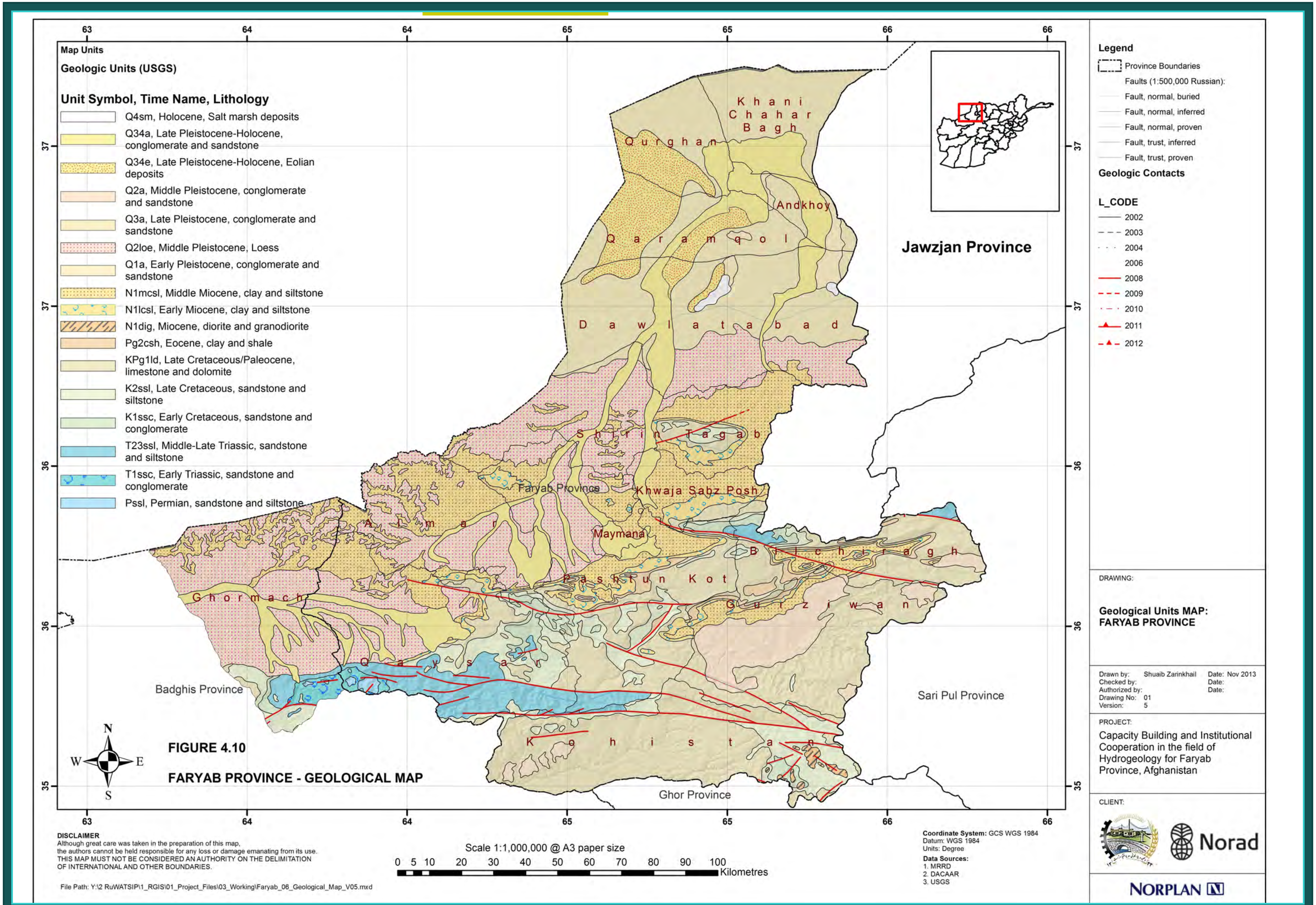


FIGURE 4.10

FARYAB PROVINCE - GEOLOGICAL MAP

5. Faryab: Hydrogeology

5.1 *Previous hydrogeological maps*

A hydrogeological map of Afghanistan was produced in 1977 by Abdullah & Chmyriov (1977a) at a scale of 1:2,000,000. This was accompanied by a map of mineral waters at a scale of 1:2,000,000 (Abdullah & Chmyriov 1977b), and a map of mineral and fresh water springs at a scale of 1:4,000,000 (Abdullah & Chmyriov 1977c).

Prior to this, however, Mishkin (1968) prepared a hydrogeological map of the Quaternary deposits of Northern Afghanistan (Faryab), which was subsequently reproduced in monochrome in Marinova's (1974) "*Hydrogeology of Asia*".

The hydrogeology of areas of Turkmenistan adjacent to Faryab province is discussed and shown in Krizhanovskii (1972).

Most recently, the Chinese Geological Survey (2012) includes the Faryab area in their set of hydrogeological and groundwater resources maps of Asia, broadly compiled according to the Standard International Association of Hydrogeologists' guidelines (Struckmeier & Margat 1995). The Chinese maps are at too coarse a scale to indicate much interesting detail regarding Faryab, however.

5.2 *Overview*

During the course of 2012-2014 an attempt has been made by the NORPLAN project team to register as many as possible groundwater features in Faryab. This has been performed largely by collating all available existing information - the majority being held by DACAAR. This information was supplemented by rapid field surveys carried out in

- Kohistan
- Bilchiragh
- Gurziwan
- Qaysar
- the area around Maimana Airport
- the four northern districts of Andkhoi, Qurgan, Qaramkol and Khani Chahar Bagh.

<u>Springs</u>

Figure 5.1 shows the distribution of registered springs in Faryab. It will be seen that these are especially abundant in the mountainous districts of Kohistan and Gurziwan, where they are largely derived from the late Cretaceous-Palaeogene limestone aquifer. In the mountain areas of southern Faryab, these springs form the backbone of potable water supply and also provide a valuable baseflow contribution to rivers.

<u>Boreholes and Dug Wells</u>

Figure 5.2 shows the distribution of registered drilled boreholes and dug wells in Faryab.

<u>Karezes</u>

It is reported that karezes were formerly used to provide groundwater for irrigation in Faryab (see Chapter 1.3). During the 2012-14 NORPLAN survey, not a single karez was registered in Faryab.

5.3 Aquifers and aquitards of Faryab

Figure 5.xx shows the hydrogeological map that has been produced as a result of this project, broadly according to the standardised hydrogeological legend of Struckmeier & Margat (1995).

The following succession considers the allocation of each stratigraphic units (based on the digitised 1:250,000 USGS maps of McKinney & Sawyer (2005), McKinney & Lidke (2005) and Wahl (2005).

For many stratigraphical units, the real quantified hydrogeological data are extremely sparse and classification has been allocated on the basis of

- anecdotal evidence from Afghan hydrogeologists.
- hydrogeological evaluation of lithological descriptions.
- information provided in literature, especially from the section of Abdullah & Chmyriov (2008b) dealing with the hydrogeology of Northern Afghanistan, which information is used to supplement the descriptions that follow.

Map legend

The standardised hydrogeological legend of Struckmeier & Margat (1995) is broadly followed, in which

- aquitards / non-aquifers are protrayed in an orange-brown colour
- granular (clastic) aquifers are portayed in a blue colour
- fractured or karstic aquifers are portrayed in a green colour.

For the aquifers, the colours become more intense as the productivity of the aquifer increases. Additionally, in the context of this project:

- cover material, overlying other aquifer strata, but which may not be fully saturated themselves, are coloured grey.

It is very important to realise that **the Hydrogeological Map in Figure 5.xx only provides information about aquifer water productivity and not about water quality or salinity**. I.e. a "good" aquifer can produce saline water!

Pre-Cimmeride basement

Carboniferous-Triassic rocks are exposed largely in the Band-e Turkestan and almost no quantified information exists on their aquifer properties.

- **C_2ls** Late Carboniferous limestones, with subordinate clastic sedimentary and volcanic rocks. Presumed to represent a fractured aquifer of weak to moderate productivity. Colour coding - pale green.
- **Pssl** Permian sandstones and siltstones, with subordinate conglomerates and mudstones. Presumed to represent a fractured aquifer of weak to moderate productivity. Colour coding - pale green.
- **T_1ssc** Early Triassic sandstone and conglomerate, with subordinate volcanics. Presumed to represent a fractured aquifer of weak to moderate productivity. Colour coding - pale green.
- **T_{23}ssl** Middle-Late Triassic sedimentary complex. Fractured, complex aquifer system containing many lithologies, dominated by sandstone and siltstone, with subordinate shale, mudstone, limestone, conglomerate, volcanics. Presumed to represent a

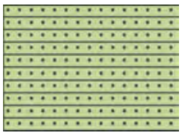
fractured aquifer of weak to moderate productivity. Colour coding - pale green.

Abdullah & Chmyriov (2008b) state that groundwater in the Triassic of the upland areas is limited to sandstones and limestones and springs seldom exceed 1 L/s in discharge. Water is fresh and usually of Ca^{++}-HCO_3^- type (occasionally HCO_3^--$SO_4^=$ or Na^+-$SO_4^=$) Groundwater in the older Palaeozoic strata is broadly of a similar nature.

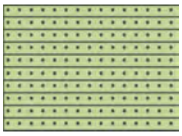
Post-Cimmeride / pre-Himalayan strata

- Jurassic strata are not exposed in outcrop in Faryab and thus are not designated a shading on the hydrogeological map. They do occur at depth beneath the northern portion of Faryab, however, and permeable sandstones and limestones within the sequence can yield substantial thermal water quantities in deep boreholes.

  For example, Abdullah & Chmyriov (2008b) note that "*Jurassic carbonate rocks with confined waters have been drilled through by deep wells on the Bayangor and Koh-i-Alburs structures* [both of these are anticlinal structures, east of Faryab, associated with the Sheram and Shadian arch structures - see Figure 4.3]*, with the flowing well yields of 0.09 L/s and 350 L/s, respectively. The water is of the chloride-sodium type; its dissolved-solids content ranges from 66 to 78 g/l.*"

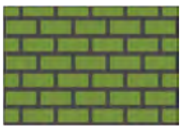


- **K_1ssc** Early Cretaceous sandstone / conglomerate complex. Fractured aquifer capable of supporting moderate spring-flow (may not be perennial). Also occurs at depth below northern part of Faryab province and may provide thermal saline groundwater. Presumed to represent a fractured aquifer of weak to moderate productivity. Colour coding - pale green.



- **K_2ssl** Late Cretaceous sandstone / siltstone complex. Fractured aquifer capable of supporting moderate spring-flow (may not be perennial). Also occurs at depth below northern part of Faryab province and may provide thermal saline groundwater. Presumed to represent a fractured aquifer of weak to moderate productivity. Colour coding - pale green.

  Abdullah & Chmyriov (2008b) confirm that sandstone, conglomerate, limestone and marl strata within the K_1ssc and K_2ssl sequence can function as aquifers, with natural spring discharges in upland areas ranging from several hundredths to 1 L/s and water typically being of calcium-bicarbonate type. As the strata plunge northward beneath later cover, salinity and temperature increases. In the Mazar-e Sharif basin, boreholes can yield substantial quantities of thermal saline water



- **KP_1ld** Upper Cretaceous and Palaeocene limestone, dolomite and marl complex. Karst aquifer capable of supporting large perennial springs, providing significant baseflow to river headwaters. Karstic aquifer of strong productivity. Colour coding - medium green.

  Abdullah & Chmyriov (2008b) confirm that the Upper Cretaceous-Palaeogene limestone forms a good, freshwater karstified aquifer. Springs from this aquifer often yield 0.1 to 7 L/s, with the

possibility of considerably higher yields under favourable conditions. Waters in the upland areas are typically of HCO_3^-, $SO_4^{=}$-HCO_3^--Ca^{++} and Ca^{++}-Na^+ types, with mineralisations of 0.3 to 0.5 g/L. Abdullah & Chmyriov (2008b) caution, however, that in mountain regions, the highly dissected topography can drain the majority of the aquifer thickness, with springs only occurring at the very base of the aquifer against the boundary with underlying lower permeability rocks. In other words, the saturated aquifer thickness in such regions can be low. They state, "*For instance, in the upper reaches of the Maymana, Balkh and Samangan rivers, the limestone forms steep 300-400m high slopes without a single water manifestation, and it is only at the base that springs can be found discharging as much as 3-5 L/s.*"

Abdullah & Chmyriov (2008b) suggest that the Upper Cretaceous-Palaeogene limestone can retain its aquiifer character as it dips northward below the later cover, with substantial yields being recorded from deep wells. The water becomes increasingly saline however (several g/L) and reducing (H_2S).

- **P_2csh** Eocene clays, shales and siltstones. Presumed to behave predominantly as an aquitard. Local groundwater resources may be associated with minor sandstone / conglomerate / limestone horizons. Colour coding - orange.

Post Orogenic Molasse, Alluvium and Igneous Rocks

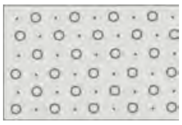
- **N_1dig** Miocene diorites, granodiorites and associated igneous rocks. Presumed to contain local occurrences of groundwater associated with fractures zones. Igneous bodies with local productivity only. Colour coding - pale orange.

- **N_{1l}csl** Neogene (early Miocene) molasse-type deposits. Red clay and siltstone more abundant than sandstone, conglomerate, limestone. Well yields typically <1-3 L/s. Contains lenses of halite / gypsum and groundwater is often saline. Higher yields and fresher water can sometimes be obtained in valley areas. Designated a granular aquifer of weak productivity. Colour coding pale blue.

- **N_{1m}csl** Neogene (Mid Miocene) molasse-type deposits. Brown clay and siltstone more abundant than sandstone, conglomerate, limestone. Well yields typically <1-3 L/s. Contains lenses of halite / gypsum and groundwater is often saline. Higher yields and fresher water can sometimes be obtained in valley areas. Designated a granular aquifer of weak productivity. Colour coding pale blue.

Abdullah & Chmyriov (2008b) appear to confirm that well yields from the Neogene tend to be lower than from recent Quaternary alluvium. They suggest that salinity increases as Neogene aquifers dip northward below the Quaternary cover.

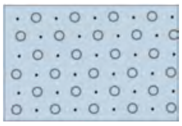
- **Q_1a** Early Pleistocene alluvium. Gravels and sands (sometimes lithified) dominate over silt and clay. Presumed to be less productive than Q_{34}a. Contains predominantly saline water in north of region. Designated a granular aquifer of weak productivity. Colour coding pale blue.



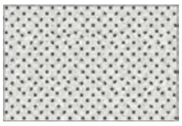
- **Q_2a (?)** Gravels and sands (sometimes lithified) dominate over silt and clay. Occurs at high elevations in south of area as a cover deposit overlying Cretaceous / Palaeogene and Neogene aquifers. It is not known whether it contains saturated portions and if it constitutes an aquifer in its own right. Either **Q_2a** mid-Pleistocene alluvium or **$Q_{34}t$** late-Peistocene-recent glacial till. Designated a granular cover material. Colour coding - pale grey.

- **Q_2loe** Pleistocene loess. Poor aquifer, silty and often yielding saline water. Where saturated, can support small yields from dug wells and is used by nomads in the Shor Darya area. Designated a granular aquifer of very weak productivity. Colour coding very pale blue.

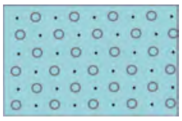
  Of the loess aquifer, Abdullah & Chmyriov (2008b) state that yields of dug wells can be 0.1 to 0.4 L/s, while "*In the Qaysar and Maymana valleys, many ascension springs are observed at the foots of coniform hills built up of loess. Their discharges vary between 0.01 and 6.6 L/s.*" The salinity of loess waters is often very high, however, typically 5-10 g/L, with a range from 0.8 to 20.3 g/L and a sulphate-chloride-sodium-calcium type.



- **Q_3a** Late Pleistocene alluvium. Gravels and sands (sometimes lithified) dominate over silt and clay. Presumed to be less productive than $Q_{34}a$. Contains predominantly saline water in north of region. Designated a granular aquifer of weak productivity. Colour coding pale blue.

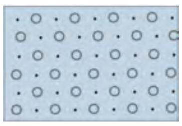


- **$Q_{34}e$** Late Pleistocene-recent aeolian sands. Occurs as cover deposits over alluvial plains in north of region. Not known if aeolian deposits contain saturated portions. Designated a granular cover material. Colour coding - pale grey.



- **$Q_{34}a$** Late Pleistocene-recent Quaternary alluvium south of Pata Baba. Gravels and sands (sometimes lithified) dominate over silt and clay. Coarser grained and more productive south of confluence with Shor Darya. Individual boreholes can produce 10 L/s or more. Here, designated a granular aquifer of moderate productivity. Colour coding medium blue.

  Of this aquifer, Abdullah & Chmyriov (2008b) say, "*The ground water of the Maymana Valley occurs in sand and coarse gravel found at a depth from 3.5 to 67 m. The depth to water table varies between 16.6 and 21.0 m. The specific yield of the wells ranges from 3.5 to 4.0 l/s.".* The water is of a HCO_3^--$SO_4^=$-Na^+-Ca^{++} chemical type, mineralisation 0.7 - 0.9 g/L and temperature 16 - 17°C.



- **$Q_{34}a$** Late Pleistocene-recent Quaternary alluvium north of Pata Baba. Less productive, finer grained and containing saline groundwater towards the north. Here, designated a granular aquifer of weak productivity. Colour coding pale blue.

  Of this aquifer, Abdullah & Chmyriov (2008b) imply that in the northern areas of Shirin Tagab, Darreh-i Siyah and Balkh deltas, groundwater can be found in sand layers with thick clayey-sandy sequences. They state that *"the specific yields* [without quite explaining what a "specific yield" is] *of the wells range from 1.2 to 3.7 L/s; the yield of the dug wells are from 0.1 to 0.7 L/s."* The water

is reported as saline, with mineralisations 3-10 g/L and usually of sodium-sulphate character. Abdullah & Chmyriov (2008b) specifically state that "*Small lenses of sulphate and bicarbonate-sulphate-magnesium-calcium waters having the dissolved solids content from 1 to 3 g/L were tapped near irrigation canals and river channels*".

- **Q_4sm** Recent Quaternary salt marsh deposits. Coloured white.

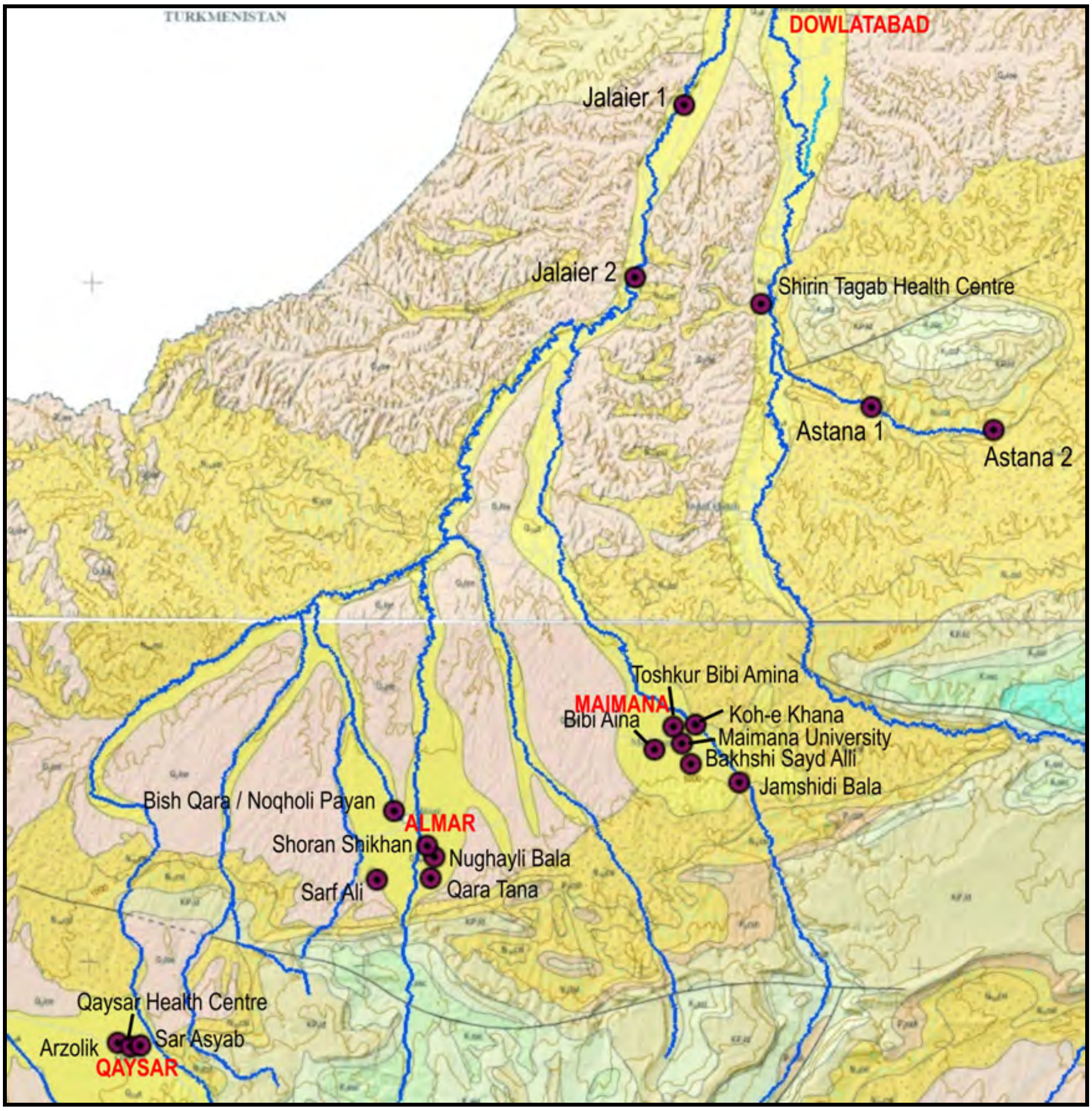


Figure 5.1. Geological map of Faryab, showing the locations of test-pumped boreholes. Background is formed by AGS/USGS 1:250,000 maps **by** McKinney & Sawyer (2005) and Wahl (2005).

5.4 Aquifer Properties in Faryab

Very few wells or boreholes have any yield data associated with them in Faryab. Even fewer have any form of test pumping data - of those, in no case is the test pumping data of adequate quality to permit any form of reliable interpretation using, for example Theis or Cooper-Jacob analysis.

In several cases, a yield (Q) figure is associated with a drawdown (s) and a pumping test duration. These boreholes are shown on Figure 5.1. This permits us to apply the Logan Approximation to estimate aquifer transmissivity (T). The Logan Approximation can be stated (Misstear et al. 2006) as:

$T = (Q/s) / 1.22$ for hydraulically ideal wells

$T = (Q/s) / 2$ for real "inefficient" wells

where T is in m^2/d, Q is in m^3/d and s is in m.

The results of these calculations are shown in Table 5.1, as "high" and "low" estimates of transmissivity, calculated from the above expressions. It should be recognised that, in no case does the transmissivity value calculated represent the transmissivity of the entire aquifer sequence, nor eve the transmissivity of the Quaternary / Neogene sequence. It merely represents the transmissivity of the aquifer strata hydraulically accessible to the well.

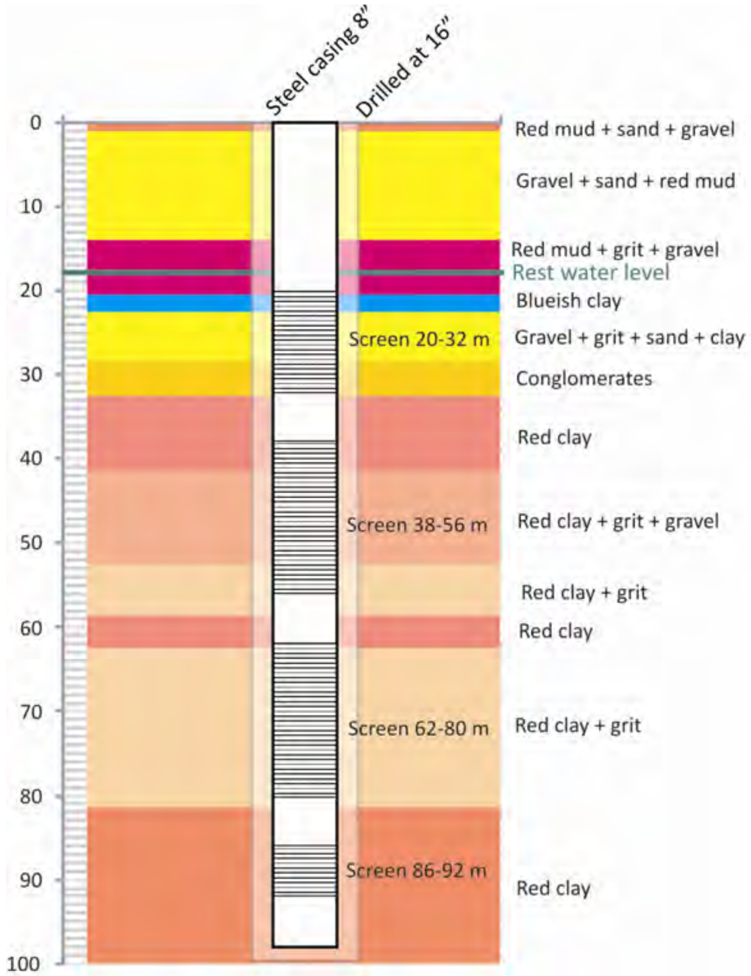


Figure 5.2. Borehole construction log for Koh-e Khana test well, District 1, Maimana city.

Table 5.1. Boreholes in Faryab with pumping / drawdown data. Transmissivity range estimated by Logan approximation. * = transmissivity very low (pump dry); $ = approximate grid reference only. SWL = static water level.

Borehole	Aquifer	Depth	Diameter	Date	SWL	Yield *Q*	Yield *Q*	Drawdown *s*	Duration	*T* (high)	*T* (low)
		m	mm		m bwt	L/s	m3/d	m	hr	m^2/d	m^2/d
Qaysar area											
Arzolik borehole		145	152	05/03/2008	91.4	4	346	13.6	8	51	31
Qaysar Health Centre$		104	254	31/03/1979	78.72		86	3.5	8	49	30
Sar Asyab borehole		150	152	04/03/2008	27.5	5	432	15.2	4	57	35
Almar area											
Sarf Ali borehole		160	152	01/06/2010	134.2	2.77	239	Pump dry	0.22	*	*
Qara Tana borehole		150	152	01/06/2010	87.1	2.9	251	Pump dry	0.27	*	*
Nughayli Bala borehole		150	152	06/03/2008	101	3	259	19	6	27	17
Shoran Shikhan borehole		150	152	03/06/2010	105	1.85	160	25	5	13	8
Bish Qara / Noqholi Payan borehole		122	152	29/05/2010	83.7	3.5	302	15.3	15	40	24
Maimana area											
Jamshidy Bala borehole	Neogene	92	203	18/03/2012	26.8	3.5	302	34.3	6	18	11
Bakhshi Sayd Alli borehole	Neogene	118	203	16/07/2012	61.8	2.5	216	47.32	7	9	6
Maimana University borehole	Quaternary	90	203	30/11/2011	41	0.7	60	1.5	6	81	49
NCA Maimana (Koh-e Khana) test borehole	Quaternary	98	203	16/10/2011	20.3		864	6.7	24	258	157
Bibi Aina borehole	Quaternary (some Neogene)	204	254	30/06/2008	65	8	691	6	5	230	141
Toshkur Bibi Amina (Maimana District)$		74	254	24/06/1979	50		216	0.7	13	617	376
Further north											
Shirin Tagab Health Centre$		42	203	21/06/1978	21.5		121	3.8	20	64	39
Astana 1 deep bore (Mahad)	Neogene	200	152	08/09/2009	10	2	173	13	7	27	16
Astana 2 deep bore (Gul Qudoq)	Neogene	200	152	09/11/2009	9	1.5	130	121	0.73	2.1	1.3
Jalaier 1 deep bore (Chokazie village)	Neogene	200	152	24/12/2009	23	4	346	11.1	8.5	62	38
Jalaier 2 deep bore (Atomchi village)	Neogene	200	152	07/02/2010	16.7	0.75	65	129.1	6	1.0	0.6

For most of the boreholes in Table 5.1, it is reasonable to assume that the borehole has been installed with well-screen in the most transmissive portions of the aquifer (see a diagram of the Maimana University borehole construction in Figure 5.2) and thus that the calculated transmissivity represents the transmissivity of the saturated section of strata penetrated by the well.

The transmissivities of the Quaternary aquifer system range from several hundred m^2/d in northern Maymana (Bibi Aina, Toshkur Bibi Amina, Koh-e Khana) down to a few tens of m^2/d around Qaysar and Almar. In an international perspective these transmissivities would probably be regarded as low to moderate.

For the Neogene, the transmissivities are even lower, ranging from around 1 m^2/d to 40-60 m^2/d.

In Table 5.2, the estimated transmissivity values have been divided by saturated depth to result in a very approximate estimate of average hydraulic conductivity (permeability).

Estimates of average hydraulic conductivity of the sequences fall in the range 1-3 m/d for northern Maimana, and in the shallower strata of the Toshkur Bibi Amina borehole it is in the range 15-26 m/d.

The aquifers in Qaysar and Almar appear to have typical average conductivities of <1.2 m/d, while the Neogene aquifers return typical average conductivities of <0.2 m/d.

	Aquifer	T (high)	T (low)	Saturated depth	K (high)	K (low)
		m^2/d	m^2/d	m	m/d	m/d
Qaysar area						
Arzolik borehole		51	31	53.6	0.9	0.6
Qaysar Health Centre		49	30	25.28	2.0	1.2
Sar Asyab borehole		57	35	122.5	0.5	0.3
Almar area						
Sarf Ali borehole		*	*	25.8	*	*
Qara Tana borehole		*	*	62.9	*	*
Nughayli Bala borehole		27	17	49	0.6	0.3
Shoran Shikhan borehole		13	8	45	0.3	0.17
Bish Qara and Noqholi Payan borehole		40	24	38.3	1.0	0.6
Maimana area						
Jamshidi Bala borehole	Neogene	18	11	65.2	0.3	0.16
Bakhshi Sayd Alli borehole	Neogene	9	6	56.2	0.16	0.10
Maimana University borehole	Quaternary	81	49	49	1.6	1.0
NCA Maimana (Koh-e Khana) test borehole	Quaternary	258	157	77.7	3.3	2.0
Bibi Aina borehole	Quaternary (some Neogene)	230	141	139	1.7	1.0
Toshkur Bibi Amina		617	376	24	25.7	15.7
Further north						
Shirin Tagab Health Centre		64	39	20.5	3.1	1.9
Astana 1 deep bore (Mahad)	Neogene	27	16	190	0.14	0.09
Astana 2 deep bore (Gul Qudoq)	Neogene	2.1	1.3	191	0.01	0.01
Jalaier 1 deep bore (Chokazie village)	Neogene	62	38	177	0.4	0.21
Jalaier 2 deep bore (Atomchi village)	Neogene	1.0	0.6	183.3	0.005	0.003

Table 5.2. Boreholes in Faryab with pumping / drawdown data. Transmissivity range estimated by Logan approximation. * = transmissivity very low (pump dry).

<u>Of Etymological Interest</u>

Aquifer: From the Latin *aqua* (water) and *ferre* (to carry). This term denotes a geological body or stratum with sufficient transmissivity(or hydraulic conductivity) and storage to permit the economic abstraction of groundwater. Note that (1) in arid areas, groundwater is scarcer and has higher "value", thus the threshold for designating a stratum an aquifer may be lower; (2) the definition says nothing about the use of the water or the water quality.

Aquitard: From the Latin *aqua* (water) and *tardus* (slow). The opposite of an aquifer. This term denotes a geological body or stratum with **insufficient** transmissivity and storage to permit the economic abstraction of groundwater. This designation does not imply that the stratum is impermeable, however.

5

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