Towards a policy for sustainable use of groundwater by non-governmental organisations in Afghanistan

David Banks · Oddmund Soldal

Abstract A 'first pass' groundwater management policy has been developed for use by non-governmental organisations (NGOs) in Afghanistan, designed to prevent derogation of existing traditional water sources, aquifer over-abstraction and chemical deterioration of soil and groundwater quality. Key elements include (1) continuing promotion of groundwater as a drinking water source, (2) a presumption against use of motorised pumps to abstract groundwater for irrigation unless other options (surface water, qanats) are not available, (3) the use of groundwater for irrigation as a temporary alternative to surface water (i.e. a strategy for drought survival) rather than as a long-term development policy, (4) limiting groundwater abstraction to a long-term average of 1 l s^{-1} km^{-2}, (5) siting irrigation wells at least 500 m from other groundwater sources and (6) analysing irrigation groundwater for electrical conductivity, sodium absorption ratio, boron and residual sodium carbonate alkalinity. Analyses of these parameters indicate that groundwater from some areas is of dubious suitability for irrigation. In some villages and towns, groundwater contains elevated nitrate and faecal bacteria concentrations, probably derived from latrines, sewage or animal wastes.

Résumé Une politique de gestion des eaux souterraines en premier examen a été mise au point pour les organisations non gouvernementales (ONG) en Afghanistan, dans le but d'empêcher des dérogations aux ressources en eau existantes traditionnellement utilisées, à la surexploitation des aquifères et à la dégradation chimique de la qualité des sols et des eaux souterraines. Les éléments clés sont les suivants (1) la poursuite de la promotion de l'eau souterraine comme source d'eau potable, (2) une présomption contre l'utilisation des motopompes pour extraire l'eau destinée à l'irrigation, tant qu'il existe d'autres options (eau de surface, qanats), (3) l'utilisation de l'eau souterraine pour l'irrigation comme une alternative à l'eau de surface (c'est-à-dire une stratégie de survie de sécheresse) plutôt que pour une politique de développement à long terme, (4) la limitation des prélèvements d'eau souterraine à un débit moyen à long terme de 1 l s^{-1} km^{-2}, (5) le positionnement des puits d'irrigation à au moins 500 m d'autres sources d'eau souterraine, et (6) la mesure de la conductivité électrique de l'eau souterraine pour l'irrigation, du coefficient d'absorption du sodium, du bore et de l'alcalinité résiduelle en carbonate de sodium. Les analyses de ces paramètres indiquent que les eaux souterraines de certaines régions ont une qualité douteuse pour l'irrigation. Dans certains villages et villes, les eaux souterraines ont des concentrations élevées en nitrates et en bactéries fécales, provenant probablement de rejets de latrines, d'égouts ou d'animaux.

Resumen Se ha desarrollado un "primer paso" en la política de gestión de las aguas subterráneas para su aplicación por parte de organizaciones no gubernamentales (ONG) en Afganistán. El objetivo es evitar la pérdida de las fuentes tradicionales existentes de agua, la sobreexplotación de los acuíferos y el deterioro de la calidad química de suelo y agua. Entre sus elementos clave, destacan los siguientes: (1) continuar promocionando las aguas subterráneas como fuente de agua potable; (2) oponerse al uso de motobombas para la extracción de aguas subterráneas para riego, salvo la no disponibilidad de otros recursos (aguas superficiales, qanats); (3) utilizar las aguas subterráneas para riego como alternativa temporal -y no a largo plazo-a las aguas superficiales, es decir, como estrategia de supervivencia ante sequías; (4) limitar los bombeos a un valor promedio a largo plazo de 1 L s^{-1} km^{-2}; (5) ubicar los pozos de riego a un mínimo de 500 m de otras fuentes de aguas subterráneas; y (vi) analizar el agua subterránea de riego, determinando los parámetros conductividad eléctrica, coeficiente de adsorción de sodio, boro y alcalinidad del carbonato sódico residual. Los resultados analíticos indican que las aguas

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D. Banks (✉) · O. Soldal
Norwegian Church Aid, Postboks 4544 Torshov,
0404 Oslo, Norway
e-mail: david@holymoor.force9.co.uk

D. Banks
Holymoor Consultancy, 86 Holymoor Road, Holymoorside,
Chesterfield, Derbyshire S42 7DX, UK

O. Soldal
Interconsult ASA, Solheimsgate 13,
Postboks 6051 Postterminalen, 5892 Bergen, Norway

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subterráneas de algunas zonas son de dudosa aplicabilidad para riego. En algunos pueblos y ciudades, contienen concentraciones elevadas de nitrato y bacterias fecales, procedentes, probablemente, de letrinas, alcantarillas o deyecciones animales.

Keywords Over-abstraction · Arid conditions · Afghanistan · Groundwater management · Groundwater quality · Salinization

About This Article

The work described in this article was carried out during June–July 2001 (Banks 2001). Since then, civil and international war, coupled with chronic drought and incipient famine, have caused a further displacement of refugees and internal migrants, the departure and subsequent return of international non-governmental organisations (NGOs) and, for a time, severe curtailment of the activities of Afghan NGOs. Nevertheless, it seems that the time has arrived when NGOs can once again work with the Afghan government and people to reconstruct a water supply infrastructure. This article contains little quantitative hydrogeology because of the almost complete loss of data relating to groundwater in Afghanistan during 20 years of war. However, the article provides an introduction to the hydrogeological setting of the country and uses simple hydrogeological considerations to recommend a policy for use of groundwater that will avoid the worst excesses of derogation and overexploitation. The policy was originally intended to be implemented by NGOs themselves, via co-ordination through UN-facilitated water management forums. However, under the new political climate, it is to be hoped that some of the recommendations within this article may contribute towards a State water management policy, to be implemented by the relevant Afghan governmental organisations.

Because of the need for a simple easily communicated policy it is likely that some aspects, particularly regarding recommendations for sustainable abstraction density, will attract criticism for being too conservative and simplistic. It is recognised that, in some areas, recharge of irrigation water or mountain runoff may increase aquifer recharge to a level permitting significantly greater abstraction than is recommended here. The recommendations are not intended to be 'cast in stone', but to be modified as more information becomes available and to be tailored to local conditions, provided that adequate site-specific hydrogeological information is available to support such modifications.

Background

Afghanistan is a landlocked nation of area 647,500 km^2, of which 30,000 km^2 was estimated to be under irrigation in 1993. The population, as of July 2001, was estimated to be almost 27 million. Health statistics are poor, with a life expectancy of only 46 years and an infant mortality rate, as of the year 2001, of 147 per 1,000 live births. In 1990, over 50% of the gross domestic product was derived from agriculture (CIA 2002).

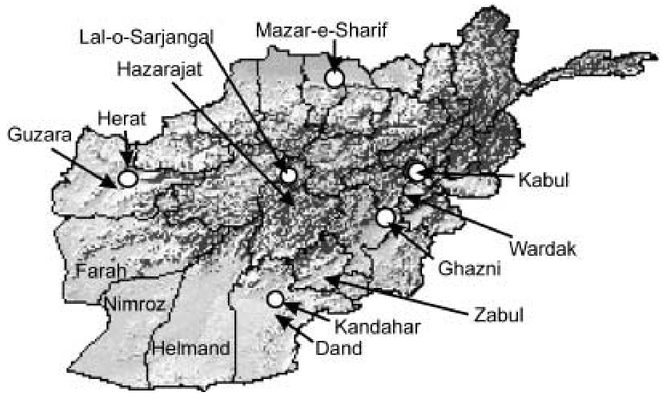

Fig. 1 Location map of Afghanistan (using a relief base map of ProMIS 2001), showing locations named in text

In 1979, the USSR invaded Afghanistan. This episode was followed by 17 years of occupation and armed resistance, followed by bloody civil war. From 1996–2001, the nation was ruled by the Islamic Taliban government, under which normal scientific and civilian institutions and structures atrophied. Towards the end of 2001, the Taliban were displaced by national and international armed intervention and an interim administration established.

Since around 1998, Afghanistan has found itself in a drought situation (Schimann 2000) that has progressively worsened and caused large numbers of the rural population to displace to refugee camps, especially around Herat and Mazar-e-Sharif (Fig. 1). In order to slow this displacement, Afghan and international NGOs and United Nations (UN) organisations have facilitated the provision of groundwater wells and boreholes to supply drinking and irrigation water to needy communities. These organisations are aware that any such development needs to be sustainable and are concerned that groundwater abstraction infrastructure installed during the recent drought period should neither

- Derogate existing traditional abstractions (such as shallow dug wells or qanats, locally called 'karezes', which skim water from the surface of the water table), nor
- Result in long-term aquifer over-abstraction. Over-abstraction may be

1. absolute, where long-term abstraction exceeds recharge, or
2. may simply be a degree of abstraction that results in unacceptable regional water table or base flow decline.

Twenty years of civil war have resulted in almost total loss of documented information on the nation's hydroge-

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ology and groundwater balance (reports have been lost or sequestered by private individuals) and the observation well network has fallen into disuse.

A Water Law was issued in 1981 by the Government of Afghanistan (reproduced by Schimann 2000), requiring that water should only be abstracted with a permit from the Ministry of Water and Power. However, during subsequent civil unrest and during the post-1996 Taliban period, there was little effective state management of water resources in Afghanistan. The NGOs and UN organisations, therefore, developed their own forums to coordinate activity and develop policy. The recommendations contained in this article have been communicated to the Land and Water Resource Development Group (LAWRD), co-ordinated by the Food and Agricultural Organisation (FAO) of the UN. In the new political climate, however, there are promising signs that government Ministries are taking steps to re-implement the Water Law and to regulate the activities of NGOs in the water and sanitation sector. It is hoped that this document may provide the seed for an initial groundwater management policy in Afghanistan.

In an Ideal World..

Despite the concerns on the part of some NGOs over groundwater over-abstraction, it should be remembered that Afghanistan possesses huge reserves of stored groundwater. Surface waters (rivers) typically respond very quickly to rainfall, snowmelt or drought events, whereas groundwater responds much more slowly. Groundwater is available in drought periods for much longer than surface water, but takes correspondingly longer to ‘recover’ after the drought breaks. Thus, the increased use of groundwater for drinking water and irrigation is an entirely correct response to a drought situation, when surface water is in short supply, provided that any groundwater deficit is allowed to recover following the drought. In an ideal world, Afghanistan would rely largely on surface water during normal years and increasingly on groundwater during drought years.

However, in the recent regulatory vacuum, private landlords and, in some cases, NGOs, in response to drought, have sunk large numbers of irrigation wells and boreholes. It is feared that this is not merely a short-term drought response. Interviews with villagers (Banks 2001) confirm that they intend to keep irrigation wells in operation following the drought, with a view to increasing the area of land under cultivation. This may mean that the aquifer will continue to be in deficit in some areas, resulting in progressively declining groundwater levels.

Increasing groundwater usage may also tend to exacerbate socioeconomic divides. There is a tendency for richer landlords to be able to afford drilled boreholes for irrigation. The large drawdowns achievable by such deep boreholes may derogate the shallow dug wells, springs and karezes used by poorer sections of the community.

Water Resources in Afghanistan – an Overview

Climate

Afghanistan suffers extremes of climate, with temperatures of up to 50 °C in the summer and tens of degrees below freezing in winter in some areas. Table 1 lists basic climatic data for several locations in Afghanistan and Fig. 2a, b illustrates the seasonal fluctuations in precipitation and open water evaporation (effectively potential evapotranspiration). Annual precipitation varies between <50 mm $year^{-1}$ in the south-west to over 1,000 mm $year^{-1}$ in the north-eastern highlands (GEOKART 1984; Klemm 1996; SS Shobair, FAO Peshawar, personal communication). The land area over 2,000 m elevation is estimated to receive on average 150 billion m^3 of precipitation per year, whereas that below 2,000 m receives only 30 billion m^3 (Prof. M.H. Hamid, Kabul Polytechnic University and NCAAP, personal communication).

Annual potential evapotranspiration vastly exceeds rainfall at all the stations in Table 1. When considered on a monthly basis, potential evapotranspiration exceeds precipitation for most months of the year (Fig. 2a, b). Typically, in December–February, potential evapotranspiration and precipitation are similar. Thus, in most of these (lowland) areas, direct recharge of precipitation to groundwater is likely to be extremely low. The most likely period for direct recharge will be around March, where the melting of accumulated snow or frost may temporarily exceed evapotranspiration.

Table 1 Climatic data for selected locations in Afghanistan. T_{max} Mean monthly temperature in month with highest mean temperature; T_{min} mean monthly temperature in month with lowest mean temperature; *RH* relative humidity (annual mean); ET_o annual potential evapotranspiration; *P* annual precipitation; P_{eff} annual effective precipitation. After data in Shobair (2001)

Location	Province	T_{max} (°C)	T_{min} (°C)	RH. (%)	ET_o (mm)	P (mm)	P_{eff} (mm)
Qadis	Badghis	30.4 (July)	–2.6 (Jan.)	56.1	1,372	323	300
Mazar-e-Sharif	Balkh	38.6 (July)	–2.0 (Jan.)	57.6	1,531	190	181
Lal	Ghor	25.2 (July)	–21.4 (Jan.)	77.1	938	282	264
Kandahar	Kandahar	40.4 (July)	0.1 (Jan.)	39.4	1,812	158	149
Kabul	Kabul	32.2 (July)	–7.4 (Jan.)	61.5	1,372	303	276
Ghazni	Ghazni	30.8 (July)	–10.7 (Jan.)	60.6	1,429	292	271
Herat	Herat	36.4 (July)	–2.9 (Jan.)	58.3	1,732	211	198
Jalalabad	Nangarhar	40.6 (June)	2.6 (Jan.)	61.8	1,342	171	164

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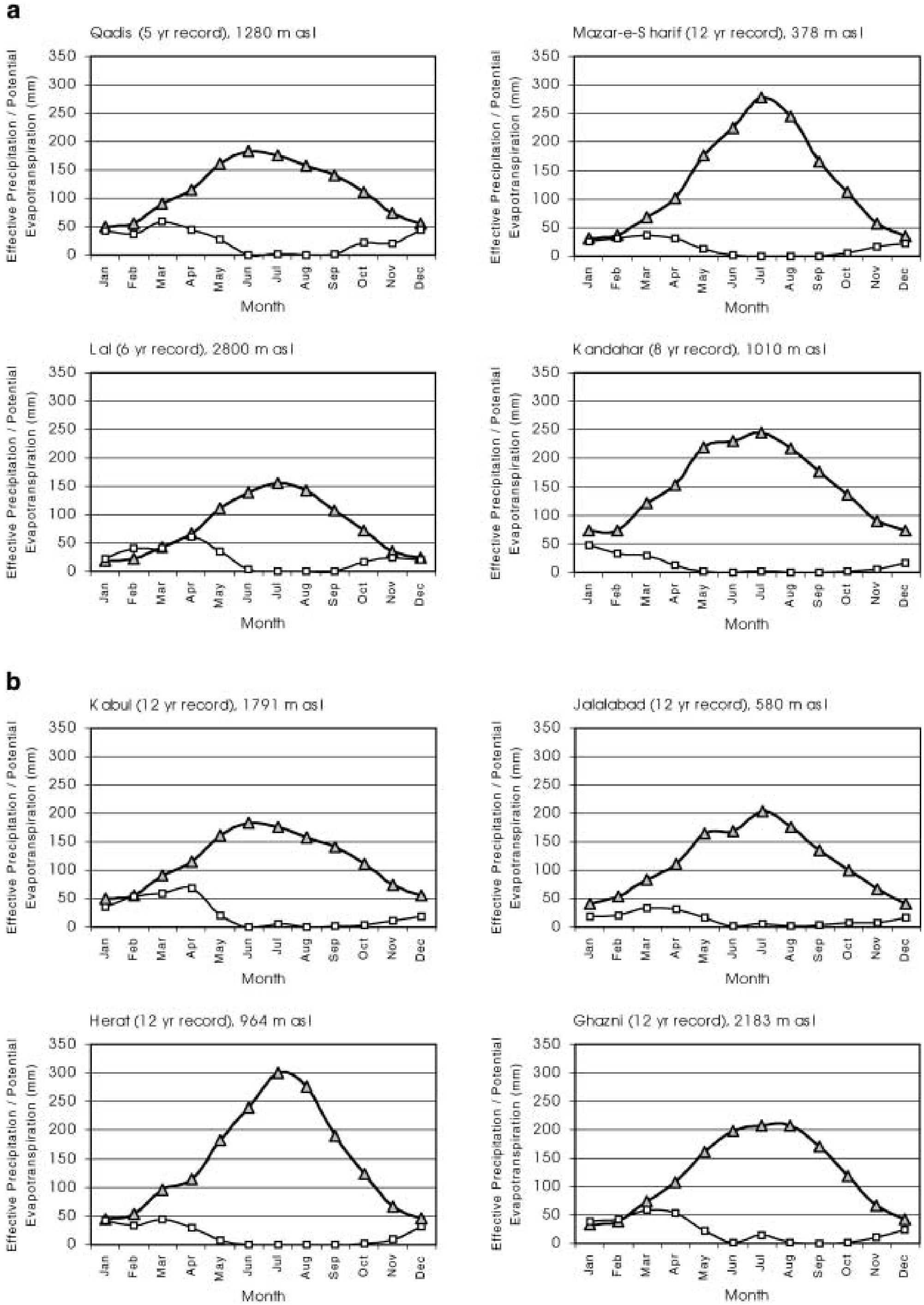

Fig. 2 Seasonal variation of monthly effective precipitation (*squares*) and potential evapotranspiration (*triangles*) at **a** Qadis, Mazar-e-Sharif, Lal-o-Sarjangal, Kandahar; **b** Kabul, Jalalabad, Herat, Ghazni. After data in Shobair (2001)

Surface Water

The territory of Afghanistan drains to three main river basins (Fig. 3), with an estimated total mean annual discharge of 84 billion m^3 (according to MH Hamid, personal communication), all ultimately supported by precipitation (and especially winter snowfall) in the mountainous core of the country (Hindu Kush, Safed Koh, Koh-i-Baba and Hazarajat ranges):

1. The south-eastern part of the country drains to the Indus basin in Pakistan (Kabul, Panjshir, Ghurband, Alishing, Alingar and Kunar Rivers). Catchment area =73,000 km^2, mean annual discharge =21.7 billion m^3 (Prof. M.H. Hamid, Kabul Polytechnic University and NCAAP, personal communication).
2. North of the mountainous spine of the country, rivers drain northwards towards the Amu Darya River (Kokcha, Ab-i-Panj, Kunduz, Wakhan Rivers), forming the boundary between Afghanistan and the former Soviet Republics of Uzbekistan and Turkmenistan. Catchment area =241,000 km^2, mean annual discharge =53.1 billion m^3.

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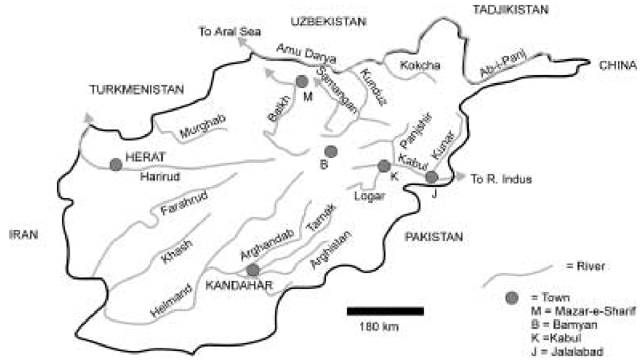

Fig. 3 Map of Afghanistan, showing locations of main surface watercourses

3. The ‘desert’ basins, including those of the Helmand (and its tributaries, the Arghandab, Ghazni, Arghistan and Tarnak Rivers), Khash and Farahrud Rivers, drain towards the internal basins of Hamun Helmand in western Afghanistan and Hamuni-i-Saberi in eastern Iran. Catchment area =328,000 km^2, mean annual discharge =9.3 billion m^3.

The Amu Darya (or Oxus) is one of the main rivers draining to the Aral Sea, whose progressive and rapid desiccation is rightly regarded as an ecological catastrophe, caused in large part by over-abstraction and inefficient irrigation of cotton (and other crops) in the former Soviet Republics. Afghanistan has long been concerned that it has not made full use of the waters of the Amu Darya for irrigation, as evidenced by the following statements:

> “Afghanistan has rich water resources, while Iran, Pakistan and Turkmenistan are using the resources. Building of dams and water diversion systems can turn the tide in the Afghan’s favour...(we propose) devising long-term plans covering building of water channels from the Amu River to the south”. (Nedaie 2000)
>
> “The average discharge potential of Afghanistan in general is 55 billion cubic metres in a year. However, it is noted with regret that merely 22 billion cubic metres of the total potential is utilised inside Afghanistan, while the remaining 33 billion cubic metres is poured outside Afghanistan into the territories of Iran, Turkmenistan and Pakistan”. (Mahmoud 2000)

Although such concerns are understandable, it must be feared that future intensive exploitation of the headwaters of the river will not only result in conflict with existing downstream users, but may also be to the further detriment of the Aral Sea (Fig. 3).

Geology

Geological maps and descriptions of Afghanistan are published by the Geological Survey of Germany (Wittekindt 1973; Wittekindt and Weippert 1973). Very simply, the dominant feature of Afghanistan’s geology is the Safed Koh/Koh-e-Baba/Hindu Kush range of mountains, which trend dominantly WSW–ENE. These are essentially a continuation of the Himalayan range. These consist mainly of lithified rocks of pre-Palaeogene age and are dominated by metasediments (sandstones, slates, metaconglomerates, limestones, metabreccias, phyllites, schists, etc.), with some igneous rocks such as granites. The rocks are faulted, folded and deformed.

The plains surrounding the mountain ranges and the valleys between the mountain ridges are filled with Neogene and Quaternary (Pleistocene) sediments (Table 2), which are the products of erosion of the mountains and deposited in proluvial, alluvial or lacustrine environments (Homilius 1966; Timmins 1996) and have not been significantly deformed. Adjacent to the mountains, the sediments are dominated by coarse deposits such as gravels and pebbles, deposited as the proximal facies of alluvial fans washing down from the mountains. Further away from the mountains, the deposits are expected to become dominated by finer sediments such as fine sands/silts (distal facies). Even here, however, layers of coarse material often can be found, possibly related to old river channels or glacial melt episodes. The Neogene and Quaternary sediments also contain some volcanogenic deposits such as tuffs and lavas.

Observation suggests that the Neogene sequences contain a lower proportion of coarse-grained layers than

Table 2 Simplified geological sequence for Neogene and Quaternary deposits in Afghanistan, after ESCAP (1995)

Period	Location	Description
Quaternary		Unconsolidated fluvial, lacustrine, glacial and alluvial sediments, with travertine and volcanics
Pliocene (Unconformably overlies Miocence)	North Afghanistan	Up to 11,000 m sandstone and conglomerate with interbedded clays and siltstone
	Other parts	Up to 2,000 m sandstone, conglomerate, clay, siltstone. May also contain lacustrine deposits and volcanics. May be gypsum- or brine-bearing.
	South-western and western plains	Up to 100 m of lacustrine clays
Miocene (Unconformably overlies older rocks)	Northern Afghanistan	200–3000 m siltstone, sandstone and clay
	Southern Afghanistan	100–500 m sandstone

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the Pleistocene, and are more compacted/lithified. Along current river valleys, modern alluvial deposits occur. These can be several tens of metres thick and can be extremely coarse grained.

Hydrogeology

The following conceptual hydrogeological framework is based on:

1. An assumption of hydrogeological analogy between Afghanistan and other better known mountainous inland semi-arid areas, such as the Intermontane Caucasus of Azerbaijan (Aliyev et al. 1992) and the Altiplano of Bolivia (Banks et al. 2002b).
2. Discussions with Afghan hydrogeologists (Banks 2001)
3. Field inspection
4. The published hydrogeological map (Anon 1976)

Groundwater recharge

In mountainous areas, where evapotranspiration is less than precipitation for many months of the year and where snow cover is persistent, pre-Palaeogene bedrock and valley infills may be recharged directly by infiltration of precipitation. As noted above, however, direct recharge of precipitation to lowland areas is likely to be very small because of evapotranspiration greatly exceeding precipitation and also because of the frequently fine-grained nature of surficial sediments. The most likely recharge mechanisms in lowland areas are likely to be as follows:

1. Neogene/Quaternary aquifers are likely to be recharged in foothills by rivers and streams descending from the high mountains and infiltrating into dominantly coarse-grained alluvial fans. The recharge is likely to be highest during snowmelt season. Thus, groundwater recharge is highly dependent on quantities of winter snowfall. Indeed, in the Kabul area, groundwater level maxima occur in May/June and minima in August/September (Timmins 1996).
2. Further away from the mountains, some recharge to Neogene/Quaternary aquifers is likely to take place by infiltration of water through the bed of perennial rivers.
3. In irrigated areas, substantial recharge may occur via leakage from irrigation channels.

In this situation, where groundwater recharge occurs only in particular zones (mountain foothills and river valleys) and then flows laterally throughout the aquifer complex, estimates of recharge are almost impossible in the absence of detailed data on, for example, river flow profiles. One may attempt to estimate an areally distributed figure for recharge (amount of recharge in foothills divided by area of aquifer fed by such recharge) by examining the response of the aquifer to recharge or drought episodes. Various NGOs have reported declines in the water table during the drought period of the last 3–4 years, as follows: 2 m in Zabul area, 2–4 m in Herat, 4–6 m in Kabul and 5–8 m in the Dand/Kandahar area [Afghan Development Association (ADA); T Thomsen and AB Afzali, Danish Committee for Aid to Afghan Refugees (DACAAR); Eng. Ehsanullah, Norwegian Project Office (NPO), personal communication].

The largest declines (Dand, Kandahar, Kabul) are probably a result of the effects of abstraction superimposed upon climatic trends. The lower figures for water table decline suggest that the climatically-related rate of decline of the water table in the Neogene/Quaternary lowland aquifer complexes is in the range 0.5 to 1.5 m $year^{-1}$. If we make the highly simplistic assumption that this decline corresponds to 1 year's deficit of recharge, and if we assume a specific yield (drainable porosity) of some 10% for these rather poorly sorted sediments, this implies a normal areally distributed recharge in the range 50–150 mm $year^{-1}$. This figure corresponds to a maximum renewable resource of 1.6–4.8 l $s^{-1}km^{-2}$ in lowland Neogene/Quaternary sediments. In higher altitude mountain valleys, the rate of recharge may be higher because of large areas of mountain slope runoff recharging to valley aquifers of areally limited extent.

On a national scale, total average groundwater recharge is estimated to be 18 billion m^3 $year^{-1}$ (Prof. M.H. Hamid, Kabul Polytechnic University and NCAAP, personal communication). If half the country's area is underlain by aquifer strata, this corresponds to an areally distributed recharge of some 56 mm per year. The documentation of the derivation of this estimate is, unfortunately, unavailable, however.

Hydraulic properties

The pre-Palaeogene bedrocks of the mountain ranges are typically of rather low permeability. Boreholes drilled in them are expected to yield less than 1–2 l s^{-1}. However, where a borehole strikes an especially permeable fault zone, or a lithology such as limestone/marble, yields may be significantly greater. Also, where bedrock underlies a Neogene/Quaternary sediment sequence, boreholes completed in the fractured and weathered bedrock surface are reported to yield 5–8 l s^{-1} in the Kabul area [Eng. Ameen, Association for Reconstruction and Energy Conservation in Afghanistan (AREA), personal communication].

Quaternary alluvial sediments in the Kabul area (Q_{II}–Q_{IV}), comprising conglomerates, pebbles and gravels are reported have borehole yields of several tens of l s^{-1} (Hamid 2002). Similar boreholes in the typically finer grained Neogene sediments (siltstones, argillites, some coarser strata) are reported to typically yield 5 l s^{-1} (Eng. Ameen, AREA, personal communication).

Aquifer horizons comprising alluvial or proluvial sand, gravel and pebbles are reported, in the Kabul area, to have a typical hydraulic conductivity of 10–70 m day^{-1} (Najibullah 1996; Timmins 1996). This will be less if the strata are poorly sorted and have a high content of fines.

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Groundwater flow

In undisturbed conditions, the lateral component of groundwater flow is thought to be from groundwater recharge areas in the foothills of mountain ranges towards discharge areas in the mid- to lower reaches of river valleys, where it discharges to the river, or towards desert areas far from the mountains, where water may be discharged via evaporation.

The vertical groundwater flow component would be expected to be downward in groundwater recharge areas in mountain foothills and upward in discharge areas (mid- to lower reaches of river valleys and desert areas).

In mountain foothills, the high topography and permeable nature of the deposits would result in the water table being relatively deep below the ground surface. Further out into the lowlands, the water table becomes shallower.

In recharge areas in mountain foothills, the aquifer deposits would be generally expected to be coarse grained, with relatively high hydraulic conductivity throughout the sequence. Away from the mountain areas, the proportion of fine-grained layers would increase, and may form aquitards, which impede the free upward discharge of groundwater. Artesian heads (i.e. overflowing wells at ground surface), thus, might be expected and are, indeed, observed in regions such as Guzara in Herat province.

Hydrogeochemistry

According to the published hydrogeological map (Anon 1976), the majority of the territory of Afghanistan, especially around the mountainous central massif, is underlain by fresh groundwater of total mineralisation <1,000 mg l^{-1}, with a hydrochemical composition typically of calcium–magnesium bicarbonate, sodium–calcium bicarbonate or calcium-sulphate–bicarbonate type.

In the low-lying desert areas away from the mountains, there is some tendency to salinisation with mineralisation of >1,000 mg l^{-1} and up to around 3,000 mg l^{-1} recorded. This is especially the case in three areas:

- The deserts in the south-west of the country: southern Kandahar, Helmand and Nimroz.
- The deserts in the extreme west of the country: western Farah and Herat
- The lowlands in the north of the country, around and to the north of Mazar-e-Sharif.

Salinisation results in a trend to a more sodium-sulphate–chloride-dominated hydrochemical type. Even in areas of saline groundwater, fresh pockets or zones of groundwater are reported to occur in valleys of rivers, creeks and ravines. Often, the tendency to salinisation is especially strong in the upper zone of the aquifer, where evapotranspiration may enhance salinity or where recirculated irrigation water recharge accumulates. The presence of evaporites in the geological sequence may also enhance water salinisation.

Water quality is obviously important for the suitability of water for human consumption. In particular, nitrate has shown itself to be an issue of concern where shallow wells have been installed in villages or cities with a high density of latrines (Bocanegra et al. 2001; Banks et al. 2002a). Nitrate is tolerated by most adults without toxic effects. However, concentrations >50 mg l^{-1} may give rise to the potentially fatal condition of methaemoglobinaemia (blue baby syndrome) in small infants, if nitrate-rich water is used for preparation of milk substitutes or drinks. Nitrate in groundwater may also be up-concentrated because of evapotranspiration in arid climates (Tredoux et al. 2001). High nitrate concentrations may also be good indicators of bacterial contamination. Indeed, Timmins (1996) conducted a water-quality survey in Kabul, which involved the analysis of 1,400 samples of water from open dug wells, wells with handpumps, springs and tap stands fed by the city's distribution network. Samples were analysed for faecal coliforms and nitrate. The findings, summarised in Tables 3 and 4, confirm both extensive contamination by faecal microbes and nitrate, and also the advantages to be gained by fitting a hand pump to a protected well-top.

Table 3 Results of water quality survey of Kabul (Timmins 1996), based on 1,400 samples. < Less than detection limit

Source	*E. coli* >5 per 100 ml (% of sources)	*E. coli* >100 per 100 ml (% of sources)	*E. coli* >500 per 100 ml (% of sources)
Well with hand pumps	45.2	11.1	1.3
Open wells	76.5	31.9	4.2
Distribution networks	49.0	15.7	1.96

Table 4 Results of water quality survey of Kabul (Timmins 1996), based on 1,400 samples. < Less than detection limit

Source	Average nitrate concentration (mg/l NO_3^-)	Minimum concentration (mg/l NO_3^-)	Maximum concentration (mg/l NO_3^-)	Percentage >45 mg/l NO_3^- (% of sources)
All sources	41.65	<	150	10.8
Well with hand pumps	39.5	<	150	32.5
Open wells	51.25	4	140	44.3
Deep wells	37.6	8	85	24.1
Springs/karezes	34.1	<	90	33

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Table 5 Classification of suitability of waters for irrigation, based on electrical conductivity (EC) and sodium absorption ratio (SAR), after Kansas Geological Survey (2001)

Class	Description	Class	Description
C1	Low-salinity water (C1) can be used for irrigation of most crops on most soils with little likelihood that soil salinity will develop. EC <250 μS/cm	S1	Low-sodium water (S1) can be used for irrigation on almost all soils with little danger of developing harmful levels of exchangeable sodium. SAR <6 for EC =750 μS/cm
C2	Medium-salinity water (C2) can be used if a moderate amount of leaching occurs. Crops of moderate salt tolerance can be irrigated with C2 water without special practices. EC >250 μS/cm, but EC <750 μS/cm	S2	Medium-sodium water (S2) will present an appreciable sodium hazard in certain fine-textured soils, especially poorly leached soils. Such water may be used safely on coarse-textured or organic soils that have good permeability. 6<SAR <12 for EC =750 μS/cm
C3	High-salinity water (C3) cannot be used on soils of restricted drainage. EC >750 μS/cm, but EC <2,250 μS/cm	S3	High-sodium water (S3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management such as good drainage and leaching and addition of organic matter. 12<SAR <18 for EC =750 μS/cm
C4	Very high salinity water (C4) is not suitable for irrigation water under ordinary circumstances. It can be used only on crops that are very tolerant of salt and then only if special practices are followed, including the provision for a high degree of leaching. EC >2,250 μS/cm	S4	Very high sodium water (S4) is generally unsatisfactory for irrigation unless special action is taken, such as addition of gypsum to the soil. SAR >18 for EC =750 μS/cm

Water quality is also important for assessing its suitability for agricultural irrigation. In this regard, four parameters are especially important (Kansas Geological Survey 2001): total dissolved solids, sodium absorption ratio [$SAR=Na^+/((Ca^{2+}+Mg^{2+})/2)^{0.5}$, where concentrations are in meq l^{-1}], boron concentration and excess alkalinity.

Total dissolved solids and sodium absorption ratio

The SAR and salinity that an irrigated soil can tolerate depends on how well-drained the soil is. In this context, a poorly drained soil can be:

- One where all or most applied water is evapotranspired by plants, such that salts are not leached out of the soil, but accumulate in the root zone (this is likely to be the case in many situations in Afghanistan)
- One which is underlain by low permeability subsoil.

On the basis of total dissolved solids and SAR, a water can be allocated to one of four classes (C1–C4 for TDS/EC, and S1–S4 for SAR) to describe its suitability for irrigation (Table 5). The boundaries between classes S1–S4 depend on the salinity of the water (Driscoll 1986; Kansas Geological Survey 2001). Values in Table 5 are cited on the basis of a water with EC=750 μS cm^{-1}.

If saline groundwater is used for irrigation in arid climates, there may also be a risk of groundwater salinisation. Irrigation water is strongly evaporated and transpired when applied to agricultural land. Dissolved salts are concentrated in the portion of water that is not lost to evapotranspiration, but which may infiltrate the ground and seep down to the water table, increasing groundwater salinity. The same groundwater may then be abstracted and reapplied for agriculture. This 'recycling' of groundwater for irrigation may thus result in a progressive increase in soil and groundwater salinity. This is a further argument for preferring surface water (which is usually less saline than groundwater) over groundwater for long-term irrigation purposes.

Boron

Boron is essential to normal plant growth, but the quantity required is very small, and large quantities are harmful. Crops vary greatly in their boron tolerance, but, in general, crops are not adversely affected by boron concentrations of less than 1 ppm (1 mg l^{-1}).

Excess alkalinity

Residual sodium carbonate alkalinity (RSCA) is defined as:

$$RSCA = \left(CO_3^{2-} + HCO_3^-\right) - \left(Ca^{++} + Mg^{++}\right),$$

where concentrations are expressed as milliequivalents per litre. The US Department of Agriculture has concluded (Kansas Geological Survey 2001) that water having more than 2.5 meq l^{-1} of residual sodium carbonate is not suitable for irrigation. Water containing 1.25–2.50 meq l^{-1} of residual sodium carbonate is marginal, and water containing less than 1.25 meq l^{-1} can be safely used for irrigation.

Analytical data

During August 2000, Soldal (2000) measured electrical conductivity (EC) in selected wells in Kandahar, Wardak and Ghazni provinces and found the salinity of groundwater to be rather low. EC varied from ca. 300–

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Table 6 Main water quality parameters determined from analyses of 15 water samples from Afghanistan (see Fig. 4 for locations). pH and alkalinity are determined in laboratory. Total mineralisation is estimated by summing the concentrations of the major species. *IBE* Ion balance error in %. Concentrations are compared with United Kingdom drinking water standards (UK DWS), which are very similar to EU standards. Exceedences are highlighted in *bold script*

Sample	pH	t-Alk (meq/l)	Cl^- (mg/l)	NO_3^- (mg/l)	SO_4^{2-} (mg/l)	Si (mg/l)	Mg (mg/l)	Ca (mg/l)	Na (mg/l)	K (mg/l)	B (mg/l)	IBE (%)	Type	Total min. (mg/l)
UK DWS			400	50	250		50	250	150	12	2			
Af 1F	6.81	12.10	23.6	31	27.3	19.7	32.1	174	48.0	2.12	0.600	–1.33	$Ca\text{-}HCO_3$	1,096
Af 2F	8.04	3.03	3.6	18	9.23	12.4	14.8	36.5	9.85	1.59	0.036	–1.46	$Ca\text{-}HCO_3$	291
Af 3F	7.91	3.82	7.1	10	12.4	8.62	17.9	47.1	11.0	1.56	0.063	–1.15	$Ca\text{-}HCO_3$	349
Af 4F	7.82	3.59	307	**367**	134	9.84	**63.6**	155	**157**	2.95	0.213	–2.67	Ca-Na-Cl	1,416
Af 5F	8.01	4.11	8.0	11	13.2	9.28	20.0	48.8	13.4	1.32	0.084	–0.88	$Ca\text{-}HCO_3$	375
Af 6F	7.85	5.69	62.6	14	79.0	6.01	45.8	52.6	58.5	3.18	0.362	–1.66	$Mg\text{-}HCO_3$	669
Af 7F	7.90	3.82	217	**75**	**477**	5.40	**75.6**	93.2	**208**	2.40	0.476	–2.69	$Na\text{-}SO_4$	1,387
Af 8F	7.74	8.24	169	35	**325**	7.37	**89.7**	89.2	**169**	3.08	0.962	–2.71	$Na\text{-}Mg\text{-}HCO_3\text{-}SO_4$	1,391
Af 9F	8.13	3.63	9.9	12	41.2	6.50	17.4	38.1	32.3	1.62	0.099	–1.95	$Ca\text{-}(Mg, Na)\text{-}HCO_3$	381
Af 10F	7.95	2.98	4.2	7	16.5	5.56	15.2	35.0	11.3	0.83	<0.02	–0.71	$Ca\text{-}HCO_3$	278
Af 11F	7.87	10.16	109	3	**275**	8.46	**66.3**	47.9	**234**	9.29	1.050	–2.03	$Na\text{-}HCO_3$	1,375
Af 12F	7.83	10.35	185	2	**379**	8.33	**70.6**	49.6	**319**	6.56	1.400	–2.54	$Na\text{-}HCO_3$	1,653
Af 13F	7.88	6.47	55.7	24	**301**	5.55	38.3	64.6	**165**	3.17	0.400	–3.76	$Na\text{-}HCO_3\text{-}SO_4$	1,053
Af 14F	7.99	3.76	48.3	23	136	7.28	26.9	39.0	87.2	2.93	0.253	–1.84	$Na\text{-}HCO_3$	600
Af 15F	7.63	10.99	137	**50**	106	12.1	**92.7**	90.3	112	9.12	1.120	–1.79	$Mg\text{-}HCO_3$	1,281

600 µS cm^{-1} in karezes, with up to 700 µS cm^{-1} in groundwater from wells in the lowland area. However, groundwater from wells in the upper aquifer in the Kandahar area was found to be much more saline, with conductivities of 1,940–>3,000 µS cm^{-1}. Deeper groundwater in Kandahar is less mineralised.

During June/July 2001, Banks (2001) took samples from a limited number (15) of groundwater sources, encompassing a range of well/karez types and land-use categories, in areas where NCA funds projects, which were subsequently analysed by the Geological Survey of Norway. Sampling and analytical protocols are documented by Banks (2001). Table 6 summarises the most important water quality parameters, and also estimates total mineralisation (salinity) by summing the major dissolved species presented in the table (and assuming that 1 meq l^{-1} of alkalinity is equivalent to 61 mg l^{-1} HCO_3^-).

It will be noted from Table 6 that three samples (Af4F, 7F and 15F) exceed the WHO (1996/1998) drinking water standard for nitrate of 50 mg l^{-1}. Of these, two (Af4F, 15F) are in urban areas (Nonga village 367 mg l^{-1}; Kabul city 50 mg l^{-1}) and the source of nitrate is very likely to be sewage and leachate from latrines. In such cases, nitrate may be an indicator of pathogenic bacterial contamination. The third high nitrate concentration (Af7F) is from an agricultural area (Toora village 75 mg l^{-1}) where the source may be fertiliser/manure or simply leaching of soil nitrogen from ploughing activity. Exceedences of drinking water standards also occur for salinity-related parameters such as magnesium, sulphate and sodium, although these are of lesser health-related concern.

In Table 6, ion balance errors are all <±5%, indicating the quality of analyses to be extremely good. Water type is variable, but is dominated by calcium bicarbonate in the least saline samples. The soluble cations sodium and magnesium become increasingly dominant with increasing salinity. In the more saline samples, sulphate and bicarbonate (rather than chloride) tend to be the dominating anions (which is not untypical for inland semi-arid areas, Parnachev et al. 1999). Estimates of electrical conductivity (EC) from cation/anion sum (1 meq l^{-1} cations or anions is equivalent to 100 µS cm^{-1} conductivity: Appelo and Postma 1996) are shown in Table 7. Sodium absorption ratio (SAR) is calculated, as is residual sodium carbonate alkalinity. The waters are classed according to suitability for irrigation by means of EC and SAR, and the risk of using water for irrigation is assessed according to EC, SAR, boron concentration and residual sodium carbonate alkalinity.

From Table 7 it can be seen that a substantial proportion of sampled waters have a conductivity >750 µS cm^{-1}, placing them in class C3 or C4, rendering them of dubious quality for agricultural irrigation. SAR is generally acceptable. Especially the wells sampled in Dand district are of poor suitability for agricultural irrigation in the long term (high conductivity/salinity, high boron concentrations and a high residual sodium carbonate concentration). The combination of poor water quality and probable over-abstraction in Dand district, suggests that use of groundwater for agricultural irrigation in the long term should be strongly discouraged, with a reversion to surface water following the drought. The elevated salinity and boron in the Kabul well (Af15) may be related to leaking latrines/sewage.

Sources of Water

Agricultural irrigation in Afghanistan

There are essentially four types of agricultural land in Afghanistan:

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Table 7 Classification of 15 groundwater samples from Afghanistan according to suitability for agriculture. *EC* Electrical conductivity based on Appelo and Postma's (1996) relation (1 meq/l cations or anions =100 µS/cm EC). *SAR* Sodium absorption ratio; *Res. $NaCO_3$* residual sodium carbonate [alkalinity – (Ca + Mg) in meq/l]. For locations, see Fig. 4. Exceedences are highlighted in **bold script**

Sample	EC (µS/cm)	SAR	B (mg/l)	Res $NaCO_3$ (meq/l)	Class	Risk	Location	Type	Land use
Af 1F	**1,365**	0.79	0.60	0.78	C3-S1	Mod.	CoAR compound/Sayyidabad/Wardak	Dug well	Rural/(urban)
Af 2F	356	0.29	0.04	–0.01	C2-S1	Low	Hoji-Aziz village/Sayyidabad/Wardak	Karez	Rural
Af 3F	439	0.29	0.06	0.00	C2-S1	Low	CoAR compound, Moqur/Moqur/Ghazni	Dug well + bore	Urban
Af 4F	**2,042**	2.26	0.21	–9.37	C3-S1	Mod.	Nonga village/Nawa/Ghazni	Dug well	Urban
Af 5F	474	0.34	0.08	0.03	C2-S1	Low	Nr. CoAR compound, Moqur/Moqur/Ghazni	Dug well	Urban
Af 6F	**917**	1.13	0.36	–0.70	C3-S1	Mod.	Shahdo/Qalat/Zabul	Dug well + bore	Agricultural
Af 7F	**2,053**	3.10	0.48	–7.05	C3-S1	Mod.	Toora/Qalat/Zabul	Dug well	Agricultural
Af 8F	**1,980**	2.37	0.96	–3.59	C3-S1	Mod.	Korkaron/Qalat/Zabul	Dug well	Agricultural
Af 9F	487	0.91	0.10	0.30	C2-S1	Low	Sadukhan/Shinkai/Zabul	Karez	Rural
Af 10F	353	0.34	<0.02	–0.01	C2-S1	Low	Ghogi reservoir, Suhi/Shinkai/Zabul	Spring	Rural
Af 11F	**1,864**	3.95	**1.05**	**2.32**	C3-S1	High	Well 2, Mashoor/Dand/Kandahar	Dug well + bore	Agric./ (urban)
Af 12F	**2,291**	5.23	**1.40**	**2.06**	C4-S2	High	Well 1, Mashoor/Dand/Kandahar	Dug well + bore	Agricultural
Af 13F	**1,416**	3.29	0.40	0.10	C3-S1	Mod.	Karez Bibi village/Kushk-e-Kohna/Badghis	Spring	Urban/(rural)
Af 14F	**818**	2.12	0.25	–0.39	C3-S1	Mod.	Mazrah/Guzara/Herat	Bore (artesian)	Agricultural
Af 15F	**1,755**	1.55	**1.12**	–1.15	C3-S1	Mod.	German Club Street/Kabul City	Dug well	Urban

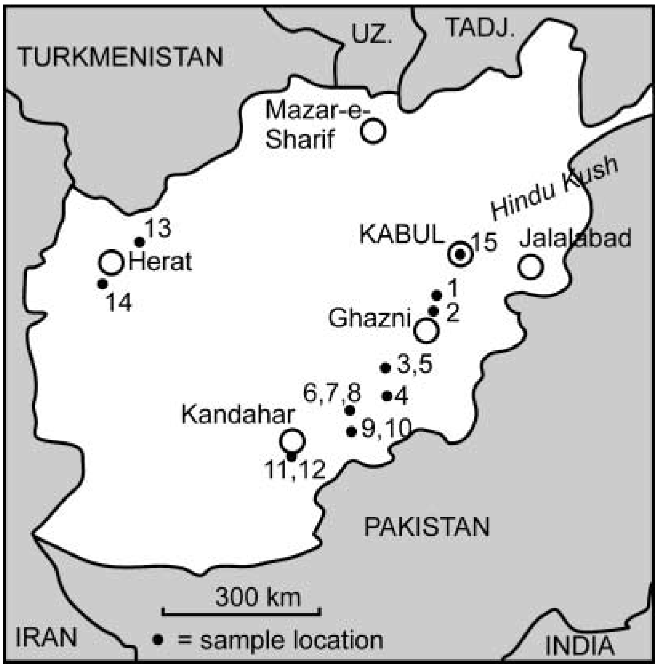

Fig. 4 Map of Afghanistan, showing approximate locations of water sample localities (Af1–15) described in text and Tables 6, 7. *UZ.* Uzbekistan, *TADJ.* Tadjikistan

1. Rain-fed agriculture in upland areas (e.g. upper valley slopes of Hazarajat), where crops are cultivated on extremely inclined ground. This land is fed only by direct precipitation. Around 80% of land in the Lal area of Ghor (Fig. 1) is rain-fed. Terracing is not commonly practised.

Table 8 Total number of springs, karezes and shallow wells; area under irrigation from each source. After data compiled from the Government of Afghanistan Statistical Yearbook 1980 (data for 1967–1968), after Shobair (2000)

	Total	Area per unit (ha)
Springs (number)	5,558	34
Area irrigated (Ha)	187,430	
Karezes (number)	6,741	25
Area irrigated (ha)	167,750	
Shallow wells (number)	8,595	1.4
Area irrigated (ha)	12,060	
Total irrigated by groundwater (Ha)	367,240	

2. Irrigation from surface waters (river-canal systems) is practised on land on and close to flood plains both in mountain and lowland valleys. Often, water is led off from the river channel upstream of the land to be irrigated by means of a canal or 'dewi', which follows the contours of the topography. Thus, irrigation in such areas can be achieved purely via gravity. In lowland areas, the use of pumping from the river is becoming increasingly common and many NGOs have assisted communities with the construction of river pumping intakes.
3. Irrigation from karezes and springs (traditional usage of groundwater)
4. Lift-irrigation from wells and boreholes. In Table 8 it can be seen that, in 1967–1968, most land was irrigated either by surface water or by groundwater from karezes or natural springs. Very little land was irrigated by wells and boreholes. This situation is rapidly changing. Pumped irrigation from dug wells and

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boreholes is a new technology and, although in overall terms it still accounts for a relatively modest share of total irrigated land, its use is growing explosively. This expansion is stimulated by the drought and, to some extent, by the activities of NGOs.

Of these four types of agricultural land, rain-fed agriculture has been most seriously decimated by drought conditions. Irrigation depending on karezes and springs has also been seriously affected, as these sources are highly vulnerable to small falls in water table. Several of the larger rivers continue to flow in drought years, though at a much-reduced rate, permitting some agricultural activity to continue. The situation will, however, become more critical if the current drought progresses. Irrigation from deep dug wells and boreholes is a relatively new phenomenon, which is expanding rapidly in the current drought conditions, partially promoted by NGOs. In many river valley flood plains, lift irrigation wells are being sunk to supplement or replace surface water irrigation

Some estimates place the efficiency of irrigation as low as 25–30% (Schimann 2000, SS Shobair, FAO, personal communication). The main reasons for inefficiency are:

- Leaking canals
- Losses to evaporation
- Improper levelling and terracing of irrigated land.

Springs

Springs may be used, via gravity flow, for irrigation purposes (e.g. in Hazarajat). Additionally, springs are used as drinking water sources, often via gravity flow in open channels that allow the possibility of contamination of the water prior to consumption. NGOs should ideally encourage the enclosure of such springs in sealed 'spring boxes' and pipe the water to a reservoir and thence to distribution points in the user community.

Karezes

The karez is a local form of 'qanat' (Ruden 1993). Afghan karezes are often very old, having been constructed several hundred years ago. They are typically located in proluvial deposits in mountain foothills, but can be constructed anywhere where the water table is relatively shallow and there is a consistent slope to the terrain.

Traditionally, karezes are commenced by digging a well at the upper end of the karez route. This may be up to 20 m deep before the water table is encountered. From this 'mother well' an underground karez tunnel is constructed with a shallow gradient downhill. Wells are dug at 20–30-m intervals along the karez route to allow access during construction. The gradient of the karez is less than that of the topography and, thus, the karez tunnel eventually intersects the ground surface and a flow of groundwater emerges. Karezes may be several kilometres long and have several branches.

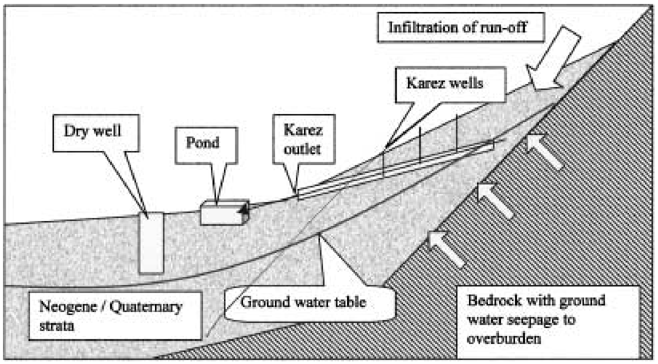

Fig. 5 Schematic cross section of a typical karez (after Soldal 2000)

Karezes (Fig. 5) are used both for irrigation and drinking water. They essentially skim water off the top of the water table. This means that, in effect, it is practically impossible to overexploit an aquifer using karezes. On the negative side, they are extremely vulnerable to even relatively small drops in the water table caused by climatic factors or pumping of nearby wells.

Karez tunnels are often unsupported, or may have stone roof supports. Due to collapses, karezes require regular cleaning and maintenance, and after the past 20 years of war in Afghanistan, traditional maintenance routines have been disrupted. NGOs have thus focussed on reinstating karez rehabilitation programmes. In most cases, karez cleaning has resulted in increased discharges. To improve karez stability, NGOs have started programmes to line access shafts with concrete rings and masonry and to line tunnels with reinforced concrete ellipses. Rehabilitation of karezes is, however, expensive, time-consuming and the yield improvement is often low compared with construction of a new well.

It should also be noted that, in the portion of the karez that is below the water table, the karez will gain groundwater inflow. In the portion of the karez above the water table, losses will occur. This situation could conceivably be improved by lining the unsaturated portion of the karez with blank pipe. Such lining of karezes with pipe would also reduce the amount of maintenance necessary.

Dug wells

Dug wells may be used for drinking water, in which case they are typically fitted with a bucket and pulley or an Afridev-type handpump (Davis and Lambert 1995). Such wells will often be dug at ca. 1.5 m diameter and lined either with stonemasonry or with concrete rings. In stable soils they may even be unlined. Depths can reach some 40 m. Dug wells for drinking water seldom penetrate more than 2 m below the original water table. Thus, they also abstract water from the very top of the aquifer and are vulnerable to climate-related or abstraction-related declines in water table. Wells lined with concrete rings can be deepened by under-digging and then sinking

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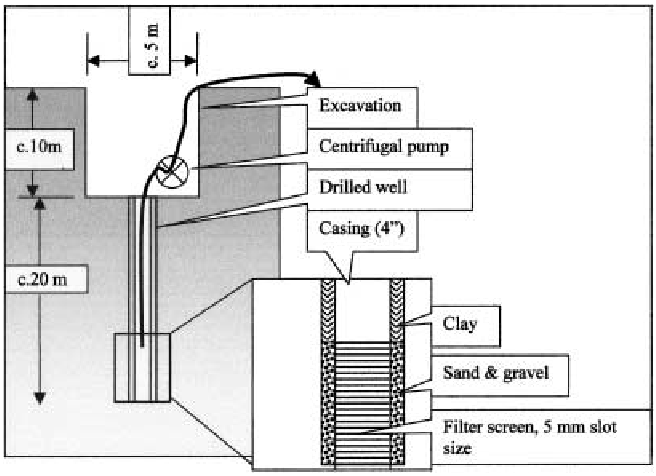

Fig. 6 Schematic diagram of a typical dug lift-irrigation well, deepened by use of a borehole (after Soldal 2000)

the concrete caisson string, unlike wells lined with masonry.

Dug wells for lift irrigation are typically some 4–5 m in diameter and exploited by 15–20 Hp diesel suction pumps, mounted on platforms close to the water table. Lining types may vary, although a favoured design involves lining with brick masonry at 5-m diameter down to the water table. Below the water table a caisson structure of lesser diameter (say, 4 m), comprising either concrete rings or brick masonry on top of a single concrete ring, is sunk.

The use of suction pumps for dewatering allows large-diameter lift irrigation wells to be constructed to a maximum of some 6 m below the original water table. This modest penetration of the aquifer renders them somewhat susceptible to declines in water table because of drought. Wells fitted with an internal caisson structure may be deepened by digging. Otherwise, lift irrigation wells may be deepened by drilling boreholes in the well base (Fig. 6).

The use of diesel suction pumps means that drawdowns in lift irrigation wells are unlikely to exceed 5–6 m. Net yields may vary from <2 l s^{-1} to around 5 l s^{-1}, and pumping may be continuous or based on drawdown/recovery cycles.

Drilled boreholes

Boreholes are typically drilled using percussion techniques in Neogene and Quaternary sediments. Boreholes for drinking water are typically drilled at 150–200 mm diameter and fitted with 100-mm casing. They are often drilled to 15–20 m below the water table and fitted with an Afridev hand pump. Because the borehole penetrates deeper below the water table than a dug well, boreholes are less susceptible to declines in water table. If fitted with a hand pump, the amounts of water able to be abstracted are of little significance in terms of the overall aquifer water balance.

Boreholes may also be drilled for irrigation purposes and fitted either with a submersible pump or a surface-mounted spindle pump. A typical NGO-funded borehole at Qala-e-Fatoo, just south of Kabul (Fig. 1), comprises a 61.5-m-deep irrigation borehole, completed with a 450-mm drilled diameter and 250-mm casing string. Positive displacement pumps mean that the drawdown and yield are not limited by available suction. Such boreholes, thus, can achieve very large yields and/or substantial drawdowns.

In some areas, artesian aquifer horizons may exist at depth. In this case, pumps are not required in boreholes, they simply overflow under their own pressure. In the Mazrah area of Guzara District (Herat, Fig. 1), private irrigation boreholes drilled to 60–65 m deep encounter artesian resources of fresh groundwater. Typical yields of some 5 l s^{-1} flow uncontrolled 24 h day^{-1} from these boreholes. Such uncontrolled overflow is extremely undesirable from a water resource point of view.

Selected Case Studies

Banks (2001) uses a number of case studies to document the social and hydrological impacts of increased usage of pumped groundwater in irrigation. In this paper, two case studies are briefly described.

Rahmat Abad Village, Chaharasiab District, Kabul Province

Here, irrigation water used to be supplied by canals from the Kabul and Logar River systems. An NGO has assisted in the construction of at least two 5-m diameter dug irrigation wells, serving five families (prioritised on the basis of them being returning refugees) and ca. 4 ha irrigated land each. Wells are pumped for four 2-h periods per day (8 h day^{-1} total) at the pump capacity of ca. 4–5 l s^{-1}. The water table has fallen by 1 m in the last year in both wells, and the wells will be deepened by hand. The farmers indicate that they will revert to using surface water following the current drought, provided that enough is available (pumping costs make use of groundwater an expensive option).

The NGO has a policy of not placing lift irrigation wells <200 m from other wells or karezes, nor placing wells <30 m from latrines. Recently, however, a new private irrigation well has been constructed only 150 m away from the NGO's first well, and a similar private well has been constructed only 120 m from the NGO's second well. It is likely that NGO's original two lift irrigation wells 'advertised' the technology and stimulated other private farmers to construct their own wells, without adhering to the NGO's guidelines on well spacing. This case illustrates the danger that NGO projects involving groundwater irrigation in needy cases may actually be promoting a potentially unsustainable technology to the private sector.

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Mashoor Area, Dand District, Kandahar Province

In this area, just south of Kandahar, irrigation has traditionally been accomplished by use of river water. Before the current drought, the water table was only 2 m below ground level (b.g.l.). Two dug irrigation wells (to 9–10 m depth) with boreholes in their base (to a total depth of ca. 30 m) were sunk with NGO support in the year 2000.

The first well serves some seven families. The well may pump for up to 10 days continuously. The nearest other irrigation well is some 500–600 m away. The water table is currently at 9–10 m b.g.l. The second well serves 12 families and irrigates some 14 ha of land. The estimated pump discharge is 4–5 l s^{-1}, pumping typically 5–10 h day^{-1}. The water table is now at some 12 m b.g.l. and the pump has recently had to be placed at the very base of the dug well at 9 m b.g.l.

Analyses (Table 7) have also documented that the water quality from these wells is likely to be unsuitable for long-term irrigation use (risk of salinisation/alkalisation, possibly boron toxicity).

Drinking water in the village is typically from dug wells some 13–14 m deep, which dry up when the irrigation wells are pumping, but which recover when the pumping stops. As these dug wells are owned by the same families operating the irrigation wells, the villagers accept this as a price worth paying for irrigation water. Families also use the irrigation wells for drinking water.

The families plan to continue to use the new wells even after the drought breaks, potentially increasing the total area of land under irrigation. In the same area, several other wells have also been sunk to the same aquifer horizon, and a progressive groundwater decline is expected (Soldal 2000).

This case documents the derogation of drinking water wells by irrigation wells, over a distance of tens/hundreds of metres. This can be acceptable provided that the derogated party also receives the benefit of the irrigation well. The case also highlights the fact that provision of irrigation wells is usually not a temporary measure: families will not necessarily revert to traditional irrigation practices once a drought breaks. Also, unless groundwater is adequately analysed, NGOs may inadvertently promote a water source that carries a long-term risk of soil salinisation.

Recommendations for Sustainable Use of Groundwater

Derogation

The case studies presented by Banks (2001) document that derogation by lift irrigation wells in Quaternary and Neogene aquifer complexes occurs over a range (radius of influence) of at least 100 m.

Afghan hydrogeologists (Engineer Ehsanullah, NPO, personal communication) utilise the following formula for calculating the radius of influence (R) of wells. The theoretical basis for the formula is unclear, but it is believed to derive from the Soviet hydrogeological tradition: $R=C.s_w.(K)^{0.5}$, where s_w = drawdown in pumping well (m), K = hydraulic conductivity (m day^{-1}), R = radius of influence of pumping (m). and C is a factor ranging from 2–10, depending on geological circumstances.

Table 9 Radii of influence (m) of lift irrigation wells, with assumed drawdowns of 6 m, using Soviet formulae in common use in Afghanistan

Variant of formula	Hydraulic conductivity (K)	
	K = 30 m/day	K = 60 m/day
C = 2	66 m	93 m
C = 10	329 m	465 m

Table 10 Calculated drawdown (m) at various distance (r) from an irrigation well pumping at 5 l/s after 0.5 and 10 days, with aquifer hydraulic conductivity =30 and 60 m/day. Aquifer thickness is assumed to be 6 m, specific yield =10%

r (m)	K =30 m/day, *t*=0.5 day	K =60 m/day, *t*=0.5 day	K =30 m/day, *t*=10 day	K =60 m/day, *t*=10 day
10	1.01	0.57	1.59	0.86
20	0.75	0.44	1.32	0.73
50	0.41	0.27	0.97	0.55
100	0.18	0.15	0.71	0.42
150	0.08	0.08	0.56	0.34
200	0.03	0.05	0.45	0.29
250	0.01	0.03	0.37	0.25
300	0.00	0.01	0.31	0.22
350	0.00	0.01	0.26	0.19
400		0.00	0.22	0.17
450		0.00	0.18	0.15
500		0.00	0.15	0.13
750			0.06	0.07
1,000			0.02	0.04

Given that the hydraulic conductivities of alluvial and proluvial strata are believed to be in the range 30–60 m day^{-1}, and given that the maximum achievable drawdown with a diesel suction pump is some 6 m, Table 9 suggests that, with worst case assumptions, the radius of influence of a lift irrigation well could be as large as almost 500 m.

The Theis equation (Theis 1935) calculates the drawdown (s) at radius (r) from a pumping well at time (t) after pumping at a rate Q commenced. For the purposes of calculation, we will assume that:

- Q=5 l s^{-1} (0.005 m^3 s^{-1})
- Hydraulic conductivity =30–60 m day^{-1}
- Effective aquifer thickness =6 m
- Transmissivity =180–360 m^2 day^{-1}
- Storage coefficient =0.01
- t=12 h (12 h on/12 h off daily pumping cycle)
- or t=10 days (prolonged pumping)

It will be seen (Table 10) that the drawdown is less than 10 cm at distances of ca. 130 m after 12 h pumping. After 10 days, however, the cone of depression (based on s <10 cm) has expanded to just over 500 m. In summary,

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therefore, both the Soviet formulae and the Theis equation suggest that an irrigation well can have a radius of influence of around 500 m. Irrigation wells should thus be situated no less than 500 m from other springs, wells or karezes, as a general rule.

Over-Abstraction

It has been seen above, that an areally distributed recharge of 50–150 mm year^{-1} corresponds to a maximum renewable resource of 1.6–4.8 l s^{-1} km^{-2} in lowland Neogene/Quaternary sediments. Clearly, it is not possible to abstract 100% of this renewable resource without causing unacceptable water table declines or environmental impacts. We can assume that only a fraction of this is available for abstraction, often estimated as between 30 to 65%, according to differing workers in, for example, Chile (Muñoz and Fernández 2001) and the UK [Environment Agency (Midlands), UK, personal communication]. Thus, the exploitable resource could be as little as 0.5 l s^{-1} km^{-2} in some areas. For the purpose of a 'first pass' policy, a reasonably conservative assumption has been made that 30 mm year^{-1} (1 l s^{-1} km^{-2}) can be abstracted without serious consequences for regional water table level or environment in lowland Neogene/Quaternary sediments. In other words, wells should be sited such that the average long-term abstraction density does not exceed 1 l s^{-1} km^{-2}. Assuming a hexagonal distribution of wells with an average abstraction rate of 2.5 l s^{-1}, the wells should be situated 1,700 m apart to achieve this density. If we make alternative assumptions about sustainable exploitable resources, average well spacings are found in Table 11. Of course, if the arrangement of wells is not hexagonal (and it seldom will be), and if the wells are pumped at a lower rate or used for a limited period (e.g. just during drought years), a closer spacing can be acceptable. From the above, one might conclude that, as a rule of thumb, in order to avoid over-abstraction in a well-field of irrigation wells, spacings between irrigation wells should be on the order of at least 1 km. Ideally, calculations should be made of abstraction density in each individual case.

It should be noted that the above calculations do not assume that any of the water abstracted for irrigation is recycled to the aquifer via infiltration recharge. Because of the extremely high evapotranspiration rates it is likely that a large proportion of the water applied by flooding of fields is lost via evapotranspiration. If, however, it can be demonstrated that a significant proportion of water is returned to the aquifer via infiltration from alluvial fans, canals or fields, then higher abstraction densities can be allowed.

Conclusions and Recommendations

Based on the extremely limited amount of data available, NGOs are recommended to adhere to the following code of practice for exploitation of groundwater in Afghanistan, in addition to requirements imposed by Afghanistan's Water Law (Schimann 2000):

Table 11 Average irrigation well spacings (L) to achieve given abstraction densities, assuming an abstraction of 2.5 l/s on average per well, and a hexagonal arrangement of wells

Abstraction density (l s^{-1} km^{-2})	L (km) (assuming 2.5 l s^{-1} per well)
0.5	2.40
1	1.70
1.5	1.39
2	1.20
2.5	1.07
3	0.98

Part A: general guidelines to avoid over-abstraction

1. NGOs need to work with rural communities, private abstractors and government to develop a mutual understanding of water-management issues, when implementing new water supplies. NGOs should carry out their activities in the water-supply sector with the full involvement and permission of the relevant government authorities.
2. The use of groundwater, abstracted by a bucket or hand pump, for drinking water purposes, has little significance in terms of aquifer water balance.
3. There should be a presumption, however, against the use of motor-pumped or artesian groundwater for irrigation purposes by NGOs, until a proper management framework exists to license abstractions.
4. If use of motor-pumped or artesian groundwater for irrigation is absolutely necessary to prevent unacceptable poverty or displacement of populations from their homes, the guidelines in part B should be observed.
5. NGOs should give attention to improving the efficiency of irrigation systems to reduce losses from leakage and evaporation (Schimann 2000).

Part B: specific guidelines to avoid over-abstraction

– 6. Usage of motor-pumped or artesian groundwater for irrigation should only be temporary, during a drought period. The recipient community should revert to traditional sources (surface waters, karezes, springs) following the drought. This may be achieved by:
  – promoting hydrogeological awareness within the recipient community.
  – signing a contract between NGO and community that usage of motor-pumped groundwater will cease when the drought breaks
  – if the above are not effective, the NGO should consider providing diesel pumps and other equipment as temporary loans, rather than as permanent donations.

- 7. All artesian wells must be fitted with a control valve and usage strictly regulated, by agreement with the community according to points 6–12.
- 8. Where NGOs plan to use motor-pumped or artesian groundwater for irrigation, a simple risk assessment should be carried out. This will include:

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– identification of all wells, springs and karezes within 1 km of the proposed well
– assessment of the existing density of abstraction (l s^{-1} km^{-2}) within a 3-km radius (28 km^2) of the proposed well

- 9. The proposed irrigation well should not be within 500 m of existing wells, springs or karezes, in order to avoid derogation of sources. It should be remembered that wells may be constructed in an area free of existing wells and karezes (e.g. a river flood plain) and water piped or channelled in to the fields or village where it is to be used.
- 10. The irrigation well can only be constructed within 500 m of such sources if:
  – the owners of the wells, springs or karezes are the same community that will benefit from the irrigation water, and have all agreed that derogation is acceptable, or
  – the owners of wells, springs or karezes have been offered and accepted compensation for derogation in terms of well deepening or provision of alternative water sources, or
  – a cogent hydrogeological argument is forwarded, and accepted by the funding agency and the local community, that the local hydrogeological conditions will prevent derogation of nearby sources.

- 11. New motor-pumped or artesian wells for irrigation should not be constructed if the long-term net abstraction density within a 3-km radius of the new well will exceed 1 l s^{-1} km^{-2} (i.e. total abstraction within that 3-km radius should not exceed a long-term average of 28 l s^{-1}). Exceptions can be made where:
  – the proposed well is known to be only temporary, to be decommissioned after cessation of drought conditions
  – a cogent hydrogeological argument is put forward to demonstrate that sufficient recharge occurs to support a greater abstraction density (e.g. proximity of infiltrating river).

- 12. An abstraction density lower than 1 l s^{-1} km^{-2} may be appropriate in low-recharge (e.g. desert) areas, far from mountain recharge areas.

Part C: water quality

- 13. All wells, springs or karezes used for drinking purposes should be located at least 30 m from latrines or other pollution sources (cattle watering holes, manure stockpiles, rubbish tips etc.)
- 14. In villages or towns where the density of latrines or other pollution sources is high, this distance to groundwater supply sources should be increased. In such cases, consideration should be given to locating the drinking water source outside and up-gradient of the village, even though this may be less convenient for the consumers (this issue should be discussed openly in a community meeting). The pollution potential from such sources is highlighted by elevated nitrate concentrations found in wells in Nonga village and Kabul city during this study. NGOs should also investigate alternative sanitation solutions to minimise contaminant fluxes to groundwater (Banks et al. 2002a).
- 15. Demarcation of wellhead, karez and spring protection zones should be promoted (typically 30 m radius around the source).
- 16. Ideally, different users should be separated from the source. For example, flow from a spring or karez can be piped to a reservoir and thence to distribution points for drinking water. A separate pipe can convey water from the reservoir to a livestock watering point.
- 17. Use of groundwater for irrigation over a prolonged period may carry a risk of soil and groundwater salinisation. The salinity (and ideally also the sodium absorption ratio) of water to be used for irrigation should be determined. As a general rule, groundwater used for irrigation in Afghanistan should have a salinity in class C2 or lower (EC <750 μS cm^{-1}), and an SAR in class S2 or lower, unless drainage can be shown to be adequate to prevent accumulation of salts in the soil.

Because of the need for a simple, easily communicated policy it is likely that some aspects of these recommendation, particularly regarding sustainable abstraction density, will attract criticism for being too conservative and simplistic. It is recognised that, in some areas, recharge of irrigation water or mountain runoff may increase aquifer recharge to a level permitting significantly greater abstraction than is recommended here, and vice-versa in desert areas. These recommendations may be modified as more information becomes available. They may also be tailored to local conditions, provided that adequate site-specific hydrogeological information is available to support such modifications.

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