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Sustainability and management of groundwater resources in the Minchin Basin, Gansu Province

Report to Royal Society - end of link report (PEK/0992/306)

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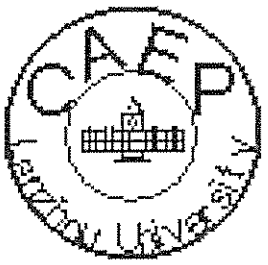

Sustainability and management of groundwater resources in the Minchin Basin, Gansu Province

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Sustainability and management of groundwater resources in the Minchin Basin, Gansu Province

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Introduction

This project is concerned with a study of the sustainability of irrigation agriculture in the Minqin Basin in Gansu Province, China. In this region agriculture is dependent on water supply from groundwater resources. However, recharge rates from precipitation are very low and surface flow from the Tibetan Plateau is intercepted upstream to provide water for the city of Wuwei and its region. Future climate change may further decrease supply. Already many shallow wells have been exhausted or abandoned because of salinity problems, and new wells are now being drilled to pump water from depths up to 300m.

In this project we have three main goals:

- To assess the quantity and quality of groundwater in the Minqin Basin.
- To understand how local people manage water and how they make decisions about water usage.
- To understand natural variability in the climate system.

To address these issues the study area of the project extends beyond the Minqin Basin to include the Qinghai Hu Basin in the Tibetan Plateau to the south and the Badain Jaran Desert to the north-west (Figure 1).

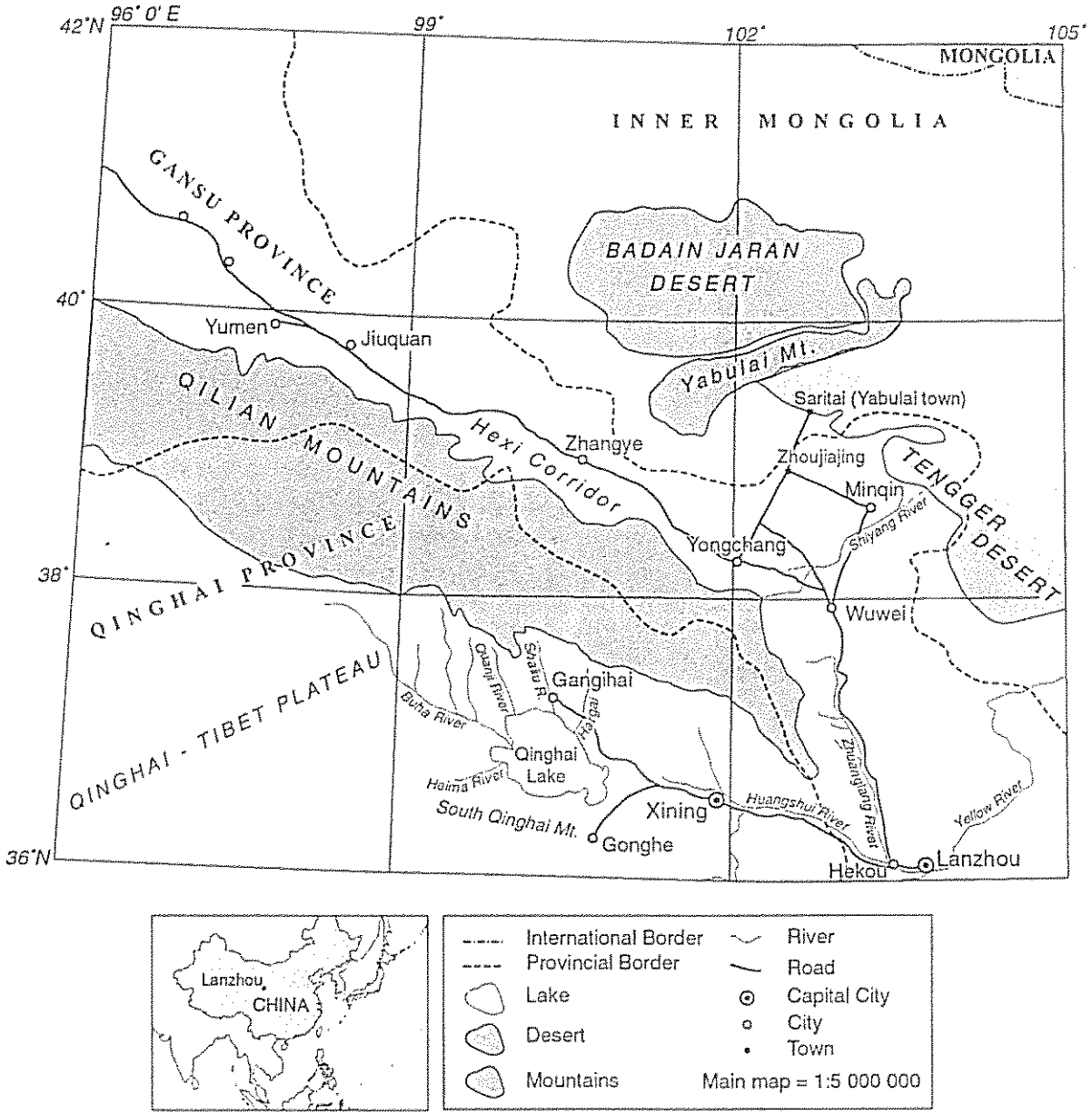

Figure 1. Study area showing the location of the Minqin Basin and reference sites in the Tibetan Plateau (Qinghai Hu) and the Badain Jaran Desert.

Assessment of quality and age of groundwater in the Minqin Basin and Badain Jaran Desert

The scientific work has concentrated on the problems of the origins, age, quality and availability of groundwater in the Minqin Basin. However some additional results have been also obtained from the area of the Badain Jaran Desert, some 200 km to the northwest. These results were obtained over two field seasons in summer 1999 and 2000.

The Minqin Basin

Work in the Minqin Basin has included several different strands. Recent information on the surface and groundwater resources was available in several recent Chinese publications and these data were summarized as the basis for the water balance in the present work. Human activity, characterised by large-scale water resources development and rapid population

growth in the past 50 years has led to tremendous changes in the groundwater regime and changes in the fragile ecology. Groundwater recharge from the Shiyang River has been reduced by 50% and water levels in wells in the Minqin Basin have been widely reduced by 3~5 metres with a maximum of 50m. There are currently 14,200 boreholes in the basin and groundwater abstraction has now reached 1.16 x 10^9 m^3yr^{-1}, significantly exceeding the 0.41 x 10^9 m^3yr^{-1} available for recharge. Thus, springs have dried up, natural flow to the terminal lakes has long ceased and salinization of the upper aquifer horizons has taken place.

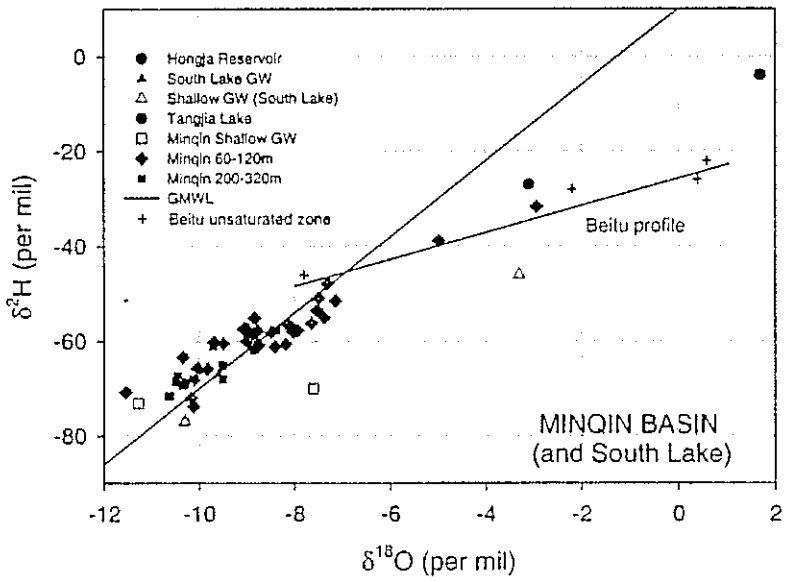

Figure 2a. Stable isotope ratios in Minqin Basin. The composition of unsaturated zone profile waters are shown from Beitu.

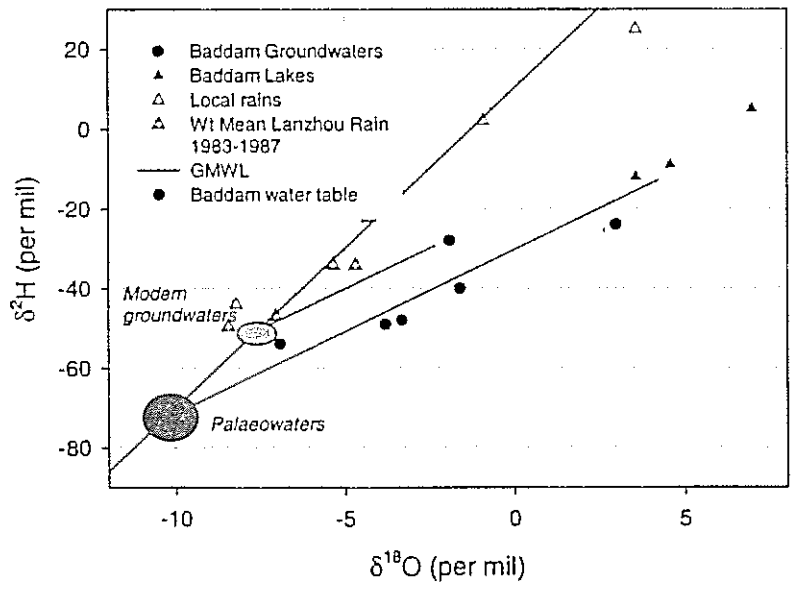

Figure 2b. Stable isotope ratios in Baddam Desert. The compositions of unsaturated zone profile waters are shown from Baoritelegai.

Field work was conducted in the first two years of the programme and a comprehensive series of samples was collected for chemistry, stable isotopes, radiocarbon and dissolved noble gases. A profile in the unsaturated zone was constructed to extract moisture for chloride analysis to estimate the direct (diffuse) recharge. Direct rainfall recharge was found to be 2 mm/yr in the Minqin Basin area (Beitu).

A clear picture is now emerging of the extent of recharge of groundwaters in the basin both now and in the past from the radiocarbon and stable isotope data. The general picture of the groundwater history can be read from the stable isotope ($\delta^{18}O$ vs δ^2H) plot (Figure 2a). The weighted mean composition of local rainfall at Zhangye is –6.8 per mil and this composition matches the intercept of the unsaturated zone moisture data from the Beitu profile on the Global Meteoric Water Line (GMWL) and provides the reference point for modern local waters; the Hongya reservoir, slightly evaporated, has a similar composition. In comparison with these the groundwaters in the Minqin Basin are generally more negative and the deepest waters (100-300m) are notably depleted in the heavy isotopes, by 3 to 4 per mil, suggestive of cooler recharge conditions than at the present day.

The groundwaters exhibit a range of radiocarbon activities from 0.66 to 85.0 percent modern carbon. The oldest groundwaters are the deepest ones with ages of the order 30 ka. Therefore the basin contains mainly fossil waters at depth with some mixture with water supplied by the Shiyang River in the recent past as indicated by the spectrum of isotopic data. At present this water is not being renewed. It is, however, of good chemical quality (except in the north of the basin where saline waters from the former lake are being drawn down) and in the present study full chemical analyses were carried out for potability assessment as well as origin. The strontium isotope data are suggesting that a different recharge source from the north may have taken place in the late Pleistocene.

The noble gas results are awaited since these will indicate for the first time what the temperature difference was at the time of recharge to the aquifer compared to the present day. This has global interest in terms of the amount of cooling that took place at the time of the last glaciation and also will link with the other palaeoclimatic data from the project.

Badain Jaran Desert

Interpretation of results on regional groundwaters from the Badain Jaran Desert (chemical and stable isotopes) now show that no effective modern recharge is taking place, but that the lakes are supported by regional groundwater flow, the age of the water being late Pleistocene as inferred from the isotopic compositions. The very small rates of recharge that actually do occur, however, allow an archive of recharge history to be reconstructed of the past 700 years.

The main results are summarized in Figure 2b where the evolution of groundwaters is clearly indicated by their isotopic compositions. The unsaturated zone profile provides the composition of modern water which intercepts the global meteoric water line (GMWL) at around –7 per mil. This is consistent with measured heavy rains in the area (as well as the Zhangye mean values quoted above). In sharp contrast all the shallow groundwaters show a slightly evaporated isotopic signature and lie on a line with slope about 3 indicating evaporative enrichment, as do the lakes themselves. These waters however intercept the GMWL at around –10 per mil, indicative of a palaeowater origin. No radiocarbon samples were taken (due to possible exchange with modern CO_2) but an age in excess of 12ka is inferred. The recharge source must be somewhere in the mountains to the south.

The shallow profile indicates that a very small amount of modern recharge is taking place (1.3 mm/yr) and that over 500 yr of past climatic information is recorded in the unsaturated zone to 7m depth. The interpreted profile (Figure 3) suggests that oscillations between wet and dry conditions have taken place over the last half century, although at present no independent historical data or other archives are available for comparison.

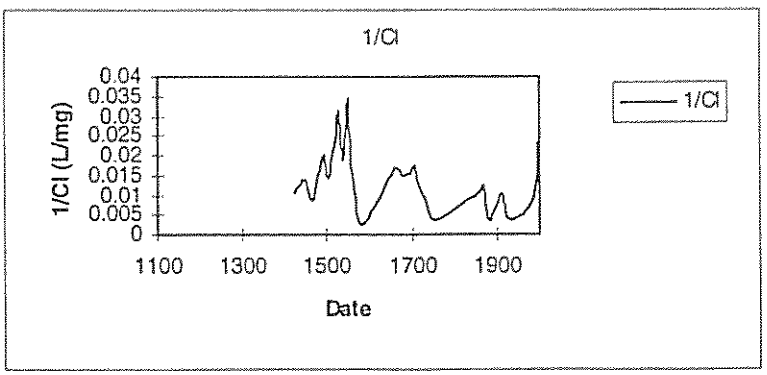

Figure 3. Past climatic data obtained from the unsaturated zone moisture of the Baoritelegai Lake area, Badain Jaran; 1/Cl is proportional to wetter periods.

Farming Practices and Attitudes Towards Water Use in the Minqin Basin

Farming practices and attitudes towards water were explored during both field visits in 1999 and 2000. During the first visit a research strategy was developed, which combined quantitative and qualitative social science approaches to understanding farming practices in Minqin.

Pilot semi-structured interviews with farming households and also local doctors indicated a high degree of concern about water-related issues ranging from agricultural production to individual health. Anxieties about the permanence of the water supplies, and appreciation of the problems of increasing salinity were evident. Domestic water use, especially where houses had to collect water from wells, was low and burdensome for women and children required to collect it. A pilot questionnaire was drafted, which covered all the issues raised in the informal interviews, using the language and concepts of the informants. In addition to the themes outlined above, the questionnaire also attempted to collect data on household characteristics, patterns of expenditure, details of domestic and farming practices and water budgets. Open-ended questions were included to explore people's experiences of climate change, their lay knowledge of groundwater variations, and also additional pressures on water use that might arise if provision became easier.

Following an initial tranche of questionnaire-based interviews a survey of villages was undertaken across the Minqin Basin where wells were sampled. This work was completed between November 25th and December 5th 2000. Approximately 200 questionnaires were completed.

The results of the questionnaire survey and experiences of the first field visit were used to inform the design of the second field visit. In particular, a different methodological approach was adopted to understand water resource management policy in Minqin and also to explore gender issues relating to water use. In September 2000, 47 semi-structured interviews were carried out with farming households, including women, water managers, electricity managers, and senior administrative officials for the Minqin area.

A total of 33 interviews with farmers and members of their households, including 12 women, were completed near Minqin city (north and south), villages bordering the Langpoquan mountains and North Lake. A small number of farmers were also interviewed in South Lake. The selection of villages reflected the sites were wells were being sampled.

Discussions with farmers focused on: farming and irrigation, water conservation techniques, impacts on household, climate change and the future of development and farming in Minqin. Female members of the household were also asked about the effects of water on health and their families. The findings reinforce and extend many of the results from the fieldwork undertaken.

In terms of climate change, almost all interviewees reported a change in the local weather patterns over the past 10 years, particularly less rainfall, higher summer temperatures, increased frequency and intensity of desert sand storms and higher wind speeds. Storm damage to some crops, particularly melon, was reported, but remains unquantified.

In recent years, agricultural production has been characterised by a switch to cash crops, e.g., melon, at the expense of grain crops. Nonetheless, falling market prices for all crops is reducing farm incomes. This situation is particularly acute in the North Lake area, where officials estimate up to 40% of land has been abandoned in some villages due to lack of good quality water and salinization of soil. Farmers, and their families, are moving to other parts of Minqin (including South Lake) and in some cases outside the basin completely, although the exact numbers remain uncertain.

Farming in areas to the north and south of Minqin city remain relatively prosperous, but farmers report a lowering of the water table (estimated at approximately 1m/yr). There is a slight, but notable deterioration of water quality. Land supply is the main constraint on production rather than access to sufficient water resources of suitable quality.

In response to land and water supply issues in other parts of the Minqin Basin, farmers are 'commuting' to South Lake and opening up new areas for cultivation. This represents a significant cost in terms of time and labour (journey time is typically 2-3 hours one way over rough roads). There is some evidence that traditional camel and sheep grazing lands are under threat. The water table in this area is reported to have fallen by 3-4 metres in the last 5 years, although farmers did not report any deterioration in water quality. It is likely that pressure on water resources in South Lake will continue to increase in the next 10 years.

The system for managing water resources in the Minqin Basin is complex and is the focus of increasing tension between farmers and various authorities. Up to about 1995, farmers regularly used a combination of surface water and groundwater to irrigate crops. Surface water from the Hongya reservoir was used several times a year, especially during the growing season. Groundwater sources were generally used to supplement surface water irrigation.

In the past few decades, the practice of irrigating using a combination of surface and groundwater has diminished. This is the result of reduced supply and changes in demand. The supply of water flowing into the Minqin Basin from the Shiyang River has been steadily reducing from approximately 4.5×10^8 m^3 in 1960 to 1.5×10^8 m^3 in 1995. The reduction is primarily due to abstraction pressures upstream and downstream of the Minqin Basin.

With the reduction in surface water supply, farmers in the Minqin Basin report that the price of surface water has almost doubled in relation to groundwater, so many farmers are discouraged from using surface water for irrigation. Additionally, farmers report that water managers will only permit surface water irrigation if the villages concerned have installed concrete lined channels to reduce wastage through seepage. This policy, although designed to conserve water, effectively excludes the majority of villages, particularly those in the North Lake area, from access to surface water, regardless of price per unit. Official figures for the whole of Minqin indicate that the area of irrigated land has halved since 1960, while the area of cultivated land has remained reasonably constant. This suggests that farmers in Minqin have become heavily reliant on groundwater for crop production.

Whether unwilling or unable to use surface water, farmers still recognise that using surface water on the fields is important to reduce salt build-up in the soil and maintain crop yield. Farmers in North Lake report a fall in yield due to lack of surface water irrigation. As incomes fall with reduced yield, it initiates a cycle of positive feedback so that farmers, increasingly unable to pay for surface water *and* also irrigation efficiency improvements, are eventually forced to rely almost exclusively on groundwater supplies for crop irrigation, leading to further reductions in yield.

In the North Lake area, where water quality in shallow wells is particularly poor, village leaders suggest that up to 40% of land has been abandoned in some villages as a direct result of water shortages and soil salinization arising from lack of surface water. Reports of depopulation were common among interviewees in the North Lake area and seem to be supported by broad trends in population change documented in official statistics. For example, in DongHu Zhen, official figures show that some 5000 people have moved out and just over 1700 people moved into the area during the period 1991-1999. While it is very likely that water supply problems are a major factor in explaining these population changes, more detailed research is required to determine the scale and impact of other causal factors (eg changes in agricultural subsidies).

Interviews with water officials at the local and basin level reveal that they are aware of supply problems and farmers' concerns, but are also mindful that current farm practices are unsustainable in the long term. A number of initiatives have been introduced to reduce demand for water including a 'new for old' licensing system for wells. The effectiveness of this measure is questionable as farmers report being able to obtain licences to open new and deeper wells and close shallower, and often unpotable, wells with relative ease.

It is also apparent that demand for water is also being limited by daily interruptions to the electricity supply, thereby halting groundwater pumping. Many farmers interviewed during the course of the fieldwork reported that the electricity supply is cut every other day during the summer months. The research team also observed a number of farmers in different parts of the basin making electrical circuits to overhead power lines suggesting that some form of electricity rationing is in place on a regular and known basis. Interviews with the electricity and water managers suggest that power supply interruptions are not an explicit water management policy. The electricity manager was adamant that the interruptions in the power supply to farmers were due to insufficient generating capacity, but these would be resolved within three years as additional power stations were built in the region.

Irrespective of whether the supply of electricity is being deliberately managed to reduce demand for groundwater, farmers are responding by increasing the density of wells in villages and on farms to be able to irrigate the same area of land in the reduced time available. Although increasing the density of wells effectively restores the status quo at present, the prospect of an increased number of wells and a *continuous* electricity supply over the next three to five years can only serve to increase pressure on groundwater resources.

The reduction in surface water supply, increased costs. stipulations on irrigation channel construction and cuts in the electricity supply is creating considerable friction between farmers and the water and electricity managers in Minqin. Farmers are not supportive of 'imposed' measures and, with declining farm incomes, are also either unwilling or unable to accept the higher cost of using surface water despite recognising the importance of using surface water to maintain soil fertility and crop yield. Water managers, although sympathetic, are unwilling to increase surface water irrigation volumes until villages and farmers are more water efficient.

The use of water conservation techniques varies across the Minqin Basin. In the more prosperous farming areas around Minqin city, the state has funded a small number of 'model' water conservation schemes, mostly involving use of concrete lined irrigation channels to reduce leakage. It was difficult to determine what effect these initiatives have had on improving efficiency of water use because farmers were generally ambivalent or openly resentful about these initiatives. Some were also concerned about the cost implications of maintaining the linings in the long term. During field visits in 2000, the research team observed that a number of the concrete channels were damaged. It remains to be seen whether this particular initiative will be effective in the long-term and whether voluntary uptake widens to other parts of the basin.

At farm level, a variety of methods are used to conserve water. Use of plastic film on cash crops, particularly melons, is widespread. Farmers report this also helps to increase soil temperature. Most field boundaries are also raised to enable flood irrigation. Crude, but often locally effective, improvements to field irrigation channels are common, such as using polythene linings to reduce channel erosion and seepage. The research team saw no evidence of either any form of drip-irrigation technology or any supplementary on-farm rainfall storage areas.

In the context of reduced supply of surface water, unfavourable price differentials between surface and groundwater, and relatively ineffective demand management policies, the

research suggests that farmers, although aware of the problems of salinization, will increasingly be focused on meeting short-term needs using groundwater rather than longer-term sustainability of the water resource and farming system in the Minqin Basin.

The on-going impacts on households, farm and village prosperity are difficult to determine accurately. Many interviewees in the central and northern part of the basin report long term health problems, particularly persistent skin and stomach complaints. Interviews with health officials suggest that rises in other diseases e.g., cancer, may be related to demographic changes and/or increased use of fertilisers, pesticides and herbicides on crops. At a broader level, changing economic fortunes brought about by water and/or land supply problems are forcing farmers and their families to rent or move to new farming areas within the basin, placing increased stress on family roles and relations between family members.

Interviews with female members of households reveals that much of the burden to obtain water for the household falls on women and children. Although most villages have access to several wells, some interviewees in the northern part of the area report travelling five or six kilometres every three days to find potable water. This represents a considerable allocation of resources simply to secure drinking water. As expected, use of water within households is minimal (estimated to be less than 10% of total demand for water in Minqin) even in the more prosperous farming areas near to Minqin city where some farmers have installed a single tap in the courtyard of the household.

In the long term, farmers were keen to be able to provide for their children's education by ensuring the farms were profitable. Alongside depopulation pressures, the relationship between farm incomes, water availability and access to education will be central in determining long term social impacts of water scarcity. More research is needed on the current and potential scale of this issue.

Since the fieldwork was completed, the Chinese part of the research team report that some 50 million m^3 of water from the Yellow River has been imported into the basin to supplement storage in the Hongya reservoir under China's national water resource management strategy. This has increased the potential for irrigation in the basin, particularly the northern part. Although the price of surface water has risen overall, water managers report that irrigation using surface water has increased considerably as a result of increased supply. There are reports that farmers are now moving back to the villages bordering the North Lake area and increasing the area of cultivated land. There are also anecdotal reports of farmers returning from South Lake to farm in the North Lake area. Although this shift would suggest that availability, rather than the price, of water is the key limiting factor, in reality the picture is probably more complex. Farmers near Minqin are still reliant on groundwater since surface water is relatively more expensive than the cost of irrigation from wells. Despite increases in cultivated area in the North Lake area, farming in the basin remains unsustainable in the long term and also increasingly subject to future policy changes relating to mass transfers of water from river basins.

Climate Variability

Investigations of natural climatic variability are focused in three areas: the main project area of Minqin Basin, and the adjacent areas of Qinghai Hu in the Tibetan Plateau and the Badain Jaran Desert lakes. The climatic histories were recovered by documented changes in the lake sediment record from Qinghai Hu (c. last 1,000 years), Badain Jaran (c. last 300 years), and the Minqin Basin (c. last 10,000 years) and by measurements of moisture in the unsaturated zone in the Badain Desert (see 3.1.1 above). These studies were designed to assess how groundwater recharge and water supply in the Minqin Basin is controlled by natural changes in climate.

Qinghai Hu

Investigations into the recent lake-sediment record from Qinghai Hu have been ongoing during the past three years (1999-2001) (for further details see the various end of year reports). These investigations were aimed initially at an assessment of natural climatic variability in the region over the past 250 years during the first stage, and then subsequently extended to the past 1,000 years. Oxygen and carbon isotope analyses of authigenic and biogenic (ostracod) carbonates were coupled with sedimentological analyses in order to reconstruct changes in the limnology of the lake. The oxygen isotope ($\delta^{18}O$) record is especially important because it is closely related to water volume in the lake, which is in turn controlled primarily by effective precipitation. For example, a fall in lake level and a shift to more positive $\delta^{18}O$ values is best explained by a reduction in effective precipitation. This can be largely attributed to variations in the balance of precipitation to evaporation, which are controlled by changes in monsoon circulation. The lake-sediment archive allows us to extend the climate record of the region for periods before instrumental records existed. The $\delta^{18}O$ record from the most recent part of the record, covering the past 250 years, shows marked variability, reflecting substantial changes in effective precipitation. In particular, the dramatic decline in lake level over the past *c.* 50 years (approx. the upper 5 cm within the sediment sequence) is represented by a marked positive shift in oxygen isotope values (Figure 4). Calibration of this information with a 40 year instrumental lake level data set highlights the value of $\delta^{18}O$ as a proxy indicator of lake level (Figure 5). Since the lake level highstand approximately 50 years ago, there has been a steady decline in lake volume, suggesting that the climate has become more arid. Recharge of groundwater in the region will, therefore, have been greatly reduced.

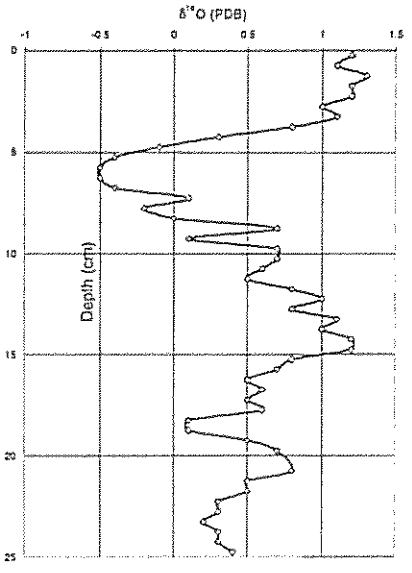

Figure 4. 250yr $\delta^{18}O$ record for Qinghai Hu from a lake sediment core

This decline in recent years following a historical high stand is an important consideration when assessing and predicting the impact of anthropogenic reduction of aquifer in the Minqin Basin.

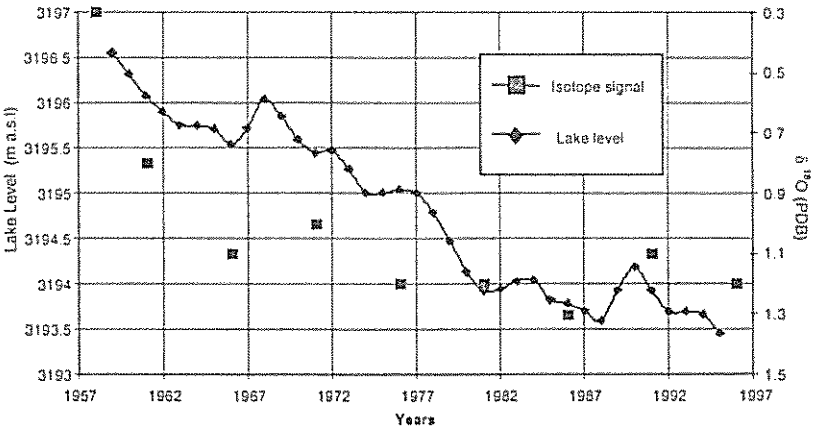

Figure 5. Lake level change versus authigenic carbonate $\delta^{18}O$ (PDB)

Moreover, farmers' and water managers' perceptions of what are 'normal' lake levels, may be based on the rather extreme and atypical, high lake levels that we now know to have prevailed during living memory, some 30 to 50 years before present day.

Samples from the longer part of the sediment cores from Qinghai Hu have also been analysed. These records show a general trend of increasing humidity since 800 AD with a very clear periodicity of 200 years. This trend may coincide with northern hemisphere temperature changes, related to cyclical changes in solar variance. However, improved dating of these older records will be needed to verify this. We tentatively suggest that monsoon rainfall in the mountain regions becomes enhanced when regional or global temperatures become low, which is very clearly shown during the well-known Little Ice Age (LIA). This probably indicates that less water resources could be provided by the mountain region for Minqin Basin under future predicted global warming, and therefore the basin will meet even more serious water crisis due to natural processes.

Badain Jaran Desert

Further fieldwork for palaeoclimate studies was carried out in the Badain Jaran Desert in September 1999 and 2000. Several saline lakes were sampled for water chemistry and lake sediment samples. Analyses of these samples are currently underway in both the Lanzhou and UCL laboratories.

To date, we have focussed our efforts on cores from Lake Baoretulegai and Lake Sayin Wusu West. Preliminary ^{210}Pb and ^{137}Cs analyses show that the short cores from the lakes cover the past ~300 years, although further refinements in the chronologies are needed. Once chronological information is complete, we will be able to correlate our records from the Badain Jaran Desert with those from Qinghai Hu and elsewhere. For Lake Baoretulegai, we have completed loss on ignition, carbon and oxygen isotope measurements on authigenic carbonates (Figure 6), together with diatom analyses (Figure 7).

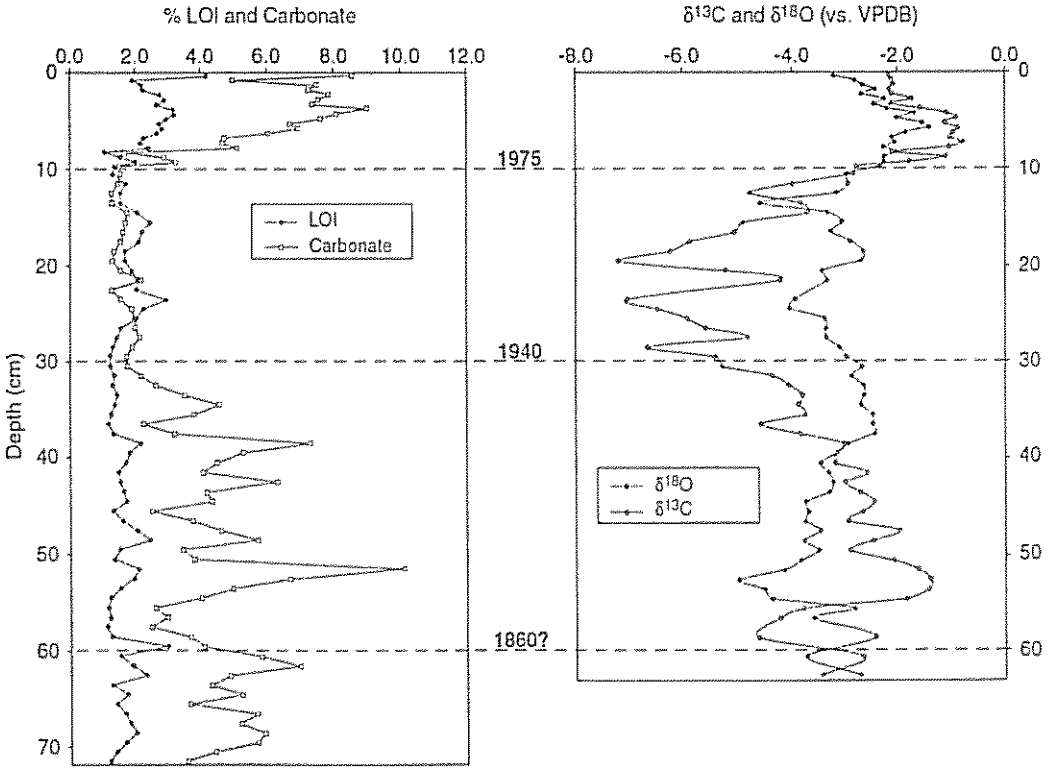

Figure 6. Loss on ignition (LOI), carbonate, $\delta^{13}C$ and $\delta^{18}O$ values for BAOR3, a sediment core from Baoretulegai, Inner Mongolia.

For lake Sayin Wusu West, we have isotope and ostracod analyses. Basic sedimentological data exist for both lakes. The oxygen isotope data for these lakes provide a record of change in effective precipitation. The isotope records from both lakes point to a decline in effective precipitation over the past few decades, but a relatively wetter period during the mid 20th century, a similar pattern to that observed in Qinghai Hu. This interpretation is supported by the diatom assemblages from Lake Baoretulegai (Figure 7).

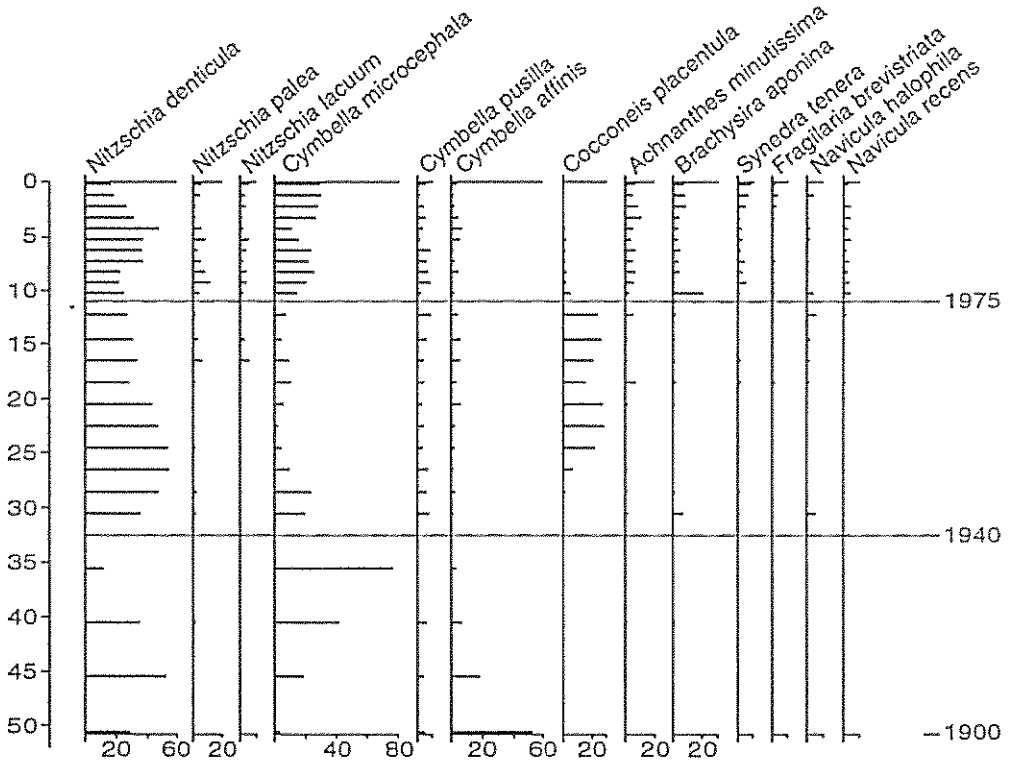

Figure 7. Diatom diagram from BAOR3, a sediment core from Baoretulegai, Inner Mongolia.

The data from these Badain Jaran lakes are especially important in understanding recent precipitation history in the Minqin Basin as these lakes lie in the same climatic and topographic region as the Minqin Basin but are unaffected by problems of groundwater abstraction. They support the view that not only is abstraction in the Minqin Basin increasing but also that natural recharge is decreasing.

Minqin Basin

Whereas the work in the Badain Desert and on the Tibetan Plateau has focussed on climate variability in the very recent past, climate change studies in the Minqin Basin itself has been concerned with the longer term history of the basin and has documented the evolution of the basin from a large freshwater lake in the early Holocene (approximatley 10,000 years ago) to a dry basin at present.

A 6-m sediment core from the basin was analyzed using pollen, grain size and isotope geochemical methods. The results show that the early Holocene was humid with a stronger summer monsoon and a high lake level, whilest the late Holocene experienced dry/humid alternations and progressive aridification and desertification. The pollen data also revealed that the middle Holocene from 7,000 to 5,000 years ago was dry. Higher resolution studies

show a series of millennial- and centennial-scale changes in the intensity of the summer monsoon, with a periodicity of 1600 years during the whole Holocene, and of 800 years during the early Holocene (Figure 8). These rapid climatic changes may be representative of a global climatic change pattern during the Holocene and indicate that the area is very sensitive to variations in the intensity of the regional monsoon and to wider global climate changes that strongly influence water resources in the region.

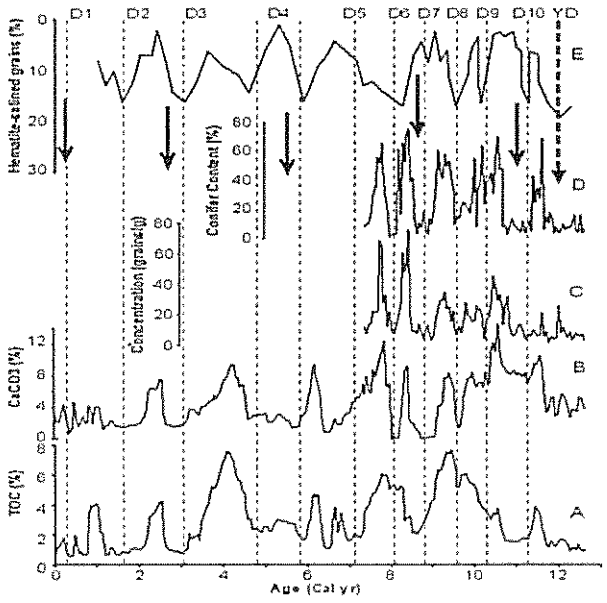

Figure 8. Variations of the climatic proxies (A~D) at SJC section with time and their comparison with climatic record (E) of Core V28-298 in North Atlantic. The long solid line with arrowheads points to the continental dry events documented in the Greenland ice core, and the dotted line with arrowheads points to the Younger Dyras (YD) event. D1 ~ D10 indicates the main dry events recorded in the SJC Section.

In summary, the results of this project has confirmed the nature of the problem of water resources in the Minqin Basin. Current groundwater abstraction rates are unsustainable and current climate trends are exacerbating the problem. The need for local farmers to modify the way in which they use water is clear although implementing a more sustainable approach is difficult and requires the involvement of all stakeholders.

Publications

F.H. Chen, Y. Zhu, *et al.* 2001, Abrupt Holocene changes of the Asian monsoon at millennial- and centennial-scales: evidence from lake sediment in Minqin Basin, North China. Chinese Science Bulletin, 46(17):1414-1418. (Both in Chinese and English).

Chen, F.H., Zhu, Y., Holmes, J., Madsen, D. and C.J. Zhang, Middle Holocene drought documented by lake depositions in E. Asian monsoon margin. Prepared for *Geology*.

Henderson, A. *et al.*, 2002, Sediment isotope record of recent environmental change from Qinghai Hu, NE Tibetan Plateau. Chinese Science Bulletin (Special issue for RACHAD Symposium) (in press).

Zhang, J. *et al.*, 2002, an 800 yr record of climate change as indicated by lake sediments of Qinghai Hu. Chinese Science Bulletin (Special issue for RACHAD Symposium) (in press).

Battarbee, R.W. *et al.*, Recent environmental and lake level change in Lake Baorletugai and lake Sayin Wusu West, SE Badain Jaran Desert, Inner Mongolia. Chinese Science Bulletin (Special issue for RACHAD Symposium) (in press).

Ma, J. & Edmunds W.M., 2002, Groundwater recharge and climatic change over the last 1000 yrs in the unsaturated zone, SE Badain Jaran Desert, Gansu. Chinese Science Bulletin (Special issue for RACHAD Symposium) (in press).

Ma, J., Edmunds, W.M. & Shi P. 2002, Impact of human activity on groundwater and the fragile ecology in the Shiang River Basin. To be submitted to *Hydrology Journal*.

Edmunds, W.M. & Ma, J. 2002 Groundwater recharge history and geochemical evolution in the Minqin Basin. To be submitted to *Applied Geochemistry*.

Ma, J. & Edmunds, W.M. 2002, Lake and groundwater evolution in the Badain Jaran ecosystem. To be submitted to *The Holocene*.

Collins, K. *et al.*, Attitudes of farmers to water resource issues in the Minqin Basin (in preparation).

Collins, K. *et al.*, Social impacts of water resource issues in the Minqin Basin. To be submitted to *World Development*.

Yuchun Li et al., 2001, Sustainable use and management of water resource in the Minqin Basin. *Journal of Mountain Research*, 19(5): 465-469. (In Chinese).