INSTITUTE of HYDROLOGY

DOHA WATER TABLE INVESTIGATION

This report is prepared for
ASCO (Qatar) Consulting Engineers
by

Institute of Hydrology
WALLINGFORD
OXON
U.K.

March 1982

DOHA WATER TABLE INVESTIGATION

The enormous increase in the water supply to Doha over the past 5 years has resulted in an aquifer being formed under the city. As the rate of recharge to this aquifer exceeds the rate of natural drainage to the sea and inland, the water table has risen at an alarming rate, resulting in flooded cable ducts and building basements and also in the water table being at approximately ground level in low lying parts of town. This groundwater body is also affecting the water quality of the blending boreholes for water supply and fears exist that bacteriological contamination from septic tanks or sewerage soakaways may also result.

The purpose of this study is to investigate the regional extent and magnitude of the rise in water table, to identify the causes for the rise and advise what measures may be taken to remedy the situation.

A similar problem is beginning to occur at Umm Said where groundwater levels have risen to the land surface in certain areas. Unlike Doha there is virtually no data concerning the rate of rise, distribution or cause of this problem and consequently a study to set up a data base is necessary before a more detailed investigation can be formulated.

This report will therefore primarily consider Doha but recommendation will be given for a study of Umm Said.

Water supply

The primary source of water[1] for Doha is from the desalination plants at Abu Aboud and Ras Abu Fontas. Since 1977 when the Ras Abu Fontas plant began to augment supply a large part of Doha relied on a Tanker Service for water supply. Since then a rapid growth in the commissioning of primary and secondary distribution mains has occurred and at present these account for about 95 per cent of supply distribution. The total production of water each year from the desalination plants and wellfield blending water is shown in figure 1 and it can be seen that since 1977 the total supply has increased from 21 million m^3 per year to 54 million m^3 per year in 1981 of which approximately 2 million m^3 is used by Umm Said.

Water Department, Doha

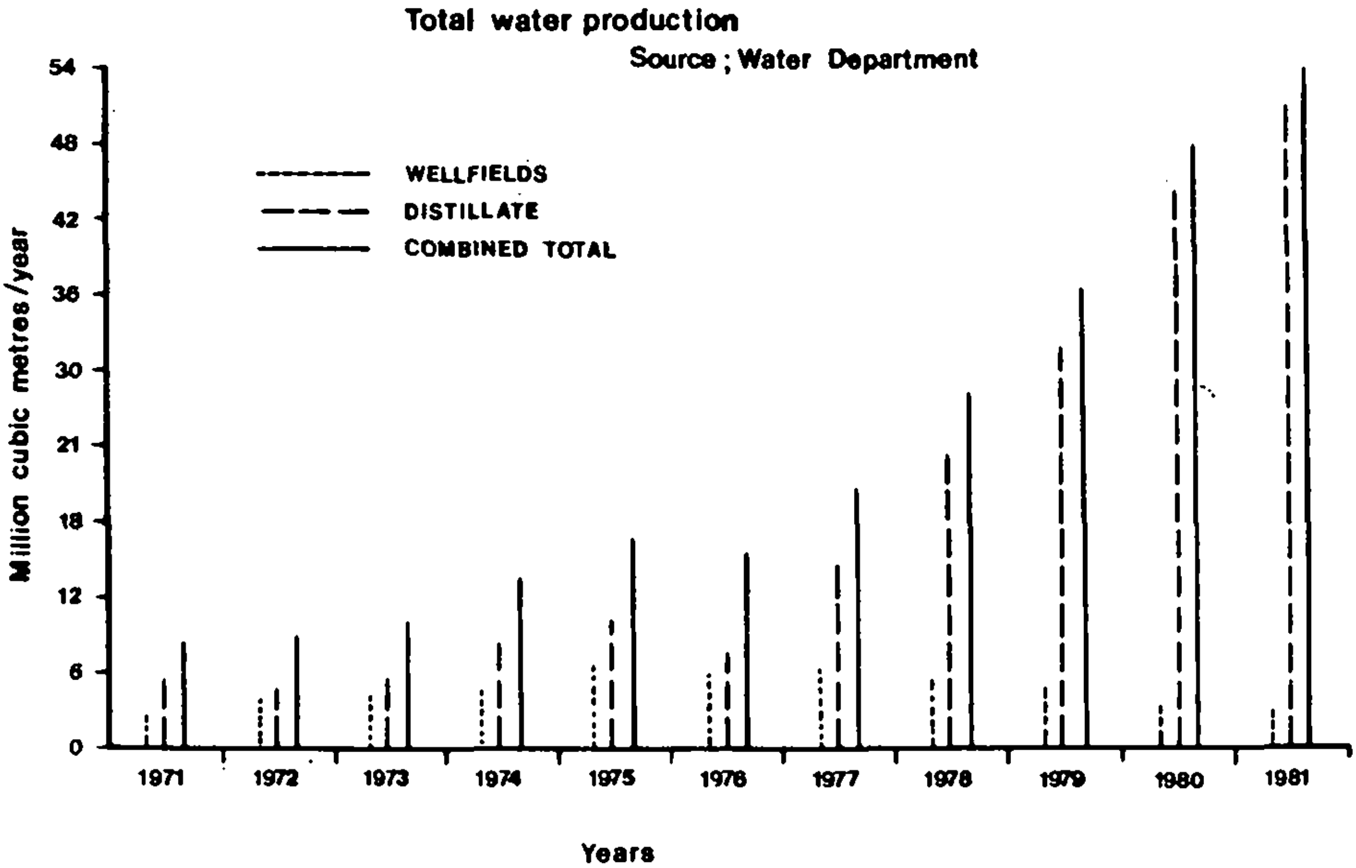

Figure 1

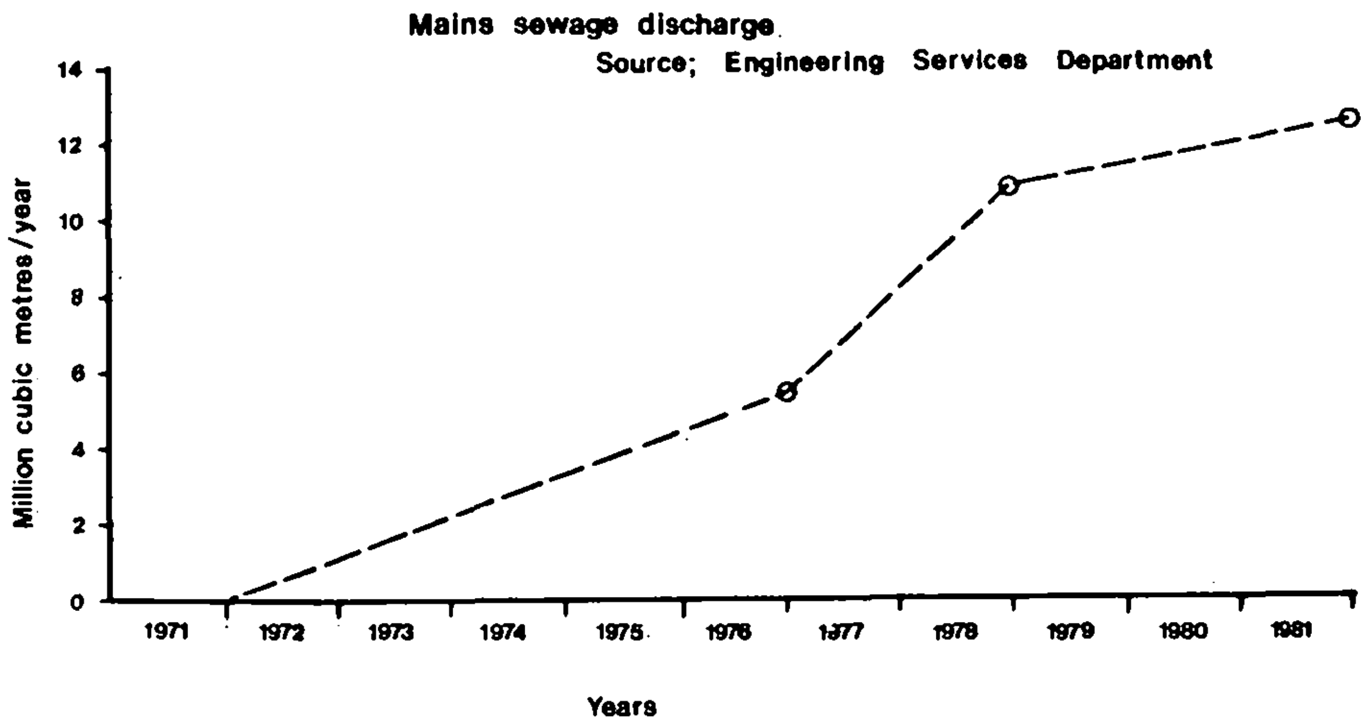

Figure 2

Demand however still exceeds supply and further desalination units are being installed which should bring the total supply up to about 88 million m^3 per year by 1983.

Water disposal

The construction of the Doha mains sewerage system has developed steadily since about 1972 and at present the treatment works handle about 12.8 million m^3 per year. Properties that are not connected to the main sewer system rely on septic tanks many of which are emptied by tanker and disposed of at the treatment works. Figure 2 shows how the outflow has increased with time from 1972 to the present day. Until recently this effluent was discharged to the desert some 7 km south of Doha but at present it is being piped some 30 km to the south west at Abu Nkalah where it is lagooned. Approximately 10 per cent of the effluent is treated further and returned to Doha for municipal irrigation. A limited surface water sewerage system, separate from the foul sewer network, helps drain the central part of Doha. The location of this system is shown on figure 3 and it discharges via a screw pumping station at the Central Bank to sea.

The Study Area

Doha, the capital of Qatar, has a population of about 190,000 people and at present covers a land area of approximately 25 square kilometres. Topographically the Doha area is of low relief with land elevations typically in the range 2-to-16 metres above sea level. Although natural drainage channels did exist through the city, as shallow wadis, extensive development has infilled the majority of these and urban runoff often gives rise to flooding in the lower lying parts of town which once was part of the wadi system. Natural drainage is generally seaward within the 'C' ring road.

The climate of Qatar has been extensively discussed in the FAO report[1], the average annual rainfall is low approximately 65 mm in Doha and this normally occurs during the winter months of November to March. Although not common, intense storms can occur; for example 150 mm was recorded at Doha over a period of 3 days in December 1963; however such a storm has a recurrence interval of about 28 years. The mean maximum monthly temperature is 41.5°C which occurs in July and falls to a mean minimum monthly temperature of 13.1°C in January. The total potential evaporation is approximately 2070 mm per year for Doha which greatly exceeds the average rainfall. However as the groundwater is at or close to the surface in many part of town, groundwater evaporation will take place possibly at a rate of 0.40 of the total potential[1], 828 mm per year.

Geology

A detailed description of the geology of the Qatar Peninsular is given in the FAO report. Underlying Doha, the Rus Formation of Lower Eocene age may attain a thickness of 100 m. The Rus is predominantly a limestone interbedded with marls, clays and massive gypsum beds. Occasionally solution cavities in the gypsum beds give rise to collapse structures, dahls, which result regionally in a hydraulic connection with the overlying formation. The Rus is water bearing throughout Qatar and provides an aquifer of sulphate rich water in the Doha area.

Conformably overlying the Rus is the Lower Dammam Formation which is also of Lower Eocene age. This formation can be between 1 and 12 metres thick and is comprised of shales,marls and clays, with subordinate limestone. The Lower Dammam is an aquitard hydraulically separating the overlying strata from the Rus Formation except in areas where collapse structures exist, when the two are connected.

The Simsima Dolomite and Limestone of the Upper Damman Formation is of Middle Eocene age and provides the eroded land surface for the whole of the Doha area. The dolomite is a diagenetic replacement of the original chalky limestone and may extend to up to 10 metres below ground level. The total thickness of the Simsima is unlikely to exceed 30 metres and may in places

Water resources of Qatar and their development
FAO Doha 1981

be considerably thinner in the Doha area. Fissures appear to be fairly common in the dolomite but not in the chalky limestone.

The Simsima is normally non water bearing in Qatar but beneath Doha an aquifer is being formed. Along the coastline superficial beach deposits of calcareous and locally cemented sands are present and these in part have been reclaimed by rock fill along the corniche and by compacted dredged calcareous sand forming the peninsular to the north of Doha bay.

Water level

As a consequence of the rapid development of Doha, numerous trial pits and cored boreholes are constructed each year for site investigation purposes. During a 9 month period in 1981 Pencol collected water level elevation data from 33 of these sites within the city. The Water Department[1] has also started to routinely measure water levels and these two sets of data with the exception of pumped water levels are shown together on figure 3 as elevations above sea level. We have contoured these data using a 2.5 metre interval to show the general form of the water table. A closer contouring interval is not possible as water levels are changing with time at different rates but we believe that the water levels were unlikely to have altered by more than 1 metre in this nine month period.

It can be seen that an extensive groundwater mound corresponding with the developed area of town with an elevation more than 7.5 metres above sea level has formed beneath the city which is draining radially with a steep gradient towards the coast and a more shallow gradient inland. However, this mound is complicated by the fact that there would appear to be two substantial depressions within it where the groundwater elevations fall to 1.3 and 2.4 metres above sea level. Consequently, as well as the radial groundwater movement inland and towards the coast groundwater is also draining within the mound towards these two groundwater lows.

Preliminary report on groundwater under Doha City
N.R.G. Walton October 1981 WD/A20.

Water table contours

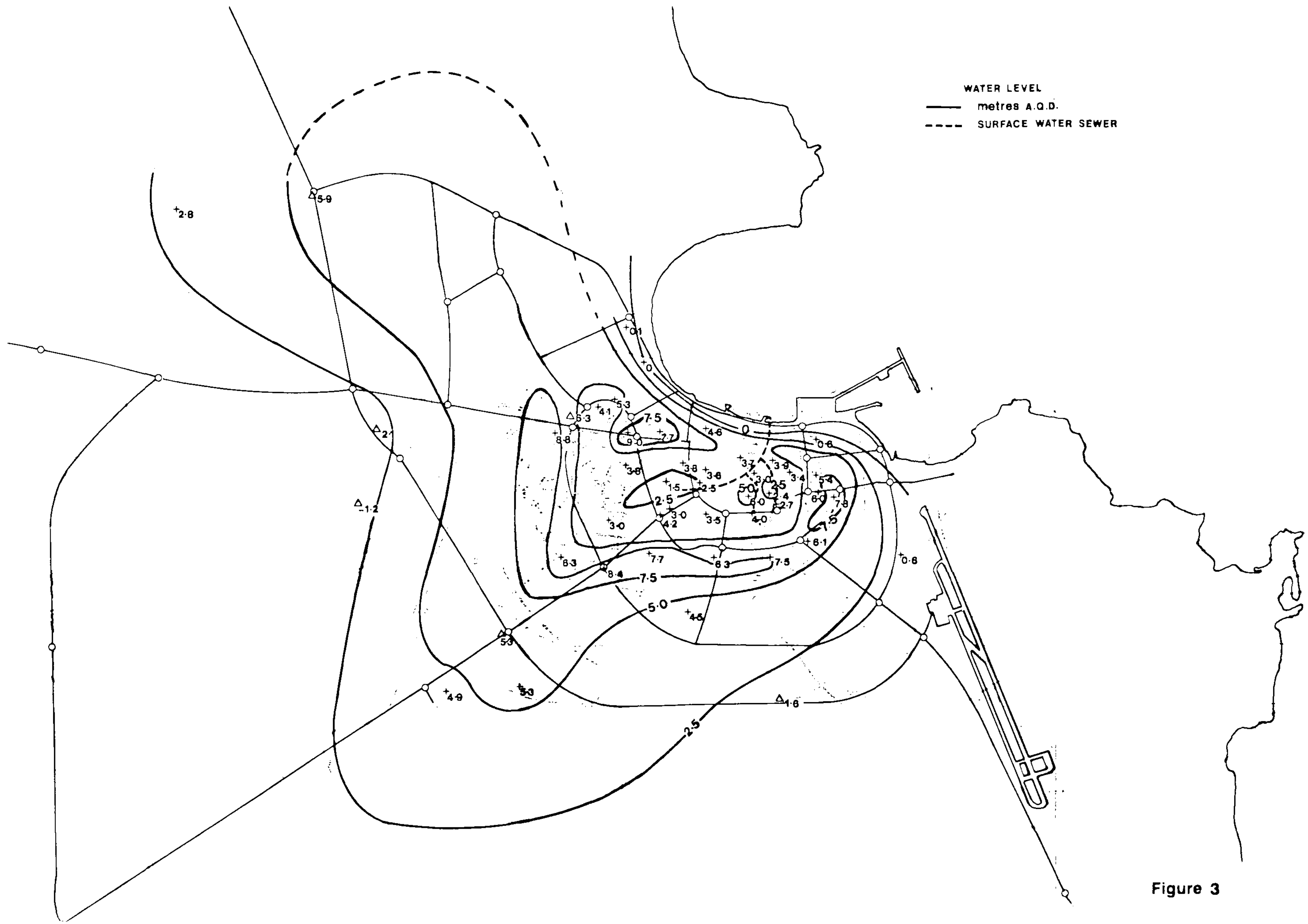

Figure 3

The correspondence of these lows with the main surface water sewers main may in fact account for these groundwater depressions. Alternatively, the historic natural drainage of the surface water catchments may have resulted in collapse structures being formed which would provide natural groundwater sinks to the system. It may also be noted that some, although not all, of the groundwater highs appear to be associated with surface water gullies which discharge to soakaway boreholes and that in fact the soakaway boreholes are behaving as recharge wells. The general nature of the groundwater contours do surprisingly tend to suggest uniform aquifer conditions. However further exploration would be necessary to confirm this and it could be that our data base is too sparse to make this observation.

Aquifer characteristics

The aquifer that we are considering is within the Simsima dolomite and chalky limestone, the base of which may be defined as the top of the Midra shales. As this formation is non water bearing little data concerning the aquifer characteristics are available. However, Wimpey as part of the Qatar National Museum dewatering study have carried out pumping tests and obtained average permeabilities of 80 m/day and 1400 m/day.

Their calculations assumed a saturated thickness of 6 metres which was equivalent to the depth of the well below the water table. It is more likely that the saturated thickness is 20 metres regionally and a recalculation of permeability gives 30 m/day and 500 m/day. The low permeability is obtained from water level observations taken in 40 mm diameter observation wells and the high permeability from water level observations taken in a pit measuring 1.9 x 2.0 metres. These results can be considered to be consistent with each other if it is assumed that high values for the pit results from the effect of more fissures being intercepted and also by the greater volume of water stored in the pit. Because of the effect of storage it might be more appropriate to assign a value of say 100 m/day rather than 500 m/day as an upper limit for the permeability.

Obviously more tests are necessary to determine the range of permeabilities that do apply to the Simsima formation. However we feel that low permeabilities in the range 1-10 m/day would apply to the primary permeability with perhaps 30-100 m/day being the range appropriate for the fissured part of the formation.

The Wimpey test data does not produce a solution for the storage coefficient of the aquifer. However, the lithology of the Simsima suggest that the storage coefficient is very unlikely to exceed 0.01.

Water level changes

Until 1981 no routine water level measurements have been carried out in Doha. However, data from site investigations carried out several years ago can occasionally be compared with recent water level data obtained from investigations at adjacent sites[1]. These, together with the routine water level observations initiated by the Water Department, are shown in figure 4. These show an even more alarming rate of rise within the range 0.7 to 1.0 m/year over the past five years. We have no data to show when this rapid rise in water level started but it is known from observations recorded by Le Grand Adsco in 1959 that the water levels at the State Hospital and Montaza Park were only 0.5 m AQND and towards the end of 1981 at Montaza Park the water level is 4.5 m AQND.

It is unlikely that the water levels will have risen uniformly during this period and seasonal and other fluctuations must exist. However, the overall trend is that of a rising water table and it is well known that groundwater is at or close to the surface in many of the lower lying parts of town. The data collected by the Water Department from the Peugeot Roundabout appears to be away from the main recharge area, but as the development of Doha expands it seems reasonable to assume that the groundwater mound will also expand in area.

Aquifer storage

If we assume that the average rise in water level over the area say 50 km^2 bound by the 2.5 m contour shown in figure 3 has been 4 metres

[1] Wimpey - verbal communication

Water level changes

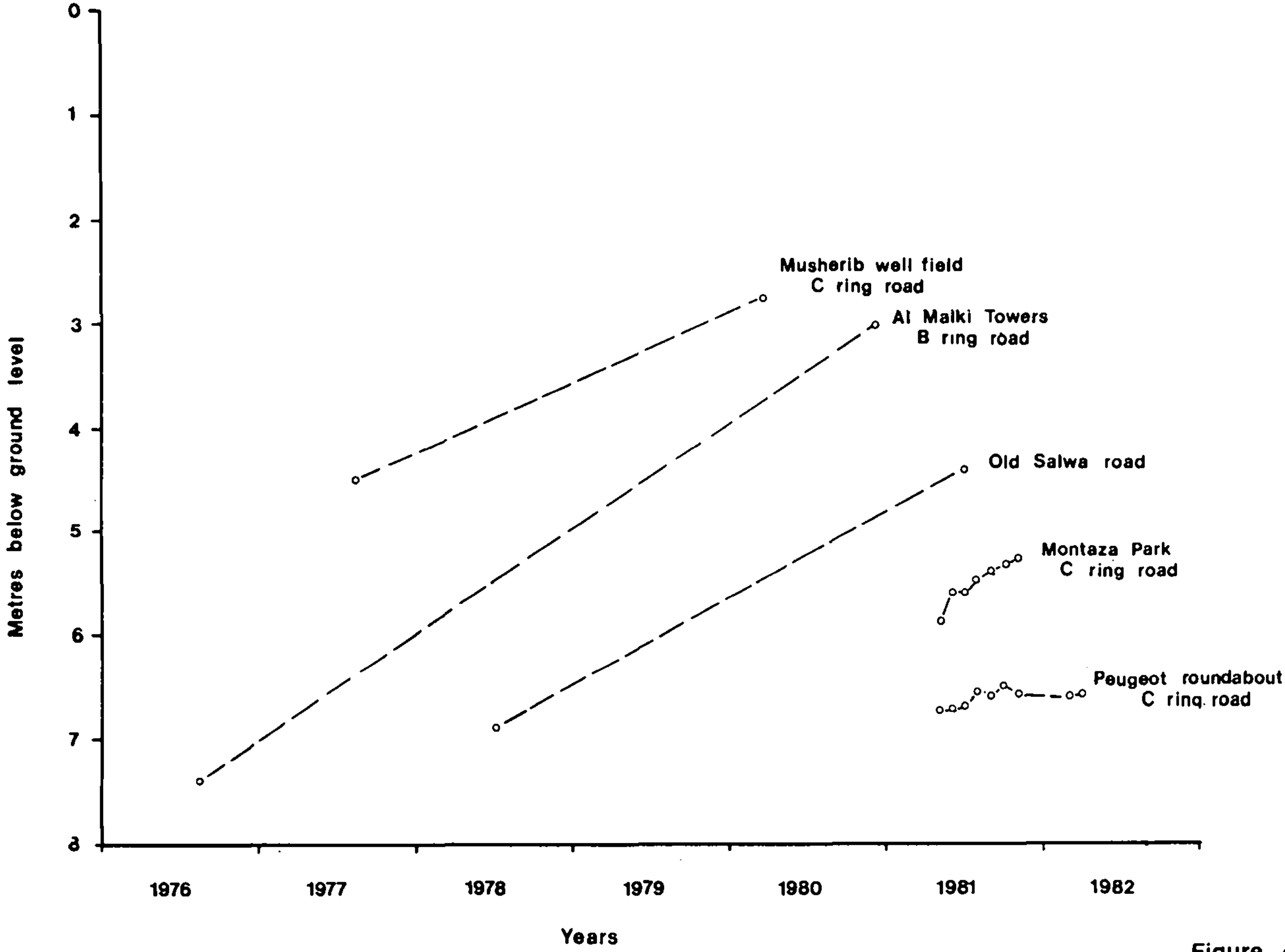

Figure 4

and that the storage coefficient of the aquifer is 0.01, then the total volume of water added to storage is $2 \times 10^6 m^3$ since water levels started rising from their natural level possibly 10 years ago. If over the past year, the average overall rise was 0.5 metres, then this is equivalent to a change in storage of 0.25 million m^3.

Recharge

The potential sources of recharge to groundwater are easy to identify; however it is extremely difficult to quantify them. The possible sources are as follows:

Rainwater
Domestic fresh water irrigation return
Treated sewage effluent irrigation return
Foul sewer leakage
Leakage from effluent network
Leakage from cess pits and septic tanks
Leakage from water distribution system
Overflow from domestic freshwater storage tanks
Fresh water leakage from reservoirs
Fresh water spillage from tanker filling stations

In assessing the recharge to groundwater it is also necessary to estimate losses from the system. As with recharge these are easy to identify but difficult to quantify. The possible losses are:

Subsurface flow of groundwater away from the mound
Evaporation of groundwater close to the surface
Piped removal of sewage effluent from the system
Evapotranspirational losses from vegetation
Leakage to other aquifer systems
Losses resulting from the change in aquifer storage
Storm water sewer outflow

It has been reported by both FAO and Halcrow Balfour[1] in the context of water resources studies, that perhaps 30 per cent of the water supplied to Doha is lost by subsurface leakage from the system. This figure however has not been obtained by direct measurement but is simply an assumption; it represents the average leakage to be expected from a water distribution system based on a world-wide range from a minimum of 10-15 per cent to a maximum of 40-50 per cent. Since the Doha distribution system is for the most part modern it is consequently reasonable to assume that the leakage rate will

Master water resources and agricultural development plan
Halcrow- Balfour Ltd. September 1981

lie within the lower half of the worldwide range. For this reason we will consider that 30% is an upper limit and assume that loss is in the range 15 to 30 per cent of the total water supply. Thus for 1981, this recharge component is in the range 8 to 16 million m^3. Similar rates of leakage are assumed to take place from the piped sewage network (see Table 1).

Of the remaining 45 to 37 million m^3 FAO suggest that 30% is used for domestic irrigation of which 20% will recharge the aquifer, which is 2.7 to 2.2 million m^3. Thus between 31.5 and 25.9 million m^3 of waste water remains.

Of this 31.5 to 25.9 million m^3, 12.8 million m^3 is piped away from the city as sewage, thus between 18.7 and 13.1 million m^3 of waste sewage water ends up in septic tanks and cesspits. For the purposes of this report let us assume that all of this soiled water is available for recharge because those septic tanks that are emptied are handled by the sewerage works and this volume is included in the 12.8 million m^3 discussed earlier. Approximately 10% of the 12.8 million m^3 of sewage is treated and returned to the city for Municipal irrigation. Of this, 20% is likely to recharge the aquifer, 0.26 million m^3. We will assume that 20% of the yearly rainfall recharges the aquifer over a 50 km^2 area; this is certainly an overestimate as much of the area is built up and water will pond on impermeable surfaces. However, using this assumption the rainfall recharge will be 0.65 million m^3 each year.

We are unable to quantify the remaining sources of recharge to the system from

reservoir leakage
foul sewer leakage
tanker filling station spillage
effluent distribution mains
overflowing domestic storage

but we will assume that in total this recharge source is not greater than 3 million m^3 per year.

The remaining losses of groundwater from the system which have not been included as part of the recharge estimates are

leakage of groundwater to other aquifers
storm water sewer outflow
evaporation of near surface groundwater
groundwater flow through the aquifer
changes in groundwater storage.

As there appears to be no change in water level when the lower Rus formation is penetrated during drilling, we would conclude that there is little if any transfer of water between the two aquifer systems. Direct evaporation of near surface groundwater can be assessed if we make the assumptions that water within 2 m of the surface will evaporate at a rate which will not exceed the potential evaporation of 2000 mm per year. A more realistic evaporation figure may be to use that derived by Pike for Sabkha which would be 700 mm per year. Using the data for depth to groundwater, the surface area with groundwater within 2 m of the surface is 2.25 million m^2. Thus the groundwater evaporation will be in the range 1.6 to 4.5 million m^3 each year, and let us assume 3 million m^3 for this report.

Additions to groundwater storage during the year can be considered to be equivalent to a loss from recharge, and as shown earlier, even if what we consider to be a high storage coefficient of 1 per cent is used in the calculations, this change in storage is only equivalent to 0.25 million m^3/year.

The storm water sewer discussed earlier would appear to exert a very strong control on the form of the water table contours within the recharge mound. The maximum capacity of the system is 0.75 m^3/second and if we make the assumption that pumping takes place in total for 12 hours each day, then this sewer effectively drains about 12 million m^3 per year from the recharge mound.

Table 1 summarises all these components of recharge that we have discussed including the losses from the system. Surprisingly Table 1 shows that groundwater recharge is largely insensitive to the amount of distillate leakage. Using the high figure of 30 per cent leakage the total recharge is 35 million m^3, but the 15 per cent leakage reduces this estimated recharge volume to 33 million. However the two main components of recharge are predominantly those due to sewage recharge of the aquifer from properties which are not yet connected to the main sewer system whose septic tanks

Table 1

Water Balance Components for 1981
million m^3/year

	Leakage through piped systems Lower limit	Upper limit
Additions	15%	30%
Assumed distillate distribution leakage	8	16
Assumed sewage network losses	1.9	3.8
Domestic irrigation groundwater return	2.7	2.2
Septic tank losses	18.7	13.1
TSE irrigation groundwater return	0.26	0.26
Rainfall	0.65	0.65
Others	3.0	3.0
Total	35.2*	39.0*
Losses		
Groundwater evaporated	3.0	3.0
Groundwater leakage to other aquifers	0	0
Changes in groundwater storage	0.25	0.25
Storm water sewer discharge	12	12
Subsurface groundwater outflow	0	0
Total	15.3 + Q	15.3 + Q

Note: The subsurface groundwater outflow Q is calculated in the text.

*NB: Total recharge is relative insensitive to large changes in the per cent of distillate leakage.

are not routinely tankered to the main sewerage works and also to a lesser extent distillate distribution system. Obviously, further study of these recharge processes is necessary but if our assumptions are correct then our attempt to estimate recharge for the system clearly shows the main components to be waste water as well as a lesser extent distributed distillate.

Groundwater movement and water balance

We can in part attempt to interrogate our model by calculating the subsurface groundwater flow. If using our best estimate of the aquifer characteristics the groundwater flow balances the other components of the water balance, then we can have some confidence in the model. The subsurface flow of groundwater away from the recharge mound can be calculated using the Darcy equation and the water table configuration shown in figure 3. Flow will depend on the permeability we assign to the aquifer and as we have discussed earlier is likely to be in the range 1-10 m/day for primary permeability and 30-100 m/day for the overall fissure permeability. Flow will also depend on the saturated thickness which we believe to be about 20 metres. Thus the total recharge to the system should equal the change in aquifer storage, the subsurface flow of groundwater away from the recharge mound, direct evaporation of groundwater and the discharge of the storm sewer which drains groundwater from central Doha.

Using a value of say 5 m/day for the primary permeability gives, in million m^3/year

subsurface groundwater flow	1.6
direct groundwater evaporation	3.0
change in groundwater storage	0.25
storm sewer discharge	12.0

This total is approximately 17 million m^3 whereas our best estimate for recharge is in the range 35 to 39 million m^3. Thus, using a permeability of 5 m/day for the aquifer results in a discrepancy of 20 million m^3 between recharge and discharge from the system and we do not feel justified with the available data to alter any of the component to recharge to account for this large amount. The only way of approaching a balance is by raising the permeability to 50 m/day. This will increase the subsurface groundwater flow to 16 million m^3 and hence

32 million m^3 can be accounted for as the loss to recharge which is much closer to our recharge estimate. Further field investigations are obviously necessary to substantiate this high permeability and also to refine the other key components of the water balance which are distillate leakage, storm sewer discharge and unaccounted sewage ; meanwhile from our present knowledge of the aquifer lithology it does not seem unreasonable to postulate a fairly homogeneous fracture system within the dolomite.

Groundwater identity

The two main sources of groundwater which form the aquifer are sewage leakage from septic tanks, sewage network effluent and distilled water from the main distribution system. Individually these waters will have very different chemistries; however once they have entered the aquifer system their chemistries; alter due to the presence of high concentrations of sodium, magnesium, sulphate carbonate and chloride. The presence of sewage will be indicated by high potassium and nitrate concentrations, a high dissolved organic carbon content and a highly negative redox potential indicating reducing conditions. The distributed distillate on the other hand will have a lower total dissolved salts, a much higher redox potential and low organic carbon concentrations.

It may not be possible to determine the relative proportions of fresh to sewage waters in the system but the relative concentrations of, say, nitrates will indicate areas where sewage recharge is particularly high.

Temperature may also prove a useful indicator for detecting fresh water leakage for the distillate reaching Doha is at approximately 40°C as compared with about 30°C for naturally occurring groundwater.

One further parameter which may help identify the sources of sewage recharge and fresh water is the ratio of the stable isotopes deuterium and oxygen 18. As part of our reconnaissance we took 6 samples of groundwater naturally mixed with distillate and distilled water for stable isotope analysis; unfortunately these samples were taken well to the edge of the recharge mound and are probably not contaminated with sewage. The results of these analyses are shown in Table 2 and we consider that a more extensive sampling programme is necessary to show whether this approach would be successful.

Table 2

Stable isotope analyses

Location and Water type	Oxygen 18 ‰	Deuterium ‰
Gharrafa blending borehole groundwater + distillate leakage	2.1 ± 0.1	16 ± 1
Airport reservoir blending borehole groundwater + distillate leakage	1.4 ± 0.1	12 ± 1
Distillate	1.5 ± 0.1	12 ± 1
Dahl north of Doha evaporated groundwater	1.8 ± 0.1	14 ± 1
TV station roundabout groundwater	2.1 ± 0.1	13 ± 1
Musheirib wellfield groundwater	1.6 ± 0.1	10 ± 1

Conclusions

Our reconnaissance mission using existing data to investigate the rising water table beneath Doha has revealed the following disturbing features:

The average rate of rise over a 5 year period of the water table is at least 1.0 m/year in places, over twice that previously reported.

Our preliminary water balance considerations suggest the cause of the rising water table is due not only to possible leaking sewage and distillate networks but perhaps more importantly to septic tank overflow.

Recharge from the leakage of distillate must be reduced simultaneously with reduction of leakage from the sewage system in order to prevent a build up of sewage content within the groundwater body.

Some of the surface water drainage gullies connected to soakaway boreholes appear to be recharging the aquifer.

The storm water sewer, despite its limitations in performing its primary function, appears to have acted as an effective control on the rising groundwater levels.

The leakage from reservoirs and tanker filling stations do not appear to be major sources of recharge to the system.

In view of our summary conclusions we would propose that there is an immediate urgent need to prove whether extensive sewage contamination of the aquifer is taking place. This could best be effected by taking as many pumped water samples from the aquifer within the C ring road to the coast as possible, from site investigation pits, cored boreholes, flooded cable ducts etc. which are above the Midra shales aquiclude. Should the chemical analysis of these samples reveal high potassium and nitrate concentrations, these would be indicative of sewage recharge. Should this prove to be the case we would recommend that the effectiveness of the septic tank emptying service is reviewed, and that the replacement of septic tanks with mains sewage is accelerated.

The consequence of the aquifer being recharged by possible septic tank overflow and pipe sewage leakage would be that low pressure water mains beneath the water table could locally become contaminated and also that with time the belnding wellfield boreholes may also risk contamination. To give warning of wellfield contamination we would recommend the construction of boreholes from which water samples would be taken by either air lift or pumping sited between the wellfields and the city.

Further investigations are obviously urgently necessary to improve our analysis so that recommendations may be made as to where the main areas of recharge are taking place and also to identify more in detail the cause of recharge.

This exploratory programme will have the following objectives:

To accurately determine the form of the water table and its elevation above sea level.

To determine the rate of change of water levels by routine measurement.

To build up a more detailed understanding of the lithology of the aquifer.

To determine the aquifer characteristics by pumping test.

To determine the source of groundwater by the chemical and stable isotopic composition of the groundwater from pumped or airlifted water samples.

To attempt to quantify each source of recharge to the aquifer.

To measure the losses to recharge such as the storm water sewer discharge and main sewerage disposal.

To qualitatively assess whether groundwater movement by fissure flow is taking place to sea by fluid conductivity and temperature measurements in Doha Bay and possibly to complement this assessment by aerial infra-red photography.

To give particular attention to the sewage and distillate networks and to carry out leak detection work for both.

At present, the Water Department is developing a water level monitoring network using boreholes constructed by contractors such as Wimpey for site investigation purposes. Unfortunately this network is not secure as building development is likely to take place at these sites. However the network is providing a valuable set of data of routine groundwater level measurements. This network could be improved still further if the design of electrical earth boreholes for building was modified so that it included a water level measuring facility within the bore and also if part of the proposed cadastral network to be constructed within the city was also modified for this purpose. Common to all these measuring points however, it is essential that the elevation above sea level of the measurement datum is known.

As part of our exploratory investigation we would propose that this secure network is enhanced by the drilling of further observation boreholes. These boreholes should be of sufficient diameter to allow electrical logging to be carried out and also to provide either pumped or air lifted water samples for chemical and stable isotope analysis. Because of the problems of land acquisition and subsequent security of the borehole it is not possible to give borehole locations in this report; however we would envisage that the total network would comprise some 40 boreholes, predominantly constructed by rock coring techniques to an average depth of 20 metres with a diameter of 113 mm. At 5 of these sites, which can only be defined during the survey, pumped wells of diameter, say, 8⅝ inches would also be constructed so that pumping tests up to 14 days in duration could be carried out to determine the aquifer characteristics.

Finally, in advance of these exploratory works we would recommend that the routine measurements of water levels are continued and that the elevation of the measuring datums are accurately measured. As well as the urgent chemical sampling programme we outlined earlier, we would also suggest that routine measurements of the storm water sewer discharge are measured.

Umm Said investigation

It is most probable that the causes for the rise in water table at Umm Said are similar to those for Doha. Experience has shown that in such areas of rapid development the capacities of existing sewage and water networks are always under strain and frequently cannot cope with ever increasing demands. Thus we recommend that an observation borehole network for groundwater level measurement and water chemistry determination be carried out. We will then be able to establish a data base from which we will be able to show the cause for water level rise and subsequently advise which measures need to be taken for control.