# Wellfield Development for Urban Water Supplies in PDR Yemen

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## ABSTRACT

Internationally-funded groundwater projects have recently been completed for the main urban areas of PDR Yemen. The necessary resources to secure potable supplies into the next century have been proved in Cretaceous sandstone, Eocene limestone and Quaternary clastic aquifers, and their investigation has highlighted the importance of comprehensive hydrogeological studies prior to permanent works design and construction. The projects discussed will improve the quantity, quality and accessibility of potable water to nearly one third of the country's population.

*Key words:* Groundwater; Middle East; aquifer development; wellfield construction; well yields.

## INTRODUCTION

### PDR YEMEN

The People's Democratic Republic of Yemen will be remembered as Aden and the Protectorate States which received independence from Britain in 1967. Unlike most of its neighbours, it has, as yet, had no oil wealth and remains largely underdeveloped. There is much support from the Soviet bloc and China, many infrastructure projects attract funding from international agencies including the World Bank (IDA), AFESD, OPEC, the Kuwait Fund and the Islamic Bank, and there is bilateral assistance from Japan and European countries such as Denmark, France, and the UK. In 1987, a successful oil strike was reported in Shabwa and future development will doubtless increase as production expands.

### Settlement

Only 1 per cent of the country's 330 000 km$^2$ is capable of supporting agriculture and there are large sparsely populated areas including the Radfan Mountains, the Ramlat Sab'atayn Desert, the Rub' al Khali or 'Empty Quarter', and Al Mahra (Fig. 1). Settlement is concentrated along fertile inland valleys and the coastal margin, with three main areas of urbanization:

(i) Greater Aden, including the capital and satellite towns such as Sheikh Othman,
(ii) Al Mukalla, 625 km along the Gulf of Aden coast, and
(iii) the Hadramaut Valley in the central interior

Total population is approximately 2 200 000. About 33% live in urban areas, 57% are rural and 10% nomadic Bedu[1].

### Resource Development Infrastructure

Overall policy regarding water resources development is determined by the National Committee for Water Resources on which are represented the Ministries of Planning, Health, Agriculture and Agrarian Reform (MAAR) and the Public Water Corporation (PWC). On independence, the provision of potable supplies to Aden, Al Mukalla and some other towns became the responsibility of PWC, a largely autonomous Directorate reporting to the Ministry of Energy, Minerals and Petroleum.

Piped supplies in the Hadramaut Valley have been in the hands of private water companies but the recent commissioning of a new wellfield and integrated supply system for Seiyun heralded major infrastructure changes in which PWC assumed responsibility. Elsewhere water distribution is organized locally with technical support from PWC. Many rural supplies utilizing shallow hand-dug wells are the responsibility of the General Directorate of Local Government.

### GENERAL GEOLOGY

PDR Yemen comprises Mesozoic and Tertiary strata over Precambrian Basement. It has been mapped by the US Geological Survey[2] and the stratigraphic succession (Fig. 2) described by Beydoun[3]. Following the widespread deposition of Jurassic strata, the Cretaceous transgression heralded major differences in deposition between western and central/eastern PDR Yemen.

To the west, the quartzitic sandstones of the Tawilah Group were followed at the end of Cretaceous times by the lavas and pyroclastics of the Aden Volcanic Series which impart a barren, crater-strewn landscape to large areas.

Eastwards, the Tawilah classics reached the central interior where they are subdivided into the Harshiyat and Mukalla Formations, both grading eastwards to calcareous strata. Tertiary deposition commenced with the transgressive Umm Er Radhuma limestones upon which Jeza and Rus strata outcrop. After deposition of the Habshiya Formation, subsequent emergence was followed by the conglomerates, sandstones, limestones, evaporites

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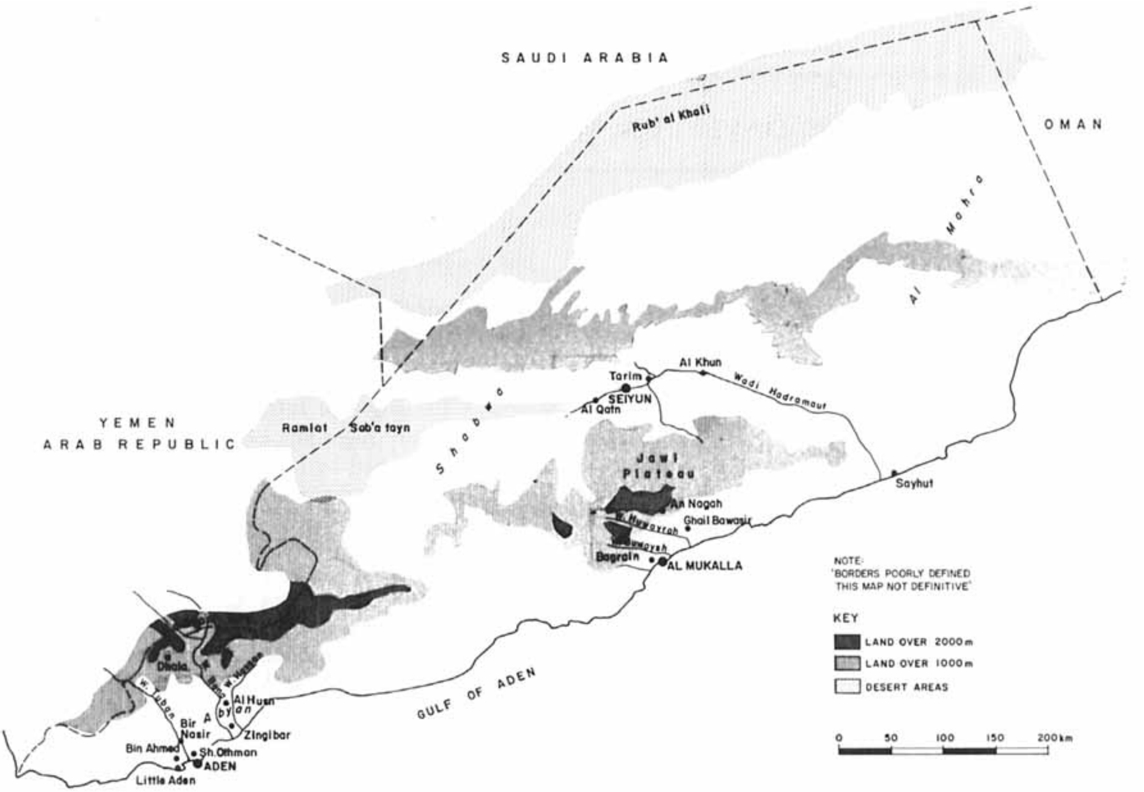

**Fig. 1. Map of PDR Yemen**

and marls of the Shihr Group which reflect the variety of depositional environments prior to the late Tertiary onset of volcanicity.

### Major Aquifer Units

South of the Radfan foothills, Jurassic limestones only occur as outliers and the Cretaceous sandstones are well cemented and poorly fractured. Both afford poor reservoir characteristics, as do the volcanics, and economic groundwater development is limited to wadi deposit aquifers.

To the east, Jurassic strata frequently subcrop at depth and the Cretaceous limestones crop out in sparsely populated areas. The Umm Er Radhuma limestones are unsaturated in the Hadramaut Valley where the poorly cemented Mukalla Formation forms the main aquifer. North-east of Al Mukalla, the Shihr deposits are of low permeability but karstic features in the Habshiya limestones limit water–rock interaction to within potable limits.

### CLIMATE

PDR Yemen has a hot, humid yet arid climatic regime. Near Aden, monthly shade temperatures average 26–32°C, with summer maxima often exceeding 40°C. Mean humidities of 64–75% mask the high values frequently experienced and monthly maxima are over 95%. Rainfall increases inland, from 46 mm/y in Aden to 375 mm/y in the mountains around Dhala.

Exposed to Indian Ocean breezes, Al Mukalla enjoys a wider range of mean monthly temperatures, 16–40°C, and reduced rainfall, 32 mm/y, without the humidity suffered in Aden. Rainfall in the Hadramaut Valley averages 50 mm/y while the plateau, up to 2 500 m in height, through which it is incised, receives 60 mm/y and 200 mm/y on its northern and southern slopes respectively. Elsewhere, the interior is much more arid as evidenced by the presence of the Ramlat Sab'atayn and Rub' al Khali deserts.

## GREATER ADEN

The capital is home to about half the country's urban population and has grown up in and around an ancient volcano with its central area, aptly named Crater, delimitated by sheer rock walls which form an impressive purple backdrop to the light coloured buildings. Newer suburbs have spread onto the adjacent coastal plain and the lower Wadi Tuban floodplain.

### LOWER WADI TUBAN

Rising in the YAR mountains, the Wadi Tuban has laid extensive fluviatile deposits[4] and recent

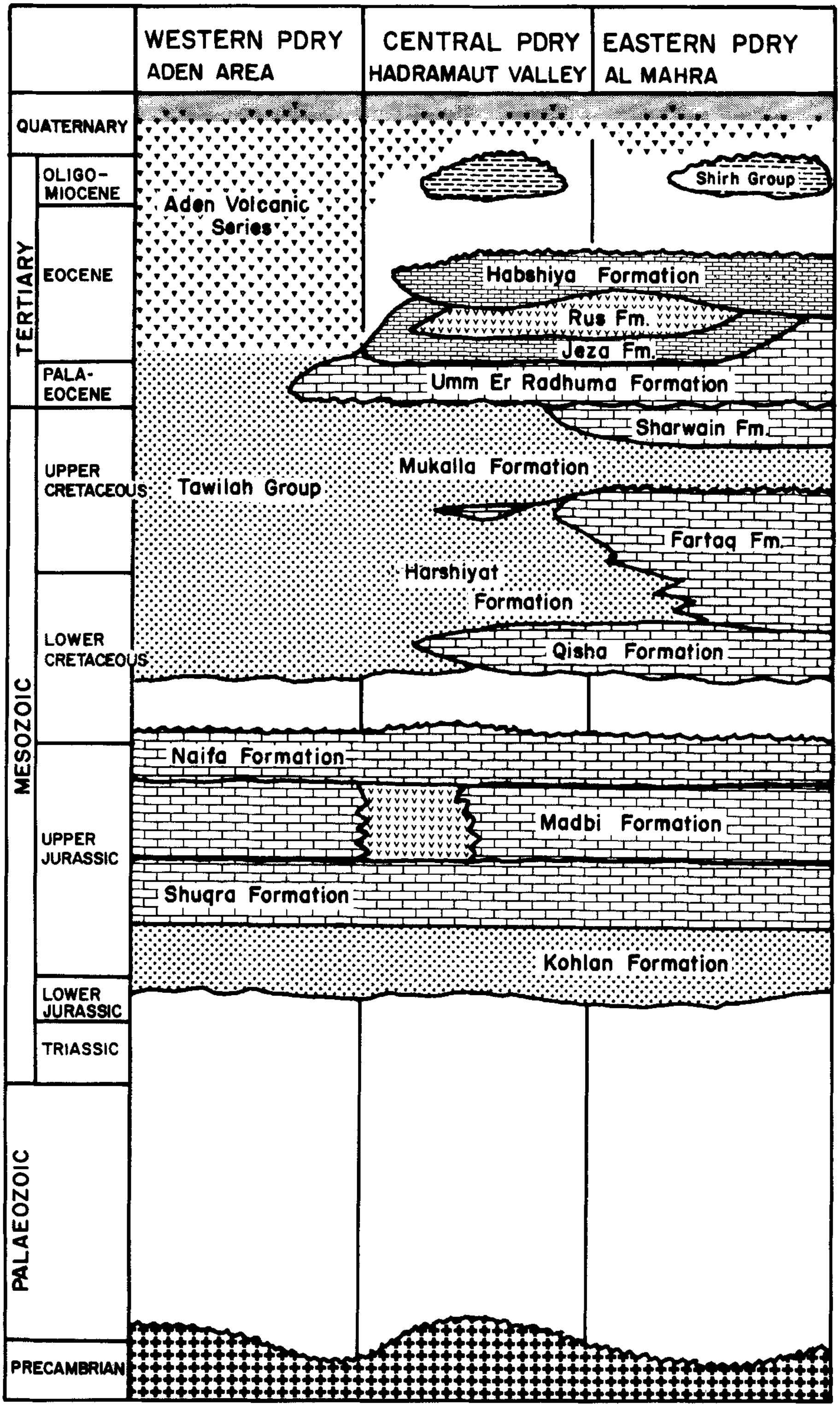

Fig. 2. Stratigraphic correlation[3]

drilling to 200 m failed to penetrate fully the sands, pebbles and cobbles which have for many years provided Aden with potable water.

### Sheikh Othman Wellfield

In 1912, wells were dug just 4 km from the coast where the aquifer is semi-confined beneath clays and sandy clays (Fig. 3). With subsequent deepening by drilling, they sustained demand for many years but by the early 1950s, the increased abstraction had increased salinities. By the 1980s, this wellfield provided only 20% of Aden's water and was abandoned in 1986.

### Bir Ahmed Wellfield

Also located in the semi-confined aquifer, Bir Ahmed continues to supply Little Aden, but well discharges are slightly saline and any wider distribution will depend upon blending with distillate from a newly-completed desalination plant.

### Bir Nasir Wellfield

As Aden grew, additional sources were required. At Bir Nasir, fourteen 70 m deep production wells were drilled in 1956 and supplemented by a further fourteen along a parallel line 700 m away in 1961. Additional wells were subsequently constructed along an intermediate line and there was replacement of earlier boreholes where yield had declined. By 1981, Bir Nasir comprised fifty-five wells of which forty-one were operational. Average yield was 12.7 l/s and total wellfield output 42 Ml/d, 80% of demand.

Water resources planning foresaw Bir Nasir continuing as Aden's primary source until supplemented by new wellfields in Abyan and the Upper Wadi Tuban. However, between 1957 and 1983 water levels had declined by 0.8–1.0 m/y and in many boreholes aproached pump intake. Remedial measures were clearly required.

Wellfield testing was limited by the need to maintain supply and each well could be out of service for only 24 h with adjacent wells kept operational. Nevertheless, several replacement boreholes were within 20–25 m of their predecessor which afforded useful observation well data. A finite difference radial flow model[5], with two layers to allow for head differences between the original 70 m deep wells and later ones to 150 m, was employed to predict future water level decline and indicate the merits of well replacement options. Historical records suggested the approximation of drawdown to a radial pattern to be broadly acceptable. Aquifer transmissivities were 550–850 $m^2$/d with average permeability 4–5 m/d. Downhole geophysics indicated some increase in fines content with depth but any decrease in permeability appeared neither marked nor consistent.

It was considered that additional short-term abstraction, to satisfy increasing demand before new sources could be commissioned, would not substantially increase water level decline provided wellfield efficiency was improved. This was achieved through an effective increase in well spacing by abandoning those yielding less than 5 l/s; constructing new wells to depths of 200 m; and not replacing wells in adjacent locations. Ten new wells were drilled in 1984–85 and with each giving some 20 l/s wellfield production exceeded 55 Ml/d.

With deep boreholes replacing shallower wells, groundwater quality improved from conductivities of 2 200–2800 µS/ cm to 1 800–2100 µS/ cm with individual constituents (Table I) within WHO Guidelines[6].

Such a level of abstraction can, however, only be temporary and in order to curtail groundwater level decline, output is to be reduced to 33 Ml/d. To provide stand-by facilities during periods of maintenance and peak demand, total installed capacity will remain at about 49 Ml/d and future works to complete the phasing out of old wells and improve well spacing include a further five production wells.

## ABYAN

50 km east of Aden, Wadis Bana and Hassan, again rising in the southern YAR mountains, have deposited fertile alluvium to make their lower reaches the most productive region in PDR Yemen.

In the northern mountains, Precambrian metamorphics are overlain by Shuqra limestones and Tawilah sandstones but southwards, bedrock is only seen as isolated outliers within extensive wadi deposits which comprise the main aquifer. Its hydrogeology has been previously documented[7] and was thought to contain upper unconfined and lower semi-confined sections with only poor hydraulic continuity. Groundwater quality was believed to be similar in both, with conductivities less than 2 000 µS/cm near the mountains, increasing southwards until saline intrusion became dominant beyond Zingibar.

### Wadi Bana Wellfield

Previous consultants had designed the first of the new wellfields to supplement Bir Nasir and located northwest of Al Husn it was to provide 36 Ml/d via a 56 km pipeline. Production drilling under Acer supervision commenced with the first well penetrating 35 m of unconsolidated wadi deposits, a 2 m thick well cemented conglomerate, and cemented Tawilah sandstones (Fig. 3). Test pumping at just 2 l/s produced a drawdown of 19 m and indicated the need to reanalyse the design data.

Using a finite difference radial flow model it was possible to simulate both new and old test pumping data with aquifer transmissivities of 60–130 $m^2$/d for the wadi deposits and 28–70 $m^2$/d for the sandstones, as opposed to 860–2600 $m^2$/d and

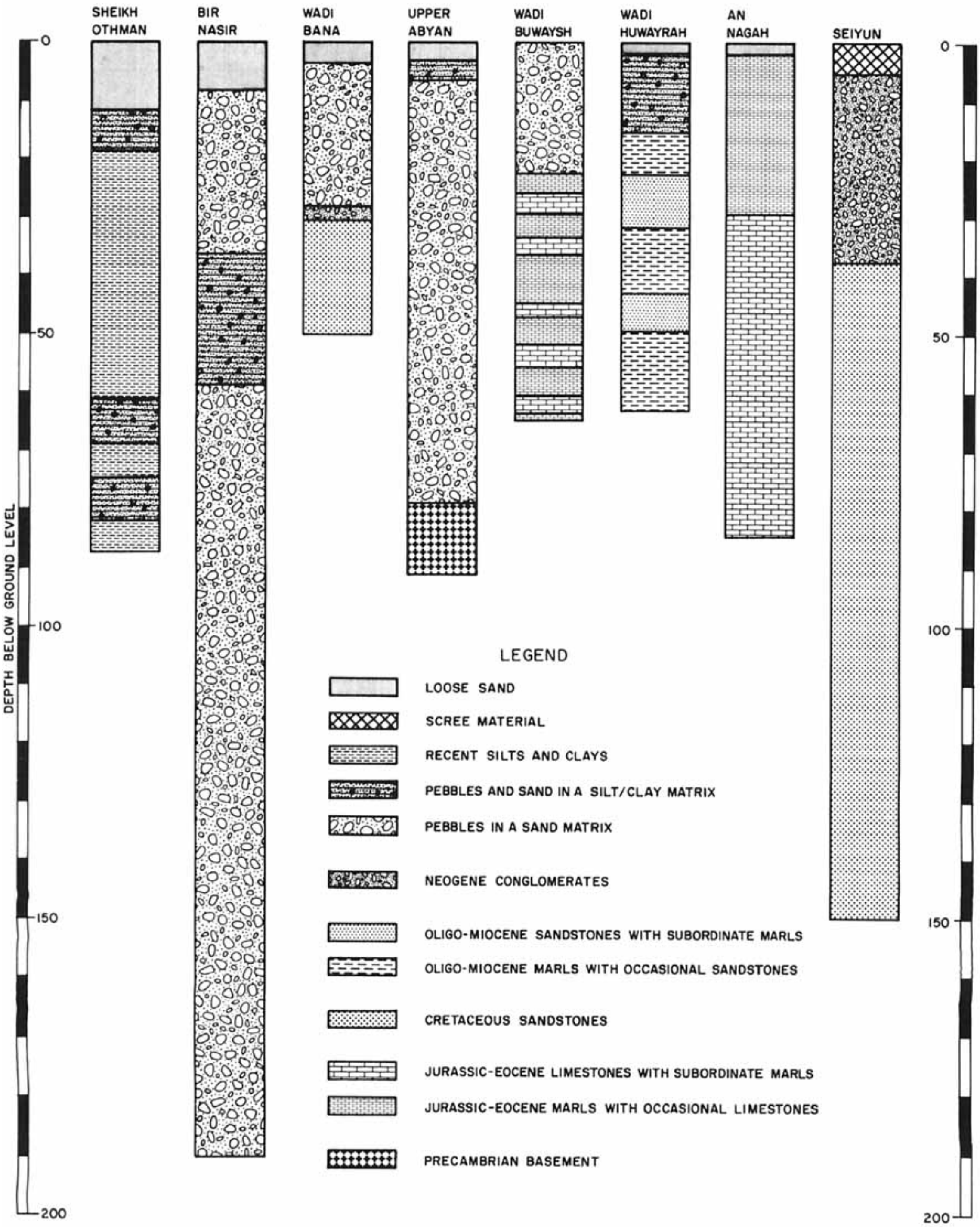

**Fig. 3. Borehole logs**

**TABLE I.** Selected Groundwater Quality Analyses

| | GREATER ADEN | | | AL MUKALLA | | | W. HAD | WHO GUIDE LINES |
|---|---|---|---|---|---|---|---|---|
| | Bir Nasir | Wadi Bana | Upper Abyan | Wadi Buwaysh | Wadi Huwayrah | An Nagah | Seiyun | |
| Conductivity | 1850 | 2460 | 1580 | 1810 | 1260 | 1800 | 730 | |
| pH | 7.38 | 7.33 | 7.40 | 7.00 | 7.08 | 7.3 | 7.55 | 6.5–8.5 |
| Ca | 88 | 120 | 76 | 211 | 138 | 158 | 64 | |
| Mg | 28 | 49 | 32 | 41 | 29 | 25 | 33 | |
| Na | | 450 | 223 | 31 | 40 | 182 | 57 | 200 |
| K | | 24 | 17 | | | | 6 | |
| HCO3 | | 232 | 319 | 108 | 165 | 97 | 245 | |
| SO4 | 220 | 487 | 225 | 360 | 240 | 355 | 84 | 400 |
| Cl | | 400 | 211 | 212 | 120 | 210 | 87 | 250 |
| NO3 | 5.5 | 0.6 | 15.4 | 1.8 | 6.6 | 4.3 | 5.3 | 45 |
| F | 1.10 | 1.70 | 1.50 | 1.80 | 1.10 | 1.10 | 0.85 | |
| Total Fe | | | | | 0.06 | <0.05 | 0.04 | 0.30 |
| Total alkalinity | | 380 | 261 | 182 | 260 | 162 | 201 | |
| Total hardness | 364 | 476 | 320 | 695 | 466 | 490 | 295 | 500 |

(All concentrations in mg/l except conductivity (μS/cm) and pH ((units)).

430–860 m$^2$/d used for the original wellfield design, and vertical hydraulic conductivity of the intervening conglomerate 0.01–0.04 m/d. With conductivities 1 600–3 000 μS/cm groundwater quality (Table I) was also poorer than had been expected.

With the pipeline from Bir Nasir already under construction, investigations to secure the necessary groundwater development had to be completed expeditiously.

### Additional Studies

Reconnaissance commenced in the vicinity of the original wellfield and expanded across the Upper Abyan region. East and southeast of Al Husn the water table was 1–10 m below ground level and groundwater conductivities frequently less than 2 000 μS/cm. Over part of the area, a resistivity survey had previously been undertaken to investigate the Jurassic limestones for cement making. Although comparison with recent drilling results showed absolute thicknesses for wadi deposits to be in error, 5–15 m being postulated near Wadi Bana where 35–40 m had now been proved, this work indicated the presence of a broad ancient alluvial channel west of Wadi Hassan. Further resistivity profiling and EM geophysics suggested aquifer thicknesses up to 80 m.

Subsequent drilling and testing at three sites confirmed such thicknesses (Fig.3), reduced silt and clay units and the absence of a low permeability basal conglomerate. Transmissivities were up to 675 m$^2$/d, groundwater conductivities 1 600–1 940 μS/cm, and it was concluded that the area would support some 80% of the originally anticipated abstraction.

### Upper Abyan Wellfield

Provisional wellfield design anticipated twenty-four production wells, each 80 m in depth, sited along three west-east lines but the construction sequence was designed to quickly improve areal data coverage; the number of wells was reviewed as test pumping results became available, and depths varied to fully penetrate the alluvial sequence.

Twenty-three wells and three piezometers were completed. Largely dictated by changes in permeability, each line gave a different range of aquifer transmissivity, 300–940 m$^2$/d in the north, 1 470–2 915 m$^2$/d along the centre and 2 520–8 185 m$^2$/d in the south, with respective means of 500, 2 400 and 4 000 m$^2$/d. Conductivities were 1 450–2 200 μS/cm and with the exception of fluoride, individual constituents were generally within WHO Guidelines.

Four wells penetrating fine grained interfluve areas with atypically low aquifer properties and poorer quality groundwater were not commissioned. From the remaining nineteen, proposed long term yields were 10–30 l/s, giving a total wellfield output of some 28 Ml/d when commissioned in 1988, 78% of the original design yield for Wadi Bana.

## AL MUKALLA

Al Mukalla is a long-established trading centre crowded onto a sheltered embayment mid-way between Aden and the Oman border. Total population was 65 000 in 1983 and is expected to rise to 105 000 by the year 2000[8].

### Bagrain Springs

The original water source was located where rainfall onto the plateau foothills is prevented from deeper infiltration by marl bands within the Mukalla Formation. Although precipitating much carbonate material, its accessibility and relatively high yield at about 11 l/s satisfied demand for many years.

### WADI BUWAYSH WELLFIELD

Pre-Independence advisors recommended, on administrative rather than technical criteria, that a wellfield exploit cemented wadi deposits and Jeza strata (Fig. 3) in Wadi Buwaysh. Five wells, 45–50 m in depth, were drilled in 1965 and by 1985 there were nineteen, stretching 2 km along its southern bank. Of these, nine had been abandoned or never commissioned and the others only yielded 3–13 l/s with total wellfield output less than 5 Ml/d. Water levels had declined over time, in one well from 14.9 m in 1967 to 28.3 m in 1985 and several had effective screen lengths of less than 10 m. Groundwater quality had remained locally acceptable with conductivities 1 700–2 100 μS/cm.

Heavy carbonate deposition led to Bagrain being abandoned in the early 1980s but by 1985 increased demand, even though suppressed by limiting the availability of piped supplies, was more than the wellfield could reliably supply. The spring was reinstated and studies undertaken to maximize the return on investment in Wadi Buwaysh.

These studies comprised wellfield monitoring and the drilling of three deep wells. Although yielding nearly 5 l/s, apparently without competing for the resources exploited by the shallower wells, these boreholes failed to prove major new resources capable of sustaining long-term development. Wellfield monitoring indicated that even with better resource management and engineering, a long-term output of only 3.6 Ml/d, less than 20% of Al Mukalla's estimated year 2000 requirement, could be sustained.

### WADI HUWAYRAH

The major new development was to be a wellfield 40 km northeast of Al Mukalla in Wadi Huwayrah, where three boreholes had been drilled by previous consultants. The first, in its upper reaches, encountered wadi deposits and Umm Er Radhuma limestones but no groundwater. The second, 18 km downstream, penetrated wadi deposits and Shihr sandstones with groundwater conductivities up to 3 000 μS/cm and 4 000 μS/cm respectively. Between these two, a third borehole exhibited two distinct aquifer units; 16 m of wadi deposits and the uppermost 22 m of sandstones giving conductivities below 1 500 μS/cm, the deeper sandstones giving 3 000 μS/cm or more. Test pumping at 37 l/s followed a rare major recharge event and it was concluded that the upper unit could be exploited if further exploration also proved succesesful.

This commenced in 1985 when a well only 26 m from the third borehole penetrated just 1.5 m of superficial deposits and gave a much lower yield. Further drilling showed the original borehole to have penetrated a narrow infilled wadi channel of greater permeability than the silts and sandstones into which it had eroded.

Investigations over the broad floodplain showed that while wadi deposits could be up to 20 m thick (Fig. 3), the area over which they were unsaturated was extensive. Water levels were as deep as 35 m, below the most permeable part of the succession and within a gypsiferous zone giving conductivities in excess of 3 000 μS/cm and drawdowns up to 15 m for discharges less than 5 l/s. In addition, the original borehole exhibited continued recession from the high levels at the time of the pumping test, the decline of 4.5–5.0 m effecting a 13% reduction in aquifer saturated thickness. It was therefore concluded that sustainable development could not be assured and further exploration of Wadi Huwayrah was curtailed.

### ALTERNATIVE SOURCES

Following a review of all available data, potential alternative source areas were identified in adjacent wadis and plateau foothills where existing wells indicated the presence of good quality groundwater. With the exception of the foothills north of Wadi Huwayrah, expeditious investigations suggested that existing abstractions were already exploiting much of the available resources.

The presence of good quality groundwater north of Huwayrah became apparent from three sources. An abandoned borehole gave conductivities of 1150 μS/cm; a hand-dug well near An Nagah gave 1450 μS/cm, and karst collapse caverns further south contained water of 1 780 μS/cm despite being open to evaporation. All three were located near strike-slip faults cutting the step faulted southern edge of the plateau, and after further investigations exploratory drilling was undertaken near An Nagah.

Because it was uncertain to what degree faulting determined the successful operation of the existing well, the first exploratory borehole was drilled on the same structural feature and three others at intervals along a line stretching 2.4 km westwards.

All penetrated marls with gypsum and occasional marly limestones which changed with depth to crystalline karstic limestones with only thin marls (Fig. 3). Pumping tests at up to 42 l/s gave drawdowns of less than 0.5 m at three sites and 12 m at the fourth which afforded reduced secondary permeability. Water quality was acceptable even though some constituents approached WHO Guideline values.

### AN NAGAH WELLFIELD

It was concluded that the An Nagah area could sustain abstraction of 16 Ml/d and a wellfield comprising ten 85 m deep boreholes 300–350 m apart and each yielding 20 l/s was proposed. Although the existing source at the eastern end of this wellfield is expected to continue in operation over the short term, the nearest exploratory borehole will be commissioned should there be long-term derogation. Construction of this wellfield is expected to commence in the next few months.

## HADRAMAUT VALLEY

PDR Yemen's Hadramaut Valley is one of the ancient centres of Arab civilization and its flat fertile bed was traversed by many of the ancient and medieval Incense Routes. Only the central section is settled, with numerous villages spread between the main towns of Al Qatn, Seiyun and Tarim.

The sheer valley walls up to 500 m in height expose Jeza strata, Umm Er Radhuma limestones and Mukalla sandstones, with the overdeepening of a previous climatic regime infilled with Neogene conglomerates below Quaternary and Recent deposits (Fig. 4). The superficial deposits traditionally satisfied water requirements but a central brackish zone, thought to originate from salt domes in the Ramlat Sab'atayn Desert, was induced throughout these aquifers as abstraction increased.

Attention then focused on the Mukalla sandstones where adequate supplies were often beyond the traditional limit of exploitation by hand-dug wells. The concentration of effort required for construction gave rise to the formation of private water companies which, through narrow diameter distribution systems, could each supply up to 500 households from just one or two deep wells[9]. Each major settlement was served by one or more of these companies, Seiyun, the largest, by no fewer than ten.

### SEIYUN

Master Plan studies throughout the western half of the Valley in the late 1970s concluded that the north-easterly flowing groundwater was best exploited beneath southern tributary valleys before it passed under the brackish zone which could be induced downwards by pumping.

Detailed studies in the valley above Seiyun included two exploratory boreholes which yielded 28 l/s for a water level drawdown of 5.8 m and gave an aquifer transmissivity of 1 800 $m^2$/d. The chosen wellfield location along stable scree slopes offered a number of advantages. It was distant from areas susceptible to flash flooding, minimized the risk from brackish water recharge, and reduced the thickness of superficial deposits to be penetrated. Sited on coarse detrital material, it afforded no conflict of use with urban expansion or agricultural interests and its elevation permitted the distribution system to be gravity fed from a nearby reservoir.

Seven wells each yielding 27 l/s were required to satisfy immmediate demand and a further three will be added as this increases. Although they could have been spaced at 200 m intervals, the first seven were set 400 m apart and future expansion may be achieved at minimal cost by drilling at intermediate locations, collector mains and overhead power cables having been designed for the longer-term

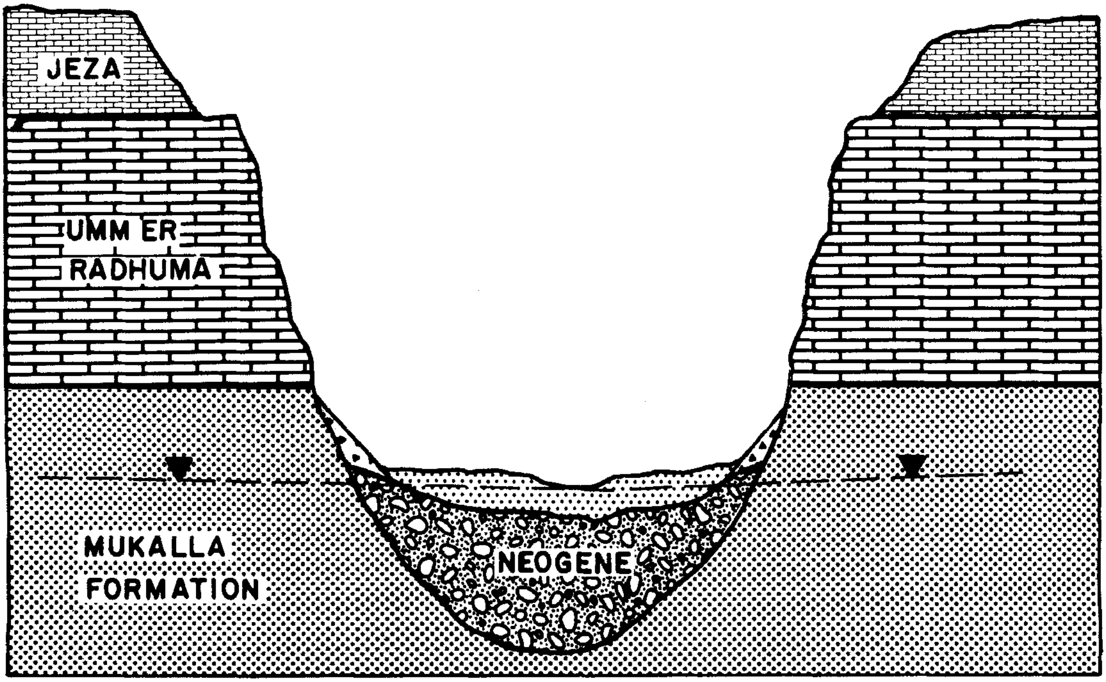

Fig. 4. Geological section through the Hadramaut Valley

requirement. This also affords the opportunity to check wellfield performance during the early years of operation against predicted behaviour and continued water quality acceptance.

The first-phase wells were drilled in 1986 to depths of 145–205 m and penetrated 5–12 m of weathered angular limestone scree above fractured well cemented Neogene conglomerates to 48 m below ground level. The underlying aquifer comprises thinly bedded, fine–coarse grained quartzitic sandstones and orthoquartzites, compacted but only weakly cemented (Fig. 3). The superficial deposits and uppermost 25–35 m of sandstones were cased out to restrict any vertical leakage. Test pumping at up to 40 l/s gave average drawdowns of 5.30 m. Groundwater quality was excellent with conductivities 730–885 µS/cm and all constituents well within WHO Guidelines.

Distribution system civil works followed well construction, and a new integrated supply system providing nearly 14 Ml/d to Seiyun and adjacent villages was commissioned in mid-1988.

### TARIM

Prior to construction at Seiyun, feasibility and design studies were extended to Al Khun, a further 65 km along the Hadramaut Valley. Tarim, the largest town, has a population of 25 000 which was expected to rise to 38 000 by the year 2000, when the area would house 67 000 and require a water supply of 12 Ml/d.

Although the hydrogeological regime is similar to that further west, the Tarim area afforded more data from which to assess individual aquifers. Alluvial deposits average 50 m in thickness, with transmissivities up to 800 $m^2/d$ and average permeability 10 m/d. Natural salinity is enhanced through the leaching of salts by returning irrigation water, and conductivities are occasionally over 20 000 us/cm. The Neogene conglomerates are up to 150 m thick, with as much as 70% clays and mudstones but their high fracture density gives transmissivities up to 1 000 $m^2/d$ and mean permeability 20 m/d. Water quality varies widely, with conductivities 900–8 000 µS/cm.

The Mukalla Formation becomes argillaceous north-eastwards and in places pre-Neogene erosion has resulted in superficial deposits resting directly on the Harshiyat subcrop. More typically, sandstone thicknesses may be limited to about 100 m but they still give transmissivities up to 2 000 $m^2/d$ and average permeability 14 m/d. Water quality continues to be good, with conductivities below 1 000 µS/cm.

The basic concept of exploiting the Mukalla Formation in tributary valleys was again adopted but the lower and widespread demands of the Tarim area dictated the requirement for small wellfields to serve the larger settlements and individual boreholes to serve the scattered villages. Financing arrangements for the implementation of these proposals are currently being formulated.

## CONCLUSIONS

1. The requirement for increased volumes of potable quality water led the Public Water Corporation to recognize the benefits of an integrated approach to resource development and recent projects have now secured the resources to sustain PDR Yemen's three main urban areas, nearly one-third of its population, into the next century.
2. Improvements at Bir Nasir and the commissioning of the Upper Abyan wellfield have led to enhanced supplies throughout Greater Aden. Abstraction rates at Bir Nasir can now be reduced to curtail further water level decline, and supplies will be further improved when a second new wellfield is constructed in the upper Wadi Tuban.
3. Having suffered shortages for many years, Al Mukalla can look forward to adequate water supplies when the An Nagah wellfield is commissioned and remedial works to optimize existing investment at Wadi Buwaysh are completed.
4. Seiyun and adjacent settlements already enjoy a new water supply system and further developments here and further east will help to spread its benefits throughout the Hadramaut Valley.

## ACKNOWLEDGEMENTS

Sincere thanks are afforded to all colleagues with whom the author worked on the various projects over the last seven years. In particular, Tony Harris OBE, Acer Group's Local Director, has given much support and encouragement throughout. Drilling supervision was undertaken by Bernie Cato, David Howard and Alvin Temple, the geophysical work by David Fursman and the modelling of the Abyan test pumping results by Prof. Ken Rushton. Sally Sutton undertook much of the early Hadramaut Valley work and the Bir Nasir simulations.

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