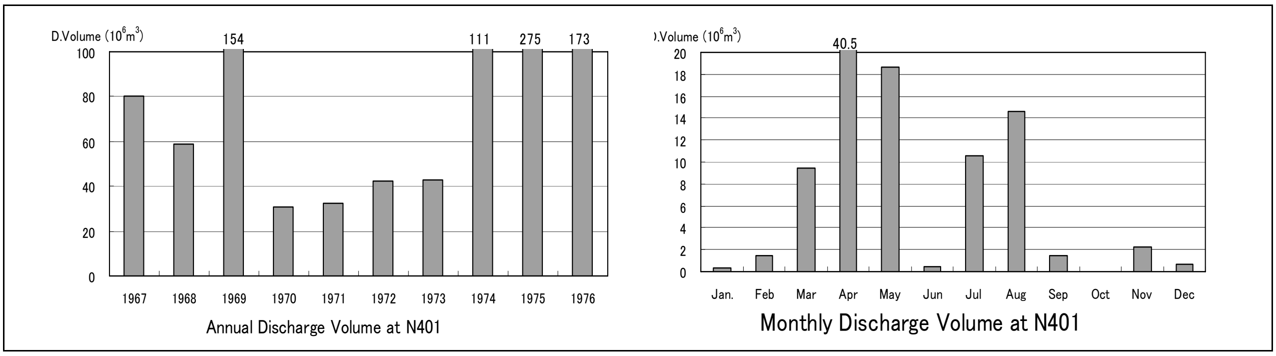


Sources: MOW.E

Figure3-12 Change Over Years and Monthly Flow Distribution in Najran Region

4. Runoff Data by Monitoring in Three Wadis

4.1 Location of Monitoring Stations

Monitoring Stations are installed to grasp of Wadi discharge in this study. The monitoring station sites are settled through the field survey and after consultation with MOWE.

The outline of three Wadis are summarized in Table3-7. The locations of those monitoring stations in Three Wadis are shown in Figure3-13.

Table3-7 Outline of Three Wadis

Item	Hirjab Station	Tabalah Station	Habawnah Station
Region	Asir	Asir	Najran
Width of Wadi	80m (monitoring site)	290 m (at Bridge)	84 m (at Bridge)
Catchment Area (km^2)	594	1,039	1,000
Town in the neighborhood	Samakh	Bisha	Habawnah
Remarks	Planned Dam Site of MOWE	Monitoring was carried out in the 1980s.	Monitoring was carried out in the 1980s.

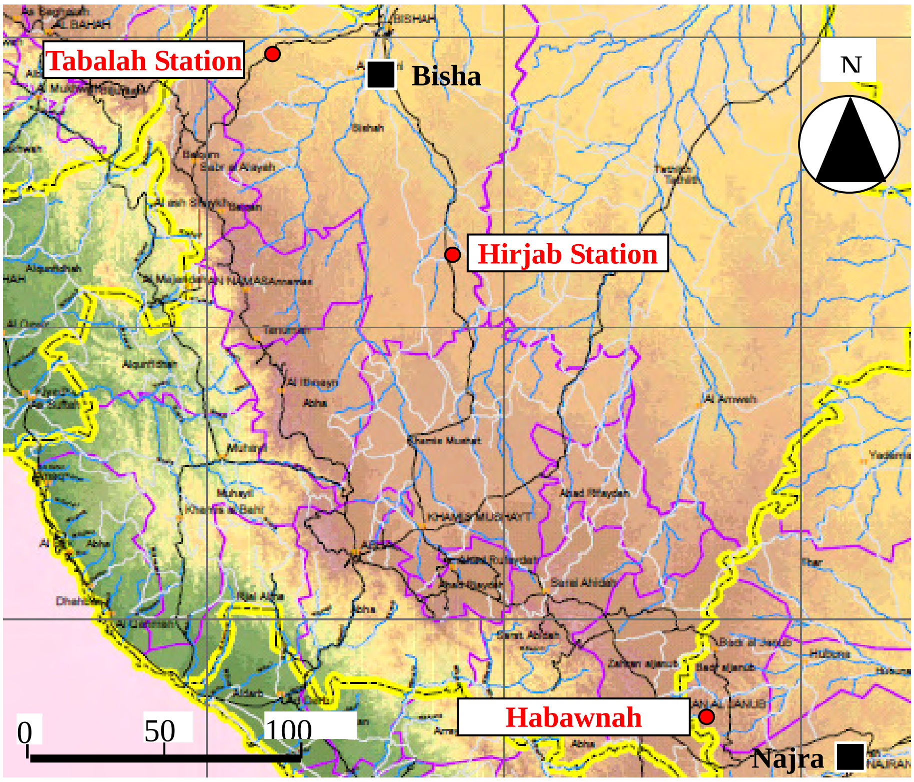


Figure3-13 Location Map of Monitoring Stations

(1) Equipments of Monitoring Stations

Table3-14 shows equipments installed in the three monitoring stations. Each of the equipments is shown in Photo-1～Photo-11.

Table3-8 Equipments in the Three Stations

Station	Latitude	Longitude	Catchment Area (km^2)	Equipments
Hirjab	19° 19´59"N	42° 50´02"E	594	・Staff Gauges ・Water Level Recorder ・Cableway System
Tabalah	20° 00´24.3"N	42° 13´47.7"E	1,039	・Staff Gauges ・Water Level Recorder ・Portable Current-meter
Habawnah	17° 46´9.59"N	43° 53´45.76"E	1,000	・Staff Gauges ・Water Level Recorder ・Portable Current-meter

Photo-1 Staff Gauge (Hirjab)

Photo-2 Water Level Recorder (Hirjab)

Photo-3 Cableway System (Hirjab)

Photo-4 Cableway System (Hirjab)

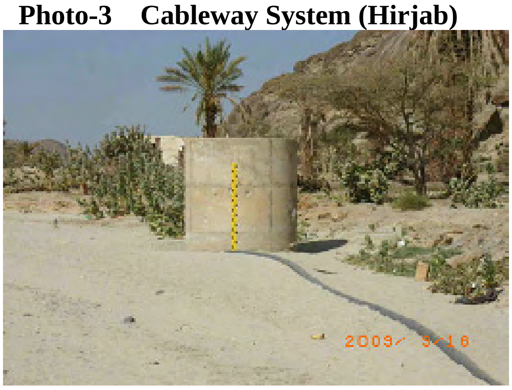


Photo-5 Staff Gauge (Tabalah)

Photo-6 Staff Gauge on Pier (Tabalah)

Photo-7 Water Level Recorder (Tabalah)

Photo-8 Portable Current Meter (Tabalah)

Photo-9 Staff Gauge (Habawnah)

Photo-10 Water Level Recorder (Habawnah)

Photo-11 Portable Current Meter (Habawnah)

(2) Observed Floods (As of February 2009)

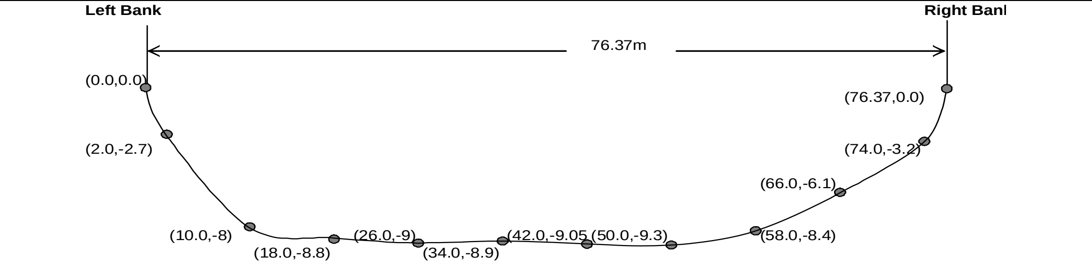
Since the monitoring started on June 2008, there occurred two floods at Hirjab Station and Tabalah Station, and one flood at Habawnah Station up to February 2009. Table3-9 shows the discharge measurement.

Table3-9 Discharge Measurement in the Three Stations

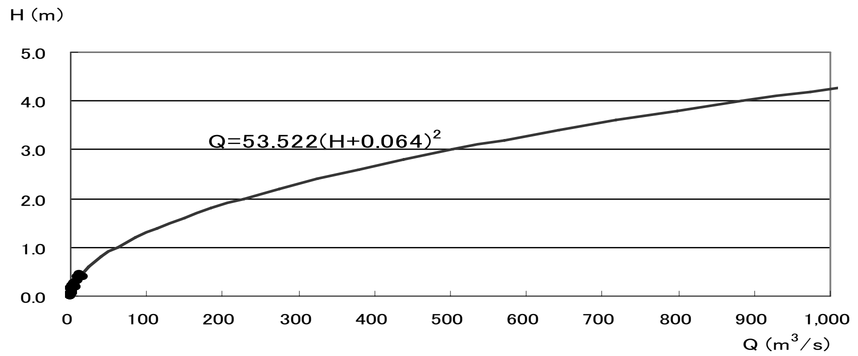
Station	Flooding Time	Observed Discharge (m^{3}/s)	Remarks
Hirjab	25 Oct. 2008 6:25p.m.～1:40a.m.(26 Oct.) 2 Nov. 2008 5:30p.m.～12:40a.m. (3 Nov.)	0.2～15.7 0.2～7.1	18 times carried out 12 times carried out
Tabalah	25 Oct. 2008 5:10a.m.～12:30p.m. 2 Nov. 2008 3:34p.m.～11:30a.m. (3 Nov.)	0.3～1.2 0.1～50.3	9 times carried out 19 times carried out
Habawnah	25 Oct. 2008 8:27p.m.～1:05a.m.(26 Oct.)	0.4～4.7	16 times carried out

Stage-Discharge Curve is obtained as below based on the observed flood data. The cross section and the stage-discharge curve of each stations are shown in Figure3-14.

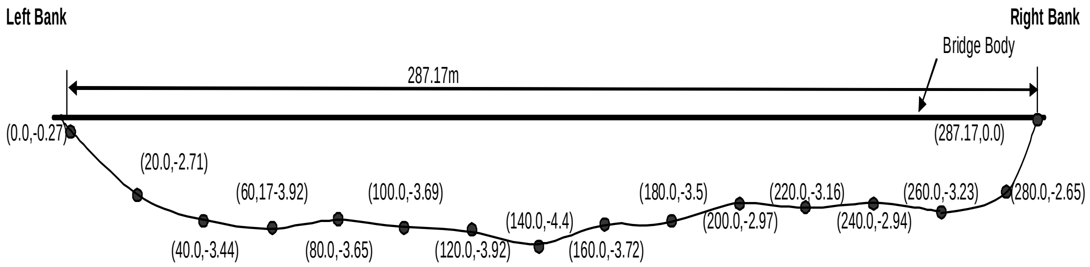
Station	Stage－Discharge Curve
Hirjab	$Q = 53.522 (H + 0.064)^2$
Tabalah	$Q = 56.923 (H + 0.017)^2$
Habawnah	$Q = 188.633 (H - 0.049)^2$



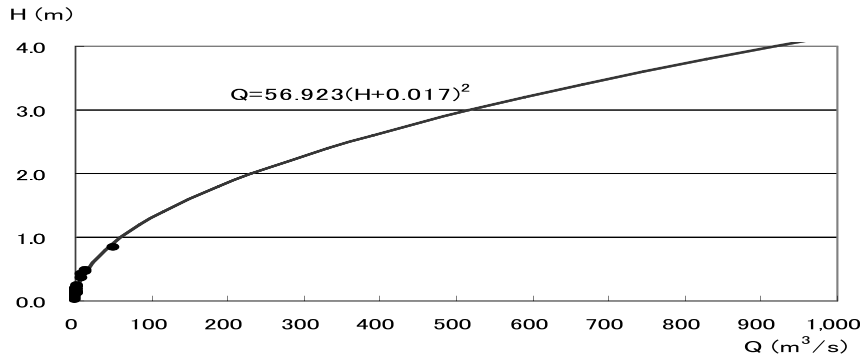
Cross Section（Hirjab）



Stage－Discharge Curve(Hirjab)

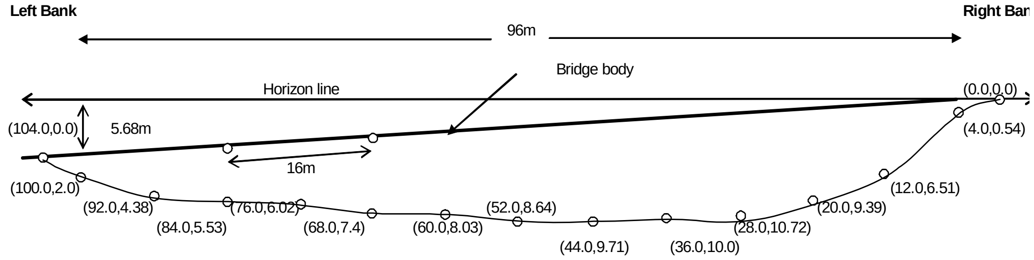


Cross Section(Tabalah)

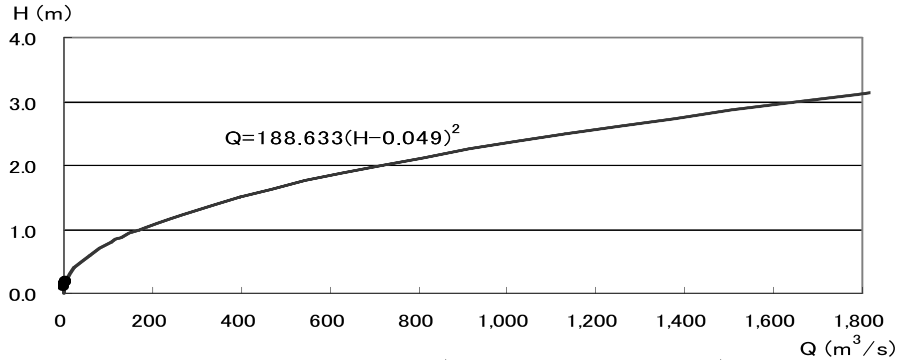


Stage－Discharge Curve(Tabalah)

Figure3-14(1)　Cross Section and Satge-Discharge Curve(Hirjab, Tabalah)



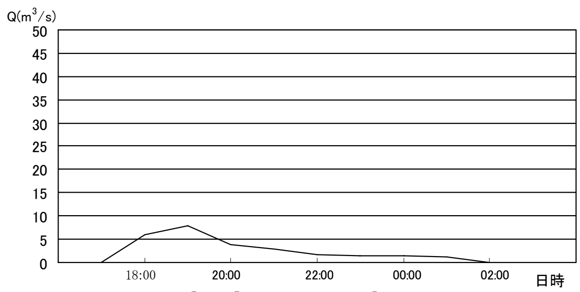
Cross Section(Habawnah)



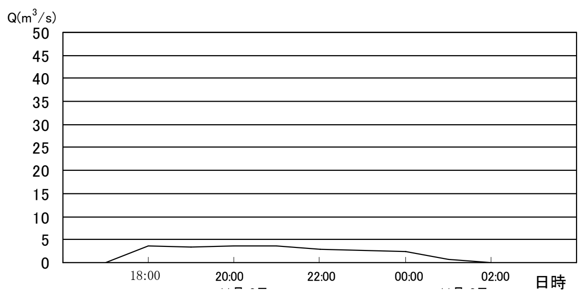
Stage－Discharge Curve(Habawnah)

Figure3-14(2) Cross Section and Satge-Discharge Curve(Habawnah)

The discharge of each stations can be obtained by converting from water level using the stage－discharge curve in Figure3-14. Those discharge are shown in Figure3-15 to Figure3-17.



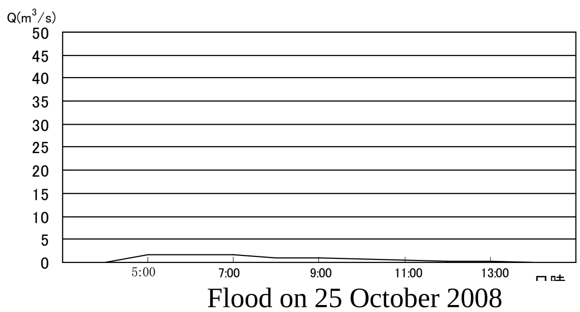
Flood on 25 October 2008



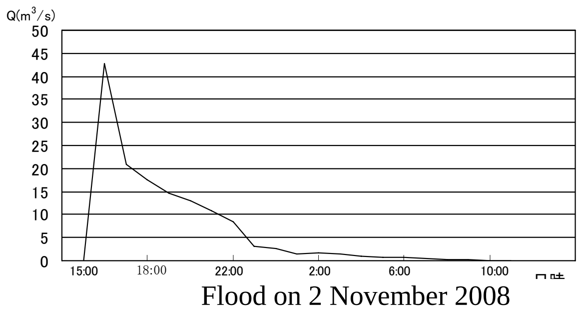
Flood on 2 November 2008

Hirjab

Figure3-15 Observed Discharge(Hirjab)



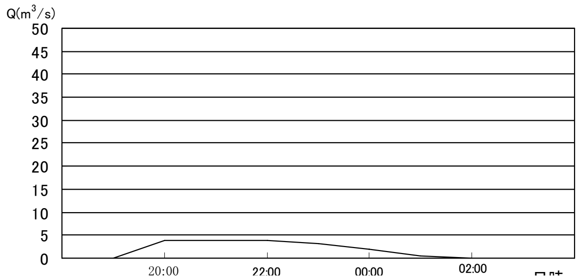
Flood on 25 October 2008



Flood on 2 November 2008

Tabalah

Figure3-16 Observed Discharge(Tabalah)



Flood on 25 October 2008

Habawnah

Figure3-17 Observed Discharge(Habawnah)

Table3-10 shows the peak discharge observed at runoff station (B405,C.A.= 1,090km^2 ,Wadi Tabalah) which has same size of the catchment area. The observed discharge at Tabalah Station this time are neither big nor small.

Table3-10 Observed Discharge at Runoff Station(B405)

No.	Occurrence Day	Qp (m^3/s)
1	1969 Jun. 30	58.0
2	1971 May 20	0.15
3	1973 May 3	14.7
4	1974 Mar. 23	78.0
5	1975 Apr. 3	570.0
6	1976 Mar. 21	44.4
7	1977 Oct. 24	23.5
8	1978 May 1	59.2
9	1979 Dec. 27	44.0
10	1980 Feb. 10	108.4
11	1981 Mar. 13	72.0
12	1982 Apr. 15	142.0
13	1983 Mar. 15	183.0
14	1984 Mar. 21	804.0

Sources: MOW.E

The observed discharge volume and runoff ratio to the neighborhood rainfall station data are shown in Table3-11. The flow ratios at Tabalah Station indicate extraordinary numbers because of the rainfall data too small. This is caused by the inadequate rainfall data. The flow ratios for Hirjab Station and Habawnah Station show between 10 percent and 18 percent are rather higher than the observed data in wadis and dam sites shown in Table3-12 and Table3-13, but there is no major difference between them as shown in Figure3-18.

This time, they are just the results of the small 2 floods in 2008, and it is necessary to improve the accuracy by the accumulation of more data. Furthermore, there is still problem to grasp the appropriate mean rainfall over the basin with a few rainfall stations nearby.

Table3-11 Observed Discharge Volume at 3 Stations

Station	C.A. (km^2)	Flood	Discharge Volume ($1000m^3$)	Rainfall (mm)	Flow Ratio (%)
Hirjab	594	Flood in 25 October 2008 Flood in 2 November 2008	2,258 1,995	39.0(24～25 Oct.) 30.0(1～2 Nov.)	9.7% 11.2%
Tabalah	1,039	Flood in 25 October 2008 Flood in 2 November 2008	745 12,292	2.2(24～25 Oct.) 2.4(1～2 Nov.)	32.6% 492.9%-
Habawnah	1,000	Flood in 25 October 2008	1,460	43.0(24～25 Oct.)	17.9%

Note）Rainfall Station：Hirjab; A103、Tabalah ; MET-03(GTZ)、Habawnah ; N001

Table3-12 Flow Ratio in 5 Wadis

Wadi	Catchment Area (km^2)	Rainfall Amount (10^6m^3)	Discharge Volume (10^6m^3)	Flow Ratio (%)
Yiba	2,830	982.0	8.4	0.9
Al-Lith	3,079	583.2	2.3	0.4
Tabalah	1,900	346.7	9.6	2.8
Habawnah	4,930	695.7	8.4	1.2
Liyayah	456	134.6	4.3	3.2

Sources:Five Wadis Study Report (February, 1988)

Table3-13 Flow Ratio at 13 Dam Sites

No.	Dam Site	Catchment Area（km^2）	Period	Mean Annual Rainfall (mm)	Mean Discharge Volume (10^6m^3)	Flow Ratio (%)
1	Rabigh Dam	3,456	1969-1985	98	83.34	24.6
2	Muruwai Dam	2,762	1966-1981	96	31.50	11.9
3	Al-Lith Dam	1,838	1984-1985	234	14.03	3.3
4	Ranyash Dam	4,379	1973-1982	201	88.76	10.1
5	Aqiq Dam	304	1967-1981	329	10.05	10.1
6	Tabalah Dam	863	1969-1984	267	12.04	5.2
7	Bisha (K.Fahad) Dam	7,600	1967-1981	269	101.43	5.0
8	Qanunah Dam	1,382	1971-1984	321	20.19	4.6
9	Hali Dam	4,843	1967-1985	375	95.62	5.3
10	Wadi Baysh Dam	4,600	1970-1985	391	74.48	4.1
11	Damad Dam	903	1970-1985	492	39.70	8.9
12	Qissi Dam	272	1970-1984	475	8.56	6.6
13	Sabya Dam	336	1970-1984	461	9.92	6.4

Sources:Final Report on each dam (1983-1987)

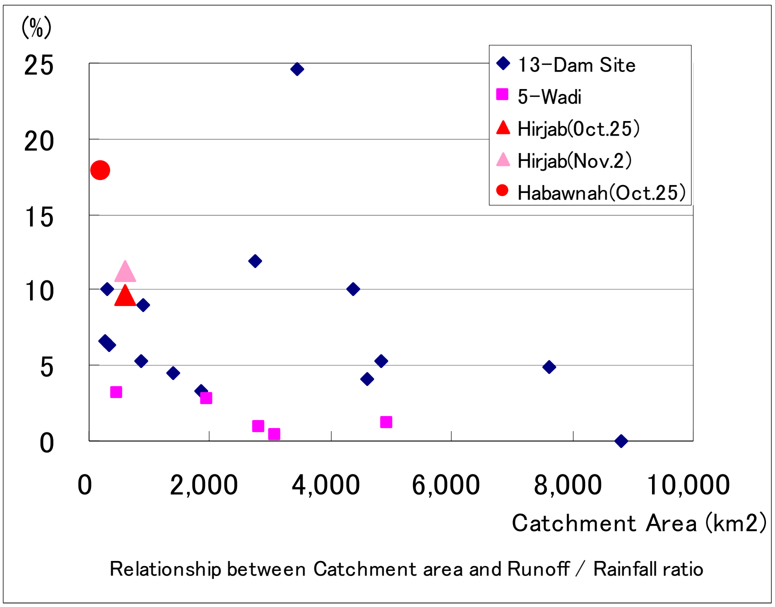


Figure3-18 Observed Flow Ratio

4.2 Evaluation and issues of Monitoring System

(1) Monitoring System

There are 115 rainfall stations, owned 105 by MOWE and 10 owned by PME, in the study area which is nearly equal to the total land area of Japan. Each rainfall station is placed per 3,000 km^2 to 4,000 km^2 by roughly calculation, and this is not enough. Actually, there are many rainfall stations concentrated in areas along the Red Sea but a few rainfall stations are found in desert areas extent of the eastern part of the study area. This might be the result of the degree of difficulty of the maintenance of stations as it is with ease in areas along the Red Sea, but with difficulty in desert areas. For this reason, the accuracy of rainfall observations in desert areas extent of the eastern part of the study area is not be as good as it in areas along the Red Sea.

Taking into consideration of the rainfall characteristic that there is much rain in the Hijaz Asir Highlands over the area from Taif through the borders of Yemen, and quite few rain in desert areas in the eastern part, it is required to add more rainfall stations preferentially at and around the Hijaz Asir Highlands. Moreover, it is necessary to place rainfall stations in central and eastern area in Najran Region on account of three being only 3 rainfall stations concentrating in the border of Asir Region.

(2) Observation Data Collection

Although automatic rainfall recorders with telemeter are found at some stations, most rainfall stations consist of manual type and observed data are being sent by facsimile transmission in KSA.

Meanwhile, it is said that observation stations without watchman are likely to suffer a theft or get damages, and this prevents the realization of laborsaving and telemetry. It is recommended to advance telemetry in future at regional offices of MOWE and managing facilities (dams and well fields) under MOWE because that it is relatively easy to maintain equipments at those places.

(3) Analysis of Observation Data and Utilization it for Water Resources Development

MOWE has mainly done no more than collection and accumulation of the observation data in the past, without analyzing the data or utilizing it for water resources development. It is requirement to utilize the data aggressively for water resources development in future.

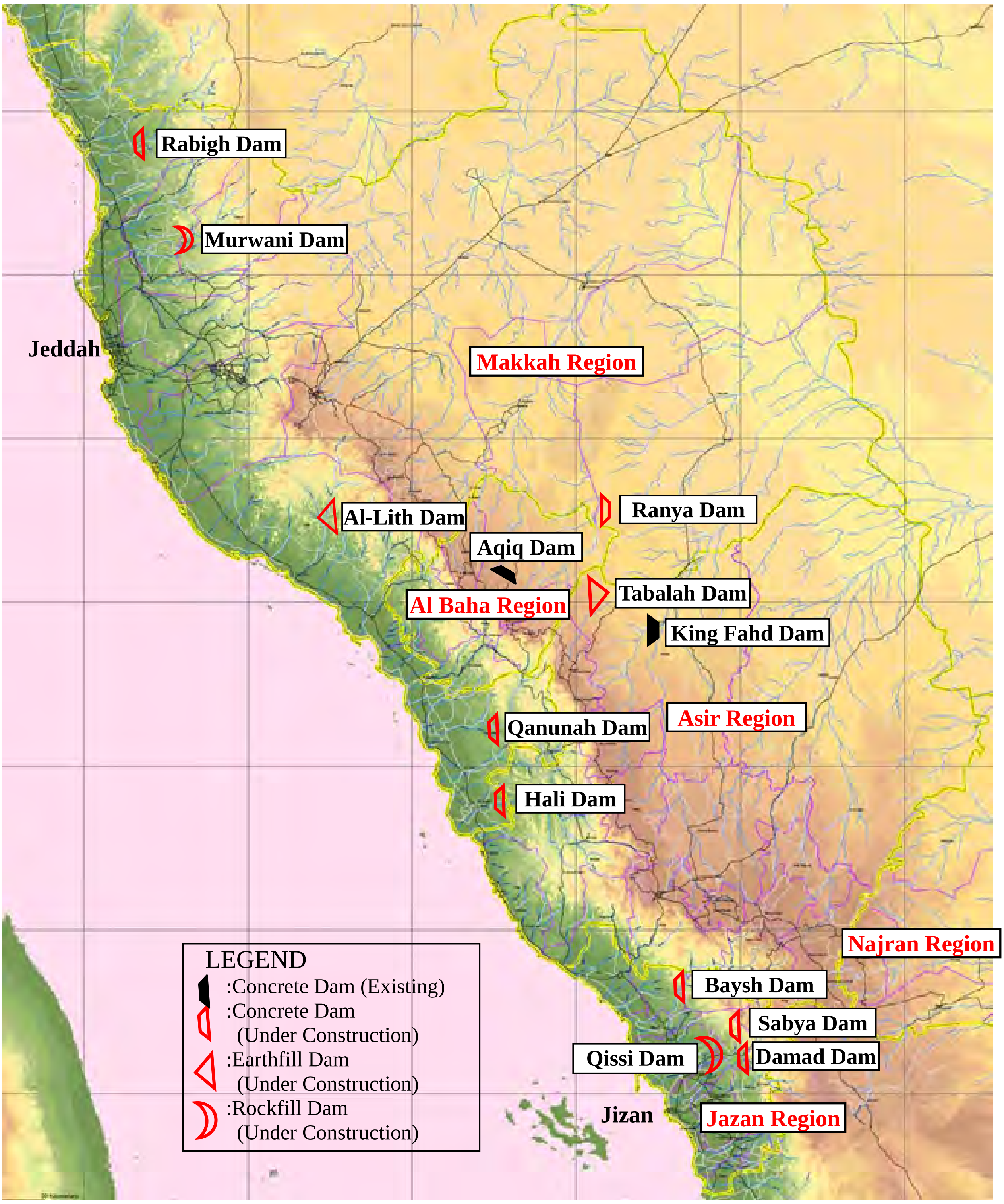


Figure3-19 Location of 13 Dam Sites

The Kingdom of Saudi Arabia

The Ministry of Water and Electricity (MOWE)

THE STUDY ON MASTER PLAN

ON

RENEWABLE WATER RESOURCES DEVELOPMENT IN THE SOUTHWEST REGION

IN

THE KINGDOM OF SAUDI ARABIA

FINAL REPORT

(SUPPORTING REPORT)

C. GEOLOGY AND HYDROGEOLOGY

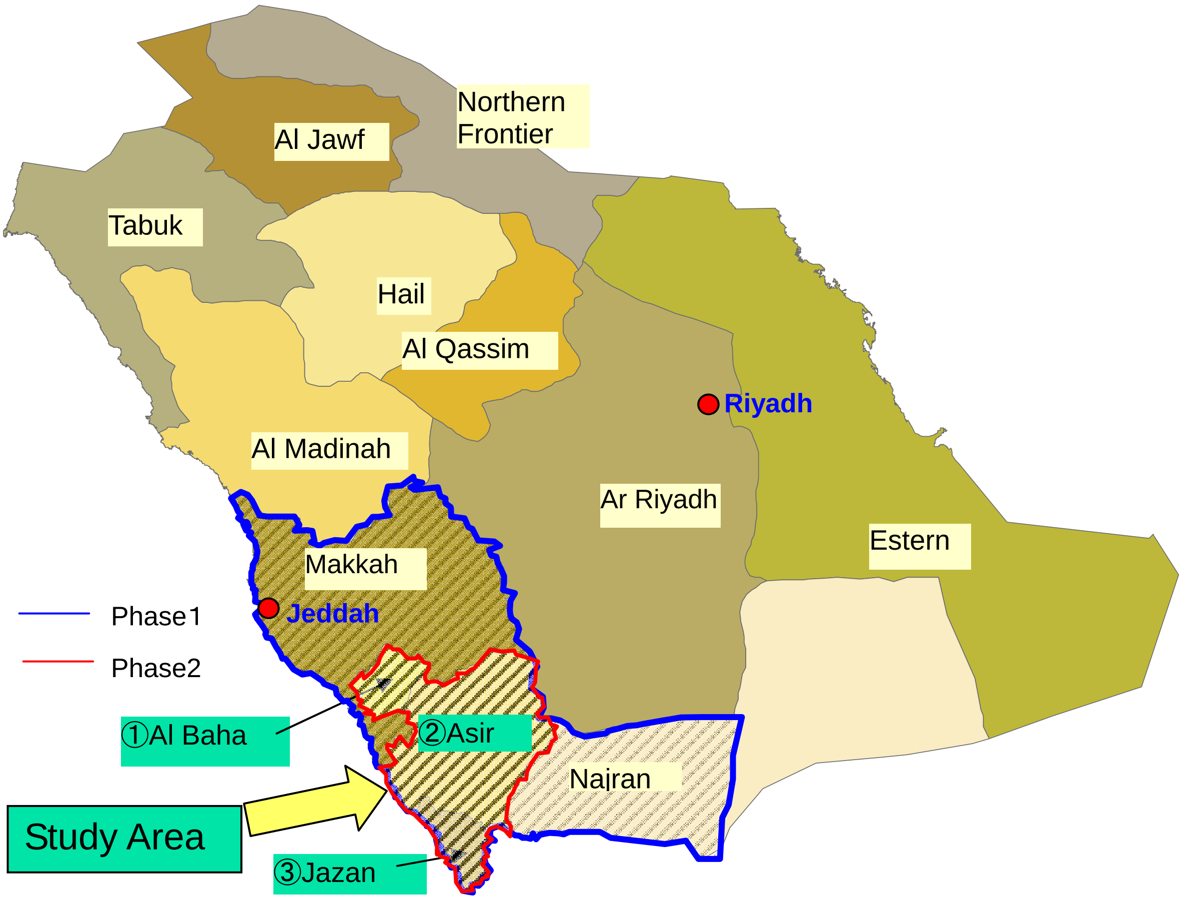
OCTOBER 2010

JAPAN INTERNATIONAL COOPERATION AGENCY

YACHIYO ENGINEERING CO., LTD.

SANYU CONSULTANTS INC.

The Kingdom of Saudi Arabia Location of Map



Final Report
Supporting Report (C)

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List of Abbreviations

Abbreviation and Acronym	English	Arabic (عربي)	Japanese (日本語)
BCM	Billion Cubic Meters	مليار متر مكعب	10 億立方メーター
CBD	Convention on Biological Diversity	اتفاقية التنوع البيولوجي	生物多様性保全条約
C/P	Counterpart	النظير	カウンターパート
EIA	Environment Impact Assessment	تقييم الأثر البيئي	環境アセスメント
ER	Effective Rainfall	الأمطار الفعالة	有効雨量
ET	Evapotranspiration	البخرنتح	蒸発散
FAO	Food and Agriculture Organization, United Nations	منظمة الأغذية والزراعة للأمم المتحدة	国連食料農業機関
GIS	Geographic Information System	نظام المعلومات الجغرافية	地理情報システム
GPS	Global Positioning System	نظام تحديد المواقع العالمي	グローバル・ポジショニング・システム
GDP	Gross Domestic Product	الانتاج المحلي الإجمالي	国内総生産
GDW	General Directorate of Water		地方水事務所
GNI	Gross National Income	الدخل القومي الإجمالي	国民総所得
GSMO	Grain Silos and Flour Mills Organization	صوامع الحبوب ومطاحن الدقيق	サイロ・製粉公団
GTZ	Deutsche Gesellschaft fur Technical Zusammenarbeit GmbH	الجمعية الألمانية للتعاون التقني المحدودة	ドイツ技術協力公社
IC/R	Inception Report	تقرير الإنشاء	インセプション・レポート
IEE	Initial Environmental Examination	الفحص البيئي الأولي	初期環境調査
IUCN	World Conversion Union	اتحاد التحويل العالمي	国際自然保護連合
IWPP	Independent Water and Power Project	المياه المستقلة وطاقة المشروع	独立水道・発電事業
IWRP	Integrated Water Resources Planning	التخطيط المتكامل للموارد المائية	総合水資源計画
JCCME	Japan Cooperation Center for Middle East	مركز التعاون الياباني للشرق الأوسط	財団法人中東協力センター
JICA	Japan International Cooperation Agency	الوكالة اليابانية للتعاون الدولي	独立行政法人国際協力機構
KSA	Kingdom of Saudi Arabia	المملكة العربية السعودية	サウジアラビア王国
LCD	Liter per Capita per Day	لتر للفرد يوميا	リッター/人/日
MAW	Ministry of Agriculture and Water	وزارة الزراعة والمياه	水・農業省
MEPA	Meteorology and Environment Protection Administration	ادارةالأرصاد الجوية و حماية البيئة	気象環境保護庁
MCM	Million Cubic Meters	مليون متر مكعب	100 万立方メーター
M/M	Minutes of Meeting	ملخص الاجتماع	会議の議事録
MMW	Million Megawatt	مليون ميغاوات	100 万メガワット
NAS	National Agriculture Strategy	استراتيجية الزراعة الوطنية	国家農業戦略
NGO	Non-Governmental Organization	المنظمات غير الحكومية	民間公益団体
NMS	National Mining Strategy	استراتيجية التعدين الوطنية	国家鉱業戦略
NSS	National Spatial Strategy	استراتيجية العمران الوطنية	国家特別戦略
NWC	National Water Company	شركة المياه الوطنية	国家水会社
MWS	National Water Strategy	الاستراتيجية الوطنية للمياه	国家水戦略
MOA	Ministry of Agriculture	وزارة الزراعة	農業省
MOEP	Ministry of Economy and Planning	وزارة الاقتصاد والتخطيط	国家経済計画省
MOF	Ministry of Finance	وزارة المالية	財務省
MOI	Ministry of Interior	وزارة الداخلية	内務省
MOMRA	Ministry of Municipal and Rural Affairs	وزارة الشؤون البلدية والقروية	地方自治省
MOWE	Ministry of Water and Electricity	وزارة المياه والكهرباء	水・電力省
M/P	Master Plan	الخطة الرئيسية	マスタープラン
MSR	Million Saudi Riyals	مليون ريال سعودي	100 万サウジリアル

Abbreviation and Acronym	English	Arabic (عربي)	Japanese (日本語)
NCWCD	National Commission for Wildlife Conservation and Development	اللجنة الوطنية لحماية و تطوير الحياة البرية	国立動物保護開発協会
NIA	National Irrigation Authority	السلطة الوطنية للري	国家灌漑局
PME	Presidency of Meteorology and Environment Protection	الرئاسة العامة للأرصاد وحماية البيئة	国家気象環境保護
P/O	Plan of Operation	خطة العمل	プラン オブ オペレーション
PPP	Public Private Partnership	شراكة القطاعين العام والخاص	官民連携
RWPC	Renewable Water Production Corporation	شركة إنتاج المياه المتجددة	再生可能水生産公社
REWLIP	Red Sea Water Lifeline Project	شريان الحياة للمياه البحر الأحمر المشروع	紅海水ライフライン事業
OJT	On the Job Training	التدريب المهني	研修
SAGIA	Governor Saudi Arabian General Investment Authority	محافظ الهيئة العامة للاستثمار العربي السعودي	サウジアラビア総合投資庁
SAMA	Saudi Arabian Monetary Agency	مؤسسة النقد العربي السعودي	サウジアラビア通貨庁
SAR	Saudi Arabian Riyal	الريال السعودي	サウジアラビアリアル
SCT	Supreme Council for Tourism	المجلس الأعلى للسياحة	最高観光委員会
SEA	Strategic Environment Assessment	التقييم البيئي الاستراتيجي	戦略的環境アセスメント
SGS	Saudi Geological Survey	هيئة المساحة الجيولوجية السعودية	サウジ地質調査
SOIETZ	Saudi Organization for Industrial Estates and Technology Zone	الهيئة السعودية للمدن الصناعية و للمنطقة التكنولوجية	サウジ産業国家技術団体
SR	Saudi Riyals	الريال السعودي	サウジリアル
STP	Strategic Transformation Plan	خطة التحول الاستراتيجي	戦略的転換計画
STP	Sewerage Treatment Plant	محطة معالجة الصرف الصحي	下水処理プラント
S/W	Scope of Works	العملنطاق	業務範囲
SWAT	Soil and Water Assessment Tool	أداة تقييم التربة والمياه	土壌水アセスメントツール
SWCC	Saline Water Conversion Corporation	المؤسسة العامة لتحلية المياه المالحة	海水淡水化公社
UFW	Unaccounted For Water	مياه غير محسوبة	無収水
UNDP	United Nations Development Programme	برنامج الأمم المتحدة للتنمية	国連開発計画
UN-ESCWA	United Nations Economic and Social Commission for Western Asia	اللجنة الاقتصادية والاجتماعية للأمم المتحدة لغربي آسيا	国連西アジア経済社会委員会
WB	The World Bank	البنك الدولي	世界銀行
WHO	World Health Organizations	منظمة الصحة العالمية للأمم المتحدة	世界保健機関
WMO	World Meteorological Organization	المنظمة العالمية للأرصاد الجوية	世界気象機関

C. GEOLOGY AND HYDROGEOLOGY

1. Geography

The project area lies on the south-western part of the Kingdom that rises abruptly from the Red Sea in the west and dips gently towards the Najd in the east. In the trunk of the project area, Hijaz-Asir highlands rises up to about 3,000 meters in the south near Abha, while at northern boundary of the area near Tailf, the elevation is about 1,500 meters (refer to Figure1-1 and Figure 1-2).

There is distinct coastal plain, locally known as Tihama, separated from the hills by an imposing scarp wall that runs parallel to the Red Sea along 700 km in the project area.

Toward east form the peak of Hijaz-Asir highlands, hills peter out further east to the interior, and give way to an extensive plateau covered by lava flow (Harrat: basaltic area), and very thin veneer rock debris and alluvium over a basalt and crystalline basement, which is frequency outcrop as knolls and low hills. In large scale geographic view, the project area is divided into three geographic regions:

(1) Western Coastal Lowland – *Tihama*,

(2) Al Hijaz-Asir Plateau,

(3) Crystalline *Najd*.

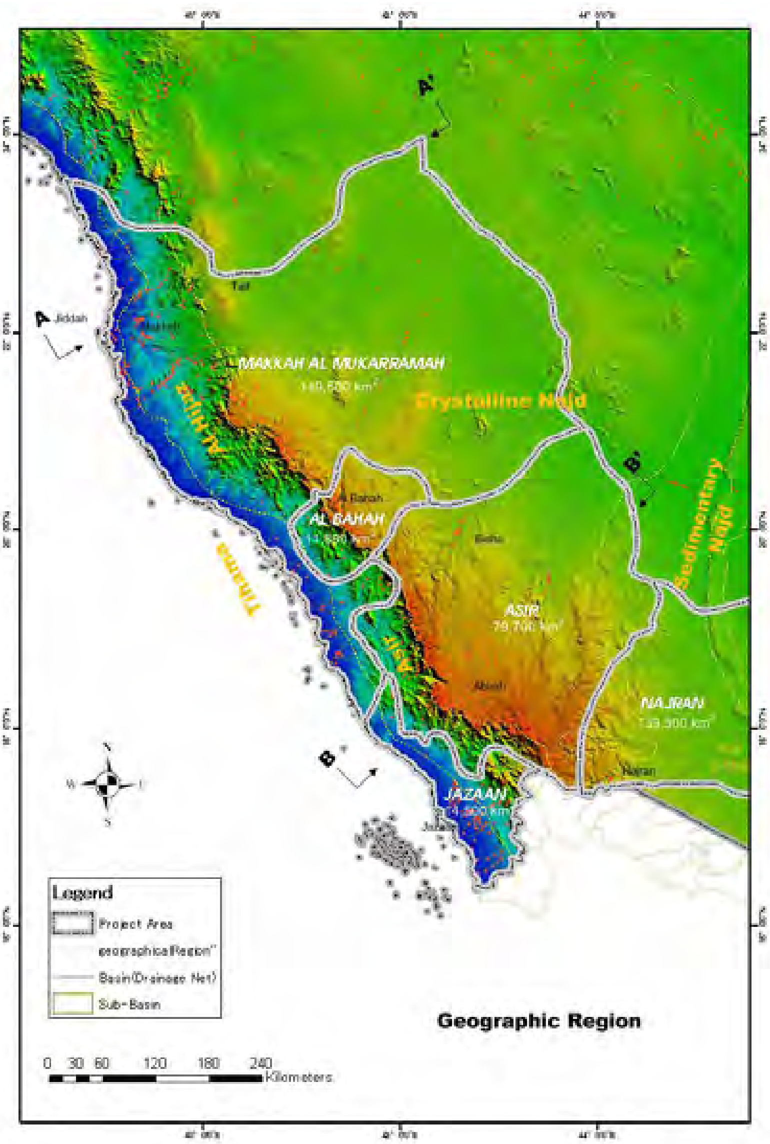
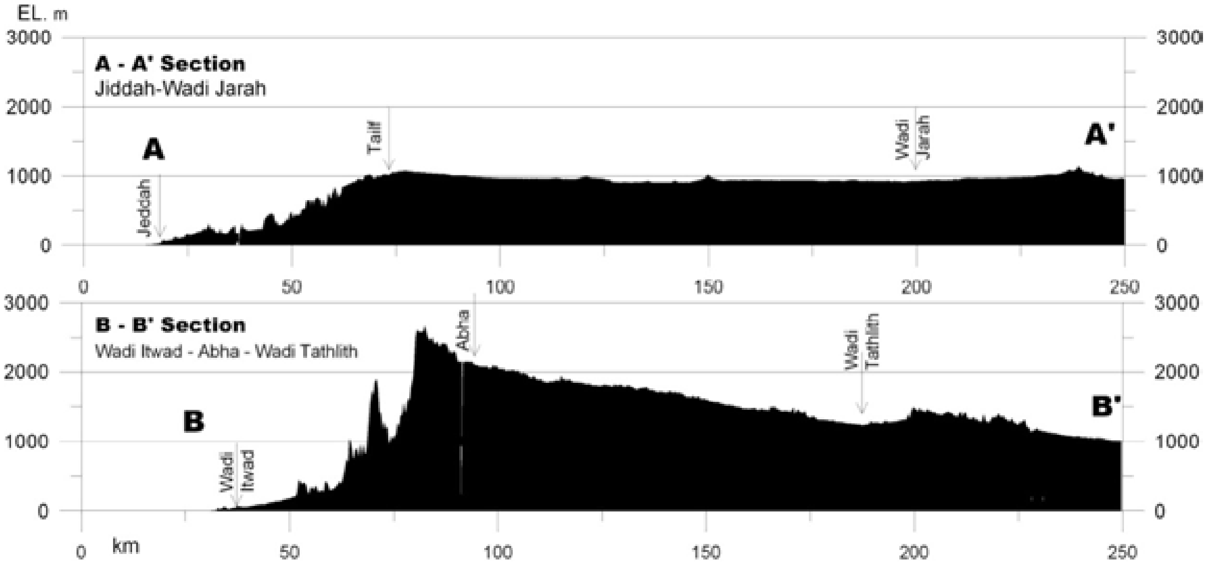


Figure 1-1 Geography of Project Area



Note: Section line is shown in Figure 2.2.12

Figure 1-2 Topographical Section

1.1 Geographic Regions

Geographical features of the project area is shown in Table 1-1.

Table 1-1 Geographic Regions of Project Area

Western Coastal Lowland – *Tihama* –
This region, locally called as '*Tihama*' forms narrow strips along the Red Sea coast. In the north in the area it starts as a plain near Jeddah to gradually widen to over 40 kilometers near Jazan in the south. This plain is low depositional surface mostly on a coral plain that grades upward to the east to form a pediment on hard crystalline rock of geologic basement. Along the eastern edge, the coastal plain is set apart from Hijaz-Asir Plateau by an escarpment wall, which runs parallel to the sea. The landforms are of alluvial nature, formed as a result of the downward transportation of soil material from Hijaz-Asir Plateau by the many wadis and drainages channels that drain out in the sea. The water courses are gently sloping which extends inland to a long distance. Landforms in the form of alluvial fans, alluvial plains, deltas or forms of footslopes of colluvial nature are common. Along the shore, tidal flats and beaches are developed by tidal activity of the sea.
Hijaz-Asir Plateau
The Hijaz-Asir plateau forms the tops of the southern half of the Red Sea escarpment, extending from Taif into Yemen, In the project area, it occupy 700 km along with the Red Sea. The plateau slopes gently to east and north. The Wadi Bisha and Wadi Turabah: large and important drainage system of the plateau; flow eastward to the desert plains of Najd region. The northwestern highlands are called as 'Hijaz' while 'Asir' in southeastern area. The crest of Hijaz is 2,580 meters near Madinah, where is standing outside the project area. In the Asir, the peek is 3,015 meters in Dahyat al Maghabah near Abhah. Most of the rocks outcropping in the area belong to the Precambrian basement complex that is split into many fault blocks associated with the formation of the Red Sea rift. In many places, volcanic emissions overlie the older rock formation and add heights to the peak. In the northern plateau, wadis show as flat-bottomed crevices between hills while V-shape in the south. The Hijaz-Asir highlands include the highest mountain ranges in the Kingdom, they form summit of the western escarpments and include the zone of maximum rainfall in the Kingdom. It varies in width from a minimum of about 50 kilometers to maximum of 180 kilometers in the south. There summits support the natural forest of Juniper trees. In high rainfall area, steep slopes are terraced to make field for cultivation. In the lower reach of southern wadis, dikes are built across the channels to divert splash floods and harness them for irrigation. The hills slope gently to harness them for irrigation.
Crystalline *Najd*
The crystalline Najd is the part of the Najd region that is underlain mainly by resistant rocks of igneous and metamorphic origin. The plain is a rocky expanse of coalescing pediments and desert, as much as 500 km wide, and is dotted with prominent, isolated rock knobs or spires. The surface has gentle, gradual slope eastward and southeastward, reflecting the buried basement's configuration. Along the western edge, lava fields ranging in extent from a few hundred square kilometers have issued from lava cones and north-trending fissures, Elsewhere, there are about 10,000 square kilometer of salt flat, as well as several terminal basins, which were apparently formed by wind sour.

1.2 Landforms

In three geographic regions of the project area, various morphological features were found and classified in the previous study (MAW, 1983) as 'Mountains', 'Slopes', 'Hills', 'Terraces', 'Pedi-plains', 'Alluvial plains' and 'Coastal plains'. The classification was given a feature in both of morphology and surface hydraulic (hydro-geographical) condition, which related closely to runoff process and even groundwater recharge. The detail feature is shown in Figure 1-3 and Table 1-2.

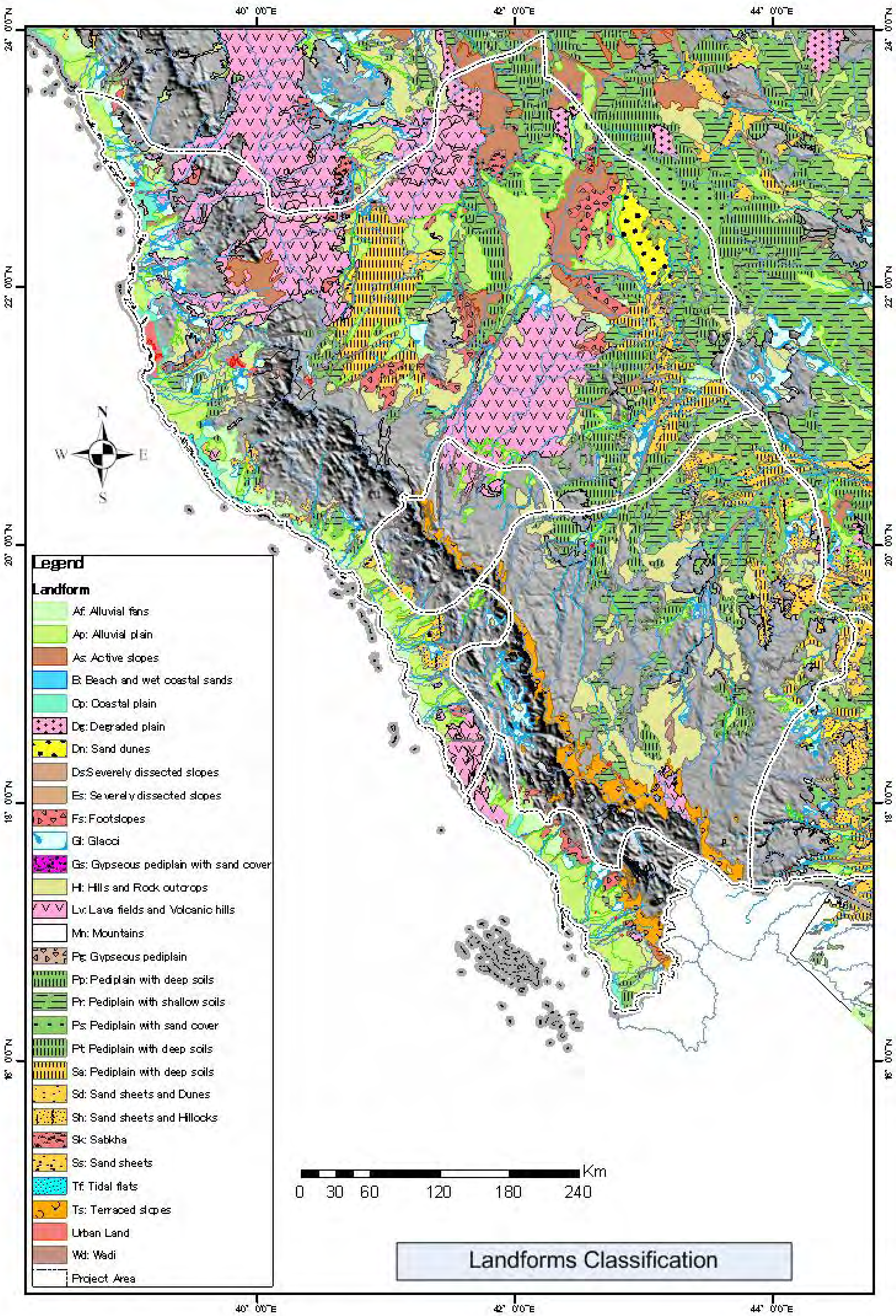


Figure 1-3 Landform Map

Table 1-2 Legend of Landform Map (1/2)

Active slopes:
An Active slope are dominant landscape in the western and northern parts of the plateau of central part of the project area where geologic erosion has led to dissection of soft geologic strata, creating ramified gullies that toward the east and northeast. They are mostly piedmont slopes, in sub-dendritic forms which fade out in their own sediment deposits at their lower reaches. The land slope is generally steep to moderately rolling with slopes ranging from 5 to 30 percent. Gullies cover about 20 to 50 percent of the area. They are rather flat narrow with thin stones and pebbles covering 10 to 50 percent of the surface.
Alluvial fan:
Alluvial fans are characteristic landforms in the coastal plain of Tihama fringing Asir-Hijaz Plateau. They occur in foot slopes of Jabal Tuwayq escarpment (east of the project area) and on toes of active slopes in sedimentary Najd in regions, and occasionally, in the hilly part of the crystalline Najd. The slope is gentle, ranging from 2 to 5 percent. Occasionally, there are some gullies, especially in raised, old alluvial fans.
Alluvial plan:
Alluvial plain is in the major wadis, more commonly in their lower reaches. Tihama presents the largest conglomeration of alluvial plains formed by scores of small streams that emanate in the Hijaz-Asir Plateau. On the other side of the highlands, in the Najd, large wadis generally spread out into extensive alluvial plains. All the alluvial plains are in fact, alluvial terraces, as they are above the reach of normal floods in their parent streams. Occasionally the surface is gravelly.
Beach and wet coastal lands:
Beach and wet coastal lands are characteristics landform of the coastal lands of the Red Sea with unconsolidated materials forming the seashore and cover a gently sloping zone, extending landward from the low water line to the place where there is a definite change in physiographic form marked by a bluff or an increase in slope gradient. The loose water -borne materials- usually sand, fine gravel, coral and shells, are either in transit or have been deposit in the zone between the limited of low water ad high water.
Coastal plain:
Coastal plan is the plain fronting the coastal and generally represents a strip of recently emerged sea bottom. In the area, plain is also used for inland flat border lands affected by the sea but separated from it by sand beaches and tidal flats. The surface is covered by thin sheets of overblown sands which, in places, form low dunes.
Degraded plain:
Degraded plain is a land surface subsided by erosion to a nearly flat or broadly undulating plain. Degraded plain is found in the eastern border of the project area. It is generally undulating slopes with very thin soils or rock surfaces and outcrops. V-shaped steep-sided gullies cover considerable parts of these plains.
Dunes:
Dunes are located in the east-southern part of the area in Najran, where is western end of Rub al Khali. They are most of types of dunes in large and small scales of which are barchans, longitudinal, seif, transverse, honeycomb etc.
Escarpment:
They are dominant landforms in sedimentary Najd and occur in a repeated pattern that gives the region its identity. Jabal Tuwayq escarpment (east of the project area), the most dominant feature near by the project area, extends for more than thousands kilometers cress-centric to the crystalline Najd to the west. Escarpments are very steep having slopes exceeding 60 percent. Gullies cover about half of the surface area.
Footslope:
Footslopes are common in Hijaz, Asir highlands region as well as in hilly parts of the Arabian Shield region. Footslopes occur wherever mountainous or hilly landscapes are found. Their continuity and extent depends on whether the hills or mountains are in a chain or occur on whether the hills or mountains are in a chain or occur as isolated knolls or spires.
Glacis:
Glacis occur at the foot of a mountain or a hill and its main components. Glacis are piedmont slopes and mostly gently undulating. The slopes range from about 1 percent in the lower part, to nearly 5 percent in the upper part or more near the hills. The soils are sometimes saline.

Table 1-2 Legend of Landform Map (2/2)

Gypseous Pediplain:
Gypseous Pediplian is few in the project area. It is a kind of degraded plain where the soil is impregnated with crystalline gypsum.
Hills and Knolls:
The hills and knolls are found all over Najd region and dominance in Asir and Makkah province. Hills are natural elevations of the land surface rising as high as 300 meters above surrounding low lands, usually of restricted summit area and having a well defended outline. Knolls refer to remnants of hills that have undergone severe erosion and weathering.
Lava fields:
Lava fields are found in the north of the project area, where the majority in Makkah province, lava beds is derived from one of largest regions of volcanic activity. They are piled-up sheets of hardened lava, cracked into rough blocks, stones and boulders. They cover slopes of volcanic hills (cone) and large plains of ancient lava flows, and are locally known as *Harrat*.
Mountains:
Mountains lies on the highlands of the area, and are primarily formed by deep-seated earth movements. They occur as individual isolated forms or in small groups without forming any continuous range. Mountains are natural elevation of the land surface rising more than 300 meters above surrounding lowlands, usually of restricted summit area, and generally having steep side and considerable bare rock surface.
Pediplain :
Pediplain occupy large areas of the landscape in the plateaus, especially in the eastern frank of the highlands. A Pediplain is a widely-extending surface formed by coalescence of a number of pediments, associated with erosion remnants. They are gently sloping surfaces developed at the foot of a receding hill or a mountain slope.
Sabkha :
Sabkha is few in the area. It is shown as a low-lying inland drainage catchments area having no outlet and is intermittent ponding of water or wet in dry season. It is kind as evaporation ponds and remain evaporation reside.
Sand sheets :
Sand sheet lies on the eastern area of Makkah, Asir, and Najran province as isolated traces. It is thick deposits of aeolian sand laid on other landforms. Their thickness varies from half-a-meter to about three meters. The sands, in most cases, are fine grained and are mobile with dunes.
Severely dissected slopes:
Severely dissected slopes are few in the area. These are slopes of the land surface, roughly determined by and approximately conforming with the dip of underlying bedrock and can also be referred to as structural back－slopes.
Terraced slopes:
The hill-slopes of Asir-Al Baha in Hijaz are prominent location. It has horizontal contour lines of equal elevation. These are man-made structure, created by the construction of parallel lateral retaining walls along hill slopes. Sediment carried by rapid runoff during winter months is deposited behind the retaining structures, creating fertile strips of agricultural land on slopes normally too steep to support agriculture. The terraces also retard the runoff and thereby increase water infiltration into the soil.
Tidal flats:
Tidal flats occupy a part of the coastal lands. They are narrow and elongated strips, which sometimes protrude inland. It is marshy, muddy or barren tract of land in the sea shore that is covered and uncovered by the rise and fall of the tide.
Wadi :
Wadis flow toward east and northeast to drain out in vast plain of Najd. Some cut through the escarpment of the Jabal Twauq (at the east and outside the project are). The wadi is wide, flat-bottomed, usually dry drainage channels in arid regions. They are, in fact, intermittent stream that, in the event of occasional heavy rains, get flow, usually a splash flood that travel for short distance and then dissipate in the desert. Notable wadi, as originating from the project area, is Wadi Dawasir.

2. Geology

Southern western Saudi Arabia is underlain by tightly folded, regionally metamorphosed volcanic-clastic, and epi-clastic rocks and many mafic to felsic plutons all of late Proterozoic age. It is called as ‘Arabian Shield-Nubian Shield’ and is just exposed in the major part of the project area with concealed by the sedimentary cover rock that dips gently toward the east. As covered rock, in the project area, Palaeozoic sandstones, comprising the Cambrian-Ordovician Wajid sandstone, are found on the southeastern range of the project area and overlie Proterozoic rocks.

In the project area, several episodes of volcanism are recognized in the geologic age. Of those events, older volcanic activity occurred in Precambrian age and formed a volcano-clastics and subordinate flow rocks, complexly inter-layered with volcanically delivered and epi-clastic sedimentary rocks. While the younger rocks, Tertiary and Quaternary basalt-flows and gabbro-dikes are found in particular the north of the project area. Both are associated with the Red Sea rifting: the basalt is part of a large area of a flow rocks and volcanic cones resulting from volcanic activity, whereas the gabbro dikes were intruded into tension fractures.

Overlying the bedrock are unconsidered Quaternary deposit that included wadi alluvium, fanglomerate delivered from the Red Sea escarpment, terrace gravels, coastal-plain silt and eolian sand. These formed during the period of active erosion following the uplift of the region and the opening the Red Sea, which caused the development of wadi system draining to the east and west and the erosional retreat of the Red Sea escarpment. Typical litho-stratigraphy and geologic map of the project area is shown in Figure 2-1 and Figure 2-2.

Era	Lithostratigraphy	Intrusive Rock	Age	Orogenic Events
Quaternary				
	Alluvium			
	Basalt Cones			
	Basalt necks and dikes			Red Sea rifting
Tertiary	Basalt flows		27	
	Laterite			
Ordovician–Cambrian, Permian	Wajid Sandstone		570?	Local uplift
Upper Precambrian				
	Muradama group		600?	Najd faulting (south strand)
		Granite Suite / Diorite and gabbroic rocks		
	Atura formation		640	Extension and uplift
			660	
		Granodiorite and granite suite	690 735	Crustal shortening (continental collision)
	Halaban group		760 780	Andean–type island arc
		Tonalite and granodiorite suite		Shortening (collision)
	Ablah group		800	Andean–type island arc
		Diorite suite	900	Ensimatic
	Baish, Bahah, and Jiddah groups	?		
Lower Precambrian			110	island arc

Figure 2-1 Litho-stratigraphy (Central Part of Project Area: Abha Region)

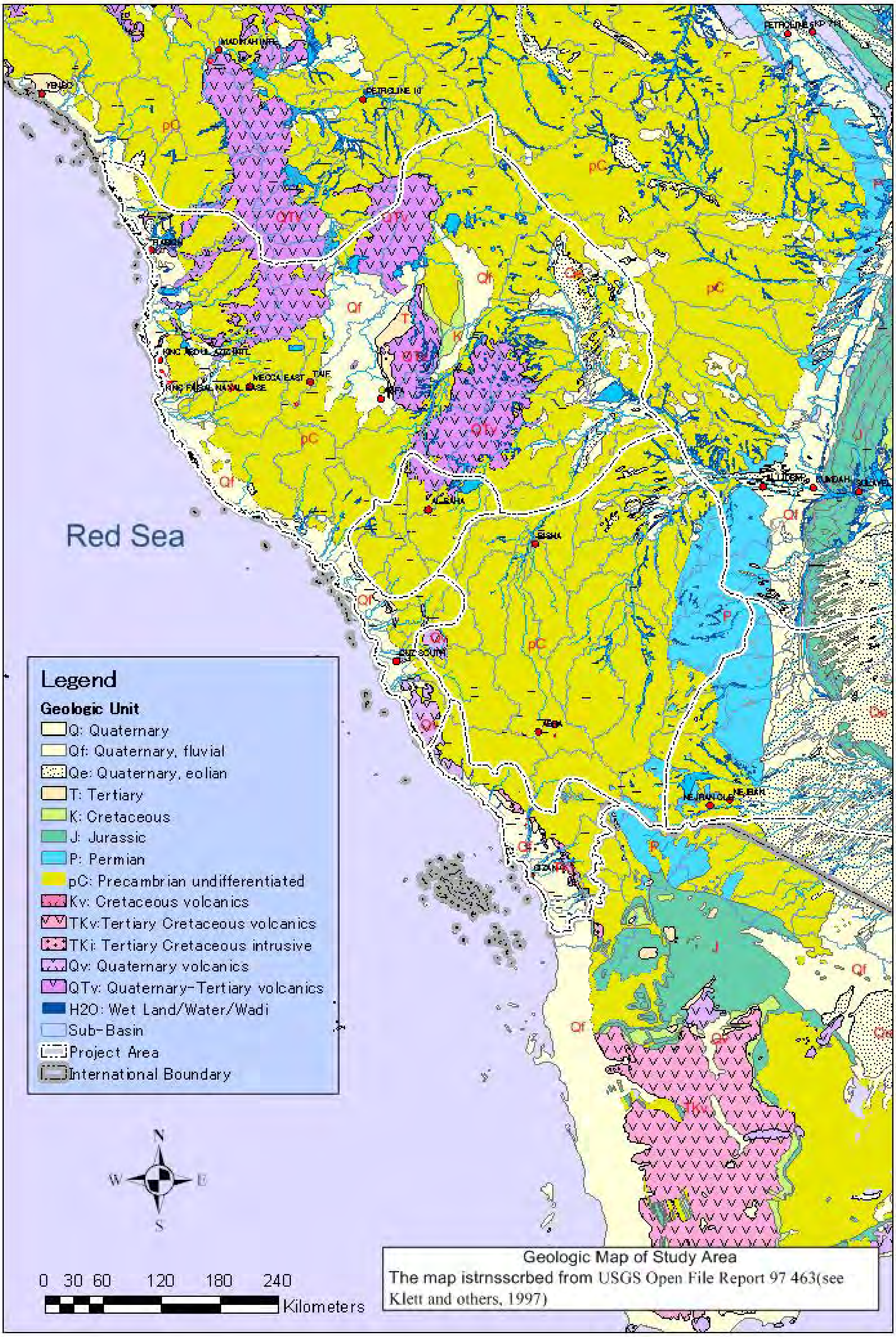


Figure 2-2 Geologic Map of Project Area

3. Hydrogeology

In the project area, the natural groundwater storage systems involve both aquifers of the oldest and the youngest of the geologic ages. The oldest one is Precambrian crystalline rocks from the former age and the youngest one is Recent alluvial deposits and eolian sands from the later age. The productive aquifer occurs within the sedimentary strata and porous volcanic rocks overlying Precambrian basement of the project area. The lithlogic sequence has been divided into eight major aquifers based on previous study (Water Atlas of Saudi Arabia, 1985) as shown in Table 3-1.

Table 3-1 Lithlogic Sequence and Major Aquifers

Lithlogic Sequence	Principal Aquifers	Secondary Aquifers
1 Quaternary and Tertiary	-	**Alluvium**
2 Pliocene and Miocene Clastic Rocks	**Neogene**	**Basalt**
3 Eocene Carbonate to Upper Cretaceous Rocks	Damman Umm er Radhuma	Aruma
4 Middle and Lower Cretaceous Clastic Rocks	Wasia-Biyadh	Sakaka
5 Lower and Upper Jurassic Cretaceous Carbonate	-	Buwaib Yamama Sulay Arab Juballa Hanifah
6 Middle and Lower Jurassic Clastic and Carbonate Rocks	-	Dhruma
7 Jurassic, Triassic, and Permian Clastic Rocks	Mijur **Minjur/Dhruma**	Jilh Jauf
8 Lower Paleozoic Clastic Rocks	Tabuk **Wajid** Saq	

Note: Aquifer name shown in **bold** is recognized in the project area.

The distinction between principal aquifers and secondary aquifers occurring in the sequence is based on their hydrologic properties and areal extent. The principal aquifers have greater permeability and larger yields than the secondary aquifer, and the amount of water in storage are observed larger amount in principal aquifers. The layer primary consists of sandstone, limestone, and dolomites, compose the aquifer which has large areal extent and great volumes of stored water. The sedimentary section consists of sandstone and interspersed with less permeable strata which act as confining beds.

The principal sandstone aquifers are widely distributed in the southeastern of the project area and locally possess excellent water-bearing properties vary greatly from place to place and can differ considerably within relatively short distances. Water-bearing sandstone and limestone beds of the Mesozoic age, being correlative to Wajid and Minjur/Dhruma aquifer in the south eastern part of the Asir and Najran province, are good aquifers.

Important also, but of less water storage and lower yields, are the secondary aquifers. These aquifers are located throughout all the project areas are generally minor sources of water, especially for local use. Some, however, are hydraulically connected with underlying principal aquifers and provide large quantities of water to wells.

In the project area, three principal aquifers: Neogene, Minjur/Dhruma, Wajid: and Two secondary aquifers: Alluvium and Basalt: are principal groundwater resources. Aquifers' distribution is shown in Figure 3-1.

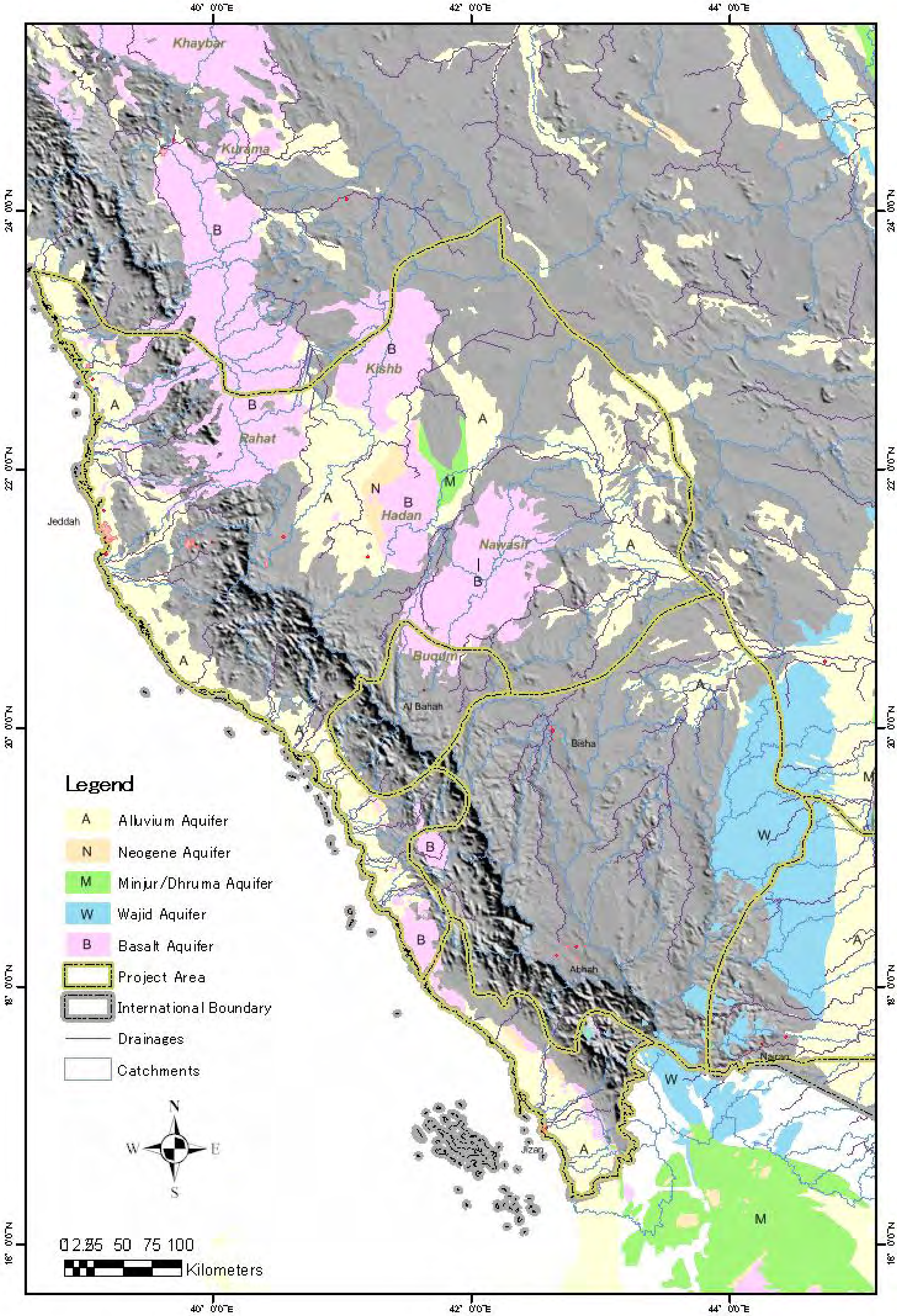


Figure 3-1 Aquifers in Project Area (1/2)

The stratigraphic setting and hydrogeologic description of aquifers are given in Sub-section 3.1.

3.1 Hydrological Features

As described above, the important aquifer in the project area is five (5), as below.

1. Lower Paleozoic Clastic Rocks (Wajid Aquifer)
2. Jurassic, Triassic, and Permian Clastic Rocks (Minjur/Dhruma Aquifer)
3. Pliocene and Miocene Clastic Rocks (Neogene Aquifer)
4. Quaternary and Tertiary Volcanics (Basalt Aquifer)
5. Quaternary Sediments (Alluvium)

The principal aquifers are distributed in the southeast of the project area and locally possess excellent water-bearing properties (1 and 2 aquifer of the above). They comprise of Paleozoic to Mesozoic sandstone and limestone beds. Less water storage and lower yields are of the Basalt and Tertiary to Quaternary beds (3, 4 and 5 aquifer of the above). In the Figure 3-2, the distribution of five aquifers is shown.

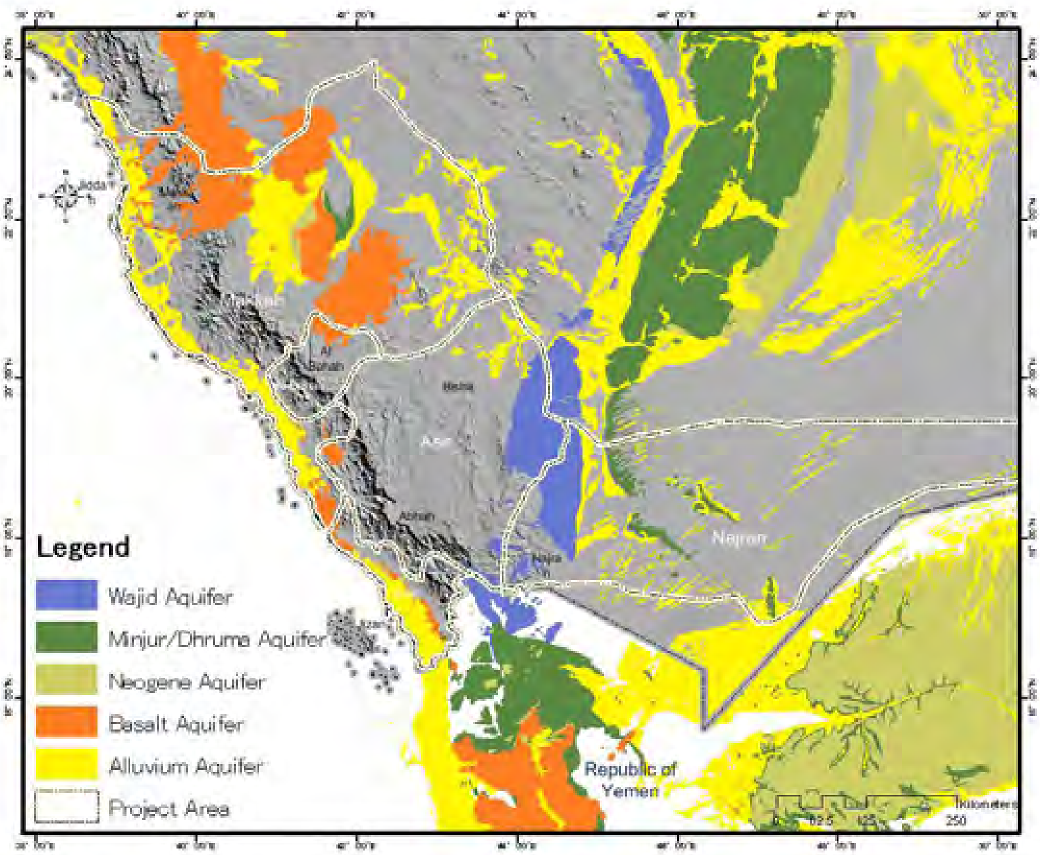


Figure 3-2 Aquifers in Project Area (2/2)

The hydrogeologic feature of aquifers is described as follows.

(1) Lower Paleozoic Clastic Rocks (Wajid Aquifer)

The Wajid Sandstone, named for the Jabal Wajid at latitude 19°06' N and longitude 44°27' E, overlaps the southeast edge of the Arabian Shield where is on the border of the area. The age of sandstone, of which is considered to be Permian (USGS, 1997) or Cambrian to Ordovician (Water Atlas of Saudi Arabia, 1985) was determined by the stratigraphic position of the formation.

The rock is predominantly a fine to coarse-grained sandstone. The rocks are generally homogeneous, very porous, poorly cemented and interbeded with shale horizons. Large planar cross bedding is displayed throughout the sandstone horizons. The color of the rocks in different part of the section varies from white to yellow to gray-green with many red and purple hematitic bands. Topographically, the outcrop forms a sloping rock surface which is partly covered by a veneer of alluvium. Its isolated hills and mesas rise as much as 150 meters above the plain.

Location of Wajid Sandstone outcrop is exposed for about 300 kilometers south of the Wadi Dawasir to Wadi Habawnah and for about 100 kilometers to the west, dipping beneath the land surface near the escarpment of Jabal Tuwayq. The formation dips to the east and to the north beneath the Jabal Tuwayq. Although the limit of the subsurface extent is uncertain, data from test holes indicate that the Wajid Sandstone extends for at least 200 kilometers eastward beneath the Rub al khali.

Thickness increases downdip from than 200 meters north of the outcrop to more than 400 meters east of the northern end of the outcrop near the Wadi Dawasir. Although only scant data are available for much of the subsurface rocks, due to the lack of test holes and wells, these data indicate that the rocks thicken to as much as 900 meters in the southern dip to the east at a ratio of about 1: 60.

The base of Wajid Sandstone lies unconformably on igneous and metamorphic rocks of the basement complex. The Wajid Sandstone is overlain disconformably by carbonate rocks and sandstones of the basal Khuff Formation of the Upper Permian and to the southeast, limestones of Jurassic age lie unconformably on the Wajid Sandstone.

Groundwater flows from the recharge area in the southern part of the Wajid Sandstone extent to the natural discharge areas in the northeast, where groundwater from the Wadi Aquifer seeps into the alluvium of the Wadi Dawasir. The yield is 50 lit/sec at an average rate in the eastern part, show in range of 10 to 130 lit/sec in the Wadi Dawasir, and from 5 to 15 lit/sec in the southwestern Rub al-Khali. Depth of well is 100 meters to over 1,000 meters deep.

The annual recharge to the aquifer, which was estimated at about 114 million cubic meters per year (Water Atlas of Saudi Arabia, 1985) was extremely small, particularly in relation to the amount of stored water. The amount of water in storage was estimated as much as 30,000 million cubic meters. However, the groundwater level have been falling in the southern part by the present because the natural discharge from the aquifer appeared to be exceeding the recharge that the aquifer could yield over 100 million cubic meters from storage with serious declines in the head or water level. Shallow wells, therefore, would have to be deepened to accommodate the decline.

The water quality is generally good and the dissolved-solids concentration of water in the aquifer is generally less than 1,000 milligrams per liter. The best quality of the water is found in the south near the recharge area. However, the mineralization increased toward the north and the east.

(2) Jurassic, Triassic, and Permian Clastic Rocks (Minjur and Minjur/Dhruma Aquifer)

The Minjur Sandstone is located in the east of Najran at latitude with a coordinates of 18°30’ N and longitude 45°00’ E. The geologic age of Minjur Sandstone is dated as Late Triassic. The Minjur Sandstone, which is originally continental origin, is a massive bed with course to very coarse quartzitic sandstone with thin layers of limestone, shale, conglomerate and gypsum. The sandstone crops out in narrow band 10 to 30 km wide for 800 km stating from the central Saudi Arabia and ended to Najran province. In the Najran it emerges with Rub al-Khali eolian sand. The Minjur Sandstone is 300 m thickness and decreases both to the east and south.

While, Dhruma Formation is correlated to Middle Jurassic age and is predominantly sandstone and shale and the maximum thickness of Dhruma Formation itself is about 100 m. Dhruma Formation overlies Minjur Sandstone and may hydrologically act as a single arenaceous complex.

The average potentiometric surface is lowering by the present from 45 m at 1940’s, but has declined more than 200 meters or more in some area below the ground by the present. Near the border of the study area, the potentiometric surface was about 600 meters above sea level. Water from the aquifer appeared to discharge into the Alluvial aquifer of the Wadi Dawasir. Near Sulayel, transmissivity is about 1 to 3 x 10-2 m^2/sec and storage coefficient is about 10-3 according to the previous study (Water Atlas of Saudi Arabia, 1984).

Water quality data has indicated that the saline increase with depth. The dissolved solids ranged from 1,000 to 6,000 milligrams per liter.

(3) Pliocene and Miocene Clastic Rocks (Neocene Aquifer)

The Neogene Formation is the name given collectivity to an extensive variable series of beds of the Miocene and Pliocene ages. In the project area, Neogene formation lies on 100 km south of Taif. It may distinctive patches of sandy deposits and forms local interbeded clay and marls, producing a local aquifer. The aquifer overlies unconformably Precambrian formation and is overlain by alluvial deposits in the west and contacts basalt layers in the east. The hydraulic properties of the aquifer have been found to vary considerably because of the rapid lateral and vertical changes in the lithology. The yield might be 0.5 to 50 liter/sec.

(4) Quaternary and Tertiary (Basalt Aquifer)

Lava fields (Harrat), along with numerous spatter or cinder cones and small flows or ash fields are scattered over an areas of Makkah of high lands and the Red Sea coastal area of Asir and Jazan Province. The basalt flows resulted from a series of eruptions during the Tertiary and Quaternary ages. The basalt generally overlies Quaternary ages. The basalt generally overlies sedimentary deposits. In places, basalts cover ancient alluvial deposits. These rocks display different propertied within the sequence of flows; that is, some are vesicular with highly fissured and cavernous sections, and some are massive and impermeable. The Basalt aquifer exists where crevices, joints, and fractures have developed in the rocks. Direct recharge from rainfall these aquifers can be locally significant. Rainfall, however, is low over many of the outcrops and the relatively impermeable rocks additionally prevent infiltration. The most important aquifers were formed where the overlying Recent alluvium, basalt, and underlying sub-basalt alluvium are hydraulically connected and to form a single aquifer system. Generally, most aquifers are narrow but, in some places in Makkah Province (Harrat Rahat), appreciable amounts of water are available from storage. Harrat Rahat covers about 10,000 square kilometers and an average about 60 km in width. The basalt, which ranges in thickness from 40 to 70 m, overlies the ancient plain of the Upper Aqiq Basin in Al Baha. The sub-basalt alluvium has good storage and is the principal aquifer in the area. The yields to some wells are about more than 20,000 cubic meters per day. The natural discharge from the basalt feeds the salt plain along the eastern margin of the Hharrat. In the southern part of Basalt, data are limited about the Harrat Kishb, Hadan and Nawasif southeast of Rahat. However, sub-basalt alluvial deposits probably exist in some areas, Small lava flows, which include Harrat Birk, Lunayyir, Kurama, Hutaym, Sirat and Jabal Jilab, overlie parts of the coastal plain and the lower slower slopes of the Red Sea escarpment. Mineral concentration of the water from the Basalt Aquifer was shown to be generally low. The specific concentration was reported as a range from 400 to 8,000 μS per centimeter with a medium value of 1,000 μS per centimeter.

(5) Quaternary and Tertiary (Alluvium)

Alluvial aquifer lies on Eastern Slope and Red Sea Coastal Plain in the project area.

＜Eastern Slope＞

The area has wadis that radiate outward from the crystalline rocks of the Arabian Shield eastward to the sedimentary strata. In these areas the valley are wide irregular in shape, and contain buried ridged and relict stream channels. In the relict channels, the lowermost part of the alluvium consists of coarse sand and silt. The maximum thickness of these deposits was shown generally to range from 30 to 60 m, but in the major wadis – the Wadi Dawasir – it measured as much as 100 m thick. Wells that penetrate the older coarse material in the middle of the wadis generally yield more water than wells that penetrate the more recent overlying sand and silt. Large deltaic gravel fans are associated with the major wadis and were shown to have deposit about 10 meters thick which are good aquifers, but some are dry. Smaller gravel fans, which ate associated with wadis draining the Taif to Tuwayq Mountains, contain aquifer that is locally important water supplies for domestic and agriculture uses.

The Alluvial Aquifers in many of the drainage areas, and, in others, the volume of water in storage was sufficient to meet only local demands. Nevertheless, it is evident that problems related to groundwater development are shown to be the small aquifer size, the nature of the recharge, the rapid development of soil salinity when used for irrigation and the low permeability due to high silt content. In the project area, the most promising aquifers are in the Wadi Dawasir, of which the drainage is partly located in the eastern area of the Najran and Jazan areas. Other areas thought to be worth considering are the Wadi Bisha.

<Red Sea Coastal Plain>

Wadis that drain westward from the crystalline rocks to the Red Sea coastal plain are short and steep. In the headwaters, the wadis have cut deeply dissected narrow valleys. Although aquifers in these wadis and the Red Sea coastal plains, the alluvium in the wadis increases from 10 m thick in the upper reaches to as much as 100 m at the intersection with the plains. Along the Red Sea coast area, the deposit generally ranges from 10 to 20 m thick but, locally, can be much thicker.

Alluvial deposits fill many drainage areas on the coastal plain. The deposits are laid down by flood waters as superficial material on the wadi floors and in the terraces above the wadi floors, deposited when the streams flowed at a high elevation. Alluvial deposits are also found in old wadi valleys where the flow has followed new drainages. Some of these deposits in abandoned wadis were later buried by lava flows or windborn deposits. Alluvium is carried by stream that drains to the coast form large fans that coalesce and grade into wide tracks on the coastal plain. The fans are formed at the base of the escarpment of Hijaz plateau where the land slope flattens.

Alluvium is made up of material that ranges various particle size from clay, sit, and sane to gravel and boulders. This material is laid down in the streambed as a series of fine to coarse deposits. Streambeds that are filled with coarse material serve as the best water-bearing deposits because of their ability to serve as a storage reservoir and to easily transmit water. The aquifer is generally unconfined but may be semi-confined or confined where silt and clay are interbeded with sand layers. Studies have shown that Transmissivity generally varies from 1×10^{-3} to 1×10^{-1} meters squared per second and the coefficient of storage from 1×10^{-3} to 1×10^{-5}. The higher values were found in deposits near the center of the wadis. Yields varied greatly, from 5 liters per second from dug wells with hand drawn buckets to as much as 50 liters per second from modern, well-designed cased wells with pumps. The alluvial aquifers are generally long and narrow corresponding with the wadi the channel and they vary greatly in thickness.

Aquifers in these deposits are mainly used for domestic and livestock supply but, locally, some are used for irrigation. The aquifers have often been tapped by galleries and wells. Yields to wells are small to moderate. The specific conductance of this water was found to vary greatly, ranging from 130 to 70,000 μS per centimeter. The percentages of sodium and chloride were slightly higher than the other dissolved minerals.

As for storage and development potential was evaluated by previous study made 1980's as shown in Table 3-2 (Water Atlas of Saudi Arabia, 1984).

Table 3-2 Alluvium Aquifers, Storage and annual Yield

Alluvium Aquifer Areas	Main Wadis	Catch-ments Area (Sq.km)	Storage (MCM)/ Annual Yield (MCM/a)	Groundwater Assessment	Water Quality
Red Sea Coast	Jizan, Dhamad, Baysh, Hail, Yiba, Qanunah, Lith, Qudayd/Sitarah, Rabigh, Fatimah, Khulays, Ifal, Aqiq East, Khaybar, Dama	24,1600	14,260/105	Limited local development to good potential for future development	Poor to good
Taif – Faidhat Mislah	Waji, Liyyah, Aqiq	43,200	50+ / 0	Aquifers are fully developed, others are local significance	Generally very good
Asir-Dawasir	Torabah, Ranyah, Bishah, Tathlith, Dawasir	18,000	17700+ / 25+	Further development may be possible in certain areas	Good in upper reaches to very poor in plains
Asir-Najran	Najran	38400	33350 / 45	Increased pumpage may be possible in Najran basin.	Data available indicates good

Note: This table is transcribed from Water Atlas of Saudi Arabia (Water Resources Development Department, Ministry of Agriculture 1984)

3.2 Hydrogeologic Formations

The stratigraphic setting of the five aquifers in the project area is correlative to other sedimentary sequences overlain the Kingdom. In Table 3-3(1) to Table 3-3(3), the stratigraphic position of five aquifers is shown in the Kingdom’s stratigraphy.

Table 3-3(1) Hydrogeologic Stratigraphy Table in Saudi Arabia 1/3 (MAW, 1984)

Age	Formation	Lithology	Thickness (m)	Lithologic Description	Aquifer Characteristics	Total Depth (m)	Static Water Level (m)	Yield (lit/sec)	Total Dissolved Solids (mg/lit)	Locality	Correlation to Study Area (Hydrogeological Map)
Recent & Quaternary	Surficial Deposits		varies	Gravel,Sand,Silt,Basalt, etc.	Yield and water quality vary depending on location and amount of local recharge. Most of promising aquifers are in the Wadi Dawasir, Najran and Jizan areas.						Q/Qf/Qe: Quaternary Aquifer Located in Rea Sea Coast & Macca(Taif); QTv: Quaternary Volcanic Aquifer located in Asir & Al Bahah
Cenozoic / Tertiary / Pliocene & Miocene / Neogene	Kharj		30	Limestone, Gypsum and Gravel	Not developed extensibly because underlying aquifers are more consistently waterbearing. Water levels about land surface in some areas. Considered a good aquifer in Hasa Oasis. Wadi Miyah, and some other locations. Water in the Neogene is likely delivered from upward leakage from Umm er Radhuma Formation, especially in the Hasa area. Further development may be possible in the northern part of its occurrence.	50-100	30-14	0.63-95	1170-4300	Hasa Area	
	Hufuf		95	Sandy Marl & Sandy Limestone		±150	0-10	0.63-50	<1500	Coastal Belt	
	Dam		90	Marl, Shale, Subordinate Sandstone		±250	(-)	0.63-13	680-950	Southern Region - Eastern Region	
	Hadrukh		85	Silty, Sandstone, Sandy Limestone		±80	(-)	3	500-800	Northwestern Area	
Cenozoic / Tertiary / Eocene / Dammam	Alat		51	Limestone, Dolomite, Marl & Shale	Only the area and Khobar Formation are water bearing yield from wells tapping these formations are generally moderate. Water quality ranges from poor to good for domestic and agriculture uses. The Alat and Khobar members are tapped by wells in the Hasa area, costal belt, Wadi Miyah, and the southern part of the Eastern Province. Further development of the Alat is limited in the most areas. Khobar could probably be developed in the costal belt, Wadi Sahba Haradh, and Hasa.	Alat/Khobar ±200/250	Alat/Khobar 5-24/±15	Alat/Khobar N.D/N.D	Alat/Khobar 1200/1000-3500	Hasa Area	
	Khobar					±170/150	5-(+4)/±0	14/19	1200/±2400	Coastal Belt	
	Aeolian Limestone					/±350	±75	N.D/N.D	N.D/3100	Eastern Province	
	Salla Shale					±150/±200	±40/±0	9/10	1300/±2000	Northwestern Area	
	Midra Shale					±130/±190	0/3-(+10)	N.D/N.D	1400-2300/±2000	Wadi Miyah	
Cenozoic / Tertiary / Eocene	Rus		55	Marl, Chalky Limestone & Gypsum	Acts as a confining bed						
Cenozoic / Tertiary / Paleocene	Umm er Radhuma		245	Limestone and Dolomite	Considered good aquifer throughout much of the Eastern Province. Water levels range form below land surface in outcrop area to near and above land surface to the east. Water quality for domestic and agriculture range from poor to good in the Hasa area where it is believed that most of the spring are fed excellent hydrologic properties and its dependability.	+300	(+2)-(+3)	32	900-3600	Hisa Area	
						+220	(+5)-(+10)	13	1800<3500	Coastal Belt	
						+400	(*)	22	1700-2500	Wadi Miyah	
						±180	±170	95	900-1320	Haradh	
						10-(±300)	2-(±110)	4	1700-10,000	Northeastern Area	

Note: Geological age of Wajid Aquifer is different between USGS (1994) and Water Atlas of Saudi Arabia (1984)

Table 3-3(2) Hydrogeologic Stratigraphy Table in Saudi Arabia 2/3 (MAW, 1984)

Age		Formation	Lithology	Thicknes s (m)	Lithlogic Description	Aquifer Characteristics	Total Depth (m)	Static Water Level (m)	Yield (lit/sec)	Total Dissolved Solids (mg/lit)	Locality	Correlation to Study Area (Hydrogeological Map)
	Recent & Quaternary	Surficial Deposits		varies	Gravel,Sand,Silt,Basalt, etc.	Yield and water quality vary depending on location and amount of local recharge. Most of promising aquifers are in the Wadi Dawasir, Najran and Jizan areas.						Q/Qf/Qe: Quaternary Aquifer Located in Rea Sea Coast & Macca(Taif); QTv: Quaternary Volcanic Aquifer located in Asir & Al Bahah
Mesozoic	Cretaceous	Aruma		140	Limestone with Subordinate Dolomite, Dolomite and Shale	Poor aquifer with low yield except where it forms part of the Cretaceous Sands Aquifer. Water quality changes from very poor to poor.						
		Wasia (Sakaka sandstone in Northwestern Region)		42	Sandstone with Subordinate Shale and Local Dolomite Lenses	Considered good aquifer and most properly constructed wells tapping this formation have high yields. Water quality ranges from very poor through good. Water levels range from below land surface to the east. At the outcrop and nearby, the Wasia and underlying Riyadh are constructed a single hydrologic unit. Near Wasia Dawasir, the Riyadh-Wasia and Aruma grade together as a thick sandstone unit.	70-250	-15	19	±900	Sakaka Area	
							400-550	±65	14	1300	Lina Area	
							400-1300	(+)	-	400-<1500	Hisa Area	
							±300	±250	19-6	550-1550	Khurais Area	
							±800	-	-	-	Sudair Area	
		Riyadh		425	Sandstone, Subordinate Shale	Properly constructed wells tapping this formation generally have poor to high yields. Quality ranges from very poor in the Eastern Province to fair in the Kharj area to very good at Nisah. The Riyadh and overlying Wasia are considered a single hydrologic unit at and near the outcrop.	370-600	(-)	±25	±1500	Khurais Area	
							50-200	50-60	±38	500-900	Wadi Nisah	
										+600	Eastern Province	
							±60	50	±25	1100	Kharj Area	
		Buwalb		18	Biogonic Calcarenite and Calcarenitic Limestone							
		Yamama		46	Biogonic-Pelle Calcarenitic Limestone							
		Sulay		170	Chaljy Aphanitic Limestone ,Rare Calc. Limestone	Produced water locally in the Kharj area.						
	Jurassic	Hit		90	Anhydrite	Generally poor aquifer - water bearing in limited area only. Water is often highly mineralized. Contains sulfate.						
		Arab		124	Calcarenite, Calcarenitic and Aphanitic Limestone, Dolomite and some Anhydrite	Yield from wells vary depend on location. Contaminated and highly mineralized water in Riyadh area. Heavily pumped in Yamama area of Kharj. Believed to be fed from this formation.						
		Juballa		118	Aphanitic Limestone & Dolomite, Subordinate Calc. & Calc.	Similar characteristic to overlying Arab Formation. Pumped in Riyadh area especially in the Wadi Hanifah where water occurs in the fractured zone of the limestone.						
		Hanifah		113	Aphanitic Limestone, Calc. Limestone and Calcarenite							
		Tawayq Mountains		203	Aphanitic Limestone, Subordinate Calcarenitic Limestone and Calcarenite							
		Dhruma		375	Aphanitic Limestone, Subordinate Calcarenite, Dominant Sandstone. South of 22 N and North of 26 N	Moderate yield and poor to fair part of 26° N. Moderate to high yield and good quality south of 22° N. The Dhruma Formation considered a single hydrologic unit to the south.						J: Jurassic - Triassic Aquifer Located in Najran
		Marat		103	Shale and Aphanitic Limestone, Subordinate Sandstone	Low yields from sandstones. Poor to fair quality. Lower members are single hydrologic unit with underlying Minjur Formation.						
	Triassic	Minjur		315	Sandstone and Some Shale	Good aquifer, yield from wells to Riyadh. Poor to fair quality. Water levels range from below land surface to flowing above land surface to east. Minjur is also tapped at Sudair, Washem and Kharj. The upper sandstone is usually developed	±400	60-100	50	1400	Riyadh Area	
							±1200	160-220	±50	1600	Sudair Area	
							±900	150-180	±50	1800	Washem Area	
							±1600	(+)	158	2820	Kharj Area	
							±590	(-)		4100	Ajlaj Area	
		Jilh		±326	Shale and Aphanitic Limestone, Subordinate Gypsum	Poor aquifer poor to fair quality .Generally considered as single hydrologic unit with overlying Minjur Formation.						
		Sudar		115								

Note: Geological age of Wajid Aquifer is different between USGS (1994) and Water Atlas of Saudi Arabia (1984)

Table 3-3(3) Hydrogeologic Stratigraphy Table in Saudi Arabia 3/3 (MAW, 1984)

Age	Formation	Lithology	Thickness (m)	Lithologic Description	Aquifer Characteristics	Total Depth (m)	Static Water Level (m)	Yield (lit/sec)	Total Dissolved Solids (mg/lit)	Locality	Correlation to Study Area (Hydrogeological Map)
Recent & Quaternary	Surficial Deposits		varies	Gravel,Sand,Silt,Basalt, etc.	Yield and water quality vary depending on location and amount of local recharge. Most of promising aquifers are in the Wadi Dawasir, Najran and Jizan areas.						
Mesozoic, Cretaceous	Aruma		140	Limestone with Subordinate Dolomite, Dolomite and Shale	Poor aquifer with low yield except where it forms part of the Cretaceous Sands Aquifer. Water quality changes from very poor to poor.						Q/Qf/Qe: Quaternary Aquifer Located in Rea Sea Coast & Macca(Taif); QTv: Quaternary Volcanic Aquifer located in Asir & Al Bahah; J: Jurassic-Triassic Aquifer Located in Najran
Paleozoic, Permian	Sudar		115		Poor aquifer, water highly mineralized. Formation yield water to wells in Qasim and Wadi Dawasir area. Believed to be recharge by upward leakage from underlying aquifer. Most favorable in the southern area.						
Paleozoic, Permian	Khuff										
Paleozoic, Permian	Pre-khuff		170								
Paleozoic, Carboniferous	Aburwath		Wajid Pre-Khuff in South. Thickness 434 m.	FAW							
					Fair to moderate yields of good quality water in a strip extending south from Area for 50 km.	±1400		28	700	Sulaymaniyah Area	
Paleozoic, Devonian	Jauf			JAUF Limestone, Shale, and Sandstone (Thickness 229m)	Poor to fair yields of good quality. Yield water to wells in the Jauf and northern area. Important as a local supply of water.	±80-100	(+)	9	300	Jauf Area	
						±300	(+)	19	640	Sakaka Area	
						±1400	140	13	950	Arar Area	
						±770	80	11	800	Turaba (North) Area	
Paleozoic, Devonian	Tabuk: Tawail	Faw Thic…		TABUK Sandstone and Shale (Thickness 1072m)	Fair to high yields, fair to good quality. Water levels above land surface in some areas. Yields water to wells in Qasim and Tabuk areas. Wells yield water from three water-bearing units, lower, middle and upper. Principal supply of water for Tabuk.	150-300	(+)	8	700	Buraydah Area	
						±350	40	19	800	Unaizah Area	
Paleozoic, Silurian	Tabuk: Qusaiba	Lower				1200-1400	(+)	16	2500	Asyah (Qasim Area)	
						±100	(-)	13	1000	West of Qasim Area	
Paleozoic, Silurian	Tabuk: Middle Tabak					250-300	(±)	5	950	Tabuk Area	
Paleozoic, Ordovician	Tabuk: Raan					±250	20	19	250	Jauf Area	
Paleozoic, Ordovician	Tabuk: Lower Tabuk			SAQ Sandstone	One of the best aquifers in the Kingdom. Water levels are declining in the Buraydah area due to intensive pumping. Developed mainly in the Qasim, Hail and large flows. In the Tabuk area, wells have low heads and moderate flows in Saq equivalent units.	600-800	±10	32	750-1500	Buraydah Area	
Paleozoic, Ordovician	Tabuk: Hanadir					500-600	-50	25	800	Unaizah Area	
Paleozoic, Cambrian	Saq (pre-Khuff in Nor. Th. Thickness + 600 m.)					±450	(+10)-(-70)	22	400-1000	Sirr (Qasim Area)	
						±1400	(+40)-(+100)	76	700	Asyah (Qasim Area)	
						150-200	-25	11	900-3000	West of Buraydah Area	
						±1000	(+)	13	900	North of Buraydah	
						±1200	+30	28	850	East of Braydah Area	
						±120	(-)	9	800	Tayma Area	
						±100	(-)	8	300	Ula Area	
						±450	(+)	22	500	Tabuk Area	
						450-900	(+)	13	500	Southern Hail Area	
						±170	(-)	19	1200	Northeast Hail Area	
				WAJID Sandstone, General, and Basement Erratics *1	Considered excellent aquifer. Quality generally good, improving down dip to the east. Depth to water decreases to east, wells flow above land surface in Wadi Dawasir. Quality is good in southern Rub al-Khali. Yields water to wells in Southern Saudi Arabia and part of Democratic Republic of Yemen. Hydrogeologic data are scant south of Wadi Dawasir.	±150	±20	9	1000-3000	West of Wadi Dawasir Area	P: Cambrian-Permian*1 Aquifer Located in Najran
						±250	(-)	16-126	±1000	East of Wadi Dawasir Area	
						900-1200		4-13	±800	Southwestern Rub Al-Khali	
Precambrian				Basement Complex, Igneous and Metamorphic Rocks	Generally poor aquifer.						Pc: Precambrian

Note: Geological age of Wajid Aquifer is different between USGS (1994) and Water Atlas of Saudi Arabia (1984)

3.3 Groundwater Level

(1) Monitoring Well

Aquifer in the sedimentary strata in the project area contains substantial volumes of water, whereas, aquifers in the crystalline areas dominating the highland of the project area generally contain lesser quantities to develop. Nevertheless, the water level in an aquifer in response to changes in the volume of water storage is necessary information for the future groundwater development and management. In decades, lowering of the water levels, resulted from pumping wells, has been observed in the Ministry of Water and Electricity (MOWE)'s observation wells (refer to Figure 3-4).

In the study, available record is of 20 wells' as shown in Figure 3-3.

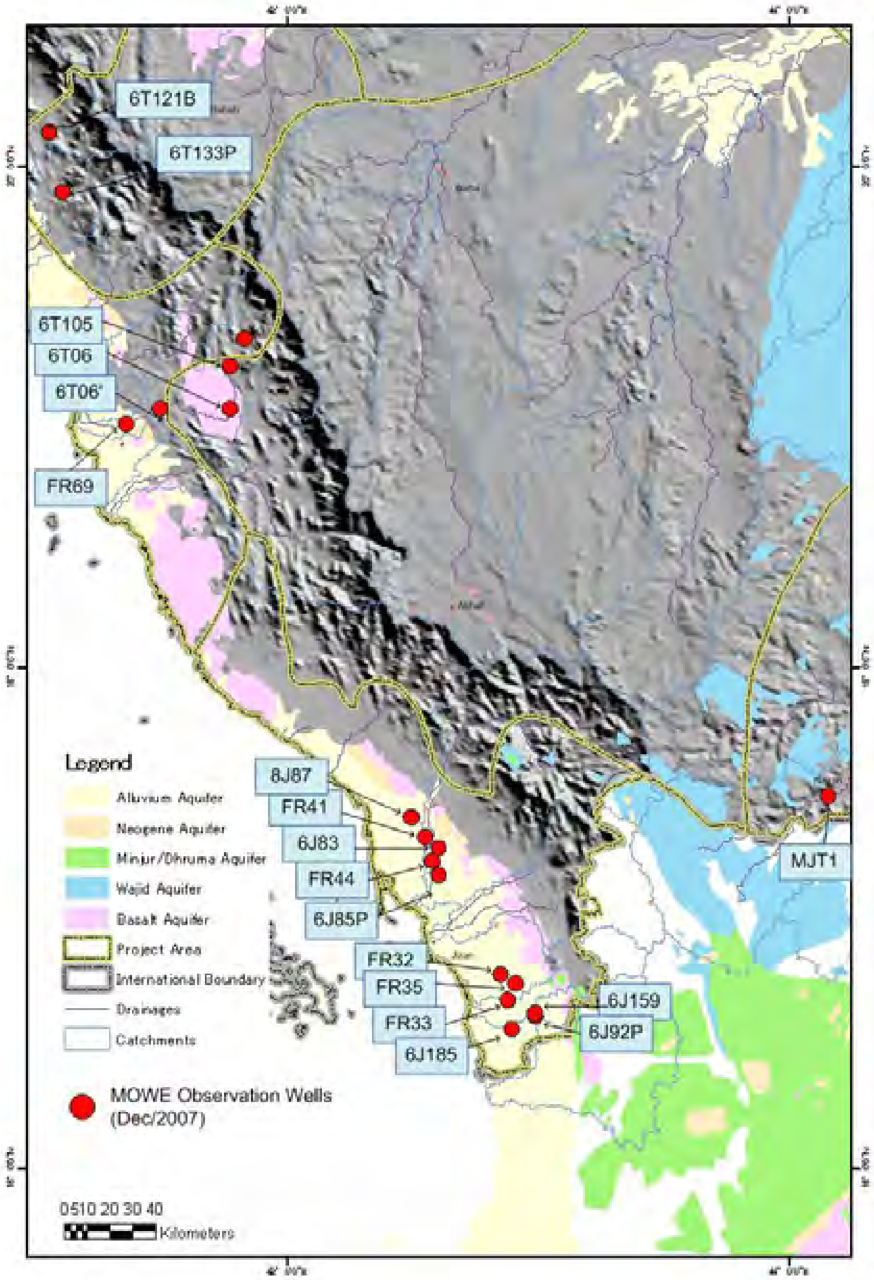


Figure 3-3 Observation Wells

Figure 3-4 shows the selected record of four (4) wells, of which has been influenced with several meters lowering of groundwater since 1980's in Jazan and Najran area.

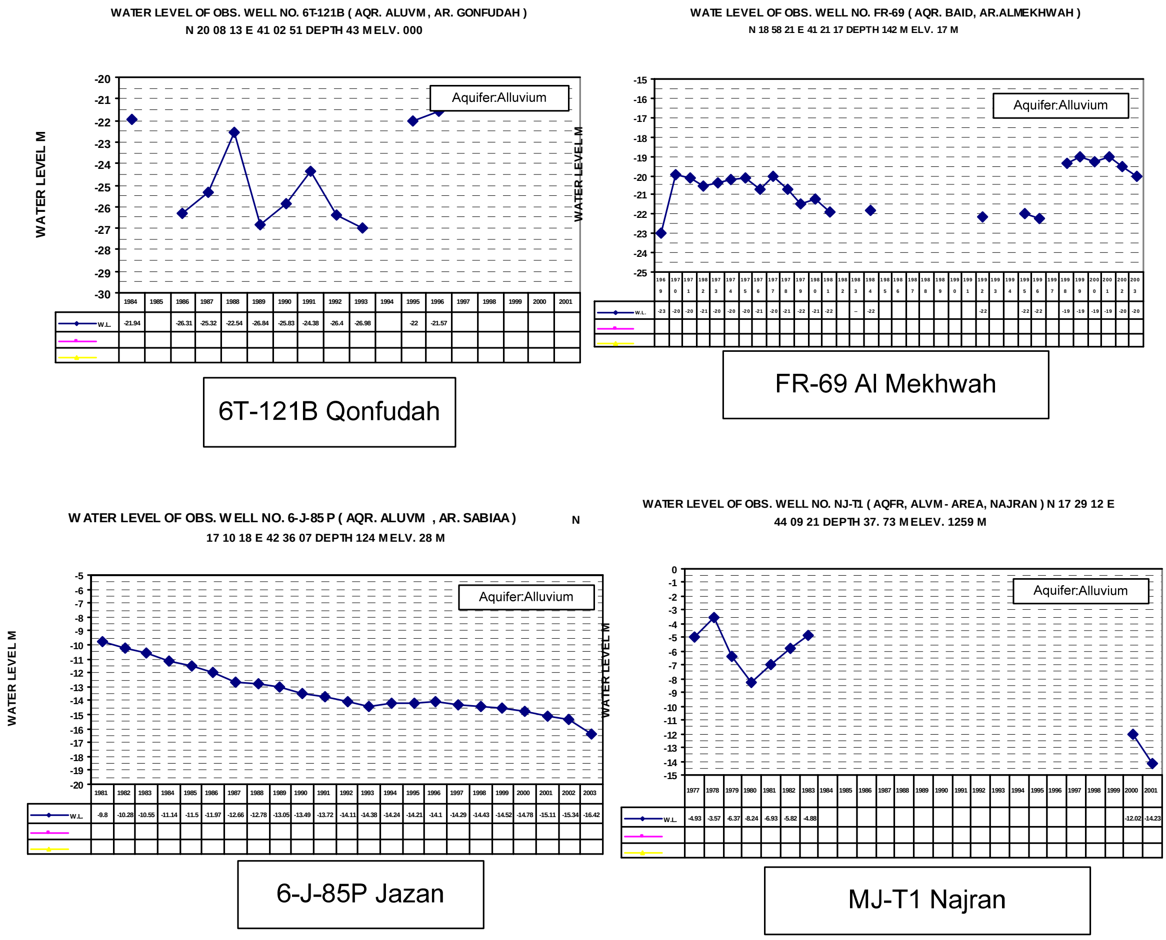


Figure 3-4 Groundwater Level (4 Wells Selected from 20 Wells)

The spatial distribution of groundwater table is delineated for Yiba, Jazan and Najran area. The ground water depth was in a range from GL -40 m to GL -5 m, which showed a descending groundwater level toward the sea or downstream. However, along the upper portion of the wadi courses, a rise in groundwater levels was observed, which may suggest seasonal ground water recharge. Figure 3-5 shows the contour map of groundwater depth in 1998.

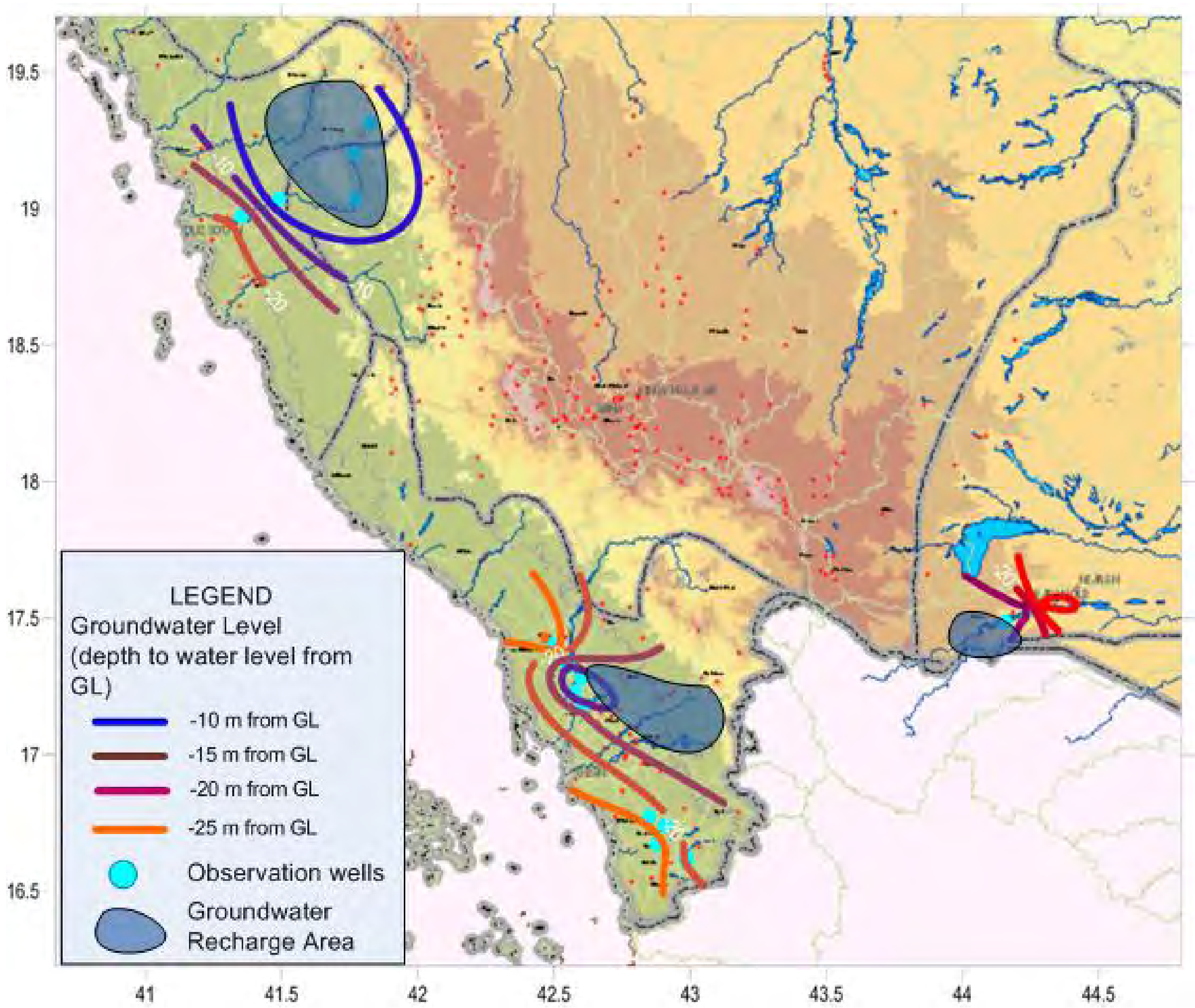
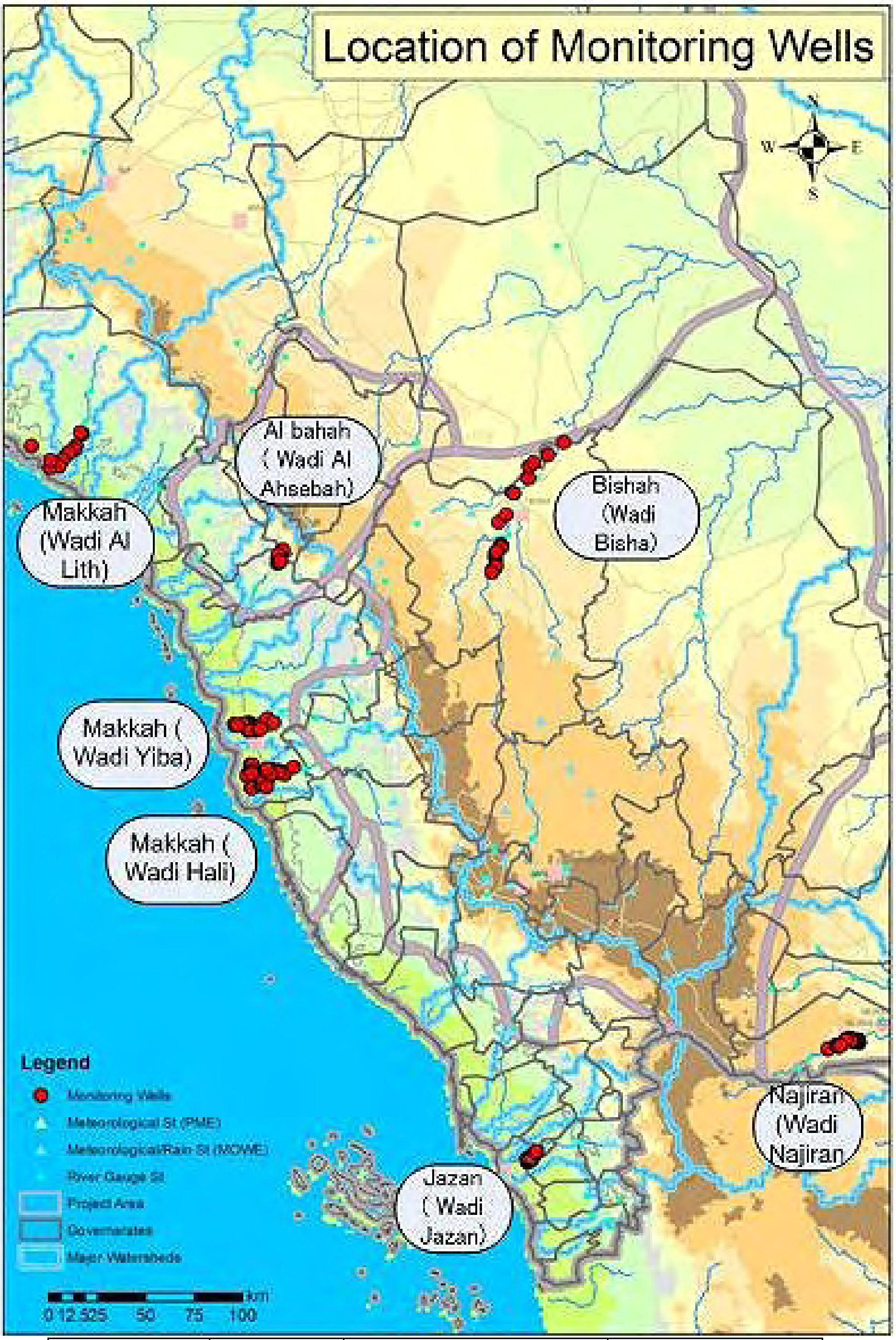


Figure 3-5 Contour Map of Groundwater Depth (1998, Yiba, Jazan and Najran)

(2) Well Inventory Survey

Observation wells were constructed since the middle of 1960's with the purpose of monitoring the groundwater level. By 1985, 300 wells had been built in the project area. However, they had not been maintained and then gradually being un-functioned or discarded by the moment.

In the study, 200 points were newly selected for the one (1) year's survey of 2007/08 from May 2008 to April 2009. Most of observatories were production wells located on Recent wadi bed or river terrace in seven (7) major wadis as shown in Figure 3-6.



Wadi	Region	Area/villages	No. of Observation
Al Ahseeba	Al Baha	Al Mukhwan	14
Al Lith	Makkah	Al lith/Omegah	13
Bisha	Asir	Bisha/Al Hazmi	35
Hali	Makkah	Al Qunfudan/Hali	33
Jazan	Jazan	Al Matery	45
Najran	Najran	Najran	38
Yiba	Makkah	Al Qunfudan /Al Gouz	22
Total			200

Figure 3-6 Location Map of Monitoring Well

In order to review and update the hydrogeologic database which was linked to the MOWE's observatories, the items of the survey were composed of water level, EC and others as shown in Table 3-4.

Table 3-4 Items of Water Sampling Survey and Water Quality

<water sampling survey>

ID No.	· Latitude （D.D）	· Elevation （GPS, m）
Name of Region	Longitude（D.D）	Elevation （SRTM, m）
Agency	Casing Detail (mm/inch)	Dynamic Water Level （m）
Name of District	Total Depth (m)	Aquifer （m）
Name of Village	Static Water Level （Depth,m）	Purpose of well
Name of Wadi	Static Water Level （EL, m）	Pumping Rate （lit/sec）
Well No	Static Water Level measured at (Date)	Hours of Use （hr）

<water quality survey＞

Item of In-situ Test	Item of Laboratory Test		
＜field parameter＞	＜Hydro chemical＞	＜General＞	Cr(mg/l)
Odor	Ca(mg/l)	COD(mg/l)	Cd(mg/l)
Color	Mg(mg/l)	Hardness(mg/l)	As(ppb)
Turbidity(FTU)	Na(mg/l)	TDS(mg/l)	F(mg/l)
Temp(C)	K(mg/l)	＜Heavy Mineral＞	＜Biological＞
EC(uS/cm)	So4(mg/l)	Cyanide(mg/l)	Bacteria（CFU/100ml）
pH	Cl(mg/l)	Mercury(ppb)	Fecal_Coliform（CFU/100ml）
DO (%)	CO3(mg/l)	Cu(mg/l)	＜Environmental＞
Salinity（PSU）	HCO3(mg/l)	Fe(mg/l)	Foaming_Agent(mg/l)
Eh（mV）	NO3(mg/l)	Mn(mg/l)	Phenolic_Compound(mg/l)
	NO2(mg/l)	Zn(mg/l)	Organo_Phosphorus(mg/l)
	NH4(mg/l)	Pb(mg/l)	

As a rule, groundwater level was measured in early morning due to prevent well-interference from the existing wells. The summary of measurements (average, maximum, minimum value) is shown in Table 3-5. In Najran, groundwater level was as deep as 40 m from the ground. While in other wadis, 20 to 30 m of depth was observed.

Table 3-5 Summary of Water Level Measurement

Wadis	Al Asheeba	Al Lith	Bisha	Hali	Jizan	Najran	Yiba
（No.of wells）	（14）	（13）	（35）	（33）	（45）	（38）	（22）
Average	19.4	19.1	26.2	26.4	29.8	42.1	23.1
Min. （m）	11.8	8.1	7.4	7.1	22.3	22.9	15.7
Max （m）	33.8	33.8	63.0	41.8	37.6	57.3	54.3

The contour map of groundwater table showed the water flows towards the center of wadi from the mountain. At convergences with tributaries, extruding/disturbance of contour lines was found as result of side-flow effects. In some places nearby pumping wells, depression cones were also observed.

Near the coastal strip of the Red Sea, lying on the outlets of wadi Al Lith, Hali, Yiba and Jizan, the water level was lowered beneath the sea level. In Figure 3-7, groundwater contour of Al Lith, Najran are shown.

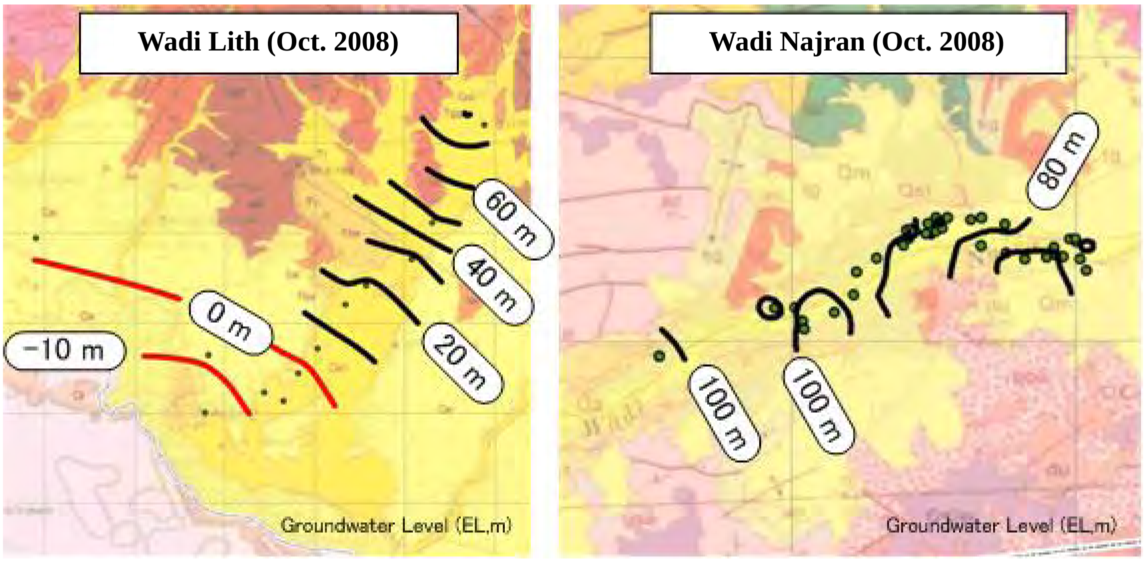


Figure 3-7 Contour Map of Groundwater Table (Wadi Al Lith, Wadi Najran)

3.4 Groundwater Quality

(1) Water Quality and Aquifer

In the project area, as described in sub-section 3.2, five formations are regarded as the productive aquifers which have enough permeability and storage to extract bulk water. Their general hydrologic characteristics and groundwater quality are as follows.

(a) Wajid Aquifer (Lower Palaeozoic Clastic Rocks)

Wajid Aquifer lies on eastern area of Asir province and Najran province which occupy a part of Wadi Dawasir basin. The water quality is generally good and the dissolved-solids concentration of water in the aquifer is generally less than 1,000 milligrams per liter. They quality of the water improves eastward toward the Rub al Khali basin, but eventually the trend reverses and mineralization increases. Confined Wajid aquifer contained hydrogen sulfide gas is corrosive. The quality of the water in the unconfined part of the aquifer deteriorates westward from the Wadi Dawasir and northward.

(b) Minjur/Dhruma Aquifer (Jurassic, Triassic, and Permian Clastic Rocks)

Minjur/Dhruma Aquifer is limitedly found in Makkah province as remnant, and Najran province overlaid by Recent eolian sand in Rub al Khali. Water quality data had indicated that the saline increase down-gradient and with depth. The dissolved solids ranged from 300 to 8,000 milligrams per liter and 2,5000 years of water age was taken by Carbon-14 analysis made in 1980's scientific research (it was made for well at same aquifer but was far from the Project area: near Riyadh).

(c) Neogene Aquifer (Pliocene and Miocene Clastic Rocks)

Neogene aquifer lies between Basalt aquifer and Alluvium aquifer in the highland of Makkah province. The data of water quality is few because of the limited distribution in the area. The water quality is generally fair and the dissolved-solids concentration of water in the aquifer is rather higher than other aquifer, as much as 2,000 to 3,000 milligrams per liter.

(d) Basalt Aquifer (Quaternary and Tertiary)

Basalt Aquifer covers extensive area in the Makkah province. Mineral concentration of the water from the Basalt Aquifer was generally low. The specific concentration was reported as a range from 300 to 5,400 μS per centimeter with a medium value of 1,130 μS per centimeter. Sodium and chloride were the dominant ions.

(e) Alluvium (Quaternary and Tertiary)

Alluvium aquifer is located everywhere in extensive areas: the Red Sea coastal strip, along with wadi courses, mountainous basins and even in eolian sands in the project area. The specific conductance of this water was found to vary greatly, ranging from 150 to 20,000 μS per centimeter. The percentages of sodium and chloride were slightly higher than the other dissolved minerals. As total mineralization increased, however, the sodium and chloride concentrations became increasingly dominant.

The record of Eclectic Conductivity (EC) had been collected by the 1980's to evaluate potable water quality. Figure 3-8 shows EC distribution of the area delineated with maximum values from a survey well (Water Atlas of Saudi Arabia, 1984).

EC of less than 2,000 μS per centimeter (indicated in blue and light blue in Figure 3-8) would require no treatment for the drinking purpose in the local use except possibly for chlorination to insure bacteriological safe. Water with EC of 2,000 to 6,000 μS per centimeter can be used for livestock watering and some crops in irrigation. Water with EC in excess of 6,000 μS per centimeter has only limited use without extensive treatment.

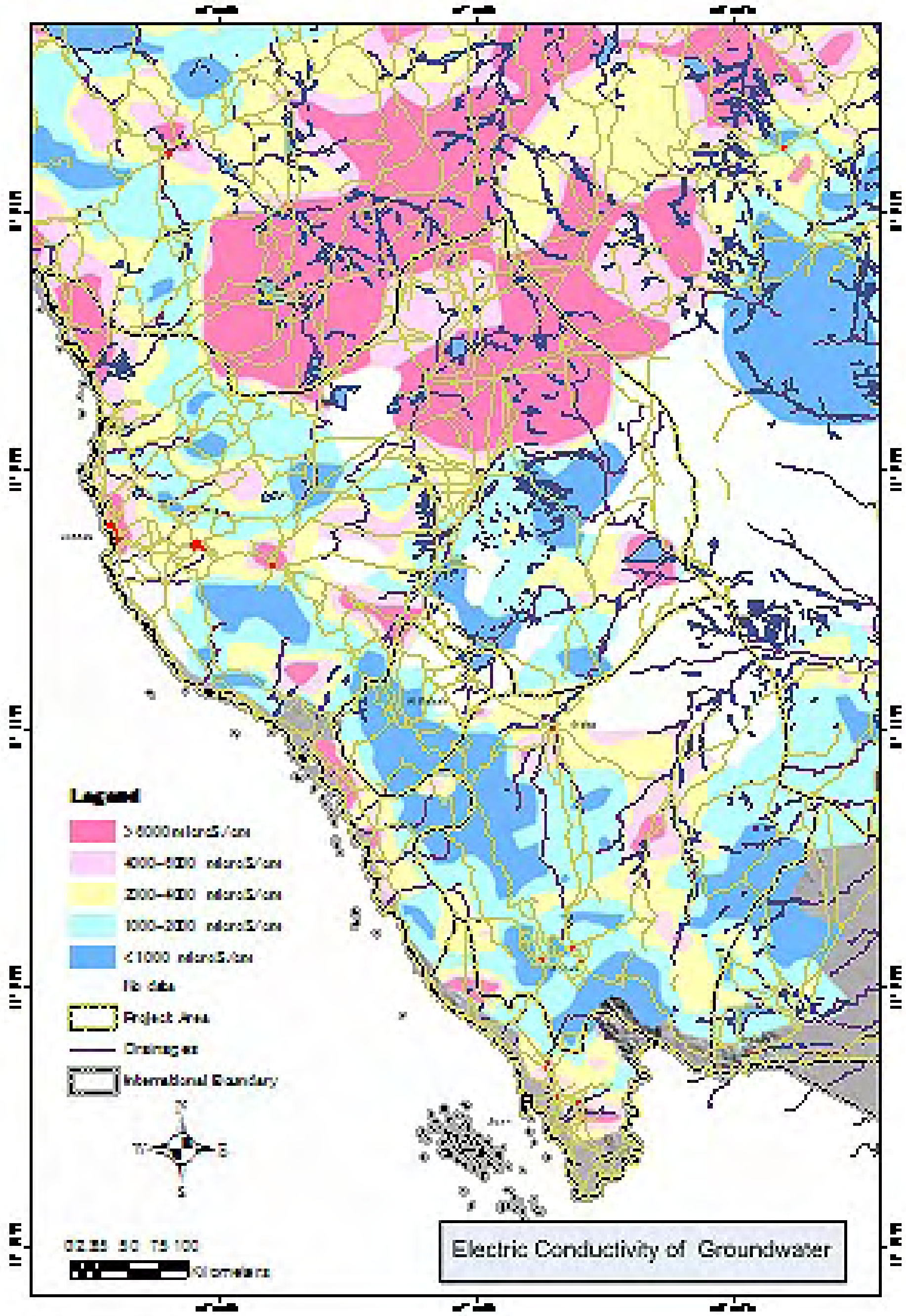


Figure 3-8 Electric Conductivity of Groundwater in Project Area

(f) Water Type

In the project area, there are not perennial streams to provide dependable water supply, even if dams are constructed, part of water being used is groundwater as well as desalinated water. A groundwater quality reflects the geology of an aquifer because the water tends to dissolve minerals with which it comes in contact. The major ions dissolved in ground water are sodium, calcium, magnesium, bicarbonate, chloride, and sulfate. There are other ions in the water, but usually they are present in relatively small amount.

Although the new data of water quality is few, the summary of water quality is shown in Table 3-6 and Figure 3-9.

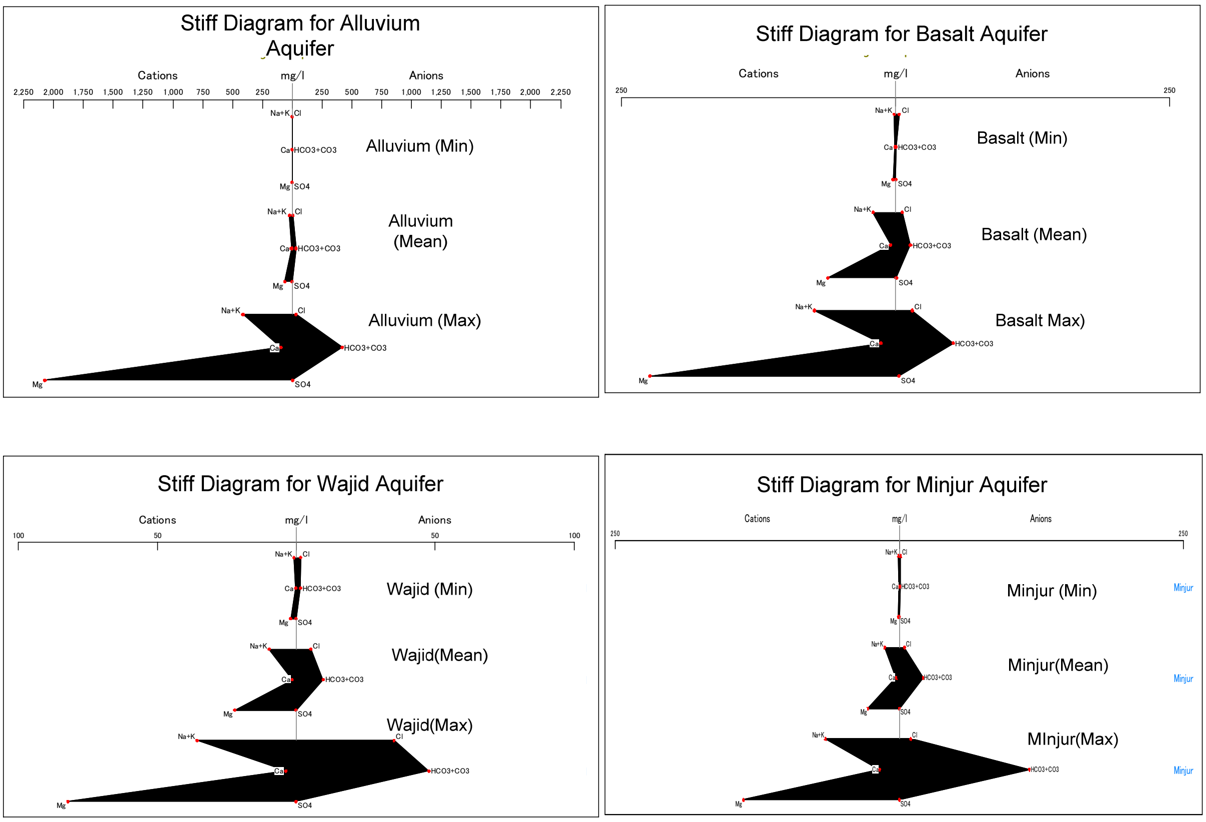
Table 3-6 Water Quality of Aquifers

Parameter	Unit	Wajid Aquifer			Minjur Aquifer			Dhruma Aquifer		
		Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
Specific Conductance	μS/cm (25℃)	280	2,210	7,100	500	1,560	7,000	470	2,740	10,400
Calcium	mg/Lit	10	128	394	14	162	505	74	353	880
Magnesium	mg/Lit	4	28	75	6	60	352	21	140	420
Sodium	mg/Lit	13	149	590	14	204	1,200	41	358	1,430
Bicarbonate	mg/Lit	56	188	1,250	43	165	356	73	169	262
Chloride	mg/Lit	25	269	1,000	14	338	1,670	71	606	2,910
Sulfate	mg/Lit	30	194	960	14	419	2,300	67	953	2,040
Nitrate	mg/Lit	–	–	–	–	–	–	–	105	–
TDS (ROE) *1	mg/Lit	83	1,200	7,600	360	1,390	5,860	400	2,740	8,300
TDS (SUM) *2	mg/Lit	–	–	–	–	–	–	–	–	–

*1: Total Dissolved Solid, residue on evaporation
*2: Total Dissolved Solid, calculated

Parameter	Unit	Neogene Aquifer			Basalt Aquifer			Alluvium Aquifer		
		Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
Specific Conductance	μS/cm (25℃)	742	3,450	48,100	400	2,130	7,900	130	2,600	62,800
Calcium	mg/Lit	6	256	2,460	21	116	352	4	210	6,190
Magnesium	mg/Lit	3	157	9,200	9	87	262	0	100	1,910
Sodium	mg/Lit	43	495	13,400	16	400	1,490	4	437	5,840
Bicarbonate	mg/Lit	0	183	634	128	224	540	6	206	1,160
Chloride	mg/Lit	4	1,630	90,200	25	746	2,720	7	757	25,200
Sulfate	mg/Lit	15	865	94,500	10	274	1,060	5	649	8,450
Nitrate	mg/Lit	1	30	660	7	40	152	0	15	154
TDS (ROE) *1	mg/Lit	200	2,600	50,100	298	1,830	5,720	155	2,320	20,000
TDS (SUM) *2	mg/Lit	910	4,850	90,500	–	–	–	–	–	–

*1: Total Dissolved Solid, residue on evaporation
*2: Total Dissolved Solid, calculated



Note: Stiff Diagram is drawn by the value of Table 6.3.6.

Figure 3-9 Stiff Diagrams for Major Aquifers

(2) Water Sampling Survey

Along with the water level measurement, water-sampling survey was conducted, and field parameters (EC, pH and etc.) of water quality were observed as shown in Table 3-7.

Table 3-7 Summary of Water Sampling Survey

Wadi		Odor	Color	Turbidity	Temp.	EC	pH	DO	Salinity	EH
AL_AHSEEBA	Avg.	NO	NO	0.6	29.2	1,329	7.7	89.9	0.7	80.0
14 samples	Min	NO	NO	0.0	27.6	727	7.0	80.0	0.4	12.5
	Max	NO	NO	2.5	32.1	3,902	8.4	100.0	2.1	148.7
AL_LITH	Avg.	NO	NO	1.6	30.4	1,834	7.7	22.1	0.9	62.1
13 samples	Min	NO	NO	0.0	27.6	727	6.7	4.6	0.1	12.5
	Max	NO	NO	6.0	32.6	3,902	8.5	100.0	2.1	148.7
BISHA	Avg.	NO	NO	1.3	27.6	3,750	7.6	27.4	2.0	18.3
35 samples	Min	NO	NO	0.0	25.6	560	7.2	16.1	0.3	0.4
	Max	NO	NO	7.6	30.1	12,280	8.5	78.2	7.0	43.3
HALI	Avg.	NO	NO	1.8	27.2	2,263	7.7	17.8	1.2	57.4
33 samples	Min	NO	NO	0.0	24.0	983	7.2	0.0	0.6	9.1
	Max	NO	NO	5.9	34.0	7,785	8.2	31.7	4.3	107.3
JIZAN	Avg.	NO	NO	7.3	27.5	1,369	8.1	89.9	0.7	47.8
45 samples	Min	NO	NO	0.0	24.3	434	7.2	49.0	0.2	15.5
	Max	NO	NO	47.3	29.3	4,151	8.4	120.0	2.2	92.7
NAJRAN	Avg.	NO	NO	0.7	27.6	1,210	8.1	44.6	0.6	84.0
6 samples	Min	NO	NO	0.0	23.1	427	7.1	7.3	0.2	1.1
	Max	NO	NO	2.4	31.8	3,656	8.4	97.3	1.9	121.3
YIBA	Avg.	NO	NO	1.5	29.3	1,766	7.3	9.8	0.9	51.1
4 samples	Min	NO	NO	0.1	26.9	906	6.5	2.1	0.4	28.2
	Max	NO	NO	5.8	32.9	6,498	8.6	20.2	3.5	78.1

Note : Unit used in table refers to Table B.3-14 'Items of Water Sampling Survey and Water Quality'

EC of fresh water was 400 µS per centimeter while 12,000 µS per centimeter of brackish water. The average of EC was 1,500 to 2,000 µS per centimeter in respective wadi, which was available quality for irrigation purpose. The fresh water indicating less than 1,000 μS per centimeter was only found in wadi channel and the upper stream, and its water quality was abruptly worsen as was far from wadi center and toward the downstream. In Bisha area, deterioration on water quality caused by excessive pumping was also found in the survey.

Highest turbidity was observed at Jazan by silt inclusions, and acidic water affected by hot springs was also observed at Al Lith and Yiba wadi. Other samples showed in general pH 7.5 as weak alkaline. EC distribution of Wadi Bisha and Wadi Hali-Yiba are shown in Figure 3-10.

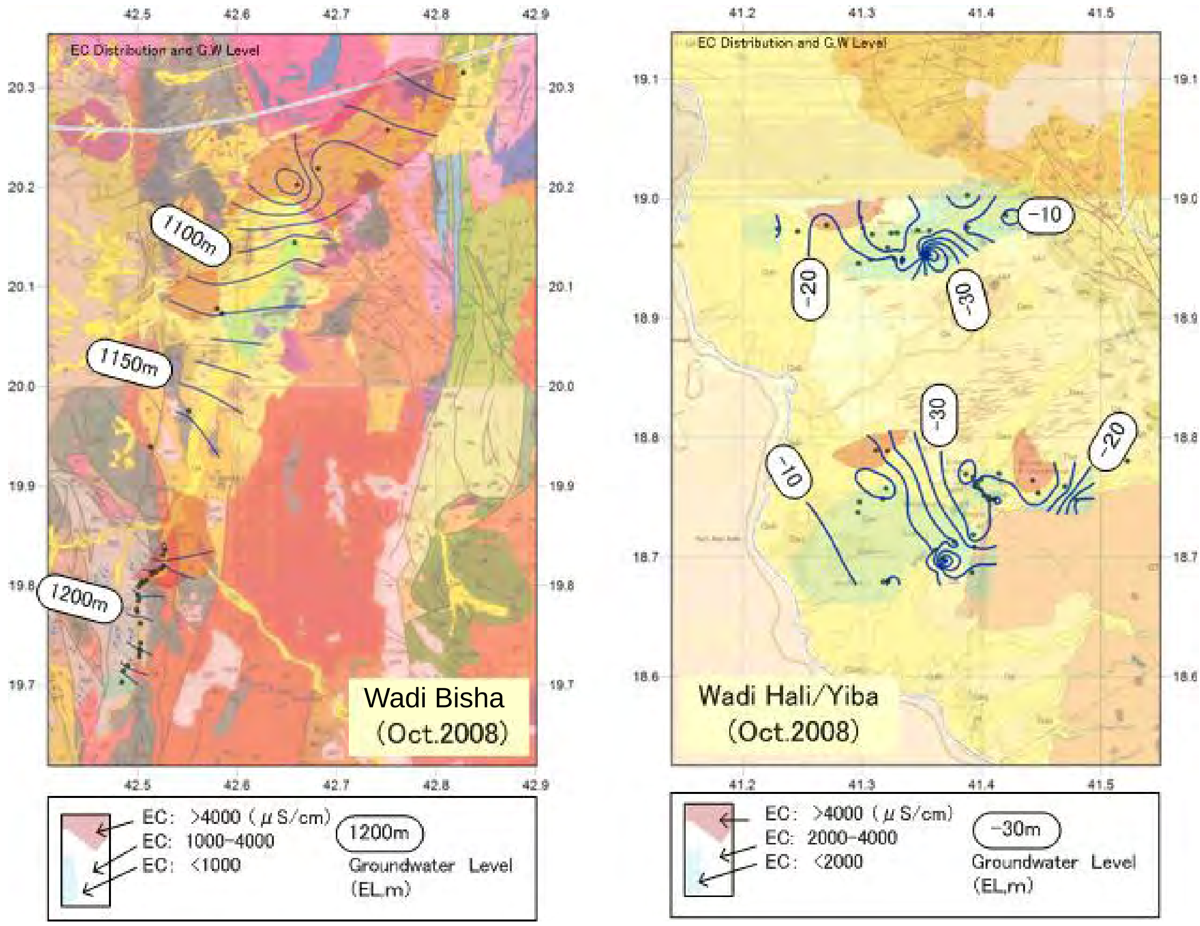


Figure 3-10 EC Distribution (Wadi Al Bisha, Wadi Hali-Yiba)

(3) Water Quality (Laboratory) Test

Laboratory test was made for 200 samples (taken from observatory wells) with items of hydrochemistry, inorganic compound, heavy mineral, bacteria and environment. Summarized table is shown in Table 3-8(1)-(3).

Table 3-8 (1) Summary of Water Quality Test

<Hydrochemistry>

Area		Ca	Mg	Na	K	SO4	Cl	CO3	HCO3	NO3	NO2	NH4
AL_AHSEEBA	Avg.	151.3	28.6	51.7	1.9	138.1	189.8	0.0	219.7	4.8	0.1	0.0
14 samples	Min	88.1	17.0	12.5	0.0	60.0	65.0	0.0	207.5	0.3	0.0	0.0
	Max	404.4	82.6	252.6	9.4	530.0	815.0	0.0	234.3	9.9	0.4	0.3
AL_LITH	Avg.	172.4	41.1	180.6	6.4	327.3	342.0	0.0	177.4	8.7	0.1	0.0
13 samples	Min	8.0	4.9	12.5	0.0	19.0	30.0	0.0	43.9	0.3	0.0	0.0
	Max	404.4	92.3	534.3	20.0	850.0	815.0	0.0	234.3	41.0	0.4	0.3
BISHA	Avg.	373.0	92.5	322.5	12.1	680.3	772.7	0.0	270.7	1.9	0.0	0.0
35 samples	Min	48.1	9.7	43.5	1.6	29.0	55.0	0.0	156.2	0.2	0.0	0.0
	Max	1401.5	340.0	890.3	33.3	1150.0	3900.0	0.0	356.3	9.7	0.1	0.2
HALI	Avg.	186.0	76.5	259.5	9.5	523.6	423.8	0.0	217.7	6.0	0.0	0.0
33 samples	Min	104.1	24.3	55.4	2.1	220.0	160.0	0.0	146.4	0.3	0.0	0.0
	Max	688.7	344.8	1273.8	47.6	2200.0	2000.0	0.0	258.7	96.0	0.3	0.4
JIZAN	Avg.	102.7	38.5	143.3	5.4	203.3	181.1	0.0	210.8	5.6	0.0	0.0
45 samples	Min	12.1	19.4	63.6	2.4	80.0	80.0	0.0	146.4	0.1	0.0	0.0
	Max	253.0	94.7	462.6	17.3	810.0	597.5	0.0	366.1	19.6	0.5	0.1
NAJRAN	Avg.	156.5	31.6	46.3	1.7	237.5	157.2	0.0	177.3	5.4	0.1	0.1
6 samples	Min	64.1	2.4	2.7	0.1	21.0	30.0	0.0	134.2	1.1	0.0	0.0
	Max	460.0	126.3	164.3	6.1	741.0	658.0	0.0	246.5	59.8	0.6	0.6
YIBA	Avg.	151.0	48.3	276.4	9.0	366.1	394.0	0.0	180.0	2.5	0.0	0.0
4 samples	Min	56.1	14.6	0.0	4.1	200.0	0.9	0.0	122.0	0.0	0.0	0.0
	Max	680.7	238.0	1110.7	36.6	880.0	2675.0	0.0	224.5	12.0	0.1	0.0

Note：Unit used in table refers to Table B.3-14 'Items of Water Sampling Survey and Water Quality'

Table 3-8 (2) Summary of Water Quality Test

＜Inorganic Compound, Heavy Mineral＞

Area		Cyan	Hg	Cu	Fe	Mn	Zn	Pb	Cr	Cd	As	F
AL_AHSEEBA	Avg.	ND	<0.001	0.0	0.0	0.0	-	<0.01	0.0	<0.01	<1	0.6
14 samples	Min	ND	<0.001	0.0	0.0	0.0	0.1	<0.01	0.0	<0.01	<1	0.3
	Max	ND	<0.001	0.3	0.1	0.0	0.5	<0.01	0.0	<0.01	<1	0.9
AL_LITH	Avg.	ND	<0.001	0.0	0.0	0.0	-	<0.01	-	<0.01	3.6	1.9
13 samples	Min	ND	<0.001	0.0	0.0	0.0	0.1	<0.01	<0.01	<0.01	1.0	0.1
	Max	ND	<0.001	0.3	0.1	0.0	0.5	<0.01	0.0	<0.01	5.0	11.7
BISHA	Avg.	ND	<0.001	0.0	0.1	0.0	-	<0.01	0.0	<0.01	-	0.7
35 samples	Min	ND	<0.001	0.0	0.0	0.0	0.2	<0.01	0.0	<0.01	<1	0.1
	Max	ND	<0.001	0.1	0.4	0.1	0.2	<0.01	0.0	<0.01	1.0	1.2
HALI	Avg.	ND	<0.001	0.0	0.1	0.0	-	<0.01	0.0	<0.01	-	0.8
33 samples	Min	ND	<0.001	0.0	0.0	0.0	0.0	<0.01	0.0	<0.01	<1	0.2
	Max	ND	<0.001	0.1	1.5	0.2	0.4	<0.01	0.0	<0.01	9.0	2.1
JIZAN	Avg.	ND	<0.001	0.0	0.1	0.0	-	<0.01	0.0	<0.01	-	0.5
45 samples	Min	ND	<0.001	0.0	0.0	0.0	0.0	<0.01	0.0	<0.01	<1	0.2
	Max	ND	<0.001	0.1	0.8	0.1	0.0	<0.01	0.0	<0.01	3.0	0.9
NAJRAN	Avg.	ND	<0.001	0.0	0.2	0.0	-	-	0.0	<0.03	-	0.6
6 samples	Min	ND	<0.001	0.0	0.0	0.0	<0.01	<0.01	0.0	<0.04	<1	0.1
	Max	ND	<0.001	0.1	3.9	0.1	0.1	0.0	0.1	<0.05	17.0	2.2
YIBA	Avg.	ND	<0.001	0.0	0.1	0.0	-	-	0.0	<0.01	-	0.6
4 samples	Min	ND	<0.001	0.0	0.0	0.0	<0.01	<0.01	0.0	<0.01	<1	0.1
	Max	ND	<0.001	0.0	0.5	0.3	0.2	<0.02	0.0	<0.01	9.0	1.2

Note：Unit used in table refers to Table B.3-14 'Items of Water Sampling Survey and Water Quality'

Table 3-8 (3) Summary of Water Quality Test

＜Bacteria and Environment＞

Area		COD	Bacteria	Fecal Coliform	Phenolic Compound	Organo Phosphorus	Hardness	TDS	Foaming Agent
AL_AHSEEBA	Avg.	27	925	ND	ND	0.0	496	803	-
14 samples	Min	24	300	ND	ND	0.0	300	497	Nil
	Max	36	1,200	ND	ND	0.0	1,350	2,348	2.0
AL_LITH	Avg.	39	567	ND	ND	0.0	602	1,289	-
13 samples	Min	9	200	ND	ND	0.0	40	138	Nil
	Max	158	1,200	ND	ND	0.0	1,350	2,634	2.0
BISHA	Avg.	35	724	-	ND	0.0	1,310	2,533	-
35 samples	Min	13	200	ND	ND	0.0	180	445	Nil
	Max	57	1,200	100.0	ND	0.1	4,840	7,821	1.0
HALI	Avg.	65	877	ND	ND	0.0	675	1,533	-
33 samples	Min	0	300	ND	ND	0.0	480	100	Nil
	Max	230	1,800	ND	ND	0.1	1,380	6,538	1.0
JAZAN	Avg.	28	784	ND	ND	0.0	421	963	-
45 samples	Min	21	200	ND	ND	0.0	220	538	Nil
	Max	50	1,200	ND	ND	0.0	1,020	2,620	2.0
NAJRAN	Avg.	30	650	ND	ND	0.0	518	821	-
6 samples	Min	21	200	ND	ND	0.0	180	273	Nil
	Max	75	1,200	ND	ND	0.0	1,700	2,283	2.0
YIBA	Avg.	35	507	ND	ND	0.0	601	1,432	-
4 samples	Min	10	200	ND	ND	0.0	220	734	Nil
	Max	46	900	ND	ND	0.0	2,680	5,697	1.5

Note：Unit used in table refers to Table B.3-14 'Items of Water Sampling Survey and Water Quality'

(a) Groundwater Type (Piper Diagram)

To identify the groundwater Type, Piper diagram analysis was made (Figure 3-11).

The Piper program shows eight "standard" ions: 4 cations (Na, K, Ca, and Mg) and 4 anions (Cl, HCO3, CO3, SO4). Concentrations are translated to milli-equivalents per liter for plotting on the diagram. Besides, the concentration of TDS shows the size of circle. The following findings are obtained through the analysis.

The groundwater type is classified into two of Type I and Type V. Type I is indicated as Non-bicarbonate-Calcium chemical component and is common in hot spring or un-renewable water. Type V is intermediate type of Type I and renewed water such as baseflow and river water originated from rainwater.

In the project area, Type I is common in Wadi Najran, Bisha and Hali of un-renewable water. Type V is dominant type in Wadi Jizan, Al Lith, Yiba, Al Ahseeba of mixed water of river water, base flow water and un-renewable water. In the coastal area, in particular Wadi Hali and Yiba, the chemical component of seawater (rich in Cl, Na+K) are included in both types of water.

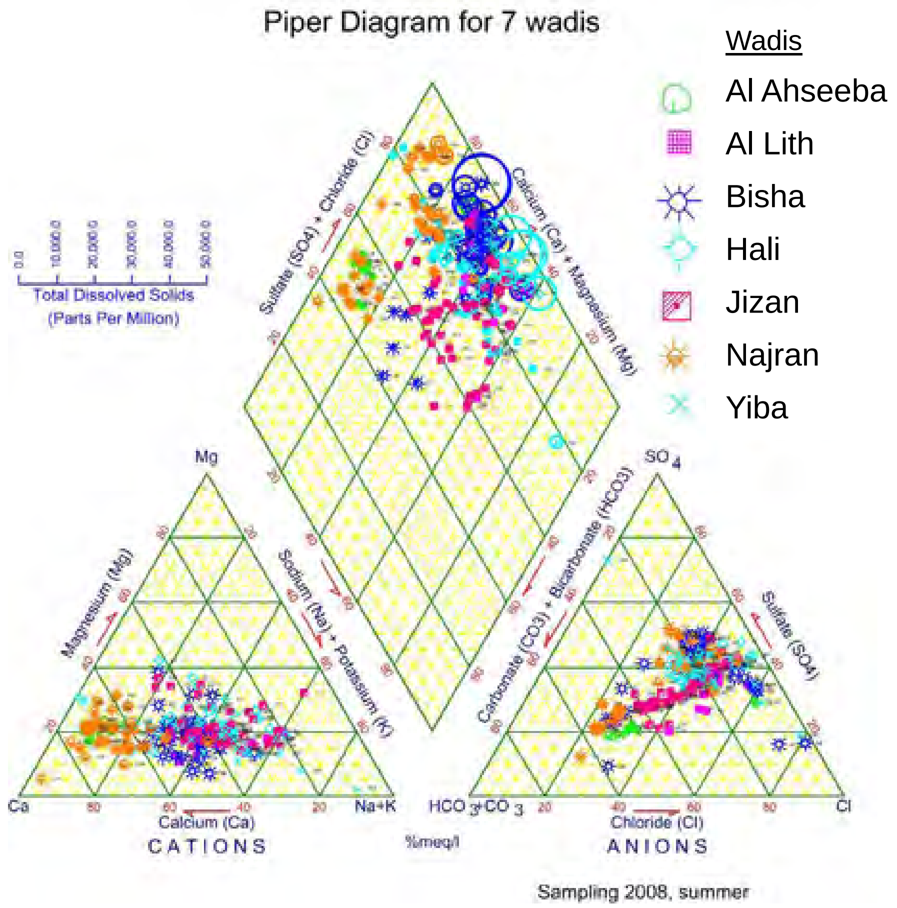


Figure 3-11 Groundwater Type (Piper Diagram)

(b) Water Quality Components in Wadis

For visualizing the changes of water quality, Stiff diagram is delineated. The stiff diagram has information (in any order) for eight "standard" ions: 4 cations (Na, K, Ca, and Mg) and 4 anions (Cl, HCO3, CO3, SO4). Concentrations are entered in parts per million (ppm) or milligrams per liter (mg/l); concentrations are translated to milli-equivalents per liter for plotting on the diagram. The Type I (Non-bicarbonate-Calcium type) is characterized by higher concentration of Ca at the left-middle. While for Type V shows squire shape. As well, contamination with seawater indicates high concentration of Cl at the right-low corner of diagram.

Figure 3-12(right figure) shows the water quality changes along Wadi Yiba. At the upper stream, the Type V is dominant type which indicates the contamination with renewable water. Toward downstream, it turns into Type I and is mixed with seawater.

Figure 3-12 (left figure) represents Wadi Bisha. It includes fresh water at upper stream while un-renewable water categorized to Type I at downstream.

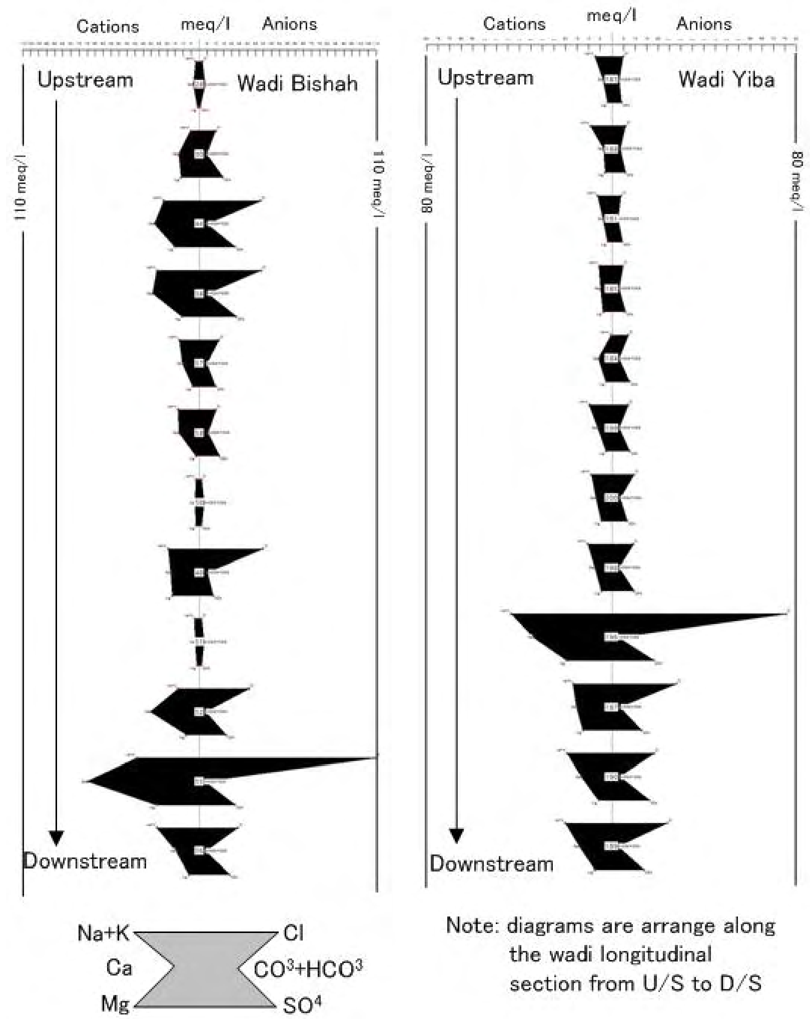


Figure 3-12 Changes of Water Quality in Wadi (Stiff Diagram)

(c) Drinking Water Quality

The renewal water source, replenished from rainwater and other surface sources are limited in its distribution in the study area, and most of them belong the Type I and V of un-renewable water, which is characterized by high contents of sodium, calcium, chloride and sulfide. Table 3-9 (1)-(2) shows a correlation table which is examined by drinking water standard (MOWE). In the table, shaded part is hazardous concentration as potable water.

In the most of wells, high EC is detected. Particularly half of samples taken from Wadi Al Lith, Bisha, Hali, Yiba indicate the higher than the standard's. As for the content of Na, K, Cl, SO4, the values also exceed those of the standard. Content of chloride measured in Wadi Bisha and Yiba shows 10 times of standard value. Coli form is detected in every samples and even fecal coliform is found out in Wadi Bisha's sample.

The silt contamination is also found in the Wadi Jazan, Hali, Yiba, and those are higher than the standard. Nirtite content is also high in Wadi Hali and Najran, and the highest reaches several to 10 times of the standard. The fact means groundwater resource may be deteriorated from fertilizing, domestic sewerage and animal excrement.

The result of heavy minerals and inorganic tests shows the ferric water (high contents of Fe and Mn) derived from basaltic lavas and fluoric water originated from Precambrian rocks or volcanic ash. As for other items, harmful components and high concentration are not found in the test.

Table 3-9 (1) Summary of Water Quality Test

Area		Odor	Color	Turb	EC	TDS	pH	Ca	Mg	Na	SO4	Cl	NO3	NO2
AHSEEBA	Avg.	NO	NO	0.6	1,329	803	7.7	151.3	28.6	51.7	138.1	189.8	4.8	0.1
14 samples	Min	NO	NO	0.0	727	497	7.0	88.1	17.0	12.5	60.0	65.0	0.3	0.0
	Max	NO	NO	2.5	3,902	2,348	8.4	404.4	82.6	252.6	530.0	815.0	9.9	0.4
AL_LITH	Avg.	NO	NO	1.6	1,834	1,289	7.7	172.4	41.1	180.6	327.3	342.0	8.7	0.1
13 samples	Min	NO	NO	0.0	727	138	6.7	8.0	4.9	12.5	19.0	30.0	0.3	0.0
	Max	NO	NO	6.0	3,902	2,634	8.5	404.4	92.3	534.3	850.0	815.0	41.0	0.4
BISHA	Avg.	NO	NO	1.3	3,750	2,533	7.6	373.0	92.5	322.5	680.3	772.7	1.9	0.0
35 samples	Min	NO	NO	0.0	560	445	7.2	48.1	9.7	43.5	29.0	55.0	0.2	0.0
	Max	NO	NO	7.6	12,280	7,821	8.5	1401.5	340.0	890.3	1150.0	3900.0	9.7	0.1
HALI	Avg.	NO	NO	1.8	2,263	1,533	7.7	186.0	76.5	259.5	523.6	423.8	6.0	0.0
33 samples	Min	NO	NO	0.0	983	100	7.2	104.1	24.3	55.4	220.0	160.0	0.3	0.0
	Max	NO	NO	5.9	7,785	6,538	8.2	688.7	344.8	1273.8	2200.0	2000.0	96.0	0.3
JIZAN	Avg.	NO	NO	7.3	1,369	963	8.1	102.7	38.5	143.3	203.3	181.1	5.6	0.0
45 samples	Min	NO	NO	0.0	434	538	7.2	12.1	19.4	63.6	80.0	80.0	0.1	0.0
	Max	NO	NO	47.3	4,151	2,620	8.4	253.0	94.7	462.6	810.0	597.5	19.6	0.5
NAJRAN	Avg.	NO	NO	0.7	1,210	821	8.1	156.5	31.6	46.3	237.5	157.2	5.4	0.1
6 samples	Min	NO	NO	0.0	427	273	7.1	64.1	2.4	2.7	21.0	30.0	1.1	0.0
	Max	NO	NO	2.4	3,656	2,283	8.4	460.0	126.3	164.3	741.0	658.0	59.8	0.6
YIBA	Avg.	NO	NO	1.5	1,766	1,432	7.3	151.0	48.3	276.4	366.1	394.0	2.5	0.0
4 samples	Min	NO	NO	0.1	906	734	6.5	56.1	14.6	0.0	200.0	0.9	0.0	0.0
	Max	NO	NO	5.8	6,498	5,697	8.6	680.7	238.0	1110.7	880.0	2675.0	12.0	0.1
MOWE Water Standard for Drinking		NO	15	5.0	160-1600	100-1000	6.5-8.5	200	150	200	400	250	10	1

Note：Unit used in table refers to Table B.3-14 'Items of Water Sampling Survey and Water Quality'

Table 3-9 (2) Summary of Water Quality Test

Area		F.Col	Cyan	Hg	Cu	Fe	Mn	Zn	Pb	Cr	Cd	As	F	Hard
AHSEEBA	Avg.	ND	ND	<0.001	0.0	0.0	0.0	-	<0.01	0.0	<0.01	<1	0.6	496
14 samples	Min	ND	ND	<0.001	0.0	0.0	0.0	0.1	<0.01	0.0	<0.01	<1	0.3	300
	Max	ND	ND	<0.001	0.3	0.1	0.0	0.5	<0.01	0.0	<0.01	<1	0.9	1,350
AL_LITH	Avg.	ND	ND	<0.001	0.0	0.0	0.0	-	<0.01	-	<0.01	3.6	1.9	602
13 samples	Min	ND	ND	<0.001	0.0	0.0	0.0	0.1	<0.01	<0.01	<0.01	1.0	0.1	40
	Max	ND	ND	<0.001	0.3	0.1	0.0	0.5	<0.01	0.0	<0.01	5.0	11.7	1,350
BISHA	Avg.	-	ND	<0.001	0.0	0.1	0.0	-	<0.01	0.0	<0.01	-	0.7	1,310
35 samples	Min	ND	ND	<0.001	0.0	0.0	0.0	0.2	<0.01	0.0	<0.01	<1	0.1	180
	Max	100.0	ND	<0.001	0.1	0.4	0.1	0.2	<0.01	0.0	<0.01	1.0	1.2	4,840
HALI	Avg.	ND	ND	<0.001	0.0	0.1	0.0	-	<0.01	0.0	<0.01	-	0.8	675
33 samples	Min	ND	ND	<0.001	0.0	0.0	0.0	0.0	<0.01	0.0	<0.01	<1	0.2	480
	Max	ND	ND	<0.001	0.1	1.5	0.2	0.4	<0.01	0.0	<0.01	9.0	2.1	1,380
JIZAN	Avg.	ND	ND	<0.001	0.0	0.1	0.0	-	<0.01	0.0	<0.01	-	0.5	421
45 samples	Min	ND	ND	<0.001	0.0	0.0	0.0	0.0	<0.01	0.0	<0.01	<1	0.2	220
	Max	ND	ND	<0.001	0.1	0.8	0.1	0.0	<0.01	0.0	<0.01	3.0	0.9	1,020
NAJRAN	Avg.	ND	ND	<0.001	0.0	0.2	0.0	-	-	0.0	<0.03	-	0.6	518
6 samples	Min	ND	ND	<0.001	0.0	0.0	0.0	<0.01	<0.01	0.0	<0.04	<1	0.1	180
	Max	ND	ND	<0.001	0.1	3.9	0.1	0.1	0.0	0.1	<0.05	17.0	2.2	1,700
YIBA	Avg.	ND	ND	<0.001	0.0	0.1	0.0	-	-	0.0	<0.01	-	0.6	601
4 samples	Min	ND	ND	<0.001	0.0	0.0	0.0	<0.01	<0.01	0.0	<0.01	<1	0.1	220
	Max	ND	ND	<0.001	0.0	0.5	0.3	0.2	<0.02	0.0	<0.01	9.0	1.2	2,680
MOWE Water Standard for Drinking		ND	0.005	0.001	1	0.3	0.1	2	0.05	0.05	0.005	50	0.6-1.7	500

Note：Unit used in table refers to Table B.3-14 'Items of Water Sampling Survey and Water Quality'

(d) Pumping Un-renewable Water

In the analysis of groundwater type by Piper diagram, a pumping of un-renewable water is suggested overall the project area (refer to sub-section 3.4.3(1)). It is also supported by factual phenomena in field survey, such as,

- Groundwater quality degradation,
- Groundwater level lowering,

- Insufficient water amount for agricultural use,
- Not enough recovery of groundwater level and
- Seawater intrusion.

The groundwater obstacles listed above are seen with various forms extensively in five (5) regions and are MOWE's main enumeration which shall take immediate countermeasure for their solutions. Thus, the phenomena may be led by the over extraction beyond natural water replenishment from rainwater, and it gives clear evidence that supports the result of water type analysis which is pumping un-renewable resources. As well, SWAT output (refer to Chapter 4) indicates that the renewable amount is less than present consumption of water in Jazan and Najran Regions.

However, with present water quality data, the further detail analysis of un-renewable water cannot be progressed. Thus, to estimate the residence time of groundwater (age of water) and check up the storage of resources with time axis vs. demand, a different way of approach is suggested as next step.

Residence times can be estimated in two ways. The more common method relies on the principle of conservation of mass and assumes the amount of water in a given reservoir is roughly constant by which is applied by groundwater modeling involving both renewable and un-renewable resource. With this method, residence times are estimated by dividing the volume of the reservoir by the rate by which water either enters or exits the reservoir. An alternative method to estimate residence times, which is gaining in popularity for dating groundwater, is the use of isotopic techniques.

3.5 Aquifer Property

(1) Aquifer Property and Aquifer

The hydraulic information of aquifer is few in the project area. The summarize table for aquifer property is given in Table 3-10.

Table 3-10 Hydraulic Information for Aquifers

Aquifer	Lithlogic Description	Thicness (m)	Total Depth (m)	Static Water Level (m)	Yield (lit/sec)	Trans-mmisivity	Stora-tivity	Total Dissolved Solids (mg/lit)	Locality
Alluvium	Gravel,Sand,Silt,etc.	10-100	-	-	5-50	1×10^{-3} to 1×10^{-1}	1×10^{-3} to 1×10^{-5}	-	-
Basalt	Basalt, etc.	40-70	-	-	-	-	-	-	-
Neogene	Sandy Marl & Sandy Limestone	-	±150	0-10	0.63-50	-	-	<1500	Coastal Belt
Minjur/ Druma	Sandstone and Some Shale	300 (Minjur) 100 (Druma)	±400	60-100	50			1400	Riyadh Area *1
			±1200	160-220	±50			1600	Sudair Area *1
			±900	150-180	±50			1800	Washem Area *1
			±1600	(+)	158	1×10^{-2} to	10^{-3}	2820	Kharj Area *1
			±590	(-)				4100	Ajlaj Area *1
WAJID	WAJID Sandstone, General, and Basement Erratics *1	400	±150	±20	9			1000-3000	West of Wadi Dawasir
			±250	(-)	16-126			±1000	East of Wadi Dawasir
			900-1200		4-13			±800	Southwestern Rub Al-Khali

Note *1: Hydraulic information of Minjur aquifer nearby the project area is not colleced so the reference value is shown in the table.

(2) Aquifer Test

To obtain the aquifer coefficient, the aquifer test was conducted with two processes of the continuous pumping test and the recovery test at two sites of Hirjab and Habawnah. However, the tests had to be made in the end of dry season being in the lowest level of groundwater in the year. The thickness of saturated layer was thus not enough for the proper aquifer test, and even drawdown (displacement caused by pumping) of observation well was too little to estimate the aquifer coefficients. Considering the field condition in the aquifer test, the single-well method was applied for the analysis.

Due to the lowest groundwater level, the testing section had to be placed in the basement at Hirjab while proper position of aquifer at Habawnah. The result of analysis is shown in Figure 3-13.

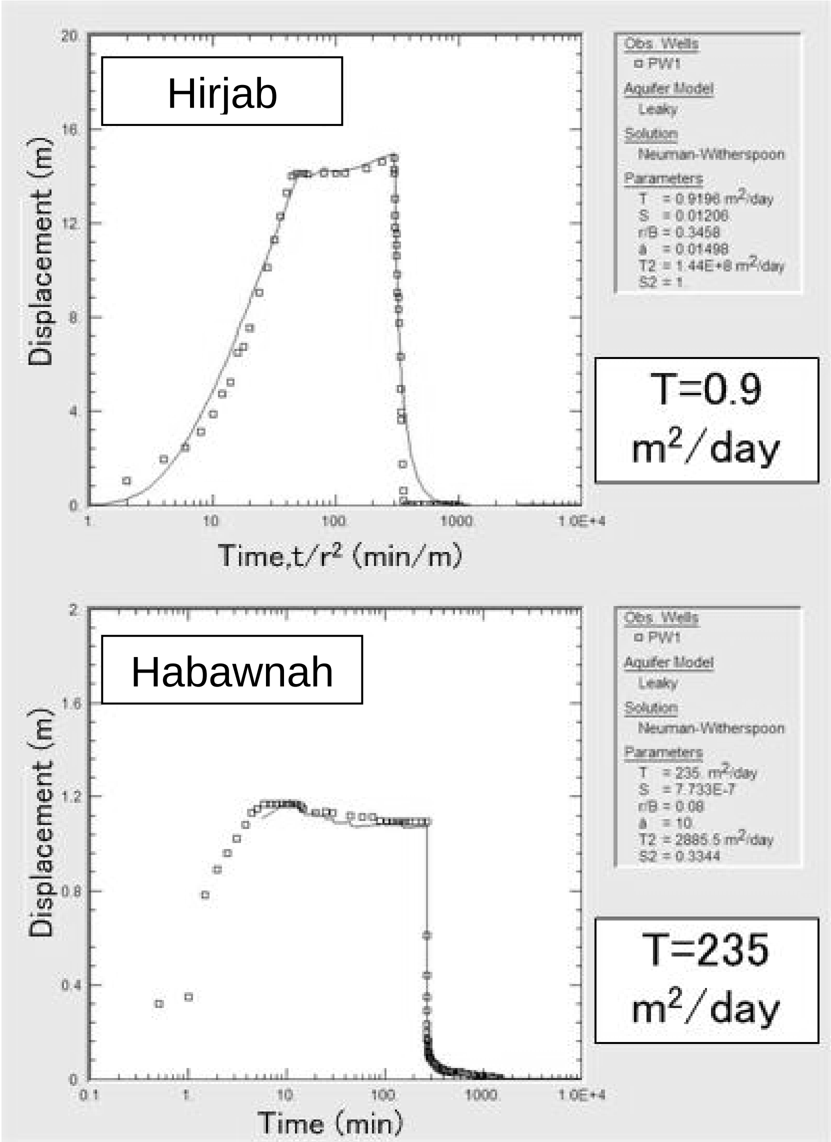


Figure 3-13 Analysis of Aquifer Test

Transmissivity (T) = 0.9 to 1.0 m^2/day was taken from Hirjab's and the range of 150 to 270 m^2/day was calculated from Habawnah's observation as shown in Table 3-11. Among all analytical solutions, 'Neuman-Wetherspoon method (refer to Figure 3-13)' resulted in a best matching (refer to Table 3-10), and Transmissivity (T) = 235 m^2/day was taken as typical value for alluvial aquifer.

Consequently, a design value for Permeability (k), $8x10^{-3}$ cm/sec was calculated by the thickness of aquifer which was observed in the drilling as 3-4 m of gravely layer.

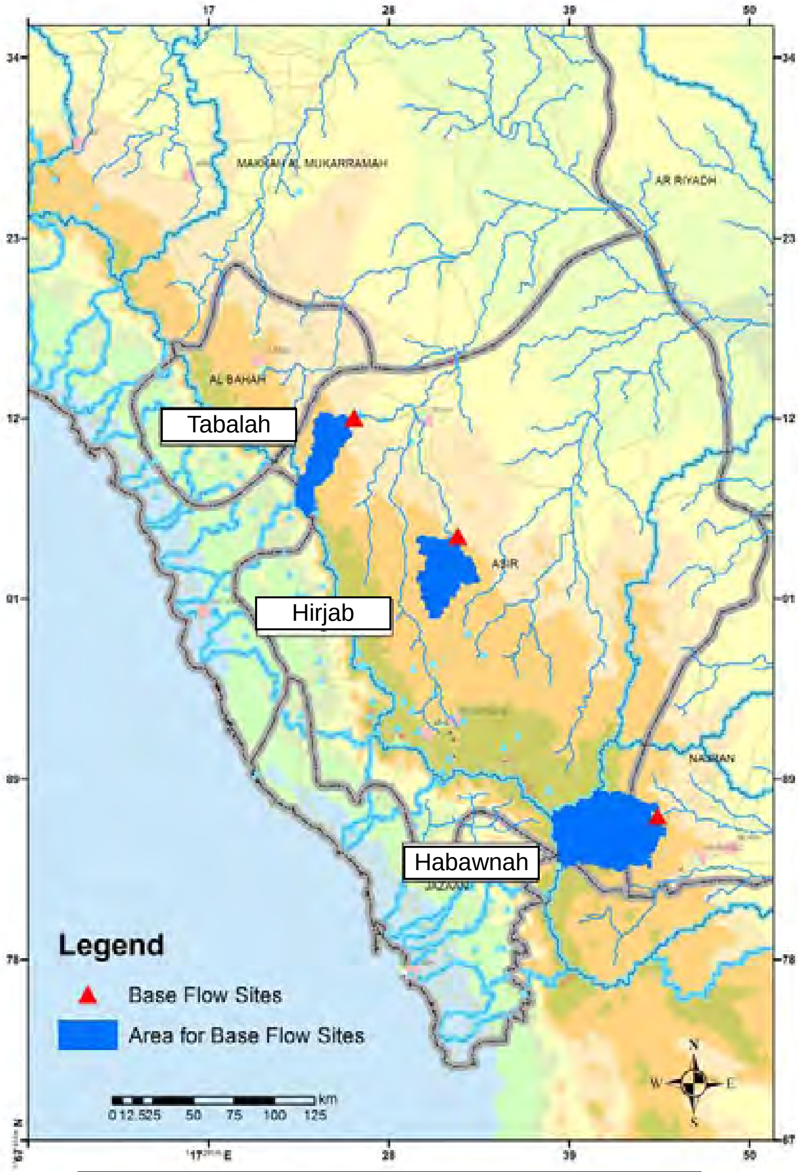
Table 3-11 Summary of Pumping Test

＜Hirjab＞		
Method	Transmissivity（T）	
Tartakovsky-Neuman	0.98	m^2/day
Neuman-Witherspoon	**0.92**	
＜Habawnah＞		
Method	Transmissivity （T）	
Tartakovsky-Neuman	267	m^2/day
Huntush	157	
Neuman-Witherspoon	**235**	

3.6 Baseflow Survey

In the baseflow survey, three observatories were installed in Asir and Najran region. Two of them were located in Asir region, and the other one was in Najran region as shown in Figure 3-14. The observation period was one year since July 2008 by June 2009, and the procedure of the baseflow estimation was followed with four steps, as below.

Step 1: Installing observation wells at upstream and downstream of measurement points in wadi,
Step 2: Measuring water levels at both points, and leveling wells' elevation to connect the both wells and calculate the hydrologic gradient of water table,
Step 3: Carrying out geophysical observation along wadi section to decide shape and thickness of aquifers,
Step 4: Obtaining transmissivity of aquifer by aquifer test, and calculating daily discharge at three sites.



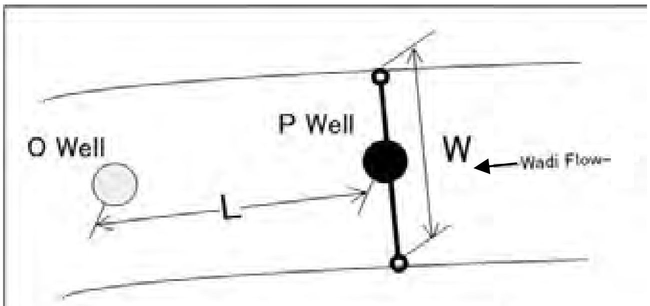
Wadi (states)	Co-ordinates (Lat/Lon,D.D)	Area (sqkm)
Tabalah（Asir）	17.79/44.00	1,030
Hirjab（Asir）	19.34/42.82	1,220
Habawnah（Najran）	19.99/42.20	2,620

Figure 3-14 Location of Baseflow Survey Site

In the step 1, two (2) observation wells were newly constructed, and geophysical survey was carried out. Figure 3-15 shows the layout of base flow survey site.

On the wadi bed, pumping well (P-well) was placed at the upstream, and observation well (Ob-well) was located at the downstream, apart 250-300 m far from P-well in order to maintain the accuracy on the measurement of hydraulic gradient. For the measurement of drawdown, P-well was used as mother (pumping) well while Ob-well was applied as a child (observation) well.

As for geophysical survey, the survey line was planned to cross wadi section and pass P-well. In Hirjab and Habawnah site, the automatic recorders were installed in new wells for the time-series measurement of the water level. However in Tabalah site, due to using existing well for P-well, manual measurement was only made with monthly basis.



Site	L(m)	W(m)
Tabalah	285	170
Hirjab	300	197
Habawnah	250	167

L: Length between P-Well and O-well
W: Width of Wadi along Resistivity Survey line

Figure 3-15 Layout of Baseflow Measurement Site

(1) Aquifer Test and Geophysical Survey

(a) Drilling

The wadi basement of Hirjab site is made up of Pre-Cambrian granite/gneiss, while Habawnah site is of metamorphics. The depth of basement is 12 m at Hirjab while 20 m at Habawnah. The aquifer thickness at Hirjab is thus 6 m to 12 m and Habawnah's is 11m to 20m. The lithology of aquifer is mainly composed of sand, gravel and minor intercalations of silt/clay, In Figure 3-16, the well log is shown.

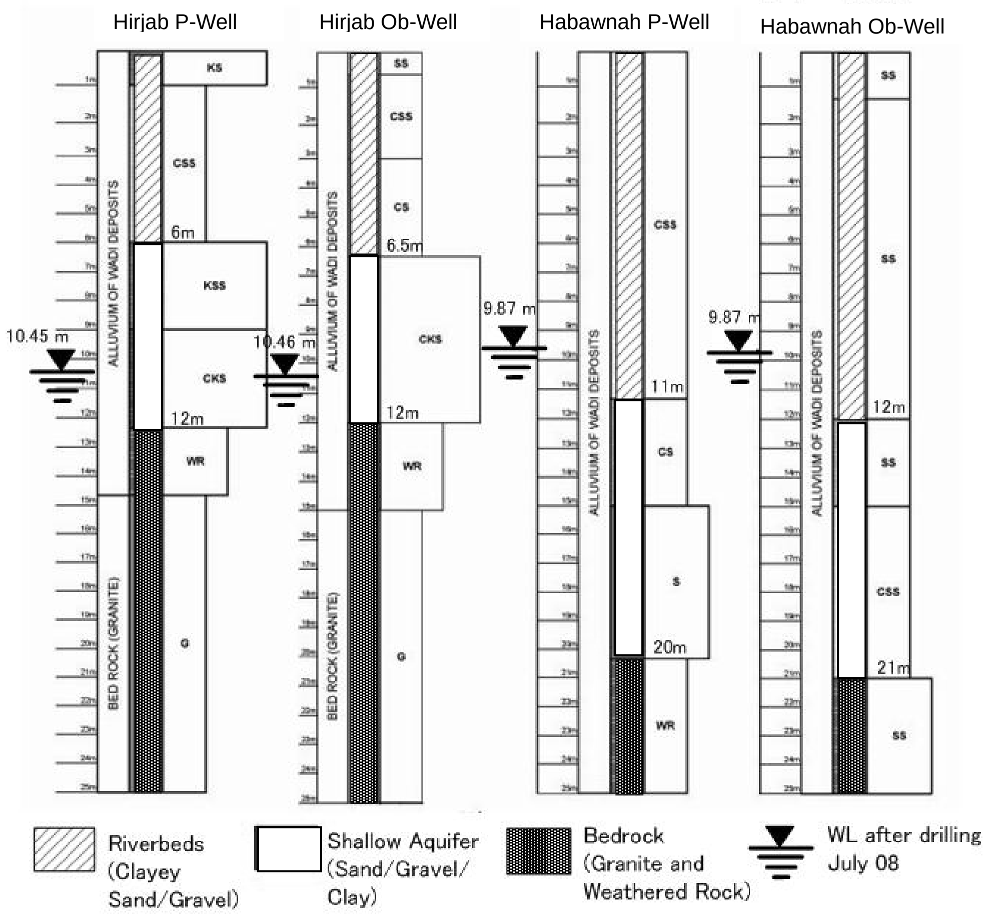


Figure 3-16 Well Logs

The water level was 10.45 m deep after drilling (July 2008) at Hirjab. It was only 1-2 m shallower than the basement. While at Habawnah, water level was 9.9 m, and 11 m of saturated zone was observed.

(b) Geophysical Survey (Resistivity Survey)

The vertical resistivity sounding (Schlumberger Method) was conducted with 100 m deep along the wadi cross-section which traversed P-well. Using smooth inversion analysis, the specific resistivity was calculated and the aquifer position was delineated through the correlation to drilling logs of P-well.

The resistivity pattern showed the clear contrast between the low of 100 ohm-m at aquifer portion and the high of more than 1,000 ohm-m at the surface layer and basement.

In Figure 3-17, cross-section of aquifer is shown. The thickness of aquifer and shape of basement are as follows.

- 10 m at Hirjab site and 12 m at Tabalah site, and the shape of basement is U-shaped with sight deeper at the center of wadi.
- Habawnah's basement is 25 m deep at the left bank, which forms V-shaped valley.

The aquifer lies on the basement and characterized by silt intercalations. The aquifer is not uniformed aquifer but it consists of multi-aquifers divided into several layers of sand and gravel.

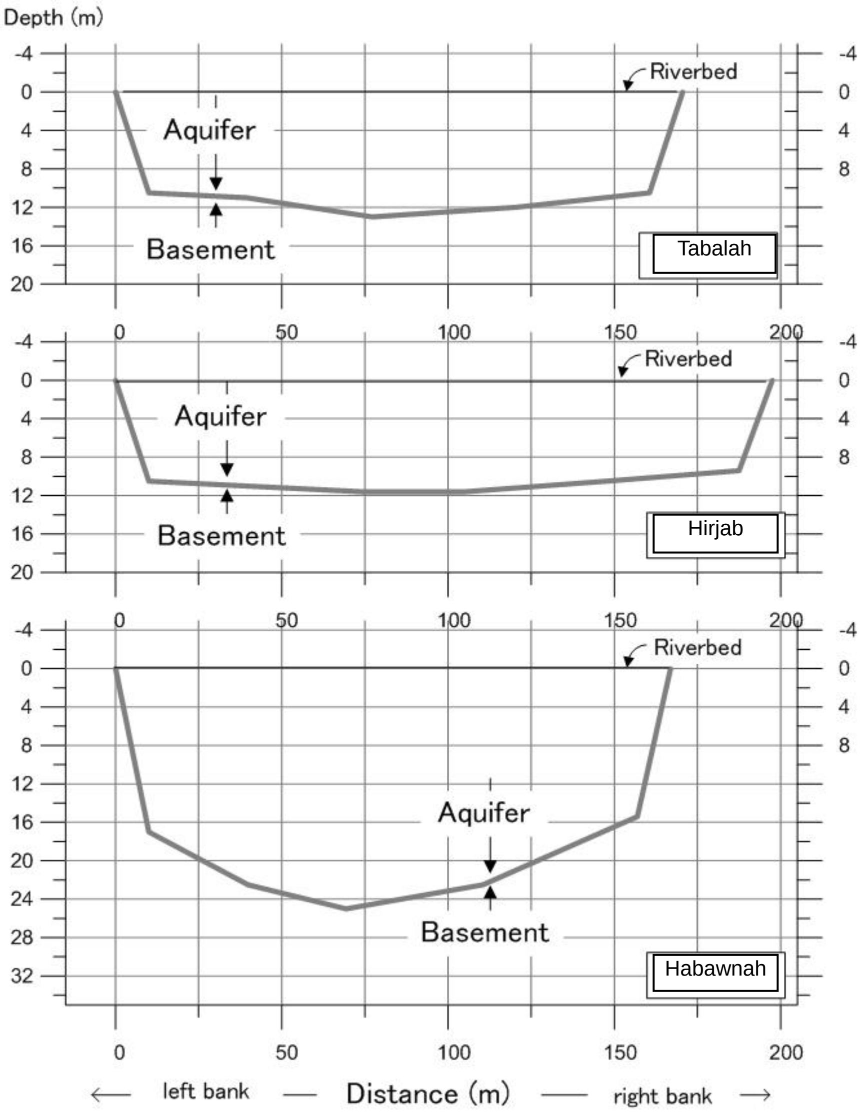


Figure 3-17 Thickness of Aquifer

(2) Measurement of Groundwater Level

The observation of groundwater level had begun since July 2008. The measurement was carried out by the automatic logger at five (5) minutes interval for 5 wells of Tabalah (P-well), Hirjab (P-Well, Ob-Well), Habawnah (P-Well, Ob-Well), and by the manual reading at Tabalah (Ob-well) in monthly basis.

In Figure 3-18, the result of measurement from Aug. 2008 to Jan. 2009 is shown. From the observation record, following findings are taken.

- Habawnah site was suffered by the lowering groundwater level at the beginning of observation and groundwater level declined at rate of over 1 meter/month.
- However, after rainfall and surface discharge taken place on 25 Oct. 2008 to 1 Nov. 2008, the groundwater level turned to increase at every site.
- It indicated groundwater recharge which generally observed from 5 days later from wet day, particularly largest response for rainfall was on 25 and 26 Oct 2008 at Hirjab and Habawnah site.
- Groundwater recharge was thus recognized quickly within several days after wet day.
- However, rainfall did not continue, and it once rose 0.2 to 0.5 m and decreased again after one month.

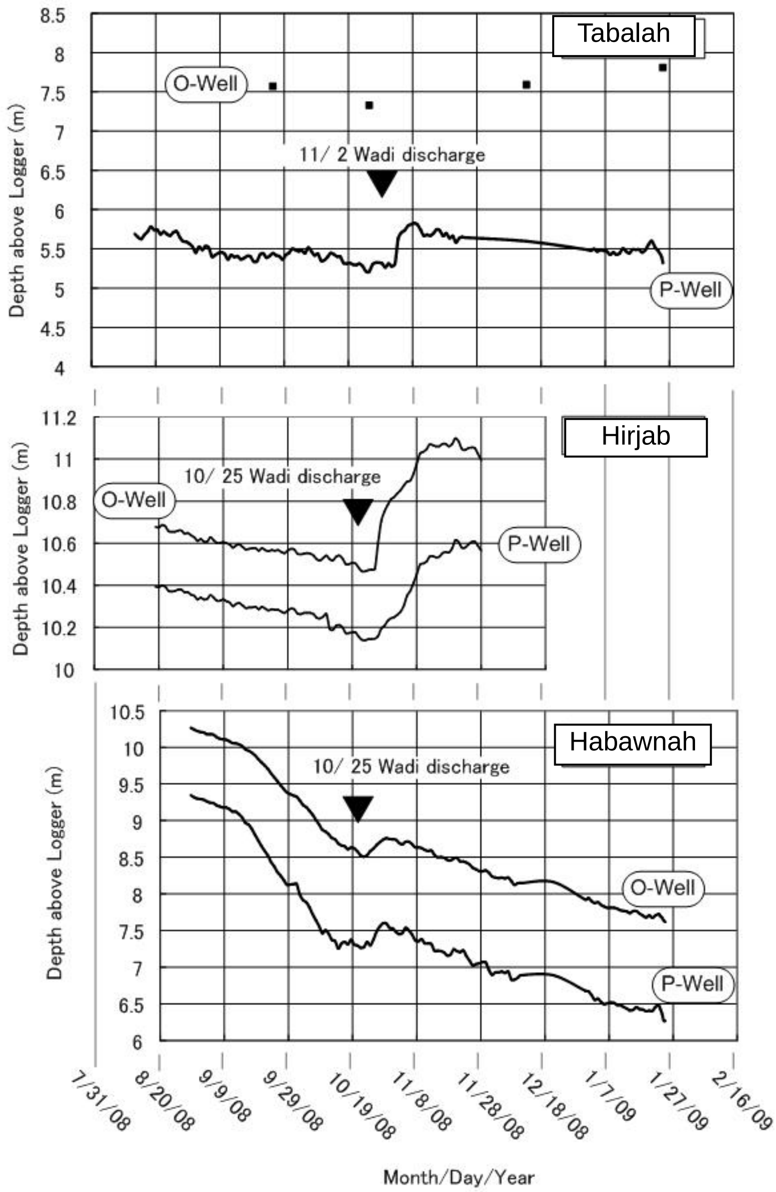


Figure 3-18 Groundwater Changes of Baseflow Stations

(3) Wadi Baseflow

Base Flow was estimated by Darcy law

Darcy law:

$$Q = k \times \Delta h \times A$$

- Q: Discharge of wadi base Flow
- k: Permeability
- Δh: Hydraulic gradient
- A: Section area (Sectional area for wadi aquifer)

Based on pumping test as referred in subsection 3.5.2, the value of permeability (k) is 8×10^{-3} cm/sec. As well, Δh (hydraulic gradient) is taken from the slope of observed groundwater level, which is dividing the difference of groundwater level between Ob-well and P-well by their distance. Furthermore, A (sectional area for wadi aquifer) is red from H-A curve which is plotted the depth to area of aquifer resulted in geophysical survey as shown in Figure 3-19. Using values of k, Δh and A, the daily baseflow is calculated. In Figure 3-20, the daily discharge values of Hirjab and Habawnah site and monthly value of Tabalah site are shown.

< Hirjab Site>
In Hirjab site, the baseflow do not observe before 25 Oct. 2008 in the observation record. After rainfall on 25 Oct the groundwater recharge abruptly take place in the wadi, and the groundwater flow begins. Even though, flow amount do not exceed 20 m^3/day.

<Tabalah Site>
In Tabalah site, because of high pumpage from the existing wells nearby, the flowing rate do not exceed 350 m^3/day. After wet day of 1st to 2nd Nov 2008, the amount of baseflow increases to 430 m^3/day. However, its rate decreases again to 300 - 350 m^3/day as same level of being before rainfall within two (2) months.

＜Habawnah Site>
Habawnah site behaves in the different way from other two sites. The interference from rainfall on 25 Oct is not observed. Even though, baseflow increases from September. Since the area of Habawnah basin is large as 2,600 km^2 and its basin border extends to the highland peak of Hijaz mountains, the August rainfall in the mountain area may affect the increment of baseflow. However, the rate does not exceed 300 to 350 m^3/day.

Rate of base flow of three wadis is low during the survey. Its relationship to rainfall is however high and quick. It means a permeable condition of wadis has enough potential to recharge groundwater in to wadi bed when flood is caused.

The size of aquifer and its rechargeable area may act as limited factor. If the maximum rainfall, permeability and aquifer size are taken into account for a same size of mountain wadi, the available amount of baseflow is estimated to be 2,000 to 6,000 m^3/day.

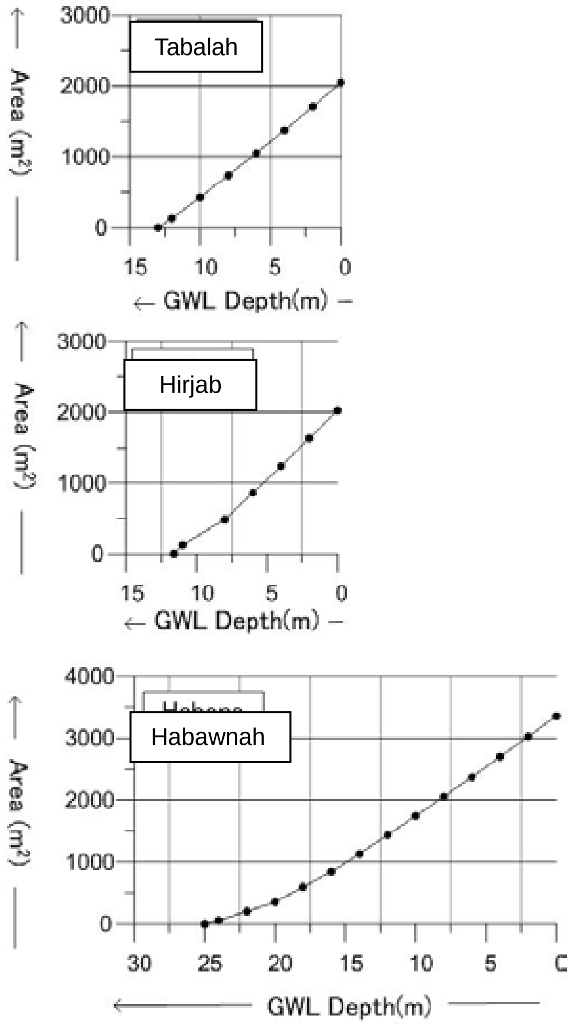


Figure 3-19 Cross Section of Wajid Aquifer H-A Curve