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
(ADDITIONAL STUDY RESULTS GROUNDWATER SIMULATION TOR FOR FEASIBILITY STUDY)

OCTOBER 2010

JAPAN INTERNATIONAL COOPERATION AGENCY

YACHIYO ENGINEERING CO., LTD.

SANYU CONSULTANTS INC.

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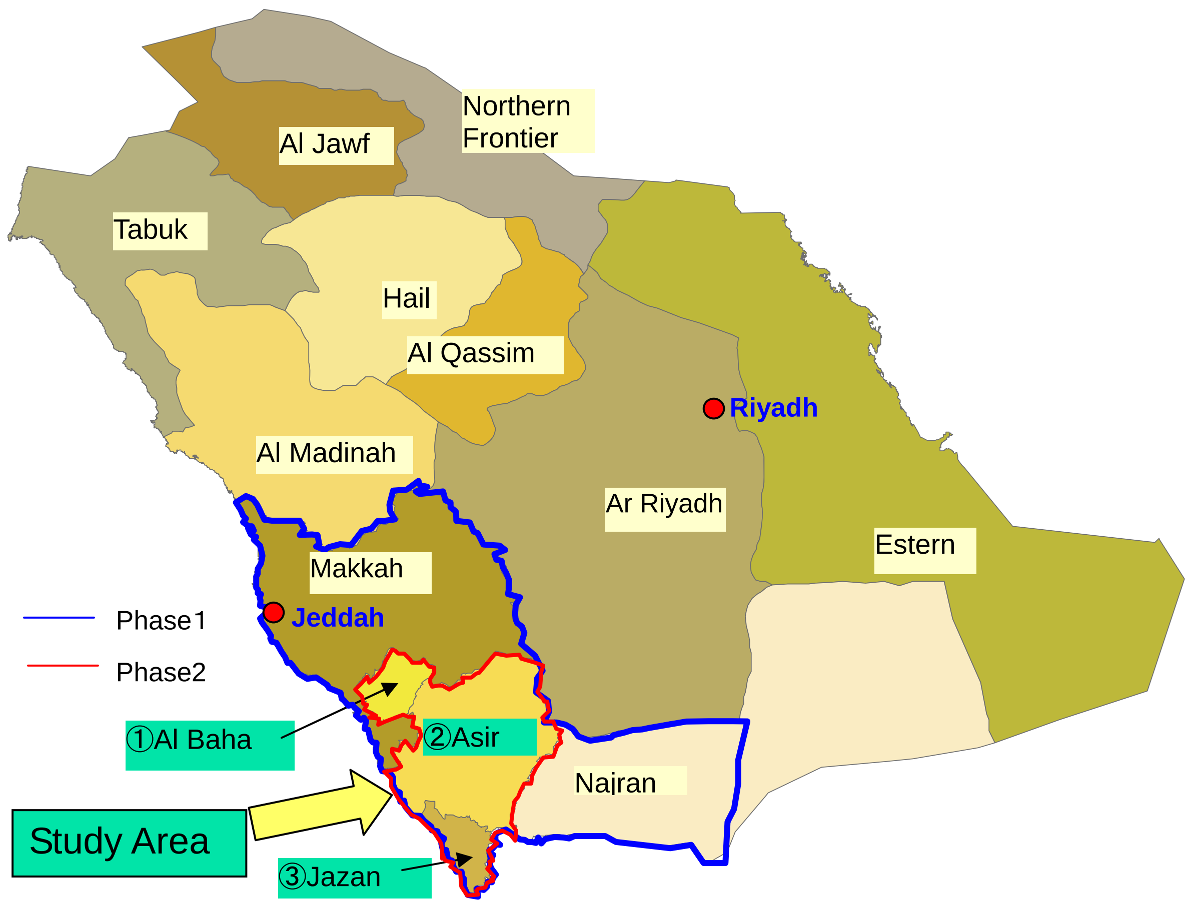
Foreign Exchange Rate

1.00 US Dollar=3.74 Saudi Arabia Riyal=¥89.0

(WEB：1st March, 2010 US Dollar/Saudi Arabia Riyal)

The Kingdom of Saudi Arabia Location of Map



Final Report
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Groundwater simulation)

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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 億立法メーター
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	التبخر	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
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
MOAW	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 万立法メーター
M/M	Minutes of Meeting	ملخص الاجتماع	会議の議事録
MMW	Million Megawatt	مليون ميغاوات	100 万ワット
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 Cooperation	التعاون الوطني للمياه	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
NCWCD	National Commission for Wildlife Conservation and Development	اللجنة الوطنية لحماية و تطويرالحياة البرية	国立動物保護開発協会
NIA	National Irrigation Authority	السلطة الوطنية للري	国家灌漑局

Abbreviation and Acronym	English	Arabic (عربي)	Japanese (日本語)
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 عملية	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	نطاق الأشغال	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 مسجلة	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	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

CHAPTER 1 INTRODUCTION

The surface water and groundwater coupled flow simulation to assess the water resources development plans have been performed as a part of the preliminary studies on the sustainable water resources management in Jazan. The combination of dam and aquifer is considered as the promising reservoirs of available water resources. The expected usage of that is to storage the precipitation and recharge the outflow water from dam to aquifers.

Figure 1-1 shows the concept of such water resources development plan. The essential feature of this idea is to control the natural water flow to reduce the short-term water loss by runoff or evaporation. That is synchronizing the available water resources for drinking or irrigation use by combined usage of dam, Wadi network and aquifers.

Modeling the following features on reservoir characterization is likely to be crucial in this study.

- Direct representation of topographical relief, hydrogeological structures
- Saturated/Unsaturated groundwater flow in vadose zone
- Interaction of freshwater and saltwater
- Interaction of surface water and subsurface fluids(Water infiltration, discharge/spring)
- Production wells for groundwater resources
- Dam construction, water inflow and outflow
- Distributed meteorological forces (precipitation, evapotranspiration, solar radiation, etc)

In order to take into account these features our simulations, it is necessary to trace the terrestrial water flow in 3D model including the interaction between surface water and groundwater flow. The Study Team have employed the general purpose terrestrial fluid-flow simulator named GETFLOWS and have discussed its applicability to the water resources management through the preliminary simulations.

The Study Team selected Jazan basin which is located in south area of Saudi Arabia as a study field and has conducted the demonstration runs by the 3D numerical model based on the existing available information on meteorology, topography, geology and so on. These demonstrations provided us the preliminary evaluation on the development of the available water resources. Furthermore, it has reproduced that the enforced recharge water can be effective to improve the groundwater depletion and seawater intrusion caused by withdrawing in the coastal area.

Moreover, the Study Team has discussed the applicability of the water resources development plans which doesn't induce the irreversible groundwater failure for the various water environments.

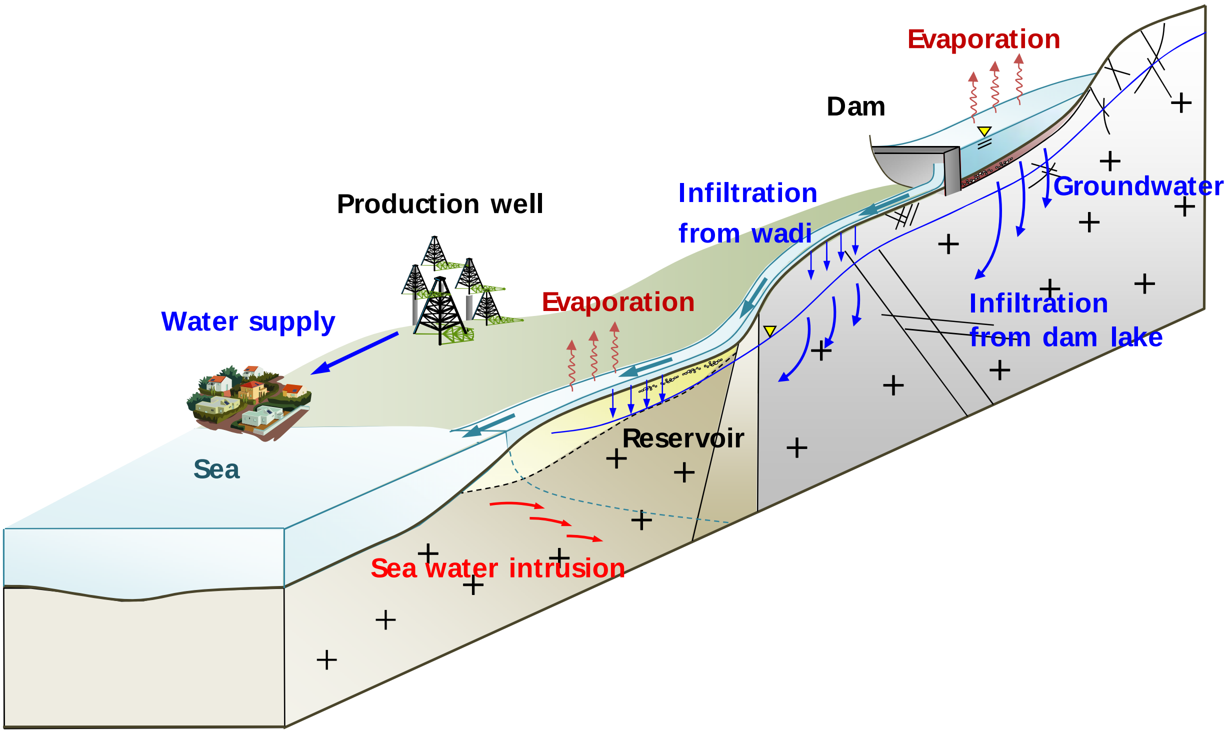


Figure 1-1 Schematic view of water resources development by the combination of dams and aquifers

CHAPTER 2 GENERAL PURPOSE TERRESTRIAL FLUID-FLOW SIMULATOR: GETFLOWS

2.1 Brief Overview of GETFLOWS Simulator

The characteristic feature of GETFLOWS simulator is to formulate the terrestrial water circulation system as the multi-phase and multi-component fluid system and to simulate the fully-coupled surface water and subsurface fluids. The GETFLOWS simulator can synthesize the various interactions between surface and subsurface environment, which includes solute, heat and sediment transport. Such nature based modeling helps us to interpret and predict the feature of the water environment beyond our imaginations.

Figure 2-1 shows the conceptual model of the water circulation system in GETFLOWS from water source to mouth. GETFLOWS makes it possible to simulate the terrestrial fluid-flow in geosphere for the various types of water related problems such as groundwater flow, runoff, flood/inundation, surface water and subsurface fluid coupled flow, contaminant transport and heat transport.

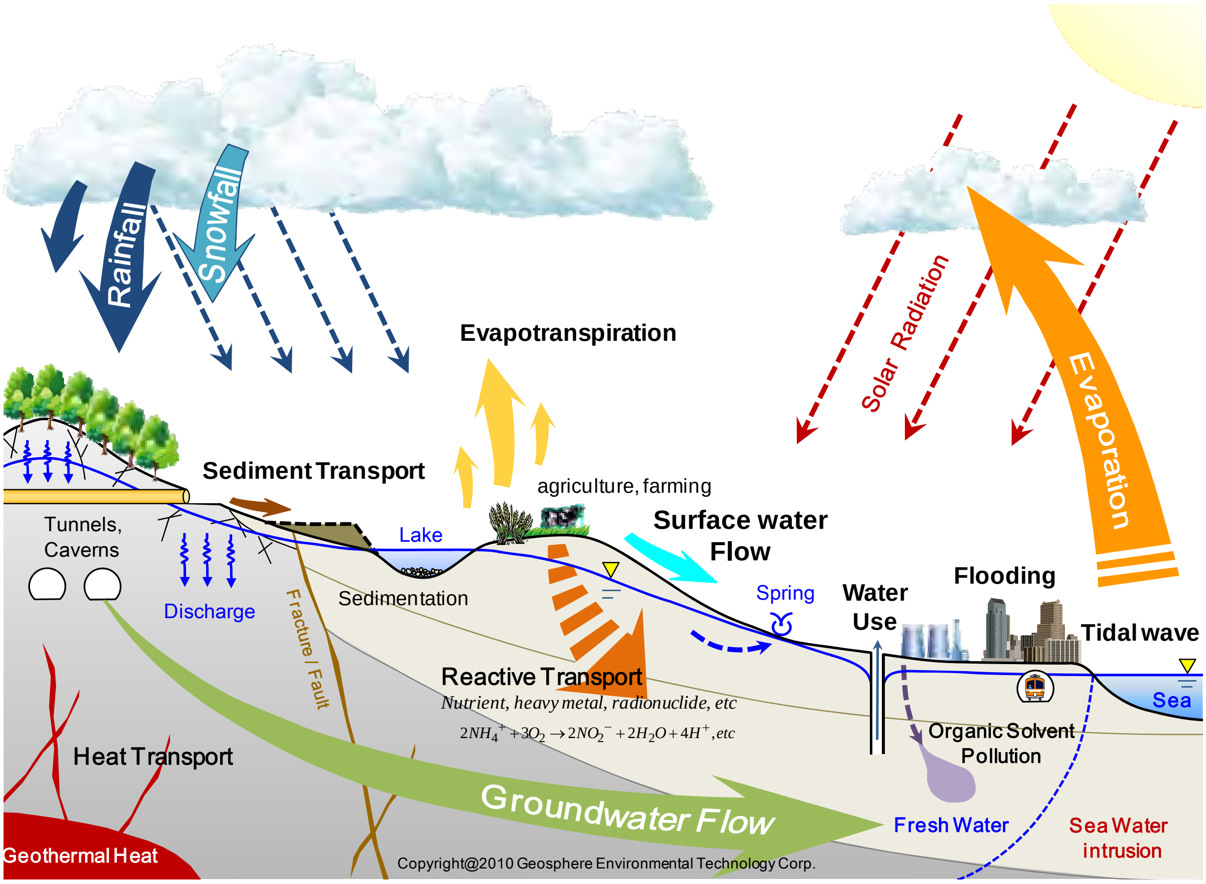


Figure 2-1 Conceptual model of terrestrial fluid-flow in GETFLOWS

2.2 Features

- Three dimensional corner-pointed finite difference simulator
- Isothermal, non-isothermal multiphase and multi-component fluid flow (water, gas, miscible and immiscible liquid etc.)
- Fully-coupled surface water and subsurface fluid
- Distributed, dynamic land surface conditions(land use, air temperature, precipitation, water body, man-made structures)
- Directional permeability (heterogeneity)
- Stress-dependent soil/rock properties
- Upstream weighted fully-implicit Newton-Raphson scheme with Successive Locking

Process(SLP) for the strong nonlinearity of fluids

- Fast and robust matrix solver by preconditioned conjugate residual (PCR) algorithm
- Domain decomposition on parallel computers

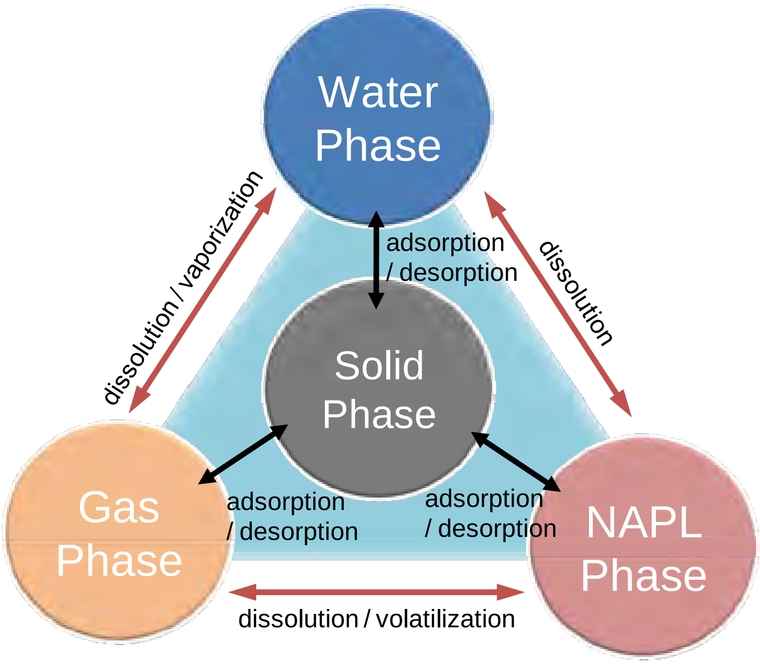


Figure 2-2 Fluids and solid phase system in geosphere

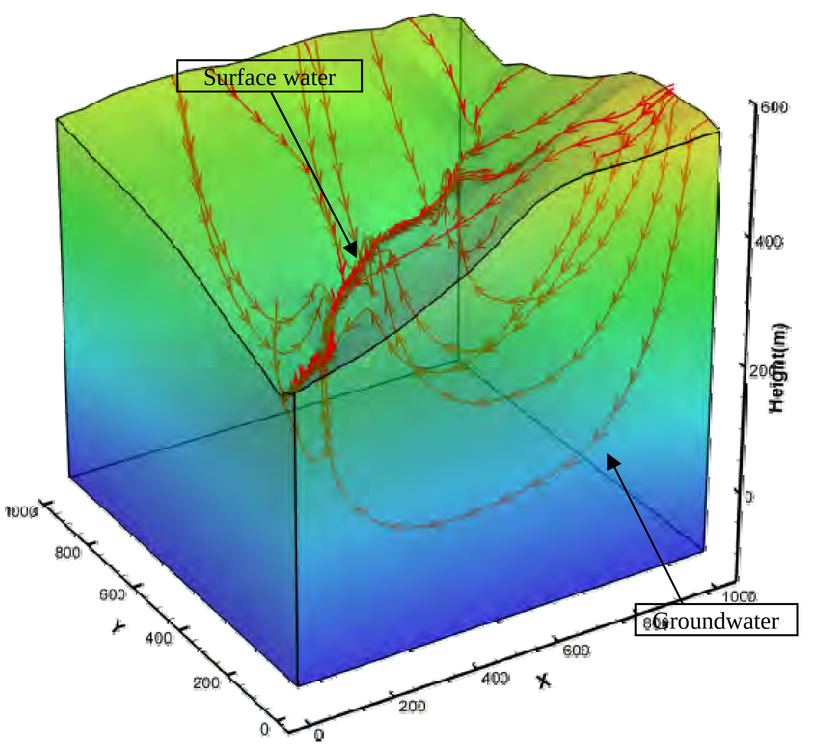


Figure 2-3 An example of simulated SW and GW coupled flow

CHAPTER 3 PROTOTYPING OF 3D WATERSHED MODEL IN JAZAN

3.1 Study Field

The whole area of Wadi Baysh basin including mountainous, coastal plain and sea area was selected as the study field. The Study Team has successfully developed a 3D numerical model to simulate the terrestrial water flow with the precipitation, evapotranspiration, runoff, subsurface fluid movement and these interactions.

Figure 3-1 shows the study field. The area is approximately 18,000km^2 which has 150km distance in the NS direction and 120km distance in the EW direction. Sea area (approximately 40km distance from coast line) has been included in this area in order to take under consideration the seawater and freshwater interaction in the coastal plan area. Topographical relief in study area is comprised of the high altitude area in upstream area and the complex fan area in coastal plain area. The range of the grand slope in coastal area is approximately 1/400 to 1/200. Baysh Dam is located in upstream valley of Wadi Baysh which has much water than other basins. In addition a road distance of 113 km to the Jizan city.

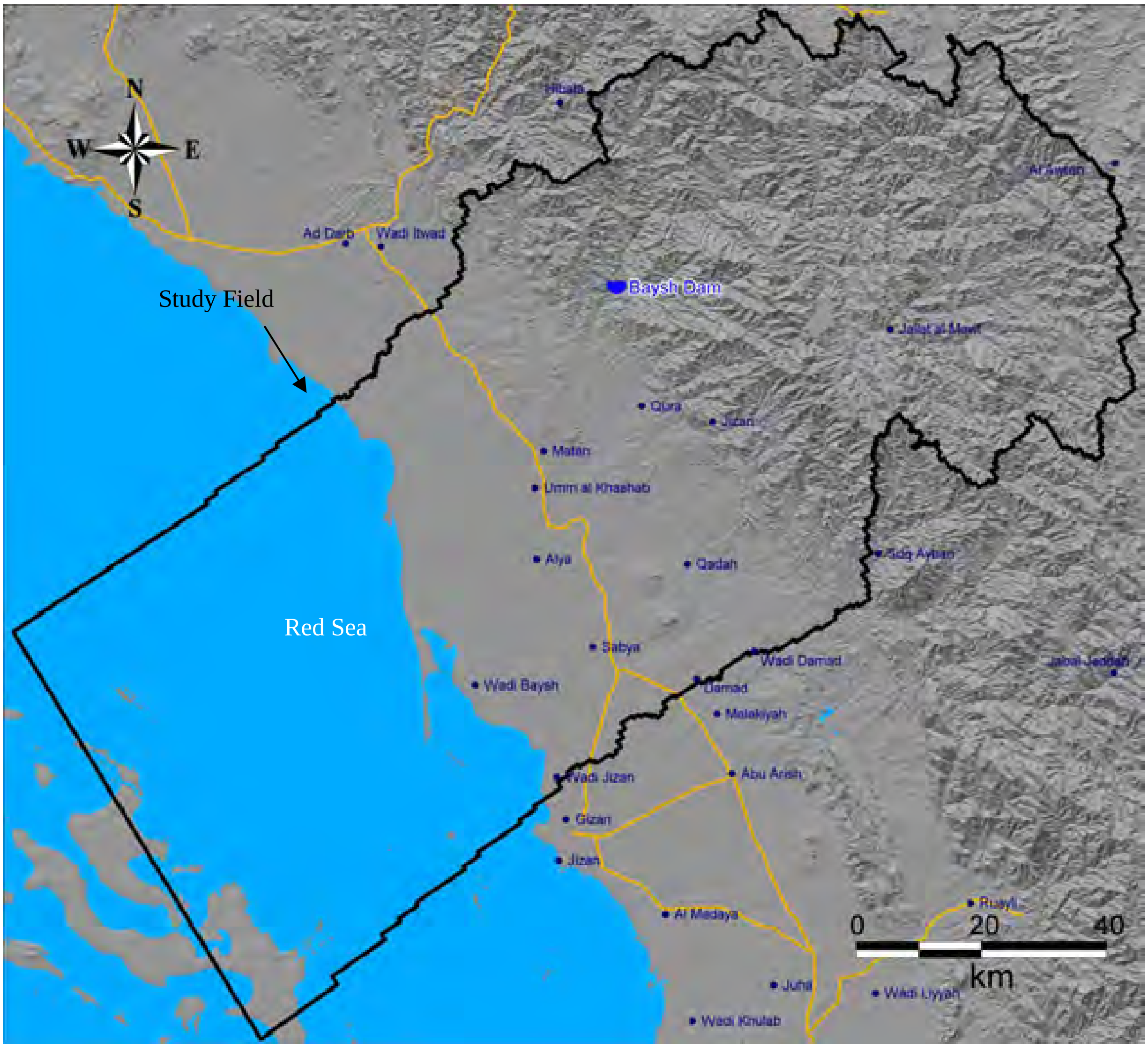


Figure 3-1 Study area for Watershed Modeling

3.2 Available Information

The numerical modeling is implemented based on the existing site investigation data and widely published information. Table 3-1 shows the available information and its source for this work.

The SRTM90 (Shuttle Radar Topography Mission) data published by NASA was used as the Digital Elevation Model (DEM) in land area. And ETOPO1 which involves bathymetry data in the sea area from NOAA (National Oceanic and Atmospheric Administration) was combined to the SRTM 90.

The observed precipitation data during 1968 to 2004 which has been stored in the MOWE database is summarized in the 2009 JICA report. It indicates that the annual average precipitation in the south region of study area is over 400mm, although there is no observation around the upstream of Baysh Dam basin. Figure 3-2 shows the observation points in study area and its daily precipitation data during from April to September in 2007. The Study Team systematically found that the spatial distribution and temporal variations of this precipitation are inhomogeneous.

Air temperature data is used to estimate the potential evapotranspiration. The monthly average temperature data in Gizan, which is published in the general weather forecast, was applied to representative the data of study area (see Figure 3-3).

The surface geology map was used from the USGS geoscience data catalog (see Figure 3-4). Shallow aquifers are mainly comprised of the quaternary in coastal area and the pre-cambrian sediment in the east part of upstream area. The outcrop of the tertiary, cretaceous and permian sediment can be seen in midstream area which is the junctional region of high attitude and coastal plain.

Although the detail structure of hydrogeology in study area is still uncertain, the following feature has been clarified.

- The thickness of aquifers in the valley of the east area is 10m approximately. It reaches almost 100m around the junctioanl region of the valley and coastal plain area.
- The alluvium is comprised of clay, silt, sand and gravel deposit which has various grain sizes. Particularly river sediment along wadis is comprised of the coarse-grained deposit and these are expected to be a good reservoir.
- These aquifers are almost confined due to the interbedded silt and clay layer which exists in them.

The land cover data is used from GLCNMO (The Global Land Cover, National Mapping Organizations). Which processes spatial resolution of 1km (30 arc seconds) (see Figure 3-5). The study area is mostly bare. The sparse vegetation area can be seen in the south region. In the eastern upstream area, the shrub, cropland and other vegetation mosaic can be also seen clearly.

Table 3-1 Available Information and Sources

Items		Available Information and Sources
Topography	Land area	SRTM 90 Digital Elevation Data (Spatial resolution 90m) http://srtm.csi.cgiar.org/
	Sea area	ETOPO1 Global Relief Model (Spatial resolution 1 minutes) http://www.ngdc.noaa.gov/mgg/global/global.html
Meteorology	Precipitation	MOWE database Japan international cooperation agency, et al: The study on master plan on renewable water resources development in the southwest region in the Kingdom of Saudi Arabia, Draft final report, May 2010
	Air temperature	Monthly averaged temperature at Gizan (WeatherBase, http://www.weatherbase.com)
Geology		USGS Geoscience Data Catalog http://geo-nsdi.er.usgs.gov/metadata/open-file/97-470/b/geo2a.faq.html Japan international cooperation agency, et al: The study on master plan on renewable water resources development in the southwest region in the Kingdom of Saudi Arabia, Draft final report, May 2010
Land cover		The Global Land Cover, National Mapping Organizations (GLCNMO), http://www.iscgm.org
Satellite image		Landsat, Global Land Cover Facility Earth Science Data Interface (ESDI), http://glcfapp.glcf.umd.edu:8080/esdi/index.jsp

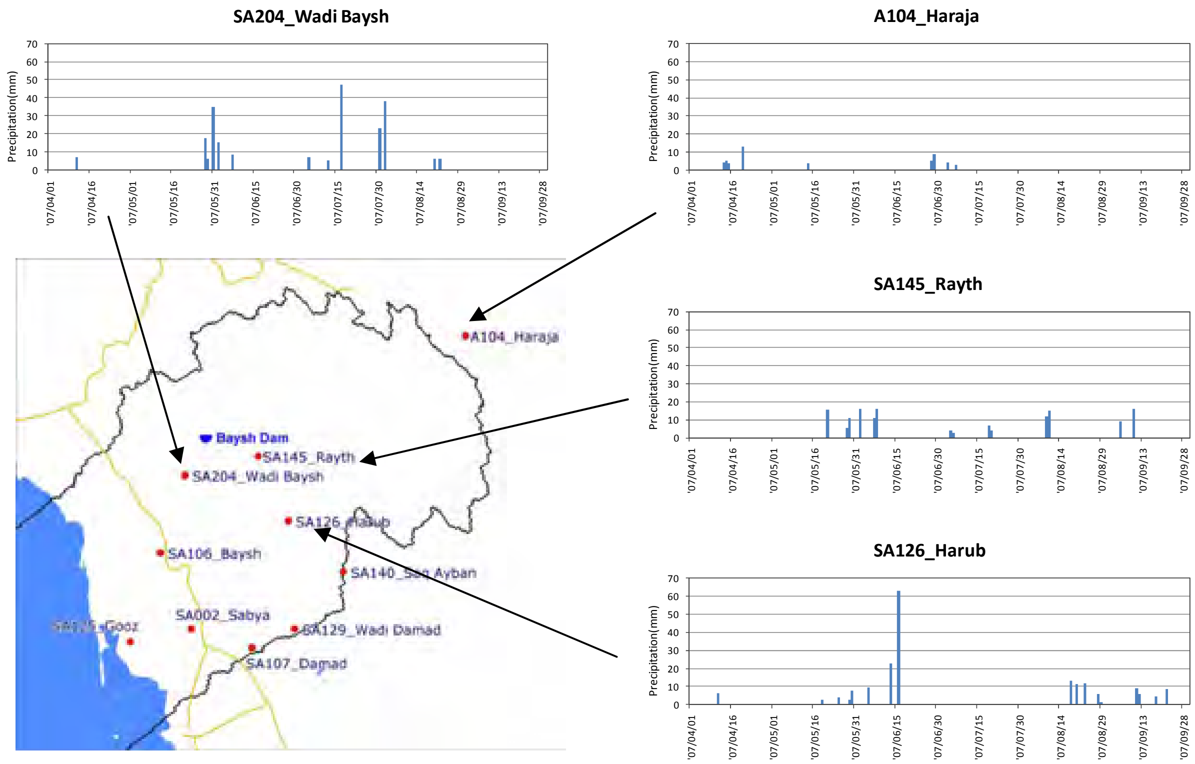


Figure 3-2 Examples of Daily Precipitation in 2007 (MOWE database)

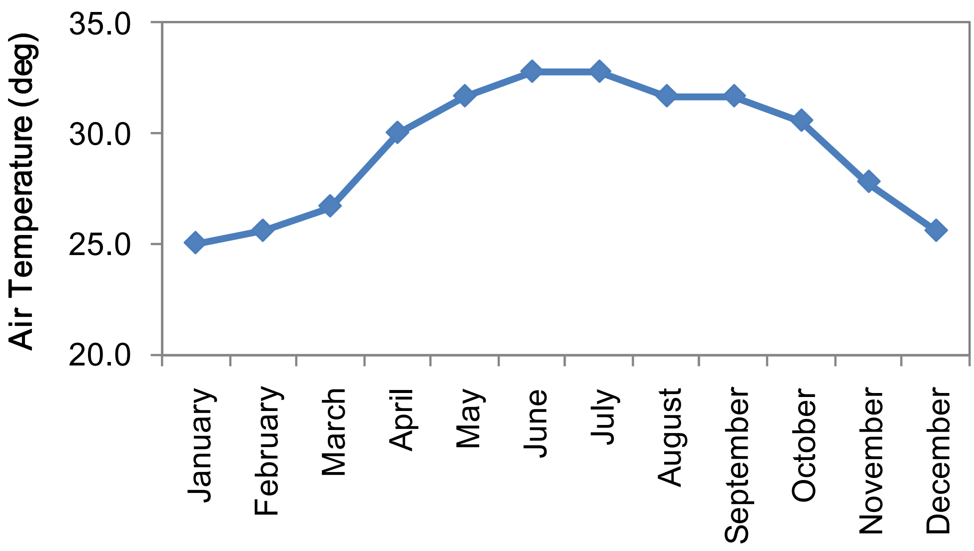
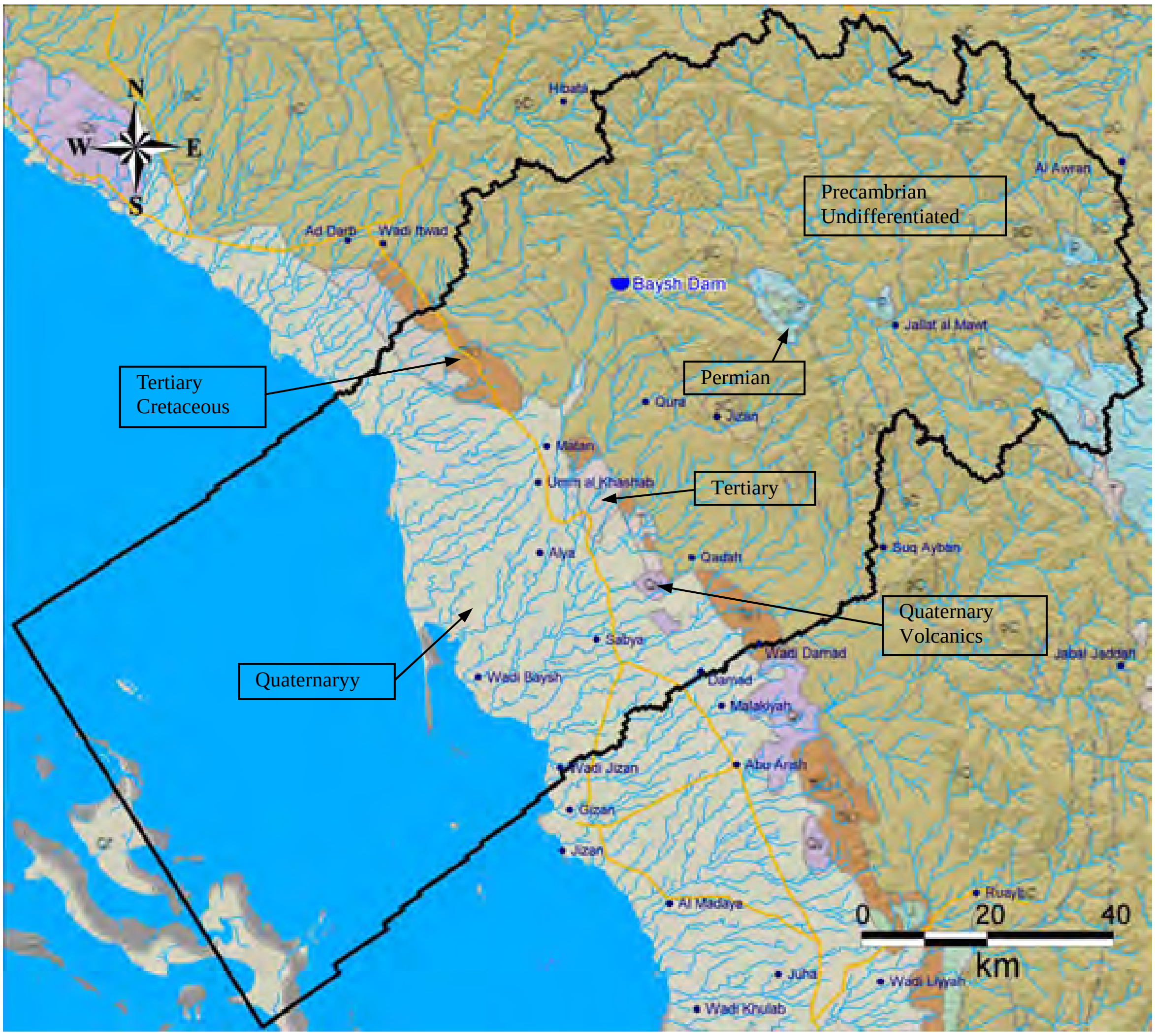


Figure 3-3 Monthly Average Air Temperature (Gizan, Elevation 5m, 16 54N/042 30E)



http://certmapper.cr.usgs.gov/arcgis/rest/services/geology/arabian/MapServer

Figure 3-4 Surface Geology (USGS Open File Report 97470b)

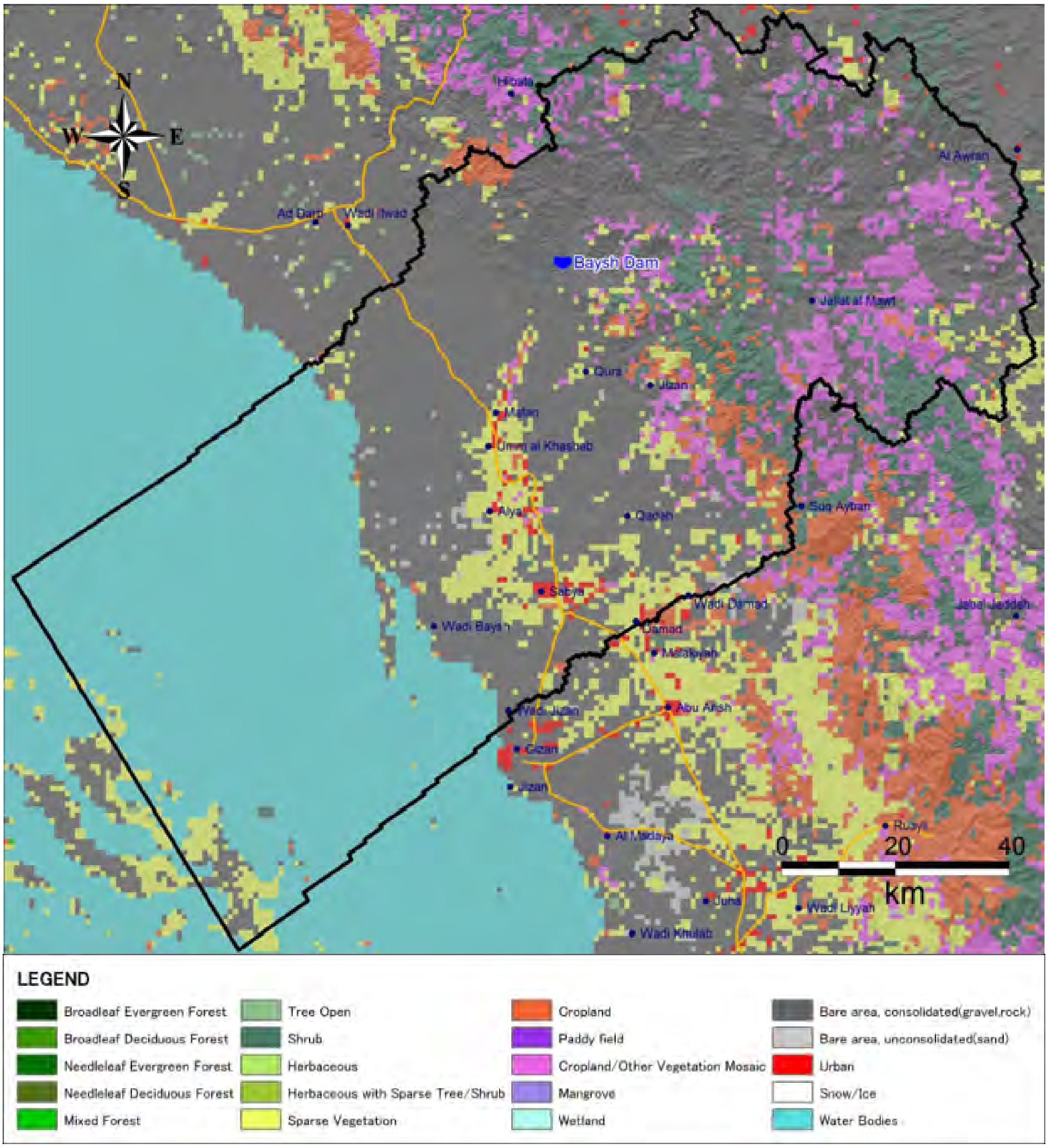


Figure 3-5 1km(30 arc second)-mesh Land Covers (The Global Land Cover by National Mapping Organizations, GLCNMO)

3.3 Development of the 3D Grid-block System

The Study Team has discretized the study area spatially by plygones (grid-blocks in the 2D plane) which has the particulary finer resolution in coastal plain area. Other area was discretized by the sightly rough resolution.

Figure 3-7 shows the discretized 2D grid-block system. The size of each grid-block is approximately 10m and 50m in such fine and corase region, respectively. Since the spatial resolution of SRTM90 is 90m, the continuoues elevation data was generated by the spatial interporation data processing. The processed secondary data were assighned into the corner-point cordinate. Then the 2D plain grid-block system is enlarged into depth direction and discretized again along Z axis to generate the 3D grid-block system. Figure 3-8 shows the 3D grid-block system. Figure 3-8(a) shows the bird's eye view of the interpolated continuous DEM as mentioned above. Figure 3-8(b) is discretization of that by the corner-pointed hexahedral gird-blocks. The bottom elevation of the 3D grid-block system is

-3,000m and discretized finely near the ground surface. The heights of grid-block increase gradually with depth.

In GETFLOWS, the top layer of grid-block system is called atmospheric layer and the second layer is the surface layer. Usually the atmospheric layer has huge capacity and maintained standard pressure condition. The distributed precipitation condition is assigned into the surface layer. The surface water flow is represented in this layer. The interaction of surface water and groundwater such as infiltration and groundwater discharge is simulated as the water flux between surface layer and the next third layer.

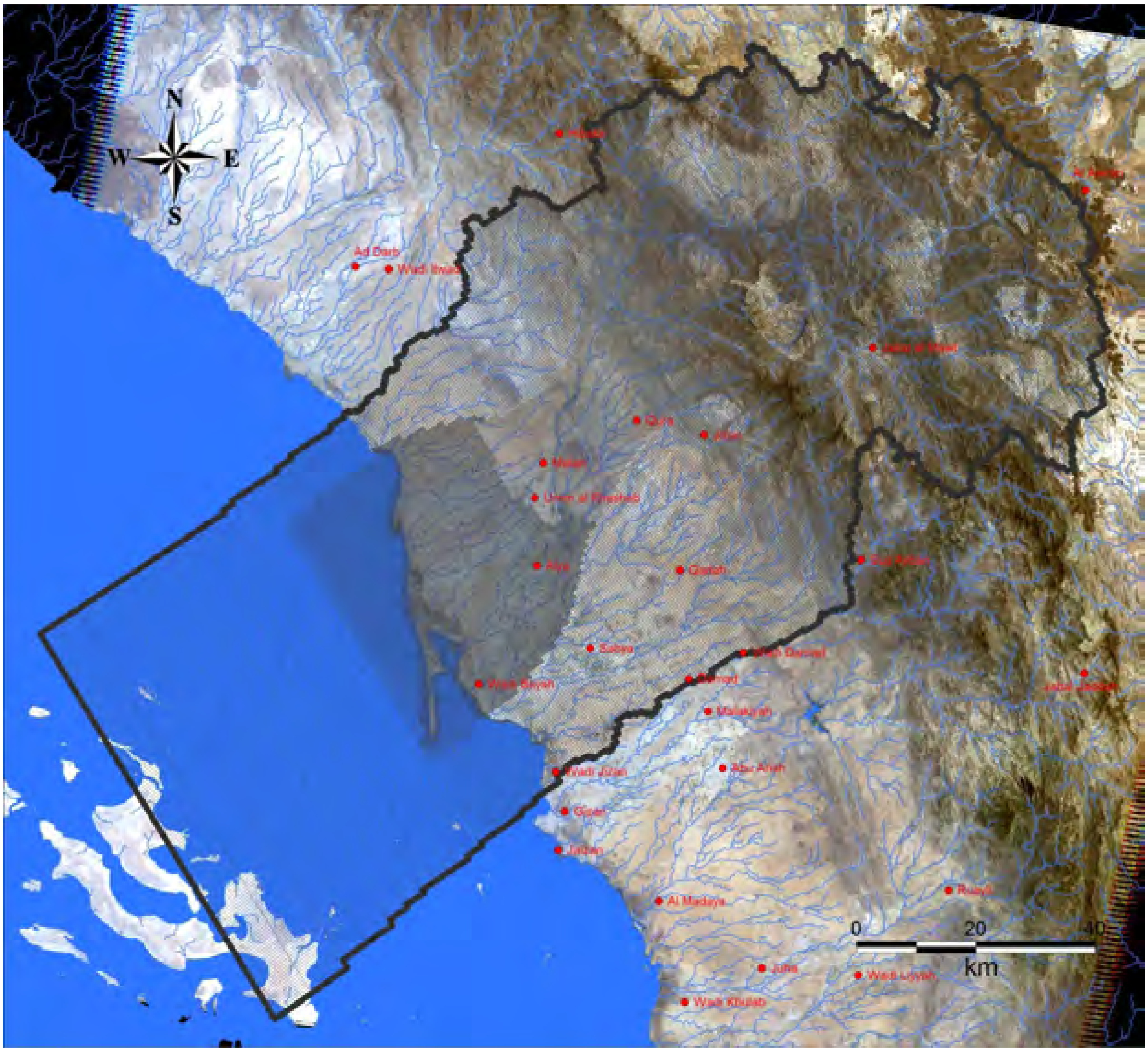


Figure 3-6 Discretized Grid-block in 2D Plane (1)

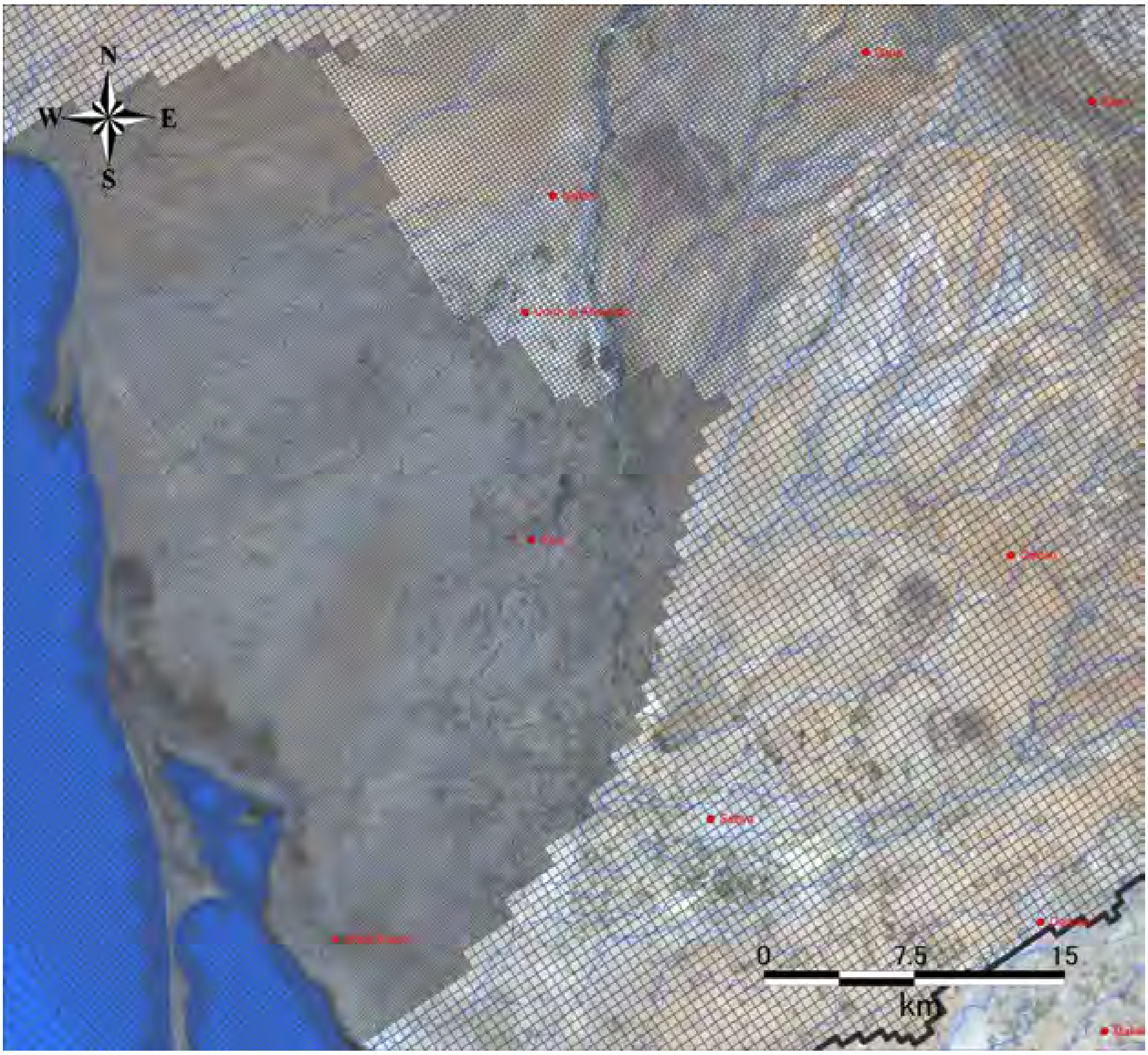
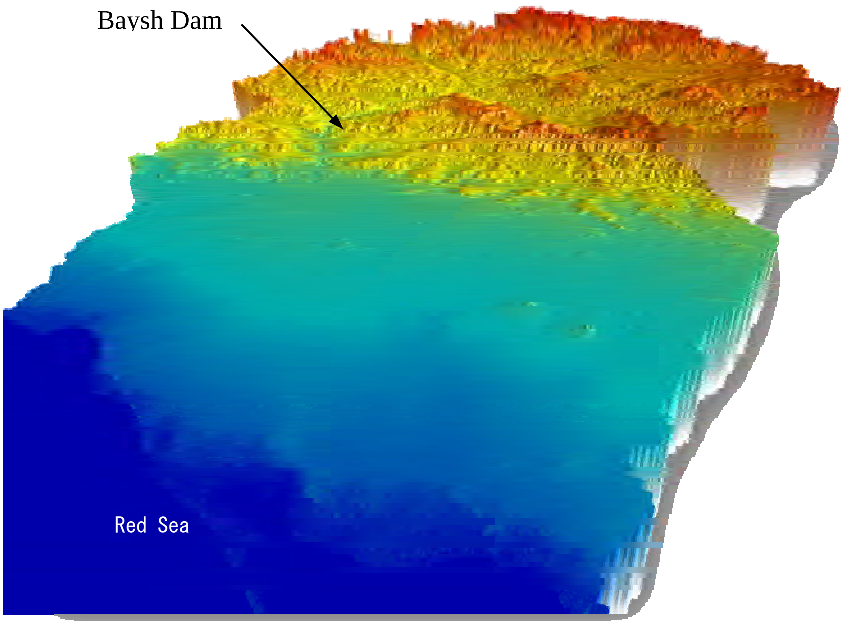


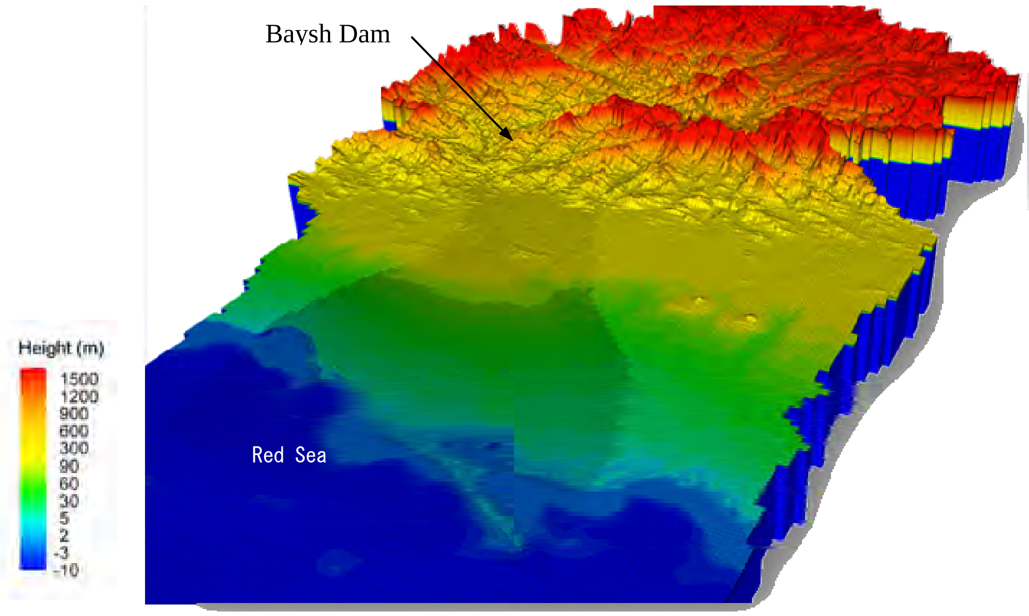
Figure 3-7 Discretized Grid-block in 2D Plane (2)

Figure 3-9 shows the 3D hydrogeological structure which was assigned to grid-block system. As mentioned before, the thickness of aquifers, which become variables depending on the area, is incorporated into the model.

Figure 3-10 shows the grid-blocks and assignment of geology of a certain vertical section.



(a) Digital Elevation Model(DEM) by SRTM90



(b) 3D Grid-block system (Total number of grid-blocks are 313,880)

Figure 3-8 Bird's Eye View of Digital Elevation Model (DEM) and grid-block system of study field

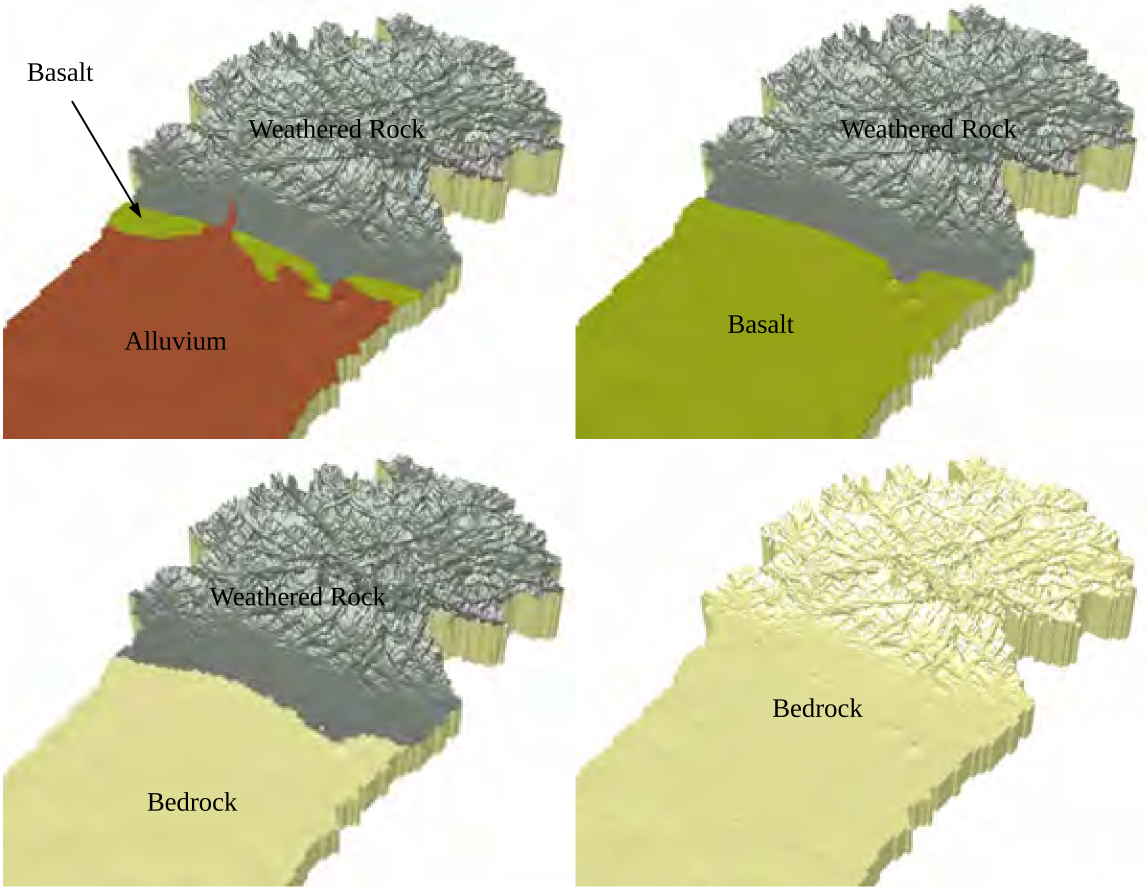


Figure 3-9 Assignment of 3D Hydrogeological Structure to Grid-blocks

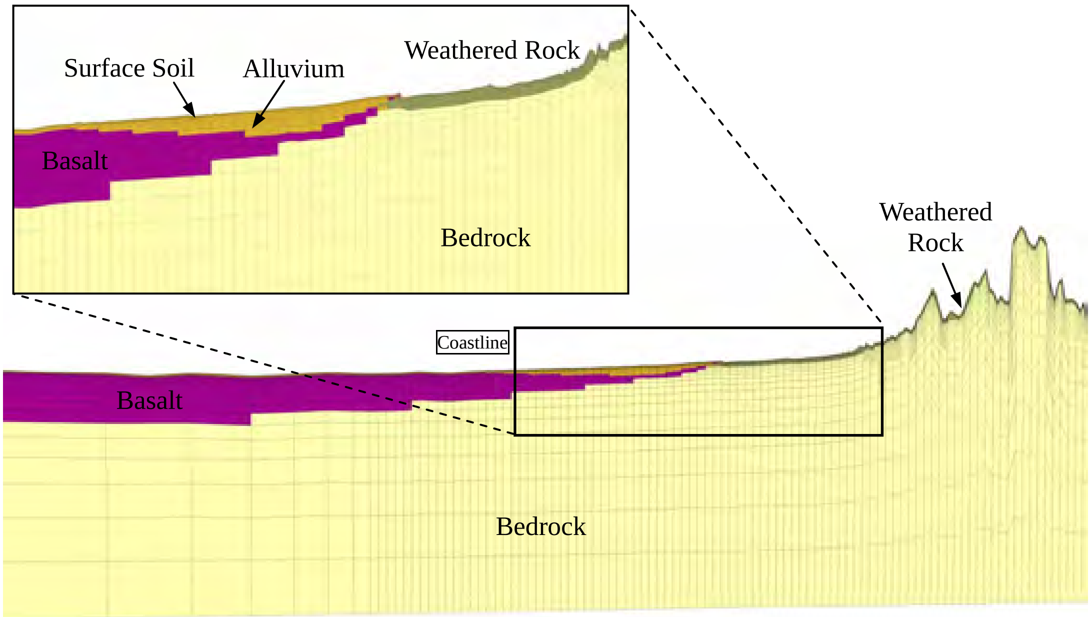


Figure 3-10 A Vertical Section of Grid-blocks and Geology Assignment

3.4 Reproduction Simulations of Terrestrial Water Flow Field

3.4.1 Governing Equations of Air-Water-Brine Fluid-Flow

The Study Team considered the objective fluids system as the water and air 2-phase flow in both surface and subsurface environment. The governing equations of this in isothermal flow condition are described by the following mathematical forms which are derived from the mass balance equation and the generalized Darcy's Law.

$$\nabla\left(\frac{Kkr_w}{\mu_w B_w}\nabla\Psi_w\right) - q_{wS} = \frac{\partial}{\partial t}\left(\phi\frac{S_w}{B_w}\right)$$

$$\nabla\left(\frac{Kkr_g}{\mu_g B_g}\nabla\Psi_g\right) - q_{gS} = \frac{\partial}{\partial t}\left(\phi\frac{S_g}{B_g}\right)$$

Where, K is the absolute permeability (m^2), k_{rp} is the relative permeability (-), Ψ_p is the fluid potential (Pa), μ_p is the viscosity coefficient ($Pa \cdot s$), B_p is the formation volume factor (m^3/m^3), ϕ is the effective porosity (-), S_p is the saturation (-), は q_{pS} is the production and injection rate of fluids per unit volume in standard condition ($m^3/m^3/s$). The subscript p indicates the quantities on each fluid phase. The diffusion wave approximation is introduced for the surface water flow and the governing equations can be expressed by the identical forms.

The brine transport model in water phase (advection-dispersion equation) is used to compute the saltwater and freshwater interaction which takes place around the coastal area.

$$\nabla\left(\frac{Kkr_w R_s}{\mu_w B_w}\nabla\Psi_{cw}\right) + \nabla\left(D_s\nabla\frac{R_s}{\alpha_{cw}}\right) - q_{cS} = \frac{\partial}{\partial t}\left(\phi\frac{S_w R_s}{B_w}\right)$$

Where, R_s is the volumetric concentration of brine in water phase (m^3/m^3), D_s is the hydrodynamic dispersion coefficient (m^2/s), q_{cS} is the production and injection rate of brine per unit volume in standard condition ($m^3/m^3/s$).

These equations can be solved to maintain the local and global material balance exactly. The primary variables in each grid-block are pressure, saturation and brine concentration. The fluid properties (viscosity, formation volume factor and so on) are pressure dependent and soil and rock properties (relative permeability, capillary pressure and so on) become nonlinear function with saturation. To deal with such strong nonlinearity, The Study Team has employed the method of Newton-Raphson iteration scheme.

3.4.2 Simulation Method

The representative background flow field, which is used as the initial condition for the post prediction runs, has been reproduced firstly. The Study Team simulates the equilibrium flow field by time transient analysis from the fully saturated condition by the seawater. The average precipitation data (freshwater) are continuously forced to the model in this analysis. During the computation, the seawater in subsurface is replaced by the freshwater with time. The groundwater level decrease gradually and water discharge takes place around the lower portion. Finally the equilibrium flow field which balances with the given conditions can be reproduced. It can be considered that this initialization process corresponds to the long-term simulation to reproduce the uplift of seabed.

The simulated results, which are obtained by this initialization process, should be compared with the various observed data quantitatively to verify the reproducibility of the constructed model. However, the qualitative tendency of simulated results is particularly verified in this study due to its demonstrative objectives.

3.4.3 Analysis Conditions

(1) Precipitation and Evapotranspiration

The effective precipitation, which can be obtained by removing the evapotranspiration from the total precipitation, is used as the average precipitation for the initialization process. However, the annual precipitation of the study area is totally 200mm/y to 400mm/y. It is extremely small value comparing to the annual evapotranspiration which can be estimated by using air temperature and daylight hours. The estimated evapotranspiration by Harmon’s method is over 1,000mm/y. Initialization process of such dried area requires the long-term simulation with the historical climate change.

In this study, the Study Team assumed that the past effective average precipitation is 100mm/y due to the simplicity of the computation. The displacement of saltwater by precipitated freshwater is computed during a certain period by using such assumed precipitation. Secondly, the effective precipitation is reduced to 20mm/y. The latest value of effective precipitation is considered to be almost 0mm/y. These processes are tentatively corresponding to that of aridification.

(2) Fluids Properties

The fluid properties of water, air and brine is represented by the typical value in standard condition as shown in Table 3-2.

(3) Soil and Rock Properties

Since there are no measured data on hydraulic parameters of solid phase, the typical parameters which can be estimated from the geological reconnaissance and soil compositions have been introduced. Table 3-3 shows the summaries of the soil and rock properties. The permeability of outcrops of basalt, weathered rock and bedrock was considered to be small according to the information obtained from the field investigation.

(4) 2-Phase Flow Parameters

Capillary pressure and relative permeability, which describe the interaction between water and air, is required for the flow simulation. These 2-phase parameters often become important in the shallow aquifer which exist both water and air. These depend on the water content in pore space and are expressed as the nonlinear function of the water saturation. Although many experimental functions such as the Van-Genuchten or Brooks-Corey model are usually applied to the each aquifer, The Study Team have used the typical relationship as shown in Figure 3-11.

Table 3-2 Fluid Properties

Fluids	Surface water flow		Diffusion wave approximation
	Groundwater flow		Generalized Darcy’s flow
	Fluids system		Water, air and brine (2-phase 3-component)
	Water	Density	1.0 [g/cm^3]
		Viscosity	1.0×10^{-3} [Pa・s]
		Compressibility	0.45[GPa^{-1}]
	Air	Density	1.3×10^{-3} [g/cm^3]
		Viscosity	1.82×10^{-5} [Pa・s]
		Compressibility	Function of water saturation
Sea water	Density		1.0184[g/cm^3]
	Brine Concentration		0.0160[m^3/m^3]

Table 3-3 Soil and Rock Properties

Soil/Rock	Density		2.5[Mg/m^3]
	Compressibility		10[GPa^{-1}]
	Geology		Surface soil, Alluvium, Basalt, Weathered rock, Bedrock
	Absolute Permeability	Surface soil Alluvium Basalt Weathered rock Bedrock	5×10^{-2} [cm/s] (exists only the above of alluvium) 1×10^{-2} [cm/s] 1×10^{-5} [cm/s] 1×10^{-6} [cm/s] 1×10^{-6} [cm/s]
	Effective Porosity	Surface soil Alluvium	0.50 (exists only the above of alluvium) 0.15
		Basalt	0.10
		Weathered rock Bedrock	0.10 0.10
Land Use	Roughness Parameter		Water 0.035 [m$^{1/3}$s] Others 0.100 [m$^{1/3}$s]

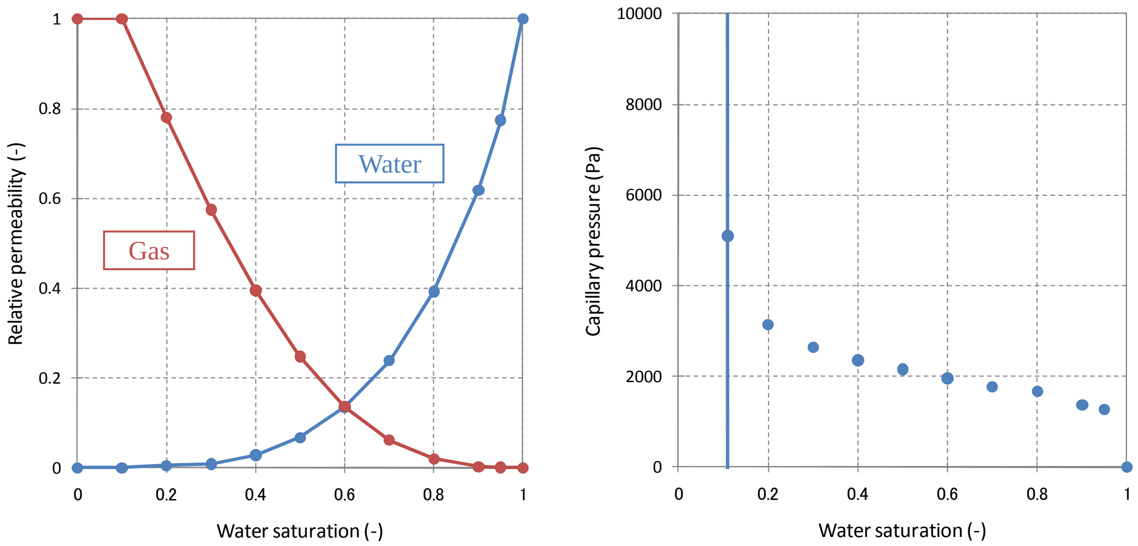


Figure 3-11 2-Phase flow Parameters (Relative Permeability and Capillary Pressure)

3.4.4 Results

The reproduced results on the background flow field are shown in Figure 3-13 to Figure 3-16.

(1) Groundwater Level

Figure 3-13 shows the contour maps of groundwater level in shallow and deep aquifer. The shallow groundwater level corresponds to the regional topography patterns. According to this contour map, it can be seen that the hydraulic gradient in coastal area is different from that of east area.

The hydraulic gradient around the coastal area, which is the western side of the road, is approximately 0.002 and the spatial distribution of that is almost consistent with the grand slope of complex fan deposit. On the other hand, the hydraulic gradient around the road is approximately 0.005.

The eastern side of this road has more gradual values. In deep aquifer, the spatial pattern of hydraulic gradient is consistent with the global-scaled topography features. The representative value is almost 0.003 and the regional different patterns as shown in shallow groundwater cannot be seen.

The groundwater velocity in the shallow aquifer estimated by the hydraulic gradient and permeability is in the range of 5 to 20m /y.

(2) Streamlines of Water Flow

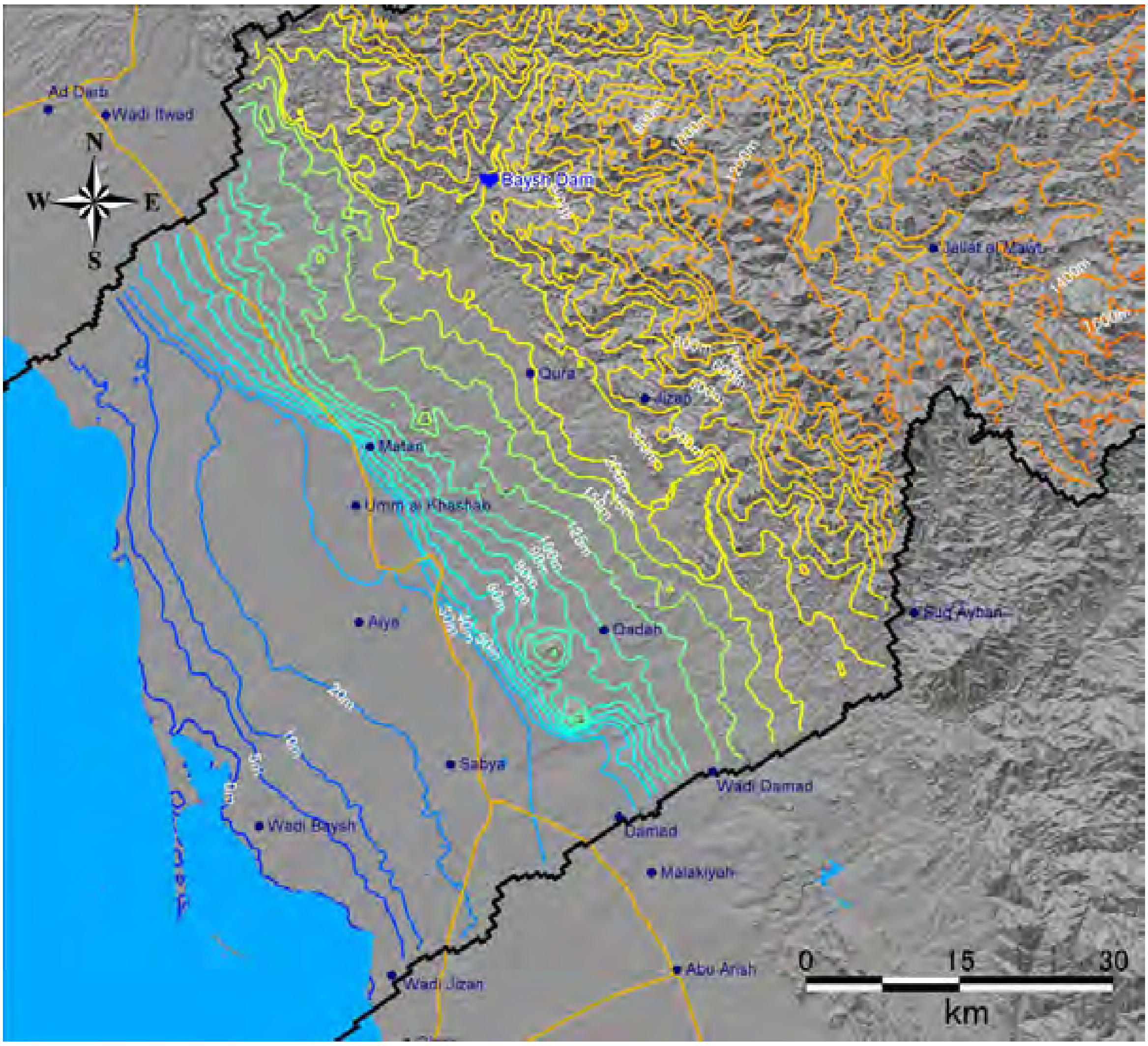
The particle tracking analysis was carried out using reproduced water velocity to extract the 3D trajectories of water flow. Figure 3-14 shows the projected streamlines in the 2D plane. It can be seen that the groundwater flow pattern in coastal plain corresponds to the topographic features.

The streamlines which indicates seawater intrusion can be recognized around the coast line. The infiltrated groundwater flows in the eastern inland area forms the interface of seawater and freshwater in the coastal area.

(3) Brine Concentration

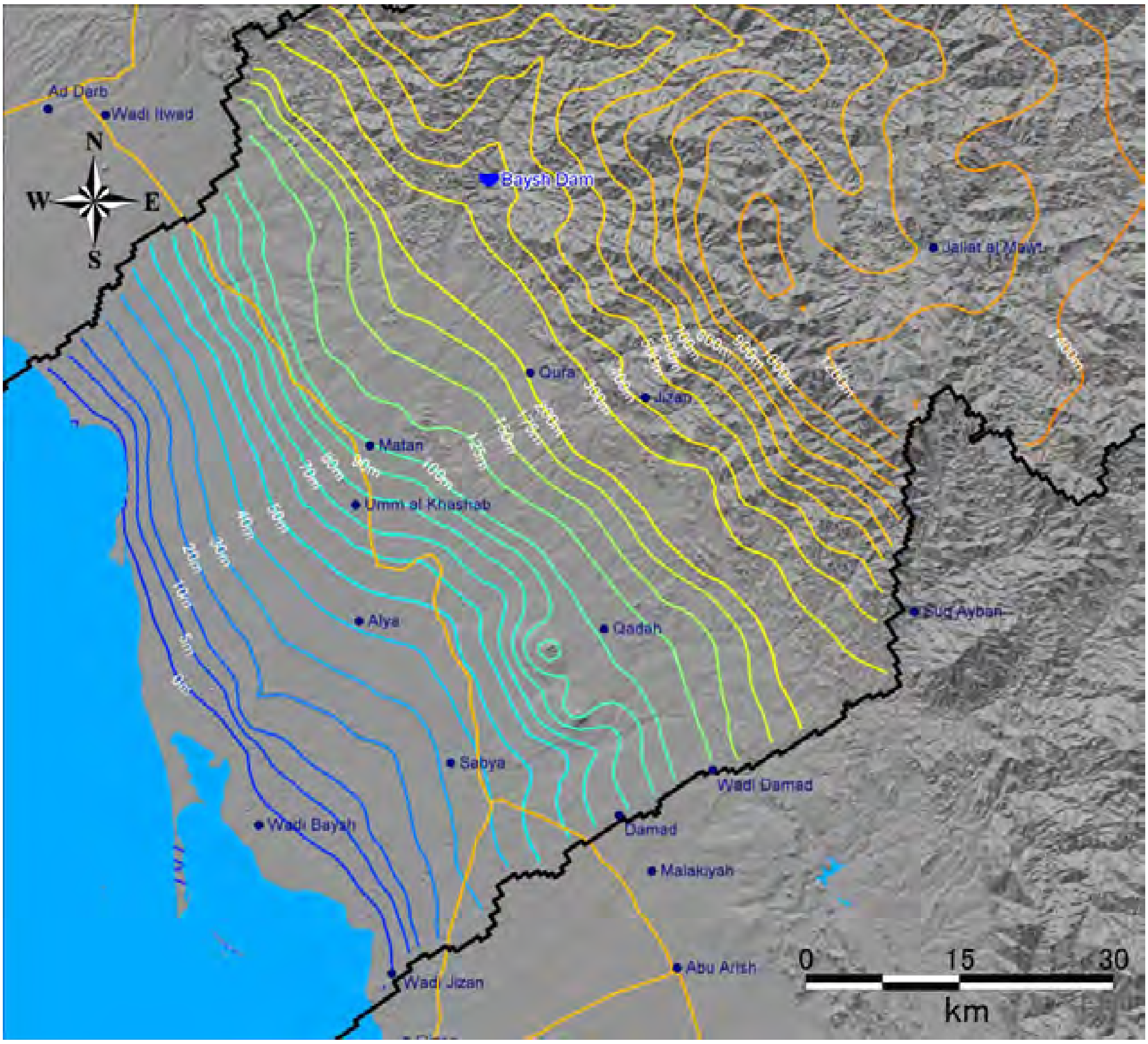
Figure 3-15 shows the brine concentration in the vertical sections. The interface of seawater and freshwater is depicted by the 3D iso-concentration surface contour.

Figure 3-16 shows the contour map of the brine concentration in each depth. The brine concentration in shallow groundwater below 100m depth around coast line is relatively high.



(a) Shallow aquifer

Figure 3-12 Contour map of Reproduced Groundwater Level (1)



(b) Deep aquifer

Figure 3-13 Contour map of Reproduced Groundwater Level (2)

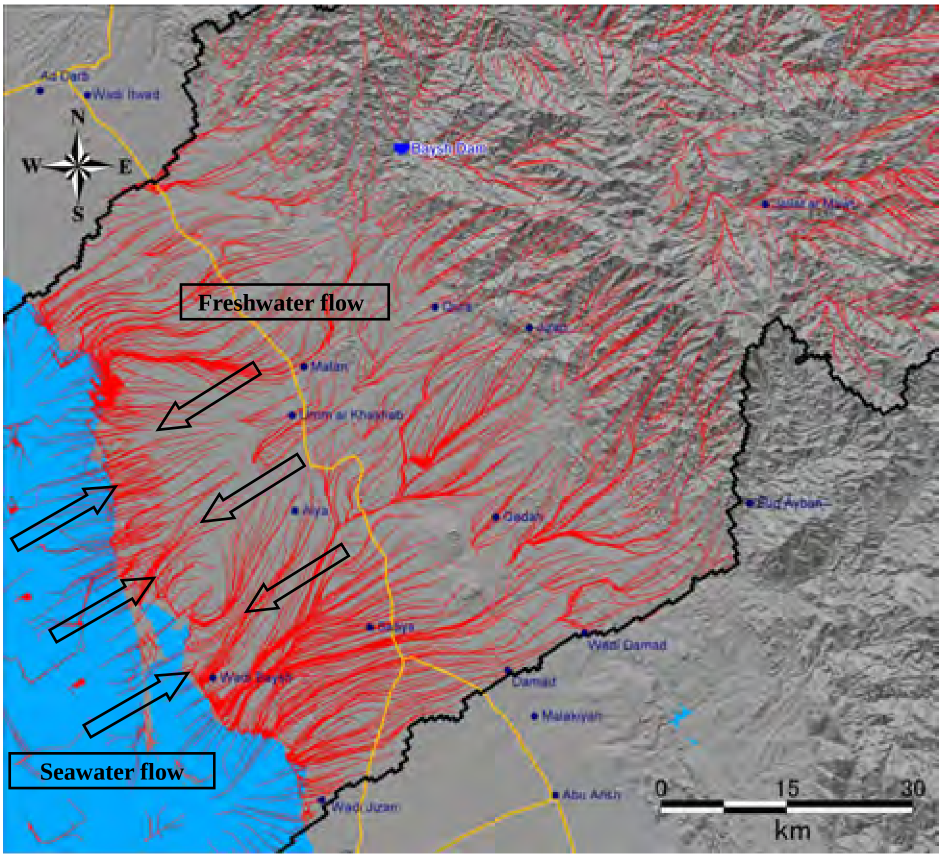


Figure 3-14 Reproduced Streamlines

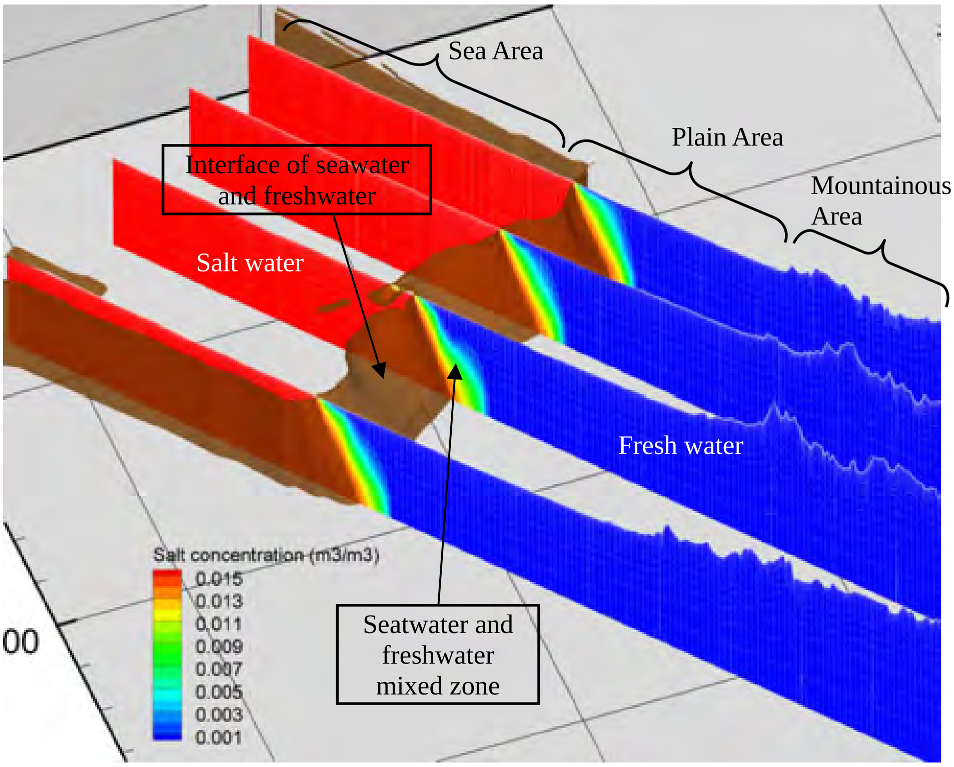


Figure 3-15 Reproduced Seawater Intrusion (Contour Map of Salt Concentration)

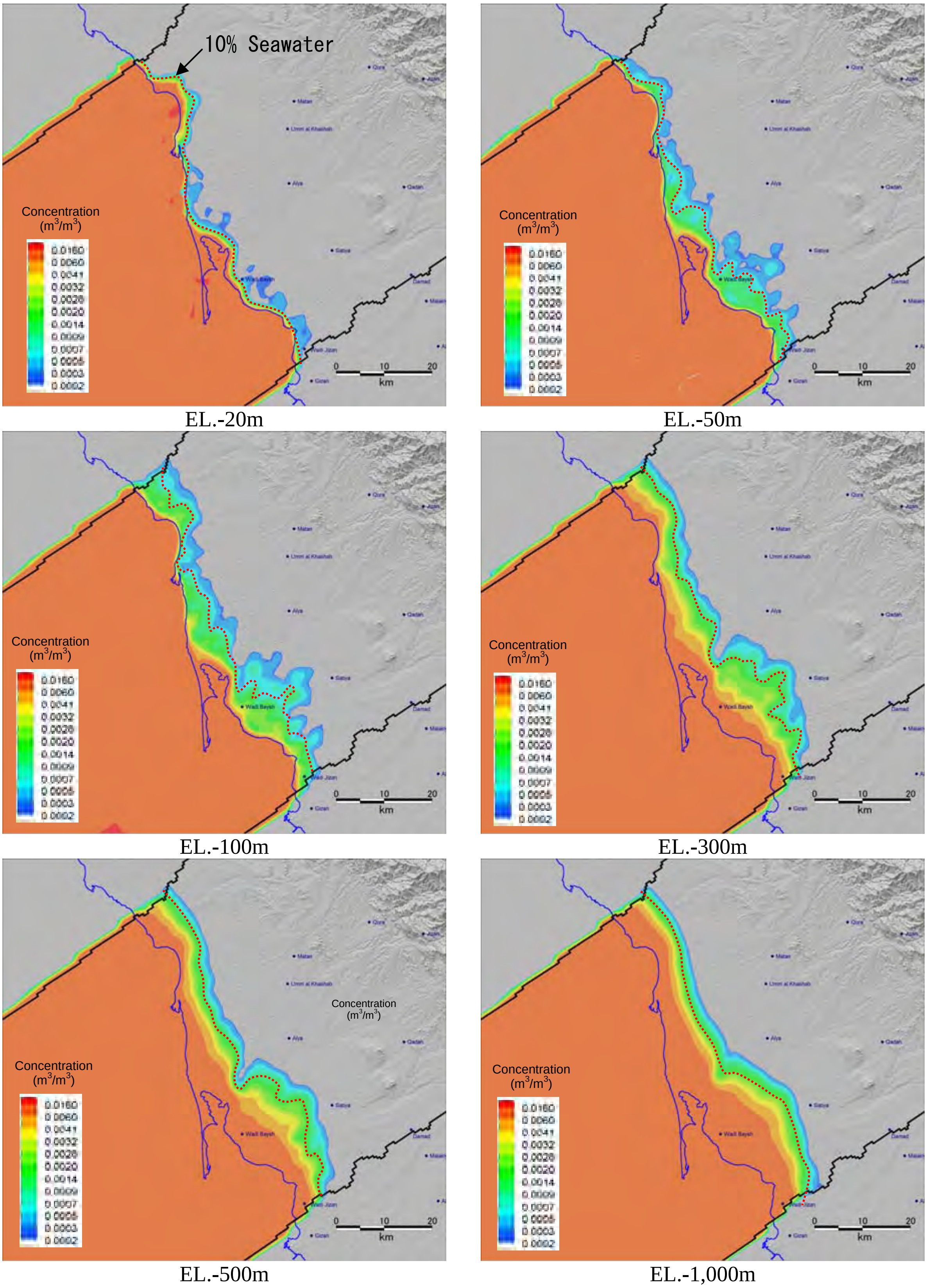


Figure 3-16 Reproduced Brine Concentration in each Depth

CHAPTER 4 PRELIMINARY SIMULATIONS OF WATER RESOURCES DEVELOPMENT

4.1 Case Settings

Based on the reproduced background flow, the preliminary simulations on the effect of water resources development plans have been carried out. Table 4-1 shows the simulation cases.

In case A1 and A2, the Study Team has discussed the possibility of water storage by dam, water discharge from dam and water recharge to the aquifers. And the effect of the water resources development has been demonstrated. In case A3, only the water storage by dam have been considered. Comparing the estimated water loss by evaporation of case A2 and A3, The Study Team can identify the differences between the combined use of dam, wadi and aquifers (case A2) and the single use of dam (case A3) for the water resources development. The rainfall 100mm/d during 1.0 day has been forced in the upstream area.

In case B1 and B2, the Study Team has simulated the groundwater depletion and the seawater intrusion by withdrawing around the coastal area. And the impact of groundwater level and brine concentration by the enforced water recharge has been predicted. According to the 2009 JICA report, the total amount of groundwater pumping around Jizan is 229 MCM/y during 1990 to 2009. However, the water volume, well arrangements and depth within our study area is uncertain. The Study Team has assumed the total amount of groundwater pumping is 110 MCM/y as the rough estimation. And the embedded perforated pipes which have the 1km distance have been considered as the facility for the reclaimed waste water recharge.

Table 4-1 Simulation Cases for Water Resources Development Plans

Case	Options of Water Resources Development		Note
	Enforced Recharge of Reclaimed Waste Water	Combination of Dam and Aquifers	
A1	NOT Considered	NOT Considered	This case is the reference case. The effect of the water resources development has been verified through the comparison with case A2.
A2	NOT Considered	CONSIDERED	Possibilities of the water storage by dam, the water discharge from dam and water recharge to the aquifers have been simulated.
A3	NOT Considered	CONSIDERED	Only the water storage by dam has been considered.
B1	NOT Considered	NOT Considered	Groundwater depletion and seawater intrusion by withdrawing have been simulated.
B2	CONSIDERED	NOT Considered	Response of the groundwater level and brine concentration by the enforced water recharge has been simulated.

4.2 Simulation of Water Resources Development by the Combination of Dams and Aquifers

4.2.1 Water Flood/Inundation Patterns with and without Recharge Dam

The effect of water storage dam can be seen as the different patterns of flood and inundation in the downstream area. Figure 4-1 shows the simulated inundated area with the different time. As mentioned above, the heavy rainfall 100mm was forced for a day. Figure 4-2 shows the enlarged same results of the downstream area at 1.8 day after. The precipitated water in upstream area has induced the flood flow through the Wadis. The inundated water area in plain has developed by the network of flood flow.

This behavior can be seen in the reference case A1. The Baysh dam has worked for the flood control in case A2 and the flood flow in downstream of Wadi Baysh have not been recognized.

4.2.2 Groundwater Responses in Downstream by Discharged Water from Dam

The water discharge from Baysh Dam has been considered in the case A2 simulation. From the beginning of the computation, rainfall was kept constantly for a day. The rainfall was stopped from the day two and the outflow 500,000m^3/d has continuously started from the day three.

Figure 4-3 shows the simulated groundwater fluctuations along the downstream points of Baysh Dam. The simulated results of case A1 during the same period of case A2 have been represented for the comparison. Although these patterns vary depending on the points, the rising of groundwater table can be seen clearly in case A2. The differences between points are almost consistent with the surface soil permeability. The fluctuations of groundwater table in No8 and No10 is small due to the low permeability of surface soil. The water infiltration from the surface is limited around there. However, the groundwater response at No8 is considered to be a good example to indicate the expected effect by dam and aquifer.

That is, in case A1, the increased groundwater level by rainfall and flooding have decreased quickly after rainfall was stopped. On the other hand, the groundwater level in case A2 increases by outflow and keeps it stably.

Since the permeability is enough large in downstream points No6, No4 and No2, the discharged water from dam can easily infiltrate into the underground. The groundwater level at No6 has increased approximately 20m with the time delay. This delay is due to the infiltration from the surface to the groundwater table. Although the groundwater levels have been increased by flood in case A1, it has gradually decreased with time. This tendency becomes remarkable when the amount of groundwater supply reduces. The water discharge from Baysh Dam has influenced to the increasing of the groundwater table. Since the most of outflow have infiltrated into the aquifer in upstream (around No6), the groundwater level in downstream (No2 and No4) have not changed.

The Study Team has showed that the outflow water from the storage dam can infiltrate to the aquifers and increase groundwater level in downstream area. However The Study Team also found that such effect depends on the surface permeability distribution of Wadi sediment. It can be considered that the pathways and its surface permeability for the outflow water might be sensitive to the amount of developable water resources.

4.2.3 Effects of Discharged Water (Water Loss by Evaporation)

The Study Team has compared the simulated water loss by evaporation between case A2 and A3. In case A3, the water storage by dam, the evaporation from the lake surface and the groundwater recharge from the lake bottom has been considered. The controlled outflow from dam doesn’t consider in case 3A.

Figure 4-4shows the comparison of total volume of developable water resources in these cases. In case A2, the storage of water by Baysh dam (Vd) and the recharge water from surface (Vr) have been considered as the total water volume (Vt=Vd+Vr). Only the storage of water Vd in case A3 has been compared with Vt of case A2. These quantities were calculated per a year.

According to this result, it can be seen that the total water volume Vt in case A2 is less than that of case A3. The difference between them is corresponding to that of water loss by evaporation from surface of water. Because case 2A has the additional water table by the discharged water flow, the total surface area becomes larger than that of case A3. To avoid such water loss, the kinds of pipeline can be effective to recharge water to the aquifers. Figure 4-4 involves such scenario case as case 2A’.

The Study Team has to recognize that the detail of outflow operation and shrinkage of surface area of the dam lake may determine the amount of developable water resources.

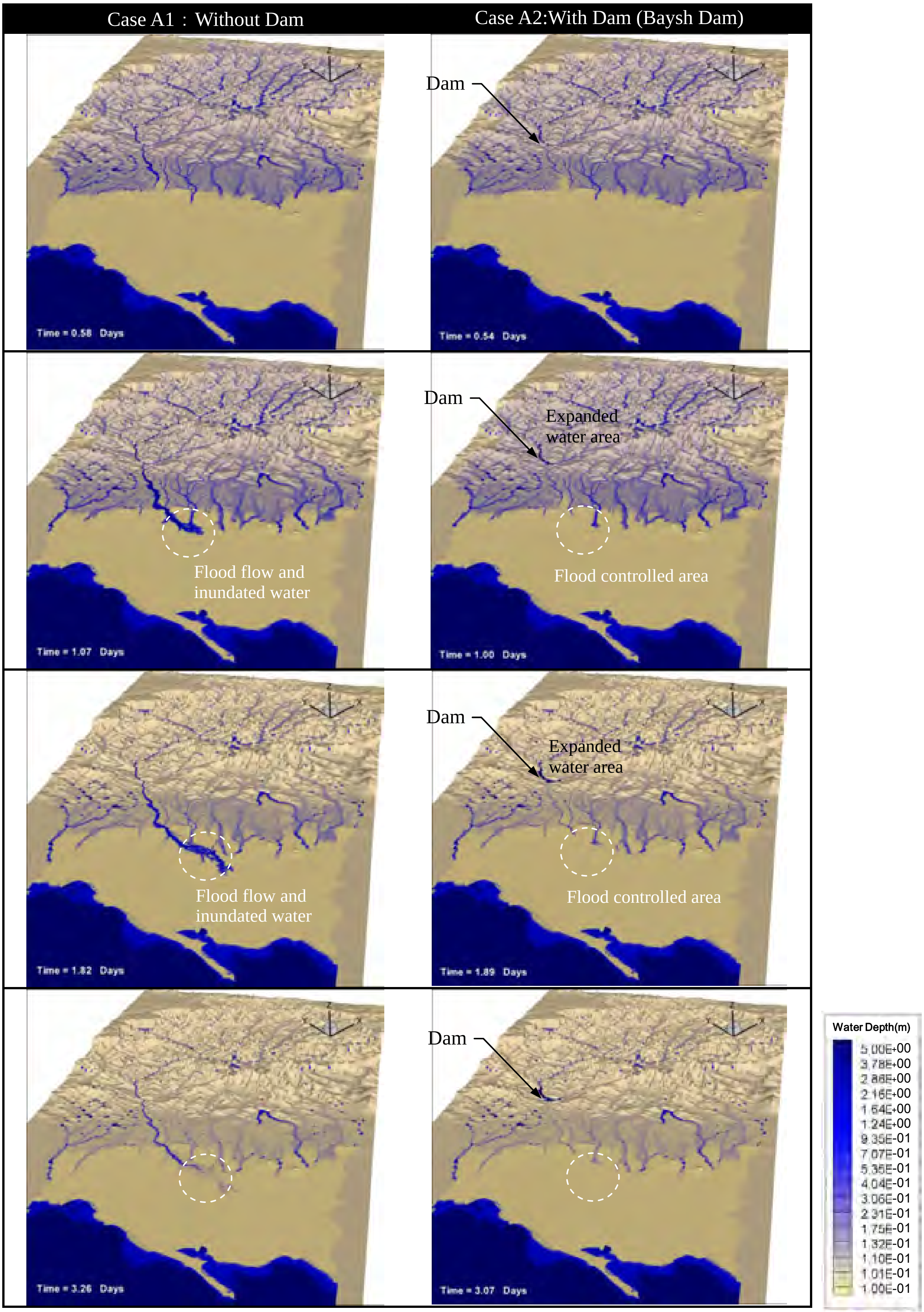
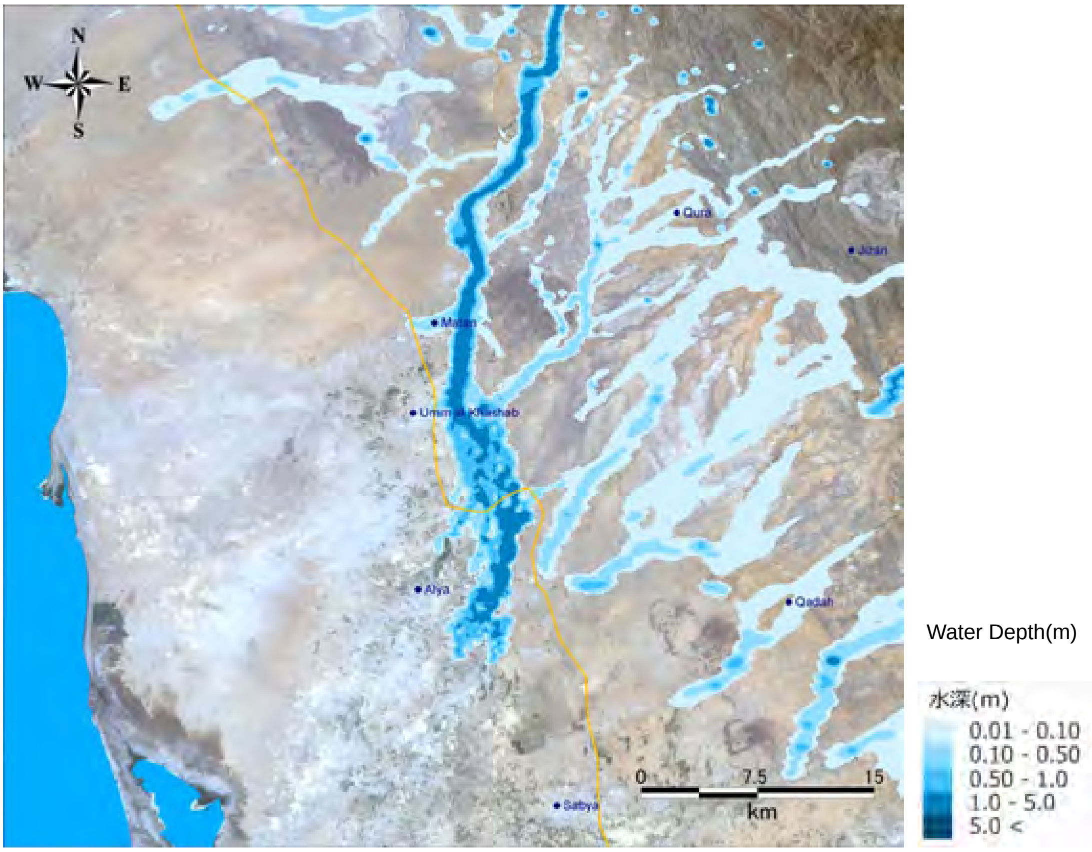
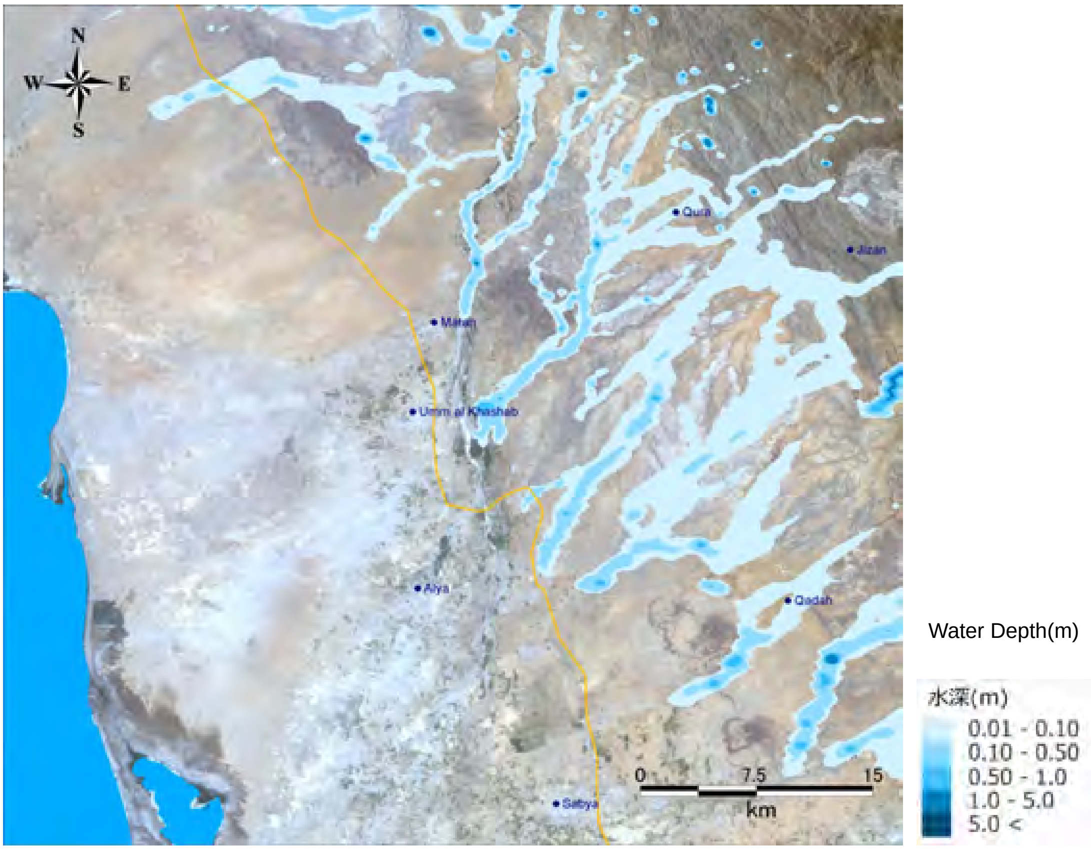


Figure 4-1 Simulated Surface Water Flow with and without Recharge Dam



(a) Case A1: Without dam



(b) Case A2: With dam

Figure 4-2 Simulated Surface Water Flow with and without Recharge Dam (An enlarged view around Downstream Plain Area)

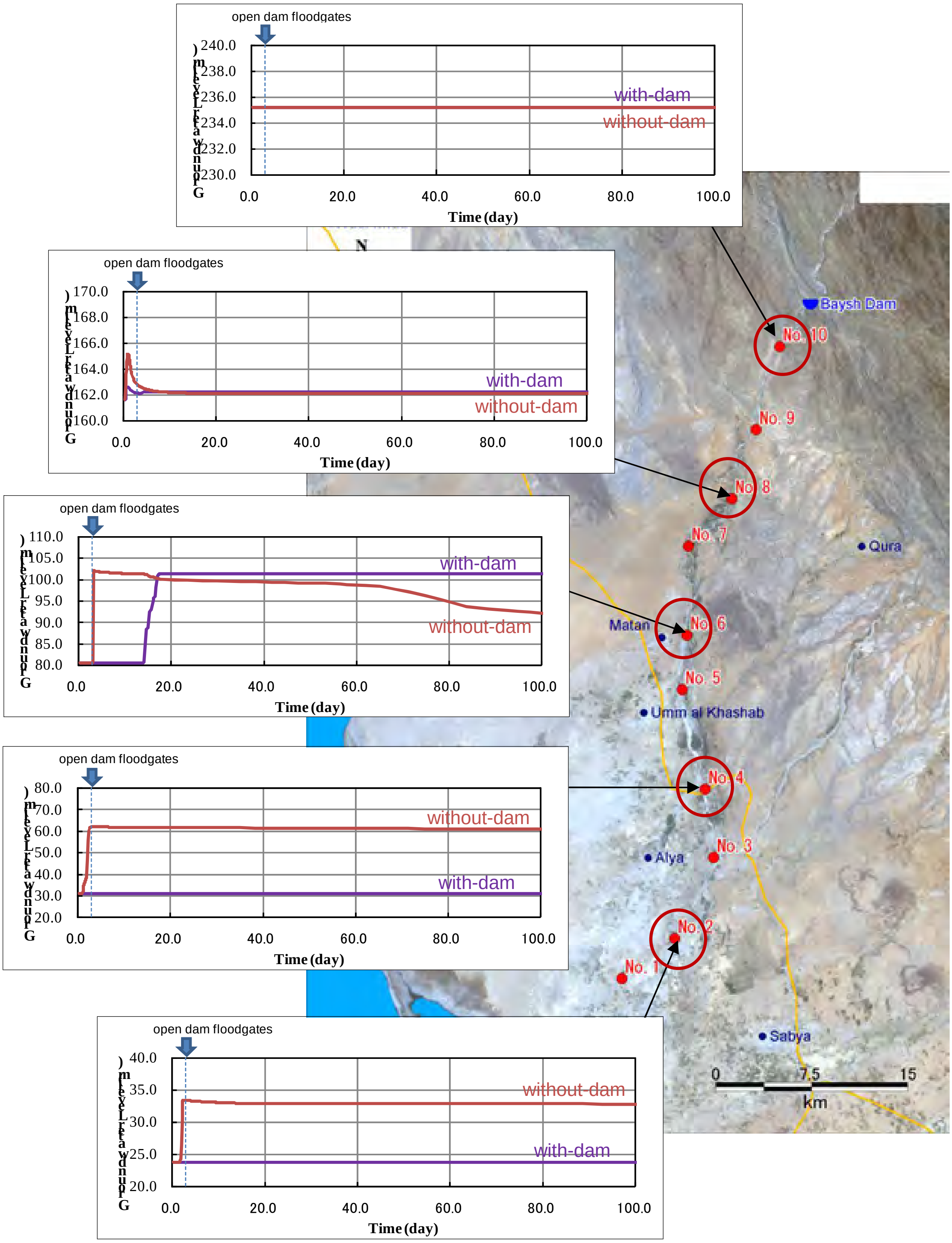


Figure 4-3 Groundwater Responses in Downstream by Discharged Water from Dam

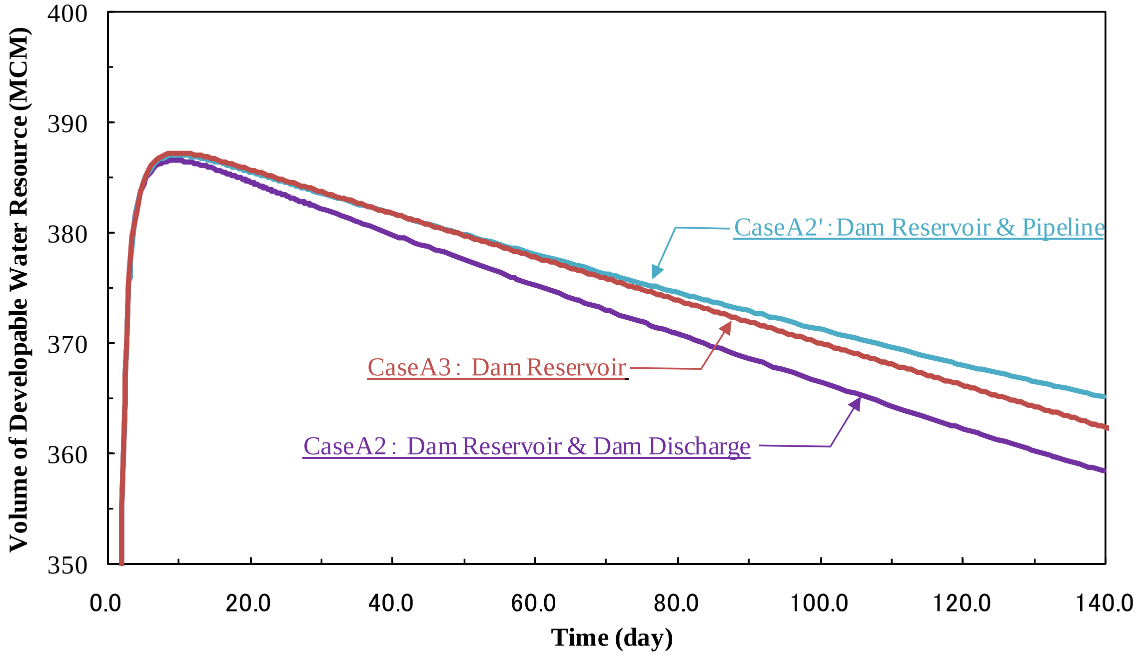


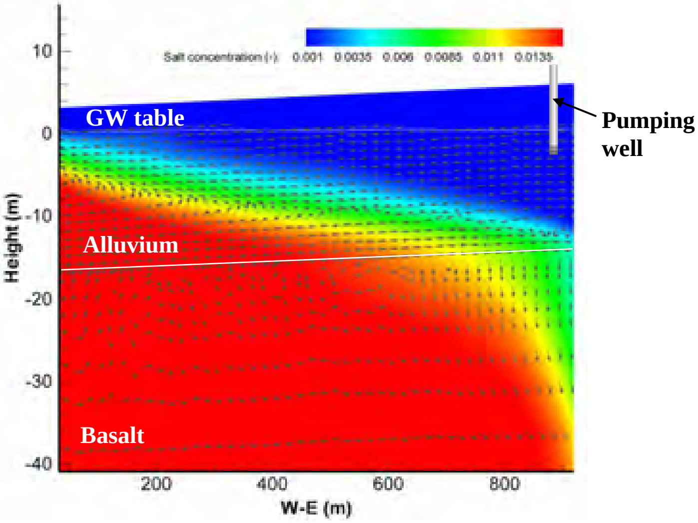
Figure 4-4 Comparison of available water Resources between with and without Dam

4.3 Simulation of Water Development by Enforced Recharge of Reclaimed Waste Water

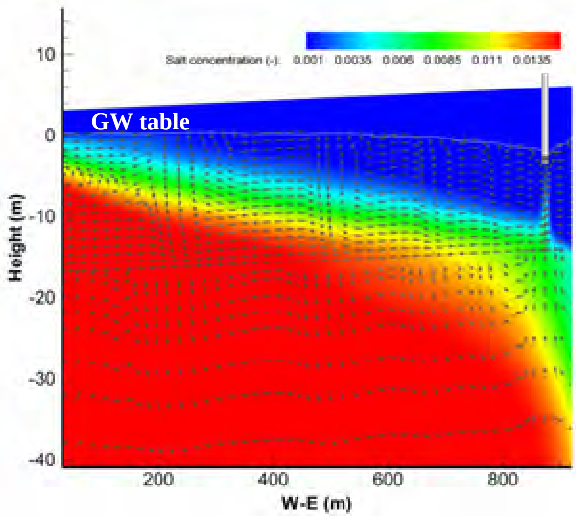
The overmuch groundwater abstraction around the coastal area induces groundwater depletion and sea water intrusion. Figure 4-5 shows the computed groundwater table and the contour of brine concentration representing such situation. The arrow head in the figure represents the direction of groundwater flow. It can be seen that the seawater intrudes from west to east through the deep aquifer. The time represents the elapsed time from the beginning of the pumping. The tendency of groundwater depletion and seawater intrusion around the well has been reproduced.

Then the effect of the enforced recharge of reclaimed waste water has been predicted. The water recharge was considered at the 100m distance west from pumping well. Figure 4-6 shows the simulated results. The recovery from the groundwater depletion and seawater intrusion by the enforced recharge of reclaimed waste water has been reproduced. This simulation has reproduced the tendency of the increased freshwater area in the shallow aquifers with the shrinkage of unsaturated zone and increasing of the groundwater level.

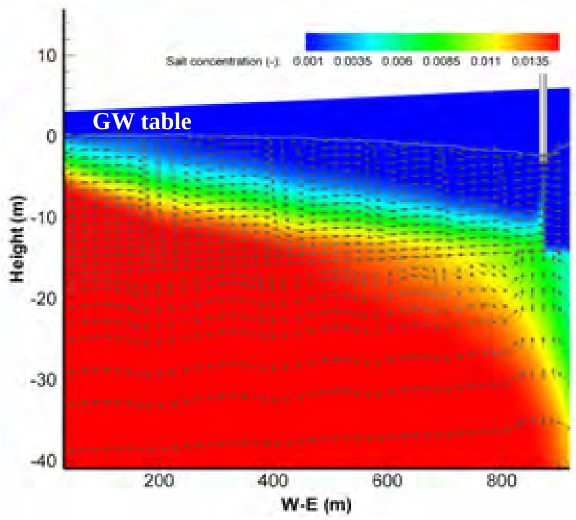
Based on these results, total volume of available freshwater is roughly estimated. In case B1, the volume of available freshwater is 0.65MCM in the area of 1km distance and 1km width around the pipeline. And the enforced recharge water in case B2 is 2.94MCM/y and the available freshwater in aquifer is 1.08MCM.



(a) 0 days

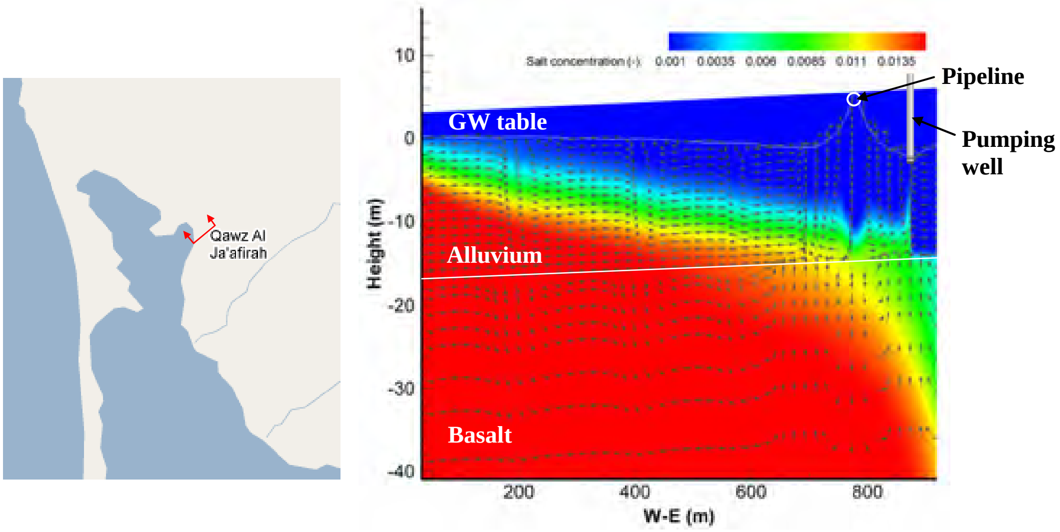


(b) 28days

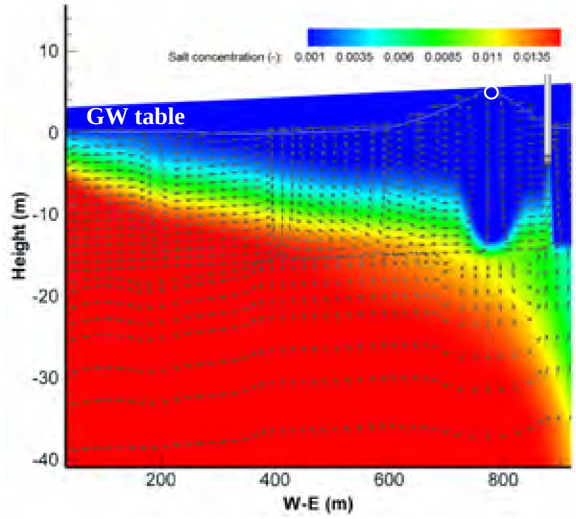


(c) 80 days

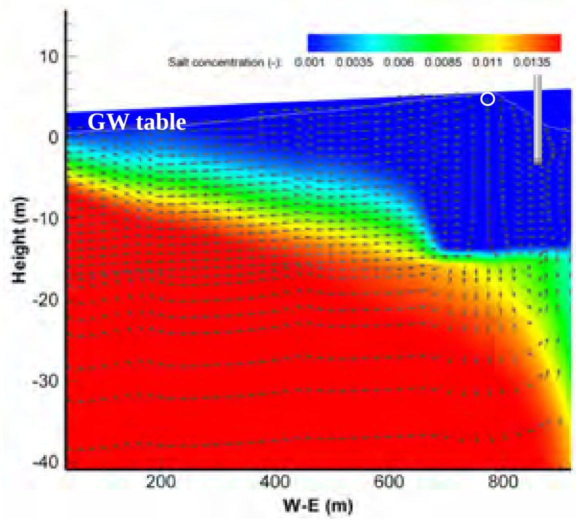
Figure 4-5 Reproduced GW Depletion and Seawater Intrusion by Pumping (Case B1)



(a) 1 day



(b) 10 days



(c) 120 days

Figure 4-6 Simulated Recover from GW depletion and Seawater Intrusion by Enforced Water Recharge(Case B2)

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

The 3D numerical modeling of the regional-scaled dam basin to assess the water resources development have been implemented as a part of the preliminary studies on the sustainable water resources management in Jazan.

The current conclusions of this study can be summarized as follows.

1) The 3D regional-scaled numerical model which covers the whole catchment area of the Baysh dam basin (18,000km^2) was developed. The terrestrial fluid flow including the interaction between surface water and groundwater flow and the sea water intrusion have been simulated in this model.

2) Through the trial and error calculations by computer code GETFLOWS, the tentative water flow field of the objective site has been successfully reproduced and its applicability to the assessment of the water development planning has been confirmed.

3) The effect of the water resources developments by i) the combination of dam and aquifer and, ii) the enforced recharge of reclaimed waste water has been preliminary predicted.

4) The Study Team has showed that the outflow water from the storage dam can infiltrate into the aquifers and increase groundwater level in downstream area. However The Study Team also found that such effect depends on the surface permeability distribution of wadi sediment. It can be considered that the pathway and its surface permeability of outflow water are likely to be sensitive to the amount of developable water resources.

5) The Study Team has found that the water loss by evaporation in the combined use of water storage dam and aquifers may be slightly greater than that of the single use of dam. However, The Study Team should also recognize that the detail specifications of outflow operation and shrinkage of surface area of the dam lake may determine the amount of developable water resources.

6) The Study Team has successfully reproduced the recovery from the groundwater depletion and seawater intrusion by the enforced recharge of reclaimed waste water. Accordingly, the simulation has reproduced the tendency of the increased freshwater area in shallow aquifers with the shrinkage of unsaturated zone and increasing of the groundwater level.

Through these preliminary simulations, the Study Team has showed that the employed numerical model of the Wadi Baysh basin can evaluate the effect of the water resources development plans. However, it was not simple procedures obtaining the suitable situation for the water resources development and visualize it, and the Study Team had to carry on the trial and error runs repeatedly. Since many site-specific data such as precipitation in upstream area, geological structure and water use conditions is uncertain in current work, it can be considered that the estimated developable water resources had been considerably influenced by these settings.

One of the final goals of this modeling work is to provide the quantitative information on the developable water resources for the alternative plans. To improve the model for the reliable simulations becomes important. The future work should be focused on the followings.

- <u>Improvement of the numerical model</u>: The distributed field data such as meteorology, geology and water use should be incorporated into the model for the realistic modeling. In addition, the spatial and temporal patterns of the observed groundwater level and river flow should be reproduced.

- <u>Determine and optimize the design variables on the water resources development by the combination of dam and aquifer</u>: The design variables and reference (nominal) conditions which determine the developable water resources should be specified. Based on the reference conditions, the effectiveness should be discussed through the sensitivity and uncertainty analysis.
- <u>Provide the multiple options on the water resources development</u>: Through the predictions of effectiveness of the multiple options on the water resource development, the adaptation of that to the site-specific conditions should be discussed.

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
(ADDITIONAL STUDY RESULTS)
-TOR FOR FEASIBILITY STUDY-

OCTOBER 2010

JAPAN INTERNATIONAL COOPERATION AGENCY

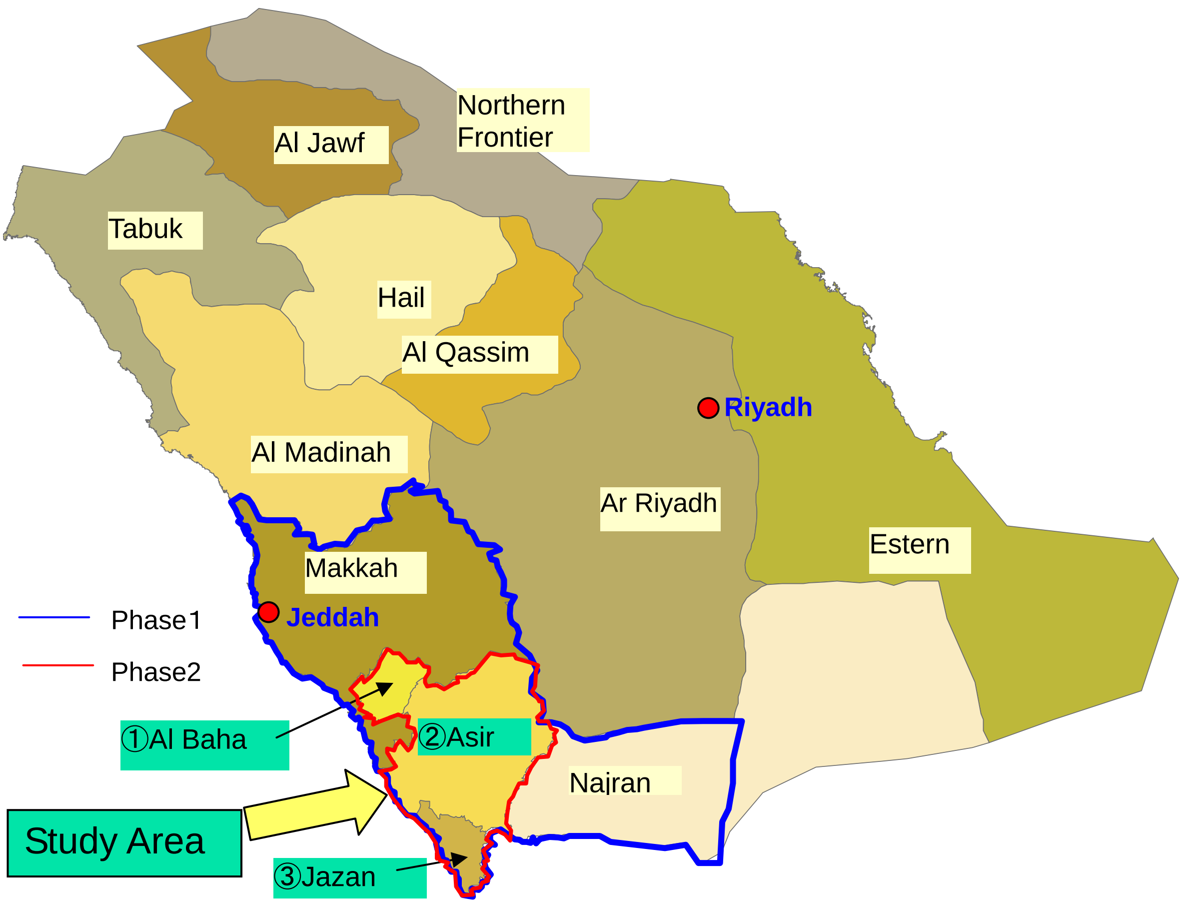
YACHIYO ENGINEERING CO., LTD.
SANYU CONSULTANTS INC.

Foreign Exchange Rate

1.00 US Dollar=3.74 Saudi Arabia Riyal=¥89.0

(WEB：1st March, 2010 US Dollar/Saudi Arabia Riyal)

The Kingdom of Saudi Arabia   Location of Map



Final Report
(ADDITIONAL STUDY RESULTS)
-TOR for Feasibility Study-

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List of Tables and Figures

List of Abbreviations

Abbreviation and Acronym	English	Arabic (عربي)	Japanese (日本語)
BCM	Billion Cubic Meters	مليار متر مكعب	10 億立法メーター
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	التبخر	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
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
MOAW	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 万立法メーター
M/M	Minutes of Meeting	ملخص الاجتماع	会議の議事録
MMW	Million Megawatt	مليون ميغاوات	100 万ワット
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 Cooperation	التعاون الوطني للمياه	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
NCWCD	National Commission for Wildlife Conservation and Development	اللجنة الوطنية لحماية و تطويرالحياة البرية	国立動物保護開発協会
NIA	National Irrigation Authority	السلطة الوطنية للري	国家灌漑局

Abbreviation and Acronym	English	Arabic (عربي)	Japanese (日本語)
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 عملية	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	نطاق الأشغال	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 مسجلة	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	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

CHAPTER 1 OUTLINE OF THE STUDY

1.1 Background of the Study

Although the Al Baha, Asir, and Jazan Regions located in the southwestern part of Saudi Arabia (KSA) are regions blessed with the renewable water resources (surface runoff water and shallow groundwater) primarily from rain, they are now facing a situation where a vital supply of municipal water by non-conventional water resources such desalinated seawater is imperative due to the decrease in rainfall from recent years.

By constructing dams and developing wells, renewable water resources are able to flow through the Wadi as surface runoff and groundwater, and then be recharged. Because these resources can be developed without difficulty, they were accepted and used for municipal and agricultural water in the project area. As a result of the water demand exceeding the amount of the water supply, water became over developing, as groundwater levels lowered in many areas, and the phenomena of seawater intrusion occurred in the Red Sea coastal areas.

According to the water master plan conducted by JICA and aimed at completion in 2035, the possible of developing renewable water resources volume to that of municipal water demand is predicted. In the three Regions, the present situation is where water supply cannot respond to the increased demand. The collective cooperation and operation amongst the neighboring dams and aquifers situated downstream will be necessary to examine the possibility of the water resources development.

Desalinated seawater represents the most effective water resources at the time of an urgent corresponds to drought, such as water shortages, and is also already supplied to the projected areas. MOWE implements extensive projects for desalinated seawater and represents the most effective water resources to meet the future increase in demand. It is indispensable for SWCC to continue and expand the desalination projects to meet the future water demand of municipal and industrial water. However, production cost of desalinated seawater is still higher than that of renewable water. In the future, it is necessary to aim at the reduction of seawater cost as a vital water resource.

In the main cities of the target regions, MOWE employs reclaimed wastewater projects. In the KSA, reuse of the reclaimed water has been performed since 1982. Regarding the use of reclaimed wastewater for recycling purposes, municipal and industrial water utilization is limited and relatively small yet more abundant for agricultural water. In the Al Baha and Jazan Regions, there are presently no sewerage treatment plants, but treatment plants are planned for construction up to the year of 2020. The volume of reclaimed wastewater in the three regions will be 57MCM.

In these highland mountainous areas, the JICA Study Team recommends the Distributed Waste Water Treatment System suitable for this kind of topography for targeting the promotion of the reuse of reclaimed wastewater. In addition, a protection project form the seawater intrusion by recharging reclaimed wastewater is recommendable in the Jazan Region. The feasibility study on the reuse of reclaimed wastewater is recommendable.

Based on the essential aspects of securing less expensive water and water sufficiency in a wider area through using diverse water resources, the JICA Study Team proposed the Red Sea Water Lifeline Project (REWLIP). This project consists of desalination plants, dams and well-connected water conveyance systems with a total distance of 1,300km. This large project, which produces desalinated seawater and renewable water and distributes water in the four Regions, is the first and very important project not only for the area but also for the entire KSA.

The Water Master Plan formulated by JICA proposed recommendations such as to perform efficient and economical management practices while combining different water resources into an integrated water network represents the total basic water service management system.

The Master Plan also proposed a new organization known as of RWPC (Renewable Water Production Corporation) as a core of the total water service management system. The objectives of RWPC are to implement and develop the operation and maintenance of renewable water resources, and coordinate with concerned stakeholder organizations. In the feasibility study, the roles and activities of the water related organizations, such as MOWE and the General Directorate of Water office (GDW), and other ministries and governmental offices, SWCC, and NWC, will be reviewed, examined, and determined when establishing the work to be performed by RWPC.

1.2 Objectives and Work Items of the Study

The feasibility study shall be done regarding the water resources development plans and measures which were proposed in the Master Plan Study Plan, its objectives include to test, monitor and execute of the pilot projects, and to monitor the effects, or usefulness and availability, cost evaluations.

The objectives of the feasibility study and work items are shown as follows.

(1) To examine the renewable water resources development

In order to supply the municipal water at the minimum cost possible, developing the renewable water resources through a combination of dams and downstream aquifers shall be adopted.

As part of the examination of the development method for renewable water resources through the combination of dams and downstream groundwater aquifers, the target dam shall be selected and the relationship between groundwater levels in wells and discharge from dams shall be monitored and simulated.

The study and work items are shown as follows.

1) Monitoring and simulation on the combination of dams and downstream groundwater aquifers
2) Evaluation of the effects on recharging volume in the Wadi aquifers by discharge of dams and cooperative operation with neighboring dams
3) Calculation of possible development volume on renewable water resources

(2) To plan and design the REWLIP

The REWLIP is the wider area water conveyance project consisting of desalination plants, dams and wells connected by pipelines with a total distance of 1,300km. This project produces desalinated seawater, develops renewable water and distributes water in the four Regions.

To plan and design the REWLIP for developing and operating renewable water resources and desalinated seawater.

The plan, design and examination items are shown as follows.

1) Production volumes of desalinated seawater and renewable water resources development
2) Dimension of desalination plants, dams and pipelines, and supplying directorates
3) Conveyance routes
4) Facilities of the Red Sea Water Lifeline (REWLIP)
5) Cost estimates and implementation plan

(3) To identify and examine the reuse plan for the reclaimed waste water

To identify and examine the possibility of an effective use of water resources, through developing the pilot project of the distributed wastewater treatment system in the mountainous area in the Asir Region, reuse of the reclaimed waste water for agricultural and industrial use.

Moreover, in the area along the coastal area in the Jazan Region, as part of the practical use of reclaimed water as a measure against seawater intrusion, monitoring of groundwater levels and field test by artificial recharging of the reclaimed wastewater in wells shall be evaluated.

The plan, design and examination items are shown as follows.

1) Commencement and monitoring of the pilot project for the distributed reclaimed wastewater treatment system
2) Examination of feasibility on the distributed treatment system

3) Recharging test with the reclaimed wastewater in the wells
4) Evaluation of the recharging effects
5) Counter measures for seawater intrusion

(4) To examine the management and operation of RWPC

To observe and identify a new organization called RWPC which becomes a core part of the comprehensive water management system, coordination with other resources such as desalinated water and effective water resources development for renewable water shall be examined and identified.

Examination items are shown as follows.

1) Management and operation plan for renewable water resources
2) Capacity developments for relevant agencies
3) Management and operation training in Japan
4) Data processing, communication system and information transmission

CHAPTER 2 STUDY ITEMS FOR THE FEASIBILITY STUDY

2.1 Data Collection and Reviews

To identify the characteristics of the project area, data and materials on social conditions, natural conditions, and facilities such as dams, water treatment facilities and sewage facilities, as well as development plans aiming at the target year of 2035 shall be gathered.

Collection and analysis of the following data and information will be conducted. In addition, data and information for the three regions and Makkah Region shall also be collected and reviewed.

1) Social conditions (Population, Institution, Industry)
2) Natural conditions (Land use, Hydrogeology, Vegetation)
3) Hydrological data
   (Rainfall, Water level in reservoir, groundwater, water quality in the area of seawater intrusion)
4) Dam (Dimension, Drawings Operation manuals, Construction cost, Operation cost)
5) Municipal water (Total supply volume, Drawing for facilities, Operation cost, Tariffs)
6) Desalination facilities (Dimension, Production, Drawings, Construction cost, Operation cost)
7) Pipelines (Routes, Dimension, Drawings, Construction cost, Operation cost, Unit Cost)
8) Sewage Facilities (Dimension, Drawings, Treatment volume, Operation cost, Unit cost)
9) The 10th development plan
10) Municipal water plan in the Region
11) Desalinated water development plan
12) Sewage treatment plan
13) Agricultural plan
14) Industrial development plan
15) Environment

2.2 Surveys and Monitoring

For the feasibility study, topographic surveys for the design of the REWLIP, test operation of dams and monitoring of aquifers in the downstream of dams and the control test for the measuring the seawater intrusion in Jazan shall be carried out in the initial phase.

2.2.1 Topographic Survey

The longitudinal survey along the construction routes for REWLIP currently planned is also executed. The routes and specifications for surveys are shown as follows. The un-surveyed section shall be surveyed after checking the existing topographic survey results.

Table 2-1 Routes and Specifications for Survey

Section	Route	Distance (Km)
A	Dawqa- Al Baha	115
B	Hali- Dawqa	108
C	Al Baha – Al Alayah	105
D	Shuqaiq - Abha	124
E	Shuqaiq – Al Birk	96
F	Shuqaiq- Samta	151
G	Abha – Al Alayah	216
H	Abha – Al Janoub	148
I	Al Alayah - Bisha	96
Total Length		1,159

The routes of REWLIP for survey are shown in Figure 2-1.

Figure 2-1 Routes for REWLIP (Section A-I)

2.2.2 Monitoring and Analysis on Groundwater Recharge with Dam in Wadi

Groundwater is recharged from Wadi beds in the Study Area. The groundwater recharge can be controlled by discharge from the dam. It is necessary to know the relationship between Wadi flow and groundwater recharge for the formulation of optimum dam operation methods and to maximize groundwater recharge. For this purpose, the monitoring of wells should be newly drilled along the Wadi (see Figure 2-2) to observe the long term fluctuation of groundwater levels. The monitoring wells should be located in the Wadi Baysh basin of the Jazan Region where large amounts of groundwater is pumped up for agricultural use. The structures of these monitoring wells are shown in Figure-2-2, and the specifications of the wells are shown in Table 2-2.

Table 2-2 Specification of Monitoring Well

Items	Specifications
Area of monitoring wells	Wadi Baysh Basin (See Figure)
Number of monitoring wells	10 wells. (See Figure).
Diameter	4 inches
Depth	50 m
Automatic groundwater level recorder	Pressure type instrument
Note) Soil samples should be taken during drilling of the monitoring well to determine the know geological condition of the well	

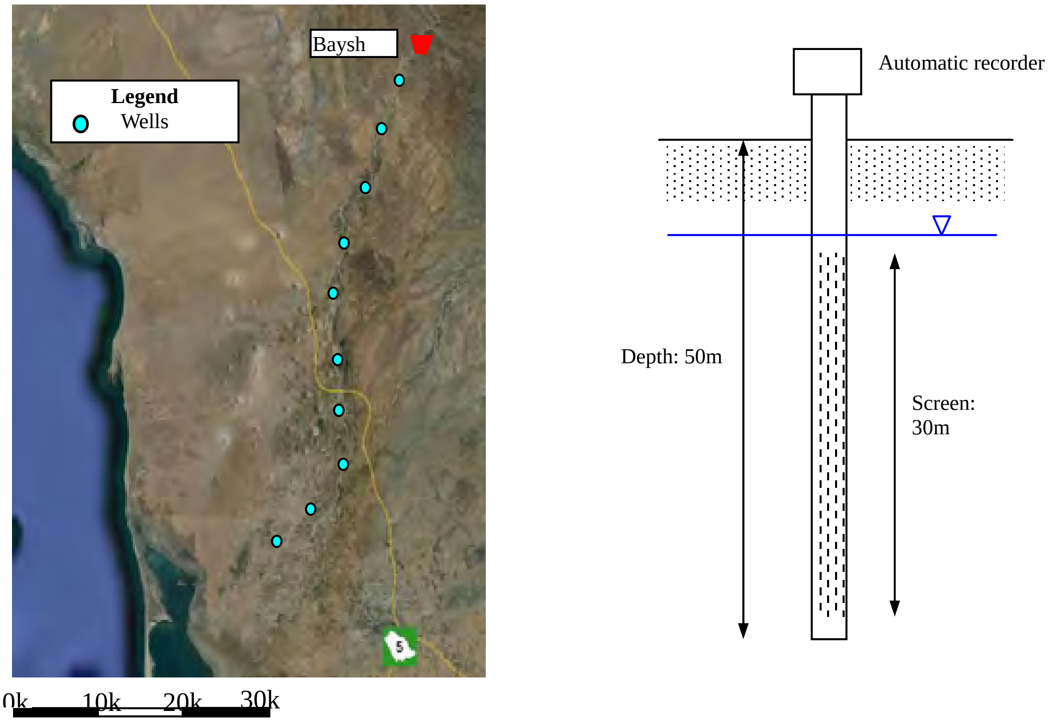


Figure 2-2 Monitoring Wells along Wadi Baysh

The matters below should be taken into consideration when installing the monitoring wells.

- The monitoring wells should be located in alluvial (flood) plain within 100m from the natural levee of Wadi Baysh.
- PVC casing and screen should be installed into the monitoring wells. The screen should be set by covering sand and gravel layers.
- Aquifer of the monitoring well should be alluvial sand and gravel. An automatic groundwater level recorder should be installed into the monitoring wells to observe long-term fluctuations in the groundwater levels.
- The assumption is that the groundwater is flowing form the Wadi bed into alluvial aquifer surrounding Wadi. Estimations of the amount of groundwater flowing from the Wadi to the surrounding aquifers based on the fluctuation in groundwater levels observed at the monitoring wells.

2.2.3 Control of Seawater Intrusion by Use of Reclaimed Water

A large amount of groundwater is pumped up from the Quaternary aquifer in the Jazan Region. It is expected that seawater intrusion into inland aquifers are taking place in coastal area. Artificial recharge of groundwater into the coastal aquifers is shall be proposed to control seawater intrusion. Water sources for artificial recharge should be reclaimed waste water from Jizan city. The reclaimed waste water will be injected into the coastal aquifers through pipelines, which will be installed into underground near the ground surface around Jizan city, where seawater intrusion seems very most serious. Monitoring wells should be newly drilled along the pipelines. The purpose of the monitoring wells is as follows:

- Current condition of seawater intrusion will be analyzed using observed results of the monitoring wells. Then, information for planning and designing of artificial recharge facilities can be obtained.
- Condition of seawater intrusion after construction of the artificial recharge facilities will be examined to judge the effectiveness of this method.

Structure of monitoring well is shown in Figure 2-3, and specification of the monitoring well is shown in Table2-3.

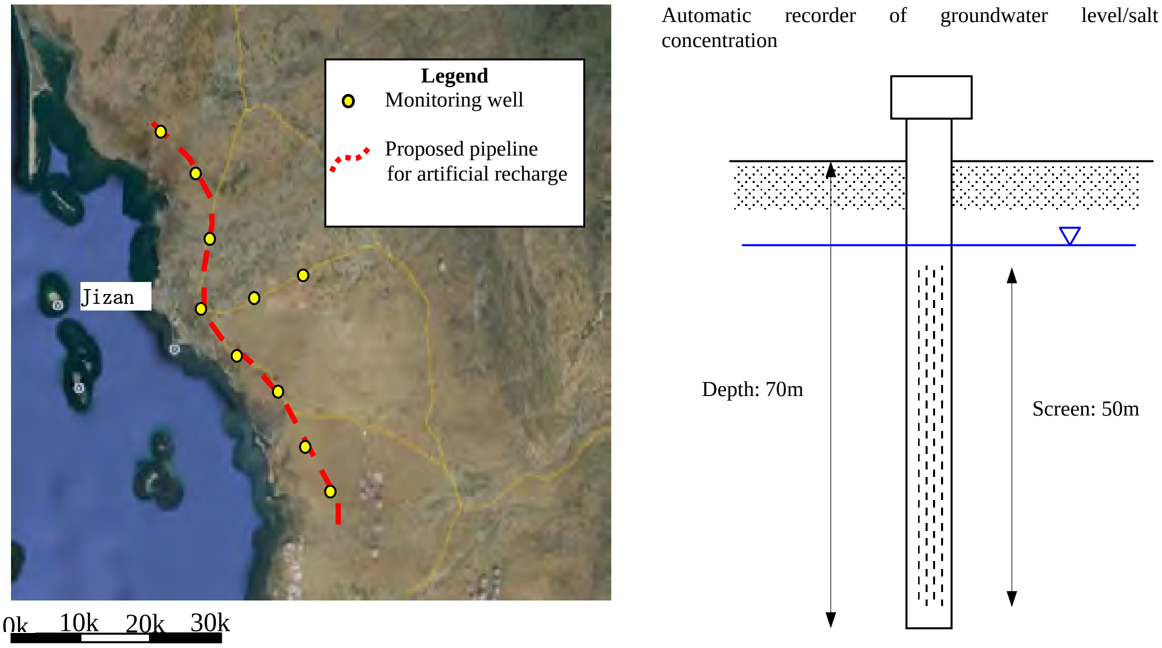


Figure 2-3 Proposed Pipeline for Artificial Recharge and Monitoring Wells

Table 2-3 Specification of Monitoring Well

Item	Specifications
Area of monitoring wells	Coastal area around Jizan city (see Figure-3)
Number of monitoring wells	10 wells (see Figure-3)
Diameter	4 inch
Depth	70m
Automatic groundwater level recorder	Pressure type instrument
Automatic salt concentration recorder	Instrument with sensor to observe salt concentration
Note） Soil samples should be taken during drilling of monitoring wells to access the geological condition of the well	

The issues below should be considered when construction of the monitoring wells.

- Monitoring wells will be classified into two groups (see Figure. The first group is located along the coastal line, and the second group is located from the coastline toward the inland.
- The monitoring wells should be located in alluvial plain along the coast.
- PVC casing and screens should be installed into the monitoring wells. The screens should be set covering sand and gravel layer.
- Automatic recorders should be installed into the monitoring wells to observe groundwater levels

and salt concentration (electric conductivity).

- Condition of seawater intrusion can be analyzed based on salt concentration (electric conductivity) of groundwater observed by the recorder.
- Location of seawater/fresh-water interface can be analyzed based on the relationship between groundwater levels and salt concentration. The analyzed results can be used for designing of facilities for artificial recharge.

2.3 Reuse Plan on Reclaimed Waste Water

2.3.1 Execution of the Pilot Project

The recycle rate of reclaimed waste water for agricultural use (more than 20%) is high in the Al Baha and Asir Regions. Therefore, to promote agricultural use of reclaimed waste water, a distributed sewage treatment system shall be recommended and facility plan shall be conducted.

In order to carry out this system as a pilot project, the project area in the Asir Region shall be selected, and preliminary designs for the reuse plan shall be also drawn up. The treatment volume per day shall be set at 500m^3 to 1,000m^3, monitoring period shall be planned for one year.

Examination and analysis items for distributed waste water treatment system are shown as follows.

1) Selection of targeted project areas (Candidate sites; Abha, Kamis Mushayt, Bisha)
2) Facility plan for the implementation of the pilot project
(Design volume, Dimension of treatment plant, Plant scale)
3) Monitoring for pilot project (one year)

2.3.2 Evaluation of the Pilot Project

The issues on distributed waste water system were identified and arranged, and the evaluation of the treatment capacity shall be done and dissemination method for the system shall be also considered.

2.4 Simulation by GETFLOWS

2.4.1 Renewable Water Resources Development Simulation in Wadis

A numeric model carries out lattice division of the three-dimensional space domain of the whole region in consideration of space distribution on the geographical features and geology in domain. The example of the formulation of a numerical model is shown in figure 2-4.

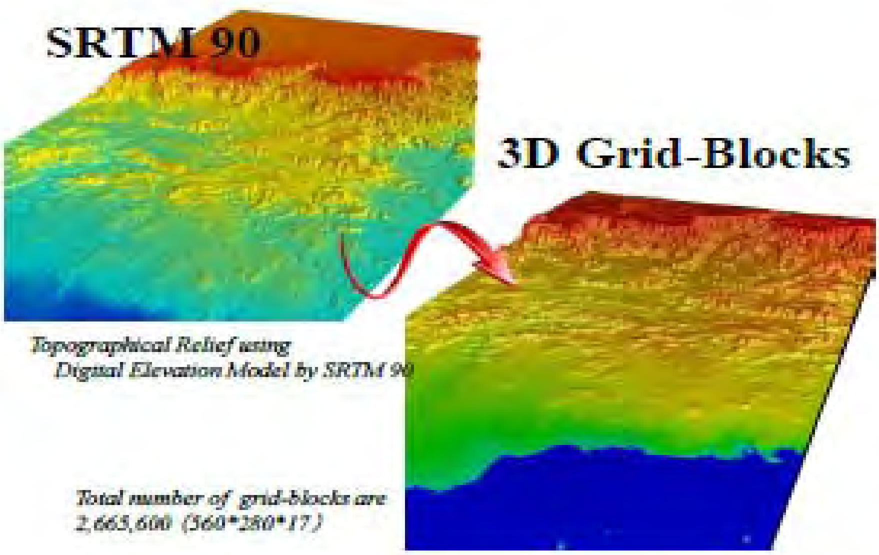


Figure 2-4 Three Dimensional Numerical Model by DEM (Digital Elevation Model)

Items for analysis and simulation are shown as follows.

1) Data preparation and identification for water resource facilities
2) Preparation of initial conditions (Wadis, Dams, Aquifers)
3) Initialization simulation for targeted basin
4) Numerical simulation
   - Location of groundwater distribution
   - Contour map for groundwater (Shallow groundwater)
   - Distribution on groundwater seepage
   - Hydraulic potential
   - Hydraulic flow direction (Plan, Three Dimensional)

Based on the simulation results, the following items on surface runoff as well as groundwater are estimated.

1) Potential of surface runoff and groundwater in Wadi basin
2) Optimum discharge and development water at dams
3) Development volume in wells

2.4.2 Simulation on Combination Operation with Dams and Aquifers

As for the effective use on renewable water resources, the cooperative operation among the neighboring dams and the combination of operations with dams and aquifers laid on the downstream will be necessary to examine the possibility of the water resources development.

In this simulation, based on the monitoring results in the Wadi Baysh, the usefulness of the application technique of the cooperative operation of dams and downstream aquifers shall be examined by the fluid-water simulator, GETFLOWS.

Targeted dams for analysis are shown as follows.

Table 2-4 Targeted Dams for Analysis (Existing and Under Construction)

Name of Dam	Location of Wadi	Catchment Area (km^2)	Annual Flow (MCM/y)	Reservoir Volume (MCM)	Specific Flow *1 ($MCM/y/km^2$)	Specific Reservoir Volume *2 (y)
King Fahd	East(Desert)	7,600	69.1	325.0	0.009	4.7
Baysh	West (Red Sea)	4,600	104.6	193.6	0.023	1.9
Hali	West (Red Sea)	4,840	122.3	249.9	0.025	2.0

Note) *1: Specific Flow=Annual Mean Flow / Catchment Area,
*2: Specific Reservoir Volume =Reservoir Volume/ Annual Mean Flow

2.4.3 Simulation on Seawater Intrusion

In the Jazan Region, the groundwater level has been fallen due to the abstraction of water for agricultural use and municipal water. In the monitoring well (6J85P) in Jazan, the groundwater level has fallen by 6m or more for the last 22 years from 1981 to 2003.

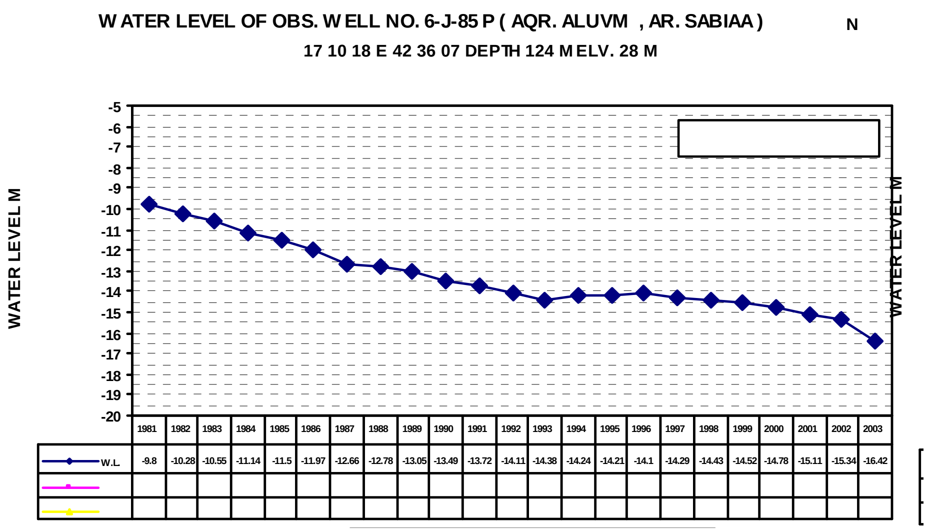


Figure 2-4 Tendency of Groundwater Level (1981-2003, Al Sabya, Jazan)

Based on the monitoring results and data for groundwater levels, the tendency of groundwater fluctuation and seawater intrusion shall be identified by using GETFLOWS, and the following items shall be examined.

1) Selection of study areas in the Jazan Region
2) Modeling and initialization
3) Preparation for simulation
   (Area for simulation, descending area of groundwater, area of seawater intrusion)
4) Simulation of groundwater descending
5) Simulation of seawater intrusion
6) Effects by artificial injection of reclaimed waste water for seawater intrusion (Specifications, Injection volume, Location of injection facilities)

Based on the above mentioned items, the following items shall be evaluated.

- The tendency of the groundwater level when the current volume of water abstraction continues
- Optimum volume of water abstraction for groundwater level recharge
- Effects of the measure for seawater intrusion by artificial injection of reclaimed waste water

2.5 Demand Projection for Municipal Water and Industrial Water

The demand for municipal (domestic water + institutional and commercial) and industrial water targeted for the year 2035 in the three regions are shall be planned and predicted.

While reviewing the existing plan such as the an examination results from the JICA master plan, and supply water plan formulate by MOWE, water demand shall be projected for every five years to the year 2035 in consideration with the estimated population results, 10th national development plan and a long-term development plan.

Based on the population for each governorate, water demand of municipal water shall be planned and formulated.

For industrial water, the daily per-labor water consumption shall be used for the projection.

About industrial water, since a part of reclaimed waste water is used, this quantity is deducted from industrial water.

The amount of demand planned for municipal water was calculated in accordance with the criteria of MOWE in the master plan study plan. Comparing with the per-capita consumption rate and service coverage, these values are larger than the actual conditions, and the growth rate of demand shall be identified appropriately and shall be examined in the study.

The areas examined are shown as follows.

1) Basic condition
（Population, Water service coverage, Per-capita water consumption, Leakage ratio, Number of labor）
2) Water demand for municipal water (Future population, Demand projection)
3) Water demand for industrial water (Labor population, Demand projection)
4) Estimated water demand for the facility plan (2035)

2.6 Water Resources Supply Volume in Three Regions

2.6.1 Renewable Water Resources

Based on the GETFLOWS simulation results, the development volume at dam sites and well fields in the Wadi basin shall be identified and examined. Effects on recharging volume in the Wadi aquifer by discharge of dams and cooperative operation with neighboring dams shall be also examined.

The development volume by renewable water at reference points such as dams and well fields is computed.

2.6.2 Desalinated Seawater and Fossil Water

The amount of supplied by the new desalination plant in the supply plan (up to 2035) by SWCC and in the Al Baha, Aisr and Jazan Regions shall be identified and examined.

As for the fossil water from Wajid aquifer in the Najran Region, the supply plan by MOWE shall be arranged and considered.

As a result, the supply plan considering the desalinated seawater and fossil water for every main period at the existing plants, including newly planned new plants in the three regions form 2015 to 20315 shall be arranged.

2.6.3 Reclaimed Waste Water

Based on the study results prepared within the Study, "Investigation and Engineering Design for Reclaimed waste water Reuse in the Kingdom of Saudi Arabia" in 2009, the future plans including the current situation for the reclaimed waste water from 2015 to 2035 shall be identified and reviewed.

2.7 Review of Water Supply Plan

Based on the results in 2.4 and 2.5, for the water supply plan within of the three regions, Al Baha, Asir, Jazan, domestic, institutional, commercial and industry water shall be reviewed. Water resources are categorized into four categories such as, surface water (Renewable Water), ground water (Renewable Water), ground water (Fossil and Non-Renewable Water) and Desalinated water. Since reclaimed waste water is being pulled from the water demand, it is considered as viable water resources.

The following items are planned and reviewed.

1) Existing water supply network in Al Baha, Asir and Jazan Regions
2) Location and production volumes for new plants (in the Al Baha and Jazan Regions)
3) Development facilities for supply (for dams, desalination plants, wells)
4) Water demand for the Region (2015-2035)
5) Water supply plan with Red Sea Water Lifeline Project (Alternative 1)
6) Water supply plan without Red Sea Water Lifeline Project (Alternative 2)
7) Water supply plan for design

2.8 Facility Plan for Red Sea Water Lifeline Project (REWLIP)

The dimensions for the REWLIP are examined based on the water supply plans. Considering the facility plan, the existing topographical map (in scale:1/10,000-1/50,000-1/100,000) shall be used for the design. Regarding about the existing facilities such as pipelines, desalination plants, water treatment facilities and dams, the existing drawings shall be gathered and used from SWCC and MOWE.

The following items are planned and designed.

1) Identification for existing facilities on desalinate plants, dams and water pipelines
2) Design for new water resources and water facilities
3) Routes for pipelines
4) Hydraulic examination of pipelines and pumping stations
5) Monitoring and operation planning for new water resources and water facilities

2.9 Organization Plan for RWPC

A new organization of RWPC, which becomes a core part of comprehensive water management in the coordination with other resources such as desalinated water shall be examined and identified.

The roles and the activities of the water related organizations, such as MOWE, the district water office (GDW), other ministries and government offices, SWCC, and NWC, shall be reviewed, and expatiated as prior to the to establishment of RWPC.

Moreover, the unification of the operational functions (communication and information transfer procedures) amongst dams and wells shall be also examined.

As part of training in a renewable water resources management plans, mid-term training (three to five months) at the water resources operation and maintenance facilities in Japan shall be carried out.

Careful review and examination of the following items are imperative.

1) The current condition for operations and maintenance of the relevant authorities (MOWE, MOA, SWCC, NWC)
2) Interview from the relevant authorities in relation to operations and maintenance
3) Establishment of a new organization for management of renewable water resources
4) Data processing, communication procedures among water facilities
5) Proposal for new organization on management of renewable water resources
6) Recommendations for the new organization RWPC

2.10 Preliminary Design and Cost Estimate

Based on the facility plan and the purpose of the economic and financial evaluation, preliminary design on major facilities on the Red Sea Water Lifeline Project including water resources development and pipelines shall be done.

2.10.1 Preliminary Design

The preliminary design for the water development facilities and water conveyance pipelines as shown below.

In addition, the design of new desalination plants is shall be based on SWCC conditions, and targeted according to related facilities such as boosters and pumping stations. Design criteria shall be based on the standard set by MOWE.

1) REWLIP (Pipelines and related facilities)
2) Dam gates and intake facilities in the aquifers in Wadis
3) Distributed sewage treatment and reuse system
4) Facilities for prevention of seawater intrusion

2.10.2 Operation and Maintenance Plan

Operation and maintenance plan for water development and conveyance facilities designed in 2.10.1 shall be formulated.

1) REWLIP (Pipelines and related facilities)

2) Dam gates and intake facilities in the aquifers in Wadis
3) Distributed sewage treatment and reuse system
4) Facilities for prevention of seawater intrusion

2.10.3 Cost Estimate and Implementation Plan

Cost estimate for construction and operation of the facilities shall be also done. Regarding existing facilities, operation cost shall be taken into consideration.

Based on the cost estimates and facility plans, the project implementation plan containing the Red Sea Water Lifeline Project, such as water supply facilities and sewage treatment plants shall will be formulated. The construction period will be set for five years.

1) Construction quantities
2) Unit cost for construction and operation
3) Cost for construction and operation
4) Project implementation plan (construction period between five and ten years)

2.11 Project Evaluation

The study team will carry out economic and financial analyses for the overall water supply plan in housing and industry, which utilizes desalination plants, wells and dams. These analyses shall include new, planned and constructing facilities, which are necessary for the procurement of the planned water quantity. The economic/financial feasibility of the water supply plan shall be considered through the comparison between the benefits and the cost.

The financial analysis shall be carried out, applying the financial value of water to the benefit of the water supply plan. The Internal Rate of Return (IRR) shall be also calculated for the economic evaluation and shall be reviewed the standard of the discount rate in the sector of water development.

In accordance to the Article five (5) of the General Environmental Law and Rules for Implementation (2001) on the Environmental Standard, Environmental Impact Assessment (EIA) shall be done for all newly proposed facilities (i.e. dams, pipelines and desalination plants) at Feasibility Study Stage.

2.12 Comments and Recommendations

Comments and recommendation shall be summarized based on the study and result.

2.13 Training in Japan and Workshop in KSA

Training on management of water resources such as dams and water channels shall be carried out in Japan.

The in training, while introducing the history of water development of Japan, it aims at developing training the actual condition of integrated water resources management including study tours for inspection of dam management in Japan and water conveyance among dams and rivers, and the environmental measures present in dam lakes, etc.

Through thorough these training sessions, the technology of the Fluid-flow simulator GETFLOWS and the geographic information technology (GIS) concerned with about the water development techniques, planning, grasp of the management technique of dam facilities, hydrological monitoring plan and its management, an environmental measures, and water resources etc. help shall be transfer knowledge to the MOWE. A training session member consists of three members blocks per time. This training is administered in Japan shall be carried out three times during the contract period. Training period is between shall be made from three months to five months.

The workshops consist of the process of the study, presentations on three-dimensional water cycle simulation, field survey results such as the collaboration operation between dams and aquifers as well as measures for seawater intrusion results shall be held in Jazan or Riyadh.

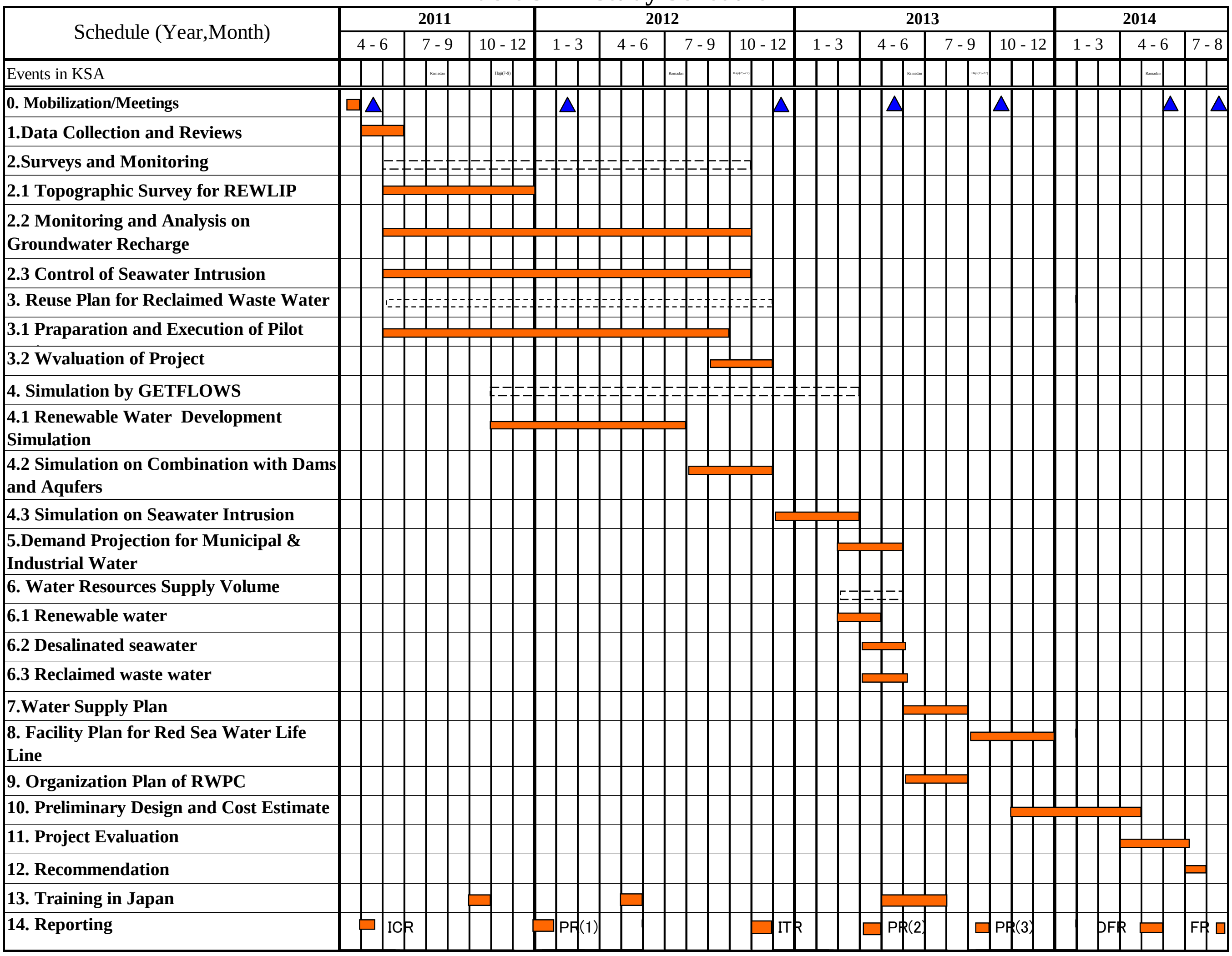
CHAPTER 3 Study Schedule and Reporting

3.1 Study Schedule

The study will start in May, 2011 and will be scheduled for 19 months until November, 2012. Ramadan and the Haji vacation / holy periods were taken into consideration in constructing the study plan schedule. The training in Japan is scheduled and planned for three sessions. On the job training for the maintenance and operation on water resources facilities in Japan will be carried out for the counterparts of the KSA.

The study schedule is shown below.

Table 3-1 Study Schedule



3.2 Reporting

The following report in English should be submitted in the Study are follows.

Table 3-2 Reporting

Report	Submission	Copies	Remarks
1) Inception report	Beginning of the study	20	English
2) Progress report (1)	Within 9 months from the commencement	20	English
3) Interim Report	Within 19 months from the commencement	20	English
4) Progress report (2)	Within 24 months from the commencement	20	English
5) Progress report (3)	Within 29 months from the commencement	20	English
6) Draft final report	Within 38 months from the commencement	30	English
7) Final report	Within 40 months from the commencement	30	English

3.3 Other Required Items for the Study

3.3.1 Required Material and Equipment

The office spaced and equipment necessary for the study will be prepared by the MOWE.

1) Office space
2) Tables and chairs for the experts : 10 sets
3) Table and chairs for the meeting : 1 set
4) Telephone with facsimile : 1 set

3.3.2 Cooperation Matters from MOWE

The facilitation and cooperation matters from MOWE are carried out as follows.

1) Visa applications
2) Cooperation on collection and request of the data, reports and drawings
3) Cooperation related safety
4) Others (Accidents, Medical treatments, etc.)