Geological Model and Groundwater Aspects of the Area Surrounding Eastern Shores of Dead Sea (DS)–Jordan

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Abstract: - Many different cross sections were created along the eastern shores of the Dead Sea (DS). These geological cross sections were used to develop a geological model of the DS area and determine the groundwater directions in the area surrounding DS. The geological model showed that the direction of the groundwater flow is to the west and northwest directions toward the Dead Sea. This model shows that the most of the geological units dip to the west and southwest directions toward the Dead Sea. In the area adjacent to the eastern shores of the Dead Sea the B2/A7 which is defined as upper aquifers were eroded and the Kurnub sand stone, Zarka and Ram sandstone group which are defined as a lower aquifers are cropping out**.** It shows that the groundwater flows from the east and northeast to the west and southwest toward the Dead Sea. At the east of the Dead Sea the upper aquifer is unsaturated because it crops out.

Key-Words: - Dead Sea, geology, Model, groundwater, Dip, Aquifer, Kurnub

1 Introduction

The DS located in the central part of the Jordan Rift Valley, which extends from Lake Tiberias in the north to the Gulf of Aqaba at the south, and includes the Jordan River in the north, the Dead Sea region in the middle and the southern Ghors (Haditha, Mazra, Safi), Wadi Araba and the Gulf of Aqaba in the south. Geologically, the Dead Sea "lake" is situated within the large Dead Sea basin, which is one of the pullapart basins that formed along the Dead Sea Rift (Quennell, 1959) and it is located in the southern sector of the Dead Sea Transform (DST), which separates the Arabian and African plates (Capaccioni et al. 2003) as shown in (Fig. 1). The Dead Sea can be traced in terms of plate tectonics to the movement of the great plates into which the lithosphere is divided (Steinhorn and Gat, 1983).

2 Geology of the Dead Sea Area

The Dead Sea area lies at the north margin of the Arabian Shield. From the plate tectonic point of view it is located at the western margin of the Arabian plate, which is separated from the Palestine Sinai plate by the Dead Sea Rift with horizontal displacement to the north relative to the Palestine Plate (Freund et al. 1970).

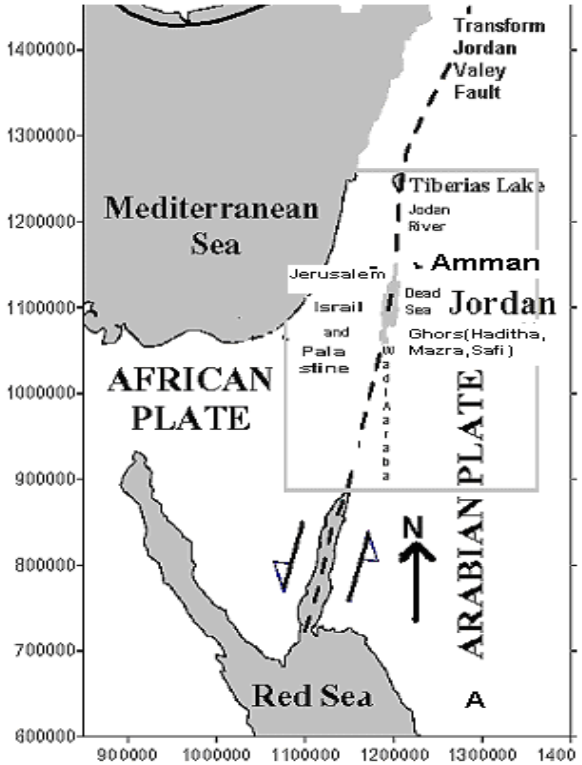

Figure (1): The location of the DS relating to the Jordan Valley Rift

According to Bender (1968) the Dead Sea area has been controlled through the geological history by two factors, namely: The Tithys Ocean, which invaded the region several times, depositing the marine successions and the presence of the neighbouring Arabian Shield in the south, which displayed an important source for sediments.

2.1 Stratigraphy of the Study Area

Cretaceous rocks cover the eastern part of the investigated area, while westwards; the oldest formations are of middle Cambrian age. Close to the eastern shoreline of the Dead Sea. Triassic and Lower Cretaceous rock crop out. Volcanic eruptions occur in many places of the area but mostly in the western part along the Dead Sea coast. The stratigraphical lowest outcropping member is the Cambrian; Umm Ishrin formation, which consists of sandstone followed up by Triassic Zarka Ma'in group consisting of sandstones, limestone and shale, followed up by the Lower Cretaceous Kurnub sandstone and the Upper Cretaceous Ajlun group being mainly a carbonate-dominated sequence. Belqa group Upper Cretaceous - Tertiary follows it. This group is missing in the end northern part of the study area. The youngest geological units are the Quaternary Lisan marl of Pleistocene age (Bender, 1974) and the basalt flows dated 0.6 Ma BP (Duffield et al. 1987). Figure (2) shows the geological and structural map of the area surrounding the Dead Sea.

The sequence of the lithological units of the Dead Sea area is shown in Table (1). The detailed of these units are described in the geological maps Ma'in, Ar-Raba and the southern part of Al-Karameh sheet in scale of 1:50,000, which were produced by the Geological Mapping Division in NRA. The details are described as the following:

1) Ram Sandstone Group

This group has named by Quennell (1951) and Burdon (1959). It is considered one of the lower aquifer in the area. This group divided into two formations in the study area as following:

- Burj Dolomite-shale Formation (BDS): Only the uppermost part of the carbonate sequence of this formation is exposed in Wadi Zarka Ma'in area. The outcrop extends about 1 km to the north along the eastern shoreline of the Dead Sea. This formation had defined by Quennel (1951). It consists of dolomitic limestone, dolomite and sandy dolomite. The age of this formation is lower to Middle Camprian.

- Um Ishrin Sandstone Formation (IN): This formation has named by Lloyd (1969). It is equivalent to Quwiera sandstone as Quennel (1951) and Burdon (1959). It crops out at the in the west along the Dead Sea escarpment north of Wadi Al Hasa and at the eastern part of the Dead Sea at Wadi Al Hidan. It is steeping rugged cliffs and deep Wadies to the south. It consists of brown, red-brown, yellowish, and red-violet colored, medium to coarse grained, massive weathered sandstone. The thickness of Umm-Ishrin formation is about 300-350m. The age of this formation is lower to Middle Cambrian (Freund et al., 1975).

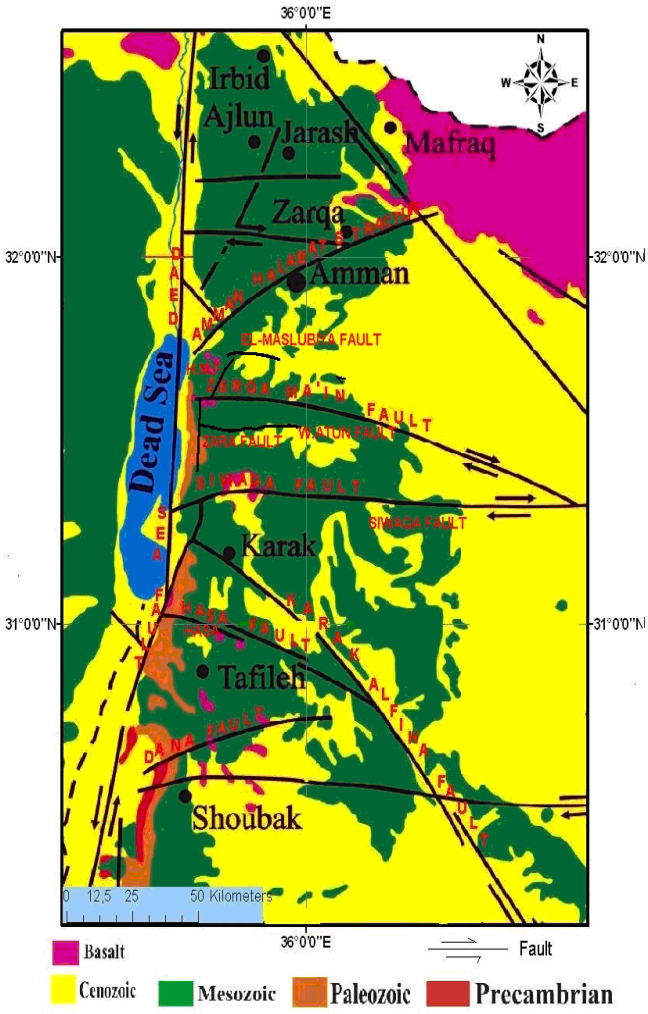

Figure 2: The geological and structural map of the DS area

Table (1): Chronological sequence of the lithological units in the DS area (Internal reports, NRA)

Period	Age	Group	Unit	Lithology
	Recent		River,Terrace	Gravel, Clay, Sand
Quaternary	Pleistocene		Lisan	Marl, Gravel, Clay, Gypsum, Sand
	Pliocene	Jordan Valley		
	Miocene		Undifferentiated	Conglomerate, Marl
	Oligocene			
Tertiary	Eocene		Wadi Shallala(B5)	No data at Dead Sea area
	Paleocene	Belqa	Umm Rijam(B4)	Limestone,Chert
	Maestrichtian		Muwaqqar(B3)	Chalky Marl
	Companian		Al Hasa(B2a)	Phosphate
Upper Cretaceous			Amman(B2b)	Silic. Limestone
	Santonian		W. Ghudran(B1)	Chalky Marl, Chalk
	Turonian		Wadi Es Sir(A7)	Limestone
		Ajlun	Shueib(A5-6)	Marly Limestone
			Hummar(A4)	Dolomatic Limestone
			Fuheis(A3)	Marl
			Na'ur(A1-2)	Marly Limestone
	Albian		Kurnub Sandstone	White Sand Stone
Lower Cretaceous	Aptian	Kurbut		Varicolored Sandstone
	Neocomian			Lst.,Shale, marl, dolomite.
Permo Triassic			Dardur	Sandstone, Marl, Shale
		Zarqa-Main	Ma'in	Sandstone, Siltstone,Clay
			Umm Irna	Sandstone, Siltst., Shale
Silurian	No Strata	Present	In The Dead	Sea Area
	No Strata	Present in	The Dead	Sea Area.
Ordovician			Umm Sahm	No strata at the Dead Sea
		Ram	Disi	No Strata at the Dead Sea
			Umm Ishrin	Sandstone, Siltstone
Camprian			Burj	Dolomite,Shale,Sandst.
			Salib	Sandstone, Siltstone
Pre-Camprian			Not presented	In the Dead Sea Area
		Safi		

2) Zarka Ma'in Group (MK-MN)

Blake (1936) described the Triassic Rocks near the mouth of Wadi Huni and Wadi Zarka Ma'in 25 km of south Wadi Hisban.

It was divided into six Formations as following:

- Umm Irna Sandstone Formation: The outcrop of this formation is restricted to cliffs adjacent to the Dead Sea shorelines. It consists of lower thin-bedded clastics unit and upper thick bedded clastic unit. It consists of sandstone upward fining sequences. It is from Permo-Triassic age (Bandel and Khouri 1981).

- Ma'in Sandstone Formation: It consists of fine to coarse-grained sandstone, siltstone, and clay intercalated with carbonate rocks. It crops out along the Dead Sea shorelines and in deep Wadis between Wadi Mukheiris to the north and Al Mamaleh to the south. It is from a Scythian age.

- Dardour Formation: This formation is from an Anisian–Carnian age. It consists of cream, yellowish, black and dark green marl, shale, dolomitic limestone with cross-bedded sandstone and dolomitic sandstone. It crops out along the Dead Sea shorelines between Wadi Abu Khusheiba to the south and Wadi Mukheiris to the north.

- Ain Musa Formation: It consists of massive glauconitic sandstone intercalated with siltstone, clay beds, marl and fossiliferous limestone. It crops out between Wadi Manshala to the south and Wadi Mukheiris to the north along the eastern shoreline of Dead Sea. It is age from Anisian (Bandel and Khoury, 1981).

- Hisban Limestone: Formation It consists of massive dolomitized limestone. Its age is early Anisian (Parnes, 1975).

- Mukheiris formation: It crops out in Wadi Mukheiris directly at the shore of the Dead Sea in Wadi Mukheiris and Wadi Dardur. It consists of calcareous sandstone intercalated with sand and clay (Bandel and Khoury 1981). Its age is from early Ladinian.

3) Kurnub Sandstone Group (KS)

Kurnub sandstone is locally cropping out along the eastern heights of Jordan Valley along the rift margins along the eastern shoreline of the Dead Sea. It forms accessible cliffs above the steep escarpment of the harder Umm Ishrin Sandstone. Kurnub sandstone is composed mainly of red, violet, purple, and brown sandstone with varying proportion of clay and siltstone beds. The upper part of this unit is characterized by the increase in the presence silty shale and marl and characterized by cross bedding. Its thickness in Zarka-Ma'in is around 330 m (Bender 1974). The age of this group is Neocommian to Cenomanian from Mesozoic Era. It is one of the deep aquifers in the area.

4) Ajlun group: discomformably overlays the Kurnub sandstone group. It has been subdivided into five formations as follows:

- Na'ur Limestone Formation (A_1-A_2). It consists of succession of limestone, dolomite and marl (Powell, 1989). Its age is from Lower Cenomanian. It crops out in the deep Wadies in the central parts of the Ma'in sheet east of the Dead Sea. It is one of the minor aquifers in Jordan.

- Fuhays Formation (A_3): It is equivalent to A_3 and the middle part of the Nodular limestone of Bender (1974). It is consisted of yellow grey calcareous siltstone, marl and marly limestone, nodular limestone and fossiliferous limestone. It exposes along the deep Wadies north of Wadi Abu khusheiba and road cuts between Ma'in village and Ma'in hot springs. The age of this formation is Cenomanian.

- Hummer Formation (A_4): It is equivalent to A_4 and to the echinoidal limestone of Bender (1974). It consists mainly of grey limestone, dolomitic limestone and dolomite. The age of this formation is Cenomanian. It is crops out north of Wadi Abu Khusheiba along the Dead Sea shoreline. It is a minor aquifer in the area.

- Shua'yb Formation (A_5-A_6): It is equivalent to A_5 and A_6. It consists of red green buff calcareous siltstone with gypsum

viens and thin limestone beds with orange algallaminated dolomite and mudstone. It crops out in north of Wadi Abu Khusheiba along the Dead Sea shoreline. Its age is Early Turonian.

- Wadi Es-Sir Limestone Formation (A7): It comprises the upper most part of Ajlun group (A7) (Mackdonaled et. al. 1965). It consists of limestone, dolomitic limestones, marly sandstone and chert. The upper part consists of thick-bedded fossiliferous limestone alternating of thin chert bands. Its thickness is about 100 m in Wadi Abu Khusheiba and 85 m north of Wadi Zarqa Ma'in. It crops out at the middle part of the Dead Sea along the shoreline.

5) **Belqa Group:** The age of this group ranges from Coniacian to Eocene. It had divided lithologically by Paker (1970) into four formations as the follows:

- Wadi Umm Ghudran Formation (B1) It is equivalent to B**1** (Mackdonald et. al. 1965), and equivalent to upper part of massive limestone (Bender,1974). This formation is well exposed above the prominent cliff, which is formed Wadi Es-Sir (A7) formation at the north and south of Zarka Ma'in fault. It consists of white or buff chalk with bed of grey chert, phosphatic sandstone and phosphatic siltstone (Bender, 1974 and Powell, 1988). The age of this formation is Coniancian – Campanian (Powell, 1988).

- Amman Silicified Limestone Formation (B2).This formation consists of limestone, dolomite intercalation with chert and laminas of chalk. It crops out in the deeply incised Wadi Al- Hidan and south of Wadi Mujeb. The age of this formation is Companion. This formation combined with B**2** formation is considering a main upper aquifer (B2/A7) in the area.

- Al Hisa Phosphorite Formation (B3): It consists of calcareous, silicified, argiallaceous phosphorites beds, limestone, chert, marl, and oyster lumlachella (coquina) beds. It crops out at the east of the southern part of the Dead Sea between Wadi Mujeb and Wadi Al Hidan and south of Wadi Mujeb (Wadi Al Hasa). The age of this formation is Campanian to Maastrichtian - Danian (Powell, 1988).

- Muwaqar Formation (B4)It poorly crops out at the southern part of the Dead Sea at south and north of Siwaqa fault. It is covering with soil in the south and north of Wadi Mujeb. It consists of soft marl and white yellowish chalk. The age of this formation is Upper Maastrichtian.

- Um Rijam Formation (B5): The outcrops of this formation are restricted to the Adh Dhira Monocline south of Wadi Al Karak. It consists of chalk, chalky limestone, and phosphatic limestone with laminas of chert. Its age is Early Palaeocene to Eocene. It consist of the followings:

Dana Conglomerate (DC): It crops out at the end southern part of the Dead Sea at the Adh Dhira area at Wadi Al Karak. It consists of marl, and sandy marl, layers and nodules of conglomerate. Its age is Oligocene.

Lisan Marl Formation (LMg): It presents adjacent to the Dead Sea unconformable on strata. It is ranging in age from Cambrian to Neogene (Bender, 1974).

Superficial Deposits: Fluviatile and Lacustrine Gravel (PL): It consists of coarse-grained sand and gravels. The latter composed of sub-angular pebbles and cobbles. Clasts are chert, limestone, dolomitic limestone, sandstone and basalt. Alluvial Fans: It consists of sand and gravel with soil covered developed in Holocene to present. Travertine: It is a carbonate rock resulting from the precipitation of limestone from hot waters and its age is Pleistocene (Bender 1974).

2.1.1 Volcanic Rocks

Basalts crops out between Siwaqa fault and Wadi Ash Shaqiq. It is recorded of 10 m basalt on the flanks of Wadi Mujeb (Barberi, et al.1980). It crops out along Zarka Ma'in fault and at some locations to the east of the Dead Sea. Figure 3 shows the locations of geologiccross-sections exposed on the geological map.

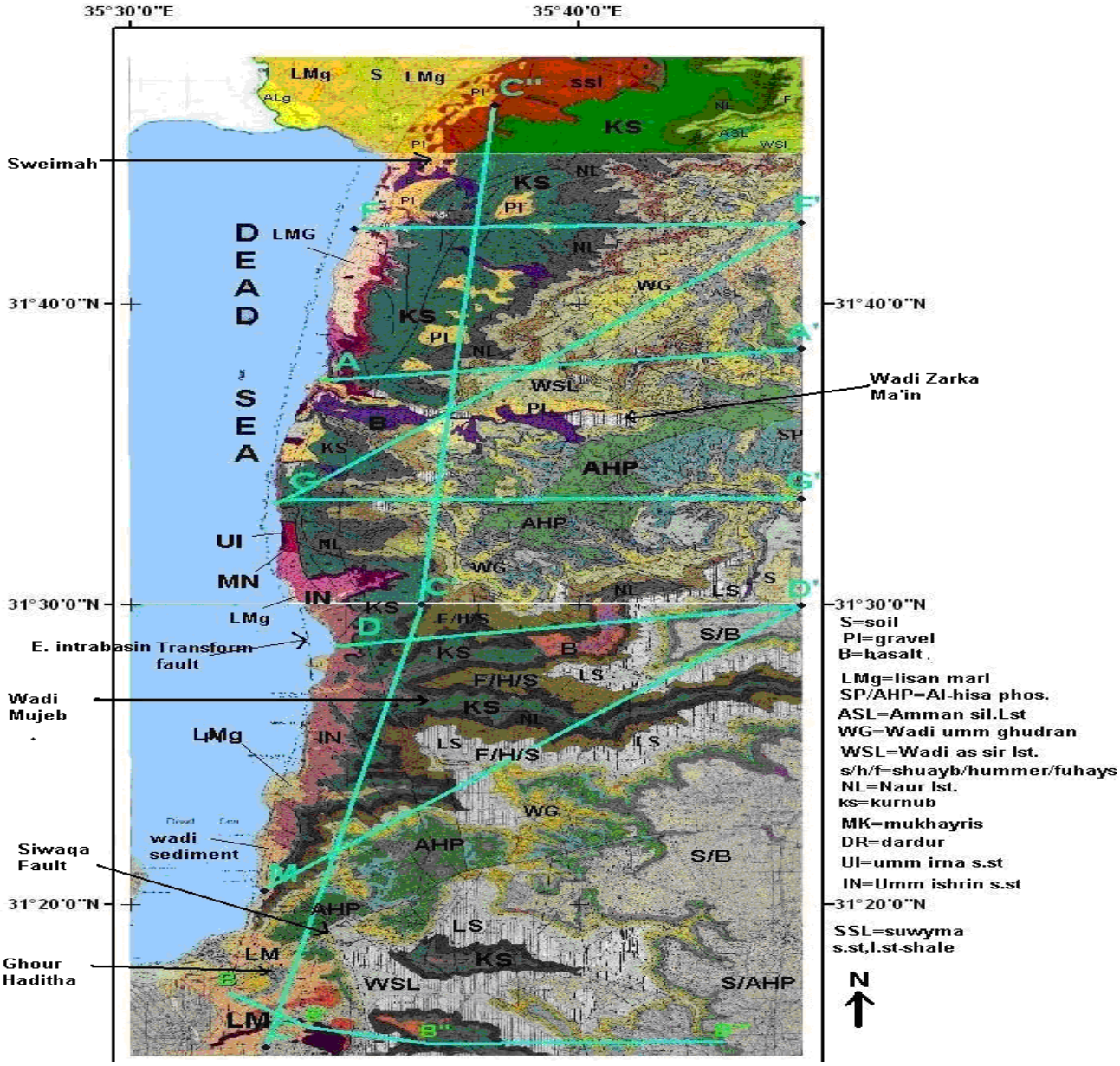

Figure 3: Locations of geologic cross- sections exposed on the geological map

2.2 Structural Settings in the Dead Sea

Most of the structural features in the study area are parts of and influenced by the prominent outstanding structural feature affecting the whole are along Jordan Graben. The Dead Sea Transform in Jordan is composed of three morpho tectonic segments; Wadi Araba at the south, Dead Sea at the middle and Jordan Valley at the north. Together they form morphological depression that extends from the Gulf of Aqaba to Lake Tiberias about 360 km long (Bender, 1974). It is a part of the east African-South Turkey rift system that has a total length of 6000 km (Bender, 1974). The Wadi Araban segment trends 15^{o} east of N with length about 200 km while the Dead Sea –Jordan Valley Riftsegments trends with 5^{o} NE with about 160 km length (Burdon, 1959, Bender,1974).In addition to the Dead Sea transform fault system, which is the major active strike – slip fault system, there are many other structural features in the area between the northern end of the Dead Sea and the northern part of Wadi Araba. These are:

- **Zarka Ma'in Fault:** This fault commences at the Dead Sea and continues eastwards.

The downthrown of this fault is about 250 m near the Dead Sea. The downthrown decreases eastwards and turns over in a flexture. On the southern part of this fault basaltic eruption occurred at the downthrown block, while hot springs issue on the northern block from Lower Cretaceous Kurnub Sandstone (Wiesemann, 1969). It trends E–W.

- **Wadi Atun Fault:** This fault trends to E–W. It extends from the Dead Sea shore to Wadi Wala. It is sub-parallel to Zarka Ma'in Fault. It divides Zara area into north and south Zara.

- **El-Maslubia Fault:** It starts at Wadi Kashem Jiwan basalt (in the northwest) and extends for about 5 km eastwards (north of Ma'in village). It trends E–W.

- **Humrat Ma'in Fault:** It is parallel to the Dead Sea coast in the southern part between Wadi Zarqa Ma'in and Wadi Manshala. It appears 2 km east of the Dead Sea coast at its southern part and 4 km distance from the Dead Sea at its northern end (Atalla 1981). It trends NE–SW and the downthrown is the NW block.

- **Zara Fault:** It trends N–S. It commences north of Wadi Mujeb and runs along the eastern escarpment of the Dead Sea. The hot springs in Zara area are related to this fault (Wiesemann, 1969).

- **Wadi er Rashsha Fault:** This fault extends from upper Wadi Zerka Ma'in to about 1 km south of Ma'in village. It is trending NE–SW and the downthrown is towards the SE.

- **Karak Al-Fiha Fault zone:** It rends NW-SE and extends about 300km.

- **Siwaqa Structure:** It is a normal fault,which strikes between NNE and ENE. It has a northern downthrown, while theeastern main fault has a southern downthrown. The faults trend NE-SW, while it trends NW-SE in the northern part of the area (Atalla 1981).

- **Amman-Halabat** Structure-NE-SW trending

- **Wadi Zarka Ma'in Syncline:** It passes gradually through a graben and pluges westwards. Its axis is almost along the Wadi and parallel to the Zarka Ma'in fault. Both the graben and the syncline are asymmetric.

- **Wadi Um Ghureiba Anticline:** It is exposed east of the Dead Sea at Um Ghureiba north of Wadi Mujeb with a NE axial strike. The extension of this anticline is about 8 km.

- **Quallat Et Taweiyil Anticline:** It extends for about 3 km in a NNE–SSW direction along the road to Zarka Ma'in hot springs.

- **Hammrat Ma'in Anticline:** It is an asymmetrical anticline NNE trending. It starts near Wadi Durdur and extends to about 3 km to the SSW.

- **Haditha Syncline :** It trends NNE-SSW and plunges NNE. According to Bender (1968), there are many flexures east of the Dead Sea dipping to the west as (Karak flexure, Wadi Mujeb and Wadi Hisban).

3 Results and Discussions

The geology of the Dead Sea is quite complicated. It includes both unconsolidated superficial geological formations and bedrock outcrops. The area is highly faulted and folded with axes extending NE-SW. The bedrock is typically highly fractured at the surface extending in the subsurface for many meters.

Different geologic cross sections were constructed parallel to the Dead Sea shores direction N-S and others E-W and NE–SW. Figure (3) shows the locations of these cross sections exposed on the geological map. That is expected to assist in understanding the hydrological and hydrogeological aspects of the area adjacent to the eastern shores of the Dead Sea. The symbols and coordinates of the geological cross sections are given in Table (2).

Table 2: The cross sections locations and the cross sections symbols

Section symbol	East	North	Section symol	East	North	Section symbol	East	North
A-A			D-D′			G-F′		
A	35° 34′30″	31° 37′30″	D	35° 34′58″	31° 28′40″	G	35° 33′30″	31° 33′30″
A′	35° 45′00″	31° 38′30″	D′	35° 45′00″	31° 29′57″	F′	35° 45′00″	31° 42′42″
B-B′-B′′-B′′′			F-F′			M-D′		
B			F	35° 35′00″	31° 42′30″	M	35° 33′00″	31° 20′28″
B′	35° 31′30″	31° 17′10″	F′	35° 45′00″	31° 42′42″	D′	35° 45′00″	31° 29′57″
B″	35° 32′56″	31° 16′00″						
B‴	35° 34′30″	31° 15′22″						
	35° 44′48″	31° 15′30″						
C-C′			G-G′			C′-C″		
C	35° 33′00″	31° 15′00″	G	35° 33′30″	31° 33′30″	C′	35° 36′30″	31° 30′00″
C′	35° 36′30″	31° 30′00″	G′	35° 45′00″	31° 33′31″	C″	35° 38′00″	31° 46′00″

3.1 Geological cross sections

Geologic cross sections were extended all over the Dead Sea area and cover a large area, which is divided into three parts. The first one extends from the northern end of the Dead Sea in Sweimah area to Zarka Ma'in fault line. The second part extends between Zarka Ma'in fault line and Siwaqa fault and the third one extends from the Siwaqa fault to end southern of the Dead Sea.

The geological cross section A-A′ is located at the north of Zarks Ma'in fault. The direction of this section is SW-NE (Fig. 4).

The section shows that the layers slope gently toward Wadi Zarka Ma'in. Kurnub sandstone aquifer (KS) crops out at the SW part of the section north of Zarka Ma'in fault. The upper aquifer (B2/A7) is cropping out along the section and missing farther to the SW direction. The expected groundwater flow direction is from NE toward Wadi Zarka Ma'in and it continues to the SW toward the Dead Sea. The geology of Sweimah area is described by using the geological cross section F-F` which is located at this area with direction W-E (Fig.5). The cross section shows that the geological strata of Sweimah area dip gently from east to west, but they are dipping with high increased slope at the west end of the cross section toward the Dead Sea. The cross section shows that the lower aquifer (KS) is cropping out in the west of the cross section. The groundwater might be flowing from the east to the west toward the Dead Sea relating to the dip direction of the layers. The geology of the area, which is located between Wadi Mujeb and Zarka Ma'in, is represented by the geological cross sections D- D` and G-G` (Fig. 6), and (Fig. 7) respectively. The direction of the geological cross section D- D` is SW-NE. It represents the geology

of the area located to the north of Wadi Mujeb. The cross section shows that the eastern part of the section is highland with horizontal geological layers covered with a layer of soil. Then the layers are sharply removed by erosion toward the Wadi Hidan to the west of the section. The upper aquifers (B2/A7) are missing and the lower aquifer (KS) is cropping out at Wadi Hidan and Wadi AnNimer.

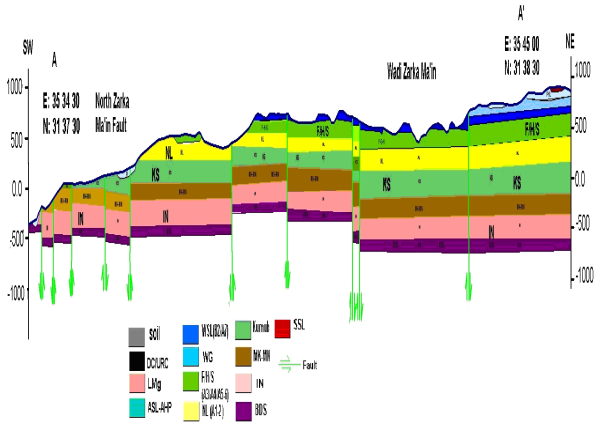

Figure 4: Geological cross section A-A′ in north of Zarka Ma'in fault

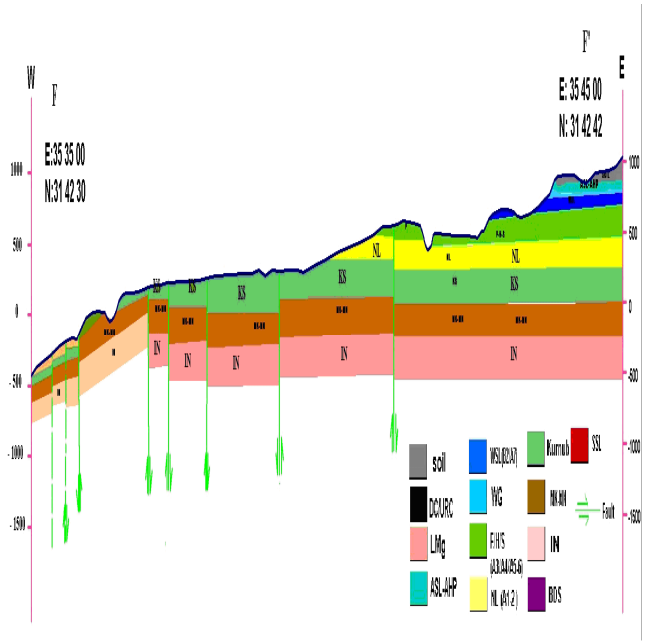

Figure 5: Geological cross section F-F` in Sweimah area

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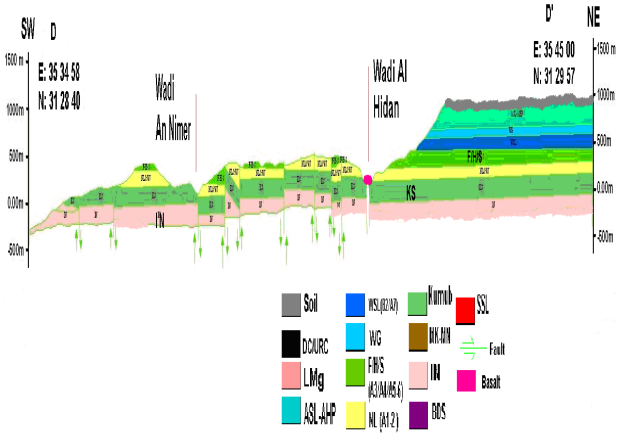

Figure 6: Geological cross section D -D`located north of Mujeb

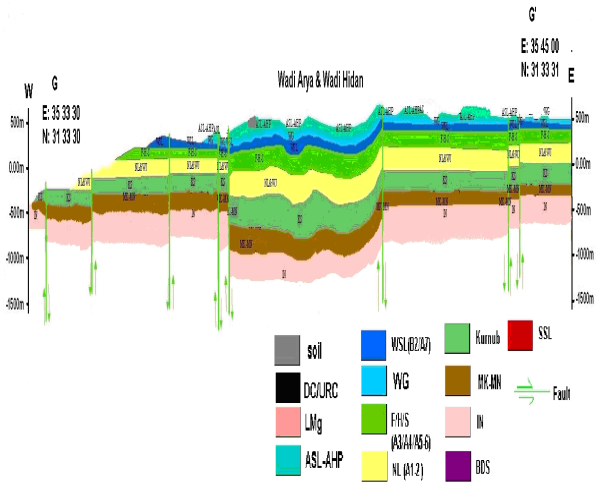

Figure 7: Geological cross section G -G`located in north Wadi Mujeb

The lower aquifer Umm Ishrin (IN) is cropping out southwest of Wadi AnNimer that adjacent to the Dead Sea. The groundwater direction is from NE to SW to Wadi Hidan and Wadi AnNimer then toward the Dead Sea The direction of the cross section G-G` is W-E and it shows that strata dip toward Wadi Arya and Wadi Hidan to the west of the section. They are uplifted again to the west of these Wadies and so the upper aquifer is cropping out and then missing farther to the west. Thereafter the upper layers are eroded and the lower aquifer is cropping out adjacent to the Dead Sea. The expected groundwater flow direction is from the eastern highland toward Wadi Arya and Wadi Hidan then continues toward the Dead Sea at the west of the section. To understand the effect of Wadi Zarka Ma'in Fault on the geology in the area surrounding this fault the geology cross section G-F` (Fig. 8) was

constructed in the SW-NE direction crossing this fault. The cross section shows that the layers are dipping toward Wadi Zarka Ma'in from both NE and SW directions. The groundwater might be flowing from NE and SW toward the Wadi Ar Rashash and Wadi Jaber which are located to both sides of Wadi Zarka Ma'in fault. From there it might be flowing to Wadi Zarka Ma'in then it continues to the west toward the Dead Sea., a surface and groundwater Also might be flowing to Wadi Abu Khushiba at the southwest of the cross section and then might be discharging into the Dead Sea to the west.

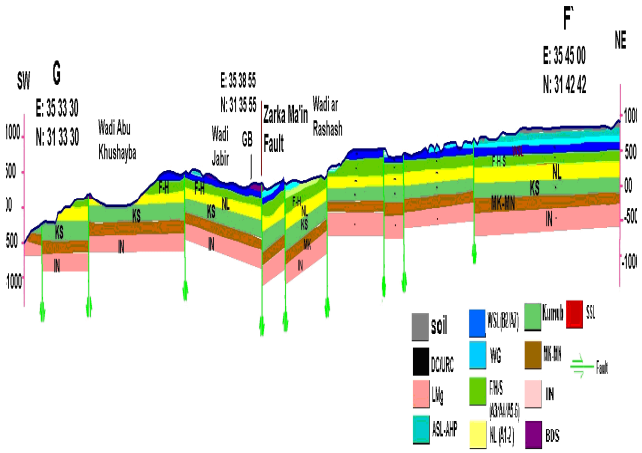

Figure 8: Geological cross section G F` crossed Wadi Zarka Ma'in

The geological cross section M-D` (Fig. 9) was drawn to understand the geology of Wadi Mujeb. This cross section is SW-NE direction crossing Wadi Mujeb. The cross section shows that the geological strata are eroded and the topography dips toward Wadi Mujeb from both NE and SW directions. At the uplifted western side of the cross section the layers are dipping to SW direction. The lower aquifer Kurnub sandstones (KS) crops out in Wadi Mujeb. The surface and groundwater might be flowing toward Wadi Mujeb. At the uplifted side of the cross section the groundwater might flowing in SW direction toward the Dead Sea. The cross section B-B′-B″-B‴ is located in the southern of the study area at Gohr Haditha (Fig. 10) close to the southern basin of the Dead Sea. The direction of this section is W-E. The section shows that the layers in the eastern part are quite horizontal and the topography is high. The topography slopes toward the west direction and the layers dip sharply to the west and then become horizontal with very small dip angle.

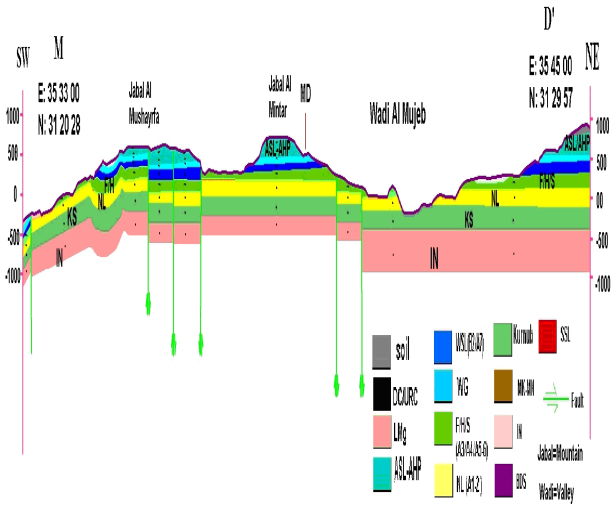

Figure 9: Geological cross section M-D`crossed Wadi Mujeb

The deep aquifers Umm Ishrin sandstone (IN) and Kurnub sandstone (KS) are outcropping in Wadi Al Karak. As well the upper aquifer crops out at east of Wadi Al karak and at Wadi Adh Dhera. The surface water and groundwater are expected to flow toward the Wadi Al Karak from the eastern mountains. The groundwater might be flowing from the east toward Wadi Adh Dhera.

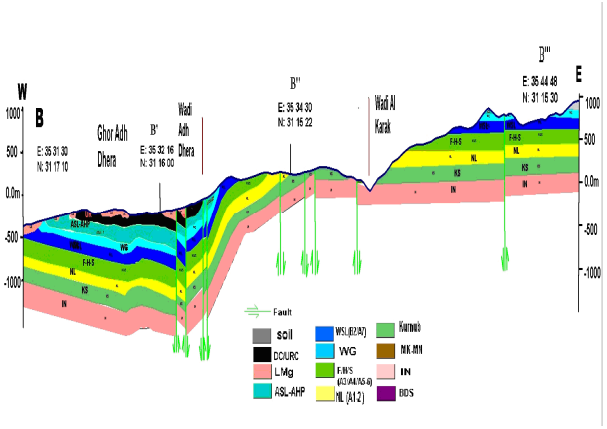

Figure 10: Geological cross section B-B′-B″-B‴ in Ghor Haditha

One cross section (C-C`-C``) was constructed parallel to the Dead Sea in a S - N direction. It extends from Ghor Hadetha, southern part of the Dead Sea, to Sweimah, northern part of the Dead Sea (Fig.11). The figure shows that the Siwaqa fault intersects the section. South of Siwaqa fault, the layers dip to the south while in the north of Siwaqa fault the layers dip to the north (apparent

dip). The lower aquifer (Kurnub sandstones) crops out at the northern part while they are overlying with the younger strata at the southern part. Consideringthe 3-D situation the groundwater is expected flows west with a southerly componentof Siwaqa.As well considering the northerly components of Siwaqa considering the northerly components north of Wadi Zarka Ma'in the groundwater might be flowing to the north direction parallel to the Dead Sea then it continues to the west toward the Dead Sea.

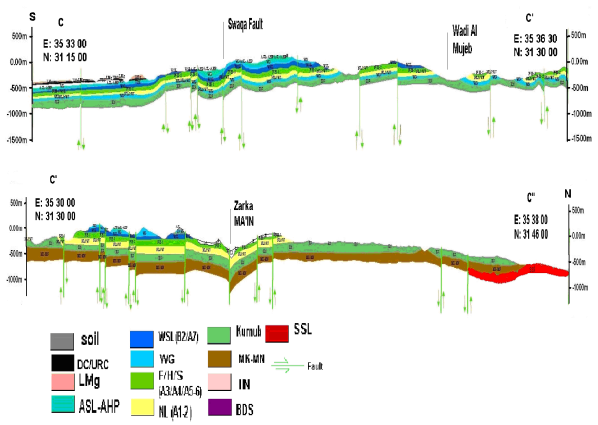

Figure 11: Geological cross section C-C`-C``parallel to the Dead Sea

3.2 Groundwater flow

Salameh and El-Naser (1999) estimated the water discharge to the Dead Sea by using water balance calculations. They compared the water balance before (predevelopment) and after water resources development. They found that the amount of water that used to flow into the Dead Sea before development was 1980 MM^3/y and after development (present day) is about 617 MM**3**/y for the total catchments area of the Dead Sea.

Salameh and El-Naser (2000), studied the saltwater – freshwater interface and transition zone in the groundwater flow system of Dead Sea in Zarka Ma'in area in detailed By using Ghyben - Herzberg formulas (Fig 12). They mentioned that the saltwater–freshwater interface starts at the shores of the Dead Sea with very steep gradient of inclination and gradually events out landward where it tends to become horizontal at an aquiclude. The quantity of groundwater discharge into the Dead Sea from the western side equals about 50 MCM/y (Salameh and El-Naser, 1999), and the flow from the eastern side 90 MCM/y. As well there is about 85 MCM/y of return flow from irrigation and subsurface flows and saltwater diversions into the Jordan River (Salameh and El-Naser, 1999). Then the total amount of groundwater inflow into the Dead Sea equals to 225 MCM/y.

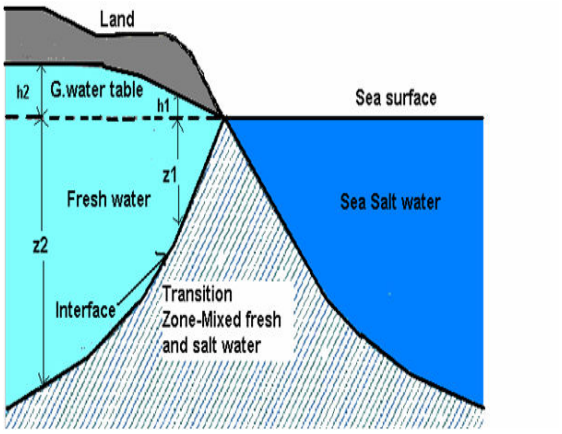

Figure 12: Schematic diagram showing the relationship between groundwater level and depth of the interface (After Salameh and El-Nasser 2000).

According to Salameh (1996) the average annual amount of precipitation all over Jordan is about 7200 MCM. Figure (2-5) shows the rainfall percentages in Jordan. This precipitation amount is flow down to the Dead Sea and Jordan Valley areas through the Wadies adjacent to these areas. Some of it also infiltrates through the fractures and porosity into the upper aquifers (B2/A7) and Jordan Valley conglomerate deposit which contain a meteoric water flow to the Dead Sea under hydrostatic head. Part of this surface water which flow toward the Dead Sea and Jordan River are collected by dams which established in these areas as Shueib, Kafrain, Al Waleh, Mujeb and Al Karameh before reaching the Dead Sea and Jordan River. The rest of the precipitation drains to the Dead Sea and Jordan River.

The deep Aquifers (Kurnub) contain fossil water in the Jordan. These aquifers In the Dead Sea area exposed and receive amount of the precipitation through faults, fractures. Then the meteoric water and fossils water are mixing in the Dead Sea area and seep to the Dead Sea under hydrostatic head. The Potential evaporation ranges from 2000mm/year at the most northwestern edge of the

country, to more than 4000mm/year in the Aqaba at the south and Azraq at the East of Jordan. It rates about 2500 mm / year at the Dead Sea (Salameh and Bannayan 1993). The floodwater from the rainfall and snowfall at the eastern highlands during wintertime and the base flow springs around the area are the main recharge source for the groundwater of the shallow aquifers in the study area. It flows through the Wadies passing adjacent the Dead Sea area.

Based on the geological maps, (http://exact-me.org/overview/p17.htm) and the available data from (WAJ) the Dead Sea basin was constructed and modified as in (Fig. 13). The Dead Sea basin is bisected by Siwaqa fault into a northern and a southern part. The fault forms a permeable discontinuity (GTZ, 1995). The groundwater flows in a west north western direction and toward Wadi Wala.

The figure shows that the upper aquifer (B2/A7) crops out in the Dead Sea basin area. On the other hand this aquifer absent on the north western part of the basin, while the minor aquifers and the aquitards crop out. The lower aquifers (Kurnub and Umm Ishrin) crop out at the area adjacent to the Dead Sea shores. Figure 13 shows the groundwater flows toward the Dead Sea. Water data bank project, Multilateral working group on water resources, and Middle East Peace Process, give the researcher the information to overview of Middle East Water Resources.

3.3 Conceptual Hydrogeological Model

A conceptual hydrogeological model of the Dead Sea was produced along NE-SW direction (Fig. 14). The model shows the main upper aquifer (B2/A7) underlay with the minor aquifers, aquitard and lower aquifer (Kurnub-Zarka-Ram groups). It shows also that the groundwater flows from the east and northeast scarpments toward the Dead Sea. It shows saltwater intrusions from the Dead Sea toward the east direction and enters the lower aquifers. The precipitations infiltrate downward to feed the unsaturated (B2/A7) aquifer through the overlay soil and rocks.

This water leaks downward to feed the lower aquifers through fractures and joints present in the aquitards which separate the upper aquifer from the lower aquifer. As well some of the groundwater flow upward direction from the minor aquifer and feed the upper unsaturated aquifers

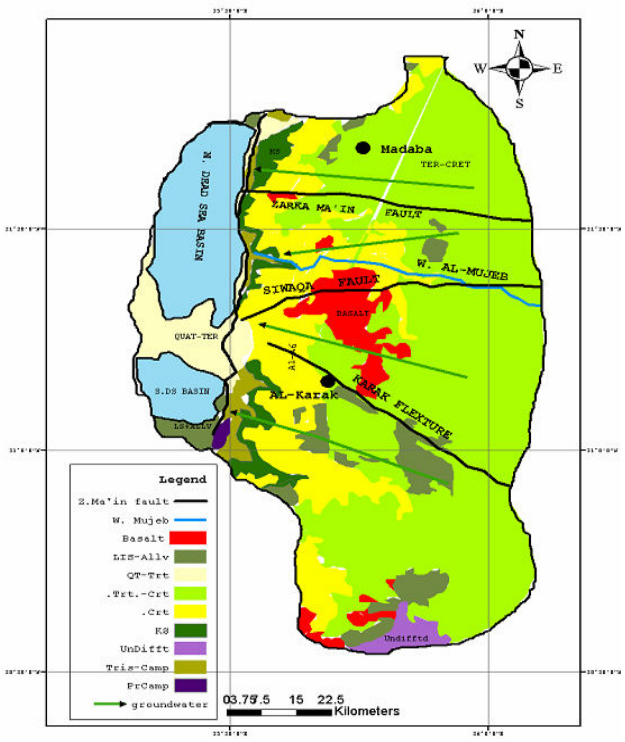

Figure 13: Dead Sea basin showing the outcropping rocks and the groundwater directions (The arrows donate to GW directions) (Modified after Water data bank **project).**

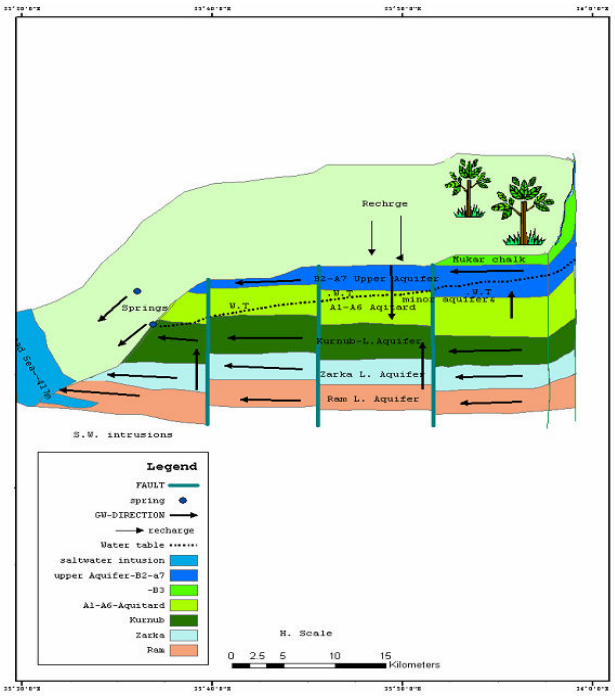

Figure 14: Conceptual groundwater model along E-W profile.

4. Conclusions

The groundwater might be flowing to the north to Wadi Mujeb then it continues to the west toward the Dead Sea. The groundwater at the area located between Wadi Mujeb and Wadi Zarka Ma'in might be flowing toward Wadi Mujeb and Wadi Zarka Ma'in then it continues toward the Dead Sea at the west. Also,

- The groundwater might be flowing from the east to the west toward the DS relating to the dip direction of the layers. The rate of the discharge is depending on the slope aspect of the area surrounding the Dead Sea.

- The geological layers that covering the both sides of the Zarka Ma'in fault dip toward the wadi Zarka M'ain.

- The Geological layers mostly dip to the west direction toward the DS.

- The cross sections show that the lower cretaceous (Kurnub formation) crops out adjacent to the eastern shores of the DS at the northern part of it.

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