

A GIS BASED MODEL FOR GOUNDWATER FLOW AND HEAT TRANSPORT IN ZARQA MA'IN – JIZA AREAS- CENTRAL JORDAN

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ABSTRACT

This paper presents the first application of the GeoSys/RockFlow Software to model the groundwater flow and heat transport based on GIS project. Where the hydrogeological conceptual model of the study area (Zarqa Ma'in-Jiza areas) is converted to (GIS Project) shape files using the ArcGIS software. All required data for modeling, such as aquifer geometry, boundary conditions, material properties, well positions and pumping rates etc. are kept in the GIS project. These data are directly imported to GeoSys/RockFlow for modeling purposes. The whole study domain is subdivided into 29 surfaces based on faults and wadis. Each surface consists of one closed polyline and has it's own average of material properties. 3D Simulation results (steady state) are presented for the flow regime in the model domain based on recharge, discharge and springs data. A fully 3D heat transport model is set up to investigate the long-term thermal regime in this region.

KEYWORDS: ArcGIS, GeoSys/RockFlow, Heat transport, Jordan, Modelling, Water flow.

1. INTRODUCTION

The study area is located in the central part of Jordan, east of the Dead Sea and covers the northern third of the Wadi El Mujib groundwater basin and Wadi Zarqa Ma'in sub basin with total area of about 2300 km² (Figure-1, coordinates in degrees).

The area consists of two major aquifer systems: the upper and the lower aquifers. The upper aquifer is considered as the main source for fresh water for domestic uses in Jordan. The aquifer recharged mainly along the northern and western parts of the study area where it is outcropping and receiving the highest averages rainfall (250– 400 mm/y). In Wadi Waleh basin, the long-term (1975-2003) infiltration average is amount to 21.5 MCM/Y. The direct and indirect recharge to Wadi Zarqa Ma'in basin is amount to 6 MCM/Y (Abu Ajameih, 1980). The groundwater within this aquifer mainly flows from north to south then to the west along the Wadi Waleh drainage pattern and from south to north then join the other flow to the west. Part of the water flows further to the east towards the Azraq groundwater basin. The main natural outlets from the aquifer are the Heidan springs and the Zarqa Ma'in spring with annual average discharge of about 15 MCM/Y and 0.7 MCM/Y respectively.

The lower aquifer consists mainly of sandstone of Lower Cretaceous and older ages. The major contribution to the lower aquifer recharge comes from the upper aquifer by infiltration, mainly in the eastern parts of Jordan. The infiltrated water receives heat under a normal to slightly elevated geothermal gradient and flows to the west towards the Dead Sea, where it inters the Dead Sea as subsurface flow or discharges to the ground surface as thermal springs, as in Zara and Zarqa Ma'in springs. The average discharge of the Zara-Zarqa Ma'in thermal springs amount to 20 MCM/Y (Salameh and Udluft, 1985).

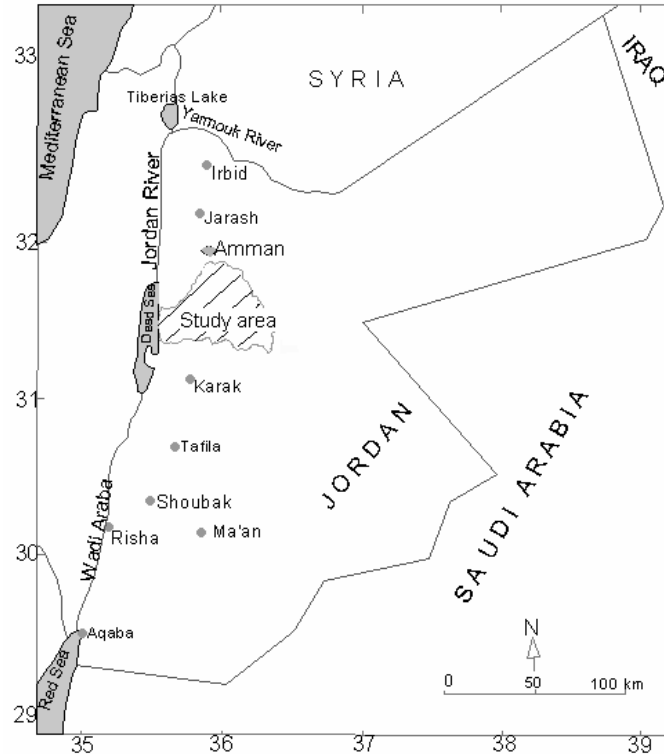


Figure-1: Location map of the study area

In the last three decades about 300 boreholes were drilled to the upper aquifer in the study area. Boreholes drilled mainly east and south east of Jiza town discharge thermal water ranging in temperatures from 30 to 46 C°. The dense faults net which affecting the area, strongly suggested that the two-aquifer systems are hydraulically connected, especially in the eastern parts of the study area. This might allow the thermal water from the lower aquifer to flow up via faults (conduits) to the upper aquifer raising the water temperature (Sawarieh, 1990). The isotope content indicates that the thermal water from both aquifers is of meteoric origin. The chemical analysis and the isotope content of the thermal water from the upper aquifer indicate that it is a mixture of the two aquifers water (Sawarieh et al, 2004).

GeoSys/RockFlow scientific modeling software (Kolditz et al. 2003) is used in developing a numerical groundwater flow within the upper aquifer system. Based on the groundwater model a heat transport between the two aquifers in the study area is considered. The hydrogeological conceptual model of the study area is converted to

(GIS Project) shape files using the ArcGIS software. All required data for modeling, such as aquifer geometry, boundary conditions, material properties, well positions and pumping rates etc. are kept in the GIS project. These data can be directly imported to GeoSys for modeling purposes (Kalbacher et al. 2003, Chen et al. 2003). The GeoSys/RockFlow software concept consists of three components (Libs); GeoLib, MshLib and FemLib. These components can be connected via a graphical user interface (GUI).

2. MODEL SETTINGS

2.1 GIS Project

The first step in setting the model for the study area is creating the GIS project where the geological data such as the geological formations, faults, wadis and the hydrogeological data like aquifers, aquitards, wells, springs, water table, top and base of aquifers and boundary conditions were converted to shape files using the ArcGIS (digitising feature) and kept in the GIS project. The GIS project for this study consists of several shape files (layers), these are: faults, wadis, springs, study domain, wells location, boundary conditions and water level contour maps. Figure-2 shows the wadis and springs as an examples of these shape files.

2.2 GeoSys project

Firstly, a new project is created and saved in GeoSys. All the data reference for the model such as geometry data (GSProject.gli), meshing data (GSProject.rfi), processing data (GSProject.rfo), are stored in this project file (Jordan project File) to keep the connection between the project and its data components.

2.2.1 Geometry

In this step, shape files in GIS project are imported into GeoSys/RockFlow and converted into its own geometric data structure – GeoLib (Chen et al. 2003) as basic geometric data for the modelling area. GLI is the input data format for GeoLib, which is composed of points, polylines, surfaces, volumes and domains. Point is the basic element of all other geometry type, which is used to define 1-D geometry elements like: source term, boundary condition. Polyline consists of points and it is used to define 2-D geometric

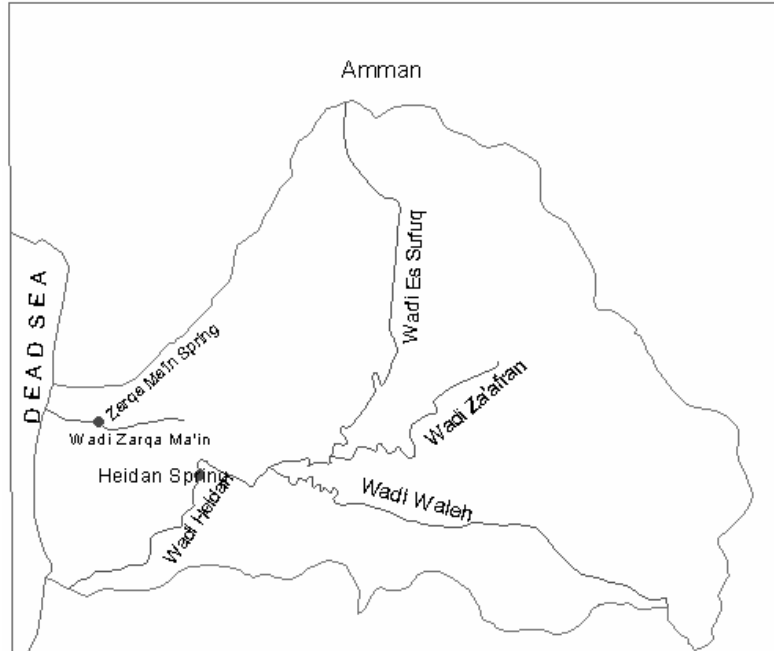


Figure-2: Wadis and springs (Layers) shape files.

elements as: boundary of study domain, boundary to assign boundary condition and line structures. Surface can be composed of several polylines or one closed polyline, which is used as 2-D boundary domains. Volume is composed of surfaces, which is the component of a domain.

The whole study domain is subdivided into 29 areas, which means surfaces in GeoSys project. Each surface is created from one closed polylines (polygon in GIS project). After all these are ready, mesh generation by using external program (GMSH), which creates triangulations for all 2D surfaces. The results are stored in RFI file, which consists of geometric information of nodes and elements of the triangulations. RFI is the real input data for simulation.

Now, TIN (triangulated irregular networks) is created for the discrete geometric description of surfaces and then for volumes as well. The generation of TIN for a surface needs the existing triangulation. For each TIN file, it has the same base name of the corresponding surface (surface_name.tin). The conceptual model of the study domain consists of three layers: upper aquifer, lower aquifer and the aquitard in between. So three copies of the surface is needed to create 2.5D

layer model based on the TINs for original 2D model. Three layers means four rows, and one is for the upper most row with the height of 0, and height for lower three layers are: -1000, -2000, -3000. Figure-3 shows the volume objects of the 3D geometric model.

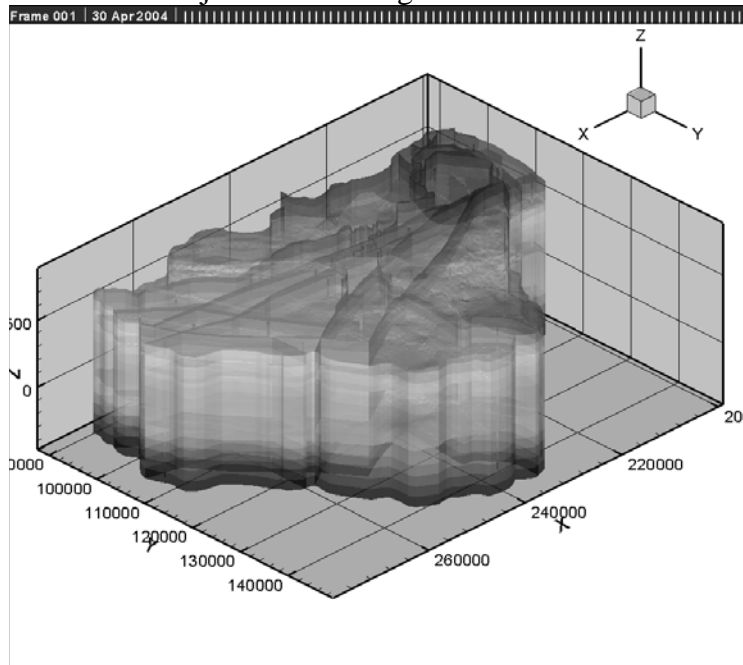


Figure-3: Volume objects of the 3D geometric model

2.2.2 Meshing

The general steps for the hybrid meshing procedure in this application are:

- 1- Create a triangulation based on surfaces (SFC) for the 2-D surface model. The surfaces must be topologically consistent.
 - 2- Create line elements for the 1D Wadis model based on the triangulation,
 - 3- Create prismatic elements for the 3D subsurface model,
 - 4- Create quadrilateral elements for the 2D fracture/faults model,
- All the above elements are attached to the existing .RFI file with triangulations. Figure-4 shows the 3D hybrid finite element mesh

2.2.3 Mapping

Surface mapping is the process of making the mesh conforms to stratigraphic irregularities, i.e. thicknesses and orientation of the mesh slices can be deformed. Different data types can be used; grid files

created with Surfer, saved as asc file or grid files created with ArcView (use extension asc!)

There are four .asc files for four rows from uppermost to lowermost: top_b2a7.asc, base_b2a7.asc, top_ks.asc, base_ks.asc. For example, the nodes of prism elements with Z coordinates equals 0.0 will be mapped using the data given in top_b2a7.asc. If prism elements are to be mapped, prepare an rfi file, which stores element data. Figure-5 shows the mapped finite element mesh consisting of line, triangle, quadrilateral and prismatic elements to represent the Wadis, surface, faults as well as aquifers and aquitards.

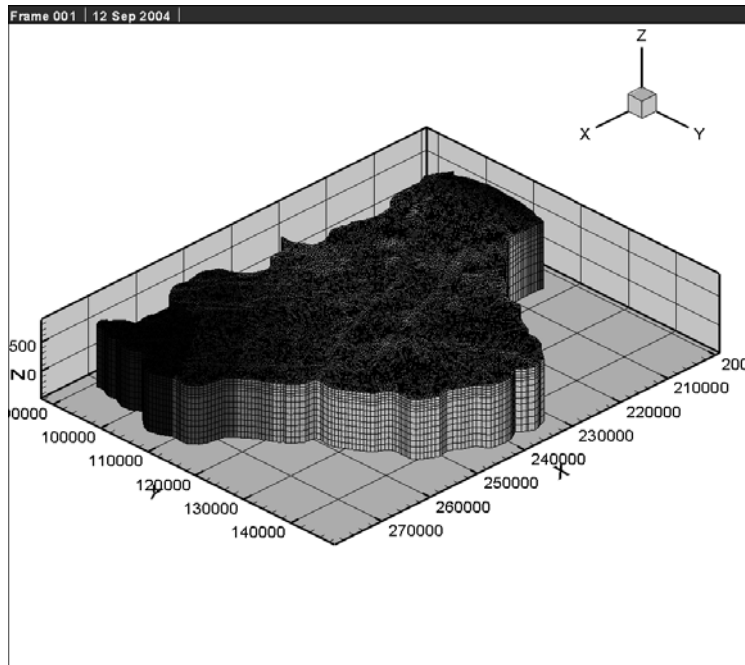


Figure-4: 3D hybrid finite element mesh

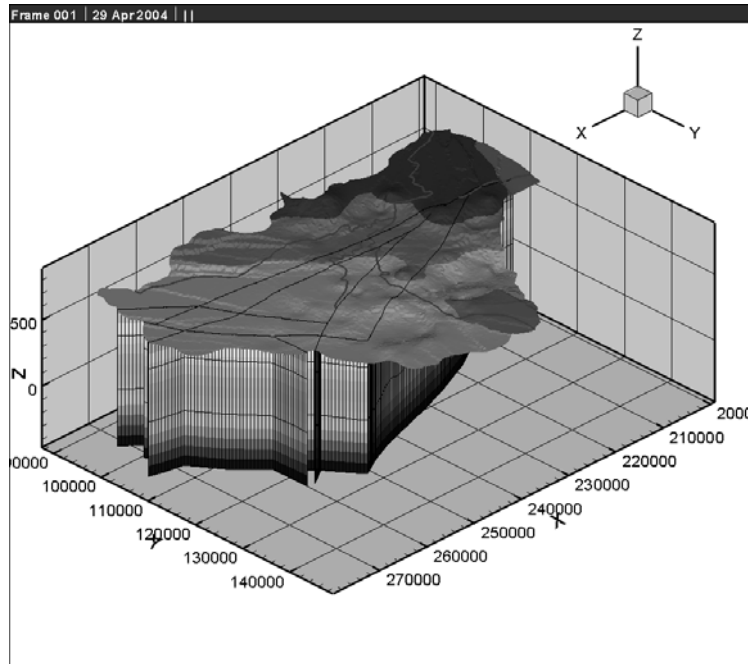


Figure-5: Inside the hybrid finite element mesh

2.2.4 Boundary conditions and source terms

The hydraulic system is controlled by recharge and discharge conditions to or from the model area as well as by discharges from several springs, which are summarized in the table below.

Upper Aquifer	Direction	MCM/a
Recharge	North- Northwest	27.5
Discharge	East- Northeast to Azraq basin	5
Discharge: Spring P408	West	15
Discharge: Spring P264	West	0.7
Lower Aquifer		
Recharge	East	25-30
Discharge: Subsurface to Dead Sea	West	?
Discharge: Spring P655	West	20
Discharge: Spring P615	West	5

The heat flow from the base (100mW/m^2) is represented by source terms distributed at the bottom surface. Figure-6 shows the object-

oriented dialog for source terms, how process, geometric and temporal information can be connected.

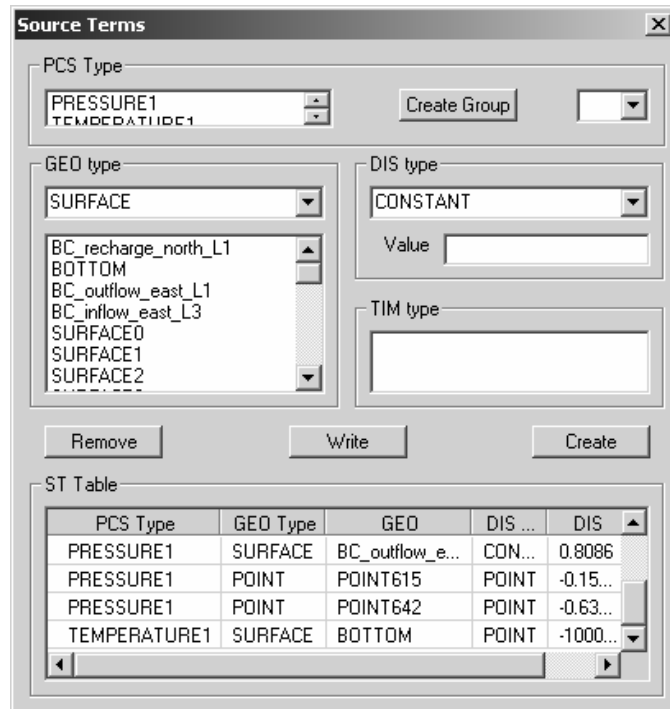


Figure-6: Connecting source terms with process, geometric and temporal information

2.2.5 Material properties

Material properties have to be specified for fluids, solids and the porous medium itself.

Figure-7 shows the geometrical distribution of material groups in the aquifer layers based on hydrogeological data. In a 3D model all material groups can be linked to volume objects (Figure-3). In a FE model all elements belonging to a specific geometric object inherit data from the material group connect with this volume. Material data can be for convenience organized, e.g. in Excel tables, which can be easily imported.

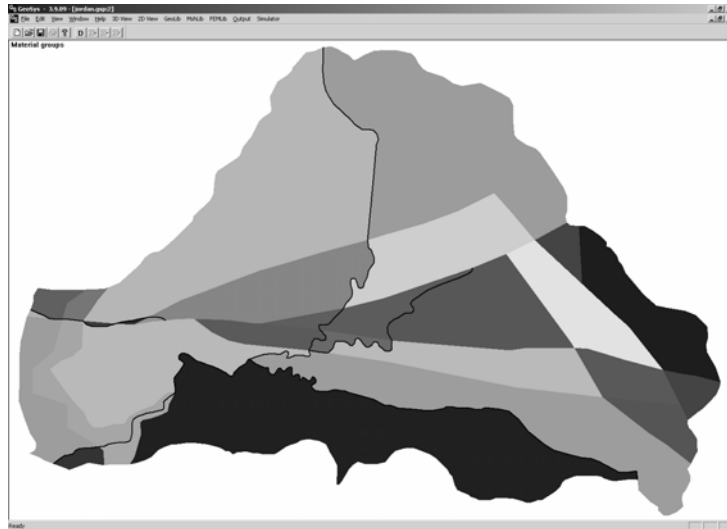


Figure-7: Distribution of material properties in the aquifer layers.

3. SIMULATION RESULTS

We present the first simulation results (steady state) of a fully 3D flow and heat transport model. The study is still under investigation.

3.1 Flow modelling

As mentioned in section 2.2.4, the hydraulic system is controlled by recharge and discharge conditions to or from the model area as well as by discharges from several springs. Figure-8 shows the distribution of the steady state hydraulic head in the model domain, where the highest values occur in the northern recharge area and the lowest values are in the western spring field.

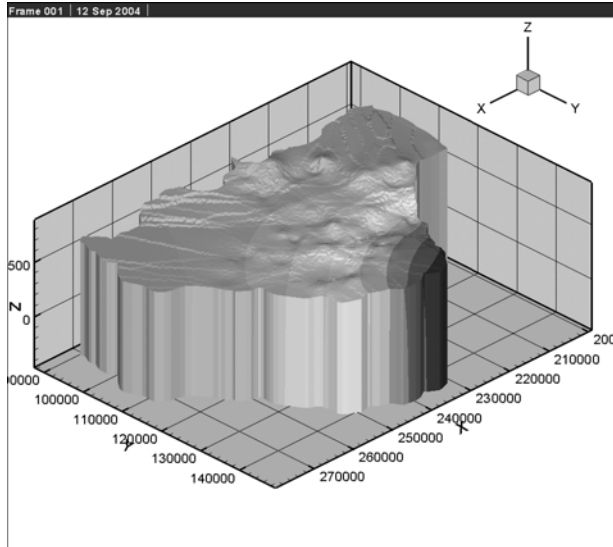


Figure-8: Hydraulic head in the model area

3.2 Heat transport modelling

The thermal basic processes are illustrated in figure-9. There is a permanent heat flow from the base to the system. Through the North groundwater is entering the upper aquifer and through the East the lower aquifer. This groundwater has to cool the whole system; otherwise the temperature will increase permanently.

Groundwater entering the system



Heat flux from the base

Figure-9: Thermal basic process in the area.

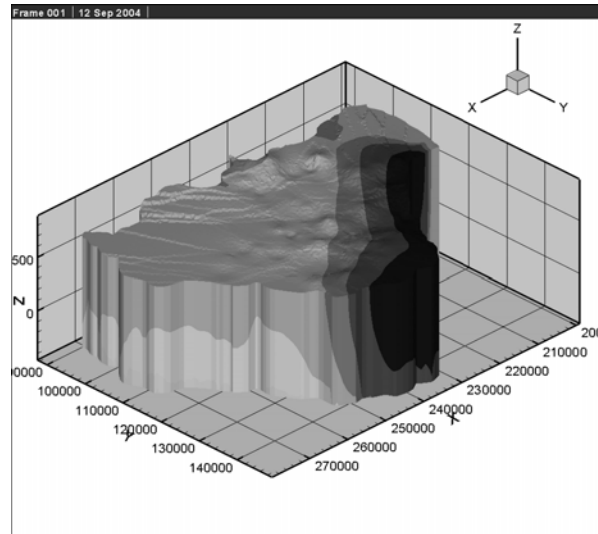


Figure 10: Temperature distribution in the model area

Figure-10 shows a first long-term simulation (30000 years) of the thermal system based on the hydraulic model presented in section 3.1. The simulation shows a permanent increase of temperatures. The groundwater entering the system is not equilibrating the base heat flux. This indicates to possible defects in the current model. First, the outside groundwater recharge to the domain is underestimated. Second, the base heat flux is overestimated. This means, involving thermal data to the simulation, the hydraulic model can be improved.

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