STUDY OF VISUAL MODFLOW APPLICATION FOR SEAWATER INTRUSION MODELLING IN PHREATIC AQUIFER

STUDI APLIKASI VISUAL MODFLOW UNTUK PEMODELAN INTRUSI AIR LAUT PADA AQUIFER DANGKAL

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Abstract *: Water plays as an important part of the element in human life, therefore its existence should be kept favorably in quantity and quality. It is a fact, the significance increase of the population growth equivalent to the total of water consumption*
Water resources in coastal areas assume a special significance since any developmental activity will largely depend upon availability of fresh water to meet domestic, industrial and agricultural requirements. However, fresh water resources in coastal aquifers are likely to experience disastrous and irreversible impacts in the coming times due to overexploitation of groundwater resources and sea level rise.
Nowadays,the intrusion of seawater is getting bigger. That is why, a hidro-geology study on this area important in helping to conserve its natural hydro-geology system.
At this time, many computer programe used in ground water modelling. One of them is software Modflow3.1, that use finite difference method to solve the equation This program can depict seawater intrusion base on chloride consentration variable at fresh water and seawater. The region that will be modeled is phreatic aquifer coastal area. The outcome will give sufficient overview of current hydro geology condition and used to forecast how far salt water intrusion could happen.

Key words*: Software Modflow, sea water intrusion, ground water modelling, aquifer*

Abstrak *: Air merupakan elemen yang penting dalam kehidupan manusia sehingga keberadaannya harus sangat diperhatikan baik dalam kuantitas maupun kualitasnya. Dengan pertambahan jumlah penduduk yang semakin meningkat maka kebutuhan akan air minum dan air bersih juga semakin tinggi.*
Sumber daya air di kawasan pantai dianggap sebagai satu hal yang membutuh perhatian khusus, seiring dengan perkembangan aktivitas dan ketersediaan air bersih di daerah pantai untuk untuk mencukupi kebutuhan domestik, industri dan pertanian. Keberadaan air bersih di daerah pantai sangat mungkin untuk mengalami dampak negatif yang tak dapat dipulihkan di masa yang akan datang, karena adanya pengambilan air tanah yang berlebihan sehingga menyebabkan naiknya permukaan laut.
Pada saat ini, terjadinya intrusi air laut semakin meningkat, sehingga studi tentang hidro-geology di daerah pantai ini penting dalam membantu untuk memelihara sistem geologi-hidro alami nya
Saat ini banyak program komputer yang dapat digunakan dalam memodelkan kondisi air tanah. Salah satunya adalah Visual Modflow yang menggunakan metode beda hingga dalam menyelesaikan persamaan transprortnya . Program ini dapat menggambarkan intrusi air laut berdasarkan perbedaan konsentrasi klorida pada air tawar dan air laut. Ruang lingkup wilayah yang akan dimodelkan adalah aquifer dangkal daerah pantai. Hasil pemodelan akan memberikan gambaran kondisi sistem hidrogeologi di masa sekarang dan mencoba membuat prediksi berupa gambaran sistem hidrogeologi, sejauh mana potensi intrusi air laut akan terjadi di masa mendatang
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Kata Kunci *: software modflow, intrusi air laut, pemodelan air tanah, akuifer.*

INTRODUCTION

Clean water is one of essential element for human life. The needs of this water level increase from year to year, to support all human activity along with resident growth and development. There are two water sources that can be used to fulfill human needs, that is: surface water and ground water.

If we seen Globally from the volume that the of, ground water have bigger capacities than surface water. From the existing balance of fresh water amount, the ground water gives quite important distribution, the number reaches 30,061% compared by surface water that only 0,349% from all fresh waters that can be utilized.(Aris Sulistyo, 1996)

Groundwater movement is a part of hidrologic cycles. Under natural conditions, the seaward movement of freshwater prevents saltwater from encroaching coastal aquifers, and the interface between freshwater and saltwater is maintained near the coast or far below land surface. This interface is actually a diffuse zone in which freshwater and saltwater mix, and is referred to as the zone of dispersion (or transition zone). Groundwater pumping can reduce freshwater flow toward coastal discharge areas and cause saltwater to be drawn toward the freshwater zones of the aquifer..

Sea water intrusion is a contamination phenomenon that cause the improvement evel of salt in the ground water. The salt level improvement causes ground water quality degradation until improper to be used as clean water source. Sea water intrusion happened at area with high pumping to ground water but less fresh water admission filling to aquifer.

At natural condition, ground water movement to the sea can pursue saltwater movement to aquifer coast. Whereas area of fresh water contact and sea water is near the coast or far from subsurface. Pumping to ground water can reduce fresh water stream toes aquifer coast and cause the sea water step into fresh water zone from aquifer coast.

Nowadays, many models are developed for planning and research objectives. 2D – model initially developed to see the interface of seawater and freshwater in seawater intrusion phenomenon. Along with growing of knowledge, model has been developed to 3D. Many codes are available, such as : FEFLOW,ROCKFLOW, HST3D, TVDT3D, METROPOL, MVAEM, MOCDENSE3D,SWICHA, SWIFT, CODESA, SUTRA, SEAWAT, and d^3f. That models are developed use finite difference and finite element method.

For this research, Visual Modflow program is used to simulates the phenomenon. Visual Modflow developed by U.S. Geological Survey. The latest release of this program is version 4.2. This program is using finite difference method and one such commercial product with license charge from United States Geological Survey (USGS).

MODFLOW, a threedimensional, finite difference groundwater flow model was used to simulate the hydrogeologic regime. MT3D, a solute transport model incorporated into the Visual MODFLOW modeling environment, was used to simulate the behavior of the chloride concentration in seawater.

The model is a predictive model that will simulate seawater intrusion causes by pumping of groundwater at coastal area , and optimized the pumping schedules may be in the design for safe condition.

METHODOLOGY

Some activity will be done in this research. To know hidrogeology condition, it studied from literature study, processing, and data analysis. Study of ground water intake influence to sea water intrusion are helped with Visual Modflow Software Version 3.1. that developed by waterloo hidrogeology. In the modelling is used two type of model boundary; Constant Head for parallel extracellular side of ground water, and potential boundary for vertical cell boundary ground water and recharge.

Visual Modflow computer program is using finite difference method to solve the transport equation in seawater intrusion problem in coastal area. To solve differential equations, discretization toward time and space is needed. In Figure 1, show the discretization of finite difference method.

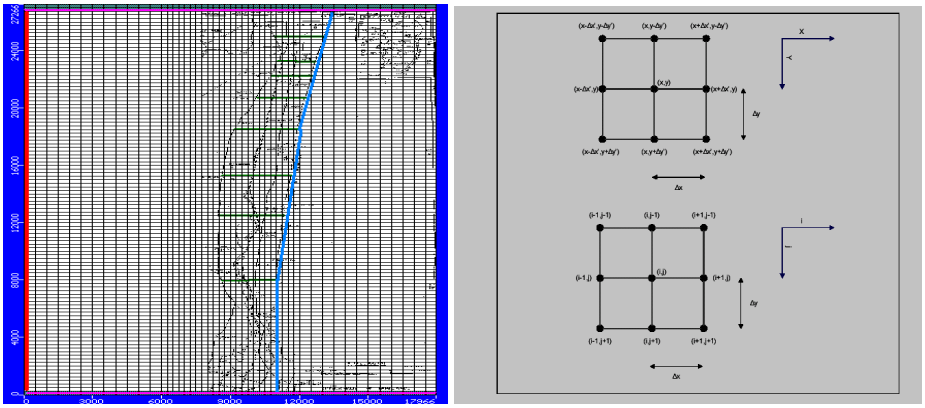

Figure 1. grid notification in computer

The following methodology has been adopted for the study.

- Problem identification and determine data required.
- Collection of relevant data.
- Model conseptualization and data preparation.
- Determine initial and boundary conditions.
- Modelling with numerical solution using Visual Modflow application.
- Model calibration and validation.
- Interpretations and conclusions.

For modelling groundwater using Modflow software is conducted in some steps, that are:

1. Input of Maximum co-ordinate value (max) and minimum (min) coordinate, this area is workplace at the site (Xmax, Xmin, Ymax and Ymin) and input the elevation (Zmax, Zmin) and also amount of layer. From this co-ordinate can be determined amount grid
2. Input the intial heads by enter surface of groundwater contour
3. Input of position sampel and coast boundary
4. Input Hydraulic conductivity value every layer
5. Input the Value of specific storage, specific yields, effective porosity and total porosity every layer
6. Input the Value of constant consentration
7. Input constant head

8. Before data will read by Modflow, desired time limit input to seemovement constant concentration that we input
9. Modflow can be run (Modflow2000 for stream simulation of groundwater and MT3DMS for simulation spreading of contaminant from model result that already simulated by Modflow2000) From the data that collected then will be made model using Modflow Software. This model that made is modeled bases spreading of contaminant.

MODELLING APPLICATION WITH VISUAL MODFLOW 3.1 FOR SEAWATER INTRUSION MODELLING

Visual Modflow is the most complete and easy to use modelling environment for practical application in three dimensional ground water flow and contaminant transport. This fully intregated packages combines Modflow, Modpath, and MT3DMS with the most intuitive and powerful graphical interface available.

Visual MODFLOW Pro 3.1 enables the user to employ MODFLOW, MODPATH, ZoneBudget, MT3DMS and WinPEST. The Visual MODFLOW interface consists of Input, Run, and Output sections. In the Input section, the user sets up conditions for groundwater flow and contaminant transport models using a graphical interface. In the Run section, the user translates the model conditions created with the Input section into the standard input files for the appropriate models. The 3D-Explorer in the Output section allows 3-D visualization and animation of model results.

MODFLOW is one of the most popular ground-water modeling programs in existence. Some reasons for this popularity may because :

(1) the program is applicable to most types of groundwater modeling problems,
(2) the original packages in the program are well structured and documented,
(3) the source code is in the publicdomain and thus can be checked for errors and modified by anyone with the necessary mathematical and programming skills,
(4) the program is accepted by regulatory agencies and in litigation

MT3D Solute Transport Simulation

MT3D is a three-dimensional numerical model for simulating solute transport in complex hydrogeologic settings, either 2 or 3 dimensional. MT3D is designed to be used in conjunction with any block-centred finite-difference model such as MODFLOW. Like MODFLOW it has a modular structure, making it possible to simulate transport processes independently or jointly, depending on which process dominate. MT3D is capable of modelling advection in complex steady-state and transient flow fields, anisotropic dispersion, first-order decay and production reactions, and linear and non-linear sorption. This version can simulate multi-species reactions and assess natural attenuation within a contaminant plume. Includes a dual porosity model for estimation of mass transfer in fractured media or extremely heterogeneous media.

Output MT3D:

Contour or gridded results of contaminant concentration distributions, time slices, mass balance results for individual or combined processes and single or multi-species reactions.

MODFLOW is a finite difference 3D, time-varying groundwater flow model that has become the industry standard for many groundwater-related studies. The general form of the governing partial-differential equation describing groundwater flow under time-varying conditions in a heterogeneous and anisotropic aquifer is:

$$\partial/\partial x(Kxx\partial h/\partial) + \partial/\partial y(Kyy\partial h/\partial y) + \partial/\partial z(Kzz\partial h/\partial z) - W = Ss\partial h/\partial t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where x, y and z are Cartesian coordinates aligned along the major axes of hydraulic conductivity Kxx, Kyy and Kzz; h is the potentiometric head; W is the flux per unit volume representing sources/sinks; Ss is the specific storage; and t is time.

MODFLOW employs a block-centred approach and a modular structure consisting of a main program and a series of sub-routines grouped into packages. Each package includes specific features of a hydrological system, such as recharge or drains, and various methods to solve the linear equations (Anderson and Woessner, 1992). A wide range of additional modules has been added since MODFLOW was developed originally (e.g. cell re-wetting or spatially variable anisotropy). A wetland module is available (Restrepo *et al*., 1998), although this was developed for swamp areas rather than grass wetlands. Commercial versions of MODFLOW provide a comprehensive suite of techniques to assist model design, to input data and analyse and present model output.

Besides ease of use, the application of a groundwater model, such as MODFLOW, to in-field water regime studies has several potential benefits. For example, it can take account of spatial heterogeneities, vertical groundwater flow and any regional groundwater flow component. Whilst vertical leakage through clay sequences will occur at a low rate, and consequently will be a minor component at the field scale, the volume of leakage could be significant over the total area of a wetland. Irregular field boundaries and steep hydraulic gradients adjacent to a drain can be accommodated, although with a finite difference approach this may result in an excessive number of grid cells particularly with multiple layers. Recharge can be distributed areally, although recharge is assumed to be added instantaneously to the saturated zone, this is not necessarily a disadvantage where the depth to water table is shallow even in low permeability sequences. Evaporation from the soil is accommodated by the Evaporation Package in MODFLOW. A maximum evaporation rate is assigned to each cell when the water table equals an assigned head value (normally ground level)

The target groundwater Modelling using software Visual Modflow are to present the ground water movement, saltwater movement coastal area. Generally, groundwater flow at free aquifer will appropriate to topography inclination, if the conductivity hydraulic of soil relative homogeneous. Because of lack of data in research area, like litology layer inexistence, assumed research area is free akuifer. Some consideration on creating a water distribution system model explains as follows

1. Topography

   Map Topografi is used to make model 3D, from this topography known the ground water's stream and then it can be predicted water direction of outflow, topography map is the main inputs to make of ground water modelling sistem.

2. Ground water's head

Groundwater's head is obtained from perception of resident well, this also is main input in making of ground water modelling sistem

3.aquifer's Parameter

aquifer's Parameter like: hydraulic conductivity's value, litologi that exist in coastal area. Hydraulic conductity are obtained from conduktivity test of sampel soil that obtained or from literature data based on type litiologi in common.

4. Precipitation Data

Precipitation Data used are the average of precipitation at every rainfall monitoring station

5. Evapotranpirasi

Evaporation is water event becomes vapour and move from ground and water level into the air, while event of plants evaporation is called transpiration, and the second Aliance is called evapotranspirasi.The quantity of evapotranspirasi influenced by some factors for example air temperature, dampness, wind speed, and pressure

7. During in simulation process Assumed does not happen changing of groundwater head drastically as a activity consequence, in this case water stream is assumed stay in condition fixed continually (steady state flow).

8. Later will be made a model that depict stream of groundwater condition and seawater intrusion in normal situation (before conducted intake/pumping of groundwater) and situation after conducted pumping of ground water

Generally, the methodology used to build a model of seawater intrusion is shown in Fig. 2.

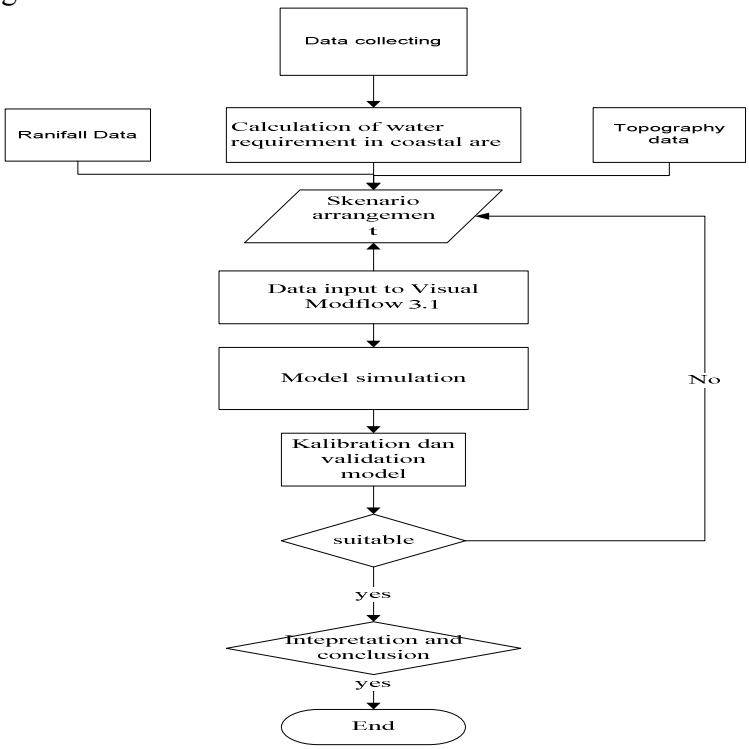

Figure. 2. Seawater intrusion system modeling process

Model Representation

Good model should provide representative data showing its actual condition in the field. The more accurate the data is, the better. Based on that consideration, to make a good model of seawater intrusion, it should contain components of a transport system, as complete as possible.

Modelling Seawater Intrusion

Example condition ground water system

The example of case study below is a modeling example of seawater intrusion, the purpose of case study is to see the ability modflow software in saltwater intrusion.

At this case study example area, the used datas is :

1. topography data.
   Aquifer size is 200x200x20 metres.
2. Ground water head, that is 0 m for coast area, and highest ground water head is 0.5 metres.
3. Parameter aquifer:
   Hydraulic Conductivity = 0.00001 m/s, representing aluvial soil.
4. Precipitation Data's
   Recharge = 1363.4 mms/year
   Evapotranspirasi = 658 mms/year
5. Other Parameter, like :
   Effective Porosity = 20%
   Specific yield = 0.2
   Specific storativity = 1e-5/m
   Dispertion = 3/m
6. Then, the model will be made that depict stream condition of groud water and saltwater intrusion, in normal situation (before pumping of ground water) and situation after conducted pumping of ground water.

Result of simulation and Disscusions

The Datas Condition in above hereinafter simulated for 1 year (365 day), using 2 intake well each capasity is $10m^3$ dan 40 m^3 .

A numerical model of flow was developed using Visual Modflow Software.The model is composed of one layers (total thickness 40 m), representing the basic aquifer structure. Each layer is built on a 80 columns, 80 rows grid consisting of 640 active cells ranging in size from 0.125 to 0.6 km2. The model is built with hydrogeological parameters compiled by the assumed boundary conditions. The calibrated model was run for a year simulation period in a steady mode, with twelve time steps for each stress period.

After enter data above then got simulation result shall as follows :

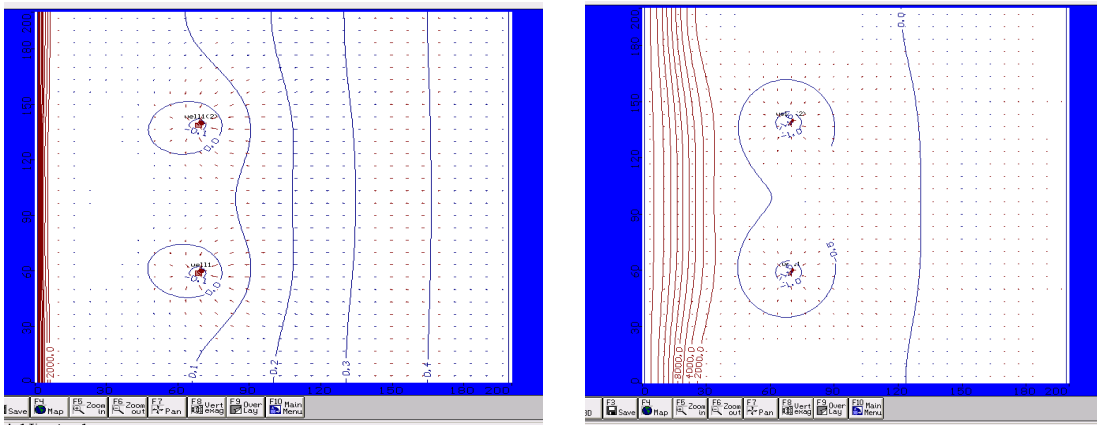

Figure 4 . Simulated choride distribution at 1 year (10 m3/day and 40m3/day)

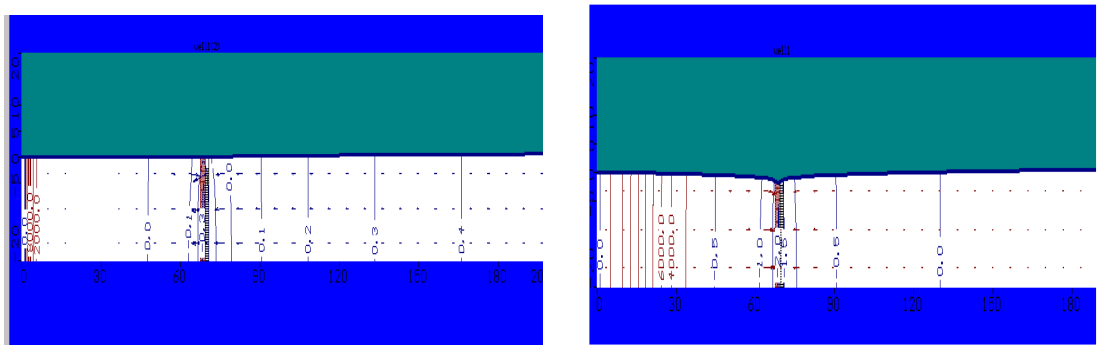

Figure 5. picture of cross profile appearance of sea water intrusion (for 10m3 and 40m3/day pumping)

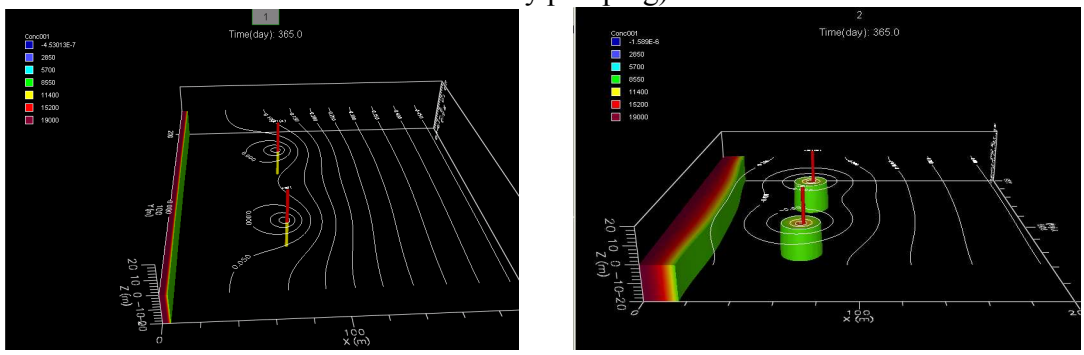

figure 6. picture of 3 dimension of chloride spreadings as a consequence of water pumping

The pictures above displays the movement of chloride concentration from saltwater to freshwater. For the frist trial, pumping capacity set to 10m^3/day, the result shows that there is no movement of saltwater to the fresh water area. At the second trial, pumping capacity set to 40m3/day, the movement of saltwater seen on the result. These water movement simulated using MT3dMS, and the result are isoconcentration contour of chloride in mixing area between fresh water and brine

from result above, its can be seen that visual modflow software applicatited for seawater intrusion modeling

CONCLUSION

Analysis of groundwater system is important for determining the optimal supply of freshwater from a coastal aquifer. It is used to make decision of groundwater management and plan the pumping rate of groundwater production.

Visual Modflow is finite difference simulation program can be use for seawater intrusion phenomenon. It can simulate base on chloride consentration between freshwater and seawater. The results of simulation are countour display of chloride consentration , contour isohead, and velocity vector. From the simulation results, the nearest and high pumping rate well have high risk of seawater intrusion.

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