Evaluation of Groundwater Flow Analysis Using Rainfall-Recharge Estimation Methods

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(Manuscript received 5 March, 2007; accepted 29 April, 2007)

This study used SCS-CN method to estimate the real recharge of the study area which is one of the most reasonable techniques to estimate groundwater recharge when there is no available runoff data in a watershed. From the results of the real recharge analysis for the study area using SCS-CN method, it was analyzed that the year 1994 when the drought was severe showed the lowest recharge of 106.3mm with recharge rate of 12.4%, and the highest recharge of 285.6mm with recharge rate of 21.8% occurred in 1990. Yearly average recharge of 213.2mm was obtained, and the average recharge rate was 16.9%/year. KOG-FLOW model which has powerful post process functions consists of setting environments for input parameters in Korean language, and help function is added to each input data. Detailed information for each parameter is displayed when the icon is placed on the input parameters, and geologic boundaries or initial head data for each layer can be set easily on work sheet. The relative errors (R. E.) for each model's observed values and calculated values are 0.156~0.432 in case of KOG-FLOW, and 0.451~1.175 in case of WINFLOW, therefore it is known that KOG-FLOW model developed in this study produced results compared to observed head values.

Key Words : Groundwater, KOG-FLOW, WINFLOW, Recharge Ratio, SCS-CN

I. Introduction

In groundwater system under natural conditions the recharge to an aquifer and drainage from the aquifer are in equilibrium. In other words the system is equivalent for a certain period so the system changes under certain normal condition which is caused by long-term climate conditions. Most of the recharge sources are precipitation and it is directly related to groundwater movement and drainage so it is very important to examine the relationship in water resources study. It is necessary to examine the recharge mechanism in aspect of the quantity because the recharge which is the connection between surface water and groundwater in water circulation process affects on the surface runoff with as much amount of groundwater augmentation by supplying water to the aquifer.

Also, getting hold of recharge amount from precipitation is certainly necessary to plan a systematic development and utilization, and optimal management of water resources. For this water resources management should include consideration about nationwide precipitation data of mid-small size watersheds. However our fundamental data needed for examination of recharge characteristics due to precipitation is insufficient because of inadequate survey, and recharge estimation technique is imperfect so that credible recharge estimation on mid to small size watershed's recharge has not been performed yet. In analysis on groundwater flow system of mid-small size watersheds recharge directly affects the flow system and development (pumping amount). First, researches on groundwater recharge, Aron[1] and Hjelmfelt[2] derived equations under the assumption that realrecharge is equal to the accumulated infiltration through the relations in SCS-CN method and estimated groundwater recharge rate by comparison of accumulated long-term infiltration with the precipitation in the same period because

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infiltration from each rainfall event can be treated as indeed groundwater recharge. Scozzafava[3] used Thornthwaite's water budget method applying SCS-CN method to estimate gross infiltration in Gran Sasso Massif area of central Italy. Choi[4] calculated groundwater recharge in Gulpocheon area considering land-use characteristics. Park[5] estimated groundwater recharge using SCS-CN method for the area selected from Chojeong-ri region, and 12.95% of recharge rate was calculated. Next, Hubbert[6] is the first for the groundwater flow analysis which analyzed groundwater flow theory with a model, Gupta[7] developed 3-D finite element model for groundwater system, and study on groundwater has been active for recent years.

Besides, estimation on groundwater recharge is necessary to set up standard for evaluation of groundwater pumping rate, and it is needed to develop an evaluation technique for adequate groundwater pumping rate by suggesting groundwater recharge estimation method considering land-use characteristics and soil properties. With the view through the past researches, it is thought that SCS-CN method is one of the most reasonable methods to estimate groundwater recharge when there is no runoff data for an area. Therefore, in this study, the practical applicability of parameter (recharge) estimation using land-use characteristics is examined through comparison and investigation of recharge and observation which are calculated by SCS-CN method and by KOG-FLOW and Winflow model.

2. Numerical Models

2.1. KOG-FLOW model

· The model developed in this study is based on MODFLOW[8] model which is a typical 3-D groundwater analysis program and is verified on its applicability. However there are many difficulties for the users in case of the MODFLOW because of the complicated interfaces and parameters. KOG-FLOW model developed in this study allows users to set up input data easily, and consists of all parameters in Korean, and accurate parameter assignment is available through the help function which contains values for observation and existing data for applied value and understanding on each input data and parameter. KOG-FLOW model consists of 5 independent sub-

routines called main program and module, and simulation time is divided into serial stress periods that assigned stress parameters are constant and each stress period is divided into time intervals.

The Table 1 is a brief explanation for various packages that are included in the KOG-FLOW model. Two important packages in the category are the flow component package and the solver package, and the flow component package includes the stress package. The flow component package executes the calculation of the coefficients in the finite difference equation for each cell, and the solver package performs the algorithm for the solution of the finite difference equation system. The Fig. 1~2 are the execution processes of KOG-FLOW model.

Table 1. Modules of KOG-FLOW model

| Module	Contents of program
Main Program	Title, Operation range, Aquifer boundary, Initial head, Calculation period, etc.
BBF	Kinds of aquifer, Cell length, Hydraulic parameter, Elevation
WELL	Well number, Pumping quantity, Layer number, etc.
RECH	Recharge of each cell
RIVER	Cell number of river, Cell condition(Water level, Riverbed level, Hydraulic conductivity)
SIP	Strongly Implicit Procedure
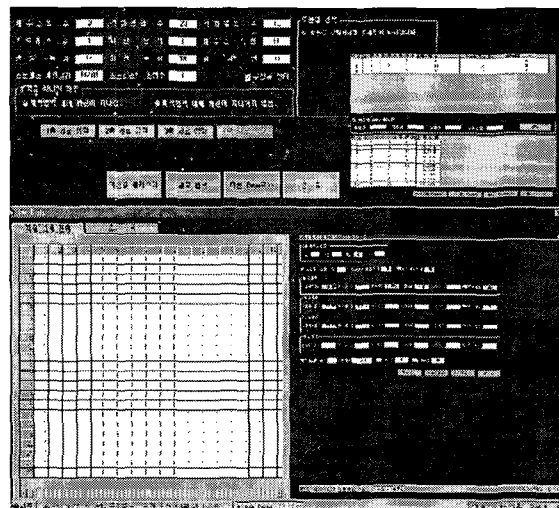
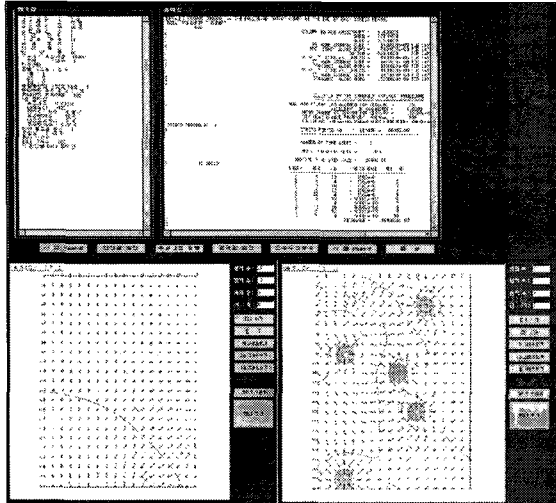Fig. 1. Input sheet of KOG-FLOW model.

Fig. 2. Output sheet of KOG-FLOW model.

2.2. WINFLOW model

WINFLOW[9] model is based on the finite element method, easy to establish a model for study area, and has been demonstrated as it shows similar analysis results to MODFLOW model. The WINFLOW model which is different from 3-D MODFLOW model has somewhat difficulties for groundwater movement analysis under various geologic conditions, however, has advantages of that model establishment is easy under relatively simple aquifer conditions, and can analyze groundwater movement, effect distribution of a well, and contamination path using groundwater level of a well, geographic and geologic conditions like reservoirs, streams, and geological structures, and several hydrologic parameters. The governing equation for 2-D groundwater flow in non-isotropic and non-homogeneous aquifer[10] in the basic theory of the WINFLOW model can be expressed as following equation (1).

$$S \frac{\partial h}{\partial t} = \frac{\partial}{\partial x}(T_{xx}\frac{\partial h}{\partial x}) + \frac{\partial}{\partial y}(T_{yy}\frac{\partial h}{\partial y}) + Q + \frac{K'}{B'}(h_a - h)$$

(1)

Where, S is storage coefficient, h is average head, T_{xx} is transmissivity in x-direction, T_{yy} is permeability in y-direction, Q is vertical flow rate in the aquifer, K' is vertical permeability of the upper or lower region of the aquifer, B' is the thickness of the upper or lower region of the aquifer, h_a is the

head in adjacent aquifer and t is time.

3. Application and Analysis

3.1. Hydrological Properties

3.1.1. Geographical and Geological Properties

The study area is 150 Yangchon-dong, Sangju, Gyeongbuk, which is located at the east longitude 127° 5'~128° 13', and north latitude 36° 25"~36° 50". The slope is gentle and Byeongseong-cheon flows nearby. Most of the area consists of the 4th alluvial bed, and the bed consists of earth and sand bed, weathering soil bed, weathering rock bed, and soft rock bed from the top, and is covered by reclamation bed, which is alluvial bed, or paddies and dry soil bed from the top of the weathering soil bed. Geological state of the area is shown in Fig. 3.

3.1.2. Present condition of observation for each period according to pumping amount

Groundwater heads for total 5 wells in the analysis locate below almost E.L. 100m, and P1 and P4 show the highest and lowest value of E.L. 83.557m and E.L. 80.871m respectively. Pumping wells are P and P1, observation wells are P2, P3, and P4, and the dimension of each well is seen in Table 2.

A continuous observation was performed to estimate precise hydraulic parameters through the observation data of the study area, Yangchon-dong, Sangju. Total 11 observation data were collected for the 1st pumping period from January 14th to September 9th in 2002.

There was some difference in head decrease between single well(P) pumping and double well(P & P1) pumping. Single well pumping with 4㎥/hr for P
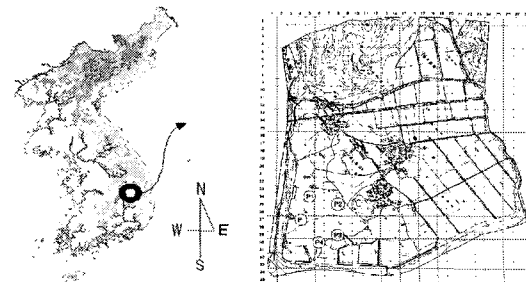

Fig. 3. Study area.

Table 2. Characteristics of each well
(Unit : EL. m)

Well No. \ Dist.	Elevation	Stable W. L.	From P Station (Height Difference)	From P Station(Distance Difference)	
				X	Y
P	85.00	82.05	0.00	0.00	0.00
P1	86.95	83.56	1.95	58.20	79.30
P2	86.34	83.46	1.34	150.20	88.60
P3	82.99	80.99	-2.01	129.30	130.50
P4	83.02	80.87	-1.98	42.50	143.70

* P Station : 3HP, Pumping Q=5m³/hr, P1 Station : 1HP, Pumping Q=1.5m³/hr

resulted in about 12m head decrease at P, and about less than 0.3m at P1~P2. However double well pumping with 4m³/hr for P and with 1m³/hr for P1 caused more significant effects that head decreased at P, P1, and P2~P4 about 13m, about 6m, and around 0.3m respectively, and it means that the double well pumping showed more influence than single well pumping.

In addition, in case of increasing the pumping rate to 5m³/hr at P, head decrease differences appeared as 0.17m, 0.15m, and 0.14m at P3, P4, and P2 respectively. It can be thought that from the head observation data for each well, the reason of P2 well showed relatively less head decrease than observation wells in down stream area is that the well is located at the upper area of P and P1, and relatively in distance from other observation wells in addition to the effect of somewhat small amount of pumping.

3.2. Infiltration experiment and Comparison of soil maps

3.2.1. S value estimation using the infiltration capacity curve analysis

Potential maximum retention, S was estimated using the value of infiltration capacity curve which is obtained by infiltration experiment and S value calculated using CN values according to hydrologic soil group and land cover of the test area were compared to verify field applicability of the detailed soil maps. Infiltration experiment was performed for paddy field, dry field, pasture, mountain, orchard, and so on according to land use conditions, however, an area which experienced artificial soil improvement is not suitable for the comparison to apply hydrologic soil group that is determined by soil categories in detailed soil maps. Experiment results from application to mountainous area were applied for CN estimation. S values were estimated through 4 infiltration experi-

ments in mountainous area. S values using experiment results were calculated by equation (2).

$$S = P_c F/Q \qquad (2)$$
$$S = F(1 + F/Q)$$

where, S is potential maximum retention (cm), Pe is effective rainfall (cm), F is cumulative infiltration (cm), and Q is direct runoff (cm). The two experimental sites are mixed wood with both of coniferous trees and latifoliate trees, and the experiment results are shown in Fig. 4.

3.2.2. Comparison of S values according to estimation methods

S is a characteristic value of an area which is the potential storage in the basin for the soil to be saturated completely, and is the only parameter for direct runoff estimation for each rainfall in non-observed area by the SCS-CN method. Potential storage which is needed for the soil to be saturated totally, S is determined by SVL (soil, vegetation, and land-use) and antecedent soil moisture index. Upper and lower limits exist for each SVL.

S value for the experiment site was calculated by applying CN values according to the experiment results and hydrologic soil groups on the detailed soil maps, and the Table 3 shows the results from the calculation methods using infiltration capacity curve (CASE-I), soil group classification from the experiment result (CASE-II), and soil group classification by the detailed soil maps (CASE-III).

3.2.3. Field applicability investigation through the analysis of the results

Experiment 1 resulted in similar S values for CASE-I and CASE-II of 30.6cm and 28.6cm, respectively, while CASE-III was different with the value of 6.8cm. In experiment 2, S for CASE-I was

(Experiment 1)

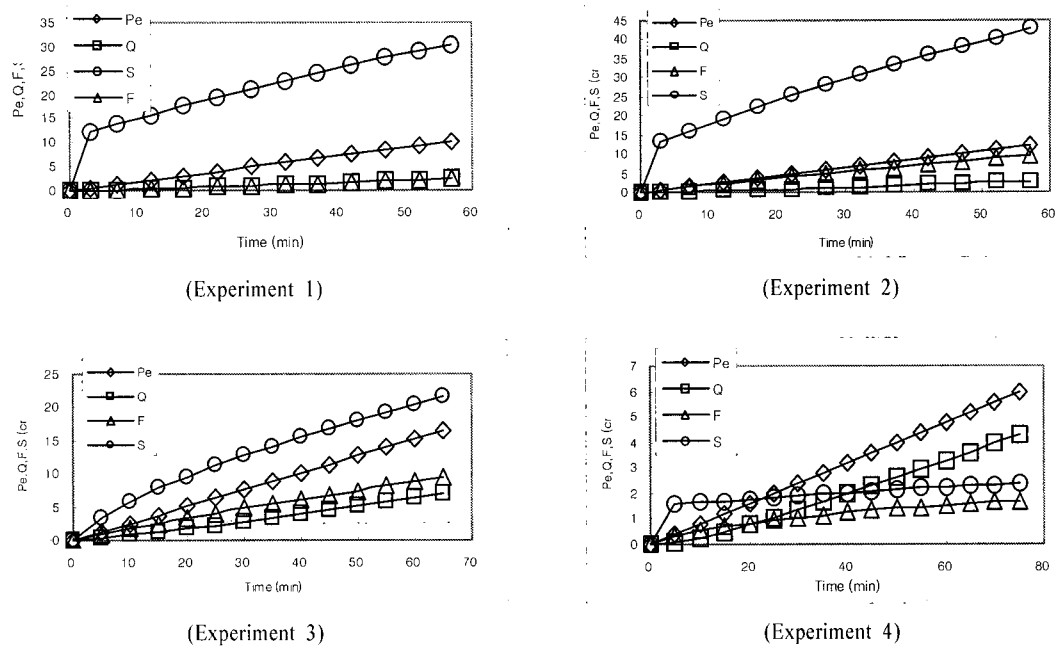(Experiment 2)

(Experiment 3)

(Experiment 4)

Fig. 4. Comparison of S, Pe, F, Q values.

42.7cm, and CASE-II and CASE-III were the same as in experiment 1 because the site of the experiment 1 and 2 falls into the same soil group. There is a tendency that S values of CASE-I and CASE-II in experiment 1 and 2 are greater than the result from CASE-III. This can be explained that CASE-III reflects the overall characteristics of the soil group rather than a characteristic of a particular area like CASE-I or CASE-II, because it estimated S values by classifying the hydrologic soil groups on the detailed soil maps. The different results from each CASE were obtained because a site which is not likely to occur infiltration of the rainfall can exist in a soil group. This tendency is well observed in experiment 3 and 4 that are executed in the same soil group.

In experiment 3 and 4, CASE-I and CASE-II showed relatively close S values to CASE-III. This result can be explained by the bedrock properties of the experiment site. The site 4, adjacent and classified as in the same soil group, reveals rock foundation with almost no surface soil. Experiment 3, relatively plain site, has S values of 21.6cm, 28.6cm, and 12.0cm for CASE-I, CASE-II, and CASE-III respectively. Thus it reflects well the overall soil characteristics of the site.

It is found that the tendency is different according to the site characteristics from the estimation of the potential maximum retention in each case for comparison between groundwater recharge analysis technique by hydrologic classification of soil series in the detailed soil maps and the experimental values from

Table 3. Calculation of parameter S value

Zone	No.	final infiltration capacity (mm/hr)	Hydrologic Soil Group		Curve Number(CN)		S (cm)		
			Experiment result	detailed soil map	Experiment result	detailed soil map	CASE I	CASE II	CASE III
I	1	73	A	C	47	79	30.6	28.6	6.8
	2	92	A	C	47	79	42.7	28.6	6.8
II	3	74	A	B	47	68	21.6	28.6	12.0
	4	7	B	B	68	68	2.4	12.0	12.0

rainfall-infiltration. The different results were obtained where the site can not reflect the overall soil group properties. This is caused by local characteristics like the conditions of the surface soil which affect largely on the infiltration, exposure of the rock foundation and openings where the infiltration does not occur, or relatively poorly covered area.

The comparison between the experimental results of the site that can reflect the overall characteristics and the calculation using hydrologic classification of the soil series in the detailed soil maps shows a similarity, therefore it is suitable for the field application.

3.3. Estimation of Groundwater recharge
3.3.1. CN estimation using GIS

Groundwater recharge was estimated by SCS-CN method with GIS for the study area. Hydrologic soil groups are classified to estimate CN values using the 1:25,000 detailed soil maps created by the National Institute of Agricultural Science and Technology.

The study area consists mainly of agricultural area of $0.941km^2(51.23\%)$ and orchard area of $0.401km^2$ (21.80%) with other areas like forest of $0.132km^2$ (7.27%), uncultivated of $0.267km^2(14.46\%)$, and farmhouse of $0.095km^2$ (5.24%) within the total area of $1.836 \ km^2$ as shown in Table 4. Most of the study area falls into the hydrologic soil group A and D of 45.86% $(0.842 \ km^2)$ and 38.23% $(0.702 \ km^2)$ respectively, while group B and C of 7.14% (0.131 km^2) and 8.76% (0.161 km^2), respectively occupy relatively small parts within the study area.

CN values were calculated using hydrologic soil group which was obtained by the detailed soil maps and the soil vegetation maps for each area of vegetation. Rainfall data from Korea Water Resources Corporation were referred to use the obtainable data

for 1990~2002, and the final recharge was estimated by applying weight to total area after calculation of the recharge for vegetation index and each area of hydrologic soil group without using average CN value of the study area.

3.3.2. Groundwater Recharge according to CN estimation

The final recharge was estimated by applying weight to total area after calculation of the recharge for individual vegetation index and each area of hydrologic soil group without using average CN value of the study area.

Groundwater recharge can be calculated from the comparison between long term cumulative infiltration and the rainfall for the same period because the infiltration for each rainfall event can be thought as the groundwater recharge, and the estimation results of the recharge of the study area using this are shown in Fig. 5.

According to the analysis results, the minimum groundwater recharge occurred during 1994 which was the year of severe drought with 106.3mm (12.4% of recharge rate) recharge, and 1990 was the maximum groundwater recharge year with 285.6mm (21.8% of recharge rate). It is analyzed that theaverage annual recharge and recharge rate are 213.2mm and 16.9%, respectively. The reason for the year 1992 recorded less recharge than other similar rainfall years is that the concentrated heavy rain events were not frequent as the other years and the rainfall distributed evenly throughout the year.

3.4. Establishment of Parameters and Boundary Condition

It is analyzed that the values of transmissivity of

Table 4. Estimation of CN values in study area

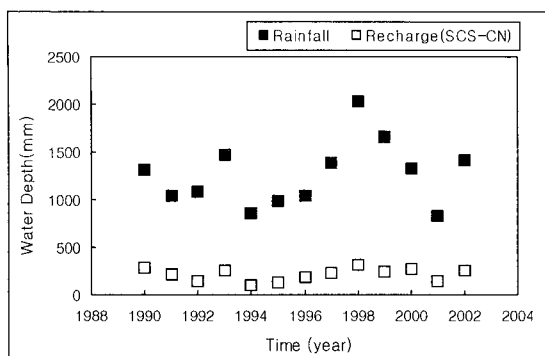| Section | Hydrologic Soil Groups | | | | | | | | Total area (km²) |
| | A | | B | | C | | D | | |
	Area(km²)	CN	Area(km²)	CN	Area(km²)	CN	Area(km²)	CN	
Farmhouse	0.085	79	0.000	86	0.000	90	0.011	92	0.095
Wood	0.015	47	0.077	68	0.041	79	0.000	86	0.132
Upland field	0.151	77	0.018	86	0.023	91	0.075	94	0.267
Orchard	0.354	44	0.016	66	0.018	77	0.013	83	0.401
Paddy	0.238	63	0.021	74	0.079	82	0.603	85	0.941
Total(km²)	0.842	-	0.131	-	0.161	-	0.702	-	1.836

Fig. 5. Results of groundwater recharge analysis.

P1, P2, P3, and P4 locations in the unconfined aquifer of Yangchon area in Sangju are 0.004995, 0.005045, 0.005466, and 0.00738(m^2/sec), respectively by Theis method using observation data. The average recharge rate of 16.9% analyzed from the calculation according to the CN estimation was applied to the computation to understand the groundwater movement which is the main purpose of the modeling without considering the drought or flood.

3.4.1. KOG-FLOW model

In the case of the finite difference grids for KOG-FLOW model which was applied in this study, the hydraulic factors were defined for the geologic properties of the individual layer by surveying rocks around the study area. Also, it was constructed considering that the square elements have the difficulty of representing exact curves of the area. The grids consisted of 28 along X axis and 5 along Y axis, total 1960 elements, and the 50cm intervals. And, Byeongseong cheon and a stream which flow nearby the study area were determined as the general head boundary. Boundary was determined after deep consideration of the watershed, and grid boundary was determined as water divide line and non-supply boundary.

3.4.2. WINFLOW model

Modeling was executed based on the understanding of hydro-geologic properties in the study area. Area was classified and element network was constructed including the area with consideration of the hydro-geologic properties of the area.The finite element grid network for groundwater movement analysis in this study consisted of 58×7 elements along X axis and Y axis, and the interval was 30m×30m, and 1:25,000 digital map was used.

3.5. Steady state flow analysis

The results of statistical analysis with the observed groundwater head and the computed values from each model operation to obtain the groundwater potential distribution are shown in Table 5.

P and P2 wells in KOG-FLOW model and P in WINFLOW model showed the smallest difference between the observed and computed values of 0.13m and 0.37m, respectively. The biggest difference between the observed and computed values occurred at P3 with 0.35m and P4 with 0.95m in case of KOG-FLOW and WINFLOW, respectively. Relative errors between the observed and the computed values in this analysis were 0.156~0.432% and 0.451~1.175% in case of KOG-FLOW and WINFLOW respectively, and it is shown that KOG-FLOW model yields the closer results to the observed values. Groundwater head distribution under steady state in the study area presented very similar results to the observed values by showing that the general groundwater flow runs with slow slope to the down stream area of the observation well where Byeongseong-cheon and the small stream flow.

3.6. Unsteady state flow analysis
3.6.1. KOG-FLOW model
Analysis on groundwater head distribution change

Table 5. Comparison between observed and computed head values   (Unit : EL, m)

Well No.	Elevation	Stable water level	Analysis water level		Relative Error(%)	
			KOG-FLOW	WINFLOW	KOG-FLOW	WINFLOW
P	85.00	82.05	82.18	81.68	0.158	0.451
P1	86.95	83.56	83.42	82.77	0.168	0.945
P2	86.34	83.46	83.33	83.06	0.156	0.479
P3	82.99	80.99	80.64	80.11	0.432	1.087
P4	83.02	80.87	80.59	79.92	0.346	1.175

under unsteady state flow in Yangchon area was performed, and the simulation results according to the time change when pumping rate was 5m³/hr at P and 1m³/hr at P1 are shown in Fig. 6. First, it is known from the groundwater potential distribution that the groundwater flow system around the wells represents nearly no change showing very similar groundwater head distribution with the case of the steady state except the decreased head at P and P1 after simultaneous pumping for 1 day. Next, from the groundwater potential distribution after 30 days of pumping, it is appeared that the head decreased somewhat largely at P and P1, and the occurrence of the groundwater head decrease was clear at nearby areas unlike the steady state.

Lastly, from the groundwater potential distribution after 90 days of pumping, it is found that the head decrease at P and P1 was almost same as the 30 days of pumping, and this is because of the less pumping amount compared to the recharge and the storage of the area. And this study found that the observed and computed values were almost similar to each other in the case of 1 day pumping.

3.6.2. WINFLOW model

In the case of P1 well, the overall groundwater flows slowly from the upstream to downstream, and the effective radius from the upstream shows smaller magnitude than P due to the less pumping amount.

Although the magnitude of the effective radius of 30 days pumping at P and P1 shows somewhat more complicated tendency than 1day pumping according to the change of pumping duration, it is analyzed that there is no change of head after 30 days by showing very similar results with KOG-FLOW model. And it is interpreted that the flow path is nearly straight to the downstream direction regardless of the changes in pumping duration.
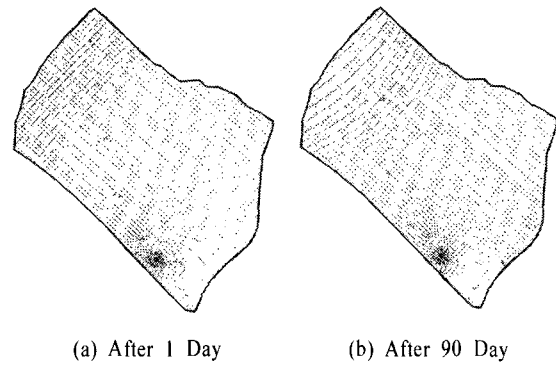

(a) After 1 Day   (b) After 90 Day

Fig. 6. Groundwater level distribution from unsteady flow simulation.

3.7. Notes and Considerations

This study proposed the KOG-FLOW model for the groundwater head distribution analysis under steady state in Yangchon area, and computed and observed heads were compared in the head distribution table which was created according to each well. Relative errors between observed and computed values were 0.156~0.432 and 0.421~1.175 for KOG-FLOW and WINFLOW, respectively, and it is known that KOG-FLOW produced closer results to the observed data than WINFLOW. It is analyzed that slow and stable head inclination runs from north to south. The following Table 6 shows the head distribution of the adjacent wells in cases of single or simultaneous pumping at P and P1 for 1 day.

4. Conclusion

This study used SCS-CN method to estimate the real recharge of the study area which is one of the most reasonable techniques to estimate groundwater recharge when there is no available runoff data in a watershed. Also this study reconstructed and established the KOG-FLOW model which has more powerful graphic functions in post process to develop a

Table 6. Relation of observed values and computed values(After 1 day pumping) (Unit : m)

| Pump. Well / Well No. | Water level drawdown values | | | | | | | | | Remark |
| | P | | | P1 | | | P & P1 | | | |
	Obser.	Compu.	R. E.	Obser.	Compu.	R. E.	Obser.	Compu.	R. E.	
P2	0.06	0.11	-0.833	0.02	0.03	-0.500	0.14	0.16	-0.143	-
P3	0.08	0.20	-1.500	0.03	0.05	-0.667	0.17	0.27	-0.588	-
P4	0.09	0.22	-1.444	0.04	0.07	-0.750	0.15	0.32	-1.133	-

groundwater movement analysis program that concerns field applicability first for the practitioners to approach easily, and the comparison and analysis results between field application and model simulation are as follows.

1) From the results of the real recharge analysis for the study area using SCS-CN method, it was analyzed that the year 1994 when the drought was severe showed the lowest recharge of 106.3mm with recharge rate of 12.4%, and the highest recharge of 285.6mm with recharge rate of 21.8% occurred in 1990. Yearly average recharge of 213.2mm was obtained, and the average recharge rate was 16.9%/year.

2) KOG-FLOW model which has powerful post process functions consists of setting environments for input parameters in Korean language, and help function is added to each input data. Detailed information for each parameter is displayed when the icon is placed on the input parameters, and geologic boundaries or initial head data for each layer can be set easily on work sheet.

3) Active cells are used to input parameters for steady or non steady flow analysis along with characteristics for each aquifer, so it is not complicated like other existing models and the flow map or vector map is produced for the analysis results.

4) The relative errors (R. E.) for each model's observed values and calculated values are 0.156~0.432 in case of KOG-FLOW, and 0.451~1.175 in case of WINFLOW, therefore it is known that KOG-FLOW model developed in this study produced results compared to observed head values.

5) It is analyzed that simultaneous pumping from P and P1 resulted in increased effective radius and complicated conditions, and in the view of variations of cone of depression due to the changes in pumping amount, the groundwater level decreases at the sides of the well and downstream area other than upstream area when the groundwater flows from the south to north (Byeongseong cheon).

In this study favorable results were obtained in groundwater movement analysis due to decrease of physical uncertainties of flow system along with rela-

tively easy model application from the groundwater movement analysis using KOG-FLOW model which has powerful post process graphic functions, and it is thought that the better estimation results can be obtained with accumulated hydrologic, geologic, and water level observation data for accurate parameter estimation in using the model.

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