GROUNDWATER RECHARGE ESTIMATION USING ARCGIS-CHLORIDE MASS BALANCE APPROACH

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Abstract: Groundwater recharge is defined in an addition of water to groundwater reservoir. Recently, many people have been moving to the Edwards aquifer and urban and agricultural industry have been expending. Hydrologists and water planning managers concern about insufficient groundwater amounts and irrigation water price variability. In this paper, I focus on estimates of local recharge volumes and quantify preferential flow through GIS technique. Chloride Mass Balance (CMB) and hydrochemical components have been widely applied to recharge rate and evaluate flow paths. The CMB method is based on relationship between wet-dry chloride deposition data and Rainfall data. These data are manipulated using ArcGIS. Especially, hydrochemical concentration distribution is good index for groundwater residence times or flow paths such as $[Mg^{2+}]/[Ca^{2+}]$,[Cl] and $\log([Ca^{2+}]+[Mg^{2+}])/[Na^{+}]$. Well information such as hydrological-hydrochemical data are imported into ArcGIS and manipulated by interpolation techniques. For each potentiometric surface and water quality, point data are converted to spatial data through each Kriging and Inverse Distance Weighted (IDW) techniques.

Keywords: GIS, CMB(Chloride Mass Balance) method, Hydrochemical components, groundwater recharge

1. INTRODUCTION

Recently, systematic recharge studies carried out in the Edwards-Trinity aquifer system (Plateau system). Most of study area is focused on the Edwards-Trinity aquifer system (Rose, 1972; Kuniansky and Holligan, 1994; Baker and Ardis, 1996). But recharge studies do not carried out enough about Edwards aquifer near Edwards-Trinity aquifer. The Edwards aquifer recharge area has been protected from Edwards aquifer authority. The groundwater from Edwards aquifer serves the diverse agricultural, industrial, municipal, recreational and household over needs over 1.7 million users in south-central Texas. In the aspect of hydrology, estimates of recharge volumes are calculated from water balance method through SCS curve number, rainfall and discharge rate. Moreover, in the aspect of hydrochemistry, they are calculated from combined chemical mass balance based on dating groundwater using the Chloride Mass Balance (CMB). The information of hydrochemistry in groundwater provides interpretations of groundwater age and preferential pathway.

2. MATERIALS AND METHODS

2.1 Hydrogeology of the Edwards aquifer

The Edwards aquifer is a karst aquifer of the most permeable and productive aquifers in Texas. The Balcones fault zone portion extends from west near Brackettville in Kinney County to the city of San Antonio in Bexar County and up to the northeast near Kyle in Hays County and it also is groundwater flow path and a distance of about 180 miles. The aquifer is the major water source for industrial, agricultural, municipal and 1.7 million people household needs. Water in the Edwards aquifer is continuously being recharged and discharged from aquifer. Rainfall is direct source on the recharge zone. It contains extremely cavernous porosity and permeability, the Edwards aquifer, karst aquifer, creates the conditions to allow extremely productive wells, the rapid infiltration of surface water and the rapid recovering groundwater level under rainfall events.

2.2 Precipitation and Recharge

Precipitation is the source of recharge to the Edwards Aquifer. Rainfall infiltrates directly-indirectly through the unsaturated zone to a groundwater body. For seven decades (1933~2003), annual average rainfall amount is approximately 30 inches/year (762mm/year) in this region. For this project, mean annual rainfall data are obtained from PRISM (Parameter-elevation Regression on Independent Slopes Model) that composed of grid.

Rate of recharge is estimated by assuming that discharges by base flow into stream and at spring under stand state condition.. Kuniansky (1989) mentioned that recharge rate is equal to discharge rate. However this conclusion has uncertainty. Actually, geological structure and groundwater flow path have not known well about this region.

Potentiometric surface data are obtained from Well information at Groundwater Water Development Board (GWDB). However, potentiometric surface data (point) are loaded and into ArcGIS with Kriging technique. Kriging method is useful tool for prediction of unmeasured potentiometric surface values.

2.3 Hydrochemistry

The recharge area and volume in the Edwards aquifer are estimated by based on Chloride Mass Balance methods. Chloride is concentrated in the dry deposition and in the wet deposition by raining within soil. Chloride(Cl^-) is easy to soluble and dissolve in the groundwater and it tend to make compounds with other ions (Ca^{2+}, Na^+, Mg^{2+}). For wet deposition by raining, chloride bearing rain arrives at surface and then, chloride percolates up to water table through unsaturated zone. For dry position distribution, it has not known in the Edwards aquifer region. However, Hope(2001) suggests that value of dry deposition distribution is half that of wet deposition distribution as well as chloride concentration in rain is 1/100 of that of groundwater in the Edwards aquifer region.

$$\frac{[Cl]_{wet\_chloride}}{[Cl]_{dry\_chloride}} = 2 \qquad (1)$$

$$\frac{[Cl]_{rain}}{[Cl]_{groundwater}} = \frac{1}{100} \qquad (2)$$

For this project using GIS, dataset of wet chloride deposition are obtained from National Atmospheric Deposition Program. They are measured from chemical measurement stations

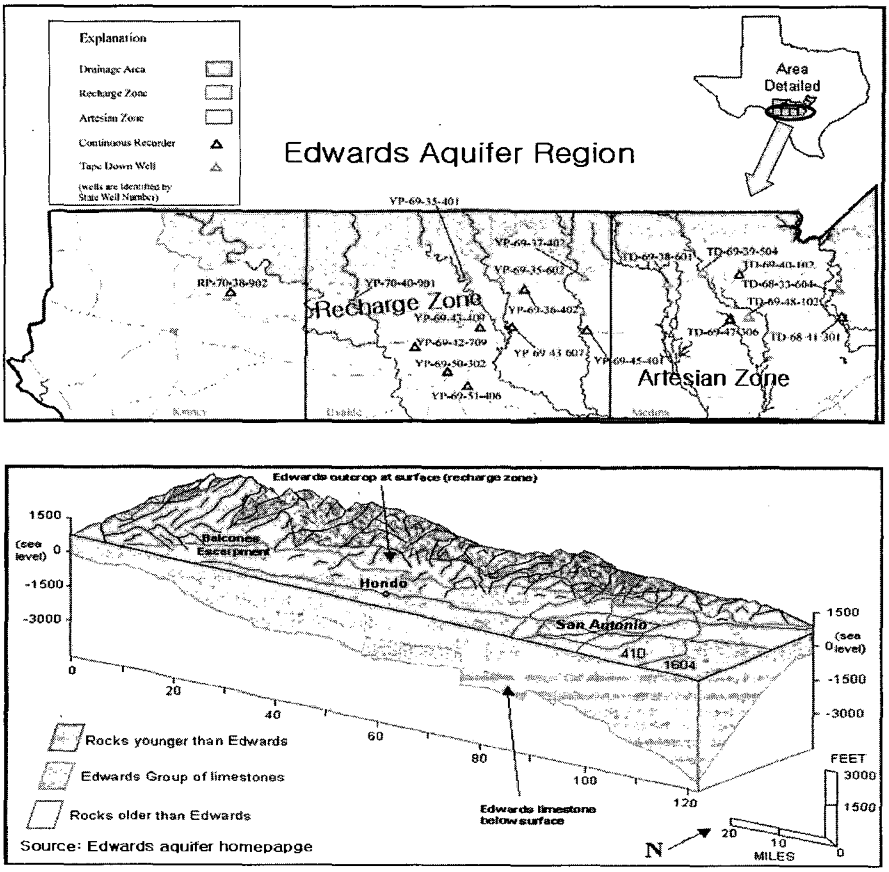

Figure 1. Edwards Aquifer region

of precipitation. Chemical measurements require through quality assurance, quality control and verification procedures to obtain meaningful data. Figure 2 shows the map of distribution of wet chloride deposition(mg/L) as raster formats for using ArcGIS. Groundwater chloride data are obtained from Texas Water Development Board (TWDB). Actually, water quality dataset are obtained from wells as point data. However, groundwater chloride data (Point data) as well as other hydrochemical data from TWDB are loaded into ArcGIS with Inverse Distance Weighed (IDW) technique and then, groundwater chloride data (point data) are converted to raster formats. Figure 3 shows the map of distribution of groundwater chloride concentration(mg/L). For IDW technique, it has assumption that is close to one another are more alike than those that are farther apart (ESRI, 2001). Groundwater chloride concentration measured in well closest to the prediction location will have more influence on the predicted value than those farther away. Thus, IDW assumes that each hydrochemistry data measured has a local influence that diminishes with distance. It weights the points closer to the prediction location greater than those farther away, hence IDW formula is;

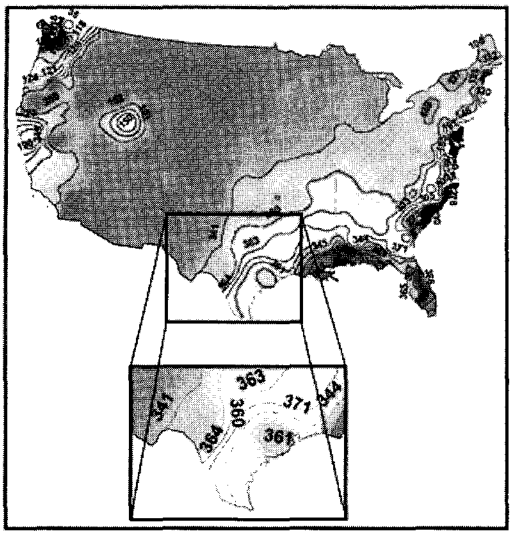

Figure 2. Map of distribution of wet chloride deposition(mg/L) in Edwards Aquifer region.

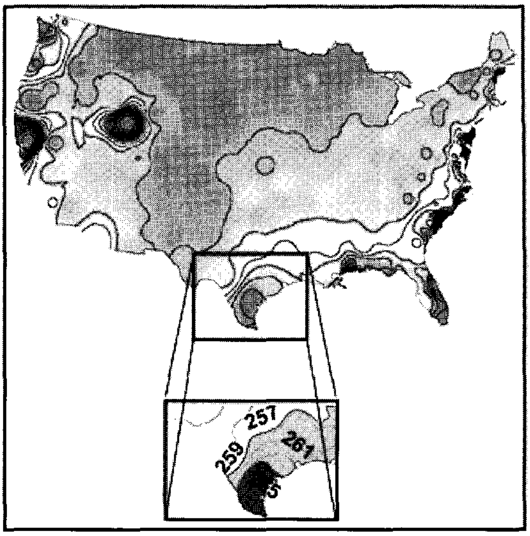

Figure 3. Distribution of chloride concentration (mg/L) in groundwater using IDW

$$z_j = \frac{\sum_i \frac{z_i}{d^n_{ij}}}{\sum_i \frac{1}{d^n_{ij}}} \qquad (3)$$

Where Zi is value of known point, dij is distance to known point, Zj is the unknown point, and n is a user selected exponent

Also, Recharge volume is calculated using Chloride Mass Balance like equation (4)

$$R_{echarge}(mm/yr) = \frac{[Cl^-]_{wet}}{[Cl^-]_{groudwater} - [Cl^-]_{Dry}} \times Rain_{annual(mm/yr)} \quad (4)$$

Figure 4 and 5 show that annual average(1971~2000) rainfall amount(mm/yr) and annual recharge volume(mm/yr) are calculated by wet-dry chloride deposition, chloride in groundwater and average annual rainfall using ArcGIS-ArcInfo.

The major mineral components of the Edwards aquifer consist mainly of limeston ($CaCO_3$), dolomite ($CaMg(CO_3)_2$) and feldspar ($NaAlSi_3O_8$). Total Dissolved Solids(TDS) median value is 320mg/L in this region. The most important cations are calcium(Ca^{2+}), magnesium(Mg^{2+}), and sodium(Na^+), meanwhile anions are bicarbonate(HCO^{3-}), chloride (Cl^-), surfate(SO_4^{2-}) and fluride(F) for delineation of preferred flow paths. Table 1 shows concentration of the most abundant and most commonly analyzed components in Edwards aquifer. Here, water-mineral reaction are the following,

Calcite dissolution,

$CaCO_3 \rightarrow Ca^{2+} + CO^{3-}$

Dolomite dissolution,

$CaMg(CO_3)_2 \rightarrow Ca^{2+} + Mg^{2+} + 2CO_3^{2-}$

Feldspar dissolution,

$2H_2CO_3 + 9H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 2Na^+ + 2HCO^{3-} + 4H_4SiO_4$

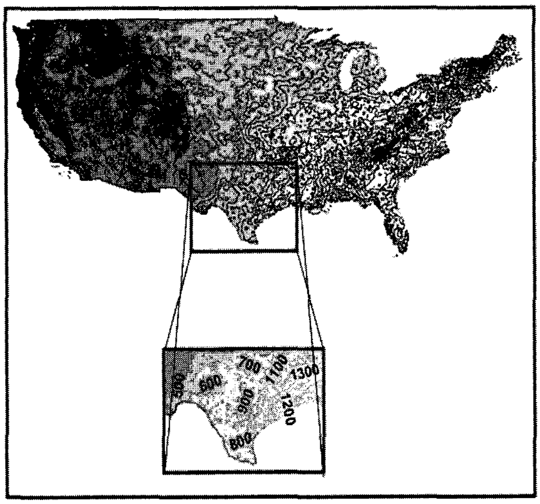

Figure 4. Distribution of annual average rainfall (mm/yr)(1971~2000)

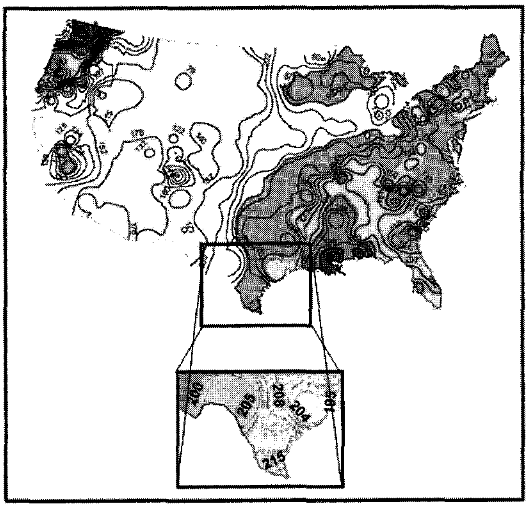

Figure 5. Distribution of recharge volume(mm/yr).

Halite dissolution,

$NaCl \rightarrow Na^+ + Cl^-$

Chloride is produced by evaporation of rainfall-bearing chloride prior to recharge or dissolve from halite (NaCl) under aquifer rock.

For the delineation of preferred flow paths in this region, three analysis are considered whether determination of groundwater youth or not. First index is chloride concentration. The most recently recharged or fastest downward flowing waters have lower chloride concentration. Meanwhile, slower infiltrated waters and longer resided groundwater in the aquifer have higher chloride concentration. Second index is $[Mg^{2+}]$ / $[Ca^{2+}]$. Kehew(2001) explained that calcite $(CaCO_3)$solubility is higher than that of dolomite$(CaMg(CO_3)_2)$. For dolomite$(CaMg(CO_3)_2)$ solubility, Ca^{2+} and Mg^{2+} are released by infiltrated water or groundwater. Hence, higher $[Mg^{2+}]$ / $[Ca^{2+}]$ are groundwater with long time residence. Figure 6-1 shows the distribution of $[Mg^{2+}]$ / $[Ca^{2+}]$.

Figure 6-2 shows that third index is Log $([Ca^{2+}]+[Mg^{2+}])/[Na^+]^2$. Cation exchange occurs when $[Na^+]$ has lower affinity than Ca^{2+} and Mg^{2+} , then increasing $[Na^+]$ means that groundwater with higher bearing $[Na^+]$ is fresh groundwater with lower residence time. Moreover, high values of Log $([Ca^{2+}]+ [Mg^{2+}])/[Na^+]^2$ are related to the least extent of cation exchange and higher recharge rate.

Then, figure 7 shows that flow directions inferred from correlations between real groundwater flow direction and two index.

3. RESULTS AND DISCUSSION

In the Figure 5, the amount of recharge estimates ranges from 205mm/yr to 215mm/yr in the Edwards Aquifer region. And also it is 760 mm/yr of mean annual rainfall in that region. As shown figure 5, in the recharge zone in the Edwards Aquifer, the highest recharge percentage occurs about 28% of total annual rainfall amount in the direction of north-east in the Edwards Aquifer and the lowest recharge

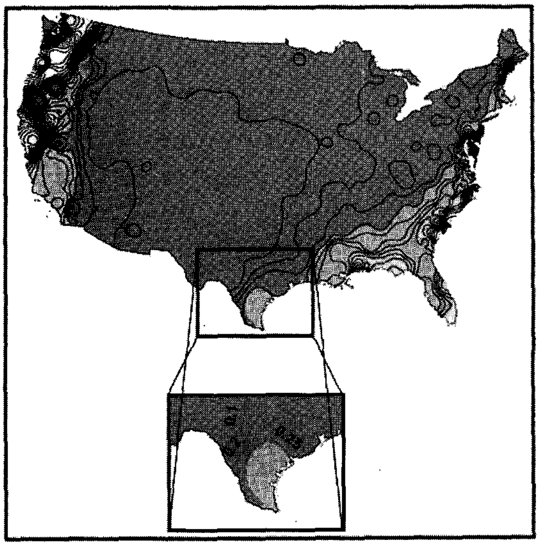

Figure 6-1. Distribution of [Mg^{2+}] / [Ca^{2+}]

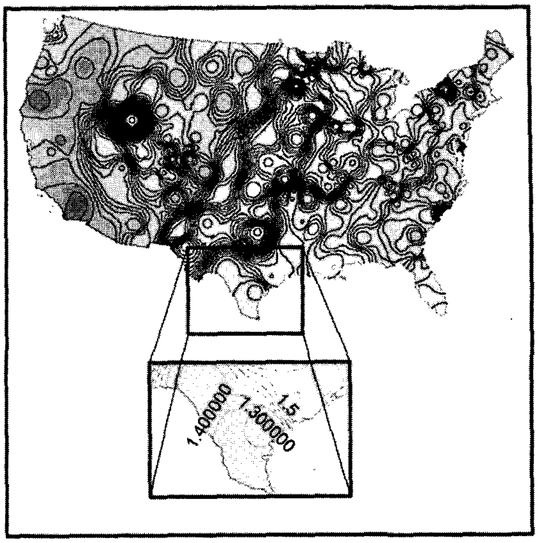

Figure 6-2. Distribution of Log ([Ca^{2+}]+[Mg^{2+}])/[Na^{+}]^2

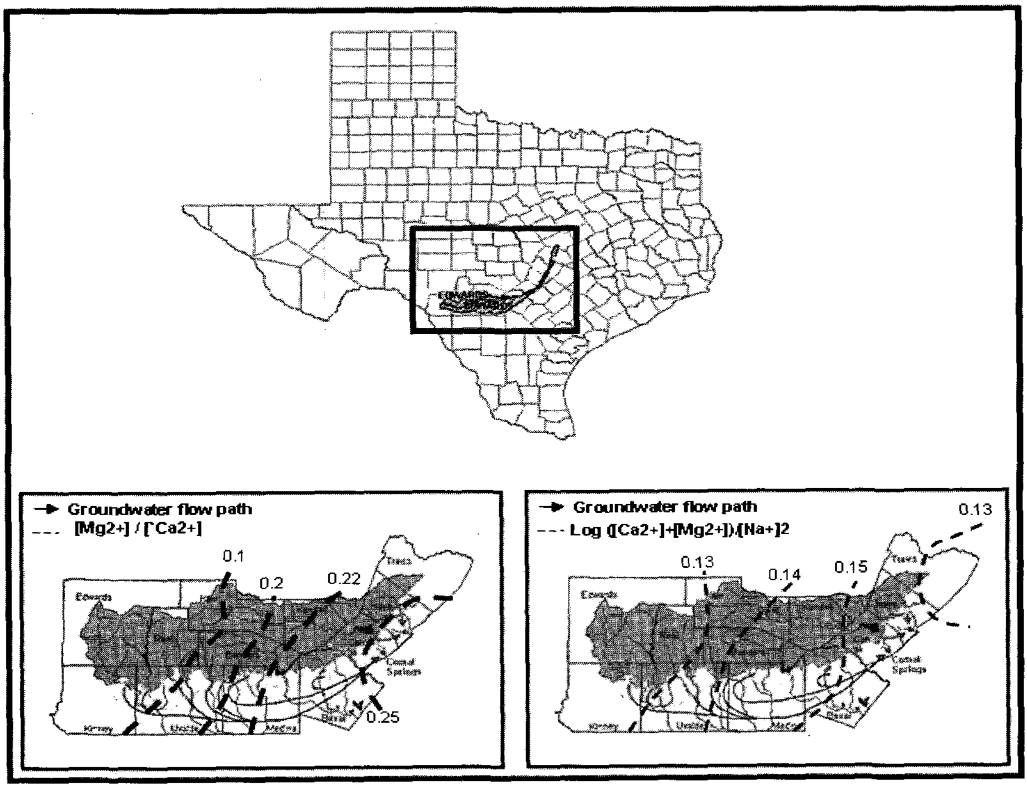

Figure 7. Map of interpreted flow path

Table 1. Concentration of main components in Edwards aquifer.

Major Ion	Conc.(mg/L)
Ca	80~120
Mg	10~20
Na	3~10
K	1~2
CO3	250~400
SO4	10~30
Cl	10~30
F	0.1~0.5
SiO4	10~20

percentage occurs 26% in direction of near east coast in the Edwards Aquifer. For the recharge of artesian zone, it is indirectly recharged from recharge zone and directly recharged from faults and a number of well in this region.

For the interpreted flow path using three parameters, Figure 6 and 7 show that three hydrochemistry index such as [Cl-], $[Mg^{2+}]$ / $[Ca^{2+}]$ and Log $([Ca^{2+}]+[Mg^{2+}])/[Na^{+}]^2$ depend on preferred flow path. In addition, Figure 7 shows that the interpreted flow path's results using three parameters are similar to real flow path in the Edwards Aquifer. The relationship between low Mg/Ca, Log $([Ca^{2+}]+[Mg^{2+}])$ $/[Na^{+}]^2$ and real flow paths have strong correlation. As the groundwater age is the younger, three parameters value is the lower. However, there is exceptional case in some geological characteristics. The preferred flow path is not interpreted by three hydrochemistry index with cation exchange because the highest potentiometric gradients depend on flow path in unconfined aquifer or karstic terrain gives the highest pressure to groundwater in confined aquifer.

4. CONCLUSION

This method presented for computing and mapping recharge volumes and interpreted hydrological flow path using ArcGIS seem to give reasonable results. Moreover, this method for application to other place should be possible if there are sources of chloride in rock and the rate of deposition of chloride over the region. Most of all, over most of other regions, there are generally limited data that are insufficiently focused to solve recharge volumes and preferred flow path. Then, hydrochemical method is adequate for this limitation.

For economic aspects, the survey of recharge volumes and preferred groundwater path is expensive and inefficient. For example, using radio isotopes(^{14}C or ^{3}H) cost hundreds of dollars a piece in the market place.

Meteoric recharge and groundwater-based rock interactions make hydrochemical ions, hydrochemical ions are used for estimates of recharge volumes and flow path using chloride mass balance(CMB) and annual rainfall amount. Currently, many water quality data from Texas well data are easily exploited. Therefore, CMB approach can provide good information to resource managers for protecting groundwater and water conservation.

But, CMB has a limitation. It is only used by poor data about chloride concentration. Most of all, the distribution of dry deposition data is poorly known. Hence, a local survey of that information has to be performed precisely and solubility of aquifer rock is also poorly known

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