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A method to estimate groundwater recharge

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Abstract: The conventional method of groundwater recharge estimation is reviewed and a computer program to ease the estimation is presented. The calculation takes into account precipitation, evaporation, soil moisture and the resultant recharge. The validity of the program is tested against MORECS data. An assessment of recharge to aquifer system in Langat river basin with the program suggests that preliminary annual recharge varies between 429.13 mm to 1,493.72 mm.

Abstrak: Keadah konvensional dalam menganggarkan imbuhan air tanah dinilai semula dan satu program komputer yang memudahkan penganggaran tersebut dipersembahkan. Pengiraan ini mengambilkira kerpasan, evaporasi, kelembapan tanih dan hasilan imbuhan. Ketepatan program ini telah diuji dengan data MORECS. Suatu penilaian imbuhan kepada akuifer dalam lembangan Sungai Langat dengan menggunakan program ini telah dijalankan dan mencadangkan anggaran awal imbuhan tahunan akuifer adalah di antara 429.13 mm dengan 1,493.72 mm.

INTRODUCTION

Recharge is one of the essential input parameters to any groundwater modelling and should be represented adequately. Recharge to groundwater table determine the water quantity available for abstraction in the long term and therefore of prime importance in the assessment of any groundwater resource. Since direct measurement of the recharge component is not possible, an indirect method to quantify the recharge needs to be selected from the few available theoretical methods. One of the most widely used conventional method of estimating recharge is based on the studies of Penman and Grindley (Penman, 1949, 1950; Grindley, 1967, 1969). Recharge can be regarded as a function of effective rainfall (precipitation minus evaporation) which is distributed according to a simple land use model. This method is used widely particularly in agricultural aspects of the water balance. This paper reviews the conventional method in estimating groundwater recharge and outlines a simple computer program written using Visual Basic to ease the calculation. The program has been used to calculate recharge to the aquifer in the Langat river basin.

THE CONVENTIONAL METHOD OF RECHARGE ESTIMATION

General

The conventional method is primarily concerned with the determination of actual evaporation and soil moisture deficits rather than estimating recharge (Rushton and Ward, 1979). However, this approach can yield an acceptable estimate of recharge provided that the ground surface is relatively flat, the soil zone is in direct contact with the aquifer, the hydraulic conductivity of the aquifer is high and the water table is some distance below the top of the aquifer (Jackson and Rushton, 1987). These conditions are met mostly in coastal areas in Peninsular Malaysia.

With this method, recharge is calculated as the remainder when losses, identified in the form of runoff and evaporation (also envelops transpiration), have been deducted from precipitation.

Outline of the Recharge Calculation

Many published papers discuss the above conventional method of recharge calculation (e.g. Howard and Lloyd, 1979; Rushton and Ward, 1979; Jackson and Rushton, 1987). An outline of the method given by Howard and Lloyd (1979) was followed in this study.

During periods when precipitation exceeds evaporation, generally in the monsoonal periods in a tropical environment, soil moisture content may increase to field capacity, the saturation value. Then, when free drainage under gravity will begin and recharge occurs.

As soon as evaporation exceeds precipitation, the soil moisture begin to dry out, a soil moisture deficit develops and according to the classical model all recharge will cease. However, under normal atmospheric conditions, plant transpiration or evaporation cannot completely dry out a soil and in most cases evaporation will proceed at the maximum or potential rate until an amount of water equal to RC, the root constant, or drainage factor has been removed from a soil which was originally at field capacity. Evaporation now proceeds at a much slower rate, and consequently the previous rapid rise in soil moisture deficit is checked. Lloyd *et al.* (1966) proposed that the change in soil moisture be taken as one tenth of the excess of potential evaporation over precipitation less runoff. While the potential evaporation continues to exceed precipitation, the soil moisture deficit will increase at a reduced rate until a maximum soil deficit (SMDmax) is reached.

Mathematically, the balance may be represented by basic equation (source: Lloyd *et al.*, 1966):

$$P = AE + Ro + \Delta S$$

where P = precipitation (mm)

Ro = direct surface runoff (expressed as mm over the catchment)

ΔS = the potential change in soil moisture content in mm

AE = actual evaporation

AE may in turn be represented by;

AE = PE (for P > PE)

and in the case where P< PE, by;

AE = PE (for 0 = SMD = RC)

AE = P+10%(PE-P) (for RC = SMD = SMDmax)

AE = 0 (for S = SMDmax)

where PE = potential evaporation

SMD = soil moisture deficit

RC = root constant

SMDmax = maximum soil moisture deficit

Periodical estimates of P, AE, Ro, RC and SMDmax allow ?S the potential change in soil moisture content to be calculated. It is a good practice to start the calculation in a wet month to avoid complications in estimating the initial value of soil moisture deficit. The progressive estimates of soil moisture deficit allow recharge to be determined.

To ease the calculation, a Visual Basic program was written (see Appendix 1). The program calculates the actual evaporation, soil moisture deficit and effective rainfall or recharge using precipitation and potential evaporation input data. The calculation can be executed on a daily, monthly or yearly basis. To check the validity of the programme, the estimated recharge calculated by the programme for chalk aquifer in West Norfolk, UK had been compared with effective rainfall calculated by the Meteorological Office Rainfall and Evaporation Calculation System, MORECS developed by Meteorological Office, UK as shown in Figure 1 (Yusoff, 2000).

AN ASSESSMENT OF RECHARGE TO THE LANGAT RIVER BASIN AQUIFER

The study area

Langat river basin is an important water catchment area providing raw water supply and other amenities to approximately 1.2 million people within the basin. Important conurbations served include towns such as Cheras, Kajang, Bangi, Government Centre of Putrajaya and others. Comprising two reservoirs (Semenyih and Hulu Langat) and 8 water treatment plants, they provide clean water to the users after undergoing treatment (Fig. 2).

The usage of the water is not limited to water supply but can also be used for other purposes such as recreation, fishing, effluent discharge, irrigation and even sand mining, to name a few. These multi faceted usages of the river water lead to conflicting interests from the perspective of various stakeholders. Therefore, there is a need for proper resource optimization and resolution of conflict.

Geology

In reference to Figure 3, bedrock in the mountain area near the source of the river is granite that forms the mountainous bone of the peninsula and it extends around hilly areas near Kg. Cheras. The foothills are hilly areas

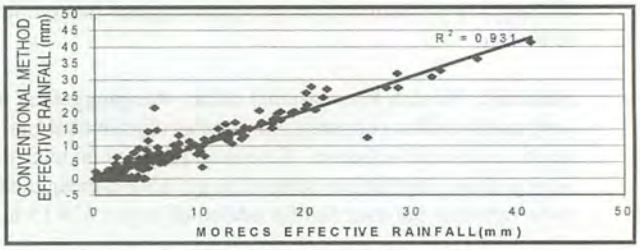

Figure 1. Comparison of recharge calculated by the 'conventional method' and by MORECS. The 'root constant' used in the conventional method is 70 mm.

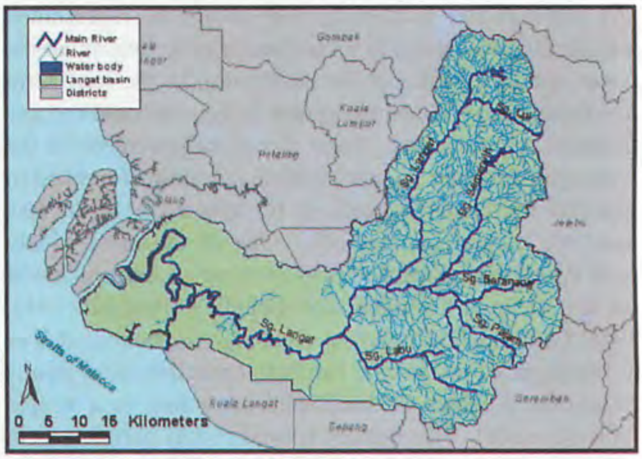

Figure 2. Langat river basin.

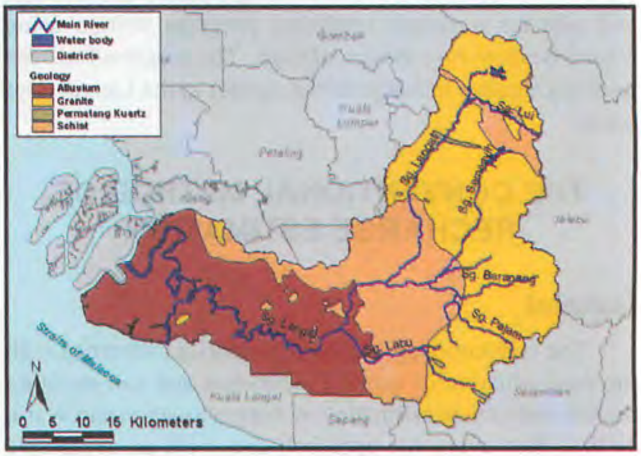

Figure 3. Geological map of Langat river basin.

mapped as the Kenny Hill Formation and Kajang Formation, consisting of metamorphosed sandstone, shale, mudstone, and schist. The layers overlying the bedrock, including those on granite, is weathered. Some parts are highly weathered with depths of several meters (DMG, 2001).

In the lower flatlands, thick Quaternary layers are deposited on the bedrock. The Quaternary deposits, from the top to the bottom, consists of 0.5 to 5.5 m deep Beruas Formation with peat layer at the top, clayey Gula Formation and Kempadang Formation starting in the hilly areas and having a 40 to 50 m depth near the coast. These are underlain by the Simpang Formation of sand and gravel with thickness of several meters in the hilly area and about 50 m to more than 100 m in the low flatlands (DMG, 2000).

Hydrogeology

The Quaternary sediments in the subject groundwater basin are divided into four layers, namely from the ground surface peat/peaty clay layer (Layer 1), clayey soil layer (Layer 2a and 2b), sandy and gravely soil layer (Layer 3) and the bedrock (Layer 4), as shown in Figure 4.

Very soft peaty soils (Layer 1) of Beruas Formation consist mainly of peat with a total thickness of about 1 to 5 metres. Soft clayey soils (Layer 2a) consist of light/greenish grey to grey marine silty clay of Gula Formation. The thickness of the layer increases from several metres at the northern part of the basin to more than 20 m at the seacoast. The thickness also increases towards the west side of the basin. Medium to stiff clayey soils (Layer 2b) mainly consist of light grey to grey clay with thickness varying between several metres to over 10 metres. This layer is also considered as Gula Formation.

Layer 3 consists mainly of sandy and gravely soils of the Lower Member of Simpang Formation and widely spread over the Groundwater Basin. The thickness of the layer varies considerably, ranging from several metres in the northern part of the basin to over 100 metres at the

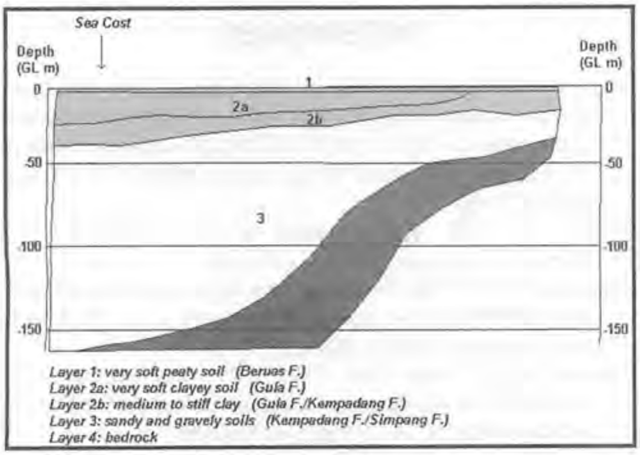

Figure 4. Cross section of Langat river basin.

Table 1. Sample output for Pusat Pertanian Teluk Datuk station in Selangor.

RECHARGE CALCULATION PROGRAM - OUTPUT
P : Precipitation / Rainfall
PE : Potential Evaporation
AE : Actual Evaporation
SMD : Soil Moisture Deficit
diff : difference between Root Constant & SMD before adjustment to SMD
Excess : Excess Rainfall
Root Constant = 93

Month	Year	P	PE	AE	Recharge	SMD	diff	Excess
Jan	1990	83.30	102.00	102.00	0.00	18.70		
Feb	1990	69.30	114.00	114.00	0.00	63.40		
Mar	1990	26.90	129.00	90.65	0.00	100.25	56.50	72.50
Apr	1990	216.10	116.00	116.00	0.00	0.15		
May	1990	57.50	110.00	110.00	0.00	52.65		
Jun	1990	28.90	108.00	102.03	0.00	96.88	69.25	38.75
Jul	1990	105.40	107.00	105.56	0.00	97.04		
Aug	1990	42.40	113.00	49.46	0.00	104.10		
Sep	1990	261.00	106.00	106.00	50.91	0.00		
Oct	1990	209.60	109.00	109.00	100.60	0.00		
Nov	1990	221.00	95.00	95.00	126.00	0.00		
Dec	1990	193.00	99.00	99.00	94.00	0.00		
Jan	1991	95.00	99.00	99.00	0.00	4.00		
Feb	1991	31.50	107.00	107.00	0.00	79.50		
Mar	1991	73.60	124.00	164.39	0.00	96.69	87.10	36.90
Apr	1991	111.40	112.00	111.46	0.00	96.75		
May	1991	270.40	108.00	108.00	65.65	0.00		
Jun	1991	200.90	110.00	110.00	90.90	0.00		
Jul	1991	66.50	108.00	108.00	0.00	41.50		
Aug	1991	124.00	108.00	108.00	0.00	25.50		
Sep	1991	377.20	98.00	98.00	253.70	0.00		
Oct	1991	54.10	95.00	95.00	0.00	40.90		
Nov	1991	278.80	87.00	87.00	150.90	0.00		
Dec	1991	391.80	82.00	82.00	309.80	0.00		
Jan	1992	39.80	108.00	108.00	0.00	68.20		
Feb	1992	158.20	106.00	106.00	0.00	16.00		
Mar	1992	26.30	124.00	131.67	0.00	95.07	103.30	20.70
Apr	1992	93.80	116.00	96.02	0.00	97.29		
May	1992	154.40	111.00	111.00	0.00	53.89		
Jun	1992	71.20	106.00	106.00	0.00	88.69		
Jul	1992	208.30	106.00	106.00	13.61	0.00		
Aug	1992	92.80	114.00	114.00	0.00	21.20		
Sep	1992	134.40	111.00	111.00	2.20	0.00		
Oct	1992	182.80	108.00	108.00	74.80	0.00		
Nov	1992	207.00	93.00	93.00	114.00	0.00		
Dec	1992	200.20	93.00	93.00	107.20	0.00		
Jan	1993	109.50	102.00	102.00	7.50	0.00		
Feb	1993	21.10	104.00	104.00	0.00	82.90		
Mar	1993	283.00	118.00	118.00	82.10	0.00		
Apr	1993	126.30	112.00	112.00	14.30	0.00		
May	1993	97.90	109.00	109.00	0.00	11.10		
Jun	1993	181.30	110.00	110.00	60.20	0.00		
Jul	1993	127.80	108.00	108.00	19.80	0.00		
Aug	1993	75.50	110.00	110.00	0.00	34.50		
Sep	1993	128.30	109.00	109.00	0.00	15.20		
Oct	1993	278.00	107.00	107.00	155.80	0.00		
Nov	1993	232.70	95.00	95.00	137.70	0.00		
Dec	1993	152.90	89.00	89.00	63.90	0.00		

Table 2. Summary of recharge calculation results for Langat Basin.

Rainfall Stn	Land Use	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Average
C1	grass	371.51	870.95	311.81	541.30	445.85	616.42	143.52	366.75	605.64	500.50	477.43
(P.Pertanian Teluk Datuk)	towns	346.11	823.25	272.46	466.30	386.65	560.52	101.52	341.62	551.54	441.30	429.13
C2	grass	711.00	1,395.63	1,079.00	1,590.70	1,061.80	1,438.80	1,286.00	1,103.44	782.60	1,347.71	1,179.67
(PORIM, Bangi)	towns	636.00	1,340.83	1,004.00	1,521.10	993.60	1,363.00	1,212.00	1,055.21	708.60	1,282.01	1,111.64
C3	grass	813.50	1,396.83	997.00	1,623.30	1,044.70	1,500.10	1,101.30	968.00	744.10	1,251.19	1,144.00
(MARDI Serdang)	towns	738.50	1,342.03	929.74	1,548.30	977.50	1,423.30	1,027.30	908.79	670.10	1,189.79	1,075.54
C5	grass	511.93	1,355.80	731.46	1,034.01	1,310.50	1,575.70	943.50	846.10	945.30	1,471.20	1,072.55
(MARDI Klang)	towns	473.03	1,283.80	664.76	969.81	1,240.50	1,502.70	874.50	776.10	872.30	1,401.20	1,005.87
C8	grass	774.19	1,423.90	1,034.50	1,572.90	832.10	1,681.70	872.46	1,014.20	1,030.50	1,394.10	1,163.06
(Ampangan Ulu Langat)	towns	723.49	1,352.90	959.50	1,497.90	760.10	1,609.70	809.26	946.80	987.64	1,322.10	1,096.94
C10	grass	850.10	2,028.00	1,297.50	1,734.50	1,351.22	1,766.90	1,226.00	1,585.40	1,311.20	1,786.40	1,493.72
(TUDM Sungai Besi)	towns	775.10	1,957.00	1,222.50	1,659.50	1,285.52	1,694.90	1,152.00	1,514.40	1,237.20	1,714.40	1,421.25
R4	grass	569.61	1,274.22	742.23	725.70	886.80	1,214.70	595.85	602.12	565.59	374.27	755.11
(Banting Oil Palm Research Station)	towns	546.10	1,222.11	687.77	650.70	816.80	1,141.70	543.05	565.42	530.48	315.07	701.92
R6	grass	215.38	904.61	613.60	1,469.70	1,643.70	1,623.10	1,429.20	1,071.70	1,277.10	1,024.70	1,127.28
(LPA Salak Tinggi)	towns	187.18	844.41	538.60	1,394.70	1,571.70	1,551.10	1,355.20	1,010.51	1,203.10	957.79	1,061.43
R7	grass	836.90	1,539.20	870.70	1,404.80	1,046.20	1,680.00	1,098.00	854.90	620.61	1,506.10	1,145.74
(Ampangan Air Sungai Semenyih)	towns	761.90	1,468.20	795.70	1,329.80	974.20	1,608.00	1,029.40	783.90	565.51	1,434.10	1,075.07
R8	grass	704.32	1,227.80	659.50	811.30	1,330.83	1,731.20	1,117.50	746.41	555.90	914.65	979.94
(NEB Connaught Bridge Power Station, Klang)	towns	642.02	1,155.80	591.54	736.30	1,276.13	1,658.20	1,048.50	696.84	482.90	860.85	914.91
R9	grass	436.20	967.60	439.10	688.10	990.30	1,508.40	717.60	368.82	714.94	840.79	767.19
(Marine Dept, Port Klang)	towns	362.20	895.60	388.15	617.69	920.30	1,435.40	648.60	341.30	670.65	786.99	706.69
R13	grass	329.78	866.90	449.39	960.70	1,361.50	991.10	578.60	358.50	551.25	912.00	735.97
(Dusun Labu Valley)	towns	283.58	795.90	396.89	885.70	1,289.50	919.10	504.60	329.35	498.40	840.00	674.30

seacoast. Although the sandy/gravelly soil layers are grouped in a single unit, alternating clayey soil layers and sandy/gravelly soil layers are common features of Layer 3.

Input data and Results

Monthly rainfall (precipitation) data was obtained from Department of Irrigation and Drainage (DID) and Malaysian Meteorological Services (MMS) while PE data was calculated using Penman Procedure's Program developed by Hydrology Branch, DID Malaysia in 1991 (Shaaban *et al.*, 1991). This program uses climate data from MMS as inputs. The climate data includes mean daily sunshine hours (hour), mean temperature (°C), mean relative humidity (%), and mean surface wind speed (m/sec). 10 years data (from 1990 to 1999) were used to calculate PE.

Root Constant value was estimated using land use maps. Root Constant is calculated based on 60% of MORECS values of available water capacity for different kinds of land use (Thompson *et al.*, 1981). Total Root Constant value for each rainfall station is then summed up and divided by total area to get Areal Root Constant value.

With 10 years monthly P and PE data (1990-1999) together with the above mentioned areal root constant value, average yearly recharge is calculated using Recharge Calculator. Sample output from Recharge Calculator for one of the stations within Langat river basin is given in Table 1. Recharge for each station together with the average recharge values is tabulated in Table 2. Net Recharge value for Langat river basin area varies from 429.13 mm to 1,493.72 mm. All water bodies have no recharge value.

CONCLUSION

This paper describes a quantitative method to estimate groundwater recharge. A simple computer programme has been developed to ease the estimation. The conventional method or soil water balance method is considered a reliable method in estimating recharge to the aquifer that has passed through the soil. The effect of plants in form of root constant value in controlling the amount of recharge is also considered by the method. This factor is always ignored in the simple water balance method to estimate recharge. Further modification of the method may be made subject to detailed study of groundwater recharge mechanism and proper method to define the root constant value.

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Appendix 1

Source Code for Recharge Calculation
'Recharge Calculation'

```
smd = 0

For i = 1 To totRec
ep(i) = p(i) - pe(i)

If ep(i) >= 0 Then
smd = smd - ep(i)
recharge(i) = ep(i) - smd
If smd < 0 Then
recharge(i) = smd * -1
smd = 0
End If

If smd > 0 Then
recharge(i) = 0
End If

ae(i) = pe(i)

Else
recharge(i) = 0
If smd >= rc Then
ae(i) = p(i) + (-0.1 * ep(i))
smd = smd + (ae(i) - p(i))

ElseIf (((ep(i)) * (-1)) + smd) < rc Then
smd = smd - p(i)
ae(i) = pe(i)
smd = smd + ae(i)
Else
smd = smd - p(i)
diff(i) = rc - smd
If diff(i) < 0 Then
diff(i) = 0
End If
xcess(i) = ((smd + pe(i)) - rc) * 1
ae(i) = p(i) + diff(i) + (0.1 * xcess(i))
smd = smd + (ae(i) - p(i))
End If

End If
Next
```