Historical Groundwater Fluctuation in Suffolk, Virginia Simulated Using Effective Monthly Recharge (W_{em}) Model

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ABSTRACT

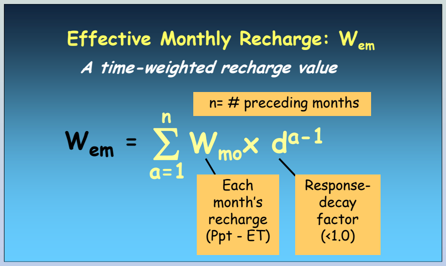
Estimates of historical long-term water-level fluctuations provide guidance to wildlife habitat managers, wetland design professionals, and agency regulators about the probable availability of groundwater and will be used in a comprehensive package of water-budget models now under development. The Effective Monthly Recharge (W_{em}) model generates a synthetic hydrograph of water table elevations for precipitation-driven systems. A time-weighted averaging technique, the W_{em} water-budget model simulates recharge fluctuations with historical weather data. Recharge equals precipitation, adjusted for interception (I), minus Penman evapotranspiration estimates. Model users calibrate calculated monthly W_{em} values against monthly head data by varying the number of months of weather data (n) used in the calculation, and the weight (d) applied to antecedent conditions. The combination of n and d that generates the best correlation of W_{em} vs measured heads is used to estimate monthly head values for preceding years; the estimates are generated with historic weather data. Thirty years of local weather data and daily head data from a USGS well in Suffolk allow us to test the model using the head on first day of each month. Data from 2003-2005 suggest n=18 months and d=0.9 provide the best fit (R^2=0.87) for this site; this correlation exceeded that generated by using unfiltered data (R^2=0.56) by excluding head values affected by recent rain. Comparison of all monthly USGS well data (unfiltered) and the model-generated head values for 1981-2002 produces a significant correlation (R^2=0.59). Sensitivity analyses of interception estimates suggest an I=0.25 maximizes the correlation coefficient for these data.

RESEARCH GOALS

Our goal is to **verify the calibration procedure** of the Effective Monthly Recharge (W_{em}) model. We wanted to **calibrate** the model using a short portion of a long record of groundwater levels from a precipitation-driven unconfined aquifer system at a site with an equally long set of weather data. Subsequently we wanted to **verify** the model using the rest of the long record.

PREVIOUS WORK

The Effective Monthly Recharge (W_{em}) model generates a synthetic **hydrograph of water table elevations** for groundwater systems driven by only precipitation and evapotranspiration. The W_{em} water-budget model simulates recharge fluctuations over time using historical weather data. Model inputs are monthly recharge (total monthly **precipitation** minus **evapotranspiration**) and monthly water levels (e.g. **heads** in wells collected at the first of the next month). The model calculates a **time-averaged recharge** value based on variables **n** (number of months of antecedent weather data used) and **d** (response-decay factor).



Effective Monthly Recharge: W_{em}

A time-weighted recharge value

n= # preceding months

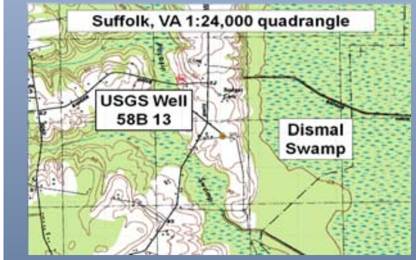
$$W_{em} = \sum_{a=1}^{n} W_{mo} \times d^{a-1}$$

Each month's recharge (Ppt - ET)

Response-decay factor (<1.0)

Most previous studies using the W_{em} model generated long synthetic hydrographs for historical periods but at sites without well records sufficiently long to verify model results.

SITE DESCRIPTION

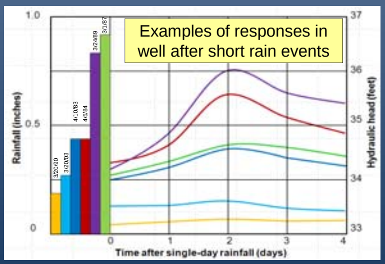


To verify the model, we used hydraulic heads measured at a 5m (15ft)-long monitoring well maintained by the U.S. Geological Survey in Suffolk, Virginia. This site has a **relatively long record (25+ years)** of daily water levels and sits on an isolated interfluve of unconsolidated marine sediment. Here, this **unconfined groundwater system is recharged exclusively by precipitation**. Weather records exist, gathered at a local airport. These characteristics make this an excellent site for a W_{em} analysis.

MODEL PROCEDURE: Data Set Development

Data required to make W_{em} calculations include **hydraulic head** readings for as many months as possible during the calibration period, and **total precipitation** and **evapotranspiration** (ET) values for those months and for 24 preceding months.

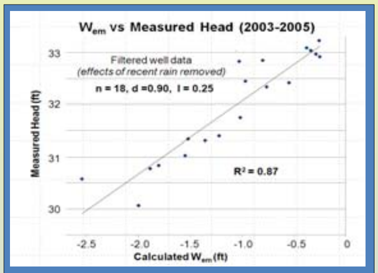
Months should be **filtered** from the analysis if well readings were not taken soon after the first of the month, and if sizable recharge occurred soon enough before the well reading to affect the water level (**2 days** at this site). Penman-Monteith ET values often generate results with stronger correlations than Thornthwaite ET values, but a lack of solar radiation data needed for Penman calculations may limit their use for long historical analyses.



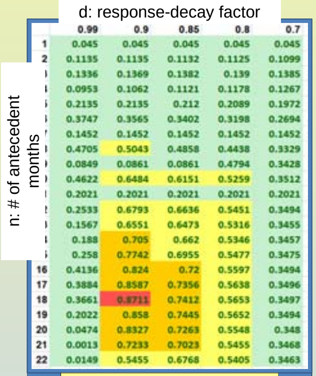
Examples of responses in well after short rain events

MODEL PROCEDURE: Calibration

Model results are calibrated to monthly head data by systematically varying the **n** and **d** used in the calculations to determine which combination generates the best correlation coefficient (R^2) for W_{em} vs measured heads. The best correlations come from data sets filtered to remove months with head readings affected by recent rainfall. At the Suffolk site, the choice of interception factor also improves correlation values.



Highest correlation coefficient for data from calibration period using filtered data



d: response-decay factor

n: # of antecedent months

n	0.99	0.9	0.85	0.8	0.7
1	0.045	0.045	0.045	0.045	0.045
2	0.1135	0.1135	0.1132	0.1125	0.1099
3	0.1336	0.1369	0.1382	0.139	0.1385
4	0.0953	0.1062	0.1121	0.1178	0.1267
5	0.2135	0.2135	0.212	0.2089	0.1972
6	0.3747	0.3565	0.3402	0.3198	0.2694
7	0.1452	0.1452	0.1452	0.1452	0.1452
8	0.4705	0.5043	0.4858	0.4438	0.3329
9	0.0849	0.0861	0.0861	0.4794	0.3428
10	0.4622	0.6484	0.6151	0.5259	0.3512
11	0.2021	0.2021	0.2021	0.2021	0.2021
12	0.2533	0.6793	0.6636	0.5451	0.3494
13	0.1567	0.6551	0.6473	0.5316	0.3455
14	0.188	0.705	0.662	0.5346	0.3457
15	0.258	0.7742	0.6955	0.5477	0.3475
16	0.4136	0.824	0.72	0.5597	0.3494
17	0.3884	0.8587	0.7356	0.5638	0.3496
18	0.3661	0.8711	0.7412	0.5653	0.3497
19	0.2022	0.858	0.7445	0.5652	0.3494
20	0.0474	0.8327	0.7263	0.5548	0.348
21	0.0013	0.7233	0.7023	0.5455	0.3468
22	0.0149	0.5455	0.6768	0.5405	0.3463

Comparison of correlation values for range of n and d

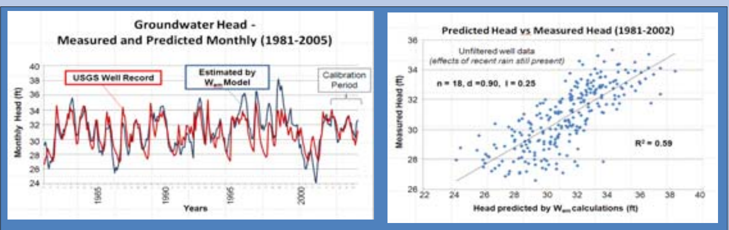
	Unfiltered	Filtered
I = 0.20	0.54	0.61
I = 0.25	0.56	0.87

Table 1.
Result of changing interception(I) and filtering effects of recent rain

We expected interception rates to vary between 8% and 30% due to forest types and crop schedules, but sensitivity analyses suggest little seasonal effect occurs here. I values shown are annual, averaged across seasons.

MODEL PROCEDURE: Verification

To get estimates of water table elevation during specific months before the calibration period, model users process **historical weather data** using the calibrated values of n and d. For the Suffolk well site, these estimates of groundwater levels for 1981-2002 can be verified by comparison of with well records for the same period.



CONCLUSIONS

1. Effective Monthly Recharge calculations can **reconstruct a useable approximation of water table fluctuations** during periods with sufficient weather data but prior to periods with well data
2. **Filtering data sets** by not analyzing months that show the effects of recent rains improves the model.
3. **Effects of interception and torrential rainfall can be substantial** upon W_{em} model results and should be evaluated further.

W_{em} MODEL APPLICATIONS

Examples of settings where hydrological analyses could use the Effective Monthly Recharge Model:

In **natural wetland habitats driven by precipitation**, users can estimate the lengths of droughts during the past century that would have desiccated ponds or swamps, and evaluate the effects of potential future changes in precipitation and ET upon water level fluctuations

Uphill of potential **mitigation wetland sites in toe-slopes**, one can estimate the probability that a given hydraulic head, and potential water source, will recur during specific months in a normal, wet, or dry year.

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