Stream-Aquifer seepage estimation *with a simple analytic algebraic tool*

by the team of
Hubert Morel-Seytoux, presenter,
Cinzia Miracapillo,
Fachhochschule Nordwestschweiz,
Steffen Mehl, CSU Chico, and
Calvin Miller, Millergroundwater

Motivation for study

As an example, in a study for the Santa Rosa Plain Watershed Groundwater Management Plan, the horizontal square grid size is 660 feet and the area under investigation is 262 square miles. None of the rivers in the area have widths that exceed 100 feet. **Thus all river reaches are included in cells that have dimensions far in excess of the river widths**. The water table aquifer that always exceeds 90 feet of thickness is **treated as a single calculation layer in the vertical direction**.

In such context the boundary condition to determine the seepage discharge is chosen to be of the third type. The discharge is calculated as being proportional to the difference between the head in the river, h_S, and the head in the aquifer, h_a, at the center of the vertical thickness of the cell that contains the river. The proportionality coefficient depends upon (1) the length of the river reach, L, within the cell that includes it (the river cell), (2) the hydraulic conductivity of the aquifer in the vicinity of the river, K, and (3) that chosen distance where aquifer head, h_a, is calculated from the overall domain calculation matrix. Symbolically the relation is:

$$Q = \kappa K L (h_S - h_a) = C_{riv}(h_S - h_a) \qquad (1)$$

In most groundwater models used commercially, the determination of the coefficient C_{riv} is pretty much left to the user and most often determined by calibration when historical data are available.

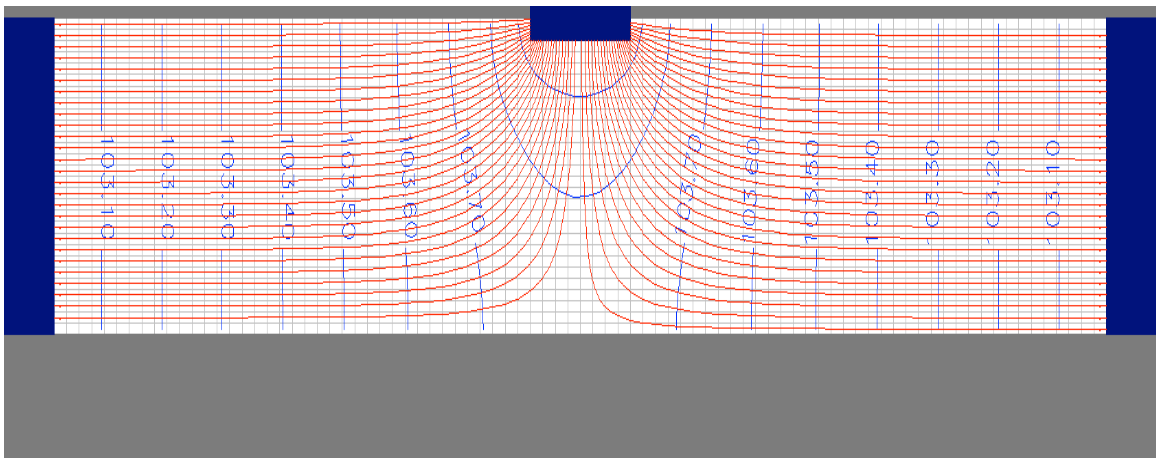
Thus the need for a more rigorous estimation of that coefficient.

Slightly penetrating river

(Figure not to scale.)

River width 2B= 40 m. Aquifer thickness D= 70 m.
Far distance Xfar = 197.5 m.

Isotropic condition



$$Q_{iso} = \Gamma K_H L(h_S - h_{far})$$

Q : one-sided(right or left) seepage discharge (volume per time)

Γ : one sided SAFE (Stream Aquifer Flow Exchange) dimensionless conductance in case of isotropy, no clogging layer and standard far distance.

K_H : aquifer horizontal hydraulic conductivity

L : length of river reach

h_S : head in the river

h_{far} : head at the far distance in the horizontal direction

Slightly penetrating river

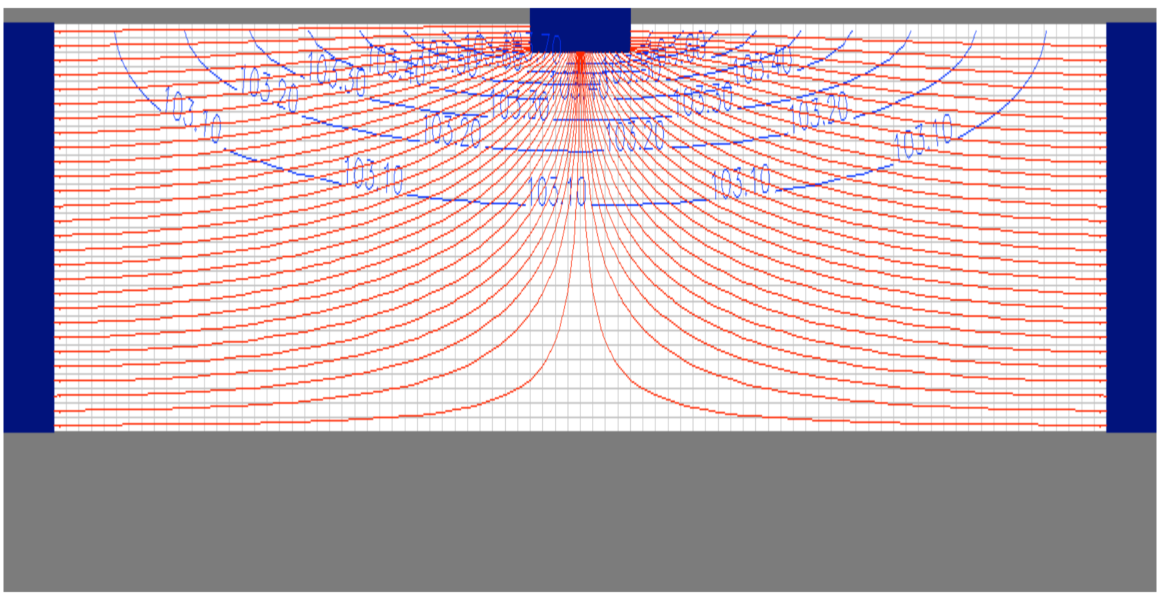
(Figure not to scale)

Same parameters as for the isotropic case

Anisotropic condition

Anisotropy ratio, RANIS $= K_V / K_H = 0.01$

Reduction factor = 0.204



$$Q_{anis} = R_f(\xi) Q_{iso}$$

$$\xi = (1 - DOP)(1 - \sqrt{RANIS})$$

$DOP =$ Mean depth of penetration/aquifer thickness

$$R_f = 1.00064 - 0.395577\xi - 0.647687\xi^2$$

Derivation of formulae

Case of isotropy

For the case of elliptical, rectangular and trapezoidal river cross-sections the results were obtained exactly analytically and verified with very refined grids in numerical models such as MODFLOW. (see bibliography)

If the wetted perimeter and the degree of penetration are the same, the shape of the cross-section has practically no impact on the value of Γ_{iso}, the SAFE (Stream-Aquifer Flow Exchange) dimensionless conductance

Derivation of formulae

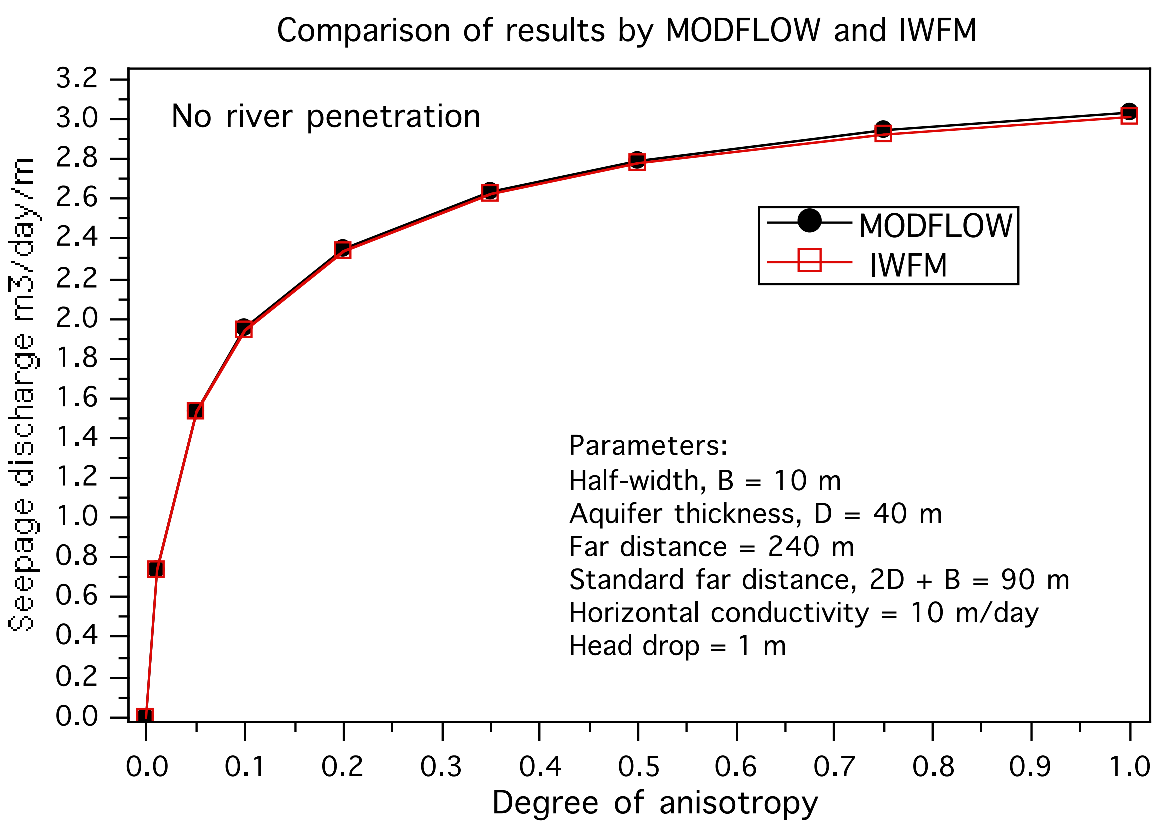
Case of anisotropy

Again the results were obtained exactly analytically and numerically

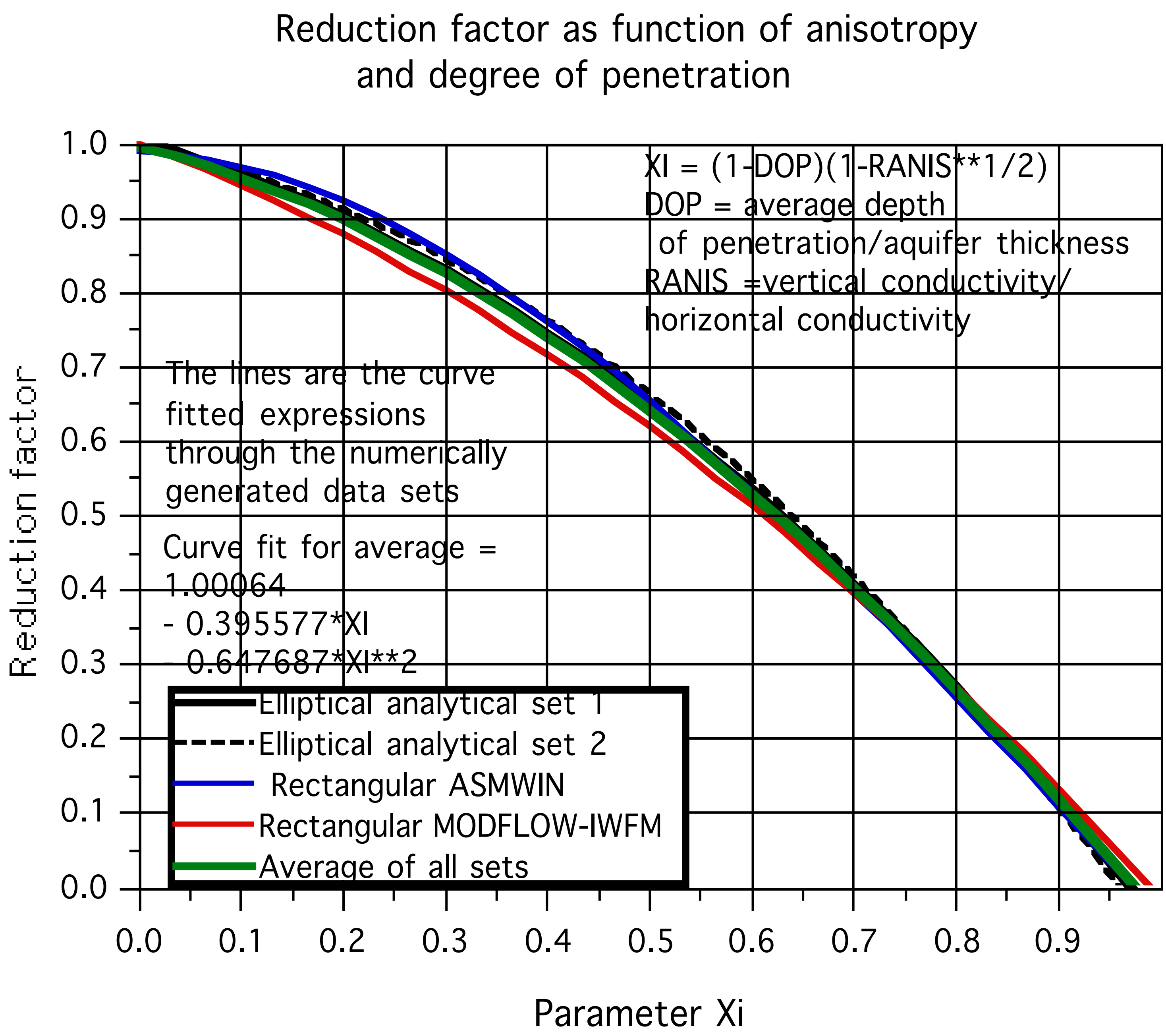
and verified with very refined grids in widely used numerical models such as MODFLOW, IWFM and ASMWIN.

(see attached bibliography)

Independent runs by MODFLOW and IWFM with the same refined grid scheme for a rectangular cross – section gave essentially identical results.



Comparison of Reduction factor for elliptical and rectangular cross sections. The river cross-section shapes have little influence on th river seepage as long as the wetted perimeter and the degree o penetration are the same. This figure applies for the constant hea boundary condition prescribed at a far distance **twice** the aquife thickness away from the river bank.



Advantages

The research has led to the estimation of the seepage discharge accounting for
(1) the wetted perimeter,
(2) the degree of penetration,
(2) a clogging layer,
(4) aquifer anisotropy, and
(5) location of the far distance.

It eliminates the burden of numerous numerical calculations while maintaining a superior accuracy

Conclusion

Having investigated all the factors that influence seepage it remained to show how to incorporate the new approach into models like MODFLOW for estimating the coefficient "C_{riv}" without any change to MODFLOW's code.

In the bibliography see item (5) and if interested enter your name and email address in the sign-up sheet.

$$C_{riv} = 2GK_H\left\{\frac{\Gamma_{anis-\Delta-rcl}}{1-\left(\frac{G}{D}\right)\Gamma_{anis-\Delta-rcl}}\right\}$$

G : grid size i.e. side length of horizontal square cell

$\Gamma_{anis-\Delta-rcl}$: SAFE dimensionless conductance associated with a level of anisotropy, an excess far distance over the natural standard far distance for that anisotropy ratio and a real clogging layer

$\Delta = G - xfar_{anis-standard}$

$xfar_{anis-standard}$: natural standard far distance for that anisotropy ratio

D : aquifer thickness

K_H : horizontal aquifer conductivity

(1) Morel-Seytoux, H.J. (2009), The turning factor in the estimation of stream-aquifer seepage, *Ground Water*, 47, 205-212, doi: 10.1111/j.1745-6584.2008.00512.x.

(2) Miracapillo, C., and H. J. Morel-Seytoux. (2014), Analytical solutions for stream-aquifer flow exchange under varying head asymmetry and river penetration: Comparison to numerical solutions and use in regional groundwater models, *Water Resour. Res.*, 50, doi:10.1002/2014WR015456.

(3) Miracapillo, C., Steffen Mehl and H. J. Morel-Seytoux. (2016). Stream-Aquifer Flow Exchange dimensionless conductance under conditions of anisotropy. Submitted January 26, 2016 to Groundwater Journal. Under review.

(4) Morel-Seytoux,H.J., Steffen Mehl and Kyle Morgado. (2013), Factors influencing the stream-aquifer flow exchange coefficient, *Ground Water*, 49(5): 775-781. doi: 10.1111/gwat.12112, 7 pages.

(5) Morel-Seytoux,H.J., Calvin Miller, Steffen Mehl and Cinzia Miracapillo, (March 2016). River seepage conductance in large-scale regional studies. Draft in final stage of preparation.

Sign-up sheet

Write **clearly** your name and email address if you would like to receive an electronic version of all or some of the papers. Write item number(s).

Item(s)	Name	Email	Affiliation (optional)