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GROUNDWATER MANAGEMENT INSTITUTE

Estimation borehole sustainable yield in a typical confined porous aquifer

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IUCN BRIDGE International Association of Hydrogeologists the World-wide Groundwater Organisation IWMI International Water Management Institute GRIPP Groundwater Solutions Initiative for Policy and Practice igrac International Groundwater Resources Assessment Centre BGS British Geological Survey IGS Institute for Groundwater Studies University of Botswana The University of Zambia

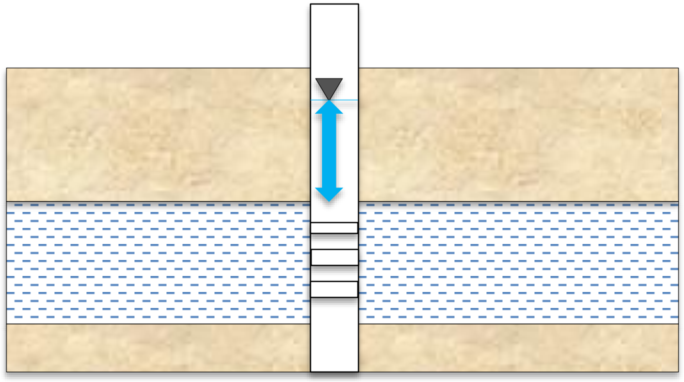
Introduction

- Estimation of borehole sustainable yield is important in order to operate a borehole in a manner which can maintain the aquifer productivity.
- Other terms which are used interchangeably with borehole sustainable yield are safe and reliable yield.
- For the purposes of this study and proposed application, borehole sustainable yield is defined as the constant discharge rate at which a borehole can be pumped during its operating life with without causing aquifer dewatering.

Introduction

- In a typical porous confined aquifer, dewatering occurs when water level drop below the top of the aquifer.
- This dewatering due to pumping can empty the aquifer causing the borehole to dry
- It is therefore important to ensure that borehole operational pumping rates that does not result in aquifer dewatering are used for borehole operation purposes.
- In principle, this can be achieved when borehole operational yield does not cause the water level to drop below the top of the confined aquifer.

- This principle has been used in the Flow Characteristics (FC) method for estimating borehole sustainable yield in fractured-rock aquifers (van Tonder et al. 2001). The applicability of this approach in porous and confined aquifers is investigated in this study.



Approach

- The first component of the paper present the principle basis for applying the FC method approach in porous confined aquifer.

- Thereafter MODFLOW numerical modelling is used to illustrate how this approach can be applied.

FC – method (van Tonder et al. 2001)

- The first component of the paper present the principle basis for applying the FC method approach in porous confined aquifer.
- The method determine the sustainable yield (Qs) of a borehole in fractured-rock aquifer based on the following equation:

$$Q_{Sustainable} = Q_{pump\ test} \frac{s_{available}(t = t_{long})}{s_{pump\ test}(t = t_{long})}$$

- Where t_{long} describes the maximum operation time in which the drawdown s shall not exceed a maximum drawdown $s_{available}$ during operation period of the borehole,
- The extrapolation of the measured pumping test drawdown is used to determine the $Q_{sustainable}$

FC – method (van Tonder et al. 2001)

Extrapolation of pumping test drawdown

- The drawdown measured during a pumping test is the sum of the drawdowns due to the production well (s_{well}) and the boundaries ($s_{boundary}$)

$$s(t = t_{long}) = s_{well} + s_{boundary}$$

- If other pumping wells exist, their drawdown should also be included

- *Where* s_{well} is extrapolated by a Taylor series expansion

FC – method (van Tonder et al. 2001)

- FC method considers 3 scenarios of the following impermeable/no flow boundaries:
  - Single no-flow boundary,
  - 2 no-flow boundaries
  - Closed-no flow boundaries

- ❑ To cater for the boundary FC considers an imaginary well taking equal amount of water to the abstraction well

FC – method (van Tonder et al. 2001)

Extrapolation of pumping test drawdown

- s_{well} is extrapolated by the expansion using a Taylor series (only first 2 terms) around the late measurement points of the drawdown at $t = t_{EOP}$ (EOP - end of pumping test).

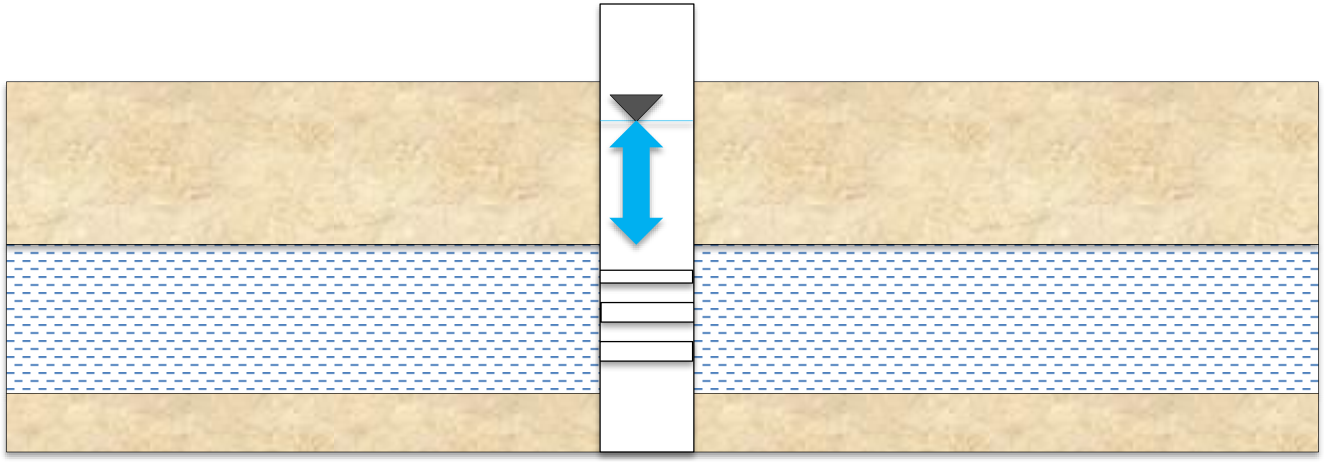
Average maximum first derivative

$$s_{well}(t = t_{long}) \approx s(t = t_{EOP}) + \left[\frac{\partial s}{\partial logt}\right]_{t=t_{EOP}} (\log t_{long} - \log t_{EOP}) + \frac{1}{2}\left[\frac{\partial^2 s}{\partial (logt)^2}\right]_{t=t_{EOP}} (\log t_{long} - \log t_{EOP})^2$$

Average second derivative

Proposed application of FC method in Typical porous confined aquifers

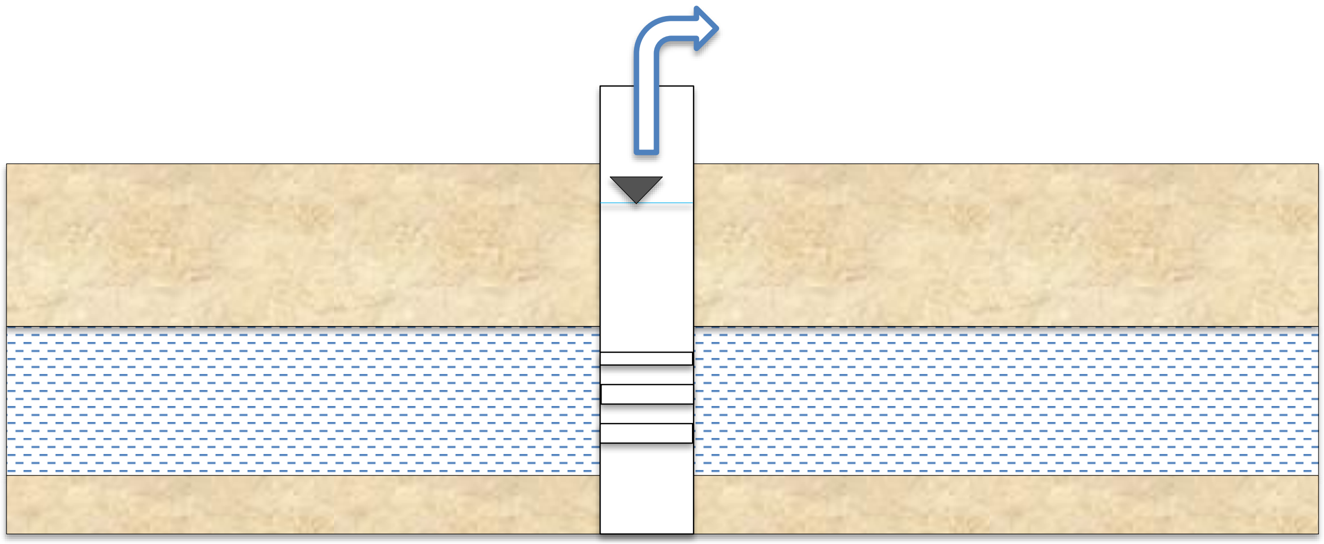
- The idea is to determine the operational pumping rate that will not result in drop the water level below the top of the confined aquifer to prevent dewatering of the aquifer



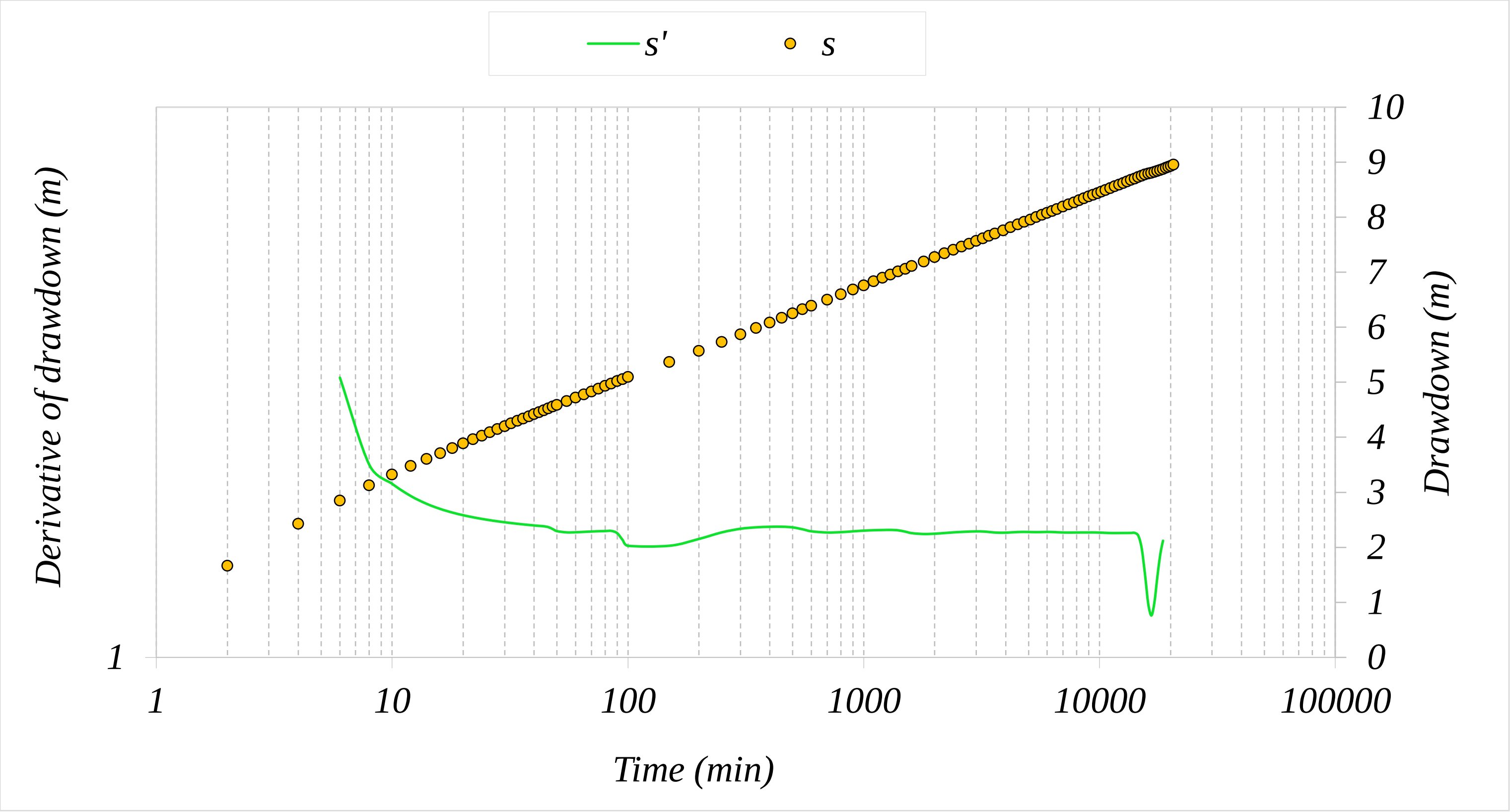
Model simulation of constant discharge pumping test

- The pumping test data is then used to estimate the sustainable borehole yield using the FC method

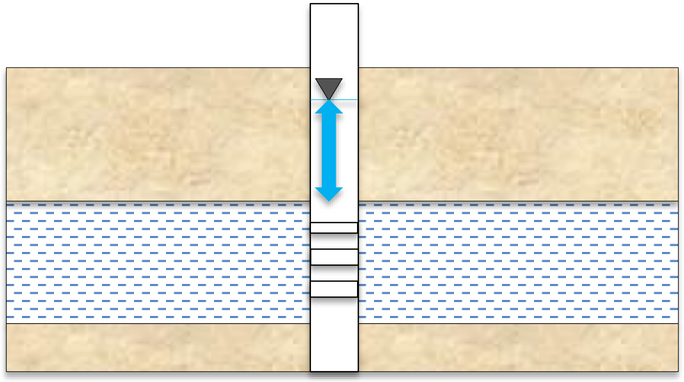
Model property	Value
Model dimensions (length x width)	10000m x 10000m
Storativity	0.001
Aquifer thickness (m)	15
Initial head (m)	24
Transmissivity (m^2/day)	38
Pumping well discharge (m^3/day)	950.4
Pumping well discharge (L/s)	4
Duration of pumping (days)	14.3
Predicted Theis drawdown (m)	<0.00005



Simulated drawdown from constant discharge pumping test



Using simulated drawdown to estimate sustainable borehole yield using the FC method



FC-METHOD : Estimation of the sustainable yield of BACL | Main | Deriv | Inflection point method

Extrapolation time in years = (enter)	2	1051200	Extrapol.time in minutes
Q (l/s) from pumping test =	4	1.88E-05	← S-late ← Change r_e
s_a (available drawdown), sigma_s = (enter)	9.0		← Sigma_s from risk Down
Annual effective recharge (mm) =		9.00	s_available working drawdown(m)
t(end) and s(end) of pumping test =	20600.0064	8.953865	End time and drawdown of test
Average maximum derivative = (enter)	1.8 ←	1.8	Estimate of average of max deriv
Average second derivative = (enter)	0.0 ←	0.0	Estimate of average second deriv
Derivative at radial flow period = (enter)	1.96 ←	1.96	Read from derivative graph

BASIC SOLUTION

(Using derivatives + subjective information about boundaries)

(No values of T and S are necessary)

	No boundaries	Maximum influence of boundaries at long time: 1 no-flow	2 no-flow	Closed no-flow
sWell (Extrapol.time) =	12.02	15.09	18.17	27.39
Q_sust (l/s) =	2.99	2.38	1.98	1.31
	Best case	→		Worst case
Average Q_sust (l/s) =	2.08			

Evaluating the performance of estimated borehole yield

- ❑Use MODFLOW numerical modelling to is used to **Evaluating the performance of estimated borehole yield**
- ❑**Best case – 3.0 L**
- ❑**Worst case – 1.31**

FC-METHOD : Estimation of the sustainable yield of BACL — Main | Deriv | Inflection point method

Extrapolation time in years = (enter)	2	1051200	Extrapol.time in minutes
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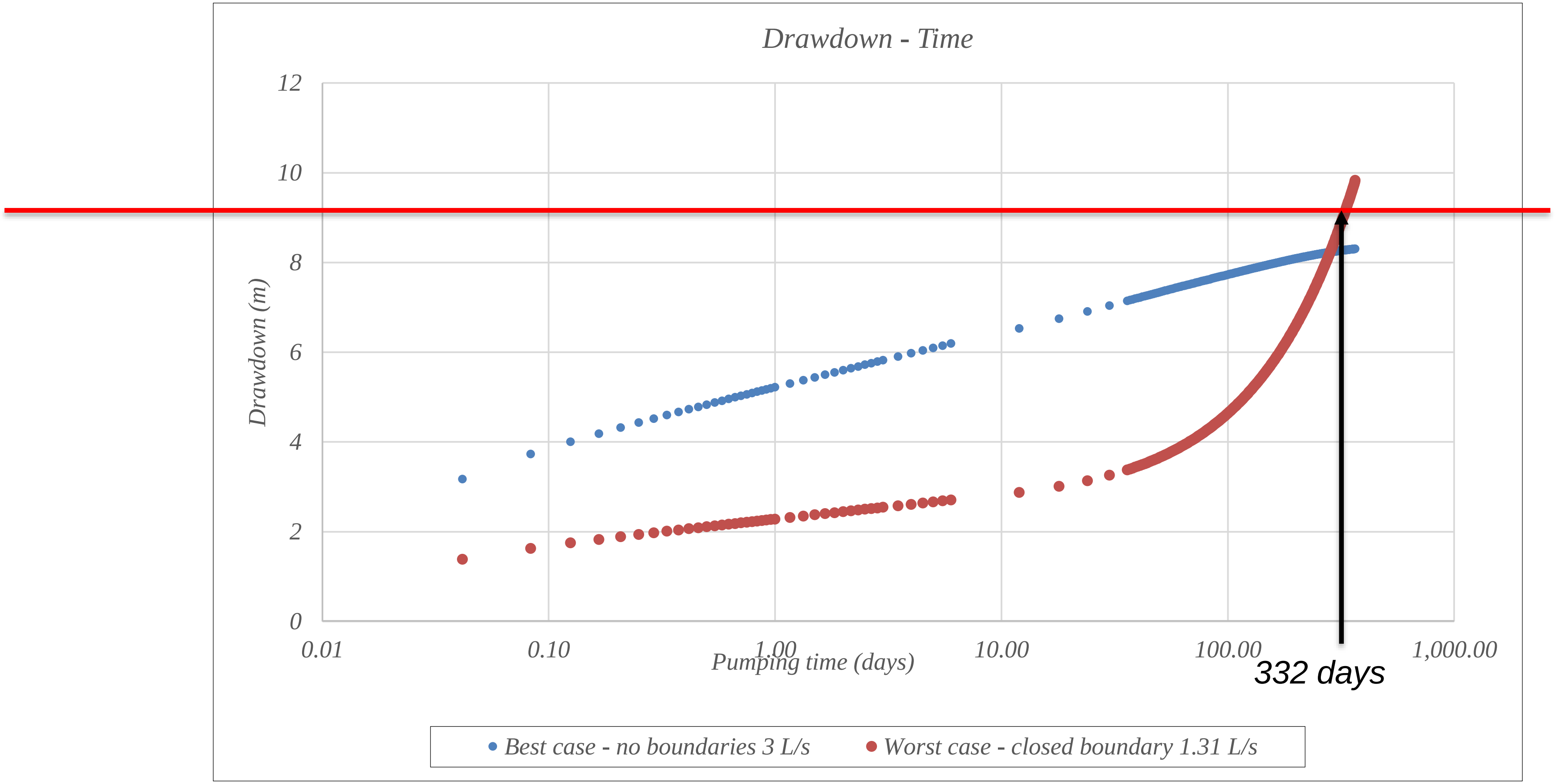
Average Q_sust (l/s) =	2.08			

Simulated drawdown from operational pumping

Available drawdown – 9m



Conclusions

- The study illustrates how FC method initially meant for typical fractured rock aquifers can be used to estimate borehole sustainable yield in a typical confined porous aquifers.
- The emphasis should be on groundwater levels monitoring and adjust the operational yield accordingly.

References

van Tonder G.J. , J.F. Botha, W.-H. Chiang, H. Kunstmannb, Y. Xu (2001). Estimation of the sustainable yields of boreholes in fractured rock formations. Journal of Hydrology 241 (1-2): 70–90