Package ‘rhytool’

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Type Package

Title Hytool library for R users

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Description
Hytool library for R users. Hytool is originally a matlab toolbox for the interpretation of hydraulic tests in wells. The toolbox contains analytical solutions used to describe groundwater flow around wells, and functions for importing, displaying, and fitting a model to the data. Rhytool is the R version of this toolbox (S4). To cite this toolbox, please use the following reference: Renard Philippe (2017), Hytool: an open source matlab toolbox for the interpretation of hydraulic tests using analytical solutions, _Journal of Open Source Software_, 2(19), 441.

Imports optimx (>= 2013.8.7), expint (>= 0.1-3), stats (>= 3.3.2),
methods (>= 3.3.2), graphics (>= 3.3.2), robfilter (>= 4.1),
NISTunits (>= 1.0.1)

Encoding UTF-8

LazyData true

RoxygenNote 6.0.1

Suggests testthat

NeedsCompilation no

Repository CRAN

R topics documented:

`curve.gfamodel` *Plot typical response curves*

Description

Plot one or several typical response to pumping curve(s) for known groundwater flow analytical models.

Usage

```
curve.gfamodel(mod = list("ths", "thc", "thn", "blt", "war", "htj", "pcw",
  "grg", "grf"), cex.legend = 0.8, log = "xy")
```

Arguments

`mod`	character or list of characters. A keyword or list of keywords from the list of known analytical model: "ths", "thc", "thn", "pcw", "blt", "war", "htj", "grg", "grf". Can also be a gfamodel class object.
`cex.legend`	numeric. factor for sizing the legend.
`log`	character string which contains "x" if the x axis is to be logarithmic, "y" if the y axis is to be logarithmic and "xy" or "yx" if both axes are to be logarithmic.

Details

If mod is a gfamodel class object, only the model type of the mod object is used for plot. If available in the mod object, analytical solution parameters are ignored.

See Also

`gfamodel`

`drawdowns` *Create drawdowns objects*

Description

Function that creates drawdowns objects, i.e. objects that hold the information necessary for being adjusted to an analytic groundwater flow model (class gfamodel) for the interpretation of a constant rate or variable rate pumping test. It fundamentally contains time (or reduced time) and drawdowns (or reduced drawdowns). It can be constructed from variable flow rate test and/or for recovery period.

Usage

```
drawdowns(t, s = NULL, q = NULL, fn = NULL, model = NULL,
  sample = FALSE, miscDdOptions = list())
```

Arguments

`t` numeric vector or matrix; time from the begining of the pumping test unless Argarwal type is selected. In this case, time from the begining of the recovery period.

`s` numeric vector representing the drawdown measured for the corresponding time. If s is null and t a matrix, s is set to the second column of the t matrix. If s is NULL and t a vector, s is calculated from the gfamodel parameter model.

`q` numeric or numeric matrix; ignored if fn = NULL, otherwise, q is a parameter giving the pumping rate. In case of constant pumping rate, value of the pumping rate. In case of variable pumping rate, a double columns matrix, each row containg time (since the begining of the test) at which the period ends and flow rate during the period.

`fn` a character string setting the nature of the treatment applied to the original t and s values. See details.

`model` object of class gfamodel used to calculate the s value for every t data. If s is not null, model is ignored.

`sample` logical. If TRUE, data set is sampled at regular intervals on a logarithmic scale (points are extracted from the data set). A number of samples can be indicated in the list of parameters with the nval keyword.

`miscDdOptions` list with named arguments that provide additional control over the treatment applied to the original t and s values. For example: list(defunc = "std"). If the list is empty, drawdowns uses default values. The following parameters can be set:

- **nval** maximum number of resulting data points when sampling raw data is activated.
- **defunc** nature of the function used for calculating the derivative. See Details.
- **df** additional parameter for the function used for calculating the derivative. For spline function, represents the degree of freedom. See Details.
- **filter.width** a positive integer defining the window width used for robust regression filter of the derivative values. Default value is 7. See `robreg.filter`.
- **filter.method** a character string containing the method to be used for robust regression filter of the derivative values. Possible options are: "DR" for Deepest Regression, "LMS" for Least Median of Squares regression, "LQD" for Least Quartile Difference regression, "LTS" for Least Trimmed Squares regression, "MED" for Median, "RM" for Repeated Median regression. Default method is "RM". See `robreg.filter`.

Details

The fn parameter is used to generate drawdowns either from raw drawdown data (s) or from the gfamodel clas object model. When NULL, raw original values of s are used. Available keywords are:

- "birsoy", the Birsoy and Summers (1980) time is calculated based on the q series of pumping rates. q is there a a double columns matrix with column 1 giving the time (since the begining of the test) at which the period ends, and column 2 giving the flow rate during the period.
- "agarwal", result is the equivalent Agarwal (1980) time for recovery tests. Agarwal has shown in 1980 that recovery test can be interpreted with the same solutions than pumping test if one interprets the residual drawdown sr = s(t) - s(end of pumping) as a function of an equivalent

time that is computed from the pumping rates history. The theory is based on the superposition principle. t should be the time since the begining of the recovery period. q can be either a unique value for the duration of the pump test (constant pumping rate test) or a double columns matrix with column 1 giving the time (since the begining of the test) at which the period ends, and column 2 giving the flow rate during the period (variable pumping rates).

- "variablerate", the drawdowns are calculated for the specified dates t, based on the model parameters (aquifer parameters aqpar should be given as well as test data testdata with pumping rate Q=1) and on the pumping rate data q. q is there a double columns matrix with column 1 giving the time (since the begining of the test) at which the period ends, and column 2 giving the flow rate during the period (variable pumping rates).

The function to be used for the computation of the derivative points can be set in the miscDdOptions parameters list, with the defunc keyword. The default value is the spilne function. Available options are:

- "spline", this function approximates logarithmic derivative with spline, usign the smooth.spline function of the stats package. Use df keyword to set the degree of freedom (see `smooth.spline`). Default value for df is 2/3 of the number of data points.
- "std", this function approximates logarithmic derivative with centered differences.
- "bourdet", this function approximates logarithmic derivative with Bourdet's formula. Use df keyword to set the distance parameter of the Bourdet function. Default value is 2.
- "horne", this function approximates logarithmic derivative with the Horne's formula.

Value

An object of class drawdowns containing time or reduced time and drawdowns or reduced drawdowns ready for adjustement with a gfamodel

References

Renard, Philippe (2017). Hytool: an open source matlab toolbox for the interpretation of hydraulic tests using analytical solutions. Journal of Open Source Software, 2(19), 441, doi: 10.21105/joss.00441.

Agarwal, R.G., 1980. A new method to account for producing time effects when drawdown type curves are used to analyse pressure buildup and other test data. Proceedings of the 55th Annual Fall Technical Conference and Exhibition of the Society of Petroleum Engineers. Paper SPE 9289, doi: 10.2118/9289-MS

Birsoy YK, Summers WK (1980) Determination of aquifer parameters from step tests and intermittent pumping data. Ground Water 18(2):137???146, doi: 10.1111/j.1745-6584.1980.tb03382.x.

See Also

`smooth.spline`, `gfamodel`, `robreg.filter`

Examples

```
# Generate drawdowns object for a standard series of t and s
MyDd <- drawdowns(t = pumptest$ths_ds1[,1], s = pumptest$ths_ds1[,2])
MyDd <- drawdowns(t = pumptest$ths_ds1[,1:2])

# Generate drawdowns object for a series of date knowing
# aquifer parameters (T = 1E-3 m2/s and S = 5E-4) and
# pumping conditions (pumping rate 3.6E-1 m3/s and distance 50 m)
MyDd <- drawdowns(t = (10^seq(2,5,length=30)),
```

```
            model = gfamodel("ths", aqpar = c(1E-3, 5E-4),
            testdata = c(3.6E-1, 50)))

# Generate drawdowns object for a large series of t and s after sampling
MyDd <- drawdowns(pumptest$thc_ds2[,1:2], sample = TRUE,
           miscDdOptions = list(nval = 70))

# Generate drawdowns object from recovery data for a constante rate pumping test
MyDd <- drawdowns(pumptest$agt_ds1, fn = "agarwal", q = 240*60,
          miscDdOptions = list(df = 10, defunc="spline"))

# Generate normalised drawdowns object from variable rate pumping test
q<- cbind(c(1800, 4800, 7800),c(500/24/60/60, 700/24/60/60, 600/24/60/60))
MyDd <- drawdowns(pumptest$tmr_ds1, fn="birsoy", q=q)
```

`drawdowns-class` *Class "drawdowns"*

Description

Class for representing drawdowns (and corresponding derivative of the drwadowns) at a well or a piezometer, for positive times during or after pumping (recovery).

Usage

```
## S4 method for signature 'drawdowns'
show(object)
```

Arguments

`object`	A drawdowns class object

Methods (by generic)

- show: Display the object, by printing.

Slots

`dd`**:** Object of class `"data.frame"`, containing the times and the corresponding numerical values of the drawdowns.

`ldiff`**:** Object of class `"data.frame"`, containing the times and the correspondinf davlues of the calculated derivative of the drawdowns.

Author(s)

François Bertone

fit.gfamodel *Fit parameters of the analytical solution*

Description

Function that fit the parameters of the analytical solution of a gfamodel object to the drawdowns describes in a drawdowns object.

Usage

```
fit.gfamodel(x, dd)
```

Arguments

x	A gfamodel object. See details.
dd	A drawdowns object used for fitting the analytical parameters of the returned gfamodel object.

Details

The analytical solution parameters of the x object are used as initial parameters. The general-purpose optimization function `optimx` is used. Result from the best fitting from 3 methods ("Nelder-Mead","nlminb", "L-BFGS-B") is used.

Value

An object of class gfamodel of the same model type as the x object in argument. Analytical solution parameters aspar are adjusted to fit the dd object in argument. If test data parameters testdata are given in the x object, it is copied in the return object and the aquifer parameters aqpar are computed.

See Also

`optimx`

gfamodel *Create gfamodel objects*

Description

Create objects of class gfamodel, i.e. objects that hold the information relative to a known groundwater flow analytical model

Usage

```
gfamodel(model, aspar = NULL, aqpar = NULL, testdata = NULL)
```

Arguments

- `model` — A keyword or a gfamodel object. When a keyword is given, it should be one of a known model from the following list: "ths", "thc", "thn", "htj", "blt", "war" or "grg". See details
- `aspar` — Parameters for the analytical solution for model computation. It can be obtained from a guess fuction, adjusted manually, or obtained from a fit function
- `aqpar` — Aquifer's parameters for the selected model (such as Transmissivity and Storage coefficient for the Theis model). See details
- `testdata` — If provided, information about pumping conditions used for calculating aquifer parameters aqpar from analytical solution parameters aspar or analytical solution parameters aspar from aquifer parameters aqpar

Details

If model is set from keywords, the options to date are:

- "ths" for a Theis (1935) solution. Analytical solution parameters are: a, the slope of Jacob Straight Line; and t0, intercept with the horizontal axis for s = 0. When the model is constructed from aquifer parameters and test data, aqpar should be a vector of 2 numeric (Transmissivity and Storativity), and testdata a vector of 2 numerics (Pumping rate and Distance to the pumping well).
- "thc" for a confined aquifer with a boundary effect using the Theis (1941) solution. Analytical solution parameters are: a, the slope of Jacob Straight Line; t0, intercept of the first segment of straight line; and ti the time of intersection between the 2 straight lines. When the model is constructed from aquifer parameters and test data, aqpar should be a vector of 3 numeric (Transmissivity, Storativity, Distance to image well), and testdata a vector of 2 numerics (Pumping rate, Distance to the pumping well).
- "thn" for a confined aquifer with an impermeable boundary with the Theis solution. Analytical solution parameters are: a, the slope of Jacob Straight Line; t0, intercept of the first segment of straight line; and ti the time of intersection between the 2 straight lines. When the model is constructed from aquifer parameters and test data, aqpar should be a vector of 3 numeric (Transmissivity, Storativity, Distance to image well), and testdata a vector of 2 numerics (Pumping rate, Distance to the pumping well).
- "pcw" for the Papadopulos and Cooper (1967) solution for well with well-bore storage effect. Analytical solution parameters are: a slope of late time straight line, t0 intercept of late time straight line, Cd dimensionless well-bore storage coefficient. When the model is constructed from aquifer parameters, aqpar should be a vector of 1 numeric (aquifer transmissivity T). The testdata parameters are compulsory for the construction of the gfamodel object, as a vector of 3 numerics (pumping rate Q, Radius rw of well screen, Radius rc of well casing).
- "htj" for a confined aquifer with leakage with the Hantush and Jacob (1955) model. Analytical solution parameters are: a, the slope of Jacob Straight Line; and t0, intercept with the horizontal axis for s = 0; and r/B. When the model is constructed from aquifer parameters and test data, aqpar should be a vector of 3 numeric (Transmissivity, Storativity, Aquitard conductivity), and testdata a vector of 3 numerics (Pumping rate, Distance to the pumping well, Thickness of the aquitard).
- "blt" for a Boulton (1963) model for unconfined aquifer. Analytical solution parameters are: slopea of the late time Jacob's straight line"; intercept time t0 with the horizontal axis for s = 0; intercept t1; and empirical parameter phi that trigger the delay. When the model is constructed from aquifer parameters and test data, aqpar should be a vector of 3 numeric (Transmissivity, Storativity, Drainage Porosity), and testdata a vector of 2 numerics (Pumping rate and Distance to the pumping well).

- "grg" for a Gringarten and Ramey (1974) model for infinite conductivity fracture in a confined aquifer. Analytical solution parameters are slope a and intercept t0. When the model is constructed from aquifer parameters and test data, aqpar should be a vector of 2 numeric (Transmissivity and Sxf2), and testdata a numeric (Pumping rate)
- "war" for the Warren and Root (1965) solution. Analytical solution parameters are: the slope a of the Jacob straight line, the time t0 when the horizontal axis intercept with the early time asymptote, the time t1 when the horizontal axis intercept with the late time asymptote, the time tm of the minimum of the derivative. When the model is constructed from aquifer parameters and test data, aqpar should be a vector of 4 numeric (Transmissivity, Storativity Sf, Storativity Sm, Interporosity flow lamda), and testdata a vector of 2 numerics (Pumping rate and Distance to the pumping well).
- "grf" for the Barker (1988) general radial flow model. Analytical solution parameters are: a equivalent of the slope of Jacob model, t0 equivalent of the time of Jacob model, n the fractional flow dimension. When the model is constructed from aquifer parameters, aqpar should be a vector of 3 numeric (equivalent transmissivity Tn, equivalent storativity Sn, flow dimension n). The testdata parameters are compulsory for the construction of the gfamodel object, as a vector of 3 numerics (pumping rate Q, distance r to the pumping well, radius rw of the pumping well).

If model is an existing gfamodel, testsdata parameters should be given: the aspar of the resulting object is then calculated if model have valid aspar, or the aqpar of the resulting model is calculated if model have valid aspar.

Value

An object of class gfamodel the type of selected model, the corresponding description, and model parameters of type aqpar or aspar. If model is a gfamodel object, the returned gfamodel object is constructed from this object and in priority order either the analytical solution parameters (if avilable) or the aquifer parameters. A testsdata parameter should then be provided.

References

Renard, Philippe (2017). Hytool: an open source matlab toolbox for the interpretation of hydraulic tests using analytical solutions. Journal of Open Source Software, 2(19), 441, doi:10.21105/joss.00441

See Also

fit.gfamodel, guess.gfamodel

Examples

```
# Load samples test data
data("pumptest")
# Construct initial guess of a Hantush and Jacob model for the htj_ds1 data set
mod1 <- guess.gfamodel(gfamodel("htj"), drawdowns(pumptest$htj_ds1))
# If the first guess is not satisfactory, adjust the model manually
mod1 <- gfamodel("htj", aspar = c(5.3,0.3,4e5))
# perform automatic fitting and plot result
mod2 <- fit.gfamodel(mod1, dd = drawdowns(pumptest$htj_ds1))
plot(pumptest$htj_ds1, model = mod2)
print(mod2)
```

`gfamodel-class` *Class "gfamodel"*

Description

This class is used to reprent the groundwater flow analytical models.

Usage

```
## S4 method for signature 'gfamodel'
show(object)
```

Arguments

`object` A gfamodel class object

Methods (by generic)

- `show`: Display the object, by printing. Print everay parameters of the gfamodel object, starting with the applicable analytical model type. Also print the analytical model parameters, the aquifer parameters and the test data. When parameters are not yet defined, prints 0 value.

Slots

`model`**:** Matrix of class `"character"`, containing the keyword reprensenting the analytical model.

`description`**:** Object of class `"character"`, containing the detailed description of the analytical model.

`aspar`**:** Object of class `"data.frame"`, containing the list of the analytical parameters and the corresponding numerical values (when defined).

`aqpar`**:** Object of class `"data.frame"`, containing the list of the aquifer parameters and the corresponding numerical values (when defined).

`testdata`**:** Object of class `"data.frame"`, containing the list of the test data and the corresponding numerical values (when defined).

Author(s)

François Bertone

`guess.gfamodel` *First guess for the analytical solution parameters*

Description

Function that guess intial analytical solution parameters for fitting a gfamodel to a drawdowns object

Usage

```
guess.gfamodel(x, dd)
```

Arguments

`x`	A gfamodel object. See details.
`dd`	An drawdowns object used for extracting a first guess.

Details

Only model type of the entry x object is used. If available, in the analytical solution parameters of the x object are ignored.

Value

An object of class gfamodel of the same type than the entry x object with new analytical solution parameters. If available in the entry x object, aquifer parameters and test data are copied in the constructed object.

`plot,drawdowns-method` *Class "drawdowns"*

Description

Function that plots drawdowns objects.

Usage

```
## S4 method for signature 'drawdowns'
plot(x, model = NULL, log = "xy", col = c("blue4",
  "aquamarine4", "deepskyblue3", "darkolivegreen3"), derivative = TRUE,
  legend = TRUE, leg.pos = "bottomright", unit.slope = FALSE,
  ylab = "Drawdown", xlab = "Time")
```

Arguments

`x`	drawdowns object to be plotted
`model`	gfamodel object to be superposed to x. Data are calculated for the x time series. if NULL no model is plotted.
`log`	character string which contains "x" if the x axis is to be logarithmic, "y" if the y axis is to be logarithmic and "xy" or "yx" if both axes are to be logarithmic.
`col`	colors vector for the x data, model data, x derivative and model derivative respectively. If there are fewer colors than 4, color are recycled.
`derivative`	logical. If TRUE the derivatives for x argument, and for model argument if any, are ploted.
`legend`	logical. If TRUE a lengend is printed.
`leg.pos`	single keyword setting the location of the legend, from the list "bottomright", "bottom", "bottomleft", "left", "topleft", "top", "topright", "right" and "center".

Details

Plot drawdowns and derivative of drawdown curves for the x object. If a the model argument is set, supperpose a line for the corresponding drawdowns and derivative.

`plot,gfamodel-method` *Class "gfamodel"*

Description

Function that plots gfamodel objects.

Usage

```
## S4 method for signature 'gfamodel'
plot(x, title = TRUE, legend = TRUE, log = "xy")
```

Arguments

`x`	gfamodel object to be plotted
`title`	logical. Indicates if the analytical model type is to be printed
`legend`	logical. Indicates if the legend type is to be printed
`log`	character string which contains "x" if the x axis is to be logarithmic, "y" if the y axis is to be logarithmic and "xy" or "yx" if both axes are to be logarithmic.

Details

Plot standard drawdowns and derivative of drawdown curves for the analytical model set in the x object.

`pumptest` *A dataset describing examples of pump tests*

Description

A series of 4 examples of pump test data:

ths_ds1 Data set of a pumping test in a confined aquifer (pumping rate Q=1.3888e-2 m3/s, radial distance r=250 m) typed from: Table 5.1, page 172 in the following book: C.W. Fetter, 2001, Applied Hydrogeology, Fourth Edition. Prentice Hall, Upper Saddle River, 598 pp.

ths_ds2 Data set of a pumping test in a confined aquifer aquired with automatic data logger. Author's personal data.

htj_ds1 Data set of a pumping test in a confined aquifer with leakage through an aquitard. The data set for this example comes from the following reference: Hall, P. Water well and aquifer test analysis 1996, Water Resources Publications, LLC, 412 pp. Example Fig 11.14 p.267-268 (pumping rate Q=6.309E-3 m3/s, distance to the pumping well r=3.048 m, thickness of the aquitard e'=6.096 m)

agt_ds1 Data set of a precovery after constant rate pumping test. The data set for this example comes from: Todd D.K.(1980), Ground Water Hydrology, John Wiley & Sons, New York, Batu, V., Aquifer Hydraulics: A Comprehensive Guide to Hydrogeologic Data Analysis, John Wiley, New York, 1998. Example 4-12, Pages 183-186 (pumping rate Q=2500/24/60/60 m3/s, distance to the pumping well r=60 m, duration of pumping tp=240*60 s)

tmr_ds1 Data set of a variable rate pumping test, from Kruseman and de Ridder (1994) pp. 185. The data are collected in a piezometer located at 5 m from the pumping well.

pcw_ds1 Data set for a pumping test, from Rushton K.R. and Holt S.M., 1981, Estimating aquifer parameters for large-diameter well. Ground Water, 19(5): 505-509. The data is digitized from figure 3b page 508.

Usage

```
pumptest
```

Format

Data are organised in a list of data.frame. For each data.frame, V1 describes the time in second from begining of the pump test and V2 describes the drawdowns mesured in meter at the corresponding time.

Author(s)

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References

Renard, Philippe (2017). Hytool: an open source matlab toolbox for the interpretation of hydraulic tests using analytical solutions. _Journal of Open Source Software_, 2(19), 441, [doi:10.21105/joss.00441] http://joss.theoj.org/papers/10.21105/joss.00441

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rhytool *The rhytool package*

Description

Hytool library for R users for the interpretation of hydraulic tests in wells.

Details

Hytool is originally a matlab toolbox for the interpretation of hydraulic tests in wells. The toolbox contains analytical solutions used to describe groundwater flow around wells, and functions for importing, displaying, and fitting a model to the data. The rhytool package is the R version of this toolbox (S4).

For a complete list of classes and methods, use library(help = "rhytool").

Author(s)

François Bertone

References

To cite this toolbox, please use the following reference: Renard Philippe (2017), Hytool: an open source matlab toolbox for the interpretation of hydraulic tests using analytical solutions, _Journal of Open Source Software_, 2(19), 441. doi: 10.21105/joss.00441

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