

Introductory analysis of daily streamflows with hydroTSM

Mauricio Zambrano-Bigiarini*

version 0.1, 17-Jan-2024

1 Installation

Installing the latest stable version (from CRAN):

```
install.packages("hydroTSM")
```

Alternatively, you can also try the under-development version (from Github):

```
if (!require(devtools)) install.packages("devtools")
library(devtools)
install_github("hzambran/hydroTSM")
```

2 Setting up the environment

Loading the *hydroTSM* package, which contains data and functions used in this analysis:

```
library(hydroTSM)
```

```
## Loading required package: zoo
```

```
##
```

```
## Attaching package: 'zoo'
```

```
## The following objects are masked from 'package:base':
```

```
##
```

```
##      as.Date, as.Date.numeric
```

Loading daily streamflow data at the station Cauquenes en el Arrayan, Maule Region, Chile, from 01/Jan/1979 to 31/Dec/2020.

```
data(Cauquenes7336001)
```

Selecting only a 30-years time slice for the analysis

```
x <- window(Cauquenes7336001, start="1981-01-01", end="2010-12-31")
```

Dates of the daily values of 'x':

```
dates <- time(x)
```

Amount of years in 'x' (needed for computations):

```
( nyears <- yip(from=start(x), to=end(x), out.type="nmbr" ) )
```

```
## [1] 30
```

*mauricio.zambrano@ufrontera.cl

The `Cauquenes7336001` dataset stores 5 variables (in this order): `P`, [mm], `Tmx`, [degC], `Tmn`, [deg C], `PET`, [mm], `Qobs`, [mm], `Qobs`, [m3/s]. For the rest of the analysis, only streamflows (`Q`, [mm]) and precipitations (`P`, [mm]) will be selected:

```
P <- x[, 1]
Q <- x[, 5]
```

3 Basic exploratory data analysis (EDA)

1) Summary statistics of streamflows:

```
smry(Q)
```

```
##           Index           Q
## Min.      1981-01-01      0.0014
## 1st Qu.    1988-07-02      0.0583
## Median     1996-01-01      0.1708
## Mean       1996-01-01      1.2220
## 3rd Qu.    2003-07-02      0.8375
## Max.       2010-12-31     118.5000
## IQR        <NA>           0.7791
## sd         <NA>           4.1753
## cv         <NA>           3.4180
## Skewness    <NA>          11.2980
## Kurtosis    <NA>          190.5046
## NA's        <NA>          274.0000
## n          <NA>        10957.0000
```

2) Amount of days with information (not NA) per year:

```
dwi(Q)
```

```
## 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996
## 363 364 363 365 365 364 365 366 365 365 359 326 365 365 297 366
## 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010
## 365 337 365 366 365 365 365 366 365 348 365 305 318 365
```

3) Amount of days with information (not NA) per month per year:

```
dwi(Q, out.unit="mpy")
```

```
##      Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
## 1981 31  28 31  30 31  29 30  31 30 31 30 31
## 1982 31  28 31  30 31  30 31  31 29 31 30 31
## 1983 31  28 31  30 31  29 30  31 30 31 30 31
## 1984 31  29 31  30 31  30 30  31 30 31 30 31
## 1985 31  28 31  30 31  30 31  31 30 31 30 31
## 1986 31  28 31  30 31  29 31  31 30 31 30 31
## 1987 31  28 31  30 31  30 31  31 30 31 30 31
## 1988 31  29 31  30 31  30 31  31 30 31 30 31
## 1989 31  28 31  30 31  30 31  31 30 31 30 31
## 1990 31  28 31  30 31  30 31  31 30 31 30 31
## 1991 31  26 31  30 31  30 27  31 30 31 30 31
## 1992 31  29 31  30 31  30 31  13  8 31 30 31
## 1993 31  28 31  30 31  30 31  31 30 31 30 31
## 1994 31  28 31  30 31  30 31  31 30 31 30 31
## 1995 31  28 25 15 20  5 20  31 30 31 30 31
```

```
## 1996 31 29 31 30 31 30 31 31 30 31 30 31
## 1997 31 28 31 30 31 30 31 31 30 31 30 31
## 1998 31 28 31 30 31 30 31 31 30 30 19 15
## 1999 31 28 31 30 31 30 31 31 30 31 30 31
## 2000 31 29 31 30 31 30 31 31 30 31 30 31
## 2001 31 28 31 30 31 30 31 31 30 31 30 31
## 2002 31 28 31 30 31 30 31 31 30 31 30 31
## 2003 31 28 31 30 31 30 31 31 30 31 30 31
## 2004 31 29 31 30 31 30 31 31 30 31 30 31
## 2005 31 28 31 30 31 30 31 31 30 31 30 31
## 2006 31 28 31 30 31 30 31 14 30 31 30 31
## 2007 31 28 31 30 31 30 31 31 30 31 30 31
## 2008 31 29 13 0 18 30 31 31 30 31 30 31
## 2009 31 28 31 30 31 30 24 0 21 31 30 31
## 2010 31 28 31 30 31 30 31 31 30 31 30 31
```

- 4) Since v0.7-0, hydroTSM allows the computation of the amount/percentage of days with missing data in different temporal scales (e.g., hourly, weekly, seasonal). By default, the `cmv` function returns the percentage of missing values in the desired temporal scale using decimal values:

```
( pmd <- cmv(Q, tscale="monthly") )

## 1981-01 1981-02 1981-03 1981-04 1981-05 1981-06 1981-07 1981-08 1981-09 1981-10
## 0.000 0.000 0.000 0.000 0.000 0.033 0.032 0.000 0.000 0.000
## 1981-11 1981-12 1982-01 1982-02 1982-03 1982-04 1982-05 1982-06 1982-07 1982-08
## 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000
## [ reached getOption("max.print") -- omitted 340 entries ]
```

Identifying months with more than 10 percent of missing data:

```
index <- which(pmd >= 0.1)
time(pmd[index])

## [1] "1991-07" "1992-08" "1992-09" "1995-03" "1995-04" "1995-05" "1995-06"
## [8] "1995-07" "1998-11" "1998-12" "2006-08" "2008-03" "2008-04" "2008-05"
## [15] "2009-07" "2009-08" "2009-09"
```

- 5) Computation of monthly values only when the percentage of NAs in each month is lower than a user-defined percentage (10% in this example).

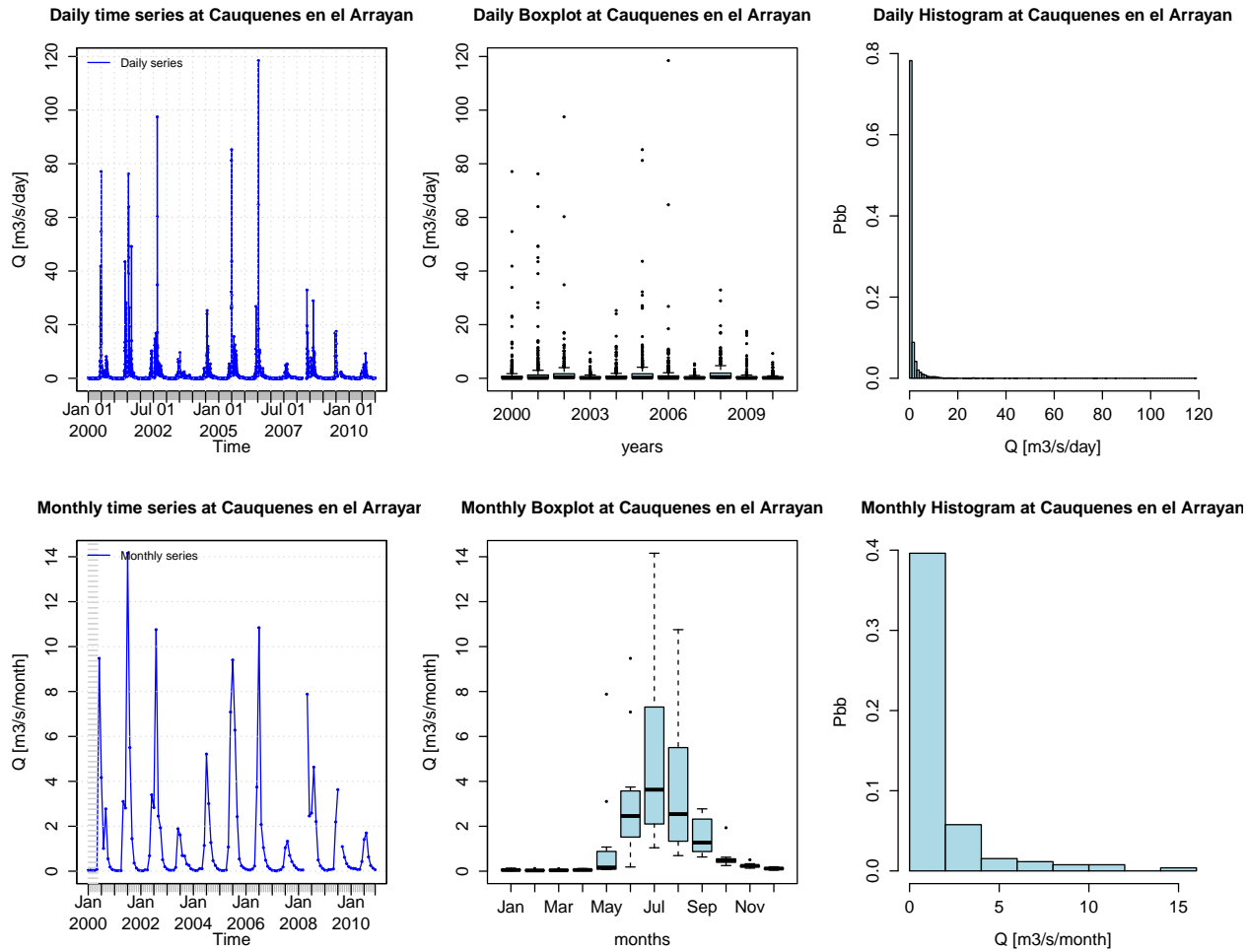
```
## Daily to monthly, only for months with less than 10% of missing values
(m2 <- daily2monthly(Q, FUN=mean, na.rm=TRUE, na.rm.max=0.1))

## 1981-01-01 1981-02-01 1981-03-01 1981-04-01 1981-05-01 1981-06-01 1981-07-01
## 0.06963541 0.04992439 0.03557262 0.09975684 6.70602042 2.87502617 2.29693512
## 1981-08-01 1981-09-01 1981-10-01 1981-11-01 1981-12-01 1982-01-01 1982-02-01
## 1.72374858 1.75745744 0.35827986 0.18224559 0.08523987 0.05131148 0.04476578
## 1982-03-01 1982-04-01 1982-05-01 1982-06-01 1982-07-01 1982-08-01
## 0.03753045 0.04709608 3.75221201 8.93496883 7.40797474 4.60248712
## [ reached getOption("max.print") -- omitted 340 entries ]
```

- 6) Basic exploratory figures:

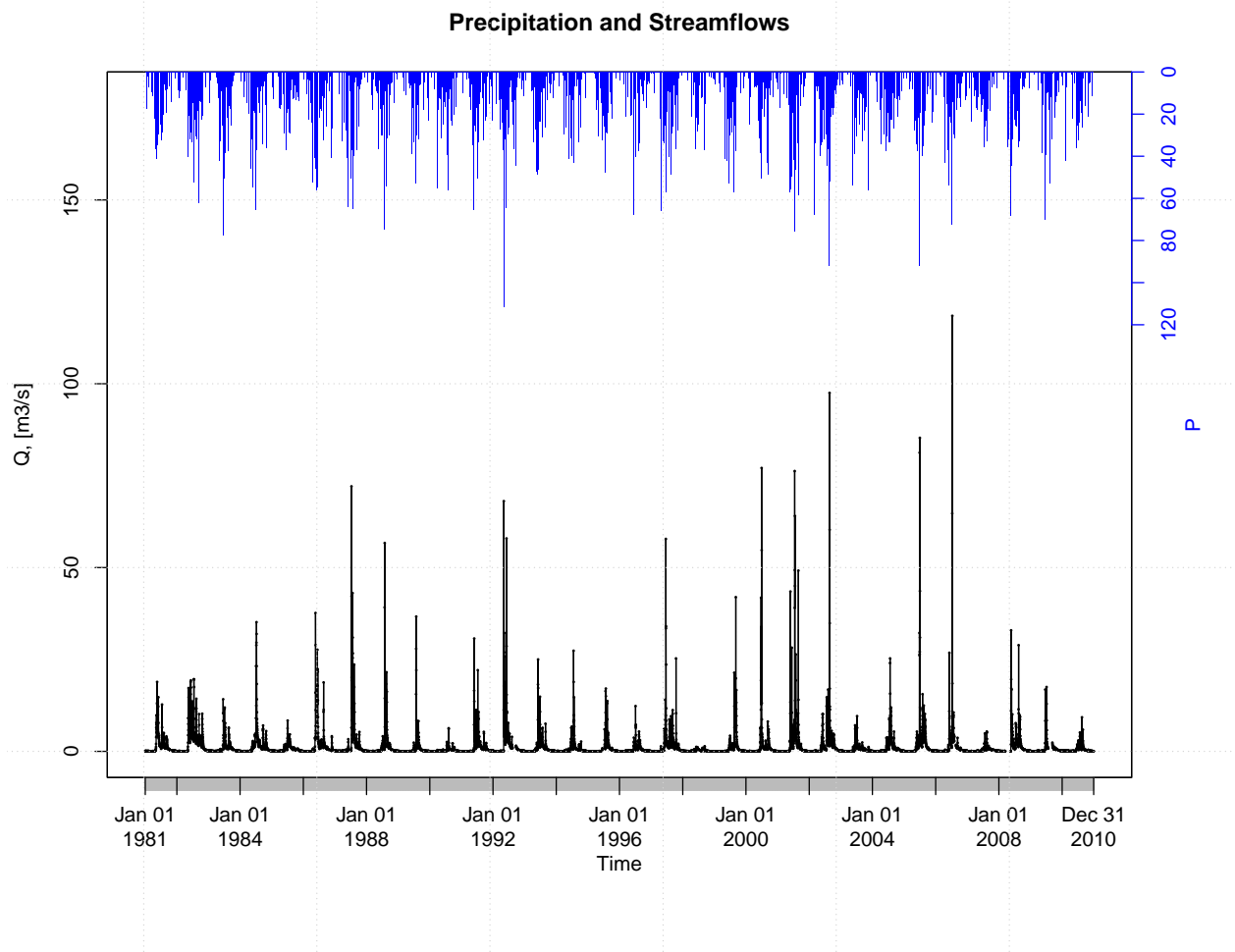
Using the `hydroplot` function, which (by default) plots 9 different graphs: 3 ts plots, 3 boxplots and 3 histograms summarizing 'x'. For this example, only daily and monthly plots are produced, and only data starting on 01-Jan-1987 are plotted.

```
hydroplot(Q, var.type="Flow", main="at Cauquenes en el Arrayan",
          pfreq = "dm", from="2000-01-01")
```



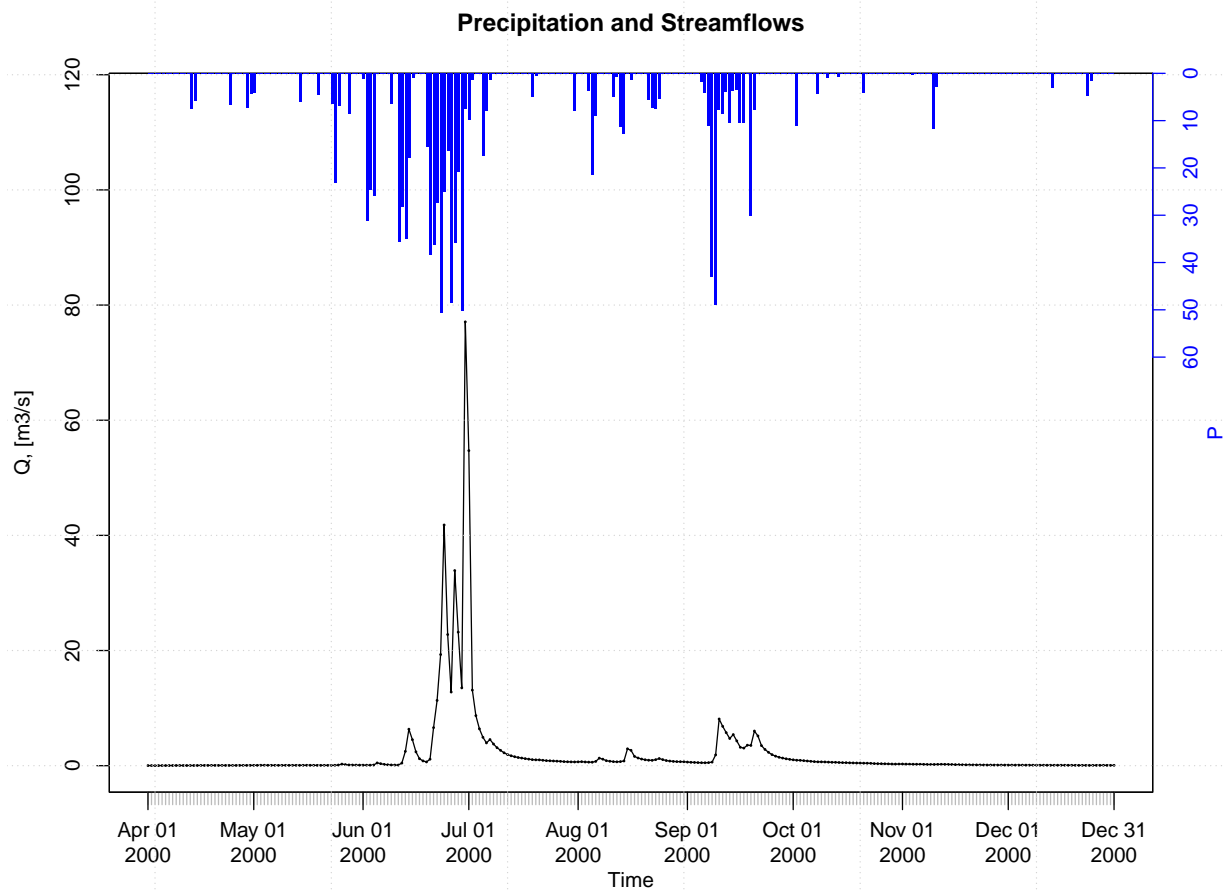
Plotting P and Q for the full time period of both time series:

```
plot_pq(p=P, q=Q)
```



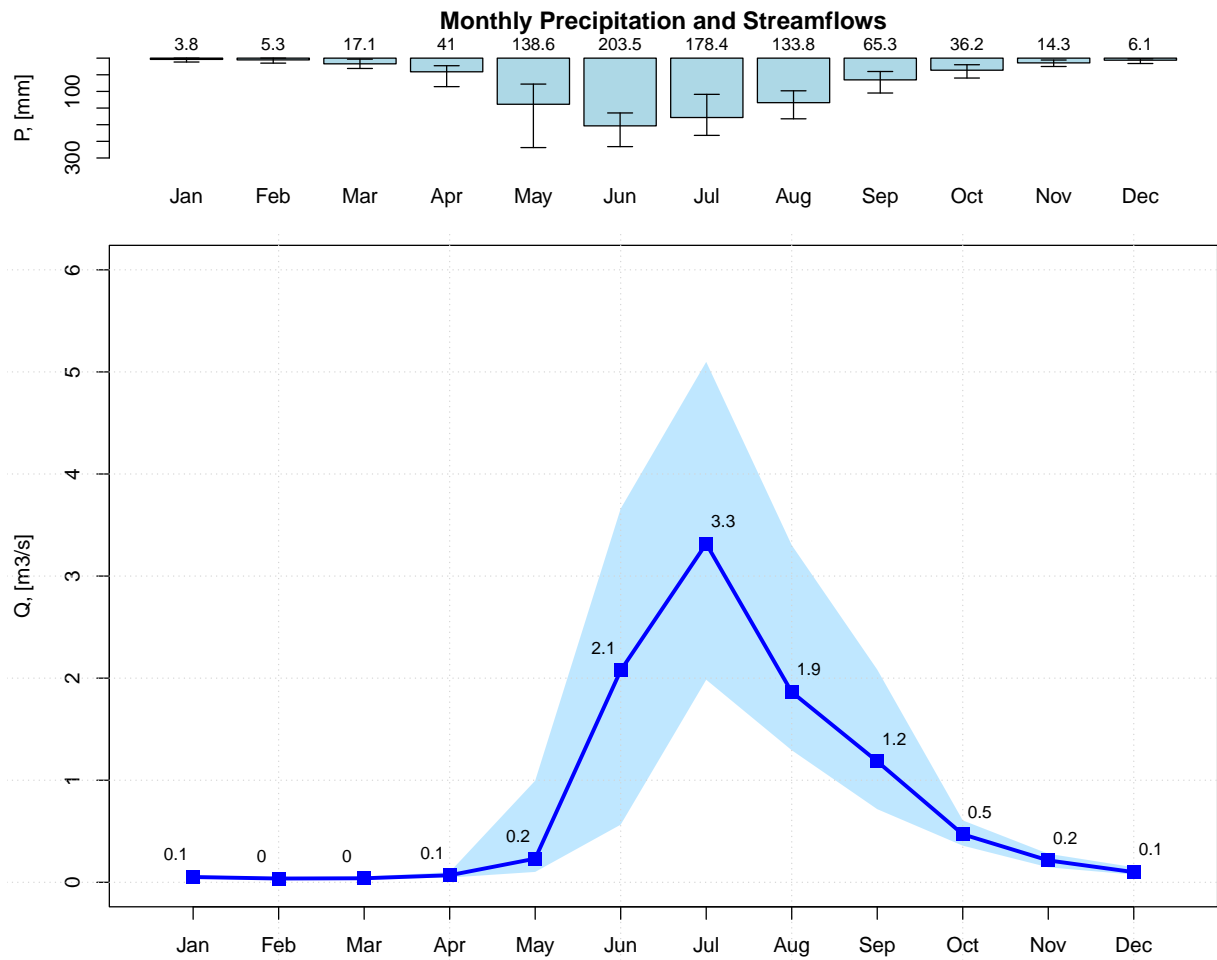
Plotting precipitation and streamflows only for a specific time period, from April to December 2000:

```
plot_pq(p=P, q=Q, from="2000-04-01", to="2000-12-31")
```



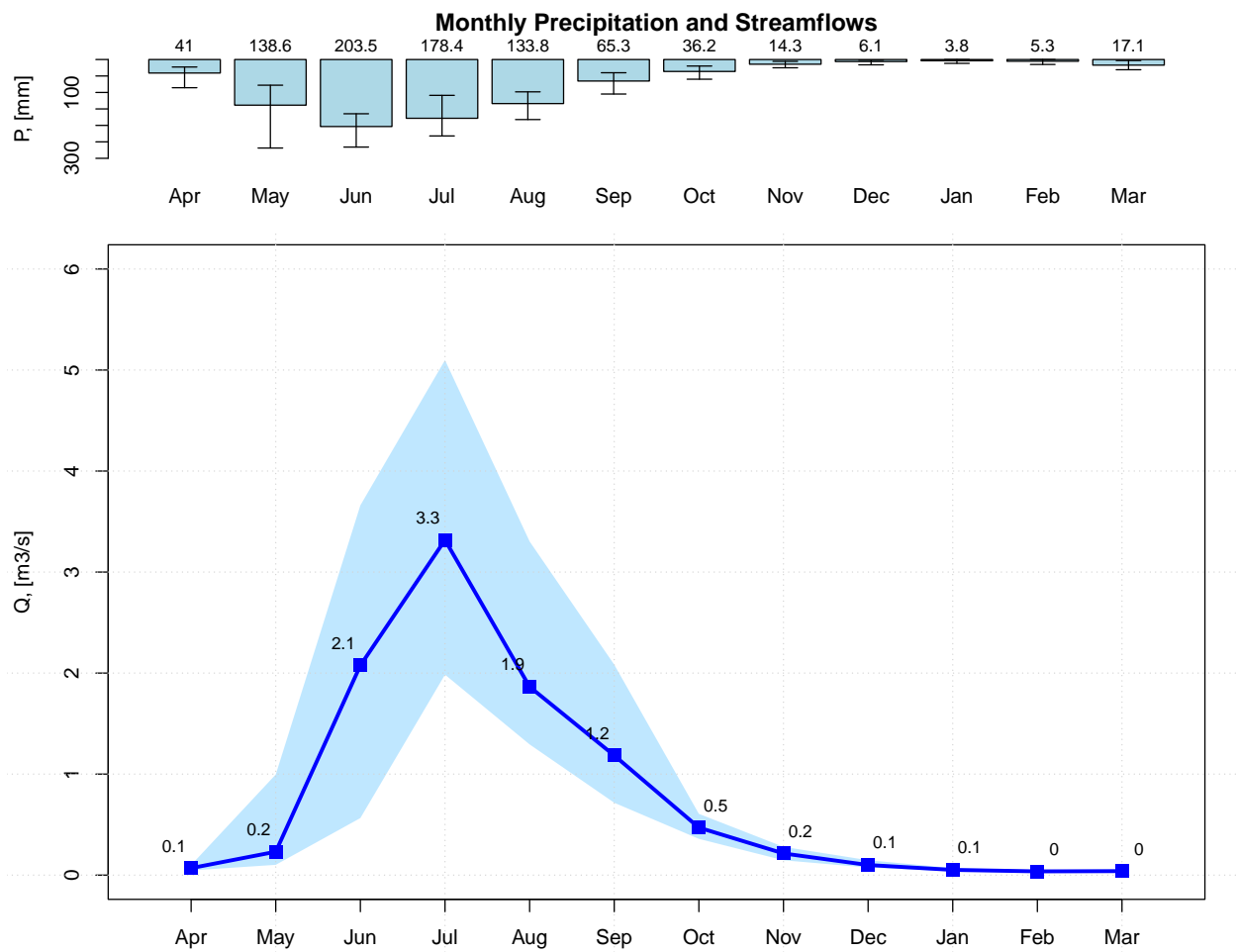
Plotting monthly values of precipitation and streamflows for the full time period of both time series:

```
plot_pq(p=P, q=Q, ptype="monthly")
```



Plotting monthly values of precipitation and streamflows for the full time period of both time series, but using a hydrologic year starting on April:

```
plot_pq(p=P, q=Q, ptype="monthly", start.month=4)
```

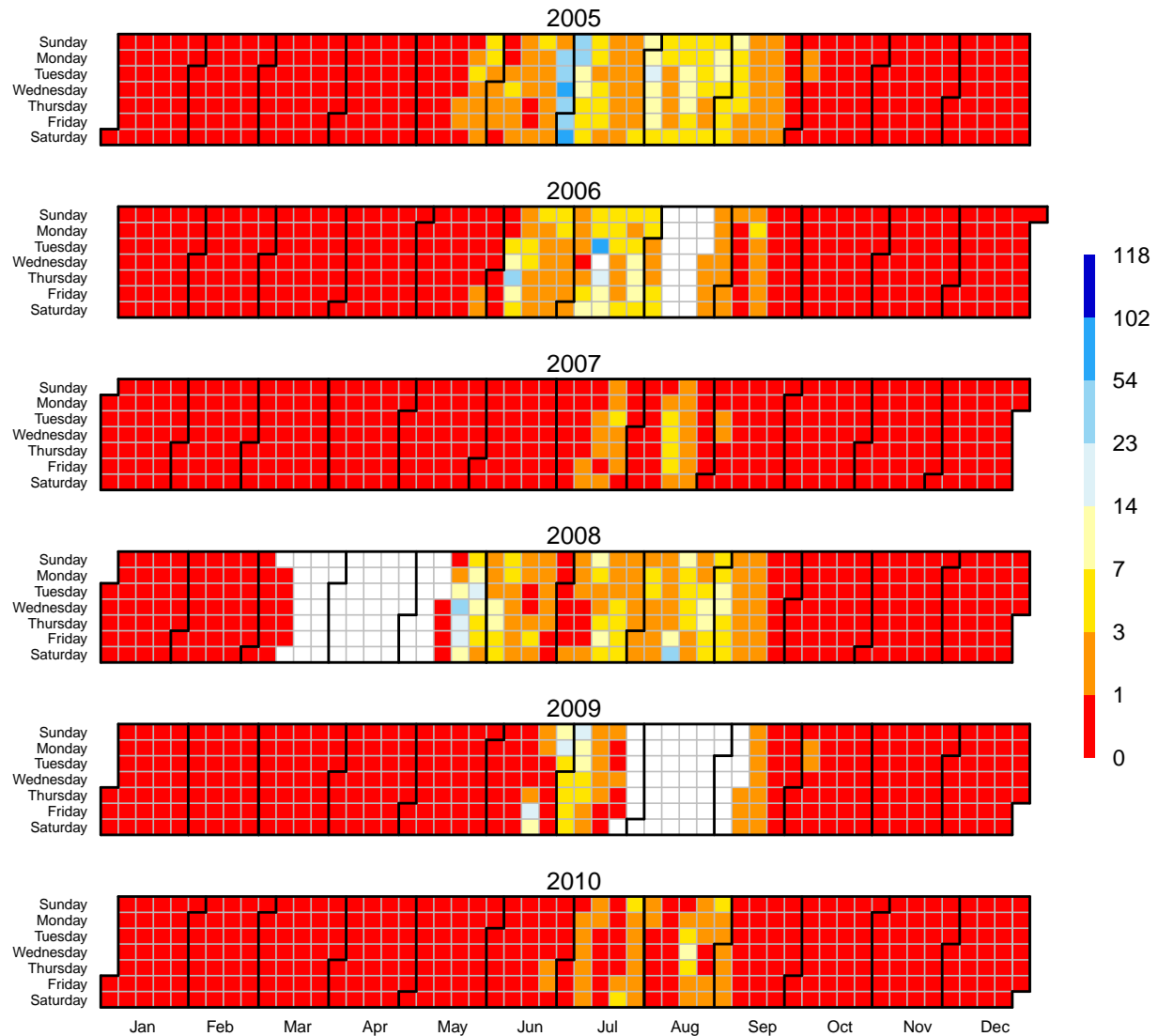


Selecting only a six-year time period for streamflows and then plotting a calendar heatmap (six years maximum) to visually identify dry, normal and wet days:

```
q <- window(Q, start="2005-01-01", end="2010-12-31")
calendarHeatmap(q)
```

```
## Warning in classInt::classIntervals(temp, n = length(col), dataPrecision =
## cuts.dec, : var has missing values, omitted in finding classes
```


Calendar Heat Map

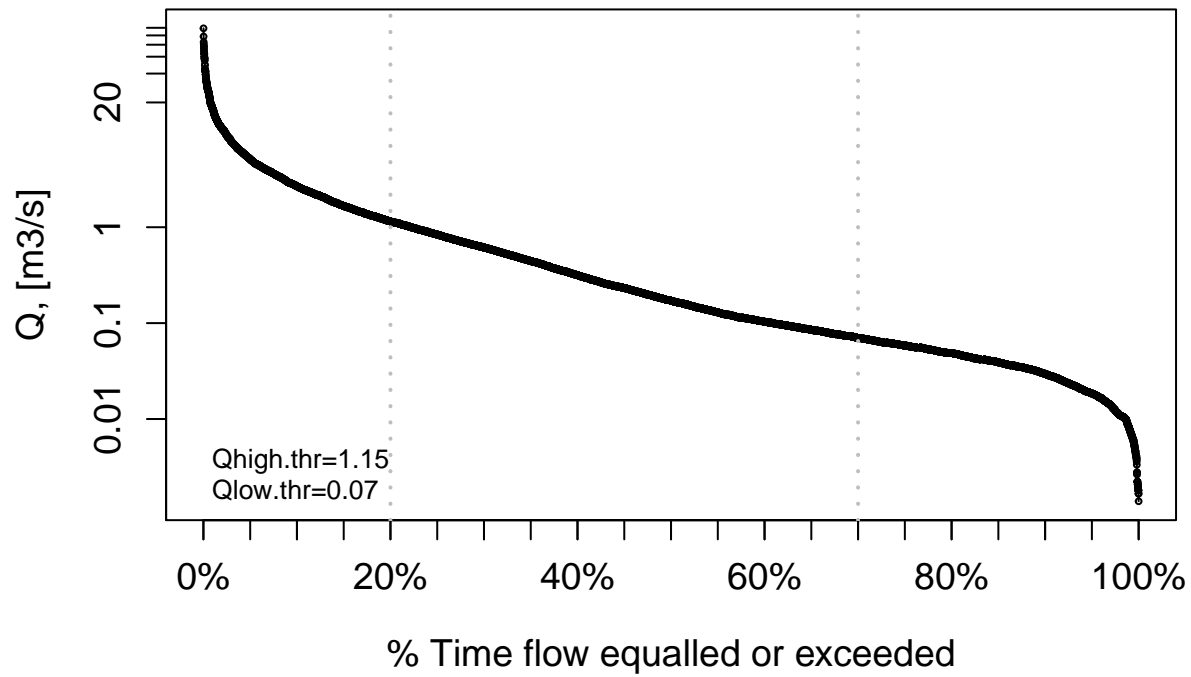


4 Flow duration curve (FDC)

Flow duration curve of the 30-year daily streamflow data using logarithmic scale for the y axis (i.e., to put focus on the low flows):

```
fdc2 <- fdc(Q)
```

Flow Duration Curve

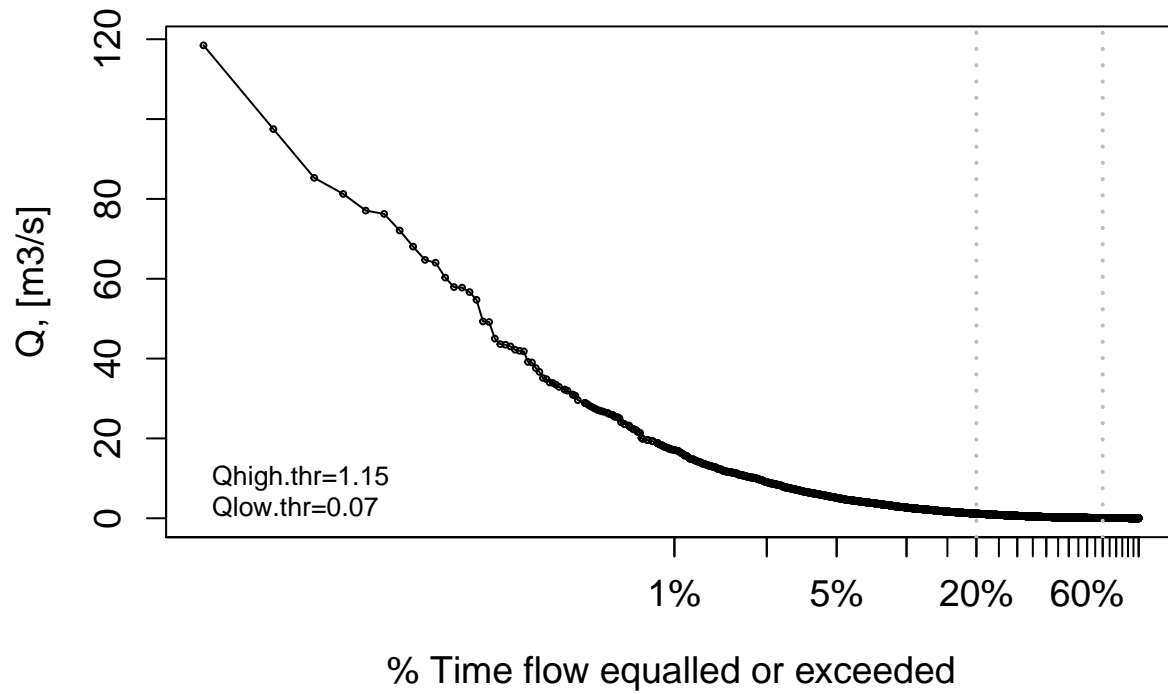


Please note that `log="y"` was not provided as an argument to `fdc` because it is the default value used in the function.

Flow duration curve of the 30-year daily streamflow data using logarithmic scale for the x axis (i.e., to put focus on the high flows):

```
fdc3 <- fdc(Q, log="x")
```

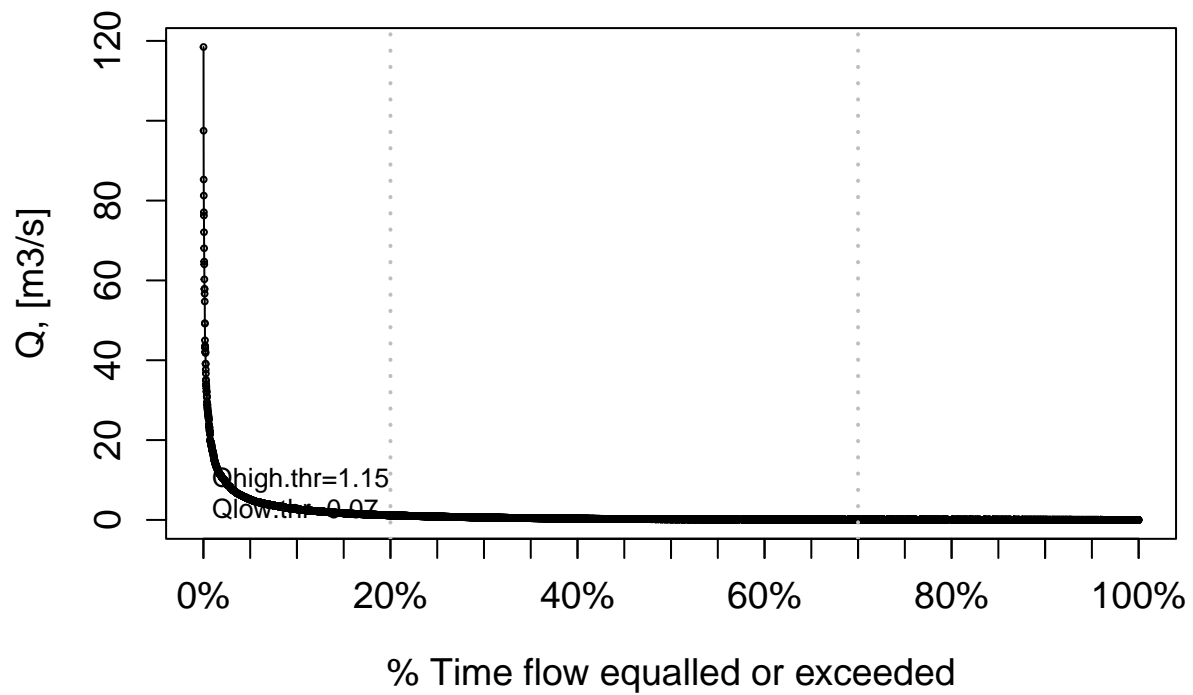
Flow Duration Curve



Traditional flow duration curve of the 30-year daily streamflow data:

```
fdc1 <- fdc(Q, log="")
```

Flow Duration Curve



5 Baseflow

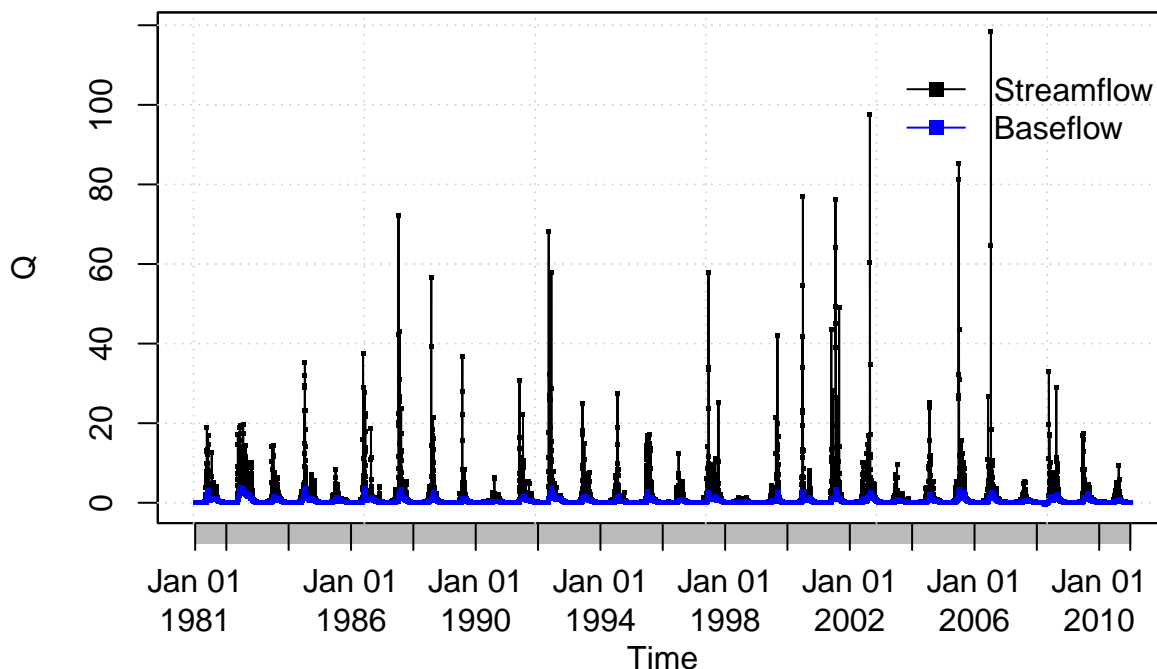
Since v0.7-0, hydroTSM allows the computation of baseflow using the filter proposed by Arnold and Allen (1999), which is based on earlier work by Lyne and Hollick (1979).

This first example illustrates the basic usage of the `baseflow` function for computing and plotting the baseflow for the full time period of a given time series of streamflows:

```
baseflow(Q)
```

The previous code did not run because the streamflow time series has some missing values. You might fill in the missing values using the technique that you like the most and then call this function again. For this example, we will use one of the two built-in techniques already incorporated in the `baseflow` function the missing data, i.e., `na.fill="spline"`:

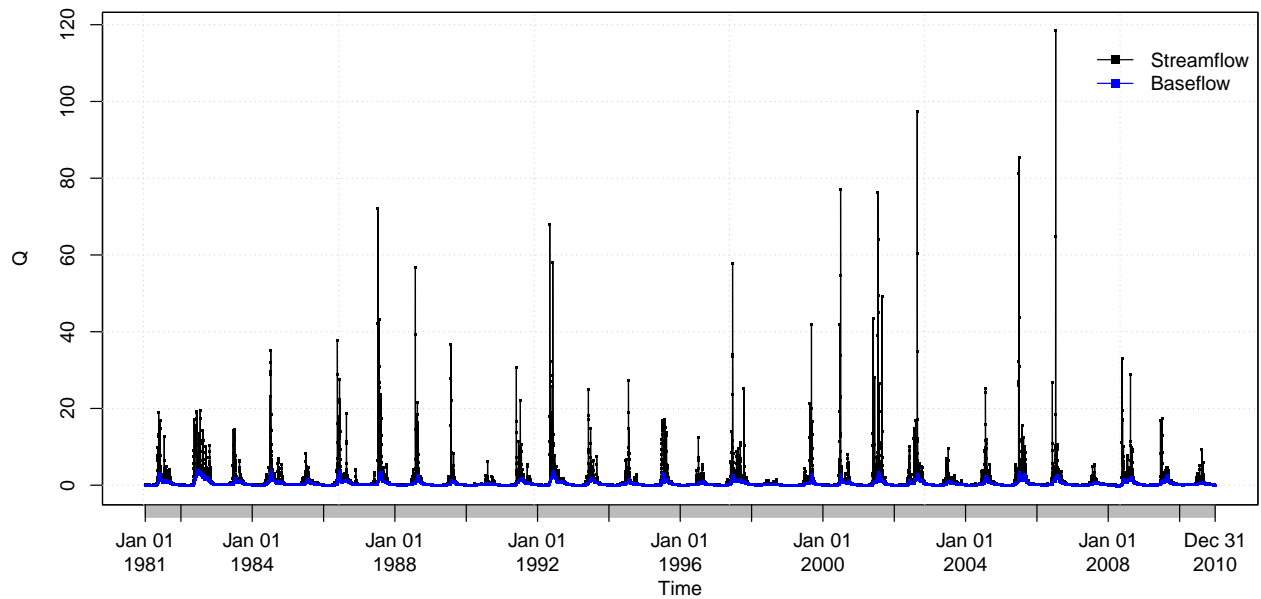
```
baseflow(Q, na.fill="spline")
```



```
## 1981-01-01 1981-01-02 1981-01-03 1981-01-04 1981-01-05 1981-01-06 1981-01-07
## 0.04583222 0.04595585 0.04629648 0.04675769 0.04722086 0.04762892 0.04797386
## 1981-01-08 1981-01-09 1981-01-10 1981-01-11 1981-01-12 1981-01-13 1981-01-14
## 0.04824942 0.04845012 0.04857058 0.04848719 0.04724127 0.04586267 0.04435630
## 1981-01-15 1981-01-16 1981-01-17 1981-01-18 1981-01-19 1981-01-20
## 0.04294380 0.04202268 0.04169691 0.04166566 0.04166566 0.04166566
## [ reached getOption("max.print") -- omitted 10937 entries ]
```

Now, we will compute and plot the daily baseflow (i.e., the value obtained after the third pass of the filter) for the full time period:

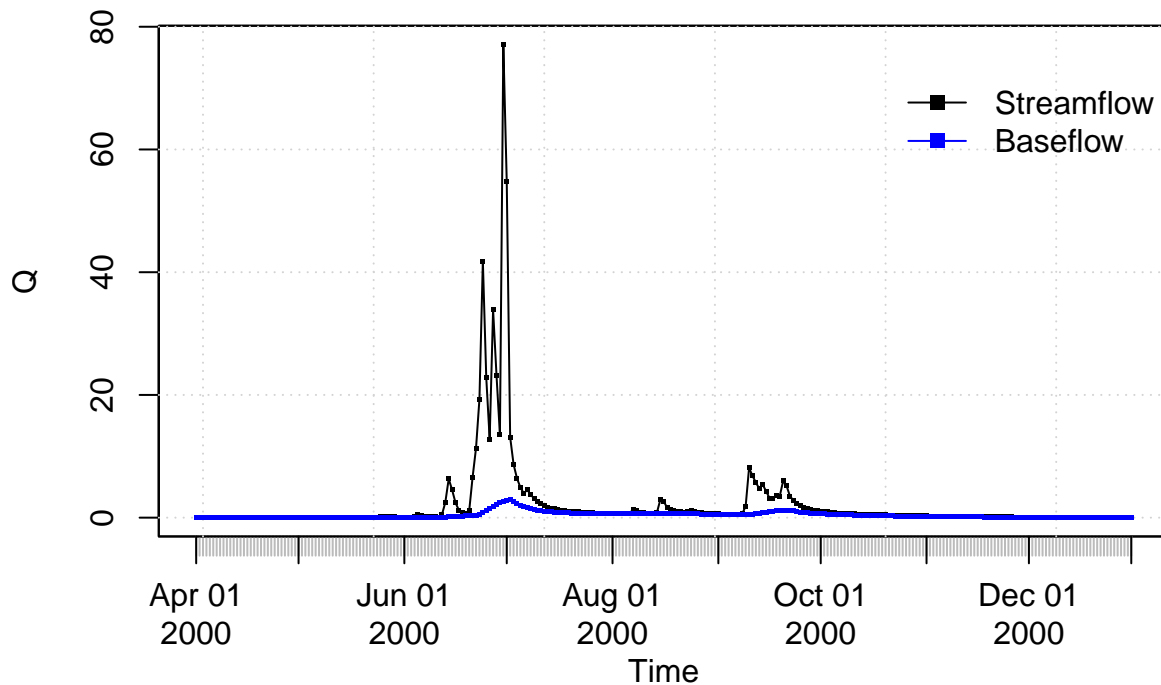
```
baseflow(Q, na.fill="spline", plot=TRUE)
```



```
## 1981-01-01 1981-01-02 1981-01-03 1981-01-04 1981-01-05 1981-01-06 1981-01-07
## 0.04583222 0.04595585 0.04629648 0.04675769 0.04722086 0.04762892 0.04797386
## 1981-01-08 1981-01-09 1981-01-10 1981-01-11 1981-01-12 1981-01-13 1981-01-14
## 0.04824942 0.04845012 0.04857058 0.04848719 0.04724127 0.04586267 0.04435630
## 1981-01-15 1981-01-16 1981-01-17 1981-01-18 1981-01-19 1981-01-20
## 0.04294380 0.04202268 0.04169691 0.04166566 0.04166566 0.04166566
## [ reached getOption("max.print") -- omitted 10937 entries ]
```

You might also want to compute and plot the daily baseflow for a specific time period. For this example, from April to December 2000:

```
baseflow(Q, na.fill="spline", from="2000-04-01", to="2000-12-31")
```

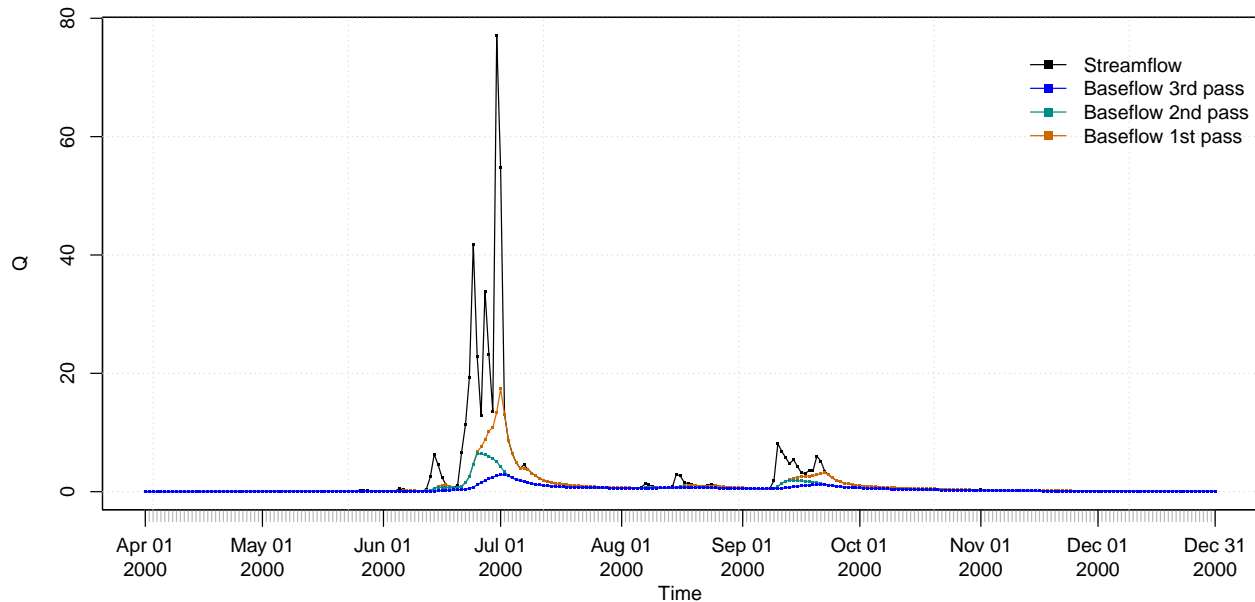


```
## 2000-04-01 2000-04-02 2000-04-03 2000-04-04 2000-04-05 2000-04-06 2000-04-07
```

```
## 0.01055530 0.01058421 0.01066581 0.01079262 0.01096092 0.01117236 0.01143301
## 2000-04-08 2000-04-09 2000-04-10 2000-04-11 2000-04-12 2000-04-13 2000-04-14
## 0.01174777 0.01212483 0.01257104 0.01307664 0.01362143 0.01419277 0.01478636
## 2000-04-15 2000-04-16 2000-04-17 2000-04-18 2000-04-19 2000-04-20
## 0.01540326 0.01605655 0.01675997 0.01751794 0.01833122 0.01919427
## [ reached getOption("max.print") -- omitted 255 entries ]
```

You might want to compute and plot the three daily baseflows (one for each pass of the filter), for a specific time period (April to December 2000):

```
baseflow(Q, na.fill="spline", from="2000-04-01", to="2000-12-31",
        out.type="all", plot=TRUE)
```



```
##          baseflow3 baseflow2 baseflow1
## 2000-04-01 0.01055530 0.01055530 0.01055530
## 2000-04-02 0.01058421 0.01132611 0.01132611
## 2000-04-03 0.01066581 0.01201829 0.01201829
## 2000-04-04 0.01079262 0.01269500 0.01269500
## 2000-04-05 0.01096092 0.01337825 0.01337825
## 2000-04-06 0.01117236 0.01418213 0.01418213
## [ reached getOption("max.print") -- omitted 269 rows ]
```

6 Software details

This tutorial was built under:

```
## [1] "x86_64-pc-linux-gnu (64-bit)"
## [1] "R version 4.3.2 (2023-10-31)"
## [1] "hydroTSM 0.6-37"
```

7 Version history

- v0.1: 17-Jan-2024

8 Appendix

In order to make easier the use of **hydroTSM** for users not familiar with R, in this section a minimal set of information is provided to guide the user in the R world.

8.1 Editors, GUI

- **Multi-platform:** Sublime Text (<https://sublime.weberup.com/>) ; RStudio (<https://posit.co/>)
- **GNU/Linux only:** ESS (<https://ess.r-project.org/>)
- **Windows only :** NppToR (<https://sourceforge.net/projects/npptor/>)

8.2 Importing data

- **?read.table, ?write.table:** allow the user to read/write a file (in table format) and create a data frame from it. Related functions are **?read.csv, ?write.csv, ?read.csv2, ?write.csv2**.
- **?zoo::read.zoo, ?zoo::write.zoo:** functions for reading and writing time series from/to text files, respectively.
- **R Data Import/Export:** <https://cran.r-project.org/doc/manuals/r-release/R-data.html>
- **foreign** R package: read data stored in several R-external formats (dBase, Minitab, S, SAS, SPSS, Stata, Systat, Weka, ...)
- **readxl** R package: Import MS Excel files into R.
- **some examples:** <https://www.statmethods.net/data-input/importingdata.html>

8.3 Useful Websites

- **Quick R:** <https://www.statmethods.net/>
- **Time series in R:** <https://cran.r-project.org/view=TimeSeries>
- **Quick reference for the zoo package:** <https://cran.r-project.org/package=zoo/vignettes/zoo-quickref.pdf>

8.4 F.A.Q.

9 How to print more than one matrixplot in a single Figure?

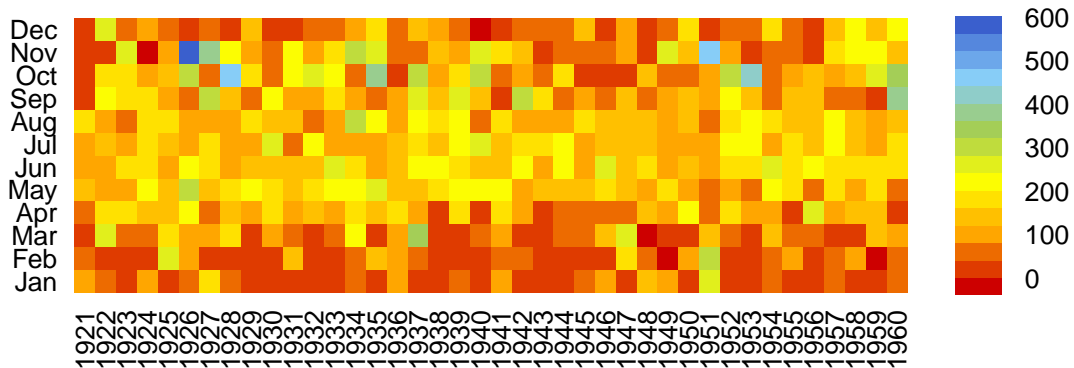
Because **matrixplot** is based on lattice graphs, normal plotting commands included in base R does not work. Therefore, for plotting ore than 1 matrixplot in a single figure, you need to save the individual plots in an R object and then print them as you want.

In the following sequential lines of code, you can see two examples that show you how to plot two matrixplots in a single Figure:

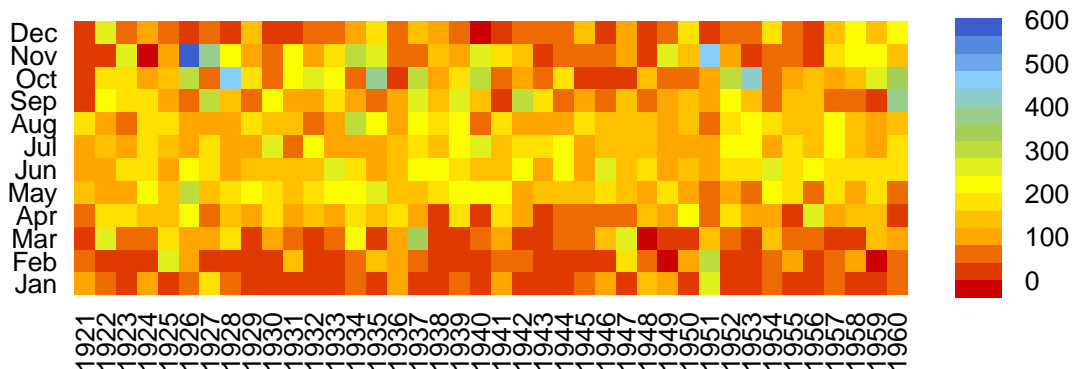
```
library(hydroTSM)
data(SanMartinoPPts)
x <- window(SanMartinoPPts, end=as.Date("1960-12-31"))
m <- daily2monthly(x, FUN=sum, na.rm=TRUE)
M <- matrix(m, ncol=12, byrow=TRUE)
colnames(M) <- month.abb
rownames(M) <- unique(format(time(m), "%Y"))
p <- matrixplot(M, ColorRamp="Precipitation", main="Monthly precipitation,")
```

```
print(p, position=c(0, .6, 1, 1), more=TRUE)
print(p, position=c(0, 0, 1, .4))
```

Monthly precipitation,



Monthly precipitation,



The second and easier way allows you to obtain the same previous figure (not shown here), but you are required to install the `gridExtra` package:

```
if (!require(gridExtra)) install.packages("gridExtra")
```

```
## Loading required package: gridExtra
```

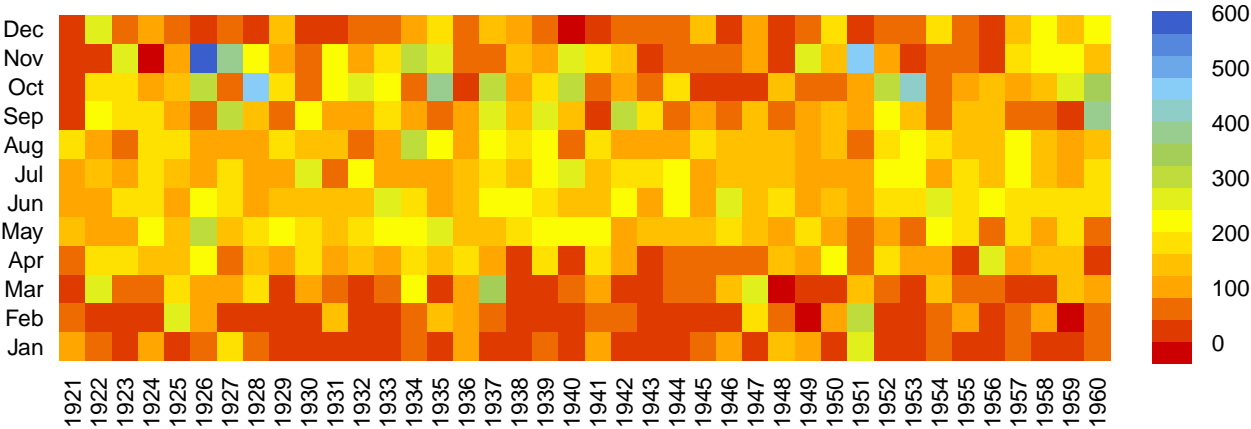
```
require(gridExtra) # also loads grid
require(lattice)
```

```
## Loading required package: lattice
```



```
grid.arrange(p, p, nrow=2)
```

Monthly precipitation,



Monthly precipitation,

