Practical 1 — River discharge & precipitation extremes (Neuchâtel)

2025-10-07

# Introduction

This report reproduces the worked solution for Practical 1. It loads the daily river discharge and precipitation data for Neuchâtel, performs exploratory data analysis, fits extreme-value models (block maxima GEV for discharge and POT/GPD for precipitation), conducts a simple declustering procedure, inspects tail dependence, and runs the provided extreme causality tests from JuroExtremes.R.

All code here is executed; figures are embedded below and results saved to practical\_1/practical1\_results.rds.

# 0. Load packages and data

## Methodology

This section installs/loads the R packages required for the analysis and reads the CSV data. The data is expected to be in practical\_1/River\_and\_precip\_Neuchatel.csv.

## Results / Notes

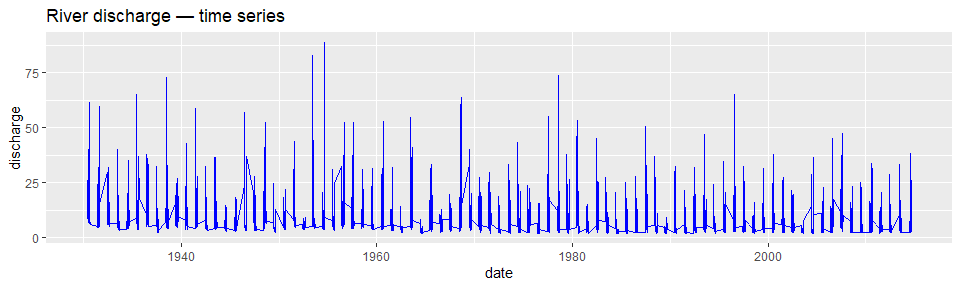
Packages will be installed if missing; the small preview table below shows the first rows of the data.

required\_pkgs <- c('readr','lubridate','ggplot2','dplyr','evd','ismev','forecast','knitr')  
missing <- required\_pkgs[!required\_pkgs %in% installed.packages()[,1]]  
if(length(missing)) install.packages(missing, repos = 'https://cloud.r-project.org')  
  
library(readr); library(lubridate); library(ggplot2); library(dplyr)  
library(evd); library(ismev); library(forecast)  
  
fig\_dir <- file.path('practical\_1','figures')  
if(!dir.exists(fig\_dir)) dir.create(fig\_dir, recursive = TRUE)  
  
data\_path <- file.path('practical\_1','River\_and\_precip\_Neuchatel.csv')  
stopifnot(file.exists(data\_path))  
raw <- read\_csv(data\_path, col\_types = cols(Date = col\_date(format = "%Y-%m-%d"),  
 RiverDischarge = col\_double(),  
 Precipitation = col\_double()))  
  
df <- raw %>% rename(date = Date, discharge = RiverDischarge, precip = Precipitation)  
  
# basic table  
kable(head(df, 6))

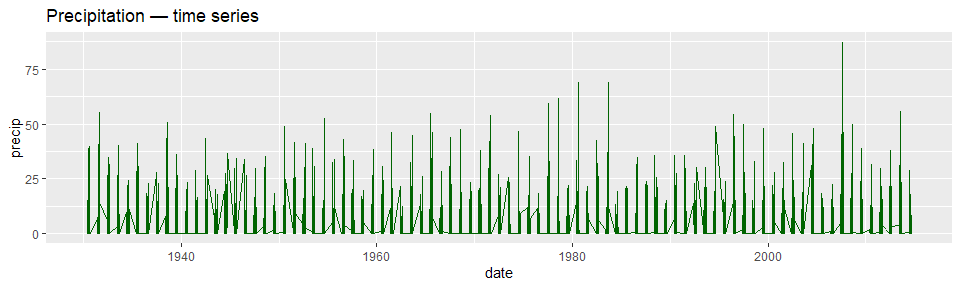
| date | discharge | precip |
| --- | --- | --- |
| 1930-06-02 | 12.30 | 15.4 |
| 1930-06-03 | 14.30 | 0.0 |
| 1930-06-04 | 18.00 | 0.0 |
| 1930-06-05 | 12.10 | 0.0 |
| 1930-06-06 | 10.20 | 5.5 |
| 1930-06-07 | 8.81 | 1.3 |

# 1 Exploratory plots (time series + seasonality)

# ggplot time series  
p1 <- ggplot(df, aes(x = date, y = discharge)) + geom\_line(color='blue') + labs(title='River discharge — time series')  
print(p1)



p2 <- ggplot(df, aes(x = date, y = precip)) + geom\_line(color='darkgreen') + labs(title='Precipitation — time series')  
print(p2)



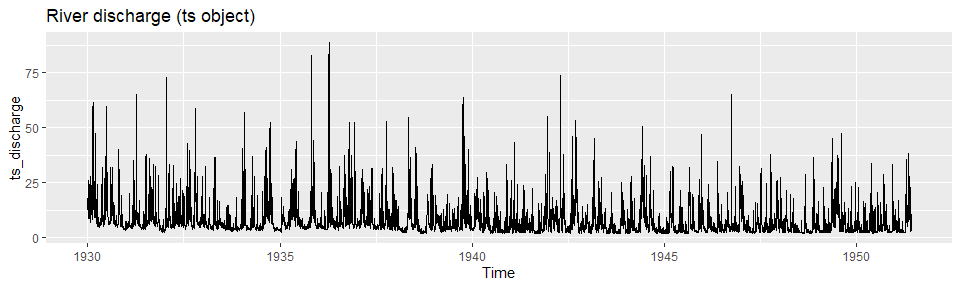
### Methodology

We produce line plots of the daily series for visual inspection of trends and large events.

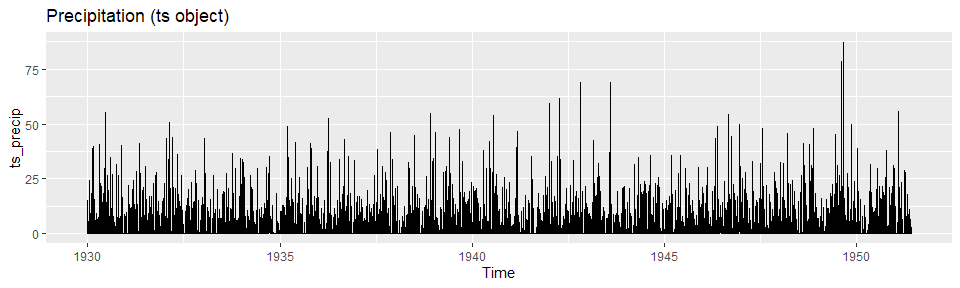
### Results / Comments

The plots below highlight periods of elevated discharge and precipitation; seasonal structure is also inspected with monthly boxplots below.

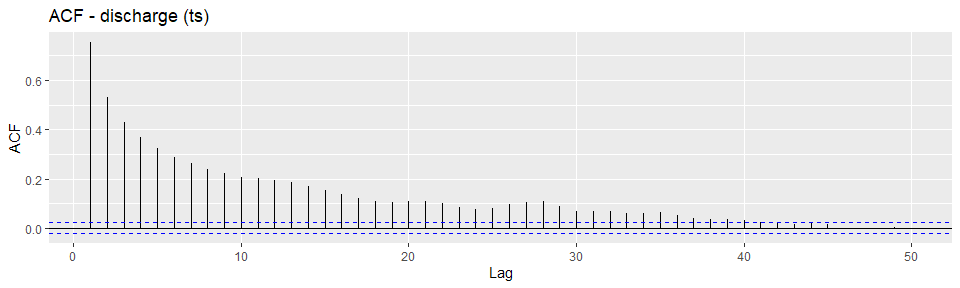
# ts objects  
ts\_start\_year <- year(min(df$date, na.rm = TRUE))  
ts\_discharge <- ts(df$discharge, start = c(ts\_start\_year,1), frequency = 365)  
ts\_precip <- ts(df$precip, start = c(ts\_start\_year,1), frequency = 365)  
print(autoplot(ts\_discharge) + labs(title='River discharge (ts object)'))



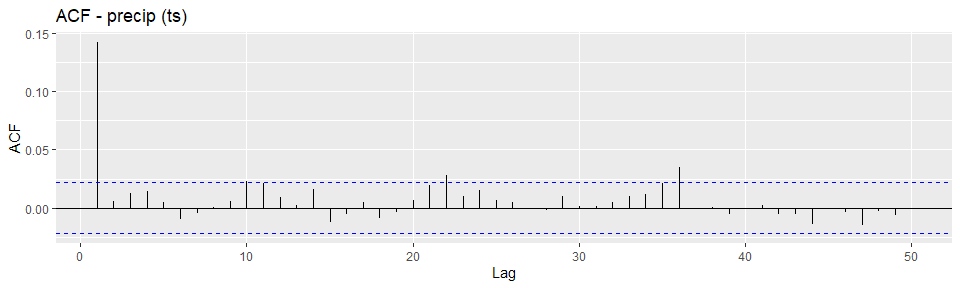
print(autoplot(ts\_precip) + labs(title='Precipitation (ts object)'))



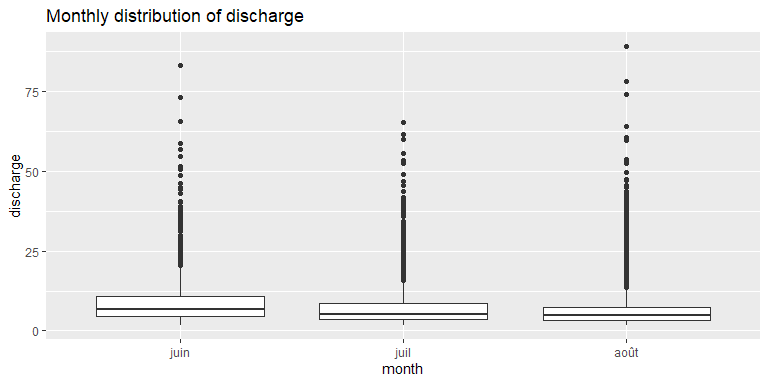
# ACFs  
print(ggAcf(ts\_discharge, lag.max = 50) + ggtitle('ACF - discharge (ts)'))



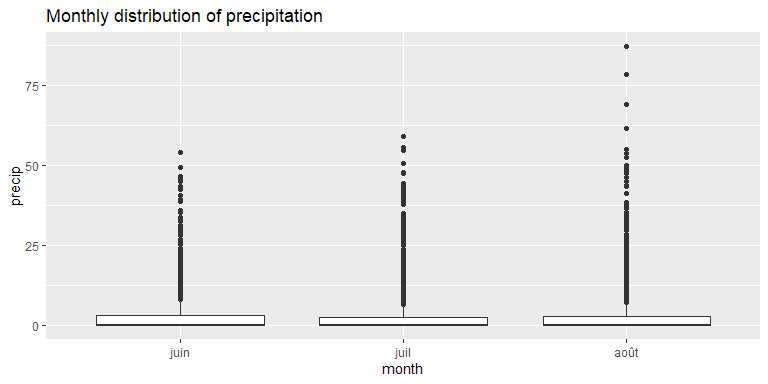
print(ggAcf(ts\_precip, lag.max = 50) + ggtitle('ACF - precip (ts)'))



df <- df %>% mutate(month = month(date, label = TRUE))  
print(ggplot(df, aes(x=month, y=discharge)) + geom\_boxplot() + labs(title='Monthly distribution of discharge'))



print(ggplot(df, aes(x=month, y=precip)) + geom\_boxplot() + labs(title='Monthly distribution of precipitation'))



# 2 Summary statistics

### Methodology

Compute simple descriptive statistics: mean, standard deviation and counts of missing values.

### Results / Comments

The summary table provides an immediate check on data completeness and scale of the two series.

summary\_stats <- df %>% summarize(  
 n = n(),  
 discharge\_mean = mean(discharge, na.rm=TRUE),  
 discharge\_sd = sd(discharge, na.rm=TRUE),  
 precip\_mean = mean(precip, na.rm=TRUE),  
 precip\_sd = sd(precip, na.rm=TRUE),  
 missing\_discharge = sum(is.na(discharge)),  
 missing\_precip = sum(is.na(precip))  
)  
  
# present a compact, human-friendly table  
summary\_stats\_fmt <- summary\_stats %>%  
 mutate(across(where(is.numeric), ~round(., 2)))  
knitr::kable(summary\_stats\_fmt, caption = 'Summary statistics (rounded)')

Summary statistics (rounded)

| n | discharge\_mean | discharge\_sd | precip\_mean | precip\_sd | missing\_discharge | missing\_precip |
| --- | --- | --- | --- | --- | --- | --- |
| 7819 | 7.93 | 7.36 | 3.07 | 6.77 | 0 | 0 |

# 3 Annual maxima and GEV for discharge

### Methodology

Compute annual block maxima of daily discharge and fit a GEV via maximum likelihood. We then compute an approximate 100-year return level from the fitted parameters.

### Results / Comments

The GEV parameter estimates and the 100-year return level are printed below. A histogram of annual maxima with the fitted GEV density is shown for visual fit assessment.

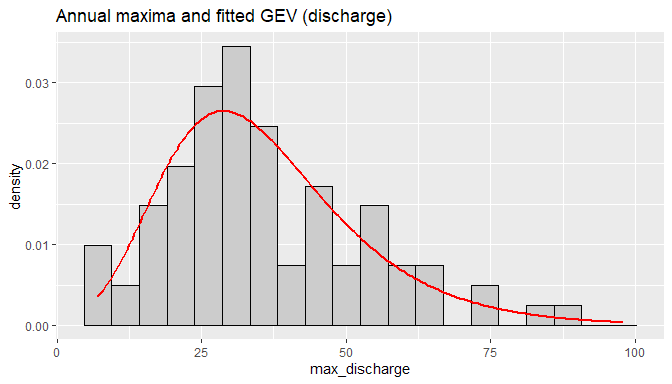
# annual maxima  
library(stats)  
df <- df %>% mutate(year = year(date))  
annual\_max <- df %>% group\_by(year) %>% summarize(max\_discharge = max(discharge, na.rm = TRUE)) %>% ungroup()  
  
gev\_fit <- fgev(annual\_max$max\_discharge)  
print(gev\_fit)

##   
## Call: fgev(x = annual\_max$max\_discharge)   
## Deviance: 713.2291   
##   
## Estimates  
## loc scale shape   
## 28.35273 13.90569 -0.03091   
##   
## Standard Errors  
## loc scale shape   
## 1.70891 1.23774 0.08415   
##   
## Optimization Information  
## Convergence: successful   
## Function Evaluations: 29   
## Gradient Evaluations: 7

loc <- gev\_fit$estimate['loc']; scale <- gev\_fit$estimate['scale']; shape <- gev\_fit$estimate['shape']  
rl\_100 <- qgev(1 - 1/100, loc = loc, scale = scale, shape = shape)  
cat('Estimated 100-year return level (discharge):', rl\_100, '\n')

## Estimated 100-year return level (discharge): 87.98176

xv <- seq(min(annual\_max$max\_discharge)\*0.9, max(annual\_max$max\_discharge)\*1.1, length.out=200)  
gev\_dens <- dgev(xv, loc=loc, scale=scale, shape=shape)  
dens\_df <- data.frame(x = xv, y = gev\_dens)  
  
p\_gev <- ggplot(annual\_max, aes(x = max\_discharge)) +  
 geom\_histogram(aes(y = after\_stat(density)), bins = 20, fill = 'grey80', color = 'black') +  
 geom\_line(data = dens\_df, aes(x = x, y = y), color = 'red', linewidth = 1, inherit.aes = FALSE) +  
 labs(title = 'Annual maxima and fitted GEV (discharge)')  
print(p\_gev)



# 4 Peaks-over-threshold (POT) and GPD for precipitation

### Methodology

Select the 95% empirical quantile as threshold and fit a GPD to exceedances (ismev::gpd.fit). Use the empirical exceedance rate to compute approximate T-year return levels.

### Results / Comments

The GPD fit and an example 10-year return level estimate are reported below.

threshold95 <- quantile(df$precip, 0.95, na.rm=TRUE)  
th <- as.numeric(threshold95)  
exceedances <- df$precip[df$precip > th]  
excesses <- exceedances - th  
cat('Threshold used (95%):', th, 'Number exceedances:', length(excesses), '\n')

## Threshold used (95%): 16.01 Number exceedances: 391

gpd\_fit <- gpd.fit(df$precip, threshold = th, show = FALSE)  
print(gpd\_fit)

## $trans  
## [1] FALSE  
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## $model  
## $model[[1]]  
## NULL  
##   
## $model[[2]]  
## NULL  
##   
##   
## $link  
## [1] "c(identity, identity)"  
##   
## $threshold  
## [1] 16.01  
##   
## $nexc  
## [1] 391  
##   
## $data  
## [1] 24.1 18.5 38.7 39.7 40.6 23.0 21.1 18.3 29.6 55.2 21.0 26.5 19.6 35.0 22.7  
## [16] 27.0 31.6 26.4 17.3 40.4 16.6 19.5 22.1 16.1 24.4 28.6 41.1 27.7 19.7 21.1  
## [31] 30.6 18.4 16.9 16.8 22.9 26.5 28.1 22.9 43.6 24.1 33.9 20.9 29.1 25.1 50.8  
## [46] 20.5 19.0 43.9 21.0 20.6 36.1 26.8 20.2 23.3 29.0 23.0 16.7 20.9 28.6 43.3  
## [61] 26.6 20.2 17.8 19.5 18.7 27.3 20.6 22.3 36.7 30.0 34.5 22.6 33.9 31.4 32.4  
## [76] 22.8 25.5 26.6 21.3 20.3 16.5 29.6 30.1 18.2 27.7 16.2 35.4 18.2 16.4 49.0  
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## [136] 46.2 29.3 25.9 33.9 17.0 17.8 20.6 19.4 21.8 22.1 32.4 29.9 21.7 45.0 43.6  
## [151] 21.0 19.0 18.1 26.1 54.8 21.4 33.0 34.4 46.4 21.6 28.1 28.4 30.5 21.7 43.7  
## [166] 22.6 16.2 47.6 27.6 18.7 32.8 27.8 17.6 16.6 18.9 19.4 23.3 21.4 19.4 19.9  
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##   
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## [2,] -0.02897301 0.002788572  
##   
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##   
## $n  
## [1] 7819  
##   
## $npy  
## [1] 365  
##   
## $xdata  
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## [15] 24.1 0.0 0.0 1.2 0.2 0.0 0.0 0.1 4.4 0.2 1.2 3.4 0.5 0.0  
## [29] 0.0 9.4 0.0 0.0 0.0 0.0 18.5 0.0 0.0 0.0 3.7 5.7 0.7 0.1  
## [43] 11.7 0.1 0.0 9.8 38.7 2.9 0.2 7.3 0.0 39.7 5.6 1.2 0.6 7.3  
## [57] 4.9 0.0 0.0 3.7 0.0 8.0 2.9 15.7 2.3 10.0 0.0 1.4 0.0 0.5  
## [71] 0.0 5.8 0.5 5.9 2.8 0.0 0.0 0.0 1.0 0.0 2.0 9.1 0.0 0.0  
## [85] 0.0 0.0 0.0 0.0 0.0 0.0 0.0 6.4 1.5 0.0 0.0 0.0 4.0 3.7  
## [99] 0.3 0.0 0.0 0.0 0.3 0.0 0.0 0.0 0.0 7.3 2.4 0.0 2.5 0.0  
## [113] 0.0 0.1 40.6 7.5 0.0 0.1 8.2 0.0 0.0 5.5 0.0 9.1 14.4 0.0  
## [127] 23.0 21.1 1.7 0.6 0.0 0.0 0.0 4.7 9.4 8.6 1.2 0.0 0.0 14.4  
## [141] 9.9 1.1 0.0 0.5 0.0 0.0 0.0 18.3 2.2 0.0 0.0 0.0 4.1 3.0  
## [155] 2.3 0.0 0.3 15.6 7.1 29.6 2.8 0.6 1.1 0.0 0.0 1.1 55.2 0.5  
## [169] 3.9 0.5 6.6 5.1 8.5 14.9 10.7 10.5 11.3 0.0 0.0 0.0 5.1 4.4  
## [183] 14.3 6.3 21.0 0.2 0.2 26.5 1.1 0.1 0.0 0.0 0.0 0.0 4.8 19.6  
## [197] 0.0 0.0 0.0 0.0 0.0 14.5 1.8 3.8 1.1 1.7 6.0 1.7 0.0 0.0  
## [211] 0.0 0.0 0.0 35.0 4.8 0.0 0.0 8.0 22.7 2.0 1.7 5.6 0.0 1.7  
## [225] 2.5 6.3 0.1 11.7 1.6 1.6 0.0 1.0 27.0 0.0 0.0 5.3 0.0 1.9  
## [239] 0.9 0.4 0.0 0.0 0.0 0.2 6.6 1.3 4.1 8.0 4.3 0.0 0.0 0.0  
## [253] 0.0 0.0 0.0 0.0 0.0 5.2 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [267] 3.5 0.0 0.0 0.0 31.6 0.0 0.0 9.3 0.0 3.4 0.0 0.0 0.0 0.0  
## [281] 0.0 0.0 0.0 0.0 1.4 1.8 7.6 2.7 0.2 0.2 0.7 26.4 7.4 17.3  
## [295] 11.8 10.6 3.6 1.5 4.8 6.6 7.2 0.0 4.3 1.7 0.1 0.0 0.0 0.0  
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## [323] 0.0 0.0 0.2 0.0 9.1 0.2 0.0 0.0 0.0 0.0 0.9 16.6 0.8 0.0  
## [337] 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 8.9  
## [351] 0.8 3.4 4.6 0.0 0.0 8.1 0.0 0.9 5.0 0.0 0.0 0.0 0.0 0.0  
## [365] 0.0 0.0 0.0 9.9 1.7 5.2 0.0 0.0 0.0 0.3 0.0 0.0 0.0 0.3  
## [379] 0.1 0.0 0.0 0.4 0.0 0.0 0.0 13.0 19.5 0.2 0.0 0.0 8.5 22.1  
## [393] 0.0 0.0 13.3 4.7 3.3 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [407] 1.6 1.6 3.0 8.8 11.5 1.2 0.0 0.0 0.0 0.0 8.9 0.9 12.2 0.7  
## [421] 7.2 7.2 0.2 0.0 0.0 0.0 0.0 4.2 0.3 16.1 24.4 2.5 0.0 0.2  
## [435] 11.7 0.0 1.7 0.0 0.6 0.0 4.3 13.5 0.1 0.0 0.0 0.0 0.0 0.0  
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## [463] 28.6 3.6 0.0 0.0 0.0 4.3 0.0 5.5 0.0 0.0 0.0 13.4 0.0 0.4  
## [477] 2.2 0.0 0.0 0.0 0.0 1.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 41.1  
## [491] 0.0 1.8 0.0 0.0 0.0 0.0 0.0 27.7 0.2 0.0 0.0 0.0 0.0 0.0  
## [505] 0.0 0.0 0.8 0.0 7.6 0.0 0.0 0.0 0.0 4.3 7.6 0.0 0.0 0.0  
## [519] 0.0 0.0 0.6 11.2 0.7 19.7 0.0 0.0 0.0 1.1 1.9 4.8 0.0 15.6  
## [533] 21.1 2.3 0.0 0.0 0.0 2.8 2.6 0.0 0.0 0.0 0.0 8.4 6.0 10.7  
## [547] 4.0 30.6 4.2 0.0 0.0 0.0 1.5 18.4 13.2 0.0 2.4 0.4 1.7 0.0  
## [561] 1.7 0.9 0.0 5.0 1.6 0.0 0.0 0.0 0.0 0.0 0.0 3.9 6.0 0.0  
## [575] 0.0 2.0 5.1 9.3 0.0 5.1 0.0 3.4 2.4 7.2 0.0 0.0 12.9 5.1  
## [589] 16.9 14.4 11.1 5.3 4.9 9.8 1.0 2.8 0.0 0.0 0.8 0.0 11.9 1.9  
## [603] 0.2 0.0 13.1 3.0 0.0 16.8 9.6 3.7 0.3 0.8 8.8 0.4 1.8 1.2  
## [617] 0.0 0.0 1.8 0.0 0.0 22.9 8.0 3.6 0.6 0.0 0.0 9.6 0.0 0.0  
## [631] 0.7 0.1 0.0 1.7 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 26.5  
## [645] 0.0 0.0 0.0 0.0 0.0 6.6 0.0 28.1 0.0 9.2 0.0 0.0 0.0 2.6  
## [659] 0.2 0.0 0.0 4.4 3.8 0.3 0.0 10.1 3.9 0.2 0.0 14.8 8.1 8.0  
## [673] 0.0 0.0 0.0 0.0 0.4 8.3 1.1 3.7 0.0 0.0 0.6 0.9 3.5 0.4  
## [687] 0.0 3.5 0.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [701] 0.0 0.0 0.0 9.2 5.7 0.0 0.0 0.0 0.0 0.0 0.0 0.0 14.7 0.0  
## [715] 0.0 15.9 8.6 6.0 0.1 0.6 1.2 0.1 0.0 2.8 1.7 8.4 0.0 0.0  
## [729] 0.0 0.0 0.0 0.0 22.9 2.3 0.0 7.8 5.6 0.0 0.0 0.6 0.0 0.0  
## [743] 0.0 12.7 5.2 5.4 43.6 24.1 0.2 0.6 0.0 0.0 0.7 0.0 0.0 0.0  
## [757] 6.8 4.5 0.0 0.2 0.1 0.0 0.0 0.0 4.9 33.9 20.9 1.7 29.1 16.0  
## [771] 0.0 0.0 25.1 0.0 2.1 0.8 9.7 0.2 0.0 50.8 2.4 0.0 0.0 0.0  
## [785] 0.0 0.0 0.0 20.5 19.0 0.0 2.4 0.0 0.1 0.0 0.0 0.0 0.0 0.0  
## [799] 0.0 0.0 0.0 43.9 0.0 0.4 0.9 0.0 3.1 4.2 10.3 2.8 0.0 0.0  
## [813] 0.0 0.0 0.2 21.0 3.5 0.1 0.0 0.0 0.0 0.0 0.5 6.6 8.4 1.7  
## [827] 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 3.3 20.6 2.8 2.1  
## [841] 0.2 0.0 2.2 4.6 0.0 3.7 0.0 0.0 2.2 7.5 6.5 15.6 6.4 0.0  
## [855] 0.0 0.9 36.1 0.0 0.9 0.0 0.0 1.0 1.4 0.0 0.0 0.3 0.0 0.0  
## [869] 0.0 0.8 14.8 12.1 12.2 0.0 0.0 1.2 5.7 6.0 4.8 5.2 8.3 12.4  
## [883] 1.6 0.8 0.0 0.0 0.0 0.4 0.0 0.0 6.1 7.3 26.8 0.4 4.9 10.5  
## [897] 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 1.7 4.2 1.5 0.5 0.6  
## [911] 0.6 0.0 0.4 0.1 0.0 0.4 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [925] 0.0 0.0 0.0 0.0 1.0 7.1 10.2 0.0 10.3 1.4 5.6 0.3 0.0 1.5  
## [939] 0.2 0.1 4.3 0.7 10.1 16.0 0.3 0.0 0.0 0.0 0.0 0.0 0.3 0.0  
## [953] 0.8 0.0 1.9 20.2 1.7 0.0 0.1 7.0 13.1 0.1 1.7 9.1 12.3 10.5  
## [967] 0.0 0.0 6.8 0.5 11.2 1.6 0.0 0.2 2.2 0.0 0.0 0.0 0.0 0.0  
## [981] 0.0 0.0 0.0 0.0 3.4 2.9 0.0 0.0 0.1 23.3 0.0 0.0 0.0 0.0  
## [995] 0.0 0.0 0.0 0.0 2.2 0.8 14.1 1.7 1.2 0.0 0.0 0.0 0.3 2.6  
## [1009] 0.0 0.0 0.0 0.0 0.9 0.0 0.1 14.8 1.9 5.5 0.0 13.2 8.6 2.1  
## [1023] 29.0 0.3 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 6.1  
## [1037] 23.0 3.8 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [1051] 2.4 6.0 0.0 15.4 0.0 5.0 1.1 0.0 0.0 0.0 0.8 0.0 0.0 0.0  
## [1065] 0.0 0.0 0.0 0.0 0.3 3.8 3.8 4.3 0.0 0.0 5.9 2.5 9.7 0.2  
## [1079] 2.5 12.7 6.1 0.0 0.0 1.4 0.0 0.0 1.5 16.7 0.1 7.2 0.1 1.8  
## [1093] 1.2 0.0 0.2 0.2 0.0 13.5 0.0 0.0 3.6 2.2 0.0 0.0 0.0 0.0  
## [1107] 0.0 0.0 0.0 4.3 20.9 4.6 28.6 43.3 12.5 0.3 4.9 2.6 3.5 0.0  
## [1121] 0.0 0.0 0.0 0.0 0.0 0.0 1.0 0.5 0.0 0.0 0.0 0.0 0.0 2.5  
## [1135] 12.1 0.2 0.0 1.8 0.0 0.1 0.0 0.6 10.0 0.1 0.0 0.0 8.3 4.1  
## [1149] 0.0 2.8 0.0 5.7 7.5 1.3 0.6 0.0 0.0 1.1 0.2 0.0 0.0 0.0  
## [1163] 0.0 0.0 6.9 7.7 15.8 1.9 1.0 0.0 0.0 0.0 0.1 0.0 0.0 0.0  
## [1177] 0.0 0.0 0.0 0.0 0.0 0.0 0.0 6.8 0.0 0.0 0.4 0.0 0.0 0.0  
## [1191] 0.0 0.0 12.4 0.0 26.6 7.3 4.3 4.6 6.1 0.0 3.4 0.0 9.4 0.9  
## [1205] 0.0 0.0 0.0 0.0 9.6 4.0 11.1 8.2 0.0 0.0 0.0 0.0 0.0 0.0  
## [1219] 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.9 7.3 20.2  
## [1233] 13.3 3.0 0.4 0.1 0.0 1.0 0.0 0.0 0.9 0.0 0.0 4.0 7.0 3.6  
## [1247] 6.0 10.9 0.0 0.0 0.0 0.2 0.0 0.0 0.0 0.0 0.0 0.0 6.9 0.0  
## [1261] 0.1 0.0 0.1 0.0 0.0 0.0 7.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [1275] 0.0 0.0 0.0 17.8 0.0 0.0 0.0 0.9 0.2 0.0 0.0 0.8 0.0 19.5  
## [1289] 0.0 0.0 0.0 10.0 1.3 0.3 0.0 1.0 18.7 0.0 0.0 0.0 0.0 0.0  
## [1303] 6.6 0.4 2.0 1.5 0.0 0.0 0.0 0.0 0.0 0.0 1.7 8.9 0.8 2.1  
## [1317] 0.0 0.0 0.0 27.3 4.1 0.0 0.0 3.1 6.0 2.3 12.1 0.8 0.0 0.0  
## [1331] 1.3 0.0 0.0 0.0 0.0 0.0 7.2 20.6 6.0 0.1 0.0 0.0 2.6 0.3  
## [1345] 0.0 1.1 0.0 0.0 0.0 0.0 0.0 11.5 0.0 0.2 0.0 0.0 0.3 0.0  
## [1359] 0.0 0.0 0.0 0.0 1.6 11.3 0.4 0.0 0.0 0.0 0.0 0.0 0.0 1.0  
## [1373] 2.3 1.9 0.2 0.9 22.3 3.0 36.7 1.1 0.0 0.0 0.0 2.5 0.0 0.0  
## [1387] 0.0 0.8 0.0 0.0 6.9 0.1 0.0 0.0 5.1 0.0 0.0 0.0 0.0 30.0  
## [1401] 0.0 0.0 0.0 0.0 13.9 0.0 4.1 0.0 0.0 0.0 6.0 0.3 0.0 0.0  
## [1415] 0.0 0.0 0.0 1.8 2.8 0.0 0.0 0.0 0.0 5.9 0.0 0.0 0.0 0.0  
## [1429] 0.0 0.0 0.0 0.0 0.0 0.0 7.0 1.1 5.6 0.0 0.0 0.0 0.0 0.0  
## [1443] 0.0 0.0 0.0 0.0 34.5 8.8 6.3 8.9 0.0 0.0 1.1 0.0 0.8 0.0  
## [1457] 0.0 22.6 14.5 0.3 1.8 14.3 5.9 0.0 0.0 0.0 0.0 0.0 3.1 14.4  
## [1471] 0.0 33.9 2.4 1.4 0.0 0.0 0.0 0.5 0.0 7.2 6.2 1.0 31.4 32.4  
## [1485] 0.0 3.6 22.8 1.2 0.3 0.0 0.0 25.5 15.8 0.9 0.6 0.7 6.3 0.0  
## [1499] 0.0 0.2 0.6 0.0 0.0 0.0 0.0 2.4 2.0 2.6 1.0 0.0 0.0 0.0  
## [1513] 0.0 1.4 0.0 0.3 0.0 5.0 10.6 0.0 2.9 4.9 0.0 0.0 0.0 0.0  
## [1527] 0.0 0.0 8.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 6.3 0.0 0.0 0.0  
## [1541] 0.0 4.0 0.2 2.3 4.0 0.0 0.0 11.4 26.6 6.7 2.3 3.1 11.1 0.0  
## [1555] 0.0 0.0 10.0 1.2 0.0 21.3 20.3 9.8 0.4 0.0 0.0 0.0 16.5 0.0  
## [1569] 10.9 1.8 0.6 0.0 0.0 0.0 9.4 6.0 10.0 3.7 0.0 0.0 0.0 5.4  
## [1583] 0.0 0.0 1.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 4.5 3.1 0.0 0.0  
## [1597] 1.1 0.0 0.0 9.3 10.8 4.3 0.1 1.0 0.0 0.0 0.0 0.0 3.8 29.6  
## [1611] 1.6 1.8 0.2 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [1625] 0.0 0.0 0.0 1.9 4.6 0.0 0.0 0.0 11.0 0.2 0.0 0.0 0.0 0.0  
## [1639] 0.3 0.0 0.0 0.0 1.4 0.0 2.7 12.2 0.0 0.0 0.0 0.0 0.0 0.0  
## [1653] 0.0 0.0 0.0 3.5 0.0 2.6 6.9 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [1667] 0.0 0.0 0.0 4.3 1.5 0.6 5.4 12.4 1.7 0.0 2.7 4.6 0.0 1.5  
## [1681] 0.0 13.8 3.2 5.5 5.2 6.1 0.0 0.0 7.9 10.7 11.6 0.0 0.5 3.2  
## [1695] 2.8 0.0 4.1 5.0 30.1 10.4 4.5 7.3 6.2 0.0 1.3 0.0 0.0 2.1  
## [1709] 15.3 0.0 0.0 0.0 18.2 0.4 3.6 0.0 0.0 27.7 8.3 5.5 0.0 2.7  
## [1723] 1.2 16.2 2.1 4.7 35.4 8.4 15.7 1.1 0.0 0.0 0.6 8.1 7.7 0.0  
## [1737] 1.3 5.5 0.0 1.4 0.0 0.0 0.0 0.2 0.0 0.0 0.0 1.7 6.4 4.6  
## [1751] 2.5 0.3 0.0 2.5 1.4 13.0 1.3 0.0 0.0 0.0 0.0 0.8 0.0 0.0  
## [1765] 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [1779] 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 2.3  
## [1793] 18.2 0.6 8.9 0.2 0.0 0.0 0.0 0.0 5.6 0.0 0.0 0.0 0.0 0.0  
## [1807] 0.0 0.0 0.0 4.8 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 1.5 0.2  
## [1821] 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.3 10.2 1.3 6.7  
## [1835] 0.2 5.6 10.1 0.0 0.0 0.5 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [1849] 0.0 0.0 13.0 0.0 3.7 5.9 7.4 10.0 0.7 0.0 0.0 12.9 0.0 0.0  
## [1863] 0.0 0.5 0.0 0.0 0.0 0.0 0.0 12.2 0.0 0.0 0.0 2.8 0.0 0.0  
## [1877] 0.0 1.8 1.2 0.4 0.1 0.0 16.4 0.0 0.0 0.0 0.0 0.0 0.0 0.9  
## [1891] 0.1 5.7 0.0 0.0 1.4 1.2 5.5 0.0 0.0 3.4 49.0 21.8 2.2 1.3  
## [1905] 0.0 0.0 17.7 0.0 0.0 7.2 0.0 0.0 0.0 0.0 0.0 0.6 15.4 0.0  
## [1919] 0.0 0.0 0.0 0.0 0.0 9.5 10.8 2.8 6.4 6.1 0.0 0.0 24.9 1.3  
## [1933] 13.6 0.0 0.1 1.1 1.6 0.6 25.4 6.4 0.0 0.0 2.7 0.0 0.0 0.0  
## [1947] 1.1 9.4 10.0 5.4 0.0 0.4 14.5 7.6 1.4 1.5 2.3 2.8 4.9 0.0  
## [1961] 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 2.4 3.1 0.0 3.7 3.4 41.5  
## [1975] 13.5 9.2 5.0 0.0 0.0 0.0 0.0 0.0 0.0 4.2 0.0 0.0 0.0 0.0  
## [1989] 0.0 0.0 0.0 2.8 0.2 0.0 13.7 5.7 0.0 1.5 18.6 8.8 0.3 3.2  
## [2003] 0.0 0.4 15.7 0.0 0.0 3.1 0.0 0.0 0.2 25.5 1.8 0.0 0.0 0.0  
## [2017] 0.0 7.5 1.3 0.0 0.0 1.4 9.1 4.6 5.0 0.0 0.0 0.0 8.8 4.4  
## [2031] 0.0 0.0 0.0 0.0 11.4 0.5 0.0 16.0 4.4 1.0 3.5 0.0 0.0 0.0  
## [2045] 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 5.3 0.1 0.0 0.0  
## [2059] 0.0 0.6 2.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [2073] 0.0 0.0 1.4 0.0 0.0 0.0 0.0 0.0 12.9 0.0 0.0 0.0 0.0 1.0  
## [2087] 0.4 0.0 0.0 30.3 0.2 0.0 12.2 0.0 0.0 0.0 0.0 0.0 20.1 5.4  
## [2101] 0.1 3.1 0.7 8.6 4.3 0.0 1.6 0.5 0.0 0.0 0.0 0.0 0.1 41.2  
## [2115] 2.5 1.2 4.6 1.9 0.0 0.0 0.0 0.7 9.5 38.7 19.5 0.1 0.0 0.0  
## [2129] 0.0 0.9 6.3 12.9 4.0 0.0 0.0 5.8 8.8 6.4 6.7 8.1 2.4 0.4  
## [2143] 1.0 3.2 0.3 0.4 0.0 6.2 0.4 17.0 1.7 0.0 0.0 0.3 15.0 0.0  
## [2157] 6.4 4.4 0.0 0.0 0.0 0.1 10.3 0.0 0.0 0.0 0.6 16.0 0.0 0.0  
## [2171] 0.0 0.0 0.0 0.3 0.7 3.1 0.1 30.5 0.1 0.0 0.0 0.1 0.0 0.0  
## [2185] 0.0 0.0 0.0 0.0 0.0 0.0 16.6 1.8 0.0 0.0 0.0 4.0 6.6 0.7  
## [2199] 0.0 2.7 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.2 0.0 4.5 0.8 1.0  
## [2213] 1.1 0.0 0.0 11.5 2.0 0.5 0.4 2.6 0.0 0.0 0.6 0.2 0.0 0.0  
## [2227] 0.0 0.6 0.0 0.0 0.0 0.0 0.0 3.8 1.0 0.0 7.0 4.3 2.2 0.0  
## [2241] 6.4 0.0 4.0 15.4 0.0 0.0 0.6 0.0 0.1 0.0 4.3 1.2 0.0 0.1  
## [2255] 1.8 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.7 4.8 0.4  
## [2269] 0.0 0.0 0.0 4.6 0.0 5.7 0.0 1.4 37.5 2.1 0.1 1.9 0.7 43.5  
## [2283] 0.6 1.9 0.0 2.4 0.0 47.7 52.7 4.9 2.3 1.7 9.4 0.9 0.0 0.4  
## [2297] 0.0 0.0 0.0 5.2 0.0 8.8 11.1 0.1 0.1 32.5 1.0 8.3 0.0 0.5  
## [2311] 8.5 0.2 0.0 0.0 0.3 1.7 1.1 5.8 1.9 0.7 1.9 0.0 0.0 0.3  
## [2325] 0.7 0.0 0.1 0.1 0.4 0.0 7.5 6.1 0.2 0.0 0.0 1.8 0.0 0.0  
## [2339] 0.0 0.4 8.6 1.4 11.6 0.2 0.0 0.0 2.4 0.4 4.5 2.3 8.7 0.0  
## [2353] 0.0 5.3 1.5 8.9 7.8 0.6 0.0 0.0 0.0 0.2 0.7 0.0 0.0 0.0  
## [2367] 5.0 0.0 0.0 0.0 15.2 2.4 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [2381] 0.0 0.0 0.0 0.0 0.7 14.0 33.7 7.1 2.9 20.8 12.0 0.0 0.0 0.0  
## [2395] 0.1 0.0 7.7 14.1 4.6 0.2 0.1 0.0 1.6 2.3 4.2 0.7 0.4 11.3  
## [2409] 0.0 0.0 0.3 0.0 0.1 0.0 0.4 0.0 0.0 0.0 0.0 0.0 0.0 17.9  
## [2423] 16.6 0.1 0.0 0.0 0.0 0.0 0.2 8.0 10.2 3.5 0.0 42.8 11.5 0.6  
## [2437] 4.9 0.0 9.0 27.5 3.6 2.2 0.0 0.0 0.0 0.0 0.0 1.0 7.1 10.2  
## [2451] 0.0 0.0 5.6 4.8 2.6 0.3 1.8 11.1 12.4 0.0 0.0 12.9 3.2 0.0  
## [2465] 0.1 0.2 0.0 0.0 14.6 7.3 0.0 35.2 4.8 3.5 3.7 4.9 16.1 2.8  
## [2479] 27.1 0.2 4.7 0.0 3.9 1.4 0.0 1.4 2.7 5.3 0.2 5.3 6.5 2.8  
## [2493] 12.0 18.5 0.5 0.0 5.5 0.3 14.5 0.6 0.0 1.4 2.0 7.9 3.2 12.5  
## [2507] 10.1 0.1 0.1 0.0 0.0 0.0 0.0 0.1 0.0 0.0 0.0 0.0 0.0 0.0  
## [2521] 0.1 0.0 3.5 0.5 1.0 0.6 0.1 2.1 8.5 20.3 7.9 3.0 6.6 33.2  
## [2535] 4.4 0.0 5.2 0.3 0.0 6.5 1.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [2549] 1.6 5.1 0.0 0.0 1.5 0.0 14.5 8.8 17.2 0.2 11.4 0.5 0.0 1.8  
## [2563] 1.5 0.0 0.4 0.0 8.3 0.2 0.7 0.0 6.0 0.1 0.0 0.0 0.0 0.0  
## [2577] 3.0 3.0 0.0 0.0 5.7 7.0 0.0 0.0 17.2 0.1 0.0 0.0 0.0 0.0  
## [2591] 0.0 0.0 0.0 4.0 15.6 3.0 3.3 0.0 15.5 1.3 9.7 1.0 0.0 0.0  
## [2605] 0.6 4.3 7.2 3.1 11.9 1.0 0.0 9.5 0.0 0.0 0.0 0.0 0.0 1.9  
## [2619] 0.0 0.2 5.5 0.0 0.0 0.0 0.0 6.4 2.8 1.8 6.8 0.0 1.9 0.2  
## [2633] 0.0 0.8 0.0 0.0 0.0 3.1 0.0 0.0 0.0 12.6 5.5 0.0 0.0 0.0  
## [2647] 6.8 0.0 1.9 0.0 0.0 0.6 9.1 0.0 19.9 1.8 9.8 10.4 1.8 3.2  
## [2661] 5.1 1.1 0.0 0.0 0.0 0.0 5.0 0.0 0.0 0.0 0.0 1.6 0.3 13.2  
## [2675] 0.0 1.0 0.0 0.0 0.5 0.4 0.0 0.0 0.0 0.1 5.7 0.5 1.0 0.3  
## [2689] 9.9 2.5 0.1 7.5 11.7 0.0 9.9 9.7 6.6 1.8 0.0 0.0 0.0 0.0  
## [2703] 0.0 0.0 0.0 0.0 0.0 2.9 13.6 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [2717] 0.0 0.0 0.0 2.4 6.4 0.0 0.0 0.0 26.6 7.6 0.0 0.6 0.0 0.8  
## [2731] 0.0 0.0 0.0 0.0 0.0 5.5 0.0 14.1 0.0 1.4 0.0 10.7 0.0 0.0  
## [2745] 0.0 0.0 0.0 0.6 3.0 38.5 4.9 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [2759] 0.0 1.2 1.8 0.6 9.0 0.0 0.4 0.0 4.1 11.1 4.2 0.0 0.0 0.9  
## [2773] 0.0 0.0 0.0 0.0 0.0 2.4 0.0 0.0 0.0 1.2 4.5 18.0 3.3 1.7  
## [2787] 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 1.4 30.5 9.1 1.2 3.3 16.0  
## [2801] 0.2 0.0 4.2 11.4 0.0 0.0 2.1 16.7 0.4 0.0 0.1 0.1 0.0 0.0  
## [2815] 0.2 1.2 0.0 0.0 0.7 15.1 5.4 3.2 0.0 27.9 9.5 0.7 16.6 3.0  
## [2829] 3.2 0.0 22.2 13.6 0.2 2.3 0.3 0.0 16.2 24.3 0.0 0.0 0.0 0.0  
## [2843] 0.0 0.0 0.0 0.0 5.8 9.3 0.0 0.5 0.4 11.6 0.2 0.0 0.0 0.0  
## [2857] 7.1 0.2 7.1 7.4 0.1 1.6 2.1 1.4 0.0 0.0 0.0 0.0 0.0 0.0  
## [2871] 0.0 2.2 46.2 0.0 0.0 6.9 29.3 25.9 0.0 0.0 0.0 0.0 0.0 0.0  
## [2885] 0.3 0.0 0.0 0.0 0.0 0.0 0.0 9.6 14.9 6.7 33.9 5.3 3.0 2.1  
## [2899] 4.8 17.0 0.0 0.0 0.0 0.0 1.2 0.0 0.0 1.6 11.9 0.7 0.0 0.0  
## [2913] 12.7 1.0 0.0 0.0 0.0 0.0 17.8 20.6 5.1 19.4 4.9 8.6 0.0 0.0  
## [2927] 2.8 5.6 0.5 0.0 0.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [2941] 0.0 0.0 0.0 21.8 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [2955] 0.0 0.0 1.4 1.8 0.0 6.3 0.0 1.6 0.0 0.0 0.0 0.0 0.0 0.0  
## [2969] 0.0 0.0 0.0 0.3 0.0 0.0 0.0 2.1 1.6 0.0 0.1 0.0 0.0 0.0  
## [2983] 3.1 0.5 0.0 0.0 7.6 7.8 5.7 0.2 0.0 0.0 0.0 0.0 0.0 0.0  
## [2997] 0.0 0.0 0.0 0.0 5.8 0.6 0.0 0.0 0.0 8.8 0.0 9.5 0.6 12.5  
## [3011] 1.2 0.6 0.0 0.0 0.0 0.0 0.0 0.0 3.0 0.0 0.1 0.0 0.0 8.3  
## [3025] 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 2.0 8.9  
## [3039] 5.0 0.0 6.8 22.1 32.4 2.4 3.3 1.5 0.2 4.9 12.8 1.6 0.0 0.0  
## [3053] 3.2 0.0 0.0 0.0 7.3 29.9 5.8 4.0 0.0 2.0 2.6 0.0 12.8 3.9  
## [3067] 0.0 0.1 0.0 4.1 0.0 9.1 0.0 0.0 2.8 0.3 0.0 7.7 0.0 0.0  
## [3081] 0.0 1.1 0.0 0.0 0.0 0.0 21.7 0.1 0.0 3.2 0.0 0.0 0.0 0.0  
## [3095] 0.0 0.0 0.0 0.0 45.0 0.0 0.0 43.6 3.9 0.8 0.6 0.0 1.4 6.7  
## [3109] 12.8 21.0 3.0 0.0 11.2 19.0 0.5 10.4 6.6 2.8 0.2 0.0 0.0 2.1  
## [3123] 12.1 1.6 0.1 0.0 0.6 13.4 0.4 0.0 0.0 18.1 0.0 3.4 0.4 0.0  
## [3137] 0.0 0.0 0.0 11.5 3.9 0.1 0.0 0.0 16.0 0.0 3.8 2.5 0.0 0.0  
## [3151] 0.0 0.0 0.5 0.4 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [3165] 0.0 4.0 1.5 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.1 0.0 0.0 0.0  
## [3179] 10.4 0.0 0.0 0.0 0.0 0.3 2.5 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [3193] 0.0 0.0 8.6 0.0 11.9 0.2 6.9 0.0 0.0 0.0 0.3 0.0 0.1 13.0  
## [3207] 0.6 0.0 2.6 3.1 0.0 0.0 0.0 0.0 0.0 0.1 26.1 0.0 0.0 0.0  
## [3221] 11.0 3.1 8.1 2.4 0.0 2.2 4.0 3.7 0.3 0.0 0.0 0.0 0.1 10.2  
## [3235] 10.8 0.2 0.0 1.2 15.8 0.7 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [3249] 0.0 11.4 0.0 3.2 0.2 0.1 0.0 54.8 8.2 5.6 0.1 0.0 0.0 0.0  
## [3263] 0.0 15.2 2.1 0.0 0.0 0.0 21.4 3.3 1.2 4.4 33.0 4.3 0.7 0.7  
## [3277] 0.0 0.0 34.4 0.0 2.2 3.0 0.0 0.0 0.0 0.0 0.3 0.0 0.0 2.1  
## [3291] 0.0 0.0 0.0 6.0 0.0 1.4 0.0 0.0 0.0 0.0 15.2 46.4 0.0 3.6  
## [3305] 1.7 0.9 6.0 0.0 0.0 0.0 7.5 0.0 0.0 0.0 0.0 3.2 0.0 0.0  
## [3319] 2.8 3.4 0.0 6.9 0.0 0.0 0.4 0.0 0.0 0.0 3.2 4.0 2.9 0.0  
## [3333] 3.8 0.1 0.8 0.0 1.7 0.0 0.0 0.1 0.0 0.0 0.0 0.6 0.0 8.1  
## [3347] 11.9 0.4 0.0 0.0 0.3 9.3 0.0 0.6 0.2 0.0 11.2 10.4 10.8 0.1  
## [3361] 0.0 0.4 0.0 1.8 0.5 0.4 0.0 0.0 0.0 0.0 0.6 0.0 0.8 21.6  
## [3375] 28.1 8.5 0.2 0.0 4.7 4.1 0.0 0.0 0.0 0.0 0.0 0.0 9.7 0.1  
## [3389] 0.7 0.0 2.5 6.5 28.4 5.6 0.0 0.0 1.9 0.0 0.0 0.0 12.7 1.7  
## [3403] 1.3 0.0 0.0 0.0 0.0 0.0 0.0 30.5 0.6 0.5 0.0 0.1 0.0 0.0  
## [3417] 0.0 0.7 0.0 0.0 1.4 0.0 0.0 0.0 0.0 0.0 0.0 0.0 21.7 9.9  
## [3431] 0.0 0.0 0.0 0.0 1.3 0.2 0.0 0.0 43.7 11.5 6.3 0.0 0.0 0.0  
## [3445] 0.0 1.5 8.9 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 1.5 7.4  
## [3459] 0.0 0.0 0.0 0.0 0.0 6.9 0.0 22.6 0.4 9.6 0.0 0.0 0.0 0.0  
## [3473] 14.5 16.2 0.0 8.7 0.0 6.9 0.0 8.6 0.7 0.0 0.0 0.0 0.0 0.0  
## [3487] 13.3 0.9 0.0 0.0 0.0 0.0 0.0 1.0 0.0 0.0 3.9 3.0 0.0 0.0  
## [3501] 0.0 0.0 1.4 0.0 0.0 0.0 0.0 1.9 0.1 11.1 0.9 4.0 0.0 1.1  
## [3515] 2.1 0.8 0.0 9.8 0.0 0.0 1.0 0.0 0.0 0.0 0.0 0.0 47.6 0.0  
## [3529] 0.0 27.6 15.3 0.0 0.0 0.0 18.7 2.8 0.0 2.2 9.3 2.2 2.0 15.2  
## [3543] 0.5 0.0 0.0 0.0 0.0 0.5 3.0 0.0 0.0 0.0 0.0 0.0 0.0 2.4  
## [3557] 32.8 27.8 5.3 0.0 17.6 11.0 2.4 1.4 0.1 1.4 2.2 5.9 10.0 16.6  
## [3571] 0.0 0.0 18.9 12.9 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 9.5 12.2  
## [3585] 14.3 12.4 0.1 0.0 0.0 13.0 0.0 8.1 1.1 0.5 0.0 0.0 0.0 0.0  
## [3599] 0.7 13.2 0.9 0.0 9.7 0.0 14.6 5.0 0.2 5.4 0.0 13.7 15.5 12.5  
## [3613] 0.0 4.1 0.0 0.0 0.0 15.6 0.0 0.0 0.0 0.0 10.1 2.7 3.6 1.1  
## [3627] 0.0 19.4 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [3641] 23.3 13.1 6.2 12.8 0.0 3.4 0.0 0.0 0.0 5.4 0.0 0.0 0.0 0.5  
## [3655] 0.0 0.0 0.0 0.0 0.0 21.4 1.9 8.8 3.2 6.3 1.9 0.0 0.0 19.4  
## [3669] 0.0 0.9 3.9 3.1 0.9 12.0 1.5 2.1 0.0 0.0 0.0 0.0 0.0 0.0  
## [3683] 19.9 6.9 0.0 7.1 5.2 0.1 4.9 1.6 0.0 0.0 3.9 0.0 20.8 11.9  
## [3697] 0.2 0.0 0.0 0.0 0.0 0.1 0.0 0.0 1.0 10.1 13.8 5.1 0.0 0.3  
## [3711] 0.0 0.0 0.0 0.0 0.0 0.0 1.4 1.6 0.0 0.0 0.0 0.0 2.0 9.5  
## [3725] 0.6 0.0 0.0 0.1 11.8 0.0 0.1 0.0 3.1 1.0 0.0 0.0 1.8 0.0  
## [3739] 0.0 0.4 0.0 0.0 0.0 2.4 0.0 1.0 6.7 5.0 0.0 0.1 0.3 0.0  
## [3753] 0.0 28.1 0.0 21.6 0.0 8.6 37.9 6.0 0.3 0.0 13.2 0.2 0.0 0.0  
## [3767] 0.0 0.1 6.7 11.0 0.0 0.0 0.0 0.1 0.0 1.8 5.1 0.0 3.9 6.7  
## [3781] 9.3 12.8 3.8 0.0 29.6 2.5 0.0 2.7 0.8 4.1 0.0 0.0 0.0 1.0  
## [3795] 2.8 5.2 5.6 0.0 1.7 2.1 5.7 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [3809] 0.0 0.0 0.0 0.0 2.8 0.0 0.0 0.0 9.1 42.2 18.0 0.0 0.0 0.0  
## [3823] 0.0 0.9 0.2 0.0 0.0 4.9 0.0 0.0 0.0 0.0 0.0 0.0 0.6 0.0  
## [3837] 1.5 2.9 13.5 0.0 0.0 27.8 15.2 0.0 0.0 3.7 0.0 0.0 0.0 0.0  
## [3851] 6.4 53.7 17.0 1.6 0.0 0.1 3.0 18.5 2.9 0.0 0.0 0.3 0.0 8.5  
## [3865] 0.1 0.0 0.7 9.8 9.6 7.0 0.0 0.0 7.5 21.6 5.1 0.0 6.3 27.0  
## [3879] 15.0 0.0 0.2 0.7 0.0 0.0 0.0 0.0 0.0 0.0 0.0 17.7 0.4 8.6  
## [3893] 0.0 4.9 0.0 0.1 0.0 0.0 0.0 0.0 0.0 10.2 1.2 2.4 0.1 0.0  
## [3907] 0.0 0.0 0.0 11.0 0.0 0.7 7.1 0.8 0.0 0.0 3.6 0.2 0.0 0.0  
## [3921] 0.0 0.0 0.0 0.3 5.1 1.2 4.5 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [3935] 0.0 0.0 0.1 0.5 21.3 3.2 3.5 2.4 3.9 0.0 0.0 0.0 0.0 0.0  
## [3949] 0.0 0.0 1.0 0.0 0.0 0.0 0.0 25.6 0.9 0.0 0.0 2.8 0.0 11.3  
## [3963] 1.4 0.0 0.0 0.0 4.5 0.3 0.0 0.0 0.0 1.7 0.0 0.0 11.7 0.0  
## [3977] 13.3 20.1 0.0 0.0 0.0 2.7 1.6 0.0 0.0 0.0 0.0 0.0 0.0 14.4  
## [3991] 2.4 0.0 0.8 13.2 0.0 0.0 0.2 0.0 2.3 11.3 23.2 1.2 2.1 0.4  
## [4005] 4.2 18.5 6.0 5.3 1.8 8.8 0.3 0.0 0.0 0.0 0.0 0.0 6.5 5.9  
## [4019] 1.7 2.5 0.0 0.0 1.8 0.0 0.0 0.1 1.9 0.0 0.0 0.0 1.4 0.0  
## [4033] 0.0 0.0 0.0 3.7 0.0 0.0 0.0 0.0 1.1 0.0 1.8 0.8 0.0 4.1  
## [4047] 0.0 0.0 0.0 0.0 0.0 7.8 0.0 0.0 0.0 0.8 3.7 0.0 0.9 0.0  
## [4061] 0.0 0.0 0.0 16.0 1.1 0.0 0.0 0.0 0.8 39.4 0.0 0.0 0.3 12.1  
## [4075] 46.6 13.0 0.0 0.1 0.0 9.3 0.0 0.0 0.9 0.0 0.0 0.0 0.0 0.0  
## [4089] 0.0 2.6 8.2 0.0 2.5 1.5 2.1 0.0 0.9 0.1 0.0 0.0 5.4 0.0  
## [4103] 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.6 0.0 0.0 0.0 0.0 5.7 10.0  
## [4117] 0.0 2.9 2.8 0.0 0.0 0.0 0.0 0.0 0.0 0.5 0.0 0.0 0.1 2.3  
## [4131] 0.0 0.0 0.0 0.2 7.7 0.0 0.0 0.0 9.3 11.9 0.6 1.0 0.5 0.0  
## [4145] 0.0 0.0 0.0 0.0 0.0 1.4 0.0 0.0 0.0 15.6 17.5 6.1 2.5 1.8  
## [4159] 0.0 1.1 6.4 6.3 0.0 0.0 0.0 2.0 0.0 2.7 4.9 0.2 0.0 0.0  
## [4173] 6.1 0.0 0.0 0.0 0.8 0.0 1.8 4.1 0.2 0.0 0.0 0.2 0.0 12.0  
## [4187] 15.0 0.0 0.0 13.9 0.0 0.0 0.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [4201] 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 35.2 4.5 13.6 0.0 1.5  
## [4215] 15.3 2.3 7.9 1.6 0.0 0.0 24.6 20.1 13.5 0.1 2.1 0.0 0.0 0.0  
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## [4243] 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [4257] 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 5.5 0.0 0.5 0.1 6.6 1.6  
## [4271] 1.5 0.0 11.9 0.1 0.0 0.0 0.0 18.3 17.1 3.2 3.5 7.0 2.0 0.2  
## [4285] 0.0 5.1 11.2 1.2 0.0 0.0 0.0 3.1 0.0 0.0 0.0 0.0 0.0 0.0  
## [4299] 0.0 0.3 1.8 9.3 0.2 0.0 0.0 0.0 5.9 2.1 0.1 0.4 0.0 0.1  
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## [4327] 0.0 4.1 0.8 17.7 11.8 2.0 4.9 0.3 0.0 0.2 7.7 0.0 0.0 0.0  
## [4341] 19.7 1.0 0.2 26.3 8.0 11.1 0.6 0.2 5.8 0.0 0.0 17.3 1.4 0.0  
## [4355] 0.0 0.5 7.4 2.2 0.0 21.0 20.6 14.2 10.0 0.0 0.0 3.8 2.6 0.0  
## [4369] 0.0 0.0 0.0 0.0 2.3 0.0 0.0 0.0 0.0 10.9 1.5 17.4 11.2 8.0  
## [4383] 12.8 59.2 0.0 0.0 0.0 0.0 0.0 0.0 4.4 0.0 2.0 0.0 3.7 0.2  
## [4397] 0.0 0.0 0.1 17.9 33.1 9.1 4.1 3.9 1.1 2.2 1.2 0.0 0.0 10.4  
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## [4425] 0.0 0.0 0.2 0.0 0.0 2.1 4.0 16.8 0.5 8.9 0.6 0.0 0.0 14.8  
## [4439] 5.4 0.2 2.2 2.6 0.0 0.0 6.8 1.5 1.8 0.2 1.9 1.2 7.8 1.7  
## [4453] 6.0 3.0 2.0 35.2 1.0 0.0 0.0 0.0 0.0 0.0 8.9 0.7 0.0 0.8  
## [4467] 0.0 0.0 0.0 0.0 4.0 0.0 0.0 0.0 2.2 4.0 1.2 0.0 0.0 0.0  
## [4481] 0.0 31.6 61.6 6.8 2.0 2.6 0.0 0.1 4.3 0.0 0.6 5.8 0.0 0.0  
## [4495] 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.5 0.0 0.0  
## [4509] 0.0 0.0 0.0 7.7 1.9 0.3 0.0 0.0 0.0 2.1 1.0 0.0 4.3 5.4  
## [4523] 6.6 0.6 2.2 0.0 0.0 0.0 3.3 0.0 2.9 0.0 0.0 13.6 0.0 0.0  
## [4537] 0.0 0.0 0.2 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.1 20.7 1.5  
## [4551] 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [4565] 0.0 10.0 1.0 2.5 0.0 0.6 0.3 0.0 0.0 0.8 0.0 2.3 4.6 0.0  
## [4579] 9.9 0.0 0.0 0.0 22.1 7.4 3.6 8.7 0.8 0.3 0.0 2.0 5.4 7.0  
## [4593] 8.5 1.1 1.8 0.0 0.0 0.0 0.0 14.3 0.3 0.0 0.0 0.0 5.0 6.8  
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## [4621] 3.0 0.7 1.9 4.9 7.5 6.3 16.8 7.5 0.0 4.7 6.8 0.0 0.2 1.7  
## [4635] 2.4 7.1 14.4 7.7 1.5 0.0 0.0 0.4 2.7 19.2 0.4 0.0 0.0 0.0  
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## [4677] 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 9.9 3.0 0.0 1.5 1.6  
## [4691] 0.1 0.0 0.0 19.4 1.3 0.0 0.0 2.9 9.4 11.8 0.0 0.0 0.0 0.0  
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## [4719] 5.8 0.0 0.0 0.0 5.7 21.7 0.0 0.0 0.0 0.0 0.0 0.0 0.1 0.8  
## [4733] 0.4 1.1 0.0 0.0 0.0 13.7 3.5 0.1 4.1 0.0 5.9 11.8 3.6 0.5  
## [4747] 0.7 0.5 0.0 0.0 0.0 0.0 0.0 0.6 0.0 0.0 0.0 8.6 0.0 9.3  
## [4761] 3.4 0.8 0.0 0.0 0.0 0.0 0.0 1.5 0.0 0.0 0.0 8.0 0.0 0.0  
## [4775] 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 6.5 0.0 0.0 0.1 1.4 0.0  
## [4789] 2.1 0.1 0.9 0.2 1.8 14.5 11.2 14.3 0.0 0.1 0.0 0.0 6.2 0.0  
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## [5209] 0.0 0.0 0.0 0.7 0.0 0.0 0.0 7.5 0.0 0.0 0.0 1.5 0.7 0.2  
## [5223] 17.4 3.8 0.0 0.0 34.7 1.9 1.2 0.4 2.4 0.0 0.0 6.4 0.2 7.1  
## [5237] 0.0 5.3 0.0 2.6 0.0 0.0 0.0 0.0 0.1 16.8 12.9 0.4 5.7 22.7  
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## [5307] 0.0 0.0 0.0 0.1 0.0 0.0 1.9 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [5321] 17.2 0.1 0.0 0.0 0.0 3.3 16.9 22.1 3.1 2.0 7.8 0.1 0.0 0.0  
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## [5377] 0.0 3.1 5.4 1.9 0.0 0.0 0.0 0.0 0.0 0.0 0.0 22.8 1.4 0.0  
## [5391] 0.0 3.5 0.0 2.9 0.0 0.0 0.6 14.0 11.3 0.0 0.0 0.0 0.0 0.0  
## [5405] 0.0 1.4 11.0 22.2 0.0 0.0 0.0 6.7 0.0 0.0 3.9 25.5 0.0 0.0  
## [5419] 0.0 14.5 0.2 0.0 0.0 21.0 0.0 0.0 0.0 0.0 11.2 0.0 10.7 0.7  
## [5433] 1.7 2.1 0.0 0.0 2.6 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
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## [5461] 0.0 0.0 0.6 2.9 5.4 0.6 10.9 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
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## [5503] 0.0 0.0 0.0 0.0 0.0 10.7 0.0 4.3 0.0 0.0 0.0 0.3 12.7 1.3  
## [5517] 0.0 0.0 0.0 6.7 9.9 3.9 1.6 9.8 0.0 12.5 16.8 5.1 4.2 0.0  
## [5531] 14.0 0.7 0.0 0.0 0.0 6.8 3.3 35.7 21.7 0.7 5.2 0.0 0.0 0.0  
## [5545] 0.1 22.2 0.0 2.5 18.1 0.0 0.0 11.6 0.0 7.7 0.0 0.0 0.0 0.6  
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## [5573] 0.0 0.0 4.4 0.0 19.7 9.9 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [5587] 0.0 0.0 0.0 0.0 0.0 0.0 0.6 12.2 0.0 2.6 0.0 0.0 0.0 0.0  
## [5601] 0.0 0.0 0.0 0.0 14.2 0.1 0.0 0.0 0.0 27.3 0.6 0.0 6.3 1.3  
## [5615] 0.0 5.3 9.6 11.9 1.2 7.8 0.0 0.0 2.8 0.0 0.0 23.1 35.6 7.1  
## [5629] 1.3 0.0 2.0 0.0 0.9 0.0 0.0 0.0 4.8 0.4 5.6 1.1 0.0 0.0  
## [5643] 0.0 0.0 0.0 0.0 4.6 8.1 0.0 0.0 0.0 0.0 2.3 1.7 1.3 0.0  
## [5657] 0.9 5.0 0.0 0.3 0.0 0.0 0.0 0.0 0.9 3.2 1.4 0.0 0.0 0.0  
## [5671] 29.9 6.7 0.0 0.0 0.0 0.0 0.0 0.0 1.5 20.8 0.0 0.0 0.0 0.9  
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## [5699] 0.0 0.0 0.0 0.0 0.0 13.7 4.1 13.0 12.5 23.0 7.1 13.1 0.9 0.1  
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## [5755] 3.5 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 3.9 0.0 3.2 0.0  
## [5769] 0.0 0.0 0.0 0.0 3.8 1.2 0.0 0.0 0.0 8.2 0.0 0.0 0.0 0.0  
## [5783] 0.0 0.0 0.2 2.9 0.2 0.0 0.0 0.0 0.0 0.0 7.8 0.0 30.3 2.1  
## [5797] 10.7 0.9 0.0 0.0 0.0 0.0 0.0 5.1 5.4 15.4 0.5 10.2 2.7 0.2  
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## [5867] 0.0 0.0 0.0 18.3 14.7 0.0 0.0 0.0 0.0 0.0 0.0 13.7 30.2 3.3  
## [5881] 3.4 3.5 21.1 0.2 0.0 0.0 0.0 0.0 4.3 4.2 10.2 0.3 0.2 0.0  
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## [6007] 0.0 0.0 0.0 1.7 13.0 2.8 0.0 0.0 0.0 0.0 0.0 0.0 4.3 0.5  
## [6021] 0.0 14.5 1.5 7.1 4.4 0.0 0.0 0.0 0.0 0.0 0.3 0.0 0.0 0.0  
## [6035] 3.4 0.0 0.0 0.0 0.0 0.1 0.0 0.0 0.0 0.0 0.0 0.2 7.2 23.9  
## [6049] 0.1 1.2 3.3 1.5 0.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.8  
## [6063] 0.8 1.1 6.9 1.0 10.6 6.1 1.5 0.0 0.0 14.2 2.0 0.0 0.0 0.0  
## [6077] 0.0 0.0 54.2 1.2 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [6091] 0.8 17.8 4.5 2.3 0.0 0.0 0.0 0.0 0.0 0.0 2.1 0.0 0.0 0.0  
## [6105] 2.6 29.5 1.6 44.4 5.3 0.4 0.2 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
## [6119] 0.0 0.0 0.0 0.0 0.0 2.4 0.0 0.0 0.0 9.1 0.7 0.0 0.0 0.0  
## [6133] 5.3 22.5 2.9 0.0 5.6 4.6 6.0 0.0 0.0 18.3 10.5 6.1 1.0 0.0  
## [6147] 0.0 0.0 0.0 0.0 0.4 13.5 15.0 1.6 6.8 1.6 0.0 0.0 2.7 1.2  
## [6161] 0.0 0.0 0.0 2.0 0.2 2.0 0.0 0.0 0.0 16.8 1.7 0.0 0.0 0.0  
## [6175] 5.3 4.5 1.6 0.0 2.5 0.0 0.0 1.3 1.7 49.6 1.7 3.2 4.7 3.8  
## [6189] 17.3 3.8 0.9 30.8 0.6 4.0 11.3 4.7 5.6 4.3 2.7 0.2 0.0 0.0  
## [6203] 0.9 8.0 3.8 6.7 14.0 0.1 0.0 3.9 25.0 0.8 5.7 0.0 2.6 3.1  
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## [6245] 0.0 0.0 0.0 0.0 4.6 0.4 4.7 18.4 1.0 2.2 0.0 0.0 12.1 5.9  
## [6259] 0.1 0.0 3.8 0.6 0.0 0.0 15.2 1.2 1.3 0.5 4.9 4.0 0.0 0.0  
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## [6287] 0.5 6.0 0.0 0.0 0.0 1.0 0.0 0.7 0.0 0.0 0.0 1.8 0.0 0.0  
## [6301] 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 5.9 33.1 0.4 0.0  
## [6315] 0.5 0.0 4.7 19.5 0.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
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## [6525] 0.0 7.4 2.1 0.0 0.0 23.7 5.2 0.0 9.2 1.3 0.0 3.9 6.2 0.0  
## [6539] 20.7 19.2 2.3 0.0 0.0 14.1 0.0 10.7 18.6 2.7 0.2 0.0 0.0 0.0  
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## [6595] 4.8 4.0 0.0 5.0 0.9 31.9 9.7 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
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## [6623] 11.5 0.0 0.0 6.2 0.1 7.0 0.4 0.0 6.6 5.8 0.0 0.0 0.0 0.0  
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## [6735] 0.0 0.0 0.0 0.0 0.0 1.7 0.0 0.0 0.0 0.0 14.6 9.1 4.9 0.7  
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## [6777] 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.4 1.3  
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## [6805] 12.6 16.7 0.0 31.2 15.0 0.0 0.3 0.0 0.0 0.0 0.0 0.0 0.0 13.0  
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## [6931] 0.0 0.0 5.0 0.0 7.2 4.7 0.0 6.1 7.2 0.0 0.0 0.0 0.0 0.2  
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## [6987] 3.0 0.0 0.0 0.0 0.0 1.2 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0  
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## [7631] 0.0 0.0 15.3 21.6 3.4 3.9 0.0 0.0 0.0 0.0 0.0 0.0 1.0 31.0  
## [7645] 5.5 0.0 0.0 5.2 0.0 0.0 0.0 0.0 0.0 0.0 29.8 0.0 0.0 1.3  
## [7659] 1.5 0.0 0.0 0.0 1.8 12.6 0.0 0.0 2.9 4.8 0.0 0.0 0.0 0.0  
## [7673] 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 2.0 5.1 0.0 0.0  
## [7687] 0.0 2.3 0.0 0.0 0.0 0.0 55.8 43.9 0.0 0.0 0.0 0.0 0.0 4.4  
## [7701] 0.0 5.7 20.9 0.2 0.0 0.0 0.0 0.0 0.0 0.0 0.0 1.7 0.0 2.8  
## [7715] 0.1 0.0 0.0 0.0 0.0 23.4 2.0 0.0 1.6 0.5 0.0 0.0 0.0 0.5  
## [7729] 0.0 0.0 6.4 0.0 0.0 0.0 0.0 0.0 0.7 0.0 0.0 0.0 0.0 0.0  
## [7743] 0.0 0.0 0.0 0.0 0.0 0.0 0.0 28.7 2.7 0.0 0.0 0.0 5.9 6.3  
## [7757] 0.0 1.1 14.6 0.0 28.1 0.2 3.1 14.6 7.6 4.7 8.0 0.2 1.4 0.3  
## [7771] 1.7 0.0 0.0 0.0 0.0 3.4 12.5 9.4 6.1 0.0 0.0 1.2 4.4 10.2  
## [7785] 18.0 0.6 2.4 0.0 1.5 1.3 1.1 0.0 0.0 0.0 3.6 11.1 10.1 8.0  
## [7799] 5.6 0.2 8.3 3.9 5.0 2.0 0.0 0.4 0.0 0.0 0.0 0.0 1.7 0.0  
## [7813] 6.1 6.6 0.0 0.2 0.6 0.0 0.0  
##   
## attr(,"class")  
## [1] "gpd.fit"

nu\_hat <- gpd\_fit$mle[2]  
beta\_hat <- gpd\_fit$mle[1]  
p\_exceed <- mean(df$precip > th, na.rm=TRUE)  
return\_level\_pot <- function(T\_years){  
 p\_annual <- 1/(T\_years\*365)  
 if(abs(nu\_hat) < 1e-6){  
 z <- th + beta\_hat \* log(p\_exceed / p\_annual)  
 } else {  
 z <- th + (beta\_hat/nu\_hat) \* ( (p\_exceed / p\_annual)^{nu\_hat} - 1 )  
 }  
 return(z)  
}  
cat('Approx 10-year return level (precip):', return\_level\_pot(10), '\n')

## Approx 10-year return level (precip): 71.34499

threshold95 <- quantile(df$precip, 0.95, na.rm=TRUE) # 5 Declustering

### Methodology

Use a simple runs declustering: within runs of consecutive exceedances keep only the maximum value. This reduces temporal dependence of peaks prior to tail modeling.

### Results / Comments

knitr::kable(gpd\_fit, caption = ‘GPD fit summary’)

decluster\_runs <- function(dates, series, threshold, run\_length\_days = 3){  
 idx\_exceed <- which(series > threshold)  
 if(length(idx\_exceed)==0) return(integer(0))  
 groups <- cumsum(c(1, diff(idx\_exceed) > run\_length\_days))  
 keep\_idx <- tapply(idx\_exceed, groups, function(idxs) idxs[which.max(series[idxs])])  
 return(as.integer(unlist(keep\_idx)))  
}  
kept <- decluster\_runs(df$date, df$precip, th, run\_length\_days = 2)  
cat('After declustering (run=2 days) kept exceedances:', length(kept), '\n')

## After declustering (run=2 days) kept exceedances: 342

# 6 Tail dependence and scatter

### Methodology

Compute the empirical conditional probability P(discharge>q\_d | precip>q\_p) at high quantiles (95%) and display a scatter of top quantiles.

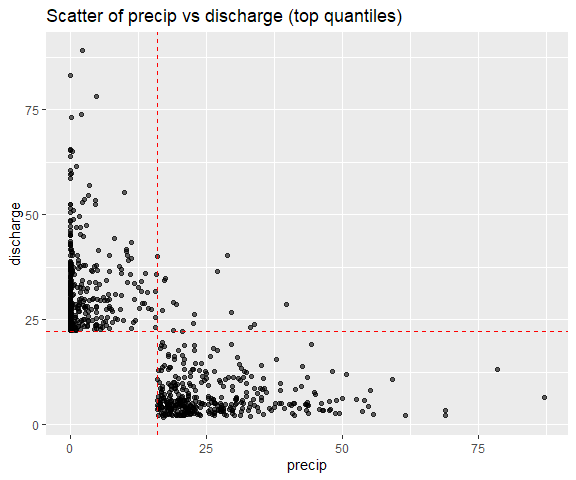
### Results / Comments

This measure gives a quick, empirical look at tail association between high precipitation and high discharge on the same day.

q\_p <- quantile(df$precip, 0.95, na.rm=TRUE)  
q\_d <- quantile(df$discharge, 0.95, na.rm=TRUE)  
cond\_prob <- mean(df$discharge > q\_d & df$precip > q\_p, na.rm=TRUE) / mean(df$precip > q\_p, na.rm=TRUE)  
cat('Empirical P(discharge>q\_d | precip>q\_p) at 95% quantiles:', cond\_prob, '\n')

## Empirical P(discharge>q\_d | precip>q\_p) at 95% quantiles: 0.03836317

top\_df <- df %>% filter(precip > q\_p | discharge > q\_d)  
print(ggplot(top\_df, aes(x=precip, y=discharge)) + geom\_point(alpha=0.6) +  
 geom\_hline(yintercept = q\_d, color='red', linetype='dashed') +  
 geom\_vline(xintercept = q\_p, color='red', linetype='dashed') +  
 labs(title='Scatter of precip vs discharge (top quantiles)'))



# 7 Extreme causality tests

### Methodology

Source JuroExtremes.R and run the provided Extreme\_causality\_test for several future lags in both directions (precip→discharge and discharge→precip). We use bootstrap repetitions for stability.

### Results / Comments

The causality test outputs indicate whether extreme precipitation precedes extreme discharge at the tested lags. Results are printed below.

helpers\_path <- file.path('practical\_1','JuroExtremes.R')  
if(file.exists(helpers\_path)){  
 source(helpers\_path)  
} else stop('JuroExtremes.R not found')  
  
common\_idx <- which(!is.na(df$discharge) & !is.na(df$precip))  
xseries <- df$precip[common\_idx]  
yseries <- df$discharge[common\_idx]  
  
res\_list <- list()  
for(lag\_f in 0:3){  
 res <- Extreme\_causality\_test(xseries, yseries, z = NULL, lag\_future = lag\_f, p\_value\_computation = FALSE, bootstrap\_repetitions = 100)  
 res\_list[[as.character(lag\_f)]] <- res  
 cat('Lag', lag\_f, ':', as.character(res$output), 'CTC=', res$CTC, 'baseline=', res$baseline, '\n')  
}

## Lag 0 : No causality CTC= 0.5188186 baseline= 0.3215919   
## Lag 1 : No causality CTC= 0.4792721 baseline= 0.2583037   
## Lag 2 : Evidence of causality CTC= 0.8267955 baseline= 0.3338323   
## Lag 3 : Evidence of causality CTC= 0.8771856 baseline= 0.3926592

res\_rev <- list()  
for(lag\_f in 0:3){  
 res2 <- Extreme\_causality\_test(yseries, xseries, z = NULL, lag\_future = lag\_f, p\_value\_computation = FALSE, bootstrap\_repetitions = 100)  
 res\_rev[[as.character(lag\_f)]] <- res2  
 cat('Reverse Lag', lag\_f, ':', as.character(res2$output), '\n')  
}

## Reverse Lag 0 : No causality   
## Reverse Lag 1 : No causality   
## Reverse Lag 2 : No causality   
## Reverse Lag 3 : No causality

saveRDS(list(gev\_fit=gev\_fit, gpd\_fit=gpd\_fit, causality\_precip\_to\_discharge = res\_list, causality\_rev = res\_rev), file = file.path('practical\_1','practical1\_results.rds'))

# Takeaways

* Discharge annual maxima were modeled with a GEV; model parameters and a 100-year return level are reported above.
* Precipitation extremes (POT) were modeled with a GPD using the 95% quantile as threshold; an approximate 10-year return level is provided.
* Declustering reduces clusters of exceedances; the retained exceedances are used for inference.
* Empirical tail-dependence at 95% shows a small conditional probability that large precip coincides with large discharge in the same day.
* The provided extreme-causality test suggests evidence of causality from precipitation to discharge at some positive lags (see outputs); the reverse direction showed no causality in this analysis.

# Rendering to PDF

This RMarkdown is set to produce a PDF via the pdflatex engine. To knit to PDF from R you can run:

rmarkdown::render('practical\_1/Practical1\_report.Rmd', output\_format = 'pdf\_document')

Note: producing PDF requires a working LaTeX installation (MiKTeX, TeX Live, MacTeX). A convenient lightweight option inside R is to install TinyTeX:

if(!requireNamespace('tinytex', quietly = TRUE)) install.packages('tinytex')  
tinytex::install\_tinytex()

If LaTeX is not available, you can render HTML instead and convert to PDF later (or use the RStudio knit button which often helps resolve path issues):

# Format results into a tidy table for presentation  
format\_res <- function(res\_list, direction\_label){  
 do.call(rbind, lapply(names(res\_list), function(lag){  
 r <- res\_list[[lag]]  
 data.frame(  
 lag = as.integer(lag),  
 direction = direction\_label,  
 outcome = as.character(r$output),  
 CTC = round(r$CTC, 4),  
 baseline = round(r$baseline, 4),  
 stringsAsFactors = FALSE  
 )  
 }))  
}  
rmarkdown::render('practical\_1/Practical1\_report.Rmd', output\_format = 'html\_document')

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## Appendix A — Full model objects and raw POT data

The full gpd\_fit object (including $data, $vals and $xdata) and other internal objects are saved in practical\_1/practical1\_results.rds. If you need to inspect the raw output, load the RDS file in R and print the components. Example:

# full <- readRDS('practical\_1/practical1\_results.rds')  
# print(full$gpd\_fit)  
# str(full$gpd\_fit)