Design Life Level

quantifying risk in a changing climate

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In the past the concepts of return levels and return periods have been standard and important tools for engineering design

They do not apply to a changing climate, whether local or global

In a nonstationary climate the basic information needed for engineering design is

(i) the design life period (e.g. the next 50 years, say 2017-2066) and

(ii) the probability (e.g., 5% chance) of a hazardous event (typically in the form of the hydrological variable exceeding a high level)

The *Design Life Level* is defined as an upper quantile (e.g. 5%) of the distribution of the maximum value of the hydrological variable (e.g. water level) over the design life period.

The concept *Design Life Level* is general: it is not tied to any specific method, say statistical or GCM based way to calculate it, and it is equally useful for independent and dependent extremes

Hypothetical example: flooding of a dike

The distribution of the highest water level at the dike during year t is assumed to follow a generalized extreme value cdf

$$G_t(x) = e^{-\left(1+\xi_t \frac{x-\mu_t}{\sigma_t}\right)^{-1/\xi_t}} \quad \text{for } 1 + \xi_t \frac{x-\mu_t}{\sigma_t} > 0$$

with

$$\mu_t = 1 + 0.002t, \qquad \sigma_t = 1 + 0.0002t$$

- 0.2% increase in mean per year – could e.g. be caused by an increase in mean water level
- 0.2% increase in scale per year – could e.g. be caused by climat becoming more variable

Results for hypothetical example

Design Life	Prob.	Design Life Level	Return Level (2015 climate)
2015-2064	0.05	11.5	10.9
2015-2064	0.01	15.2	14.4
2065-2114	0.05	12.6	10.9
2065-2114	0.01	16.6	14.4

Return levels are for $T = 975$ and $T = 4975$, respectively.

e.g. the 5% design life level for 2015-2064 is 11.5

- Technical quantification/communication:

  "the 2015-2064 5 % highest water level is 11.5 m"

- Communication with the public:

  "there is a 1 in 20 risk that the biggest flood during 2015-2064 will be higher than 11.5 m"

Results for hypothetical example, cnt.

Design Life	Prob.	Design Life Level	Return Level *(2015 climate)*	EWT	EWT *(trend stopped)*
2015-2064	0.05	11.5	10.9	251	788
2015-2064	0.01	15.2	14.4	431	3839
2065-2114	0.05	12.6	10.9	262	1008
2065-2114	0.01	16.6	14.4	453	5002

EWT is expected waiting time until first exceedance of the design life level

Expected waiting times make sense also in a non-stationary climate – but they are dramatically changed if one changes assumptions about what happens after the design life period

Complementary concepts

The *p% Minimax Design Life Level* is defined to be the level for which the maximal probability of exceedance in any one of the years in the design life period is at most p%

- Technical quantification/communication:

  "the 2015-2064 0.1% bounded yearly risk highest water level is 12.0 m"

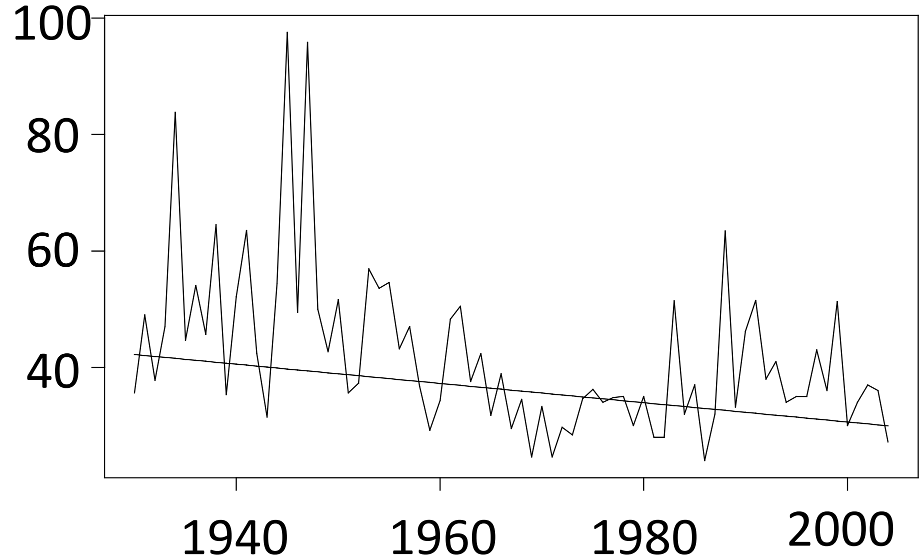
- Communication with the public:

  "the risk that there will be a bigger flood than 12.0 m is less than 1 in 1000 for each year in the time period 2015-2064"

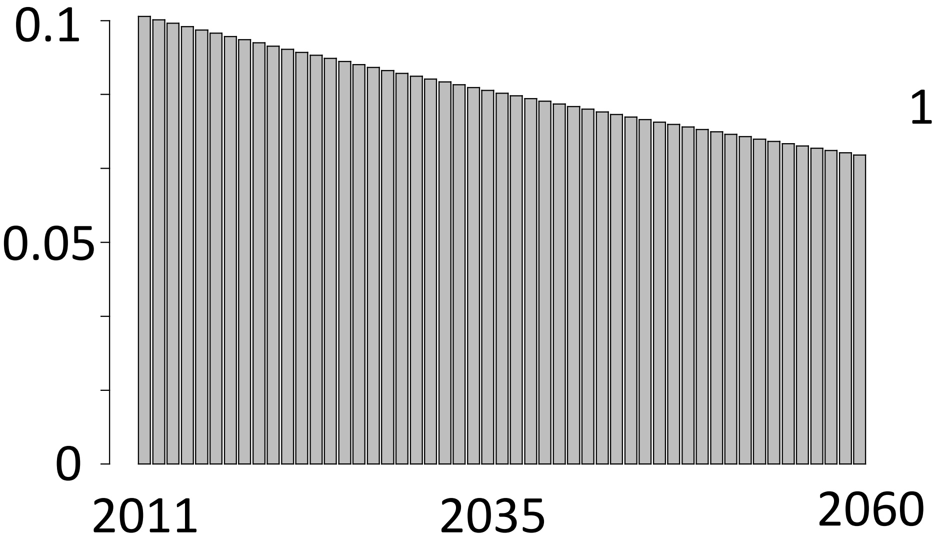
The *Risk Plot* fixes a level and shows how the risk of exceeding this level varies for the different years in the design life period

The *Constant Risk Plot* fixes a probability and for each year in the design life period displays the level which is exceeded with this probability

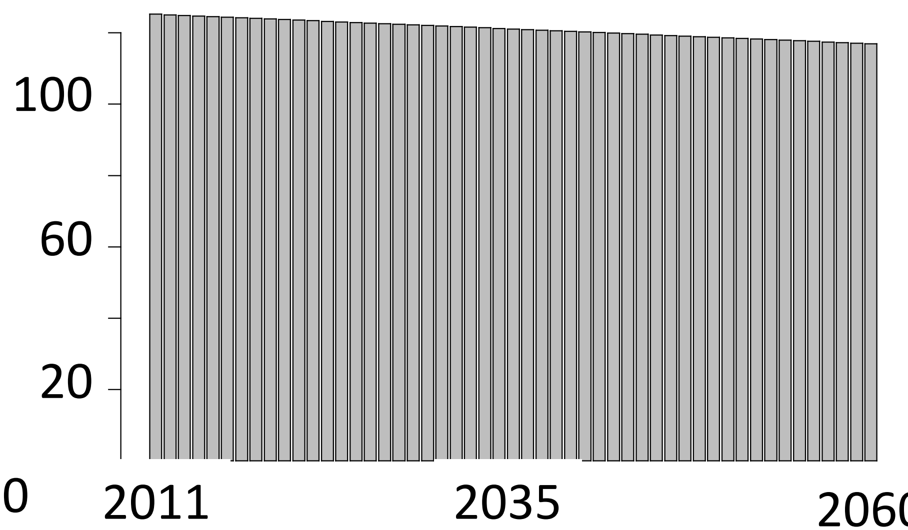
the 2011–2060 5% largest daily winter rainfall in Manjimup is 121 mm



Yearly maximum daily rainfall

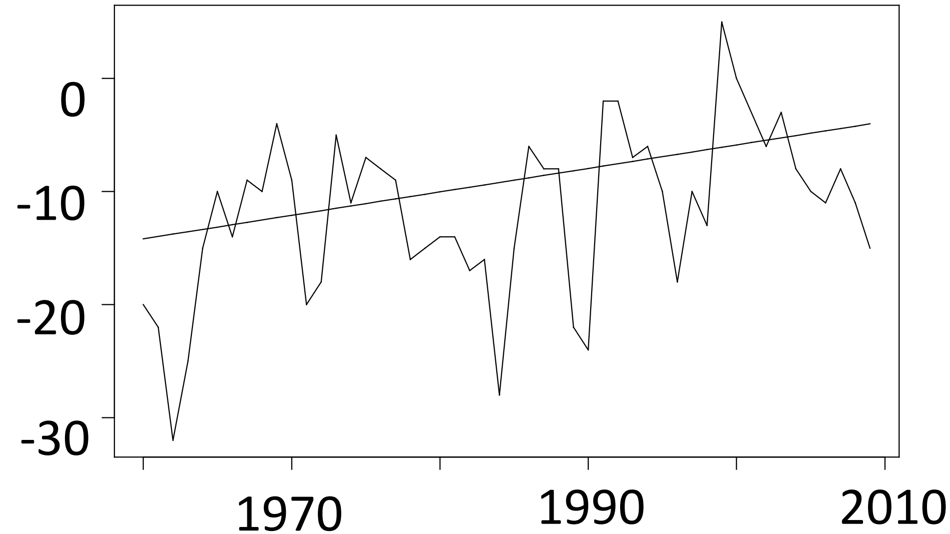


The 121 mm-s risk plot

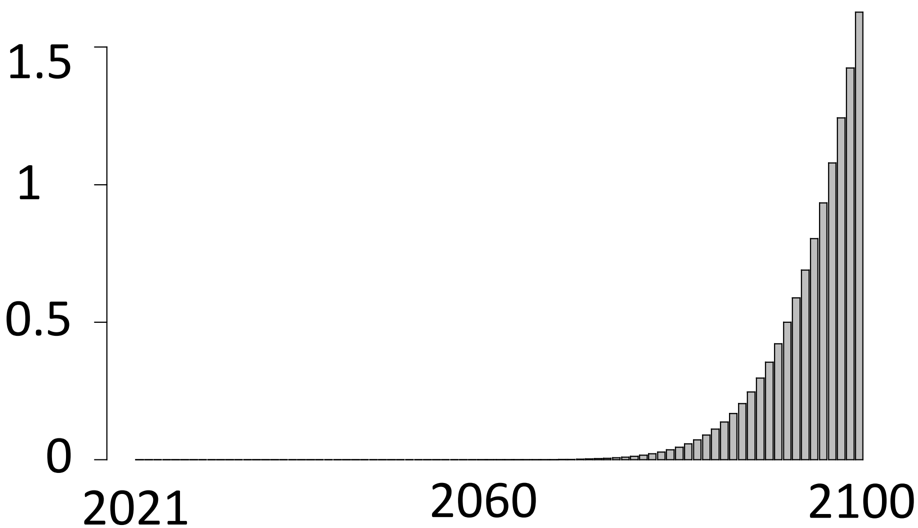


The 0.1% constant risk plot

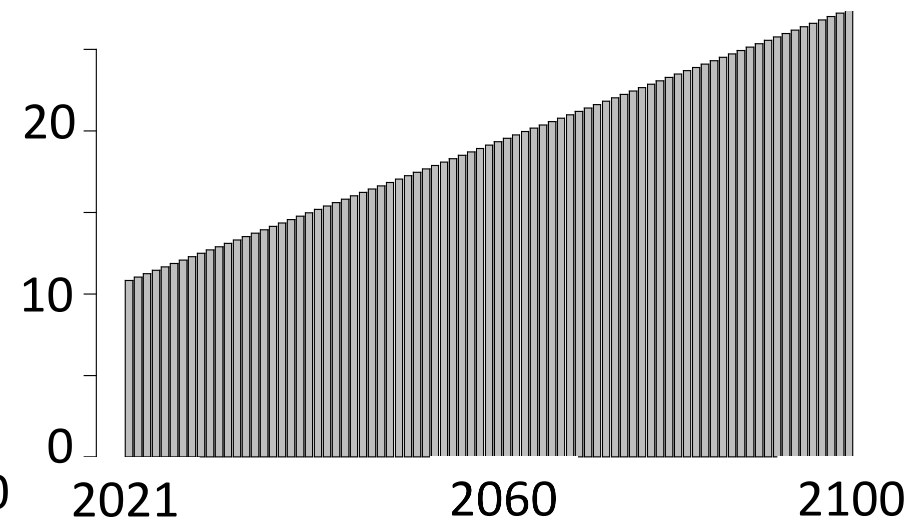
the 2021–2060 10 % highest minimum winter temperature in Fort Collins is 24 degrees



Yearly minimum temperature



The 24 degree risk plot



The 0.1% constant risk plot

Uncertainties

- Statistical uncertainties: confidence/prediction intervals
- Model uncertainties: model comparison, e.g. via maximum likelihood
- Trend uncertainties: difficult, sensitivity studies
- GCM uncertainties: choice of spatial resolution; differential equation models; future changes in human activity; extremes not well caught by models

- In design phase plan for later modification to make the construction more resistant, if need should arise.
- Plan for regular adjustment of rules for managing the construction.
- Plan for regular updating of risk measures as experience and knowledge increases.

Olsen, J.R., Lambert, J.H. and Haimes, Y.Y. (1998). Risk of Extreme Events Under Nonstationary Conditions. *Risk Analysis,* **18***, 497-510.*

Non-stationary return periods

Vogel, R.M., Yaindl, C. and Walter, M. (2011). Nonstationaritry: Flood magnification and recurrence reduction factors in the United states. *J. Amer. Water Resources Ass.* **47,** 464-474.

… A decadal flood magnification factor is defined as the ratio of the T-year flood in a decade to the T-year flood today. Using historical flood data across the United States we obtain flood magnification factors in excess of 2-5 for many regions of the United States … Similarly, we compute recurrence reduction factors which indicate that what is now considered the 100-year flood, may become much more common in many watersheds."

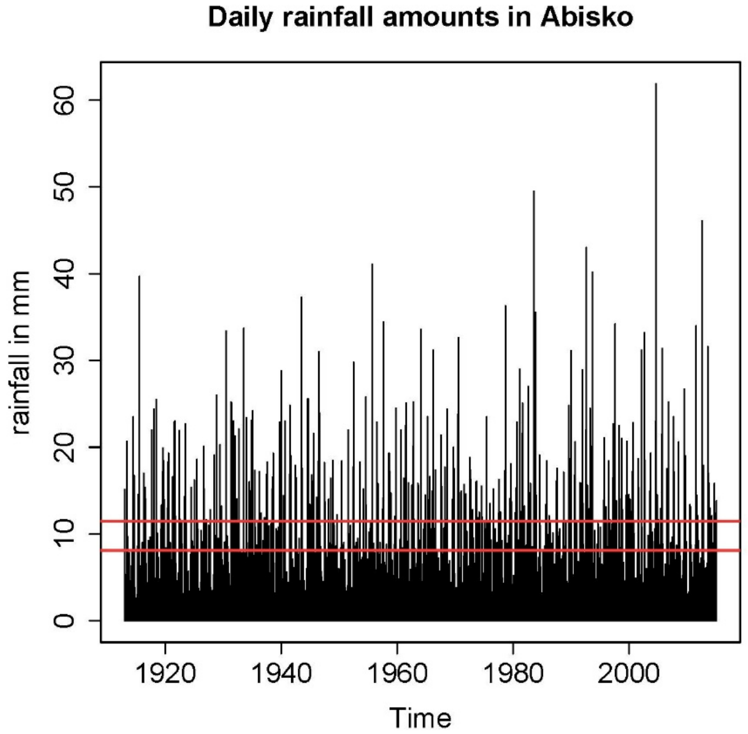
Laurent, C. and Parey, S. (2007). Estimation of 100-year-return-period temperatures in France in a non-stationary climate: Results from observations
and IPCC scenarios. *Global and Planetary Change* **57**, 177–188

100- year return period: the value of u which solves $(1 - F_1(u)) + \cdots$
$(1 - F_{100}(u)) = 1$

Rootzen, H. and R. W.Katz (2013), Design Life Level: Quantifying risk in a changing climate, Water Resour. Res., 49, doi:10.1002/wrcr.20425.

Heads up: Multivariate Peaks over Thresholds modelling is in intensive development and may be ready for routine use in a few years time

Sri Lanka 2016/05/18: three day rain



Guzetti et al, 1997. Threshold relation for highland climates in Europe: landslide risk if

39 mm rain during one day, or 57 mm during two days, or 70 mm during three days.

Risk may be estimated using MPoT with multivariate GP distribution

A. Kiriliouk, J. Segers, J. Wadsworth

Conclusions

- To handle and communicate risks in a changing climate one should specify both a period of time and a probability of failure

- If one is not aiming at design but just wants to illustrate the extent of changes simpler concepts may sometimes suffice

- We recognize that the concept of Design Life Level is a shift from more common standard-based to less common risk-based engineering design. But such a shift may be desirable even under a stationary climate.

- This paper does not provide the final and complete solution, but, we hope, contributes to a long overdue discussion

Remaining design life risk??