Sharing is encouraged

On the drought-flood conundrum

Do droughts cause more or less flooding? Let's discuss the science

Anne Van Loon & the PerfectSTORM team

Alessia Matanó, Marlies Barendrecht, Ruben Weesie, Heidi Mendoza, Maurizio Mazzoleni, Philip Ward, Marleen De Ruiter, Wouter Berghuijs, Manuela Brunner, Giuliano Di Baldassarre, Margaret Garcia, Jeroen Aerts, Johanna Koehler, Melanie Rohse, Rosie Day, Moses Mwangi, Juan Bazo, Jahir Anicama & Danai Kontou

IVM Institute for Environmental Studies

VU VRIJE UNIVERSITEIT AMSTERDAM

Limpopo river basin – southern Africa

Rhine river – the Netherlands

Surprisingly little research on drought-flood interactions

Need for consistent:

hazard analysis methods

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Hydrological change: Towards a consistent approach to assess changes on both floods and droughts

Beatriz Quesada-Montano[a,b,c], Giuliano Di Baldassarre[a,b,*], Sally Rangecroft[d], Anne F. Van Loon[d]

[a] Uppsala University, Department of Earth Sciences, Uppsala, Sweden
[b] Centre of Natural Hazards and Disaster Science (CNDS), Uppsala, Sweden
[c] Centre for Geophysical Research, University of Costa Rica, Costa Rica
[d] Birmingham University, School of Geography, Earth and Environmental Sciences, Birmingham, United Kingdom

A R T I C L E I N F O

Keywords:
Hydrological extremes
Human impact
Drought
Floods
Anthropocene

A B S T R A C T

Several studies have found that the frequency, magnitude and spatio-temporal distribution of droughts and floods have significantly increased in many regions of the world. Yet, most of the methods used in detecting trends in hydrological extremes 1) focus on either floods or droughts, and/or 2) base their assessment on characteristics that, even though useful for trend identification, cannot be directly used in decision making, e.g. integrated water resources management and disaster risk reduction. In this paper, we first discuss the need for a consistent approach to assess changes on both floods and droughts, and then propose a method based on the theory of runs and threshold levels. Flood and drought changes were assessed in terms of frequency, length and surplus/deficit volumes. This paper also presents an example application using streamflow data from two hydrometric stations along the Po River basin (Italy), Piacenza and Pontelagoscuro, and then discuss opportunities and challenges of the proposed method.

1. Introduction

The frequency, magnitude and spatio-temporal distribution of droughts and floods have increased in many regions around the world, and with this the related environmental, economic and social losses (Di Baldassarre et al., 2010; UN-ISDR, 2017; Winsemius et al., 2016). Studies examining trend detection on hydrological extremes usually: a) focus on either floods or droughts individually, while water management policies often account for both hydrological extremes, or b) are

interval of the flood events (e.g. on average 1 event per year) and normally only quantifies the event peak flow. Another commonly used approach is the use of maximum and minimum annual flow data as proxies for the severity of floods and droughts, respectively (e.g.; Burn & Whitfield, 2016; Montanari, 2012; Slater & Villarini, 2017). While using annual maxima and minima is a consistent way to look at both extremes, volume and duration characteristics of floods and droughts are not captured. For drought assessment, other widely-used methods also include standardized indices (Huang et al., 2016; Joetzjer et al.,

impact data collection & analysis

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Panta Rhei – Everything Flows
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OPINION PAPER

How to improve attribution of changes in drought and flood impacts

Heidi Kreibich[a], Veit Blauhut[b], Jeroen C.J.H. Aerts[c], Laurens M. Bouwer[d], Henny A.J. Van Lanen[e], Alfonso Mejia[f], Marjolein Mens[g] and Anne F. Van Loon[h]

[a]Section Hydrology, GFZ German Research Centre for Geosciences, Potsdam, Germany; [b]Environmental Hydrological Systems, Faculty of Environment and Natural Resources, University of Freiburg, Freiburg, Germany; [c]Department of Water and Climate Risk, Institute for Environmental Studies, Vrije Universiteit Amsterdam, Amsterdam, The Netherlands; [d]Climate Service Center Germany, Helmholtz-Zentrum Geesthacht, Hamburg, Germany; [e]Hydrology and Quantitative Water Management Group, Wageningen University, Wageningen, The Netherlands; [f]Department of Civil and Environmental Engineering, The Pennsylvania State University, University Park, PA, USA; [g]Deltares, Delft, The Netherlands; [h]School of Geography, Earth and Environmental Sciences, University of Birmingham, Birmingham, UK

ABSTRACT

For the development of sustainable, efficient risk management strategies for the hydrological extremes of droughts and floods, it is essential to understand the temporal changes of impacts, and their respective causes and interactions. In particular, little is known about changes in vulnerability and their influence on drought and flood impacts. We present a fictitious dialogue between two experts, one in droughts and the other in floods, showing that the main obstacles to scientific advancement in this area are both a lack of data and a lack of commonly accepted approaches. The drought and flood experts "discuss" available data and methods and we suggest a complementary approach. This approach consists of collecting a large number of single or multiple paired-event case studies from catchments around the world, undertaking detailed analyses of changes in impacts and drivers, and carrying out a comparative analysis. The advantages of this approach are that it allows detailed context- and location-specific assessments based on the paired-event analyses, and reveals general, transferable conclusions based on the comparative analysis of various case studies. Additionally, it is quite flexible in terms of data and can accommodate differences between floods and droughts.

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KEYWORDS
hydrological extremes; damage; dynamic risk; vulnerability; trend attribution; paired catchments; consecutive hydro-hazards

1 Introduction

Droughts and floods have widespread impacts. For instance, globally in the period 1998–2017, floods affected the larger number of people (>2 billion), followed by droughts (1.5 billion) (UNISDR and CRED 2018). In Europe in the period 1998–2009, floods and

resulting drought rich/drought poor and flood rich/flood poor periods have been described for many regions (Hall *et al.* 2014, Cook *et al.* 2015, Mediero *et al.* 2015, Hanel *et al.* 2018). Both persistence and variability at various time scales complicate the change detection and attribution of drought and flood impacts. In this context, hazard is defined as the potential

disaster risk reduction strategies

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The need to integrate flood and drought disaster risk reduction strategies

Philip J. Ward[a,*], Marleen C. de Ruiter[a], Johanna Mård[b,c], Kai Schröter[d], Anne Van Loon[a], Ted Veldkamp[e], Nina von Uexkull[f,b], Niko Wanders[g], Amir AghaKouchak[h,i], Karsten Arnbjerg-Nielsen[j], Lucinda Capewell[k], Maria Carmen Llasat[l], Rosie Day[k], Benjamin Dewals[m], Giuliano Di Baldassarre[b,c], Laurie S. Huning[n,h], Heidi Kreibich[d], Maurizio Mazzoleni[b,c], Elisa Savelli[b,c], Claudia Teutschbein[b,c], Harmen van den Berg[o], Anne van der Heijden[o], Jelle M.R. Vincken[p], Maarten J. Waterloo[o], Marthe Wens[a]

[a] Institute for Environmental Studies, Vrije Universiteit Amsterdam, Amsterdam, the Netherlands
[b] Centre of Natural Hazards and Disaster Science, CNDS, Uppsala, Sweden
[c] Department of Earth Sciences, Air, Water and Landscape Science, Uppsala University, Uppsala, Sweden
[d] German Research Centre for Geosciences, Section Hydrology, Potsdam, Germany
[e] Amsterdam University of Applied Sciences, Amsterdam, the Netherlands
[f] Department of Peace and Conflict Research, Uppsala University, Sweden
[g] Department of Physical Geography, Utrecht University, Utrecht, the Netherlands
[h] Department of Civil and Environmental Engineering, University of California, Irvine, CA, USA
[i] Department of Earth System Science, University of California, Irvine, CA, USA
[j] Department of Environmental Engineering, Technical University of Denmark, Lyngby, Denmark
[k] School of Geography, Earth and Environmental Sciences, University of Birmingham, Birmingham, UK
[l] Department of Applied Physics, University of Barcelona, Spain
[m] Hydraulics in Environmental and Civil Engineering (HECE), University of Liège, Liège, Belgium
[n] Department of Civil Engineering and Construction Engineering Management, California State University, Long Beach, CA, USA
[o] Acacia Water, Gouda, the Netherlands
[p] Vrije Universiteit Amsterdam, Amsterdam, the Netherlands

A R T I C L E I N F O

Keywords:
Floods
Droughts
Disaster risk reduction
Risk

A B S T R A C T

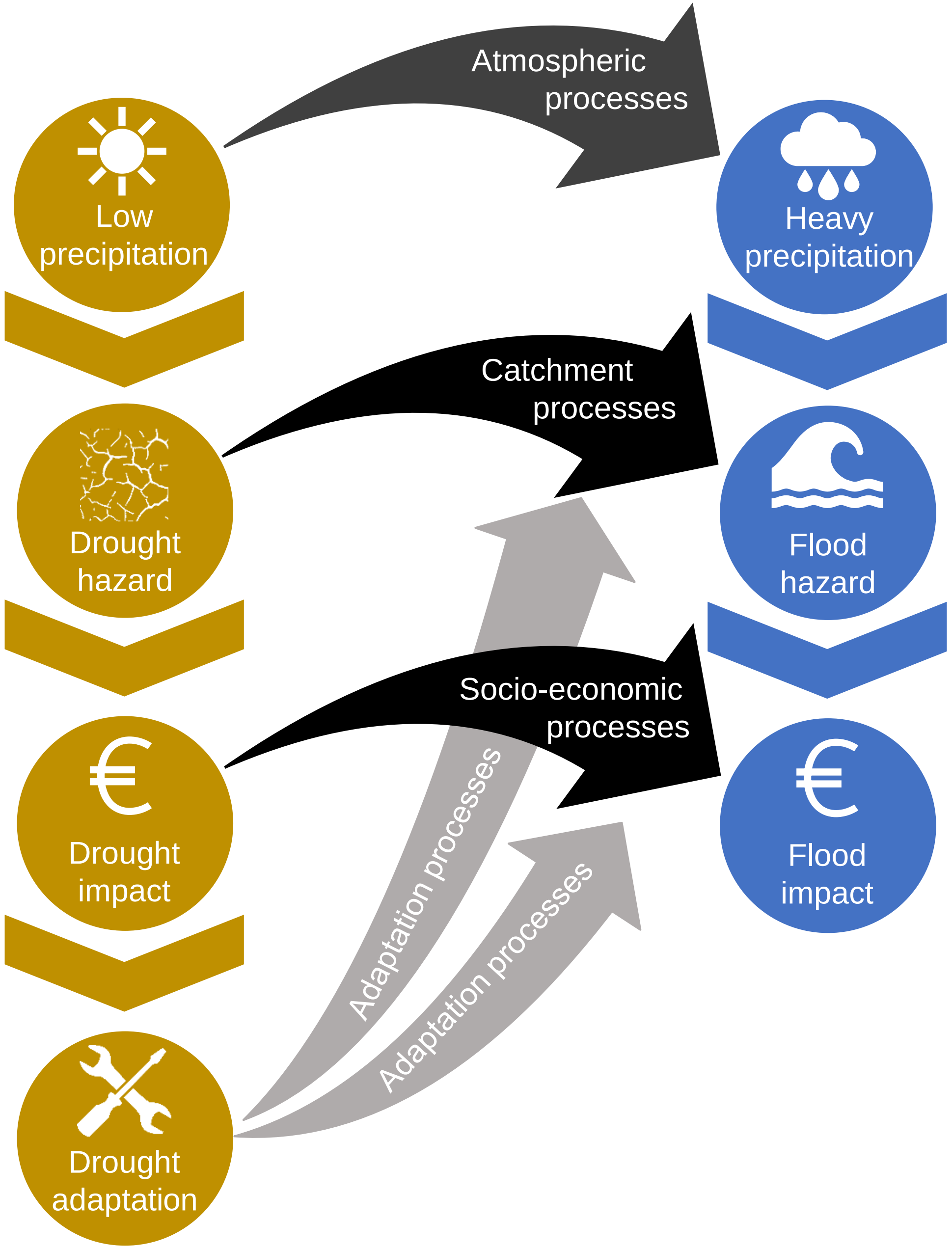
Most research on hydrological risks focuses either on flood risk or drought risk, whilst floods and droughts are two extremes of the same hydrological cycle. To better design disaster risk reduction (DRR) measures and strategies, it is important to consider interactions between these closely linked phenomena. We show examples of: (a) how flood or drought DRR measures can have (unintended) positive or negative impacts on risk of the opposite hazard; and (b) how flood or drought DRR measures can be negatively impacted by the opposite hazard. We focus on dikes and levees, dams, stormwater control and upstream measures, subsurface storage, migration, agricultural practices, and vulnerability and preparedness. We identify key challenges for moving towards a more holistic risk management approach.

What do we know from literature?

Review of literature on floods & droughts:

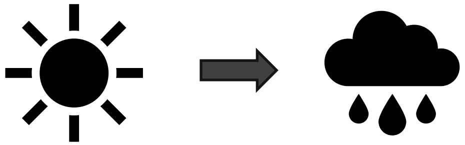
Barendrecht et al. (2024): Exploring drought-to-flood interactions and dynamics: A global case review, *Wires Water*

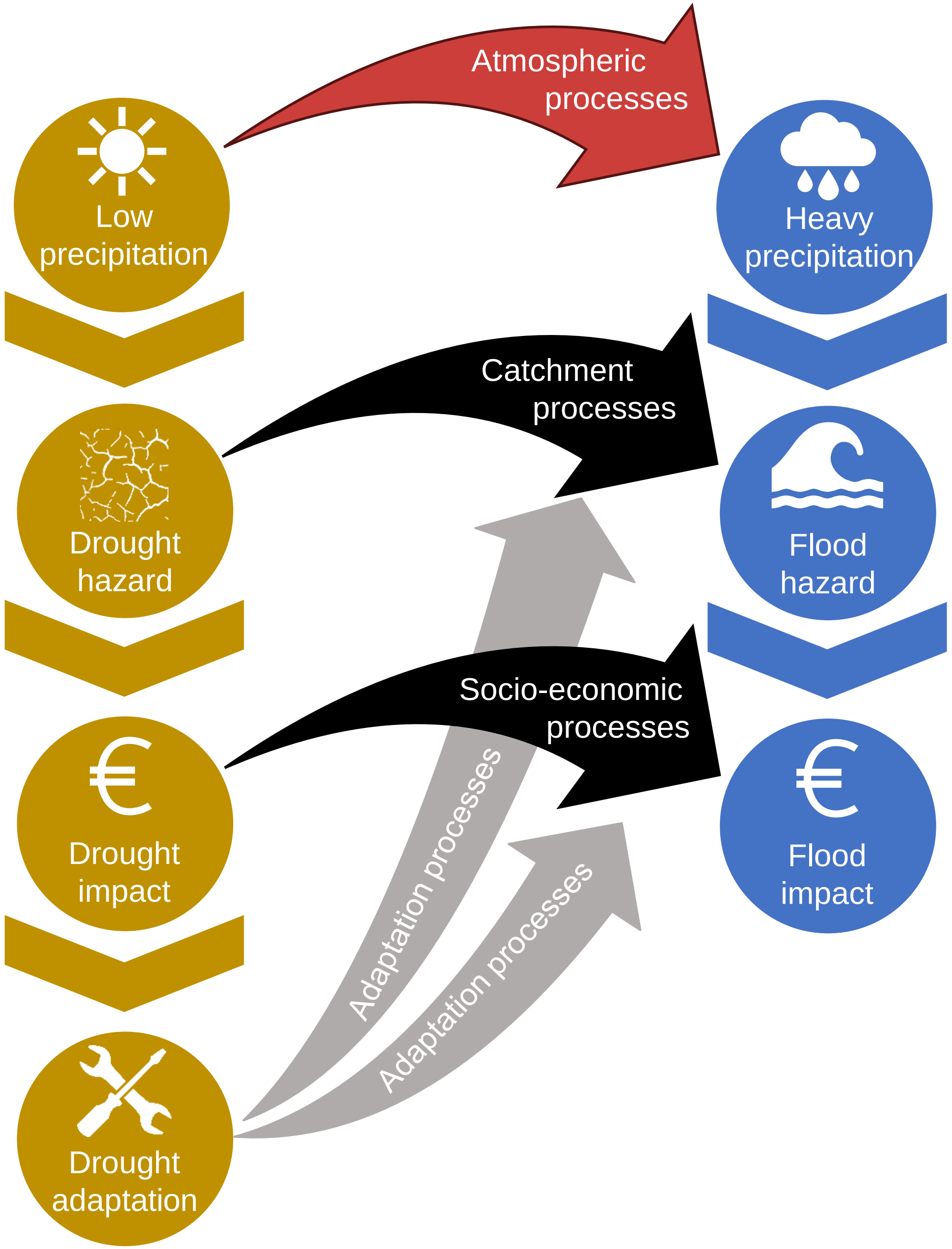
- Atmospheric processes
- Catchment processes
    - land-surface processes
    - (sub)surface storage processes
- Adaptation processes



Atmospheric processes

- frequency of rapid dry-to-wet transitions has increased over the past 30 years (He & Sheffield, 2020)
- time between consecutive dry and wet events is decreasing (Rashid & Wahl, 2022)





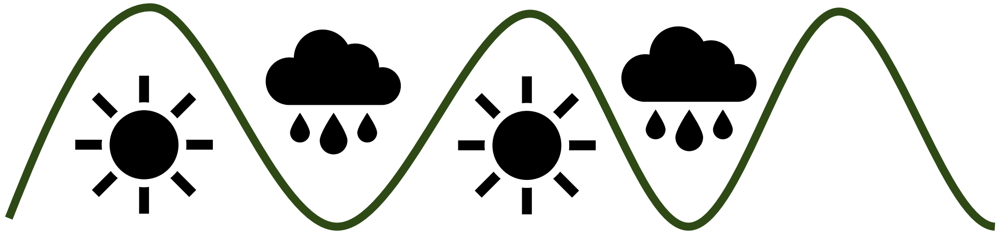
Barendrecht et al. (2024): Exploring drought-to-flood interactions and dynamics: A global case review, *Wires Water*

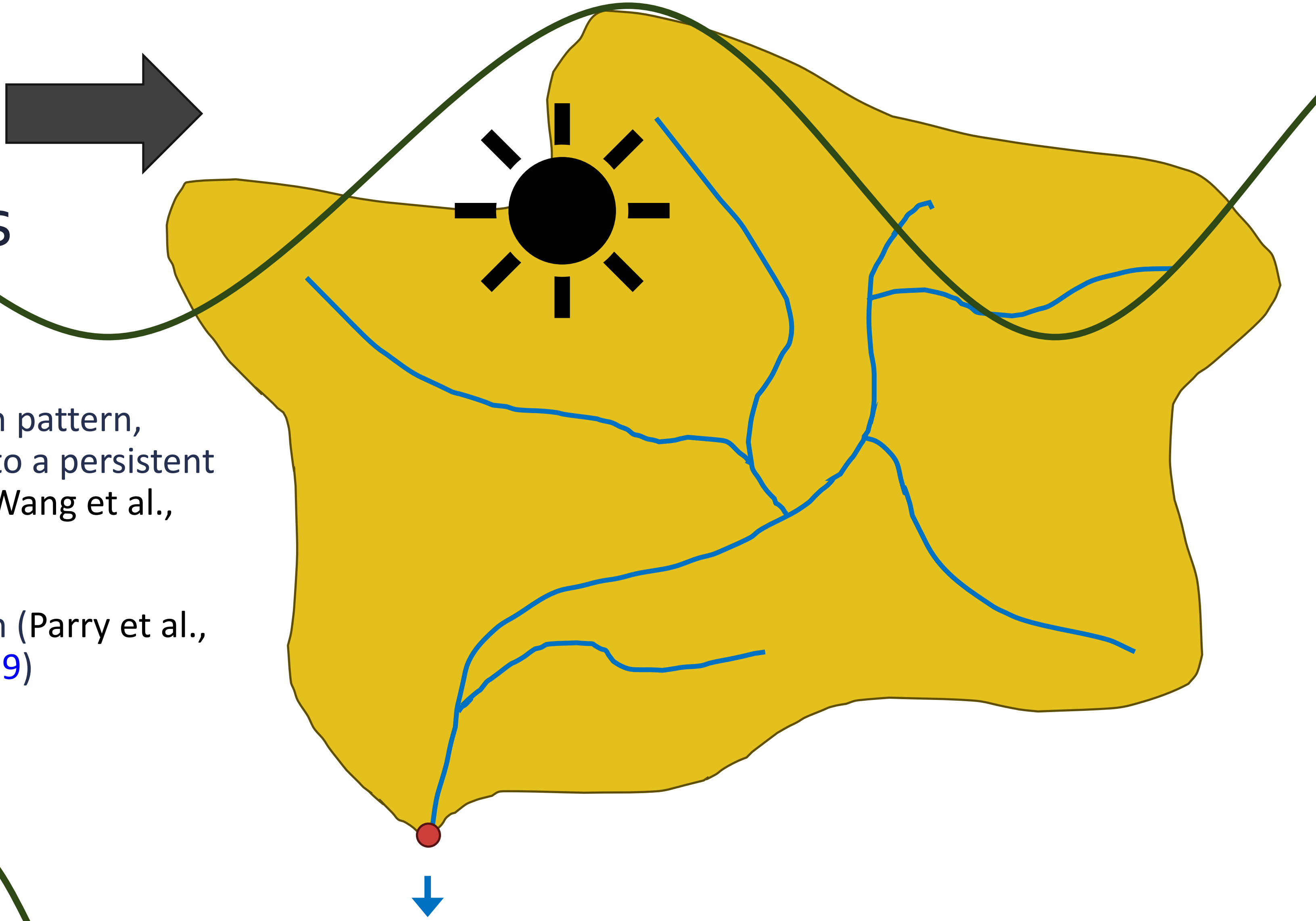
Atmospheric processes

Temperate regions (e.g. US, UK)

- reversal of the “ridge–trough” circulation pattern, persistent high-pressure ridge changing to a persistent low-pressure trough (Dong et al., 2011; Wang et al., 2017; Yang et al., 2013)
- related to the migration of the jet stream (Parry et al., 2013; Payne et al., 2020; Wahl et al., 2019)

JETSTREAM





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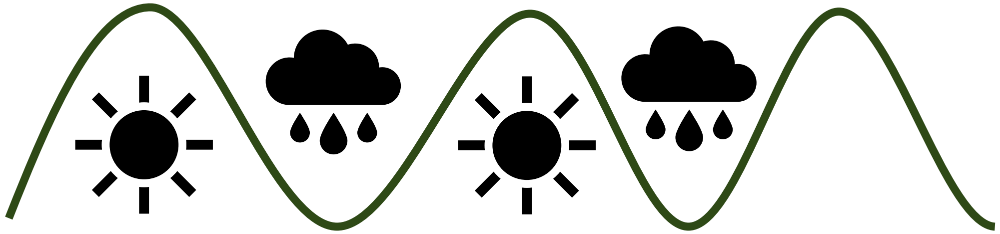
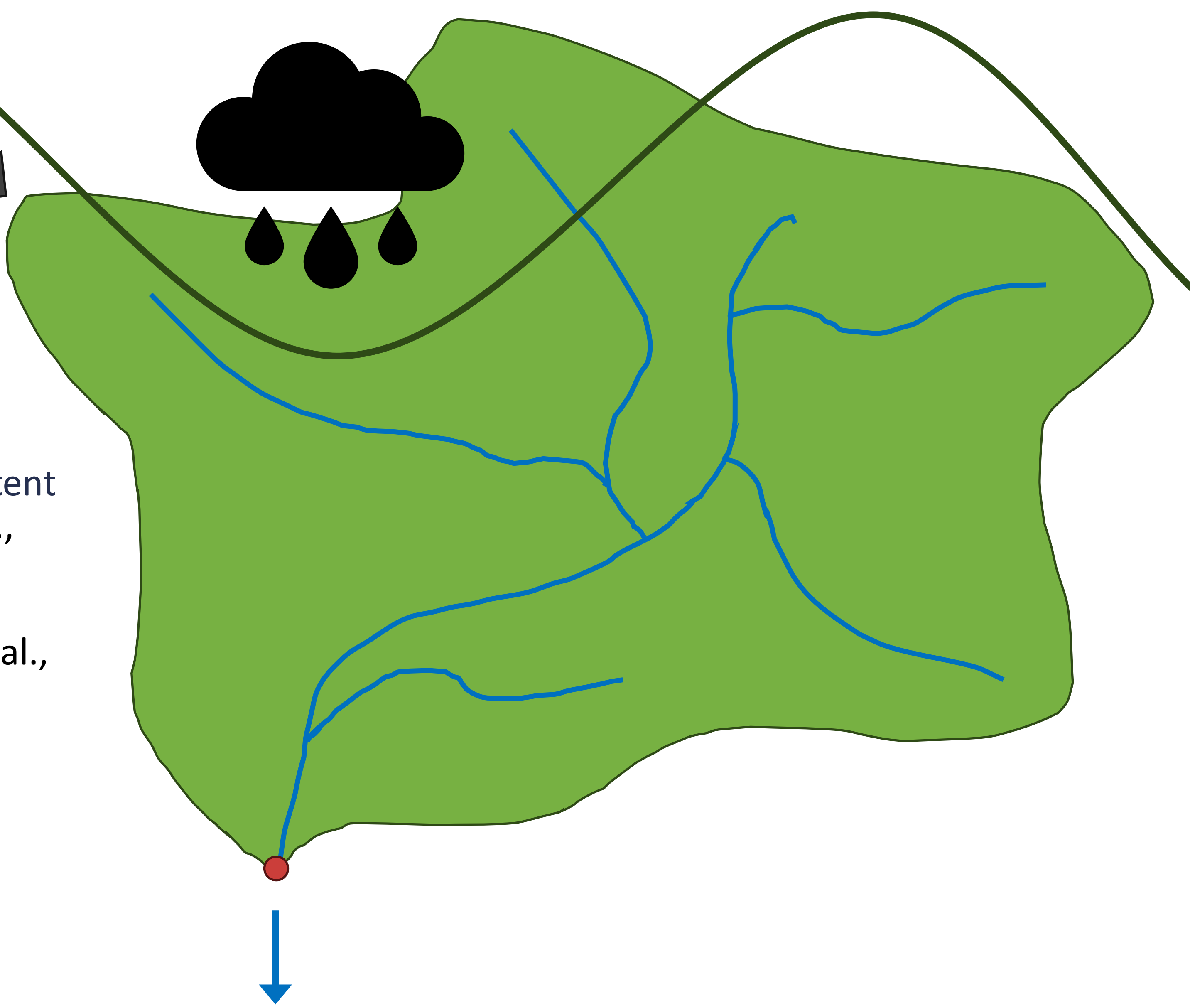


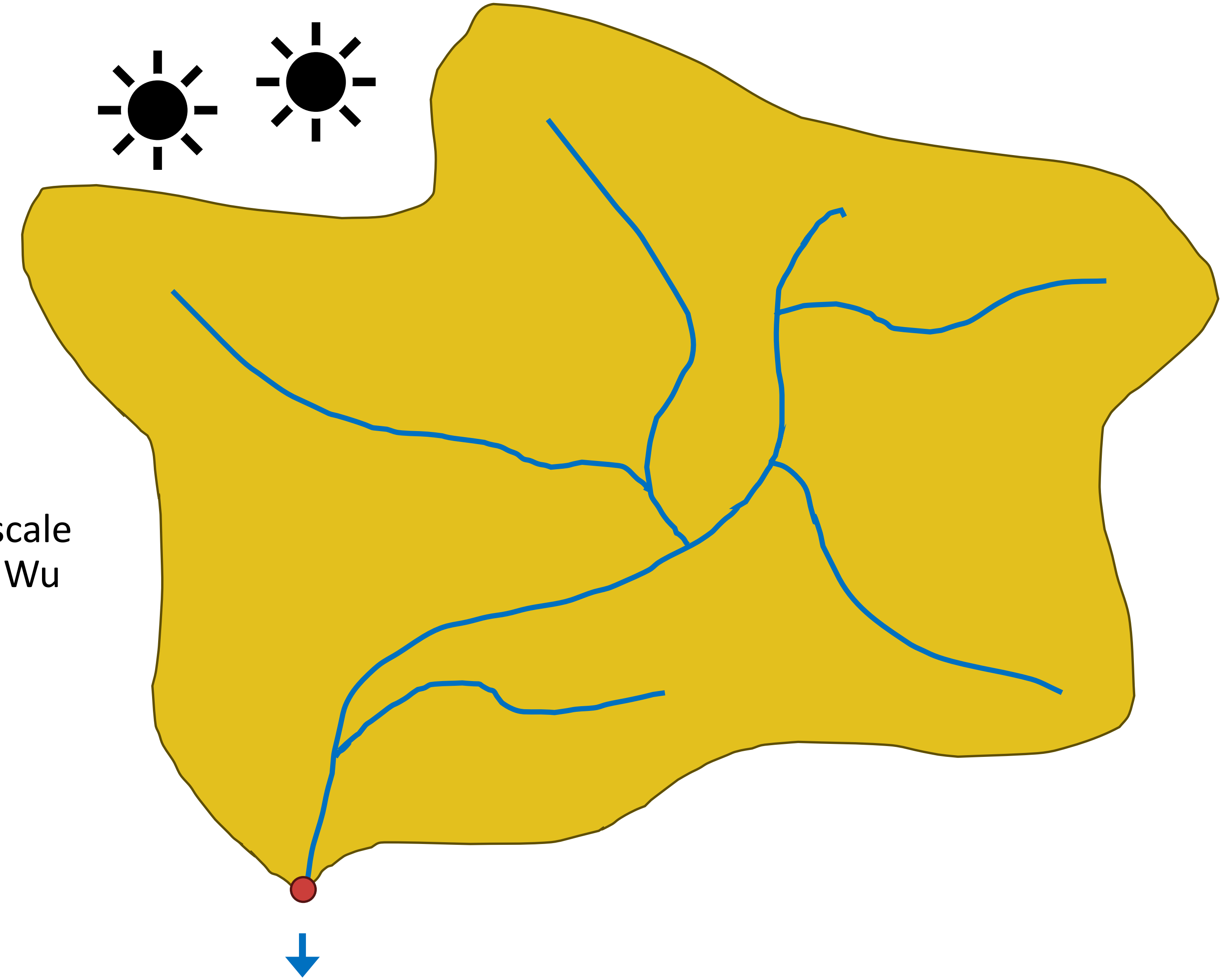


US West Coast, 33%–74% of persistent droughts over 1950–2010 were ended by atmospheric rivers (Dettinger, 2013)

Atmospheric processes

(Sub)tropical regions (e.g. Amazon)

- large-scale ocean–atmosphere processes
- anomalies in sea surface temperatures and large-scale ocean atmospheric modes (e.g., Wu et al., 2006a; Wu et al., 2006b; Espinoza et al., 2013)



Atmospheric processes

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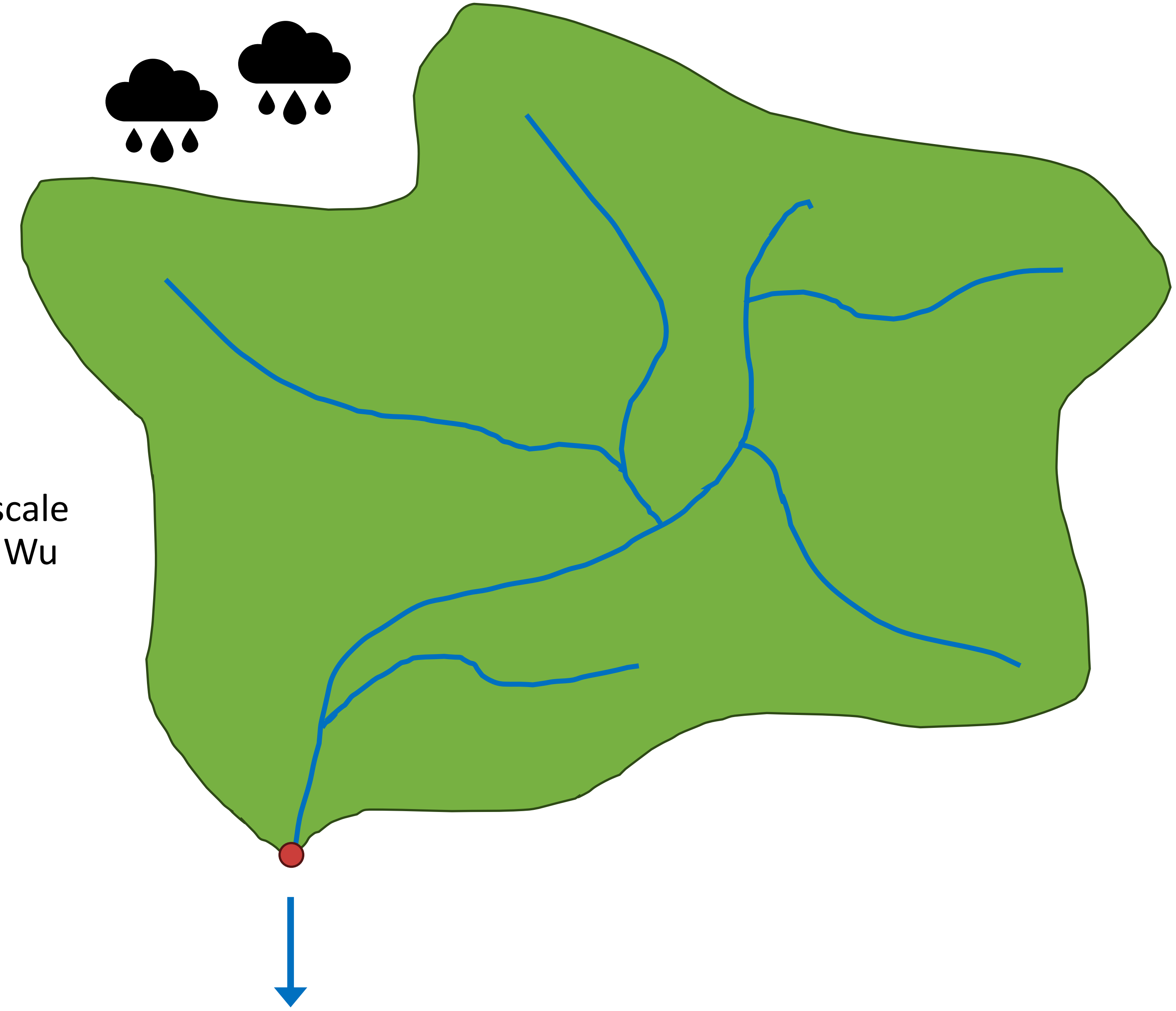
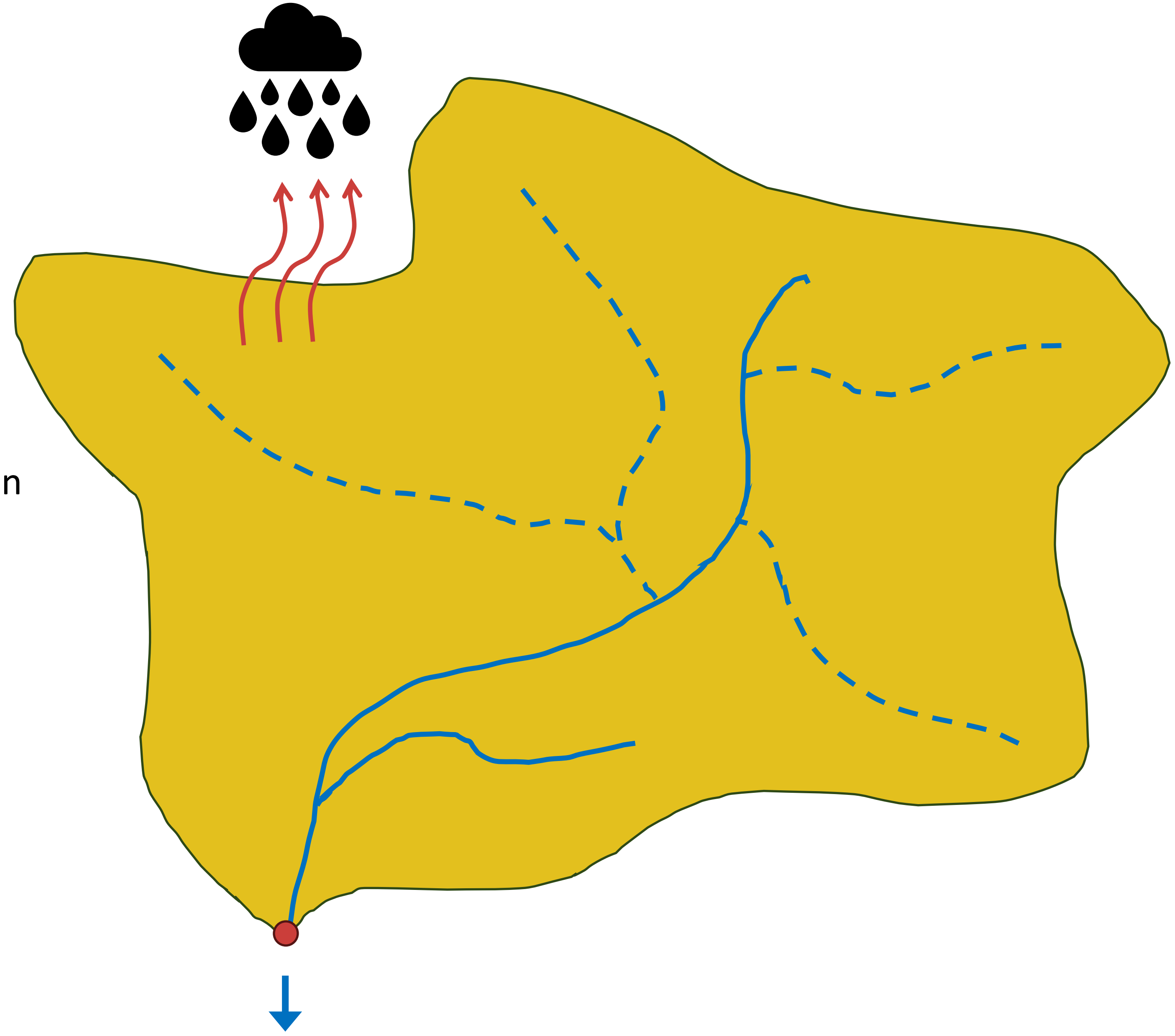


Atmospheric processes

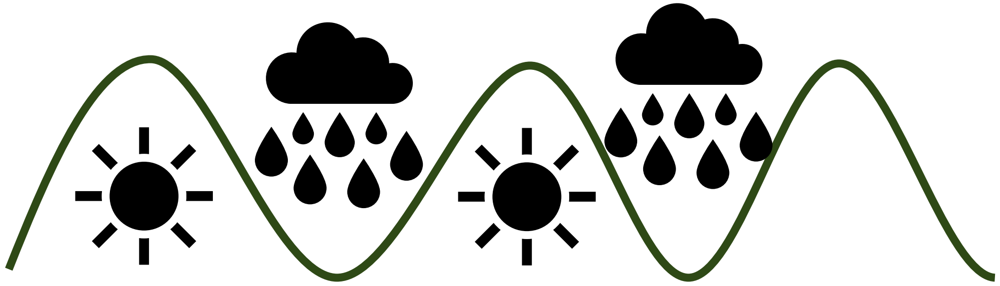
Local processes

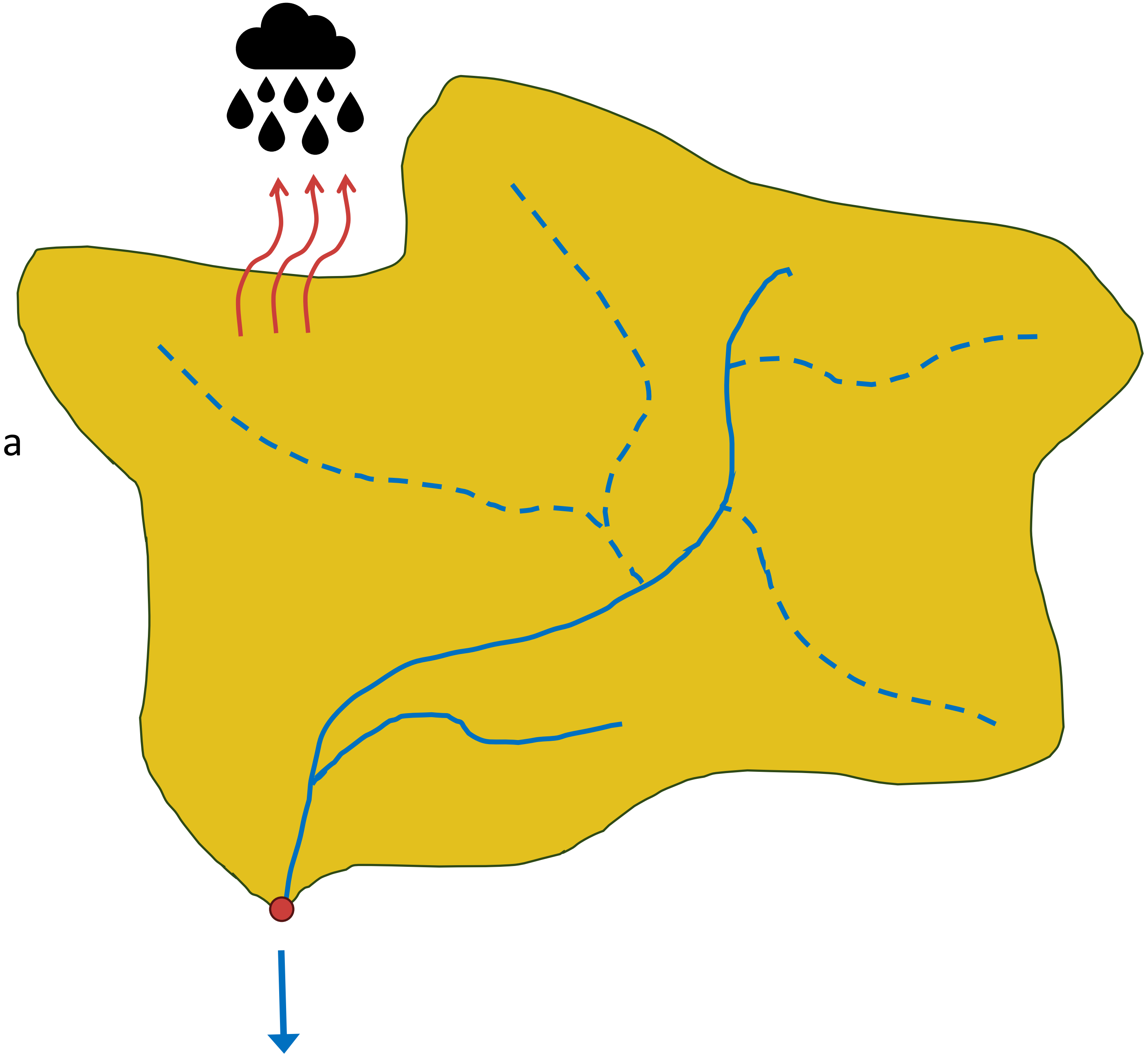
- increased convection due to dry soils leading to vertical air motion which intensifies precipitation of atmospheric rivers (Gimeno et al., 2014)



Atmospheric processes

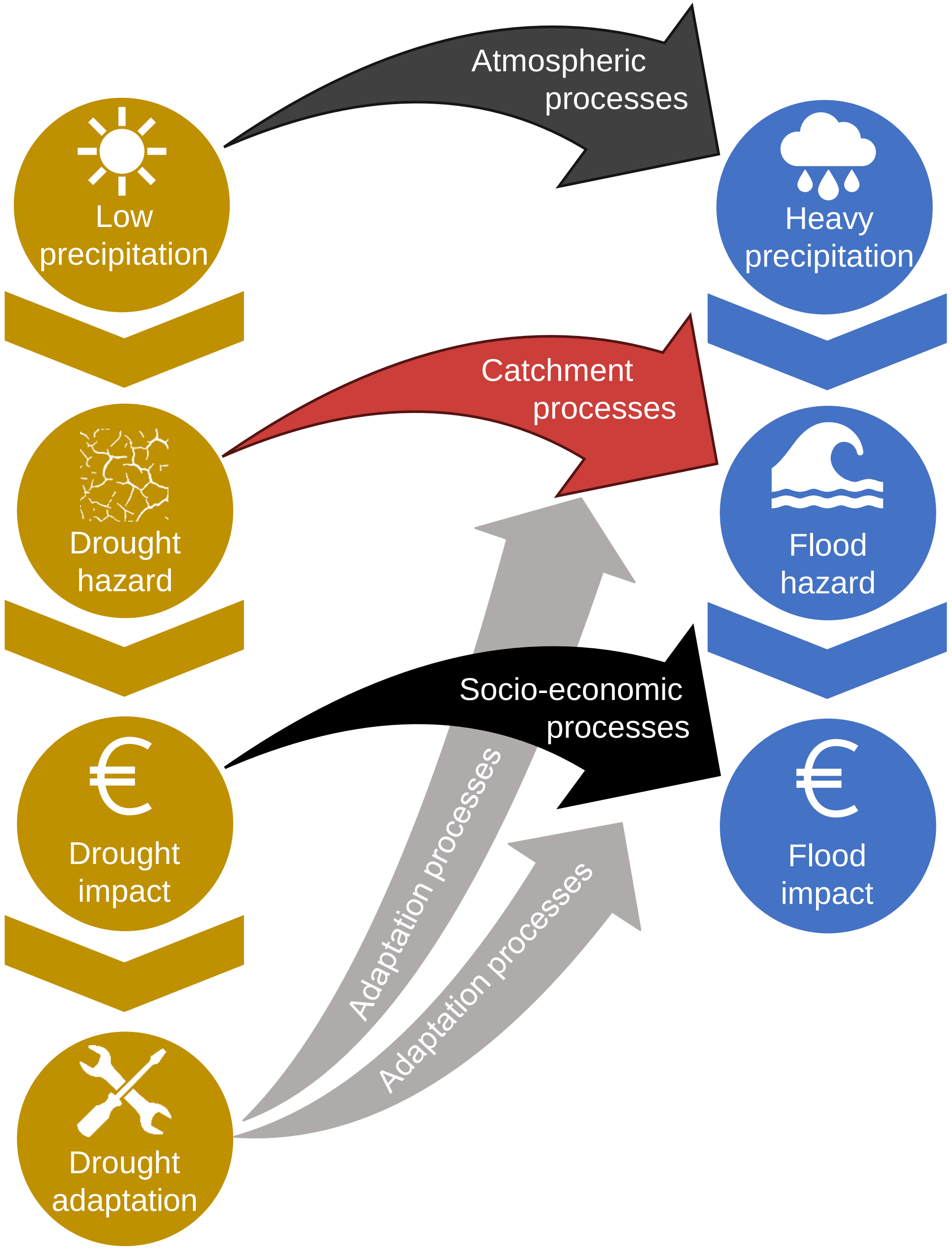
>> dry-wet transitions due to both increased moisture transport & more active rain-producing systems (e.g., Dong et al., 2011; Ma et al., 2019; Maxwell et al., 2017).





Catchment processes

- **land-surface processes (soil, vegetation, snow)**
- (sub)surface storage processes (groundwater, reservoirs)

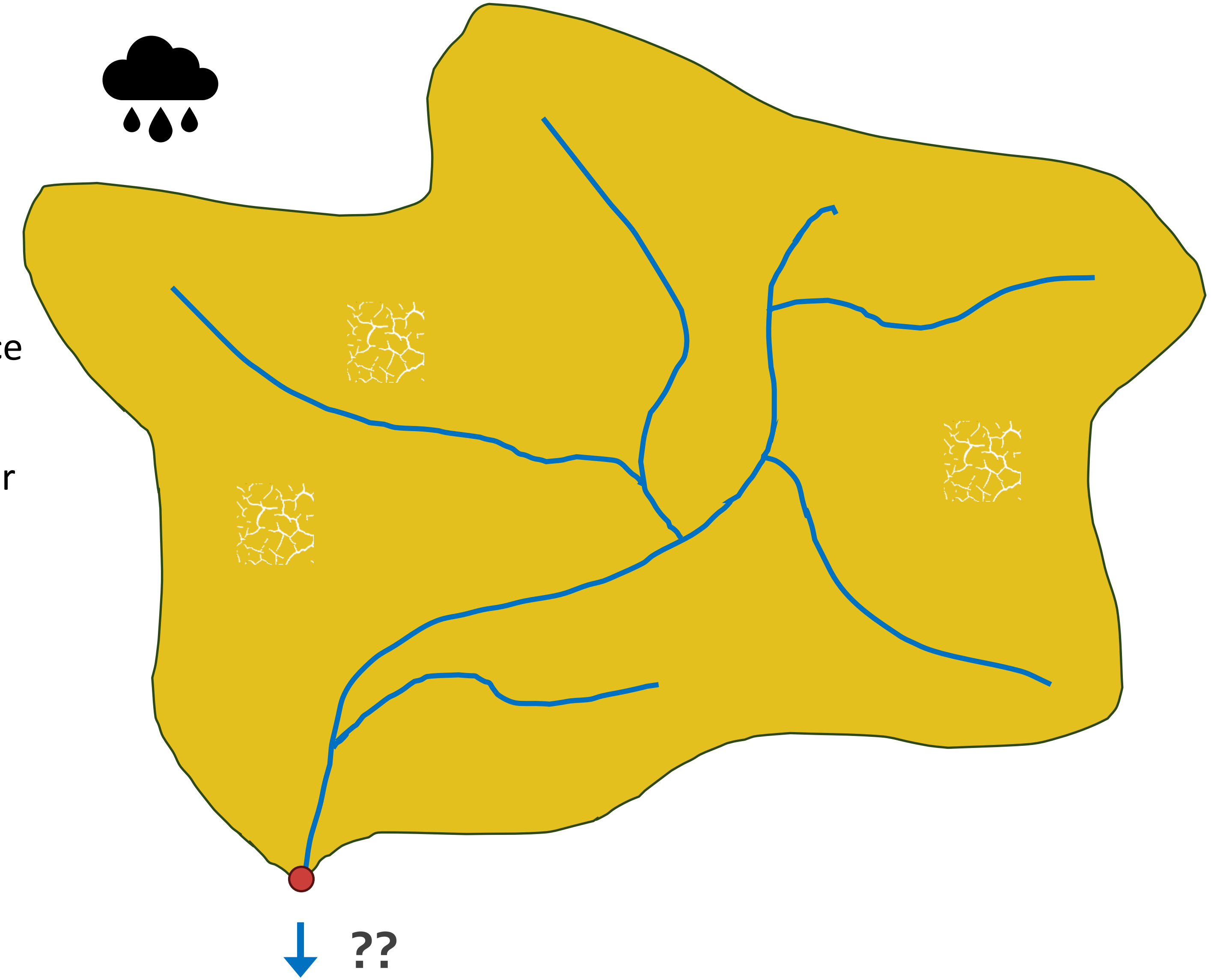


Barendrecht et al. (2024): Exploring drought-to-flood interactions and dynamics: A global case review, *Wires Water*

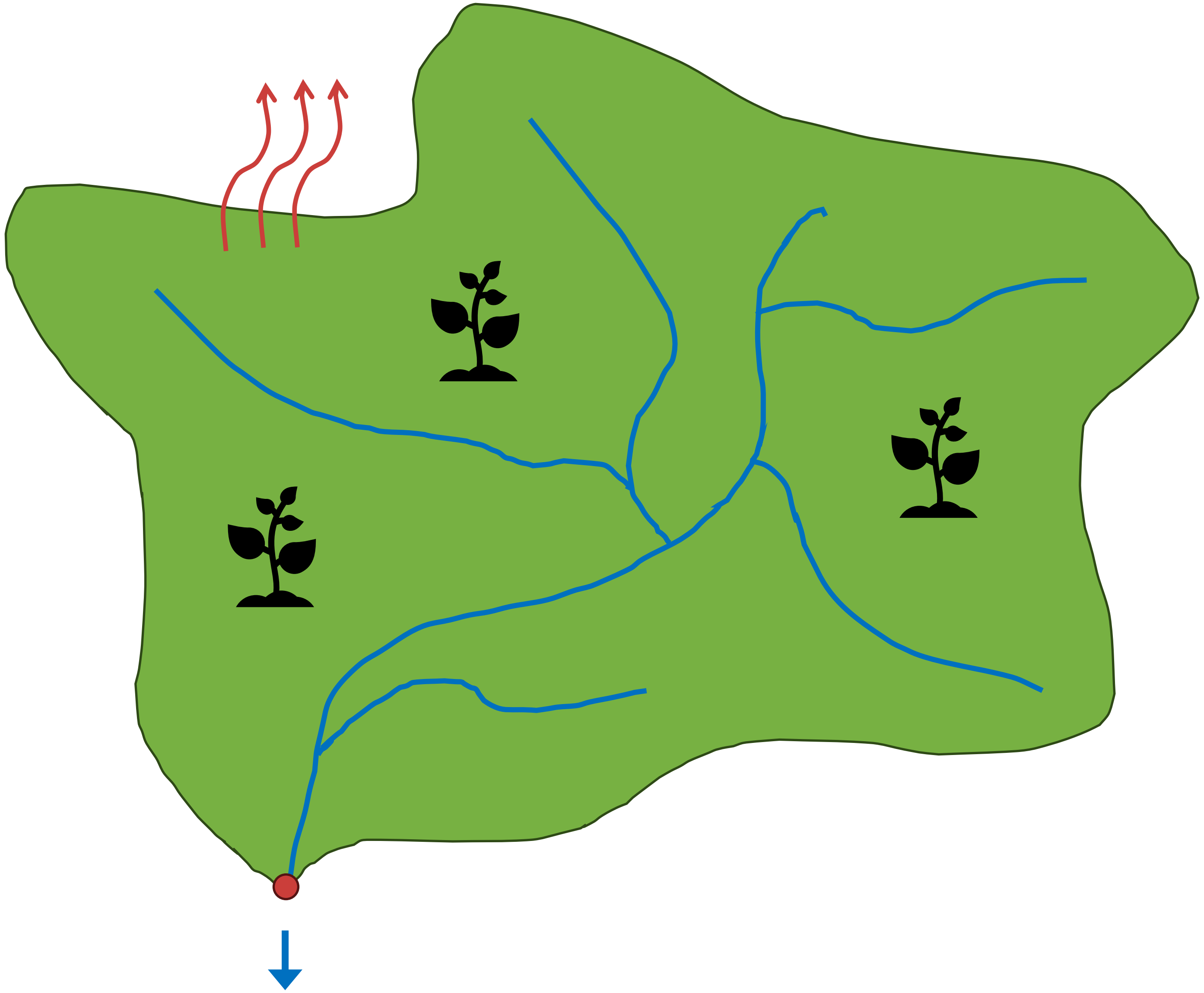

Dr Rob Thompson –
Reading University, UK
00:06:66
Damp Grass
well watered
Moist Grass
slightly watered
Dry Grass
sun parched

Soil

- decreased infiltration rates and increased surface runoff (Descroix et al., 2009)
- increased soil compaction (Alaoui et al., 2018) or hydrophobicity (Evans et al., 1999)
- soil cracking can result in quick vertical flow of rainwater (Miller et al., 1997)
- Questions:
  - persisting after the end of the drought (Worrall et al., 2007)?
  - important at the catchment scale (Alaoui et al., 2018; Blöschl et al., 2007)?

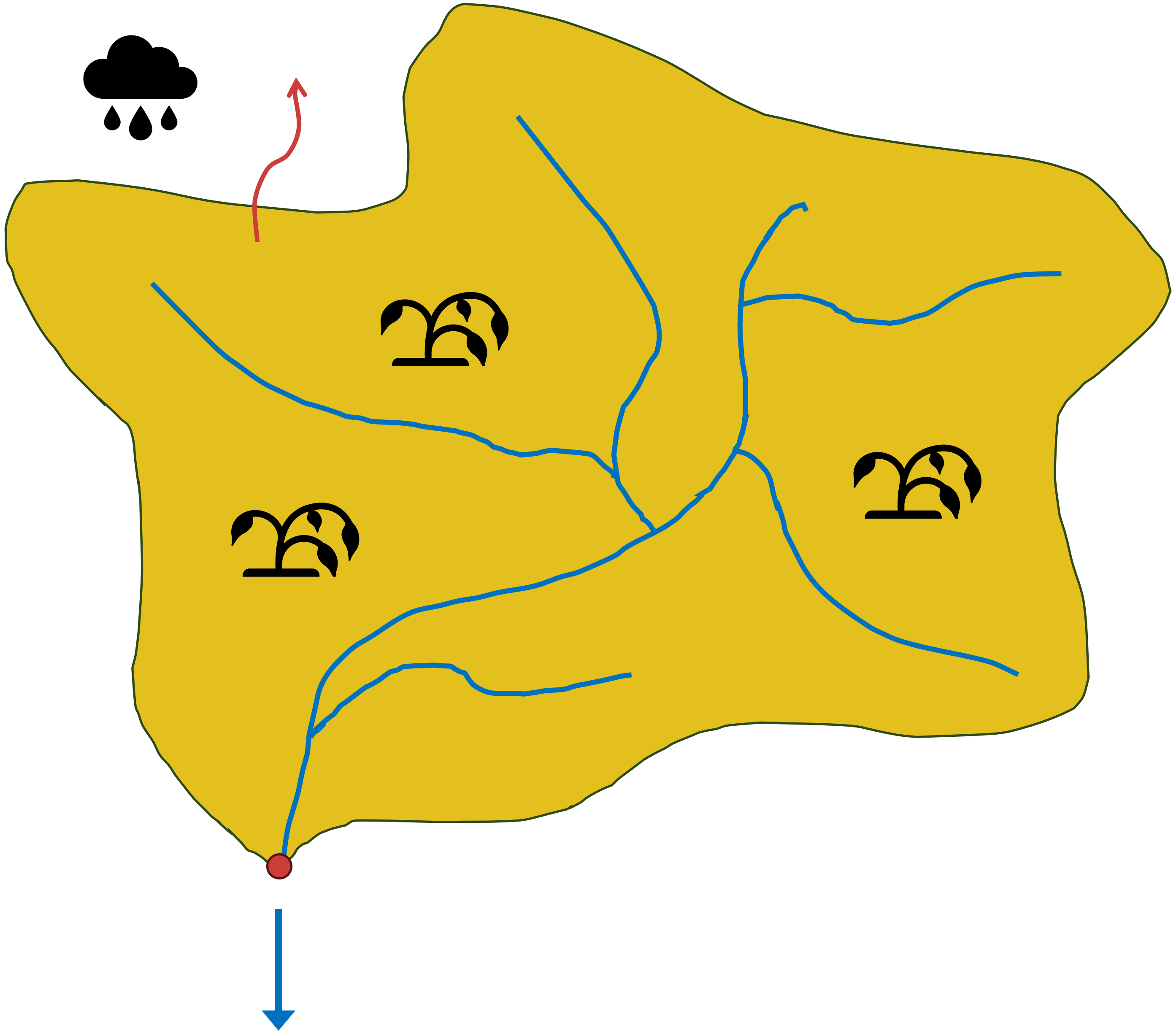


Vegetation



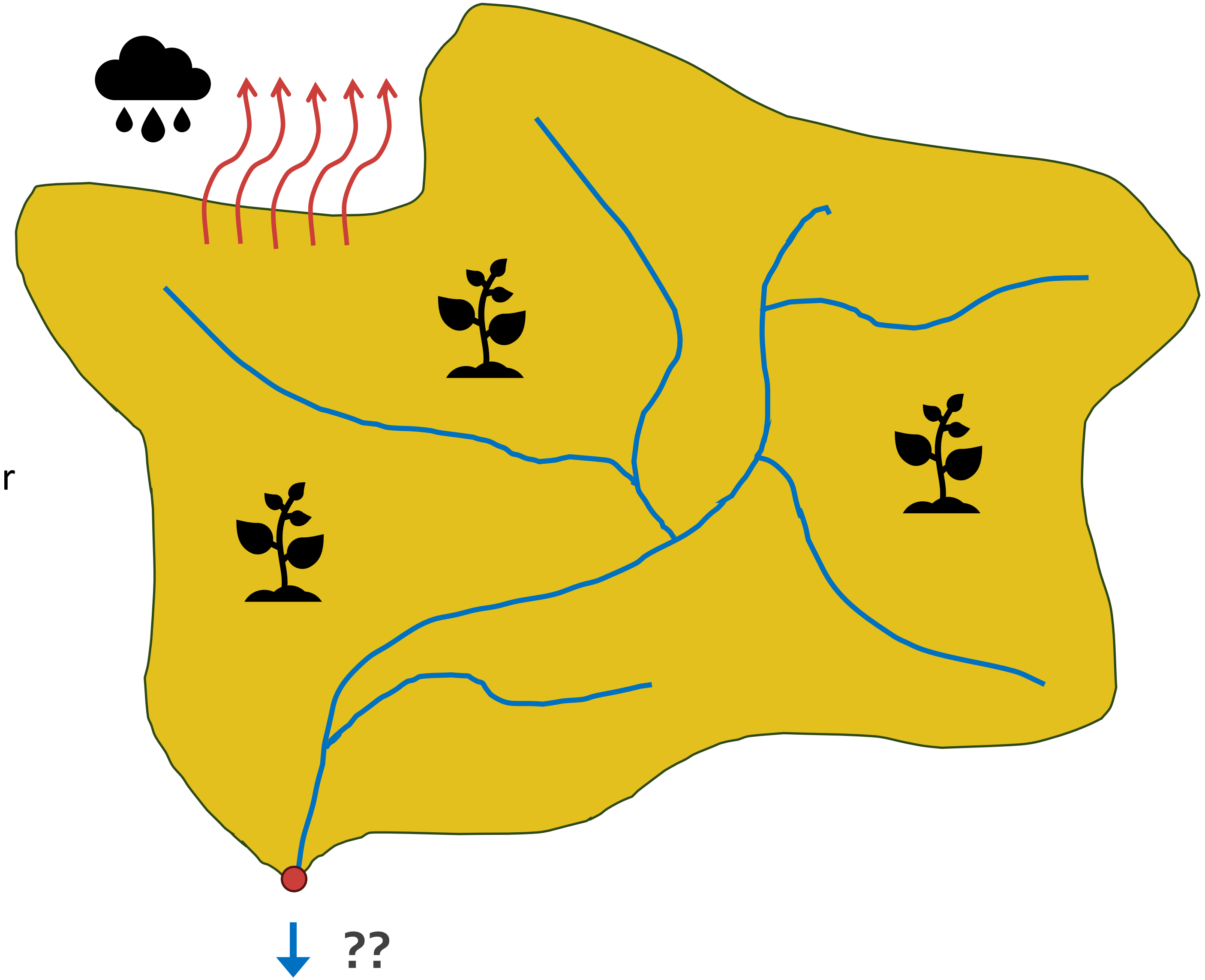
Vegetation

- **decreased transpiration** > **higher stormflow** response after drought (Scaife & Band (2017)



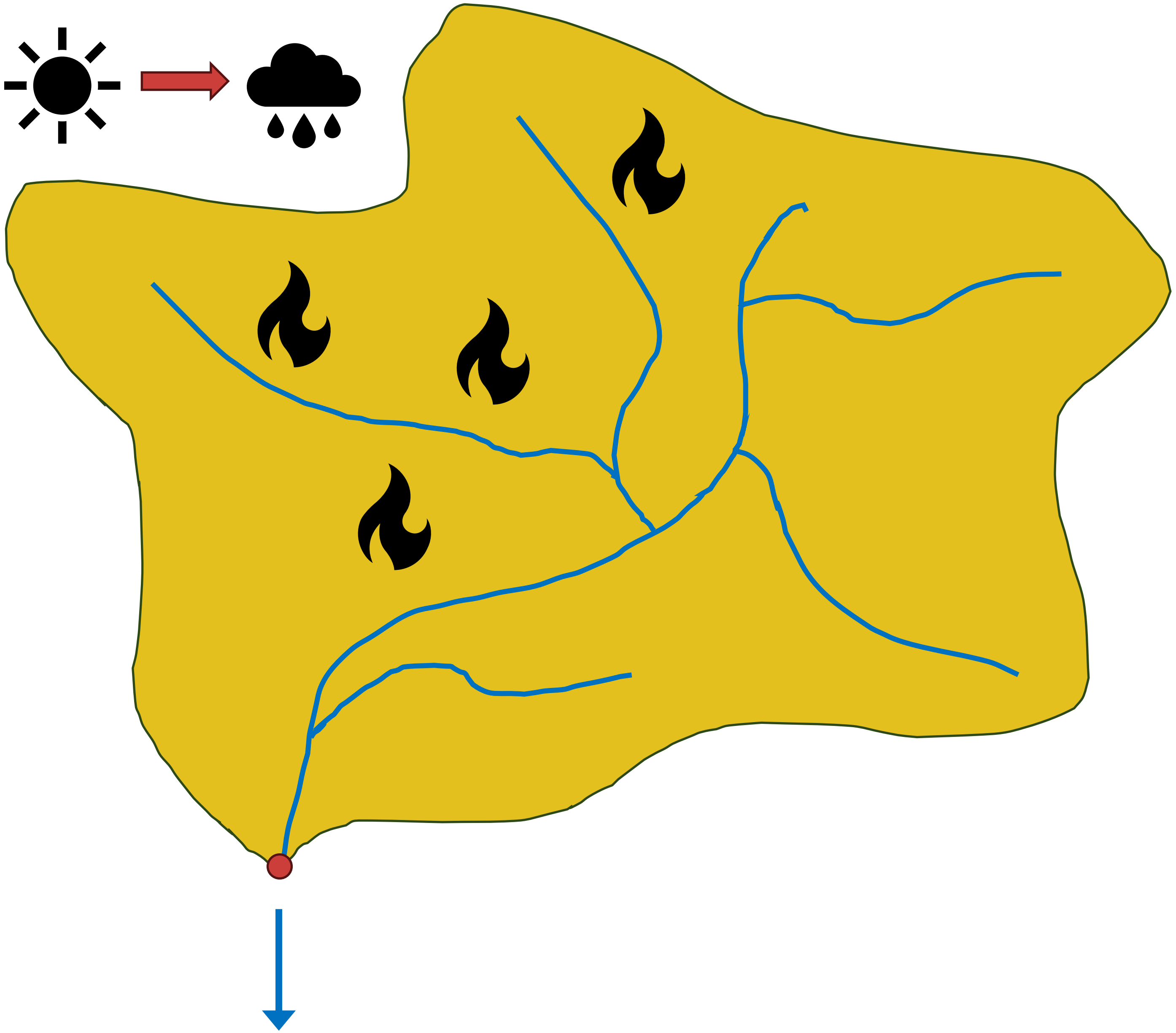
Vegetation

- **decreased transpiration** > **higher stormflow** response after drought (Scaife & Band (2017)
- **increased transpiration** > **lower streamflow** after drought (Peterson et al., 2021)



Soil & vegetation

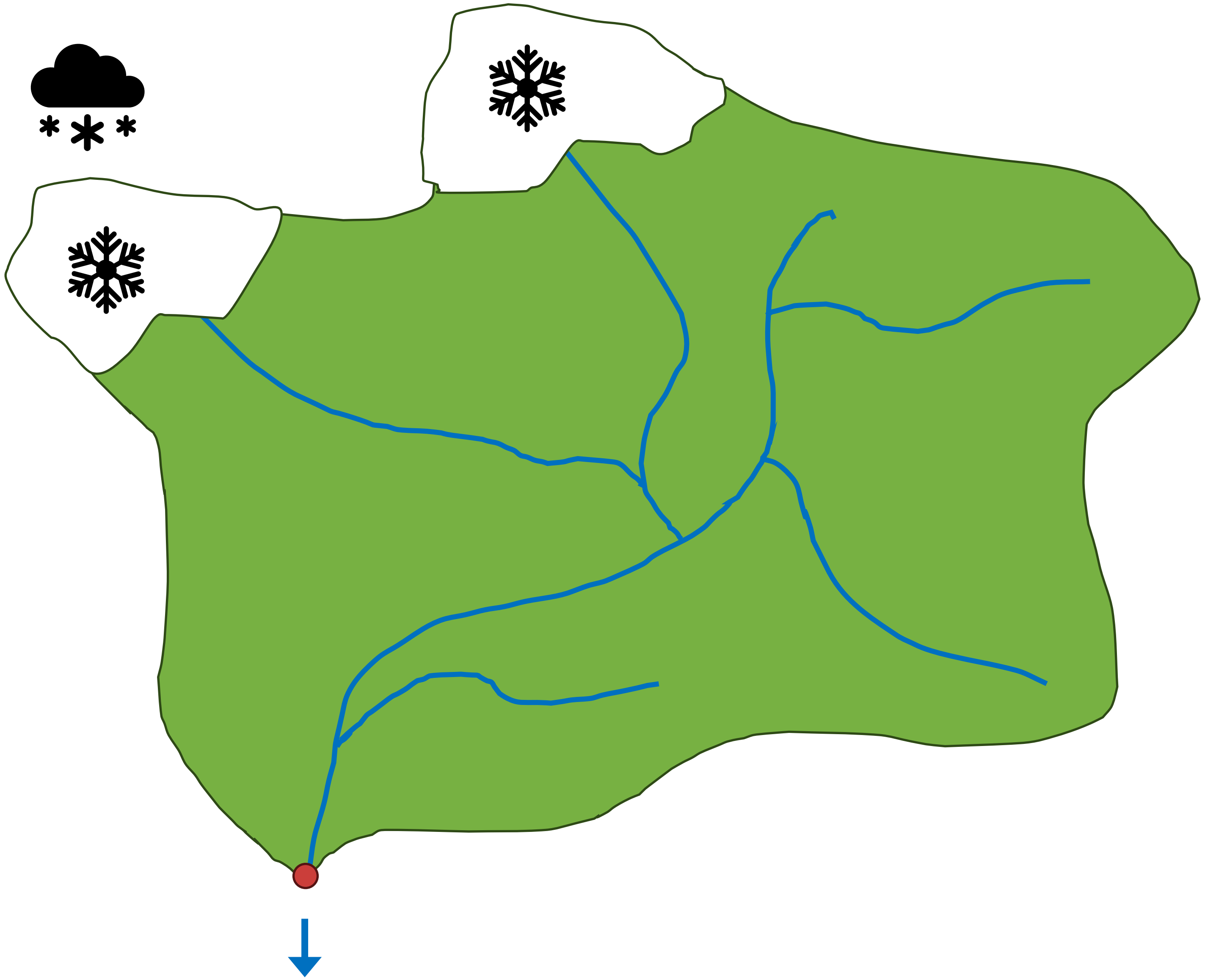
- drought-induced **wildfires** change flow pathways (Murphy et al., 2018)
- increase the risk of **flash floods**, debris flows & landslides (Moftakhari & AghaKouchak, 2019)



Snow

- decreased snowfall & more melt during winter > lower snowmelt peak in spring > lower snowmelt floods (Van Loon et al., 2015; Tabari, 2020)

- midwinter peak runoff & rain-on-snow events (Hatchett and McEvoy, 2018; Freudiger et al., 2014; Musselman et al., 2018)



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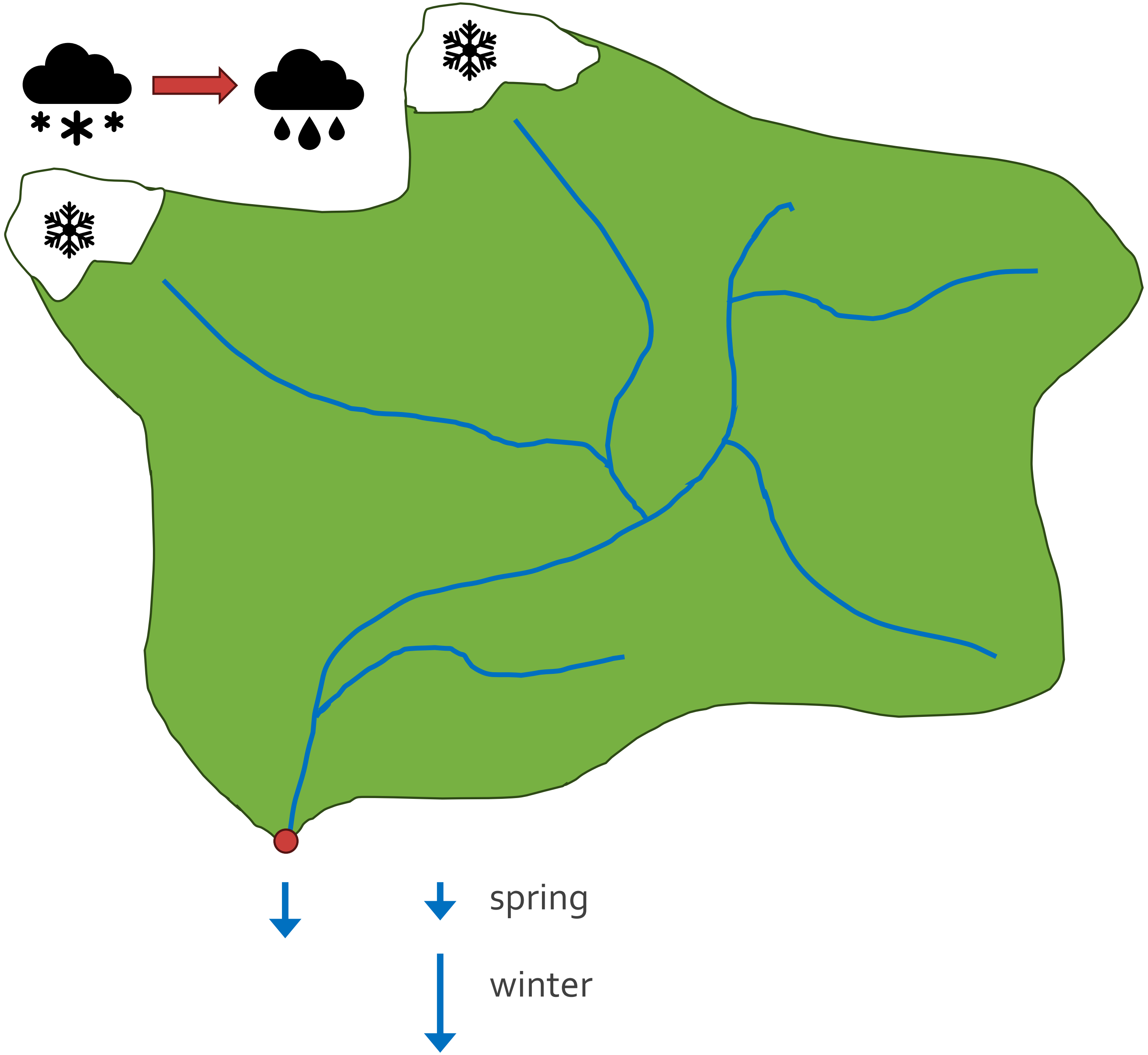
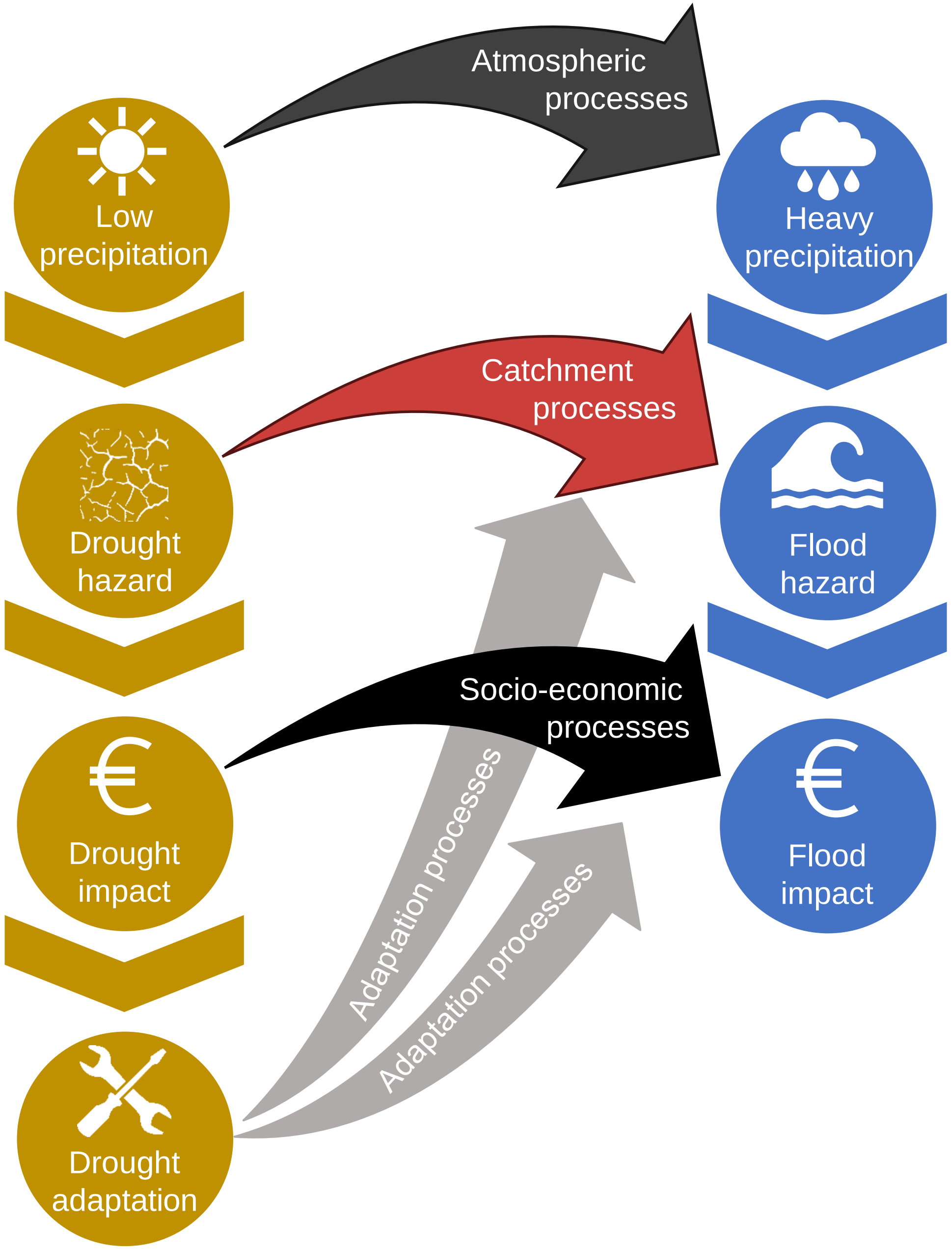


Catchment processes

- land-surface processes (soil, vegetation, snow)
- **(sub)surface storage processes (groundwater, reservoirs)**



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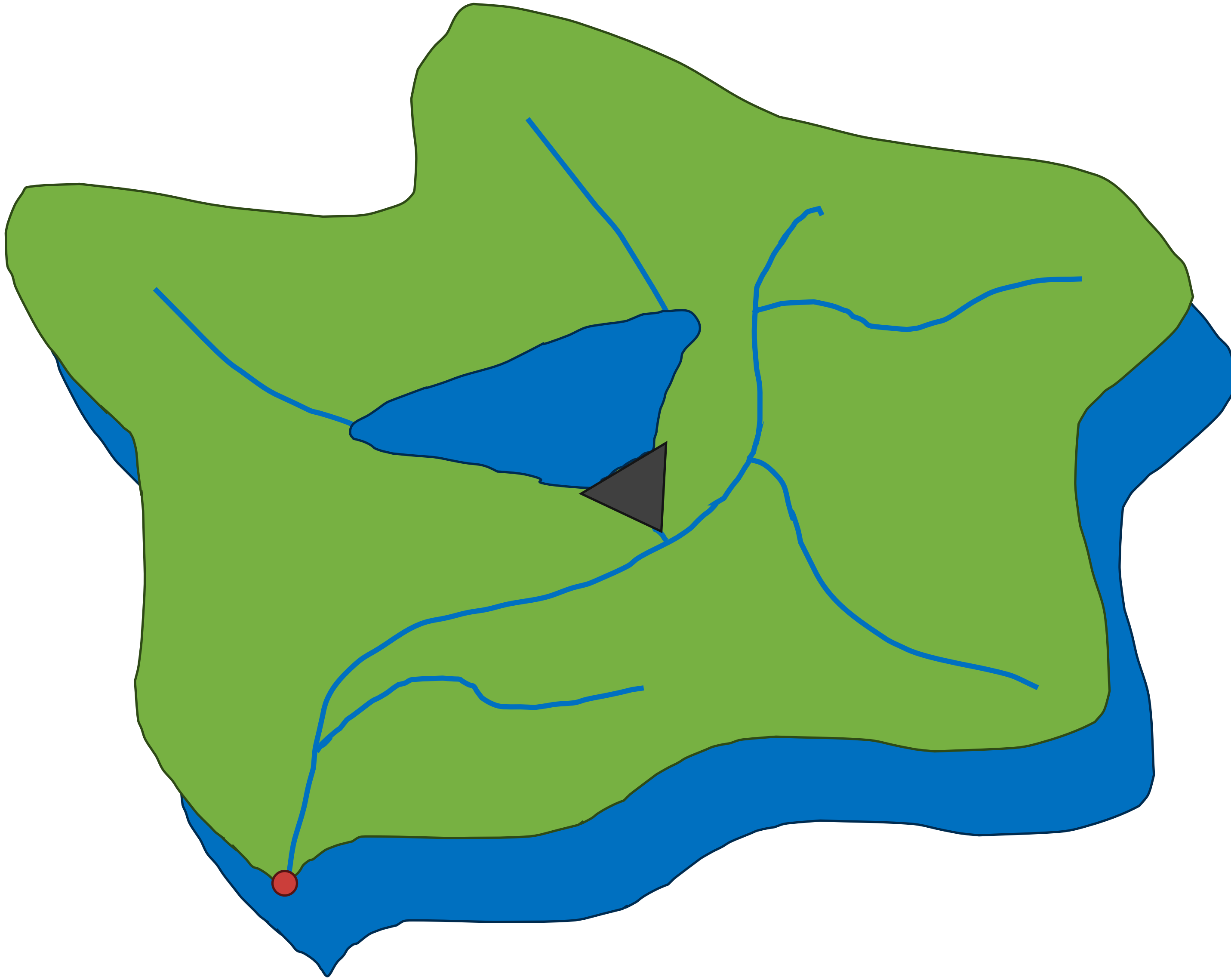
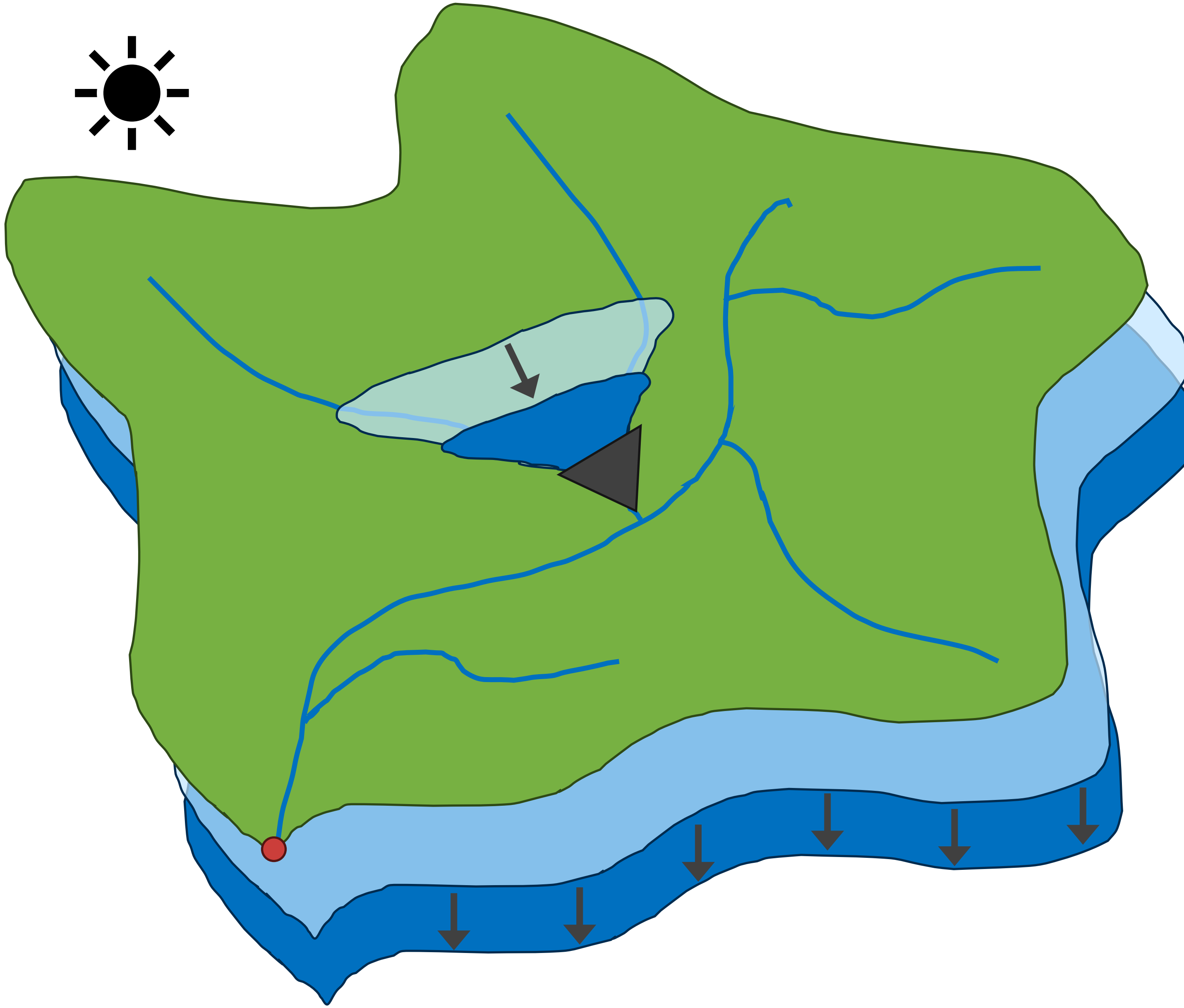
Storage

- groundwater
- reservoirs



Storage

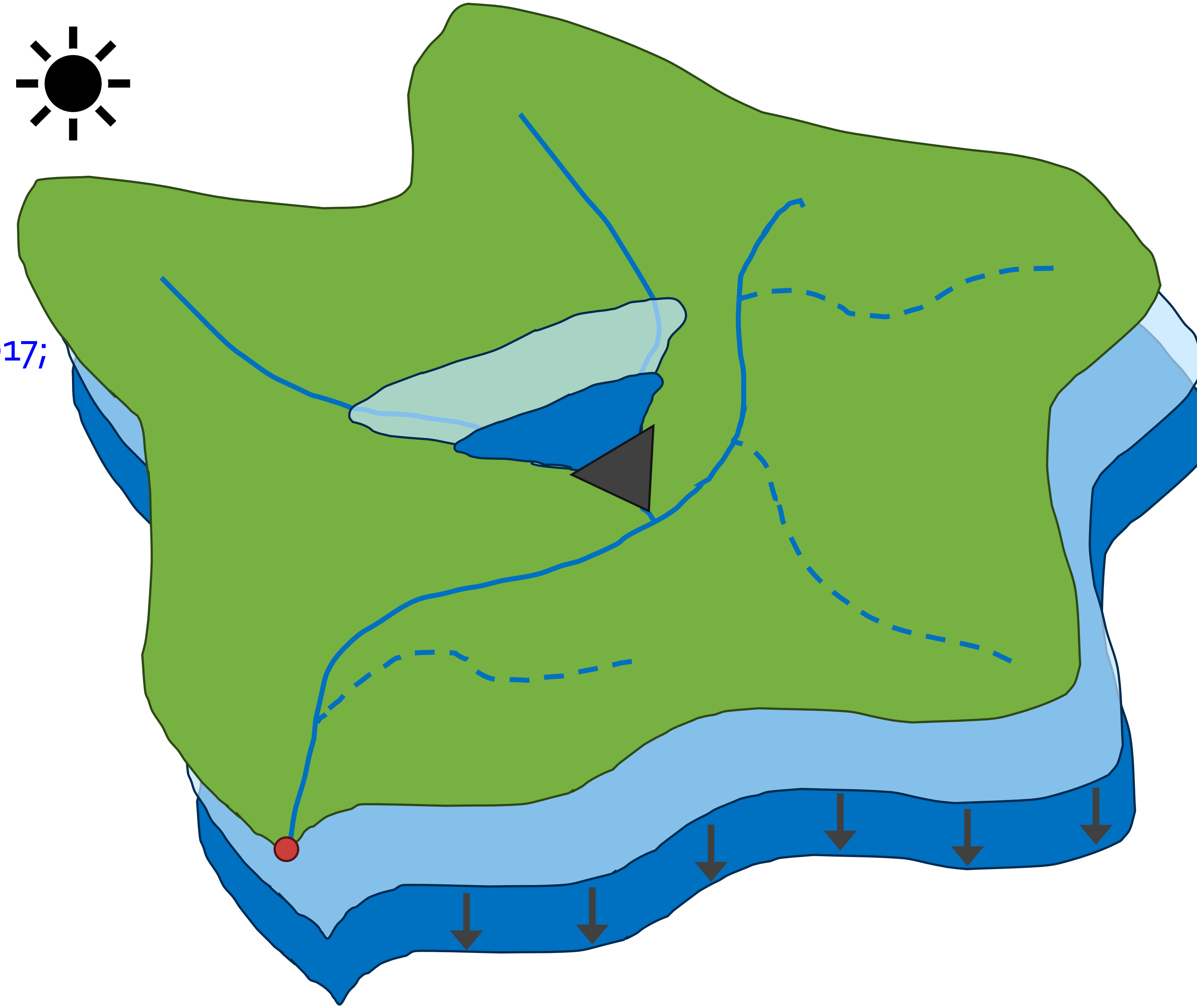
- drought > storage depletion > needs refilling before flooding can occur



Lake Oroville – California, USA

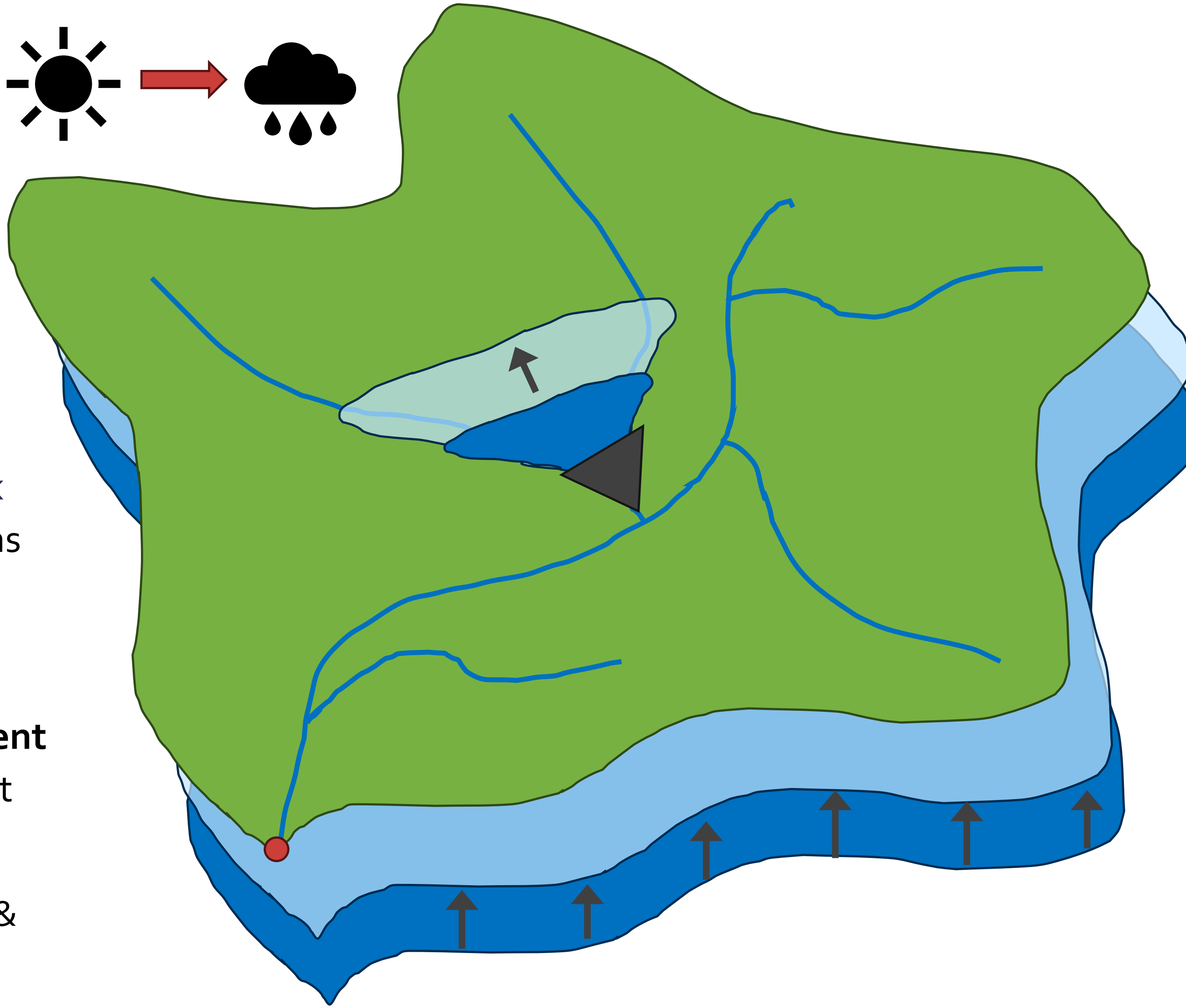
Storage

- **groundwater disconnection** (Yang et al., 2017; Saft et al., 2016; Garreaud et al., 2017)



Storage

- **groundwater disconnection** (Yang et al., 2017; Saft et al., 2016; Garreaud et al., 2017)
- **dry antecedent conditions > lower flood peak** (Berghuijs et al., 2016; Blöschl et al., 2015; Evans et al., 1999; Pathiraja et al., 2012; Brauer et al., 2011; Parry et al., 2013)
- **rate & duration of drought recovery, dependent on climate & catchment properties** (Ganguli et al., 2022; Parry et al., 2016; Yang et al., 2017)
  - elevation, slope, average catchment wetness & soil conditions

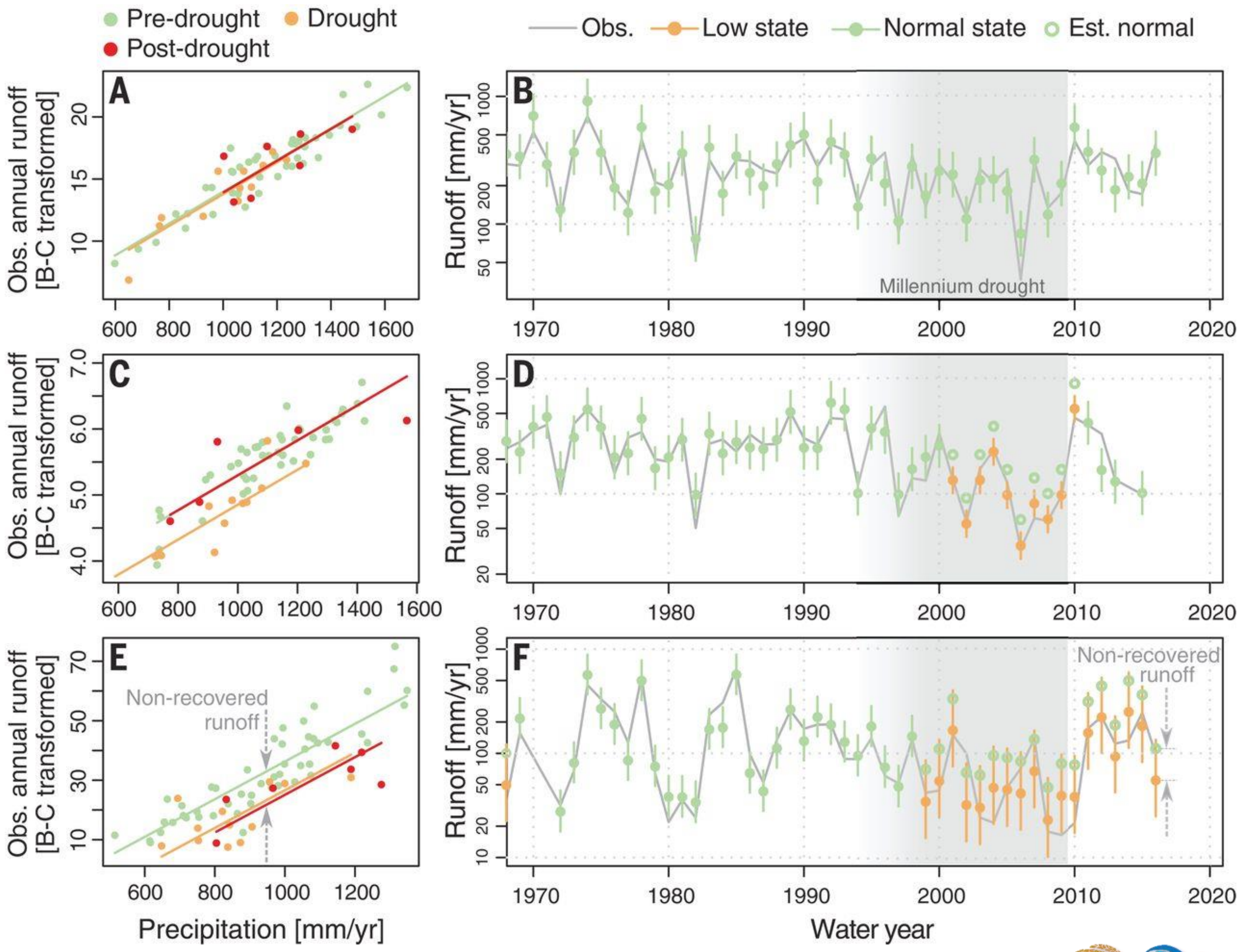


Catchment processes

- Saft et al. (2016): **lower** rainfall-runoff **during and after** drought in catchment with:
  - high aridity (Garreaud et al., 2017)
  - broad and flat valleys
  - deep soils
  - more groundwater variability
- Maurer et al. (2022): **higher** rainfall-runoff response **during** drought than expected in basins with:
  - low aridity
  - high baseflow
  - a shift from snow to rain

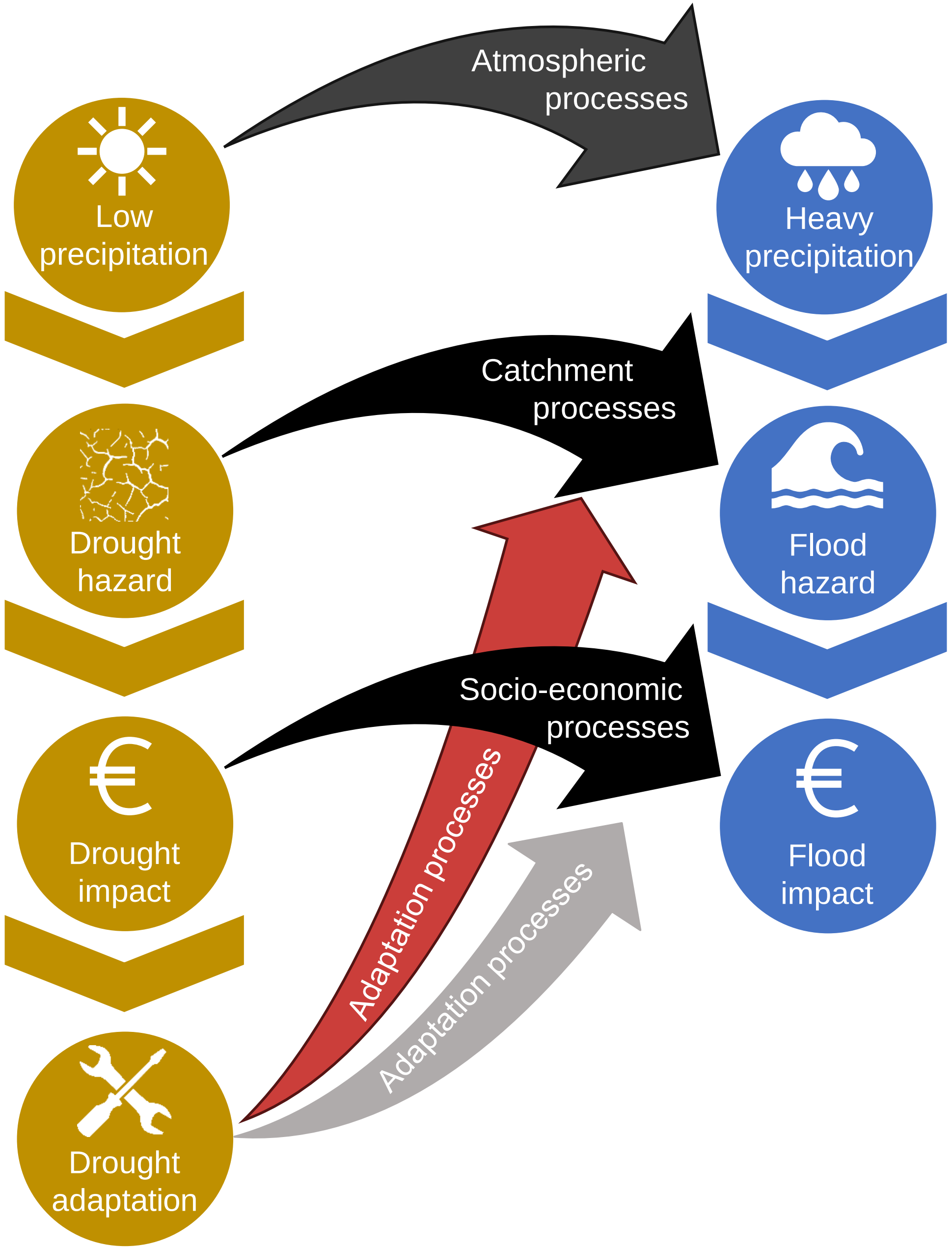
??

Peterson et al. (2021): Watersheds may not recover from drought



Adaptation processes

- Socio-hydrology



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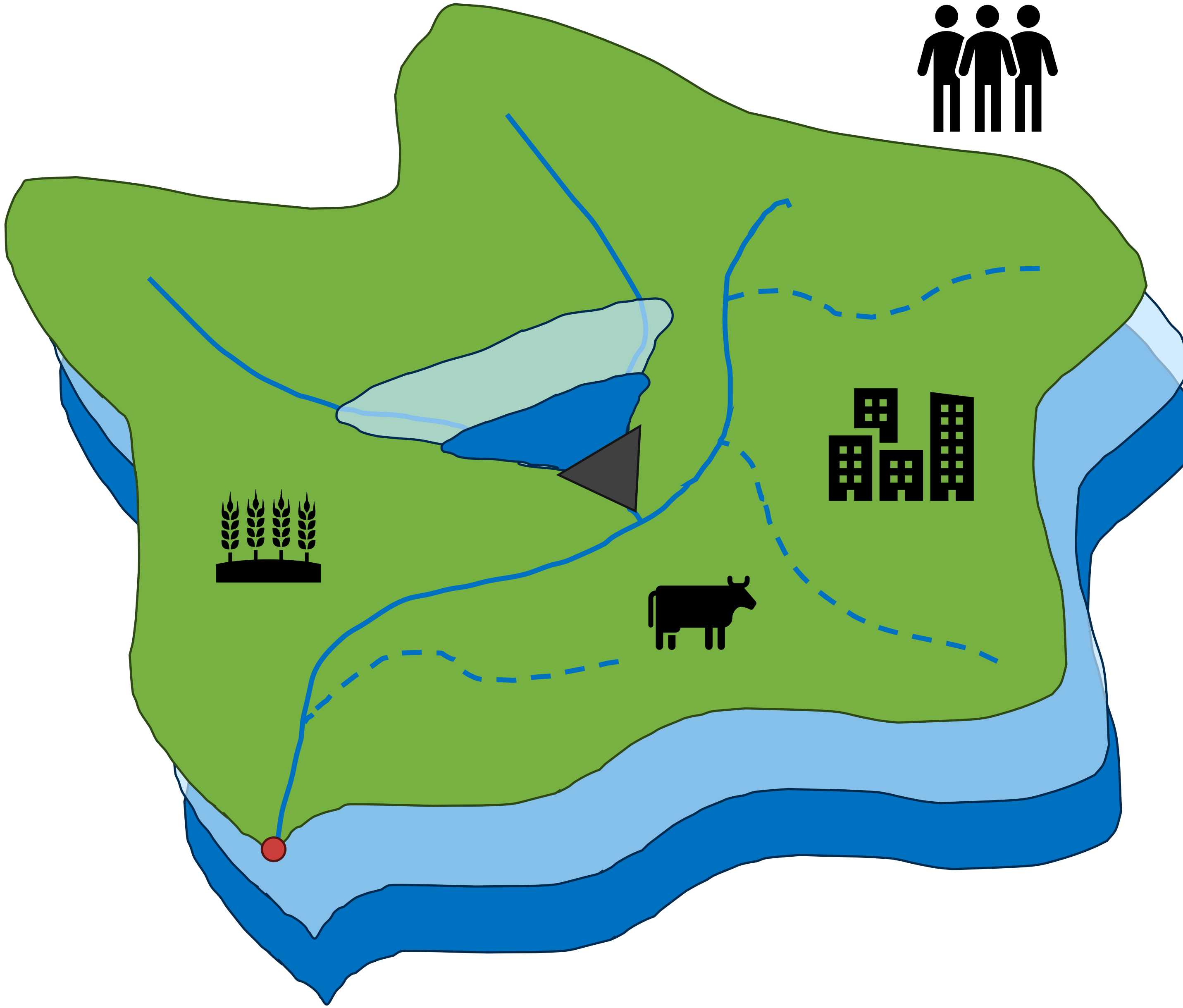
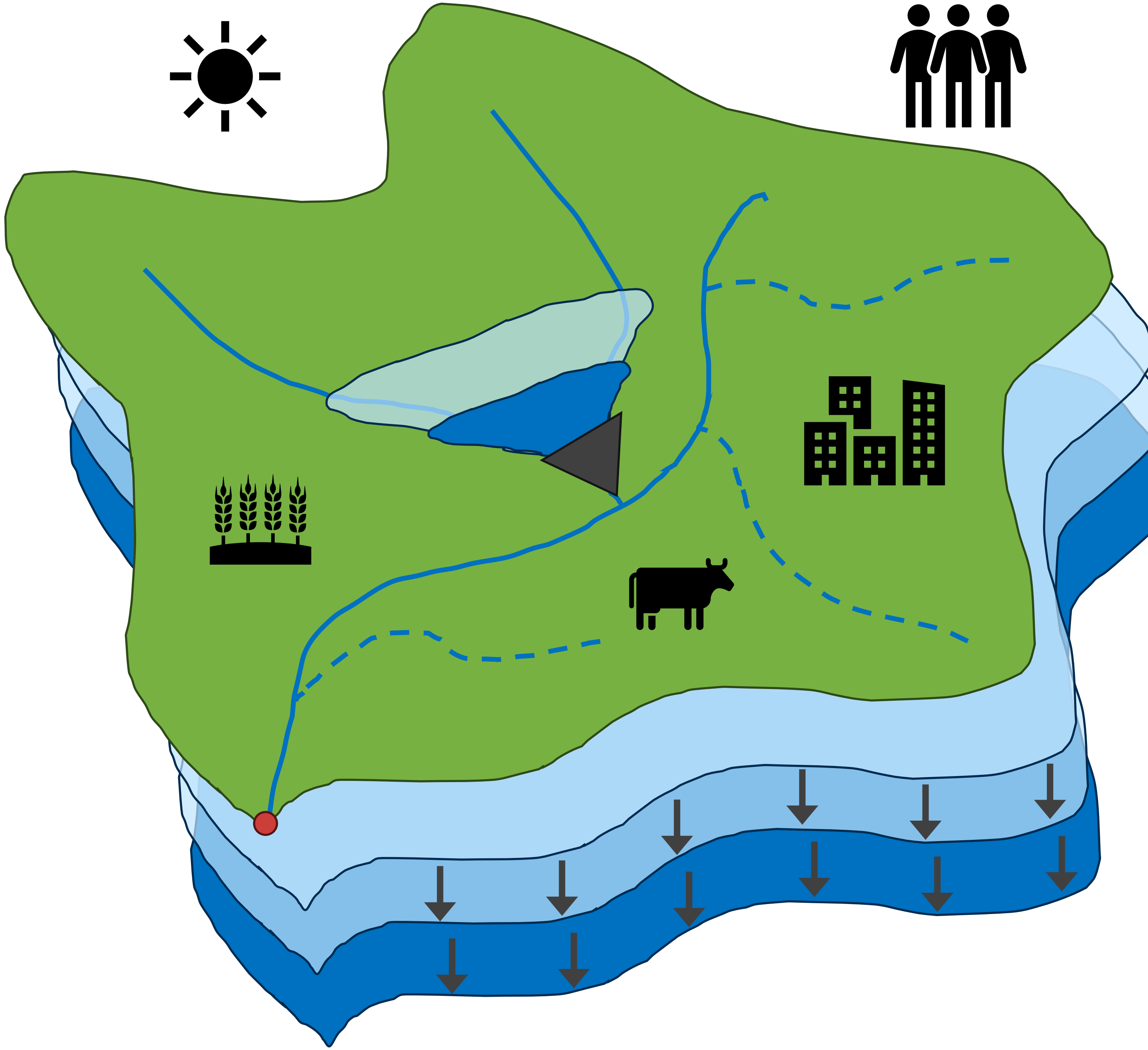
Adaptation processes



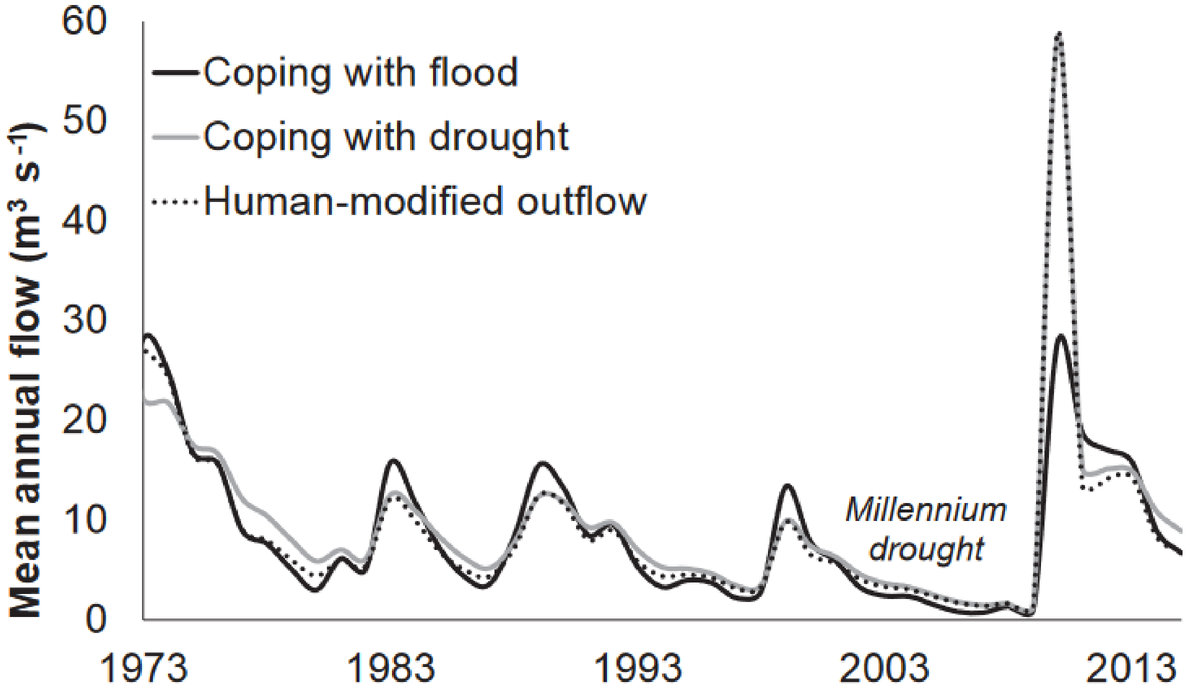
Adaptation processes

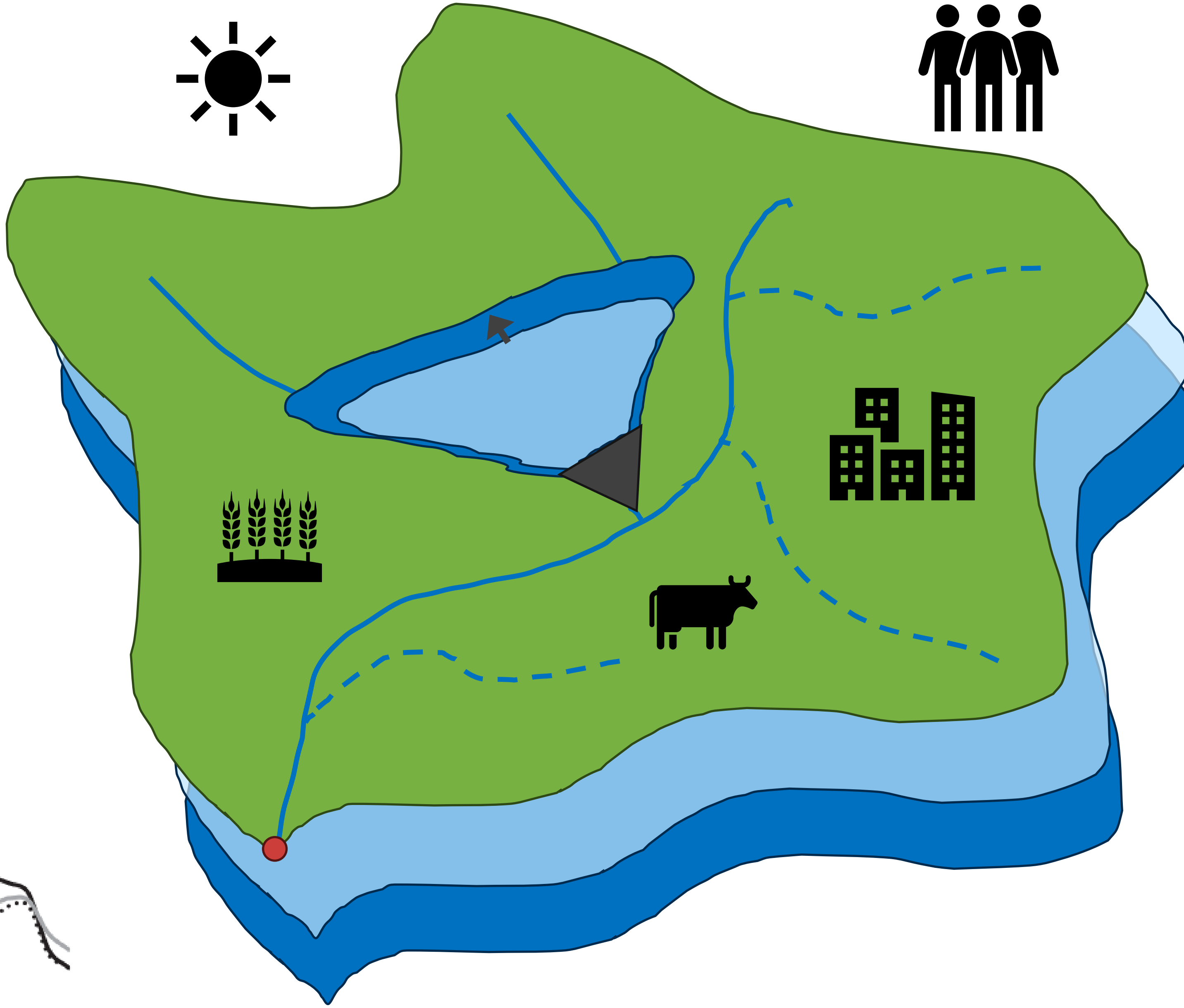
- **groundwater abstraction**: more storage space > **lower flood peak** (Apurv et al., 2017; Margariti et al., 2019)



Adaptation processes

- **reservoir operation** rules changed to save water > **higher flood peak** (Di Baldassarre et al., 2017)

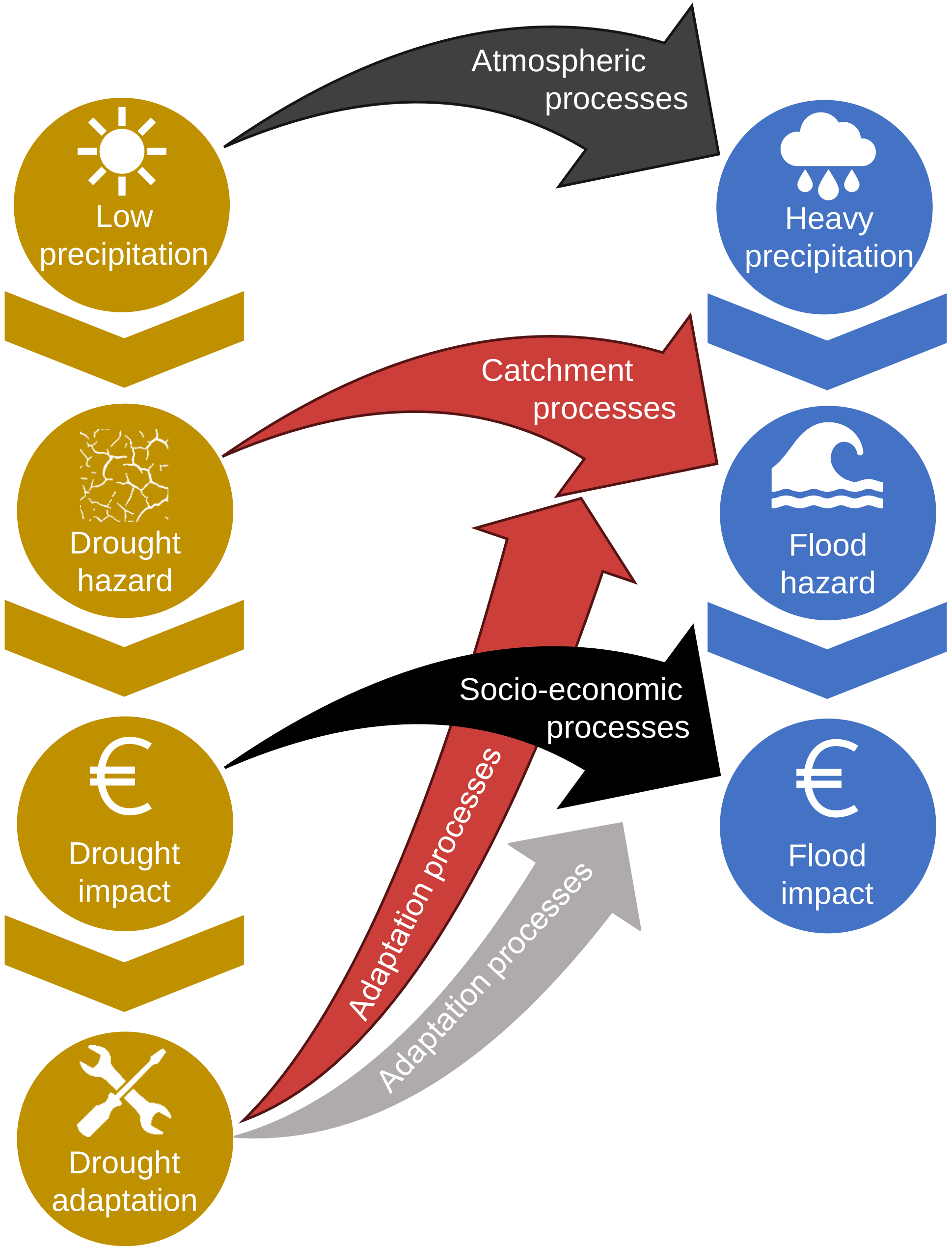




Di Baldassarre et al. (2017): Drought and flood in the Anthropocene: feedback mechanisms in reservoir opera…

What have we found with global document & data analysis?

- Evidence for both drought-induced surface runoff and depleted storage refilling
- Many floods after droughts are flash floods
- Riverine floods: mostly later flooding, some earlier
- Sensitivity of streamflow to precipitation decreased due to drought

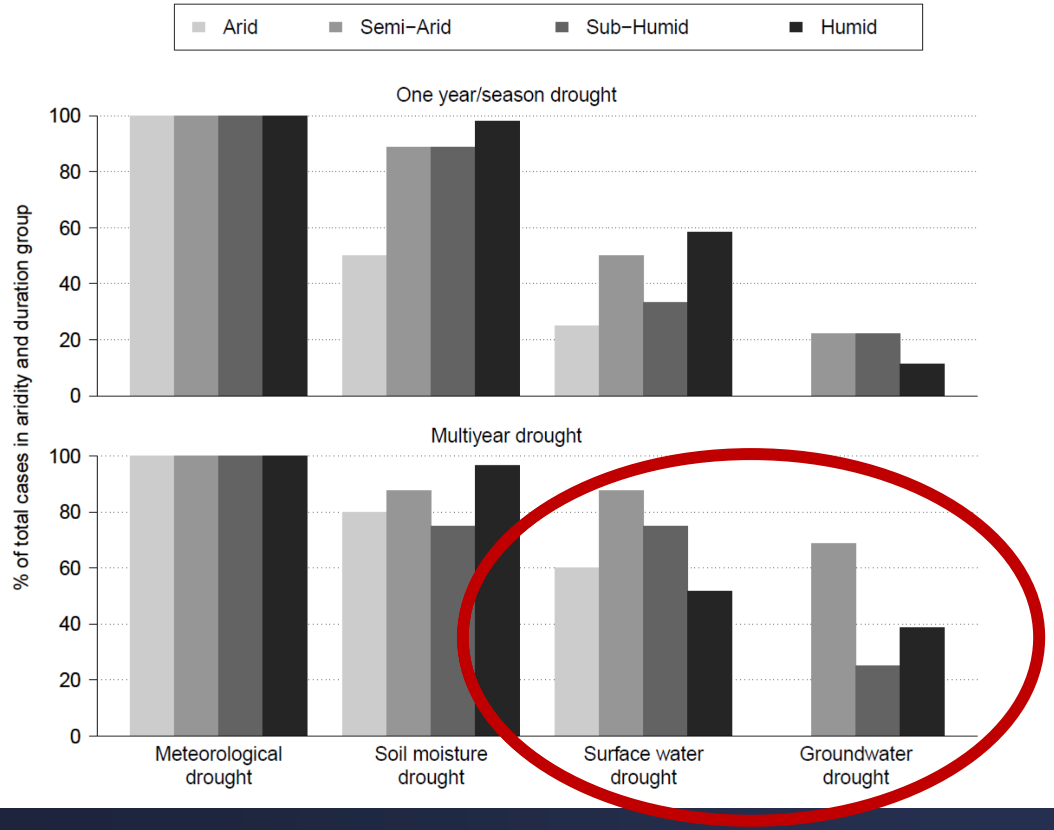


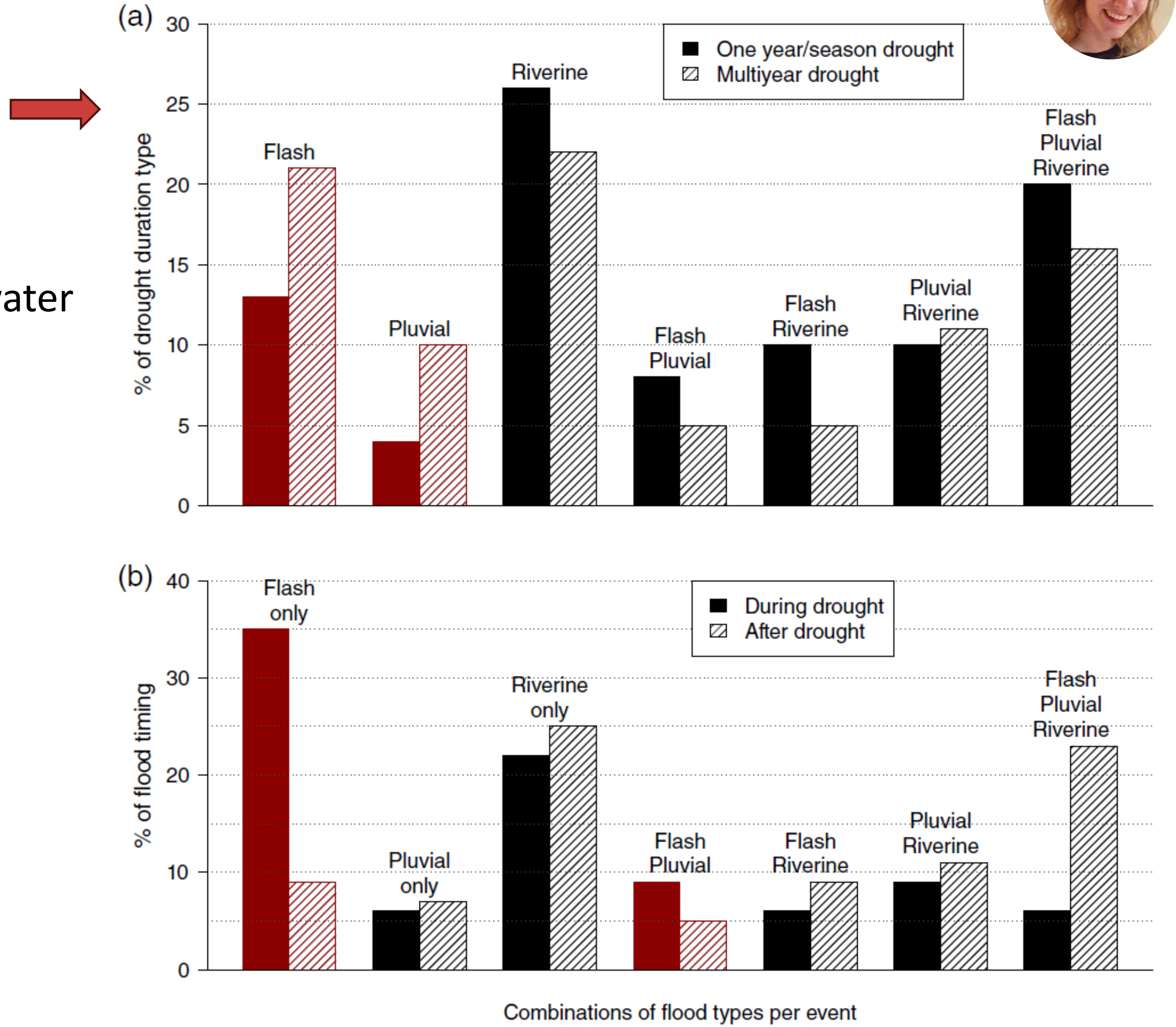
Barendrecht et al. (2024): Exploring drought-to-flood interactions and dynamics: A global case review, *Wires Water*

Methods: 192 events, from news, reports, websites

Marlies Barendrecht

- flash & pluvial floods: reported more after multiyear than within-year drought
- flash floods: reported more during than after drought
- multi-year drought > surface water & groundwater depletion (mostly in semi-arid regions)

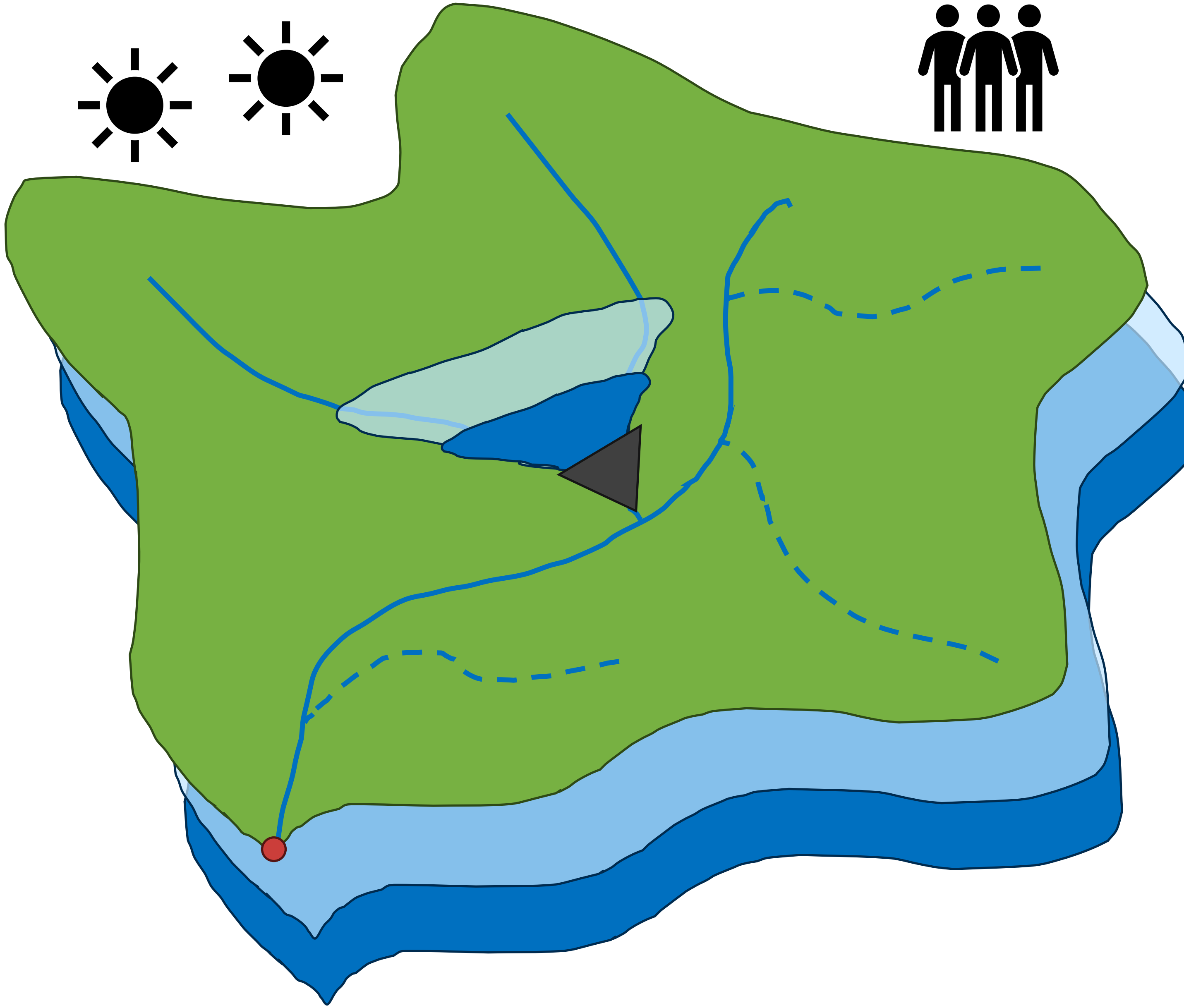




Barendrecht et al. (2024): Exploring drought-to-flood interactions and dynamics: A global case review

Adaptation processes

Long-term changes, over several droughts

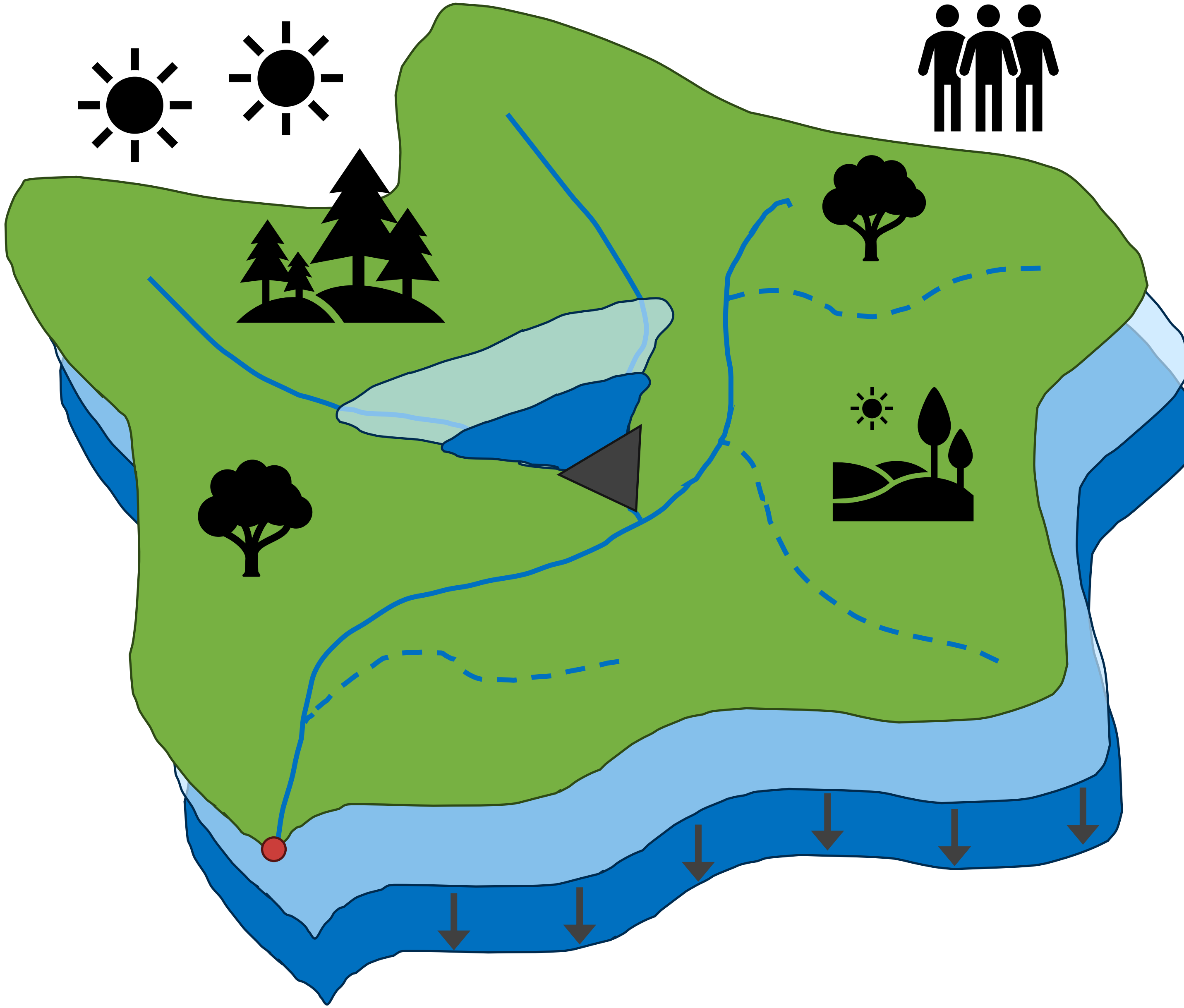


Adaptation processes

Long-term changes:

- Climate change
- Landscape changes
- Socio-economic changes

>> SOCIO-HYDROLOGICAL INTERACTIONS



Ruben Weesie

Adaptation processes

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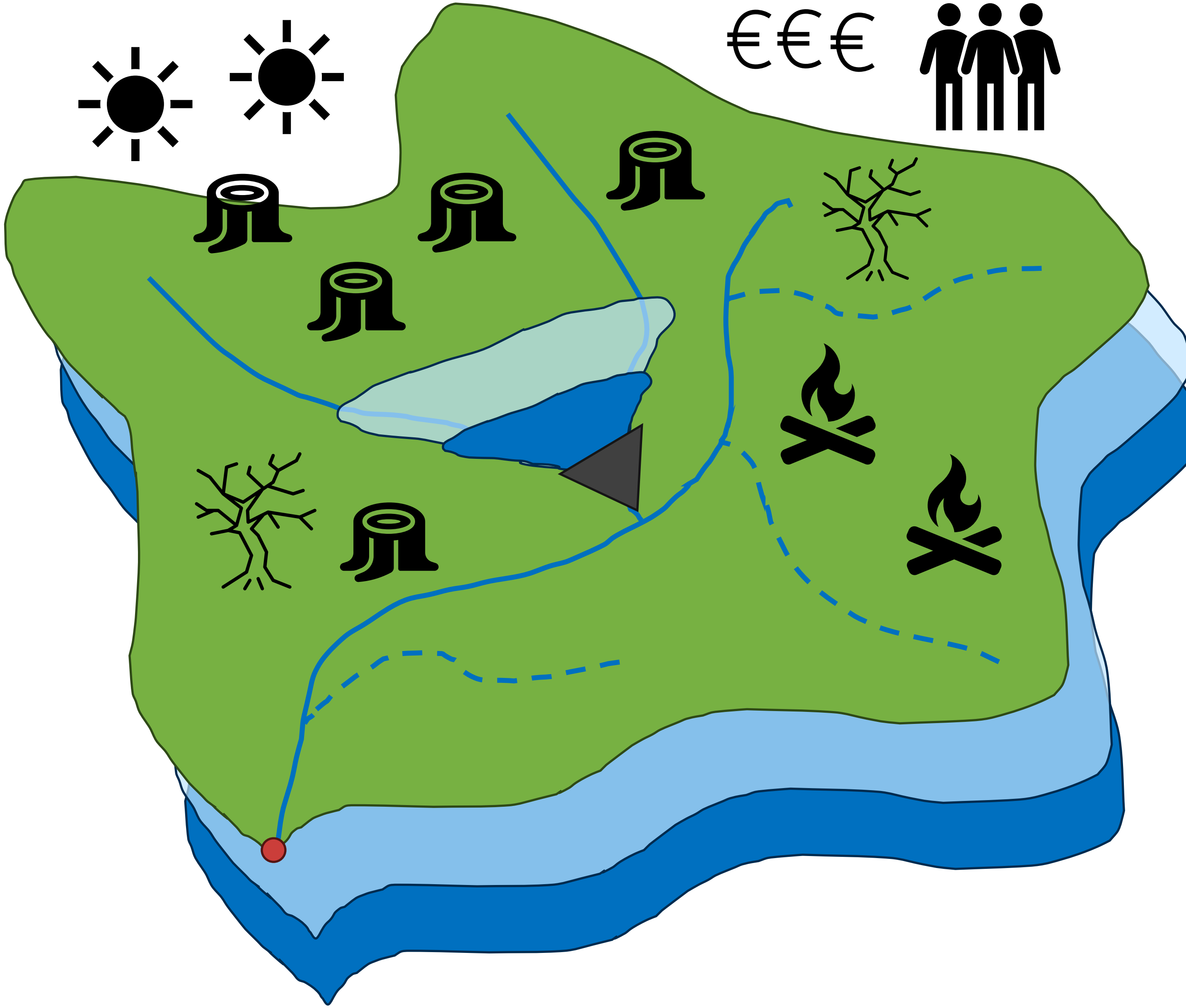
>> SOCIO-HYDROLOGICAL INTERACTIONS



Adaptation processes

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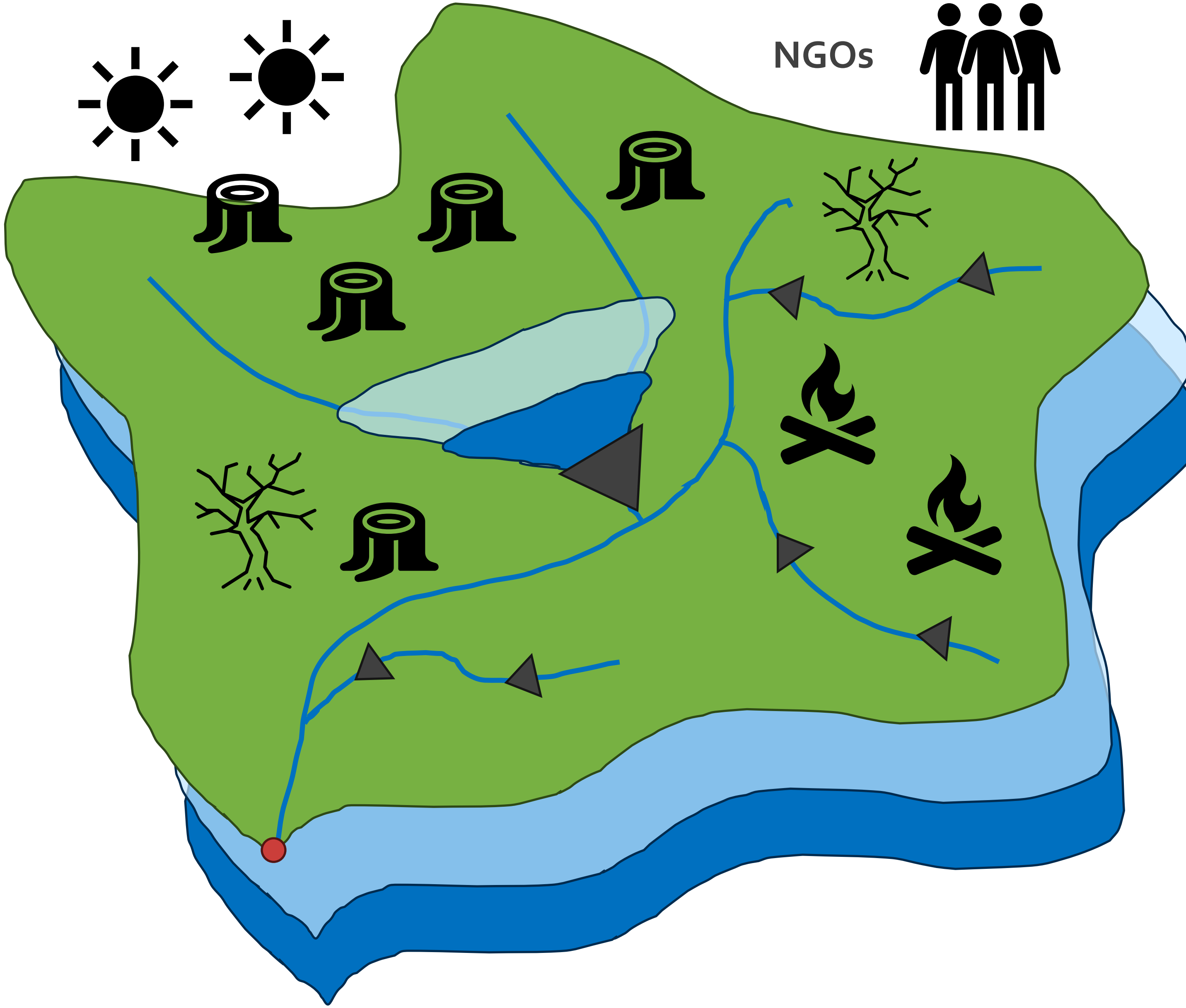

Ruben Weesie

Weesie et al. (in review): Floods after Drought: Stories of erratic waters in Southeastern Kenya, *International Journal of Disaster Risk Reduction*

Perfect STORM

Adaptation processes

Long-term changes:

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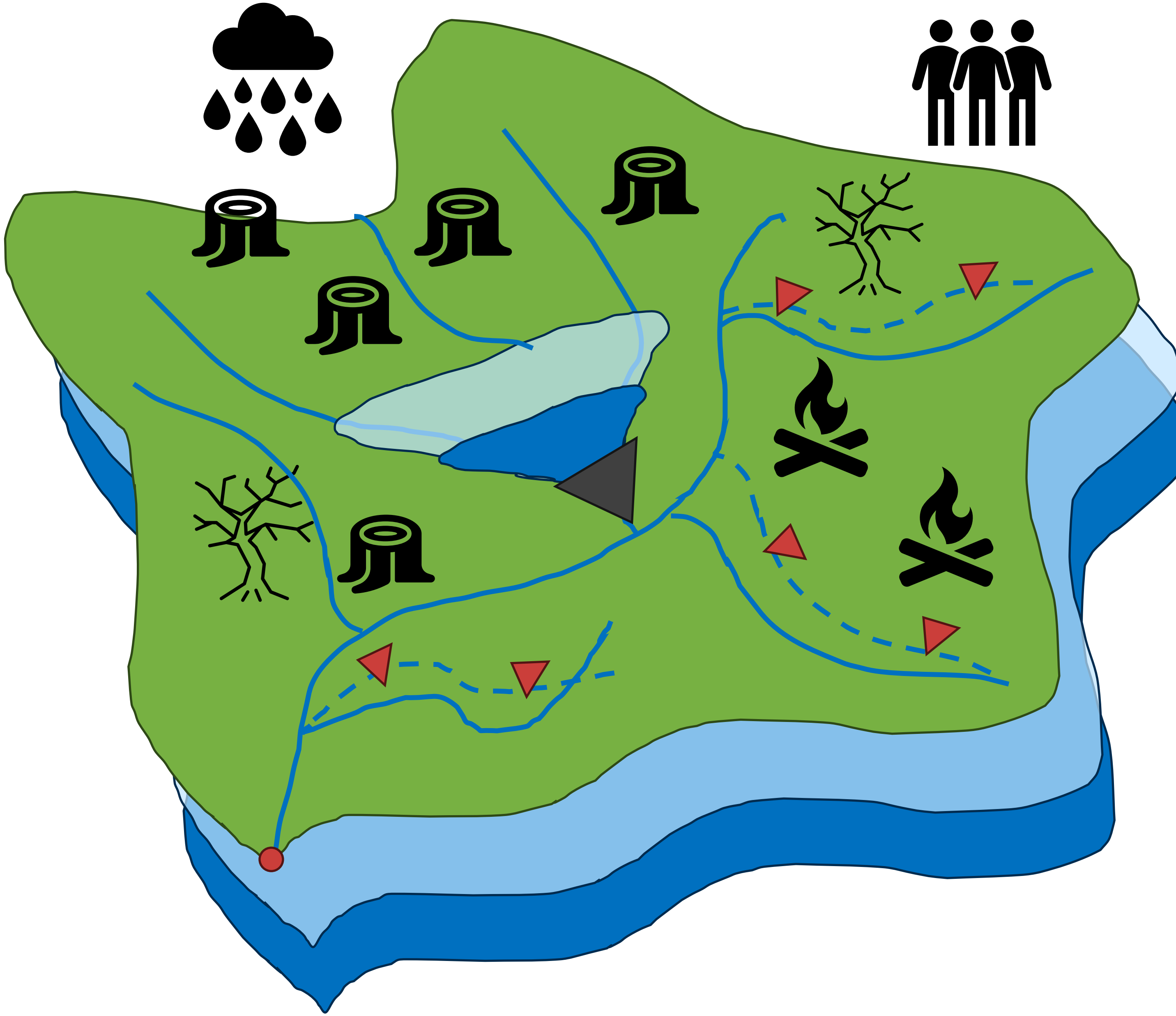
>> SOCIO-HYDROLOGICAL INTERACTIONS

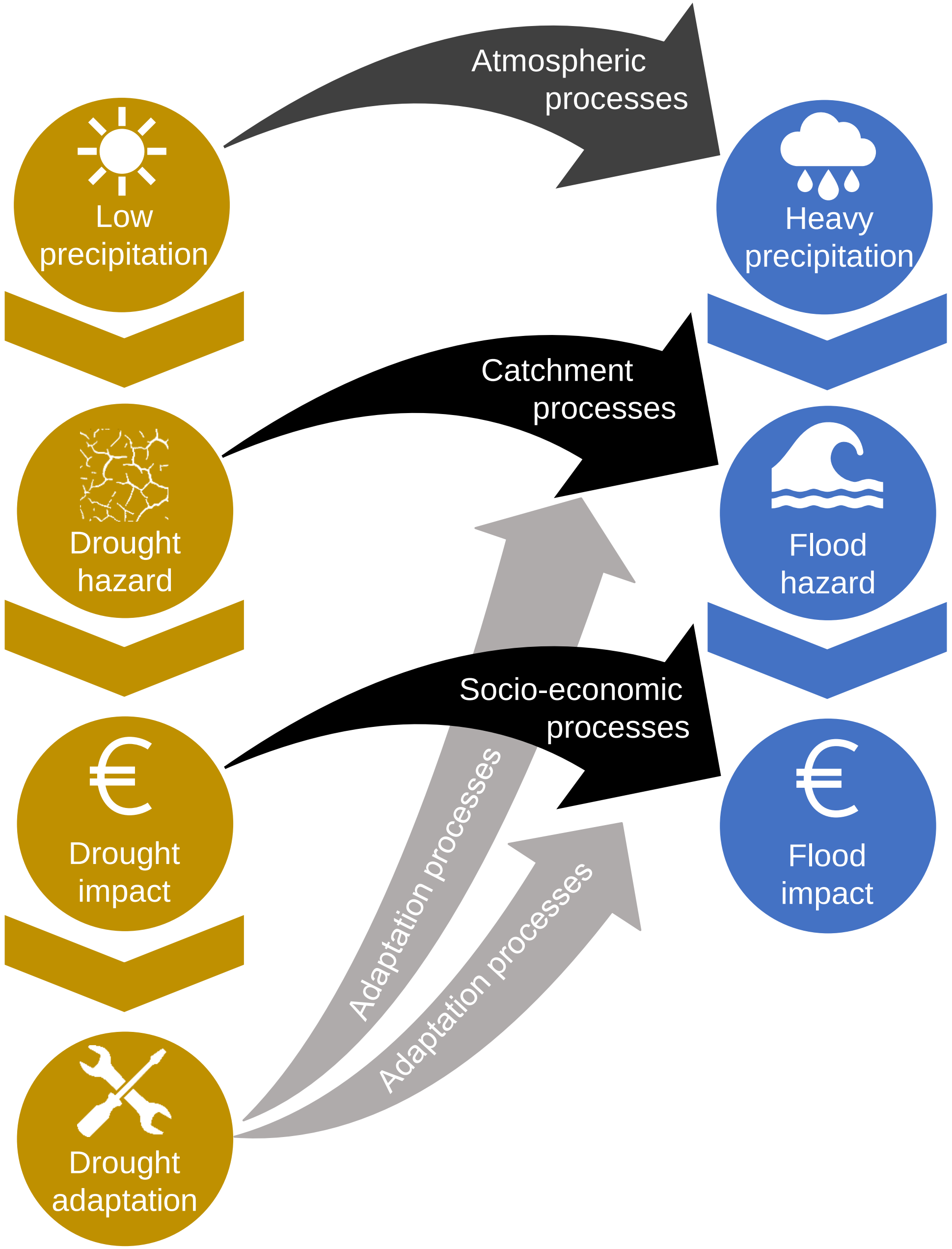


Ruben Weesie

What do we NOT know (enough)?

Still much unclear about how drought changes land-surface and subsurface socio-hydrological processes

- Role of vegetation
- Land-surface soil processes at catchment scale
- Effect of drought adaptation strategies on flood risk
- Use of flood water to restore depleted subsurface storage



Barendrecht et al. (2024): Exploring drought-to-flood interactions and dynamics: A global case review, *Wires Water*

Do droughts cause more or less flooding?

1) It's complicated; 2) We need more science

THANK YOU

Anne Van Loon & the PerfectSTORM team

Alessia Matanó, Marlies Barendrecht, Ruben Weesie, Heidi Mendoza, Maurizio Mazzoleni, Philip Ward, Marleen De Ruiter, Wouter Berghuijs, Manuela Brunner, Giuliano Di Baldassarre, Margaret Garcia, Jeroen Aerts, Johanna Koehler, Melanie Rohse, Rosie Day, Moses Mwangi, Juan Bazo, Jahir Anicama & Danai Kontou

IVM Institute for Environmental Studies

VU VRIJE UNIVERSITEIT AMSTERDAM