IVM Institute for Environmental Studies

VU VRIJE UNIVERSITEIT AMSTERDAM

Drought as a continuum

Anne van Loon & Drought in the Anthropocene group

26 June 2024

Drought in the Anthropocene workshop Uppsala – August 2022

IVM Institute for Environmental Studies

DROUGHT IN THE ANTHROPOCENE NETWORK

Consecutive drought impacts

Photos by Teun Schrieks (Kenya, May 2022)

THE THREAT OF STARVATION LOOMS IN EAST AFRICA AFTER FOUR FAILED RAINY SEASONS

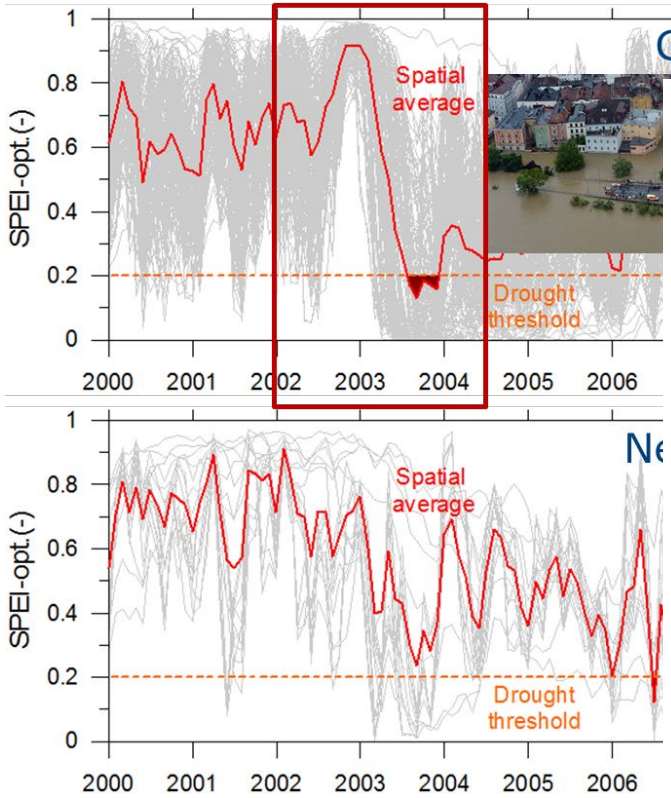
SITUATION MAY WORSEN DUE TO PROSPECTS OF AN UNPRECEDENTED FIFTH POOR SEASON BETWEEN OCTOBER AND DECEMBER

The following statement is a joint alert by meteorological agencies and humanitarian partners.

30 May, 2022; Nairobi, Kenya: The current extreme, widespread, and persistent multi-season drought affecting Somalia, the arid and semi-arid lands of Kenya, and Ethiopia's *Belg*-receiving and eastern and southern pastoral areas, is unprecedented. **Four consecutive rainy seasons have failed, a climatic event not seen in at least 40 years.** The latest long-lead seasonal forecasts, supported by a broad consensus from meteorological experts, indicate that there is now a **concrete risk that the October-December (OND) rainy season could also fail.**[1,2] Should these forecasts materialize, the already severe humanitarian emergency in the region would further deepen.

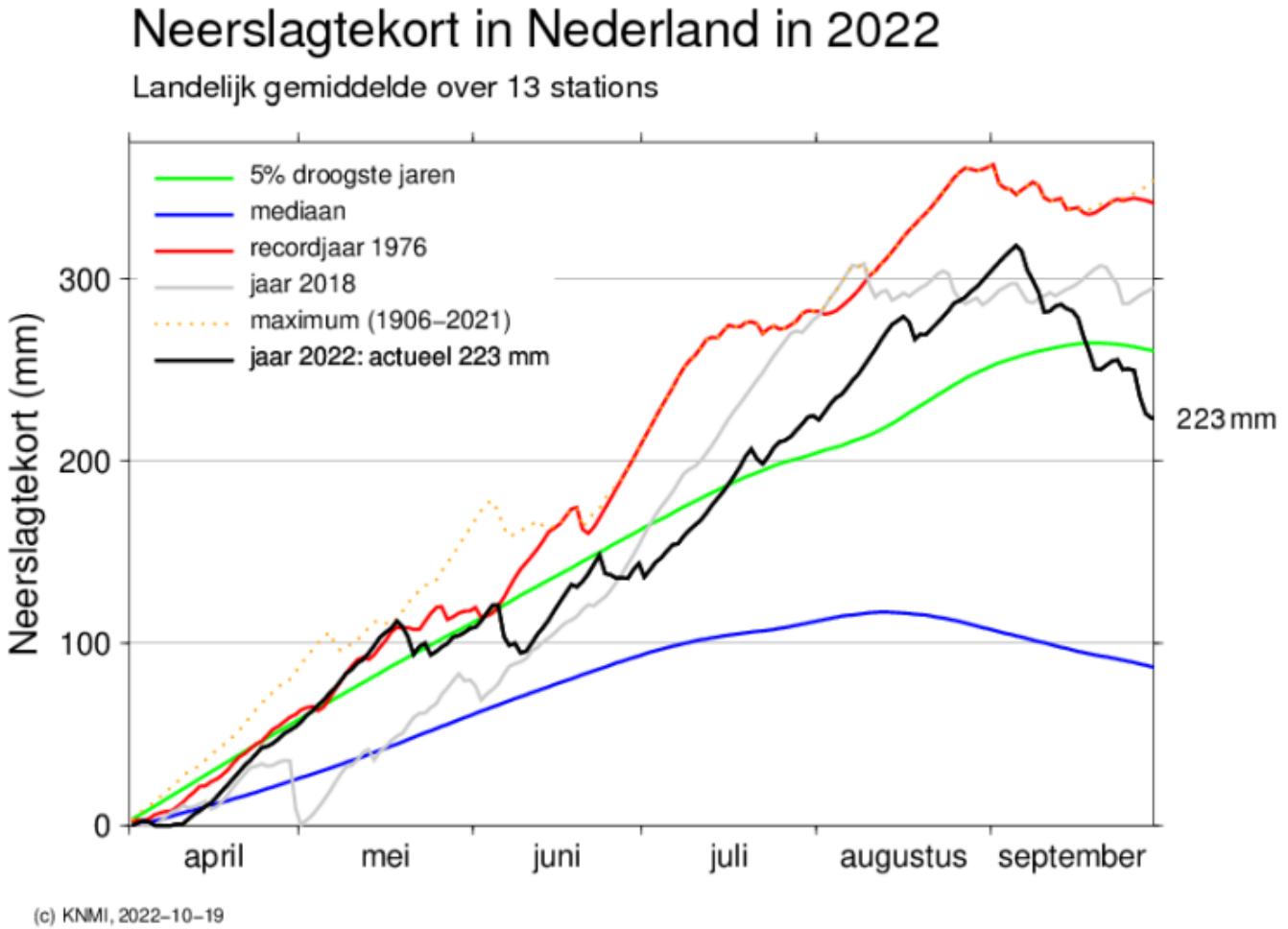
Food Security and Nutrition Working Group (FSNWG) estimates that **16.7 million people currently face high acute food insecurity** and projects figures to increase to 20 million people by September.

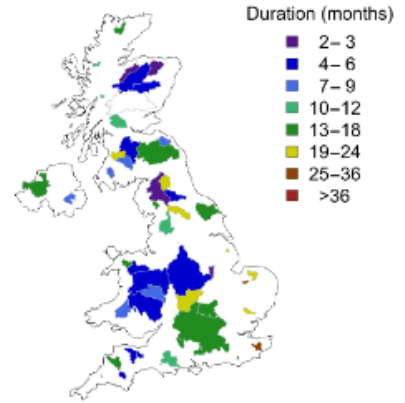
Effect of wet periods on drought - Drought recovery / termination

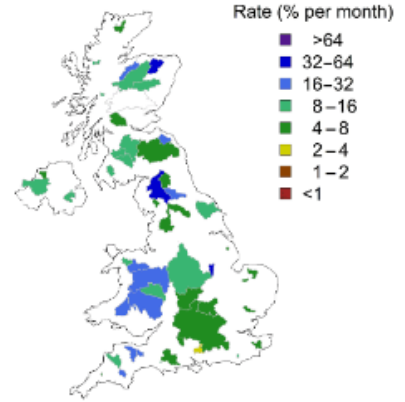


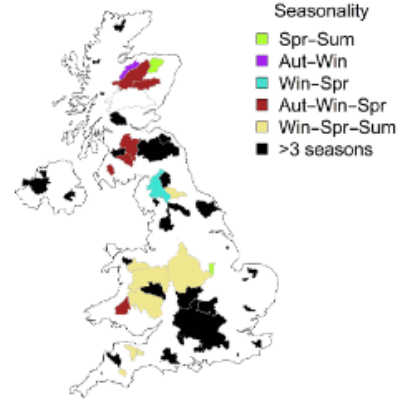
2015 groundwater drought wa
than 2003 because of dry pre-

Van Loon et al. (2017). Testing the use of standardised i
and GRACE satellite data to estimate the European 201
groundwater drought in near-real time, *Hydrol. Earth Sys*

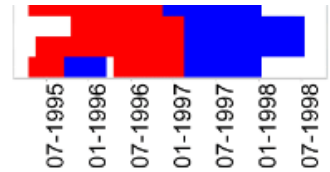








characteristics



Parry, S., Wilby, R. L., Prudhomme, C., & Wood, P. J. (2016). A systematic assessment of drought termination in the United Kingdom. *Hydrology and Earth System Sciences*.

WHY WE SHOULD NOT SEE DROUGHT AS AN EVENT

- The combination of short rainfall deficits, snow accumulation in winter and groundwater response over several years cause superposition of drought signals in the hydrological system. The longer-term processes are not always considered in drought monitoring.
- Drought impacts are gradual, indirect and lagged. Impact monitoring is binary (drought vs. no drought) and often limited to specific “drought” periods.
- Social vulnerability is highly dynamic, but often treated as static.
- Ecosystem and societal collapse can only be understood by considering background vulnerability, multiple stressors over time and resilience / recovery.
- Adaptation responses affect the system at different timescales. Drought can trigger adaptation, which can make a system more resilient or less resilient (maladaptation) over time. Responses are rarely considered.
- Short-term crisis management is implemented during drought, but during wet periods drought memory fades quickly, preventing implementation of proactive measures (hydro-illogical cycle).

Drought as a continuum paper

literature review + case studies

https://egusphere.copernicus.org/preprints/2024/egusphere-2024-421/

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Abstract Discussion Metrics

20 Feb 2024

Review article: Drought as a continuum: memory effects in interlinked hydrological, ecological, and social systems

Anne F. Van Loon, Sarra Kchouk, Alessia Matanó, Faranak Tootoonchi, Camila Alvarez-Garreton, Khalid E. A. Hassaballah, Minchao Wu, Marthe L. K. Wens, Anastasiya Shyrokaya, Elena Ridolfi, Riccardo Biella, Viorica Nagavciuc, Marlies H. Barendrecht, Ana Bastos, Louise Cavalcante, Franciska T. de Vries, Margaret Garcia, Johanna Mård, Ileen N. Streefkerk, Claudia Teutschbein, Roshanak Tootoonchi, Ruben Weesie, Valentin Aich, Juan P. Boisier, Giuliano Di Baldassarre, Yiheng Du, Mauricio Galleguillos, René Garreaud, Monica Ionita, Sina Khatami, Johanna K. L. Koehler, Charles H. Luce, Shreedhar Maskey, Heidi D. Mendoza, Moses N. Mwangi, Ilias G. Pechlivanidis, Germano G. Ribeiro Neto, Tirthankar Roy, Robert Stefanski, Patricia Trambauer, Elizabeth A. Koebele, Giulia Vico, and Micha Werner

Abstract. Droughts are often long lasting phenomena, without a distinct start or end, and with impacts cascading across sectors and systems, creating long-term legacies. Nevertheless, our current perception and management of droughts and their impacts is often event-based, which can limit the effective assessment of drought risks and reduction of drought impacts. Here, we advocate for changing this perspective and viewing drought as a hydro-eco-social continuum. We take a systems theory perspective and focus on how "memory" causes feedback and interactions between parts of the interconnected systems at different time scales. We first discuss the characteristics of the drought continuum with a focus on the hydrological, ecological, and social systems separately; and then study the system of systems. Our analysis is based on a review of the literature and a study of five cases: Chile, the Colorado River Basin in the US, Northeast Brazil, Kenya, and the Rhine River Basin in Northwest Europe. We find that the memories of past dry and wet periods, carried by both bio-physical (e.g. groundwater, vegetation) and social systems (e.g. people, governance), influence how future drought risk manifests. We identify four archetypes of drought dynamics: Impact & recovery; Slow resilience-building; Gradual collapse; and High resilience, big shock. The interactions between the hydrological, ecological and social systems result in systems shifting between these types, which plays out differently in the five case studies. We call for more research on drought pre-conditions and recovery in different systems, on dynamics cascading between systems and triggering system changes, and on dynamic vulnerability and maladaptation. Additionally, we argue for more continuous monitoring of drought hazards and impacts, modelling tools that better incorporate memories and adaptation responses, and management strategies that increase social and institutional memory to better deal with the complex hydro-eco-social drought continuum and identify effective pathways to adaptation.

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Short summary
Drought is a creeping phenomenon, but it is often still analysed and managed like an event...
Read more

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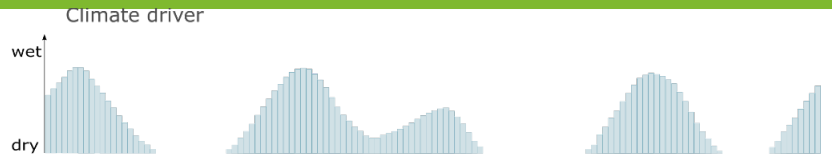
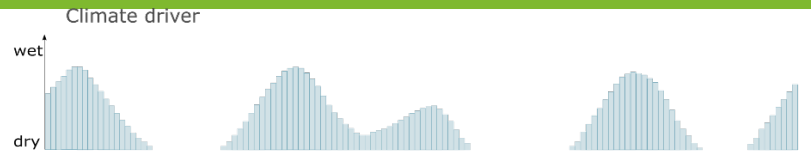
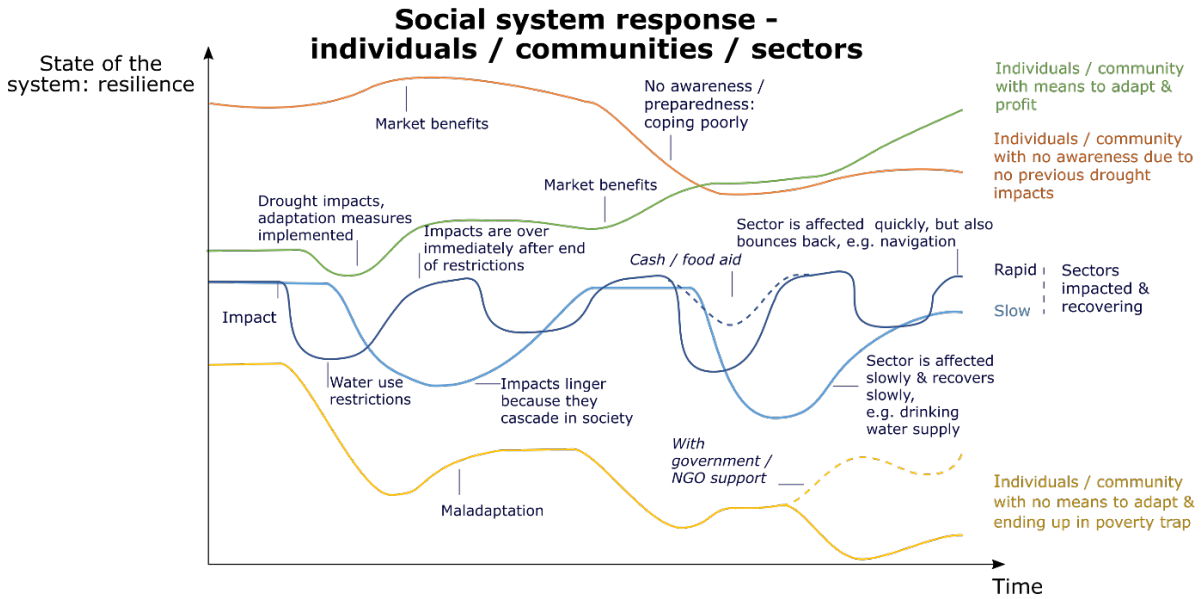
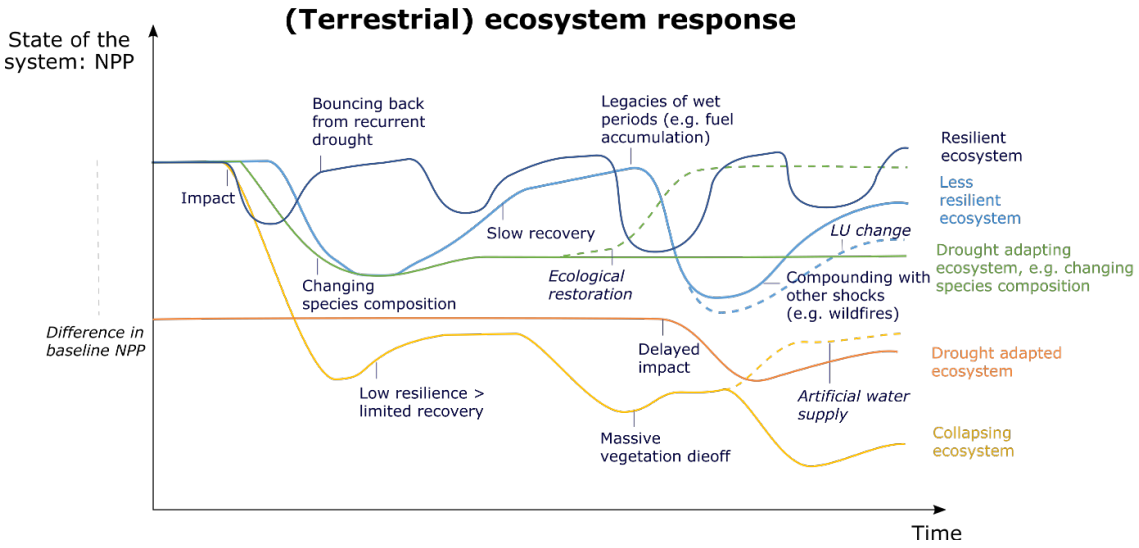
Systems thinking / system of systems

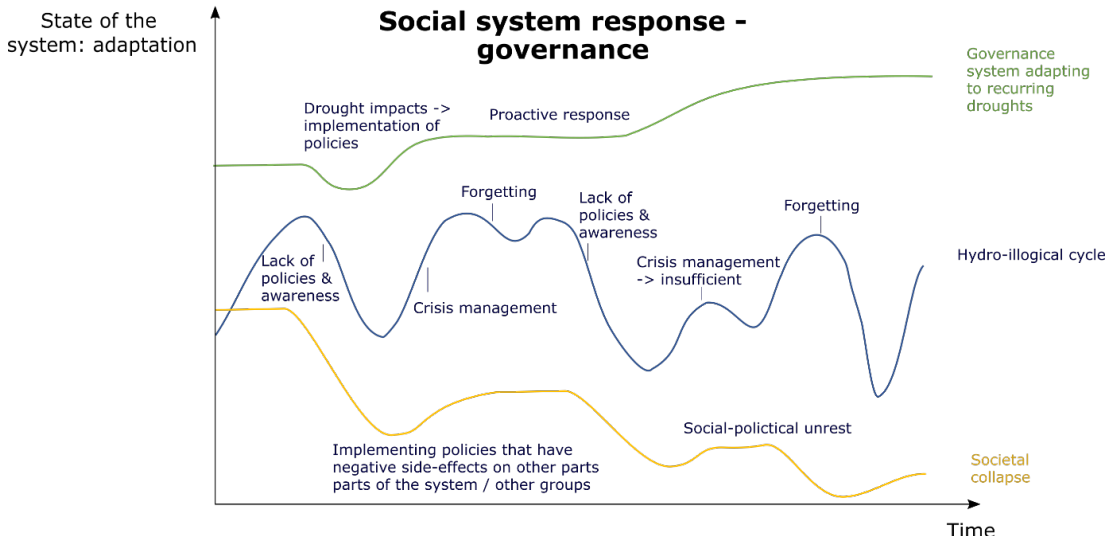
- Social-ecological systems (SES) & Earth system science (ESS)
- Temporal aspects, relate to memory
- Memory of subsystems within complex system > emerging properties:
  - self-organization & emergence
  - non-linear behaviour & tipping points
  - state shifts & feedback loops
  - resilience & adaptation
- Responses in one system influence the other systems

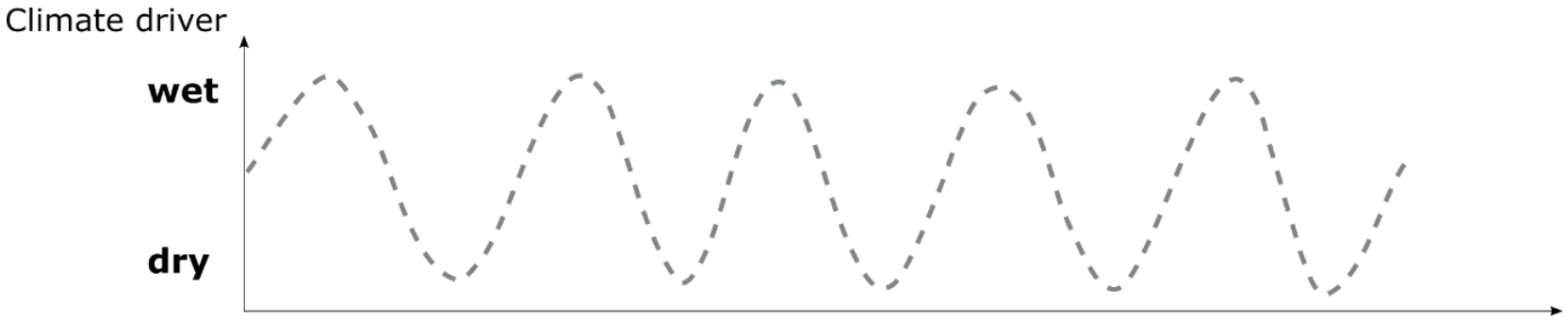

Climate driver
wet
dry

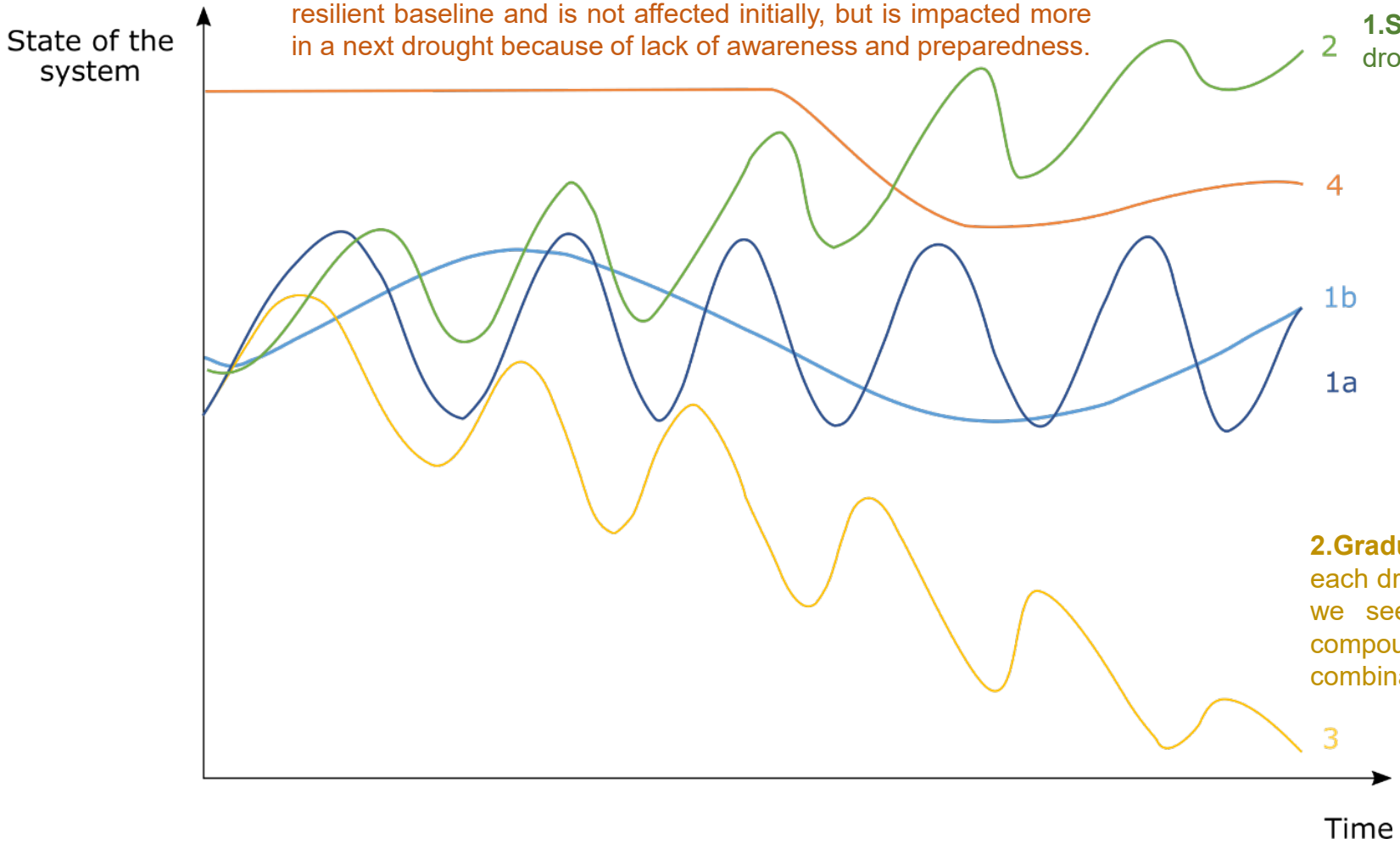

Climate driver
wet
dry


Social system response - individuals / communities / sectors
State of the system: resilience
Market benefits
No awareness / preparedness: coping poorly
Individuals / community with means to adapt & profit
Individuals / community with no awareness due to no previous drought impacts
Market benefits
Drought impacts, adaptation measures implemented
Impacts are over immediately after end of restrictions
Sector is affected quickly, but also bounces back, e.g. navigation
Cash / food aid
Rapid
Slow
Sectors impacted & recovering
Impact
Water use restrictions
Impacts linger because they cascade in society
Sector is affected slowly & recovers slowly, e.g. drinking water supply
With government / NGO support
Maladaptation
Individuals / community with no means to adapt & ending up in poverty trap
Time


(Terrestrial) ecosystem response
State of the system: NPP
Bouncing back from recurrent drought
Legacies of wet periods (e.g. fuel accumulation)
Resilient ecosystem
Impact
Slow recovery
LU change
Less resilient ecosystem
Drought adapting ecosystem, e.g. changing species composition
Changing species composition
Ecological restoration
Compounding with other shocks (e.g. wildfires)
Difference in baseline NPP
Delayed impact
Drought adapted ecosystem
Low resilience > limited recovery
Artificial water supply
Massive vegetation dieoff
Collapsing ecosystem
Time


Social system response - governance
State of the system: adaptation
Governance system adapting to recurring droughts
Drought impacts -> implementation of policies
Proactive response
Forgetting
Lack of policies & awareness
Forgetting
Lack of policies & awareness
Crisis management
Crisis management -> insufficient
Hydro-illogical cycle
Implementing policies that have negative side-effects on other parts parts of the system / other groups
Social-polictical unrest
Societal collapse
Time



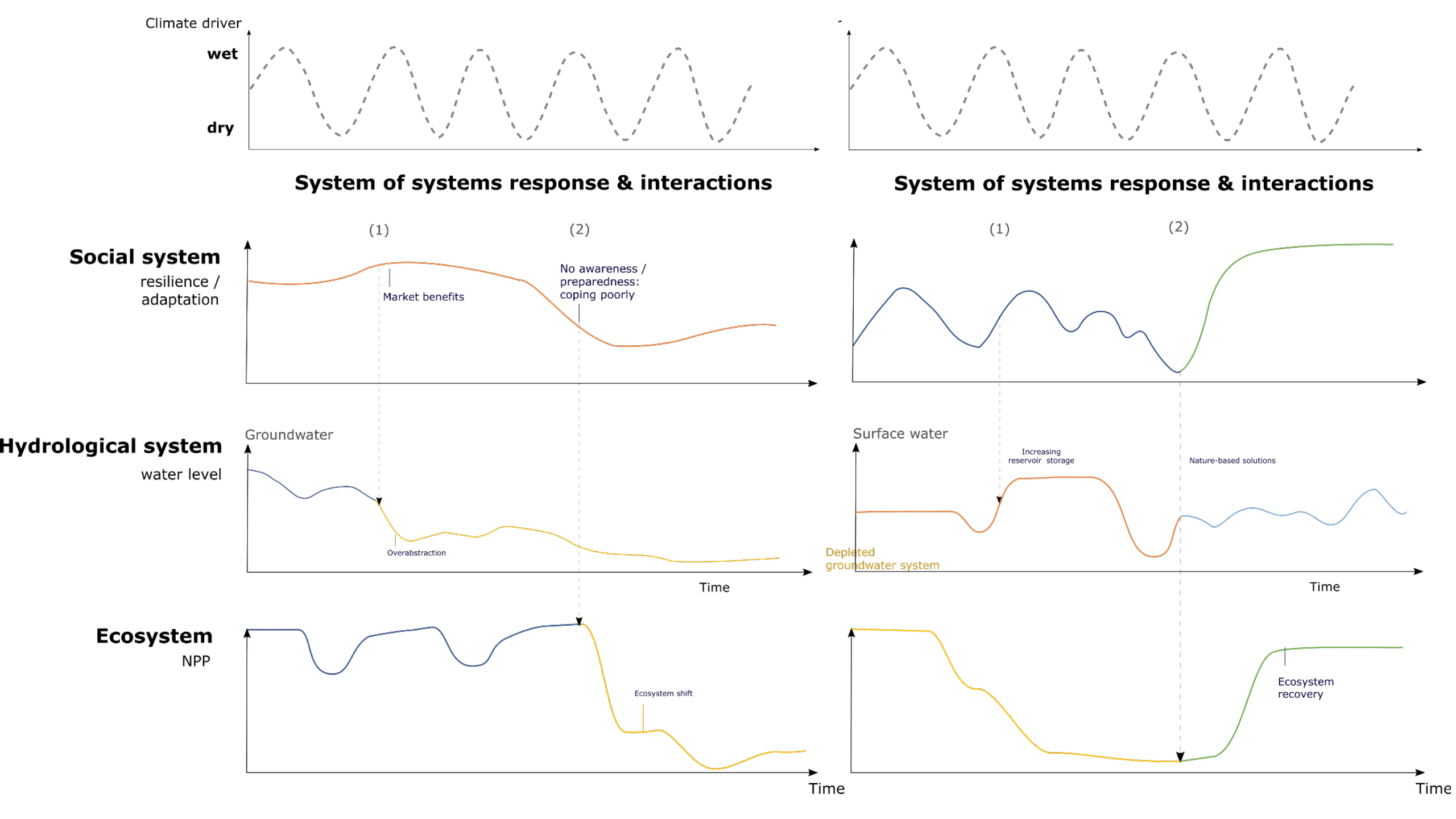


4.High resilience, big shock: the system has an initial highly resilient baseline and is not affected initially, but is impacted more in a next drought because of lack of awareness and preparedness.

1.Slow resilience building: the system adapts well to drought and drought resilience increases over time.

3.Impact & recovery: the system is affected by drought but subsequently bounces back. Depending on the type of system this impact and recovery can happen quickly or slowly, related to short or long memory (type 3a and 3b). Superposition of signals with different timeframes can occur.

2.Gradual collapse: the system becomes more vulnerable with each drought and changes to a negative state. In the ecosystem, we see this as a result of long-term legacy effects and compounding processes. In the social system, this happens as a combination of a high baseline vulnerability and maladaptation.


Climate driver
wet
dry
System of systems response & interactions
System of systems response & interactions
(1)
(2)
(1)
(2)
Social system
resilience / adaptation
Market benefits
No awareness / preparedness: coping poorly
Hydrological system
water level
Groundwater
Overabstraction
Time
Surface water
Increasing reservoir storage
Nature-based solutions
Depleted groundwater system
Time
Ecosystem
NPP
Ecosystem shift
Time
Ecosystem recovery
Time

case studies

Examples of types & type transitions, e.g.:

- one drought subsystem influencing another
- feedbacks between two subsystems can also result in type-transitions
- interactions between all three subsystems can result in a dynamic shift of the socio-eco-hydro system

Southwestern US:
"overexploitation of groundwater > depletion of aquifer systems > permanent loss of natural water storage & land subsidence"

Sweden:
"increased winter precipitation & a shift from snow to rain > dampened winter droughts & amplified spring and summer droughts"

Southwestern US:
"droughts > increasing potential for highly destructive wildfire events + threatening health of riparian environments & endemic species, some already facing extinction risks"

Germany:
"consecutive hot & dry summers in 2018 & 2019 > 2020: tree mortality rates spiked; 10 times higher than in past decade"

Brazil:
"reservoir aimed at reducing drought vulnerability > shift to intensive irrigated agriculture > recurring droughts > erosion of community financial resources"

Sub-Saharan Africa:
"recurrent drought > farmers adopted drought coping strategies > integral part of farming system > reducing drought risk"

Brazil:
"high concentration of small dams > during multi-annual droughts, these remain dry longer > reduces hydrological connectivity > decreasing downstream flow to large reservoirs"

Cape Town:
"2018 drought: wealthy drill private groundwater wells > lower water availability for poor > after 2018: larger difference in vulnerability"

Recommendations for drought management practice

Insights could be used in future studies and practices to improve drought management

- Scientific outlook > read in the paper
- Practice outlook
  1) Drought monitoring needs to move from an event-based to a continuous monitoring, for both hazard, vulnerability, and impacts
  2) Monitoring of different systems needs to be combined to provide an overview of cascading effects between systems.
  3) Drought forecasting should be based on improved modelling tools that include memory and dynamic feedback.
  4) Drought management should be more prospective.
  5) Drought management should be more coordinated and integrated across actors and systems.

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