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European Drought Observatory

User Meeting, 11-12 October 2018

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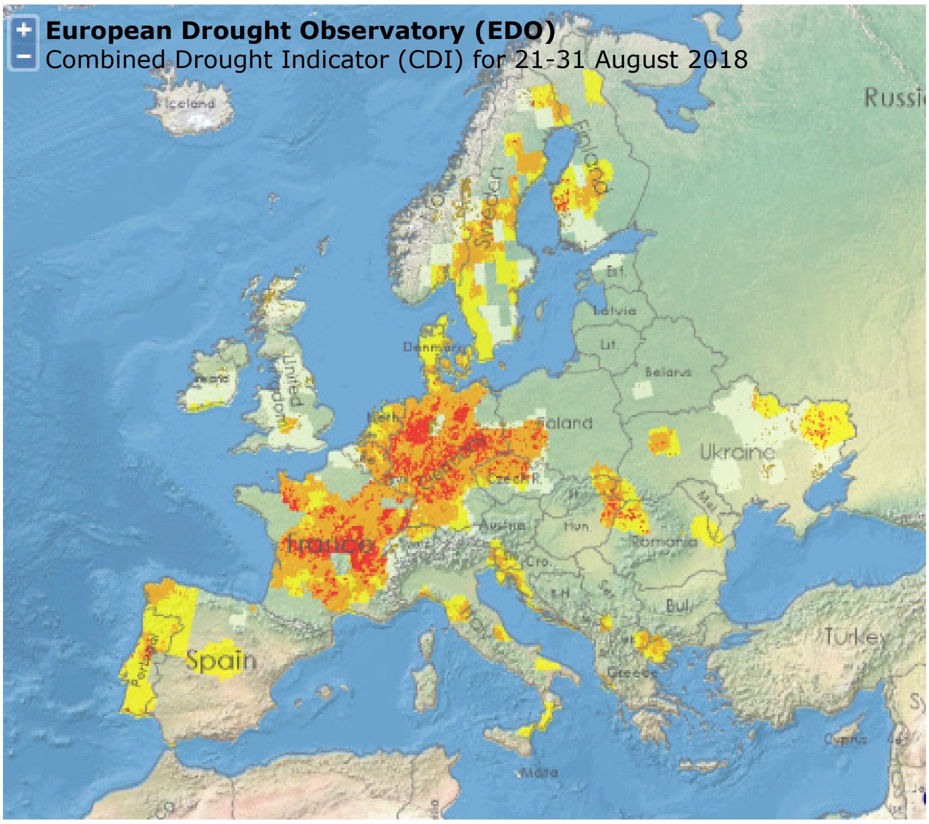

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Contents

Summary

The second User Meeting of the European Drought Observatory (EDO) was held on the 11th and 12th of October 2018, at the Joint Research Centre (JRC) of the European Commission, in Ispra, Italy. Since 2018, EDO and the closely related Global Drought Observatory (GDO) form part of the EU's Copernicus Emergency Management Service (EMS). The second EDO User Meeting gathered together experts in drought monitoring, forecasting and management, from EU Member States, meteorological services, international bodies, and universities, to discuss concepts and methodologies for drought risk assessment in different economic sectors. Specifically, discussions at the EDO User Meeting centred on the feasibility of implementing within EDO and GDO drought risk and vulnerability assessments for four sectors: public water supply, agriculture, energy production, and inland water transportation. The multiple dimensions of drought risk (i.e. hazard, exposure and vulnerability) for the four sectors were considered. Issues highlighted at the EDO User Meeting included the need to develop sustainable monitoring and forecasting systems at various scales and sectors, their inter-linkages and synergies, as well as important existing gaps in available data and information (e.g. lack of standardised information on the impacts of drought). This report provides a synopsis of the presentations and discussions during the second EDO User Meeting.

1 Introduction

The **European Drought Observatory** (EDO) was developed by the European Commission's Joint Research Centre (JRC), as a response to the need to better understand, monitor, and forecast **water scarcity and drought** in Europe, and to provide input for the formulation of evidence-based policies in the field. EDO has been developed within the context of the Commission's main legislation and policies addressing the problems of water scarcity and droughts (and the general lack of harmonized drought information at the European level), including the 2000 "Water Framework Directive" or WFD (and its four subsequent implementation reports), the 2007 Communication "Addressing the challenge of water scarcity and droughts in the European Union" (and its three follow-up reports), and the 2012 Communication "A Blueprint to Safeguard Europe's Water Resources". Development of EDO has been done in close collaboration with the EU Member States, the European Environment Agency, Eurostat, and representatives from the electricity and water industries. Since 2018, both EDO and the closely related **Global Drought Observatory** (GDO) - which extends EDO to the global level, and provides information to the Commission's Emergency Response Coordination Centre (ERCC) - form part of the EU's **Copernicus Emergency Management Service** (EMS, http://emergency.copernicus.eu/), complementing the existing EMS early warning systems for floods and forest fires.

EDO applies efficient methods for monitoring and forecasting **meteorological, agricultural,** and **hydrological droughts** at European scale, and linking with regional, national and subnational information systems. It is a distributed system, where data and indicators are handled at each spatial scale by the responsible authorities (stakeholders) and visualized through Web Mapping Services. The JRC handles data and computes **drought indicators** at a continental level, while national, regional, and river basin authorities add more detailed information for their area of interest. As spatial resolution increases, the indicators become more relevant for day-to-day water management. EDO provides a suite of drought indicators at different spatial and temporal scales, including 10-daily and monthly updated maps on the occurrence and evolution of drought events (and related heat waves), and a 7-day forecast of soil moisture. Medium- to long-term forecasting of extreme rainfall deficits, using probabilistic ensemble methods, was also introduced. At the continental scale, EDO includes a range of indicators on rainfall, soil moisture, river low flows, heat (and cold) waves, and photosynthetic activity of the vegetation cover. At the more detailed level it includes selected indicators relevant for the respective authorities that complement continental indicators. More information on EDO and GDO is available in Vogt et al. (2018).

The variety of drought indicators within EDO and GDO has proved useful for expert users and, in the case of severe drought events, for the production of analytical reports by the JRC's drought team. However, policy-makers and other high-level users also require synthetic combined drought indicators, showing different alert levels, to be used for "awareness-raising" and policy- and decision-making. Such high-level indicators need to be developed for specific economic sectors (e.g. public water supply, agriculture, energy production, waterborne transport). As a result, a first **Combined Drought Indicator** (CDI) for agriculture and natural ecosystems was developed and implemented within EDO, providing information on drought propagation within the hydrological cycle and the resulting impacts on vegetation cover. The CDI provides easy-to-understand sector-specific information for decision-makers in the form of alert levels. To analyse further how water deficits translate into **socio-economic impacts**, a first **drought risk assessment** for agricultural impacts was developed and implemented within GDO, called the **Risk of Drought Impacts** ($RDrI_{Agri}$) indicator. The RDrI serves as a high-level alert indicator, combining drought hazard with **exposure** and **vulnerability**, to evaluate the evolving drought risk for agriculture. Risk and vulnerability assessments for other sectors, such as public water supply, energy production, and waterborne transport, are currently being developed as new components of EDO and GDO.

Against this background, the 2nd User Meeting of the European Drought Observatory, which was held at the JRC in Ispra, Italy, on 11-12 October 2018, set the scene for the discussion of three **new sectoral risk assessments** to be implemented within EDO and GDO (public water supply, energy production, and waterborne transport). Results will also help to “fine tune” the already implemented $RDrI_{Agri}$. This report provides an overview of the programme of the meeting, the main points of the presentations and discussions, and the main conclusions from the meeting.

2 Meeting Programme

THURSDAY 11 OCTOBER 2018	
12:30-13:30	Registration and welcome lunch
13:30-16:00	**SESSION 1: INTRODUCTION** *(Chair: Niall McCormick, Rapporteur: Jonathan Spinoni)* ▪ Welcome, goal and organizational matters (Jürgen Vogt) ▪ Introduction to the European and Global Drought Observatories (EDO/GDO) (Jürgen Vogt) **Latest EDO/GDO developments:** ▪ Extended soil moisture window for EDO (Carolina Arias Muñoz) ▪ Global soil moisture anomalies in GDO (Carmelo Cammalleri) ▪ Global database of meteorological drought events in GDO (Marco Mazzeschi, Diego Magni) ▪ Injection of drought events in GDACS+ (Dario Masante, Diego Magni) ▪ Precipitation forecasts and temperature extremes in EDO and GDO (Christophe Lavaysse) **Keynote:** ▪ Risk Assessment Methodologies (Veit Blauhut) ▪ Discussion
16:00-16:30	*Coffee Break*
16:30-18:00	**SESSION 2: BREAKOUT GROUPS** *(Chair: Paulo Barbosa)* ▪ Introduction to the questionnaire on vulnerability indicators (Michael Hagenlocher) ▪ Introduction to breakout groups (Paulo Barbosa): i. Drought risk in Agriculture ii. Drought risk in Public Water Supply iii. Drought risk in Energy Production and Waterborne Transport
FRIDAY 12 OCTOBER 2018	
09:00-10:45	**SESSION 2: BREAKOUT GROUPS** (continued)
10:45-11:00	*Coffee Break*
11:00-13:00	**SESSION 3: PLENARY DISCUSSION** *(Chair: Jürgen Vogt)* ▪ Reports from breakout groups ▪ Discussion ▪ Conclusions on way forward (priorities for introduction of risk assessment in EDO)
14:00-16:00	▪ Bilateral discussions

3 Meeting Presentations and Discussions

3.1 EDO and GDO: Introduction and Latest Developments

3.1.1 EDO and GDO: An Introduction

An overview of the background and development of the European Drought Observatory (EDO) and Global Drought Observatory (GDO) was provided by Jürgen Vogt (JRC). The key points discussed included:

- Drought as a natural hazard in Europe, recorded impacts, damages and losses in different sectors, policy framework.
- Challenges for further development:
  - Trans-national monitoring and early warning, including a combination of different scales.
  - Forecasting for different time horizons.
  - Risk management: monitoring hazard, exposure, vulnerability, and impacts, including an analysis of the underlying processes.
  - Moving from forecasting hazards to forecasting impacts.
  - Moving from a single-hazard early warning system (EWS) to integrating different hazards into a multi-hazard EWS.
  - Harmonizing risk information between different hazards.
  - Analysing interactions between different hazards (e.g. droughts and heat waves).
  - Analysing expected trends in a changing climate and developing adaptation options.
- The history of EDO and GDO, including the stakeholders and expert groups involved. Since 2018, EDO and GDO are included in the Copernicus Emergency Management Service (EMS). Links with other global activities and programmes, such as the Global Drought Information System (GDIS) and the Integrated Drought Management Programme (IDMP).
- GDO: Analysis of global drought hazard, exposure, and vulnerability as a basis for combined (alert) indicators such as the Risk of Drought Impact (RDrI), exploiting the European Media Monitor as a soft validation, generation of semi-automatic reports, preparation of analytical reports in case of severe events.

3.1.2 Extended LISFLOOD Window

The latest improvements to EDO and GDO related to the LISFLOOD distributed rainfall-runoff-routing hydrological model were described by Carolina Arias Muñoz (JRC):

- Introduction and brief description of the LISFLOOD hydrological model.
- Extended window to a bigger spatial domain. The domain was extended to countries as Turkey, Armenia, Syria, part of Irak and along the North African coast.
- Different data files format: data are now provided as NetCDF files.
- Fraction of forest map introduced. Map values range from 0 (no forest at all) to 1 (100% forest).
- The number of soil layers increased from two to four: Soil moisture upper layer, forest fraction; Soil moisture lower layer, forest fraction; Soil moisture upper, other fraction; Soil moisture lower layer, other fraction.
- A verification of inconsistencies between the old and new LISFLOOD model versions was performed in order to ensure that the new version is providing accurate information. The Soil Moisture Anomalies between the two model versions were compared. A pixel-level linear regression over soil moisture series of ten-days was performed using a time window of 26 years. While inconsistencies were encountered due to the newly introduced hydrological parameters of the LISFLOOD model, the overall results indicate a significant positive correlation for 90% of the pixels in the study area.

3.1.3 Global Soil Moisture Product

The new soil moisture product in GDO was described by Carmelo Cammalleri (JRC):

- Challenges regarding the quality of soil moisture products moving from a European (EDO) to a global domain (GDO).
- Three different soil moisture datasets - LISFLOOD; MODIS Land Surface Temperature (LST) and ESA Climate Change Initiative (CCI) / microwave - were evaluated and implemented through a triple collocation method. The weighting factors for each product were set as the inverse of the model error variance (Cammalleri et al. 2017).
- LISFLOOD outputs are more reliable over northern latitudes, MODIS LST is more reliable over dry areas, while CCI is more reliable for the southern hemisphere.

3.1.4 Global Database of Meteorological Drought Events (1951-2016)

A new global database of past drought events was introduced in GDO. The database was described and demonstrated by Marco Mazzeschi, Diego Magni, and Jonathan Spinoni (JRC):

- A global database of past (i.e. 1951-2016) meteorological drought events was developed and implemented in the GDO (Spinoni et al. 2018).

- The database is based on two meteorological variables - precipitation and potential evapotranspiration – represented by the Standardised Precipitation Index (SPI) and Standardised Precipitation-Evapotranspiration Index (SPEI), aggregated into different time scales (-3, -6 and -12 months).

- For each drought event at country and macro-region levels, several variables can be retrieved, e.g. severity, intensity, onset and end date, duration, peak, and maximum spatial extent. In addition, an overall score is assigned to each event that makes it comparable with the other events in the database.

- A web tool (dashboard-like) to examine interactively the global database of meteorological drought events has been implemented.

3.1.5 Drought Events: from GDO to GDACS

The input of drought events from GDO into the Global Disaster Alert and Coordination System (GDACS), was described by Diego Magni and Dario Masante (JRC):

- GDACS is a cooperation framework between the United Nations (UN), the European Commission and disaster managers worldwide, to improve alerts, information exchange and coordination in case of major disasters.

- This year, drought event information was added to the already implemented disaster types: earthquakes, tsunamis, volcanoes, tropical cyclones, storm surges and floods.

- The implementation of droughts in GDACS relies on three steps: (1) automatic detection of drought events; (2) evaluation and classification of detected drought events; (3) Publication in GeoJSON (Geographical JavaScript Object Notation) format of confirmed and classified events, and display in GDACS.

- Each drought event has the following attributes: ID (unique, primary key); Geometry (multi-polygon); Name (affected country by default); Alert level (RDrI-Agri); Start and reference (last) date; affected countries and administrative reporting units.

3.1.6 Forecasting Drought and Temperature Extremes

The latest developments related to the forecasting of drought and temperature extremes in EDO, were presented by Christophe Lavaysse (Université Grenoble Alpes, Visiting Scientist at JRC):

- Monitoring heat and cold waves using EDO's Heat and Cold Wave Index (HCWI) is a new operational daily product derived from gridded observations.

- A case study of the heat wave in France in 2003 was presented: Intensities were slight under-estimated. The heat wave was forecasted with a lead-time of 7 days and a correct duration.

- Using 20 years of ECMWF reforecasts, the predictability of the HCWI showed a good skill for the detection with two weeks lead-time for the occurrence of a heat wave and one week lead-time for the onset (Lavaysse et al. 2018)

3.2 Drought Risk Assessment Methodologies

An overview of drought risk assessment methodologies was provided by Veit Blauhut (University of Freiburg):

- Presentation of the variety of drought impacts as recorded in Europe and documented in the European Drought Impact Inventory (EDII, http://www.geo.uio.no/edc/droughtdb/).

- Review of drought risk analyses from literature: misuse of the word "risk", dominated by agriculture.

- Different approaches to assessing drought risk: "Impact" versus "Factor" approach. Pros and cons of both approaches were discussed as well as the introduction of a hybrid approach (combined methodology): statistical versus conceptual.

- Selection of predictors and focus on verification of results.

- Review of risk determinants: Hazards, Vulnerability (here including Exposure), and Impacts: triple complexity for droughts.

- Presentation of statistics from recent published studies for different sectors and methodologies. In Europe agricultural impacts dominate, followed by public water supply. In China agriculture (high level of detail) dominates; hydropower is getting more attention.

- Take-home messages: consider needs of users, combine data, perform sector-specific assessments, and increase the reliability of methods.

Discussion:

The first part of the discussion dealt with mechanisms to cope with drought impacts. Then the lack of data on conflicts related to droughts and possible induced migration (e.g. Syria) was discussed. The discussion moved to the collection of impact data, possibly from insurance companies. At global scale such collection and collaboration with farmers is hardly applicable. Often data are collected without being analysed outside a specific context or without being shared. No data for ecosystem impacts are available. It was agreed that a wealth of new impact data on droughts is becoming available, but rarely quantifying loss and damage.

3.3 Global Expert Survey on Drought Vulnerability

Michael Hagenlocher (United Nations University; UNU-EHS) provided an overview of an expert survey on vulnerability indicators for global-scale sectoral drought risk assessments, launched as a joint effort between JRC and UNU-EHS, :

- Based on a literature review a comprehensive set of vulnerability indicators or proxy variables was identified over seven dimensions: social, economic, infrastructure, conflict, government, environmental, farming.

- The survey for evaluating the relevance of different vulnerability indicators will be sent to a global selection of experts and drought information users.

- Results will inform global-scale, sectoral risk assessments at JRC (GDO) and within the GlobeDrought project (https://grow-globedrought.net/).

Discussion:

Various aspects of the questionnaire (which is provided in Annex 1) were discussed and improvements proposed.

3.4 Breakout Groups

The User Meeting separated into three Breakout Groups, discussing relevant variables for drought risk assessment in four socio-economic sectors:

- Public Water Supply (Breakout Group 1),
- Agriculture (Breakout Group 2),
- Energy Production and Waterborne Transport (Breakout Group 3).

The discussions of the Breakout Groups are summarized below. The variables proposed are presented in Annex 2.

3.4.1 Breakout Group Guidelines

Guidelines for the three breakout groups were presented by Paulo Barbosa (JRC):

- The conceptual framework for the three breakout groups was introduced. Risk is conceptualised as the interaction of three components (IPCC, 2014): Hazard (probability of a drought event with a certain severity); exposure (amount of population, livelihoods, assets, resources, services potentially affected); and vulnerability (susceptibility to suffer adverse effects).

- Discussions were structured as follows:

  - Risk concept and framework.
  - Dynamic vs. static drought risk assessment.
  - Information needed to define the components.
  - Feasibility of implementing drought risk indicators for each sector.

- To facilitate interactions, three questions were addressed in each group: (1) Which hazard indicators can be proposed for the different sectors? (2) Which exposure layers can be proposed for the different sectors? (3) Which vulnerability indicators can be proposed for the different sectors?

- Vulnerability indicators and possible differences between developed and less-developed countries should be discussed.

3.4.2 Breakout Group 1: Public Water Supply

Chair: C. Prudhomme

Rapporteur: J. Spinoni

Participants: C. Prudhomme, J. Hannaford, M. Lakatos, K. Dabrowska-Zielinska, J. Vogt, P. Barbosa, C. Cammalleri, J. Spinoni

Drought Risk Concept:

The drought risk approach was found to be valid for water supply issues, and the scheme (risk = hazard * exposure * vulnerability) was well accepted for this sector. Vulnerability was considered the most difficult factor to estimate, alongside the valuation of impacts on public water supply.

Large cities are the most important hot spots, but also local settlements need to be considered. In cities, exposure can change relatively quickly. The case of the 2018 water crisis in Cape Town (South Africa) was discussed, including aspects of how big cities can face public water supply issues due to drought events.

For the case of public water supply, people are the exposed assets, and for vulnerability the relationship between the long-term demand and supply of water could be used. Part of the discussion dwelled on reservoirs, coping capacity, and the preparedness of big cities.

The conceptual framework was preferred over the impact-based approach, because it allows to understand the drivers and from there to work on risk reduction. The difficulties for statistically quantifying all variables involved was highlighted, including the need to consider public and large-scale infrastructures as well as the local coping capacity. At more local scales, the hazard and risk can be quantified, but at global scale a conceptual rather than a statistical approach is needed. In other words, a statistical approach with local data providers can be used at local scale, but at global scale the conceptual approach should be applied.

The importance of informing and guiding the users of the risk information was stressed. They often do not fully understand the underlying risk assessments model. However, models are the best way to provide the users with information at global scale. The biggest issue is the characterization of vulnerability: more data are needed for assessing the current vulnerability, and better projections for the future, which usually lack detailed socio-economic data that are often provided at country scale only.

The differences between ad-hoc produced maps of lower quality and high quality maps produced after a detailed analysis were discussed. The use of one or the other depends largely on the needs of the customers and the time available. While the former represent a pragmatic solution in case of urgent need, the latter can provide detailed information on possible options. Implicit uncertainties have to be highlighted in both cases. The risk is that users lose confidence in the information produced, while trust is a most important resource. The example of the development of GDO for the Emergency Response Coordination Centre (ERCC) was discussed: available information is provided, being clear on uncertainty. As time passes, methods and results are improved.

The need to collect feedback from the users on their level of satisfaction with the disseminated products was highlighted. Until now, GDO uses a “soft” verification of a drought alert through the European Media Monitor. Impact reporters on the ground were considered the best solution, but at global level this was considered extremely difficult to implement.

Dynamic Drought vs. Static Drought Risk Assessment:

The dynamic approach was considered adequate for drought risk assessment. However, a static approach for planners can also be suitable. In drought monitoring systems the dynamic risk should be based not only on the fast changing hazard, but also on longer-term changes in exposure and vulnerability. In this context, forecasting the drought hazard remains a challenge due to uncertainties in meteorological forecasts.

Forecasting exposure can be feasible. An example is the increase of population in popular tourist areas during summer holidays. It was agreed that forecasting drought risk with only the hazard component could be limiting. Major patterns of exposure and vulnerability should be included in a dynamic drought risk, if possible.

The differences in vulnerability of different economic sectors and ecosystems was discussed, an issue which seems to be often missed by drought risk maps. A multi-indicator approach was suggested, maybe varying the indicator depending on the season. GDO now has a dynamic risk that depends on the dynamic hazard, with a 10-day time-scale and exposure and vulnerability varying only at yearly time-scale. Depending on data availability, this could be improved.

While a dynamic risk was considered better for monitoring and forecasting, the group agreed that static maps are important and should be provided for long-term planning.

The group proposed to use the term "Drought Risk Monitoring" or "Dynamic Drought Risk Monitoring" instead of Drought Monitoring to better characterise the information provided.

The use of the term "dynamic" might not be clear for everyone. It needs to be explained to the potential users of the information. Defining the users of an early warning system and providing feedback mechanisms was considered an important aspect.

Indices for Hazard:

Looking at the suggestions presented, hazard refers to anomalies in a broad set of sources for water supply. It is important to consider water districts when talking about sources. For public water supply, one should consider that water sources could be located far away from the consumers.

The three main sources for public water supply are groundwater, reservoirs, and river flows, ideally monitored through a single combined indicator. This could best be achieved by using anomalies (current situation versus the climatology) and long-term trends.

For the case of public water supply water demand needs to be considered: The Water Exploitation Index Plus (WEI+) was considered a good candidate, as it combines water availability and demand.

Public water supply vs. industrial water supply: Both sectors are important and somehow connected. An increase in industrial or agricultural demand can have significant impacts on public water supply.

Groundwater quantities are difficult to estimate at large scales. Since it is a slowly changing quantity, a rapid monitoring of changes is less important. The situation is easier for reservoirs and satellite data are useful only for long-term evaluations.

For streamflow, models can provide an estimation of reliability. However, the information is often not sufficient, especially as water management information is often completely missing. One option to overcome this problem would be to analyse selected "hotspot" cities, including local information on management.

The scale of the information collected will depend on the variable analysed. For groundwater, for example, the spatial resolution is generally low, while for reservoirs the locations are well known. Proxy variables could help. SPI-9 or SPI-12, for example, proved able to follow water levels following the onset of major droughts. However, including local data and checking time series of water reservoirs would improve the situation.

Environmental flow data are generally lacking. Little information on water quality is available. Salty water, degraded water, and algal blooms are not usually included. Even in Europe it is difficult to model or to get data on environmental flow, with only a few studies done. Trans-boundary flows are never considered. However, the group agreed that efforts to include environmental flow in drought risk should be fostered. It was proposed to consider environmental flow as a separate sector. The use of thresholds on minimum environmental flow was suggested, followed by a two- or three-step protocol: water availability; environmental flow estimates; issues on public water supply.

Indices for Exposure:

Population is the most important quantity for exposure in public water supply. The dynamic aspect (e.g. seasonal changes in population density) is important. High-resolution population data, such as from the Global Human Settlement Layer (GHSL), are available, but these are mainly static. The challenge is to include major seasonal changes (e.g. tourism) and migrations (displaced population).

Estimations of water demand are often based on population data and consumes per capita. However, water use by industries can influence the water demand per capita. There is a high interconnection between industry and population water demand.

Agriculture and industry can compete for the same water resources. Water managers usually prioritize water consumption by citizens.

Indices for Vulnerability:

Vulnerability refers to the susceptibility to suffer from negative impacts from an event. Confidence in vulnerability indicators is higher at national level than at sub-national level, where relevant data are often lacking.

Developed countries focus on economic (and environmental) impacts, while less developed countries focus on humanitarian impacts. The user of the information is, therefore, very important.

A drought management plan is fundamental for reducing vulnerability. Evaluating both its availability and implementation (government efficiency) is important in this respect.

An access indicator (e.g. road density) was discussed as it can provide information on the distance to the water sources and on the possibilities to intervene in regions with water scarcity during an emergency.

Education was considered more important than literacy. Good communication practices can help people, even without literacy, to manage drought crises. Nowadays such communication is possible due to the broad availability of mobile phones, also in Africa.

The diversification of water sources is very important. For example, desalinization of water, or the use of other alternative (reserve) water sources when the main one is not available are options.

At a global scale, the hierarchy of priorities can be different from the one at continental, regional, or local scales. Therefore, there is no need for the same rules everywhere and the use of different indicators over different regions or countries should be considered.

One missing indicator is the number of population centres within a certain radius. The more cities or competitors, the more difficult to obtain water in case of emergency. In India and China the mega-cities close to each other are creating problems even though much water is available. Population density, therefore, was considered a good proxy variable.

It is important to distinguish between drought and water scarcity (the long-term imbalance between water availability and water consumption). Water consumption has to be distinguished from water use (e.g. for cooling). The WEI+ indicator includes some of these aspects.

Another missing parameter is conflict, which can cause migration, and conflicts between countries, such as the construction of big upstream dams (e.g. Ethiopia, Sudan and Egypt). In order to evaluate vulnerability, it is therefore useful to analyse the percentage of water used that originates from within a countries borders.

Finally, water loss, such as the spilling from pipelines, is an important factor. The age of pipelines and infrastructures to carry water can be used as a proxy variable. However, such considerations should look at cities and rural lands differently.

The re-use of grey water is another important indicator, as is the proportion between blue water and green water. In general, the industrial re-use of grey water can have a valuable impact.

Other Issues Raised:

Questions arose about the use of water supply networks. The 2018 water crisis in Cape Town was further discussed, where a big driver was inequality. One aspect here is education, which must be improved. The legal framework to prioritize aid to people was briefly discussed. Bad management or corruption on various levels can limit efforts to reduce vulnerability. Finally, the confidence in the information used was highlighted.

Summary of Key Issues:

- **Drought risk concept:** The conceptual approach was accepted, but a new name for drought risk (monitoring) was proposed in order to differentiate dynamic risk assessments from long-term risk. Assessments should always be linked to impacts. Know your users. Communicate the uncertainty and confidence (trust issues). Not one unique algorithm exists, but indicators need to be locally adapted to the sector.

- **Dynamic or static risk:** Dynamic is recommended. Include seasonality and dynamic hazard. Use static risk for long-term planning. Ask for feedback from users and engage with them (these differ for different sectors).

- **Hazard indicators:** Weigh the different sources and treat them as anomalies. Look for demand-based indicators. Evaluate the confidence of information. Use SPI-12 as a proxy variable for water scarcity. Start from hotspot cities, then move to other scales, if information is available. Treat the environmental flow as a separate sector.

- **Exposure indicators:** Population and water demand are connected, if values per capita are provided. Include tourism and displaced population changes at seasonal or 10-day scales. Sectors competing for water should be addressed in the vulnerability assessment.

- **Vulnerability indicators:** Sub-national versus national scale. Education more important than literacy. Communication is crucial, the use of mobile devices helps greatly. Diversification of water sources. Distance to water source (remove large distances). Conflicts should be included, also for trans-boundary issues. Use terrain information to aid during crises. Water loss (waste) must be studied, and age of the distribution system can be a proxy variable. Re-use of grey water and the distinction between green and blue water. WEI+ is more a vulnerability than a hazard indicator. Trans-boundary rivers and sources are critical, and the percentage of water inside and outside the country is relevant. Private mitigation measures, such as tanks on roofs, exist. Different indicators and algorithms for developed and less developed countries are needed. Water quality to be considered. Distance to other cities and competition for the same source are important.

3.4.3 Breakout Group 2: Agriculture

<u>Chair</u>: *G. van der Schrier*

<u>Rapporteur</u>: *C. Arias Muñoz*

<u>Participants</u>: *Michael Hagenlocher; Silas Michaelidis; Olga Penalba; Zornitsa Popova; Niall McCormick; Gustavo Naumann; Marco Mazzeschi, Gerard van der Schrier, Carolina Arias Muñoz.*

<u>Drought Risk Concept</u>:

Starting from the presented drought risk concept - where risk or likelihood of drought impact is a combination of hazard, exposure, and vulnerability - some ideas were discussed to enrich this concept, described below.

- There was agreement that the approach to drought analysis must move from a hazard to a holistic, risk-oriented concept (as was presented), including direct and indirect impacts. Regarding impacts, in a country where agriculture is the primary economic activity, one direct impact of drought is a decrease in food production via a decrease in cultivated areas and crop yield, leading farmers in the livestock sector to rely on additional food, and to transport water to feed cattle. In the agriculture sector, economic impacts could be identified, where crop pricing varies according to drought, and a lower production can lead to a price rise (positive impacts).

- It appears that the direct impacts of drought on soil health are ignored in drought risk analysis. Especially for agriculture, this is a crucial issue. With drought, there is a lack of nutrient uptake by crops, because water is the primary medium for moving nutrients into plants by water uptake. Besides, dry soil can be eroded by rain, where the impact of rainfall will break up the soil, and water build-up will create run-off, removing sediment. Another consequence of drought is the over-supply of water for irrigation and depletion, leading to salinization.

- The fact that soil health is ignored in the drought risk concept could be due to the fact that, when analysing drought impacts in agriculture, it is not often mentioned what specifically drought is affecting. Food security? Farm business survival? In that sense we should be more precise in order to assess hazard, vulnerability and exposure variables and impacts.

- Drought hazards mostly depends on meteorological conditions. Although their impacts can be identified, opportunities to mitigate these may be limited because they go beyond human intervention, even where appropriate risk assessments are in place. Nevertheless, there are other socio-ecological variables, such as water supply and demand, significantly affecting drought hazards.

- Finally, in the re-definition of the drought risk concept, the connectivity between different regions and economic sectors must be included, as well as the cascading effects. An open question remains: how to deal with the different interactions?

Dynamic Drought vs. Static Drought Risk Assessment:

On the one hand, a dynamic drought risk monitoring of 10 days was considered very useful and suitable for understanding drought changes and addressing possible actions, funds, etc. On the other hand, a static approach was thought to be better for long-term adaptation plans and to better influence policy-making.

Separate approaches can lead to a possible "risk threshold" region, specific to sectors, defined as the maximum risk which a society or farmer can cope with. A threshold may be identified using static data, from well-known past cases where management challenges were explicit. Emerging thresholds can be identified using dynamic data. A mix of static and dynamic components was proposed: future scenarios or decadal predictions of all components in a time horizon of 10-20 years could be developed, meaning that drought hazard indicators such as SPI should offer information in the short, medium and long-term.

Drought monitoring systems for agriculture should be directed towards the government, so that it can reduce vulnerability through policies and interventions (i.e. weather-based insurance), and towards farmers to inform them of best practices. The government plays a significant role because farmers can hardly reduce their vulnerability by themselves. Drought monitoring systems must be linked to solutions, providing warning and advice for specific users, suggesting what they should do when a red alert is on-going. It may be possible to define an economic drought threshold that determines when farmers start losing money, taking into account their coping capacity (social, individual, national).

Indices for Hazard:

Drought hazard indicators must be simple, region- or country-specific depending on the scale, and have sufficient information to cover a global scale, although this is not always possible because of availability issues, especially outside Europe and North America. More drought hazard indicators should be included in EDO and GDO (e.g. SPEI), but too many indicators can confuse users, which is why indicators must be integrated as indices, with straightforward, understandable schemes, such as "traffic light" legends.

Statistics and trends of drought hazard indicators must be considered in a drought monitoring system. The characteristics of the indicators give an idea of the severity and intensity of an event, as well as its causes and consequences. For example, on short time-scales, SPI is closely related to soil moisture, while at longer time-scales, SPI can be related to groundwater and reservoir storage. If a current drought event is severe, but its intensity only returns every 100 years, this can entail a different intervention strategy from an event that is less severe, but with a duration above the average.

Regarding the inclusion of human processes (water supply and demand) in drought hazard analysis, one proposal was to create an indicator of water demand, which includes not only how much water is extracted, but also how the extraction is managed.

Indices for Vulnerability:

Drought indicators should be proposed considering vulnerable groups and gender. Gender is a core factor in drought risk analysis. Men and women are not equally at risk from disasters in general. Therefore gender affects the capacity to cope with droughts. Depending on the country, past drought events have shown that, for example, low-income women and those who are marginalized due to marital status, physical ability, age, social stigma or religion, are especially disadvantaged.

Coping capacity is a crucial concept in vulnerability analysis. Therefore, different indicators should be created under this umbrella concept: access to information, access to education, access to loans, presence of mechanisms to alleviate the drought effects, etc. As the coping capacity can vary between municipalities, regions, and countries, coping capacity indicators should be at national, regional, farm and individual level.

The present drought vulnerability indicators only serve as measures, but hardly as instruments to act. Do people understand that they are vulnerable? Drought awareness and knowledge management are necessary to create the basis for a culture of drought risk reduction, and resilient communities. Also, the strong dependency of a country on the agriculture sector makes it more vulnerable to droughts than others.

Regarding soil vulnerability, indicators of land degradation and loss of agricultural land are being developed by the UN on a global scale and could possibly be included in GDO.

Indices for Exposure:

Drought exposure of agricultural assets includes every element of the farming system: land / soil, crops, people, livestock, and water, etc. All of these elements are amenable to being measured through indicators. Examples are the number of people depending on agriculture, price variability due to droughts, the quantity of land prone to erosion, water consumption for livestock production and soil texture.

One new indicator that could be implemented is the hydrological downstream drought area, which identifies drought areas downstream due to activities in upstream areas. This type of indicator can be computed using LISFLOOD and other hydrological models.

Regarding the feasibility of implementing a drought risk indicator for each of the sectors, the members of agriculture group recommended doing it as a working group.

Other Issues Raised:

During the questions, it was noticed that most of the topics covered overlap with the Breakout Group on Public Water Supply. The particular focus on vulnerability was appreciated. Regarding the public water supply, no particular discussion on the feasibility of a drought risk indicator for GDO was done, but is recommended as a group work.

3.4.4 Breakout Group 3: Energy Production and Waterborne Transport

Chair: *Veit Blauhut*

Rapporteurs: Dario Masante, Diego Magni

Participants: *Claudia Vezzani; Vanda Cabrinha Pires; Jaime Fraile; Elke Rustemeier; Alfred de Jager; Diego Magni; Christophe Lavaysse; Veit Blauhut; Dario Masante.*

Drought Risk Concept:

There was overall agreement on - or at least, no specific issues were raised against - the adoption of the risk concept proposed in the workshop, as a function of hazard, vulnerability and exposure. The boundary between vulnerability and exposure may be blurred at times, but would not undermine the meaning of associated risk.

In terms of modelling approaches for risk, statistical methods and conceptual, expert-driven methods have both pros and cons, but a hybrid approach would probably fit as a trade-off solution against modelling and data constraints. Whatever approach is used, a quality check is needed in some form, preferably through a structured analytical technique (e.g. sensitivity analysis, regression, etc.).

A key question is what audience to address with risk indicators, what is relevant to show at a given scale, and consequently what to look for. In general, stakeholders in a specific sector have access to fine-grained data relating to their business, but an inter-disciplinary and cross-boundary overview for policy-makers and non-specialized analysts is lacking.

One important feature for a risk indicator is its suitability for use in emergency plan evaluation and risk analysis. As a consequence, it should provide warning levels and be suitable for a “traffic light” representation (or similar), in order to be relevant and easy to grasp by non-experts in the field (e.g. Portugal has a good case study). This entails having thresholds for classes (quantitative or qualitative), that still need to be identified.

As another key feature, a risk indicator should integrate well into a forecasting or early warning system, but whose time horizon has not been discussed in detail. Some transferability for use in combination with climate projections was also deemed as a highly desirable feature, for risk analysis.

Dynamic Drought vs. Static Drought Risk Assessment:

For monitoring purposes and a short-term outlook, there was unanimous agreement on the advantages of having a dynamic view for all risk components. In addition, the elements of a dynamic system may be easily aggregated or selected, to obtain a static view for a given time interval.

However, also considering the practical constraints of data availability in real and near-real time, a static view may still be fit for purpose, especially for those components that change to the least extent over short time spans.

It was agreed that time-steps between updates of several days (e.g. ten days) or a few weeks (e.g. one month), plus a few days for technical delays, are a sufficient temporal resolution for indicators relating to drought events on a broad scale. Considering hazard, exposure and vulnerability separately, these frequencies may be relaxed further. In fact, seasonality may play a bigger role in the link between water and the energy and transport sectors, as well as multi-annual cycles and trends (e.g. shifts in technological features, market growth and downturn, etc.).

For long-term analysis, planning and forecasting, using static data may be particularly helpful or more informative, by reducing the noise of high short-term variability.

Indices for Hazard, Exposure and Vulnerability:

An extensive discussion took place about the drivers of risk, including interconnections and dependencies with other sectors. It should be noted that, depending on the context of analysis, the sectoral approach may not be fine enough to describe properly risks faced by different stakeholders, and sub-studies may be required. For instance, thermo-electric generation has different requirements from hydro-power generation, and operations for hydro-power in "run-off-river" stations differs from pumped storage plants.

It is important to identify the potential users of a given indicator. Wide-scale risk indicators would probably not fit the needs of the power industry or the inland water transport stakeholders, as operators in these sectors know best the factors driving their business. Indeed, they already hold a wealth of monitoring data specific to their system, when strategic to operations. Nevertheless, it is likely that these actors may be interested in accurate forecasting (mid- and long-term) - unless they are able to produce such information in-house - and in the risk analysis of climate change scenarios.

On the other hand, wide-scale indicators of risk may meet the needs of policy-makers and generic analysts, as well as the general public (including media outlets).

Hydrological drought was identified as the most direct factor influencing the water transport and energy sectors, due to their strong dependency on surface water. Accordingly, some variables were suggested for use as hazard indicator in a risk assessment (Annex 2, Table A2). Water reservoirs and groundwater may play a role, in the case where water reserves allow continuity of operations under prolonged precipitation deficits.

Similarly, for exposure and vulnerability, a number of factors were deemed relevant, depending on the scale considered and across boundaries, but almost exclusively related to economic or environmental impacts, since neither mass electricity production nor inland water transportation would affect population directly.

Feasibility of Implementing a Drought Risk Indicator for Each Sector:

It was agreed that risk indicators could be developed for both sectors and be meaningful enough to provide the "big picture" in case of drought events.

For electricity production, the issue of data availability relates to the fragmentation and heterogeneity of data, or their closed-source nature. In general, it was agreed that fine-scale data exist, but may be difficult to get at a global scale, especially for monitoring purposes. At pan-European level monitoring systems exist already (e.g. European Network of Transmission System Operators for Electricity / ENTSOE), but technical solutions are required to integrate these products into a risk monitoring system.

Concerning inland water transportation, real-time to mid-term historical data about traffic and amount of transported goods are available and accessible through either publicly available statistics or commercial data providers, depending on the products.

Regarding the hazard component, the group discussed briefly whether to use indicators of meteorological drought as proxy variables for hydrological drought, but concluded that it is rather difficult at a broad scale. More could be done on the research side, and empirical solutions exist for certain river basins, but there are no operational solutions or models safely applicable or transferable at a wide scale (e.g. national, continental). In fact, as well as very different hydrologic circulation dynamics exist among different catchments, water abstraction and usage pose a big challenge when trying to link precipitation to actual river flow. This is true especially for big and highly managed basins, with elements like cumulative withdrawals, interconnected canal systems, water transfers and delayed water releases after use, all of which interfere with the natural hydrology.

Therefore, river streamflow information and reservoir storage are especially required. Ideally, an indicator would rely on a network of measured data of water flows and temperatures, upon which to build sector-specific thresholds. Unfortunately, this is not available even at pan-European scale. There are interesting opportunities by integrating what already exists for certain locations into the wider context (e.g. German river water level monitor, Portuguese and Spanish reservoir storage information systems), which is merely a technical task, though somewhat challenging due to the high heterogeneity in data collection and management by river basin authorities. In fact, this is what EDO has achieved in other instances. In some cases, even improving existing monitoring networks ad hoc may be feasible (e.g. water temperature monitoring in Segura).

Information on water vessel draft (and more) is also recorded, and in theory it might be possible to model water-levels in relation to transportation only, by a thorough analysis of past traffic and market data, but this issue was not discussed in detail.

Efforts to obtain water temperature data should be undertaken, since temperature impacts are influenced by their synergy with the lack of water (e.g. fishery in freshwater bodies, plant cooling). This is also a key element in climate change analysis. According to the Water Framework Directive, water temperatures are (or should be) continuously measured, but data are seldom published consistently, often only in rough aggregated form. Sector-specific thresholds of water flow and temperature should be considered too. In the absence of water monitoring systems, heat waves and / or daily air temperature data may be employed as proxy variables for water temperature.

Concerning exposure and vulnerability, there are several issues to be addressed, in relation to both data availability and modelling methodology. In general, exact information on regulations across countries and sub-national administrative regions may help to define clear operational boundaries, to use as reference for risk components. In some cases (e.g. hydropower), decisions related to drought management may be overridden by market fluctuations and financial evaluations, which should be taken into account. Competition for water usage is a major factor of vulnerability, but no clear procedural suggestions emerged from the discussion.

If obtaining data is very challenging, priority should be given to most vulnerable regions.

Other Issues Raised:

The discussion started with a question about biomass energy production, but only some ideas are on the table, while how to collect data and consider the biomass energy production is still not known. Until now, most data and models deal with agricultural drought impacts, and the energy sector is still an unexplored territory.

4 Conclusions

At the second EDO User Meeting, experts in drought monitoring, forecasting and management, discussed the status and on-going development of EDO and the closely related Global Drought Observatory (GDO). Since 2018, both systems form part of the Copernicus Emergency Management Service (EMS), providing information for monitoring meteorological, agricultural, and hydrological droughts in Europe and globally, and complementing the other EMS early warning systems for floods and forest fires. GDO extends EDO to the global level, providing information on drought crises to the EU's Emergency Response Coordination Centre (ERCC).

Reflecting a shift from crisis management to preparedness and risk management, the meeting focussed on methods of drought risk assessment for four socio-economic sectors, and the feasibility of implementing sectoral drought risk and vulnerability assessments within EDO and GDO. In line with the terminology of the United Nations Office for Disaster Risk Reduction (UNISDR), drought risk (potential damages or losses to a system, society or community) is determined as a function of hazard (probability of a drought event of a certain severity), exposure (population and assets in hazard-prone areas), and vulnerability (susceptibility of the community or assets to suffer impacts).

At the meeting, the latest scientific enhancements of EDO and GDO were presented: a new global soil moisture product (based on three different soil moisture datasets); a new global database of meteorological drought events between 1951 and 2016; the inclusion of GDO drought alerts in the Global Disaster Alert and Coordination System (GDACS); and forecasting of drought and temperature extremes (heat and cold waves) in EDO. Most of the meeting comprised detailed discussions of the methods and data requirements for global drought risk assessments in four sectors: public water supply, agriculture, energy production, and waterborne transport. A Global Expert Survey on drought vulnerability indicators for agriculture and water supply was launched as a joint United Nations University (UNU-EHS) - JRC initiative (see Annex 1). Based on the deliberations of three Breakout Groups, detailed lists were produced of the variables representing the components of drought risk for public water supply, energy production and waterborne transport (see Annex 2).

Some key issues were highlighted at the meeting. The dynamic nature of drought risk, due to changes in hazard (seasonality, climate change), exposure (crop phenology, tourism fluxes) and vulnerability (socio-economic factors), is particularly relevant for monitoring and forecasting risk as a probability of impacts. More efforts are needed to obtain drought impact data from the private sector. Policy-makers and water managers require sector-specific, high-level drought risk indicators, combining hazard, exposure and vulnerability, and showing different alert levels. Two such indicators - the Combined Drought Indicator (CDI) and Risk of Drought Impacts (RDrI) - are already implemented for the agricultural sector in EDO and GDO. Drought risk indicators for other sectors are being developed.

The information on drought risk and vulnerability assessments produced by the meeting will support the development of drought risk indicators for the discussed sectors, and the preparation of related recommendations and guidelines. The next EDO User Meeting will be held on 21-22 May 2019 in Stresa, Italy, back-to-back with User Meetings of the other Copernicus EMS services on floods, forest fires, and rapid mapping. It will focus on global drought monitoring and forecasting, and aim to support the development of UNISDR's planned 2020 Special Report on Drought.

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Annex 1: Questionnaire for Global Expert Survey on Drought Vulnerability

Global Expert Survey

Drought vulnerability indicators for global-scale sectoral drought risk assessments

October 2018

UNITED NATIONS UNIVERSITY

UNU-EHS

Institute for Environment and Human Security

in collaboration with

European Commission

GDO - Global Drought Observatory

Copernicus Europe's eyes on Earth

Emergency Management Service

Guidelines for completing the survey:

This survey is a joint effort of the **European Commission's European and Global Drought Observatories (EDO and GDO)**, and the **United Nations University (UNU-EHS)** within its **GlobeDrought project**. The survey, which can also be completed on-line (see web-link below), seeks to synthesize expert knowledge on drought vulnerability, specifically regarding the potential impacts of drought hazards on agricultural systems and domestic water supply. Results of the survey will inform the weighting of indicators in sector-specific drought vulnerability and risk assessments at the global level. Please note the following:

- Drought risk and related impacts depend not only on the drought hazard, but also on the exposure and vulnerability of the different socio-economic sectors (e.g. agriculture, domestic water supply, energy production) or ecosystems (e.g. wetlands, forests) affected.
- On the following pages a **list of drought vulnerability indicators** derived from a systematic literature review and expert consultations is presented.
- You are kindly asked to **weigh each indicator** based on its **relevance for drought vulnerability** and **the risk of negative impacts** of drought hazards on **agricultural systems** (including people, crops, livestock, etc.) and **domestic water supply**,using a scale from 0 (= "**not relevant**") to 4 (= "**highly relevant**").
- If you do not know the answer to a question, please tick "**I don't know**".
- After each survey section, two *optional* lines are provided for you to add and weigh **additional indicators** that you think should be considered in a global drought vulnerability and risk assessment.
- The contribution of the suggested indicators to vulnerability can be either positive or negative, meaning that high indicator scores either reduce (e.g. "Availability of a drought early warning system") or increase (e.g. "Illiteracy rate") vulnerability. This should not however affect their relevance.
- **Confidentiality**: The results of this survey are fully confidential, and the data will not be shared outside of UNU-EHS or the European Commission's GDO. Individual responses are not identified.
- This survey requires approximately **15-20 minutes** to complete.

Background information:

GlobeDrought is a three year project (01-Aug-2017 to 31-Jul-2020), funded by the German Federal Ministry of Research and Education (BMBF), which aims to develop a web-based drought risk information system for comprehensively characterizing drought risk and sectoral drought impacts at global and regional levels.

The Global Drought Observatory (GDO), which forms part of the Copernicus Emergency Management Service (https://emergency.copernicus.eu/), was developed by the European Commissions' Joint Research Centre (JRC) in order to provide information for the EU's Emergency Response Coordination Centre (ERCC). GDO already includes sector-specific exposure and vulnerability information for assessing the **Risk of Drought Impact (RDrI)**.

GlobeDrought web-site: https://grow-globedrought.net/
Global Drought Observatory (GDO) web-site: http://edo.jrc.ec.europa.eu/gdo/php/index.php?id=2001
On-line version of the Global Expert Survey: https://www.e-encuesta.com/r/A1VWMTKSB994z5JOcG8TJQ/

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Drought Vulnerability Indicators

(Grouped by type: Social; Economic; Infrastructure; Crime & Conflict; Governance; Environmental; Farming Practices).

Contribution to drought vulnerability:

- **“Not Relevant”:** The indicator has no influence on vulnerability to drought at global level.
- **“High Relevance”**: The indicator has a high influence on vulnerability to drought at global level.

		Not relevant	Low relevance	Low-medium relevance	Medium-high relevance	High relevance	I do not know	*(Two socio-economic sectors of interest)*
	Social							
S1	Illiteracy rate (%)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
S2	Gender inequality (categorical)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
S3	Social capital (categorical)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
S4	Alcohol consumption litres per capita (people aged 15 years and older)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
S5	Disabled persons (%)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
S6	Population undernourished (%)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
S7	Population with ill-health (%)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
S8	Life expectancy at birth (years)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
S9	Number of physicians per 1,000 inhabitants	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
S10	Expenditure on health (out-of-pocket) (%)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
S11	Households without a health insurance (%)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
S12	Rural population (% of total population)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
S13	Refugee population (% of total population)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
S14	Population ages 15–64 (% of total population)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
S15	Risk perception (% of population who has experienced droughts in the past 10 years)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
S16	Availability of a drought early warning system (yes/no)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
S17	Households/farmers with access to information (radio/TV/internet) (%)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
Please add below any additional indicators you feel are missing:								
S01		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
S02		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply

Drought Vulnerability Indicators *(Grouped by type: Social; Economic; Infrastructure; Crime & Conflict; Governance; Environmental; Farming Practices).*		Contribution to drought vulnerability: ▪ **"Not Relevant":** The indicator has no influence on vulnerability to drought at global level. ▪ **"High Relevance"**: The indicator has a high influence on vulnerability to drought at global level.						
		Not relevant	Low relevance	Low-medium relevance	Medium-high relevance	High relevance	I do not know	*(Two socio-economic sectors of interest)*
Economic								
E1	Dependency on agriculture for livelihood (%)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
E2	Agriculture (% of GDP)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
E3	Tourism (% of GDP)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
E4	Population below the national poverty line (%)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
E5	Unemployment rate (%)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
E6	GDP per capita, PPP	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
E7	GINI index (income inequality)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
E8	Farmers/laborers without savings (%)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
E9	Farmers/laborers without access to bank loans / (micro-) credits (%)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
E10	Distance to closest market (km)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
E11	Market fragility	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
E12	Farmers with crop, livestock or drought insurance (%)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
E13	Energy consumption per capita	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
Please add below any additional indicators you feel are missing:								
E01		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
E02		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply

Drought Vulnerability Indicators

(Grouped by type: Social; Economic; Infrastructure; Crime & Conflict; Governance; Environmental; Farming Practices).

Contribution to drought vulnerability:

- **"Not Relevant":** The indicator has no influence on vulnerability to drought at global level.
- **"High Relevance"**: The indicator has a high influence on vulnerability to drought at global level

	Drought Vulnerability Indicators	Not relevant	Low relevance	Low-medium relevance	Medium-high relevance	High relevance	I do not know	*(Two socio-economic sectors of interest)*
	Infrastructure							
I1	Road density (km of road per 100 sq. km of land area)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
I2	Population without access to (improved) sanitation (%)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
I3	Population without access to clean water (%)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
I4	Water quality (categorical)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
I5	Total dam capacity (m^3)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
I6	% of retained renewable water	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
I7	Electricity production from hydroelectric sources (% of total)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
I8	Water efficiency (% of households using water saving devices)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
I9	Leakage rates (%)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
Please add below any additional indicators you feel are missing:								
I01		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
I02		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
	Crime & Conflict							
C1	(Livestock) theft (%)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
C2	Prevalence of conflict/insecurity	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
Please add below any additional indicators you feel are missing:								
C01		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
C02		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply

		Contribution to drought vulnerability: – **"Not Relevant":** The indicator has no influence on vulnerability to drought at global level. – **"High Relevance"**: The indicator has a high influence on vulnerability to drought at global level						
Drought Vulnerability Indicators *(Grouped by type: Social; Economic; Infrastructure; Crime & Conflict; Governance; Environmental; Farming Practices).*		Not relevant	Low relevance	Low-medium relevance	Medium-high relevance	High relevance	I do not know	*(Two socio-economic sectors of interest)*
Governance								
G1	Disaster risk taken into account in public investment and planning decisions (yes/no)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
G2	National investment in disaster prevention & preparedness (US$/year/capita)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
G3	Existence of national adaptation/drought plans (yes/no)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
G4	Government effectiveness	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
G5	Number of (drought-related) adaptation projects in the past 10 years	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
G6	Corruption (e.g. Corruption Perception Index)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
G7	Strength of legal rights (law enforcement)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
G8	Public participation in local policy	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
G9	Food aid (US$ per capita)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
G10	Research and development expenditure (% of GDP)	0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
Please add below any additional indicators you feel are missing:								
G01		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply
G02		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Agricultural systems
		0 ☐	1 ☐	2 ☐	3 ☐	4 ☐	? ☐	Water supply

Drought Vulnerability Indicators *(Grouped by type: Social; Economic; Infrastructure; Crime & Conflict; Governance; Environmental; Farming Practices).*		Contribution to drought vulnerability: – **"Not Relevant":** The indicator has no influence on vulnerability to drought at global level. – **"High Relevance"**: The indicator has a high influence on vulnerability to drought at global level						
		Not relevant	Low relevance	Low-medium relevance	Medium-high relevance	High relevance	I do not know	*(Two socio-economic sectors of interest:*
Environmental								
V1	Soil organic matter (g/kg)	0 □	1 □	2 □	3 □	4 □	? □	Agricultural systems
		0 □	1 □	2 □	3 □	4 □	? □	Water supply
V2	Soil depth (mm)	0 □	1 □	2 □	3 □	4 □	? □	Agricultural systems
		0 □	1 □	2 □	3 □	4 □	? □	Water supply
V3	Degree of land degradation and desertification	0 □	1 □	2 □	3 □	4 □	? □	Agricultural systems
		0 □	1 □	2 □	3 □	4 □	? □	Water supply
V4	Area protected and designated for the conservation of biodiversity (%)	0 □	1 □	2 □	3 □	4 □	? □	Agricultural systems
		0 □	1 □	2 □	3 □	4 □	? □	Water supply
V5	Veterinarians and veterinary para-professionals (per capita)	0 □	1 □	2 □	3 □	4 □	? □	Agricultural systems
		0 □	1 □	2 □	3 □	4 □	? □	Water supply
V6	Livestock health	0 □	1 □	2 □	3 □	4 □	? □	Agricultural systems
		0 □	1 □	2 □	3 □	4 □	? □	Water supply
V7	Baseline water stress (ratio of withdrawals to renewable supply)	0 □	1 □	2 □	3 □	4 □	? □	Agricultural systems
		0 □	1 □	2 □	3 □	4 □	? □	Water supply
Please add below any additional indicators you feel are missing:								
V01		0 □	1 □	2 □	3 □	4 □	? □	Agricultural systems
		0 □	1 □	2 □	3 □	4 □	? □	Water supply
V02		0 □	1 □	2 □	3 □	4 □	? □	Agricultural systems
		0 □	1 □	2 □	3 □	4 □	? □	Water supply

Drought Vulnerability Indicators *(Grouped by type: Social; Economic; Infrastructure; Crime & Conflict; Governance; Environmental; Farming Practices).*		Contribution to drought vulnerability: – **"Not Relevant":** The indicator has no influence on vulnerability to drought at global level. – **"High Relevance"**: The indicator has a high influence on vulnerability to drought at global level						
		Not relevant	Low relevance	Low-medium relevance	Medium-high relevance	High relevance	I do not know	*(Two socio-economic sectors of interest:*
Farming Practices								
F1	Agricultural machinery in use (#)	0 □	1 □	2 □	3 □	4 □	? □	Agricultural systems
		0 □	1 □	2 □	3 □	4 □	? □	Water supply
F2	Irrigated land (% total arable)	0 □	1 □	2 □	3 □	4 □	? □	Agricultural systems
		0 □	1 □	2 □	3 □	4 □	? □	Water supply
F3	Use of fertilizer (ton/ha)	0 □	1 □	2 □	3 □	4 □	? □	Agricultural systems
		0 □	1 □	2 □	3 □	4 □	? □	Water supply
F4	Access to fodder (kg purchased per year per farmer)	0 □	1 □	2 □	3 □	4 □	? □	Agricultural systems
		0 □	1 □	2 □	3 □	4 □	? □	Water supply
F5	Insecticides and pesticides used (ton/ha)	0 □	1 □	2 □	3 □	4 □	? □	Agricultural systems
		0 □	1 □	2 □	3 □	4 □	? □	Water supply
F6	Cultivation of drought-resistant crops (%)	0 □	1 □	2 □	3 □	4 □	? □	Agricultural systems
		0 □	1 □	2 □	3 □	4 □	? □	Water supply
F7	Farmers use different crop varieties (%)	0 □	1 □	2 □	3 □	4 □	? □	Agricultural systems
		0 □	1 □	2 □	3 □	4 □	? □	Water supply
Please add below any additional indicators you feel are missing:								
F01		0 □	1 □	2 □	3 □	4 □	? □	Agricultural systems
		0 □	1 □	2 □	3 □	4 □	? □	Water supply
F02		0 □	1 □	2 □	3 □	4 □	? □	Agricultural systems
		0 □	1 □	2 □	3 □	4 □	? □	Water supply

Annex 2: Relevant variables for drought risk assessment - Breakout Group results

Table A1: Proposed variables / information required to represent drought risk for the Public Water Supply sector. (Output from Breakout Group 1).

Risk Components		
HAZARD	***EXPOSURE***	***VULNERABILITY***
▪ Source type (groundwater, river flow and reservoirs) as anomalies. (Unique indicator for all hazards). ▪ Water demand. ▪ Confidence, quality of information, scale. (Start with city hotspots, move to other scale if information available). ▪ Environmental flow ("e-flow"), which affects supply side. (New sector?) ▪ Water quality. ▪ SPI (-12 to -24 months) as a proxy.	▪ Population-based. Seasonality? More dynamic (e.g. tourism)? ▪ Water demand per capita (linked with socio-economic factors). ▪ Competing water demand sectors (e.g. industry, agriculture etc.). (More for vulnerability?)	▪ National / sub-national information important. ▪ Education level (different from literacy). ▪ Communication network, mobile phones per capita. ▪ Diversity of sources. ▪ Distance to water source (not distance to coast - seawater only possible if infrastructure exist). ▪ Terrain (impact on provision). ▪ Conflict (impact on aid). ▪ Age of distribution system and GDP of country (proxy for water losses). ▪ Grey water use (water re-use). ▪ Water exploitation index. ▪ Transboundary rivers and % of source from outside nation. ▪ Algorithm to reflect local conditions. ▪ Distance to city (competition for use from same source). ▪ Water quality? ▪ Private mitigation methods (e.g. tanks). ▪ Transboundary water use / rights and related issues. ▪ Competition for water use (agriculture, public water supply, etc.) ▪ Water storage (i.e. reservoirs) capacity and levels. ▪ Ratio of water-dependent versus non-dependent energy sources. ▪ Users risk awareness.

Table A2: Proposed variables / information required to represent drought risk for the Energy Production sector. (Output from Breakout Group 3).

Risk Components		
HAZARD	***EXPOSURE***	***VULNERABILITY***
▪ Natural water storage: – Snowpack / snow water equivalent (by basin). – Groundwater levels. ▪ Low flows. ▪ Water temperatures. ▪ Heatwave occurrence.	▪ Power plant water demand / usage. ▪ Market electricity demand / usage. ▪ Power capacity.	▪ Environmental regulations: – Mandatory minimum flows. – Minimum output temperatures. ▪ Governance: – Prioritization of usage. – Water use quotas and rights. – Management efficiency and level of investments. – Incentives and financial buffers. – Drought management plans. ▪ Technological constraints: – Water withdrawal (m^3 per MWh), depending on cooling technology, hydropower plant features, etc. – Intake water temperature. ▪ Transboundary water uses / rights and related issues. ▪ Competition for water use (agriculture, public water supply, etc.) ▪ Water storage (i.e. reservoirs) capacity and levels. ▪ Ratio of water-dependent versus non-dependent energy sources. ▪ Users risk awareness.

Table A3: Proposed variables / information required to represent drought risk for the Waterborne Transport sector. (Output from Breakout Group 3).

Risk Components		
HAZARD	***EXPOSURE***	***VULNERABILITY***
▪ Natural water storage: – Snowpack / snow water equivalent (by basin). – Groundwater levels. ▪ Low flows. ▪ Water levels.	▪ Traffic density. ▪ Amount / value of goods transported. ▪ River network density.	▪ Regulations: – Water quality. ▪ Governance: – Prioritization of usage. – Management efficiency and level of investments. – Incentives and financial buffers. – Drought management plans. ▪ Technological constraints: – Fleets flexibility, tonnage. – Port facilities. ▪ Viable alternative transport routes (road / rail network density). ▪ Users risk awareness. ▪ Water storage (i.e. reservoirs) capacity and levels.

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