

## Status box

Title: **Update on Water Scarcity and Droughts indicator development**

Version: Final

Date: May 2012

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### Background:

Within the 2010-2012 CIS period, an updated mandate on water scarcity and droughts was approved, requesting to **deliver a set of common indicators for both water scarcity** (influenced by human activity) **and drought** (natural).

At the Water Directors meeting in May 2011 a set of 7 **awareness raising indicators** was agreed for testing. These indicators provide, in combination, an overview of the developments as regards water scarcity and droughts and will allow distinguishing between the natural and man-made phenomena.

At the Water Directors meeting in November 2011, two agreed indicators (SPI and FAPAR) were endorsed to illustrate drought events as elements of the future water scarcity and drought indicator system. Further technical drafting and testing of the remaining drought indicators as well as in particular of the water scarcity indicator (WEI+) was encouraged.

The testing exercise and further conceptual developments have led to the agreement by the Expert Network to include the Water Scarcity indicator WEI+ in the indicator system.

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## 1. STATE OF PLAY:

A testing exercise conducted by several Pilot River Basins and further conceptual developments have led to the agreement by the Expert Network to include the Water Scarcity indicator WEI+ in the indicator system.

The three indicators agreed so far can extensively be calculated on the basis of pan-European information, either already existing or under development (water accounts).

The three awareness-raising indicators agreed so far can extensively be calculated on the basis of pan-European information, either already existing or under development (e.g. water accounts), though their testing and reality-check with MS is recommended in order to increasingly improve their robustness.

In parallel, specific management already exist in several MS, which are taking into account the local climate, water systems and existing monitoring more fully.

## 2. FULLY DEVELOPED DROUGHT INDICATORS

The following three indicators have been agreed so far by the Expert Group (revised factsheets are attached):

- The **Standardized Precipitation Index** (SPI) is an indicator to detect and quantify meteorological drought situations by comparing the current situation to historical records. It will be hosted by the European Drought Observatory (EDO). This indicator can produce different time-related outputs, so meteorological drought evidence and evolution can be shown for the past month(s), season(s) and/or year(s), facilitating the establishment of links to other drought indicators.
- The selected Vegetation Response indicator is the **fraction of Absorbed Photosynthetically Active Solar Radiation** (fAPAR). It represents the fraction of the solar energy which is absorbed by the vegetation canopy and is a biophysical variable directly correlated with the primary productivity of the vegetation. Its anomalies (the deviation from the long-term mean for a certain period of time) are considered a good indicator to detect and assess drought impacts on vegetation canopies.
- The **Water Exploitation Index Plus** (WEI+) of a particular area is the total consumption of water divided by the renewable freshwater resources<sup>1</sup>. It provides an indication of the pressure on the water resources of a certain territory as a consequence of water withdrawals. Hence, it also identifies areas most prone to suffer recurrent or permanent situations of water scarcity.

In relation to meeting the goal of awareness raising on situations of drought and water scarcity and the establishment of effective mechanisms for its detection and analysis as a starting point for the implementation of response measures against these situations, it should be noted that:

- Drought indicators provide essentially information on climate, and indirectly on the availability of resources. Negative results or anomalies may indicate different potential impacts and reveal the occurrence of dry periods of varying intensity and duration which may require the implementation of actions in the framework of the Drought risk management plans.
- Moreover, the observation of the recurrent presence of such anomalies over time in a given territory would indicate the need to design appropriate policy measures in response to the frequency of the phenomenon observed.
- Water scarcity indicators provide information about the pressure on freshwater resources in a given area and its vulnerability to the appearance of water-scarce periods and/or potential increases in water use that may endanger the sustainability of the water supply systems as well as maintaining the environmental conditions required for the maintenance of water dependent ecosystems. This can happen at an annual or monthly/seasonal level.
- As in the previous case, there may be punctual situations of scarcity that require the launch of management actions laid down in the Drought risk management plans, but also the observation of negative developments that indicate the need to anticipate policy response measures.

### 3. NEXT STEPS

Further work might also be useful for other water scarcity indicators, e.g. a Water Demand Index or the comparison of observed outflows with natural outflows, but this initiative falls outside the current scope of this EG Mandate 2010-2012 and should be evaluated after a thorough assessment of the indicator set and its data availability, reliability and sustainability.

A number of further indicators have been discussed but not been agreed so far by the Expert Group<sup>1</sup>: Snowpack, Standardised Run-off Index (SRI), Groundwater and Soil Moisture. In particular:

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<sup>1</sup> The SRI, Groundwater and Soil Moisture indicators are also influenced by water uses, and hence not pure drought indicators

- Regarding the snowpack indicator, FI will continue leading its development, in particular regarding the quantification of the water equivalence of a certain snowpack, with the aim to develop and test the indicator for the next EG meeting.
- Regarding the streamflow indicator (SRI), ES will lead a testing exercise and integrate comments and experiences into the factsheet from those MS that have tested or will test the indicator. This development is expected to conclude by the next EG meeting.
- Regarding the groundwater indicator, FR will lead testing and improvement of the indicator factsheet, involving in particular those countries that are already using groundwater evolution as an indicator for awareness raising. This activity is planned to be developed for the next EG meeting.
- Regarding soil moisture, it is still considered as a useful indicator, but further developments and clarifications have to be checked for the validity of the data. An update is expected for the next EG Meeting, lead by ES and JRC.
- Regarding the WEI+, the EG is looking forward to validate the data from the water accounts project as well as the results of comparing the data with the current WEI thresholds with a view to updating them for use of the WEI+
- As previously agreed the EG will be sharing best practices as regards management indicators in the remaining part of the period covered by the mandate.

#### 4. ADDITIONAL WORK OF THE INDICATOR EXPERT GROUP

In parallel to the development of the indicators, the Expert Network has developed a paper with ***Working Definitions of Water Scarcity and Droughts*** in follow up to the assessment of water scarcity & droughts in the RBM plans where it became apparent that these phenomena are not interpreted in the same way by the different RB authorities. The definitions paper is now agreed by the Expert Group and attached to this paper.

Furthermore the EG has initiated work on ***Environmental flows*** as a tool to better understand the relationship between water scarcity, droughts and achieving the objectives of the Water Framework Directive. A paper is currently being finalized and given that the relevance of environmental flows is much wider than the link to water scarcity & droughts the EG suggests that that paper could be submitted and discussed more widely in the CIS structure.

#### 5. RECOMMENDATIONS TO WATER DIRECTORS:

The EG requests WDs to

- endorse the WEI+ indicator as part of the overall indicator set for water scarcity and drought, with the understanding that thresholds still need to be tested and agreed.
- Take note of the Working Definitions on Water Scarcity & Droughts (attached)
- agree to the paper on Environmental Flows (draft attached) to be circulated to other relevant groups in the CIS, in particular WG A & C and the EG Climate Change and Agriculture

### FAPAR: Fraction of Absorbed Photosynthetically Active Radiation

#### Indicator definition

Droughts affect the vegetation canopy and specifically its capacity to intercept solar radiation. The Fraction of Absorbed Photosynthetic Solar Radiation (fAPAR) is known to be strongly related to water stress. fAPAR and fAPAR anomalies (the deviation from the long-term mean for a certain period of time) are considered good indicators to detect and assess drought impacts on vegetation canopies.

#### Relevance of the indicator to drought

The Fraction of Absorbed Photosynthetically Active Radiation (fAPAR) represents the fraction of the solar energy which is absorbed by the vegetation canopy. fAPAR is a biophysical variable directly correlated with the primary productivity of the vegetation, since the intercepted PAR is the energy (carried by photons) underlying the biochemical productivity processes of plants. fAPAR is one of the Essential Climate Variables recognized by the UN Global Climate Observing System (GCOS) and by the FAO Global Terrestrial Observing System (GTOS) as of great potential to characterize the climate of the Earth.

Due to its sensitivity to vegetation stress, fAPAR has been proposed as a drought indicator (Gobron *et al.* 2005 and 2007). Indeed droughts can cause a reduction in the vegetation growth rate, which is affected by changes either in the solar interception of the plant or in the light use efficiency.

#### Policy relevance

Water Framework Directive WFD (Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy)

- Environmental objectives: Exemption for temporary deterioration in the status (Art. 4 (6))
- Programme of measures: Additional measures are not practicable (Art. 11 (5))

Communication of the EC to the Council and European Parliament: "Addressing the challenge of water scarcity and droughts in the European Union" (published on July 2007)

- Developing drought risk management plans (*Paragraph 2.3.1.*)
- Developing an observatory and an early warning system on droughts (*Paragraph 2.3.2.*)
- Improve knowledge and data collection: Water scarcity and drought information system (*Paragraph 2.7.1.*)

#### Technical Information

##### 1. Indicator

fAPAR is presented as the MERIS Global Vegetation Index (MGVI). MGVI is a remote sensing derived indicator estimating fAPAR at canopy level. MERIS stands for Medium Resolution Imaging Spectrometer, a satellite sensor operating onboard the European ENVISAT satellite platform.

## 2. Spatial scale

MGVI data cover all of Europe with a spatial resolution of 1.2 x 1.2 km<sup>2</sup>.

## 3. Temporal scale

Every 10 days aligned on the first day of each month, which corresponds to 3 images per month (day 1-10, day 11-20, day 21-last day of month).

## 4. Methodology

### a. Detailed methodology for the calculation of the indicator

fAPAR is difficult to measure directly but can be inferred from models describing the transfer of solar radiation in plant canopies, using Earth Observation (EO) information as input data. fAPAR estimates are retrieved using EO information by numerically inverting physically-based models.

The fAPAR estimates used within EDO are operationally produced by the European Space Agency (ESA). They are derived from the multispectral images acquired by the Medium Resolution Imaging Spectrometer (MERIS) onboard ENVISAT by means of the MERIS Global Vegetation Index (MGVI) algorithm, developed at the JRC (Gobron *et al.* 2004).

MGVI is a physically-based index which transforms the calibrated multi-spectral directional reflectance into a single numerical value while minimizing possible disturbing factors. It is constrained by means of an optimization procedure to provide an estimate of the fAPAR of a vegetation canopy. The objective of the algorithm is to reach the maximum sensitivity to the presence and changes in healthy live green vegetation while at the same time minimizing the sensitivity to atmospheric scattering and absorption effects, to soil color and brightness effects, and to temporal and spatial variations in the geometry of illumination and observation.

The MGVI level-3 aggregation processor is routinely operated on the ESA Grid Processing on Demand (G-POD) system. The algorithms have been developed and are maintained by the European Commission Joint Research Centre (JRC). More information on the algorithms can be found in Pinty B. *et al.* (2002) and Gobron N. *et al.* (2004).

- Data acquisition: The 10-day fAPAR estimates are regularly produced by the European Space Agency (ESA) as MERIS fAPAR Level-3 Aggregated Products following the approach by Ausedat *et al.* (2007).
- Anomaly estimation: fAPAR anomalies are produced at JRC as follows:

$$Anomaly_t = \frac{X_t - \bar{X}}{\delta}$$

where  $X_t$  is the fAPAR of the 10-day period  $t$  of the current year and  $\bar{X}$  is the mean fAPAR and  $\delta$  is the standard deviation calculated for the same 10-day period  $t$  using the available time series (archive).

### b. Reference period for calculating the Statistics

For the production of fAPAR anomalies, JRC extended the MERIS fAPAR time series (ranging from end 2002 to the current day) with fAPAR estimations obtained from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) from mid 1997 to end 2002 with an algorithm completely compatible with the MGVI (Gobron *et al.* 2002). This allowed for the creation of a **reference period starting mid 1997**.

## 5. Data source and frequency of data collection

MGVI data are delivered as a subscription service within the Service Support Environment (SSE) of the European Space Agency. This service is called "MGVI Catalogue Search and Download" and can be accessed via this link: <http://services.eoportal.org/portal/service/ShowServiceInfo.do?serviceId=7180CB90&categoryId=89802980>

Frequency of data collection: every 10 days

## 6. Quality Information

### a. Strength & weaknesses at data level

[+] Every ten days, the MGVI gives a spatially continuous picture of the vegetation status/health at a high spatial resolution (~1km) for the entire European continent.

[-] Drought and water stress are not the only factors that can cause a decrease of MGVI values/anomalies. Changes in land cover or pests and diseases can also be responsible for such variation of the signal. Therefore this indicator must be used jointly with other indicators giving information on rainfall and soil moisture deficits in order to determine if the variation in the vegetation response (signal) is linked with a drought event or not.

[-] Anomalies are dependent of the time series (reference period) available to calculate the long-term average and the standard deviations. This period should be long enough to characterize the area where the index is calculated. As the reference period is still short (1997 to today), the anomalies are to be interpreted with care.

### b. Performance of the indicator

MGVI has been used successfully to assess the impact of the 2003 drought on plant productivity in Europe (Gobron *et al.* 2005). Moreover Rossi *et al.* (2008) highlighted the potential of this indicator for drought detection and monitoring by comparing it to other drought indicators such as the Standardized Precipitation Index (SPI). Recently, fAPAR has been capable to reflect the impact of the 2011 spring drought in western Europe (mainly France, Germany, Benelux, UK) and central Europe (<http://desert.jrc.ec.europa.eu/action/php/index.php?action=view&id=118>).

## Products

fAPAR and fAPAR anomalies can be presented in the form of maps and graphs, providing information both on the spatial distribution of the vegetation activity and the temporal evolution over longer time periods. Gridded data can easily be aggregated over administrative or natural entities such as river basins. This allows for the qualitative and quantitative comparison of the intensity and duration of the fAPAR anomalies with recorded impacts such as yield reductions, low flows, or the lowering of groundwater levels, for example.

The Map Server of the European Drought Observatory (EDO) displays the latest available fAPAR 10-day composite image and the fAPAR anomaly image calculated by comparing this image to the historical series in the same 10-day period (Figure 1). In the future historical images will be retrievable.

The fAPAR product is dimensionless. It is ranging from 0 to 1 in terms of real values, with 1 corresponding to a maximum of vegetation activity. On the map these values are represented by yellow to green colours.

The fAPAR anomaly product is given in units of standard deviation. Anomalies are commonly ranging from -4 to +4, represented by colours ranging from red to green, red showing negative anomalies.

Both products are easy to read. The interpretation must take into account the fact that this indicator is showing a variation in the vegetation health and/or cover. This variation can be a consequence of a rainfall / soil moisture deficit but can also be due to other factors.

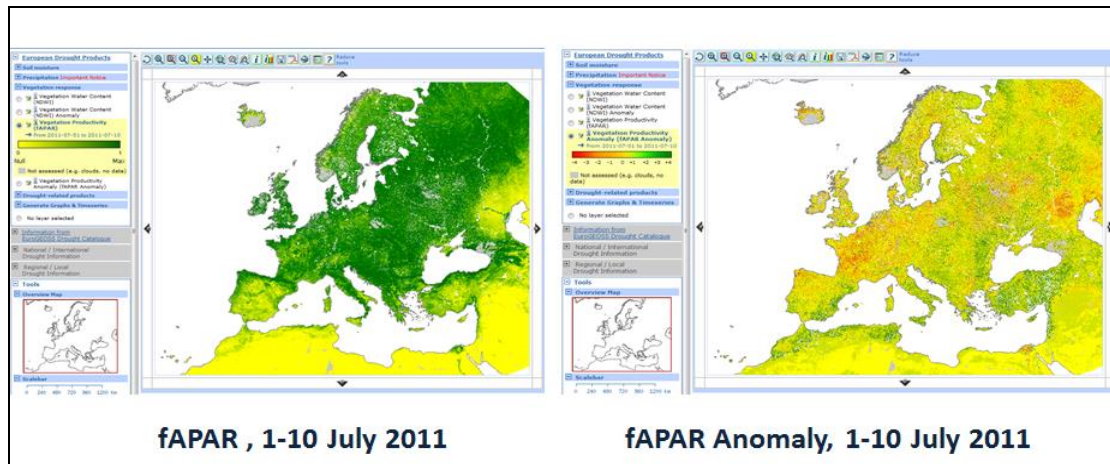


Figure 1: fAPAR (left) and fAPAR anomaly (right) images for the ten-day period of 1-10 July 2011, as shown on the EDO Map Server

### Assessment of capacity for drought monitoring

Gobron *et al.* (2000, 2006a, 2006b) present an evaluation for different canopy radiation transfer regimes using the current fAPAR products derived from SeaWiFS against ground-based estimations.

The MGVI/fAPAR algorithm seems to perform better than NDVI as a drought indicator, as NDVI shows a much larger temporal variability than fAPAR, and does not always allow for the detection of droughts (Gobron *et al.* 2007).

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## ANNEX 2

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### SPI: Standardized Precipitation Index

#### Indicator definition

The Standardized Precipitation Index (SPI- $n$ ) is a **statistical indicator** comparing the total precipitation received during a period of  $n$  months with the long-term rainfall distribution for the same period of time. SPI is calculated on a monthly basis for a moving window of  $n$  months, where  $n$  indicates the rainfall accumulation period, which is typically of 1, 3, 6, 9, 12, 24 and 48 months. The corresponding SPIs are denoted as SPI-1, SPI-3, SPI-6, etc.

In order to allow for the statistical comparison of wetter and drier climates, SPI is based on a transformation of the accumulated precipitation into a standard normal variable with zero mean and variance equal to one. SPI results are given in **units of standard deviation** from the long-term mean of the standardized distribution.

In 2010 WMO selected the SPI as a key meteorological drought indicator to be produced operationally by meteorological services.

#### Relevance of the Indicator to Drought

A reduction in precipitation with respect to the normal precipitation amount is the primary driver of drought, resulting in a successive shortage of water for different natural and human needs. Since SPI values are given in units of standard deviation from the standardised mean, negative values correspond to drier periods than normal and positive values correspond to wetter periods than normal. The magnitude of the departure from the mean is a **probabilistic measure of the severity** of a wet or dry event.

Since the SPI can be calculated over different rainfall accumulation periods, different SPIs allow for estimating different potential impacts of a meteorological drought:

- SPIs for short accumulation periods (e.g., SPI-1 to SPI-3) are indicators for immediate impacts such as reduced soil moisture, snowpack, and flow in smaller creeks;
- SPIs for medium accumulation periods (e.g., SPI-3 to SPI-12) are indicators for reduced stream flow and reservoir storage; and
- SPIs for long accumulation periods (SPI-12 to SPI-48) are indicators for reduced reservoir and groundwater recharge, for example.

The exact relationship between accumulation period and impact depends on the natural environment (e.g., geology, soils) and the human interference (e.g., existence of irrigation schemes). In order to get a full picture of the potential impacts of a drought, SPIs of different accumulation periods should be calculated and compared. A comparison with other drought indicators is needed to evaluate actual impacts on the vegetation cover and different economic sectors.

#### Policy Relevance

Water Framework Directive WFD (Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy)

- Environmental objectives: Exemption for temporary deterioration in the status (Art. 4 (6))
- Programme of measures: Additional measures are not practicable (Art. 11 (5))

Communication of the EC to the Council and European Parliament: “Addressing the challenge of water scarcity and droughts in the European Union” (published on July 2007)

- Improving drought risk management
  - Developing drought risk management plans (*Paragraph 2.3.1.*)
  - Developing an observatory and an early warning system on droughts (*Paragraph 2.3.2.*)
  - Use of the EU Solidarity Fund (*Paragraph 2.3.3.*)
- Improve knowledge and data collection: Water scarcity and drought information system (*Paragraph 2.7.1.*)

## Technical Information

### 1. Indicator

SPI gives the number of standard deviations from standardised mean rainfall for a particular location and period of time and as such reflects the statistically expected frequency (and probability) of a given event. The intensity of a dry or wet period is usually classified into the following seven categories:

SPI Values	Category	Cumulative Probability Probability of Event [%]	
$SPI \geq 2.00$	Extreme wet	0.977 – 1.000	2.3%
$1.50 < SPI \leq 2.00$	Severely wet	0.933 – 0.977	4.4%
$1.00 < SPI \leq 1.50$	Moderately wet	0.841 – 0.933	9.2%
$-1.00 < SPI \leq 1.00$	Near normal	0.159 – 0.841	68.2%
$-1.50 < SPI \leq -1.00$	Moderately dry	0.067 – 0.159	9.2%
$-2.00 < SPI \leq -1.50$	Severely dry	0.023 – 0.067	4.4%
$SPI < -2.00$	Extremely dry	0.000 – 0.023	2.3%

The SPI can be computed for any timescale of interest to the user, reflecting potential impacts from the agricultural, hydrological and water supply management perspectives (see above).

### 2. Spatial Scale

Point data, derived from observations at rain gauge stations, which may be interpolated to a regular grid at a spatial scale appropriate to the station density.

Gridded data at 0.5°, 1.0°, 2.5° derived from readily available climatological datasets such as the Global Precipitation Climatology Centre (GPCC<sup>i</sup>) and the Global Precipitation Climatology Project (GPCP<sup>ii</sup>).

### 3. Temporal Scale

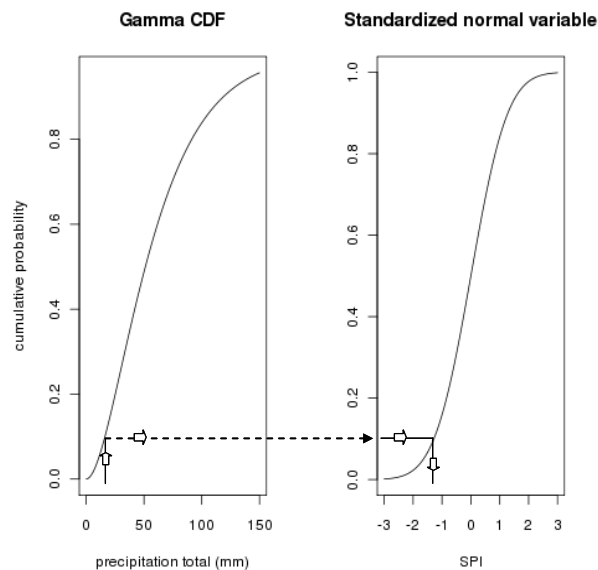
Typically of 1-, 3-, 6-, 12-, 24-, 48-months, or even longer time-periods depending on the potential impact and regional characteristics. For statistical reasons a minimum rainfall accumulation period of one month is recommended. SPI is then calculated for every month with a moving window of the selected time-length.

### 4. Methodology

#### a. Detailed Methodology for the calculation of the indicator

Computation of the SPI involves fitting a probability density function to a given frequency distribution of precipitation totals for a station or grid point and for an accumulation period. Typically the gamma probability density function is used, but others, such as the Pearson-III probability density function may also be used (see below). The statistics for the frequency distribution are calculated on the basis of a reference period of at least 30 years (see point 4.b).

The parameters of the probability density function are then used to find the cumulative probability of an observed precipitation event for the required month and temporal scale. This cumulative probability is then transformed to the standardised normal distribution with mean zero and variance one, which results in the value of the SPI. The procedure of transforming the observed rainfall via the cumulative distribution functions (CDFs) of the Gamma distribution and the standardised normal variable to the SPI is illustrated in Figure 1:



*Figure 1: Transformation of the observed rainfall via the Gamma cumulative distribution function (CDF) and the CDF of the standardized normal variable to the SPI.*

Two statistical distributions have been shown to perform equally well in estimating the SPI: the Gamma and the Pearson-III distributions. The Gamma distribution has been adopted by most centres around the world as a model from which to compute SPI. It is described by only two parameters, but offers considerable flexibility in describing the shape of the distribution, from an exponential to a Gaussian form. It has the advantage that it is bounded on the left at zero and therefore excludes the possibility of negative precipitation. Additionally, it is positively skewed with an extended tail to the right, which is especially important for dry areas with low mean and a high variability in precipitation.

However, for some stations and SPI timescales, distributions such as the beta, Pearson-III or normal distributions may fit the observations better. Ultimately the requirement is to obtain the best estimate of the probability of the observed precipitation to be transformed to the standard normal distribution for SPI. **It therefore follows that the best estimate of SPI will come from the distribution that best fits the station data.**

**As a general rule, it is recommended to use the Gamma distribution as the standard model. If, however, a satisfactory fit cannot be achieved, alternative distributions should be tested.**

A more detailed description of the procedure for calculating the SPI, including the mathematical formulations, can be found at <http://climate.colostate.edu/pub/spi.pdf> (Colorado State University).

Further references are provided at the end of this fact sheet. A detailed **example of how to compute the SPI** using the R statistics package is provided in **Annex A**.

## b. Reference period for calculating the Statistics

The World Meteorological Organization (WMO) recommends that precipitation totals for the at least 30 years are used as reference time-line for calculating rainfall statistics. Several investigators recommend calculating the statistics for the SPI from even longer time periods (e.g., 50 or more years) in order to ensure an accurate representation of extreme events. The current WMO standard reference period is 1961-1990. However several Member States use more recent periods (e.g., 1971-2000, 1981-2010) in order to accommodate changes in the precipitation regime due to climate change and to compare actual rainfall figures to a more recent situation. In order to ensure comparability of the results across Europe and across scales it is highly recommended to use a common reference period for the calculation of the SPI. Considering the results of an inventory of the reference periods used in various Member States, the specific needs for accurately representing extreme events, and possible changes in the rainfall regimes due to climate change, the Water Scarcity and Drought Expert Group strongly recommends using the period **January 1971 to December 2010 as Reference Period** for the calculation of the SPI.

In the case that a lack of data would significantly restrict the number of rainfall stations to be used, a shorter reference period may be used (e.g., 1981-2010). However, in all cases, **the Reference Period used should be clearly indicated with all data presented.**

## 5. Data source and frequency of data collection

Station precipitation data can be taken from high resolution national rain gauge networks or from lower resolution WMO SYNOP stations. Data should be available with at least a monthly time step. Historical time series should be homogeneous and as complete as possible. WMO recommends a maximum of 5 years of missing data (maximum 3 years in a row) over a 30 years period.

As a further check on the data, it is recommended that a threshold of 90% completeness be applied for all SPI timescales and months. For example, for the SPI-1 for May, there must be at least  $0.9 \times 31 = 28$  days with observations; and for the SPI-3 for May, there must be at least  $0.9 \times (31 + 30 + 31) = 83$  days with data. Furthermore, in order to have enough data to fit a distribution for the reference period, 90% of the years must have valid data for the month and SPI timescale. For example, for the SPI-3 for May and a 30-year reference period,  $0.9 \times 30 = 27$  years must have 3-month accumulations for May with at least 83 days of observations.

For data visualization, it is necessary to interpolate the SPI to a grid. The resolution of the grid should be chosen based on the density of the stations. No advantage is gained from interpolating sparse station data to a high resolution grid, and such an approach may result in misleading information. Since the SPI is a measure of the deviation from normal at a particular time and location, the localised effects of factors such as topographic barriers, sea breezes, land surface type etc. on rainfall are already included in the measure. Therefore the simplest interpolation methods are preferred. **Recommended methods** are the **basic inverse distance method** or the **Cressman/Barnes method**, which uses a successive correction technique to take advantage of higher station densities where they exist (see Xia *et al.* 1999, Barnes 1973, Cressman 1959). For details of the implementation of the Cressman/Barnes method see, for example, [http://www.atmos.millersville.edu/~lead/Obs\\_Data\\_Assimilation.html](http://www.atmos.millersville.edu/~lead/Obs_Data_Assimilation.html)).

Gridded data interpolated from rain gauges at 1° resolution are available from GPCC<sup>1</sup>. GPCC "First Guess" data are available monthly on the 5<sup>th</sup> of each month, and final analyses are available through the GPCC monthly monitoring product 2 months after the end of the month.

Gridded data at 2.5° spatial resolution, interpolated from rain gauges and satellite remote sensing observations are available from GPCP<sup>2</sup> monthly, typically 2 months after the end of each month.

## 6. Quality Information

### a. Strength & Weaknesses at data Level

Quality of the index depends on the quality of the precipitation time-series used for the computation, namely on the density of rain-gauges used and on the time length, availability and quality of the precipitation data. It is often desirable to interpolate the SPI in order to represent the index at locations other than the station. **It is preferable to compute SPI at the stations first and then interpolate** rather than interpolate the precipitation first and then compute the SPI. This is because, in order to obtain a distribution fit that best describes the precipitation data, it is important that the observations come from the same population. It is also possible to increase the number of observations used to compute the distribution parameters by clustering stations that have similar statistical properties. One such approach, amongst many that are available for achieving this, is to use to L-moments of the data to regionalize the stations as described in Hosking and Wallis 1997,

#### **b. Performance of the Indicator**

The indicator is relatively easy to calculate and straightforward to interpret. Care needs to be taken in arid areas with generally low precipitation, where the distribution of rainfall data is significantly deviating from a normal distribution. Here specific care has to be taken in estimating the parameters of the distribution in order to adequately parameterize the tails.

Since the gamma distribution is bounded on the left at zero, it is not defined for zero precipitation. If the data includes observations of zero precipitation a mixed distribution is used that takes account of the probability of zero precipitation and the cumulative probability  $H(x)$  becomes

$$H(x) = q + (1-q)G(x),$$

where  $q$  is the probability of zero, calculated from the frequency of zero precipitation observations in the time series, and  $G(x)$  is the cumulative probability calculated from the gamma distribution for non-zero observations.

This approach introduces two problems for regions with many observations of zero precipitation. Firstly, the minimum value SPI can take is determined by the probability of zero – for example if the probability of zero is 0.5, the minimum possible value of SPI is 0 (see Figure 1). Secondly, with fewer observations to compute the parameters of the gamma distribution the fit becomes less well defined. Therefore, for regions with a high probability of zero rainfall, the SPI should be interpreted with care and, where possible, alternative drought indicators should be used in addition. A high probability for zero rainfall is characteristic of an arid climate and in such cases the concept of a drought needs to be adapted. In such cases it may be useful to restrict the calculation and analysis to the normal rainy season(s). In Europe this applies to very limited areas.

Monthly precipitation data are readily available. Depending on the station density, the spatial representativity of interpolated SPIs will vary.

The indicator is suitable for probabilistic forecasting, using ensemble forecasts of precipitation fields.

The indicator can readily be integrated with other indicators.

#### **Products**

SPI can be presented in the form of maps and graphs, providing information both on the spatial distribution of the precipitation deficit and the temporal evolution over longer time periods. Gridded data can easily be aggregated over administrative or natural entities such as hydrological watersheds. This allows for the qualitative and quantitative comparison of the intensity and duration of the precipitation deficit with recorded impacts such as yield reductions, low flows, or lowering of groundwater levels, for example.

The European Drought Observatory (EDO) displays the latest available SPI maps (see Fig. 2).

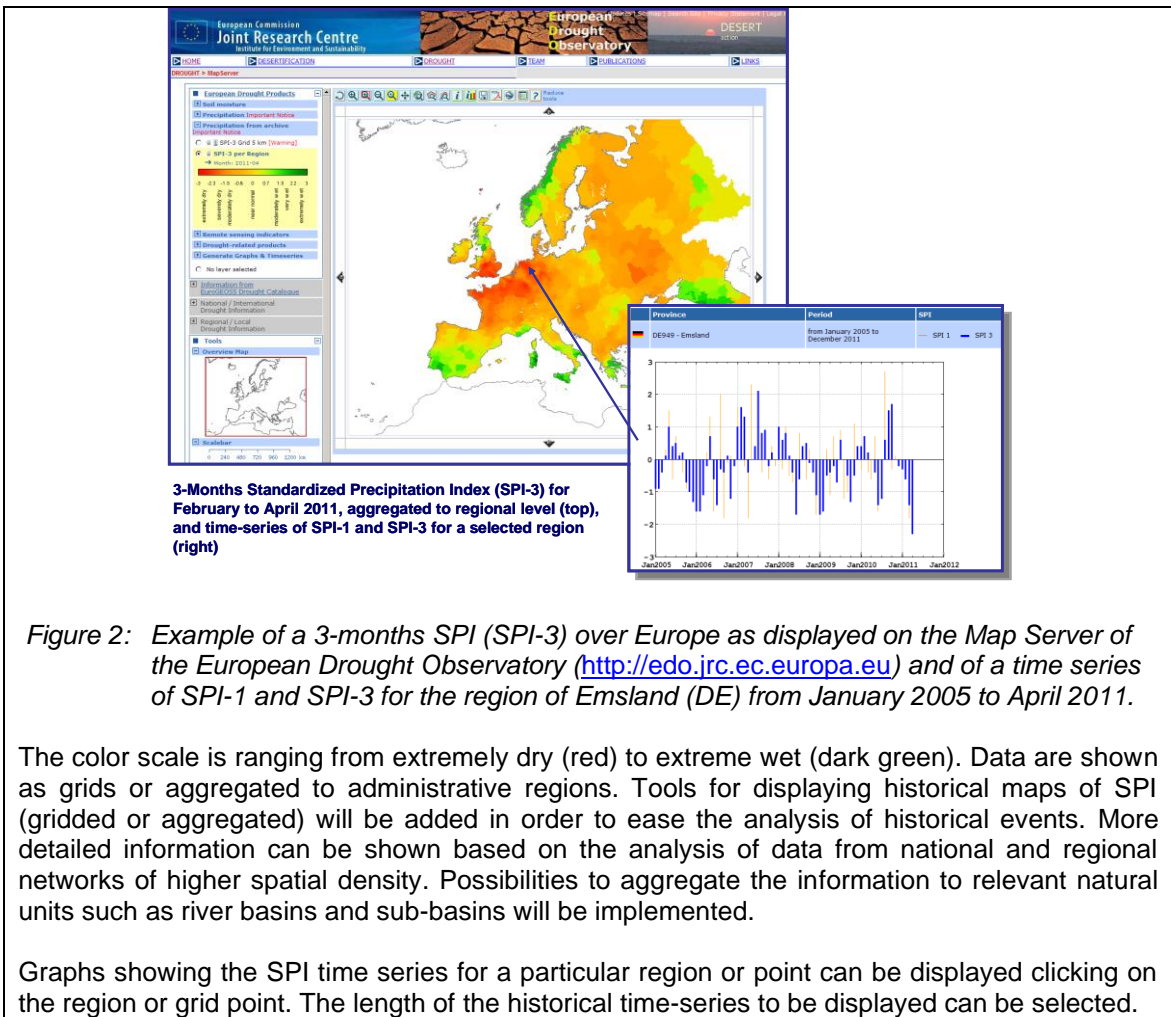


Figure 2: Example of a 3-months SPI (SPI-3) over Europe as displayed on the Map Server of the European Drought Observatory (<http://edo.jrc.ec.europa.eu>) and of a time series of SPI-1 and SPI-3 for the region of Emsland (DE) from January 2005 to April 2011.

The color scale is ranging from extremely dry (red) to extreme wet (dark green). Data are shown as grids or aggregated to administrative regions. Tools for displaying historical maps of SPI (gridded or aggregated) will be added in order to ease the analysis of historical events. More detailed information can be shown based on the analysis of data from national and regional networks of higher spatial density. Possibilities to aggregate the information to relevant natural units such as river basins and sub-basins will be implemented.

Graphs showing the SPI time series for a particular region or point can be displayed clicking on the region or grid point. The length of the historical time-series to be displayed can be selected.

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# **Water Scarcity and Drought Expert Group**

## *Update on Water Scarcity and Drought indicator development*

### **ANNEX 3**

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## **WEI+: Water Exploitation Index Plus**

### **Indicator definition**

The Water Exploitation Index (WEI) is an indicator of **the level of pressure that human activity exerts on the natural water resources** of a particular territory, helping to identify those prone to suffer problems of water stress. Traditionally the WEI has been defined as the *annual total water abstraction as a percentage of available long-term freshwater resources*. It has been calculated so far mainly on a national basis.

A review and upgrade of the index (WEI+) has been developed by the Expert Group on Water Scarcity & Droughts with the purpose of better capturing the balance between renewable water resources and water consumption, in order to assess the **prevailing water stress conditions** in a river basin. The proposed WEI+ aims mainly at redefining the actual water exploitation, since it incorporates returns from water uses and effective management, tackling as well issues of temporal and spatial scaling.

### **Relevance of the Indicator to Water Scarcity**

Water scarcity is a man-made phenomenon. It is a recurrent imbalance that arises from an overuse of water resources, caused by consumption being significantly higher than the natural renewable availability. Water scarcity can be aggravated by water pollution (reducing the suitability for different water uses), and during drought episodes.

Water abstraction to satisfy human needs is the most important quantitative pressure on freshwater resources. Excessive growth of demands in a territory in relation to the availability of water resources can result in the medium-long term in a chronic shortages situation characteristic of an unsustainable use of resources. This indicator can identify whether the rates of abstraction are sustainable, helping to analyse how changes in human consumption impact on the freshwater resources either by adding pressure to them or by making them more sustainable.

### **Policy Relevance**

Water Framework Directive WFD (Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy):

- Environmental objectives
- Quantitative status for groundwater
- Programme of measures

Communication of the EC to the Council and European Parliament: "Addressing the challenge of water scarcity and droughts in the European Union" (published on July 2007)

- Allocating water and water-related funding more efficiently: improving land-use planning
- Considering additional water supply infrastructures
- Fostering the emergence of a water-saving culture in Europe
- Improve knowledge and data collection, a water scarcity and drought information system throughout Europe (paragraph 2.7.1.)



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The WEI+ indicator can also support defining impacts of climate change scenarios, and ensuring adaptation, such as included in the 2009 White Paper on "Adapting to climate change: Towards a European framework for action", in particular chapter 3.2.3.

### **Technical Information**

#### **1. Indicator**

The EG has agreed that WEI+ would be formulated in these terms:

$$\text{WEI+} = (\text{Abstractions} - \text{Returns}) / \text{Renewable Water Resources}$$

In order to better reflect real exploitation and its effects on water scarcity this formula includes in the denominator the water resources provided by artificial reservoirs.

#### **2. Spatial Scale**

To correctly represent the problem of water scarcity and to meet awareness purposes, River Basin Districts or - following the diction of Art. 5(1) of the WFD - the portion of an international RBD falling within a Member states territory. Other relevant scales may be the smaller River Basins that constitute RBDs, respectively their national parts or significant Sub-basins respectively their national parts when relevant for water management.

#### **3. Temporal Scale**

In some basins, water scarcity is reflected only when calculating the indicator at the monthly WEI+ but not necessarily by the annual WEI+. It is recognized that the monthly index level best represents seasonal shortages that may not be revealed in the annual scale, while the annual WEI+ may be enough where the absence of water scarcity problems is evident.

Given that the application of the index on a monthly basis in some cases requires considerable effort in data acquisition, the TWG recommends a two-step approach. In a first step the WEI+ at annual scale would be applied. Where appropriate and if data are available, WEI+ at monthly scale should be calculated either for every month or in the worst month where water scarcity situations could be expected.

In any case, if the problem of data acquisition is adequately solved by the outputs of water balance models (under development at EU level); the monthly basis would be adopted as the general approach.

#### **4. Methodology**

##### **a. Water Resources and related parameters**

In **basins free of human interventions**, the hydrological balance equation is:

$$\text{ExIn} + \text{P} - \text{Eta} - \Delta\text{S} = \text{Qnat}$$

Both sides of this equation may be identified with Renewable Water Resources (RWR):

Option 1.       $\text{RWR} = \text{ExIn} + \text{P} - \text{Eta} - \Delta\text{S}$

Option 2.       $\text{RWR} = \text{Qnat}$

In this case  $\Delta\text{S}$  is the natural change in storage and  $\text{Qnat}$  equivalent to observed outflow.

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Definition of the terms of the equation follows:

Actual External Inflow (Ext.In) Total volume of actual flow of rivers and groundwater, coming from neighbouring territories (e.g. RBDs) within or outside the country. Units in mio m<sup>3</sup>.

Precipitation (P) Total volume of atmospheric wet precipitation (rain, snow, hail). Precipitation is usually measured by meteorological or hydrological institutes. Units in mio m<sup>3</sup>.

Actual Evapotranspiration (ETa) Total volume of evaporation from the ground, wetlands and natural water bodies and transpiration of plants. According the definition of this concept in Hydrology, the evapotranspiration generated by all human interventions is excluded, except rain-fed agriculture and forestry. The 'actual evapotranspiration' is calculated using different types of mathematical models, ranging from very simple algorithms (Budyko, Turc-Pyke, etc) to schemes that represent the hydrological cycle in detail. Please do not report potential evapotranspiration which is "the maximum quantity of water capable of being evaporated in a given climate from a continuous stretch of vegetation covering the whole ground and well supplied with water". Units in mio m<sup>3</sup>.

Change in storage (ΔS) Changes in the stored amount of water (>0, if storage is increasing!) during the given time period, including river bed, lakes, underground water (soil moisture and groundwater) as natural part of the storage (ΔSnat) and in regulated lakes or artificial reservoirs (ΔSart). ΔS can be ignored for long-term averages, to be evaluated in annual calculations and to be considered in monthly calculations. ΔSres is different from zero if the amount of filling in and the release are different in the given time period. Units in mio m<sup>3</sup>.

Natural Runoff (Qnat) Actual outflow of rivers and groundwater into the sea plus actual outflow into neighbouring territories (within or outside the country). Units in mio m<sup>3</sup>.

To be applied **in basins with human alterations**, since observed outflow does not equal RWR, for option 2, flow re-naturalization is necessary. It can be made by restoring consumption (abstractions – returns) and flow alteration linked with management, which may be approached by adding the variation in artificial storage:

Option 1.  $RWR = ExIn + P - Eta - \Delta Snat$

Option 2.  $RWR = Outflow + (Abstraction - Return) - \Delta Sart$

Results of the 2<sup>nd</sup> Testing Exercise show practical difficulties of considering variation of natural storage in Option 1. Some unacceptable mistakes in the results have been observed if there are no appropriate tools to assess ΔSnat (e.g. from an integrated hydrological model). Option 2 has been the preferred choice of most of the TWG members who have participated in this test. However, have come to light some issues that are mentioned below:

- Difficulties to re-naturalize flows in complex system of reservoirs on a monthly basis.
- If over-exploitation of aquifers, these fraction must be removed from the RWR.
- Significant delays in the transmission of groundwater withdrawals to flows observed on the surface.
- In case part of the water stored in the artificial reservoirs comes from a transfer (as opposed to generated within the RBD) or from a desalination plant, then the ΔSart needs to be carefully considered and corrected for the effect of these alternative water resources (i.e. water transfers, desalination)

However, when estimating RWR, the TWG recommends "using the best option based on available information and certainty".

As suggested by some TWG members, a complementary sub-indicator could be developed, reflecting the water scarcity in relation to the overall available water resources, including all storage, natural and artificial. This sub-indicator could illustrate the water availability to solve e.g. emergency situations. A way of representing this indicator might be the evolution of stored water resources over time, and comparing data with previous years or reference periods.

# Water Scarcity and Drought Expert Group

## Update on Water Scarcity and Drought indicator development

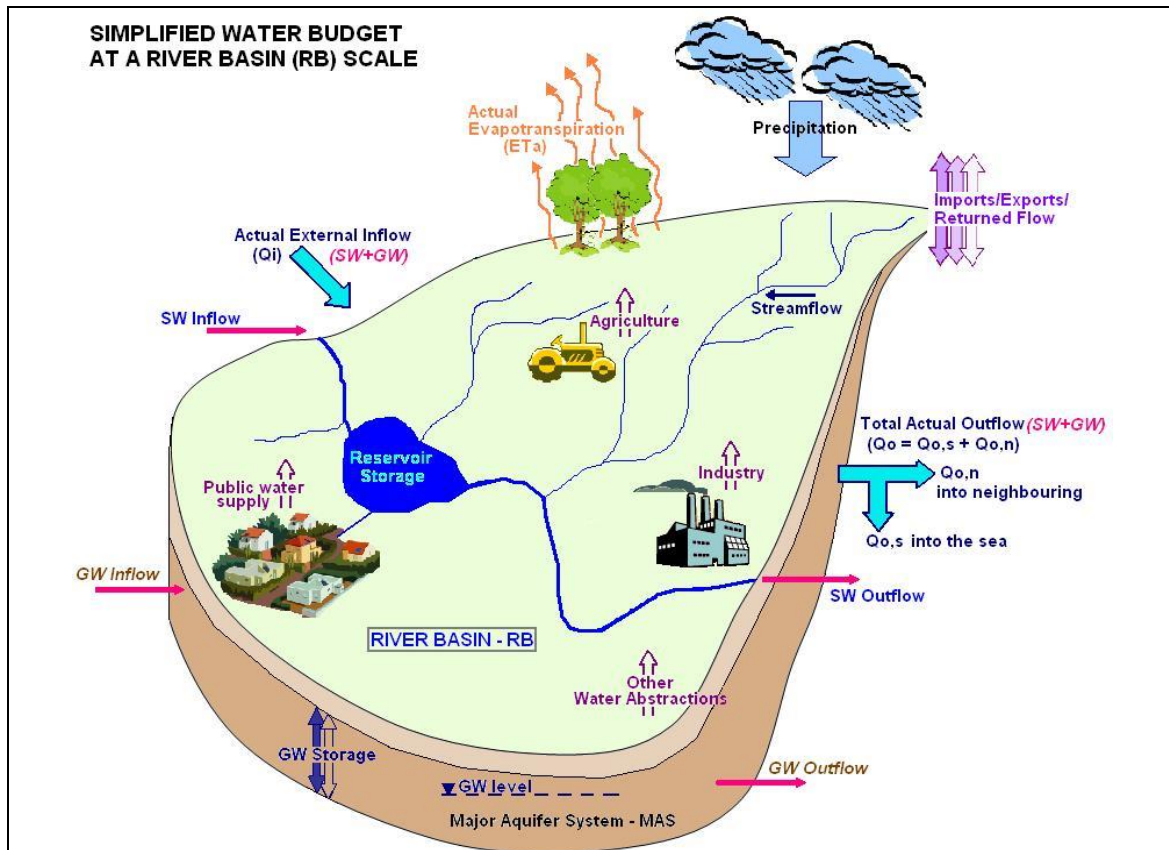


Figure 1: Schematic illustration of the simplified water budget. SOURCE: EEA, 2011.

### b. Demand related parameters

Three similar terms are used apparently with similar meaning:

Freshwater abstraction (or freshwater withdrawal) Water removed from surface or groundwater resources, either permanently or temporarily, regardless of any input from water return or artificial recharge. Mine water and drainage water are included. Water abstracted for hydropower generation should be excluded from the formulation of the Water Exploitation Index (WEI+), while water abstracted for cooling should be included. Water abstractions from groundwater resources in any given time period are defined as total amount withdrawn from the aquifer. Units in mio  $m^3$ .

Water Demand Water requirements of specific quality for different purposes, such as drinking, irrigation, etc., assuming that water availability is not a limiting factor. Water demand is theoretical (calculated or estimated) and can correspond to current situation or to future socio-economical scenarios. Units in mio  $m^3$ .

Water Use In contrast to water supply (i.e. delivery of water to final users including abstraction for own final use), water use refers to water that is used (consumed) by the end users for a specific purpose, such as for domestic use, irrigation or industrial processing. (Usually the basis for paying fees.) Returned water (at the same place and in the same time period) and recycling is excluded. Units in mio  $m^3$ .

All three of them imply a different indicator and convey a different message. "Freshwater Abstraction", evaluates the level of pressure exerted on the natural system. "Water use" reflects the amount of water that is removed from the terrestrial water cycle and returns to the atmosphere. "Water demand" may include requirements unsatisfied (actual or future) by lack of available resources and it is comparable to different availability scenarios, being more useful from a management perspective.

The TWG recommends using preferably the water abstraction parameter since it directly measures how much pressure is exerted on the natural system.

## **Water Scarcity and Drought Expert Group**

### **Update on Water Scarcity and Drought indicator development**

If water demand is significantly higher than water abstractions, the TWG recommends the use of a parallel index, depicting the imbalance. The proposed indicator to use in parallel with the WEI+ is: Water Demand Index (WDI) = water demand / water abstraction.

#### **c. Water returns**

Returned water \_\_\_\_\_ Volume of abstracted water that is discharged to the fresh water resources of the hydrological unit (e.g. RBD, RB) either before use (as losses) or after use (as treated or non-treated effluent). It includes water that was directly discharged from a user (e.g. domestic, industrial etc. including cooling water, mining), and water lost from the waste water collection system (as overflow or leakage). Artificial groundwater recharge is also considered as returned water for the current purposes of calculation of WEI+. Discharges to the sea are excluded. Units in mio m<sup>3</sup>.

The TWG believes that water return is a relevant parameter to characterize actual pressures on natural systems. In this regard recommends this factor be included in the formula to better represent the real problems of water scarcity in the basins. Given the observed effects on the indicator values, the TWG recommends considering the returns in the nominator, as a decrease of the water abstraction, and not in the denominator. It is essential that that this volume is returned to the same unit where abstracted and where the indicator is being calculated (RBD or subunits or RB).

#### **d. Artificial storage as a modification of monthly RWR**

The particular issue of whether considering or not volumes stored in artificial reservoirs has also been dealt with. Results of the 2<sup>nd</sup> Testing Exercise reflect that in those basins where artificial reservoirs manage a significant percentage of the water resources, abstractions can be higher than the natural water resources in some months, leading to WEI+ values well above 100%. This would lead to problems of interpretation.

Since artificial reservoirs provide water resources used specifically to minimize water scarcity situations these volumes should be included in the formula, reflecting a seasonal redistribution, not altering the amount of Renewable Water Resources.

However, some members of the TWG noted that the use of this variable would mean additional work and added difficulty to find information.

#### **e. The role of environmental flows**

Environmental flows \_\_\_\_\_ Water quantity dedicated to maintaining or partially restoring important characteristics of the natural flow regime (i.e. the quantity, frequency, timing and duration of flow events, rates of change and predictability/variability) in such a way that values specified for the biological quality elements should not avoid to be classified as Good Ecological Status. Units in mio m<sup>3</sup>.

Environmental Flows should be conceptually considered in the WEI+. At the moment, due to the absence of a harmonized and comparable method of calculation, eflows should be left out of the WEI+ formula itself, and be considered instead in the definition of the relevant thresholds.

In order to better reflect hydrological pressures on the natural systems, the TWG recommends using in parallel a complementary sub-indicator as a relation of observed streamflow with respect to the natural streamflows. Ratio of Observed-Natural Streamflows (RoONS) = observed streamflows / natural streamflows.

#### **f. Water requirements**

Water requirements \_\_\_\_\_ Volume of water which must be retained in the catchment (thus not actually available for abstraction) in order to meet different legal obligations (e.g. downstream navigation, environmental thresholds, as defined in transboundary treaties). Units in mio m<sup>3</sup>.

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The TWG recommends exploring the reasons for this water reserve in treaties. When it is exclusively due to environmental reasons, recommendation 8 would be applicable. When this reserve was intended for limiting water abstractions, then it should be subtracted from available resources in the WEI+ formula.

#### **g. Groundwater and surface water separation**

Surface water \_\_\_\_\_ Inland waters, except groundwater; transitional waters and coastal waters. Units in mio m<sup>3</sup>.

Groundwater (available for annual abstraction) \_\_\_\_\_ Recharge less the long-term annual average rate of flow required to achieve ecological quality objectives for associated surface water. It takes account of the ecological restrictions imposed to groundwater exploitability, nevertheless other restrictions based on economic and technical criteria could also be taken into account in terms of accessibility, productivity and maximum production cost deemed acceptable by developers. The theoretical maximum of groundwater available is the recharge. Units in mio m<sup>3</sup>.

The separation between surface water and groundwater is very relevant and should be explored at a later stage.

#### **g. Calculation**

Calculations should be based on the water balance equation of the given period, taking into account the methodological and technical recommendations stated so far and assuring the consistent estimation of the abstraction and resources side:

$$WEI+= (Abstractions - Returns) / (NWR - \Delta S_{art})$$

#### **h. Reference period for calculating the Statistics**

Not applicable.

### **5. Thresholds**

According to the literature, the warning threshold for WEI can be 20 %, which distinguishes a non-stressed region from a stressed region (Raskin et al., 1997, Lane et al., 2000). Severe water stress can occur where the WEI exceeds 40 %, indicating strong competition for water but which does not necessarily trigger frequent water crises. Some experts argue that 40 % is too low a threshold, and that water resources can be used much more intensely, up to a 60 % threshold. Others argue that freshwater ecosystems cannot remain healthy if the waters in a river basin are abstracted as intensely as indicated by a WEI in excess of 40 % (Alcamo et al., 2000).

In the framework of a “*Discussion Paper on Environmental Flows in the EU*” (Sánchez & Schmidt, 2012) a preliminary assessment of the relationship between environmental flows and ecological classes was carried out. According to these results, environmental flows lie roughly between 25% and 50% of the Mean Annual Runoff<sup>2</sup> for the Good Ecological Status class.

Some members of the TWG have worked on the issue and advanced proposals based on the comparison with environmental flows already assessed (IT, CZ) or on statistical approaches (HU). Defining thresholds for the WEI+ is challenging and it requires in-depth investigations. However, preliminary thresholds should be used considering the environment and socio-economical relevance (e.g. the expected water deficit for existing uses in the basin). In this sense the values of WEI+ could also be correlated with the expected annual deficit.

Concerning the definition and especially the complexity of the thresholds it should be kept in mind that the indicator itself is robust and valuable although the calculations are relatively simple. This pragmatic approach should also be reflected by the thresholds.

<sup>2</sup> Mean Annual Runoff is defined in this context as the long term average of the natural runoff.

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#### **6. Data source and frequency of data collection**

The required data depends mainly on the methodological option selected for calculating RWR:

- In option 1, required data are: Precipitation, Actual Evapotranspiration, External Inflow and Variation of natural storage. These elements are considered very difficult to be consistently assessed without counting with an integrated hydrological model.
- In option 2 required data are the observed outflow, the abstractions, the estimated returns and the variation of artificial storage.

This data may be provided either by Member States or by tools already under development at the European level in the framework of the Blueprint, water accounts for the abstractions side and LISFLOOD model for hydrological cycle parameters. In the future a convergence of both estimates should be expected.

All the necessary data must be generated in a monthly basis.

#### **7. Quality Information**

##### **a. Strength & Weaknesses at data level**

Quality of the index depends on the quality of the data series used for the estimates. The elements needed in option 1 to calculate the RWR are considered very difficult to be consistently assessed without counting on an integrated hydrological model.

Where available, gauging stations provide robust series of observed outflow, but re-naturalization implies the other datasets that may not be so reliable.

Total abstraction is not always well known, particularly if non-authorized uses are important. There may also be substantial changes from one year to another depending on the availability, and when it is not possible to supply actual demand.

Finally, returned water includes a variety of components which are not easy to measure and also require estimates, particularly for irrigation, where losses in distribution systems and application to plot are estimated by applying efficiency coefficients.

##### **b. Open conceptual issues**

The issue of multiple counting of the same amount of water in large river basins (internal flow of the most upstream area creates the external inflow of the next downstream area and is in both areas considered as water resource) is still not solved. Therefore a foot-note should be added to the respective WEI+ values.

The separation between surface water and groundwater should be analysed in a future development.

##### **c. Performance of the Indicator**

The indicator is relatively easy to calculate and straightforward to use.

Depending on the specific situations of the member states, it can also be readily integrated with other indicators at the same scale and used for awareness raising purposes.

## **Water Scarcity and Drought Expert Group**

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#### **Products**

The WEI+ can be presented in the form of maps and graphs, providing information both on the spatial distribution of the level of pressure that human activity exerts on the natural water resources and the temporal evolution over longer time periods. This allows for the qualitative and quantitative comparison of the intensity and duration of this pressure on water resources with recorded impacts such as yield reductions, low flows, or lowering of groundwater levels, for example.

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<sup>i</sup> Global Precipitation Climatology Centre: <http://gpcc.dwd.de>

<sup>ii</sup> Global Precipitation Climatology Project: <http://www.gewex.org/gpcp.html>