NEW METHODOLOGY FOR JOINT ASSESSMENT OF DROUGHT- RISK OF WATER SUPPLY UNDER CLIMATE CHANGE, WATER STRESS AREAS IDENTIFICATION AND ECOLOGICAL FLOW PROVISION FOR WATER FRAMEWORK DIRECTIVE

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Abstract

The Water Framework Directive (WFD) should be used as the basic methodological framework to achieve climate change adaptation. Climate change analysis and identification of water stress areas are directly related to ecological flow provision and River Basin Management Plans. Environmental flow for good ecological status (GES) was defined as the hydrological regime necessary to achieve the values specified for the biological quality elements. Low Flow and hydrological drought depends on the change of meteorological conditions and it can be considered as a natural phenomenon but the severity of drought's impacts depends on the vulnerability of water supply systems and economic and social sectors as well as on the effectiveness of the adopted mitigation measures. E-flows are a management concept.

For this end a methodology for joint assessment of drought-risk of water supply under climate change, water stress areas identification and ecological flow provision for WFD is developed. The report presents the methodological approach and system of indexes for assessment of water resources vulnerability and hydrological drought management under different climate and drought scenarios. The methodology has been developed on a transnational level, river basin level and local level – water body, WRMS and reservoir. The results from international project "Mitigating Vulnerability of Water Resources under Climate Change" (CC-WARE) will be presented. The methodology is based on DPSIR approach and identification of drought-vulnerable areas; estimation of water-shortage risk in water resources management systems; definition of long-term and short-time actions to drought management. According to the common methodology, "critical areas/hot points" are determined. A threshold for WEI in CC-WARE varies in function of dominant type of resources and according to the method for estimating the water availability side: long-term average, long term average – eco demand, characteristic low flow, characteristic low flow – eco demand. The experiments are carried out. Diverse climatic, hydrological scenarios, variants of current and future water use, various schemes for utilization of water resources are analyzed. The methodology for assessment and mapping of water stress areas and water supply vulnerability is developed.

Key words: *ecological flow, ecological status, abstractions management strategy, vulnerability, drought risk, river basin management, WFD, climate change, decision support system, water exploitation index, WEI, water stress*

1. INTRODUCTION

Climate change renders influence on water resources and runoff directly – by altering natural factors (precipitation, temperature, evapotranspiration) and indirectly – by induced as a result of climate change land use alterations (forests, agricultural lands, etc.). The growing frequency of extreme phenomena – floods and droughts, aggravates this problem. The results from international project "Mitigating Vulnerability of Water Resources under Climate Change" (CC-WARE) confirm that these trends will persist, exerting impact on water resources and water use (IPPC Report; CC-WARE, WP3 Report, www.ccware.eu). When a trend towards decreased precipitation and runoff coincides with a trend towards higher water consumption or deteriorated water quality, then a given region or river basin may turn out to be vulnerable in near or remote future. In the so identified vulnerable regions the role of adaptation measures becomes still more important.

2. ENVIRONMENTAL FLOW MANAGEMENT CONCEPT

According to the European Water Framework Directive (WFD) runoff represents one of the elements of the hydromorphologic conditions, but in the context of the last instructions and the Drought Management Plans the river runoff is a basic element of management, which is interrelated with ensuring the primary needs of society (Guidance No. 31, 2015; Acreman et. al. 2010; Ilcheva, I., A.Yordanova, 2010).

Water resource of a given river basin is the main component of the ecosystem and water resources management system (WRMS) as well (Karagiozova, Tz., 2012; Zaharieva, V., et al., 2012). In this context the ecological runoff is a part of the river runoff that should not be taken away from the river and the environment. In order to ensure it, an assessment has to be made of the extent, to which natural runoff regime could be changed without affecting the sustainable functioning of the environment.

E-flows are a management concept. Environmental flow releases from reservoirs and water resources management systems will need to be implemented as measures to mitigate impacts from their constructions and operation (Acreman et al., 2010). In this context low flow management is related to water supply and ecological runoff estimation and provision (Ilcheva, I., 2008a).

3. NEW METHODOLOGY FOR JOINT ASSESSMENT OF DROUGHT- RISK OF WATER SUPPLY, WATER STRESS AREAS IDENTIFICATION AND ECOLOGICAL FLOW PROVISION

The management of water resource management systems (WRMS) at river basin level represents a key element in achieving the balance between social-economic and ecological objectives of water use. The emphasis is laid on the assessment of various scenarios for the development of key factors related to water use and the relevant response pressure on the environment. The attainment of the ecological and social objectives may be guaranteed by the management of these factors (Ilcheva, I., 2008b). The interplay of natural and socio-economic factors is illustrated under the Drivers-Pressure-State-Impact-Response (DPSIR) framework - Fig. 1.

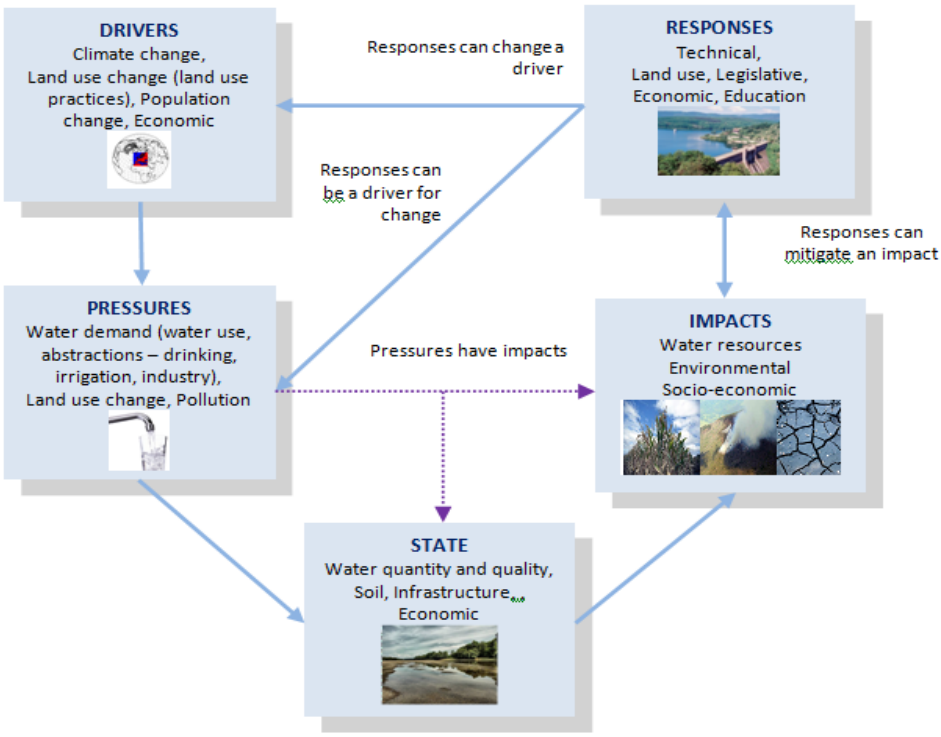


Fig.1. Water Scarcity and drought Indicator System, DPSIR framework

On the other hand, low flow management is related to the Vulnerability and Drought Risk Assessment and Management. For this end a methodology for joint assessment of drought-risk of water supply under climate change, water stress areas identification and ecological flow provision for Water Framework Directive is developed (Mitigation vulnerability…, 2014; Georgieva, D., I. Ilcheva).

3.1. DPISR approach. Vulnerability, sensitivity, adaptive capacity.

The methodology is based on DPSIR approach and identification of drought-vulnerable areas; estimation of water-shortage risk in water resources management systems; definition of long-term and short-time actions to drought management.

According to the Intergovernmental Panel on Climate Change "Vulnerability is the degree, to which a system is susceptible to, or unable to cope with adverse effects of climate change, including climate variability and extremes (IPCC, 2003). Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity" (CC-WARE, WP3, 2015, www.ccware.eu). "From water resource management perspective, vulnerability can be defined as: the characteristics of water resources system's weakness and flaws that make the system difficult to be functional in the face of socio-economic and environmental change" (UNEP 2009, CC-WARE, WP3, 2015). The vulnerability is related to: "exposure of a water resources system to stressors at the river basin scale and capacity of the ecosystem and society to cope with the threats to the healthy functionality of a water system". For this end climatic, hydrological, ecological and socio-economic indicators based on the DPSIR Indicator framework (Fig.1, Fig.4) were selected (CC-WARE, WP3, 2015; Marinov et al., 2014).

3.2. Planning framework for hydrolorgical drought risk management

According to the EC the analysis of the complex and important water resource systems and reservoir operation (including the whole River Basin) is the basic tool for evaluation in the process of planning and searching for balance between the available water resources and water use under drought conditions – Fig. 2. (DMP, 2008; Rossi et al., 2008; Georgieva and Ilcheva, 2014) presents the methodological approach for assessment of water resources vulnerability, e-flow and hydrological drought management.

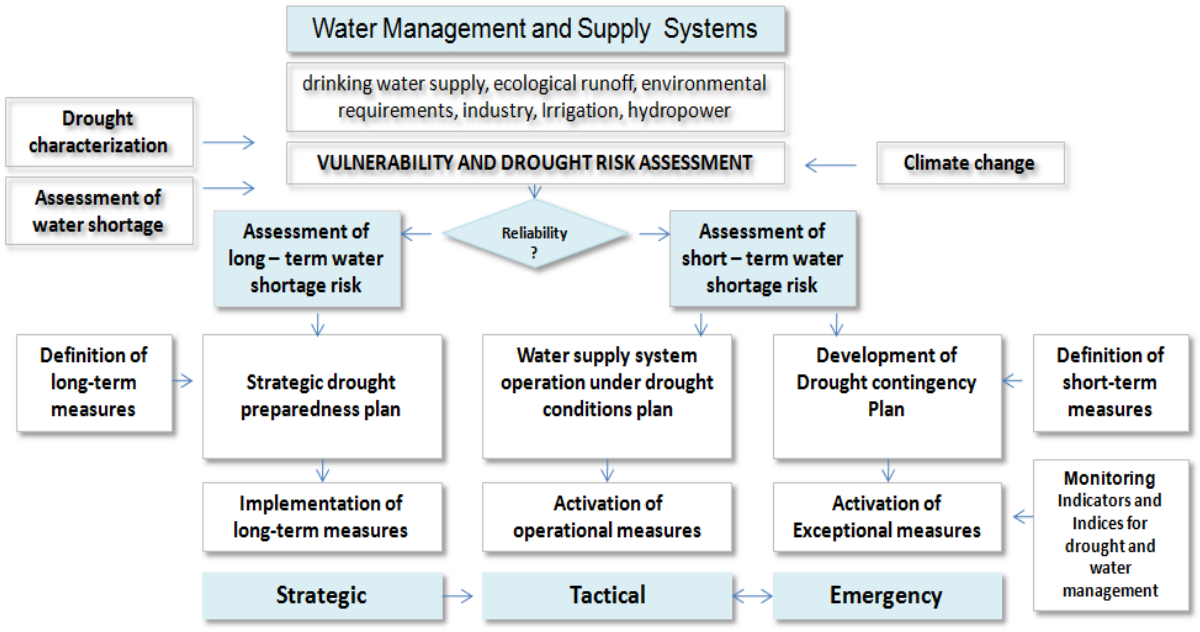


Fig.2. Coordination between basin and drought policy

Depending on the level of planning three different plans have been proposed to face water shortage risk due to drought – strategic, tactical, and emergency – Fig.2. Drought plans establish different levels of drought: normal status, pre-alert, alert and emergency (Georgieva, D., I.Ilcheva, 2014). Drought plans are related to the drought identification (Chilikova-Lyubomirova, M., D. Dimitrov, K. Krumova, 2011).

Hydrological drought risk management and abstractions management strategy

Relationship between e-flows and DMPs is related to the DPSIR conceptual framework (Fig.1, Fig.3). Driving forces (climate change, demographic and economic development, etc.), pressures (water abstractions for different users), responds (drought management actions, including abstraction licences and drought permits) are subject to an assessment of resource availability. Management of WRMSs at river basin or at local level is the basis of the drought indicators definition, water stress areas identification (WEI+), Water resources systems management for sustainable abstraction, abstractions management strategy (AMS) (Ilcheva, I., 2008a; Georgieva, D., I.Ilcheva, 2014; Acreman et. al., 2010; Managing water abstractions, 2013) – Fig.3.

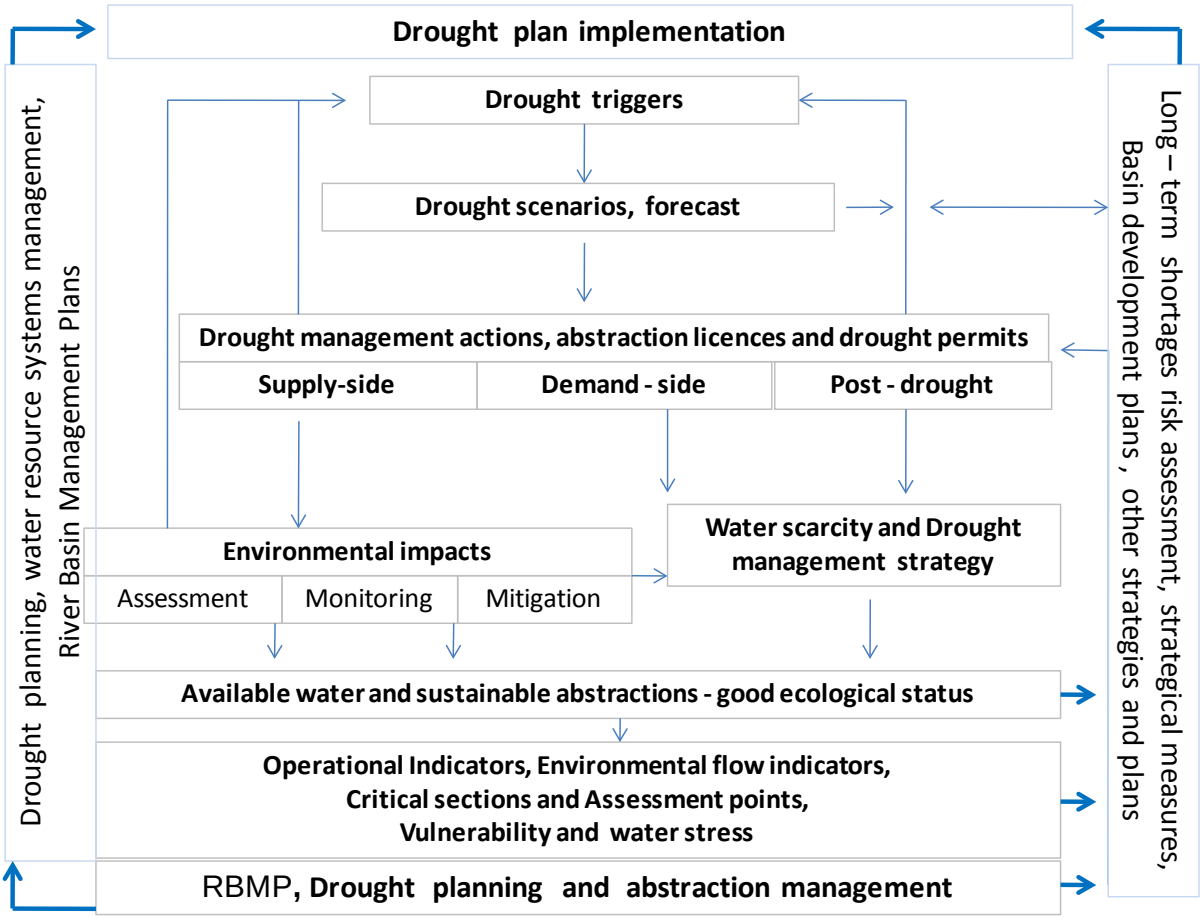


Fig.3. River Basin management, Drought planning and abstraction management strategy

3.3. Methodology for joint assessment of drought-risk of water supply, water stress areas identification and ecological flow provision

Presented methodological framework and tools are applied according to the purpose and planning framework – long-time or short-time drought risk assessment and management. It has been developed in international projects (CC-WARE, 2014; CC_WaterS, 2012). In this context, it is common

methodology for SEE countries and the Danube area. This methodology can be applied in the transnational, national, river basin, water body and local level – water resources management system and reservoir (Marinov, Iv. et al., 2014; Georgieva, D., I.Ilcheva, 2014).

3.3.1. Methodological framework

1. *First stage*. Modelling and estimation of climate factors, scenarios and indicators

The climate is the main natural driver of the variability in the water resources. In the first stage the climate characteristics at different time-frames and climate indexes for vulnerability and drought assessment are described (Mitigation Vulnerability ..., 2014; CC-WARE, 2014). The climate simulations in the Bulgarian part (WP3) of the projects are performed by making use of ALADIN mode (CC_Waters, WP3, Spiridonov and Alexandrov, 2011). The appropriate climate variables and indicators (CI) were selected (described below). In CC-WARE project the following time intervals were used:

- 1961-1990 (baseline climate; B);
- 1991-2020 (present climate; P);
- 2021-2050 (future climate; F).

2. *Second stage*. Estimation of water resources trends at different climate and drought scenarios

Water resources estimation is one of the basic tasks enabling an effective waters management. For climate changes influence some water balance models are developed and relationship between runoff and runoff formation factors is made (Marinov et al. 2012; Balabanova and Ilcheva, 2012).

A new methodological approach to the assessment of the water and WRS balance at river basin and local level has been elaborated with integrated analysis of all elements (precipitation, temperatures, evapotranspiration, soil and land cover, hydrogeology, water abstractions, water use, water transfer, water resource system, etc.) (Ilcheva, I., et al., 2014). Synthetic series (Monte-Carlo modelling by means of the ARMA models) for hydrological drought risk assessment and management are applied (Ilcheva, I., et al., 2015; Ilcheva, I., A.Yordanova, 2010). Group runoff modelling is also conducted according to the POLAR method for setting the ecological quantities.

3. *Third stage*. Development of the calculating scheme and assessment of water utilization in the river basin

In this stage are identified all the water users and consumers, water transfer from/to other watersheds, water supply systems and the whole existing water infra-structure, approved water rights (Ilcheva, I., et al., 2008). The development of the calculating scheme is a start point for the next stages of modeling, abstractions management and e-flow provision. All water users, water management systems, strategies and development projects have to be considered.

4. *Fourth stage*. Estimation of present and future water demand (incl. water permits)

Water demand includes the water needs for irrigation, domestic water supply, industrial water supply, water ecosystems and reserves, requirements for hydro power generation as well. Environmental flows should be provided with maximum priority, but its evaluation is closely related to the assessment of vulnerability and opportunities for providing it (Ilcheva, 2008; Zaharieva, V., et al., 2012). The selected for this end *Environmental Flow Indicators* (EFI) are described below.

5. *Fifth stage*. Estimation and mapping of water resources availability, vulnerability and adaptive capacity at different climate and drought scenarios, water demand and use schemes

In order to estimate water resources and water supply vulnerability it is necessary to assess the water resources (surface and ground water), climate changes influencing water quantity, to estimate and take into consideration ecological flow and water available for abstraction. At this stage the available water resources are compared (now and at different climate and/or drought scenarios) with the present and future water demand, which enables the determination of water shortages. Comparing available resource with water demand, the ensuring of water supply reliability and Catchment Abstraction Management Strategies (CAMS) are determined (Nigolov, I. et al, 2011-2015). The (CAMS) process provides information on how much water is available for future licensing and for the environment. The elements of the water balance calculation are river flows, abstractions, resource allocation for the environment and any other water uses, etc. The so-called 'Environmental flow indictors' (EFI) are used to assess whether river flows are sufficient to support a healthy ecology.

The changes of reservoir level are also an indicator of water resource vulnerability. The definition of triggers and operational indicators (OI) for multireservoir water resource management systems at river basin or local level is an issue that is accomplished by means of simulation-optimization techniques, simple rule curves (Operational Rules) for drought management and network flow optimization. The simulation models for water allocation are very important in case of low flows and dry periods (Danube WATER Project, Guidebook …, 2015). They are part of the DSS for drought planning, monitoring and management and are used for DMP – Romania, Spain, Greece, etc.

The main tasks and expected results from this stage are:

- *Development of the conceptual and simulation model of the river basin managemen system and water allocation*
- *Assessment of hydrological pressures and impacts according to the DPSIR Indicator framework*
- *Management of the water abstractions and the environment*
- *Assessment and mapping of water resource vulnerability and identification of water stress areas*
- *Definition of triggers and Operational Rules for drought management*
- *Environmental flow releases from reservoirs and WRMS (concept of compensation)*
- *Catchment abstraction management strategy*
- *Drought management plans, etc.*

This solution can be implemented at river basin level according to the requirements of WFD as well as at local level considering a single water supply system or reservoir (see below in ch.3.4.).

6. *Sixth stage*. Mitigation and Adaptation Measures.

The methodology firstly provide an assessment of water resources availability to meet different demands, then evaluates the water shortage risk; after the analysis of drought impacts on the different sectors, the actions to be taken into account to reduce vulnerability to drought (strategical, long-term measures) and action oriented to mitigate drought impacts (short-term - operation) (Rossi et al., 2008).

3.3.2. DPSIR Indicator framework. Vulnerability assessment and environmental flow management

According to (Guidance No. 31, Ecological flows …, 2015) DPISR framework to hydrological pressures and impacts is a partitive case of DPSIR Indicator framework (Fig.1 and Fig.5).

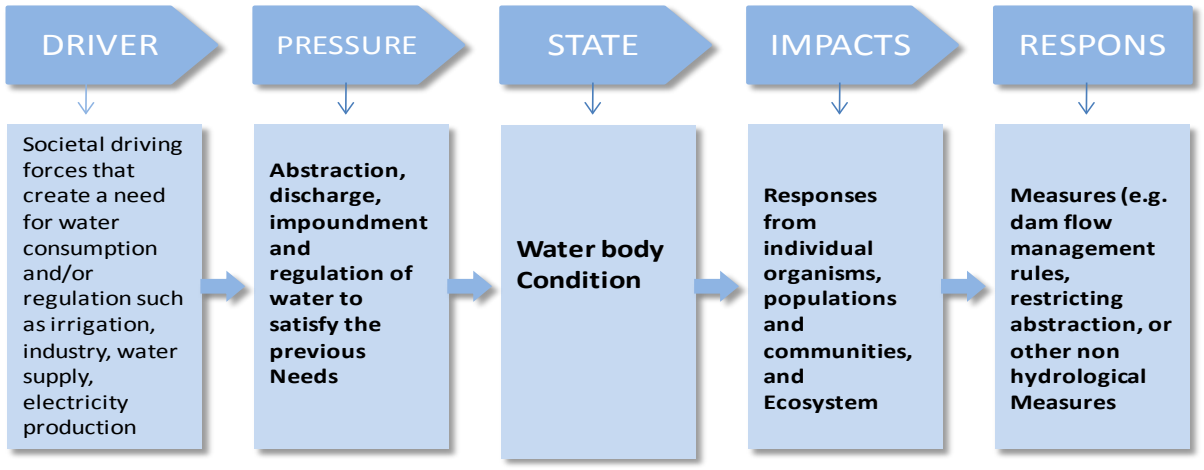


Fig.4. Application of the DPSIR framework to hydrological pressures and impacts (Guidance No.31, 2015)

Progress towards the application of common WS&D indicators has been made under the Common Implementation Strategy for the WFD – Fig.5.

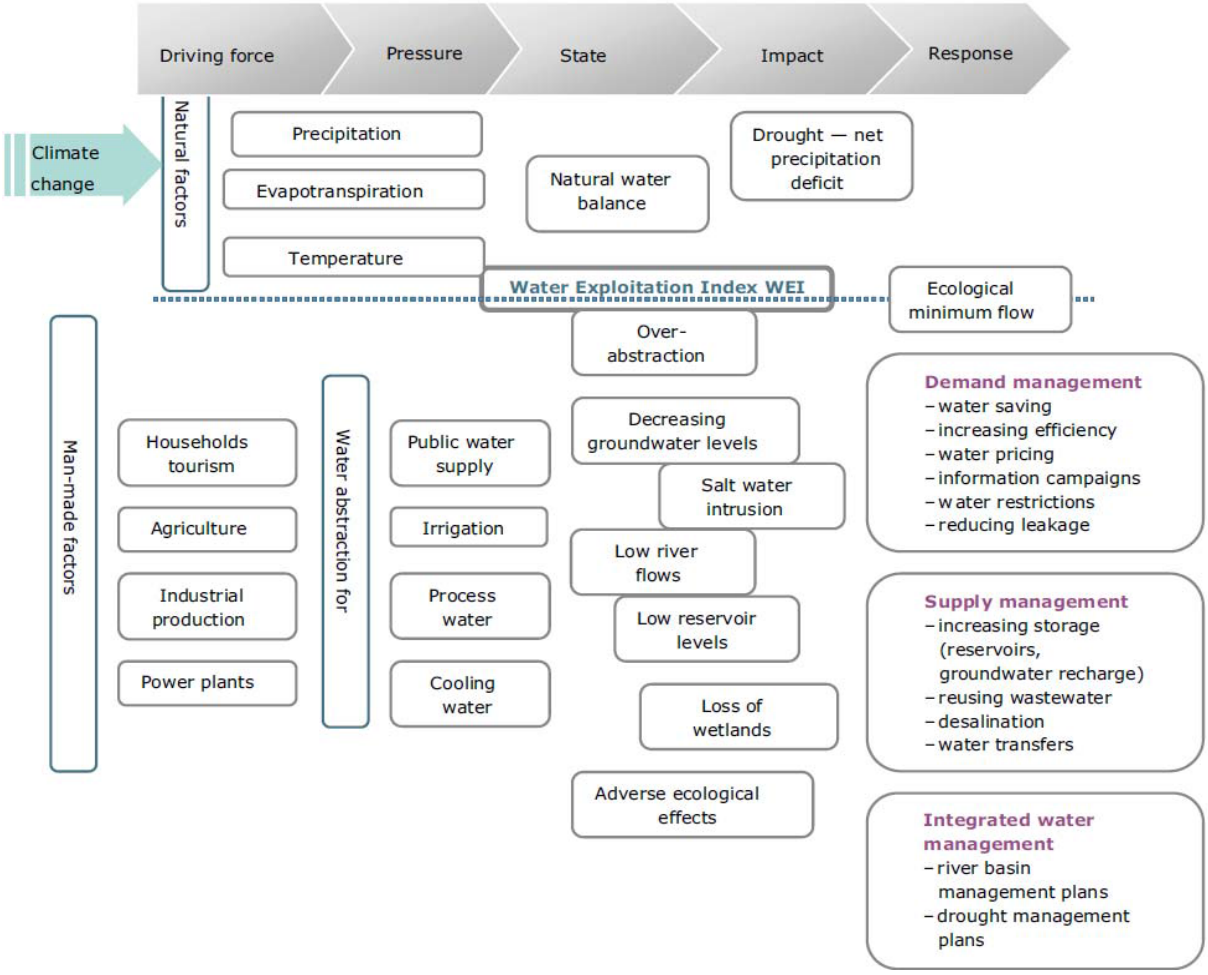


Fig.5. DPSIR Indicator framework for WS&D (Source: EEA, 2009)

3.3.2.1.Determination of climate variables and indicators (CVI).

Main climate variables are: precipitation (P), temperature (T) and potential and actual evapotranspiration (PET and AET). Additional climate variables (Indexes), which were used for the description of climate, are: De Martonne's Index of Aridity, UNEP Index, Seasonality index, SPI, SRI, etc. (CC-WARE,)

3.3.2.2. Assessment and mapping water resources quantity vulnerability.

According to CC-WARE and UNEP methodology (2009), vulnerability is a function of water availability, use and management parameters. Water quantity vulnerability indicators are**:** Local Total Runoff, Local Water Exploitation Index, Local Water Surplus, WSHI, etc.

- **Vulnerability assessment and Water stress areas identification**

- ***Water Exploitation Index* (WEI, WEI+) and water stress areas identification**

Water Exploitation Index (WEI, 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:

WEI+ = (Abstractions – Returns) / Renewable Water Resources (1)

Environmental flows should be conceptually considered in the WEI+.

At present E – flows often are considered as relevant thresholds because of the lack of harmonized and comparable methods of calculation.

- ***Thresholds for water stress and e – flow characteristic***

According to the Guidance for identification of strategic issues regarding quantity and quality (CC-WARE project, 2014), the threshold for WEI (WEI+) varies as a function of dominant type of resources (groundwater, karstic spring or creeks, lake, reservoir, river) and according to the method of estimating the water resources (water availability):

- Long-term average (for WP3 maps of vulnerability),
- Long-term average – eco demand,
- Characteristic low flow,
- Characteristic low flow – eco demand.

In RBMP or in other studies the method for estimating the "available water resources" may include critical low flow period or ecological water demand as well. In CC-WARE, WP3 LTR maps are based on long-term annual average, but, in RBMP or in other studies the method for estimating the "available water resources" may include critical low flow period or ecological water demand as well, providing more precise estimation of the real exploitation than the long-term average. As it is seen the methodology of water stress assessment by WEI+ is a common but it depends on the view point and the thresholds scale.

The flow statistics are a partitive case of co-called "drought design" scenarios. As a drought design, for the surplus estimation, abstraction license, water exploitation (WEI), and drought scenarios in Bulgaria, flow statistics are applied (Q95 (low flow), Q75 (medium/low flow), Q50 (medium flow)) (Methodology for preparation …, 2004; Ilcheva I., I. Niagolov, T. Trenkova, 2008). But according to the new aspects for e-flow (Q30 (high flow) or Q5%) flow statistics are applied.

For vulnerability (water stress) and drought assessment WEI or $WEI_{95}+$, $WEI_{75}+$, WEI_{50+} , WEI_{30+} are calculated at Water Body and WRMS level by (Mitigation vulnerability…, 2014; Georgieva, D., I. Ilcheva, 2014, Ilcheva, I., et al, 2015). Water Scarcity Indicator methodology for drought risk

assessing and mapping is based on WEI+ (Danube WATER, 2015). Risk thresholds are defined as follows (WS&D Expert Group, 2012) – Table 1.

Table 1. Risk thresholds (WS&D Expert Group, 2012)

Red	Extreme: WEI+_Limit is exceeded more of the 50% of the years
Dark orange	High: WEI+_Limit is exceeded between the 30 and the 50% of the years
Light orange	Medium: WEI+_Limit is exceeded between the 10 and the 30% of the years
Yellow	Low: WEI+_Limit is exceeded between the 5 and the 10% of the years
Green	Null: WEI+_Limit is exceeded between the 0 and the 5% of the years

- **Water resources management system performance indices**

At River Basin level, and local level (Water Resource Management System, Reservoir) for drought risk assessment for water supply (including environmental flow) simulation models for water allocation and balance computation are used (SIMYL, ALLOC, SIMOPT, etc.). The probability of exceedance PE determines the degree of provision of ecological flow and consumer needs. These indexes are included in Bulgarian water legislation and are applied together with WEI in the Bulgarian River Basin Management Plans (Water use and water balances, 2006; Shopova, D., et al., 2008; Shopova, D., 2015).

- ***Operational Indicators. Operational rules and Reservoir Management***

Triggers and available water resources depend on whether the area is below the reservoir or not. The triggers should be developed from a combination of reservoir levels, measured river flows and groundwater levels. Reservoir levels can be developed into trigger curves using water management system modeling and simulation models (Niagolov, I., 2011-2014). “Guidance on environmental flow releases from impoundments to implement the water framework directive, Project WFD82” also uses a simple reservoir simulation model as risk based tool.

3.3.2.3. Environmental flow indicators (e-flow for GES and GEP, or ecological status)

For CAMS and resource assessment the water resource balance is calculated (***Fifth stage of the methodology***). Environmental flow indictors (EFI) are used.

According to the Water Act (WA) in Bulgaria, a minimum acceptable flow is determined. According to WA and Ordinance No RD-1383/18.19.2003 of MOEW, minimum acceptable flow is determined for aquatic ecosystems and wet zones protection (Art. 117 (1)). When there are no data from biological monitoring, environmental flows must be equal to 10% from the mean annual discharge but not less than min monthly water discharge (natural runoff) with 95% probability of exceedance.

But according to the (Guidance No. 31, 2015) there is Heavily Modified Water Bodies (HMWB) and/or discharge rich water bodies. These water bodies have a modified flow that is influenced by reservoir compensation releases or they have flows that are augmented. These are known as “regulated rivers”, where the availability of water is dependent of water resource management, Environmental flow releases from reservoirs and Concept on compentation (Guidance on environmental flow releases, 2008; Ilcheva, I., 2008a).



Fig.6.a.Web-based map of risk for ecological (low) flow and high flow Q5%



Fig.6.b. Web-based map of Hydrological assessment of runoff and trends

Risk is defined as the probability of failure of the system to be studied. In this context, ***the reliability of the e-flow*** is one of the basic indicators for risk assessment and EFI. This indicator can be evaluated both in an operative manner and in monitoring and in developing the future Plans for River Basin Management by calculation as a result of water resource system balances (WRSB) at a river basin level.

The aim of the project (Niagolov et al., Web-based daily updatable map of areas at risk in terms of the flowing water quantities, contract between NIHM and MOEW, 2011) is to develop a web-based daily updatable map of areas at risk in terms of the flowing water quantities in designated hydrological stations (HS) from the network of NIMH-BAS Fig.5.a. (not functioning at present). The risk assessment is in two aspects – Fig.6.a:

1. Areas at risk in terms of ecological runoff;
2. Areas at risk in terms of high water.

The information for the assessment of ecological runoff and high water is mainly from the work "Determination of average, minimum and maximum water quantities with different repeatability" (Contract between NIMH and MEW, 2004, team leader D. Dimitrov). Initially in the map of risk the assessments in terms of water quantities with a probability of 5 % – Q5% were visualized (Fig.6.a). It is envisaged to develop further the maps of vulnerability and risk (Ilcheva, I., et al. 2014).

The reservoirs in Bulgaria currently release ecological flow, but according to the last instructions and the trends, a modification of e-flow regimes and compensation flows is needed (Guidance No. 31, 2015; Acreman, 2008). The so-called indicators of hydrologic alteration (IHA) are a good tool for assessment of modification of flow regimes and GES (Lisama, B., 2014). EFI and IHA are related to the applied in (Ilcheva, I., 2008a, Ilcheva, I., 2008b) **ecodeficit methodology and** so called **concept of compentation** – Fig.8. It makes an assessment of ecological flow based on the known "historic" approaches, using simultaneously multicriterial optimization for different management strategies.

Lotic Invertebrate Flow Index. A methodology for determination the admissible minimal river flow in Bulgaria which is a necessary condition for achieving a "good ecological status" is proposed. As an object of research macrozoobentos ecosystem are considered in accordance with the WFD (Zaharieva, V., et al.; CC_WaterS Monograph, 2012). The total number is selected as a key indicator, characterizing the state of macro-invertebrate community.

3.3.2.4. Water quality indicators

Main driver for water quality vulnerability is land use. Impact of land use on water quality is expressed with land use load coefficients and Pollution load index. Normalized Pollution load index is indicator for surface water quality (Mitigation vulnerability.., 2014). Applied data set for land use in

CC-WARE is Corine Land Cover (CLC2006). Future land use scenarios were evaluated in accordance with EEA study "Land-use scenarios for Europe: qualitative and quantitative analysis on a European scale":

- Scenario 1: Great Escape – Europe of contrast
- Scenario 2: Evolved Society – Europe of harmony
- Scenario 3: Clustered Networks – Europe of structure
- Scenario 4: Lettuce Surprise U – Europe of innovation
- Scenario 5: Big Crisis – Europe of cohesion.

3.3.2.5.Adaptive capacity assessment

- Socio-Economic adaptive capacity factors.Socio-economic adaptive capacity factors are population density, economic status, Water resources management: GDP, etc.
- Natural adaptive capacity factors – Ecosystem services (Fig.12)

3.3.2.6. Integrated assessment of water resources vulnerability. Integrated vulnerability according to composite programming formula **and multicriterial optimization** (CC-WARE, Ilcheva, I.,2008).

3.4. SCENARIOS AND METHODOLOGY APPLICATIONS

Presented methodological framework and tools are applied according to the purpose and planning framework.

3.4.1. Basic scenarios.

In order to be assessed the potential and complete operation of water resource system complex, the probability of exceedence for satisfaction of the needs of water users and as a result of this the disturbance in water discharge in the river basin is calculated the water resource system balance for different scenarios of the water resource (including drought scenarios), consumption and the water system scheme (with and without water transfer, with and without construction of new reservoirs, with and without operation of pumping stations etc.).

3.4.2. Scenarios for ecological flow provision of in case of drought and climate change.

As it was mantion the "concept of addition" represents one possibility for low flow management and ecological runoff provision according to E-flow concept – Fig.7 (Ilcheva, I., 2008; Guidance on environmental flow releases from impoundments to implement the water framework directive, Project WFD82, 2008). Three main tasks may be formulated:

The first task.

The first task is to evaluate the minimal quantities, necessary for achieving good ecological status of the river water bodies (e-flow). For the objectives of RBMP environmental flows should be provided with maximum priority, but its evaluation is closely related to the assessment of vulnerability and opportunities for providing it. For this end in the water use scheme of the river basin as top priority water users are considered the ecosystems with demand no less than a minimum ecological discharge specific for the point (Ilcheva, I., 2008; Santourdjian, O., et al. 2009). These points coincide with the designated in the Plan water quantity monitoring points.

The second task. *E-flow pressure analysis, e-flow gap analysis*

According EC the review of pressures and impacts is element of the planning process (Article 13) and also in the development of the programmes of measures (Article 11). The second task is to GAP analyses.

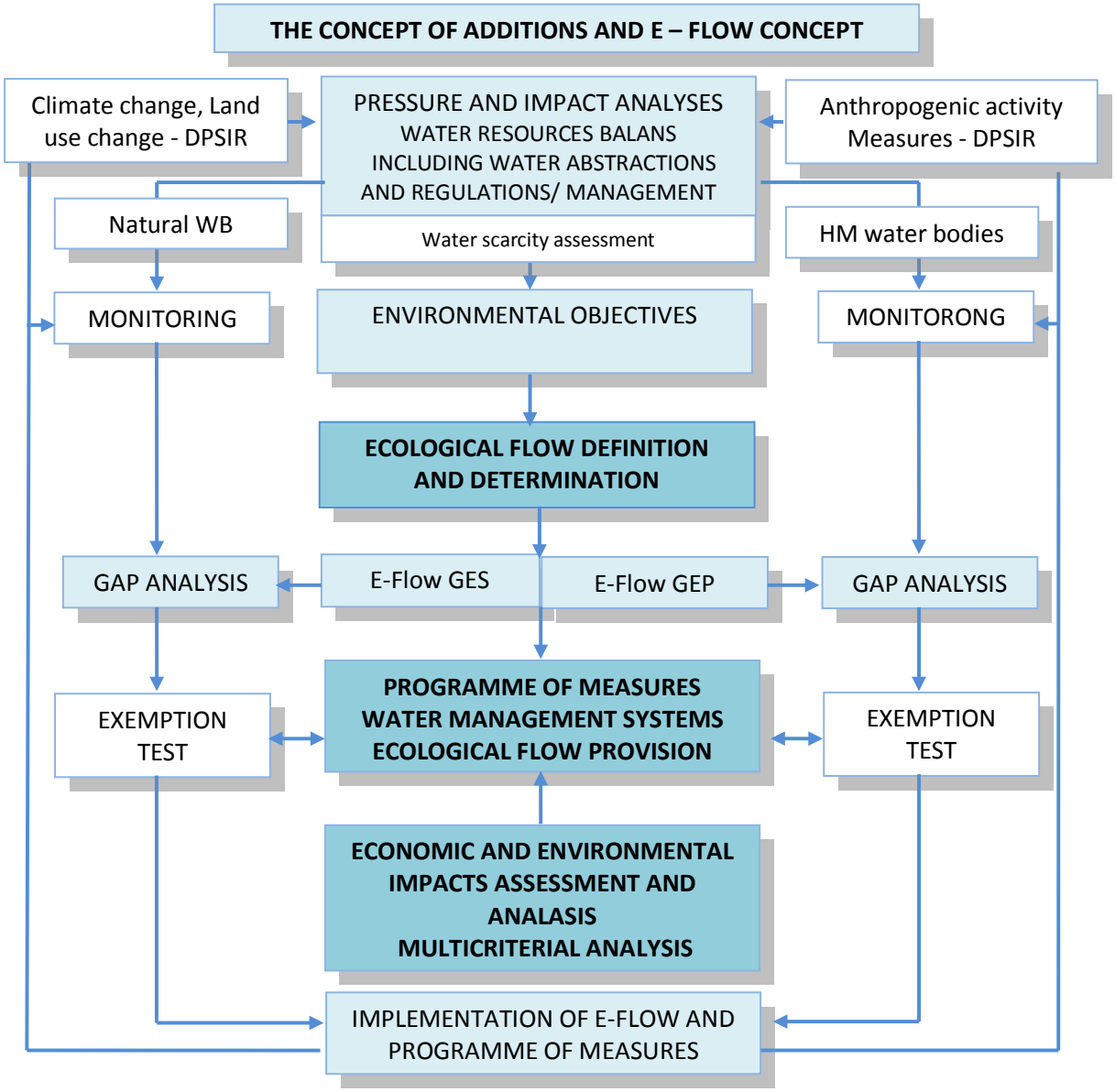


Fig.7. E-flow concept as a part of methodology of vulnerability and drought risk assessment and mitigation (Guidance № 31, 2015; Ilcheva, I., 2010; Georgieva, D., I.Ilcheva, 2014)

As mentioned environmental flow (ecological status) can be impacted by: abstractions, flow regulation, morphological alterations etc. The simulation modeling is a base for development of conceptual model and gives an idea of the whole watershed. The calculated disturbance of the discharge by the simulation model in different points from the watershed gives an assessment of the water abstraction from surface and groundwater, runoff regulations, water transfer, water derivations, climate changes etc. It could show how the change of the economic factors reflects to a related pressure on the environment (Ilcheva, I., 2008; Ilcheva, I., I.Niagolov, T.Trenkova, 2008; Shopova, D., et al. 2012).

As mentioned above indicators of hydrologic alteration (IHA) and compensation flows are a good tool for GAP analysis and GES/GAP provision. The results of the experimental application of SIMYL and Ecodeficit (drought scenario, Dragovishtitsa River) are illustrated in Fig. 8 (Ilcheva, I., 2008b). The Ecodeficit methodology evaluates the extent of reaching the ideal case – undisturbed runoff or assessment of different solutions for GAPs. Moreover, the advantage of SIMYL is that it also gives direct assessment of probability of exceedance. This is an objective criterion for the extent of reaching the ecological and social objectives in the search for a compromise solution -Fig. 8. The Ecodeficit provides a simplified representation of ecological need, as compared to the IHA and RVA (Rang of Variability approaches) hydrological approaches.

The third task. *Identification of critical problems and hot points. Concept of compensation*

- ***Identification of critical problems and hot points***

The third task consists in measures and possibilities for water resource system management, ensuring flow for good ecological status or GEP. The priority is given to the so-called critical river stretches and protected areas (Nature 2000, etc.) (Santourdjian, O., I. Ilcheva, 2009). As a result of the water system functioning of the river basin, critical sections and problems are specified for different scenarios. If the planning and methodological frameworks for hydrological drought management are correctly applied, to so-called „critical areas" and assessment points in river basin should coincide with the "hot points" of the early warning and DSS systems (*Danube WATER,… 2015*).

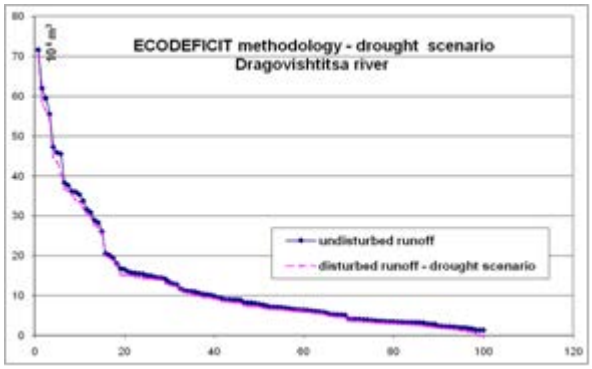


Fig.8.a. E-flow pressure analysis

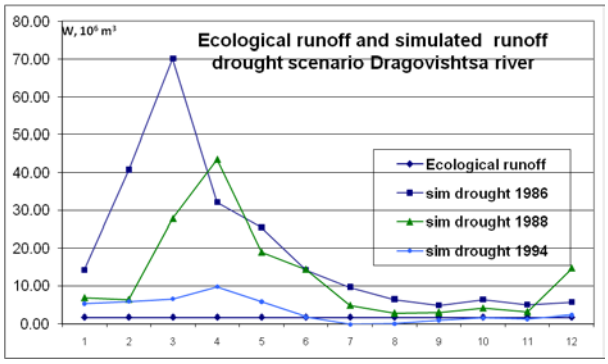


Fig.8.b. E-flow gap analysis and e-flow management **(**scenario)

Fig.8. E-flow pressure analysis, e-flow gap analysis and e-flow management (Ilcheva, I., 2010)

- ***Concept of compensation***

The so-called HMWB and "regulated rivers" have modified flow, which is influenced by reservoir compensation releases, or they have flows that are augmented. The availability of water is dependent on these operating agreements. The ***"concept of addition (compensation)"*** represents one possibility for guaranteeing the ecological runoff and e-flow concept (Ilcheva, I., 2008a). It consists in the water resource system management and runoff regulation within a certain interval in a given cross section of the river basin in order to guarantee the ecological runoff in other sections of this river basin (Ilcheva, I., 2008; Ilcheva I., I. Niagolov, T. Trenkova, 2008; Zaharieva, V., et al. 2012; Acreman, 2011).

3.4.3. Abstraction management strategy and water stress areas

Management of (WRMSs), water allocation and reservoir management rules are the basis for sustainable abstraction and Catchment abstractions management strategy (CAMS), water stress areas identification and environmental flow (e-flow) provision for good ecological status (GES) (Acreman et al. 2010; Ilcheva, I., 2010; Managing water abstractions…2013). From the rest of the possibilities

for ensuring the minimum quantities, it is rational to apply administrative management of water use by means of the "Receiver pays" principle, as well as by restrictions in the permits regime and drought permits (Ilcheva, I., 2008). To this end the basic demand scenarios are water use permits. A methodological three-stage approach to water rights modeling is developed including water resources allocation, water rights analysis and determination of unused water volumes (Kolcheva, Kr., 2012).

3.4.4. Analysis and measures for vulnerability mitigation and hydrological drought management

This includes an analysis of obtained results, identification of critical river sections and outlining a program of measures mitigating the vulnerability. The measures can be strategic, tactical and operative. Drought plan is developed by the Operational Rules for Reservoir Management and expected reservoir levels according to the inflow forecast, drought scenarios with different supply-side and demand-side management actions (Niagolov, I., et al. 2011-2014) – Fig.2., Fig.3. and Fig.13.

4. APPLICATION OF THE METHODOLOGY AT TRANSNATIONAL LEVEL

The purpose of the launched CC-WARE is to evaluate the current and future vulnerability of water resources in South East Europe on the basis of jointly developed methodology – Fig.9.

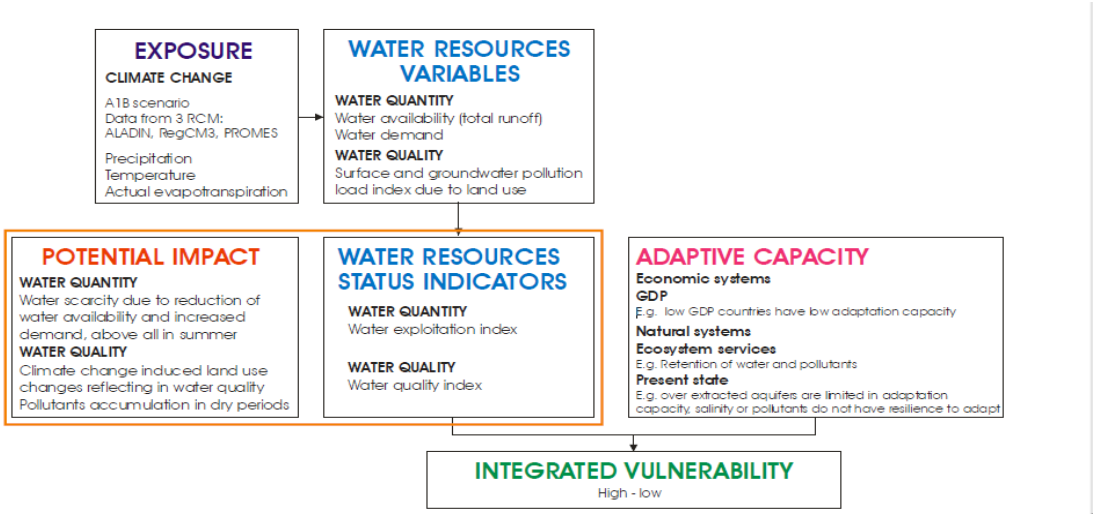
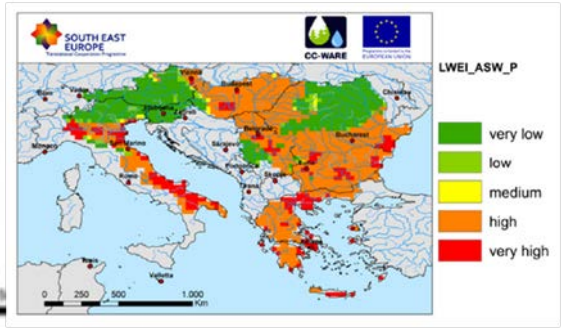


Fig.9. Components of Vulnerability (CC-WARE, Final report, 2015)

Vulnerability Water Exploitation Index (LWEIa) for present and future scenarios of water demand for countries within SEE area LWEI are given – Fig.10. Some maps of the surface water quality index and natural adaptive capacity factors are given on Fig.11.



Annual Local Water Exploitation Index (LWEIa) for present and future scenarios of water demand



Annual Local Water Exploitation Index considering seasonality (LWEIasw) for present and future scenarios of water demand for SEE countries

Fig.10.Water Exploitation Index (LWEIa) for present and future scenarios (CC-WARE, WP3, 2015)

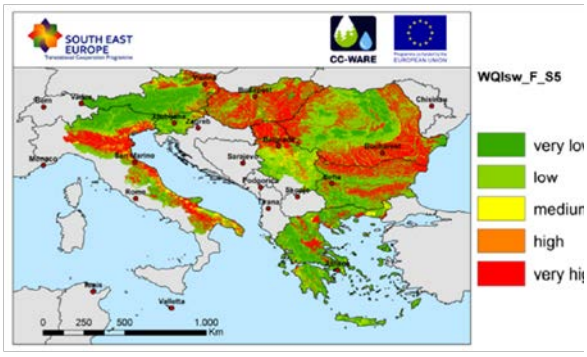


Fig.11.a. Surface water quality index for PRELUDE future land use change scenarios (EEA 2007).

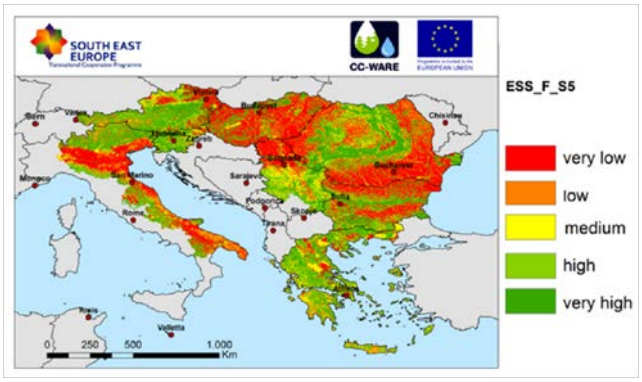


Fig.11.b. Natural adaptive capacity factors - Ecosystem services

Fig.11. Maps of the surface water quality index and natural adaptive capacity (CC-WARE, WP3, 2015)

5. APPLICATION OF THE METHODOLOGY AT RIVER BASIN AND LOCAL LEVEL

The experiments carried out along the Struma River course and the calculated reliability indices provide the grounds to conclude that in sections with water reservoirs the WEI index gives usually higher vulnerability values since it does not take under consideration the operation of dams. In similar sections imitation modeling takes into account reservoir operation and shows no deficiencies or small deficiencies. The regions of Pernik ("Studena" res.) and Dzherman ("Dyakovo" res.) are examples in this context.

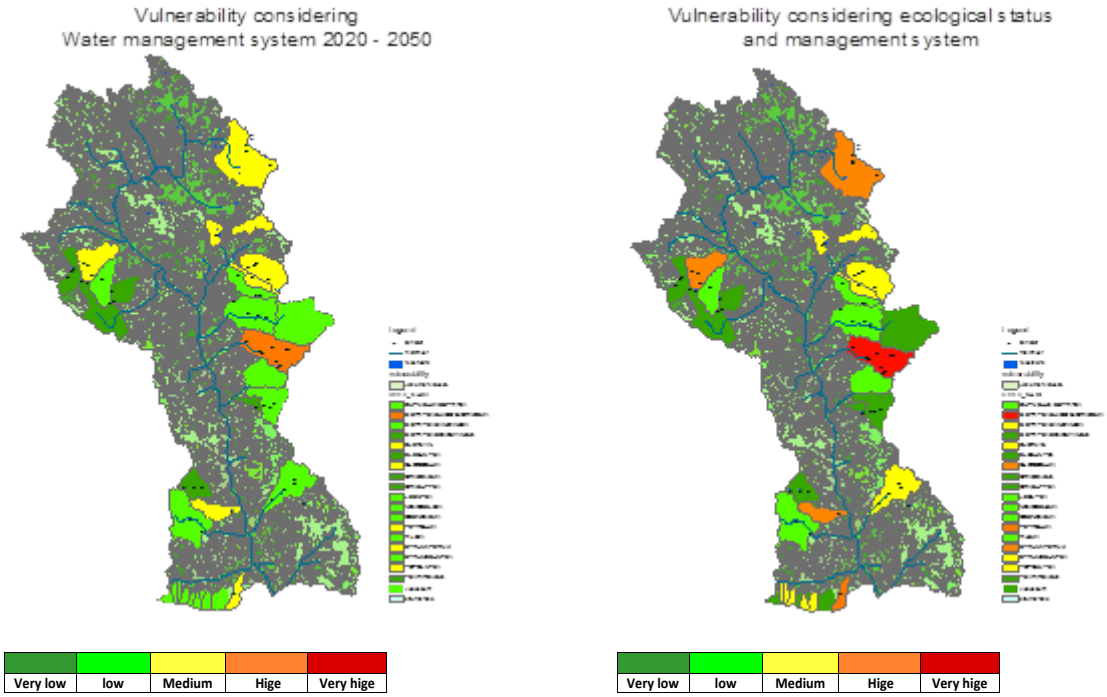


Fig.12. Assessment and mapping of the Vulnerability/Reliability at River Basin level, taking into account the operation of the water resource management system and compentation concept and ecological status

As mentioned above according to "Guidance for identification of strategic issues regarding quantity and quality" (CC-WARE project) a threshold for WEI varies in function of dominant type of resources and according to the method for estimating the water availability: long-term average, long term average – eco demand, characteristic low flow, characteristic low flow – eco demand.

Table 2. Catchment abstractions management strategy and water resource availability

CAMS water resource availability colour UK	**CAMS water resource availability colour according new methodology for risk mapping**
High hydrological status	High hydrological status
Water available for licensing	Water available for licensing
Restricted water available for licensing	Restricted water available for licensing
Water not available for licensing	High hydrological status
HMWBs Heavily Modified Water Body and regulated rivers	These water bodies have a modified flow that is influenced by reservoir compensation releases or they have flows that are augmented. The availability of water is dependent on Reservoir and Water Resource System Management , "compentation" concept for GES and GEP Demand-side and supply – side measures Very low | low | Medium | Hige | Very hige

The flow statistics are - Q_{95} (low flow), Q_{75} (medium/low flow), Q_{50} (medium flow), Q_{30} (high flow), etc.

The vulnerability of water supply is evaluated taking into account all other water users – environmental runoff, irrigation, industry, power generation. A calculation scheme has been composed based on the resource use scheme and the water demand is estimated on the base of all water intakes, classified in 44 water supply groups; 33 industrial points; 50 irrigation fields; 37 reservoirs and compensating basins; 25 pumping stations; 3 cascades and 32 small hydro power plants; 5 fishponds; 8 derivations for water transfer, points for ecological water amounts, etc. (Ilcheva, I., I.Niagolov, T., Trenkova, 2008).

The water bodies with poor ecological status or potential in the Struma River watershed are: Struma River after Studena dam, Blagoevgradska Bistritsa River, Strumeshnitsa River etc. Most of them coincide with sections, vulnerable with respect to water quantities (discharges), when ecological runoff or water supply is affected during the months of low water. The vulnerability in these areas is higher – Fig.12.

Operational indicators. Risk assessment, taking into account the impact of the ecological status

Application of the methodology at the local level is given for WRMS “Djerman” and Res. “Diakovo” - Fig.13 (“Dyakovo dam operation rules determination aiming satisfaction of prioritet water users, aloable HP generation and retention of high inflow”, Niagolov, I., et al., 2011-2014).

Operational rules and Reservoir Management by supply-side and demand-side management actions can assess effects on all water supply managemen system. This methodology ensure sustainable abstraction and the WFD objectives: priority meeting of the people water needs, minimizing the negative effect on the ecological and quantitative status, and minimizing the negative effect on economy.

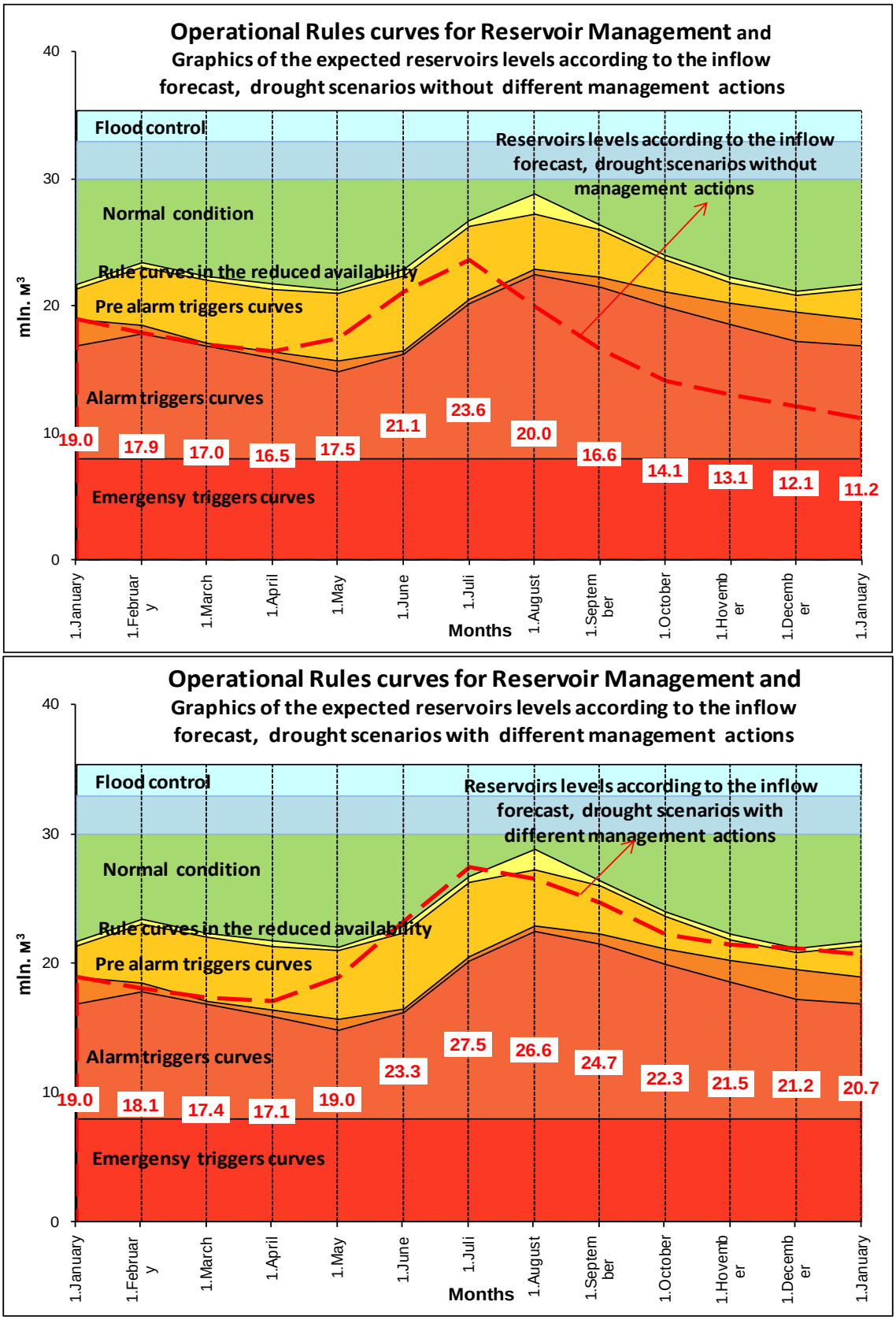


Fig.13. Rules curves for Reservoir "Dyakovo" and expected reservoir levels according to the inflow forecast, drought scenarios with different supply-side and demand-side management actions

CONCLUSIONS

According to the European Water Framework Directive (WFD) environmental flow (e-flows) for good ecological status (GES) were defined as the hydrological regime necessary to achieve the values specified for the biological quality elements. E-flows are a management concept. Environmental flow releases from reservoirs and water resources management systems will need to be implemented as measures to mitigate impacts from their constructions and operation. In this context low flow management is related to water demand and ecological runoff estimation and provision. On the other hand, low flow management is related to the Vulnerability and Drought Risk Assessment and Management.

For this end a methodology for joint assessment of drought-risk of water supply under climate change, water stress areas identification and ecological flow provision for WFD is developed. The methodology is based on DPSIR approach and identification of drought-vulnerable areas; estimation of water-shortage risk in water resources management systems; definition of long-term and short-time actions to drought management. Management of WRMS, water allocation and reservoir management rules are the basis for sustainable abstraction, abstractions management strategy and environmental flow (GES) provision.

Climatic, hydrological, ecological and socio-economic indicators based on the DPSIR Indicator framework were selected. Based on the developed approach and implementation of a system of indices to assess the vulnerability (water exploitation index WEI, water shortage index WSHI, reliability indices), an analysis of risk for drought and climate change was accomplished. The methodology for assessment and mapping of water stress areas and water supply vulnerability is developed.

The so-called HMWB and “regulated rivers” have modified flow, which is influenced by reservoir compensation releases, or they have flows that are augmented. The availability of water is dependent on these operating agreements. The “concept of compensation”, ecodeficit methodology and IHA, represents one possibility for guaranteeing the ecological runoff and e-flow concept.

According to the common methodology, “critical areas/hot points” are determined. A threshold for WEI+ in CC-WARE varies in function of dominant type of resources and according to the method for estimating the water availability side: long-term average, long term average – eco demand, characteristic low flow and characteristic low flow – eco demand.

The experiments are carried out. The methodology has been developed and applied on a transnational level (CC - WARE project), river basin and local level (water body, WRMS, reservoir). Diverse climatic, hydrological scenarios, variants of current and future water use, various schemes for utilization of water resources are analyzed.

This methodology ensure abstraction management strategy and the WFD objectives: priority meeting of the people water needs, minimizing the negative effect on the ecological and quantitative status, and minimizing the negative effect on economy.

ACKNOWLEDGMENTS

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