

# New WEAP PlugIn calculates water stress, disaggregated by sub-basin



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## SEI brief

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## Key messages

- Scarcity of water is a crucial global issue with large regional variations, requiring tools that can provide specialized insights for sustainable water resources management.
- A new PlugIn for the Water Evaluation and Planning (WEAP) software calculates water stress by catchment area to better understand water stress at the sub-basin level.
- This tool can help countries develop more robust strategies to meet Sustainable Development Goal (SDG) Indicator 6.4.2, which measures water stress as part of its greater mission to secure clean water and sanitation across the globe.

[Website](#) to download the PlugIn and instructions in English, French or Spanish

Water stress can have devastating consequences for the environment and can hinder or even reverse economic and social development. While global water stress was at a relatively safe level of 18% in 2018, the world average masks huge regional variations. Regions affected by high water stress require urgent and concrete measures to save water and increase water use efficiency. Further disaggregation of water stress subnationally by water basin and sub-basins can provide insights and information for improving sustainable management of water resources.

Water stress disaggregation is key for solving water management issues. Led by country-level technicians, this detailed view will offer better insights on the spatial aspects of water stress and will increase local ownership and participation in evaluating and developing strategies to decrease water stress.

The Water Evaluation and Planning (WEAP) software now has a new PlugIn to calculate water stress by catchment area. This tool, developed by the Food and Agriculture Organization of the United Nations (FAO), in collaboration with SEI, can help countries meet Sustainable Development Goal (SDG) Indicator 6.4.2, which measures water stress as part of its greater mission to secure clean water and sanitation across the globe.

## Understanding the building blocks of water stress

The following are definitions of the terms used within the WEAP tool and with the new PlugIn.

**Water scarcity** is defined by FAO to represent an excess of water demand from all sectors as compared to available supply (Steduto et al., 2012). It is a term commonly used to refer to a geographical area or period of time when insufficient water is available for human and environmental uses. It is very closely related to water demand satisfaction.

**Water demand satisfaction** measures the proportion of water demands that are met. It compares water delivered (amount received by users) to water needs, focusing on how human health and economic activities are affected by water scarcity and water resources management.

$$\text{water demand satisfaction} = \frac{\text{water delivered}}{\text{water demand}} \times 100\%$$

**Environmental flow (EF)** is defined by FAO guidelines, adapted from the definition in Arthington et al. (2018), as "... the quantity and timing of freshwater flows and levels necessary to sustain aquatic ecosystems which, in turn, support human cultures, economies, sustainable livelihoods, and well-being".SDG Indicator 6.4.2, focuses on resource withdrawals compared to resource availability. It is calculated as freshwater withdrawals by all economic activities compared to the total renewable freshwater resources available, after accounting for environmental flow requirements.

$$\text{water stress} = \frac{\text{TFWW}}{\text{TRWR} - \text{EFR}} \times 100\%$$

Where:

*TFWW* = Total freshwater withdrawals

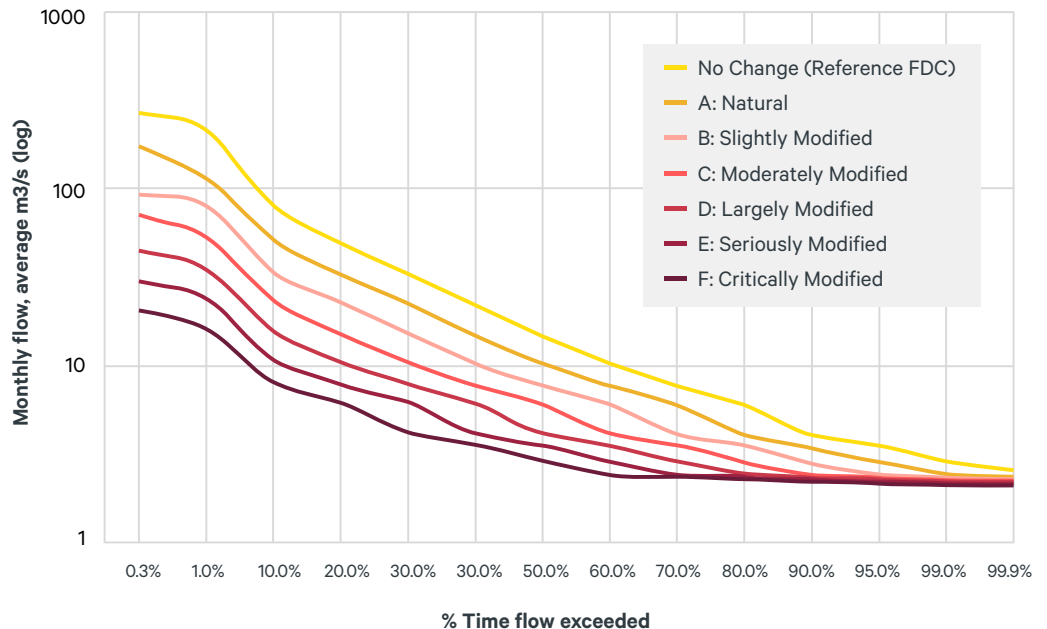
*TRWR* = Total renewable freshwater resources

*EFR* = Environmental flow requirements

### Environmental flow requirements using the FDC shift method

To standardize the calculation of SDG 6.4.2, where no minimum environmental flows have been established, FAO has developed guidelines for incorporating EF into water stress Indicator 6.4.2 (C. Dickens et al., 2019).

Figure 1: Environmental management classes as defined by Smakhtin & Eriyagama.



Source: Smakhtin & Eriyagama, 2008

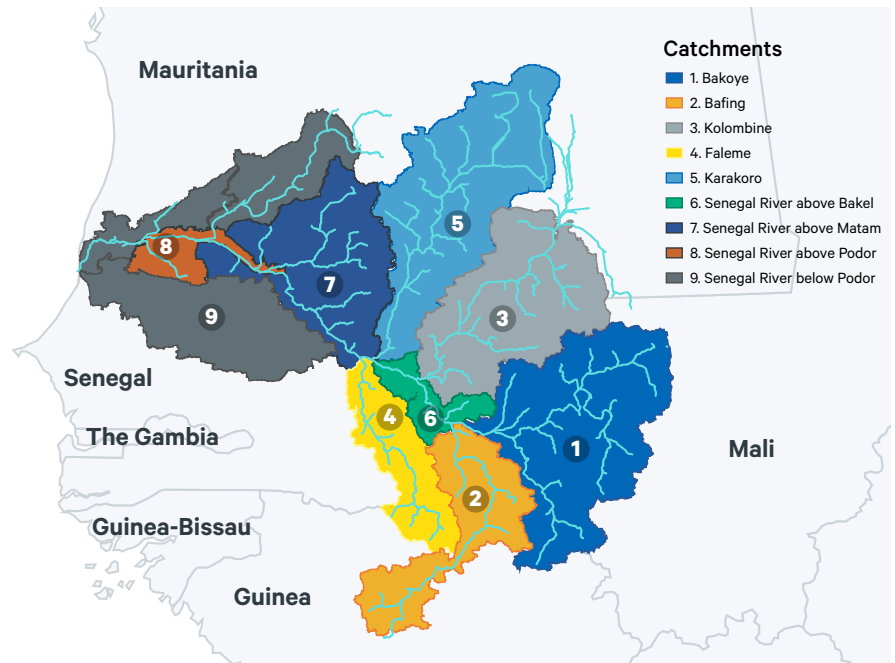
The method used to calculate EF is to use the Flow Duration Curve (FDC) Shift method, described in Smakhtin & Eriyagama (2008). WEAP can automatically calculate environmental flows using this method. It takes into account the ecological management

class of a river compared to unimpaired flows, such that rivers in natural or moderately modified conditions have stricter environmental flows than largely modified ecosystems.

## Projecting spatial and annual changes in water stress can inform water resources management decisions

WEAP software can help water resources managers to visualize the potential for water resources to meet all demands under a variety of future conditions and management scenarios. As an example, determining values for water stress for the entire Senegal River basin, which spans over portions of Senegal, Mauritania, Mali and Guinea, provides more useful information for water resources management than determining water stress on a solely country-wide basis does. The Senegal River WEAP model allows users to envision how water stress may vary from year to year depending on varying climatic conditions (e.g. wet and dry years), and how future conditions and management strategies might potentially affect water stress. It also allows users to understand how water stress varies among sub-basins, which are shown in Figure 2.

Figure 2. Spatial disaggregation of Senegal River basin, simulated by WEAP.

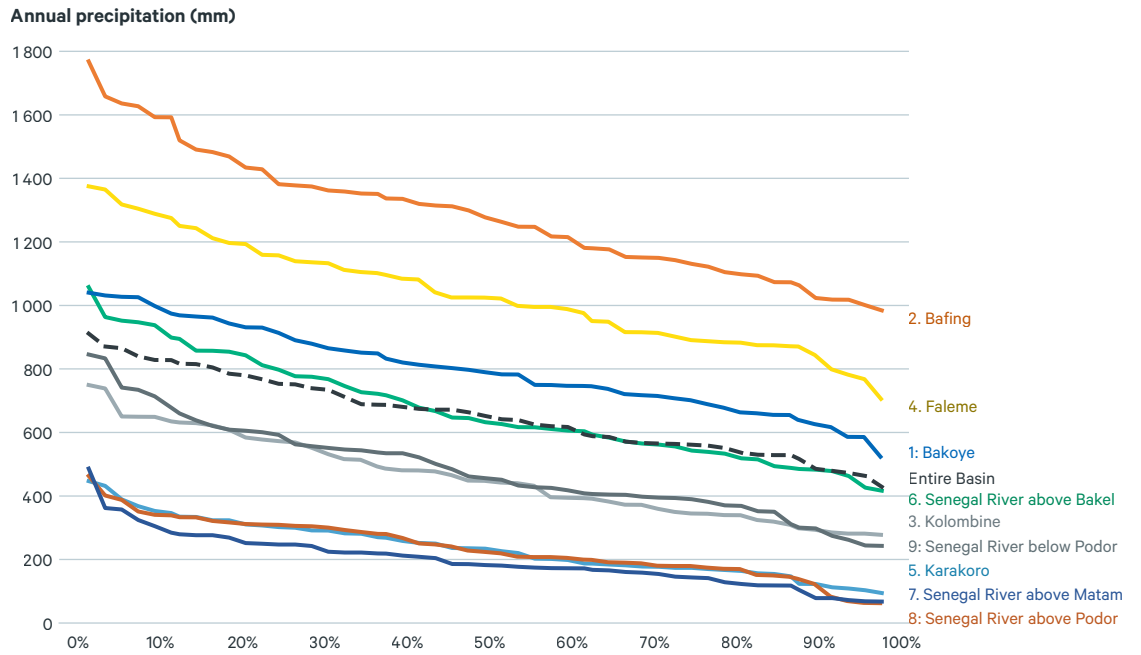


Source: Authors' own.

Annual precipitation is not homogeneous across the Senegal River basin, with its headwaters in Guinea (sub-basin 2) receiving 1200 to 2100 mm per year and the portion of the basin around its outlet in northern Senegal and southern Mauritania (sub-basins 7, 8, and 9) receiving 100 to 450 mm per year (Figure 3). Conversely, surface water withdrawals are greater in the downstream portion of the basin, suggesting that water stress should vary significantly across the basin.

For example, consider the wet year of 2021 in which water stress was very low (less than 10%) in the upstream Bakoye, Kolombine, Faleme and Karakoro basins, while it was 66% in the Bafing River basin and above 70% along the lower portions of the Senegal River below Bakel (Figure 4, Table 1). Note that disaggregation of SDG calculations for downstream

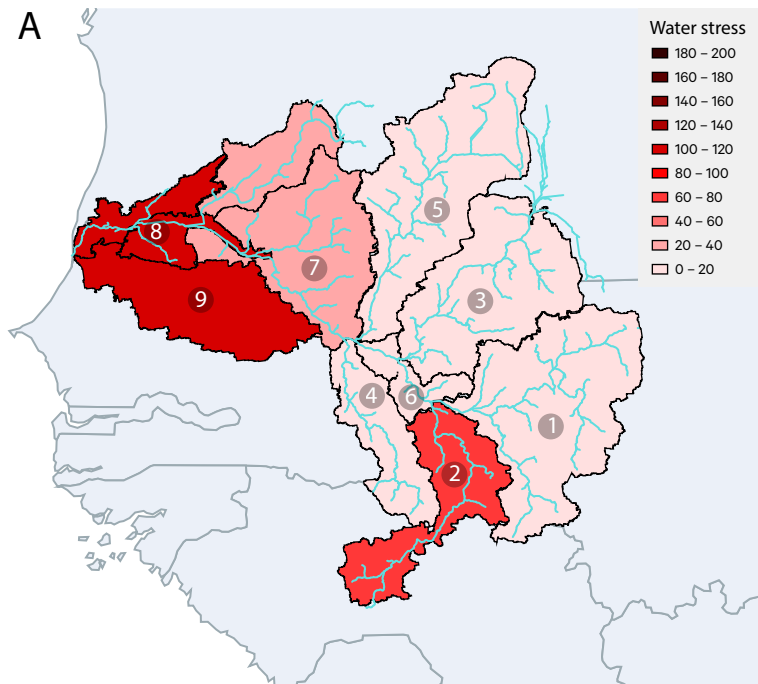
Figure 3. Flow exceedance curves of annual precipitation ranges by sub-basin, simulated by WEAP using Princeton rainfall values from 1950–2000.



Source: Authors' own.

basins requires use of the difference between the downstream and upstream EFRs (the EFR increase) in the formula to avoid double-counting. Also note that water stored in reservoirs, or increases in reservoir storage, are included as water withdrawals in the water stress calculations. Although groundwater is not included in this example, the Plugin is designed to account for groundwater withdrawals and groundwater storage.

Figure 4: Water stress in the Senegal basin in 2021, disaggregated by sub-basin, simulated by WEAP.



Source: Authors' own.

Table 1. Senegal basin water stress calculation, disaggregated by sub-basin in 2021, simulated by WEAP.

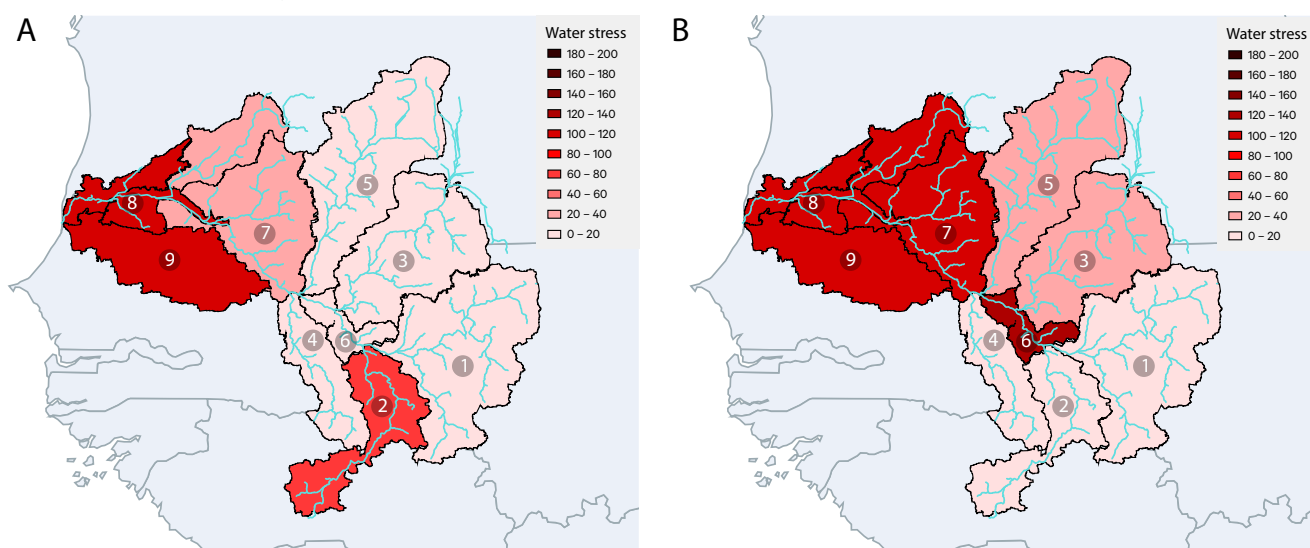
	1: Bakoye	2: Bafing River	3: Kolinbine	4: Faleme	5: Karakoro	6: Senegal River above Bakel	7: Senegal River above Matam	8: Senegal River above Podor	9: Senegal River below Podor	Basin-wide
Total basin area, km <sup>2</sup>	300	35 706	26 400	28 900	30 000	8019	48 000	40 918	2076	306 320
Precipitation, million m <sup>3</sup> (Mm <sup>3</sup> )	74 012	49 188	13 625	29 613	7082	6828	13 656	27 453	413	221 870
Precipitation, mm	858	1378	516	1025	236	851	285	671	522	6341
Surface water runoff (SW), Mm <sup>3</sup>	5112	18 231	544	4412	610	1398	745	377	599	32 028
ETactual, Mm <sup>3</sup>	68 526	31 124	13 545	24 958	6862	6058	13 642	24 850	2234	189 565
Surface water withdrawals (SWW), Mm <sup>3</sup>	20	381	15	6	7	267	1069	1483	1436	4684
EFR increase, Mm <sup>3</sup>	2698	7952	268	1784	244	29	238	255	468	14 348
Environmental Flow Requirement (EFR), Mm <sup>3</sup> (Total)	2698	7952	268	1784	244	12 975	13 213	13 468	14 348	14 348
EFR class	B	C	B	C	B	C	C	C	C	C
Downstream reserve (DSR), Mm <sup>3</sup>	575	998	63	630	86	285	96	-	-	
Upstream request (USR), Mm <sup>3</sup>	-		-		-	-		1360	2345	
Net increase (+) or decrease (-) in reservoir storage volume, Mm <sup>3</sup>	-	5735	-	-	-	-	-	-	84	6123
TRWR (SW-DSR+USR)	4537	17 233	481	3782	523	1112	648	1737	2944	32 997
TFWW (SWW+reservoir storage increase)	20	6115	15	6	7	267	1069	1483	2476	11 458
Water stress TFWW/(TRWR-EFR increase)	1%	66%	7%	0%	3%	25%	260%	100%	100%	61%

ETactual: actual evapotranspiration; TFWW: total freshwater withdrawals; TRWR: total renewable freshwater resources.

EFR increase is equal to the environmental flow requirement at the most downstream point of upstream sub-basins. For downstream sub-basins, EFR increase is the EFR at the most downstream point of the sub-basin minus EFR values of downstream points of upstream sub-basins. This method avoids double-counting of EFR values already included in calculations of water stress upstream.

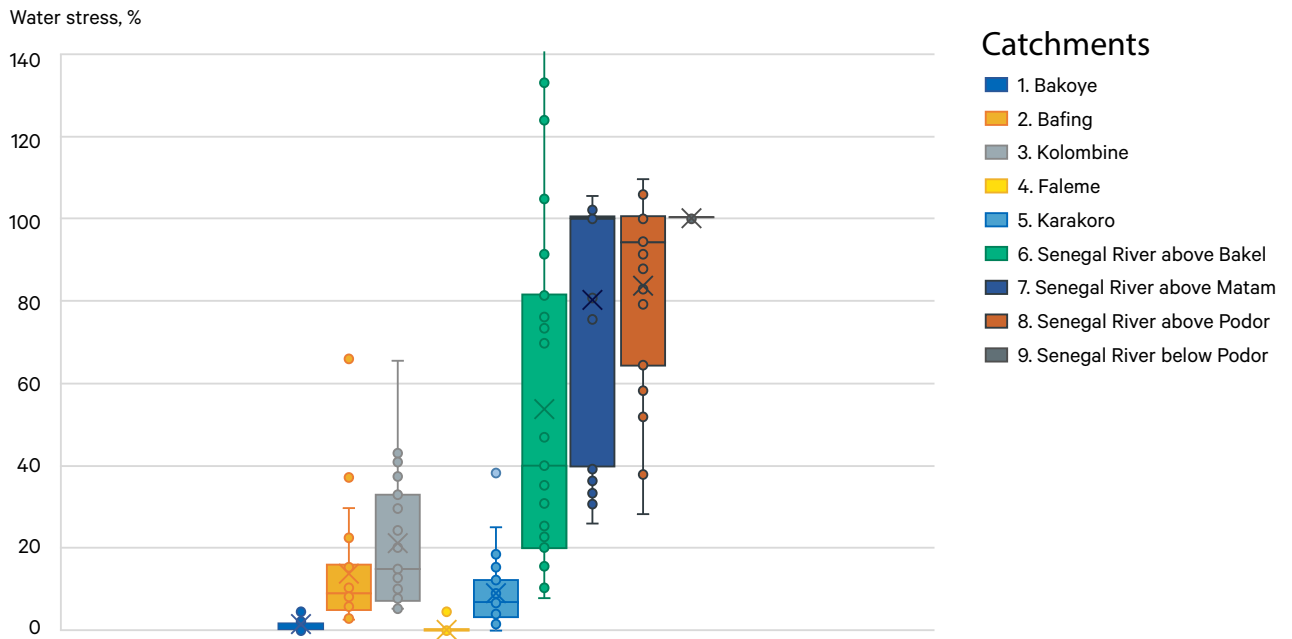
Water resource managers can use a WEAP model coupled with the new Plugin to calculate, understand and visualize variations in water stress in wet and dry years by sub-basin (Figure 3), and to explore the variability in water stress over a range of projected wet and dry years. Box and whisker plots can be helpful to understand these variations (Figure 4). In this example, water stress is consistently at or above 100% in the downstream Senegal River sub-basin 8 (below Matam), and varies the most upstream of Podor in sub-basins 6 and 7 (above Bakel and Matam).

Figure 5: Water stress in the Senegal basin in a wet year (A - 2021) and a simulated dry year (B - 2043), created by WEAP.



Source: Authors' own.

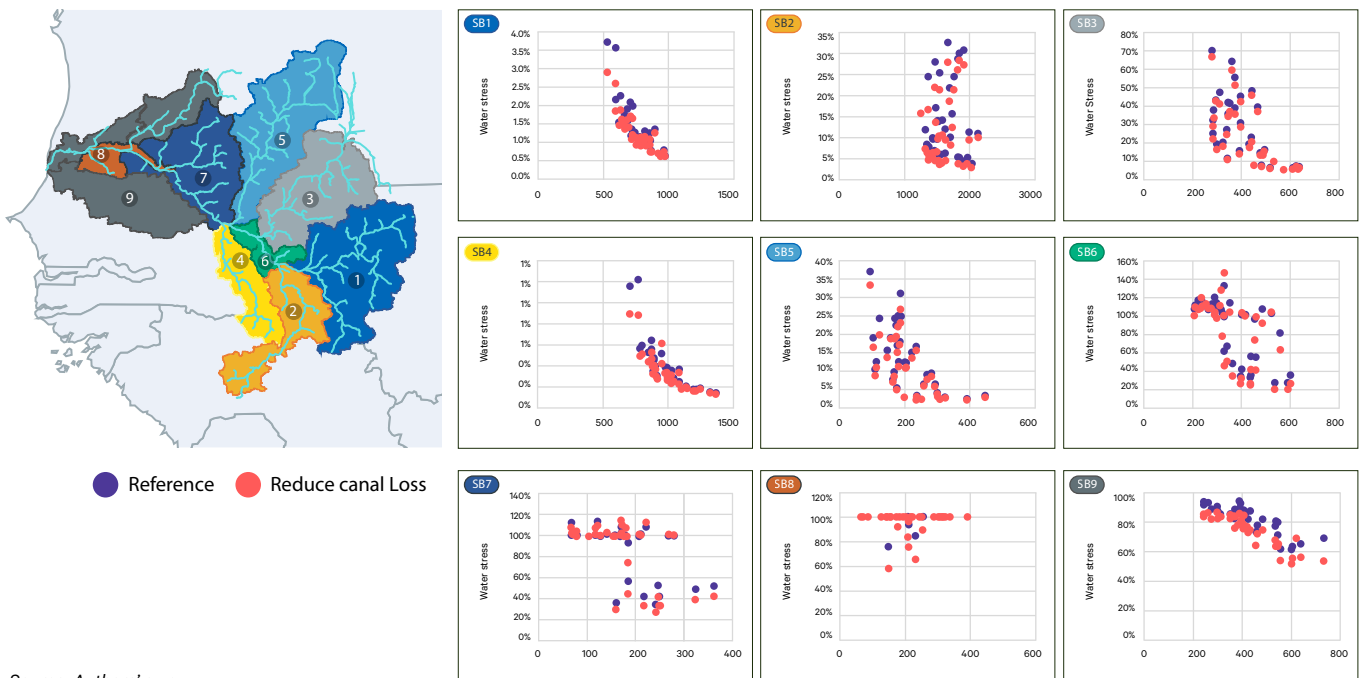
Figure 6: Box plot of simulated water stress variations, 2020–2050, simulated by WEAP.



Source: Authors' own.

WEAP software provides ample flexibility to explore how uncertainties and management strategies may impact water stress and water demand satisfaction. Future uncertainties may include climate change and population growth, while management strategies might include increased agricultural efficiency, programs to reduce domestic water use, reuse of wastewater, and use of desalinated water (which would decrease the need for water withdrawals). As an example, Figure 5 indicates how water stress over time in each of the basins is related to annual precipitation in a baseline (reference) scenario and in a scenario where canal losses are reduced from an average of 35% to 15%.

Figure 7: Water stress impacts of precipitation and reduced canal losses (from 35% -reference scenario to 15% -reduced canal losses scenario), simulated by WEAP and projected for 2020–2050.

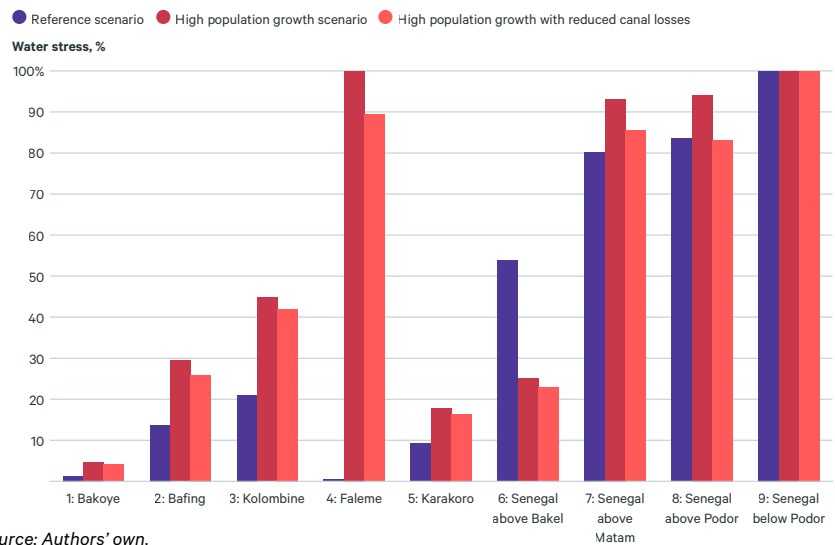


Source: Authors' own.

The example above illustrates how the WEAP software and Water Stress Plugin can be used to compare different management strategies. In this case, we observe a very clear decrease in water stress with the reduction of water losses in irrigated systems. We also observe that the correlation between water stress and annual precipitation is only apparent in the upstream sub-basins that do not receive any imports (or transferred water) from other sub-basins. Releases from storage or transfers from upstream sub-basins make this relationship much less clear for downstream sub-basins.

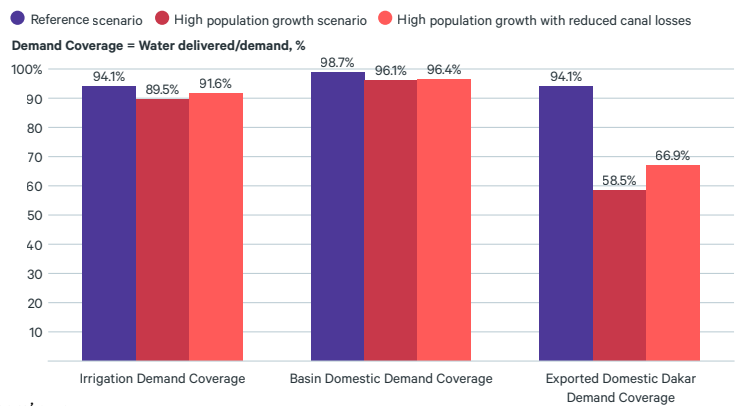
Note that water stress calculations only take into account water withdrawals in comparison to available resources; they do not calculate whether water demands have been met. Water resources managers must balance human and environmental water needs, taking water demand satisfaction (domestic, commercial and industrial) into consideration alongside water stress. If we compare demands of the current population to that of a population in 2040 under a high (4% per year) population growth scenario (both within the basin and in Dakar), both household and irrigation demands will increase. These increases, under the modeled simulated conditions, would likely result in both significant increases in water stress and decreases in water demand satisfaction, particularly in meeting water demands of Dakar. Reduced canal losses would help to alleviate water stress and increase demand satisfaction, but additional strategies would be required to meet all demands, as illustrated in Figures 6 to 9.

Figure 8: Projected average water stress under three scenarios, simulated by WEAP for 2020–2050.



Source: Authors' own.

Figure 9: Projected demand satisfaction under three scenarios, simulated by WEAP for 2020–2050.



Source: Authors' own.

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Corrections, February 2024: Missing text for captions for figures 4 and 7 has been added.



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## Recommended criteria and next steps

As of July 2023, the water stress PlugIn has been tested for four cases: a pilot project in the Cap Matifou area of Algeria in collaboration with Ministère des Ressources en Eau et de la Sécurité Hydrique; a simplified model of the Medjerda River, developed in cooperation with the DGRE (Direction Générale des Ressources en Eau); a model of Rwanda; and this simplified model of the Senegal River.

Based on these cases, the team recommends the following criteria for models that calculate disaggregated water stress:

1. Select an entire basin, not a sub-set of a basin.
2. If a significant proportion of the basin's freshwater resources are provided to or received from an external basin, model the external basins for an integrated picture of how management decisions affect water resources.
3. Include all water supplies and demands that significantly affect water resource management of the basin, including those external to the basin.
4. Do not select small catchments if they are not major freshwater sources for the basin.

Moving forward, our team is interested in working with partners to support countries or multi-country basins interested in using the PlugIn to pilot its use. We are also interested in conducting further training for water resources managers and modelers in the use of the PlugIn, particularly with those who have an existing WEAP model for water resources management. We are interested in making further enhancements to the PlugIn and its user friendliness, including automating visualization of results and reporting on seasonal water stress, as requested by interested parties in Rwanda.

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