Water scarcity footprint of a flow regulator (NEOPERL)

Case study for the WULCA consensus midpoint impact assessment model "Available WAter REmaining" (AWARE)

Content

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1. Case study description

This study aims at testing the WULCA consensus characterization model “Available WAter REmaining” (AWARE)[1] concerning practical applicability and scientific validity. It is based on an existing life cycle assessment which analysed the environmental impacts, including the water footprint, of a NEOPERL flow regulator[2] along its life cycle. For simplicity, the water inventory of the production phase of a flow regulator is used as a basis for testing the AWARE characterization factors (CFs) and calculating the associated “User Deprivation Potential” (UDP) at each production location. The following default CFs are used:

- AWARE100, non-agricultural annual average (AWARE100, yr_non_agri)
- AWARE100, annual average (AWARE100, yr_avg)

Additionally, modified CFs are applied allowing for a methodological sensitivity analysis:

- AWARE100+50%EWR, yr_non_agri with 50 % increased environmental water requirement
- AWARE10, yr_non_agri with CF_{max} = 10 instead of 100
- AWARE1000, yr_non_agri with CF_{max} = 1,000 instead of 100

In the following section results are presented and variations are explained considering the methodological differences between the CFs.

2. Results

2.1. Water inventory

The total water consumption of the production of a flow regulator amounts to 3.03E-05 m^3. As shown in Figure 1, water occurs predominantly in Germany (ca. 75%) and Italy (ca. 17%). The top ten contributing countries to the water inventory (including Sweden, United Kingdom, Netherlands, France, Russia, Norway, Spain and Belgium) cover ca. 99% of the entire water consumption.

Figure 1 Relative spatially explicit water inventory of a NEOPERL flow regulator

[1] Boulay, A.-M., et al., The WULCA consensus characterization model for water scarcity footprints: Assessing impacts of water consumption based on available water remaining (AWARE). *Environmental Science and Technology* **2016,** *submitted.*

[2] Berger, M.; Söchtig, M.; Weis, C.; Finkbeiner, M., Amount of water needed to save 1 m3 of water: life cycle assessment of a flow regulator. *Applied Water Science* **2015,** *in press, DOI: 10.1007/s13201-015-0328-5*.

2.2. UDP100, yr_non_agri

In order to obtain the user deprivation potential (UDP), i.e. the potential to deprive another user (human or ecosystem) when using water in a given area, the country-specific water consumption shown in Figure 1 is multiplied by its corresponding characterization factor (AWARE100). Since an industrial product system is analysed, the AWARE100, yr_non_agri factors are used. The resulting user deprivation potential, non-agricultural annual average (UDP100, yr_non_agri) amounts to 1.93E-04 m^3 world-equivalents and its spatial distribution is shown in Figure 2.

Figure 2 Relative spatially explicit user deprivation potential, non-agricultural annual average (UDP100, yr_non_agri) of a NEOPERL flow regulator

Results show that the composition and share of the top 10 contributing countries to water inventory changes significantly after impact assessment. Water consumption in regions with relatively low "remaining water available" after environmental and human water consumption have been met causes a relatively high user deprivation potential. For instance, Italy now shows a much higher contribution to the UDP (68%) than it did to the water inventory (17%). Vice versa, relatively large shares of water consumed in water-abundant regions like Germany (75%) contribute a relatively smaller share to the regulator's UDP (20%).

2.3. UDP100, yr_avg

As a second step, the UDP is calculated again using the AWARE100, annual average (AWARE100, yr_avg) CFs. Compared to AWARE100, yr_non_agri, these factors are determined using the total (instead of only the non-agricultural) water consumption pattern to derive weighting factors when calculating annual country average CFs from the underlying monthly basin CFs.

When using the CFs (AWARE100, yr_avg) the total UDP over the life cycle of the flow regulator is more than doubled, rising from the original 1.92E-04 m^3 world-equivalents to 4.15E-04 m^3 world-equivalents. The change in total UDP results from the increase of country-specific CFs (yr_avg) by a factor of ca. 1.1 to 3.2. Yr_avg CFs are *in most cases* larger than yr_non_agri CFs because agricultural water consumption (irrigation) occurs mainly during the dry months of the year with low available water remaining. Hence, including the agricultural water consumption – which is usually much higher than the non-agricultural water consumption and varies more strongly throughout the year – leads to high annual average CFs. However, exceptions exist with countries such as the United Arab Emirates, in which the yr_avg CF (18.56 m^3 world equivalents / m^3) is *significantly* lower than the yr_non_agri CF

(46.01 m^3 world equivalents / m^3). This is explained by the procedure of aggregating basin specific CFs to country average CFs based on consumption weighted averages. If a large share of agricultural water consumption occurs in a basin and/or month with relatively low water scarcity, this CF dominates the result of the country average.

After using yr_avg CFs instean of yr_non_agri CFs, Italy and Germany continue to be the two main contributing countries to total UDP. However, the share of Italy's contribution increases to 79% (up from the previous 68%), whereas Germany's contribution declines to 10% of total UDP. This is again the result of large differences between the two country's CFs and between each country's yr_non_agri and yr_avg CF. Italy's yr_avg CF is about 2.5X its yr_non_agri CF, indicating Italy's high agricultural water consumption which is concentrated over the summer months, while Germany's yr_avg CF is "only" 1.1X its yr_non_agri CF.

2.4. UDP100+50%EWR, yr_non_agri

In order to test the influence of methodological settings in the characterization models underlying AWARE, the UDP was recalculated applying AWARE100, yr_non_agri CFs, while the environmental water requirement (EWR) which was originally assumed to calculate the CFs is increased by 50%.

Assuming higher EWR (+50%) leads to a total UDP equal to 2.62E-04 m^3 world-equivalents, which is ca. 37% higher than first calculated using yr_non_agri CFs (1.92E-04 m^3 world-equivalents). Again, the composition and individual share of the top 10 contributing countries to total UDP changes after the EWR is assumed higher. Italy now has a share of 75.5% (up from ca. 68%) and Germany's contribution decreases to 14% (down from ca. 20%). The majority of CFs of the top ten contributing countries to total UDP increase by a factor of 1.1 – 2.5 (or remain constant). Libya which used to contribute with 0.4% to total UDP is now dropped from the top 10 list, and France which had not made the top 10 list with a contribution of 0.33% is now on the list with 0.6% contribution. This can be explained at first sight by the change in each country's CF. Frances yr_non_agri CF (EWR+50%) is 2.5X its original yr_non_agri CF, while Libya's yr_non_agri CF (EWR+50%) is "only" 1.1X its original yr_non_agri CF.

The increase in the numerator of the CF (EWR+50% on a global level) is equal in all countries. What makes the difference with regards to the *increase* (or decrease, see details further down*)* in CF (EWR + 50%) – and accordingly in UDP (EWR+50%) – are two factors: (1) the originally assumed EWR in country X and its share in total demand, and (2) the ratio between the change in the "availability minus demand" (AMD) globally (i.e. the change in the numerator) after EWR is assumed to be 50% higher and the change in AMD on a country-/ watershed-level (i.e. the change in the denominator). If the percentage change (decrease) in the global AMD is smaller than the percentage decrease in AMD at the country level, then the CF (EWR+50%) is larger than the default CF which is the case in most countries.

However, the underlying characterization model of AWARE, in which the inverse of a region's available water remaining is normalized by setting it in comparison to the global average, leads in some countries such as Sweden and Germany to CFs (EWR+50%) which are lower than the default CFs. Hence, even though the available water remaining is reduced in Sweden and Germany when the EWR is increased by 50%, the percentage change in the AMD at the country level is *smaller* than the change at the global level, which results in a smaller CF (EWR+50%) than the original CF. This is usually the case when (1) water is quite abundant in the respective country (high availability) and/or (2) the share of EWR in the total water withdrawals (in comparison to the available water) is relatively small (➔ the increase by 50% in EWR does not strongly affect the denominator).

2.5. UDP10, yr_non_agri

In the default AWARE characterization model the maximum CF was set equal to 100 and is to be applied to countries (or basins) where demand exceeds availability (representing 33% of world consumption at a monthly level) or if the available water remaining in a basin is smaller than 100 times the world average (representing 5% of the world consumption). As this represents an arbitrary value choice, its influence is analysed by recalculating the CFs with an upper limit of 10 in this section and 1,000 in the next section.

Figure 3 Relative spatially explicit user deprivation potential, non-agricultural annual average (UDP10, yr_non_agri) of a NEOPERL flow regulator

As shown in Figure 3, the UDP10, yr_non_agri shows similar results to the water inventory (Figure 1). However, once again, the composition and ranking of countries in the top 10 list changes when using the AWARE10 CFs. Countries such as Qatar and Libya which used to have relatively small contributions to the total water inventory but landed in the top 10 contributors to total UDP due to relatively high CFs (in AWARE100), disappear again from the top 10 list when using AWARE10 CFs. In contrast, countries such as France with a relatively high share in total water consumption appear back on the top 10 list. This is because in the AWARE10 model the CFs range from 0.1 to 10 (i.e. show only 2 orders of magnitude) and are thus not able to provide sufficient discriminative power to highlight changes in the water availability/ scarcity situation in each country or basin. Consequently, the impact assessment results (UDP) are mainly influenced by the inventory, i.e. the volumes of water consumed in each country, and not by the CFs.

2.6. UDP1000, yr_non_agri

Repeating this analysis while setting CF_{max} to a value of 1,000 leads to the exact opposite findings. As shown in Figure 4, the UDP1000 is mainly influenced by the location of water consumption; the actual volume of water consumed is of relatively low relevance. As a result, Italy and Spain – two relatively water-scarce countries with CFs (AWARE1000) significantly higher than that of Germany – now dominate the UDP of the flow regulator.

Figure 4 Relative spatially explicit user deprivation potential, non-agricultural annual average (UDP1000, yr_non_agri) of a NEOPERL flow regulator

3. Comparison between AWARE and WAVE

A comparison between AWARE (UDP100, yr_non_agri, Figure 2) and the Water Accounting and Vulnerability Evaluation model (WAVE, Figure 5)[3] shows some noticeable differences concerning the contributions of individual countries to the water footprint of a NEOPERL flow regulator and the identification of hot spots.

Figure 5 F Relative spatially explicit freshwater deprivation potential of a NEOPERL flow regulator according to WAVE

For instance, using the WAVE model Germany now has the highest contribution to the Freshwater Deprivation Potential (FDP) (47.8%) of a flow regulator, while Italy comes in second with a contribution of 41.8% - as opposed to Italy's largest 68% contribution in the AWARE100 (yr_non_agri) model or 79%

[3] Berger, M.; van der Ent, R.; Eisner, S.; Bach, V.; Finkbeiner, M., Water accounting and vulnerability evaluation (WAVE) – considering atmospheric evaporation recycling and the risk of freshwater depletion in water footprinting. *Environmental Science and Technology* **2014,** *48* (8), 4521-4528.

in the AWARE100 (yr_avg) model. This can be explained by the range of characterization factors, which spreads by a factor of 100 only in WAVE. Hence, similar as in UDP10, the water inventory has a relatively strong influence on the results. Moreover, it should be kept in mind that in WAVE the aggregation from monthly basin CFs to annual country CFs is accomplished based on total water consumption only.

4. Lessons learned

This case study provided insight into the AWARE characterization model and identified significant methodological settings which should be kept in mind when interpreting results of a water scarcity footprint using AWARE.

First, the provision of annual country-specific CFs based on agricultural, non-agricultural, and total consumption weighted monthly basin CFs is a relevant support for practitioners. Even if the exact basin and the month of water consumption is unknown, it is usually known whether the product comprises an agricultural or non-agricultural system. A comparison of the UDPs obtained by means of AWARE, yr_non_agri and AWARE, yr_avg has shown a significant change in the category indicator result (UDP100) depending on the weighting used to get to the yearly average CFs. This can be explained by the fact that agricultural consumption (irrigation) occurs mainly during the dry month with low available water remaining. Hence, in a consumption weighted average the high CFs of these months dominate the annual average CF. Not only does the UDP change significantly, but the composition, ranking and contribution share of individual countries to the total UDP shows relevant changes too. Depending on how strong individual countries change their CFs (yr_non_agri vs. yr_avg), so does their ranking and contribution to the total UDP.

A methodological sensitivity analysis in which the EWR has been increased by 50% revealed an increase of 37% in the UDP and changed the ranking of countries' contributions to the total UDP significantly. This can be explained by the different default EWR in different basins (30-60%) which are increased to 45-90%, respectively. Especially in basins with rather high EWRs a situation in which demand exceeds availability is easily reached leading to a setting of the CF to 100, which also influences the annual average. Hence, the setting of EWR has shown to be a significant methodological parameter which should be focused on in future research.

A difficulty in interpreting the CFs, especially in the methodological sensitivity analysis, is the normalization of the inverse of the available water remaining in a basin to the global average. This leads to the situation that a methodological setting cannot be analysed independently. It always needs to be seen in relation to the (also changed) world average. For instance, an increase in EWR of 50% (which decreases the available water remaining) leads to a counter-intuitive decrease in CFs of Sweden and Germany. Considering the normalization to the world average, this result expresses that the reduction in the available water remaining in Sweden and Germany is lower than the reduction on global average. Hence, even though the normalization to the world average increases the physical interpretation of CFs and allows for an easy to understand unit (m^3 world-equivalents/m^3), it represents a challenge for methodological sensitivity analyses.

Changing the upper limit of the CFs (10; 100; 1,000) leads to an increased discriminative power of the CFs. Comparing the annual country CFs of countries has shown that this setting does not only influence the relative difference between the countries but also the ranking of countries. This can be explained by two facts. First, monthly basin CFs are more likely to become equal if the upper limit is 10 only. Second, if the upper limit of CFs for water scarce months is 100 or even 1,000, the relative weighting of these CFs in the annual average is much higher.

In general, the setting of the upper threshold of the CFs to 100 (in basins in which demand exceeds availability or in which the available water remaining is smaller than 100 times the world average) has shown to be a good compromise. This setting balances the influence of the inventory (overrepresented in UDP10) and the CF (overrepresented in UDP1000). Nevertheless it should be kept in mind that there is no scientific justification that a range of three orders of magnitudes (0.1-100) is the "correct" setting.

5. Potential problems

As for any other water characterization model, the main hindrance for the application of AWARE in industrial product systems is the absence of spatially explicit inventory data. This case study was only possible because the inventory data had been regionalized in a top-down regionalization approach discussed in the underlying publication[4].

Even though we did not identify obvious mistakes in the CFs or obviously wrong conclusions drawn from the application of AWARE, the interpretation of the results was not always straightforward and some CFs appeared counter-intuitive.

For instance, it seems illogical that CFs based on total water consumption weighted average are lower than non-agricultural weighted CFs in some countries (like UAE). Also a comparison of CFs between countries can lead to strange findings. For instance, strong differences are detected between countries in the MENA region, ranging from 29 m^3 world equivalent/m^3 in Saudi Arabia, over 43 in Libya to 98 in Egypt. Obviously, each of the three countries is dominated by deserts and suffers from extreme water scarcity. Thus, it is hard to explain that, according to AWARE, there are significant differences between them. It also hard to justify why Saudi Arabia is considered less water stressed than Spain or Greece (31 m^3 world equivalent/m^3).

The reasons for these counter-intuitive CFs, which might reduce the acceptance of AWARE among practitioners, can be explained by the methodology of aggregating basin-specific CFs to country – specific CFs based on consumption weighted averages. If a large share of water consumption occurs in a small basin with relatively low water scarcity (as it is the case in many desert countries), this CF dominates the result of the country average. However, this aggregation procedure seems justified from a scientific point of view as it is most likely that the (spatially unknown) water consumption occurred in the basin with the highest share of the country's water consumption.

[4] Berger, M.; Söchtig, M.; Weis, C.; Finkbeiner, M., Amount of water needed to save 1 m3 of water: life cycle assessment of a flow regulator. *Applied Water Science* **2015,** *in press, DOI: 10.1007/s13201-015-0328-5*.