WRS-US Version 2—Technical Note

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WRS-US Version 2.0—Technical Note

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Abstract

The MIT Water Resource System for the U.S. (WRS-US) component of the Integrated Global System Model (IGSM) framework is modified to be more computationally efficient and more flexible. For this purpose, version 2.0 of the WRS-US model now solves all basins, or Assessment Sub Regions (ASR), simultaneously. Additionally, the model now includes two objective functions and a new calculation procedure is now adopted to estimate initial storage capacity.

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1. INTRODUCTION

The MIT Water Resource System for the U.S. (WRS-US) component of the Integrated Global System Model (IGSM) described in Blanc *et al*. (2014) models the interaction of water resources and anthropogenic water requirements using an integrated set of economic and earth system models. This model has been modified to be more computationally efficient and more flexible. For this purpose, version 2.0 of the WRS-US model now solves all basins (ASRs) simultaneously. The model also includes two objective functions. Additionally, the model now includes updated basin storage information and accounts for sustainable groundwater withdrawals.

2. MODEL SOLVING STRUCTURE

The fundamental goal of the Water System Management (WSM) module has not changed in this version. For each ASR, the model allocates available water among users each month while minimizing annual water deficits (i.e., water requirements that are not met) and smooths deficit across months. The allocation of water for each ASR is solved simultaneously for the months of each year. However, in addition to solving basin by basin, WRS-US now has the ability to solve all ASRs simultaneously. This new solving structure enables consideration of cooperation across basins. To do so, the optimization of water allocation depends on water requirements and resources across all basins within the same watershed. The structure of the model has therefore slightly changed, but the upstream/downstream relationship between basins is still respected, which is essential to represents flows appropriately.

3. OBJECTIVE FUNCTIONS

The WSM module now comprises two alternative objective functions: one linear and one non-linear.

3.1 Linear Objective Function

The linear objective function minimizes the objective function *OBJ* as follows:

$$OBJ = \sum_{asr}\left(Wasr * \left[-\sum_m (Wm_{asr,m} * RAV_{asr,m}) - \sum_m\left(Wm_{asr,m} * RANIRV_{asr,m}\right) - MINRAV_{asr} - \sum_m\left(Wm_{asr,m} * \frac{STV_{asr,m}}{stc_{asr}}\right) - \sum_m\left(\sum_{asrt}\left(Wwca_{asrt,m} * \frac{TRANSFV_{asr,m}}{transferout_{asr,m} * 12}\right)\right)\right]\right)$$

where:

- *Wasr* is an ASR-specific weight
- *Wm* is a month-specific weight
- *RAV* is the supply requirement ratio, SRR, $\left(\frac{\text{total depletion}}{\text{total requirements}}\right)$
- *RANIRV* is the non-irrigation requirement ratio, NIR-SRR $\left(\frac{\text{non}-\text{irrigation depletion}}{\text{non}-\text{irrigation requirements}}\right)$
- *MINRAV* is the minimum annual RAV
- *STV* is the basin storage

- *stc* is the basin storage capacity
- *TRANSFV* is monthly the inter-basin transfer allocated
- *transferout* is the monthly inter-basin transfer requirement

3.2 Non-linear Objective Function

An alternative objective function maximizes the non-linear objective function *OBJSQV*:

$$OBJSQV = \sum_{asr}\left(\text{Wasr} * \left[\sum_{m}\left(\text{Wm}_{\text{asr,m}} * \sqrt{\text{RAV}_{\text{asr,m}} - 1}\right) + \sum_{m}\left(\text{Wm}_{\text{asr,m}} * \sqrt{\text{RANIRV}_{\text{asr,m}} - 1}\right) + \sqrt{\text{MINRAV}_{\text{asr}} - 1} + \sum_{m}\left(\text{Wm}_{\text{asr,m}} * \sqrt{1 - \frac{\text{STV}_{\text{asr,m}}}{\text{stc}_{\text{asr}}}}\right) + \sum_{\text{m}}\left(\sum_{\text{asrt}}\left(\text{Wwca}_{\text{asrt,m}} * \sqrt{1 - \frac{\text{TRANSFV}_{\text{asr,m}}}{\text{transferout}_{\text{asr,m}}*12}}\right)\right)\right]\right)$$

where the explanatory variables are described above.

The objective function has slightly changed to facilitate the analysis of alternative priorities between sectors and across months. The main change in the objective function compared to the first version is the explicit accounting of irrigation supply requirement ratio. In the initial version of the model, only the SRR was considered in the optimization decision and irrigation was a residual user (water is allocated for irrigation only if the requirements of all other sectors have been met). In the new version, irrigation is still a residual user, but this assumption can now be easily modified to give more weight to the irrigation sector in specific regions.

Additionally, this new version of WRS-US also includes slack variables for spill, storage and inter-basin transfers (not represented in the above equations). These variables are included in order to avoid solving infeasibilities when there is not enough water available to meet minimum environmental flows, minimum storage requirements and transfers.

Weights are also included to give preference to some basins or to some months.

4. BASIN STORAGE

In this version, reservoir capacity and surface data are sourced from the Global Reservoir and Dam (GRanD) Database, Version 1.1. (Lehner *et al.* 2011b, Lehner *et al*. 2011a).

5. GROUNDWATER RECHARGE

As in the previous version, groundwater withdrawals in a given year are limited to this year groundwater capacity. In the previous version, groundwater supply (GWS) is assumed to be limited to the 2005 groundwater uses estimated by USGS (2011) at the county level based on the assumption that 2005 was representative of annual groundwater availability. However, in this version, to account for groundwater pumping sustainability, groundwater withdrawals are also limited by the amount of groundwater recharge. If in a given year, groundwater recharge is lower than 2005's withdrawal capacity, groundwater withdrawals are limited to recharge. To estimate groundwater recharge, we use USGS (2003)'s 1-kilometer resolution dataset of mean annual natural groundwater recharge. Concurrently, we account for the amount of water recharge sourced from surface storage using surface storage recharge share from IFPRI's IWSM model which vary by FPU.

6. REFERENCES

Blanc, É., K. Strzepek, C.A. Schlosser, H.D. Jacoby, A. Gueneau, C. Fant, S. Rausch and J.M. Reilly 2014: Modeling U.S. Water Resources under Climate Change. *Earth's Future* **2**(4): 197–224.

Lehner, B., C., Reidy Liermann, C. Revenga, C. Vörösmarty, B. Fekete, P. Crouzet, P. Döll, M. Endejan, K. Frenken, J. Magome, C. Nilsson, J.C. Robertson, R. Rödel, N. Sindorf and D. Wisser, 2011a: *Global Reservoir and Dam Database, Version 1 (Grandv1): Reservoirs, Revision 01*. Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC).

Lehner, B., C., Reidy Liermann, C. Revenga, C. Vörösmarty, B. Fekete, P. Crouzet, P. Döll, M. Endejan, K. Frenken, J. Magome, C. Nilsson, J.C. Robertson, R. Rödel, N. Sindorf and D. Wisser, 2011b: High-Resolution Mapping of the World's Reservoirs and Dams for Sustainable River-Flow Management. *Frontiers in Ecology and the Environment* **9**(20160107): 494–502.

USGS [U.S. Geological Survey], 2003: *Estimated Mean Annual Natural Ground-Water Recharge in the Conterminous United States.* U.S. Geological Survey (https://catalog.data.gov/dataset/estimated-mean-annual-natural-ground-water-recharge-in-the-conterminous-united-states).

USGS [U.S. Geological Survey], 2011: *Water Use in the United States*. (http://water.usgs.gov/watuse/data/).

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