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Impacts and uncertainties of climate-induced changes in watershed inputs on estuarine hypoxia

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The supplementary material is comprised of three tables (Tables S1-S3) and four figures (Figures S1-S4). Appendix A provides additional details regarding the distribution of watershed organic nitrogen loadings to ChesROMS-ECB. Table S1 describes the U.S. Geological Survey (USGS) site numbers for the three major rivers used to assess watershed model skill. Table S2 provides a list of locations for the Chesapeake Bay Program monitoring stations used to assess estuarine model skill. Table S3 lists the IDs, names, and KKZ ranks of all Earth System Models (ESMs) used in this study. Figure S1 compares regression metrics of watershed precipitation time periods used to predict annual hypoxic volume. Figure S2 shows the relative changes in watershed precipitation and temperatures for the five MACA and BCSD downscaled ESMs selected using the KKZ methodology. Figure S3 provides a representation of watershed model skill at the three major tributaries for freshwater streamflow, nitrate, and organic nitrogen loadings. Figure S4 shows the relationship between Phase 6 MACA downscaled ESM estimates of annual hypoxic volume with and without the effects of management conditions.

Table S1: USGS site numbers for major tributaries used to assess watershed model skill after applying WRTDS. Streamflow data are available from U.S. Geological Survey (2022).

Major Tributary	**USGS Site Name**	**USGS Site Number**
Susquehanna	SUSQUEHANNA RIVER AT CONOWINGO, MD	01578310
Potomac	POTOMAC RIVER AT CHAIN BRIDGE, AT WASHINGTON, DC	01646580
James	JAMES RIVER AT CARTERSVILLE, VA	02035000

Table S2: Locations of 20 Chesapeake Bay Program (CBP) stations used to assess estuarine model skill. Water Quality Monitoring Program data are available from the Chesapeake Bay Program's online database (Chesapeake Bay Program DataHub, 2022).

CBP Station ID	Latitude (° N)	Longitude (° W)
CB2.2	39.3468	-76.1747
CB3.1	39.2484	-76.2380
CB3.2	39.1635	-76.3063
CB3.3C	38.9951	-76.3597
CB4.1C	38.8251	-76.3997
CB4.2C	38.6448	-76.4177
CB4.3C	38.5565	-76.4347
CB4.4	38.4132	-76.3430
CB5.1	38.3185	-76.2930
CB5.2	38.1368	-76.2280
CB5.3	37.9118	-76.1680
CB5.4	37.8001	-76.1747
CB5.5	37.6918	-76.1897
CB6.1	37.5885	-76.1622
CB6.2	37.4868	-76.1563
CB6.3	37.4115	-76.1597
CB6.4	37.2365	-76.2080
CB7.3	37.1168	-76.1252
CB7.4	36.9957	-76.0205
CB8.1	36.9954	-76.1677

Table S3: Full KKZ rankings for MACA and BCSD downscaled ESMs based on changes to May-October atmospheric temperatures and November-June precipitation. Bolded ESM names and ranks correspond to the first five that were selected by KKZ for MACA and/or BCSD.

Model ID	ESM Name	MACA Model Rank	BCSD Model Rank
M1	bcc-csm1-1	16	18
M2	bcc-csm1-1-m	11	12
M3	BNU-ESM**	18	--
M4	**CanESM2**	**4**	**5**
M5	CCSM4	12	9
M6	CNRM-CM5	10	11
M7	CSIRO-Mk3-6-0	6	7
M8	GFDL-ESM2G	14	16
M9	GFDL-ESM2M	19	14
M10	**HadGEM2-CC365**	**3**	8
M11	HadGEM2-ES365	7	6
M12	**inmcm4**	**2**	**2**
M13	**IPSL-CM5A-LR***	20	**1**
M14	IPSL-CM5A-MR	8	10
M15	**IPSL-CM5B-LR**	**1**	15
M16	MIROC5	17	13
M17	MIROC-ESM	13	19
M18	**MIROC-ESM-CHEM***	9	**3**
M19	**MRI-CGCM3**	**5**	**4**
M20	NorESM1-M	15	17

*The IPSL-CM5A-LR and MIROC-ESM-CHEM models downscaled with MACA were also applied to the Phase 6 watershed model to produce an exact match between ESMs when calculating the relative uncertainty contributions of different climate scenario factors.

**The BNU-ESM model was available in the MACA dataset, but not in the BCSD dataset. Although the BNU-ESM model is not presented in Figure 2, it was still used in the KKZ selection process for MACA ESMs, but did not affect the first five selected.

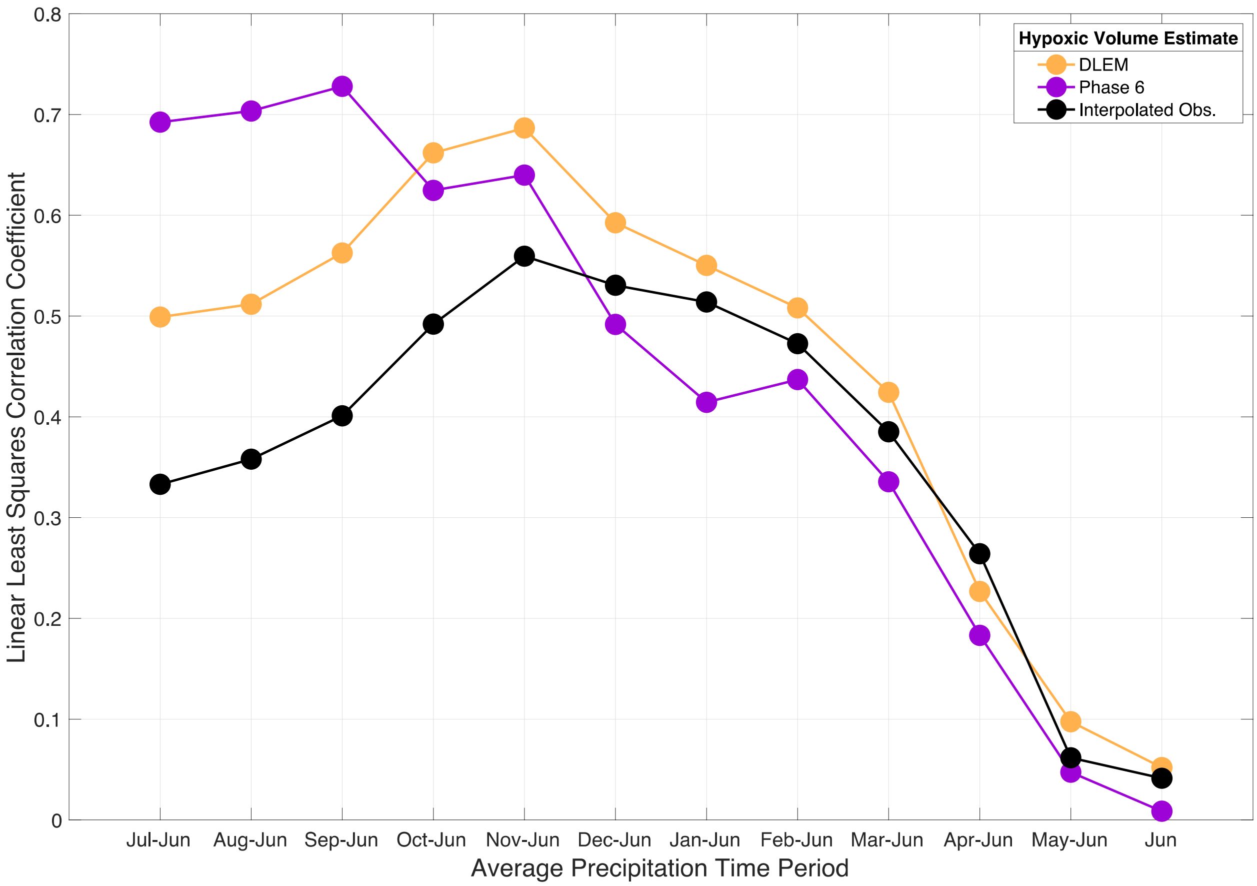

Figure S1: Correlation coefficients of annual hypoxic volume estimates (DLEM, Phase 6 and interpolated observations) as a function of average historical precipitation estimates for 1985-2014. The duration of average precipitation estimates decreases moving left to right, encompassing an entire year in the leftmost set of points and only accounting for June precipitation as a predictor of hypoxic volume in the rightmost set of points. The period November-June was chosen as the time period most predictive of AHV as it represents the highest correlations for both interpolated observations and DLEM hypoxia estimates, and has a comparable correlation for Phase 6 hypoxia.

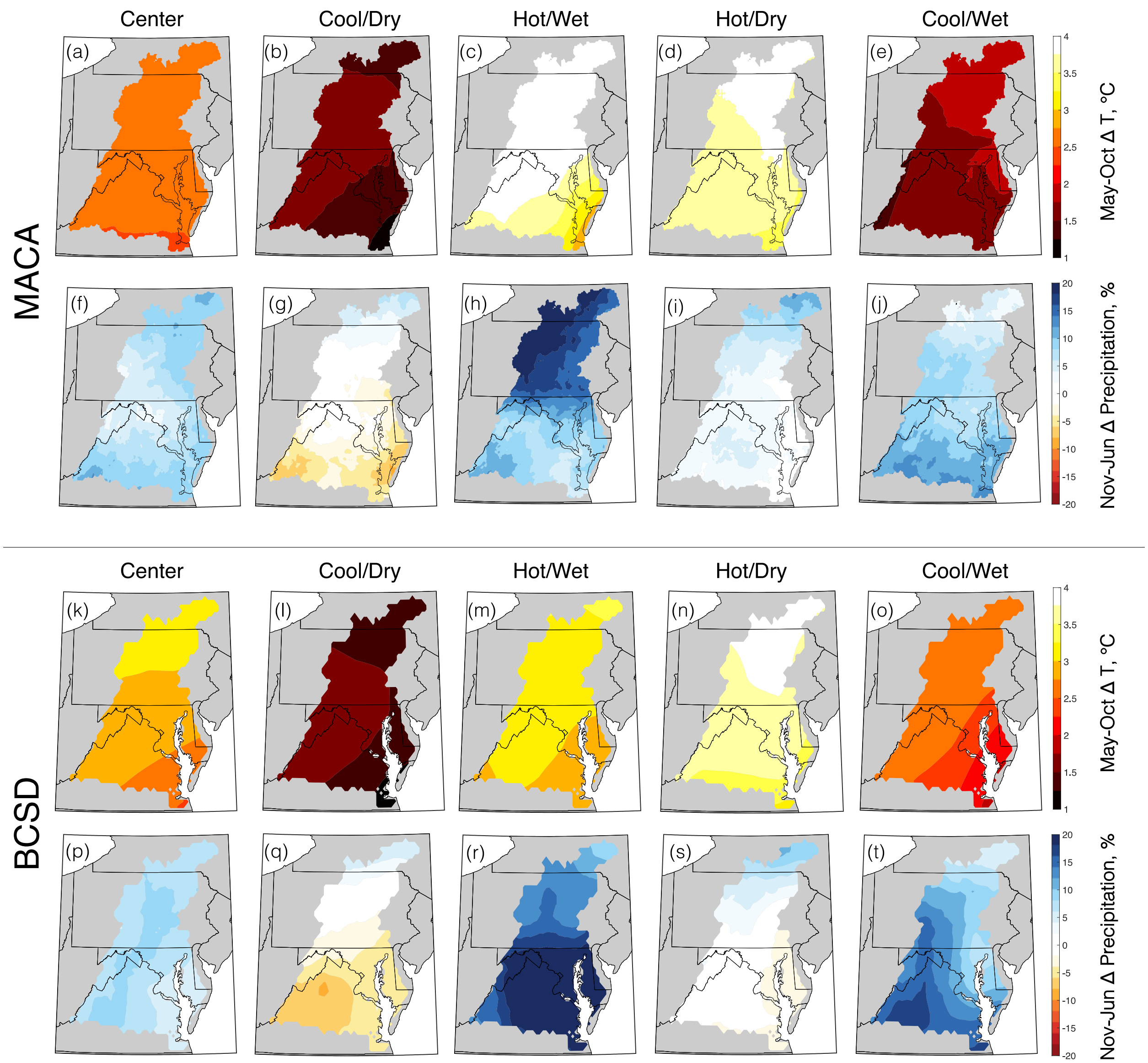

Figure S2: Relative changes in May to October temperatures (a-e, k-o) and November to June precipitation (f-j, p-t) for MACA (a-j) and BCSD (k-t) downscaled Earth System Models. Base map layers from Pawlowicz (2020).

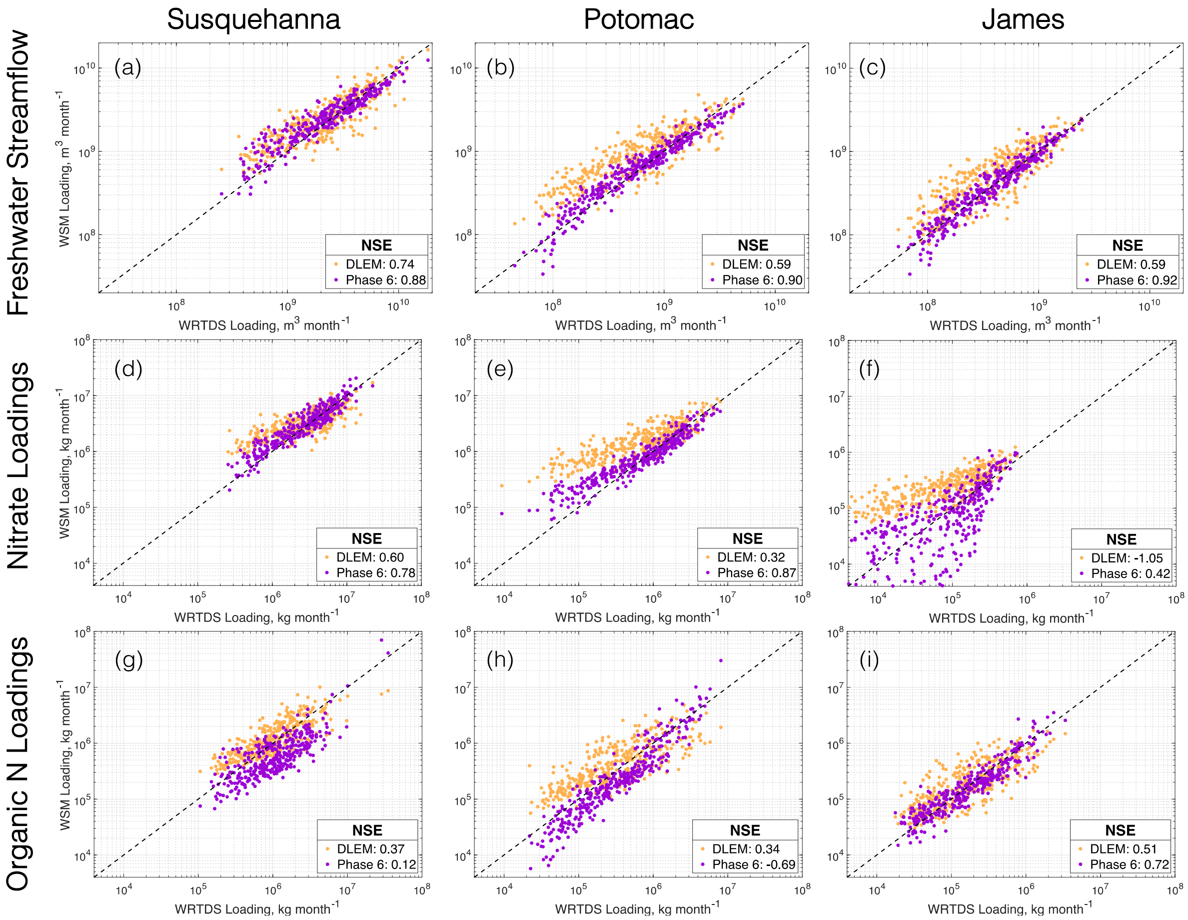

Figure S3: Comparison of monthly watershed model estimates vs. Weighted Regression in Time, Discharge, and Season (WRTDS) derived observations for freshwater streamflow (a-c), nitrate loadings, (d-f) and organic nitrogen loadings (g-i) for the Susquehanna (a,d,g), Potomac (b,e,h), and James (c,f,i) River tributaries at the respective river fall lines over the reference period 1991-2000. Nash–Sutcliffe efficiencies (NSE) reported in the bottom right of each panel for both watershed models.

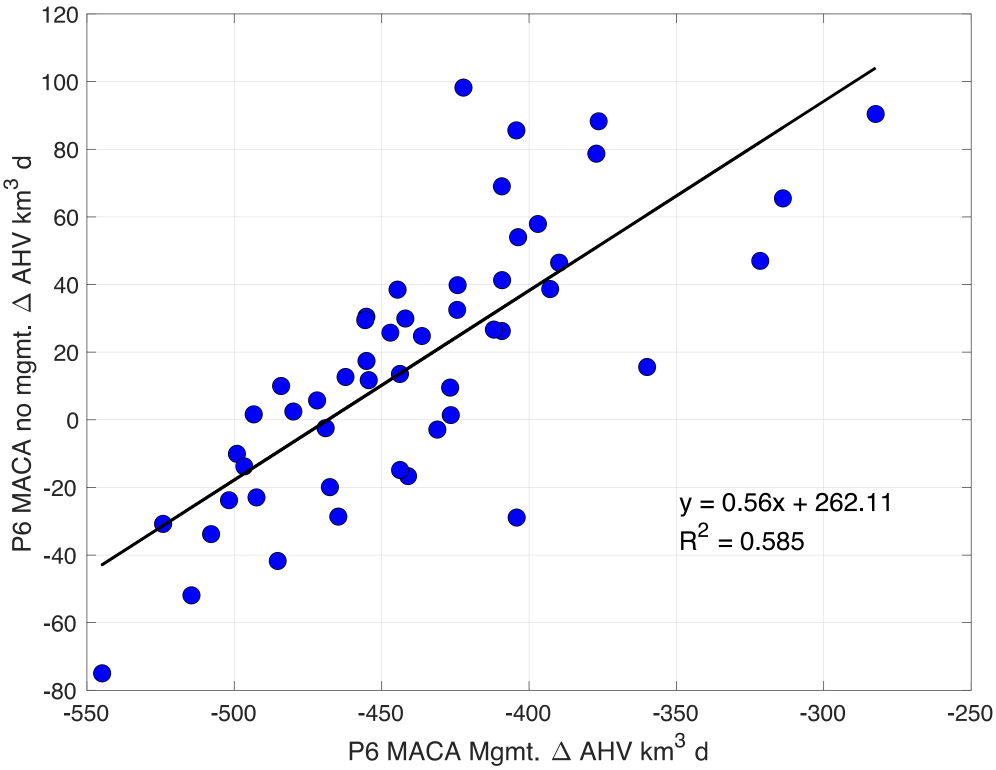

Figure S4: Relationship between MACA Phase 6 climate scenario ΔAHV with and without the effects of management actions.