Disentangling Water Quality Indices to Enhance the Valuation of Divergent Ecosystem Services

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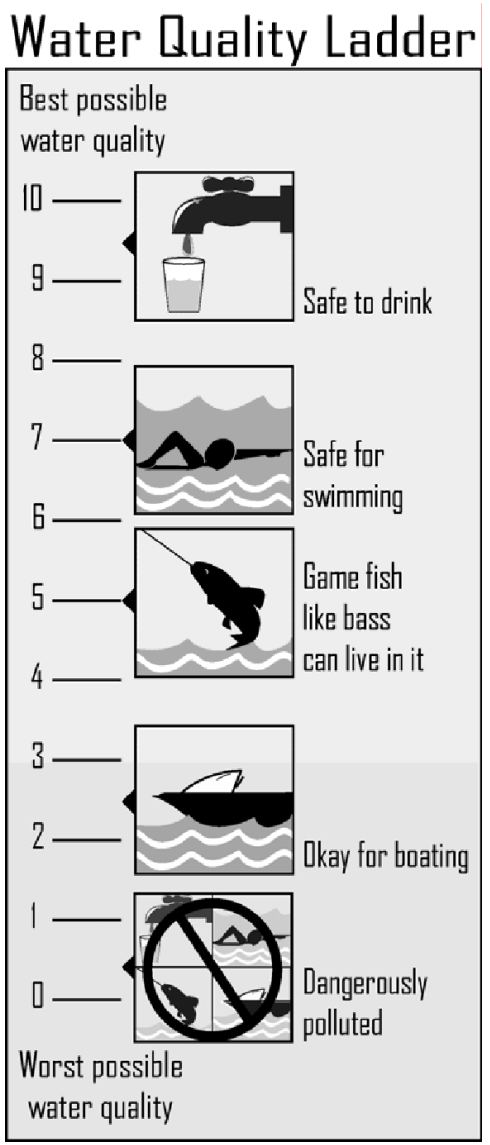
Water Quality Indices (WQI) & ladders

- Ladder from Carson and Mitchell 1993 (& Vaughan 1986)
- Large literature on multidimensional indices for water quality (e.g., Abbasi & Abbasi 2016, detail over 30 unique WQI)
- WQI from McClelland (1974) is common in valuation
  - EPA benefit cost analyses (Griffiths et *al.* 2012)
  - Used in many meta-analyses/B-Ts (e.g. Johnston et al. 2019)
  - Integrated Assessment Models (e.g., Corona et *al*. 2020)



“McClelland’s WQI”

- Cobb-Douglass function of several subindices

$$WQI = \prod_{j=1}^{J} SI_j{}^{W_j}$$

SI_j are subindices

W_j are the weights

McClelland's weights

- Often difficult to get all
- Many studies use a subset of these

Table 2. SIGNIFICANCE RATINGS AND WEIGHTS FOR NINE PARAMETERS INCLUDED IN THE WQI

Parameters	Mean of all significance ratings returned by respondents	Final Weights
Dissolved Oxygen	1.4	0.17
Fecal Coliform Density	1.5	0.16
pH	2.1	0.11
Biochemical Oxygen Demand (5-day)	2.3	0.11
Nitrates	2.4	0.10
Phosphates	2.4	0.10
Temperature	2.4	0.10
Turbidity	2.9	0.08
Total Solids	3.2	0.07
		= 1.00

Rationale and questions

- Environmental changes often have effects on ecosystem services that invoke trade-offs in some underlying services (e.g., see these *PNAS* articles: Daw et *al*. 2015; Goldstein et *al*. 2012; Raudsepp-Hearne et *al*. 2010)
- Griffith et al. (2012) discuss need for deeper research into metrics tied to ecosystem services that are salient for people
- Walsh & Wheeler (2013) simulations show WQI can go awry in some situations

Our questions:

1. Does water quality valuation differ if we disentangle some parts of WQI?
2. Does it matter for benefit estimation?

Study Overview

- Draws from EPA's work on a National WQ Survey (Moore et *al*. 2018)
- Qualtrics convenience sample for WQ changes in Michigan
- Consequential single question binary referendum CV (Carson and Groves 2007; Johnston et *al*. *JAERE* 2017; Bishop et *al*. *Science* 2018)

- Split sample with WQI-like indices at two levels of index aggregation
  - 1,500 responses for each treatment
  - One treatment is a subset of the other treatment (i.e., nested indices)

Internet survey (N=3,000)

- Split sample with different water quality indices

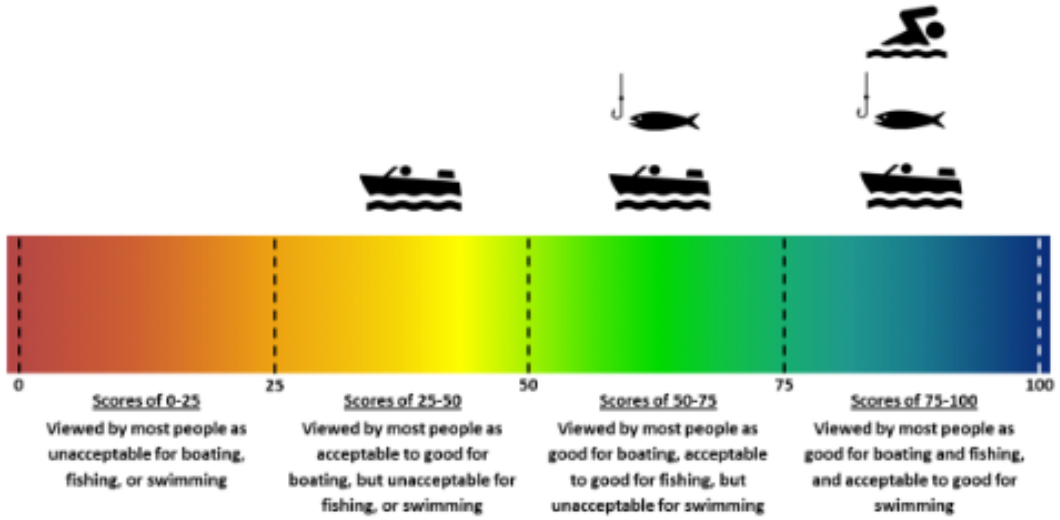
2 indices		3 indices
Wildlife score	⟷	Wildlife score
Recreation score	⟵	Water contact score (bacteria & clarity)
	↖	Rec. fishing score

$$WQI = Fn(Contact, Fishing) = Contact^{2/3}\, Fishing^{1/3}$$

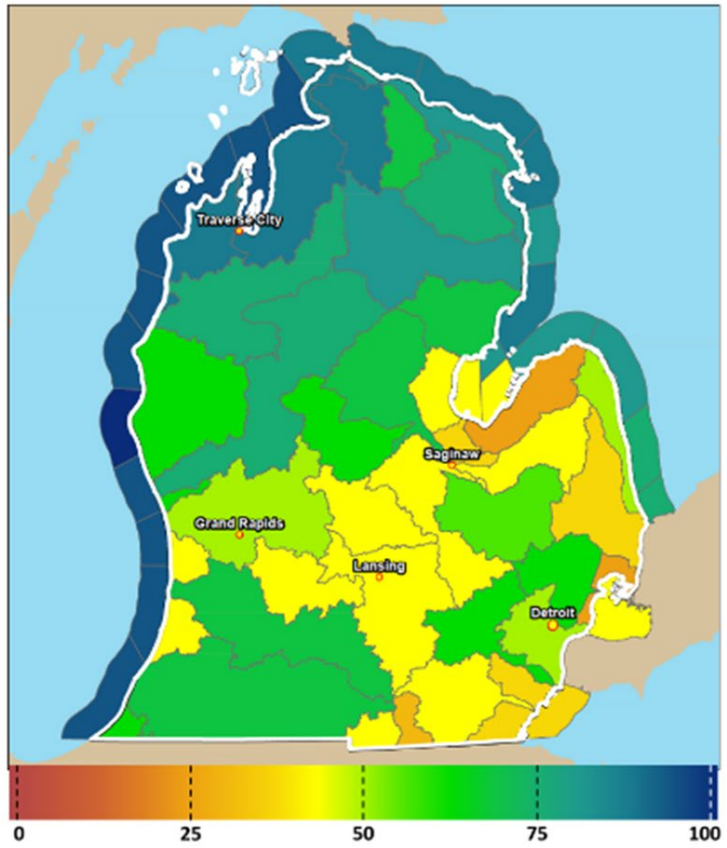
(*cf.* McClelland 1974)

Our implementation of WQI

Levels of the Recreation Water Quality Score:



The map below shows the average Recreation Water Quality Scores for lakes, rivers, and streams in the Lower Peninsula of Michigan. The mapped areas represent average water quality scores for all lakes, streams and rivers within each watershed. What is a watershed?



1. According to the map, what is the average Recreation Water Quality Score near your home?

Basic results

- Samples are well-balanced with no signif. differences in demographics
- Responses to votes (% yes by cost) not signif. different
- In models, cost & wildlife parameters are not significantly different

Some WTP results

- Marginal and non-marginal changes in water quality
- These are present values per household in Michigan

Preview of findings

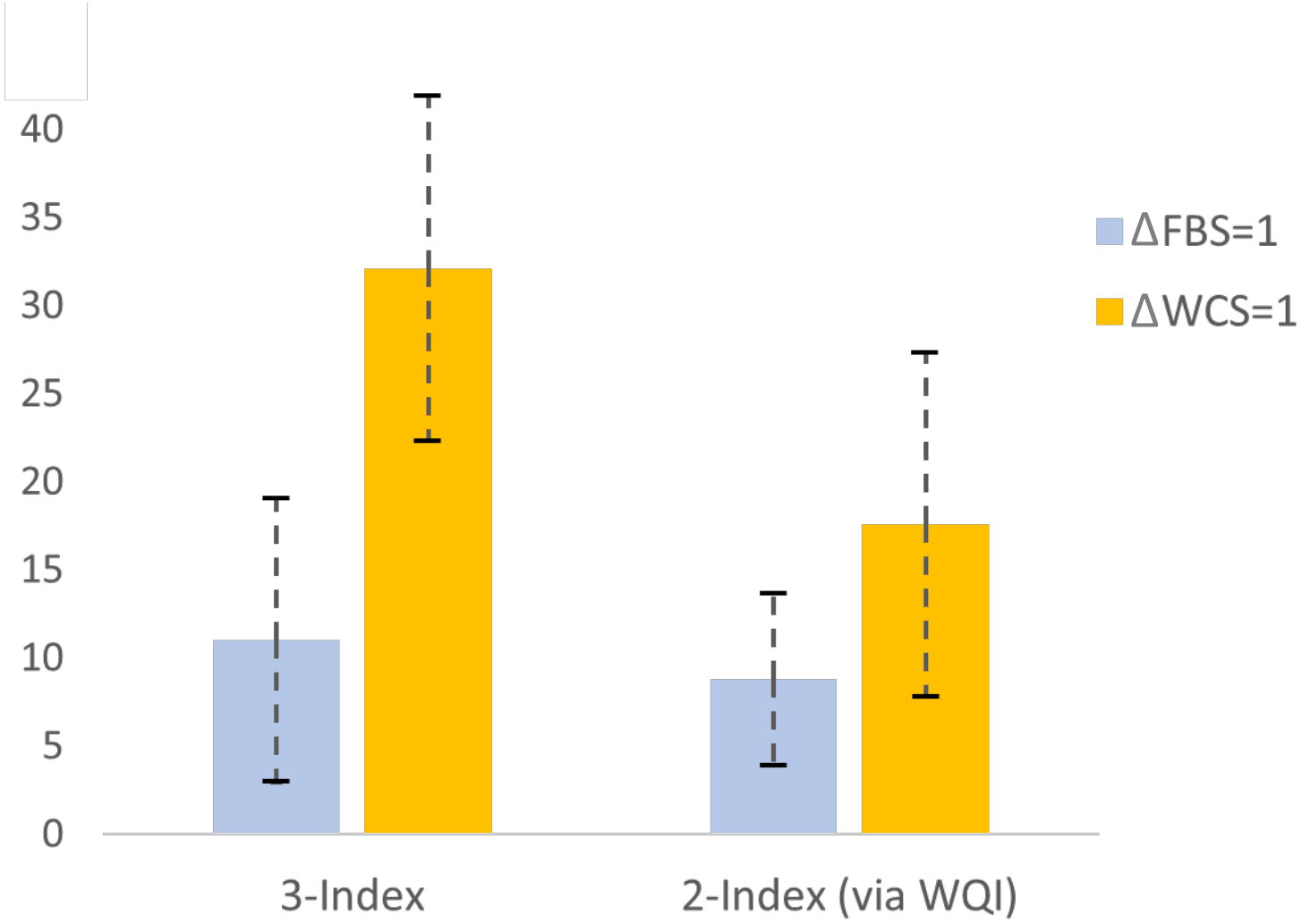
- We find significant and large differences depending on relative change in fish versus clarity/bacteria
- The disaggregate values are at least 50% larger and can get an order of magnitude larger

Marginal values for fish (FBS) & clarity/bacteria (WCS) for 3-index model and via 2-index, i.e., $\partial WQI/\partial FBS$ & $\partial WQI/\partial WCS$

Marginal value of FBS is *not* signif. different

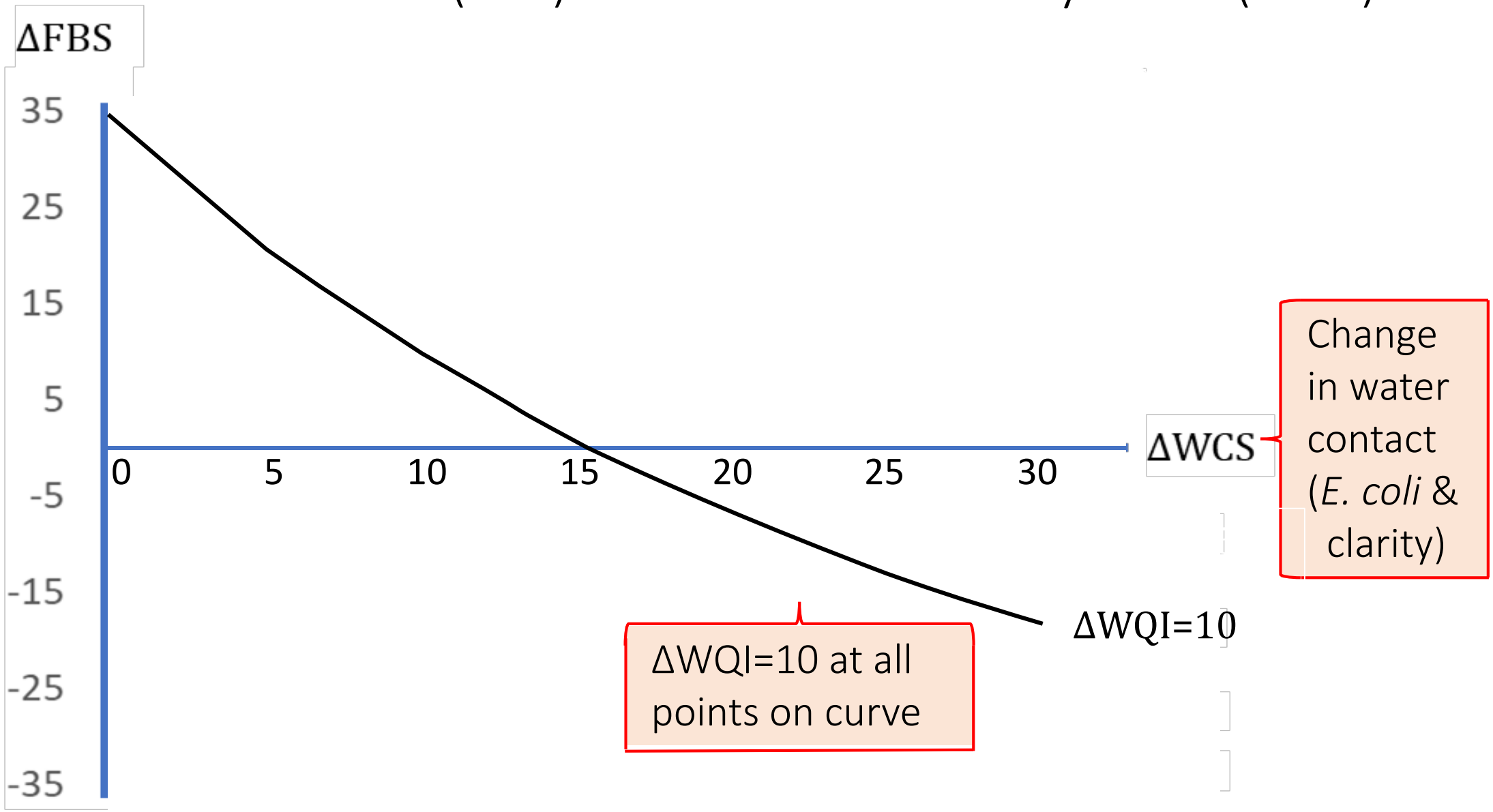
Marginal value of WCS *is* signif. Different

Marginal value for WCS 83% higher when valued directly



Implied water quality index (WQI) for combinations of fish biomass (FBS) and bacteria & clarity index (WCS)

Change in fish biomass



Change in water contact (*E. coli* & clarity)

ΔWQI=10 at all points on curve

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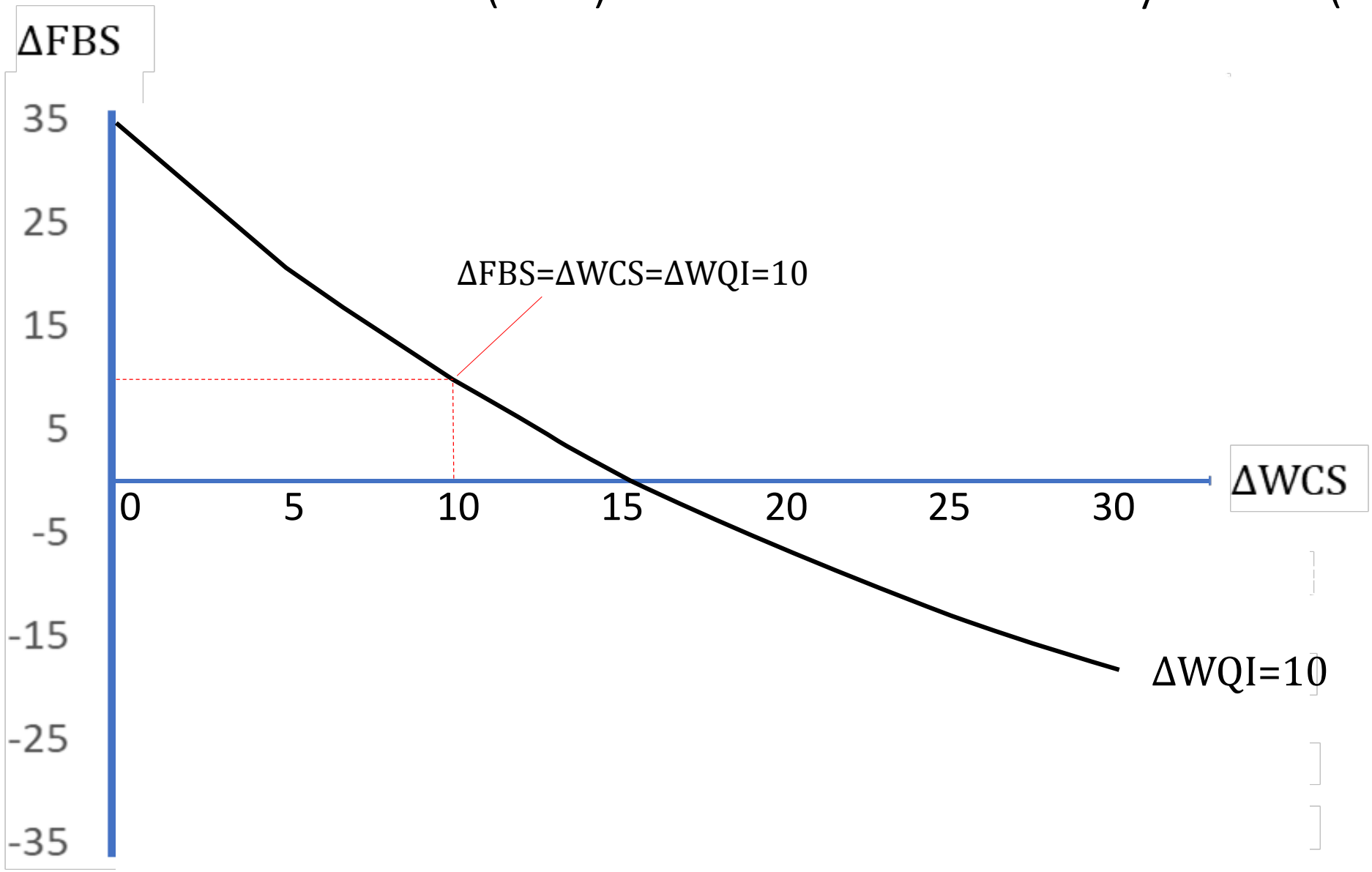

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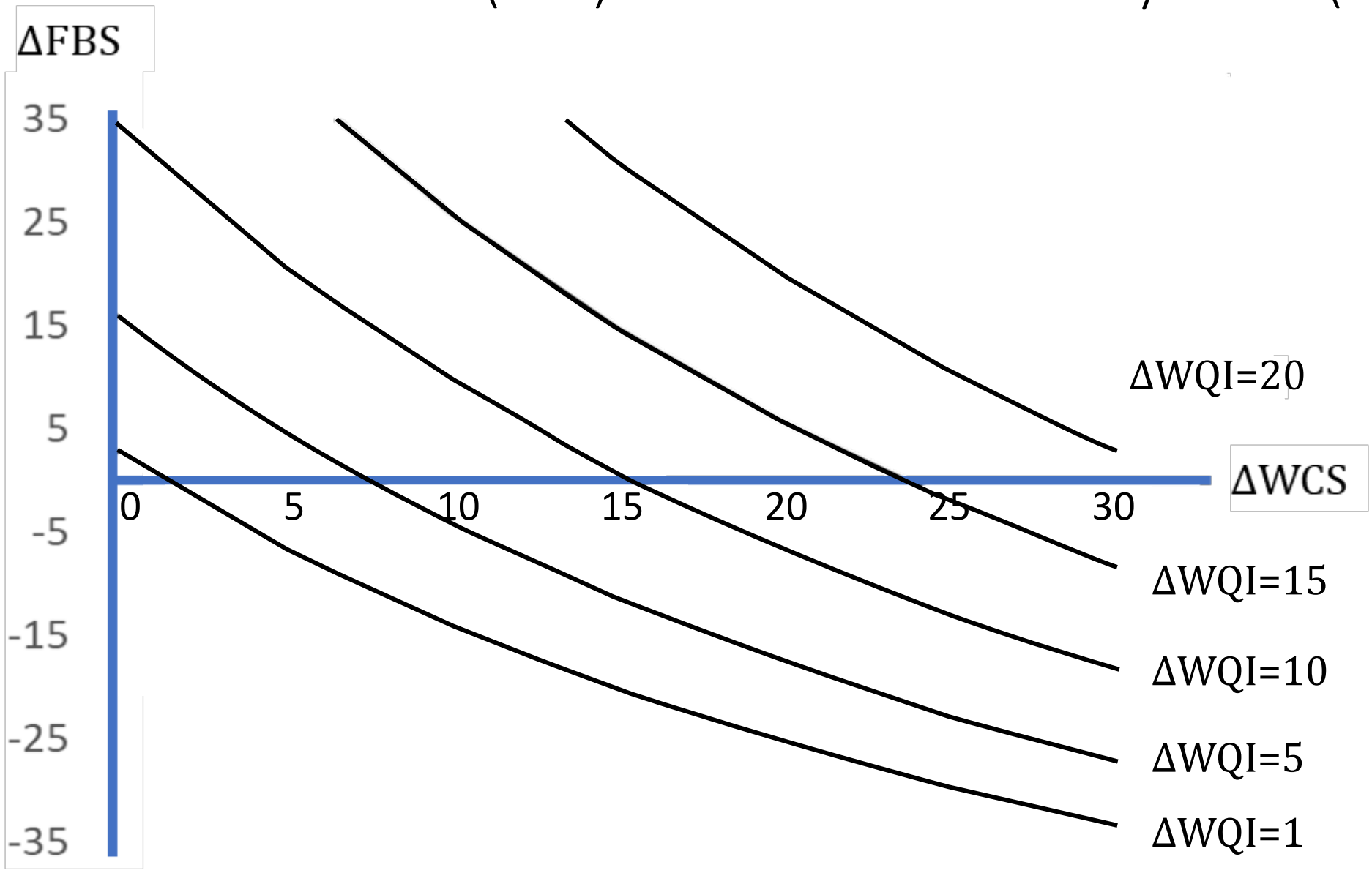
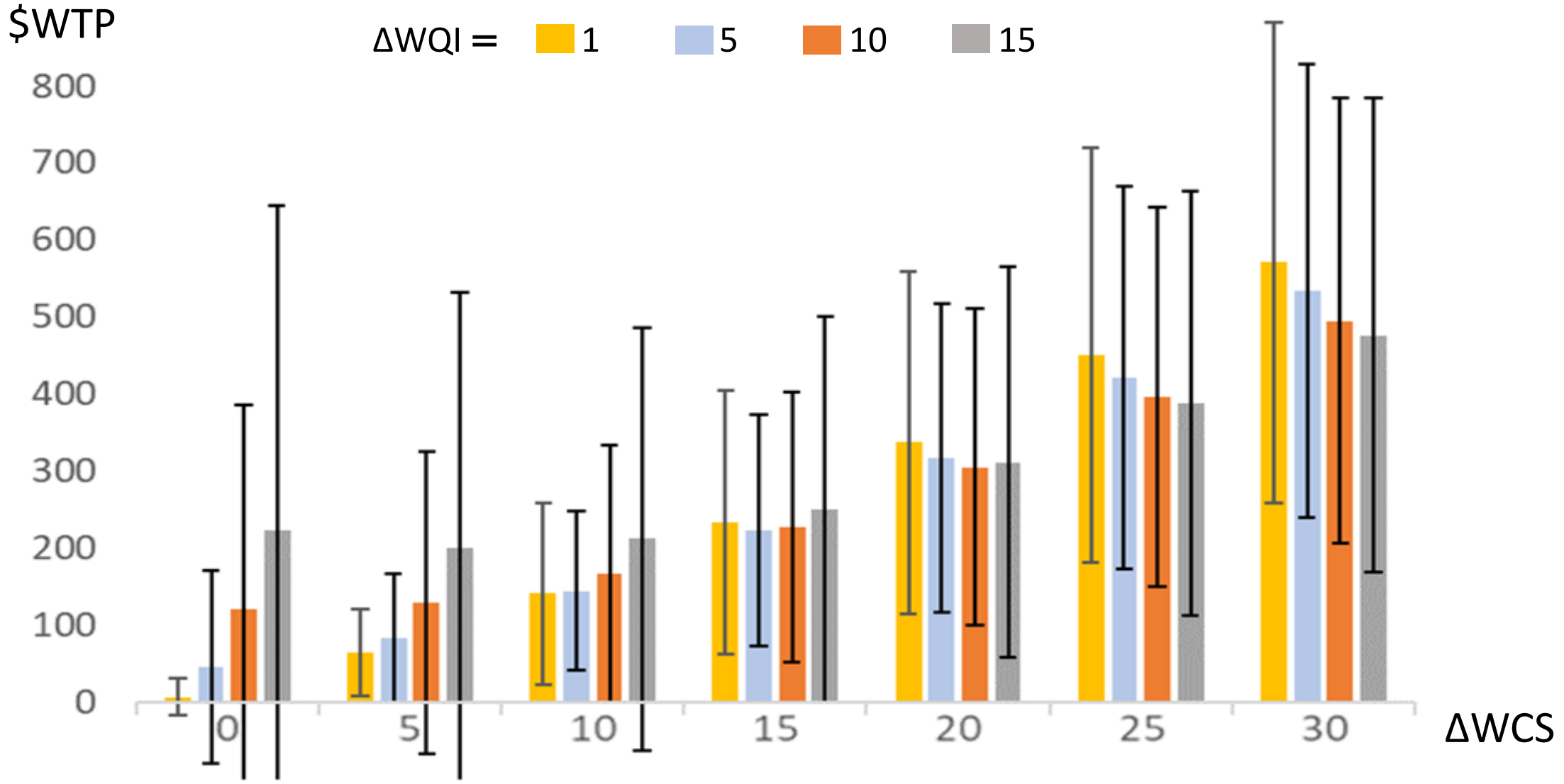


WTP‡ for non-marginal values for disaggregate value minus WQI value



‡ ΔWTP is (WTP directly in 3-index for combinations of FBS & WCS that yield each ΔWQI) minus (WTP in 2 index each ΔWQI)

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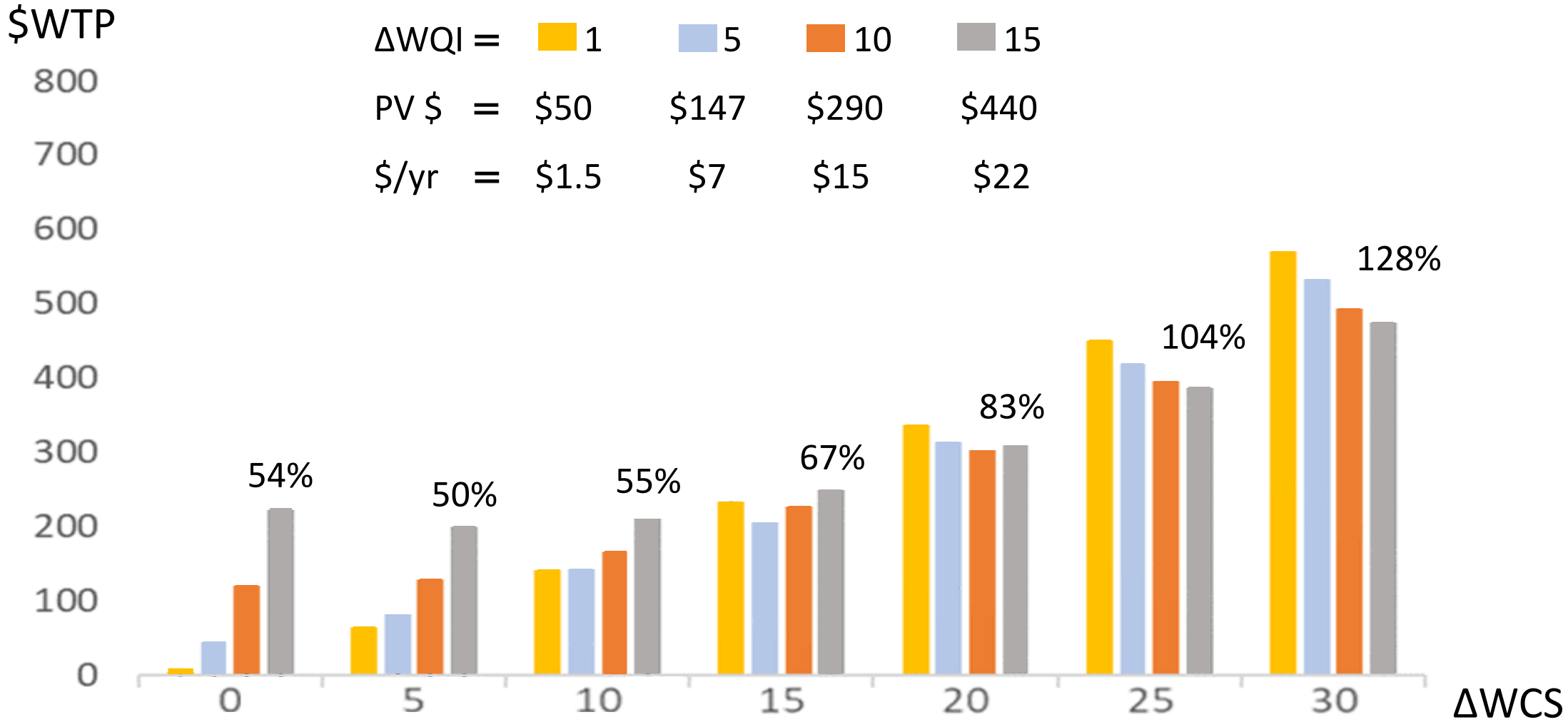

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Implications & caveats

- Applies to the diverse set of waterbodies in Michigan where some key gamefish thrive in waters with higher nutrient loads
- Purely empirical case study would be different elsewhere depending on species and relative preferences
- Not a probability sample; just intended for the A-B testing

Key take-away: In our case, disaggregate WQ matters “a lot’ and may help explain part of “missing” or low benefits in BCAs

Supplemental slide

Results robust to inclusion of demographics and log vs linear form