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Reply to comment received from Robert E. Mace, published in the Texas Water Journal (2021) 12(1):202-205, regarding "Exploring Groundwater Recoverability in Texas: Maximum Economically Recoverable Storage," published in the Texas Water Journal (2020) 11(1):152-171, by Justin C. Thompson, Charles W. Kreitler, and Michael H. Young

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Editor-in-Chief's Note: The Texas Water Journal accepted a request by authors, Justin C. Thompson, Charles W. Kreitler, and Michael H. Young, to reply to the commentary by Robert E. Mace on their article published in the Texas Water Journal (2021) 12(1):202-205, regarding "Exploring Groundwater Recoverability in Texas: Maximum Economically Recoverable Storage," published in the Texas Water Journal (2020) 11(1):152-171, by Justin C. Thompson, Charles W. Kreitler, and Michael H. Young. The opinions expressed in this commentary are the opinions of the individual authors and not the opinion of the Texas Water Journal or the Texas Water Resources Institute.

Keywords: groundwater availability, groundwater recoverability, pumping costs, total estimated recoverable storage, TERS, maximum economically recoverable storage, MERS

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Terms used in paper

Acronym/Initialism	Descriptive Name
MERS	maximum economically recoverable storage
TERS	total estimated recoverable storage
TWDB	Texas Water Development Board

We appreciate Dr. Robert E. Mace for taking the time to read our paper and for his commentary. We understand Mace (2021) to be composed of two principal elements: (1) the term "groundwater availability" and (2) the implementation of total estimated recoverable storage (TERS) by the Texas Water Development Board (TWDB).

GROUNDWATER AVAILABILITY

Mace (2021) asserts "the definition of groundwater availability the authors used in the paper is incorrect." While he notes that the term "groundwater availability" is not defined by statute and recognizes that the alleged mischaracterization "does not impact the results of the study," he finds sufficient cause to provide clarity and specificity.

We generally acknowledge and accept Mace's (2021) analysis of the term "groundwater availability." We concur that common usage and application in Texas water planning and management have ascribed to this term a specific meaning, rooted in policy, which equates to the modeled available groundwater (Texas Water Code, Chapter 36 §001(25)) volume developed by TWDB pursuant to the desired future conditions adopted by groundwater conservation districts (Texas Water Code, Chapter 36 §1084). This definition of the term "groundwater availability" was explicitly acknowledged at the 9-minute mark of the webinar associated with the Thompson et al. (2020) paper and presented for the Texas Water Journal on February 11, 2021 (Thompson et al. 2021).

At no point in our 2020 paper did we intend to attempt to redefine the term "groundwater availability" as an established term. On the contrary, we were clear that our study sought to expand and enhance the information available to groundwater managers and stakeholders related to groundwater recoverability, as it is one of many important considerations to the groundwater availability assessments embodied by the desired future condition adoption process (Texas Water Code, Chapter 36 § 108(d)). This distinction is made thematically throughout our 2020 paper, in large part with the use of terms such as "recoverability," "feasibility," and "maximum economically recoverable storage" (MERS), and particularly by the following passages:

- "While recoverability data is crucial to groundwater planning and management, particularly with respect to availability assessments, Texas' best estimates of recoverable groundwater volumes reflect only the volume in storage and take no account of well design or economic constraints" (Thompson et al. 2020, p. 153).
- "While not designed to be economically efficient, MERS is intended to establish clear and rational limits to groundwater recoverability for the purpose of evaluating groundwater availability under variable uses and infrastructure" (Thompson et al. 2020, p. 153).
- "The limitations of this MERS analysis are akin to those applied to TERS; no consideration is given to subsidence, surface water interaction, or water quality. These are all clearly important issues for groundwater managers and must be considered when adopting [desired future conditions] pursuant to Chapter 36 §108(d) of the [Texas Water Code]" (Thompson et al. 2020, p. 160).
- "The methods developed here define MERS as a simplified simulation of the physical and economic limitations to groundwater recoverability; key elements of availability common to all human groundwater demand absent from total storage and TERS" (Thompson et al. 2020, p. 167).
- "We suggest that groundwater policymakers, managers, and producers consider including MERS (or a similar metric) along with TERS and the other considerations of Chapter 36 §108(d) of the [Texas Water Code], especially in jurisdictions operating under a depth-to-water based [desired future condition]" (Thompson et al. 2020, p. 168).

We are aware that TERS, or a similarly limited metric such as the MERS term we developed, "informs decisions on groundwater availability but does not define them" (Mace 2021). Even so, we understand how certain passages of our paper could precipitate Mace's commentary.

For instance, in the section of our paper entitled "2017 State Water Plan: Water for Texas," we discuss definitions of "availability" and "supply" given by the state water plan (TWDB 2016). Mace (2021) asserts that we misinterpret these definitions. As noted above, we acknowledge and accept Mace's analysis of the term "groundwater availability," including the relevant passages he notes from the 2017 state water plan that discuss this term. However, we maintain that there appears to be some disconnect between the general definition of "availability" provided by the plan and the definition of "groundwater availability" as described by Mace (2021). Indeed, one key purpose in providing the discussion of the state water plan in our paper was to draw attention to this apparent information gap and the need for analyses like MERS to address it. To explain further, let us revisit the relevant passage of the plan quoted by our 2020 paper:

> "Water availability refers to the maximum volume of raw water that could be withdrawn annually from each source (such as a reservoir or aquifer) during a repeat of the drought of record. Availability does not account for whether the supply is connected to or legally authorized for use by a specific water user group. Water availability is analyzed from the perspective of the source and answers the question: How much water from this source could be delivered to water users as either an existing water supply or, in the future, as part of a water management strategy?" (TWDB 2016, p. 61 in Thompson et al. 2020, p. 154).

First, we ask, how does one understand the phrase: "the maximum volume of raw water that could be withdrawn" (TWDB 2016, p. 61)? Mace (2021) asserts that, for groundwater, this is equivalent to the modeled available groundwater volume developed by TWDB, pursuant to relevant desired future conditions policies, which is what has been practiced in Texas groundwater planning. However, we suggest that a layperson might understand the term "availability" broadly to have a "plain English" (Mace 2021) meaning of (a) the physical limitations on "the ability of an aquifer to transmit water to wells" (TWDB 2016, p. 65) and perhaps also (b) the relevant economic constraints thereto. Such an interpretation of the term "availability" might then be synonymous with the terms "feasibility" or "recoverability" and is clearly separate and distinct from the term "groundwater availability" as discussed by Mace (2021). In our 2020 paper and in subsequent studies, we develop methods and tools to quantify this particular lens on the term "availability," which is not currently addressed by any metric other than TERS.

Secondly, we ask, how does one understand the statement that "availability does not account for whether the supply is connected to or legally authorized for use by a specific water user group" (TWDB 2016, p. 61)? We appreciate Mace's (2021) assertion that the "legally authorized" element of this sentence is intended to describe whether or not a permit has been issued for extraction. However, we suggest that the term "groundwater availability" as discussed by Mace is, by definition, a volume that is constrained by the legal permissibility of extraction, given that it is limited by desired future condition policy (i.e., law) and is therefore separate and distinct from an "available" volume that takes no account of legal permissibility (such as TERS and MERS).

Thirdly, we ask, what does it mean that "availability" answers the question of "how much water from this source could be delivered to water users as either an existing water supply or, in the future, as part of a water management strategy?" (TWDB 2016, p. 61) Here we suggest that the limitations and assumptions of modeled available groundwater, being "the volume of groundwater production, on an average annual basis, that will achieve the desired future condition" (TWDB 2016, p. 66), are important. Consider, for example, a location that implements an enhanced recharge or aquifer storage and recovery project "as part of a water management strategy" (TWDB 2016, p. 61). In such a case, tools like MERS, which can quantify groundwater recoverability at any depth-to-water for any economic purpose, would provide critical, timely groundwater "availability" information for water managers, whereas modeled available groundwater (unless updated to reflect such changes) could not. Further, consider a location that experiences drought-of-record conditions wherein a decision is made to increase groundwater extraction on a temporary basis. As above, unlike MERS, the business-as-usual assumptions of modeled available groundwater would be insufficient to provide timely information on groundwater "availability" to water managers. This last potentiality and the limitations of modeled available groundwater are at least tacitly acknowledged in the 2022 state water plan (TWDB 2021), as it incorporates "a modeled available groundwater peak factor" (TWDB 2021, p. A-72) which "accommodates short-term pumping above the modeled available groundwater value" (TWDB 2021, p. A-72) and recognizes the existence of "potential groundwater that could be available for pumping" (TWDB 2021, p. A-73).

Similarly, in the section of our 2020 paper entitled "Total Estimated Recoverable Storage," we state: "The total storage component of TERS is the state's closest approximation of groundwater availability, or 'the maximum volume of raw water that could be withdrawn' (TWDB 2016, p. 61), as it incorporates depth-to-water and spatially variable aquifer characteristics" (Thompson et al. 2020, p. 156). Here the contiguous use of the words "groundwater" and "availability" is regrettable, as it is understandably conflated with the "groundwater availability" term described by Mace (2021). The phrase "potentially available groundwater" or similar may have been optimal. That said, we also find it unfortunate that Mace (2021) did not provide the full quotation; the latter part of that passage, the verbiage quoted from the state water plan that "the maximum volume of raw water that could be withdrawn" (TWDB 2016, p. 61 in Thompson et al. 2020, emphasis added), was very deliberately provided to help illuminate our intended meaning.

Ultimately, we hope that (a) the overarching themes and the full content of our 2020 paper, together with (b) Mace (2021) and (c) this response will allay any uncertainty or concern regarding the term "groundwater availability."

TOTAL ESTIMATED RECOVERABLE STORAGE

We appreciate Mace's (2021) unique insights into the evolution of TERS and how TWDB implemented it, particularly given that as we noted in our 2020 paper, very little information is available in the public record on this issue, nor is background information on why TWDB elected to represent TERS as 25% and 75% of "total aquifer storage" (Texas Water Code, Chapter 36 §001(24)). We respect that TWDB was given the latitude to define TERS as well as the difficulties and limitations associated with an unfunded mandate to do so.

However, we respectfully disagree with Mace's (2021) assertion that TERS (or perhaps a similar metric such as MERS) is "irrelevant" to any particular groundwater management jurisdiction. Even if a groundwater conservation district elects, as is their prerogative, to give precedence to another desired future condition consideration, such as spring flows or land surface subsidence, we suggest that TERS (or a similar metric such as MERS) provides important information on one key aspect of groundwater management. Moreover, by virtue of its inclusion in Chapter 36 §108(d) of the Texas Water Code, the Legislature has definitively determined that such information is fundamentally relevant to groundwater management in Texas.

On the other hand, we completely agree with Mace's (2021) assessment of the difficulties and complexities associated with quantifying groundwater recoverability. As we demonstrated in our 2020 paper, groundwater recoverability, as constrained by either physical or economic constraints, varies significantly with "use, aquifer characteristics, and well infrastructure" (Thompson et al. 2020, p. 167). Thus, there is no universal, one-size-fits-all solution for groundwater yields constrained by recoverability. While this reality poses challenges for the statutory requirements placed upon TWDB, we propose that the MERS model developed in our 2020 paper (or a similar analysis) could provide useful, timely information for Texas groundwater managers as it "may be applied to any aquifer and any use to estimate groundwater recoverability" (Thompson et al. 2020, p. 168) at any potential depth-to-water, thus ensuring a scientifically informed, sustainable, and prosperous future for Texas water resources.

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