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Guadalupe River Nature Trail at Canyon Lake Dam.

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Projected Reservoir Rating Curves and Their Utility for Water Planning in Texas

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Abstract: This paper presents a method for projecting future reservoir elevation-area-capacity rating curves by calculating the distribution of sediment volume by lake elevation in reservoirs in Texas. We develop reservoir rating curves for the next 50 years, assuming a constant sedimentation volumetric rate as calculated at each elevational gradient for the predicting period. Projected rating curves can be used to simulate the impact of sedimentation on future reservoir firm yield and inform estimates of future available surface water for water planning purposes in Texas.

Keywords: Texas, reservoirs, reservoir sedimentation, elevational sedimentation rate, projected rating curves, water supply planning, Texas water

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Terms used in paper

Acronym/Initialism	Descriptive Name
ft, or '	foot
ac	acre
ac-ft	acre-foot
yr	year
SV_i	Sedimentation volumetric rate (acre-feet per year) at elevation interval *i*
$\Delta V1_i$	Volume of survey *1* at elevation interval *i*
$\Delta V2_i$	Volume of survey *2* at elevation interval *i*
T	Duration between surveys *1* and *2* (in decimal year format)
ΔE_i	Length of elevation interval from *i-1* to *i*
V_i	Projected reservoir volume at elevation interval *i*
V_{i-1}	Projected reservoir volume at elevation interval *i–1*;
A_i	Projected area at elevation interval *i* is the previous area *(A2i)* minus the area change (Δ*Ai)*
A_{2i}	Previous area at elevation interval *i*
ΔA_i	Area change at elevation interval *i*
ΔV_i	Reservoir volume change at elevation interval *i*
TCEQ	Texas Commission on Environmental Quality
TWDB	Texas Water Development Board
WAM	Water Availability Model

INTRODUCTION

Reservoir sedimentation is a natural and unavoidable process that reduces reservoir storage capacity. It is also a significant problem affecting water availability in Texas (Texas Board of Water Engineers, 1961). Investigations of reservoir sedimentation have been conducted based on reservoir volumetric surveys. Texas's first suspended sediment station was established by the International Boundary and Water Commission on the Rio Grande at El Paso in 1889 (Texas Board of Water Engineers, 1959). According to Eakin and Brown (1936), Texas's earliest reservoir sedimentation studies were conducted for White Rock Lake and Lake Worth in 1910 and 1915, respectively. In 1991, the 72nd Texas State Legislature authorized the Texas Water Development Board (TWDB) to develop a nonprofit, self-supporting reservoir volumetric survey program, the Hydrographic Survey Program. Since 1992, TWDB's Hydrographic Survey Program has completed 197 hydrographic surveys on 114 unique reservoirs.

To date, most of Texas's major water supply reservoirs have been surveyed multiple times, which allows for reasonable estimates of sedimentation rates.[1] For example, hydrographic surveys of White River Lake conducted in 1971 by Freese and Nichols, Inc. (TWDB, 1974) and in 1992 by TWDB (2003e) indicate that the lake loses approximately 1.3% of its capacity per year (approximately 600 acre-feet per year), which is one of the highest sedimentation rates among Texas reservoirs. Per Texas's 2022 state water plan (TWDB, 2022), the estimated 3% decline in surface water availability between 2020 and 2070 is primarily due to reservoir sedimentation.

Sedimentation reduces a reservoir's storage capacity and therefore will eventually reduce its firm yield. Firm yield is the maximum annualized quantity of water that could be diverted without shortage from a reservoir every year—including drought of record years—based on the historical hydrological record. Texas Administrative Code (Title 31) Rule § 357.10 requires regional water planners to use firm yield "under a repeat of the Drought of Record using anticipated sedimentation rates" when estimating future water availability (Definitions and Acronyms, 2024). We examine how anticipated sedimentation rates can be used to develop projected reservoir elevation-area-capacity curves. The goal of this study is to demonstrate a methodology for predicting future reservoir capacity and elevation-area-capacity rating curves to support Texas water planning. The specific objectives of this study are to (a) examine sediment distribution in reservoirs, (b) derive the distributed sediment volume along the vertical profile of the reservoir, and (c) use this elevational sedimentation information to predict future rating curves.

[1] Major reservoirs are defined as those reservoirs having original conservation volume 5,000 acre-feet or greater.

DISTRIBUTION OF SEDIMENT IN A RESERVOIR

Sediment distribution in reservoirs can vary depending on the sediment load from contributing rivers, streams, and the local geomorphology. Sediment in a reservoir mainly comes from erosion in the reservoir catchment, and shoreline erosion due to wave action may also contribute. The mineral composition and particle size of the sediment are related to the nature of soils and geology in the catchment. Coarse materials are usually deposited at the river mouth where it enters the reservoir, while fine particles settle farther into the body of a reservoir, usually in the lower elevations of the reservoir. If multiple rivers/streams flow into a reservoir, non-main stem streams will have a significant effect on sediment distribution within a reservoir (Abraham et al., 1999).

TWDB models the distribution of post-impoundment reservoir sediment by analyzing acoustic signal returns from a multi-frequency depth sounder and sediment core samples as a part of TWDB's Hydrographic Survey Program's volumetric and sedimentation surveys (https://www.twdb.texas.gov/surfacewater/surveys/index.asp). Due to the varied climate, soil, and geology, sediment distribution in Texas reservoirs varies significantly. For example, hydrographic surveys of Lake Buchanan and Granger Lake show that more sediment was measured in the upstream area (upper reach) of Lake Buchanan (Figure 1), while more sediment was measured in the downstream portion (lower reach) of Granger Lake (Figure 2). When a reservoir is built at the confluence of two or more major streams, sediment distribution may differ in different arms of the reservoir. In Waco Lake, more sediment occurs in the southern arm, implying that there are higher sediment flows in that reach of Waco Lake (Figure 3).[2] Farmland activities in the Middle Bosque River and Hog Creek watersheds and municipal activities from the Waco area in the southeastern side may contribute to higher sedimentation in the southern arm. In addition to land use and land cover, the respective size of each tributary's contributing watershed, its hydrology, and the presence of upstream reservoirs that can trap sediment are also factors that can lead to the variability of sediment transported by different tributary streams.

To understand vertical sediment distribution, we compared the sediment volume for each one-foot interval for all vertical elevations of a reservoir listed in Figures 1-3 and 4. Results indicate that sediment can be deposited anywhere in the lake depending on the source location, reservoir topology, and shape of reservoir body. Conditions tend to vary across

[2] For more details on the methods used to develop the sediment thickness maps shown in Figures 1–3, please see Texas Water Development Board (2006), Texas Water Development Board (2003b), and Texas Water Development Board (2012).

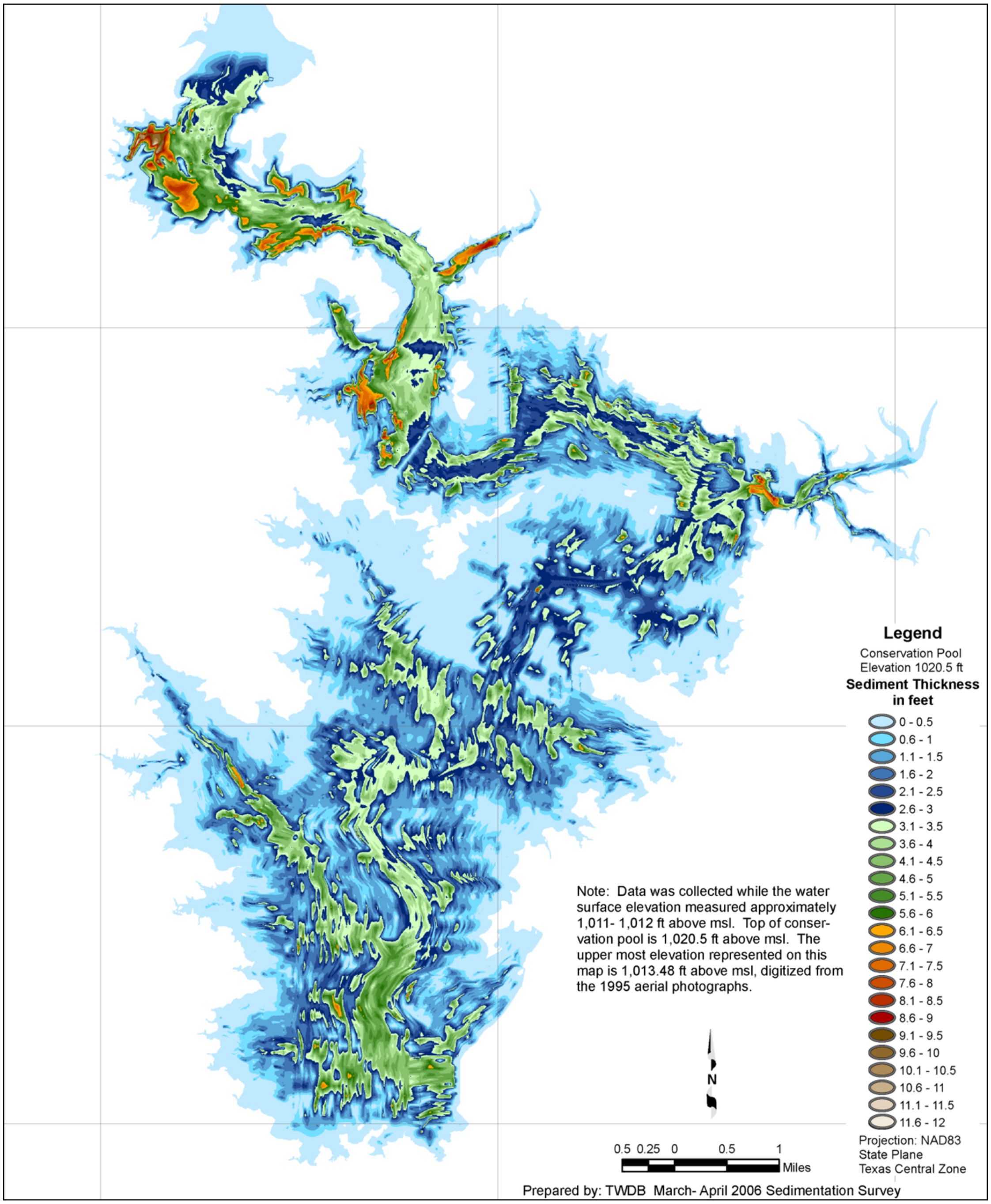

Figure 1. Sediment thickness map for Lake Buchanan (Texas Water Development Board [TWDB], 2007) shows more sediment (red and brown shading) accumulation in the upper reaches of the lake.

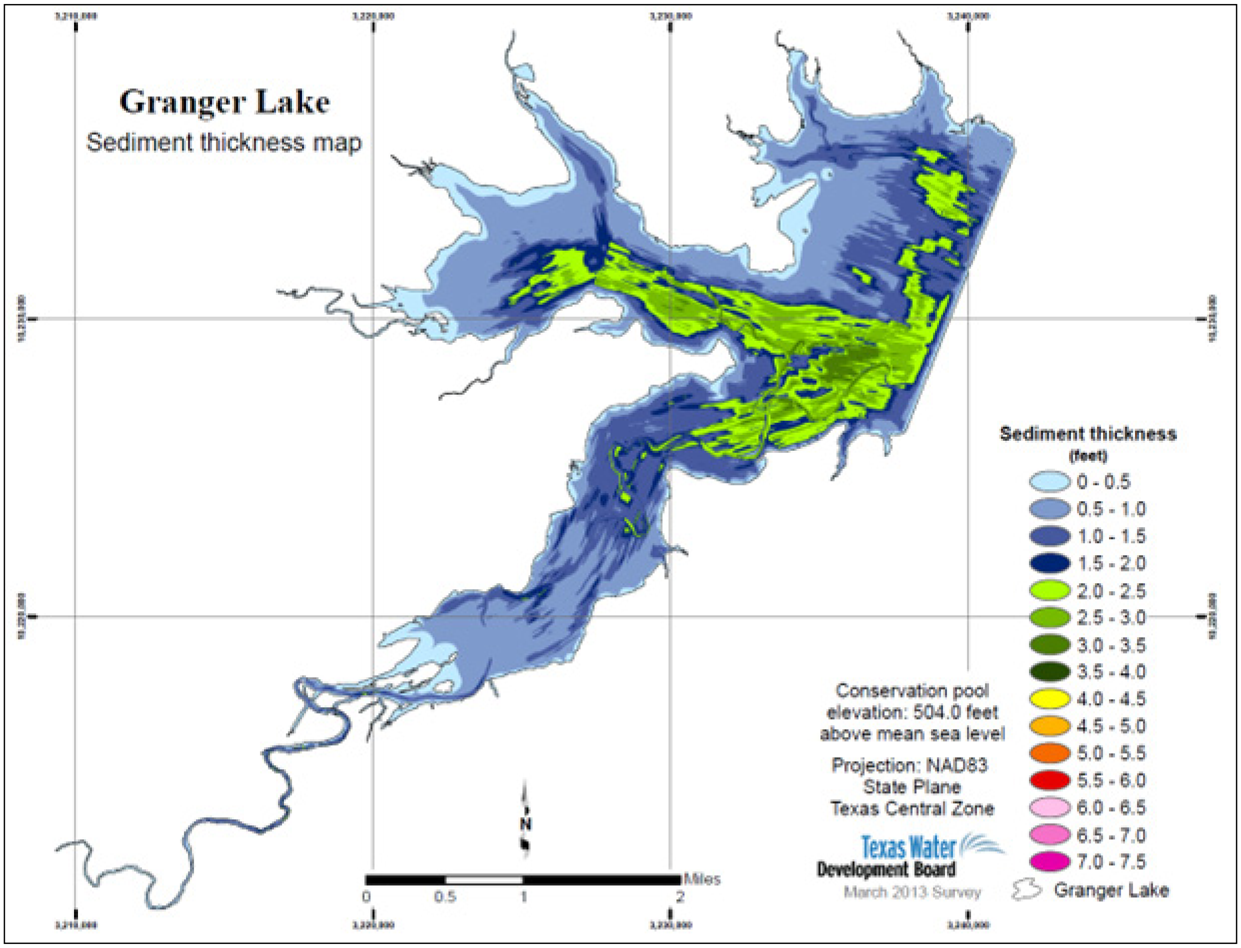

Figure 2. Sediment thickness map for Granger Lake (Texas Water Development Board [TWDB], 2014) shows more sediment (green shading) accumulation in the lower portion of the lake.

reservoirs for which the TWDB has completed hydrographic surveys (https://www.twdb.texas.gov/surfacewater/surveys/completed/list/index.asp), with no consistent pattern of sediment deposition. Figure 4 illustrates some typical patterns of sedimentation along the vertical gradient. Sediment volumes are higher at higher elevations in Lake Kemp (Figure 4a); most sediment is deposited at lower elevations in Proctor Lake (Figure 4b); sediment is nearly uniformly distributed at all elevations in Grapevine Lake (Figure 4c); and sediment is deposited randomly throughout the vertical profile in Lake Worth (Figure 4d). These findings suggests that sedimentation rates are not necessarily uniform across all elevations in a reservoir and should therefore be assessed at all elevations, because the variation in sedimentation rates by elevation can affect reservoir yields.

Annual sedimentation rate, as measured per square mile, generally varies from reservoir to reservoir across Texas. We use the TWDB reservoir hydrographic and sedimentation survey results (https://www.twdb.texas.gov/surfacewater/surveys/completed/list/index.asp) for 80 reservoirs (see Appendix A) to depict a reservoir-specific sedimentation rate (Figure 5), depicted in units of acre-feet per year per square mile. The data appear to indicate that reservoirs in East Texas are subject to a higher sedimentation rate than reservoirs in other regions of the state. Lake Athens and Monticello Reservoir, in East Texas, had the highest sedimentation rates. This high rate could be inaccurate because the original reservoir capacities may have been estimated using topographic maps, as suggested in the survey reports (TWDB, 2003b, 2003c). We consider the total catchment area above a given reservoir, without consideration of the effect of upstream reservoir(s) on sediment interception. In some cases, part of the catchment may be non-contributing, but that is not easily determined at this time. We acknowledge that the sedimentation rates depicted in Figure 5 are subject to revision based on our future data collection efforts and further study. Identifying why reservoir sedimentation rates vary across Texas was outside the scope of the current study.

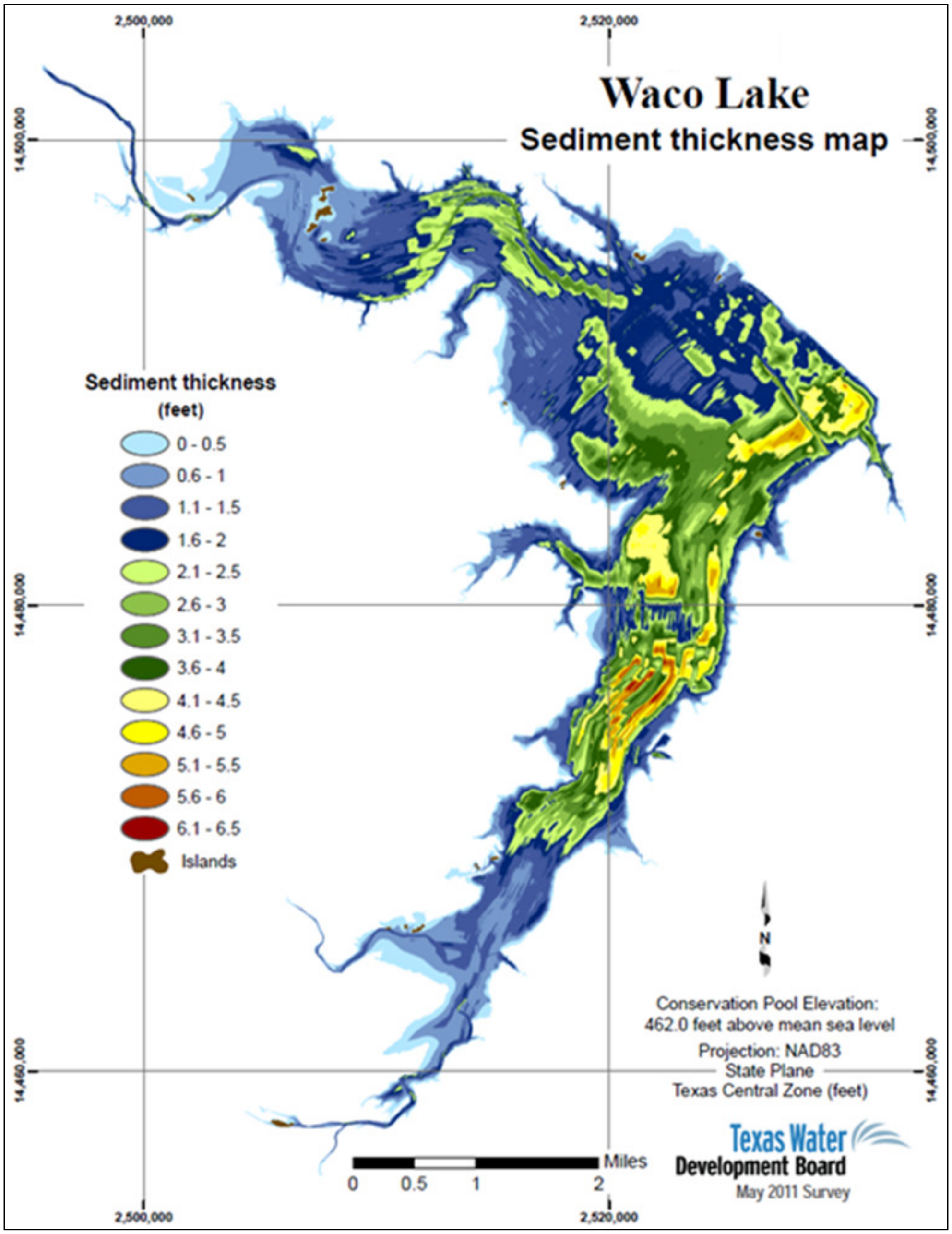

Figure 3. Sediment thickness map for Waco Lake (Texas Water Development Board [TWDB], 2012) shows sediment accumulation (yellow and brown shading) predominantly in the southern arm of the lake, with some accumulation (light green) in the lower portion of the northern arm of the lake.

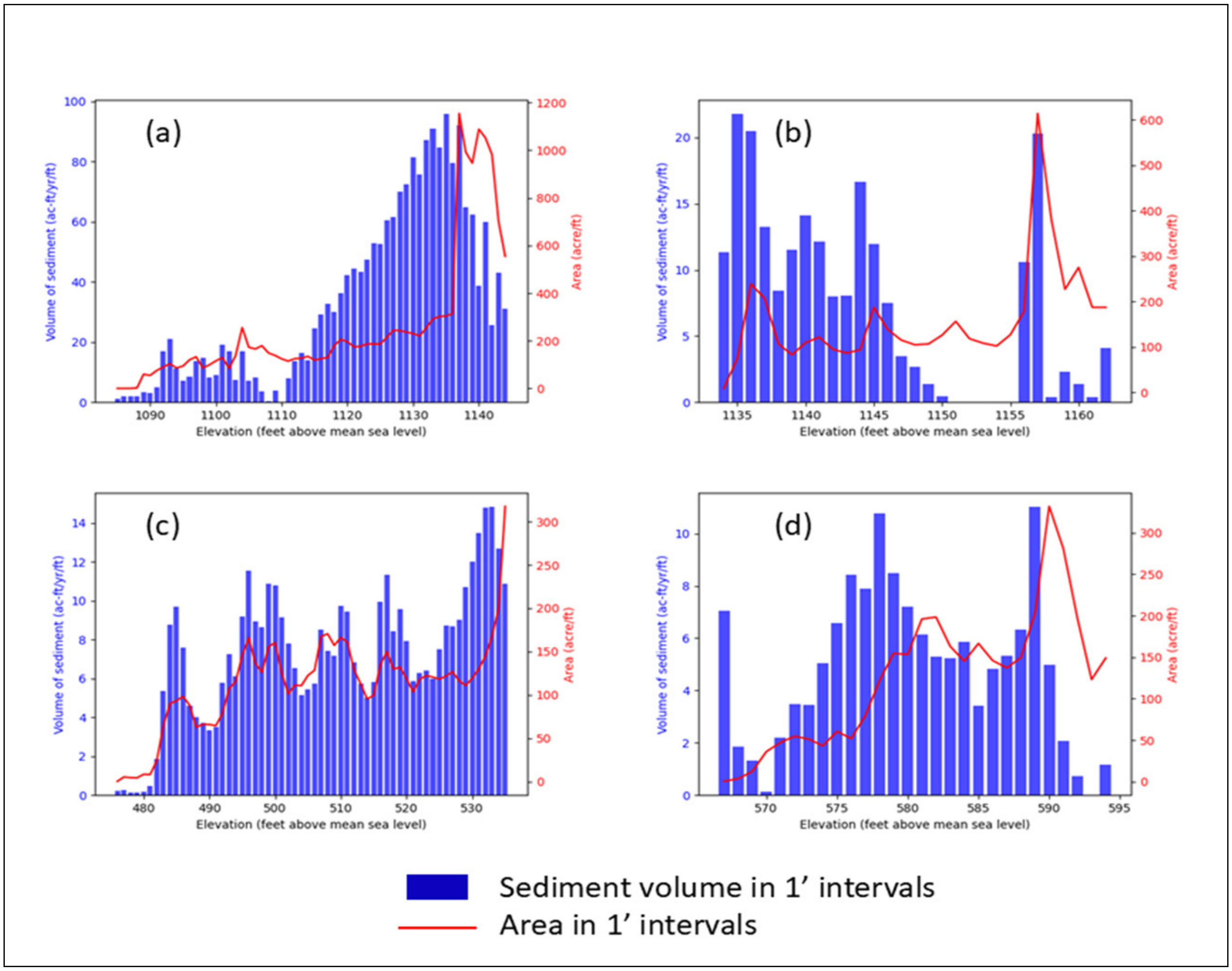

Figure 4. Examples of patterns of sedimentation along the vertical gradient for (a) Lake Kemp, (b) Proctor Lake, (c) Grapevine Lake, and (d) Lake Worth.

METHODOLOGY FOR DETERMINING VOLUMETRIC ELEVATIONAL SEDIMENTATION RATES AND PROJECTING FUTURE RATING CURVES

Although the sedimentation rate for a reservoir usually refers to an average sedimentation rate for the entire reservoir, as discussed above, sediment can settle unevenly in a reservoir. Therefore, reservoir-specific volumetric sedimentation rates vary along the elevational gradient. We refer to this variable volumetric sedimentation rate as the "volumetric elevational sedimentation rate," and the distribution plot of volumetric sedimentation rates along the elevational gradient is referred to as the "volumetric elevational sedimentation rate curve." A hydrographic survey of a reservoir may include both a sedimentation survey and a volumetric survey. We developed the elevational sedimentation curves by selecting two surveys among all available surveys for each lake evaluated.

The volumetric sedimentation rate is specific to each elevational interval in this study. For each elevation interval ΔE_i, the volumetric elevational sedimentation rate (SV_i) is computed by the following formulation:

$$SV_i = (\Delta V_{1i} - \Delta V_{2i}) \; / \; T \qquad (1)$$

where SV_i is the sedimentation volumetric rate (acre-feet per year) at elevation interval ΔE_i from E_{i-1} to E_i ;

ΔV_{1i} is the volume of survey 1 (previous survey) at elevation interval from E_{i-1} to E_i ;

ΔV_{2i} is the volume of survey 2 (current survey) at elevation interval from E_{i-1} to E_i; and

T is the duration between surveys 1 and 2 (in decimal year format).

Taking Lake Granger as an example for computing the volumetric elevational sedimentation rate (Figure 6), we first examined the available survey data and then selected the October

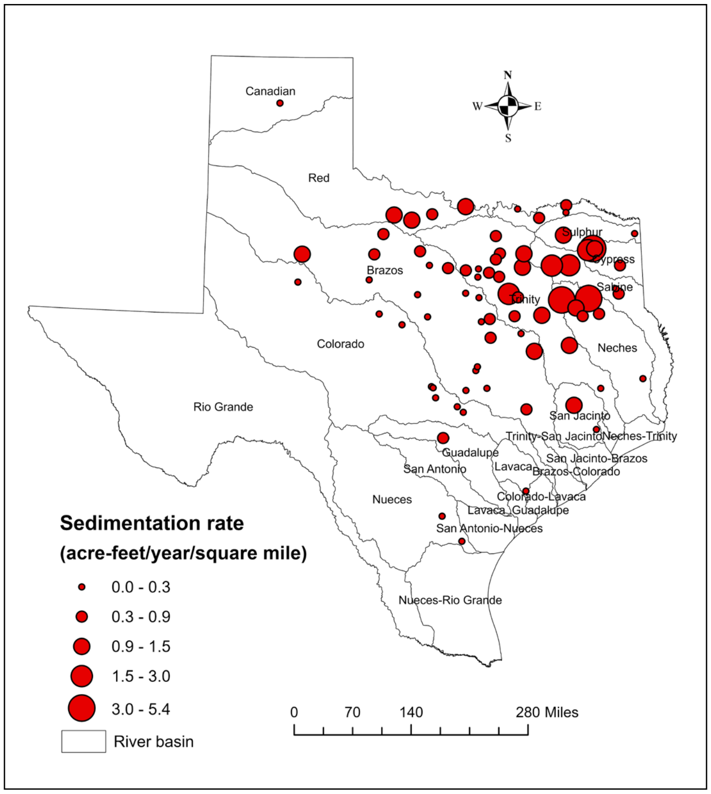

Figure 5. Reservoir sedimentation rates (acre-feet/year/square mile) at 80 surveyed reservoirs shows that several reservoirs in East Texas have high (3.0–5.0 acre-feet/year/square mile) annual sedimentation rates.

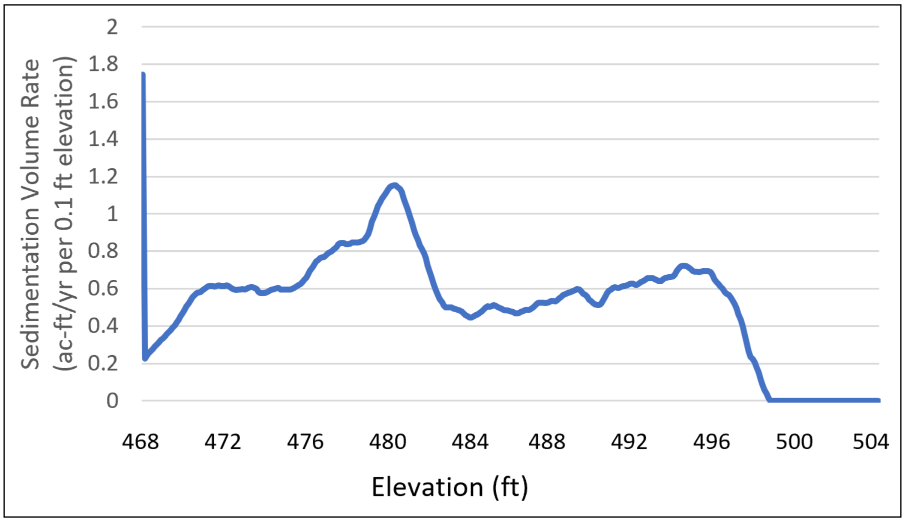

Figure 6. Volumetric elevational sedimentation rate curve for Granger Lake computed using the volumetric elevational sedimentation rate method and the 1995 and 2013 Texas Water Development Board (TWDB) sedimentation surveys. The volumetric sedimentation rate is depicted at 0.1-foot vertical intervals.

1995 survey (TWDB, 2003a) and the March 2013 survey (TWDB, 2014), with a time lapse of approximately 17.5 years, to develop the sedimentation curve. This selection was based on the following considerations: (a) longest duration between surveys, (b) similar survey technology used, and (c) sedimentation rate reflects the long-term trend.

Because each reservoir has a unique bathymetry and sedimentation rate, we developed volumetric elevational sedimentation rate curves for each reservoir.

We then projected future reservoir elevation-area-capacity rating curves based on the distribution of sediment volume by elevation. We assumed that the volumetric elevational sedimentation rates will remain constant during the projection period, which is usually a 10-year period (e.g., 2030–2040). The projection for the first timestep uses information from the latest survey, and the projection for subsequent timesteps (e.g., 2050) uses the projected rating curve (e.g., 2040).

Projected future reservoir volume from the latest survey or projection at elevation E_i is:

$$V_i = V_{i-1} + \Delta V_{2i} - SV_i * T \quad (2)$$

where V_i is the projected volume at elevation E_i (acre-feet);

V_{i-1} is the projected volume at elevation E_{i-1};

ΔV_{2i} is the volume of the latest survey or projection at elevation interval from E_{i-1} to E_i;

SV_i is the volumetric elevational sedimentation rate (acre-feet per year) at elevation interval ΔE_i from E_{i-1} to E_i; and

T is the duration between the latest surveys or projection to the new projecting year.

The projections were developed decade by decade from 2020 to 2080. The first projection decade (2020) was based on the latest survey. All other projections were based on the previous projection (e.g., the rating curve for 2040 is based on the 2030 projected rating curve, the rating curve for 2050 is based on the 2040 projected rating curve, etc.). This method always resulted in the lowest elevations of a reservoir filling in, which increased the lowest elevation of the reservoir with each passing year. Therefore, the lowest section of the volumetric elevational sedimentation rate curve needed to be omitted when we projected the rating curves for subsequent decades. For instance, if the reservoir's lowest elevation went from 100 feet in 2030 to 101 feet in 2040, the lowest elevation of the sediment curve must be raised up to 101 feet when projecting the 2050 rating curve from the 2040 curve. In the 2050 curve, the volumetric elevational sedimentation rate at 101 feet will be the sum of the 2040 curve's volumetric elevational sedimentation rate from 100 feet to 100.9 feet (e.g., 5 acre-feet/year) plus the 2040 curve's volumetric elevational sedimentation rate at 101 feet (e.g., 1 acre-feet/year). Thus, the 2050 curve's volumetric elevational sedimentation rate at 101 feet will be all sediment below and at 101 feet (e.g., 6 acre-feet/yr). This process was repeated for each decade's projection.

We used the reservoir volume change to compute the area change, because the reservoir volume change (ΔV_i) at a certain elevation interval (ΔE_i) from E_{i-1} to E_i is a product of area change (ΔA_i) multiplied by the same elevation interval (ΔE_i):

$$\Delta V_i = \Delta A_i * \Delta E_i \quad \text{or} \quad \Delta A_i = \Delta V_i / \Delta E_i \quad (3)$$

Hence, projected area (A_i) at elevation E_i is the previous area (A_{2i}) minus the area change (ΔA_i) from Equation 3 (see Figure 7):

$$Ai = A_{2i} - \Delta A_i \quad (4)$$

There are four factors that need to be considered when selecting hydrographic and/or sedimentation surveys of a reservoir to compute volumetric elevational sedimentation rates for projecting future rating curves.

1. The time between two consecutive surveys should be long enough to avoid short-term sudden sedimentation changes due to human activities or short-term climate variations (e.g., increased erosion due to flood events). Ideally, the gap between the two surveys should be 10 years or greater.
2. When multiple surveys are available, a simple regression may be derived on capacity against time. Selected surveys should be close to the regression trend line, so that the computed volumetric elevational sedimentation rate represents the general trend of silting of the reservoir. When the regression trend line is a non-linear, selected surveys should be consistent with the latest trend (i.e., trend in recent years), to give a best estimate of projected future reservoir capacity and rating curves.
3. The technology being used in reservoir volumetric and sedimentation surveys has advanced significantly in recent decades. Therefore, it is preferable to select surveys that used similar technology when computing the volumetric elevational sedimentation rate.
4. If there is no clear trend in sedimentation rate, a more conservative projection based on surveys that yield a higher volumetric sedimentation rate over a lower volumetric sedimentation rate is preferred, because it will lead to a smaller reservoir firm yield and provide a more conservative estimate of future available surface water.

Using the above method, volumetric elevational sedimentation rate curves for 80 Texas reservoirs (as of 2024) were developed based on the available survey data. Using these volumetric elevational sedimentation rate curves, we developed projected rating curves for these 80 reservoirs. These ratings curves are developed at 0.1-foot elevation for the full elevation

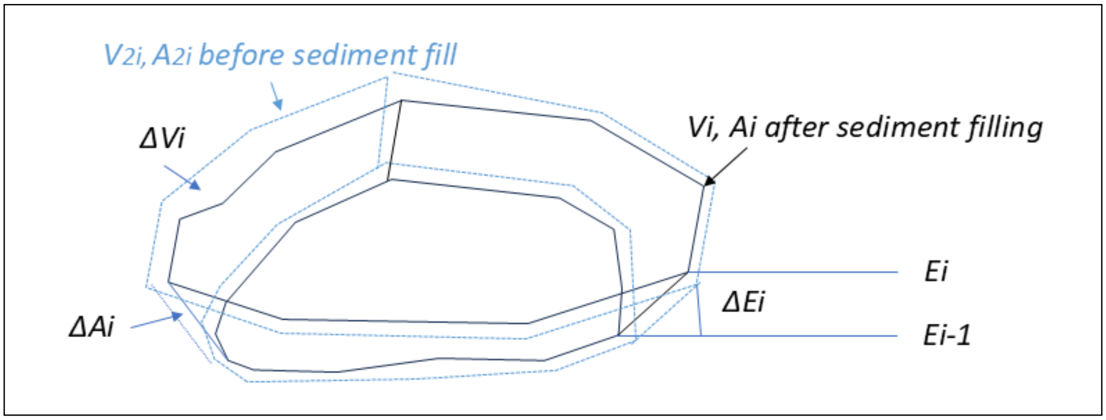

Figure 7. A diagram illustrating sediment filling depicts the change in reservoir volume (Δ*Vi*) and change in area (Δ*Ai*) at elevational intervals from *Ei–1* to *Ei*.

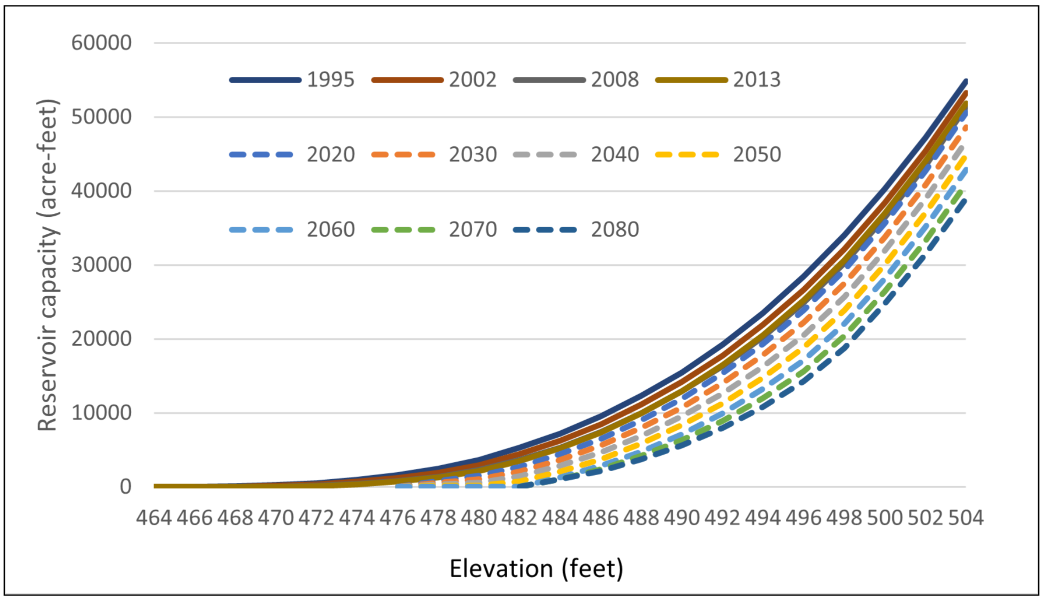

Figure 8. Existing (TWDB, 2003a, 2003d, 2009b, 2014) and projected rating curves (for 2020–2080) for Granger Lake. Using the elevational sedimentation volumetric rate method, Granger Lake is projected to lose 12,805 acre-feet, or 24.7% of total capacity from 2013 to 2080.

range in each reservoir. Figure 8 illustrates the existing rating curves from surveys (solid lines) and the projected full rating curves (dashed lines) for Granger Lake.

Regional water planning groups in Texas are required to consider anticipated reservoir sedimentation rates when they simulate reservoir firm yields using the state's water availability models (WAMs). Rating curves for the WAM can only have 12 elevation and area data pairs. When simplifying the full rating curve for the WAM, the lowest and highest elevation points of the full rating curve are used as-is. The intermediate elevation points are set to equal elevation intervals, the magnitude of which is determined by dividing the elevation difference between the highest and lowest elevation points by 11. We developed simplified projected rating curves (i.e., rating curves for 12 elevation points, suited for input to the WAMs) for 80 major water supply reservoirs for the water planning decades 2030–2080 (https://www.twdb.texas.gov/surfacewater/data/projectedratingcurves/index.asp).

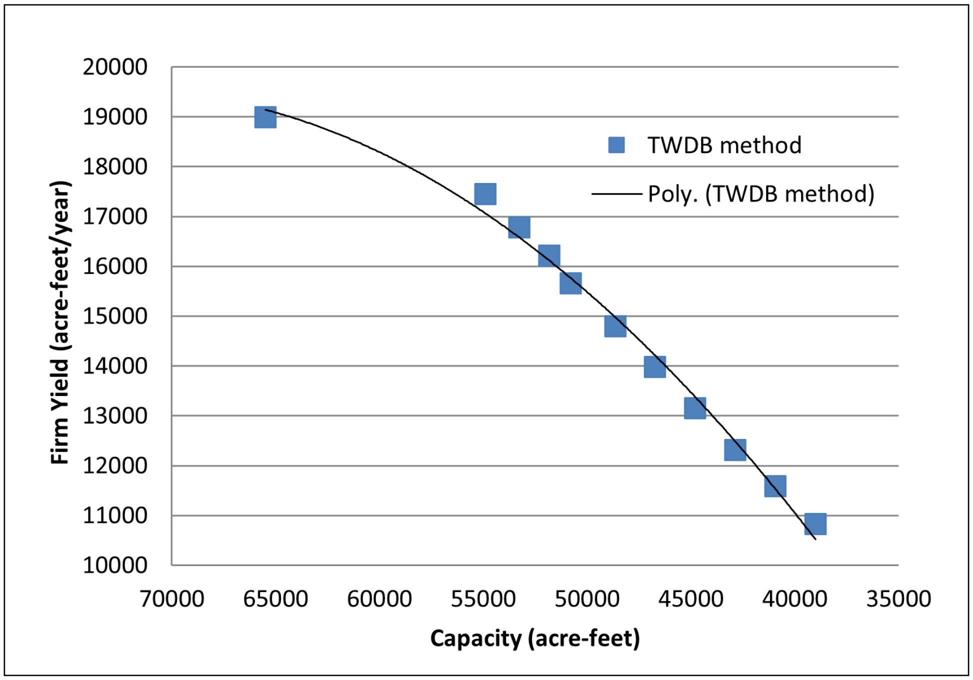

Figure 9. Firm yield versus capacity for Granger Lake. Blue squares represent firm yield, while the black line shows the best regression between firm yield and capacity.

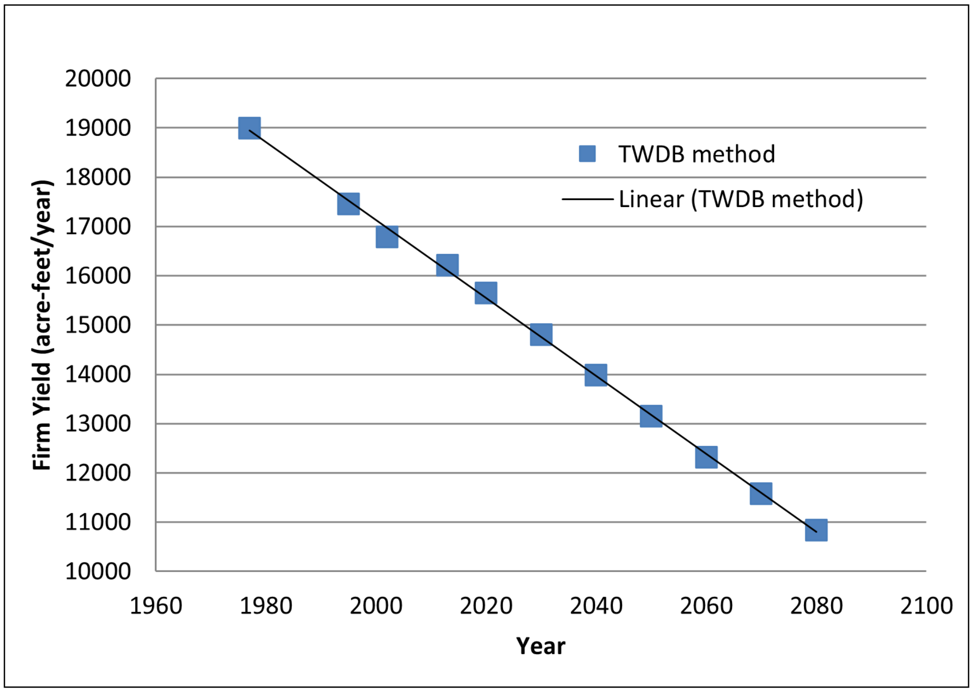

Figure 10. Firm yield versus decades since impoundment for Granger Lake. Blue squares represent firm yield, while the black line shows the best regression for firm yield over time.

Table 1. Firm yields for select reservoirs computed using projected rating curves.

Lake	Firm Yields (acre-feet per year)						
	2020	**2030**	**2040**	**2050**	**2060**	**2070**	**2080**
Joe Pool Lake	13,834	13,393	12,908	12,400	11,887	11,377	10,890
Richland-Chambers Reservoir	239,799	236,774	234,142	231,391	228,520	225,685	222,873
Alan Henry Reservoir	10,484	9,767	9,026	8,308	7,561	6,818	6,074
Possum Kingdom Lake	302,389	298,281	294,162	290,058	285,943	281,801	277,650

ESTIMATION OF RESERVOIR FIRM YIELD BY PROJECTED RATING CURVE

As mentioned before, sedimentation of reservoirs reduces conservation storage capacity and may affect firm yield. We used the projected rating curves to assess the impact of sedimentation on reservoir firm yield for all decades from 2020 through 2080. The Texas Commission on Environmental Quality's (TCEQ) WAM Run 3 was used to compute reservoir firm yield with revised reservoir capacity, area-volume rating, inactive pool capacity, seasonal pool capacity, and/or the storage related diversion algorithm (drought index card) as they are related to the rating curve updates. Using the projected rating curves, we simulated firm yields for future decades using the TCEQ WAM for the respective river basin. Reservoir firm yield at Joe Pool Lake and Richland-Chambers Reservoir were simulated using the TCEQ Trinity WAM Run 3 (version 2023). Reservoir firm yield at Alan Henry Reservoir, Granger Lake, and Possom Kingdom Lake were simulated using the TCEQ Brazos WAM Run 3 (version 2008, without the Brazos River Authority's Systems Operation).

Results for Granger Lake indicate that the reduction in reservoir firm yield associated with a reduction in reservoir capacity follows a non-linear relationship (Figure 9). When the capacity of Granger Lake reduces from 54,892 acre-feet to 39,016 acre-feet (29% loss) from 1995 through 2080, firm yield decreases from 17,455 acre-feet per year to 10,834 acre-feet/year, or approximately 38% (Figures 9 and 10).

The WAM Run 3 simulation accounts for reservoir sedimentation changes, but it does not incorporate future potential changes to naturalized flow or net reservoir evaporation. This allows for the isolation of reservoir firm yield change attributable to sedimentation. Future projected reservoir firm yields at Joe Pool Lake, Richland-Chambers Reservoir, Alan Henry Reservoir, and Possum Kingdom Lake show consistent declines over six decades due to sedimentation. Table 1 shows the change in reservoir firm yield for the decades 2020 through 2080 as a result of reservoir sedimentation, with Alan Henry Reservoir having the steepest decline in firm yield due to sedimentation. Other potential changes that might affect firm yield, such as a new drought of record or a change in evaporation patterns, are not considered.

COMPARISON OF THE VOLUMETRIC ELEVATIONAL SEDIMENTATION RATE METHOD WITH OTHER METHODS

Other methods that account for sedimentation when projecting reservoir capacity and rating curves are the empirical area reduction method and the area-increment method (Borland & Miller, 1958). These methods include, but are not limited to, trapezoidal, conic, or prismoidal formulations (Taube, 2000). Taking the trapezoidal formulation as an example, volume (V_i) from elevations E_{i-1} to E_i is computed by the following formulation:

$$V_i = V_{i-1} + (E_i - E_{i-1}) * (A_i + A_{i-1}) / 2 \qquad (5)$$

where V_{i-1} is the volume at E_{i-1};

E_i, E_{i-1} are elevation i and elevation $i–1$, respectively; and

A_i, A_{i-1} are areas at E_i, and E_{i-1}, respectively.

The total volume for a reservoir is the sum of all incremental volumes. In order to project the future capacity, an operator would reduce reservoir area by a constant for all elevations until the total capacity reaches the projected total capacity, which is the previous total capacity at the top of conservation pool minus the total sediment volume for the projection period computed by general/overall sedimentation rate. By the trapezoidal method, the capacity reduction at Granger Lake will be 192.7 acre-feet per year. The total capacity at 504 feet, the top of conservation pool elevation, is the same as that calculated using the elevational sedimentation volumetric rate method discussed above. However, the volumes estimated by the trapezoidal method are consistently higher than the volumes estimated by the volumetric elevational sedimentation rate meth-

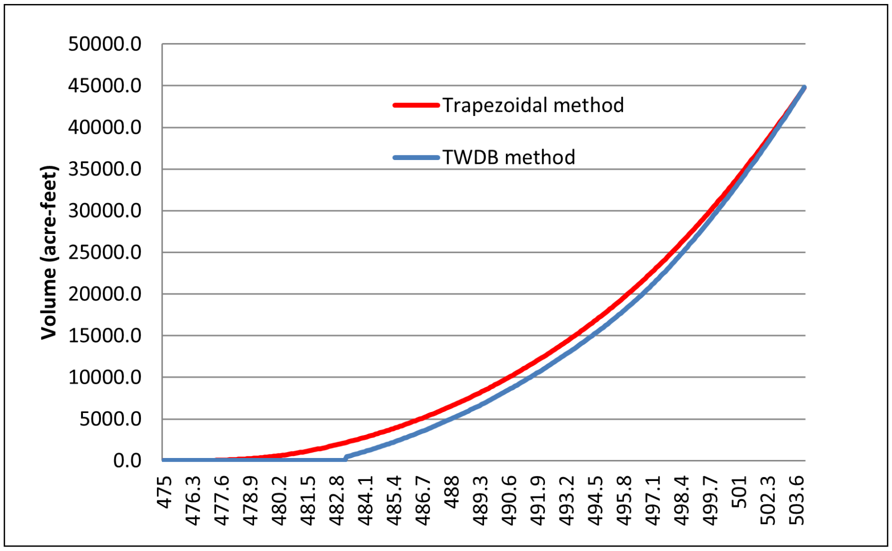

Figure 11. Estimated capacity for Granger Lake along the elevation gradient as determined by the trapezoidal method (red line) and the volumetric elevational sedimentation rate method (blue line) for 2050. The volumes below 500 feet with the trapezoidal method are about 1000–1500 acre-feet more than the volumes estimated with the volumetric elevational sedimentation rate method.

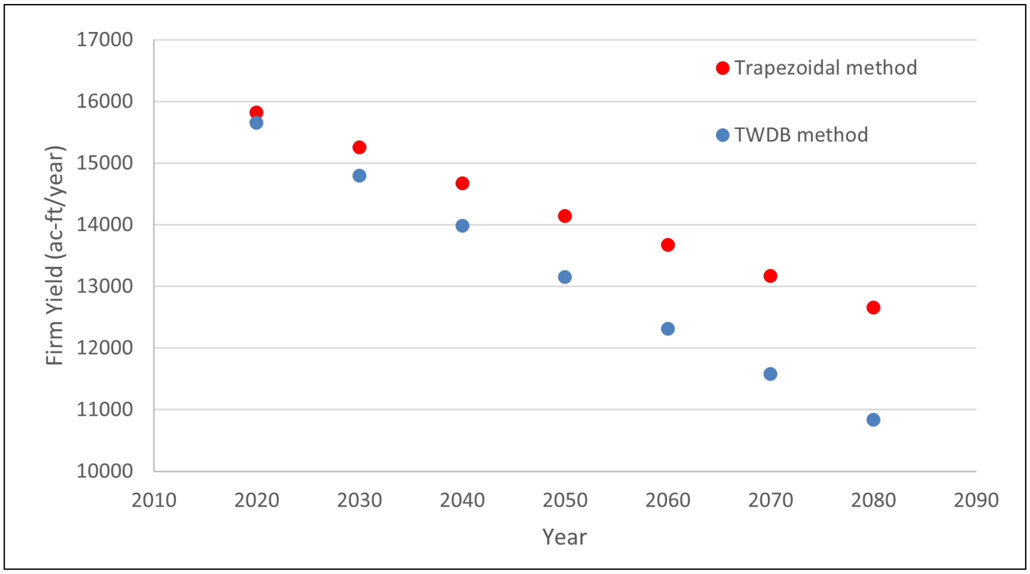

Figure 12. Granger Lake firm yields using rating curves by trapezoidal method (red points) and the volumetric elevational sedimentation rate method (blue points). By 2070, firm yield calculated by trapezoidal method is 1,589 acre-feet per year (about 14%) more than the firm yield estimated by the volumetric elevational sedimentation rate method.

od below 500 feet for 2050 projection, for example (Figure 11). As a result, firm yields computed by these rating curves are higher than those computed by the rating curves generated by the volumetric elevational sedimentation rate method (Figure 12).

Each method has advantages and disadvantages. Advantages of the trapezoidal method include that it is easy to understand and has consistent volume and area change. The disadvantages are the reservoir shape assumption and constant area reduction at all elevations. Constant area reduction means constant volume change, which is not necessarily consistent with the actual sediment distribution in a reservoir, as discussed in the previous section. An advantage of the volumetric elevational sedimentation rate method is the incorporation of varied volumetric sedimentation rates along the vertical profile. Disadvantages include the need to have at least two sedimentation surveys of reservoirs, and the potential drawback that the two surveys selected for the analysis may not represent the long-term sedimentation trend at the reservoir. It is also true that the vertical distribution of sedimentation may change over time.

DISCUSSION AND RECOMMENDATIONS

Sedimentation in reservoirs is a concerning problem in Texas. Sediment reduces a reservoir's storage capacity and therefore may affect its ability to store and yield water for beneficial use. To estimate reservoir firm yield for Texas's 50-year water planning horizon, future reservoir capacity and rating curves are projected based on a detailed understanding of sedimentation characteristics in a reservoir.

We find that sediment distribution varies inside a reservoir, and volumetric sedimentation rates vary at different elevations along a reservoir's elevational gradient. This suggests that a method that accounts for the variability of sedimentation by elevation is needed when estimating a reservoir's future capacity and associated rating curve. Based on available hydrographic and sedimentation surveys, we developed volumetric elevational sedimentation rates for 80 Texas reservoirs. Using these, and assuming a constant total volumetric sedimentation rate over a future time horizon, reservoir rating curves for the next 50 years were developed, specifically for 2030, 2040, 2050, 2060, 2070, and 2080 for regional water planning groups in Texas to consider and utilize when estimating future reservoir firm yields for each planning decade.

Reservoir sedimentation processes are dynamic. The natural sedimentation rate is not a constant rate due to changes in climate, weather pattern, and land use. The method we propose assumes that over a projection decade, the volumetric sedimentation rate will remain constant at all elevations except at the lowest elevation in reservoir. We acknowledge that the distribution of sedimentation by elevation can vary over time. It is unclear whether the physical processes we observed in the reservoirs studied — i.e., the filling up of the lowest elevations of a reservoir, and the increase in volumetric sedimentation rate over time at the lowest elevations in a reservoir — are applicable to all reservoirs and, therefore, should be further investigated. Assessing the sensitivity of reservoir capacity loss to these assumptions will be the subject of future study. We recognize that further study is needed to identify and implement improvements to the methodology we propose. Nevertheless, this method provides regional water planning groups with an easy-to-use, physically based method for estimating future reservoir firm yields. Furthermore, it yields a reservoir firm yield that appears to be more conservative than the firm yield estimates derived using other methods—such as the empirical area reduction method—for accounting for reservoir sedimentation.

While we suggest that projected firm yields for planning periods be derived using projected rating curves whenever possible, for reservoirs that have only a single hydrographic survey and no sedimentation survey, projected rating curves cannot be derived by the volumetric elevational sedimentation rate method. Water planners may still use other analytical methods, such as trapezoidal or conic formulations to compute future rating curves. In such cases, all available information on area-capacity and the sedimentation rate must be obtained by field surveys or other reliable sources. The Texas State Soil and Water Conservation Board (1991) published comprehensive sediment yield data for Texas in 1991, which may be a good reference for estimating sedimentation for a reservoir with no hydrographic survey data.

As a foundation for estimating the future capacity of a reservoir, detailed volumetric and sedimentation surveys are critical. Therefore, we recommend that reservoir owners have volumetric and sedimentation surveys completed at regular intervals for their respective reservoirs.

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Appendix A

List of 80 reservoir studied

Reservoir Name	First Survey	Recent Survey	Sediment rate (acre-feet/year)	Catchment area (square mile)	Sedimentation rate (ac-ft/year/square mile)
Alan Henry Reservoir	1993	2017	511.8	394	1.30
Aquilla Lake	1995	2014	206.6	252	0.82
Arlington, Lake	1957	2007	108.2	143	0.76
Arrowhead, Lake	2001	2013	666.5	832	0.80
Athens, Lake	1962	1998	113.6	21.6	5.26
Austin, Lake	1999	2008	0.6	38240	0.00
Bardwell Lake	1999	2020	144	178	0.81
B.A.Steinhagen	1951	2011	431.2	7573	0.06
Belton Lake	1994	2015	661.7	3560	0.19
Benbrook Lake	1952	1998	43.8	429	0.10
Bob Sandlin, Lake	1977	2017	256.7	239	1.07
Bonham, Lake	1969	2004	16.9	29	0.58
Bridgeport, Lake	1932	2020	344.7	1111	0.31
Brownwood, Lake	1997	2013	224	1535	0.15
Buchanan, Lake	1950	2019	1556.8	31828	0.05
Canyon	1964	2000	1157.3	1432	0.81
Cedar Creek Reservoir	1965	2017	836.8	1007	0.83
Cherokee, Lake	1948	2015	40.8	158	0.26
Choke Canyon Reservoir	1983	2012	1098.2	5490	0.20
Coleman, Lake	1966	2006	50.2	292	0.17
Conroe, Lake	1973	2020	547.6	445	1.23
Corpus Christi, Lake	2002	2016	442	16656	0.03
Crook, Lake	1956	2003	11.8	53.06	0.22
Cypress Springs, Lake	1970	2007	162.5	75	2.17
Eagle Mountain Lake	2008	2018	216	1970	0.11
Fork Reservoir, Lake	1980	2009	1260.8	493	2.56
Fort Phantom Hill, Lake	1938	1993	56.8	478	0.12
Georgetown, Lake	2005	2016	48.2	246	0.20
Graham, Lake	1958	1998	102.4	221	0.46
Granbury, Lake	1993	2015	325.5	25679	0.01
Granger Lake	1995	2013	192.7	709	0.27
Grapevine Lake	2002	2011	435.4	695	0.63
Houston, Lake	1954	2018	384.3	2828	0.14
Houston County Lake	1966	1999	41.4	44	0.94
Hubbard Creek Reservoir	1997	2018	556.2	1107	0.50
Inks Lake	1938	2021	10	31290	0.00
Jacksonville, Lake	1957	2006	19.2	34	0.56
J. B. Thomas	1953	1999	149	3524	0.04
Jim Chapman Lake	1991	2007	556.9	479	1.16

Reservoir Name	First Survey	Recent Survey	Sediment rate (acre-feet/year)	Catchment area (square mile)	Sedimentation rate (ac-ft/year/square mile)
Joe Pool Lake	1986	2022	246.3	304	0.81
Kemp, Lake	1971	2006	1989	2086	0.95
Kickapoo, Lake	1946	2013	290.8	275	1.06
Lavon Lake	1970	2021	957	770	1.24
Leon Lake	1954	2015	20.8	252	0.08
Lewisville Lake	1960	2007	1071.8	1660	0.65
Limestone, Lake	1993	2012	725.4	675	1.07
Livingston, Lake	1969	2019	3764	16616	0.23
Lyndon B Johnson, Lake	1951	2020	132.1	36823	0.00
Martin Lake	1999	2014	58.8	130	0.45
Meredith, Lake	1965	1995	1330.1	20220	0.07
Mexia, Lake	1996	2008	8.9	198	0.04
Millers Creek Reservoir	1974	1993	188.4	228	0.83
Mineral Wells, Lake	1970	2015	34.4	63	0.55
Monticello Reservoir	1972	1998	192	36	5.33
Navarro Mills Lake	1956	2008	267.6	320	0.84
Nocona	1961	2001	95.5	94	1.02
O' the Pines, Lake	1998	2009	496.3	880	0.56
Palestine, Lake	2003	2012	1219.2	839	1.45
Pat Cleburne, Lake	1998	2008	3	100	0.03
Pat Mayse Lake	1967	2008	132.5	175	0.76
Possum Kingdom Lake	1994	2016	513.8	22550	0.02
Proctor Lake	2002	2012	201.6	1265	0.16
Ray Hubbard, Lake	2005	2015	1519	1074	1.41
Ray Roberts Lake	1987	2008	402	692	0.58
Richland-Chambers Reservoir	1994	2018	2435.5	1957	1.24
Somerville Lake	1995	2012	373.1	1006	0.37
Stamford, Lake	1966	1999	117.2	368	0.32
Stillhouse Hollow Lake	2005	2015	276.5	1318	0.21
Striker	1996	2021	57.5	182	0.32
Tawakoni, Lake	1997	2009	1317.3	756	1.74
Texana, Lake	1980	2020	286	1314	0.22
Texoma, Lake	2002	2016	3115.2	39719	0.08
Travis, Lake	1940	2019	518.9	38800	0.01
Tyler, Lake	1997	2013	323.7	107	3.03
Waco, Lake	1995	2011	523.4	1670	0.31
Waxahachie, Lake	1956	2000	49.5	30	1.65
Weatherford Reservoir	1998	2008	81.6	109	0.75
Whitney, Lake	1959	2005	1312.9	26616	0.05
Worth, Lake	1968	2001	128.3	2064	0.06
Wright Patman Lake	1997	2018	984.6	3443	0.29