SBG
Sulphur Basin Group

5930 Summerhill Rd • Texarkana, Texas 75503 • 903-838-8533 • fax 903-832-4700

TO:	SRBA
FROM	Jon Albright
SUBJECT:	Technical Memorandum on Hydrologic Yields
PROJECT:	Sulphur River Basin Feasibility Study
DATE:	08/26/2014
CC:	

TABLE OF CONTENTS

1.0 INTRODUCTION 4
2.0 MODEL LEVELING 7
2.1 Demands 7
2.2 Hydrology 9
3.0 COMPARISON OF HYDROLOGY 11
3.1 Flow Data 11
3.2 Evaporation and Precipitation Rates 14
4.0 RESERVOIR YIELDS 16
4.1 Hydrologic Yields 16
4.2 Potential Impact of Water Right Priority on Yields 21
5.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS 24
5.1 Summary of findings 24
5.2 Conclusions 26
5.3 Recommendations 26

Table of Figures

Figure 1: Historical Period of Record for Sulphur River Basin Hydrologic Data 12
Figure 2: Comparison of Hydrologic Yields of Proposed Projects 17
Figure 3: Comparison of Elevation Traces from the Sulphur WAM and the USACE Model – Demand of 861.5 cfs 18
Figure 4: Comparison of Lake Wright Patman Inflows and Evaporation from Sulphur WAM and USACE Models – 252.5 ft Reallocation 20
Figure 5: Comparison of Modeled to Historical Surface Area –Wright Patman Lake 21
Figure 6: Comparison of Sulphur WAM Hydrologic and Priority Yields 22

Table of Tables

Table 1: Model Leveling Summary 8
Table 2: Regression Equations from Flow Comparisons 13
Table 3: Hydrologic Yield of Proposed Projects 16
Table 4: Sulphur WAM Hydrologic and Priority Yields 22
Table 5: Hydrologic Yield of Proposed Projects 25

APPENDICES

Appendix A – References

Appendix B – Comparison of WAM and USACE Hydrology

Appendix C – Comparison of Annual Inflows, Outflows and Evaporation Loss

Appendix D – Modeled Storage and Elevation Traces

1.0 INTRODUCTION

This report describes an evaluation of the hydrologic yields of proposed water supply projects in the Sulphur River Basin, performed as part of the larger Sulphur River Basin Feasibility Study (Feasibility Study). Hydrologic Yields are reservoir yields based on historical hydrology, without regard to water rights or water right priority. The Hydrologic Yield approach differs from the approach used to develop other yields in the Feasibility Study, which for the purposes of this report will be referred to as Priority Yields. Priority Yields assume that (a) all permanent water rights are diverting at their full authorized diversions and (b) that water is distributed in accordance with the priority date of each water right, with the most senior water right receiving water first. The Priority Yield approach is similar to the one used in the State of Texas for water planning. The current Hydrologic Yield study was instigated to develop an understanding of the two different approaches to reservoir yields, as well as to address concerns regarding the models that are being used to develop those yields.

The Hydrologic Yields developed for this report were calculated using two different models. The first model is a RiverWare model developed by the U.S. Army Corps of Engineers (USACE), Fort Worth District. The model includes not only the Sulphur Basin, but also the Cypress Basin and the main stem of the Red River from the Red River at Fulton gage (USGS 07341500) to the Red River at Shreveport gage (USGS 07348500). This model is based on a larger model of the Red River Basin. The USACE developed the Red River basin model primarily to simulate flood operations. The model uses RiverWare, a generalized basin model developed by the Center for Advanced Decision Support for Water and Environmental Systems (CADSWES) at the University of Colorado, Boulder. In this report, this model will be referred to as the USACE Model.

The second model is a modified version of the Sulphur River Basin Water Availability Model, originally developed by the Texas Commission on Environmental Quality (TCEQ) and subsequently modified by Freese and Nichols for the Feasibility Study. TCEQ designed this model primarily to process water rights applications. It is also used in Texas for state-sponsored regional water planning. The model is an application of the Water Rights Analysis Package (WRAP), developed by Dr. Ralph Wurbs of Texas A&M University. In this report, this model will be referred to as the Sulphur WAM and specifically refers to the modified model used for the Feasibility Study.

The models were used to develop firm Hydrologic Yields of ten different stand-alone alternatives evaluated in the Sulphur River Basin Feasibility Study:

- Wright Patman Lake reallocation at with conservation elevations 232.5 feet, 242.5 feet, and 252.5 feet,
- Marvin Nichols Reservoir with conservation elevations of 296.5 feet, 313.5 feet and 328.0 feet,
- George Parkhouse I reservoir with a conservation elevation of 401.0 feet,
- George Parkhouse II reservoir with a conservation elevation of 410.0 feet, and
- Talco Reservoir with conservation elevations of 350.0 feet and 370.0 feet.

There are several significant differences between the two models. The USACE Model only has large reservoirs while the Sulphur WAM contains all permanent water rights and authorized reservoirs. The USACE Model uses historical hydrology, adjusted only for major reservoirs, while the Sulphur WAM uses naturalized flows (flows adjusted for all significant reservoirs, diversions and return flows). The USACE Model uses a daily time step, while the Sulphur WAM uses a monthly time step. The USACE model evaluates and adjusts releases from multiple reservoirs as part of flood operations, while the Sulphur WAM simply assumes that flood storage in a reservoir is empty at the end of each monthly time step. Finally, the USACE Model is designed to distribute water from upstream to downstream, while the Sulphur WAM is designed to distribute water based on the priority date of each water right.

It is important to distinguish between the modeling application used in this study (USACE Model and Sulphur WAM) from the underlying computer programs in which the models were developed (RiverWare and WRAP). Both RiverWare and WRAP are hydrologic models developed for long-term simulation of river basins. WRAP is specifically designed to simulate water rights, while RiverWare is a more generalized model of reservoir and river systems that can simulate almost any type of river operations. Neither application used in this study fully use the capabilities of the underlying software. When comparing the results using the two different modeling applications (USACE Model and Sulphur WAM) it is important to remember that we are comparing results of specific applications (and the underlying data and assumptions used in those applications), not the software itself. In general, RiverWare is a more flexible model than WRAP. However, both models are well maintained, thoroughly documented and technically sound software packages that are well suited for determining reservoir yields. This study is not a comparison of the capabilities of the modeling software. Rather, it is a comparison of using two different applications (the USACE model and the Sulphur WAM) to determine hydrologic yields. If there are differences in the hydrologic yields, this study will endeavor to find out why the results are different, either because of differences in data, assumptions or the models themselves.

RiverWare is capable of simulating water rights on a priority basis, but this feature is not used in the USACE Model. Applying water right priorities to the USACE models would take considerable effort, and probably would not be very useful given that so few water rights are represented in the model. The USACE model also includes parts of the river basin in Arkansas and Louisiana, which have different water right systems. So instead of adapting the USACE models to the priority system, the Sulphur WAM was modified to operate in upstream to downstream order, which is called “natural order” in the WRAP documentation.

2.0 MODEL LEVELING

The first step of the current study was to identify a uniform set of input data and assumptions that could be applied to both the USACE Model and the Sulphur WAM without fundamentally altering the models themselves. This data set provides a "level" modeling space so that differences in results can be more readily identified. For example, if two different models use different area-capacity relationships, but otherwise use the same input data, they would necessarily produce different results. However, if the two models use the same area-capacity data (as well as the same input data), but still get different results, then there must be some inherent difference in the models that produces that different results. The input data that were examined in this study include demands, hydrology, reservoir elevation-area-capacity data, Wright Patman conservation curves, and low flow release policies. Table 1 is a summary of the data model leveling variables. The remainder of this section discusses the process in more detail.

One thing that was not modified is the time step used in the USACE Model or the Sulphur WAM. The USACE Model has a daily time step, while the Sulphur WAM uses a monthly time step. Both RiverWare and WRAP are capable of modeling either time step. However, the input data, modeling methods and model setups would need to be changed significantly for either the USACE Model or the Sulphur WAM to use the same time step, a process beyond the scope of this study.

2.1 DEMANDS

A fundamental difference between the USACE Model and the Sulphur WAM is the level of detail for water rights. The USACE Model only has diversions associated with the major reservoirs, while the Sulphur WAM has every permanent water right in the Sulphur Basin. Although it is possible to modify the USACE model to include all water rights, this would be a major effort and a significant modification to the approach used by the USACE. However, for major reservoirs, demands could be the same without significantly modifying the way that either model works. For Wright Patman and Jim Chapman Lakes, demands were based on recent use. Demands for Jim Chapman Lake were set to 110,000 acre-feet per year. Except for the Patman reallocation scenarios, demands for Wright Patman were set to 50,000 acre-feet per year. Monthly demand patterns for both reservoirs were also modified to reflect recent use patterns. Demands for Lake Ralph Hall were set at 45,000 acre-feet per year based on the water right application for that project. (Lake Ralph Hall is a proposed reservoir that is not part of the Sulphur River Basin Feasibility Study. To be conservative we are assuming that this reservoir will be built before the other projects examined in this study.)

Table 1: Model Leveling Summary

	USACE Model		Sulphur WAM	
	Original	**Modified**	**Original**	**Modified**
Area Capacity				
Wright Patman	Extended 1997 Survey	Extended 2010 Survey extended with COE areas	2010 survey extended with TWDB data	Extended 2010 Survey extended with COE areas
Chapman	2005/2007 survey	No change	2005/2007 survey	No change
Ralph Hall	Site Protection Study	No change	Site Protection Study	No change
Low-Flow Release				
Wright Patman	Above 220 ft - 10 cfs Nov-Apr, 96 cfs May-Oct. Below 220 ft 0 cfs	Added 10 cfs release below 220 ft	10 cfs	Above 220 ft - 10 cfs Nov-Apr, 96 cfs May-Oct. Below 220 ft 10 cfs
Chapman	5 cfs above 415.5 feet, none below 415.5 ft	No change	5 cfs at all times	5 cfs above 415.5 feet, none below 415.5 ft
Demands				
Wright Patman	50,916 ac-ft/yr	50,000 ac-ft/yr (non-yield runs) with revised pattern	180,000 ac-ft/yr	50,000 ac-ft/yr (non-yield runs) with revised pattern
Chapman	92,507 ac-ft/yr between elevations 415.5 and 440, none below 415.5 or above 440	110,000 above 415.5, none below 415.5, revised pattern	146,520 ac-ft/yr above elevation 220, none below 220	110,000 above 415.5, none below 415.5, revised pattern
Ralph Hall	None	45,000 ac-ft/yr	45,000 ac-ft/yr	45,000 ac-ft/yr
Other diversions	Not included	no change	Full use of all water rights	No change
Allocation	Natural order	no change	Priority order	Natural order
Evaporation				
Wright Patman	COE net reservoir - 1938 to 1957, evaporation only 1958-2007	no change	TWDB net reservoir	TWDB net reservoir
Chapman	COE net reservoir - 1938 to 1991, evaporation only 1992-2007	no change	TWDB net reservoir	TWDB net reservoir
Ralph Hall	Chapman Lake COE	TWDB net reservoir	TWDB net reservoir	TWDB net reservoir
Proposed projects	TWDB net reservoir	TWDB net reservoir	TWDB net reservoir	TWDB net reservoir

The hydrologic yield runs use a constant withdrawal from the reservoir. In other words, it is assumed that the same amount of water is taken out of the reservoir every day of the year. This assumption is consistent with USACE practices when determining yield. However, other yield analyses done for the Feasibility Study assumed a varying monthly pattern typical of municipal water use, with higher demands during the summer months than during the winter. Although this assumption will have some impact on the yield value, based on our experience it would not be significant in most cases.

2.2 HYDROLOGY

Hydrology consists of the flows used in the models and the evaporation and precipitation rates input for each reservoir. The flow data used by the two models are not compatible and therefore were not changed. The USACE Model uses incremental historical flow data. The only adjustments to these data are associated with the major reservoirs that are simulated in the model. For the Sulphur Basin portion of the model, this would be the construction of Jim Chapman Lake in 1991 and Wright Patman Lake in 1954. This assumption implies that future changes in diversion and return flows, or construction of smaller reservoirs, will not significantly impact the results of the yield modeling.

On the other hand, the Sulphur WAM uses naturalized flows, which are historical flows that have been adjusted to remove the effects of major reservoirs, historical diversions, and historical return flows. The hydrology is compatible with the approach used in the WAMs, which includes the modeling of all water rights, no matter how small.

The other component of hydrology is evaporation and precipitation. For existing projects, it is desirable to use evaporation and precipitation data that are consistent with the data used to develop the inflows for that project. For the historical hydrology where the reservoir was present, the evaporation and precipitation data were used as part of the inflow calculations. Using other evaporation and precipitation data would be inconsistent with the inflow data, introducing additional error into the modeling. The USACE Model and the Sulphur WAM use different data sources and approaches for hydrologic calculations. So for existing projects, the evaporation and precipitation data were retained in the respective models.

On the other hand, inflow for proposed projects is not dependent on evaporation or precipitation calculations. Therefore these data can be consistent in both models without introducing additional error. So for the proposed projects (including Lake Ralph Hall), data from the Sulphur WAM was used.

Both models were modified to use the same area-capacity data for major reservoirs. The area-capacity data for Jim Chapman and Wright Patman Lakes are from the latest volumetric surveys of the reservoirs. For Wright Patman Lake, the survey was extended to higher elevations using areas provided by the USACE.

Both Jim Chapman and Wright Patman Lakes have low-flow releases as part of normal operations. The Sulphur WAM did not include low-flow releases from Wright Patman Lake. To be consistent with the USACE Model, the Sulphur WAM was modified so that a 10 cfs low-flow release occurs from November to April. The rest of the year a 96 cfs low-flow release occurs as long as the reservoir is above 220 feet, the bottom of conservation storage. Below 220 feet, the low-flow releases is limited to 10 cfs. The USACE model did not make low-flow releases below 220 feet. However, historical operation shows that this release has occurred when the reservoir is below 220 feet, so the model was changed so that low-flow releases occur when the reservoir is below conservation. Both models had a 5 cfs low-flow releases for Jim Chapman Lake.

3.0 COMPARISON OF HYDROLOGY

Hydrology includes both the flow data and evaporation/precipitation data input into the models. The USACE RiverWare model uses hydrology from 1938 to 2007. The Sulphur WAM has hydrology from 1940 to 1996. Appendices B and C contains graphical comparisons of the inflow and evaporation data used in the two models.

3.1 FLOW DATA

The flow data for both models is derived from historical stream gage records. Where records are missing, flows are estimated based on other nearby gages. Figure 1 compares the historical period-of-record for the stream gages used to develop flow data in the models. Figure 1 also shows the period of record for the two models, as well as the two largest reservoirs in the basin, Wright Patman and Jim Chapman. (The other major reservoirs in the basin, Lake Sulphur Springs and River Crest Lake, were constructed in 1973 and 1953, respectively).

Appendix B contains plots comparing the monthly flow data from the two models at the five reservoir sites (Parkhouse I, Parkhouse II, Talco, Marvin Nichols and Wright Patman) and at two gage sites (North Sulphur near Cooper and Sulphur River near Talco). For most locations there are four plots:

- A scatter plot comparing the monthly WAM flow volumes to the monthly total flow volume from the USACE model for the full overlap period of the two models, 1940 to 1996. Included in the scatter plot is a linear regression equation and the R^2, as calculated by Excel.
- A "double mass" plot comparing the monthly cumulative flows from the two models for the same 1940 to 1996 period. These plots include a line between the first and last points on the plots to emphasize changes in the slopes of these curves.
- A scatter plot comparing the monthly WAM flow volumes to the monthly total flow volume from the USACE models for the period of the primary historical gage records used to calculate the inflows. The exception is Wright Patman. For this reservoir, the period in this plot is the period prior to construction of the reservoir. After construction of the reservoir, the two models use different methods to calculate flows. This is discussed below in Section 3.2.
- A double mass plot of the cumulative flows for the same period of historical records.

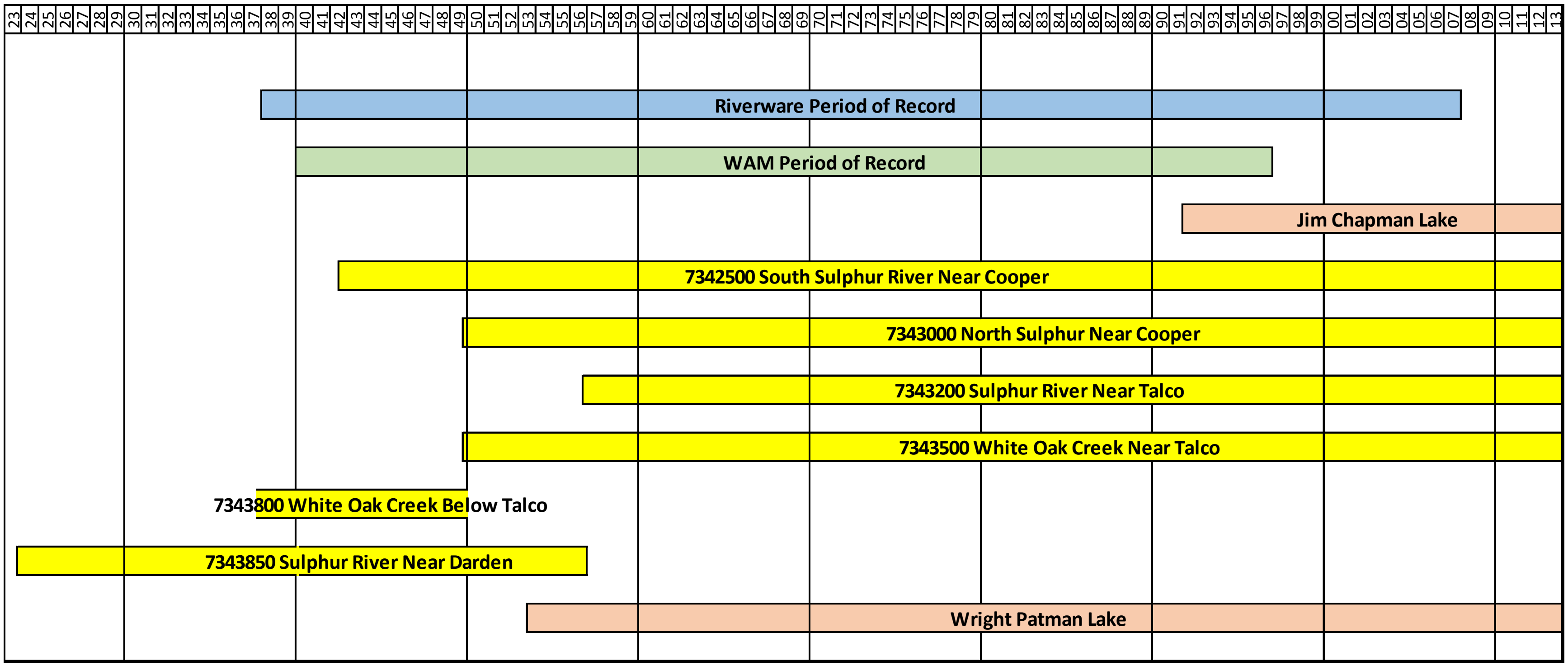


Figure 1: Historical Period of Record for Sulphur River Basin Hydrologic Data

Table 2 compares the regression equations and R^2 values for the two sets of scatter plots (full period and period of historical gage data). For most locations, the inflow data for the two models compares very well for the historical period of gage flow records, with slopes and R^2 values very close to 1. The exception is the Parkhouse I site, which has a still very good R^2 of 0.8924 but has more scatter when comparing individual monthly flows. However, the cumulative flows shown in the double mass plots show a very consistent relationship between the two datasets over longer periods of times. In general, the Sulphur WAM flows (variable y in Table 2) are slightly less than the USACE model flows (variable x in Table 2).

Table 2: Regression Equations from Flow Comparisons

Location	Full Overlap Period (1940 to 1996)		Historical Gage Period or Pre-Reservoir Period		
	Regression Equation	R^2	Regression Equation	R^2	Time Period
N. Sulphur nr Cooper	y = 1.0303x	0.8673	y = 0.9894x	0.9838	10/49 to 12/96
Parkhouse II	y = 0.9231x	0.9143	y = 0.9939x	0.9874	10/49 to 12/96
Parkhouse I	y = 0.969x	0.8742	y = 0.9905x	0.8924	10/56 to 12/96
Sulphur R nr Talco	y =0.9976x	0.9311	y = 0.9828x	0.9779	10/56 to 12/96
White Oak nr Talco (Talco Site)	y = 1.0221x	0.9225	y = 0.9801x	0.9993	12/49 to 12/96
Marvin Nichols	y = 0.9861x	0.9605	y = 1.0169x	0.9628	10/56 to 12/96
Wright Patman	y = 1.0027x	0.9341	y = 1.0429x	0.9816	1/40 to 12/57

Note: x corresponds to the USACE Model flows and y is the Sulphur WAM flows

There are some differences between the two datasets during the period of estimated flows. According to documentation provided by the USACE, the USACE Model primarily uses on the Darden gage (USGS 7343850) to fill in the earlier missing data, and estimated flows are based on drainage area ratios. On the other hand, the Sulphur WAM uses the White Oak Creek below Talco gage (USGS 7343800) when available, and uses a monthly-varying statistical relationship to estimate missing flows. As a result, the period of estimated flows is somewhat different between the two datasets, particularly for the flows that are based on estimated flows at the North and South Sulphur gages.

The most significant difference between the hydrology used in the Sulphur WAM and the hydrology from the USACE Model is the period of record. The Sulphur WAM currently only has data from 1940 to 1996. The model was developed between 1998 and 1999. The hydrology has not been updated since that time.

The USACE Model has hydrology from 1938 to 2007. This is significant because the worst drought for proposed projects examined in this study occurs between 2002 and 2006. As a result, the Sulphur WAM misses the critical drought that determines the yield of the reservoir, and yields determined with the models are not directly comparable. Further information may be found in Section 4.0 below.

3.2 EVAPORATION AND PRECIPITATION RATES

Evaporation and precipitation rates are part of the hydrologic input data for the models. These rates are multiplied by the reservoir surface area to obtain the loss from the reservoir due to evaporation and the gain to the reservoir due to precipitation on the reservoir surface. Since the calculation of evaporative loss and precipitation gain uses the same method (they just have the opposite sign to indicate either a gain or a loss), evaporation and precipitation rates are frequently combined into a single factor, usually referred to as *net reservoir evaporation*[1]. Both the USACE Model and the Sulphur WAM have a single input evaporation rate for these gain and loss calculations. Precipitation rates are not input separately. In the Sulphur WAM, these input evaporation rates are net reservoir evaporation (evaporation less precipitation) throughout the modeled period. The hydrology that has been developed for the Sulphur WAM is consistent with this assumption. However, the USACE Model uses net reservoir evaporation for the hydrologic period before the construction of the reservoir. After a reservoir has been constructed, precipitation on the reservoir surface is assumed to be part of the inflows so the input evaporation rates are for evaporation only.

In this hydrologic yield study, the input evaporation rates for Wright Patman and Jim Chapman Lakes were not changed in the individual models, so the input evaporation rates are different in the Sulphur WAM than they are in the USACE Model. This was done to be consistent with the inflow data that were used in the respective models. On the other hand, input evaporation rates for proposed projects (including Lake Ralph Hall) are the same in both models. This could be done because the underlying flow data are not dependent on loss or gain calculations from these proposed projects.

[1] Net reservoir evaporation also may include a factor called *effective runoff* which is a correction for the portion of the precipitation that would have become runoff. This may be combined with the net reservoir evaporation rates, or can be calculated by the model itself. The Sulphur WAM does not include effective runoff in the input data. However, rates with effective runoff are calculated by the model. These calculated rates were used for the USACE Model hydrologic yields of the proposed projects.

Previous modeling in the Feasibility Study used net evaporation rates developed for the July 2008 Texas Water Development Board *Reservoir Site Protection Study*. The proposed projects examined in the hydrologic yield study used these same input evaporation rates in both the Sulphur WAM and USACE Models, including Lake Ralph Hall. These net evaporation rates are based on statewide evaporation and precipitation data from the Texas Water Development Board.

Existing projects like Jim Chapman and Wright Patman Lakes require a different approach in the two models. Prior to the construction of the reservoirs, flows at these locations are based on stream gage records in both the USACE Model and the Sulphur WAM. Evaporative loss is not part of the calculations that derived the flows. However, the Sulphur WAM and USACE Model use different sources for the evaporation and precipitation data. The USACE Model uses locally measured pan evaporation and rain gage data. The Sulphur WAM uses the Texas Water Development Board data, which uses more sources of historical data (including the local data), has been spatially smoothed and uses different pan factors to calculate reservoir evaporation from pan evaporation. As a result the two data sources have slightly different evaporation and precipitation rates.

After the construction of the reservoirs the portion of the flow that is lost to evaporation from the reservoir surface and the increased volume of water from precipitation on the reservoir surface must be taken into account when developing the flow data. The Sulphur WAM and the USACE Model have different approaches to using these data. In the Sulphur WAM, precipitation is combined with evaporation, so that precipitation on the reservoir surface is removed from the inflow calculations. So the evaporation rates used in the Sulphur WAM are combined net reservoir evaporation throughout the simulation. On the other hand, the USACE model includes precipitation on the reservoir surface as part of the inflows into the reservoir. So in the USACE Model, the evaporation rates prior to construction of the reservoir are net reservoir evaporation, while the evaporation rates after construction of the reservoir are for evaporation only. So in order to be consistent with the hydrology in each model (which was not changed), the evaporation rates for Patman and Chapman Lakes were not made identical in the two models.

4.0 RESERVOIR YIELDS

4.1 HYDROLOGIC YIELDS

Table 3 is a comparison of the hydrologic yields calculated using the Sulphur WAM and the USACE Model. Figure 2 is a graphical representation of the same data. There are two yields reported for the USACE Model, one using the full period of record (1938 to 2007), and one using only the overlap period with the Sulphur WAM (1940 to 1996). The yield for the shorter period is so that the results of the two models can be directly compared. The yield for the entire period of record would be more indicative of the current estimate of hydrologic yield of the reservoir. Reservoir storage traces from the various runs may be found in Appendix D.

Looking at the yields, the full period USACE Model yields are less than either model's yields when only considering the hydrology from 1940 to 1996. This is the result of the new drought of record that occurred in the mid-2000s.

Table 3: Hydrologic Yield of Proposed Projects

Project	Sulphur WAM yield (1940 to 1996)		USACE Model Yield (1940 - 1996)		USACE Model Yield (1938 - 2007)	
	Cfs	ac-ft/yr	cfs	ac-ft/yr	cfs	ac-ft/yr
Parkhouse II	198.4	143,700	209.3	151,630	179.9	130,345
Parkhouse I	206.2	149,400	228.1	165,250	185.1	134,098
Talco 350	267.6	193,900	277.0	200,676	216.1	156,556
Talco 370	398.0	288,300	412.5	298,841	395.0	286,170
Nichols 328	889.1	644,100	933.3	676,141	733.1	531,111
Nichols 313.5	628.1	455,000	679.9	492,562	499.1	361,579
Nichols 296.5	352.3	255,200	365.0	264,429	320.8	232,408
Patman 232.5	572.8	415,000	490.0	354,987	442.3	320,394
Patman 242.5	1,008.3	730,450	897.0	649,843	658.2	476,841
Patman 252.5	1,386.0	1,004,100	1,341.0	971,504	861.5	624,124

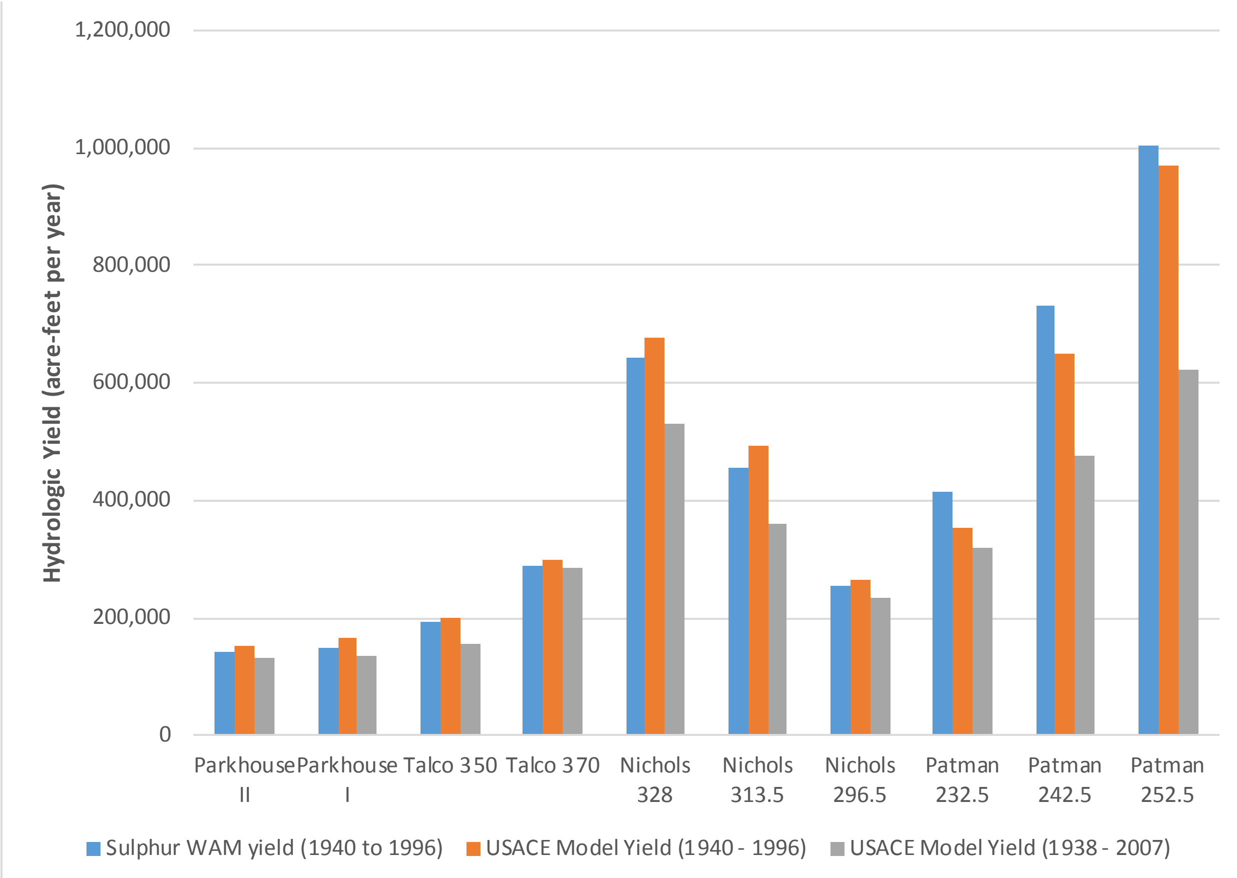


Figure 2: Comparison of Hydrologic Yields of Proposed Projects

When comparing the 1940 to 1996 yields for the two models, the Sulphur WAM yields are slightly less than the USACE Model yields for the proposed new reservoir projects (Parkhouse I, Parkhouse II, Talco and Marvin Nichols). This is not entirely surprising, since the flows from the WAM model are slightly less than the flows from the USACE model (see Table 2). However, the yields for these projects are relatively close, with less than 10% difference. The critical drought period for most of these model runs is in the 1950s. The exception is the Talco project with the storage at 370 feet. This variation of the Talco project has long periods when the reservoir is not full. The Sulphur WAM run has the minimum storage in 1966, while the USACE Model run has the minimum storage in 1957.

The Sulphur WAM yields for the Patman reallocation projects are higher than the yields using the USACE Model. In order to investigate this difference, runs were made of the Sulphur WAM using the yields calculated with the USACE Model (considering hydrology through 2008). Figure 3 shows the elevation trace from the runs with 252.5 feet reallocation. The blue line is the Sulphur WAM and the gold line is the USACE Model. Both models use the same demand of 624,124 acre-feet per year (861.5 cfs). Note that elevations below 252.5 feet (the top of the conservation pool) are very similar in the two models until about 1958. (The storage above 252.5 feet, also known as the flood pool, will be different in the USACE Model. The Sulphur WAM does not model the flood pool.) After that, the USACE Model shows more drawdown during drier periods than the Sulphur WAM.

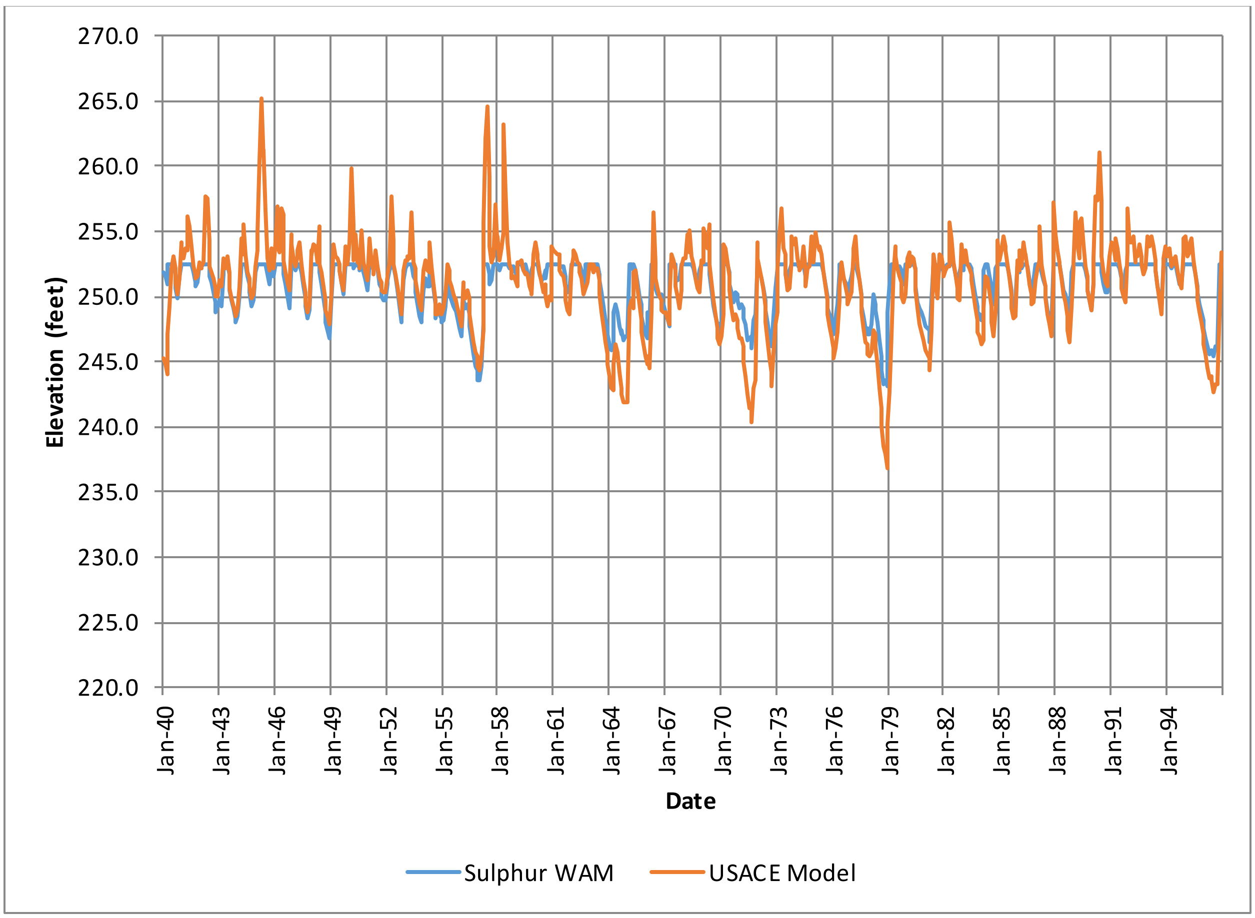


Figure 3: Comparison of Elevation Traces from the Sulphur WAM and the USACE Model – Demand of 861.5 cfs

Figure 4 compares the annual inflow and evaporation from the same modeling scenario (Wright Patman reallocation to 252.5 feet with an annual demand of 624,124 acre-feet per year). In these graphs, the data from the WAM are shown as blue bars and the data from the USACE Model are the gold line. Notice that the inflows are fairly consistent. The annual USACE annual flows are greater than the WAM flows in

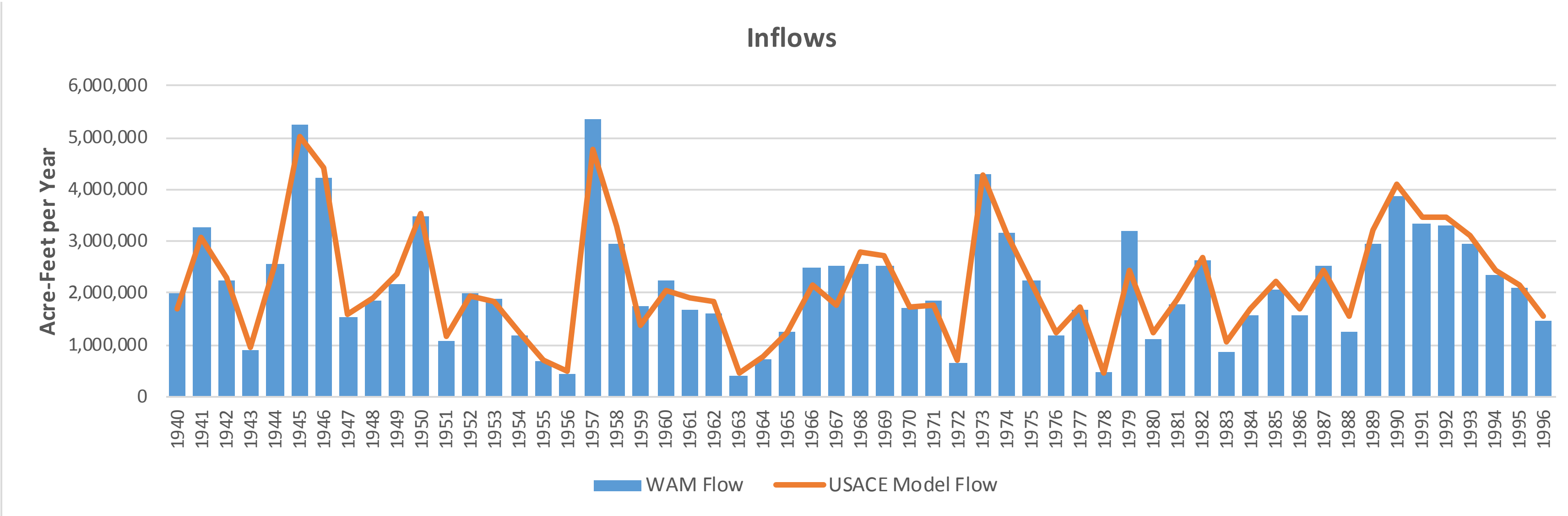
40 of the 47 years in the overlap period, with 29 of those years occurring after 1957. On the other hand, the annual evaporation from the reservoir is quite different between the two models, particularly after 1957.

According to the USACE's Pertinent Data for Wright Patman Lake, deliberate impoundment of the reservoir began in June of 1956. It is standard practice for the USACE that once a reservoir has been constructed, rainfall on the reservoir surface is included as part of the inflow into the reservoir. So during the historical period of the reservoir, precipitation on the reservoir surface is no longer modeled. Looking at the evaporation data in Figure 4, it appears that in the USACE Model precipitation is no longer part of the net evaporation calculation beginning some time in 1957.

Figure 5 compares the historical surface area of Wright Patman Lake to the modeled surface area with reallocation to 232.5, 242.5 and 252.5 feet, from 1958 to 2007. The average historical surface area during that time was about 29,400 acres. The average surface area for the reallocation scenarios over the same period is 40,300, 61,200 and 85,400 acres for the 232.5, 242.5 and 252.5-foot reallocation scenarios, respectively. With reallocation of Wright Patman, the water surface area would be larger most of the time compared to historical conditions.

Only a portion of the rainfall that falls on the land surface eventually becomes flow in a stream. However, most of the rainfall on a reservoir surface goes directly into reservoir storage. Since the USACE Model does not consider the additional surface area in the reallocation scenarios, the model underestimates the contribution of rainfall on the reservoir surface, and therefore underestimates the yield of the reservoirs.

Two factors that were not explicitly examined in this study were the impact of the different time steps used in the two models, and the associated assumption about flood storage (the monthly time step is not conducive to modeling flood storage). In general, it would be expected that these factors would have more impact on reservoirs with relatively short critical drought periods, such as Wright Patman Lake or some of the smaller proposed reservoirs. These yields would be more sensitive to conditions such as water in flood storage at the beginning of the drought period. Larger reservoirs, such as the reallocated Wright Patman Lake or the larger version of Marvin Nichols have longer critical drought periods. Because of the length of the critical drought period, water in flood storage would be spread out over a longer period and yields would not be as sensitive to initial conditions.



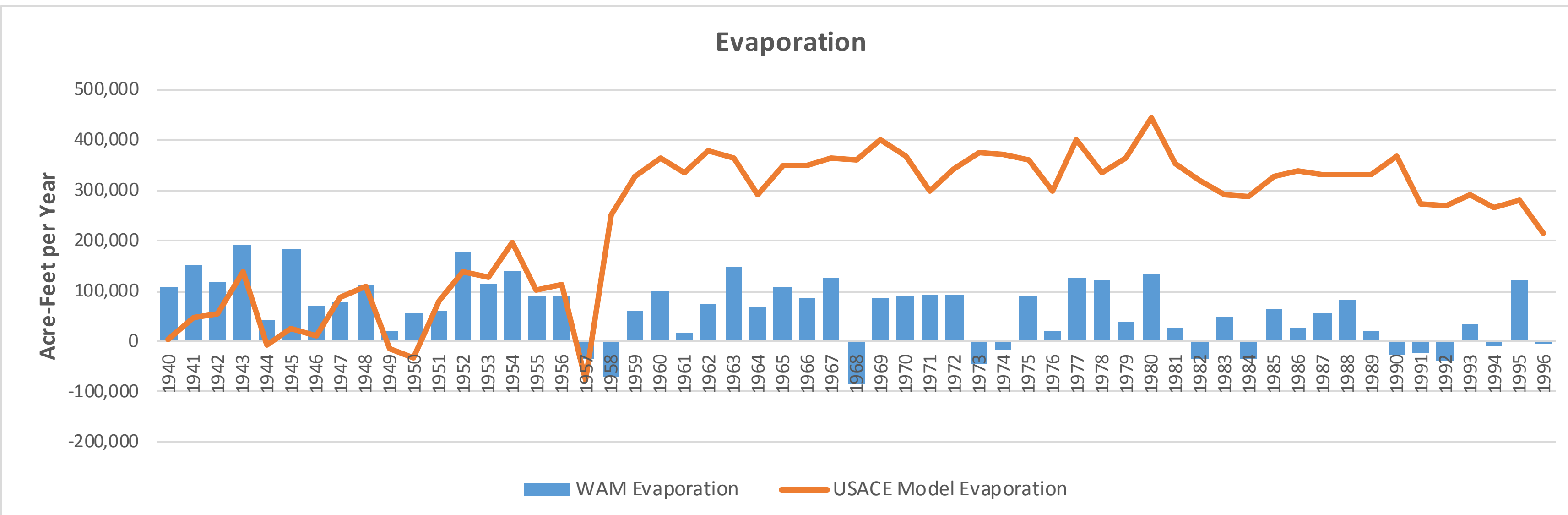


Figure 4: Comparison of Lake Wright Patman Inflows and Evaporation from Sulphur WAM and USACE Models – 252.5 ft Reallocation

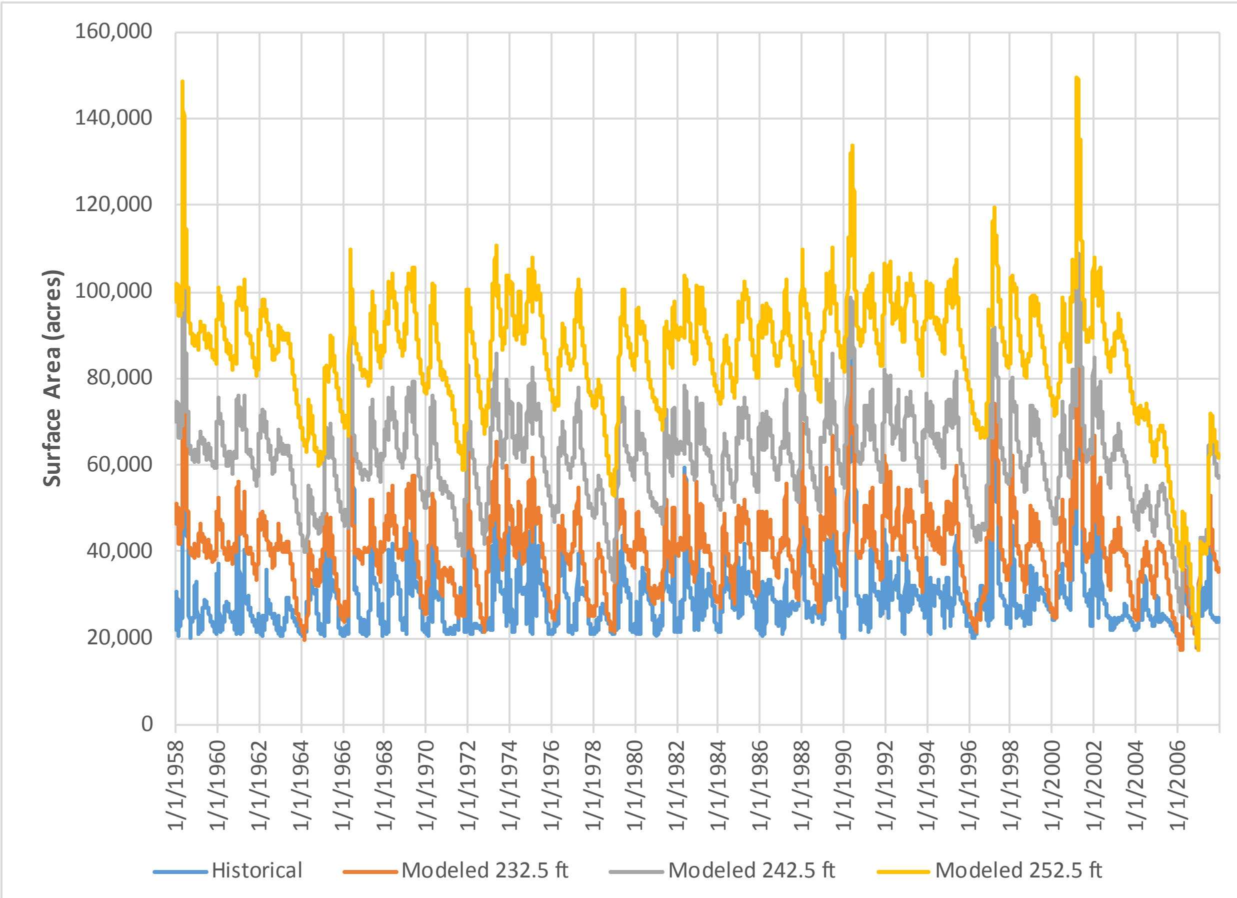


Figure 5: Comparison of Modeled to Historical Surface Area –Wright Patman Lake

4.2 POTENTIAL IMPACT OF WATER RIGHT PRIORITY ON YIELDS

The Sulphur WAM was designed to evaluate water availability considering priority water rights, with senior water rights being allocated water before more junior rights regardless of location within a basin. The yields determined for other parts of the Feasibility Study used the priority assumption. The hydrologic yields calculated in this study allocate water in upstream to downstream order without regard to the priority of a water right. In order to determine the potential impact of this assumption, the Sulphur WAM with the leveling assumptions outlined in Section 2 was run in priority order. The results of this comparison are shown in Table 4. Figure 6 is a graphical comparison of the same data. The priority assumption has the least impact on the Talco project, where yields only change by less than 4,000 acre-feet per year. The yield of the Nichols project is decreased by about 35,000 acre-feet per year.

Table 4: Sulphur WAM Hydrologic and Priority Yields

Project	Hydrologic Yield		Priority Yield	
	cfs	acre-feet/year	cfs	acre-feet/year
Parkhouse II	198.4	143,700	174.4	126,340
Parkhouse I	206.2	149,400	191.3	138,600
Talco 350	267.6	193,900	262.3	190,000
Talco 370	398.0	288,300	393.1	284,800
Nichols 328	889.1	644,100	841.7	609,800
Nichols 313.5	628.1	455,000	579.1	419,500
Nichols 296.5	352.3	255,200	306.7	222,200
Patman 232.5	572.8	415,000	626.3	453,700
Patman 242.5	1,008.3	730,450	1,044.8	756,900
Patman 252.5	1,386.0	1,004,100	1,416.9	1,026,500

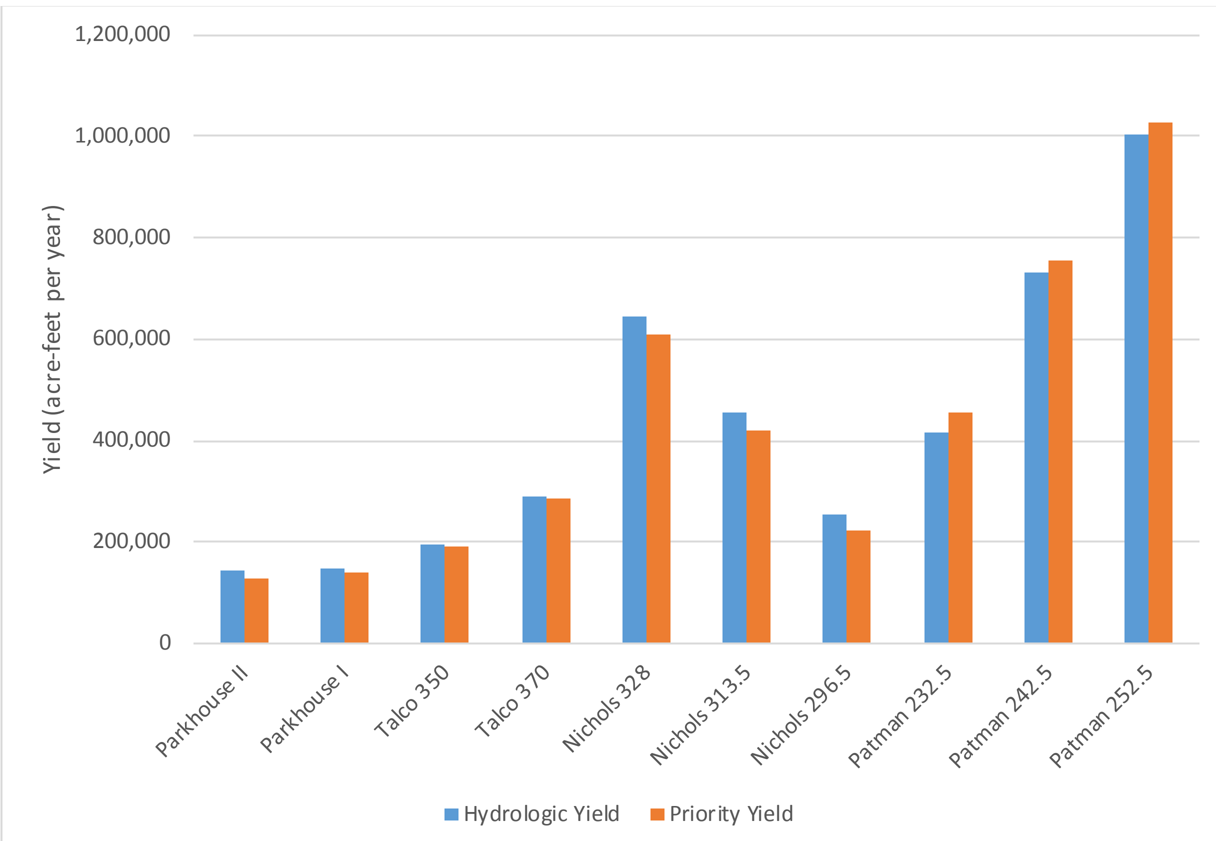


Figure 6: Comparison of Sulphur WAM Hydrologic and Priority Yields

The yields in Table 4 and Figure 6 show several trends:

- The priority yields for the proposed projects are less than the hydrologic yields. This is because the priority yields assume that the proposed projects regularly pass inflow to senior water rights (primarily Wright Patman Lake).
- The priority yields for Wright Patman Lake are higher than the hydrologic yields. This is because the Sulphur WAM assumes that upstream junior water rights will be passing flow to the senior portions of Wright Patman Lake's water right. This does not apply to the new diversions and storage associated with the reallocation. These newer authorizations would be junior to existing water rights in the basin.

The yields reported in Table 4 differ somewhat from other yields determined elsewhere in the Feasibility Study. The yields in Table 4 use the assumptions discussed in Section 2. These changes were made as part of this study to facilitate comparison with the USACE Model. Specific changes that impact the yield numbers include the use of current sediment conditions (other yields in the Feasibility Study assumed 2030 sediment conditions), and the use of a constant annual demand pattern rather than a typical municipal demand pattern. For Wright Patman Lake, the current runs include a 96 cfs low-flow release from May to October. Other Patman yields in the feasibility study only assumed a constant 10 cfs release.

5.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 SUMMARY OF FINDINGS

This report describes hydrologic yields calculated as part of the Sulphur River Basin Feasibility Study. Hydrologic yields are reservoir yields based on the inflows into the reservoirs. Inflows are not based on water right priority. The yields were determined using a USACE RiverWare Model of the Sulphur River and adjacent basins and with a modified version of the Sulphur WAM developed for the Feasibility Study. The purpose of this study was to develop an understanding of the differences between the two models.

Several modifications were identified that could be made to the two models without modifying the fundamental approach used by the two models. These modifications include using the same area-capacity data for reservoirs, low-flow release policies, demands and demand patterns for major reservoirs, and evaporation data for proposed projects. Things that could not be changed included flow data, evaporation data for existing projects, and modeling of minor water rights (minor rights are not included in the USACE Model). These items are summarized in Table 1.

A detailed comparison of hydrology may be found in Appendices B and C. During the period of historical gage records, the hydrology is very similar, with the WAM hydrology being a little lower than the USACE hydrology except for at Wright Patman Lake. During periods of estimated hydrology there was less agreement between the two datasets, but the flows were still similar.

Table 5 shows the hydrologic yields calculated for the ten proposed projects evaluated in this study. The most significant difference between the two models is the period of record. The USACE Model has hydrology through 2007, while the Sulphur WAM only has hydrology through 1996. The critical drought for the Sulphur Basin occurs between 2002 and 2006. As a result, the USACE Model necessarily gives lower yields for the proposed projects.

When yields are calculated considering only the hydrology from 1940 to 1996 (the period of record for the Sulphur WAM), the USACE Model produces higher hydrologic yields than the Sulphur WAM for the new reservoir projects. This is consistent with the higher inflows in the USACE Model when compared with the WAM model. However, other factors (time step, flood storage, etc.) that may also contribute to the differences. The impacts of these factors were not determined in this study.

Table 5: Hydrologic Yield of Proposed Projects

Project	Sulphur WAM yield (1940 to 1996)		USACE Model Yield (1940 - 1996)		USACE Model Yield (1938 - 2007)	
	cfs	ac-ft/yr	cfs	ac-ft/yr	cfs	ac-ft/yr
Parkhouse II	198.4	143,700	209.3	151,630	179.9	130,345
Parkhouse I	206.2	149,400	228.1	165,250	185.1	134,098
Talco 350	267.6	193,900	277.0	200,676	216.1	156,556
Talco 370	398.0	288,300	412.5	298,841	395.0	286,170
Nichols 328	889.1	644,100	933.3	676,141	733.1	531,111
Nichols 313.5	628.1	455,000	679.9	492,562	499.1	361,579
Nichols 296.5	352.3	255,200	365.0	264,429	320.8	232,408
Patman 232.5	572.8	415,000	490.0	354,987	442.3	320,394
Patman 242.5	1,008.3	730,450	897.0	649,843	658.2	476,841
Patman 252.5	1,386.0	1,004,100	1,341.0	971,504	861.5	624,124

Using the same 1940 to 1996 hydrology, the USACE Model has lower hydrologic yields for the Wright Patman reallocation scenarios. This appears to be the result of different approaches to modeling precipitation on the reservoir surface. The USACE Model include historical precipitation on the reservoir surface as part of the inflow into the reservoir, while the Sulphur WAM calculates the precipitation along with the evaporation. Since the Wright Patman reallocation scenarios result in a larger surface area for the reservoir (and therefore a larger area for precipitation on the reservoir surface), the USACE Model tends to underestimate yields for reallocation.

The Sulphur WAM was run using the same modeling assumptions as the hydrologic yields, except with the assumption that water rights are met in priority order. Table 4 compares the hydrologic yields to the priority yields. These yields are somewhat different than yields calculated elsewhere in the Feasibility Study because of the different modeling assumptions employed in this study. The priority yields of the proposed reservoirs are lower than the hydrologic yields. This is consistent with the assumption that these will be junior water rights that will regularly pass water to meet the needs of downstream senior rights, particularly Wright Patman Lake. The yields for the Patman reallocation scenarios are higher than the hydrologic yields, also because of the same assumption that upstream junior water rights will pass water for the senior rights.

5.2 CONCLUSIONS

These findings lead to the following conclusions:

1. When using the same assumptions, the Sulphur WAM and the USACE Model give similar results.

2. The Sulphur WAM overestimates yields because it does not include record drought conditions that occurred between 2002 and 2006.

3. The USACE Model underestimates yields for Wright Patman Lake reallocation because it includes historical precipitation on the reservoir as part of the input data rather than calculating it using the model.

4. The USACE Model can overestimate the yields of proposed projects because it does not take into account the priority system used by the State of Texas. If this system is enforced (typically through a watermaster), then the yields would be less because of the passage of water to downstream senior rights. The USACE Model can also overestimate the impact on existing projects, which would be protected by enforcement of the priority system.

5.3 RECOMMENDATIONS

The priority yields previously evaluated in the Feasibility Study are overestimated because they do not include the critical drought period from 2002 to 2006. The hydrology for the Sulphur WAM should be extended through at least 2013 to address this problem. Once this is done, it is appropriate to continue to use the Sulphur WAM to evaluate the yield of proposed projects under the priority system built into Texas water law.

The USACE model will also be useful for the Feasibility Study. In addition to its designed purpose of modeling flood operations, it could also be useful for environmental flow analyses because of the daily time step, and for operational analyses that examine the operation of proposed reservoirs while respecting the supply needed from Wright Patman Lake to meet future needs. The USACE Model has already proven useful for examining the potential impact of reallocation on International Paper. However, if the model is going to be used for further studies of the reallocation of Wright Patman Lake, the hydrology should be changed so that precipitation on the reservoir surface is calculated by the model rather than part of the inflows.

The USACE Model can overestimate the yields of new projects and underestimate the yield of existing projects because it does not take into account the priority system that governs Texas water rights. On the other hand, the Sulphur WAM (run in priority order) can underestimate the practical yields of proposed projects and overestimate the yields of existing projects because it assumes the perfect application of the priority system. In most cases it would be extremely difficult to apply the priority system so perfectly. However, the WAM does show water availability under Texas law, and unless there is some external agreement between the affected parties, new projects will need to be operated so that they protect the supply of existing projects. This issue should be addressed in future studies which examine how the proposed projected will be operated.

APPENDIX A
REFERENCES

Appendix A - References

Freese and Nichols, Inc.: Report 126 Main Database, prepared for the Texas Water Development Board, December 2008.

Freese and Nichols, Inc.: Watershed Overview Sulphur River Basin Overview, prepared for the U.S. Army Corps of Engineers, January 2014.

HDR Engineering, R.J. Brandes Company, Freese and Nichols, Inc., and the Texas Water Development Board: Report 370 Reservoir Site Protection Study, prepared for the Texas Water Development Board, July 2008.

R.J. Brandes Co.: Final Report Water Availability Modeling for the Sulphur River Basin, prepared for the Texas Natural Resources Conservation Commission, June 1999.

Texas Commission on Environmental Quality: An Order Approving the Application of Upper Trinity Region Water District for Water Use Permit No. 8521 TCEQ Docket No. 2012-00065-WR; SOAH Docket No. 582-12-5332, October 10, 2013.

Texas Water Development Board: Precipitation and Lake Evaporation, available on-line at http://www.twdb.state.tx.us/surfacewater/conditions/evaporation/index.asp.

U.S. Army Corps of Engineers: Pertinent Data – Cooper Dam and Jim Chapman Lake, available on-line at http://www.swf-wc.usace.army.mil/cgi-bin/rcshtml.pl?page=Pertinent.

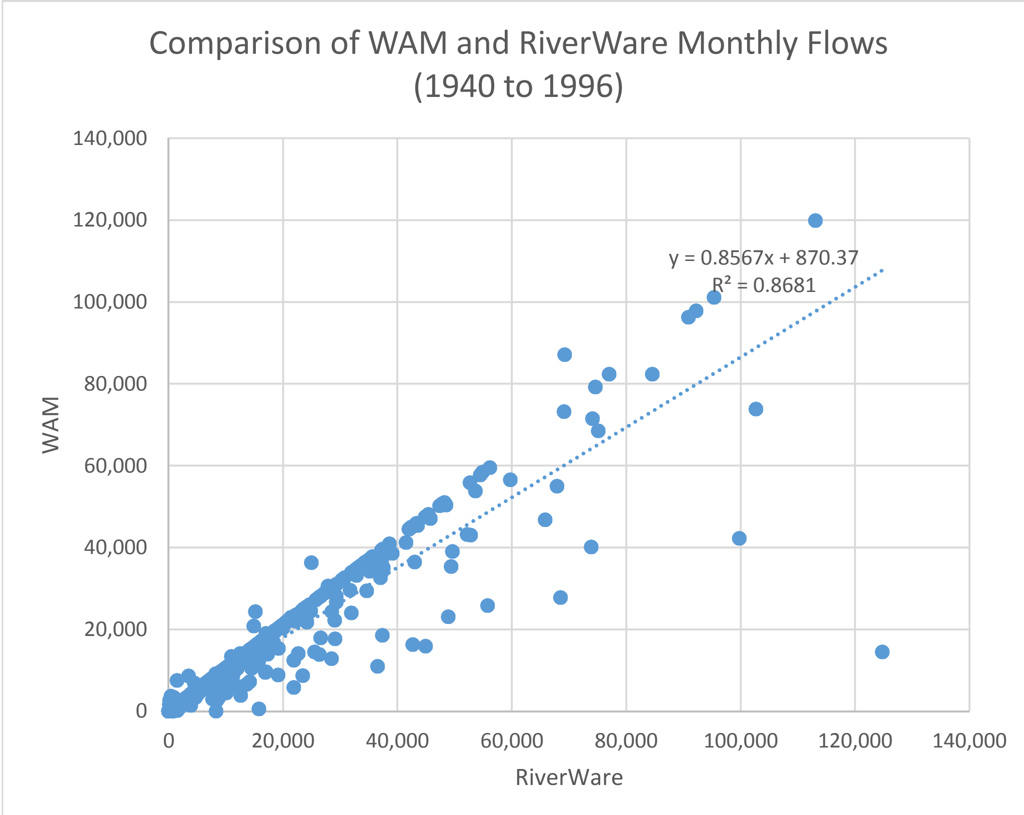
U.S. Army Corps of Engineers: Pertinent Data – Lake Wright Patman, available on-line at http://www.swf-wc.usace.army.mil/cgi-bin/rcshtml.pl?page=Pertinent.

U.S. Army Corps of Engineers, Fort Worth District: DRAFT Sulphur Hydrology Update Write-Up, December 2013.

U.S. Geological Survey: Historical gage flows for the Sulphur Basin, available on-line at http://waterdata.usgs.gov/tx/nwis/dv?referred_module=sw.

APPENDIX B
COMPARISON OF WAM AND USACE HYDROLOGY

Figure B-1: 7343000 N Sulphur Nr Cooper



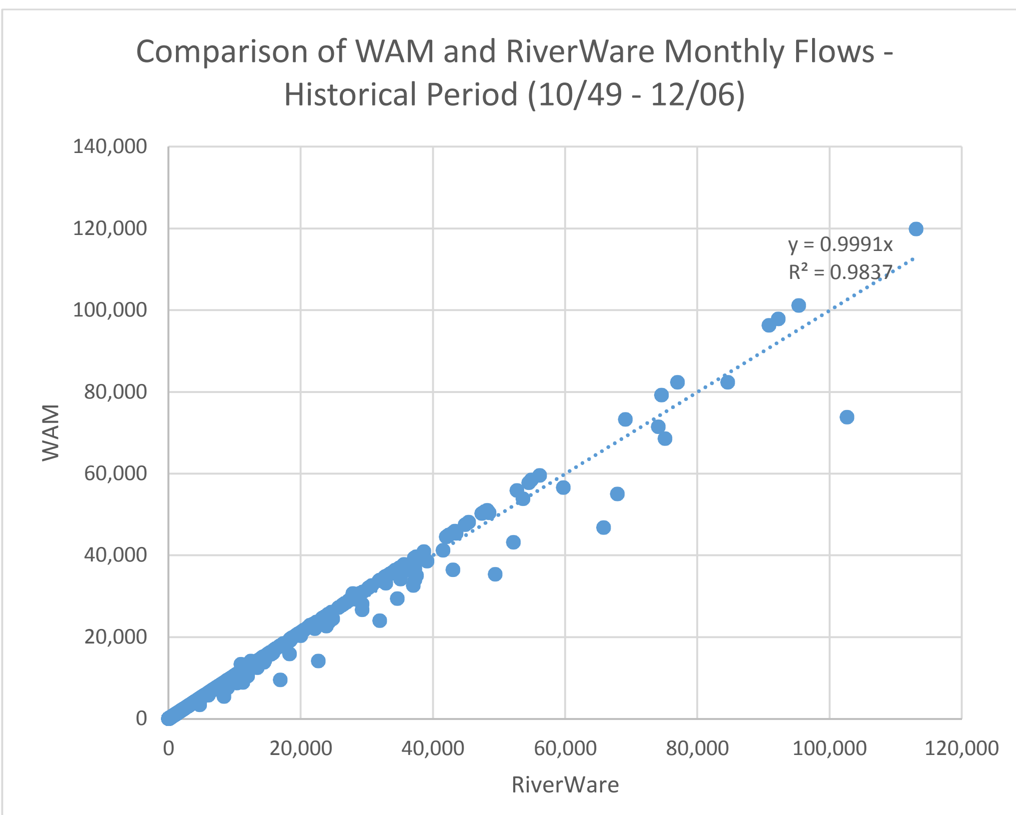
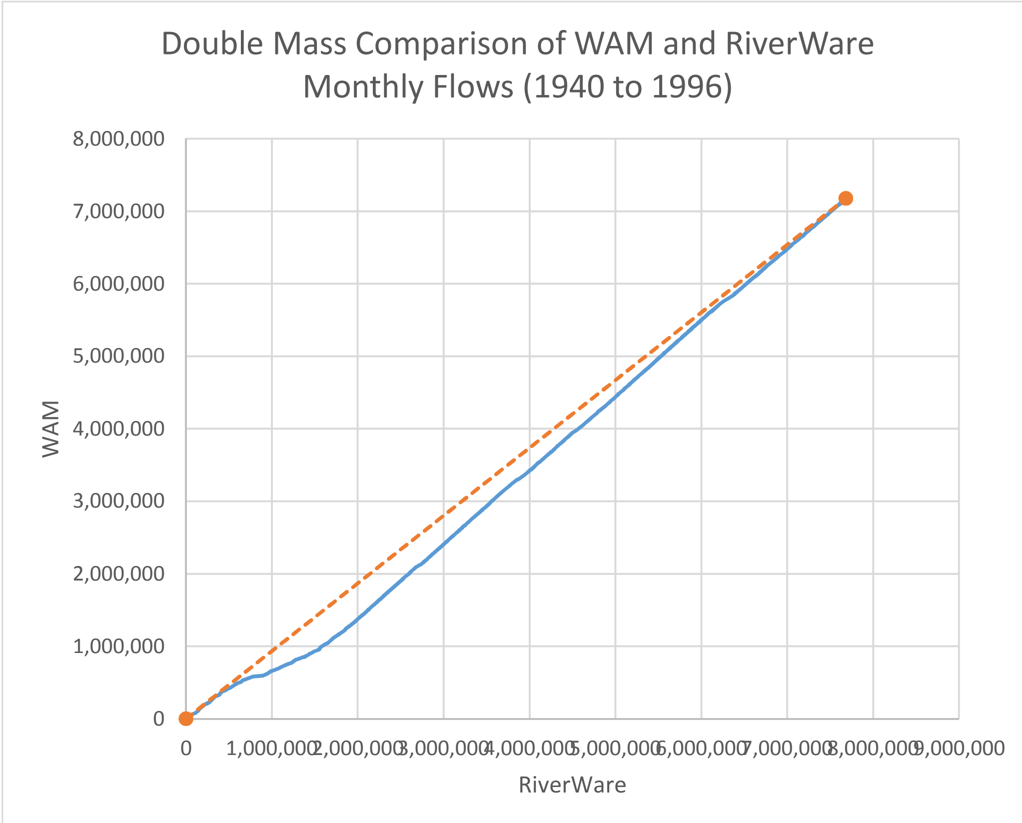


Figure B-1: 7343000 N Sulphur Nr Cooper



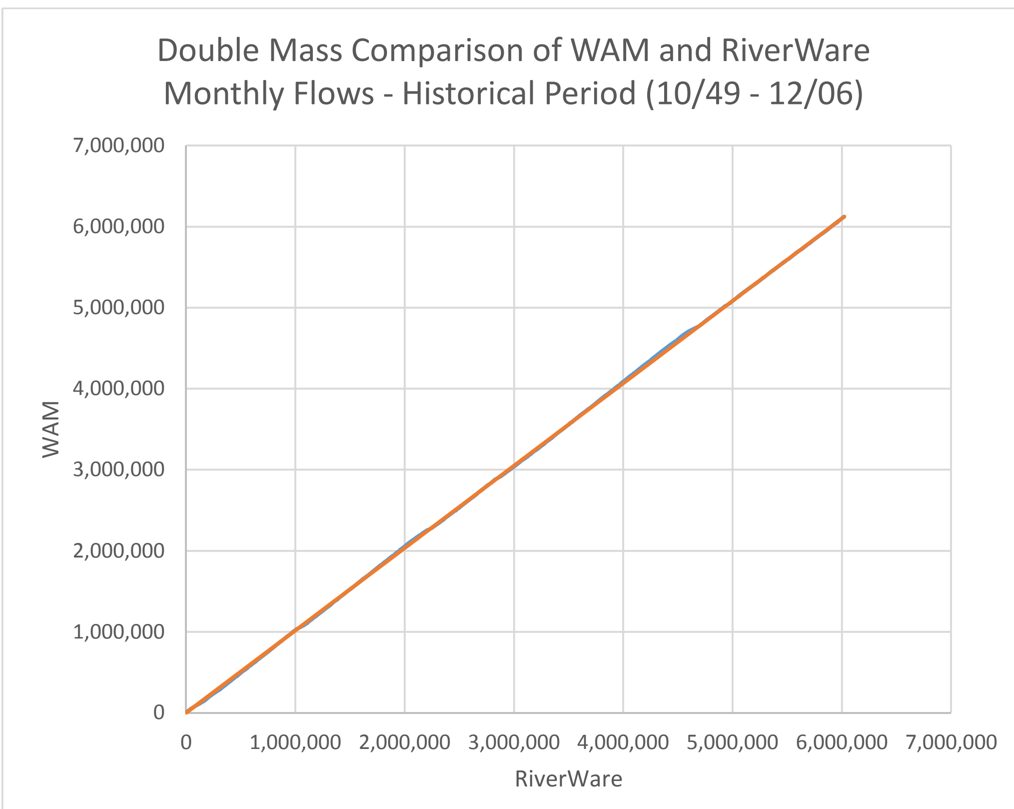
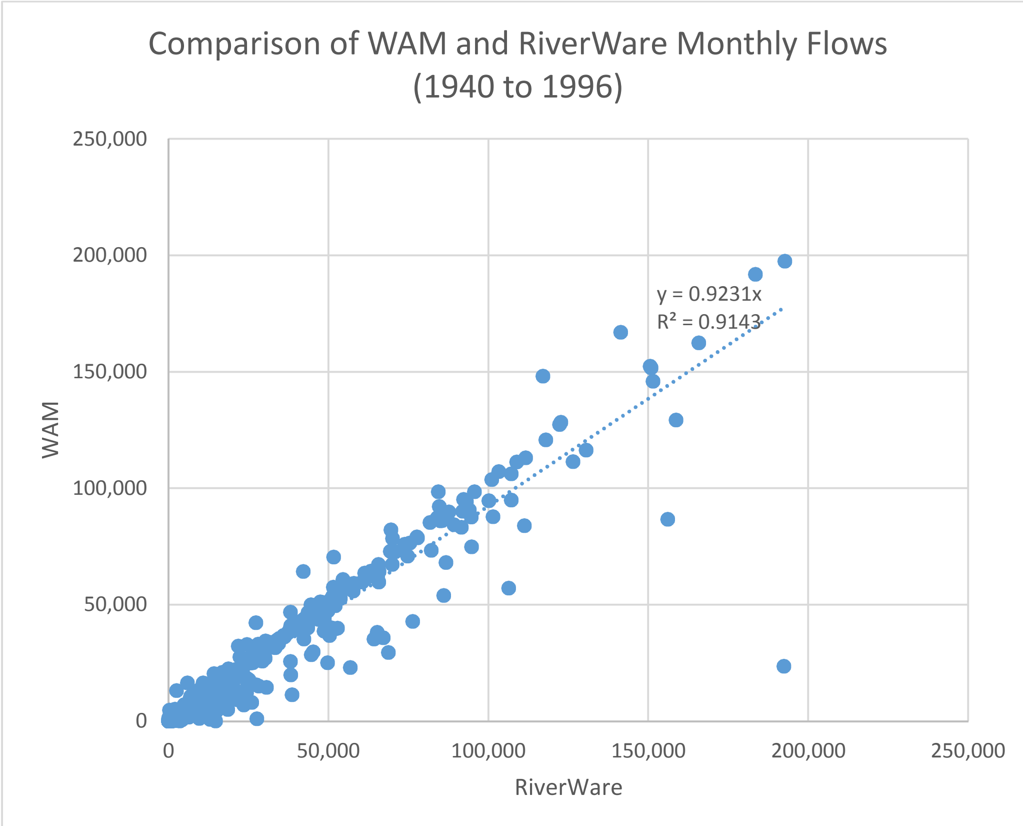


Figure B-2: Parkhouse II Inflows



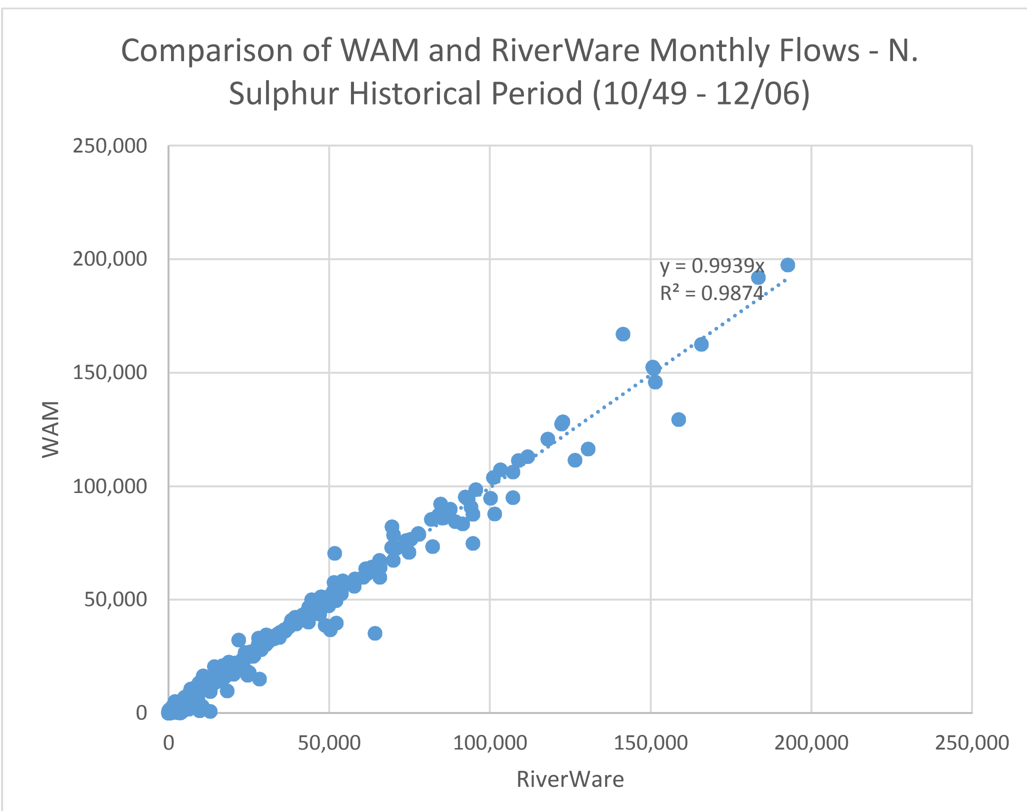
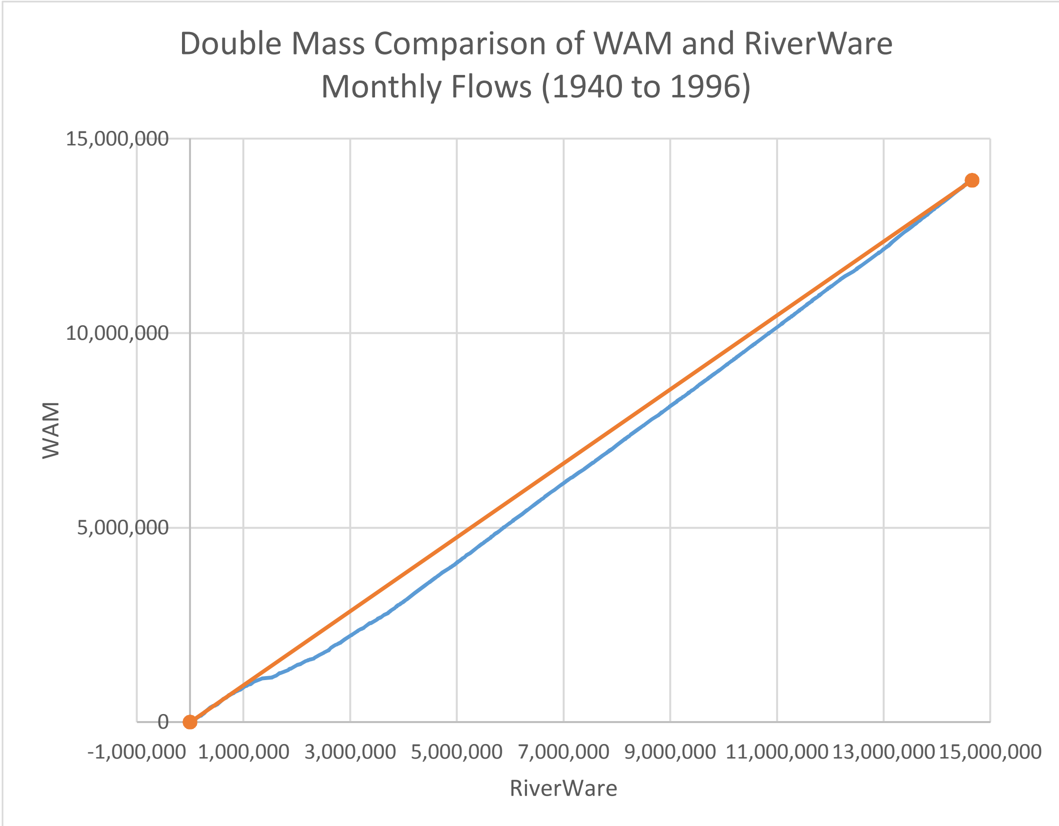


Figure B-2: Parkhouse II Inflows



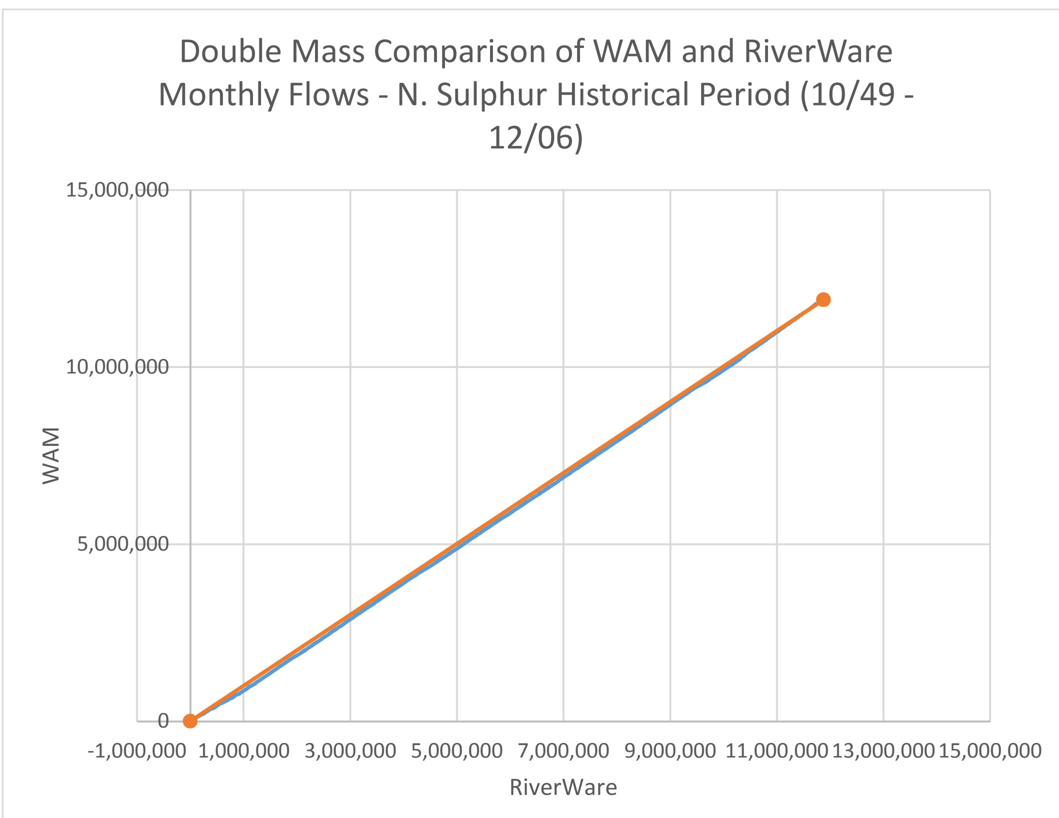
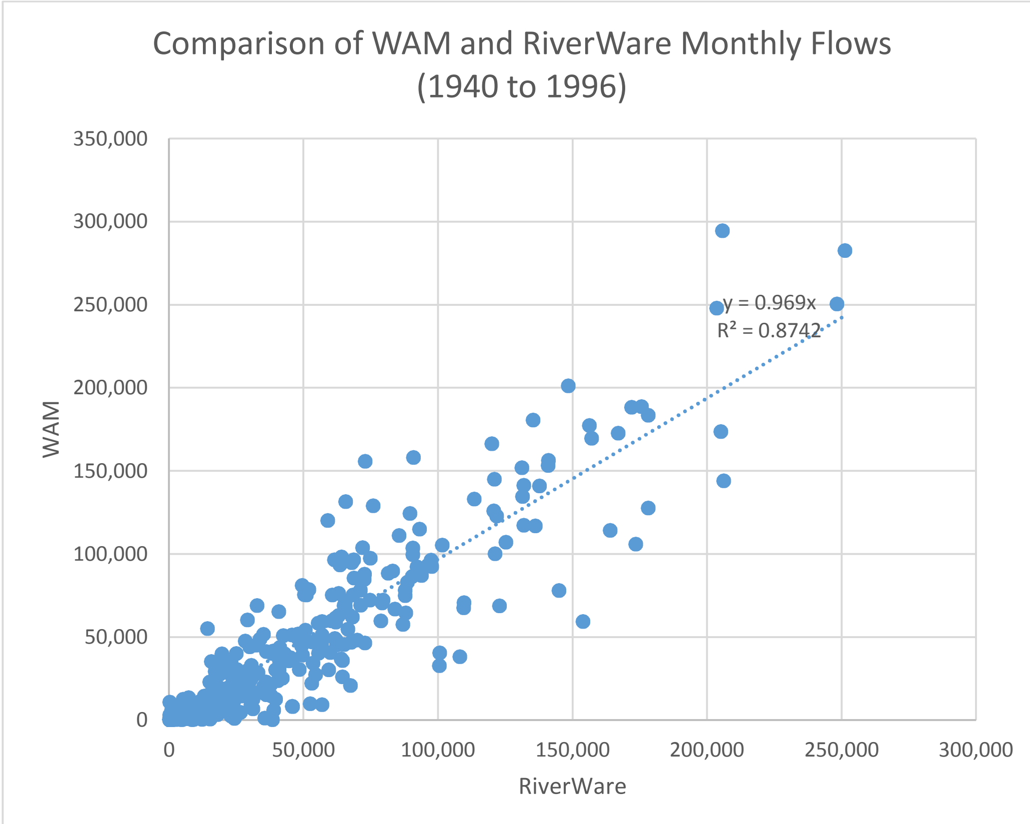


Figure B-3: Parkhouse I Inflows



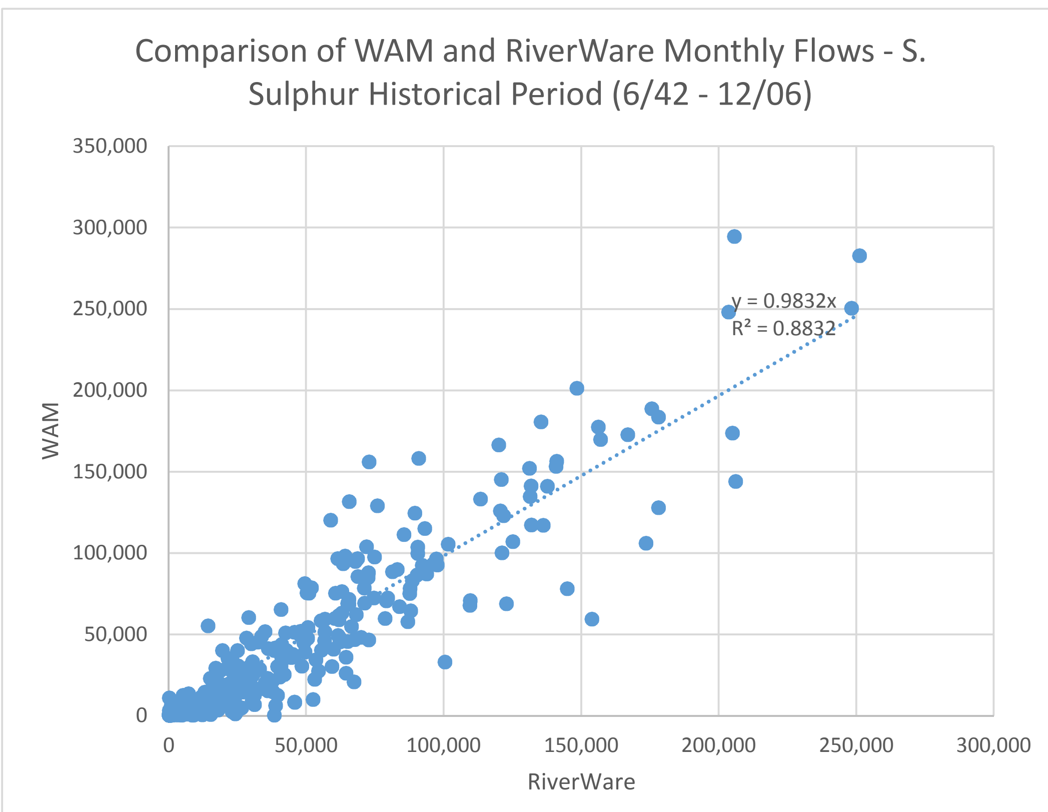
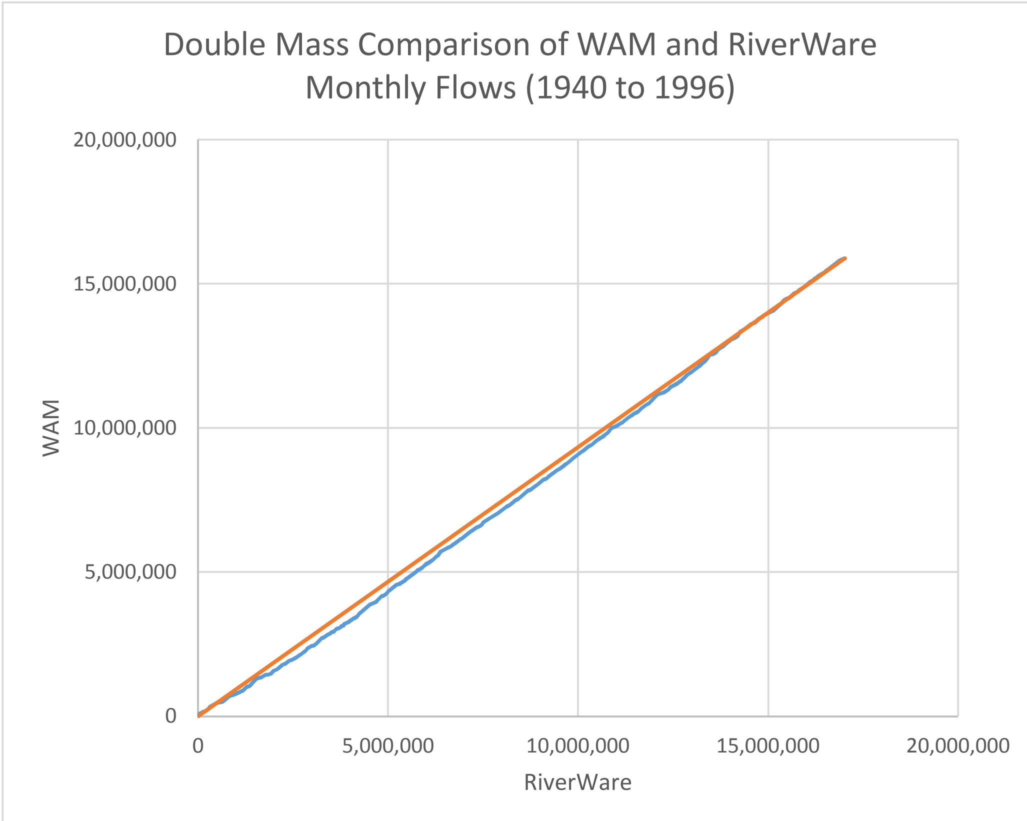


Figure B-3: Parkhouse I Inflows



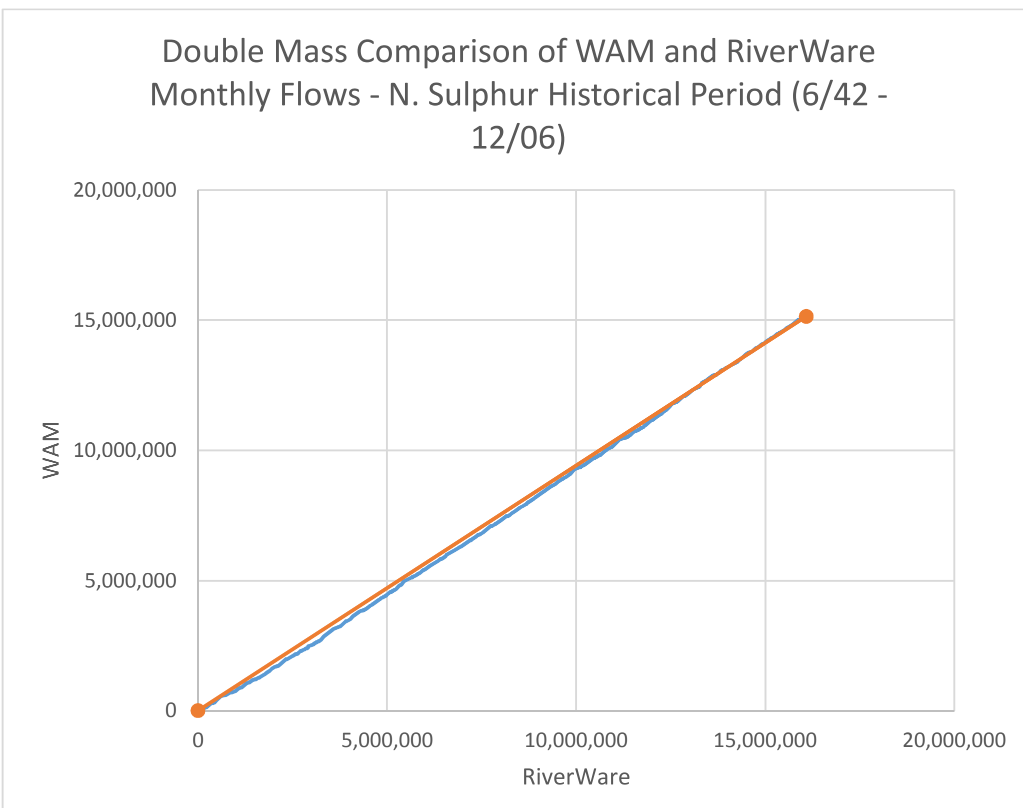
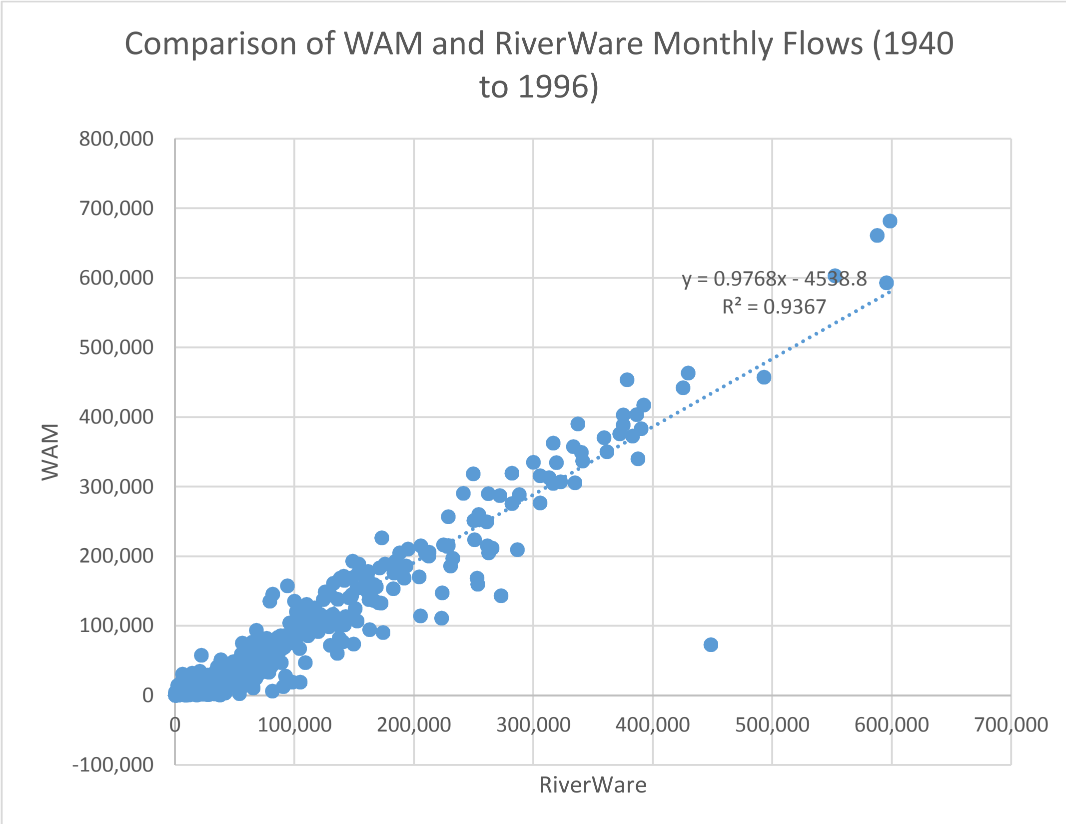


Figure B-4: 7343200 Sulphur River nr Talco



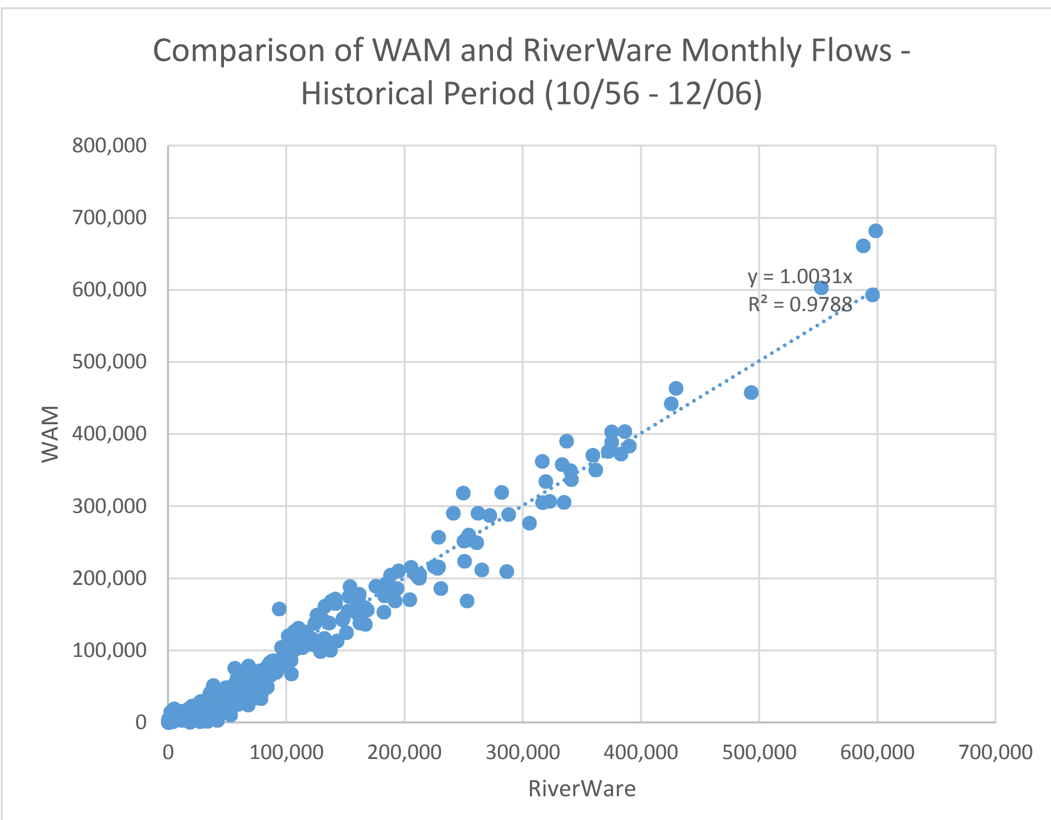
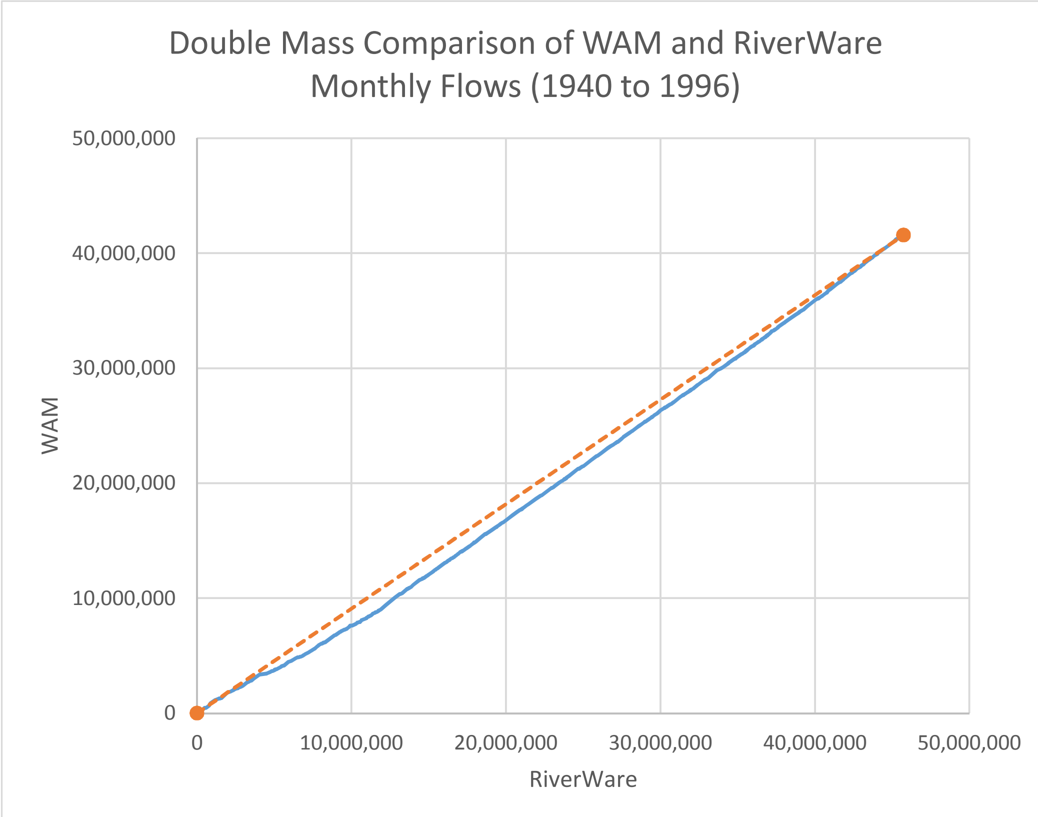


Figure B-4: 7343200 Sulphur River nr Talco



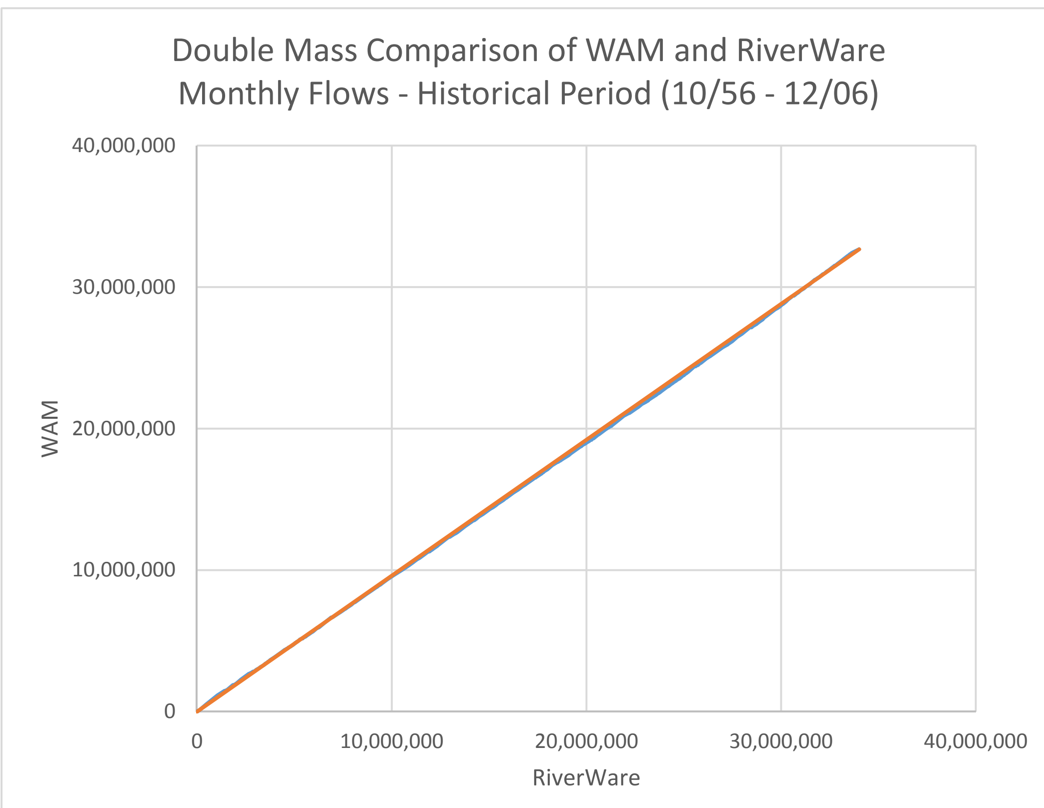
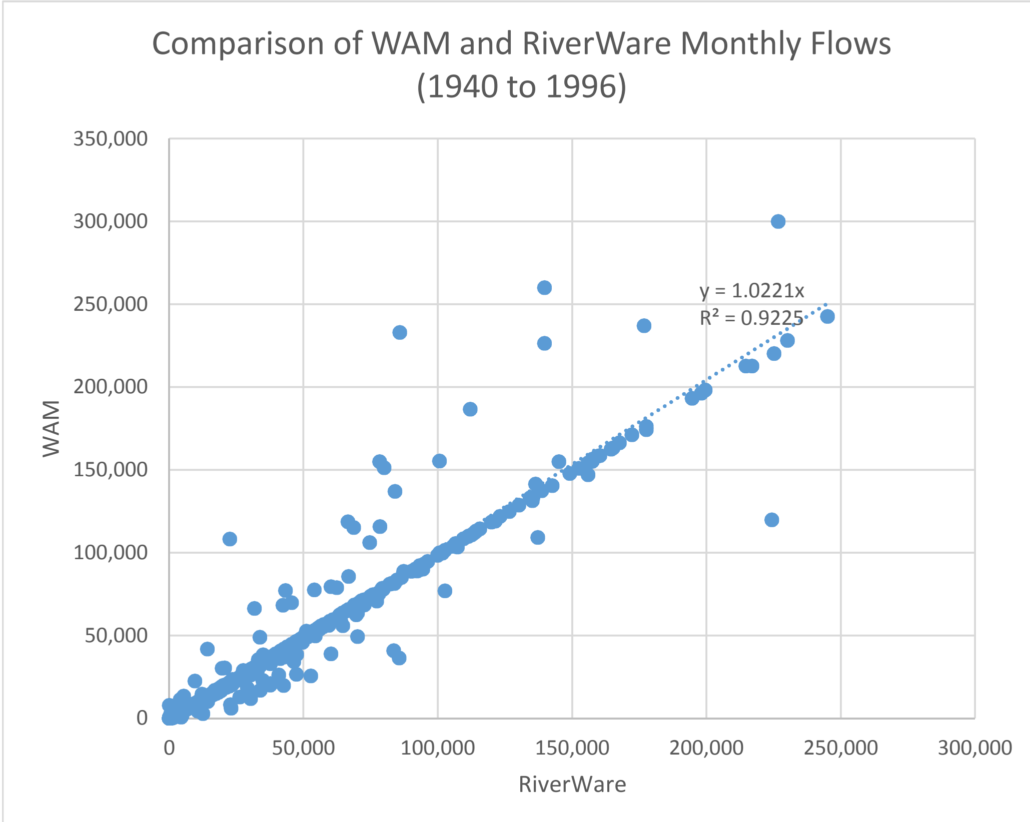


Figure B-5: 7343500 White Oak Cr nr Talco (Talco Site)



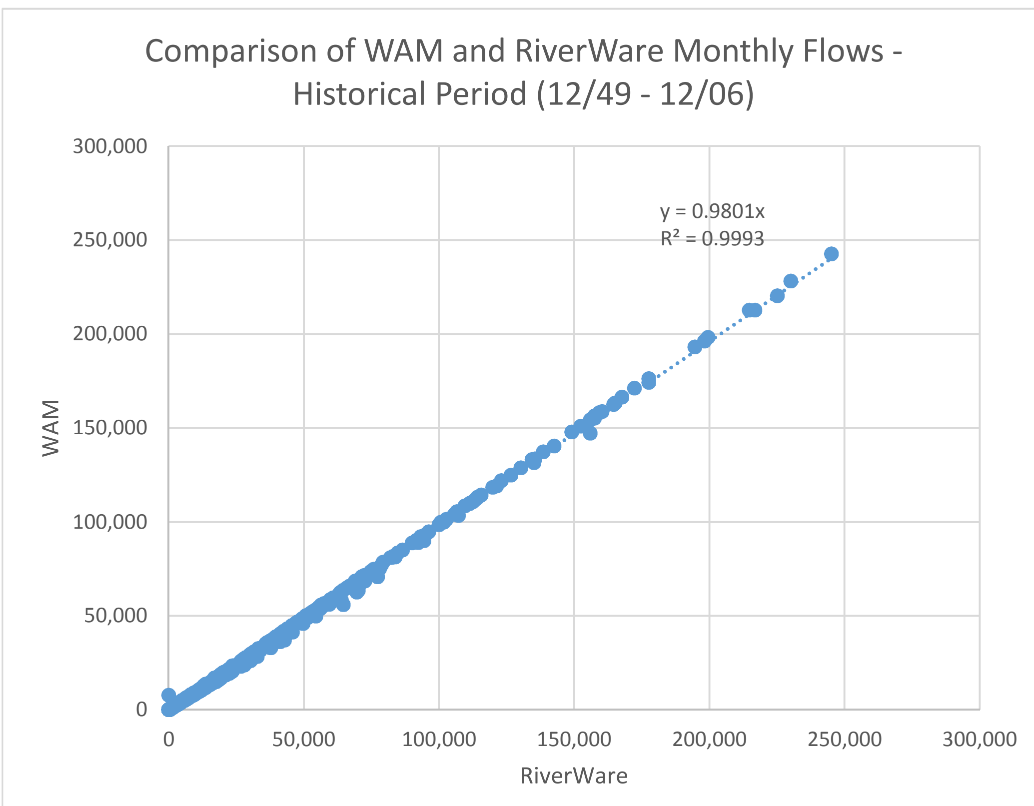
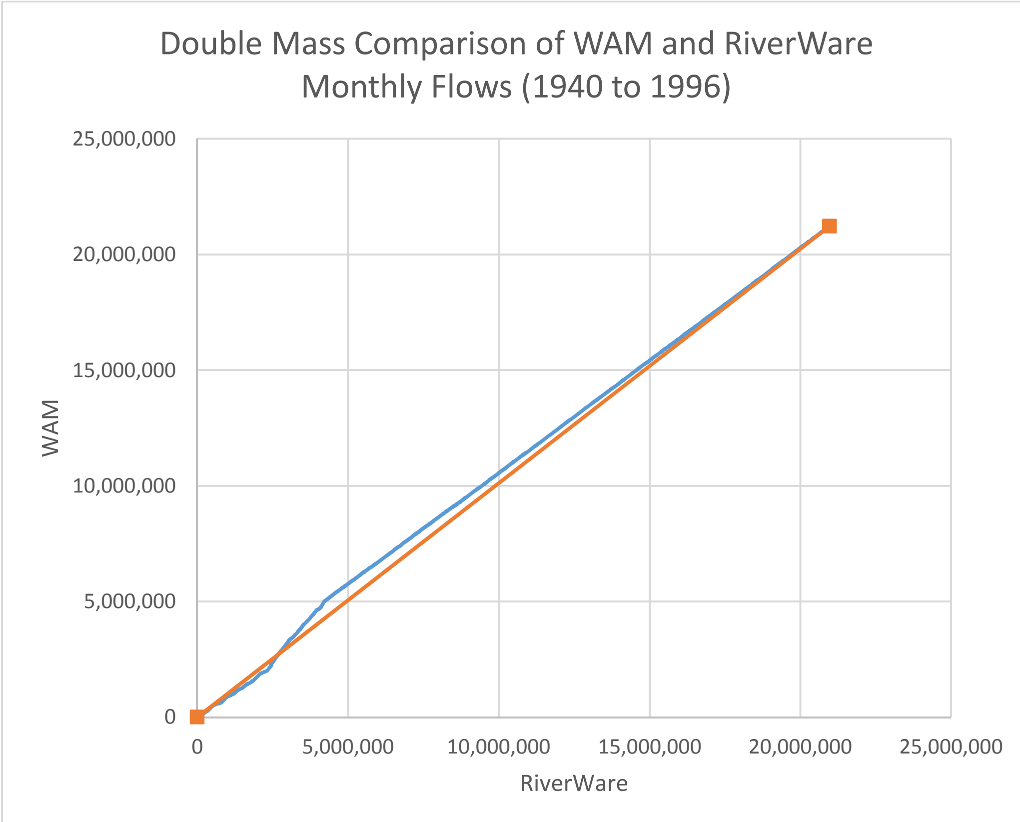


Figure B-5: 7343500 White Oak Cr nr Talco (Talco Site)



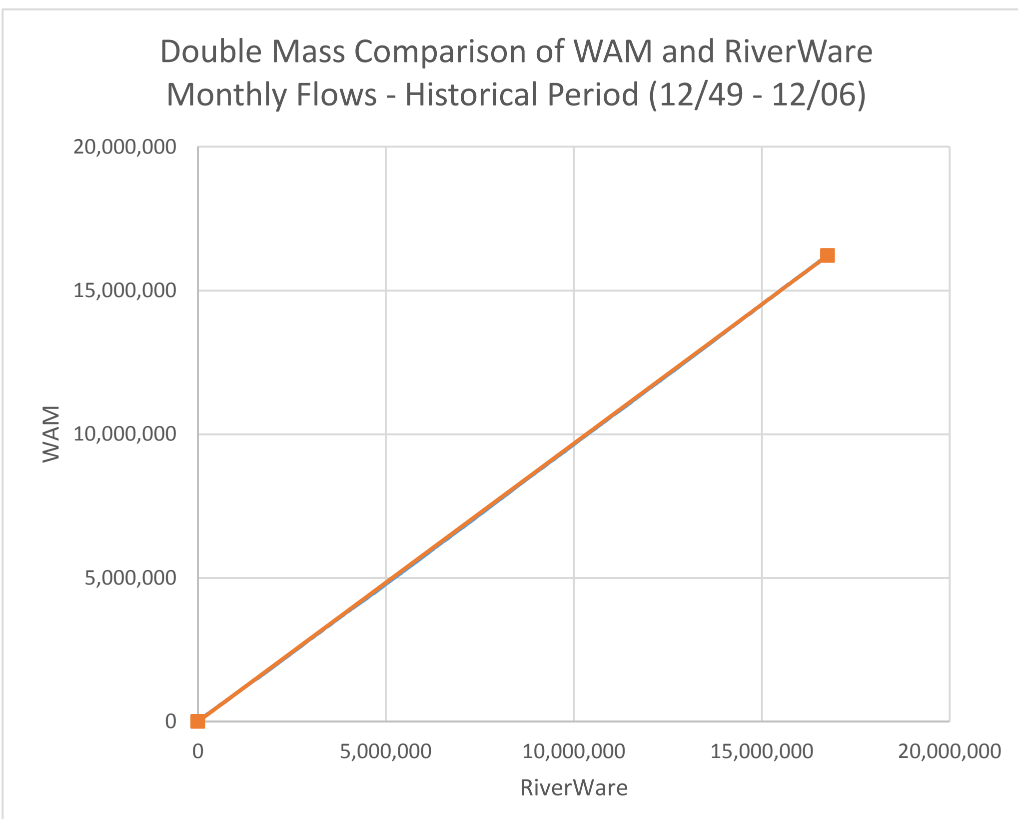
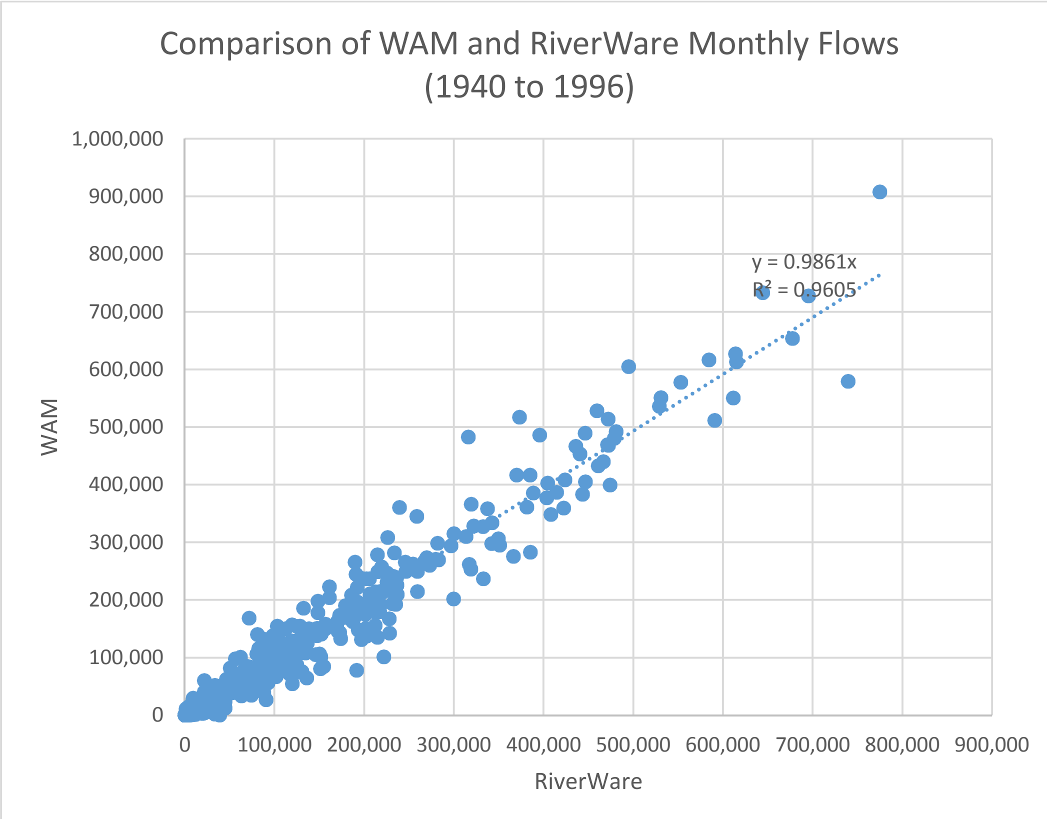
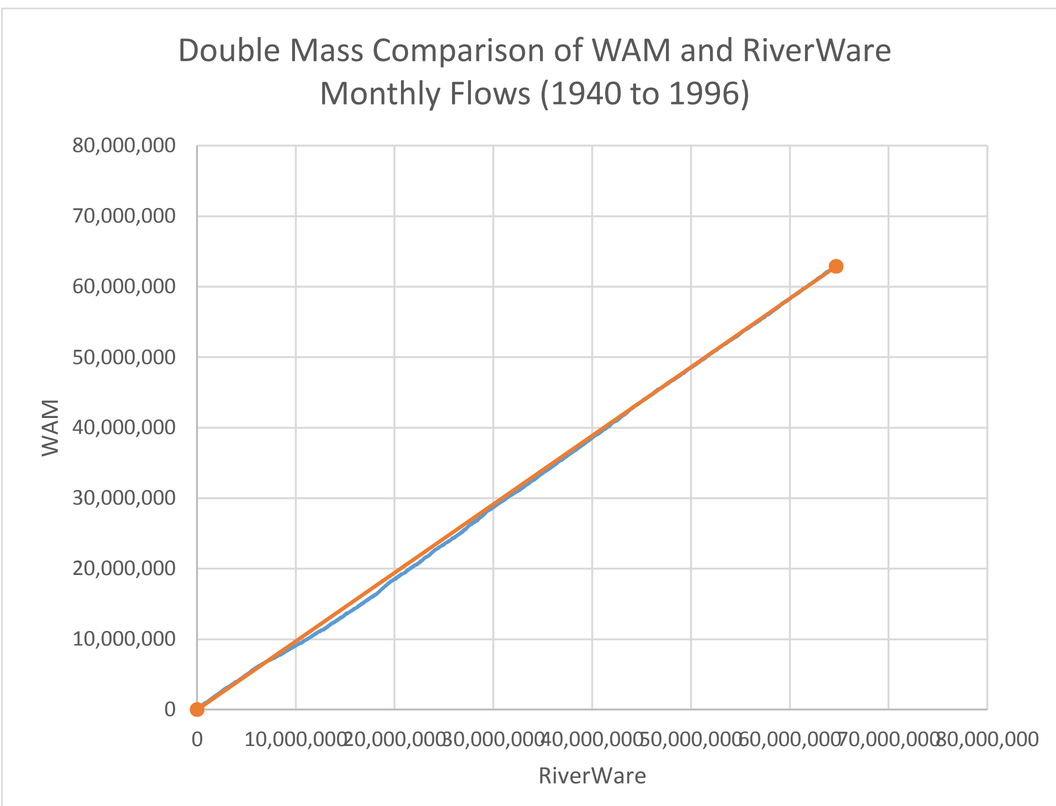


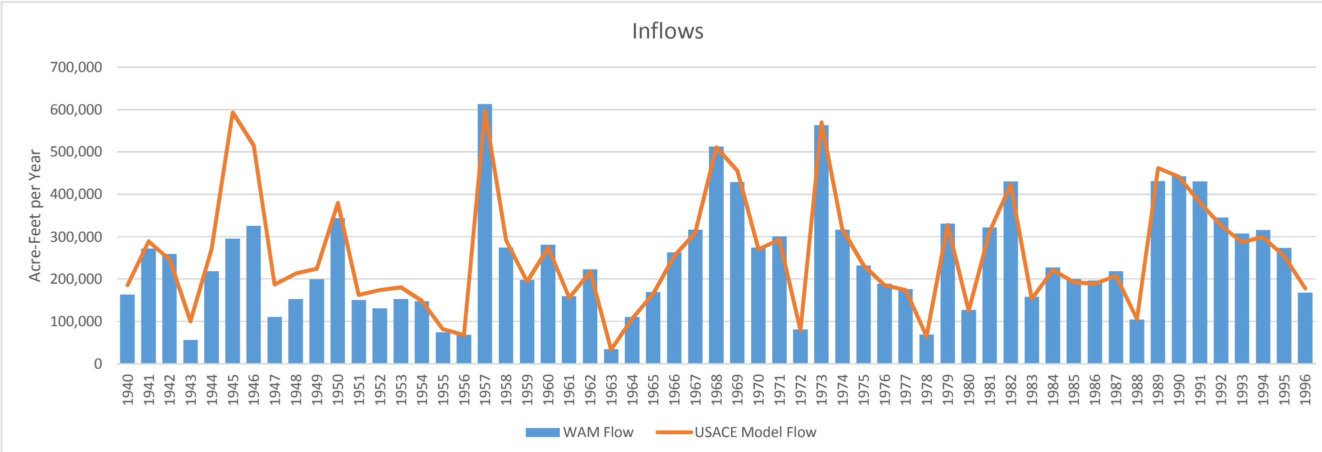
Figure B-6: Marvin Nichols Inflows

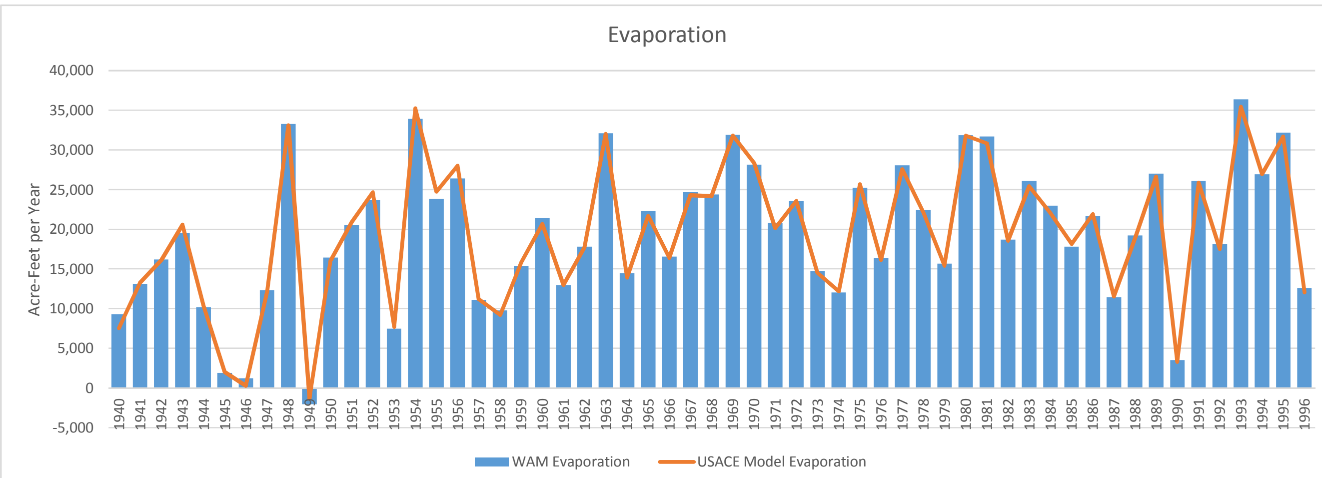




APPENDIX C
COMPARISON OF ANNUAL INFLOWS, OUTFLOWS AND EVAPORATION LOSS

Figure C-1: Parkhouse II - Annual Inflows, Evaporative Loss and Outflows





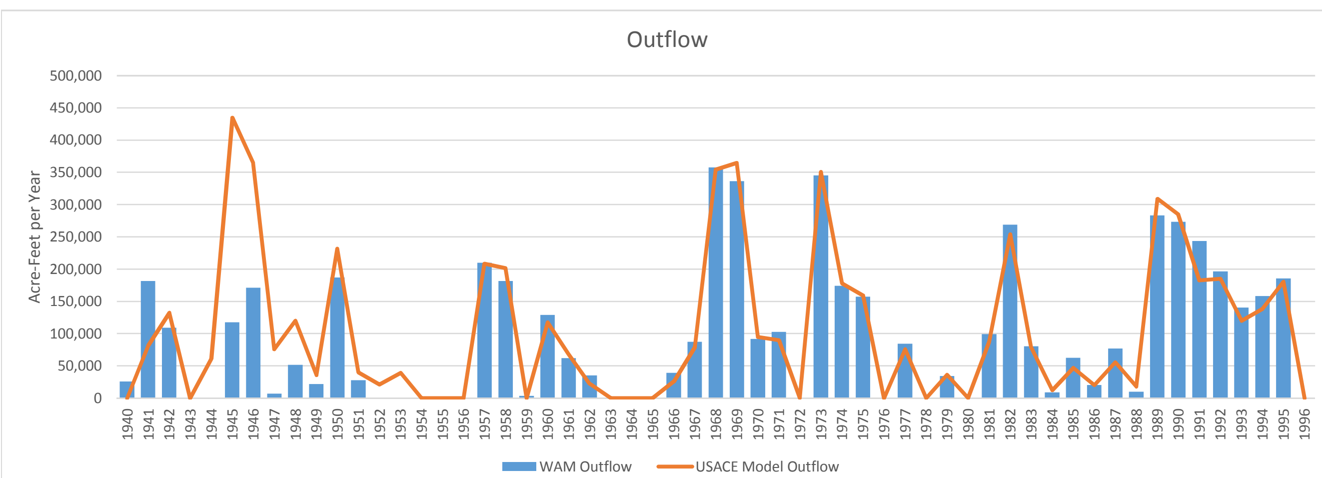
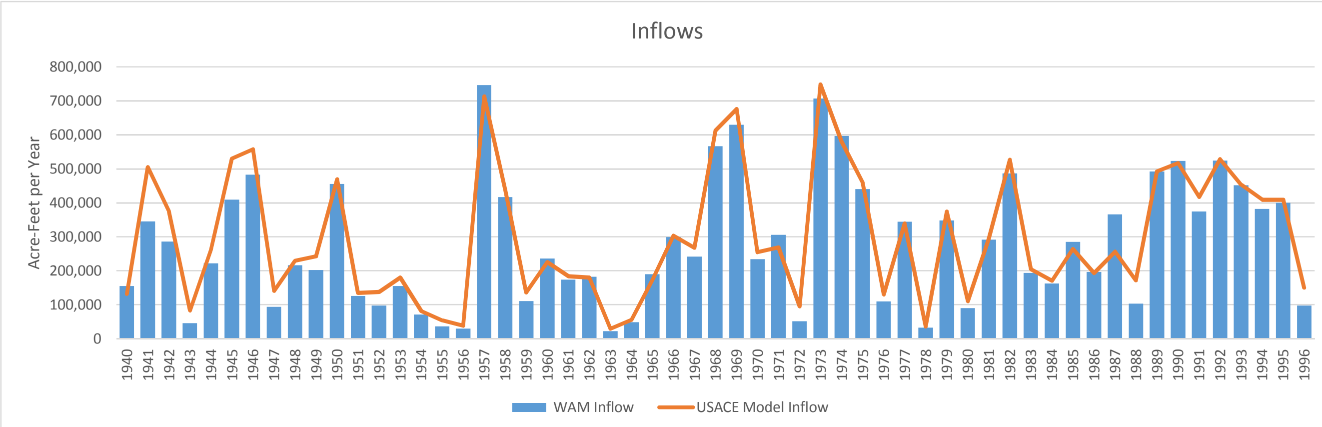
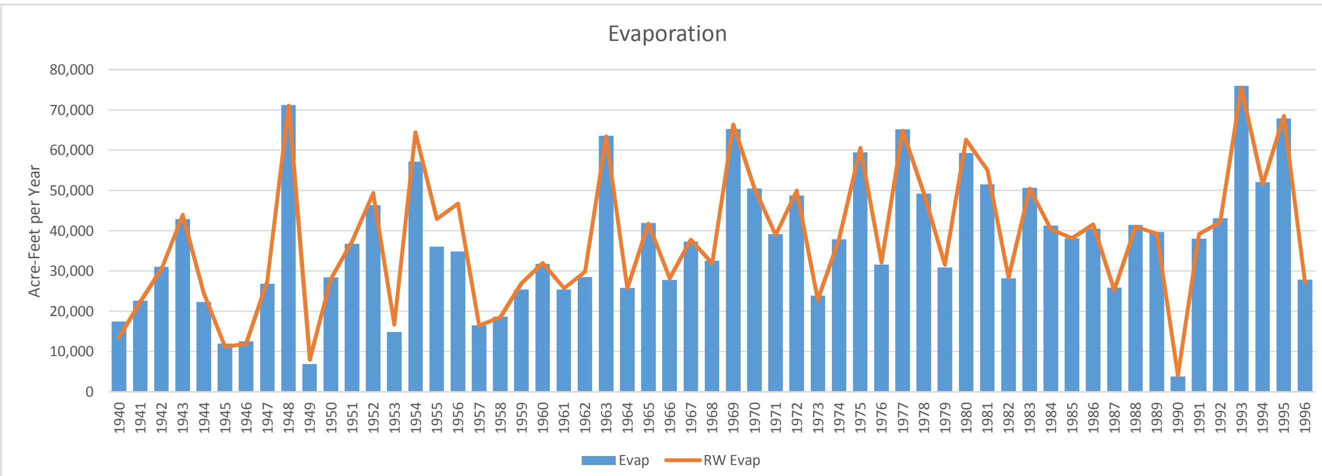


Figure C-2: Parkhouse I - Annual Inflows, Evaporative Loss and Outflows





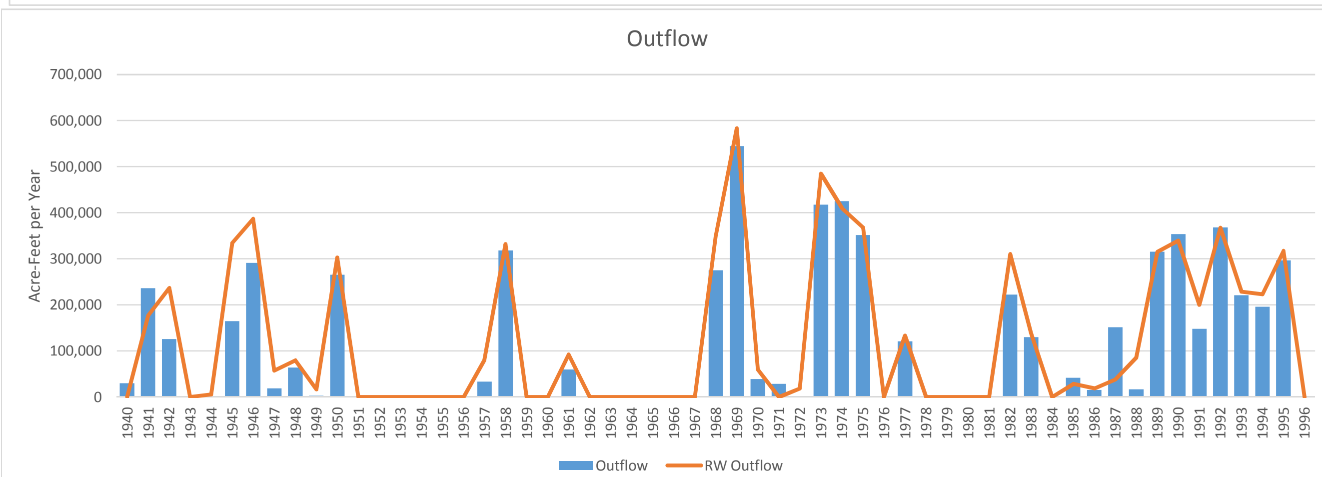
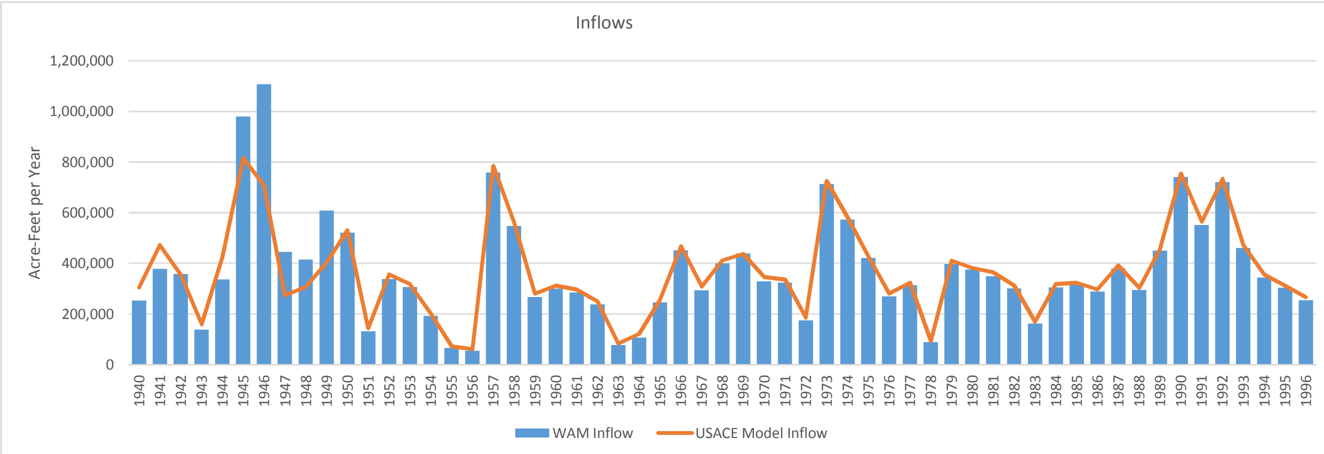
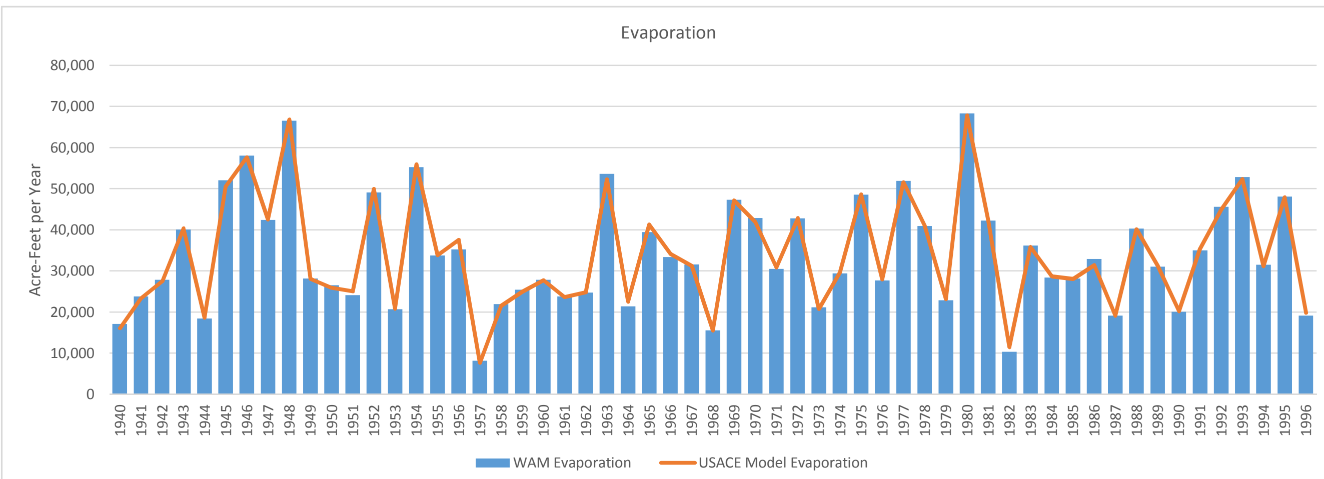


Figure C-3: Talco Conservation at 350 ft - Annual Inflows, Evaporative Loss and Outflows





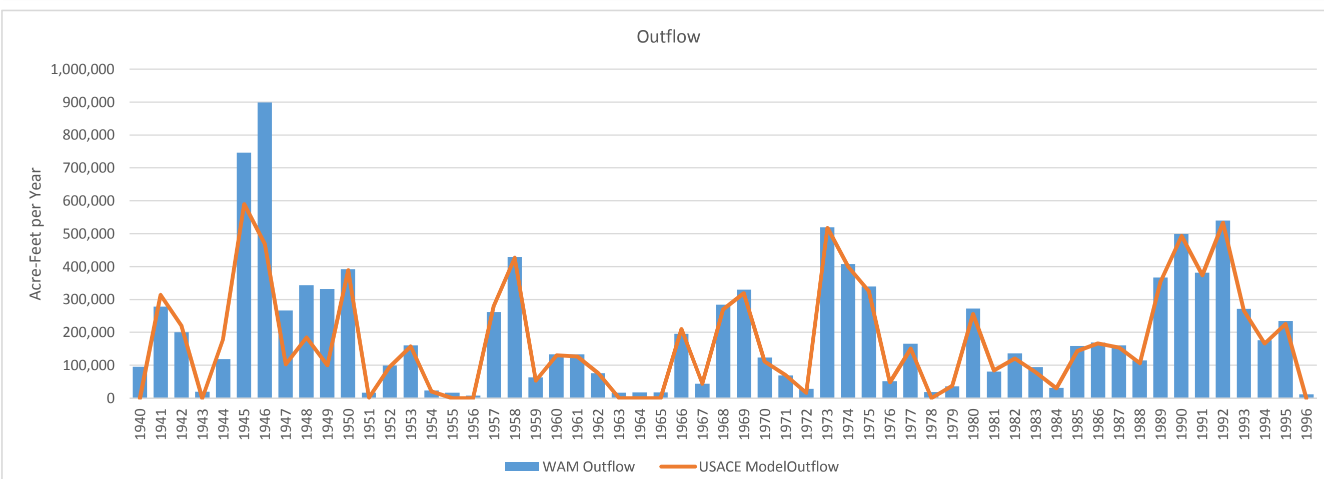
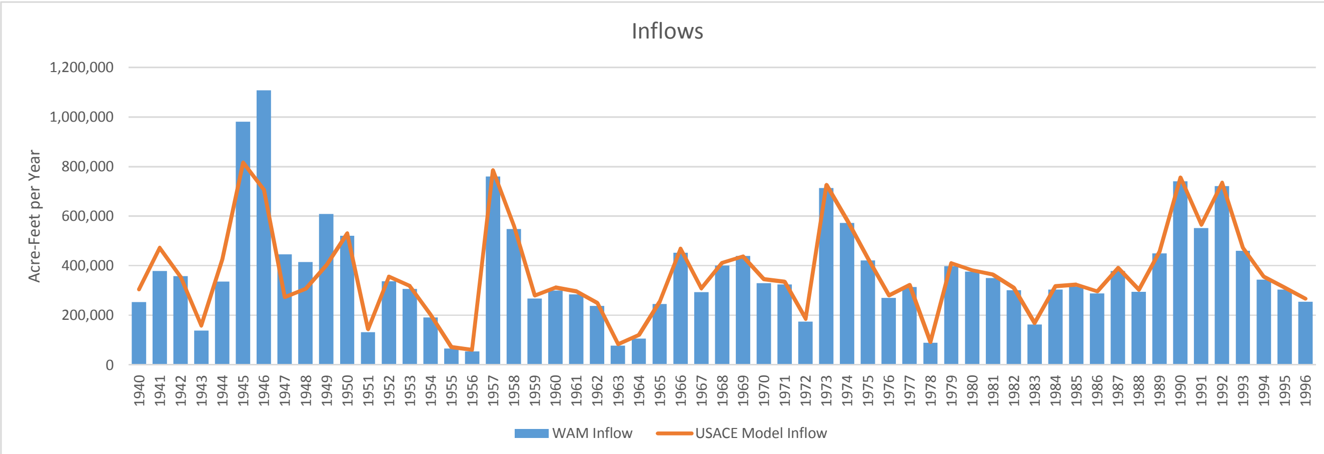
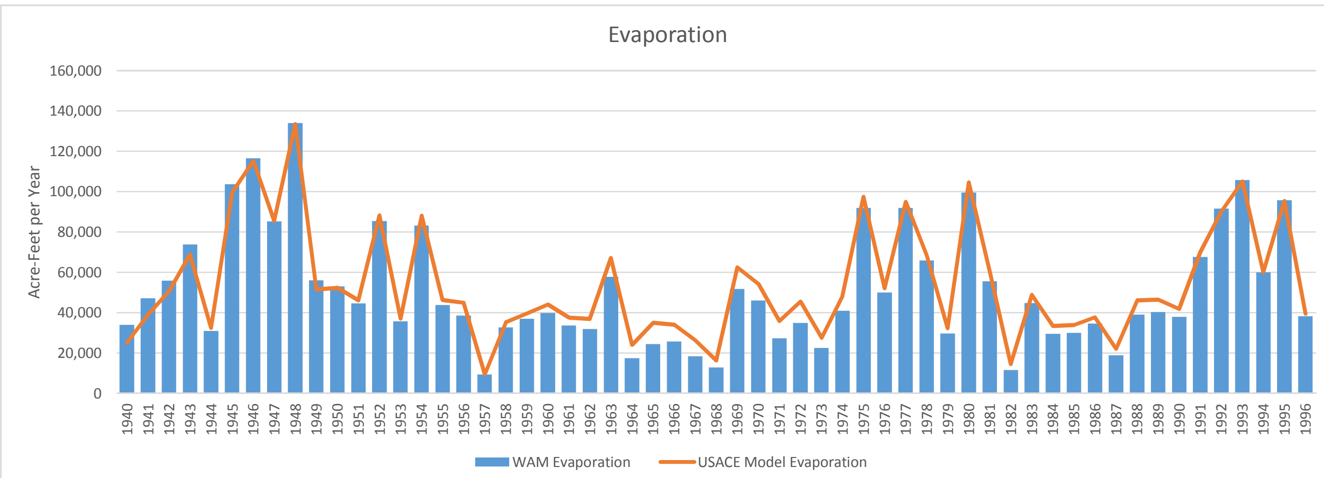


Figure C-4: Talco Conservation at 370 ft - Annual Inflows, Evaporative Loss and Outflows





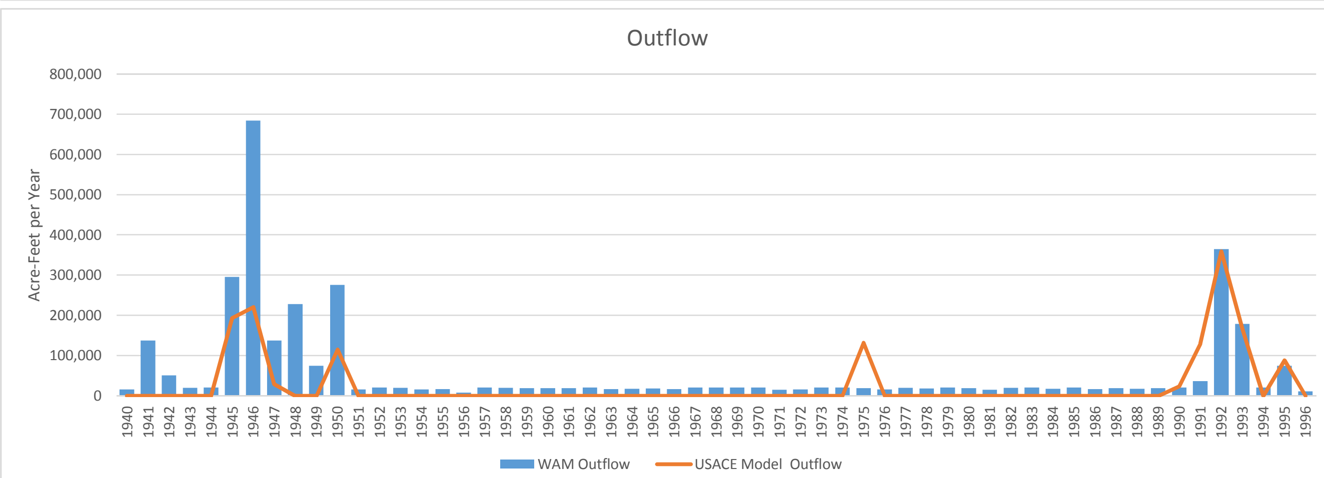
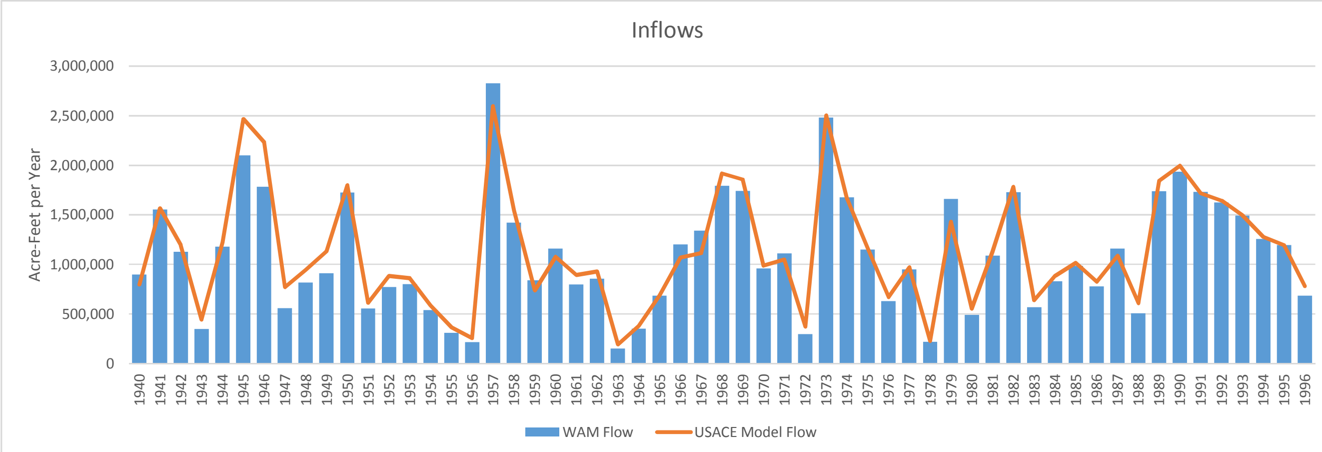
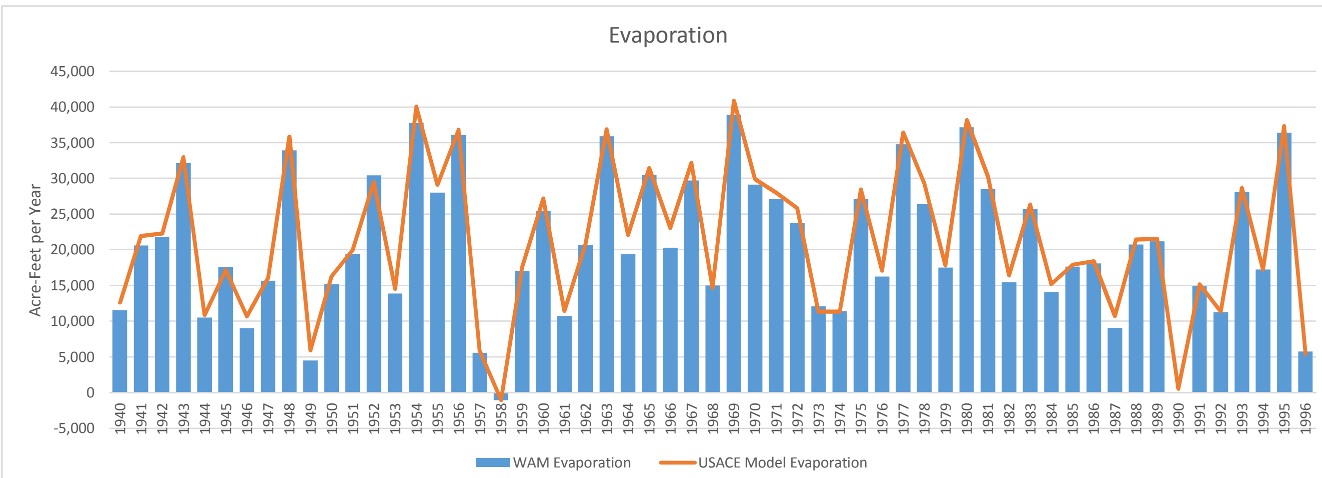


Figure C-5: Marvin Nichols at 296.5 ft - Annual Inflows, Evaporative Loss and Outflows





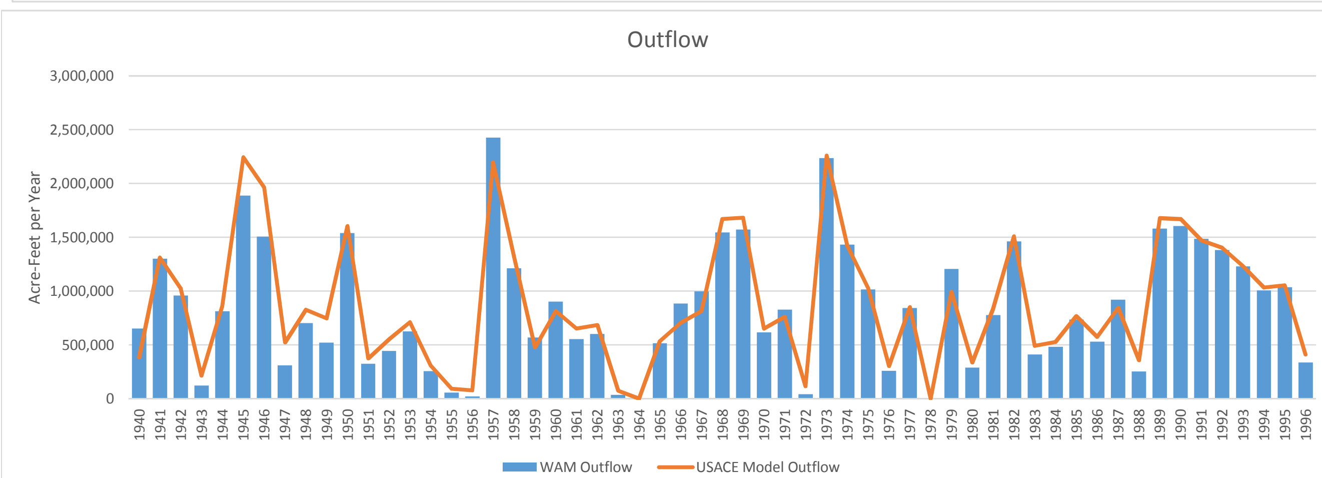
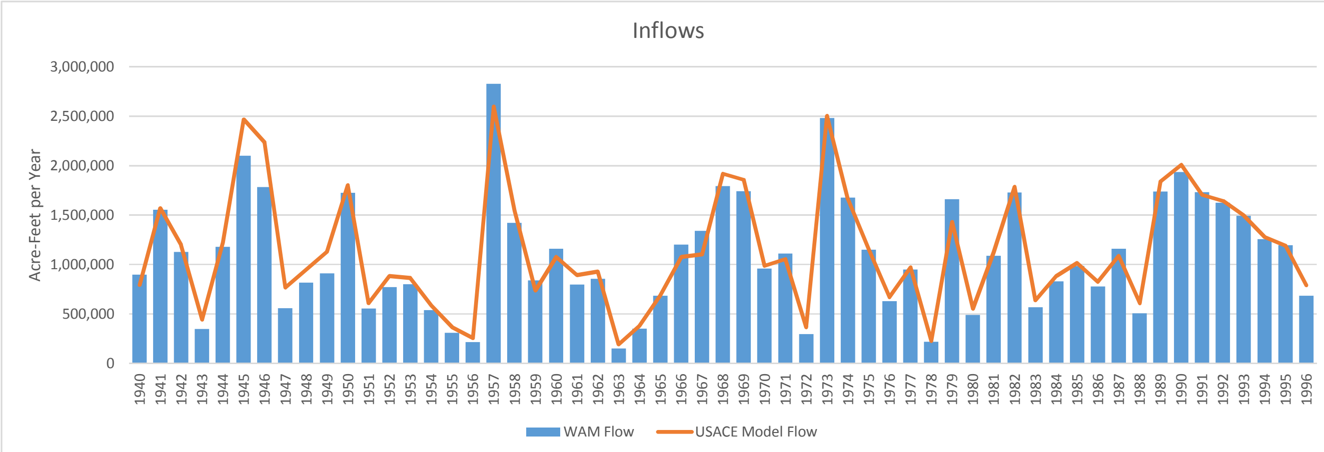
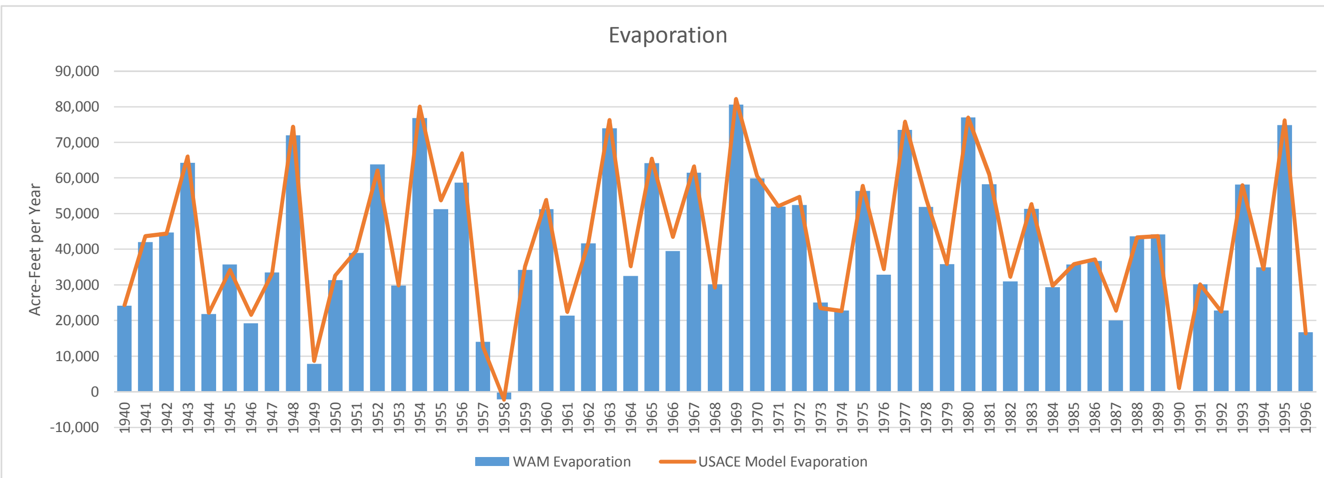


Figure C-6: Marvin Nichols Conservation 313.5 ft - Annual Inflows, Evaporative Loss and Outflows





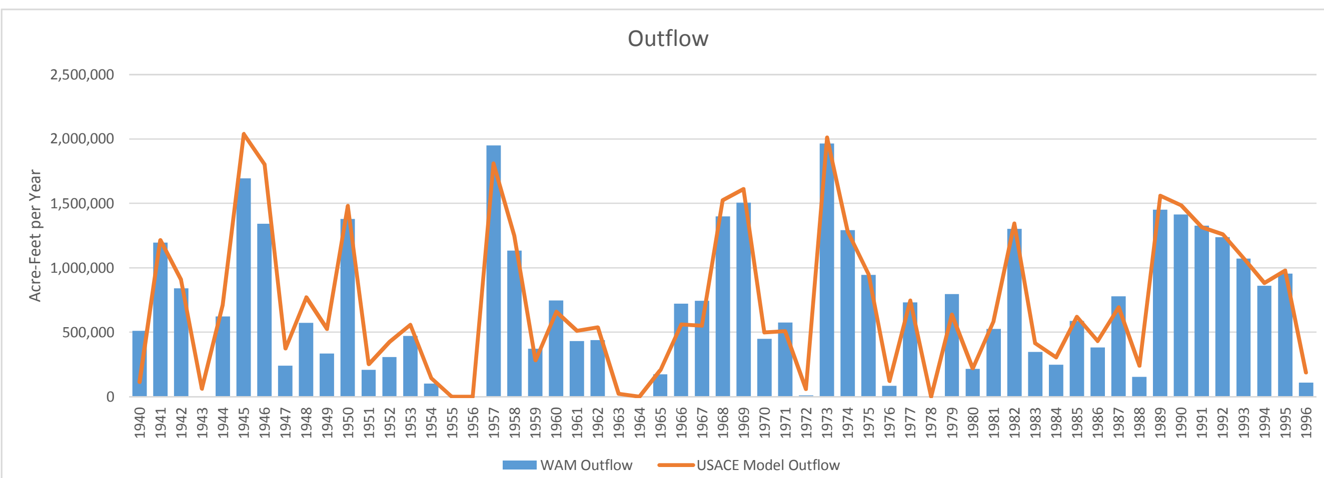
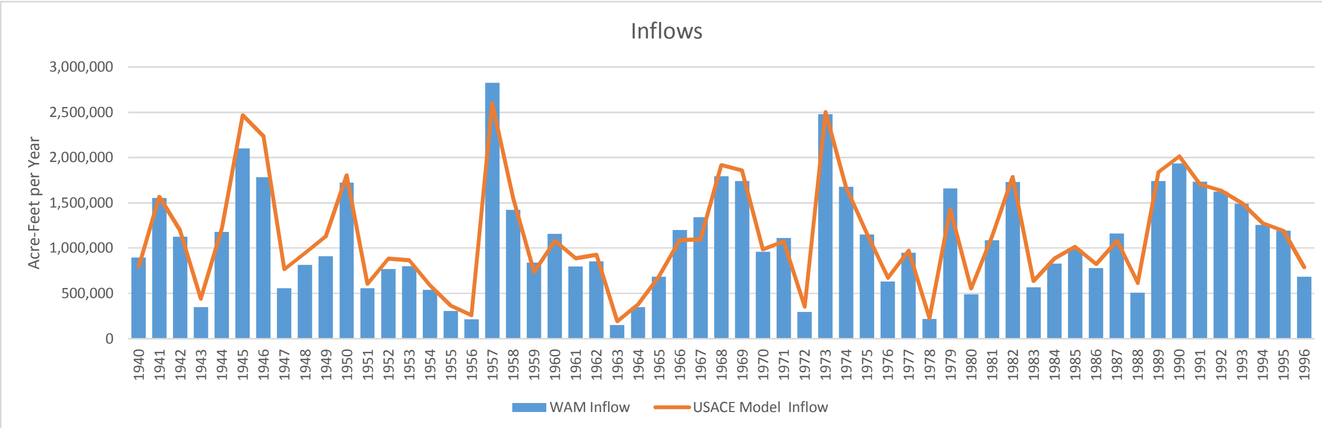
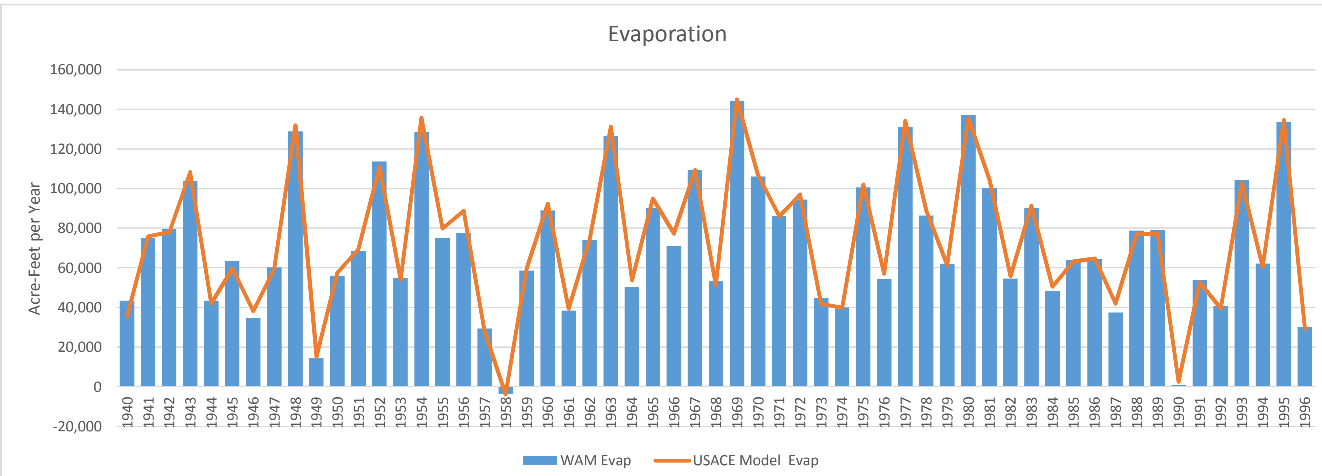


Figure C-7: Marvin Nichols Conservation at 328 - Annual Inflows, Evaporative Loss and Outflows





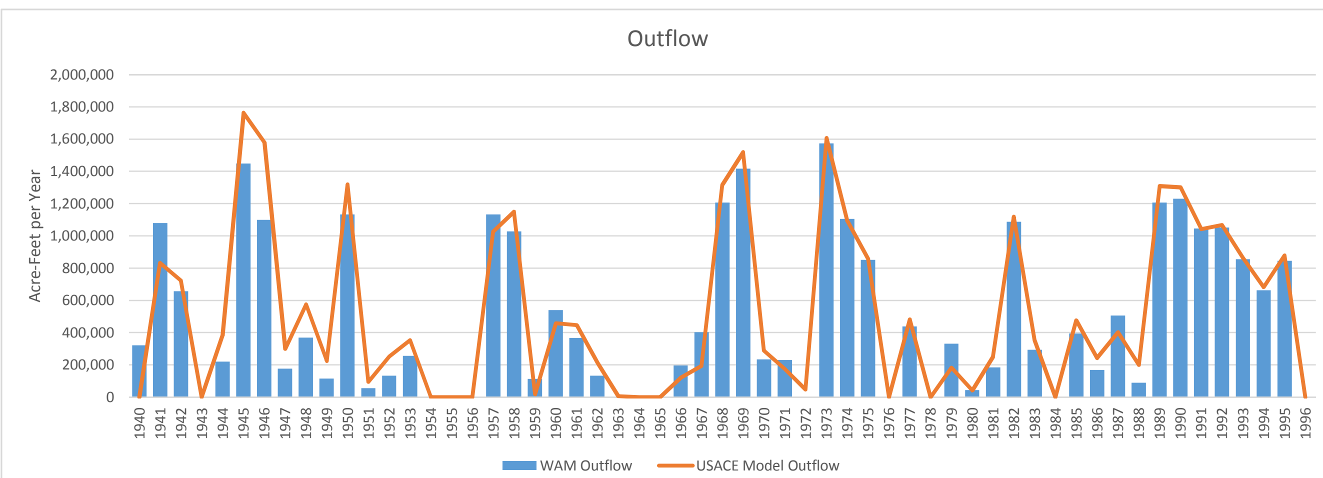


Figure C-8: Patman Conservation at 232.5 ft - Annual Inflows, Evaporative Loss and Outflows

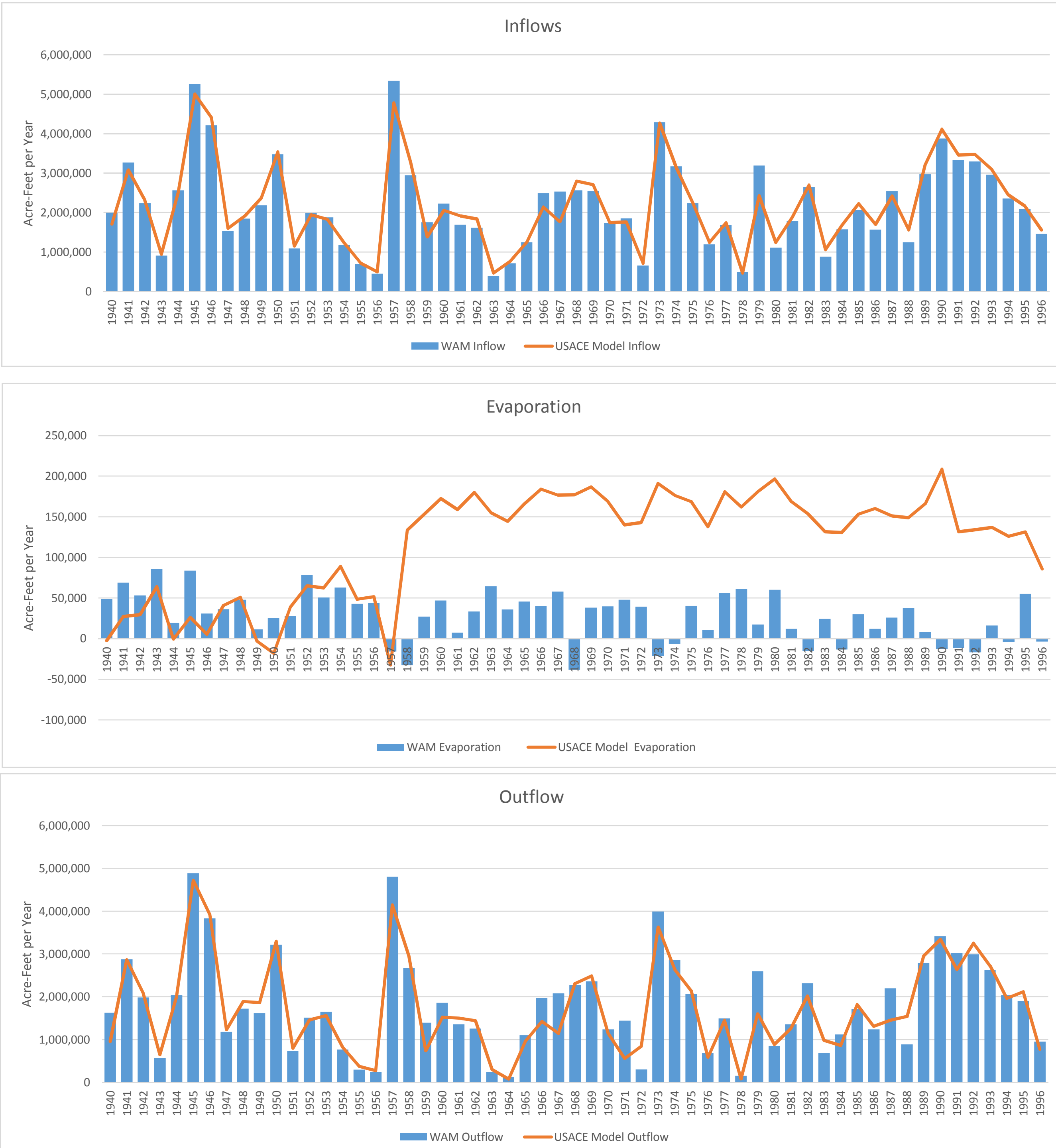
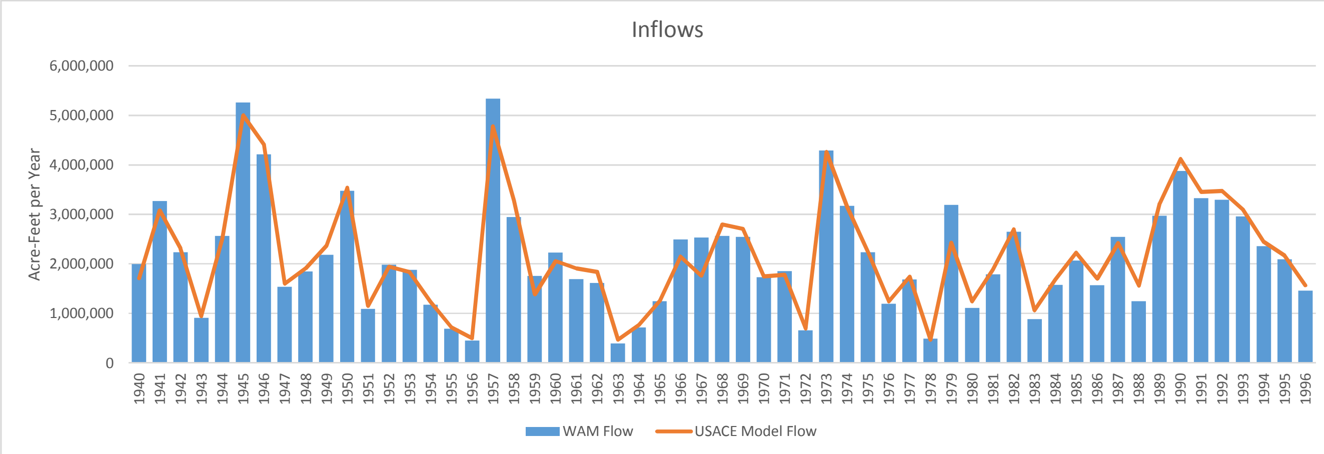
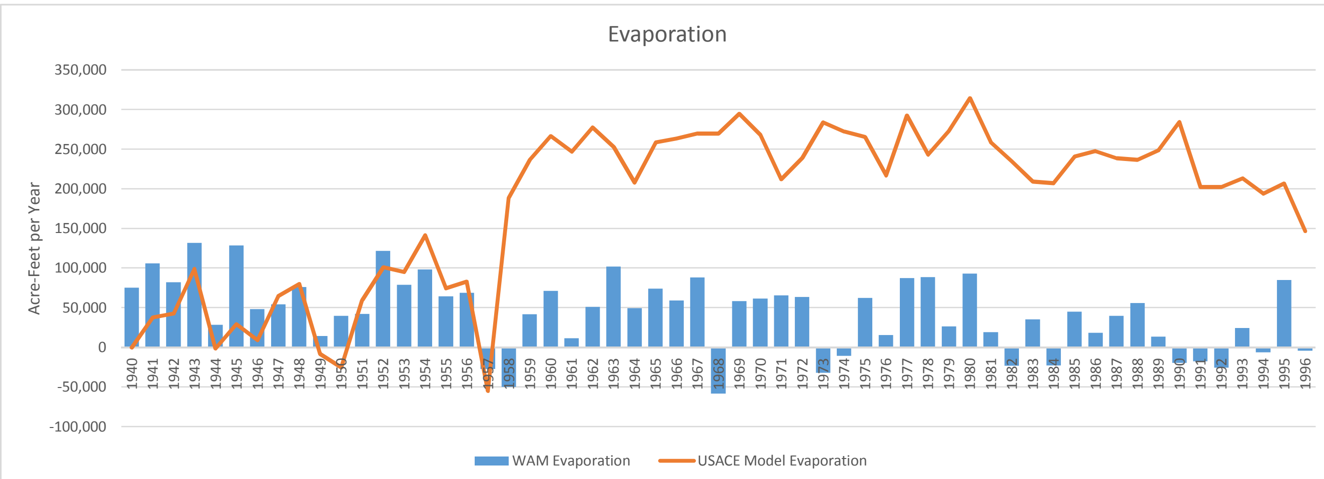


Figure C-9: Patman Conservation at 242.5 ft- Annual Inflows, Evaporative Loss and Outflows





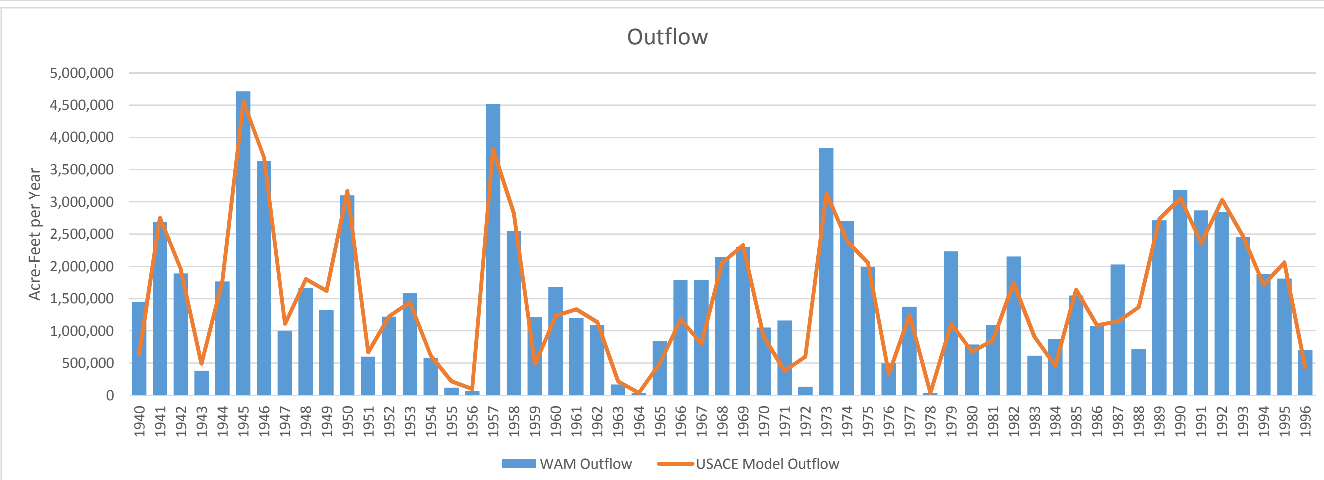
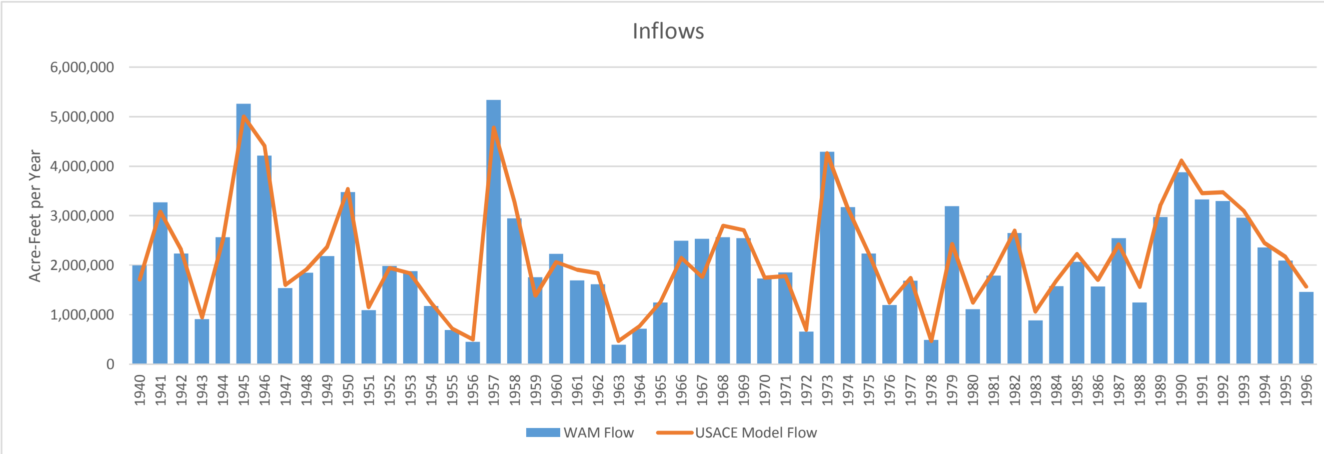
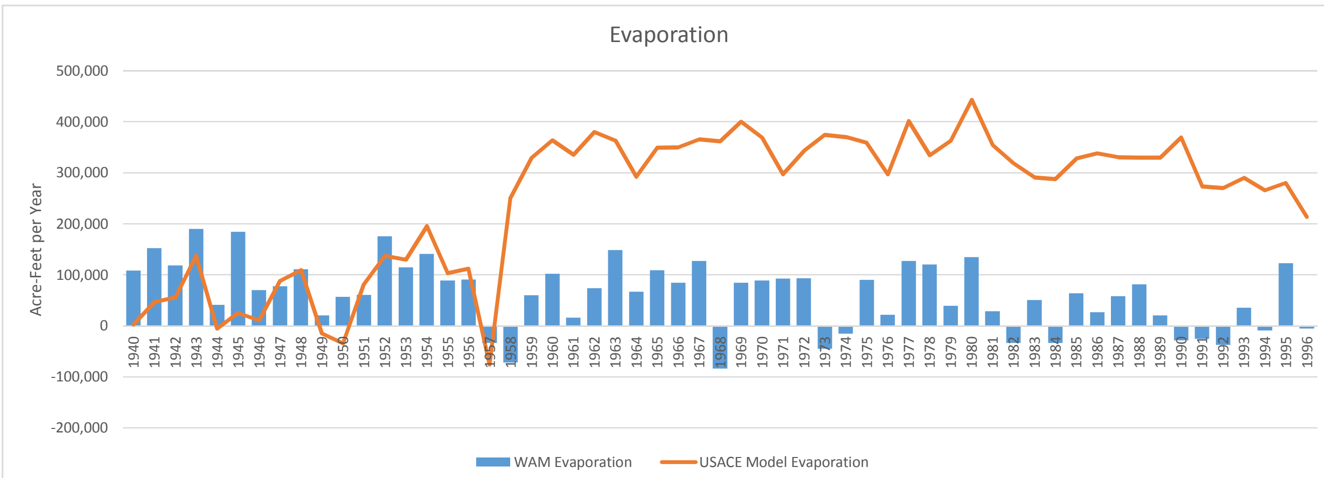
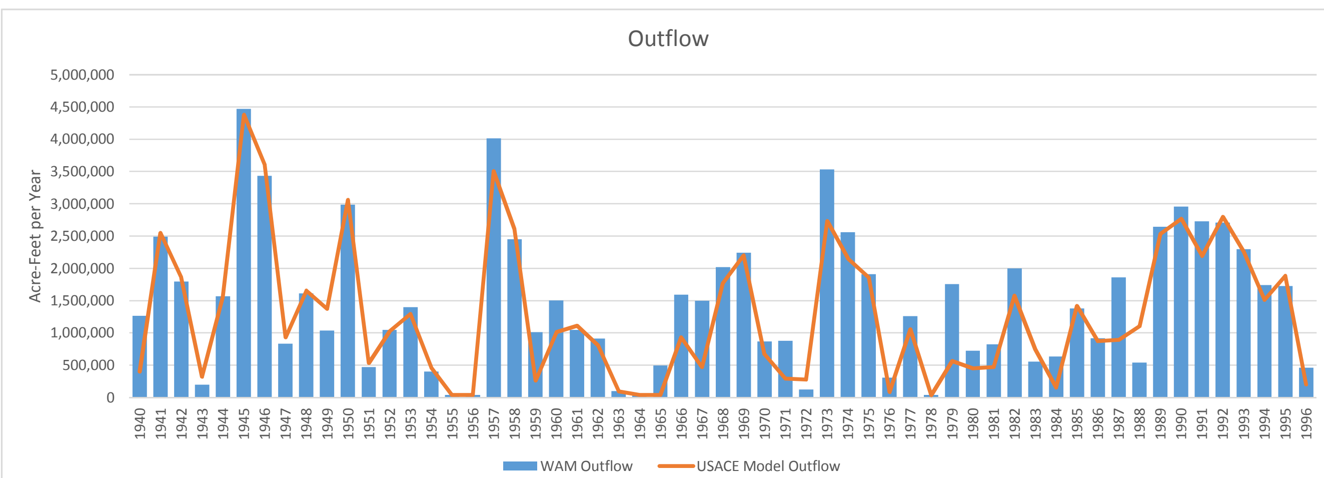


Figure C-10: Patman Conservation at 252.5 ft - Annual Inflows, Evaporative Loss and Outflows







APPENDIX D
MODELED STORAGE AND ELEVATION TRACES

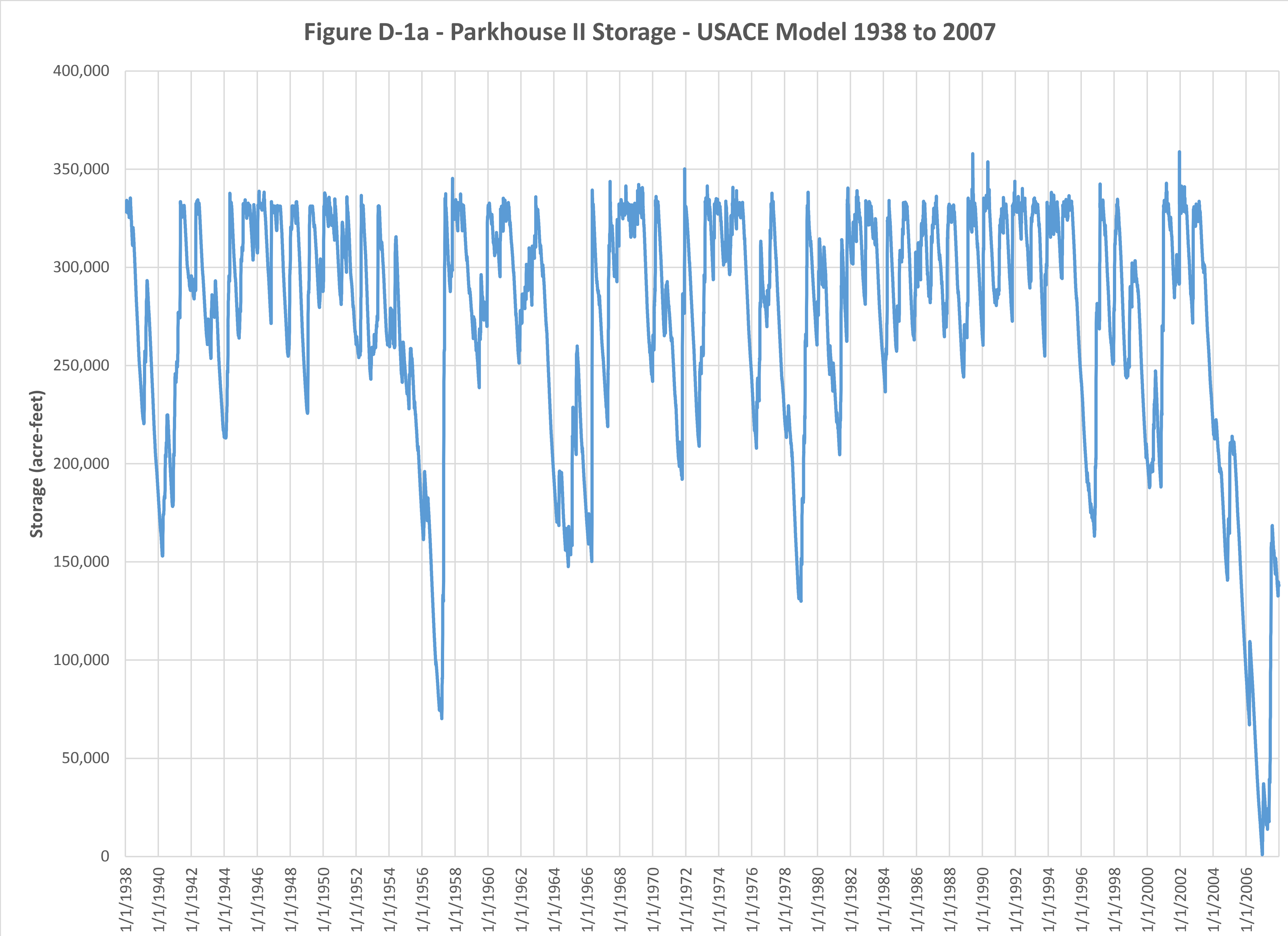


Figure D-1a - Parkhouse II Storage - USACE Model 1938 to 2007
Storage (acre-feet)
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996
1/1/1998
1/1/2000
1/1/2002
1/1/2004
1/1/2006

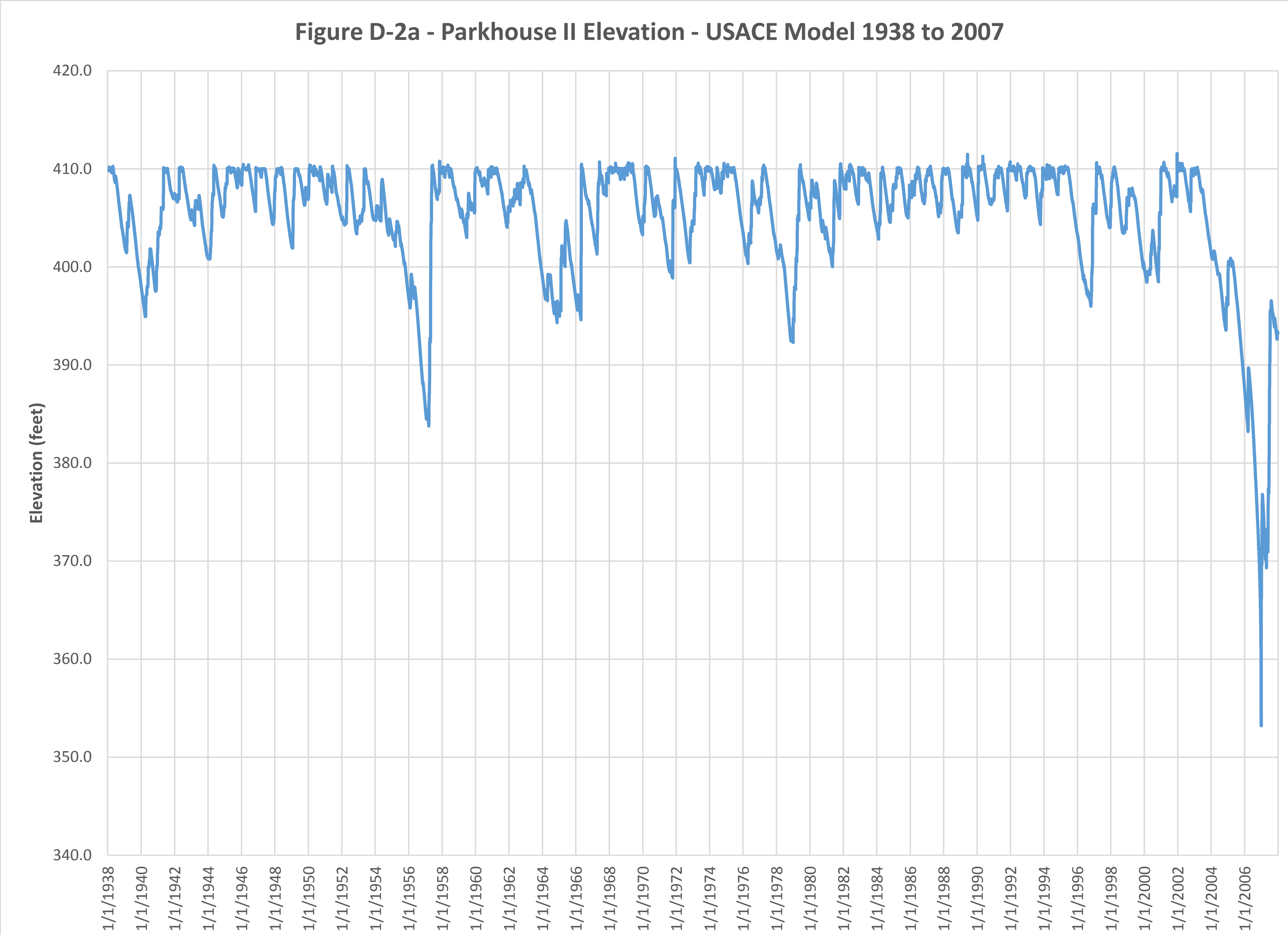


Figure D-2a - Parkhouse II Elevation - USACE Model 1938 to 2007
Elevation (feet)
420.0
410.0
400.0
390.0
380.0
370.0
360.0
350.0
340.0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996
1/1/1998
1/1/2000
1/1/2002
1/1/2004
1/1/2006

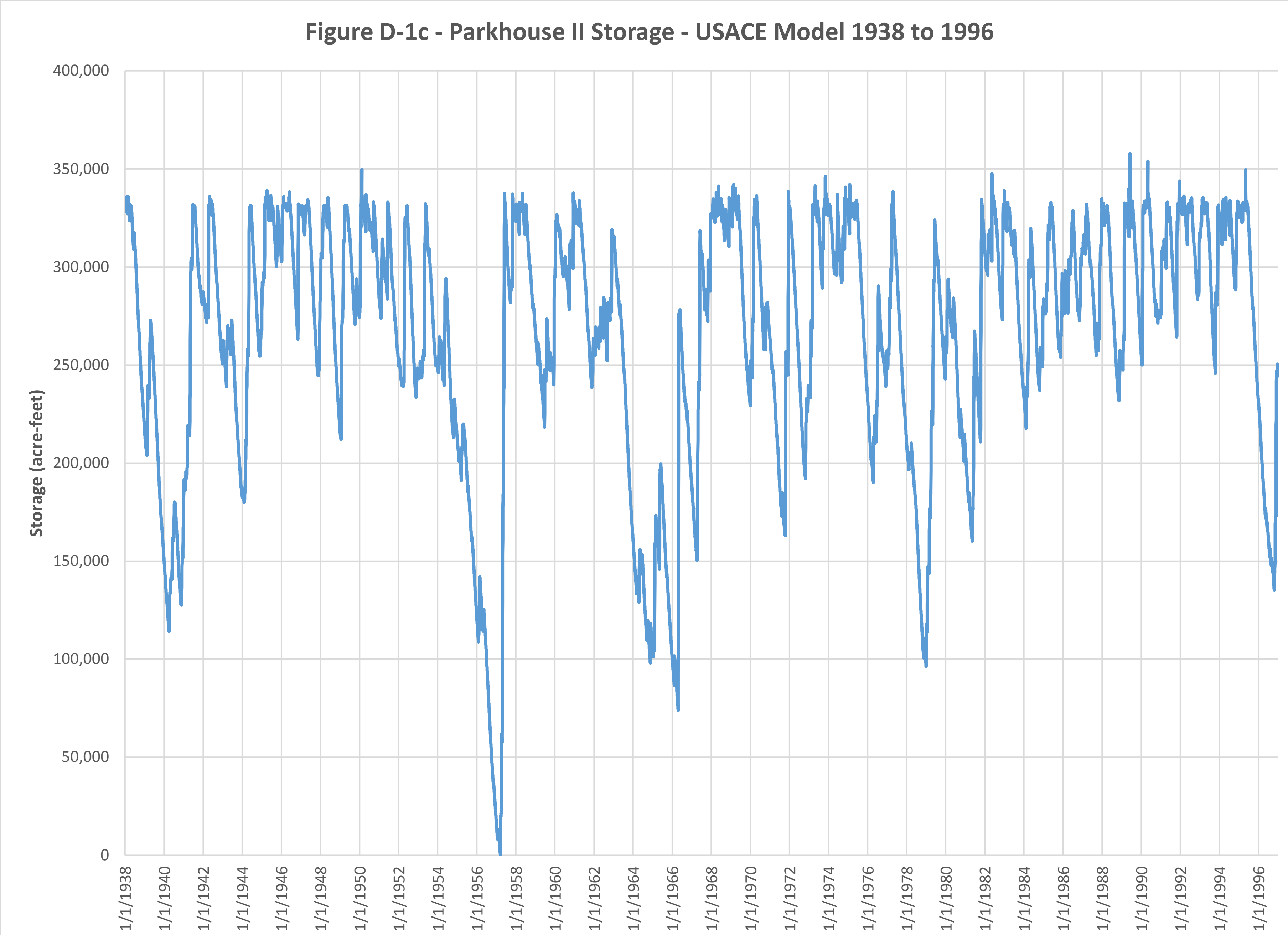


Figure D-1c - Parkhouse II Storage - USACE Model 1938 to 1996
Storage (acre-feet)
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996

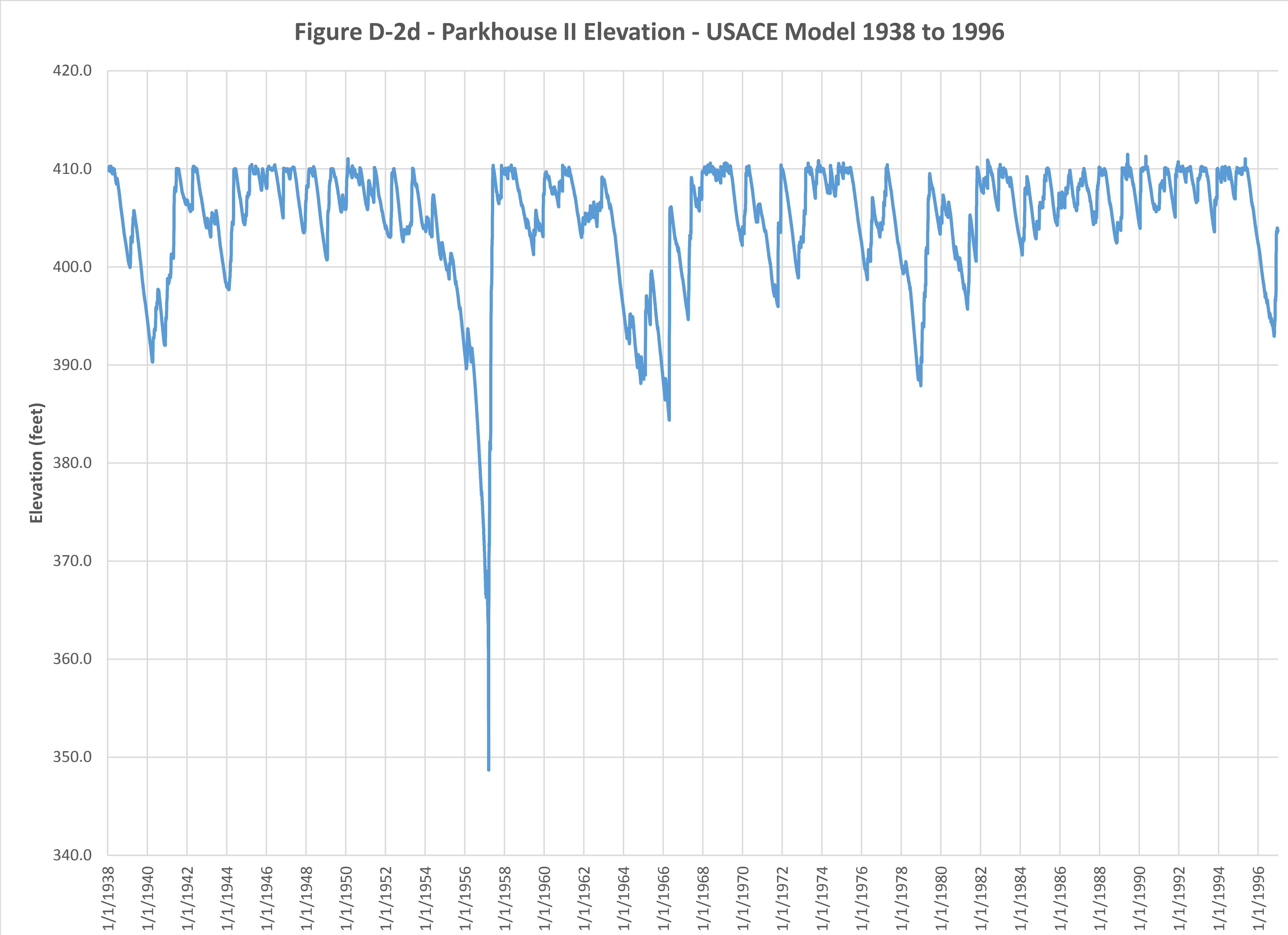


Figure D-2d - Parkhouse II Elevation - USACE Model 1938 to 1996
Elevation (feet)
420.0
410.0
400.0
390.0
380.0
370.0
360.0
350.0
340.0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996

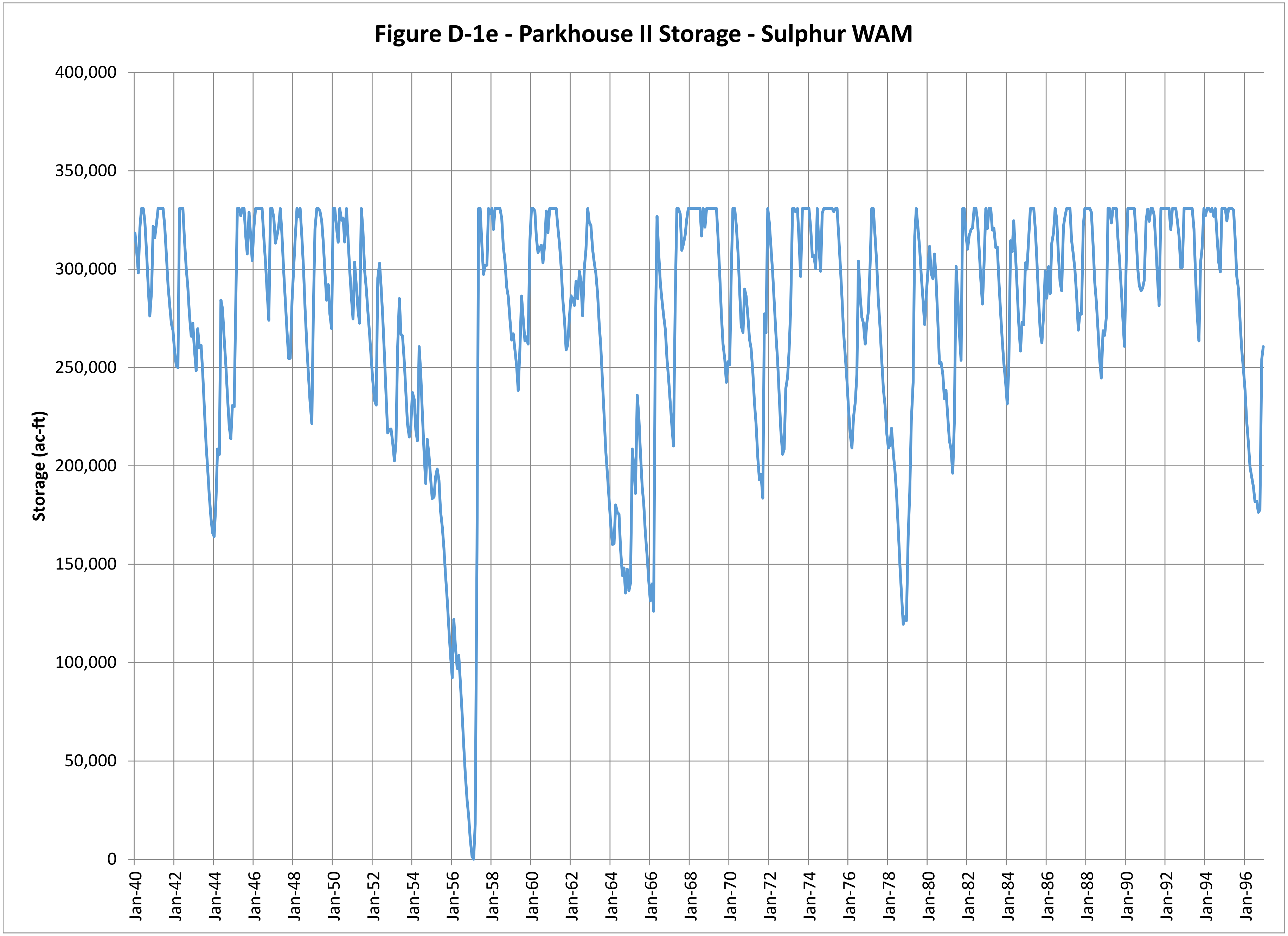


Figure D-1e - Parkhouse II Storage - Sulphur WAM
Storage (ac-ft)
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Jan-40
Jan-42
Jan-44
Jan-46
Jan-48
Jan-50
Jan-52
Jan-54
Jan-56
Jan-58
Jan-60
Jan-62
Jan-64
Jan-66
Jan-68
Jan-70
Jan-72
Jan-74
Jan-76
Jan-78
Jan-80
Jan-82
Jan-84
Jan-86
Jan-88
Jan-90
Jan-92
Jan-94
Jan-96

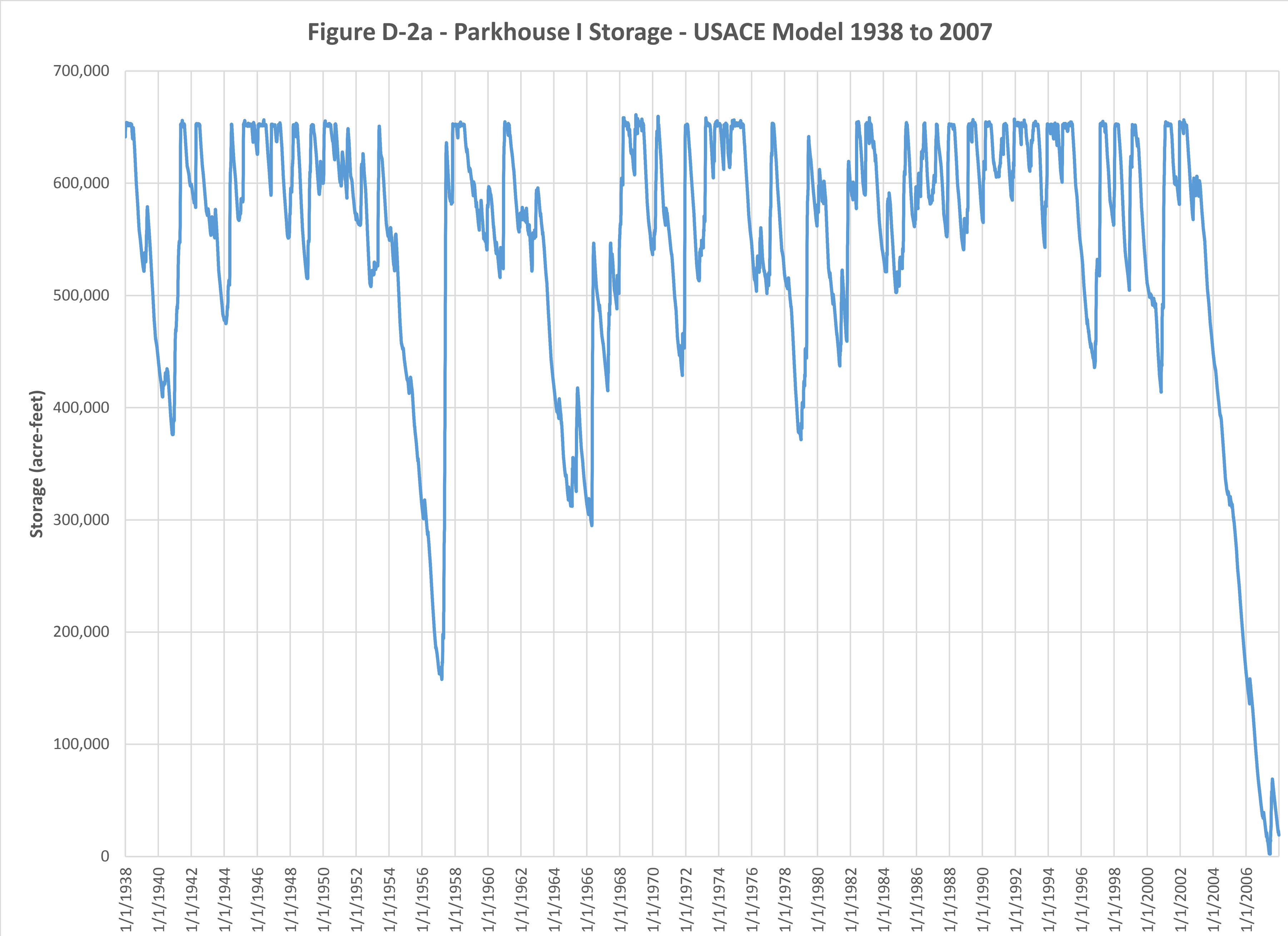


Figure D-2a - Parkhouse I Storage - USACE Model 1938 to 2007
Storage (acre-feet)
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996
1/1/1998
1/1/2000
1/1/2002
1/1/2004
1/1/2006

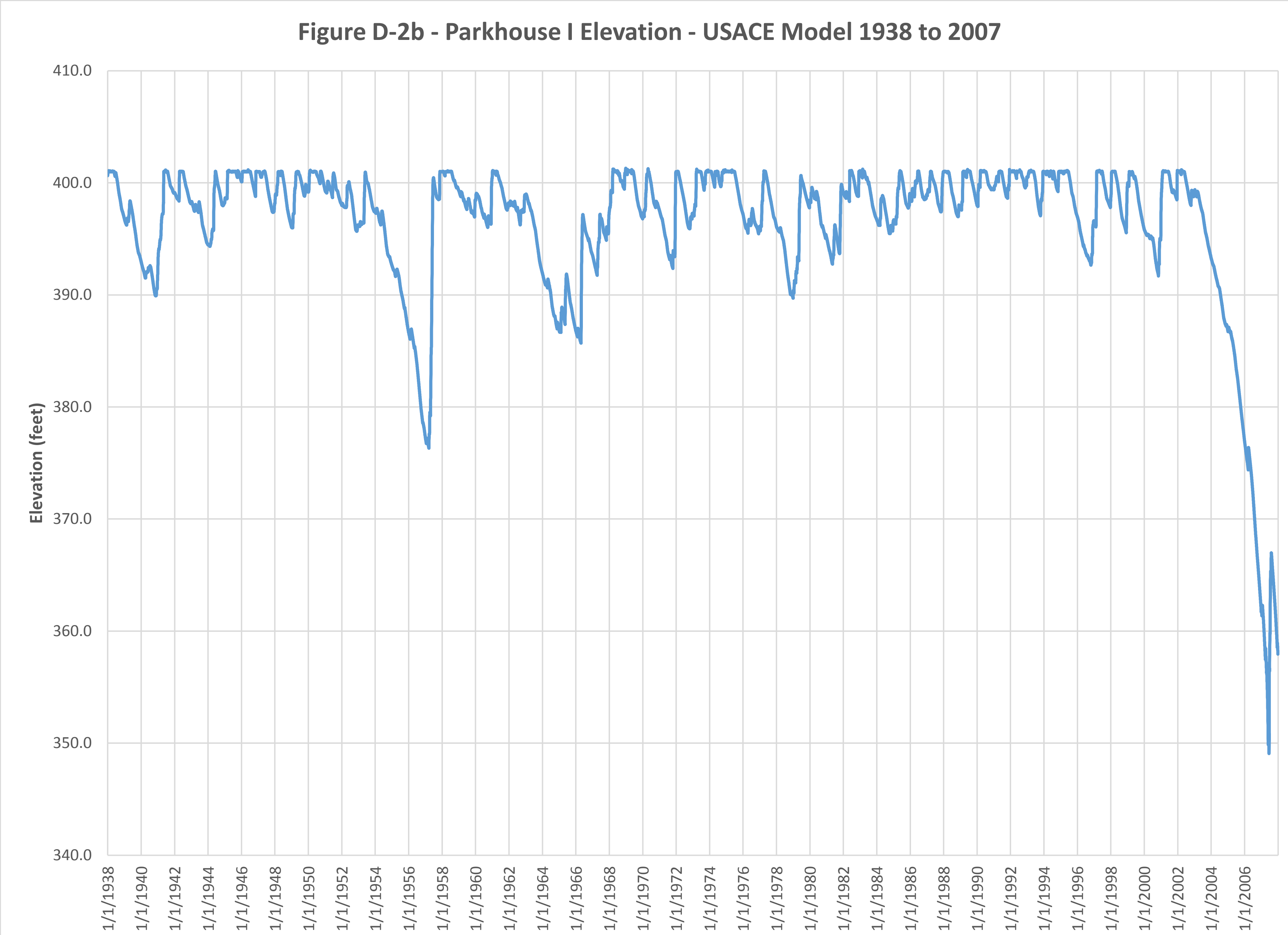


Figure D-2b - Parkhouse I Elevation - USACE Model 1938 to 2007
Elevation (feet)
410.0
400.0
390.0
380.0
370.0
360.0
350.0
340.0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996
1/1/1998
1/1/2000
1/1/2002
1/1/2004
1/1/2006

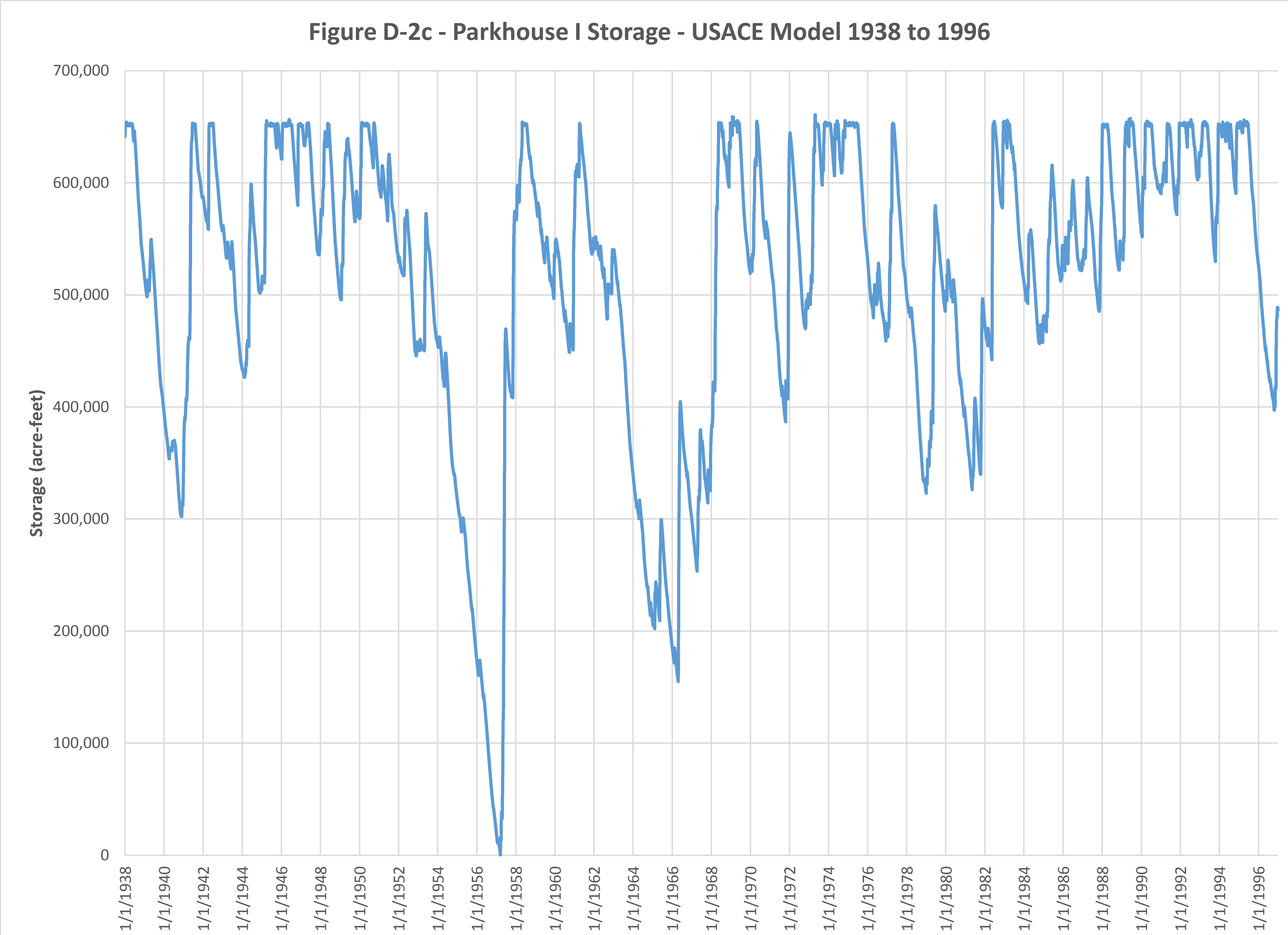


Figure D-2c - Parkhouse I Storage - USACE Model 1938 to 1996
Storage (acre-feet)
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996

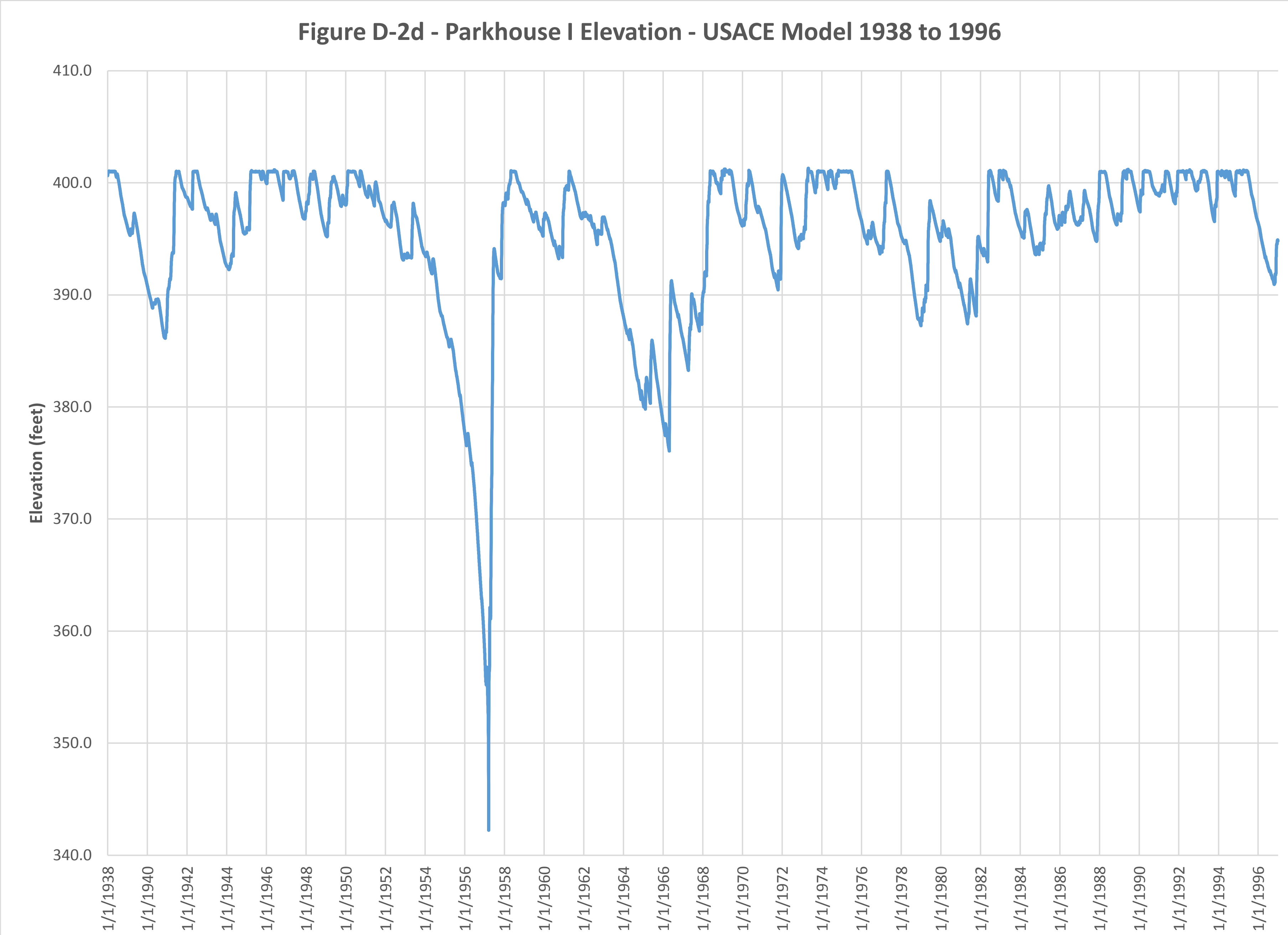


Figure D-2d - Parkhouse I Elevation - USACE Model 1938 to 1996
Elevation (feet)
410.0
400.0
390.0
380.0
370.0
360.0
350.0
340.0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996

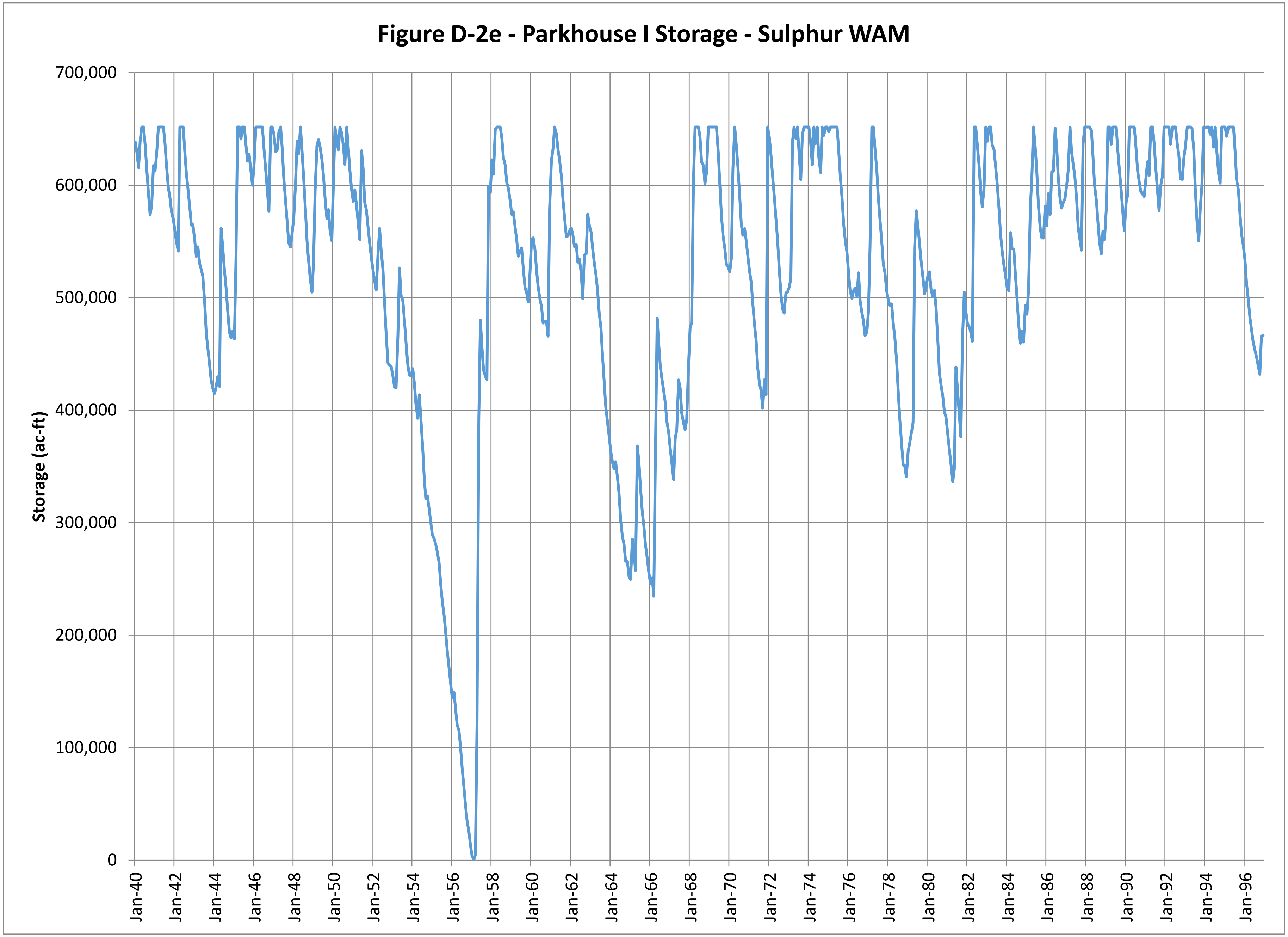
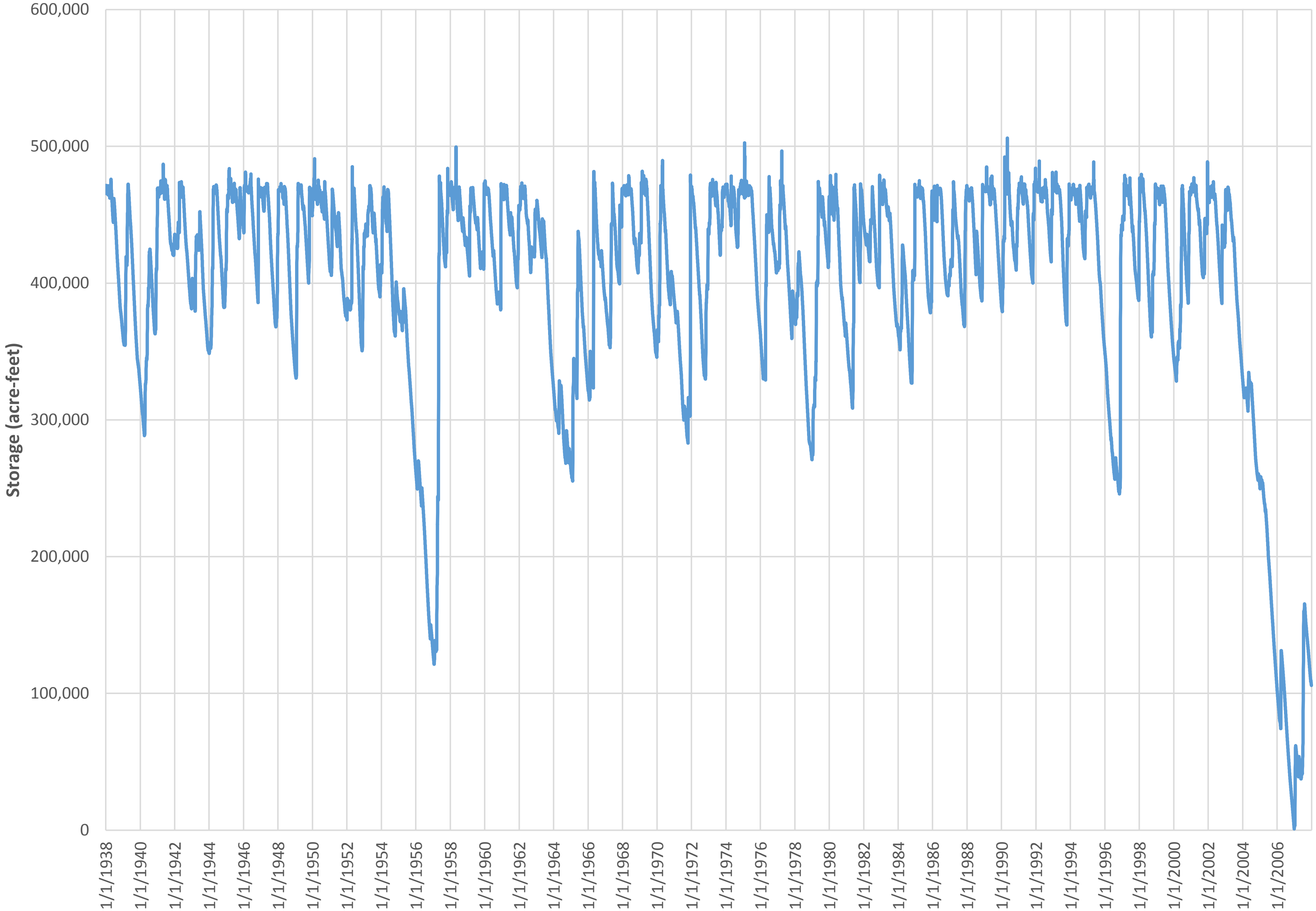


Figure D-2e - Parkhouse I Storage - Sulphur WAM
Storage (ac-ft)
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
Jan-40
Jan-42
Jan-44
Jan-46
Jan-48
Jan-50
Jan-52
Jan-54
Jan-56
Jan-58
Jan-60
Jan-62
Jan-64
Jan-66
Jan-68
Jan-70
Jan-72
Jan-74
Jan-76
Jan-78
Jan-80
Jan-82
Jan-84
Jan-86
Jan-88
Jan-90
Jan-92
Jan-94
Jan-96

Figure D-3a - Talco 350 Storage - USACE Model 1938 to 2007



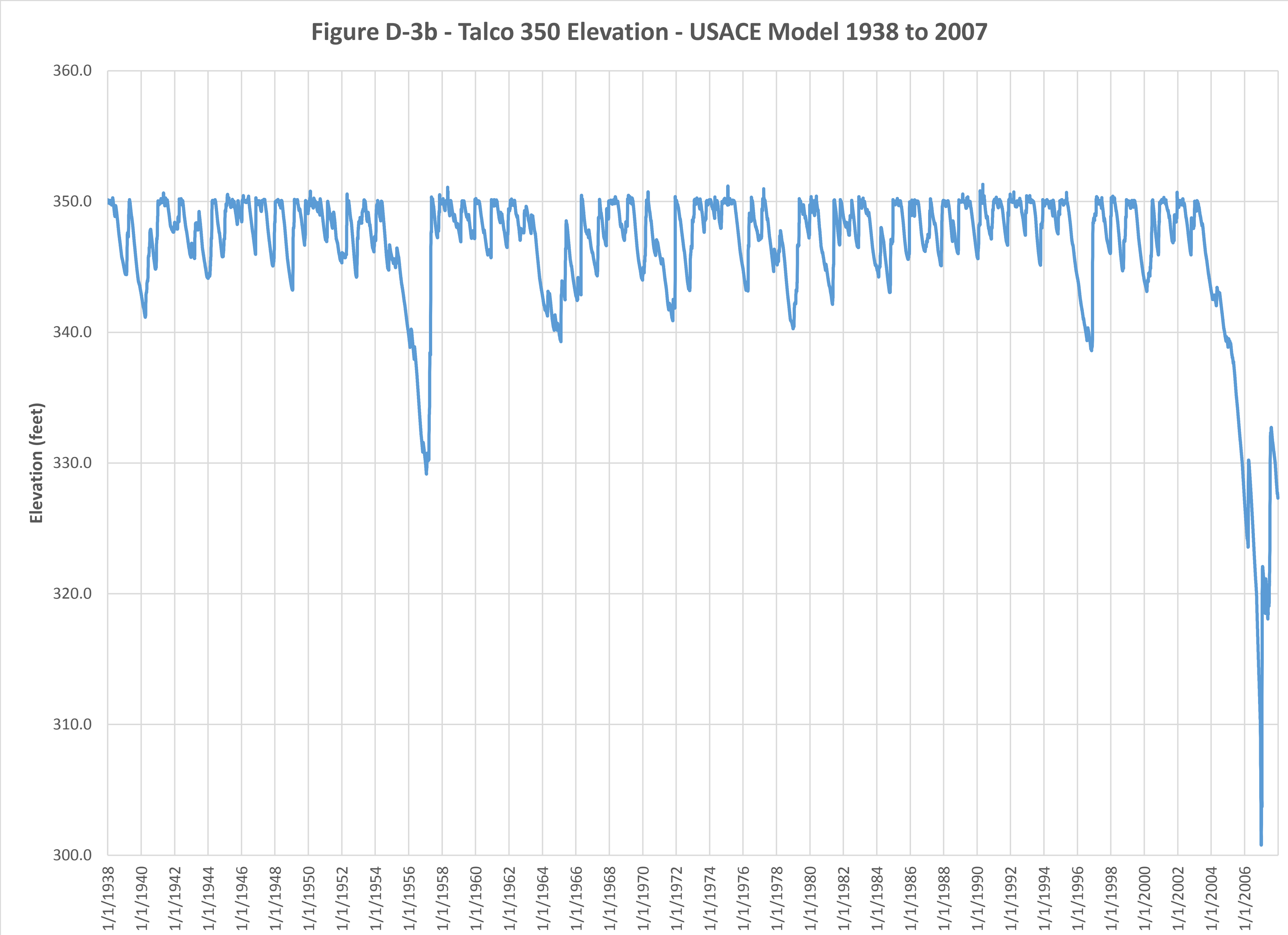


Figure D-3b - Talco 350 Elevation - USACE Model 1938 to 2007
Elevation (feet)
360.0
350.0
340.0
330.0
320.0
310.0
300.0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996
1/1/1998
1/1/2000
1/1/2002
1/1/2004
1/1/2006

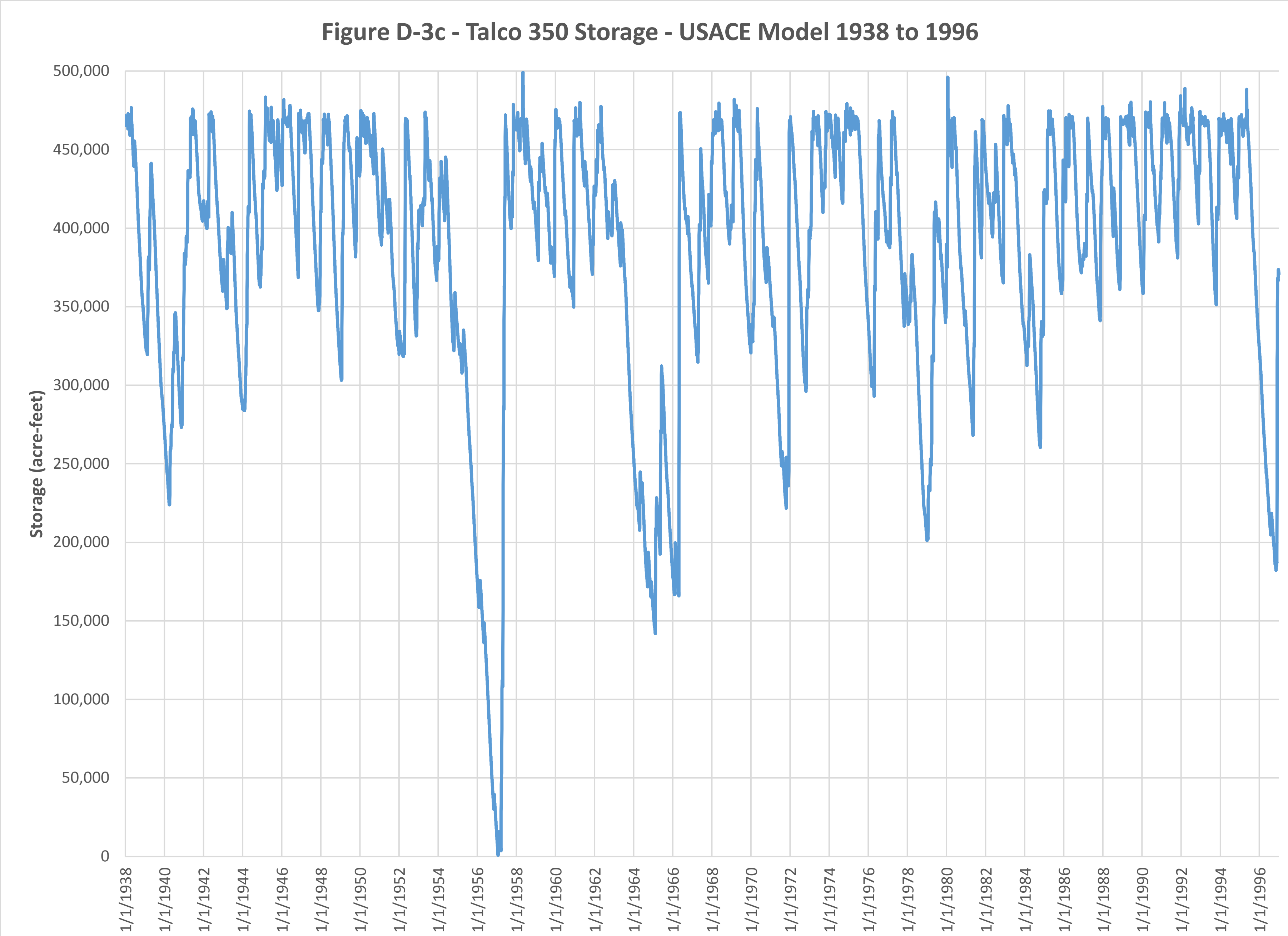


Figure D-3c - Talco 350 Storage - USACE Model 1938 to 1996
Storage (acre-feet)
500,000
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996

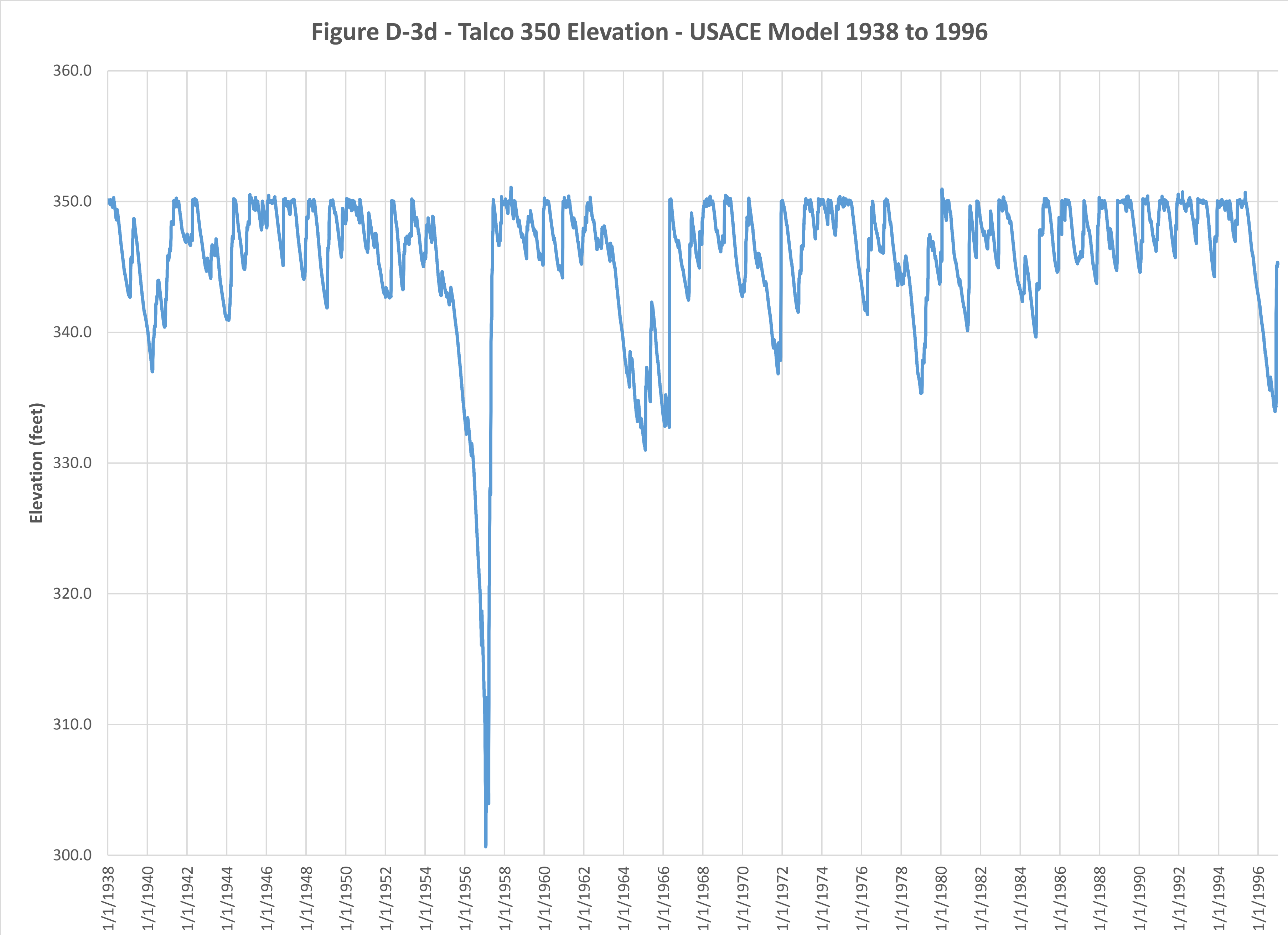


Figure D-3d - Talco 350 Elevation - USACE Model 1938 to 1996
Elevation (feet)
360.0
350.0
340.0
330.0
320.0
310.0
300.0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996

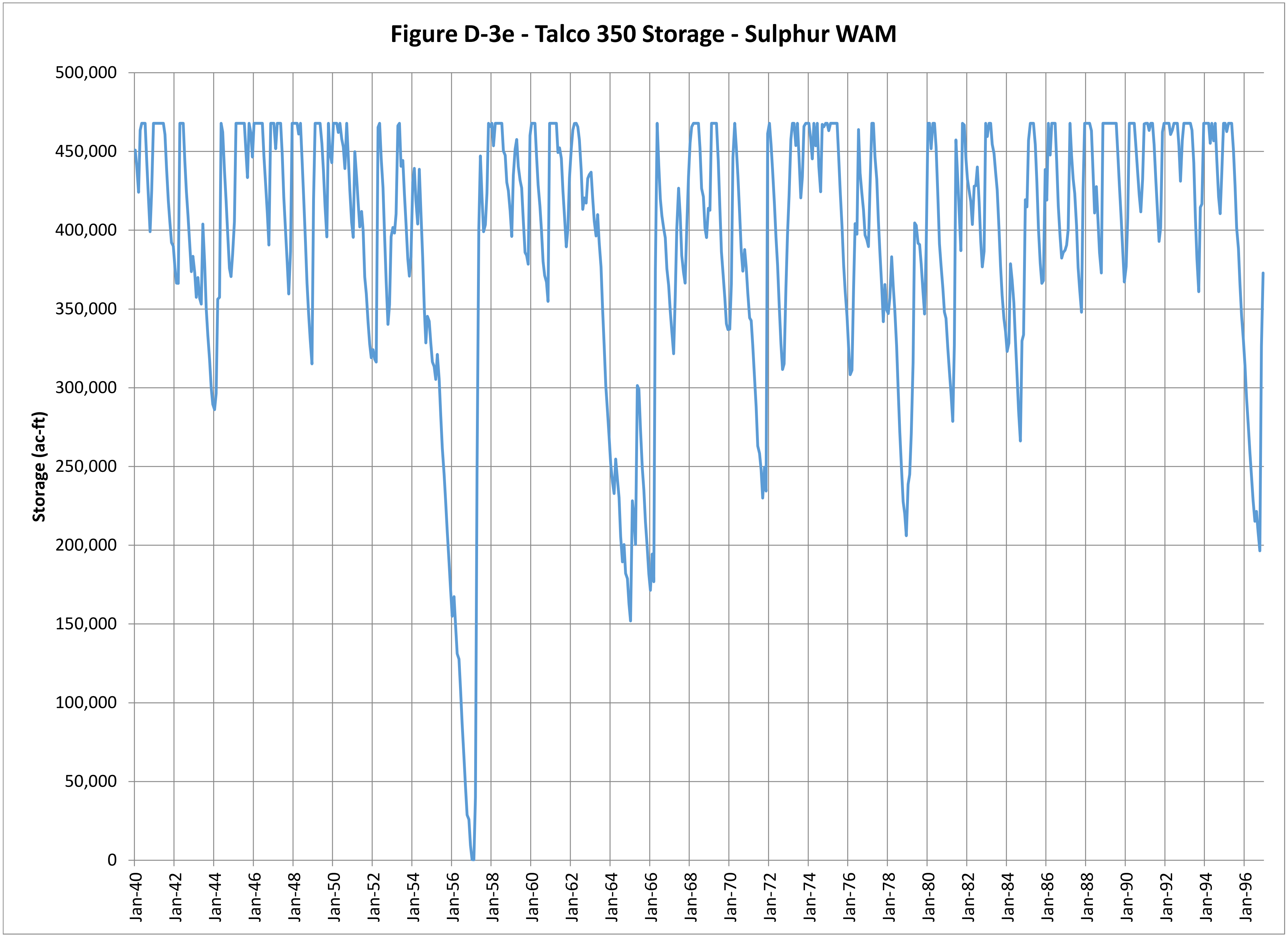


Figure D-3e - Talco 350 Storage - Sulphur WAM
Storage (ac-ft)
500,000
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Jan-40
Jan-42
Jan-44
Jan-46
Jan-48
Jan-50
Jan-52
Jan-54
Jan-56
Jan-58
Jan-60
Jan-62
Jan-64
Jan-66
Jan-68
Jan-70
Jan-72
Jan-74
Jan-76
Jan-78
Jan-80
Jan-82
Jan-84
Jan-86
Jan-88
Jan-90
Jan-92
Jan-94
Jan-96

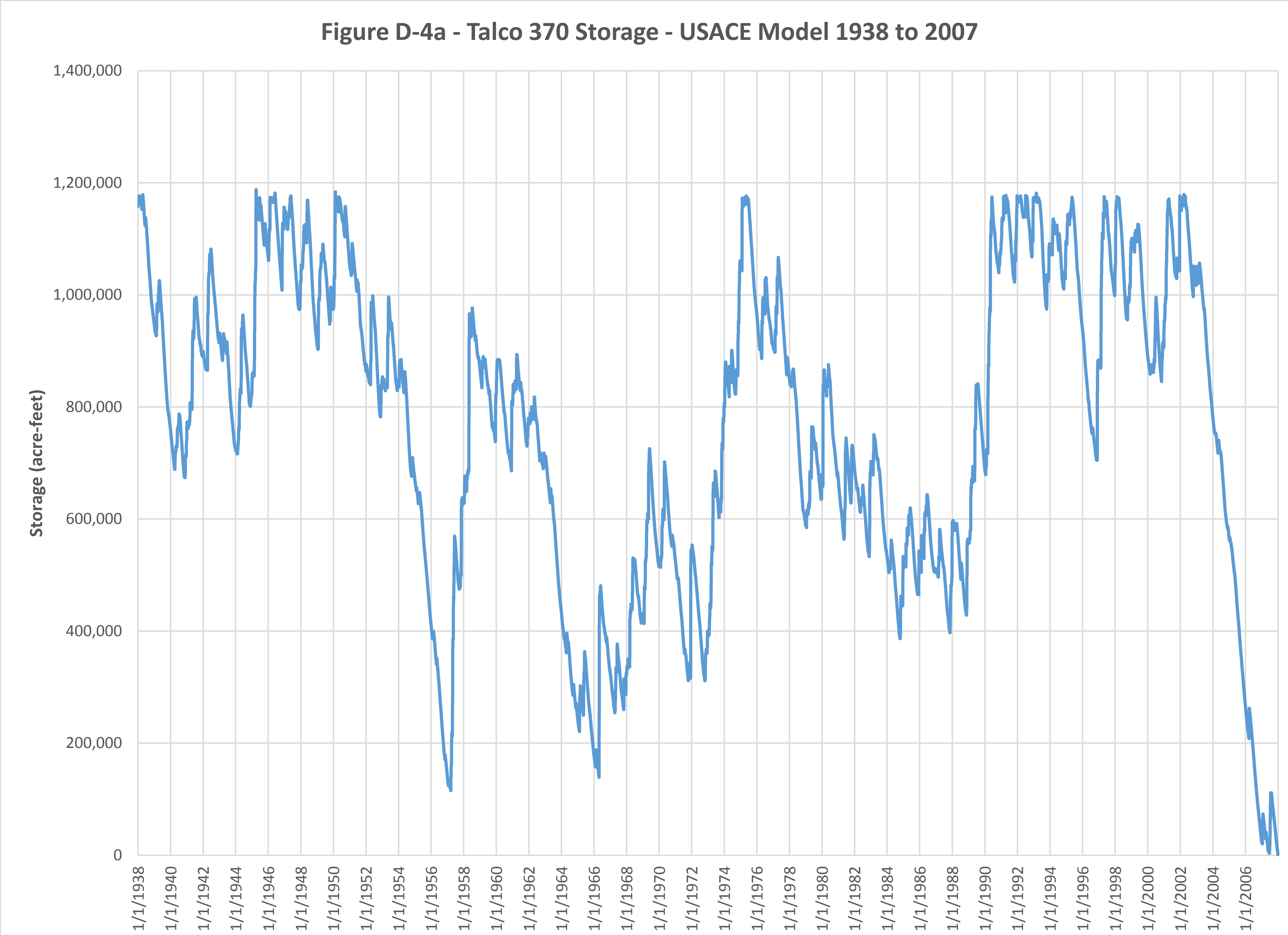


Figure D-4a - Talco 370 Storage - USACE Model 1938 to 2007
Storage (acre-feet)
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996
1/1/1998
1/1/2000
1/1/2002
1/1/2004
1/1/2006

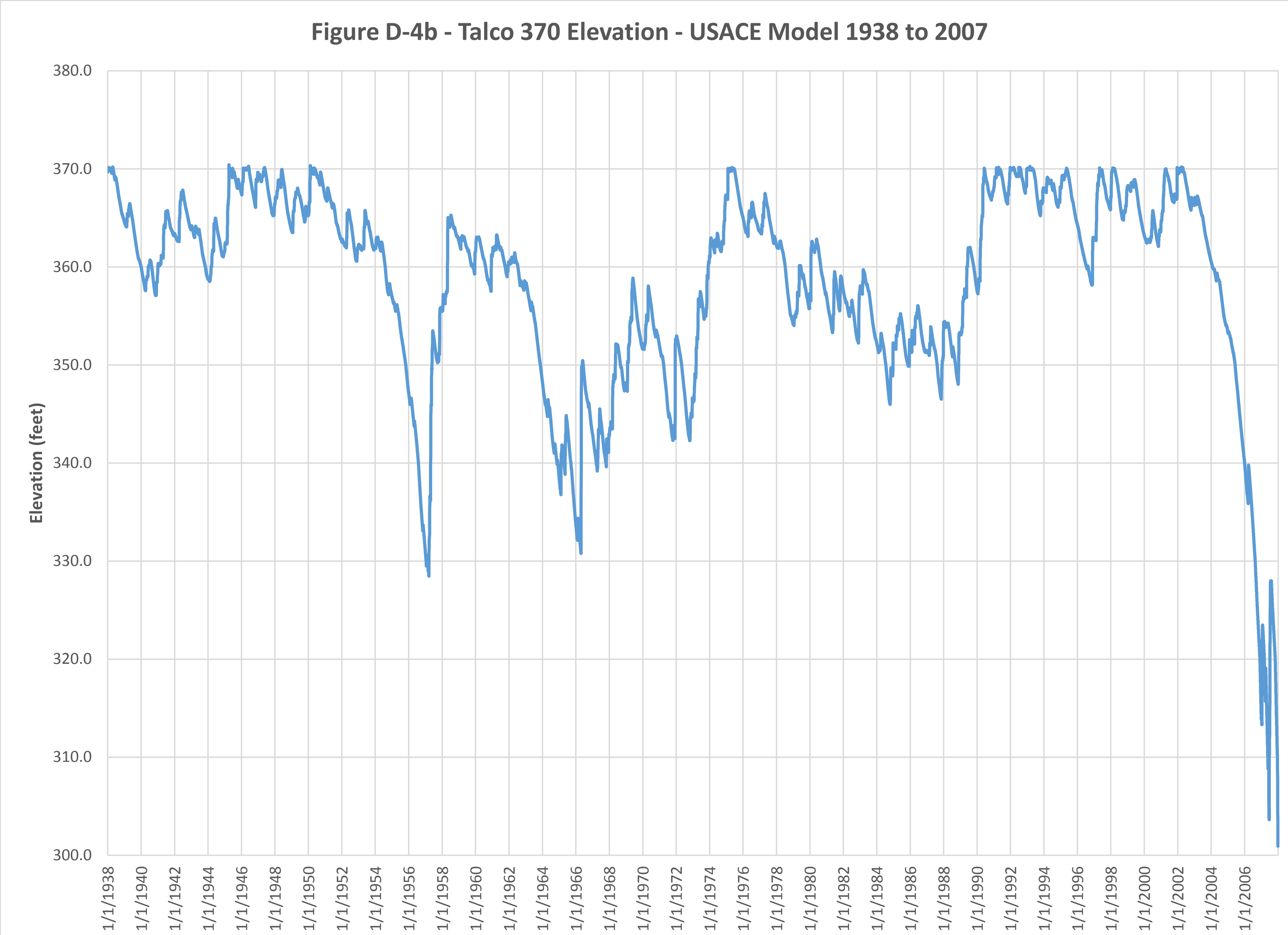


Figure D-4b - Talco 370 Elevation - USACE Model 1938 to 2007
Elevation (feet)
380.0
370.0
360.0
350.0
340.0
330.0
320.0
310.0
300.0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996
1/1/1998
1/1/2000
1/1/2002
1/1/2004
1/1/2006

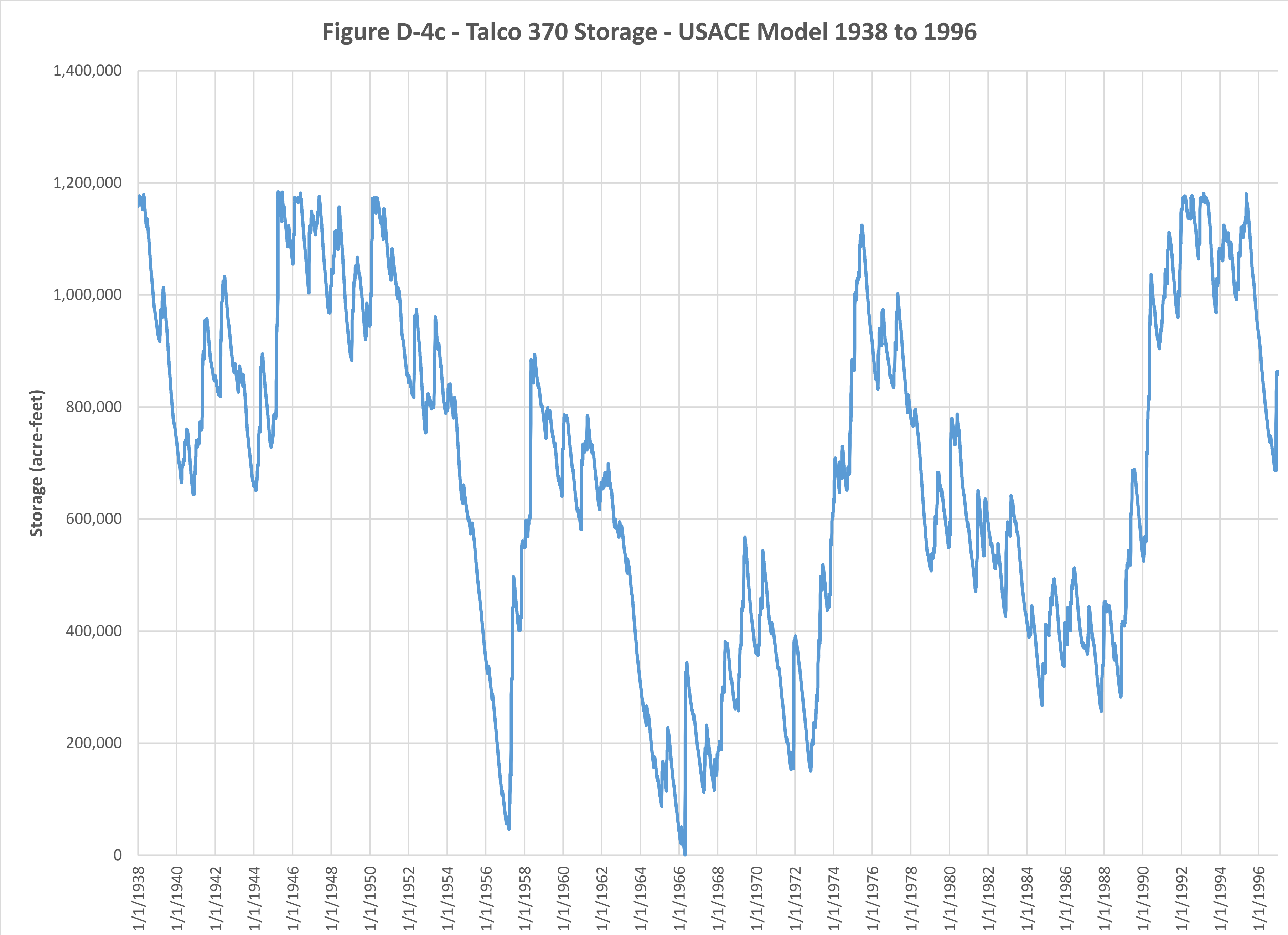


Figure D-4c - Talco 370 Storage - USACE Model 1938 to 1996
Storage (acre-feet)
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996

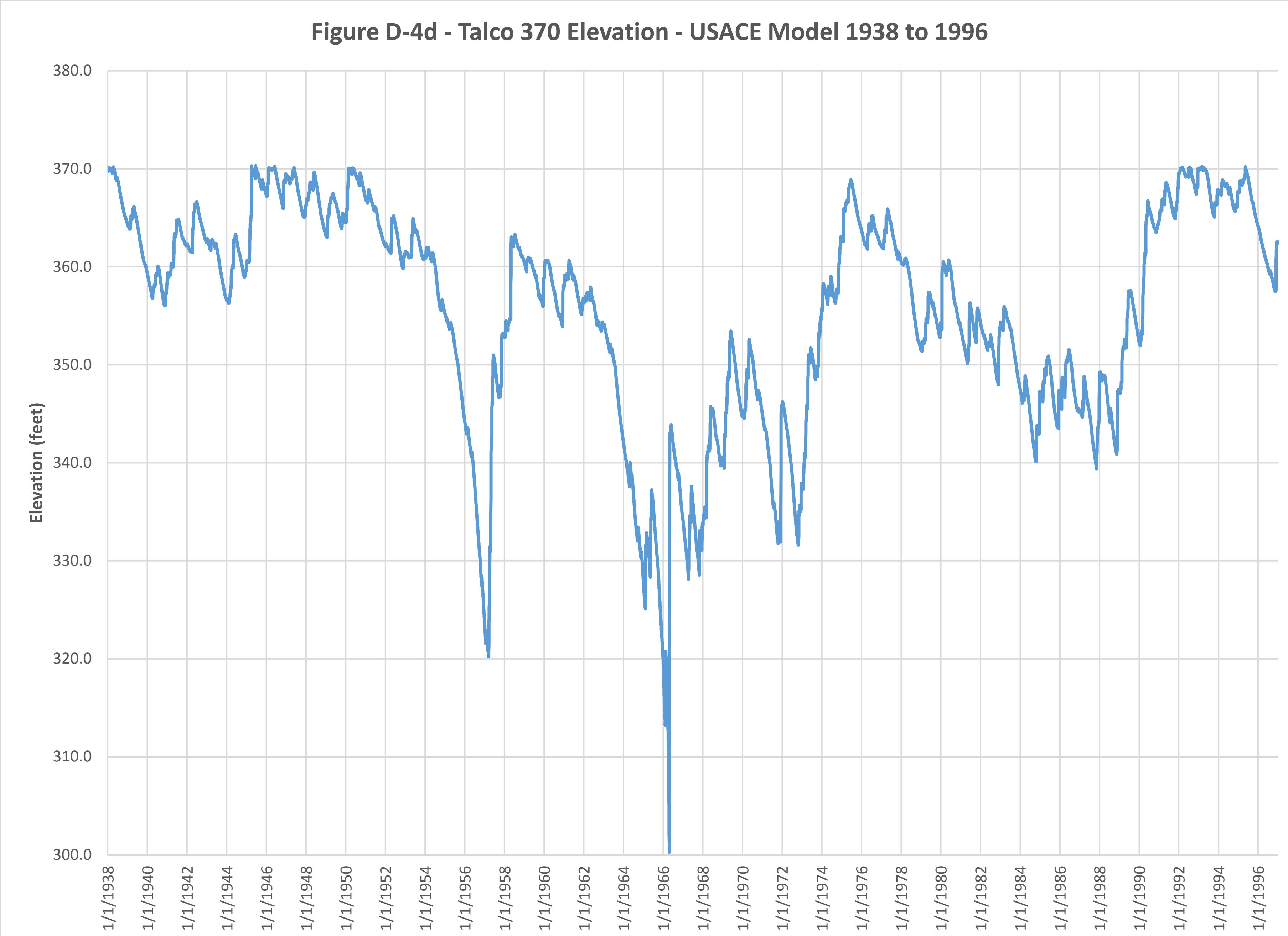


Figure D-4d - Talco 370 Elevation - USACE Model 1938 to 1996
Elevation (feet)
380.0
370.0
360.0
350.0
340.0
330.0
320.0
310.0
300.0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996

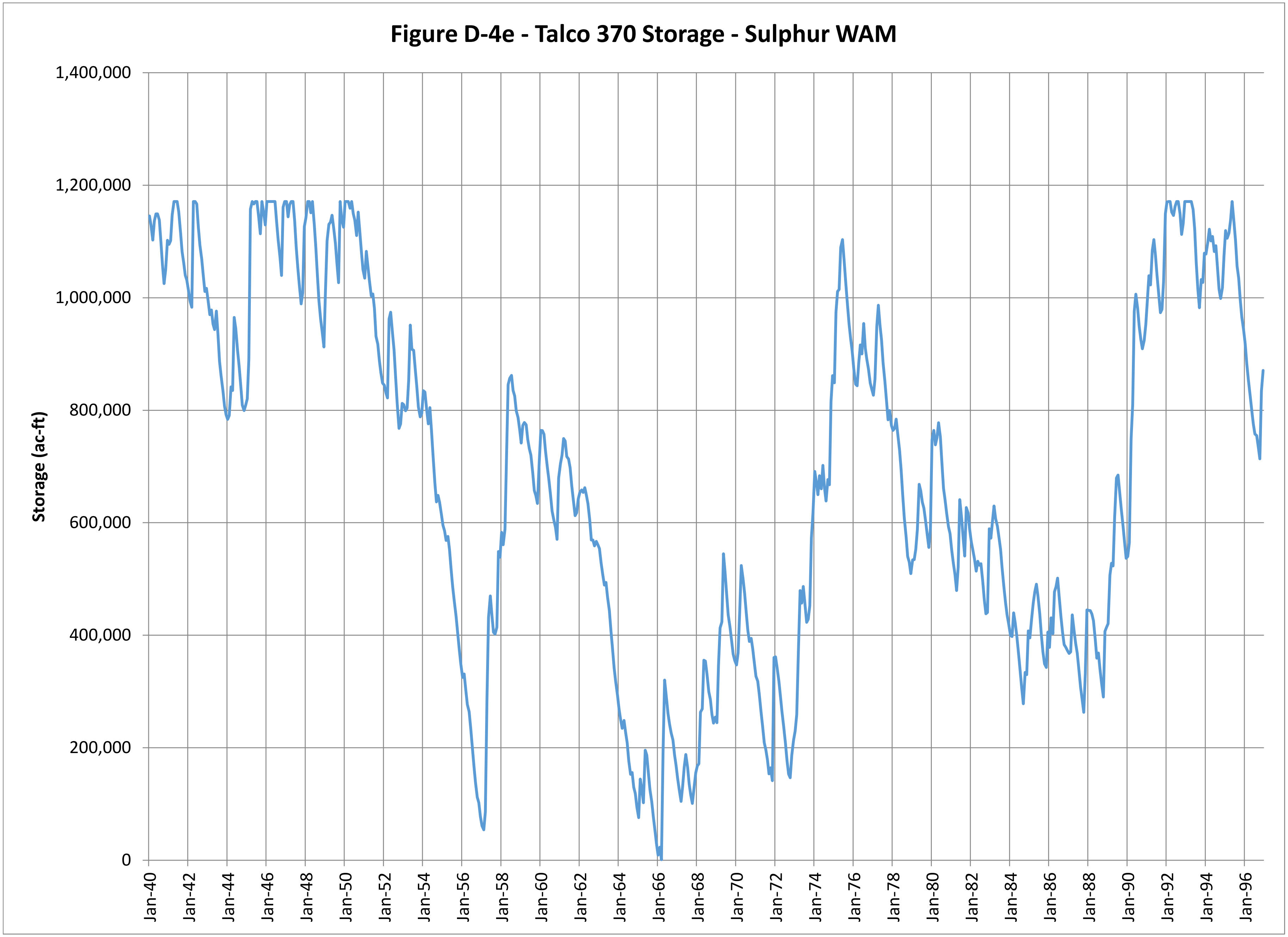


Figure D-4e - Talco 370 Storage - Sulphur WAM
Storage (ac-ft)
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
Jan-40
Jan-42
Jan-44
Jan-46
Jan-48
Jan-50
Jan-52
Jan-54
Jan-56
Jan-58
Jan-60
Jan-62
Jan-64
Jan-66
Jan-68
Jan-70
Jan-72
Jan-74
Jan-76
Jan-78
Jan-80
Jan-82
Jan-84
Jan-86
Jan-88
Jan-90
Jan-92
Jan-94
Jan-96

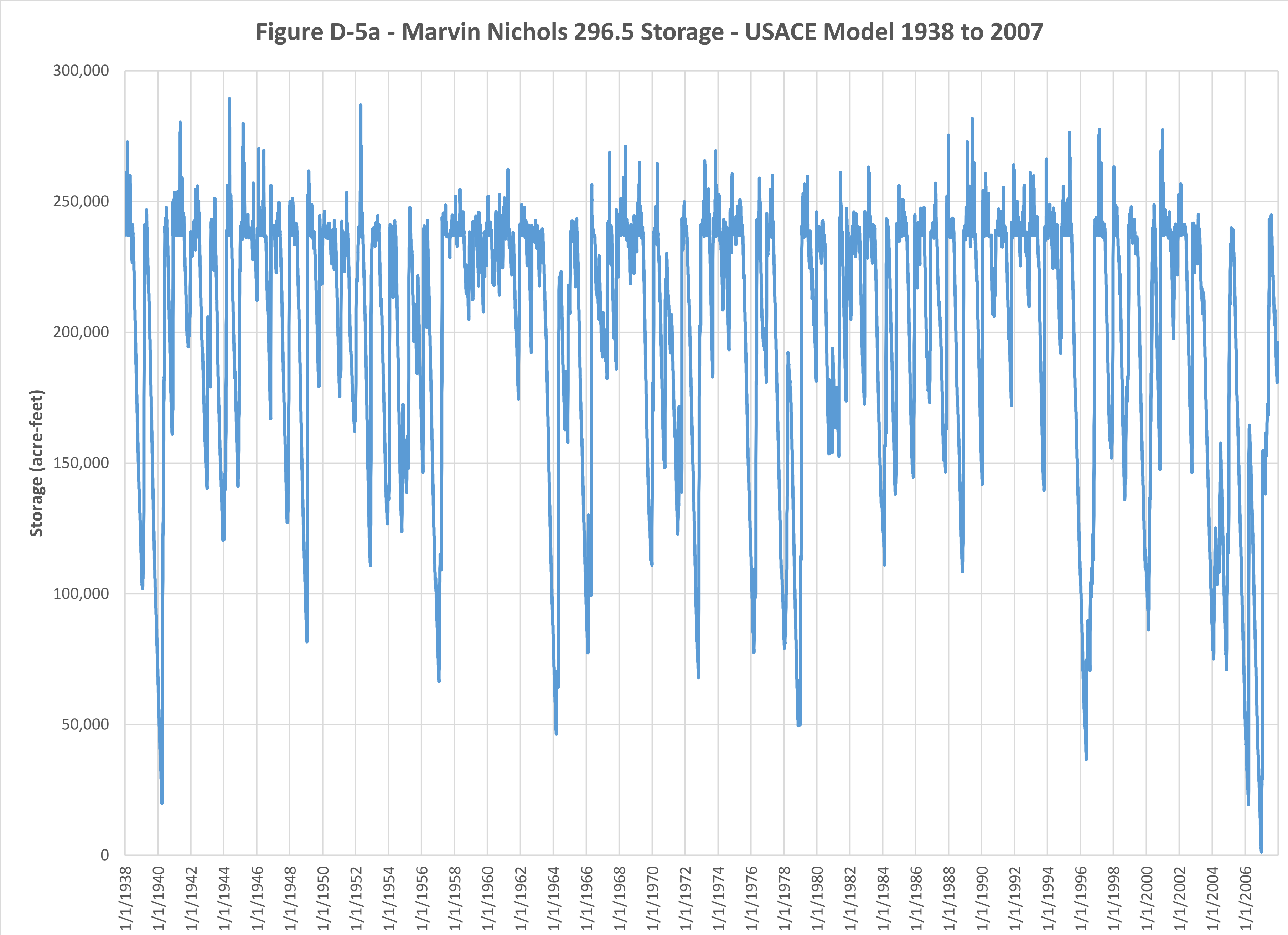


Figure D-5a - Marvin Nichols 296.5 Storage - USACE Model 1938 to 2007
Storage (acre-feet)
300,000
250,000
200,000
150,000
100,000
50,000
0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996
1/1/1998
1/1/2000
1/1/2002
1/1/2004
1/1/2006

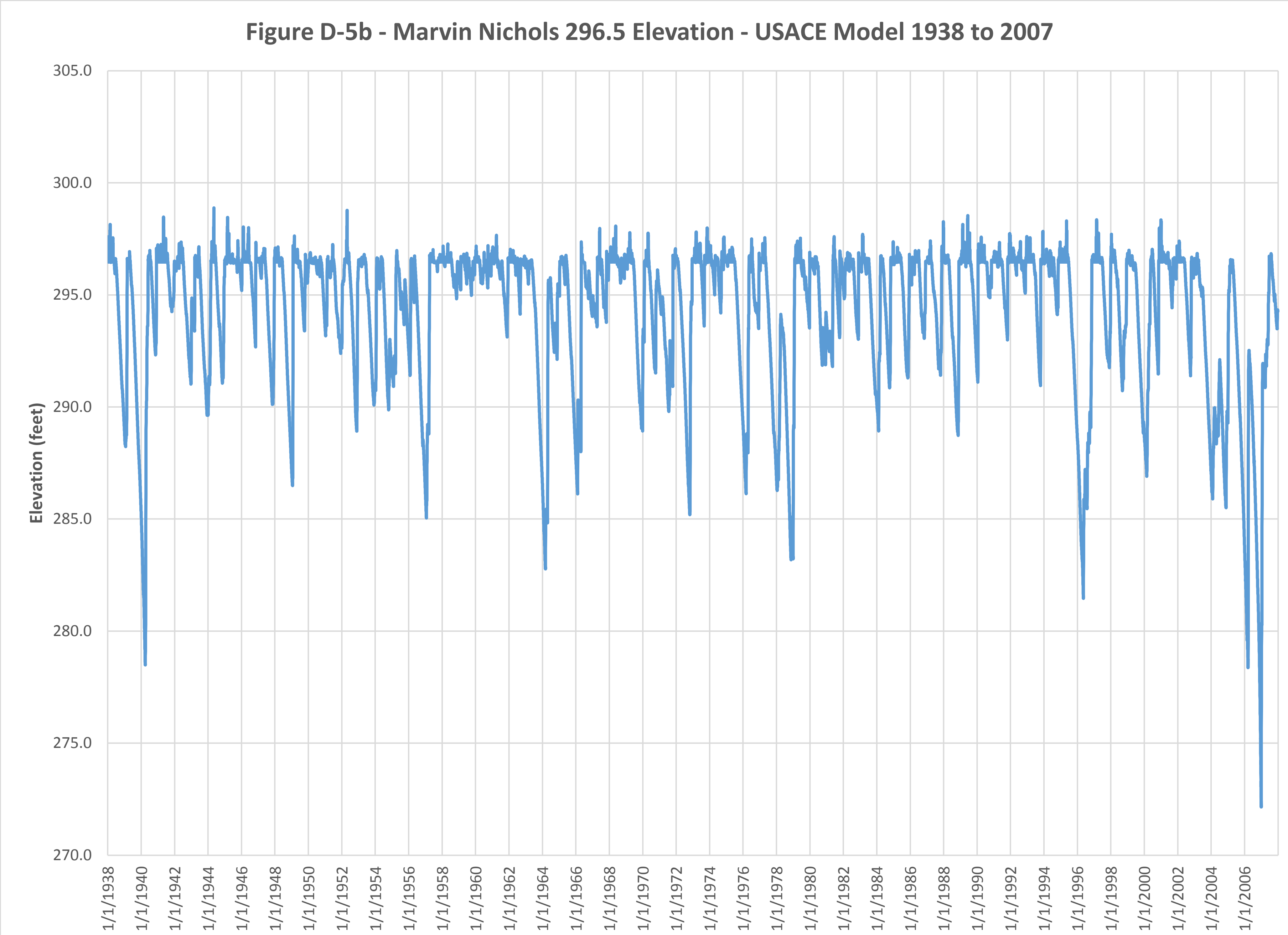


Figure D-5b - Marvin Nichols 296.5 Elevation - USACE Model 1938 to 2007
Elevation (feet)
305.0
300.0
295.0
290.0
285.0
280.0
275.0
270.0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996
1/1/1998
1/1/2000
1/1/2002
1/1/2004
1/1/2006

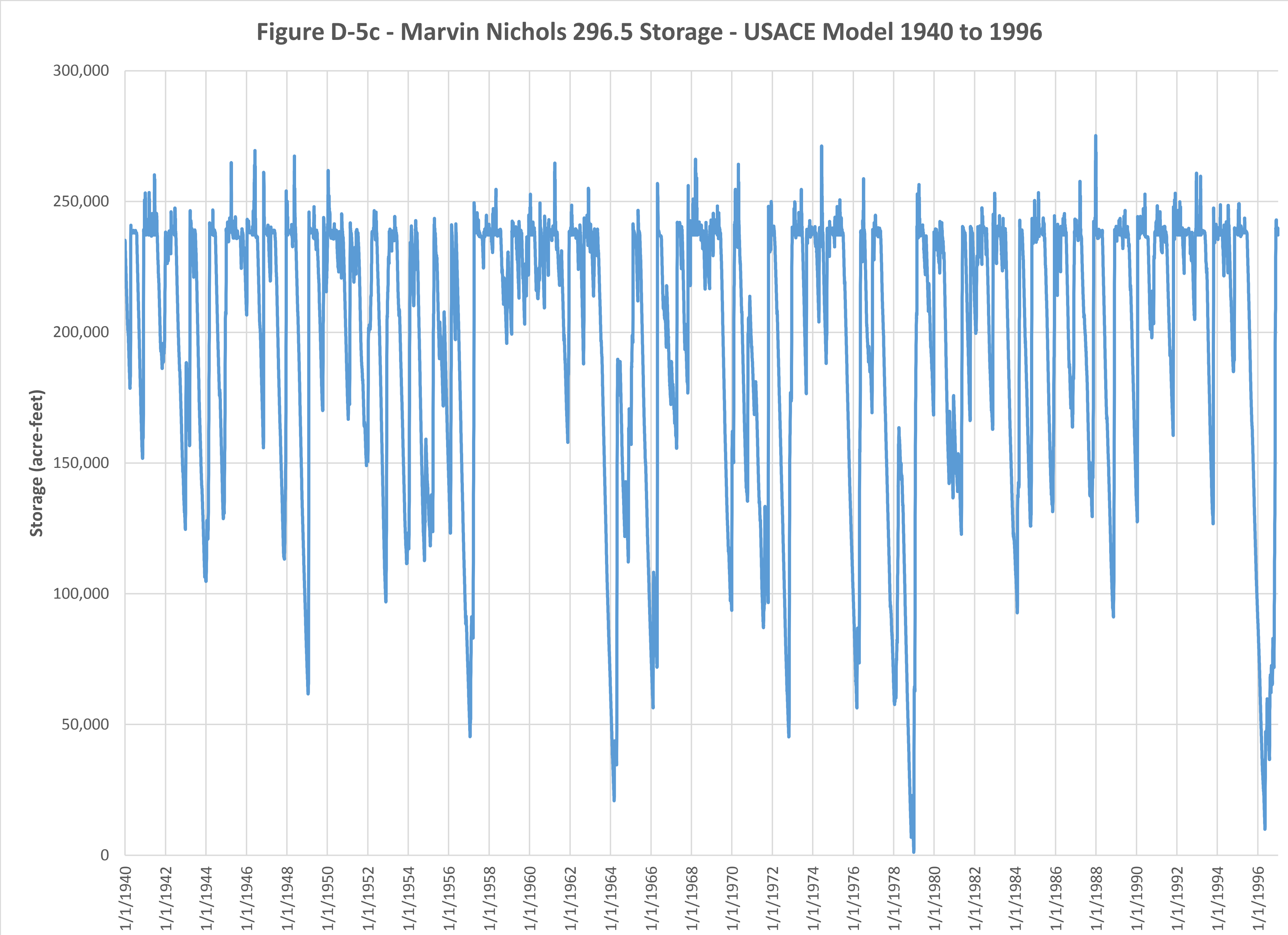


Figure D-5c - Marvin Nichols 296.5 Storage - USACE Model 1940 to 1996
Storage (acre-feet)
300,000
250,000
200,000
150,000
100,000
50,000
0
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996

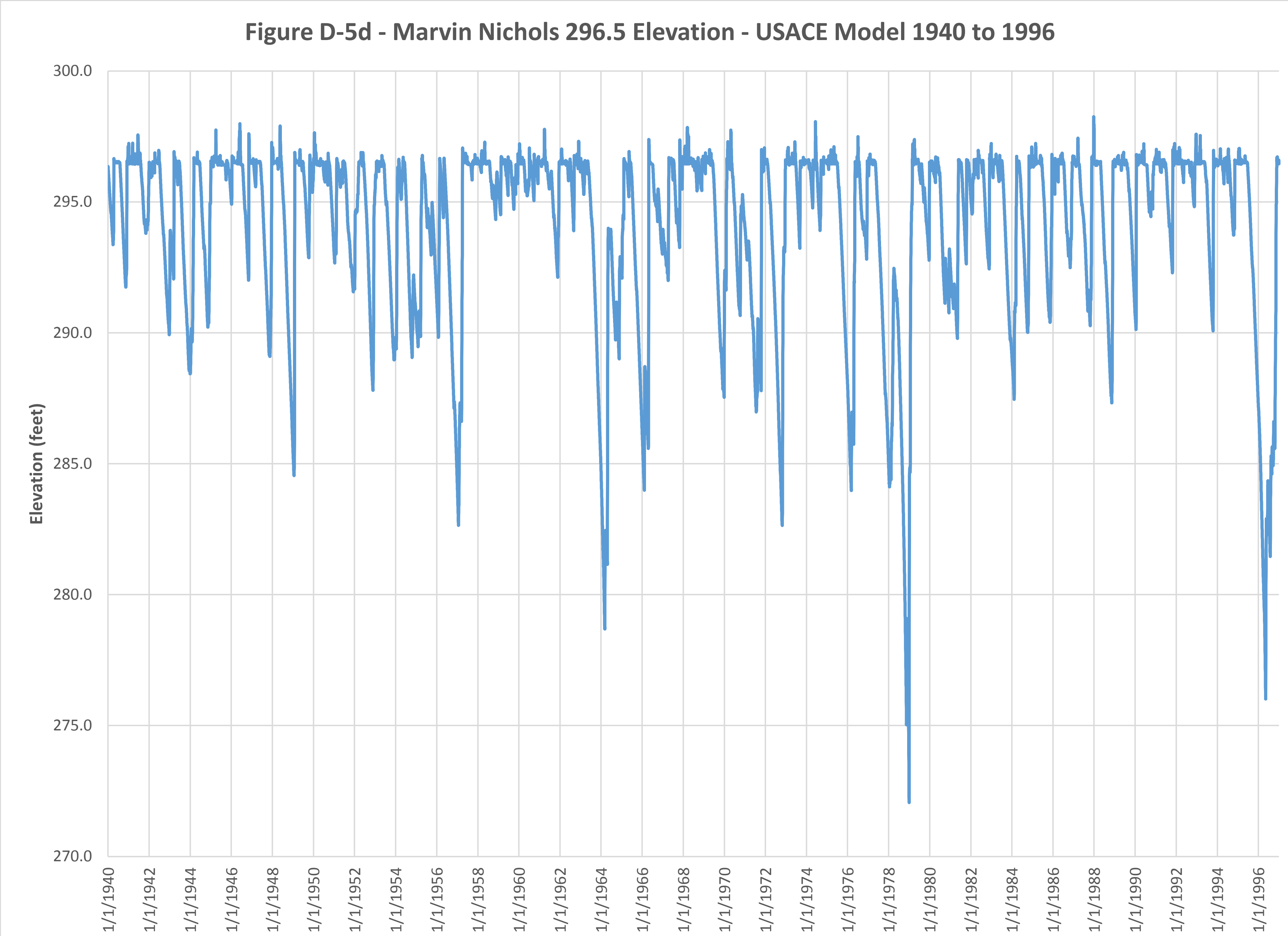


Figure D-5d - Marvin Nichols 296.5 Elevation - USACE Model 1940 to 1996
Elevation (feet)
300.0
295.0
290.0
285.0
280.0
275.0
270.0
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996

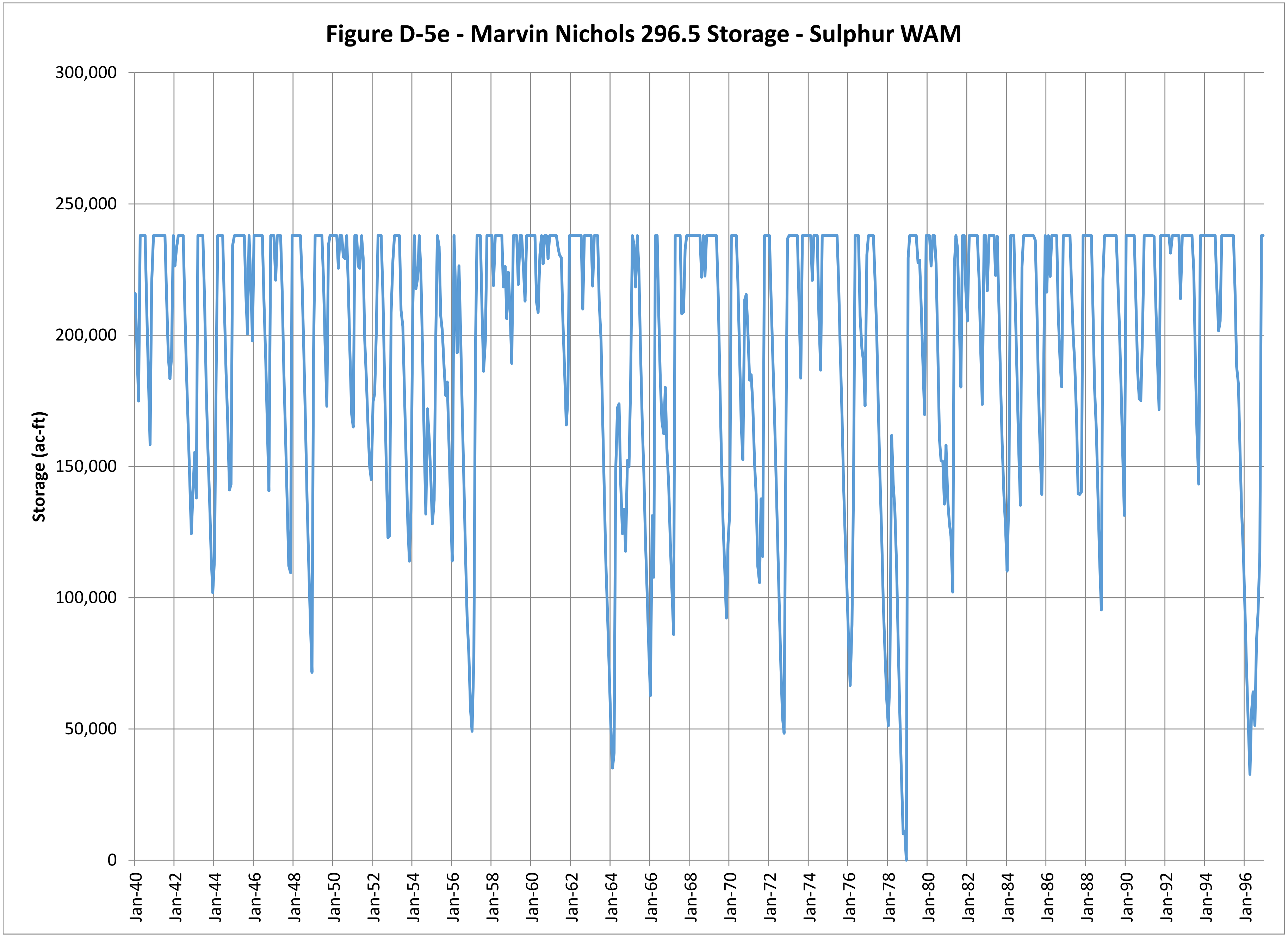


Figure D-5e - Marvin Nichols 296.5 Storage - Sulphur WAM
Storage (ac-ft)
300,000
250,000
200,000
150,000
100,000
50,000
0
Jan-40
Jan-42
Jan-44
Jan-46
Jan-48
Jan-50
Jan-52
Jan-54
Jan-56
Jan-58
Jan-60
Jan-62
Jan-64
Jan-66
Jan-68
Jan-70
Jan-72
Jan-74
Jan-76
Jan-78
Jan-80
Jan-82
Jan-84
Jan-86
Jan-88
Jan-90
Jan-92
Jan-94
Jan-96

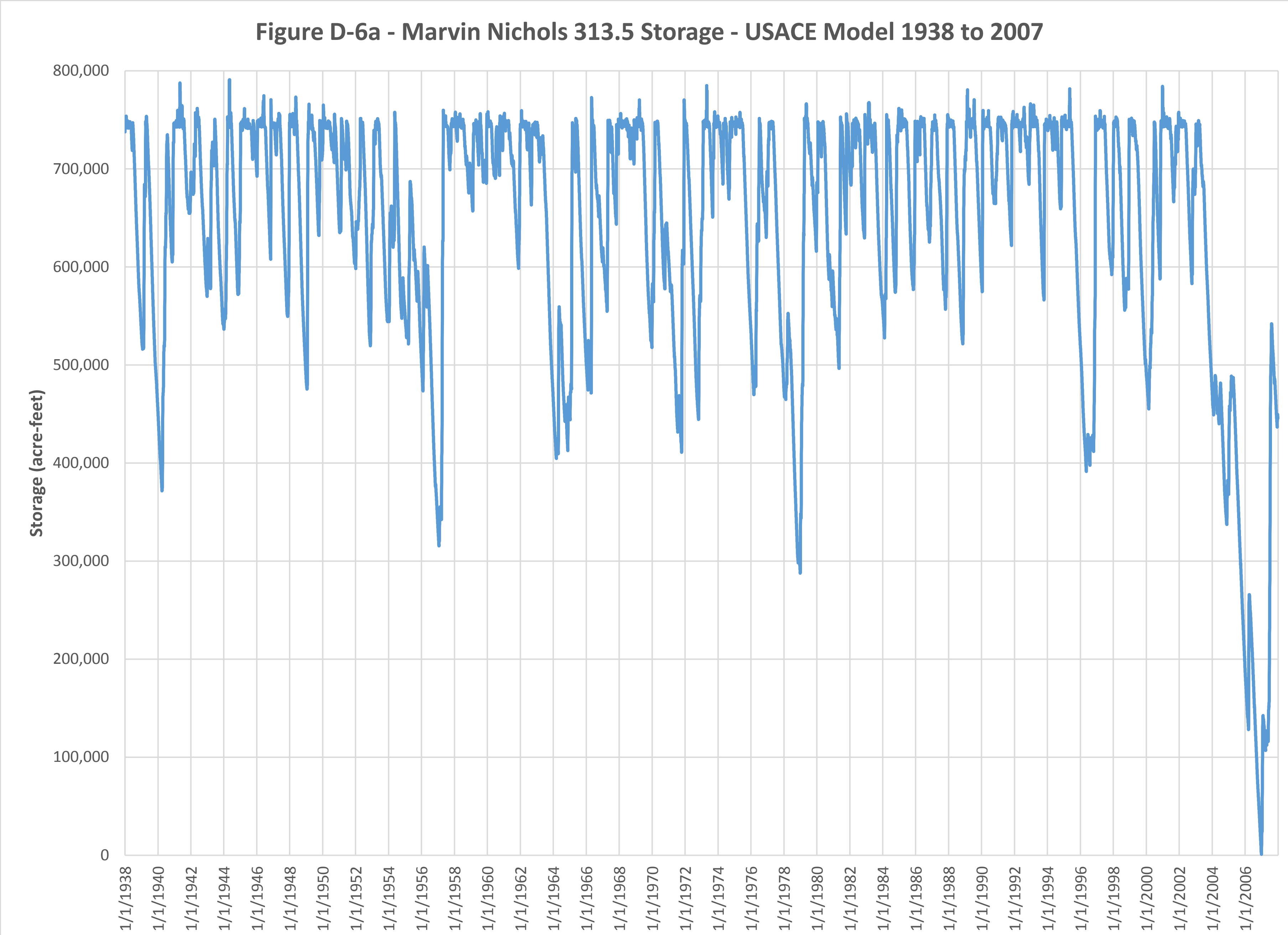


Figure D-6a - Marvin Nichols 313.5 Storage - USACE Model 1938 to 2007
Storage (acre-feet)
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996
1/1/1998
1/1/2000
1/1/2002
1/1/2004
1/1/2006

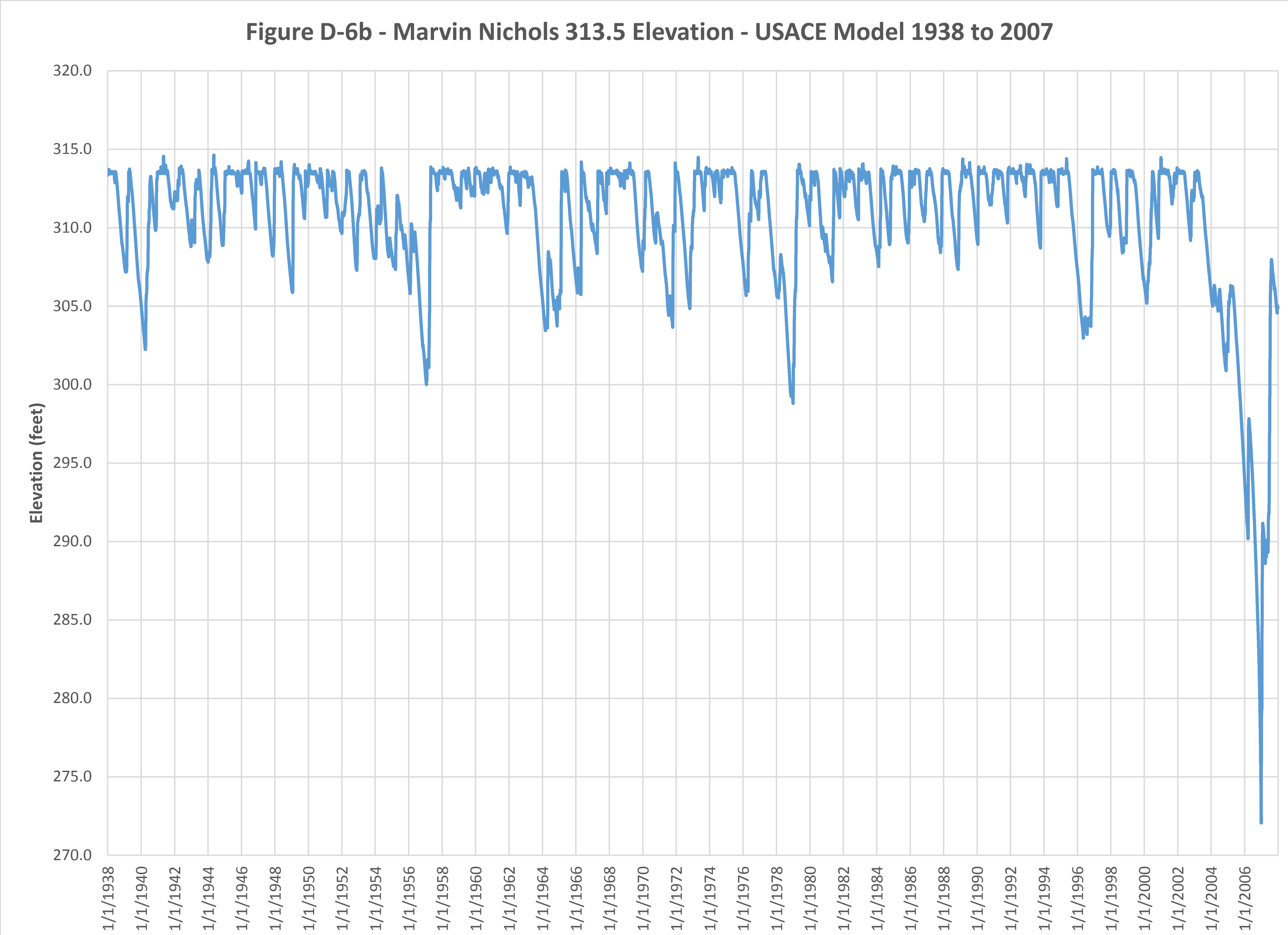


Figure D-6b - Marvin Nichols 313.5 Elevation - USACE Model 1938 to 2007
Elevation (feet)
320.0
315.0
310.0
305.0
300.0
295.0
290.0
285.0
280.0
275.0
270.0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996
1/1/1998
1/1/2000
1/1/2002
1/1/2004
1/1/2006

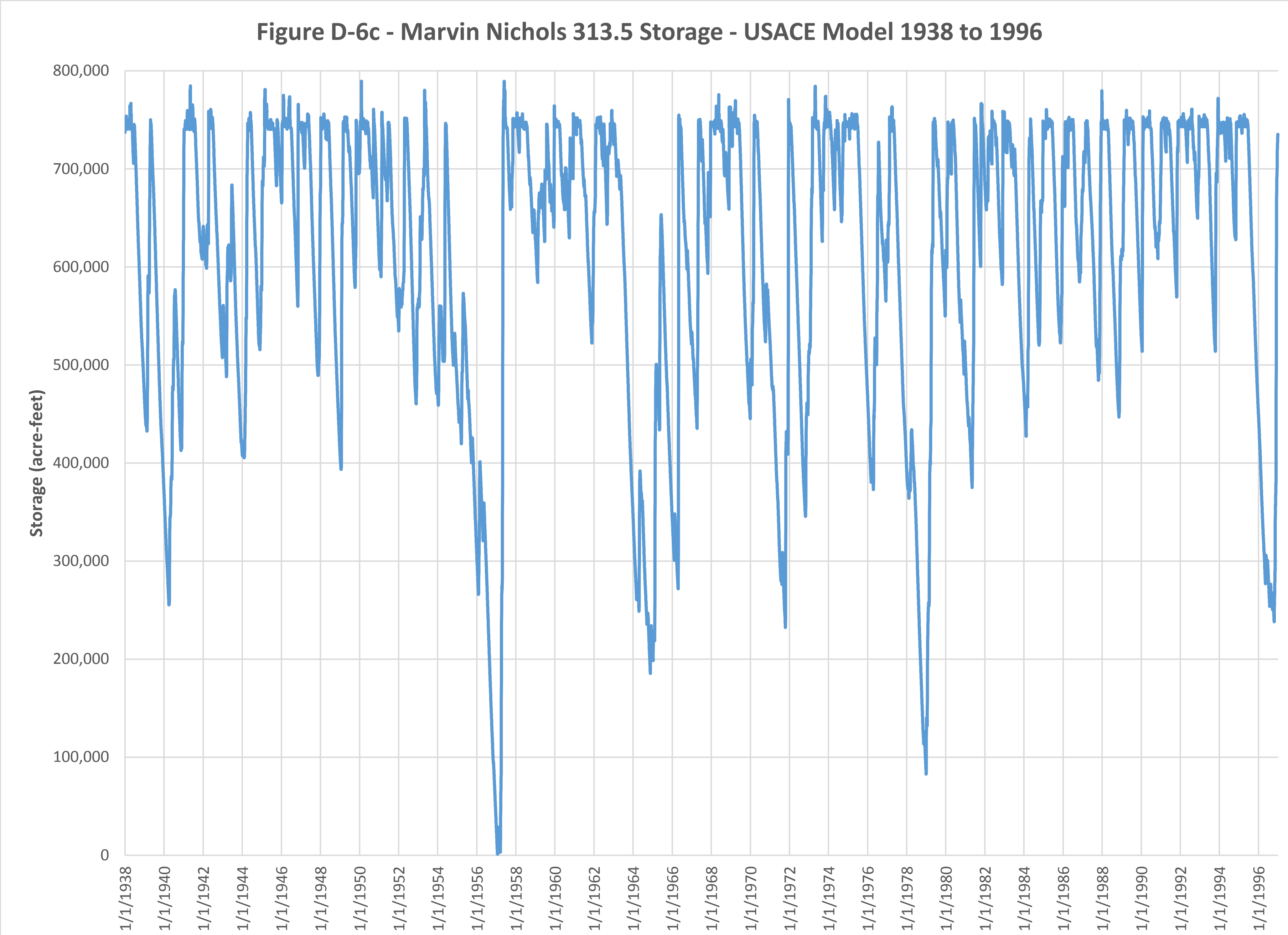


Figure D-6c - Marvin Nichols 313.5 Storage - USACE Model 1938 to 1996
Storage (acre-feet)
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996

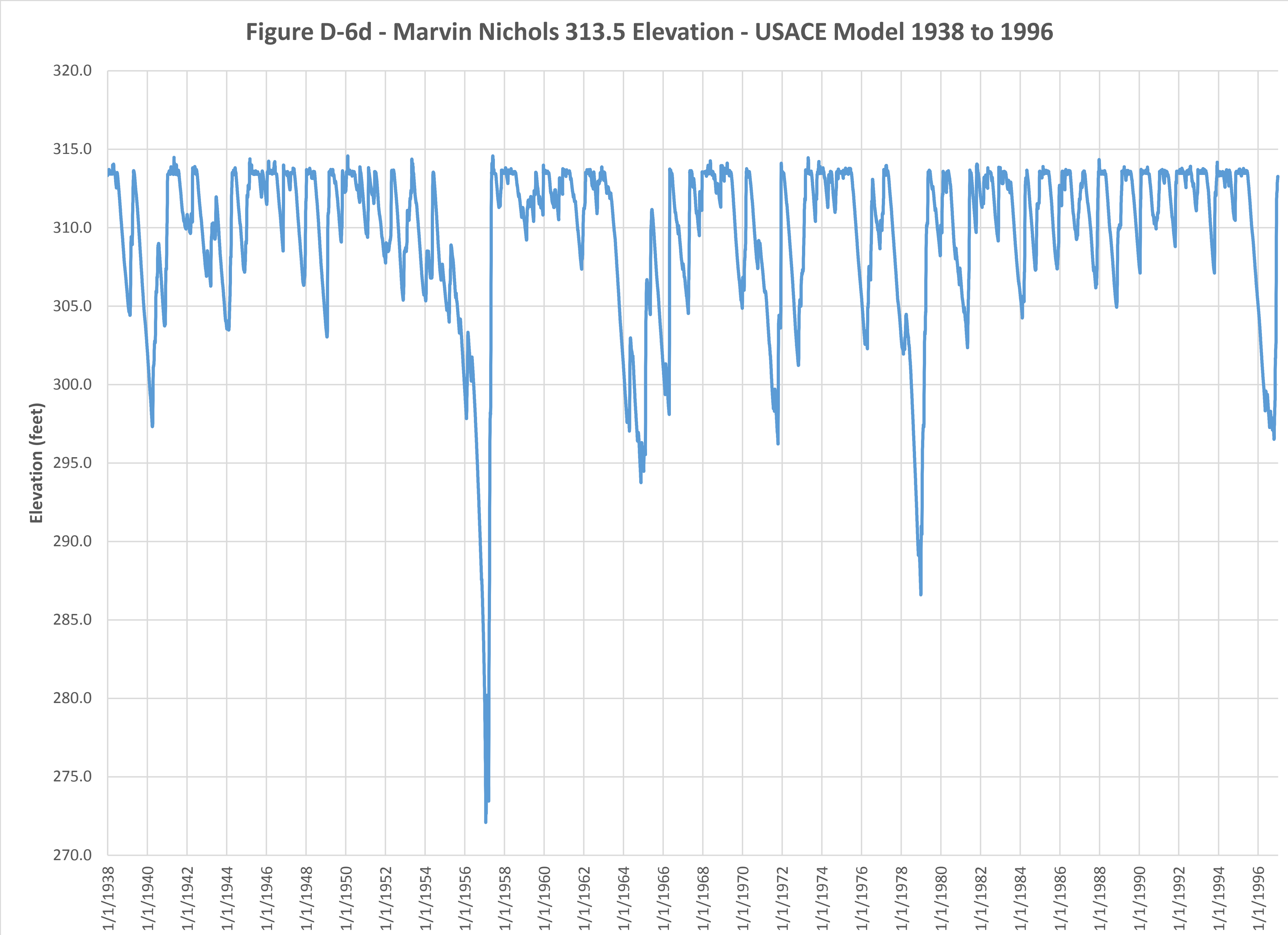


Figure D-6d - Marvin Nichols 313.5 Elevation - USACE Model 1938 to 1996
Elevation (feet)
320.0
315.0
310.0
305.0
300.0
295.0
290.0
285.0
280.0
275.0
270.0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996

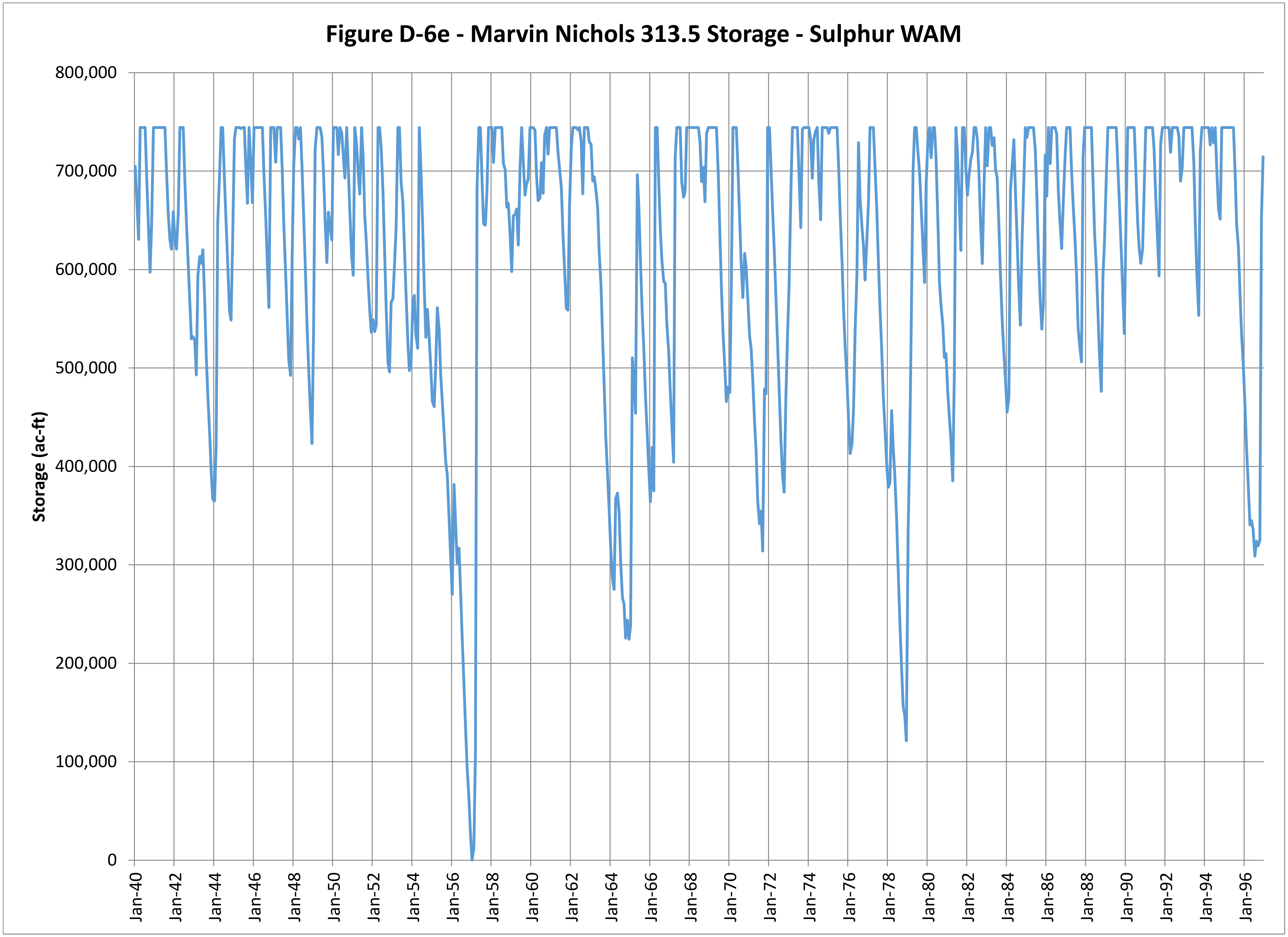


Figure D-6e - Marvin Nichols 313.5 Storage - Sulphur WAM
Storage (ac-ft)
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
Jan-40
Jan-42
Jan-44
Jan-46
Jan-48
Jan-50
Jan-52
Jan-54
Jan-56
Jan-58
Jan-60
Jan-62
Jan-64
Jan-66
Jan-68
Jan-70
Jan-72
Jan-74
Jan-76
Jan-78
Jan-80
Jan-82
Jan-84
Jan-86
Jan-88
Jan-90
Jan-92
Jan-94
Jan-96

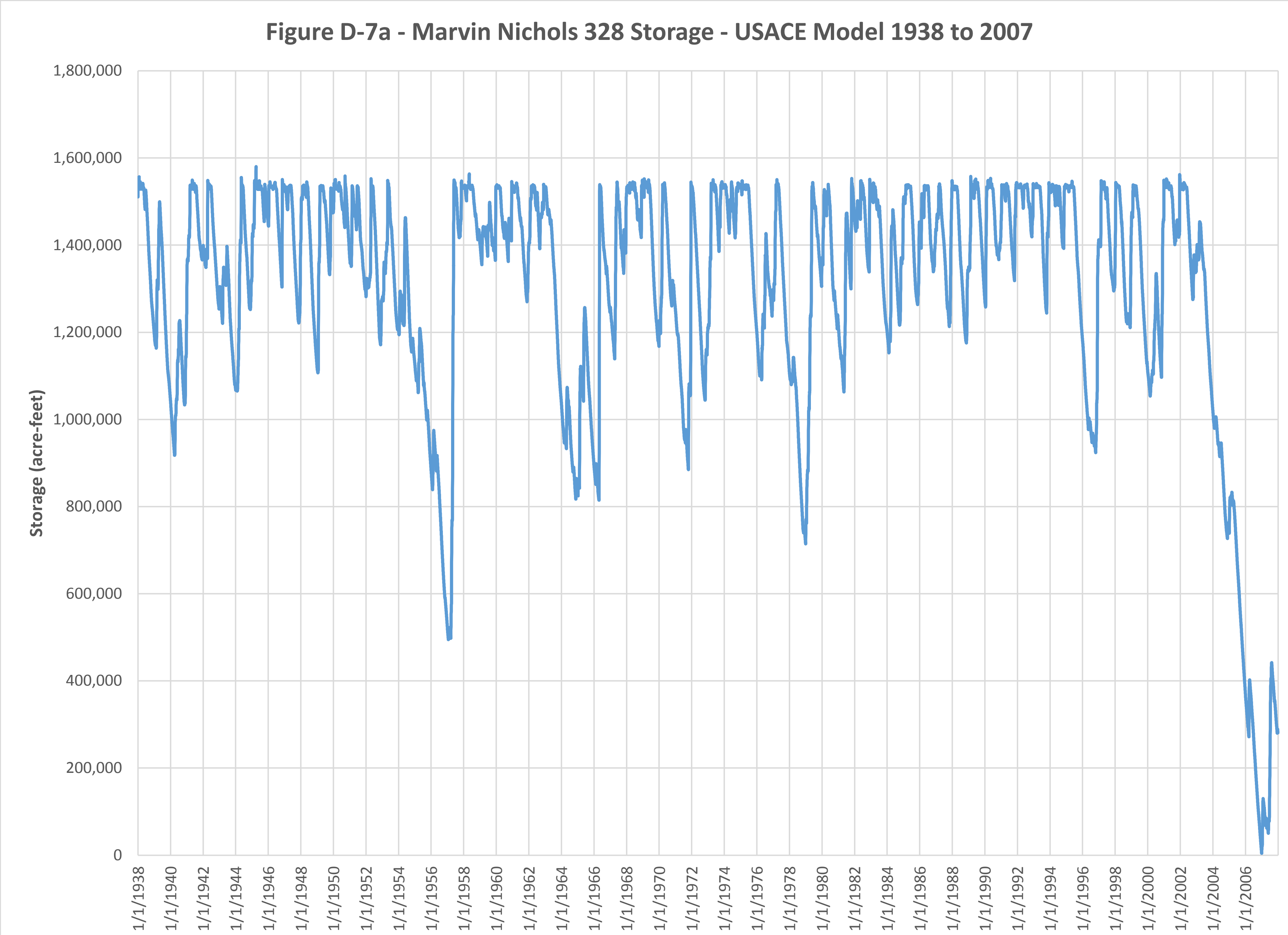
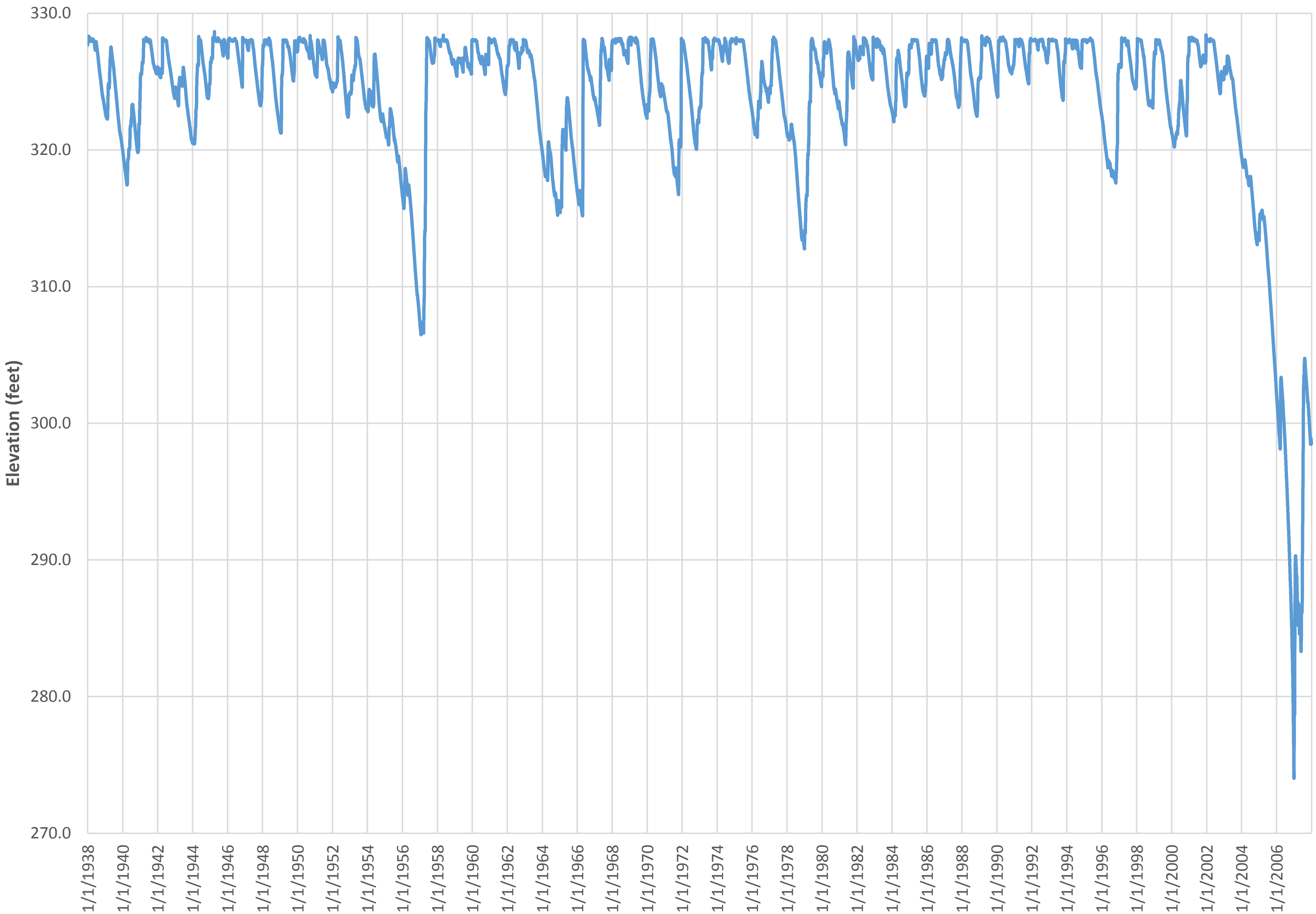


Figure D-7a - Marvin Nichols 328 Storage - USACE Model 1938 to 2007
Storage (acre-feet)
1,800,000
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996
1/1/1998
1/1/2000
1/1/2002
1/1/2004
1/1/2006

Figure D-7b - Marvin Nichols 328 Elevation - USACE Model 1938 to 2007



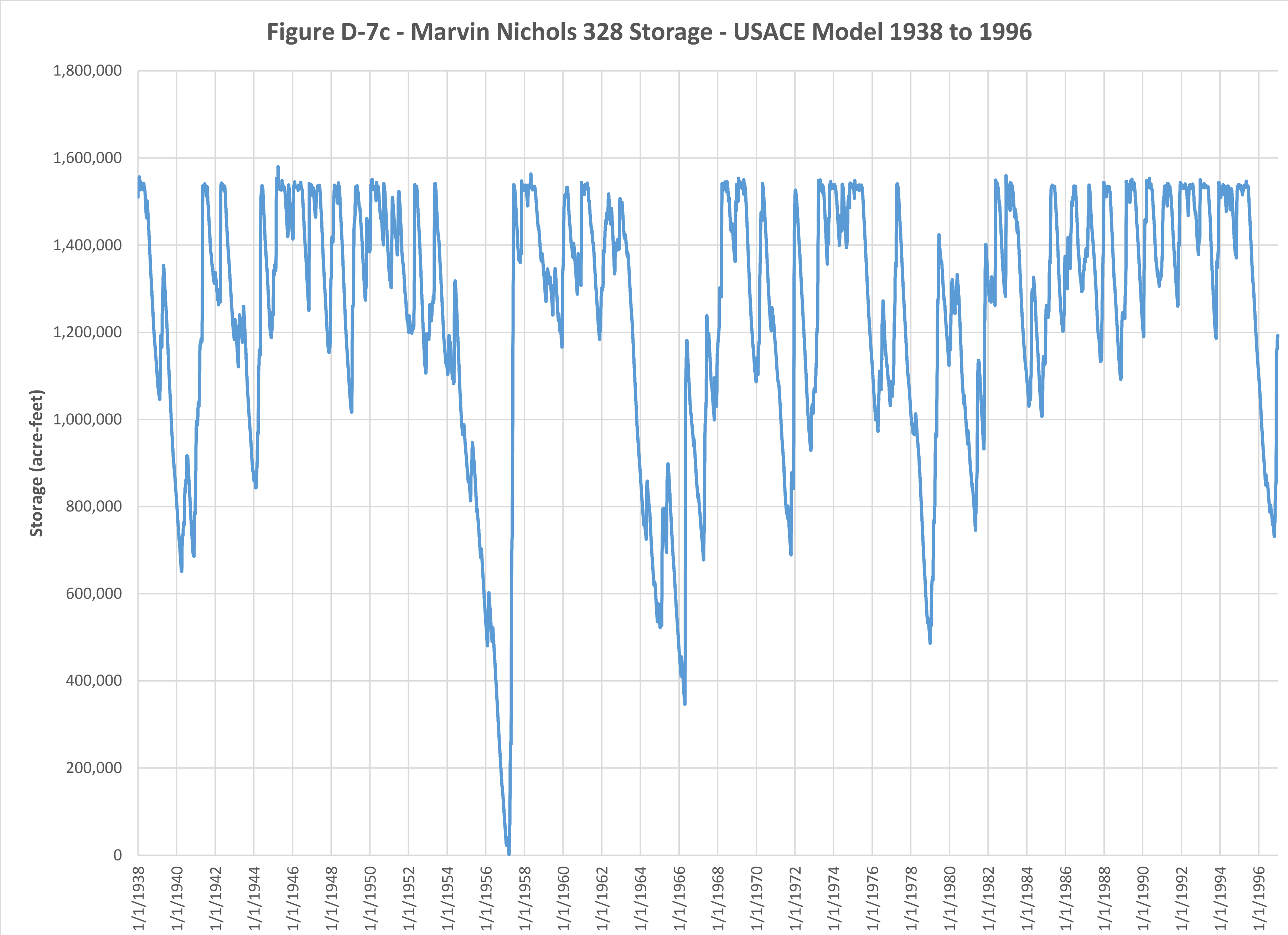


Figure D-7c - Marvin Nichols 328 Storage - USACE Model 1938 to 1996
Storage (acre-feet)
1,800,000
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996

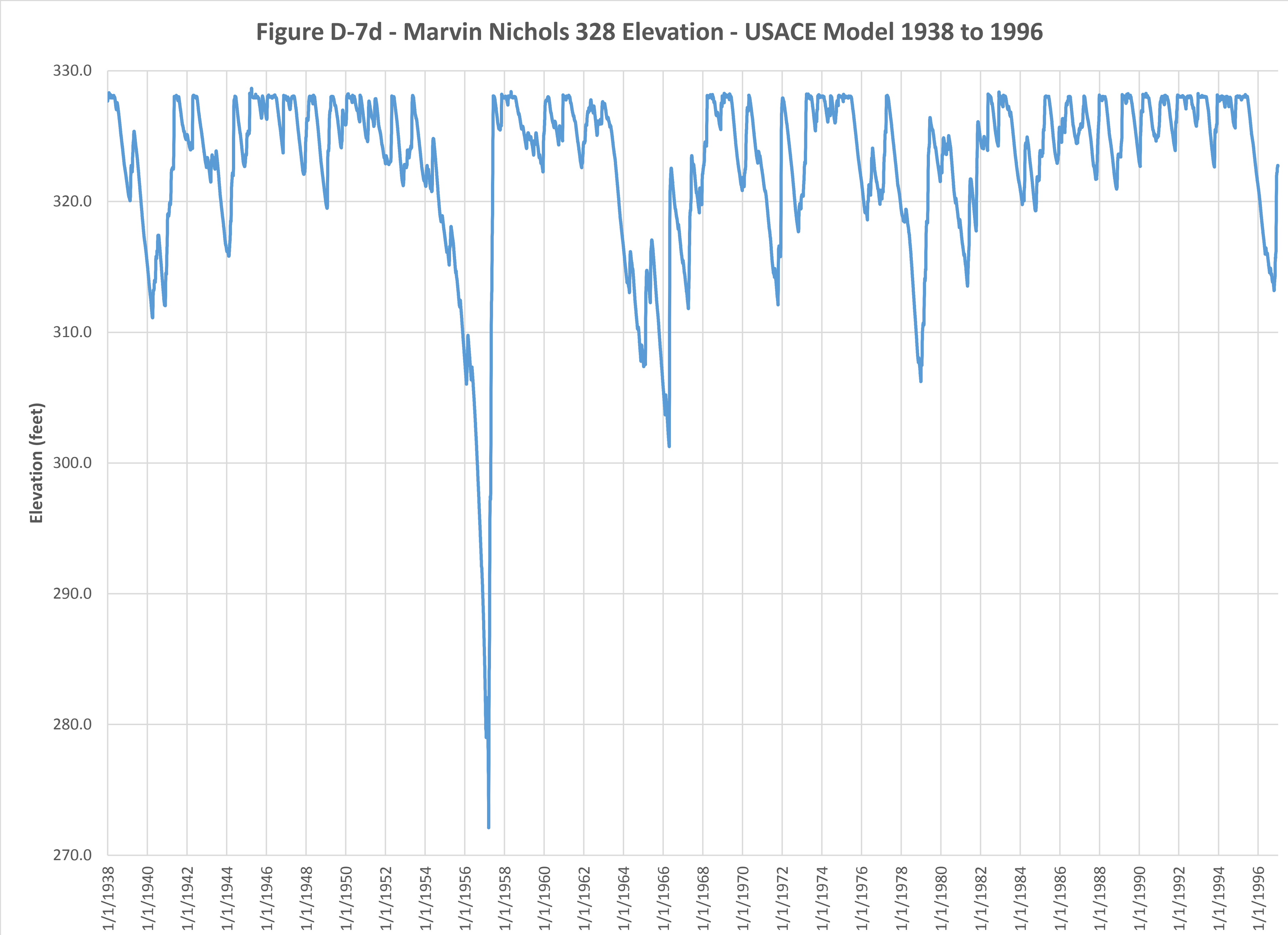


Figure D-7d - Marvin Nichols 328 Elevation - USACE Model 1938 to 1996
Elevation (feet)
330.0
320.0
310.0
300.0
290.0
280.0
270.0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996

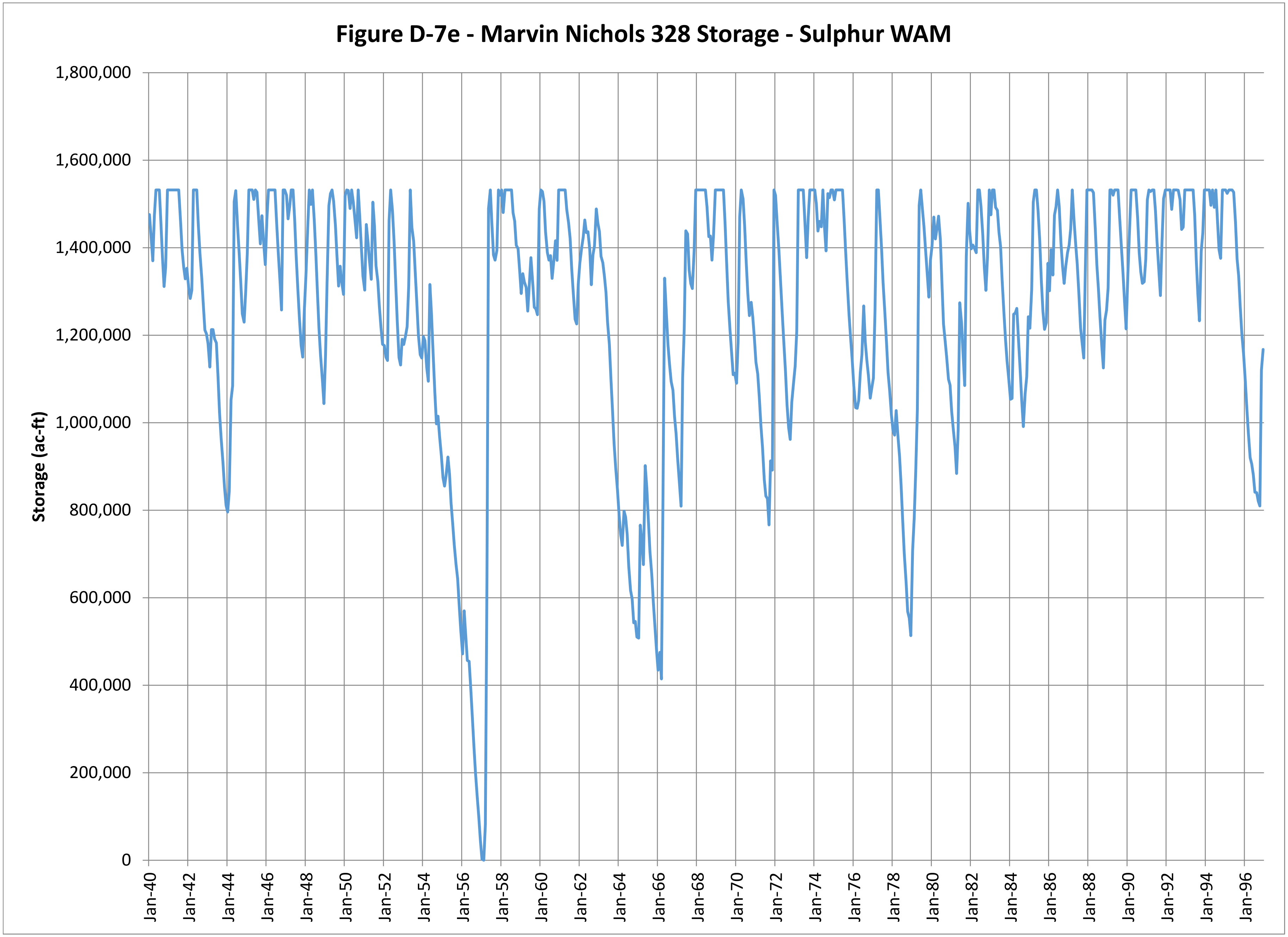


Figure D-7e - Marvin Nichols 328 Storage - Sulphur WAM
Storage (ac-ft)
1,800,000
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
Jan-40
Jan-42
Jan-44
Jan-46
Jan-48
Jan-50
Jan-52
Jan-54
Jan-56
Jan-58
Jan-60
Jan-62
Jan-64
Jan-66
Jan-68
Jan-70
Jan-72
Jan-74
Jan-76
Jan-78
Jan-80
Jan-82
Jan-84
Jan-86
Jan-88
Jan-90
Jan-92
Jan-94
Jan-96

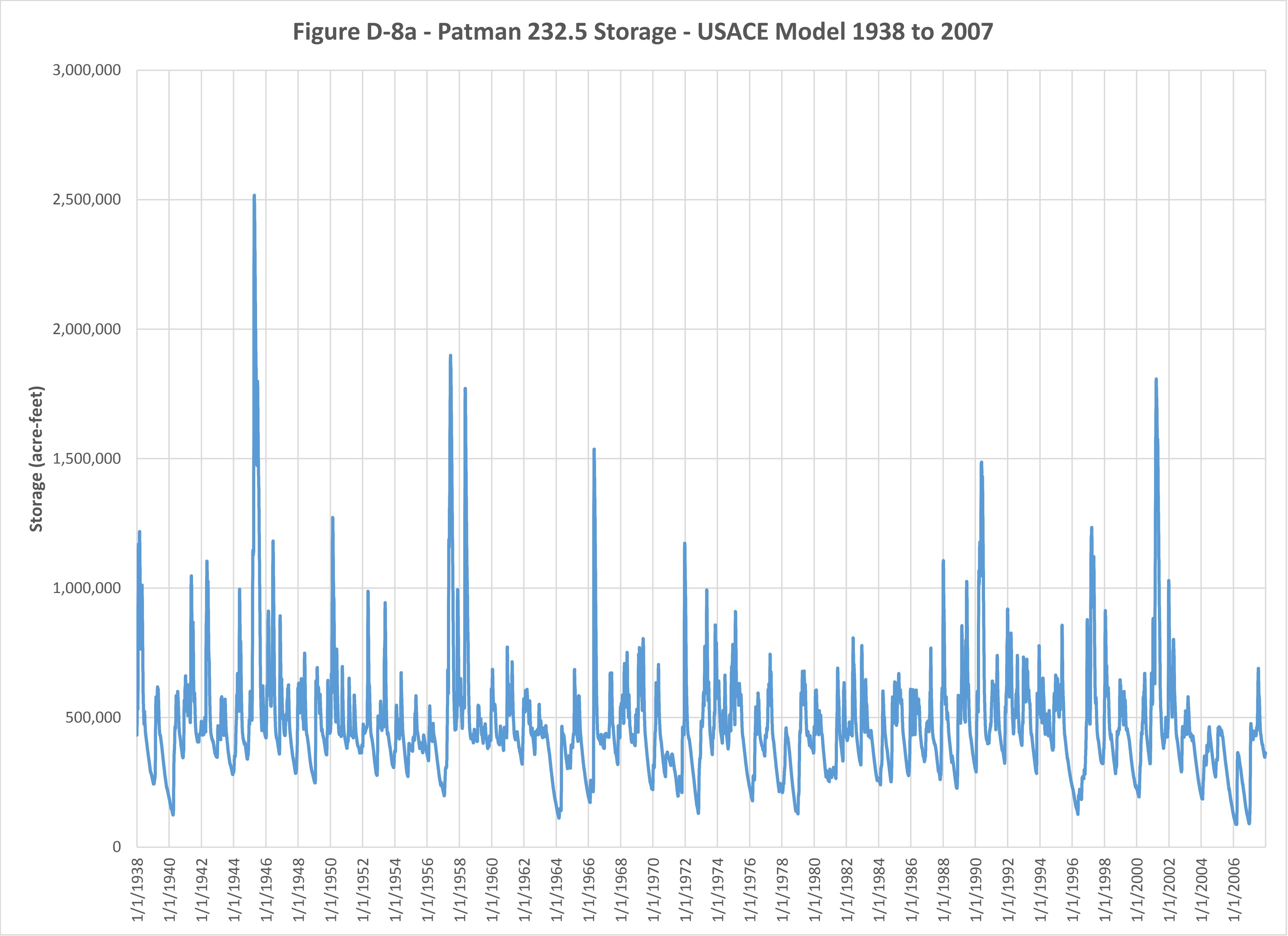


Figure D-8a - Patman 232.5 Storage - USACE Model 1938 to 2007
Storage (acre-feet)
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996
1/1/1998
1/1/2000
1/1/2002
1/1/2004
1/1/2006

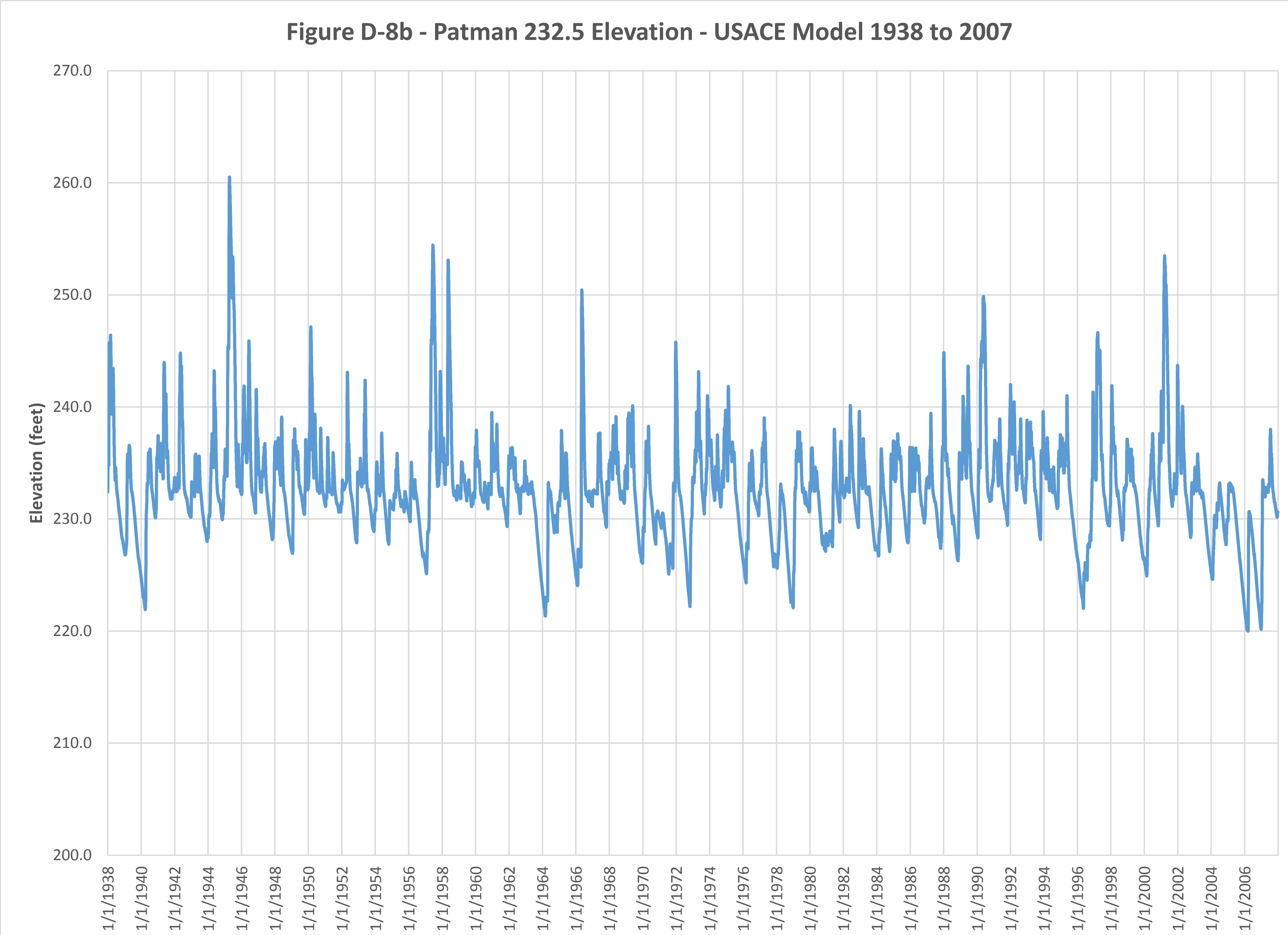


Figure D-8b - Patman 232.5 Elevation - USACE Model 1938 to 2007
Elevation (feet)
270.0
260.0
250.0
240.0
230.0
220.0
210.0
200.0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996
1/1/1998
1/1/2000
1/1/2002
1/1/2004
1/1/2006

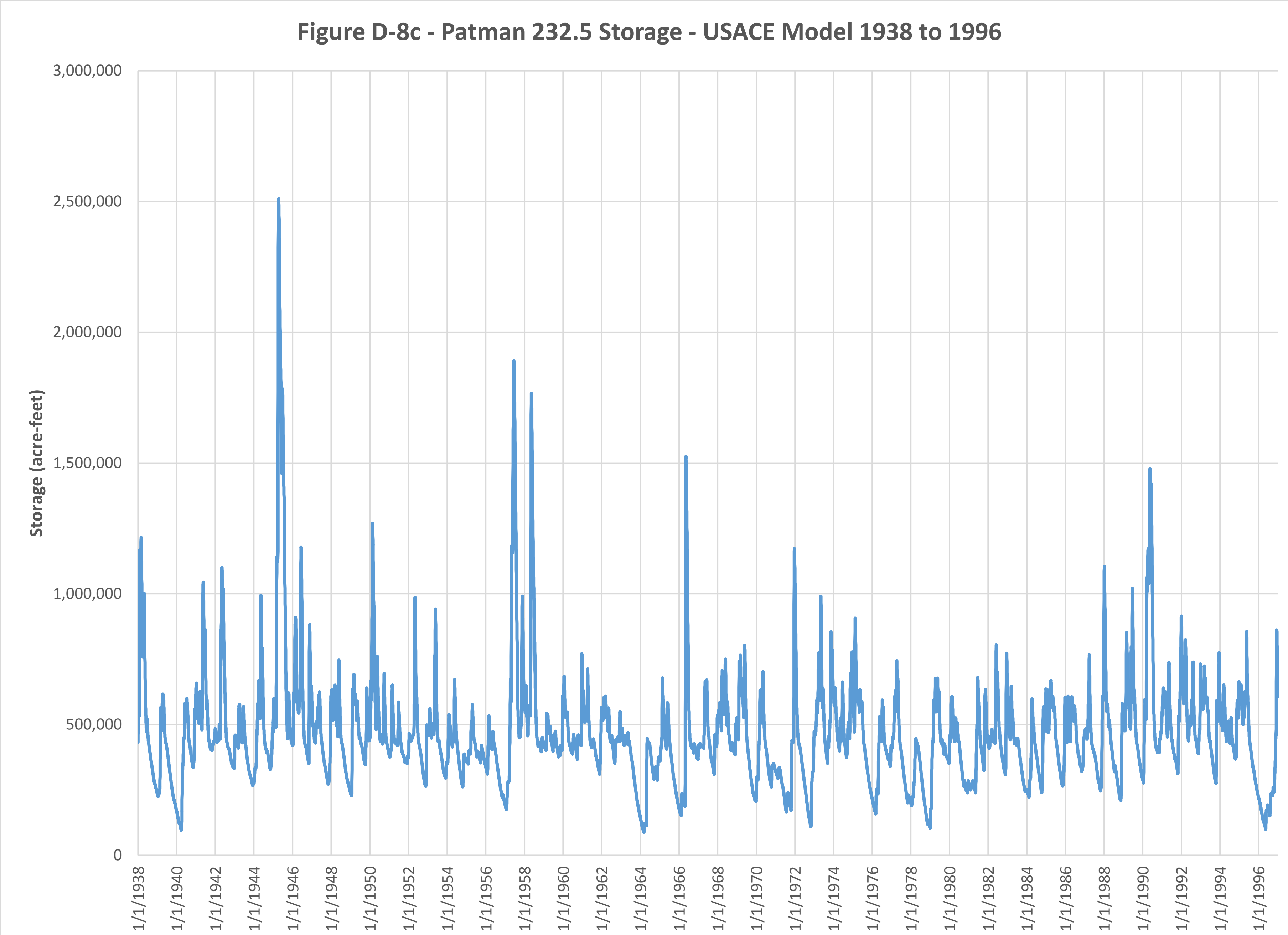


Figure D-8c - Patman 232.5 Storage - USACE Model 1938 to 1996
Storage (acre-feet)
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996

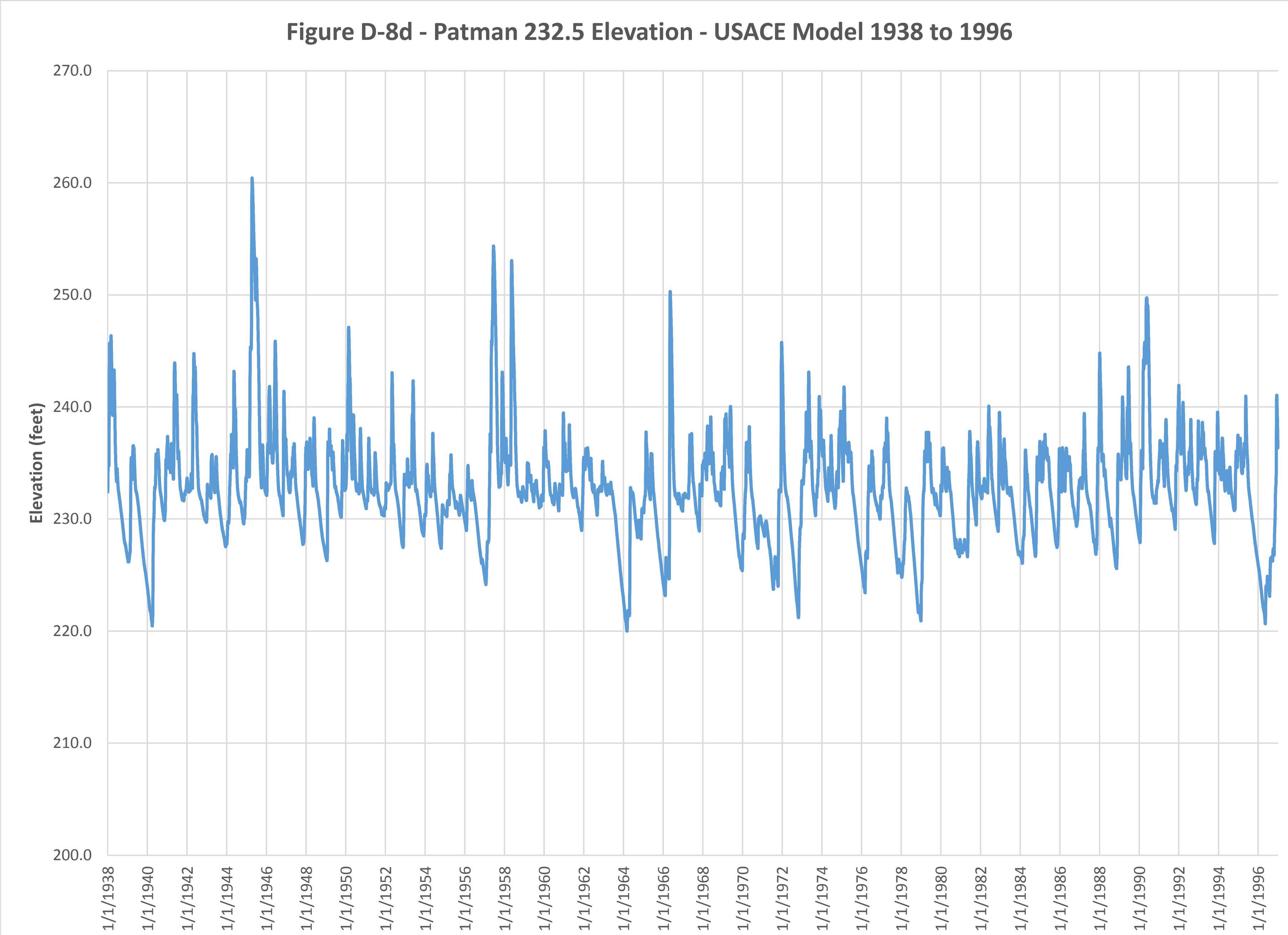


Figure D-8d - Patman 232.5 Elevation - USACE Model 1938 to 1996
Elevation (feet)
270.0
260.0
250.0
240.0
230.0
220.0
210.0
200.0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996

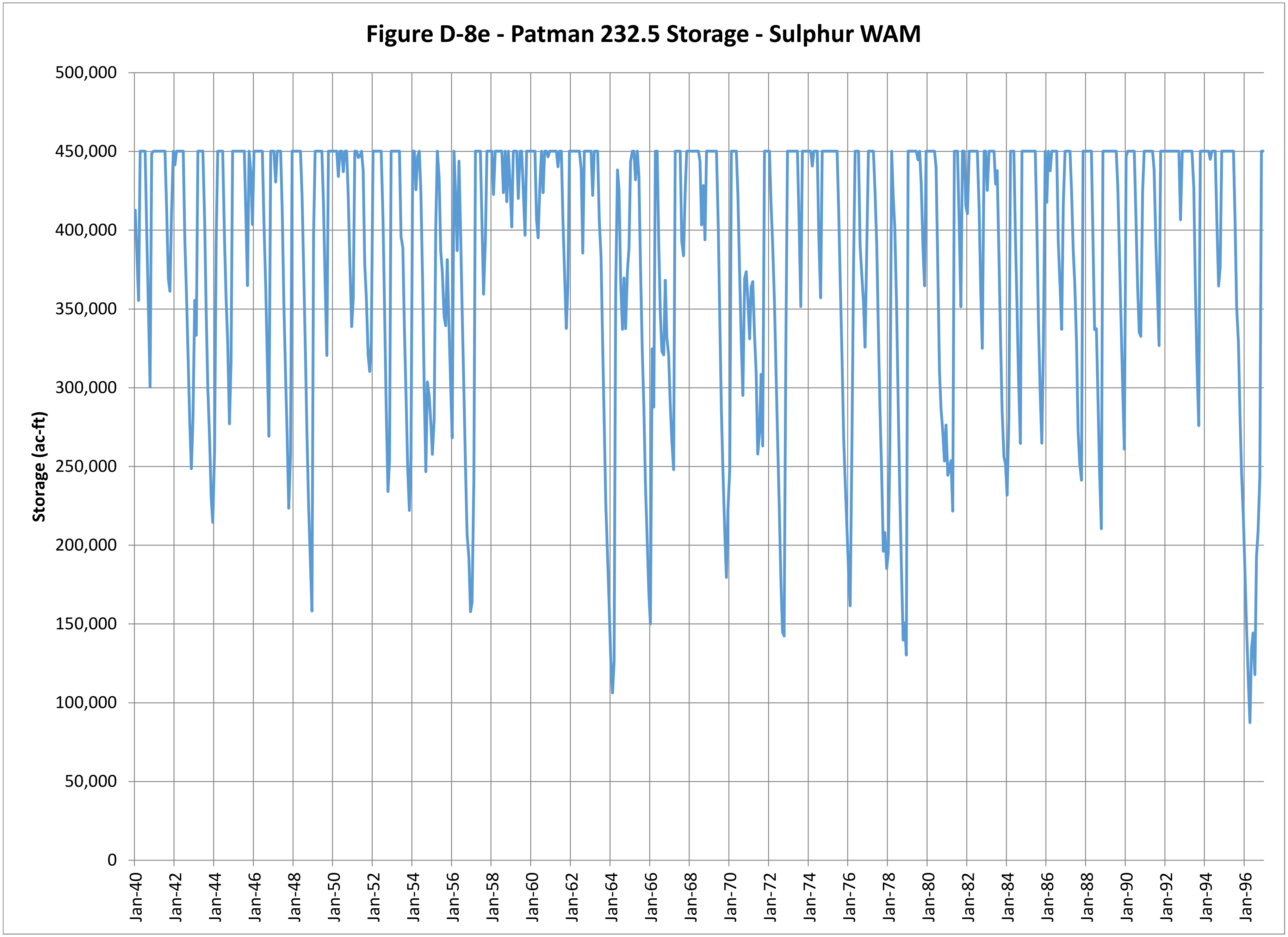


Figure D-8e - Patman 232.5 Storage - Sulphur WAM
Storage (ac-ft)
500,000
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Jan-40
Jan-42
Jan-44
Jan-46
Jan-48
Jan-50
Jan-52
Jan-54
Jan-56
Jan-58
Jan-60
Jan-62
Jan-64
Jan-66
Jan-68
Jan-70
Jan-72
Jan-74
Jan-76
Jan-78
Jan-80
Jan-82
Jan-84
Jan-86
Jan-88
Jan-90
Jan-92
Jan-94
Jan-96

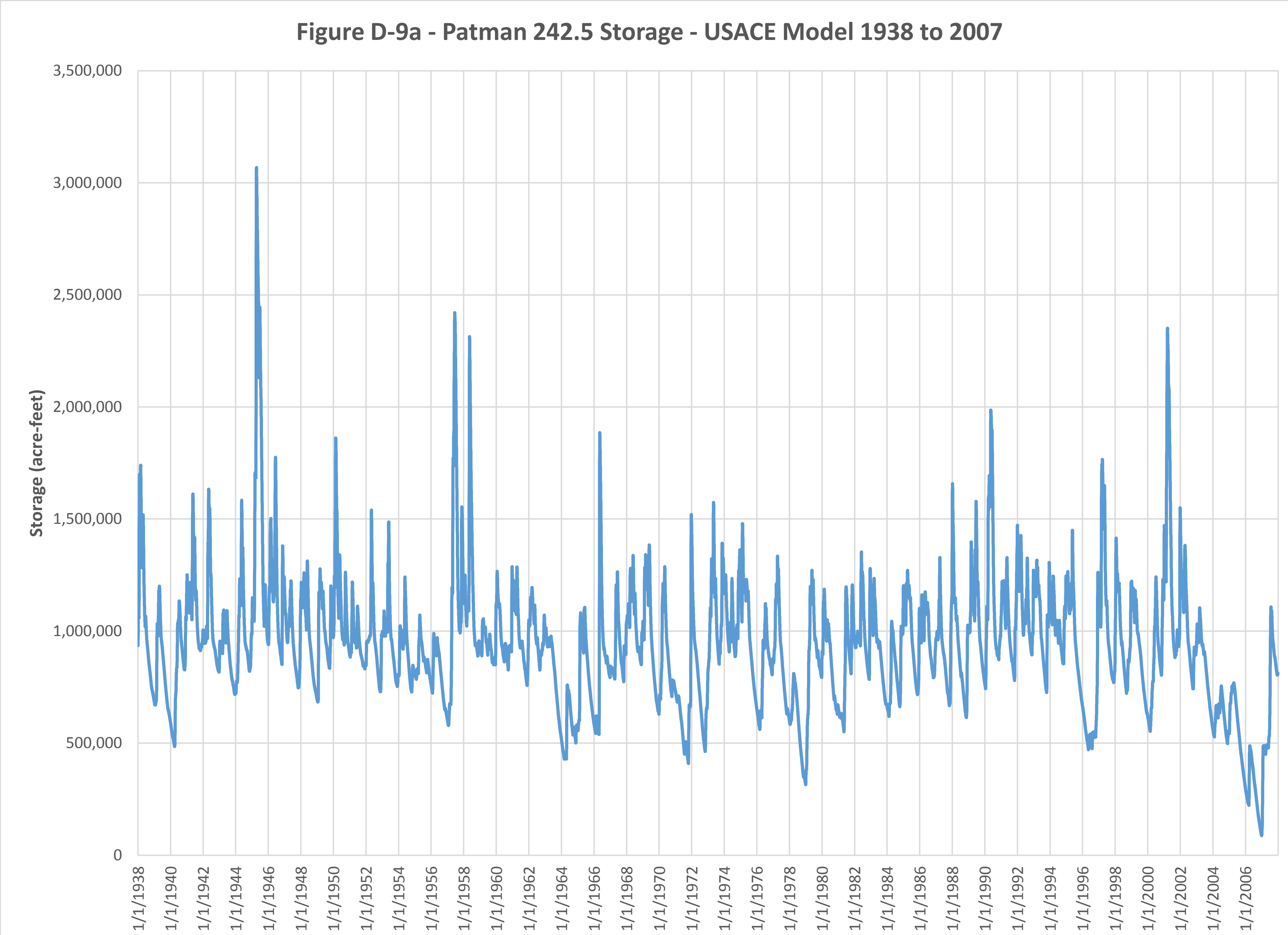


Figure D-9a - Patman 242.5 Storage - USACE Model 1938 to 2007
Storage (acre-feet)
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996
1/1/1998
1/1/2000
1/1/2002
1/1/2004
1/1/2006

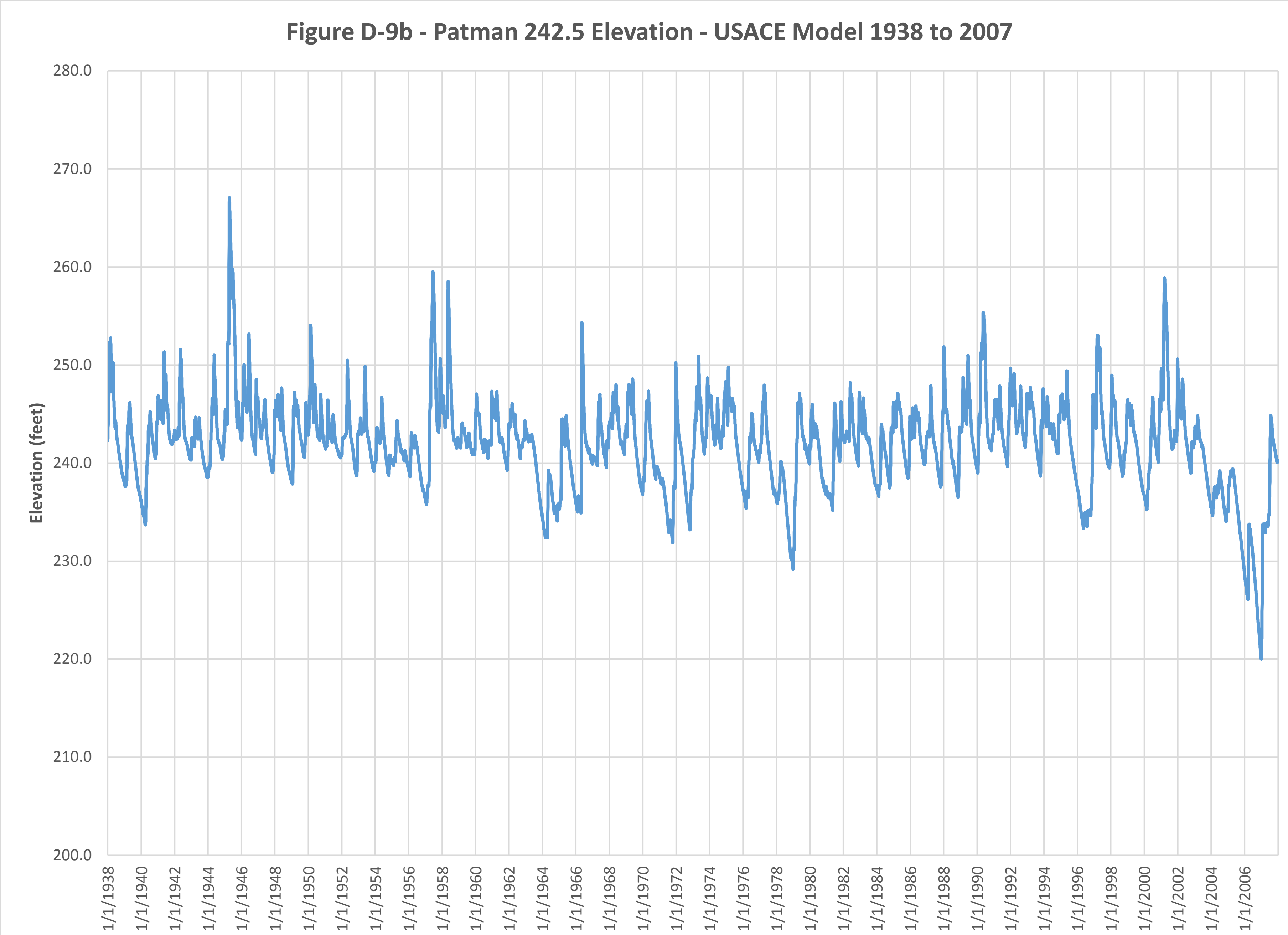


Figure D-9b - Patman 242.5 Elevation - USACE Model 1938 to 2007
Elevation (feet)
280.0
270.0
260.0
250.0
240.0
230.0
220.0
210.0
200.0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996
1/1/1998
1/1/2000
1/1/2002
1/1/2004
1/1/2006

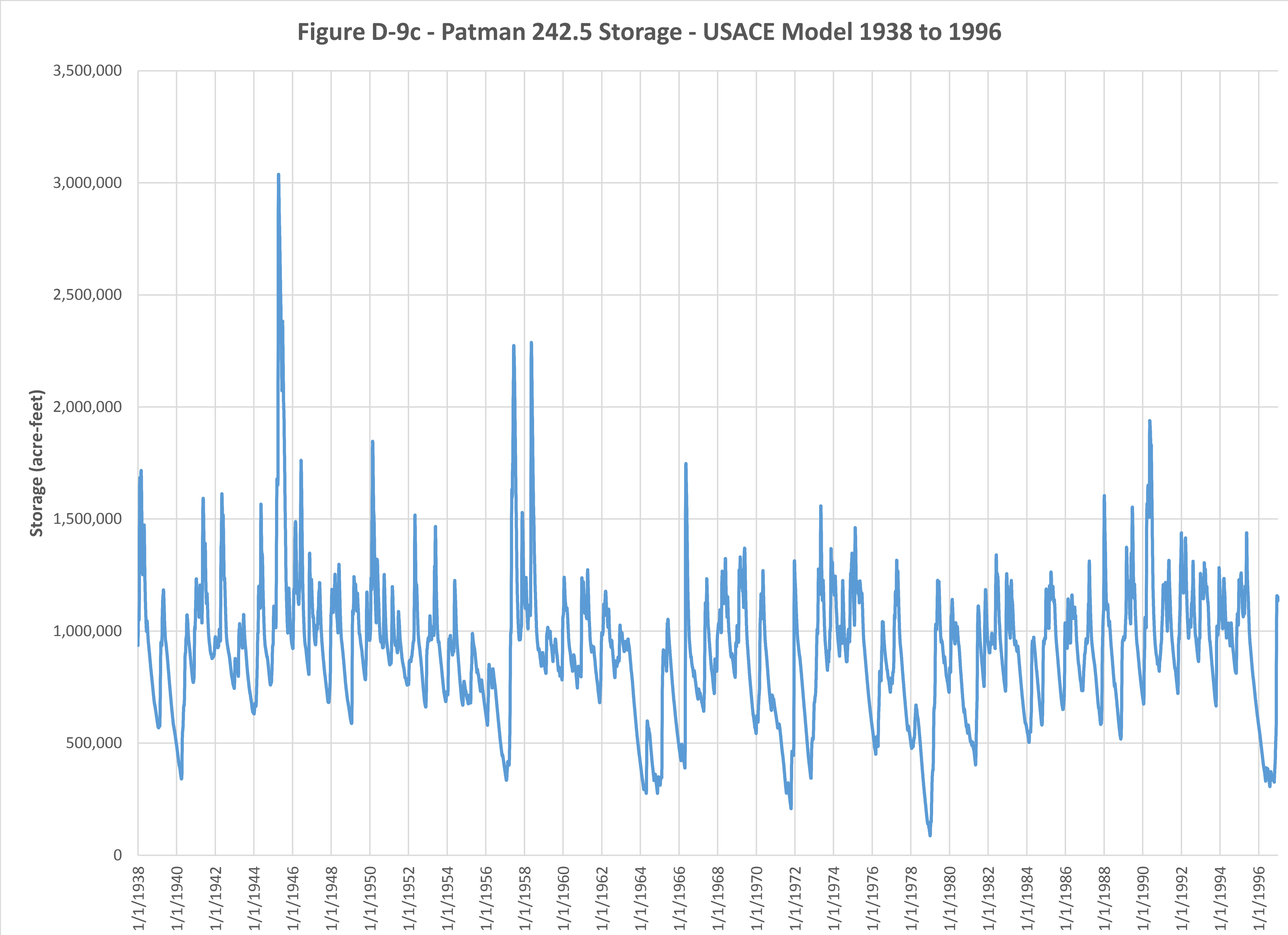


Figure D-9c - Patman 242.5 Storage - USACE Model 1938 to 1996
Storage (acre-feet)
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996

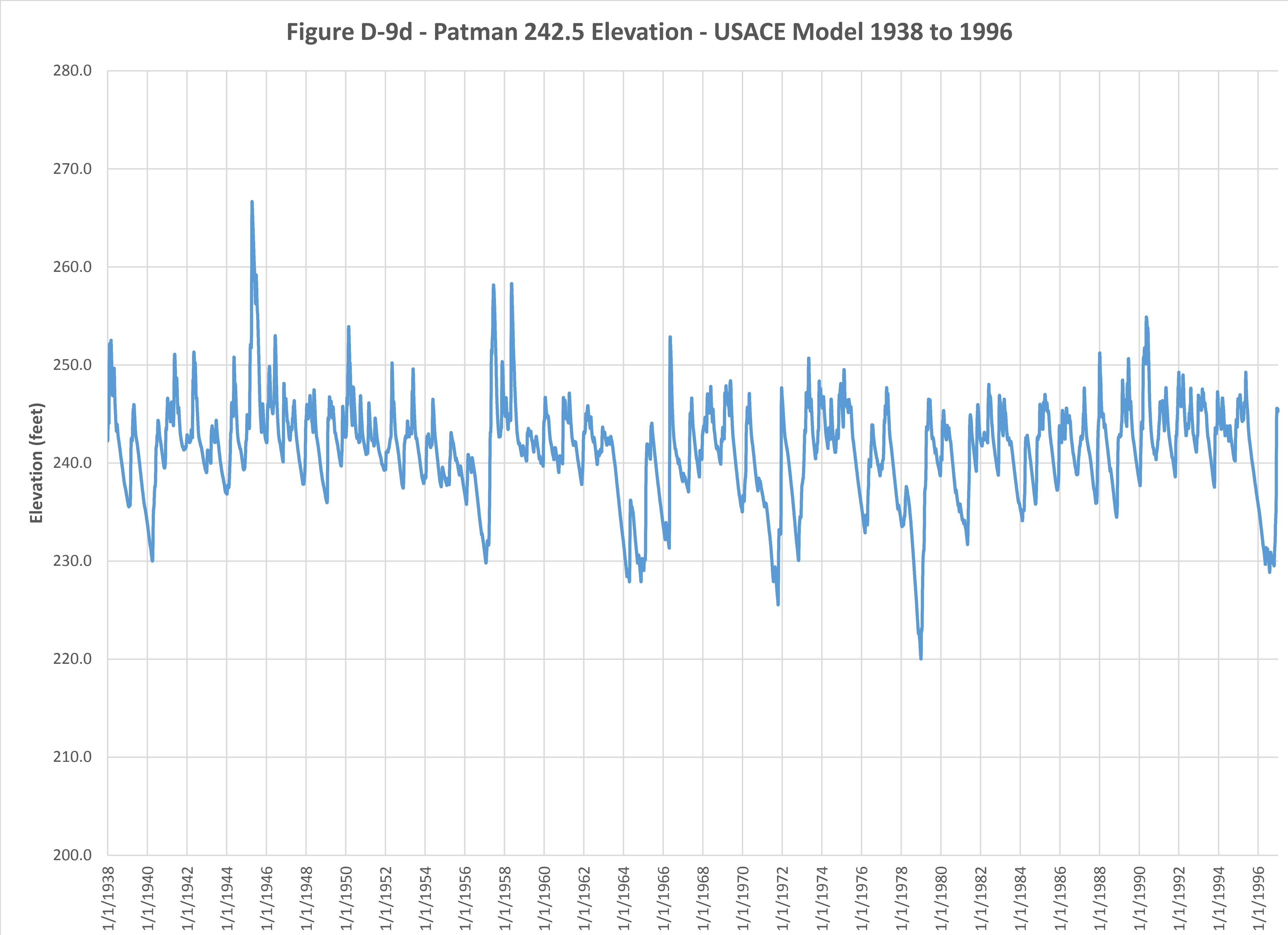
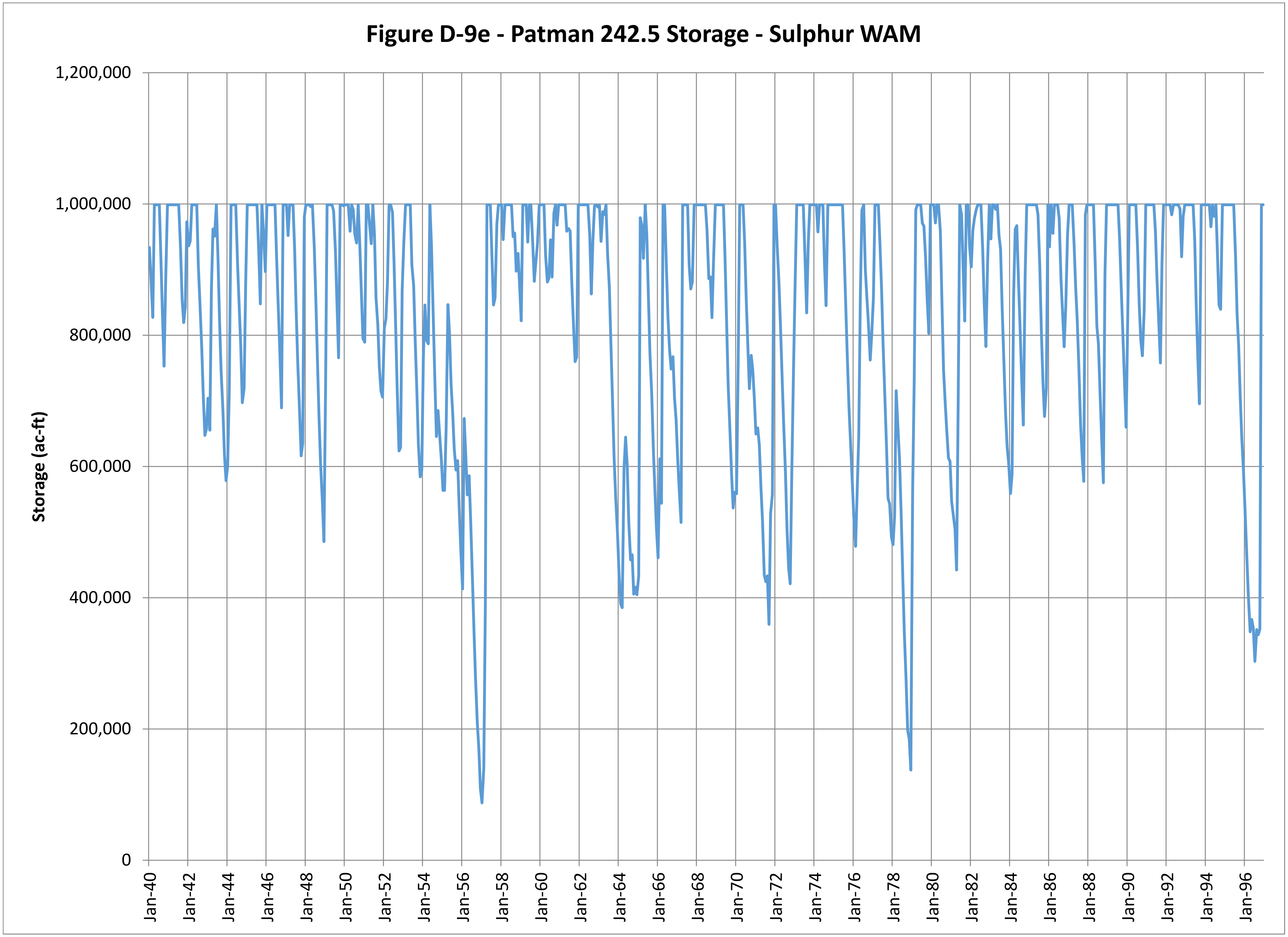


Figure D-9d - Patman 242.5 Elevation - USACE Model 1938 to 1996
Elevation (feet)
280.0
270.0
260.0
250.0
240.0
230.0
220.0
210.0
200.0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996

Figure D-9e - Patman 242.5 Storage - Sulphur WAM



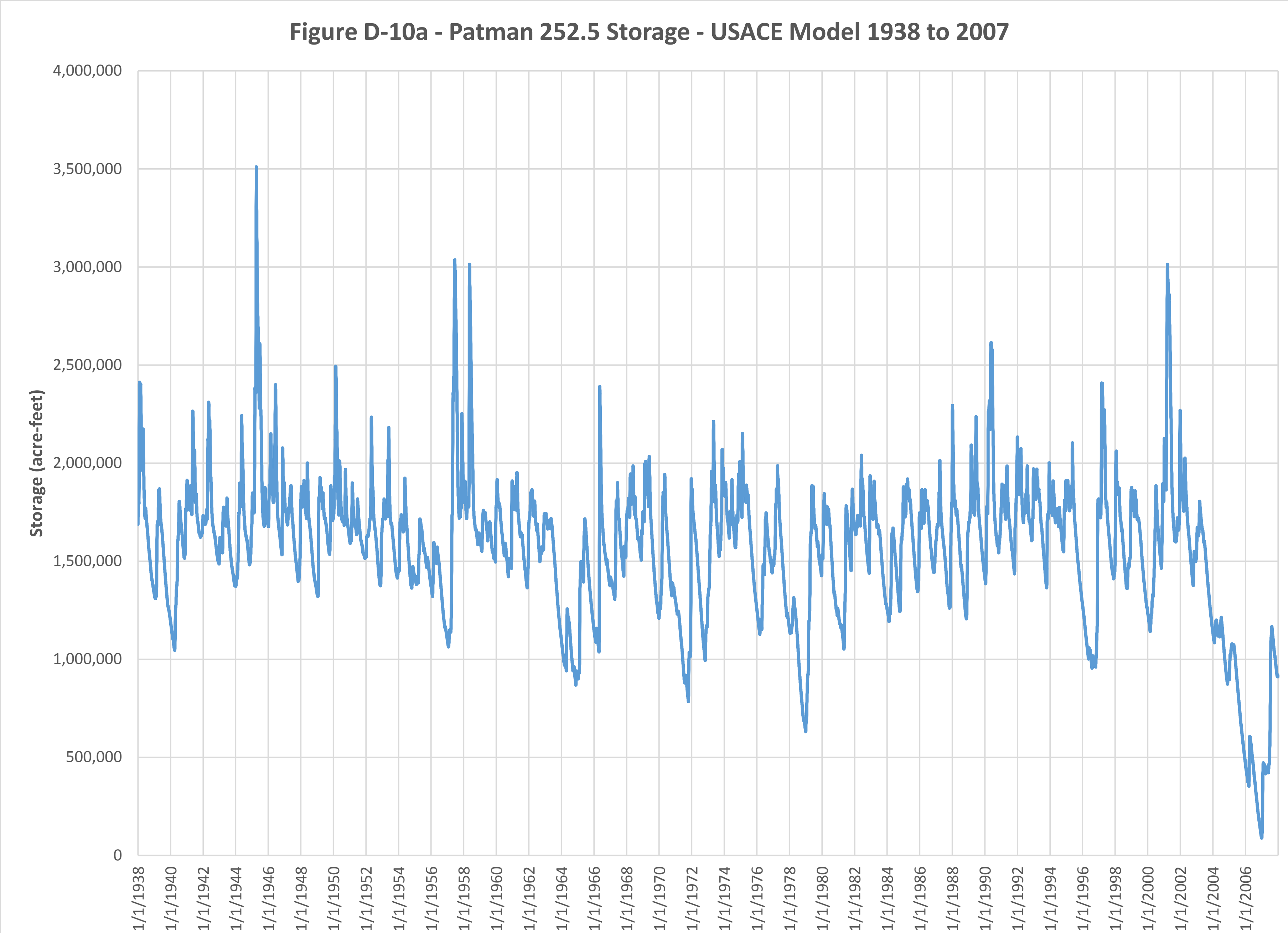


Figure D-10a - Patman 252.5 Storage - USACE Model 1938 to 2007
Storage (acre-feet)
4,000,000
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996
1/1/1998
1/1/2000
1/1/2002
1/1/2004
1/1/2006

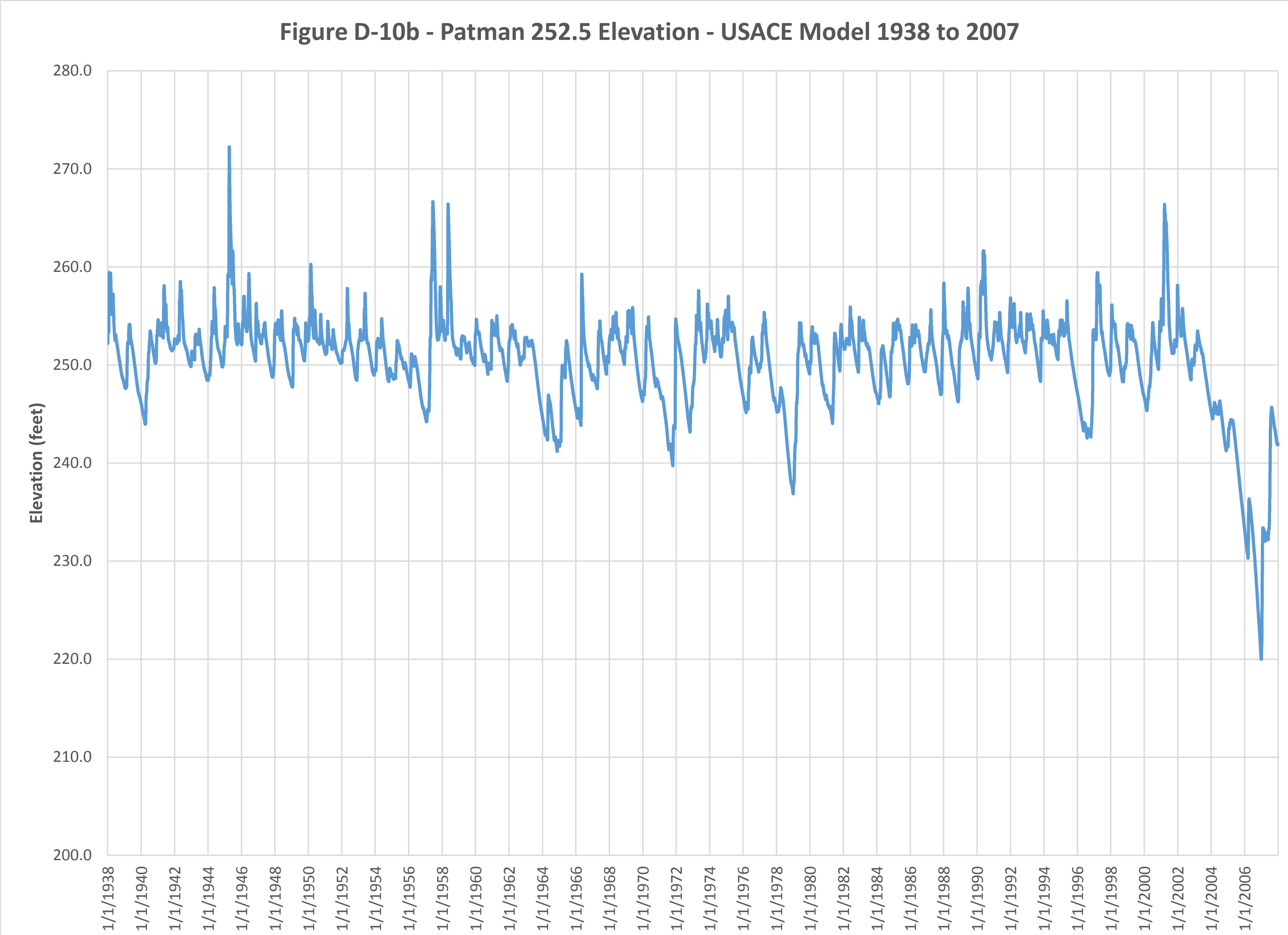


Figure D-10b - Patman 252.5 Elevation - USACE Model 1938 to 2007
Elevation (feet)
280.0
270.0
260.0
250.0
240.0
230.0
220.0
210.0
200.0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996
1/1/1998
1/1/2000
1/1/2002
1/1/2004
1/1/2006

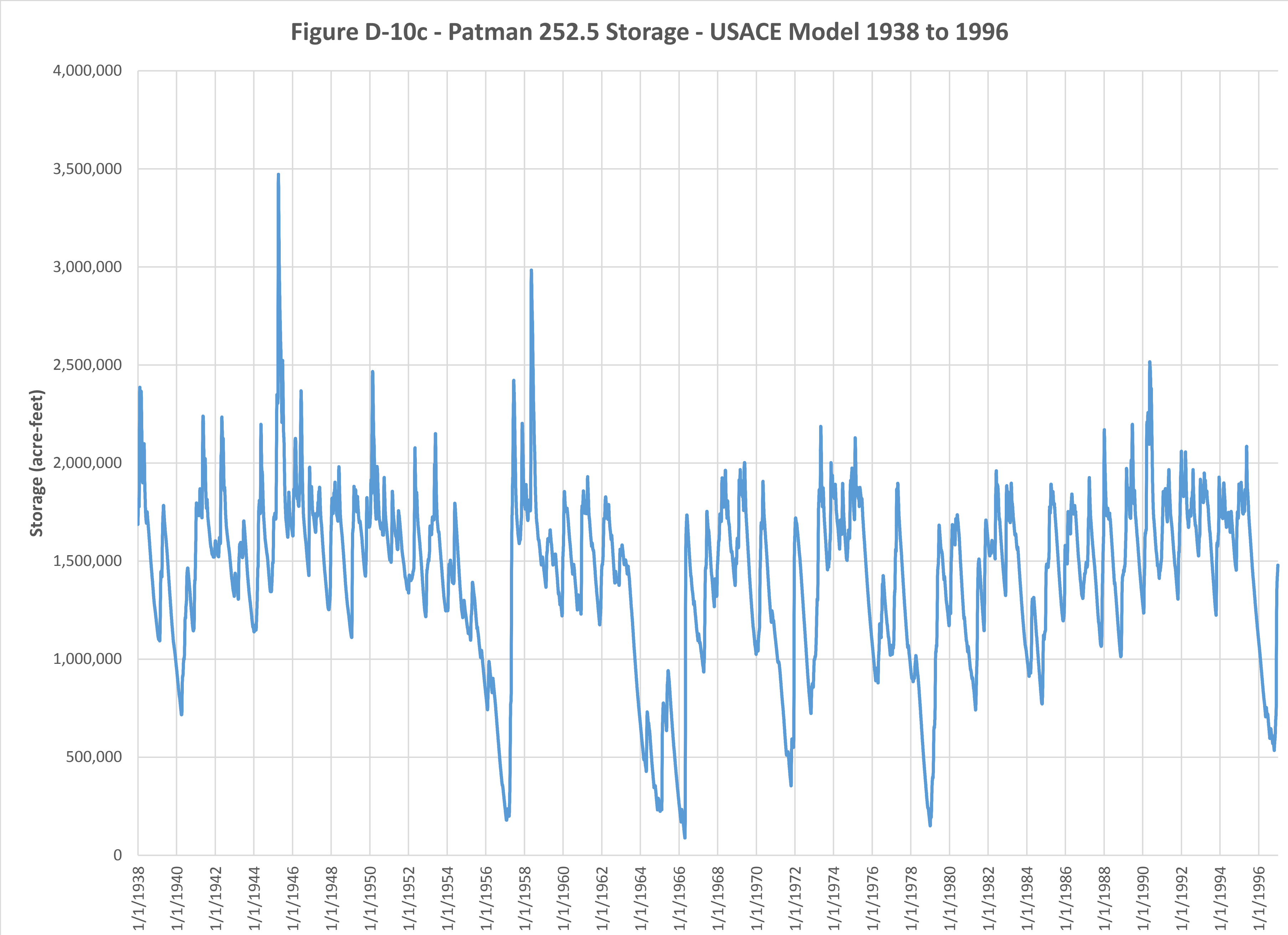


Figure D-10c - Patman 252.5 Storage - USACE Model 1938 to 1996
Storage (acre-feet)
4,000,000
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996

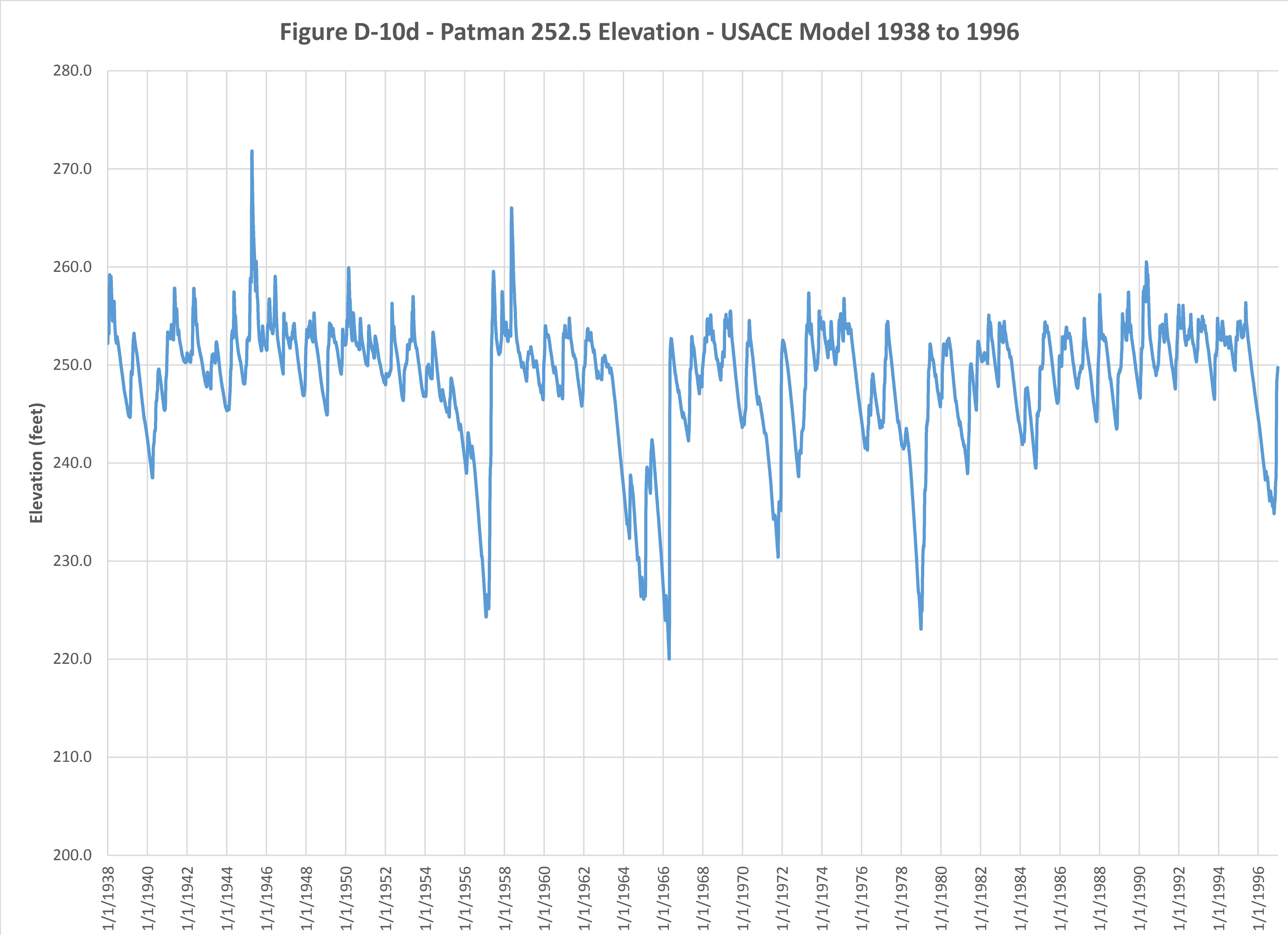


Figure D-10d - Patman 252.5 Elevation - USACE Model 1938 to 1996
Elevation (feet)
280.0
270.0
260.0
250.0
240.0
230.0
220.0
210.0
200.0
1/1/1938
1/1/1940
1/1/1942
1/1/1944
1/1/1946
1/1/1948
1/1/1950
1/1/1952
1/1/1954
1/1/1956
1/1/1958
1/1/1960
1/1/1962
1/1/1964
1/1/1966
1/1/1968
1/1/1970
1/1/1972
1/1/1974
1/1/1976
1/1/1978
1/1/1980
1/1/1982
1/1/1984
1/1/1986
1/1/1988
1/1/1990
1/1/1992
1/1/1994
1/1/1996

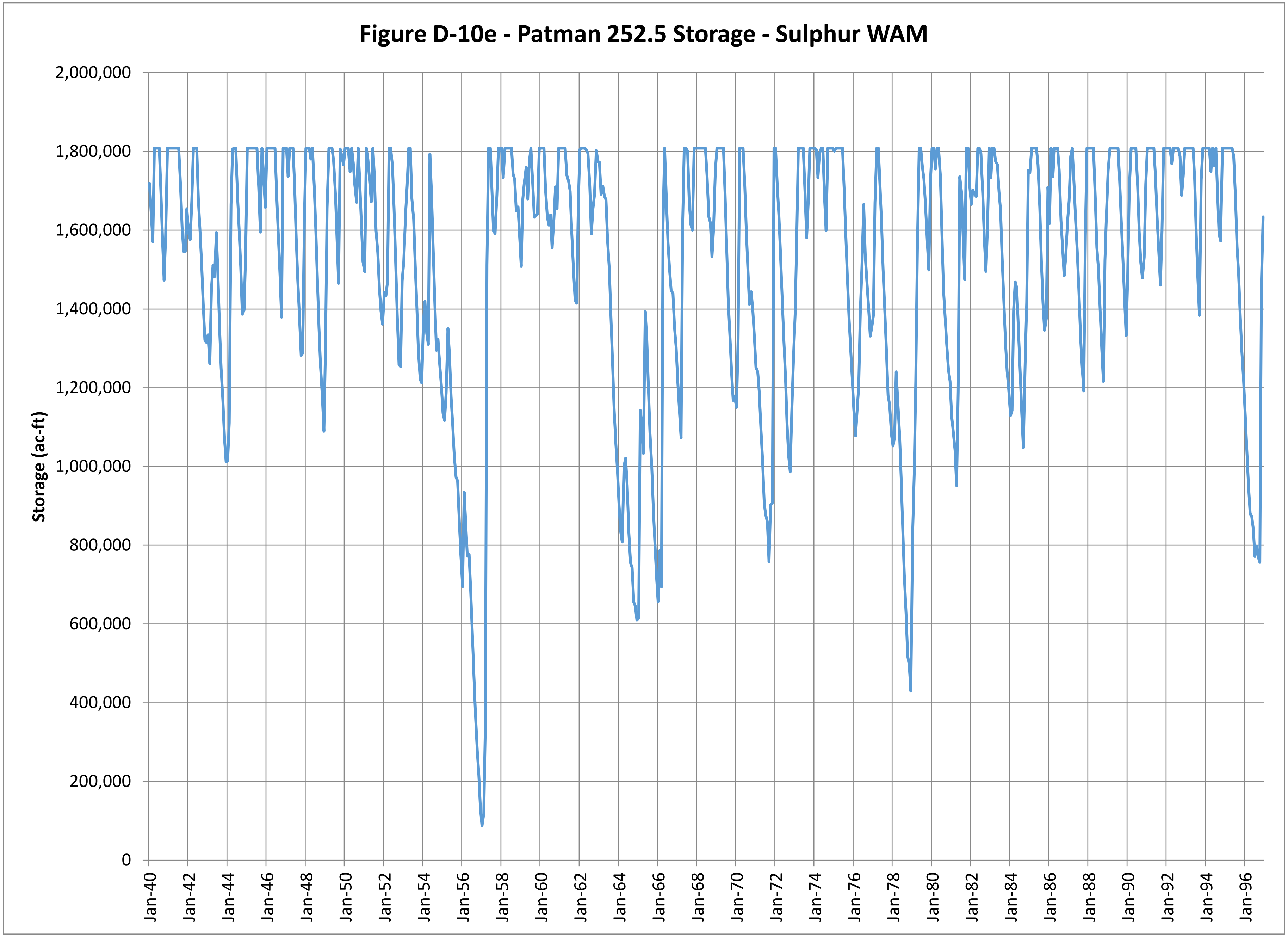


Figure D-10e - Patman 252.5 Storage - Sulphur WAM
Storage (ac-ft)
2,000,000
1,800,000
1,600,000
1,400,000
1,200,000
1,000,000
800,000
600,000
400,000
200,000
0
Jan-40
Jan-42
Jan-44
Jan-46
Jan-48
Jan-50
Jan-52
Jan-54
Jan-56
Jan-58
Jan-60
Jan-62
Jan-64
Jan-66
Jan-68
Jan-70
Jan-72
Jan-74
Jan-76
Jan-78
Jan-80
Jan-82
Jan-84
Jan-86
Jan-88
Jan-90
Jan-92
Jan-94
Jan-96