Attachment 1 – POR Hydrology Development

To: Supplemental Environmental Assessment Document

From: Greg Thompson, PE, CFM; Jun Yang, PhD, PE

Subject: Appendix D Hydrology and Hydraulics – Attachment 1 POR Hydrology Development
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Project: Fargo-Moorhead Metropolitan Area Flood Risk Management Project EA Document

1. INTRODUCTION

This Technical Memorandum (TM) was written to document the development of the Period of Record (POR) Hydrology for Plan B of the Fargo-Moorhead Metropolitan Area Flood Risk Management Project (Project).

Inflow hydrology for the Project was originally developed by the US Army Corps of Engineers (USACE) during the Fargo-Moorhead Metro Flood Risk Management Project, Feasibility Study and Environmental Impact Statement, Phase 4, 2011 (FEIS). Within that study, the peak discharge and volume-duration hydrology had been developed over a period of approximately two years as new information became available and as the project changed. Initially, POR hydrology was developed for modeling within the immediate Fargo/Moorhead Metro area, but, as documented in a series of FEIS appendices, the hydrology was revised to focus on a shorter period of record developed by an Expert Opinion Elicitation (EOE) panel. The EOE hydrology produced peak flow and balanced hydrographs that varied over time. Project design focused on assuring the project would perform for the highest peak flow and volume conditions identified via the EOE panel. This hydrology has since been referred to as the Wet Cycle Hydrology, and in this TM, it will be referred to as EOE/WET. Shortly after the EOE/WET hydrology was developed, the model was extended downstream to the Canadian Border to adequately simulate downstream impacts. Then, to offset downstream impacts, the Southern Embankment (Dam) and Upstream Staging Area were incorporated into the project, which required the modeling and subsequent inflow hydrology to be extended further upstream. Each project change resulted in a change to the hydrology. The most recent change occurred in 2017/2018 during development of Plan B where the Governors' Task Force decided that the project should use the POR hydrology instead of the EOE/WET hydrology.

Since EOE hydrology had been chosen as the path forward, the POR hydrology developed by USACE during the FEIS was not completed to support the current modeling efforts. Therefore, as documented in this TM, additional hydrology was created by Houston-Moore Group (HMG) for Plan B within a modeling effort referred to as Phase 9. The tables in this TM describe a progression of how the EOE/WET and POR hydrology components were created during and after the FEIS, and how the POR hydrology was created for Phase 9. Modeling for Phase 9 included 10-, 5-, 2-, 1-, and 0.2-percent Annual Chance Events (ACE), also commonly referred to as 10-year, 20-year, 50-year, 100-year, and 500-year flood events, respectively. The 4-percent chance event (25-year) was also included in Phase 9 because it is commonly used in flood insurance study evaluations, and the 0.5-percent chance event (200-year) was included in the Phase 9 analysis because it provides an intermediate reference point between the 100-year and 500-year events.

2. BACKGROUND/HYDROLOGY TERMINOLOGY

Peak Discharges - Annual instantaneous peak discharges were created for each streamflow gage along the Red River including gages at Enloe ND, Hickson ND, Fargo ND, Halstad MN, Thompson ND, Grand Forks ND, Oslo MN, and Drayton ND. The initial peak discharges were created by USACE, and the Plan B POR discharges were developed by HMG as described below.

Balanced Hydrographs – Volume-Duration-Frequency analyses were conducted by USACE for the EOE/WET hydrology at the gage locations along the Red River. For the Plan B modeling effort, HMG developed hydrographs that closely resemble the USACE derived balanced hydrographs using known information from the previous USACE EOE/WET hydrology analysis.

3. FEASIBILITY STUDY/ENVIRONMENTAL IMPACT STATEMENT HYDROLOGY

a) Initial Inflow Hydrology – FEIS Appendix A-2

The discharges displayed in

Table *1* originated from FEIS Appendix A-2, Table 24 (POR), and the discharges displayed in Table 2 originated from FEIS Appendix A-2, Table 25 (EOE/WET). At the time, only these locations were needed for model simulation because the focus of the modeling was near the Fargo/Moorhead Metro area. However, the remaining blank cells in

Table *1* show the locations and flood events that are required for the Plan B analysis. This TM documents the development of the remaining POR discharges and modifications made to some of the discharges presented in Table *1*. Notice that peak discharges for Enloe, Thompson, Oslo, and Drayton were not initially developed in the FEIS. Additionally, the 4-percent chance event discharges had not been developed.

Table 1: Red River Peak Discharges, POR Hydrology from FEIS, Appendix A-2, Table 24

Return Period (year)	10	20	25	50	100	200	500
% Annual Chance Event	10	5	4	2	1	0.5	0.2
Drayton							
Oslo							
Grand Forks	50,500	67,300		91,700	112,000	134,000	165,000
Thompson							
Halstad	29,800	39,900		54,600	66,900	80,200	99,200
Fargo	13,865	19,831		26,000	33,000	43,500	66,000
Hickson	8,400	12,000		19,000	23,100	28,300	35,000
Enloe							

Table 2: Red River Peak Discharges, EOE/WET Hydrology from FEIS Appendix A-2, Table 25

Return Period (year)	10	20	25	50	100	200	500
% Annual Chance Event	10	5	4	2	1	0.5	0.2
Drayton							
Oslo							
Grand Forks	56,354	70,956		91,026	106,838	123,201	145,675
Thompson							
Halstad	34,871	45,014		59,306	70,798	82,872	99,713
Fargo	17,000	22,000		29,300	34,700	46,200	61,700
Hickson	10,500	14,800		21,000	25,000	28,500	32,000
Enloe							

b) Inflow Hydrology – FEIS Appendix A-4b

The EOE/WET peak discharges displayed in Table 3 originated from FEIS Appendix A-4b, Table 24. This hydrology effort included developing additional EOE/WET hydrology peak discharges for streamflow gages at downstream locations, such as Thompson, ND, Oslo, MN and Drayton, ND. At this point in time the project was to focus on EOE/WET hydrology, therefore no POR discharges were recorded for the new locations. Also, the peak discharges for Hickson were revised from what was presented in Appendix A-2. Enloe was not considered at this point in time because the staging area was not a project component and the model did not need to be extended upstream to Enloe.

Table 3: Red River EOE/WET Peak Discharges - Inflow Hydrology - FEIS Appendix A-4b, Table 24

Return Period (year)	10	20	25	50	100	200	500
% Annual Chance Event	10	5	4	2	1	0.5	0.2
Drayton	62,847	79,061		101,292	118,757	136,789	161,486
Oslo	58,970	74,459		95,773	112,569	129,950	153,811
Grand Forks	56,354	70,956		91,026	106,838	123,201	145,675
Thompson	42,899	55,519		72,898	86,765	101,001	121,080
Halstad	34,871	45,014		59,306	70,798	82,872	99,713
Fargo	17,000	22,000		29,300	34,700	46,200	61,700
Hickson	10,500	14,000		19,000	22,000	28,500	37,000
Enloe							

c) Hickson Gage Inflow Hydrology Revision – USACE Report, January 2015

EOE/WET peak discharges for the Hickson Gage were revised in January 2015 to better reflect breakout characteristics from the Wild Rice River to the Red River near Abercrombie, North Dakota. As displayed in Table 4, revisions from this analysis were made to the EOE/WET hydrology, as documented in "The Use of Synthetic Floods for Defining the Regulated Flow-Frequency & Volume Duration Frequency Curves for the Red River at Hickson, North Dakota" (January 2015), Table 12.

Following the January 2015 report, USACE also provided peak discharges for the Enloe Gage for the WET hydrology, which is approximately 30 river miles upstream of the Hickson Gage. The Enloe Gage data was provided for use as the inflow at the upstream end of the Red River, which was needed after incorporating the Dam and Upstream Staging Area. Note that Enloe hydrology was not provided for the 4- or 5-percent chance events because they were not in the scope of the analysis at that point in time.

Table 4: Hydrology Updates – EOE/WET Hydrology, Hickson and Enloe – USACE, January 2015

Return Period (year)	10	20	25	50	100	200	500
% Annual Chance Event	10	5	4	2	1	0.5	0.2
Drayton	62,847	79,061		101,292	118,757	136,789	161,486
Oslo	58,970	74,459		95,773	112,569	129,950	153,811
Grand Forks	56,354	70,956		91,026	106,838	123,201	145,675
Thompson	42,899	55,519		72,898	86,765	101,001	121,080
Halstad	34,871	45,014		59,306	70,798	82,872	99,713
Fargo	17,000	22,000		29,300	34,700	46,200	61,700
Hickson	9,600	13,200		19,000	23,500	28,500	36,000
Enloe	10,031			20,053	24,164	29,512	35,303

d) 4-Percent Chance Event Peak Discharges – USACE, May 2015

In May 2015, peak discharges for the 4-percent chance event were provided for gages at Hickson, Fargo, and Halstad. Table 5 presents the additional EOE/WET peak discharges.

Table 5: EOE/WET Hydrology, 4-Percent Chance Event Discharge Updates - USACE, May 2015

Return Period (year)	10	20	25	50	100	200	500
% Annual Chance Event	10	5	4	2	1	0.5	0.2
Drayton	62,847	79,061		101,292	118,757	136,789	161,486
Oslo	58,970	74,459		95,773	112,569	129,950	153,811
Grand Forks	56,354	70,956		91,026	106,838	123,201	145,675
Thompson	42,899	55,519		72,898	86,765	101,001	121,080
Halstad	34,871	45,014	48,348	59,306	70,798	82,872	99,713
Fargo	17,000	22,000	23,900	29,300	34,700	46,200	61,700
Hickson	9,600	13,200	14,450	19,000	23,500	28,500	36,000
Enloe	10,031			20,053	24,164	29,512	35,303

e) Fargo Gage Hydrograph Volume Revisions – USACE, July 2015

Prior to July 2015, the shapes of the balanced hydrographs were relatively narrow compared to observed historical hydrographs of similar magnitude. In 2013, the Red River Basin Commission (RRBC) conducted a basin-wide hydrology modeling effort where a HEC-HMS hydrology model was developed for each watershed upstream of the Red River Gage at Halstad, MN. Hydrographs from this modeling effort were compared to the balanced hydrographs developed for the project. Hydrographs from the RRBC modeling effort were similar in shape to historical events, but displayed more volume than the balanced hydrographs at the time. Therefore, the balanced hydrograph procedure was reevaluated, and modifications were made to the Hickson and Fargo

Gage balanced hydrographs. Revisions reflected in this effort only changed the volume-duration relationships, not the peak discharges. Due to the scope of the project at this point in time, higher volume hydrographs were only created for the 10-, 2-, 1-, 0.5-, and 0.2-percent chance events using EOE/WET hydrology.

4. PLAN B – PERIOD OF RECORD HYDROLOGY

This section documents the POR hydrology development to be used with Plan B. As presented in Table *1*, POR hydrology was previously developed for Hickson, Fargo, Halstad, and Grand Forks. However, due to several changes following the FEIS, and an incomplete POR data set, HMG was tasked with developing the POR hydrology using relationships from available POR records as well as previously developed EOE/WET hydrology.

a) Hickson and Enloe POR Peak Discharges and Hydrographs

Annual instantaneous peak discharges for Hickson were first presented in the FEIS Appendix A-2, using both EOE/WET and POR hydrology. Now, since POR hydrology is required for Plan B, and the EOE discharges have been revised since the FEIS, the old POR/EOE relationship from the FEIS will be used to create updated POR hydrology for Hickson. Note flows for the 4-percent chance event POR and EOE/WET at Hickson (Table 6) were derived using flow frequency curves in the FEIS Appendix A-2 (Figures 34 and 35). As presented in Table 6, a unique ratio for each design event has been established to apply to the updated EOE/WET discharges from Table 5 for producing updated POR discharges as shown in Table 7 for Hickson and Table 8 for Enloe. After evaluating peak discharge and volume proportions between Enloe, Abercrombie, and Fargo, and after reviewing the discharge-frequency curves for Hickson and Enloe, the peak discharges will be further refined, with final numbers presented in Table 20.

Table 6: Discharge Relationship between EOE/WET and POR Hydrology at Hickson, ND (Source: FEIS, January 2011)

Return Period (year)	10	20	25	50	100	200	500
% Annual Chance Event	10	5	4	2	1	0.5	0.2
Hickson POR (Table 1)	8,400	12,000	13,000	19,000	23,100	28,300	35,000
Hickson EOE/WET (Table 2)	10,500	14,800	15,700	21,000	25,000	28,500	32,000
Ratio POR to EOE/WET	0.80	0.81	0.83	0.90	0.92	0.99	1.09

Table 7: New POR Discharges for Hickson Gage (Not Final)

Return Period (year)	10	20	25	50	100	200	500
% Annual Chance Event	10	5	4	2	1	0.5	0.2
Hickson EOE/WET (Table 5)	9,600	13,200	14,450	19,000	23,500	28,500	36,000
Ratio, POR to EOE/WET (Table 6)	0.80	0.81	0.83	0.90	0.92	0.99	1.09
Hickson POR (2018)	7,700	10,700	12,000	17,200	21,700	28,300	39,400

Table 8: New POR Discharges for Enloe Gage (Not Final)

Return Period (year)	10	20	25	50	100	200	500
% Annual Chance Event	10	5	4	2	1	0.5	0.2
Enloe EOE/WET (Table 5)	10,031			20,053	24,164	29,512	35,303
Ratio, POR to EOE/WET (Table 6)	0.80	0.81	0.83	0.90	0.92	0.99	1.09
Enloe POR (2018)	8,000			18,100	22,300	29,300	38,600

b) Peak Discharges for 4-Percent and 5-Percent Chance Events

Reservoirs in the upper portions of the Red River Basin and breakout flows between upstream watersheds produce complex discharge-frequency relationships upstream of Fargo. Because of this, it is understood that standard Log-Pearson Type III plotting procedures should not be used at Enloe, Hickson, or Fargo, but it can be used for locations downstream of Fargo because of the extended distance downstream of reservoirs. While recognizing this, yet also observing smooth relationships on such plots, 4-percent chance (25-year) and 5-percent chance (20-year) event peak discharges were created from larger and smaller events. Exhibits 1 through 8 display Log-Pearson Type III plots for the POR and EOE/WET hydrology at each of the streamflow gages along the Red River. From these plots, the peak discharges have been estimated for the 4-percent and 5-percent chance events for the EOE/WET hydrology (Table 9) and POR hydrology (Table 10).

Table 9: EOE/WET 0.4-Percent Chance Event Peak Discharge Development Using Discharge-Frequency Relationships

Return Period (year)	10	20	25	50	100	200	500
% Annual Chance Event	10	5	4	2	1	0.5	0.2
Drayton	62,847	79,061	84,500	101,292	118,757	136,789	161,486
Oslo	58,970	74,459	79,500	95,773	112,569	129,950	153,811
Grand Forks	56,354	70,956	75,000	91,026	106,838	123,201	145,675
Thompson	42,899	55,519	59,400	72,898	86,765	101,001	121,080
Halstad	34,871	45,014	48,348	59,306	70,798	82,872	99,713
Fargo	17,000	22,000	23,900	29,300	34,700	46,200	61,700
Hickson	9,600	13,200	14,450	19,000	23,500	28,500	36,000
Enloe	10,031	14,500	15,500	20,053	24,164	29,512	35,303

Table 10: POR 0.4-Percent Chance Event Peak Discharge Development Using Discharge-Frequency Relationships

Return Period (year)	10	20	25	50	100	200	500
% Annual Chance Event	10	5	4	2	1	0.5	0.2
Drayton							
Oslo							
Grand Forks	50,500	67,300	72,000	91,700	112,000	134,000	165,000
Thompson							
Halstad	29,800	39,900	43,200	54,600	66,900	80,200	99,200
Fargo	13,865	19,831	21,400	26,000	33,000	43,500	66,000
Hickson	7,700	10,700	12,000	17,200	21,700	28,300	39,400
Enloe	8,000	11,800	13,000	18,100	22,300	29,300	38,600

c) POR Hydrology Peak Discharge Development for Thompson, Oslo, and Drayton

As previously described, EOE/WET peak discharges are available at all reporting locations. From FEIS Appendix A-2, a POR to EOE/WET ratio was created for Grand Forks to be used in generating POR hydrology for Oslo and Drayton. This is shown in Table 11. Using the Grand Forks ratios, the POR peak discharges that were created for Oslo and Drayton are shown in Table 12 and Table 13, respectively.

Table 11: POR to EOE/WET Annual Instantaneous Peak Discharge Ratios for Grand Forks, North Dakota

Return Period (year)	10	20	25	50	100	200	500
% Annual Chance Event	10	5	4	2	1	0.5	0.2
Grand Forks POR	50,500	67,300	72,000	91,700	112,000	134,000	165,000
Grand Forks EOE/WET	56,354	70,956	75,000	91,026	106,838	123,201	145,675
Ratio POR to EOE/WET	0.90	0.95	0.96	1.01	1.05	1.09	1.13

Table 12: Oslo, Minnesota POR Peak Discharges Created from Grand Forks POR to EOE/WET Ratios

Return Period (year)	10	20	25	50	100	200	500
% Annual Chance Event	10	5	4	2	1	0.5	0.2
Oslo EOE/WET (Table 9)	58,970	74,459	79,500	95,773	112,569	129,950	153,811
Ratio POR to EOE/WET (Table 11)	0.90	0.95	0.96	1.01	1.05	1.09	1.13
Oslo POR	52,800	70,600	76,300	96,500	118,000	141,300	174,200

Table 13: Drayton, North Dakota POR Peak Discharges Created from Grand Forks POR to EOE/WET Ratios

Return Period (year)	10	20	25	50	100	200	500
% Annual Chance Event	10	5	4	2	1	0.5	0.2
Drayton EOE/WET (Table 9)	62,847	79,061	84,500	101,292	118,757	136,789	161,486
Ratio POR to EOE/WET (Table 11)	0.90	0.95	0.96	1.01	1.05	1.09	1.13
Drayton POR	56,300	75,000	81,100	102,000	124,500	148,800	182,900

The POR peak discharges for Thompson, North Dakota were created in a similar manner as the discharges for Oslo and Drayton, except for the ratios for Thompson were created using an average ratio from Fargo, Halstad, and Grand Forks. The Halstad POR to EOE/WET ratios are presented in Table 14, and the Fargo POR to EOE/WET ratios are presented in Table 15. Combining the ratios from Grand Forks, Halstad, and Fargo, Table 16 presents the average POR to EOE/WET ratio to be used for developing the Thompson discharges. Table 17 presents the POR discharges for Thompson, North Dakota.

Table 14: POR to EOE/WET Annual Instantaneous Peak Discharge Ratios for Halstad, Minnesota

Return Period (year)	10	20	25	50	100	200	500
% Annual Chance Event	10	5	4	2	1	0.5	0.2
Halstad POR (Table 10)	29,800	39,900	43,200	54,600	66,900	80,200	99,200
Halstad EOE/WET (Table 9)	34,871	45,014	48,348	59,306	70,798	82,872	99,713
Ratio POR to EOE/WET	0.85	0.89	0.89	0.92	0.94	0.97	0.99

Table 15: POR to EOE/WET Peak Discharge Ratios for Fargo, North Dakota

Return Period (year)	10	20	25	50	100	200	500
% Annual Chance Event	10	5	4	2	1	0.5	0.2
Fargo POR (Table 10)	13,865	19,831	21,400	26,000	33,000	43,500	66,000
Fargo EOE/WET (Table 9)	17,000	22,000	23,900	29,300	34,700	46,200	61,700
Ratio POR to EOE/WET	0.82	0.90	0.90	0.89	0.95	0.94	1.07

Table 16: Average POR to EOE/WET Ratios Used to Develop POR Peak Discharges for Thompson, North Dakota

Return Period (year)	10	20	25	50	100	200	500
% Annual Chance Event	10	5	4	2	1	0.5	0.2
Grand Forks Ratio (Table 11)	0.90	0.95	0.96	1.01	1.05	1.09	1.13
Halstad Ratio (Table 14)	0.85	0.89	0.89	0.92	0.94	0.97	0.99
Fargo Ratio (Table 15)	0.82	0.90	0.90	0.89	0.95	0.94	1.07
Average Ratio	0.86	0.91	0.92	0.94	0.98	1.00	1.07

Table 17: Thompson, North Dakota Peak Discharges Using Average POR to EOE/WET Ratios from Grand Forks, Halstad, Fargo.

Return Period (year)	10	20	25	50	100	200	500
% Annual Chance Event	10	5	4	2	1	0.5	0.2
Thompson EOE/WET (Table 9)	42,899	55,519	59,400	72,898	86,765	101,001	121,080
Ratio POR to EOE/WET (Table 16)	0.86	0.91	0.92	0.94	0.98	1.00	1.07
Thompson POR	36,700	50,600	54,400	68,400	85,200	100,900	129,000

d) Modifications Made to Enloe/Hickson Discharges

At the upstream end of the project, the Enloe and Hickson Gages are relatively close in proximity to each other. Also, there are no significant tributary inflows between the gages, so the calculated peak inflows are very similar to each other. Depending on the volume of the event and the magnitude of the local inflows, the peak discharges from Enloe to Hickson are either reduced due to attenuation, remain the same, or are increased due to local inflows. To verify if the newly developed POR hydrology for Hickson and Enloe seemed reasonable, the general trends from Enloe to Hickson and Enloe to Fargo were reviewed. The Enloe to Fargo relationship provides a comparison between the Red River and the Wild Rice River flow contributions. The initial iteration of Hickson and Enloe discharge development produced Enloe to Fargo relationships that were not consistent across various events (shown in Table 18). The ratios ranged from 0.58 to 0.70. Therefore, the peak discharges at Enloe and Hickson were adjusted as shown in the Table 19 and Table 20. The specific changes are noted as follows:

- 10% ACE – Enloe was increased from a calculated 8,000 cfs to 9,000 cfs, which produces an Enloe to Fargo ratio of 0.65. The difference between Enloe and Hickson from January 2015 was approximately 400 cfs. The assumption here is that the difference is approximately 600 cfs.
- 5% ACE – Enloe remained as-is, but the Hickson discharge appeared to be too low so it was increased to 11,400 cfs to produce a 400 cfs difference (Enloe to Hickson), similar to the January 2015 10% differences.

- 4% ACE – no changes. The Enloe to Fargo ratio is 0.61.
- 2% ACE – The preliminary results from the 2% ACE showed the highest ratio for Enloe to Fargo (0.70), so this was the largest change.
- 1% ACE – Enloe to Fargo was originally calculated to be 0.68, which is on the high side. The peak discharge was decreased from 22,300 to 21,000 cfs, which reduced the ratio to 0.64.
- 0.5% ACE – This calculated ratio was on the high side, but it wasn't used for the HEC-RAS analysis, so it wasn't adjusted.
- 0.2% ACE – This calculated ratio appeared very low, so it was increased from 38,600 to 40,000 cfs, which increased the Enloe to Fargo ratio from 0.58 to 0.61.

Table 20 presents the final POR discharges to be used in Plan B modeling.

Table 18: Discharges Prior to Final Calibration (Not final)

Return Period (year)	10	20	25	50	100	200	500
% Annual Chance Event	10	5	4	2	1	0.5	0.2
Fargo (Table 10)	13,865	19,831	21,400	26,000	33,000	43,500	66,000
Hickson (Table 10)	7,700	10,700	12,000	17,200	21,700	28,300	39,400
Enloe (Table 10)	8,000	11,800	13,000	18,100	22,300	29,300	38,600
Ratio, Enloe/Fargo	0.58	0.60	0.61	0.70	0.68	0.67	0.58

Table 19: Calibrated POR Discharges at Hickson and Enloe Gages

Return Period (year)	10	20	25	50	100	200	500
% Annual Chance Event	10	5	4	2	1	0.5	0.2
Fargo	13,865	19,831	21,400	26,000	33,000	43,500	66,000
Hickson	8,400	11,400	12,000	16,000	21,300	28,300	38,700
Enloe	9,000	11,800	13,000	16,000	21,000	29,300	40,000
Ratio, Enloe/Fargo	0.65	0.60	0.61	0.62	0.64	0.67	0.61

Table 20: Final POR Peak Discharges

Return Period (year)	10	20	25	50	100	200	500
% Annual Chance Event	10	5	4	2	1	0.5	0.2
Drayton (Table 13)	56,300	75,000	81,100	102,000	124,500	148,800	182,900
Oslo (Table 12)	52,800	70,600	76,300	96,500	118,000	141,300	174,200
Grand Forks (Table 10)	50,500	67,300	72,000	91,700	112,000	134,000	165,000
Thompson (Table 17)	36,700	50,600	54,400	68,400	85,200	100,900	129,000
Halstad (Table 10)	29,800	39,900	43,200	54,600	66,900	80,200	99,200
Fargo (Table 10)	13,865	19,831	21,400	26,000	33,000	43,500	66,000
Hickson (Table 19)	8,400	11,400	12,000	16,000	21,300	28,300	38,700
Enloe (Table 19)	9,000	11,800	13,000	16,000	21,000	29,300	40,000

5. PLAN B – PERIOD OF RECORD BALANCED HYDROGRAPHS

USACE developed the balanced hydrographs for the EOE/WET hydrology throughout various stages of the FEIS and as necessary during the project. HMG developed hydrographs closely resembling balanced hydrographs using HEC-DSSVue and multipliers applied to each EOE/WET hydrograph ordinate. The EOE/WET balanced hydrographs and POR analysis hydrographs are shown in Exhibits 9 through 16 for all streamflow gages along the Red River.

Exhibits

Exhibit 1 - Discharge Frequency Curve at Enloe Gage

Period of Record (POR) Hydrology vs Expert Opinion Elicitation / Wet Cycle (EOE/WET) Hydrology

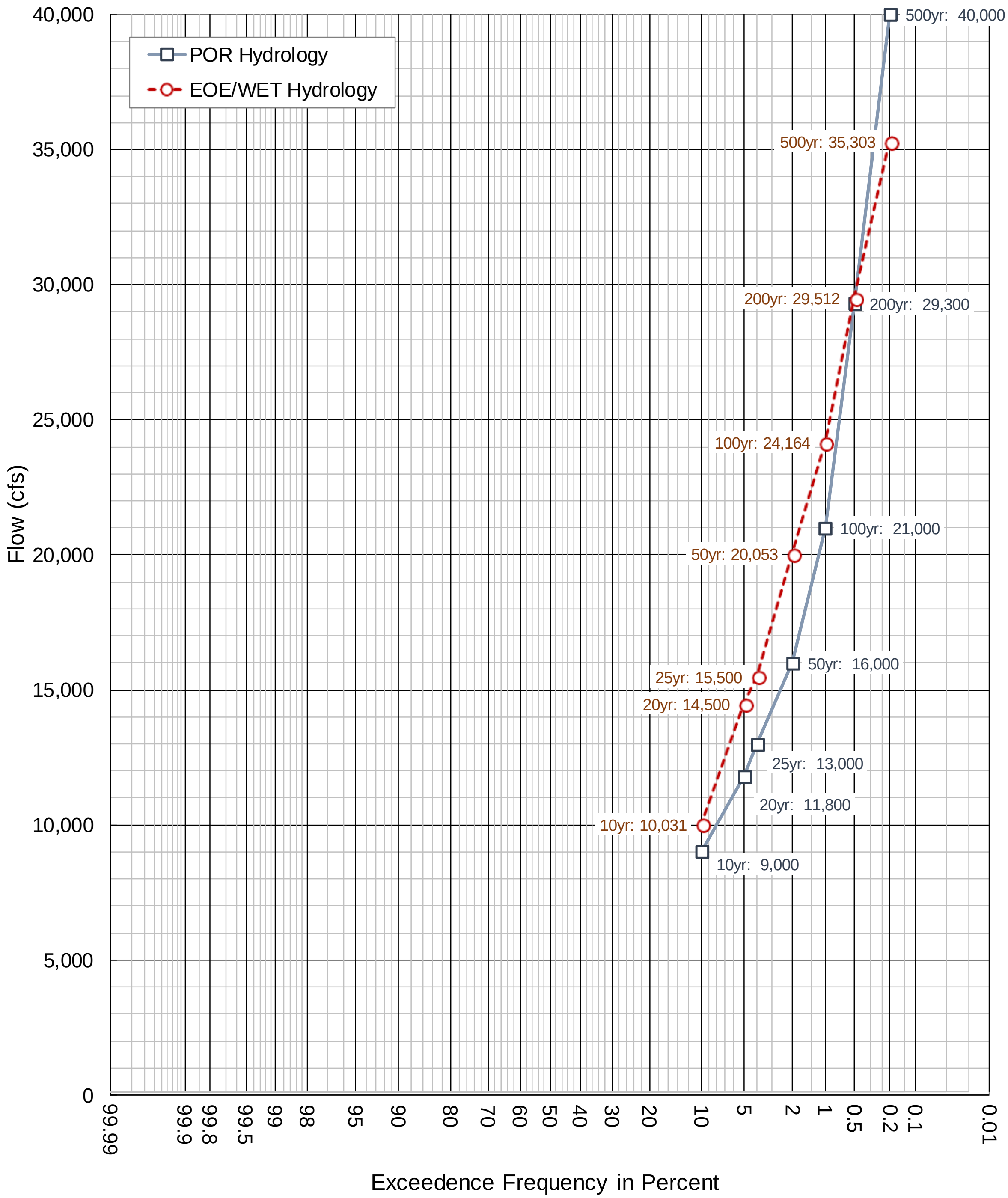


Exhibit 2 - Discharge Frequency Curve at Hickson Gage

Period of Record (POR) Hydrology vs Expert Opinion Elicitation / Wet Cycle (EOE/WET) Hydrology

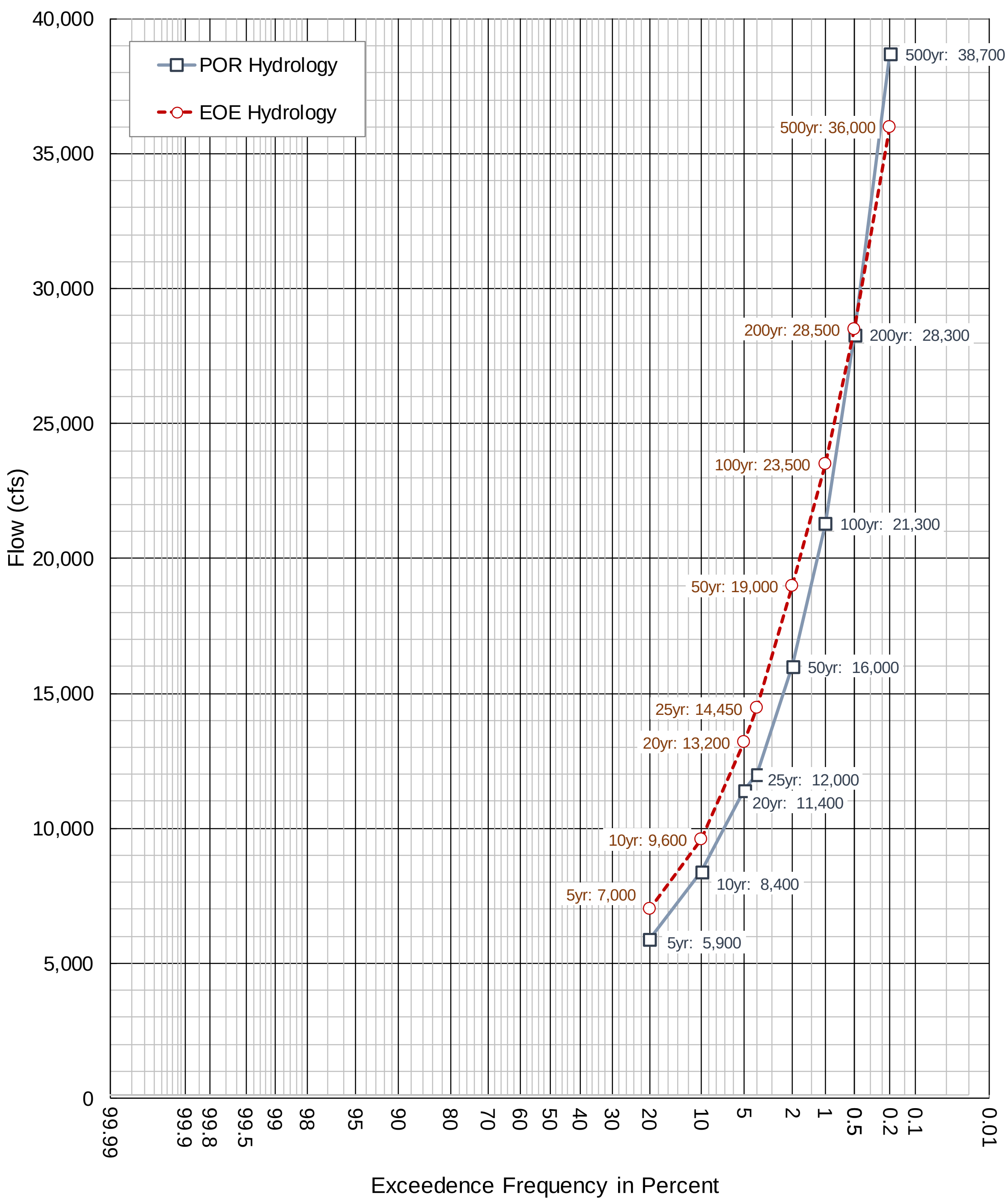


Exhibit 3 - Discharge Frequency Curve at Fargo Gage

Period of Record (POR) Hydrology vs Expert Opinion Elicitation / Wet Cycle (EOE/WET) Hydrology

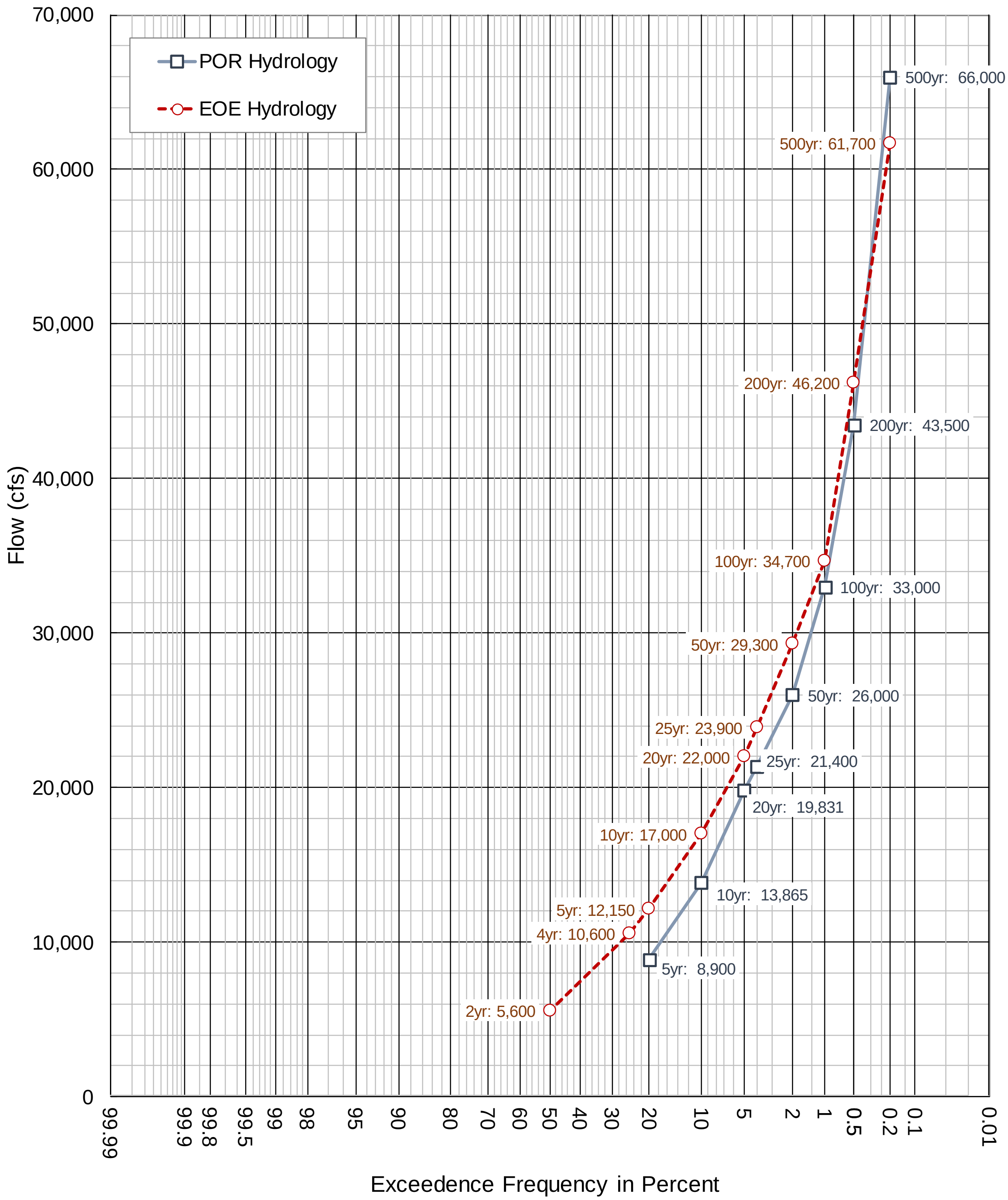


Exhibit 4 - Discharge Frequency Curve at Halstad Gage

Period of Record (POR) Hydrology vs Expert Opinion Elicitation / Wet Cycle (EOE/WET) Hydrology

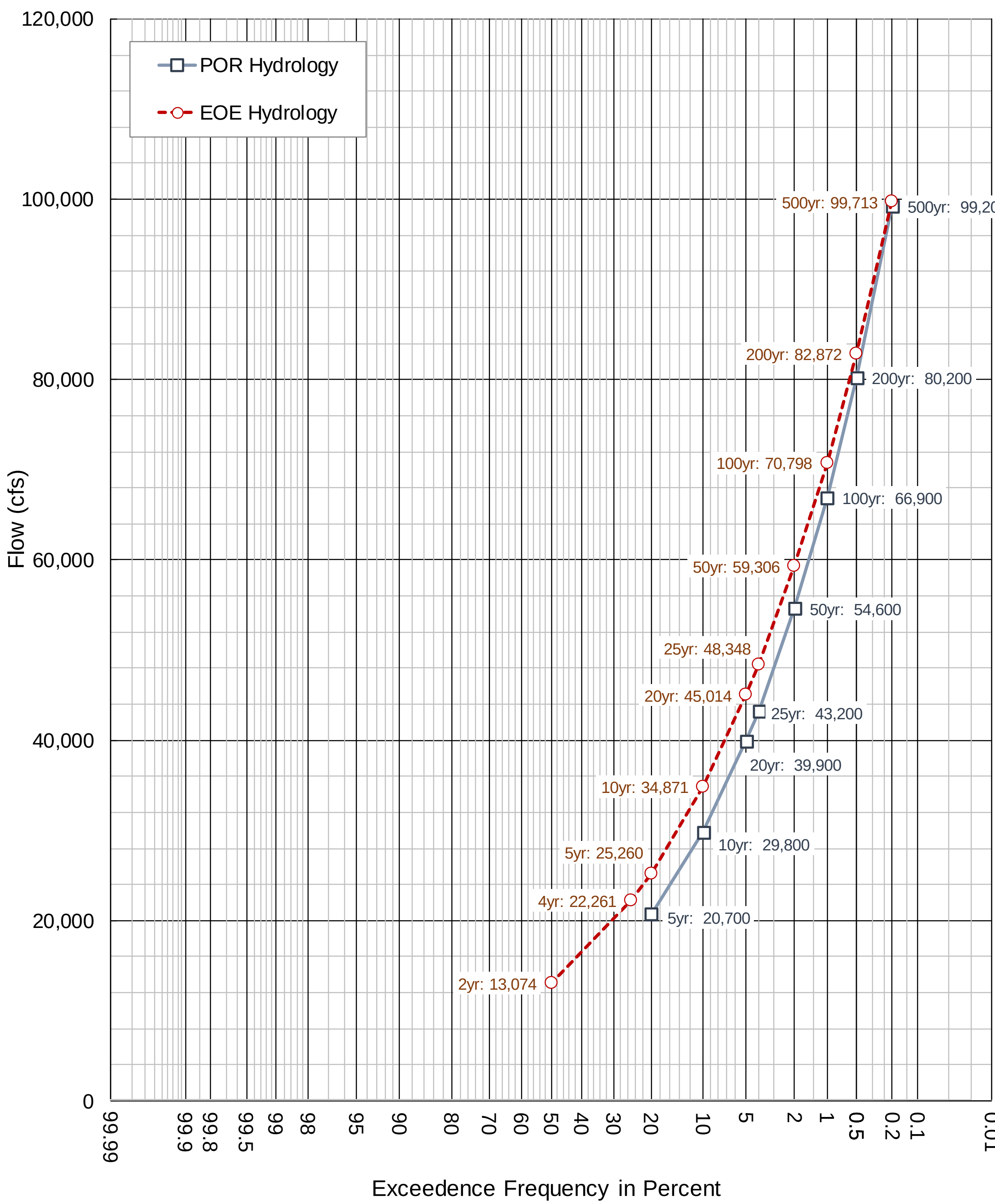


Exhibit 5 - Discharge Frequency Curve at Thompson Gage

Period of Record (POR) Hydrology vs Expert Opinion Elicitation / Wet Cycle (EOE/WET) Hydrology

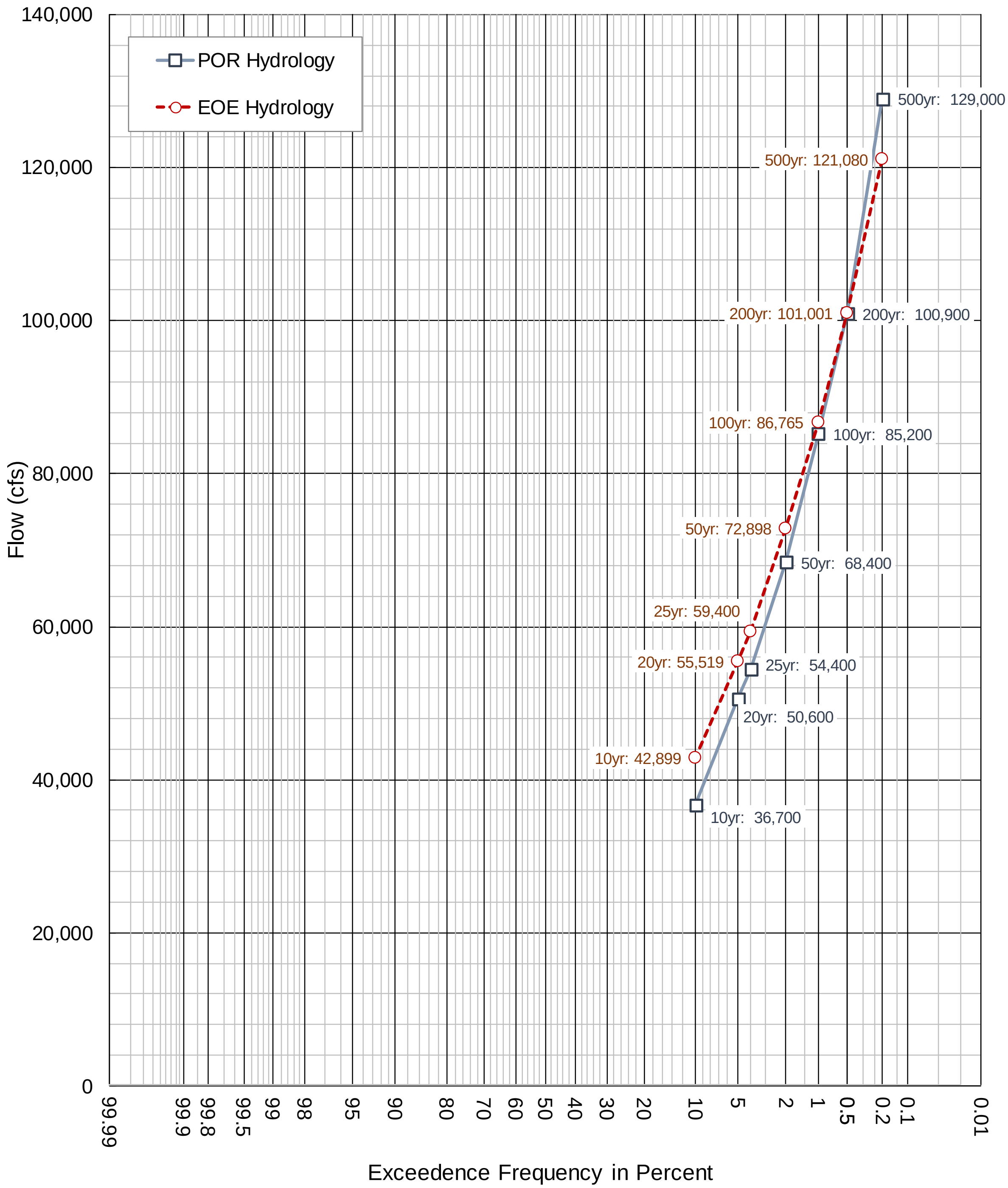


Exhibit 6 - Discharge Frequency Curve at Grand Forks Gage

Period of Record (POR) Hydrology vs Expert Opinion Elicitation / Wet Cycle (EOE/WET) Hydrology

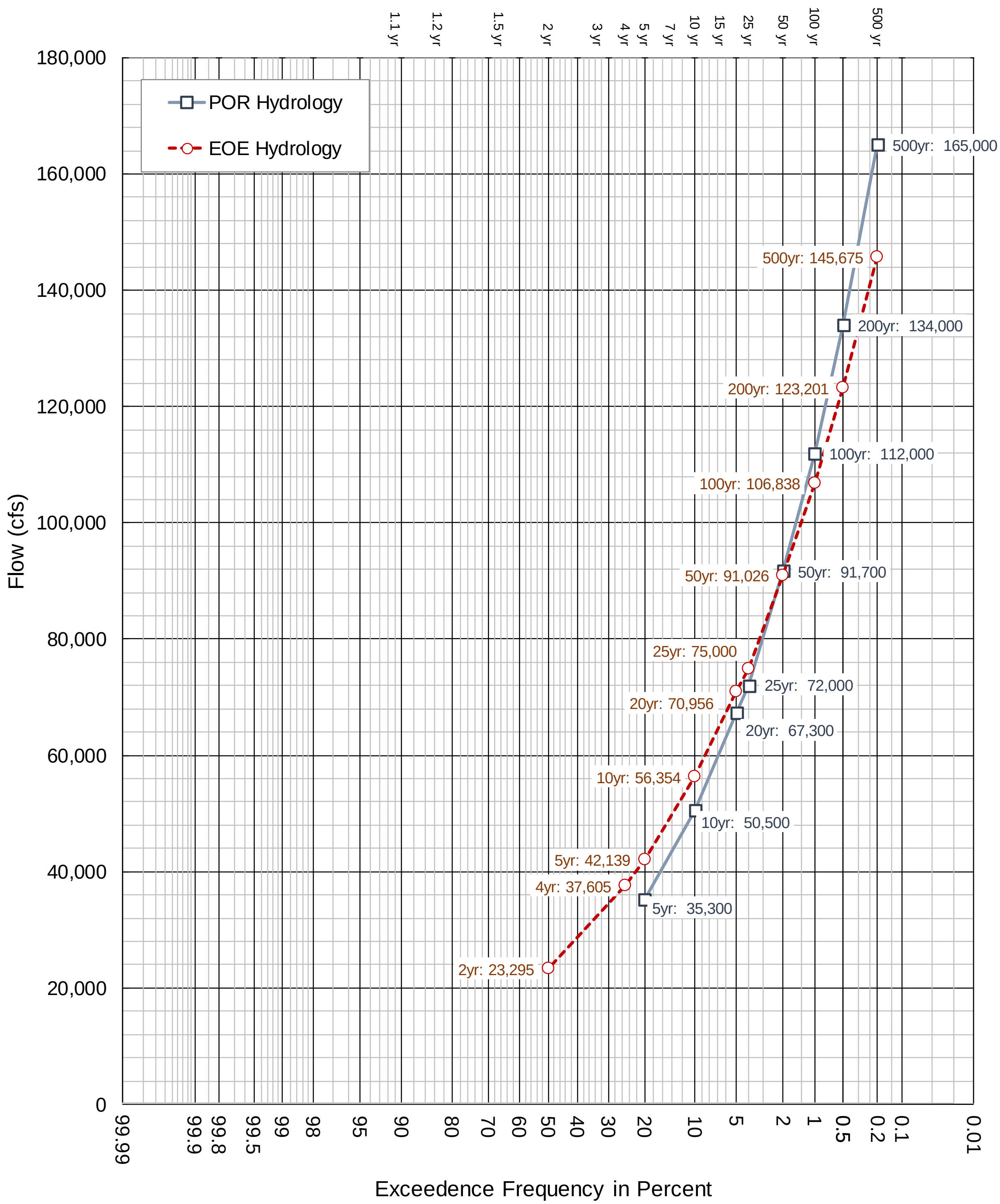


Exhibit 7 - Discharge Frequency Curve at Oslo Gage

Period of Record (POR) Hydrology vs Expert Opinion Elicitation / Wet Cycle (EOE/WET) Hydrology

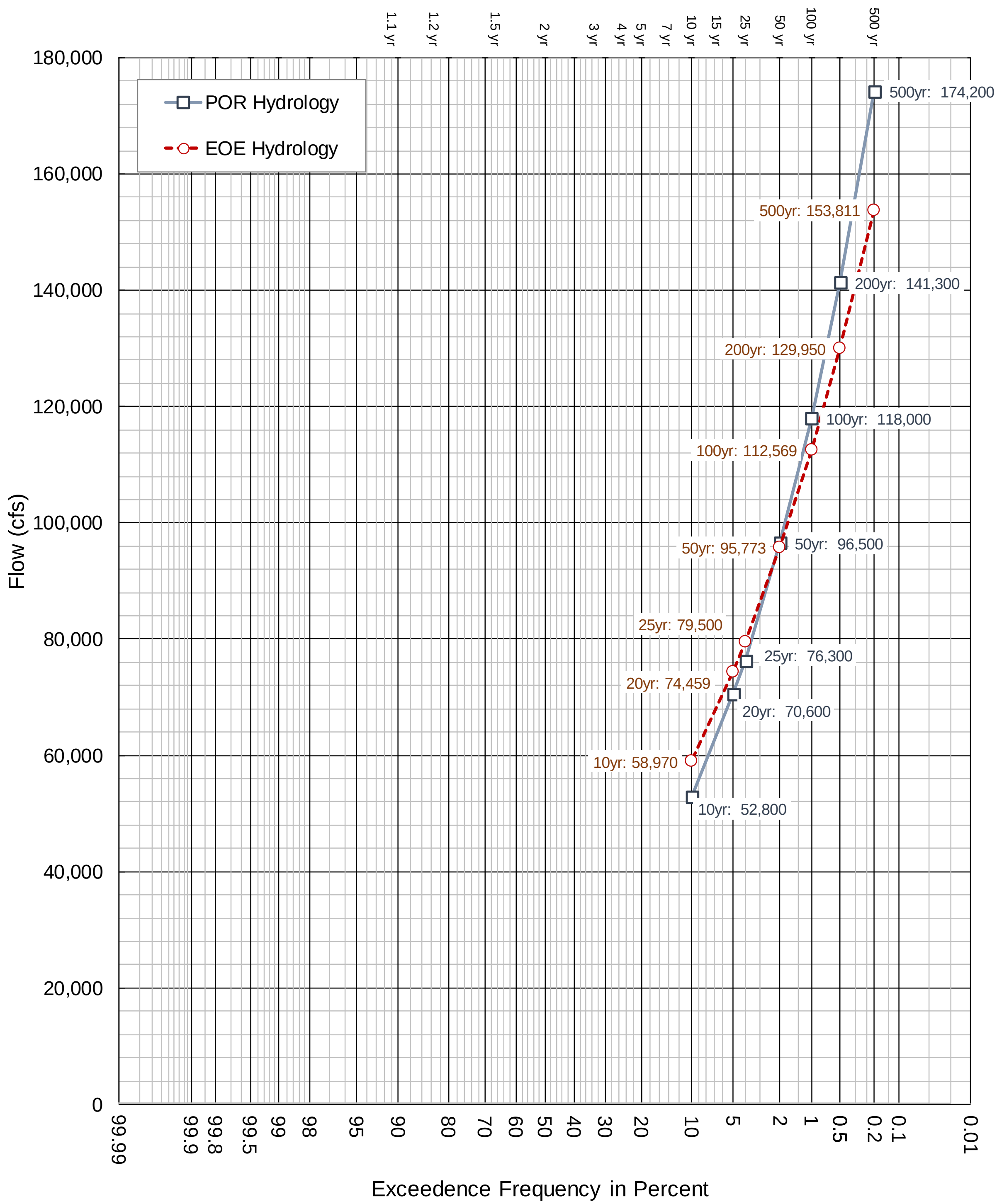
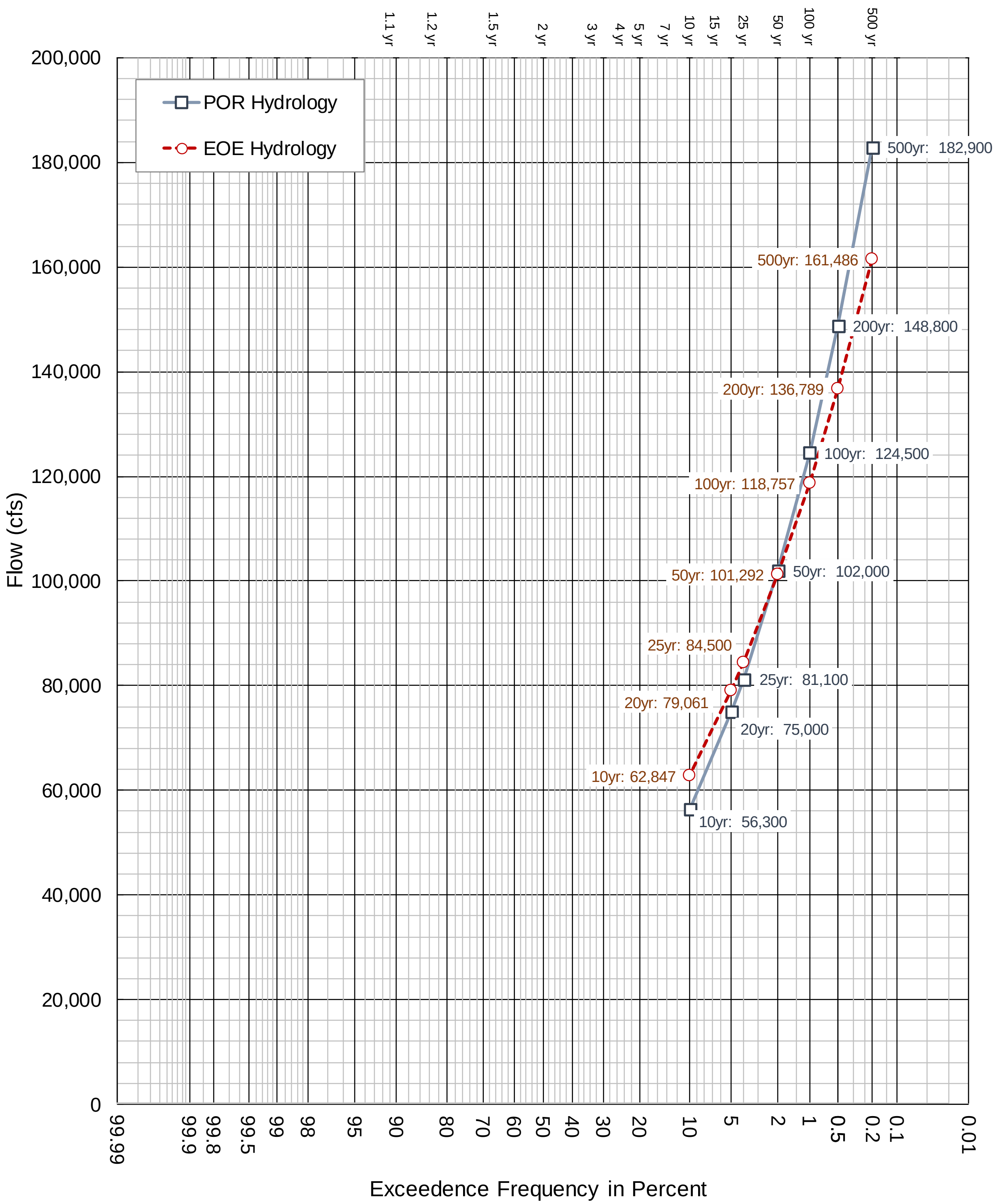


Exhibit 8 - Discharge Frequency Curve at Drayton Gage

Period of Record (POR) Hydrology vs Expert Opinion Elicitation / Wet Cycle (EOE/WET) Hydrology



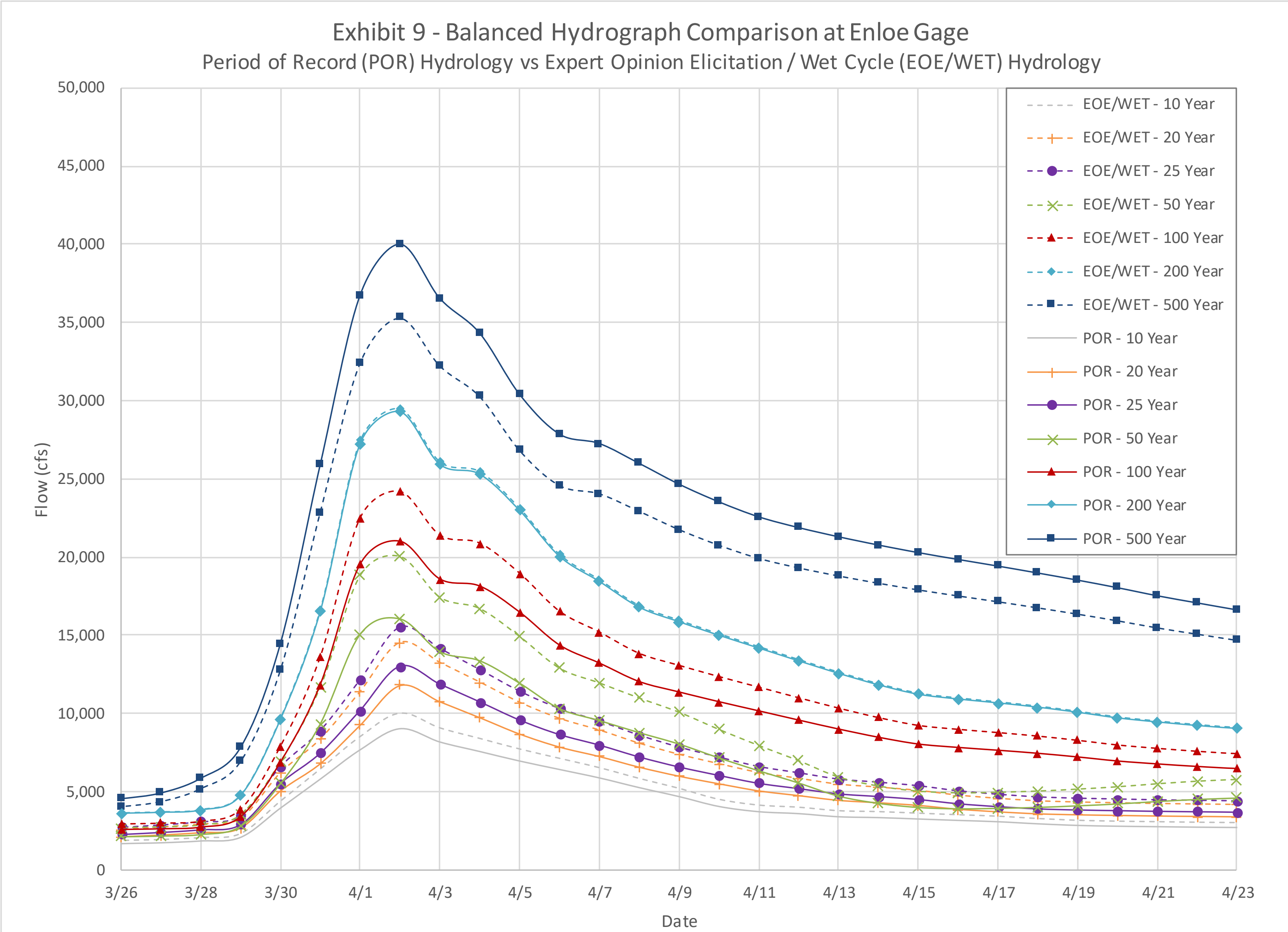


Exhibit 9 - Balanced Hydrograph Comparison at Enloe Gage
Period of Record (POR) Hydrology vs Expert Opinion Elicitation / Wet Cycle (EOE/WET) Hydrology
Flow (cfs)
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
3/26
3/28
3/30
4/1
4/3
4/5
4/7
4/9
4/11
4/13
4/15
4/17
4/19
4/21
4/23
Date
EOE/WET - 10 Year
EOE/WET - 20 Year
EOE/WET - 25 Year
EOE/WET - 50 Year
EOE/WET - 100 Year
EOE/WET - 200 Year
EOE/WET - 500 Year
POR - 10 Year
POR - 20 Year
POR - 25 Year
POR - 50 Year
POR - 100 Year
POR - 200 Year
POR - 500 Year

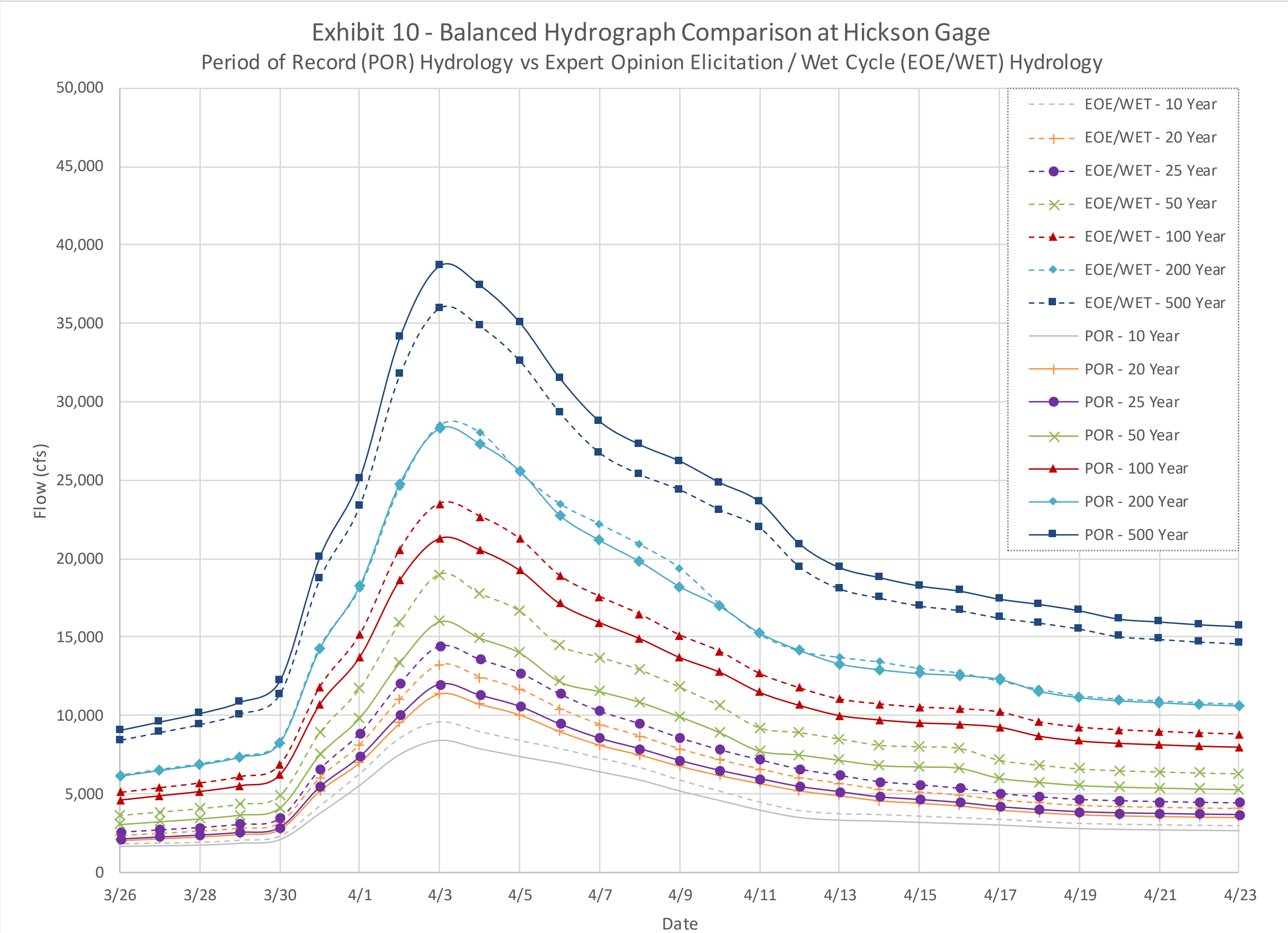


Exhibit 10 - Balanced Hydrograph Comparison at Hickson Gage
Period of Record (POR) Hydrology vs Expert Opinion Elicitation / Wet Cycle (EOE/WET) Hydrology
Flow (cfs)
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
3/26
3/28
3/30
4/1
4/3
4/5
4/7
4/9
4/11
4/13
4/15
4/17
4/19
4/21
4/23
Date
EOE/WET - 10 Year
EOE/WET - 20 Year
EOE/WET - 25 Year
EOE/WET - 50 Year
EOE/WET - 100 Year
EOE/WET - 200 Year
EOE/WET - 500 Year
POR - 10 Year
POR - 20 Year
POR - 25 Year
POR - 50 Year
POR - 100 Year
POR - 200 Year
POR - 500 Year

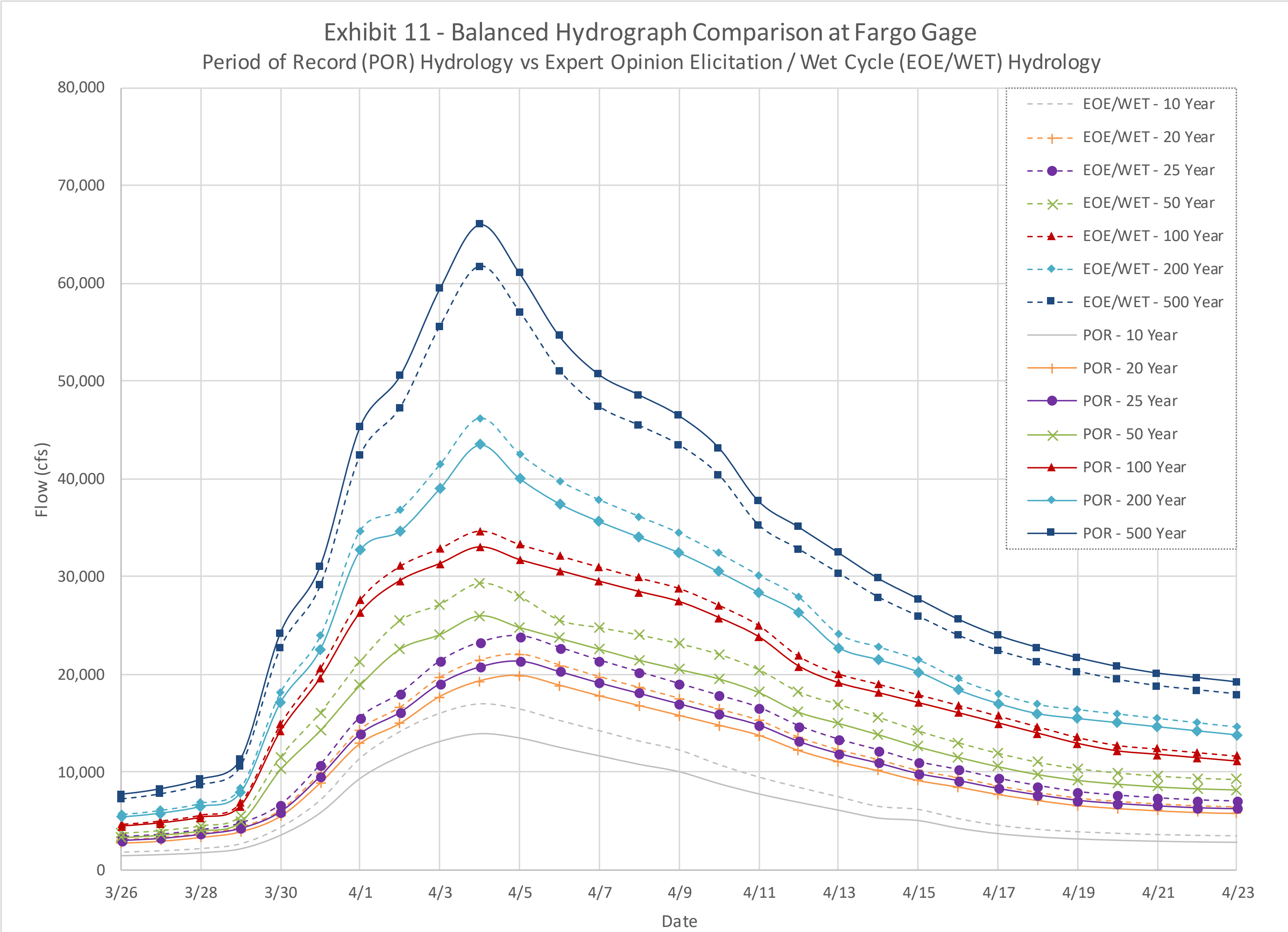


Exhibit 11 - Balanced Hydrograph Comparison at Fargo Gage
Period of Record (POR) Hydrology vs Expert Opinion Elicitation / Wet Cycle (EOE/WET) Hydrology
Flow (cfs)
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
3/26
3/28
3/30
4/1
4/3
4/5
4/7
4/9
4/11
4/13
4/15
4/17
4/19
4/21
4/23
Date
EOE/WET - 10 Year
EOE/WET - 20 Year
EOE/WET - 25 Year
EOE/WET - 50 Year
EOE/WET - 100 Year
EOE/WET - 200 Year
EOE/WET - 500 Year
POR - 10 Year
POR - 20 Year
POR - 25 Year
POR - 50 Year
POR - 100 Year
POR - 200 Year
POR - 500 Year

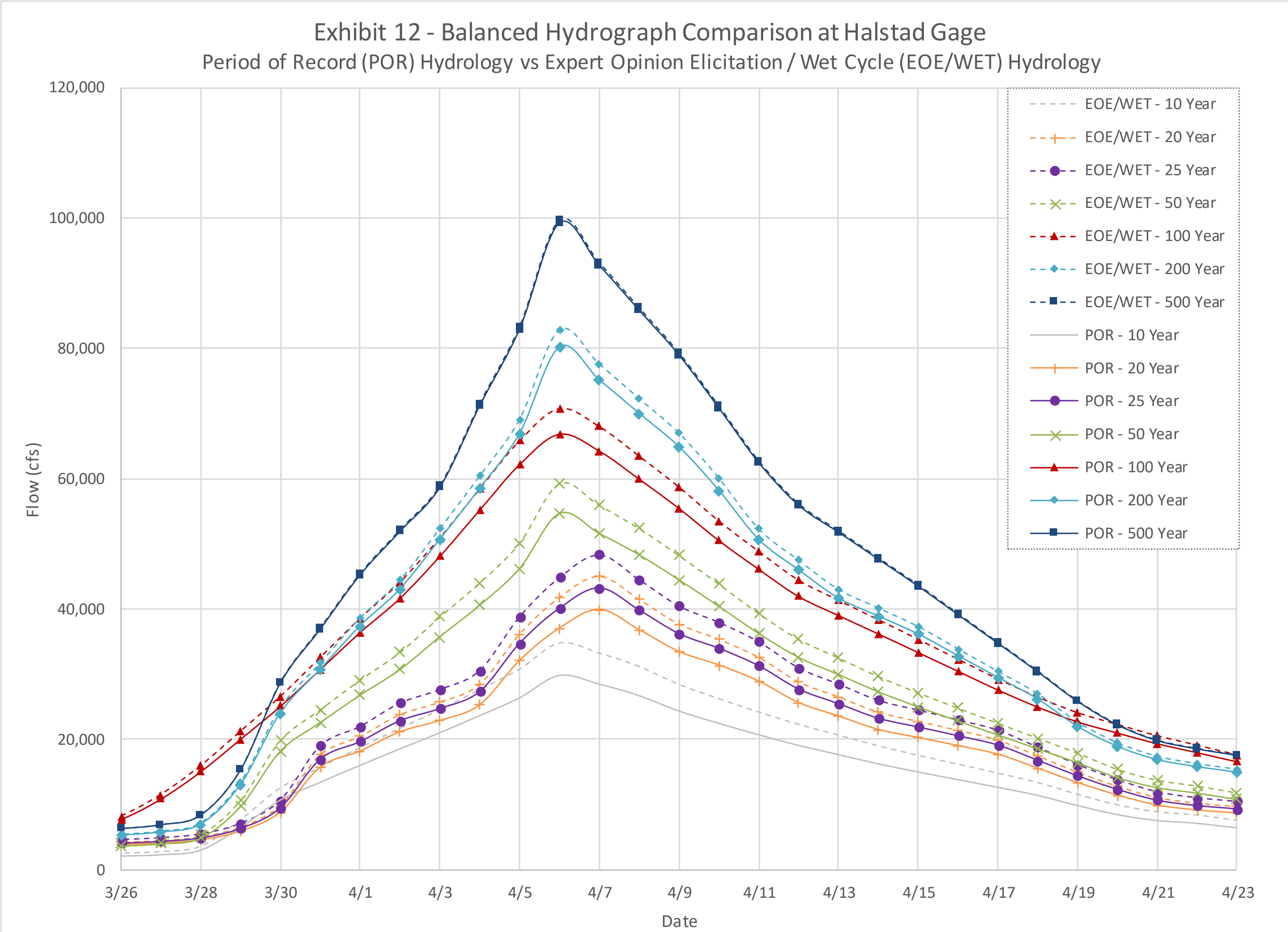


Exhibit 12 - Balanced Hydrograph Comparison at Halstad Gage
Period of Record (POR) Hydrology vs Expert Opinion Elicitation / Wet Cycle (EOE/WET) Hydrology
Flow (cfs)
0
20,000
40,000
60,000
80,000
100,000
120,000
3/26
3/28
3/30
4/1
4/3
4/5
4/7
4/9
4/11
4/13
4/15
4/17
4/19
4/21
4/23
Date
EOE/WET - 10 Year
EOE/WET - 20 Year
EOE/WET - 25 Year
EOE/WET - 50 Year
EOE/WET - 100 Year
EOE/WET - 200 Year
EOE/WET - 500 Year
POR - 10 Year
POR - 20 Year
POR - 25 Year
POR - 50 Year
POR - 100 Year
POR - 200 Year
POR - 500 Year

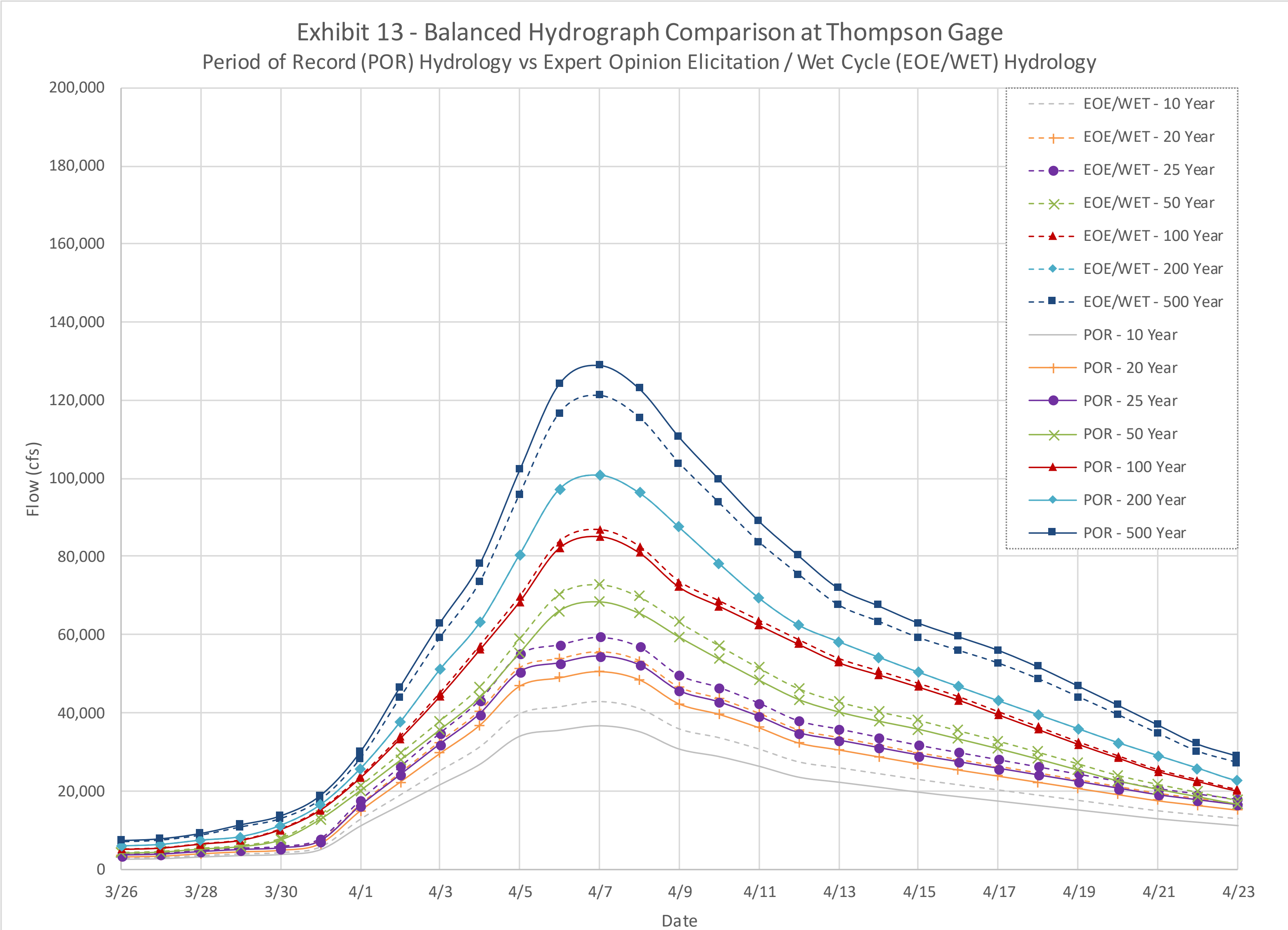


Exhibit 13 - Balanced Hydrograph Comparison at Thompson Gage
Period of Record (POR) Hydrology vs Expert Opinion Elicitation / Wet Cycle (EOE/WET) Hydrology
Flow (cfs)
0
20,000
40,000
60,000
80,000
100,000
120,000
140,000
160,000
180,000
200,000
Date
3/26
3/28
3/30
4/1
4/3
4/5
4/7
4/9
4/11
4/13
4/15
4/17
4/19
4/21
4/23
EOE/WET - 10 Year
EOE/WET - 20 Year
EOE/WET - 25 Year
EOE/WET - 50 Year
EOE/WET - 100 Year
EOE/WET - 200 Year
EOE/WET - 500 Year
POR - 10 Year
POR - 20 Year
POR - 25 Year
POR - 50 Year
POR - 100 Year
POR - 200 Year
POR - 500 Year

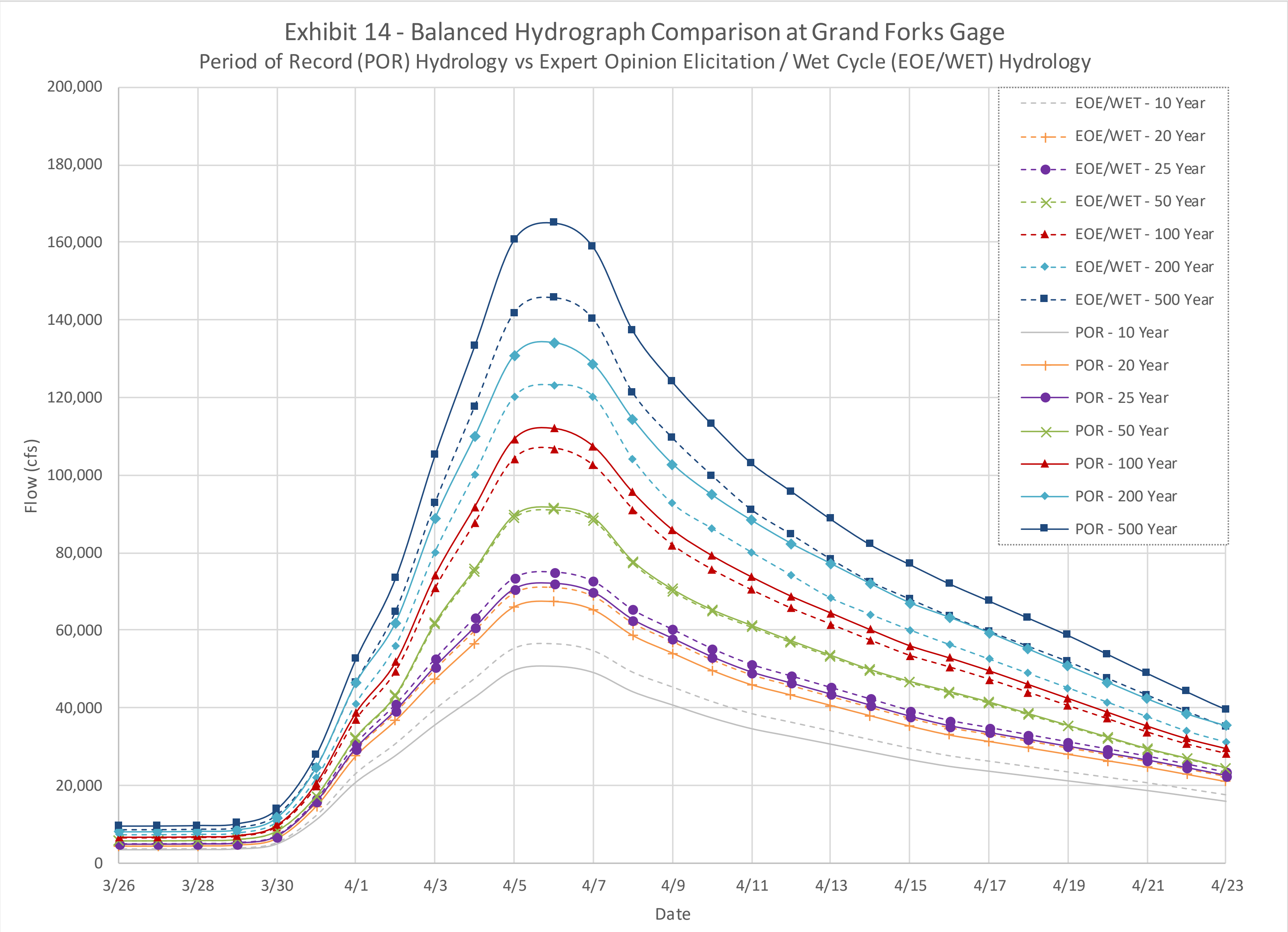


Exhibit 14 - Balanced Hydrograph Comparison at Grand Forks Gage
Period of Record (POR) Hydrology vs Expert Opinion Elicitation / Wet Cycle (EOE/WET) Hydrology
Flow (cfs)
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
3/26
3/28
3/30
4/1
4/3
4/5
4/7
4/9
4/11
4/13
4/15
4/17
4/19
4/21
4/23
Date
EOE/WET - 10 Year
EOE/WET - 20 Year
EOE/WET - 25 Year
EOE/WET - 50 Year
EOE/WET - 100 Year
EOE/WET - 200 Year
EOE/WET - 500 Year
POR - 10 Year
POR - 20 Year
POR - 25 Year
POR - 50 Year
POR - 100 Year
POR - 200 Year
POR - 500 Year

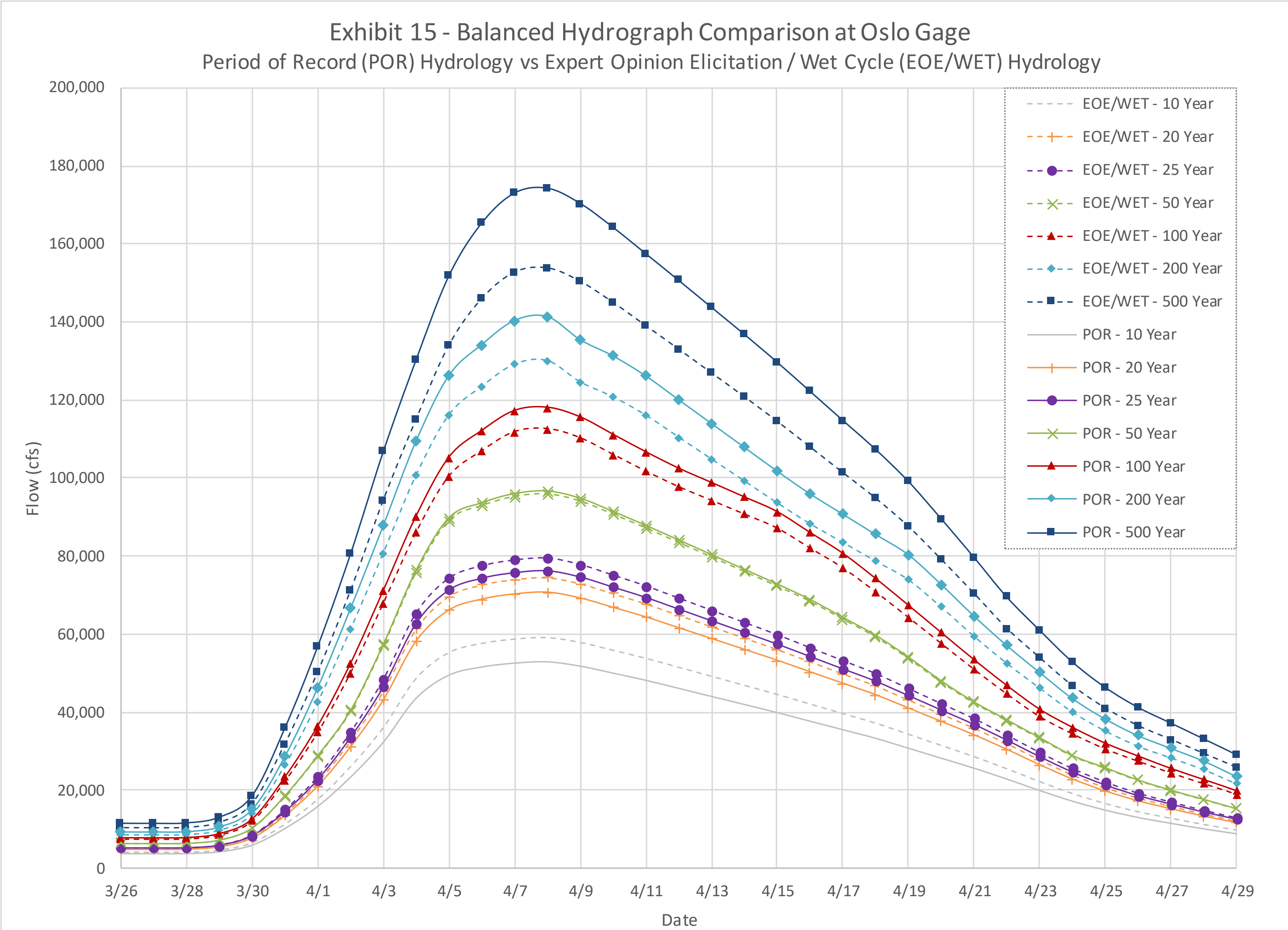


Exhibit 15 - Balanced Hydrograph Comparison at Oslo Gage
Period of Record (POR) Hydrology vs Expert Opinion Elicitation / Wet Cycle (EOE/WET) Hydrology
Flow (cfs)
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
3/26
3/28
3/30
4/1
4/3
4/5
4/7
4/9
4/11
4/13
4/15
4/17
4/19
4/21
4/23
4/25
4/27
4/29
Date
EOE/WET - 10 Year
EOE/WET - 20 Year
EOE/WET - 25 Year
EOE/WET - 50 Year
EOE/WET - 100 Year
EOE/WET - 200 Year
EOE/WET - 500 Year
POR - 10 Year
POR - 20 Year
POR - 25 Year
POR - 50 Year
POR - 100 Year
POR - 200 Year
POR - 500 Year

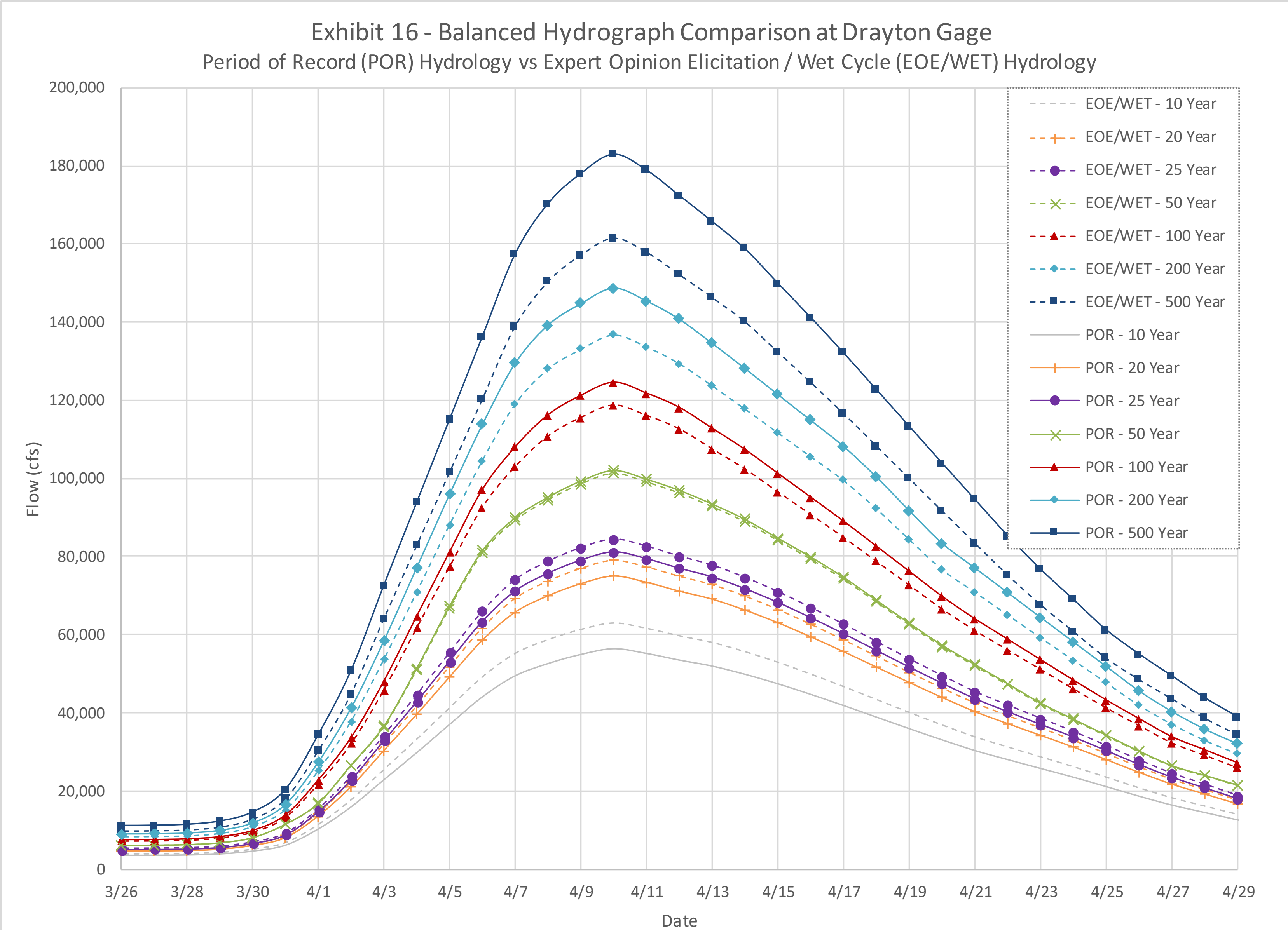


Exhibit 16 - Balanced Hydrograph Comparison at Drayton Gage
Period of Record (POR) Hydrology vs Expert Opinion Elicitation / Wet Cycle (EOE/WET) Hydrology
Flow (cfs)
200,000
180,000
160,000
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
3/26
3/28
3/30
4/1
4/3
4/5
4/7
4/9
4/11
4/13
4/15
4/17
4/19
4/21
4/23
4/25
4/27
4/29
Date
EOE/WET - 10 Year
EOE/WET - 20 Year
EOE/WET - 25 Year
EOE/WET - 50 Year
EOE/WET - 100 Year
EOE/WET - 200 Year
EOE/WET - 500 Year
POR - 10 Year
POR - 20 Year
POR - 25 Year
POR - 50 Year
POR - 100 Year
POR - 200 Year
POR - 500 Year