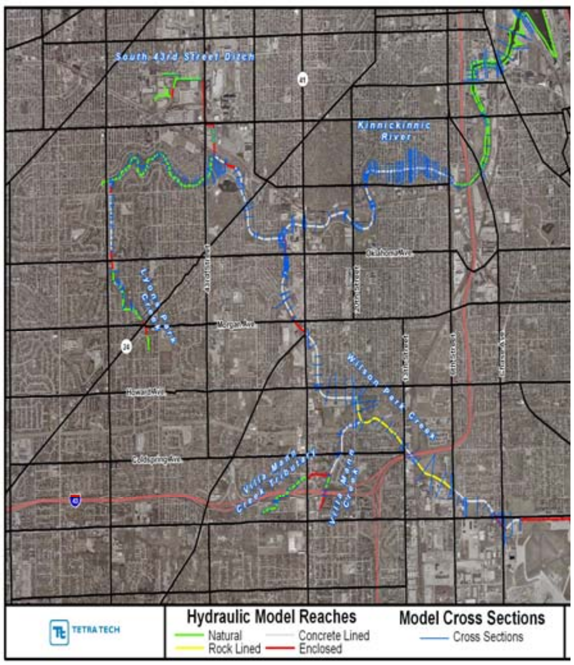
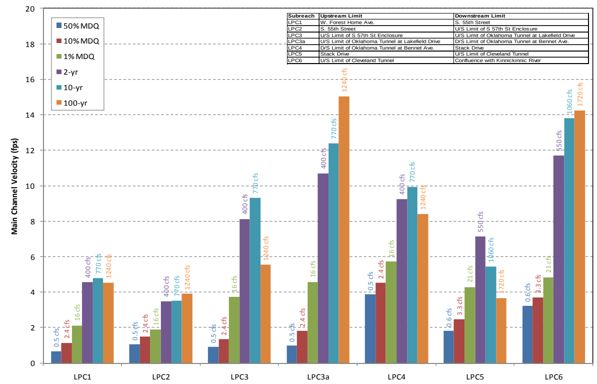
Project Code: P5000

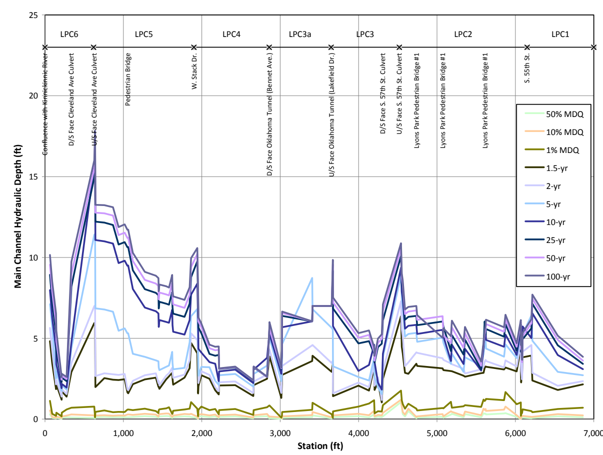
TECHNICAL MEMORANDUM

Hydraulics

Kinnickinnic River Sediment-transport Planning Study
Contract No. W40004E01







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1. INTRODUCTION AND BACKGROUND

A hydraulic analysis of the Kinnickinnic River and its primary tributaries (**Figure 1**) was carried out by Tetra Tech, Inc. [formerly Mussetter Engineering, Inc. (Tt-MEI)] to assess the channel capacity along the project reaches and to develop input for the sediment-transport analysis. The project reach along the Kinnickinnic River extends from the confluence with Lyons Park Creek to the S. Chase Avenue Bridge (5.6 miles), and the primary tributaries include Lyons Park Creek (1.3 miles), S. 43rd Street Ditch (1.1 miles), Wilson Park Creek (6.1 miles), Villa Mann Creek and its tributary (1.5 miles), and Holmes Avenue Ditch (1.2 miles; Figure 1). The work was performed as part of the Milwaukee Metropolitan Sewerage Districts (MMSD) Kinnickinnic River Sediment Transport Planning Study. In performing this analysis, available existing hydraulic models of the project reaches were obtained and reviewed, and appropriate portions of the models were updated with new cross-sectional data collected for this study to update the models or improve estimates of hydraulic conditions in the range of flows that are most important for the sediment-transport analysis. The existing models were developed using the Corps of Engineers HEC-RAS computer software, Version 4.0 (USACE, 2008), a widely accepted one-dimensional (1-D) step-backwater program.

2. EXISTING HYDRAULIC MODELS

The existing HEC-RAS models were developed for a variety of studies by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) or their consultants. The cross-sectional geometry used in each of the HEC-RAS models was developed using survey information collected between 1995 and 2005, 2-foot contour elevation mapping based on 2005 aerial photography, design plans and as-built information, or a combination of these sources. Bridge and hydraulic structures were coded into these models using information from design plans or field measurements. These models were developed to analyze the 10-, 50-, 100-, and 500-year peak flows based on the results from the original HSPF model of the Kinnickinnic River watershed developed by SEWRPC (see Technical Memorandum: Hydrology). Each of the models except the S. 43rd Street Ditch model were set up to execute in mixed subcritical/supercritical mode to account for the range of flow regimes that could occur (i.e., potential supercritical flow conditions along the concrete-lined reaches and subcritical flow conditions along the natural channel reaches). The S. 43rd Street Ditch model was set up to execute in subcritical mode, apparently since the majority of the non-enclosed portions of this reach are not concrete-lined.

The hydraulic models for each of the reaches have varying cross-sectional spacing along the main channel flow path, ranging from 70 feet in Villa Mann Creek to about 240 feet in Wilson Park Creek (**Table 1**). In some cases, cross sections were added to the model using the cross-section interpolation routine to increase the computational resolution of the model (Table 1).

Model Reach	Upstream Limit	Downstream Limit	Modeled Length (miles)	Total Number of Cross Sections	Number of Main Channel Cross Sections	Main Channel Cross-Section Spacing	Number of Inter-polated Sections	Main Channel Manning's *n* -value Range	Overbank *n* -value Range	Downstream Boundary Condition
Kinnickinnic River	Confluence with Lyons Park Ck	Union Pacific Railroad Bridge near Mouth	8	287	242	160	13	0.01-0.068	0.015-0.16	Water-surface Elevation = 579.5'
Wilson Park Creek	Headwaters below S. Whitnall Ave.	Confluence with Kinnickinnic River	6.1	190	134	240	15	0.013-0.050	0.02-0.06	Normal Depth with Slope = 0.018
Lyons Park Creek	W. Forest Home Ave. Tunnel	Confluence with Kinnickinnic River	1.3	110	83	80	0	0.013-0.050	0.01-0.12	Normal Depth with Slope = 0.023
Villa Mann Ck	Interstate 43/894 Culvert	Confluence with Wilson Park Ck	0.7	54	0	70	9	0.015-0.050	0.015-0.12	Normal Depth with Slope = 0.017
Villa Mann Ck Tributary	S. 35th Street Tunnel Outfall	Confluence with Wilson Park Ck	0.8	68	53	85	14	0.016-0.045	0.015-0.12	Internal Boundary Condition.
S. 43rd St. Ditch	W. Rogers St. Tunnel	Confluence with Kinnickinnic River	1.1	56	41	140	0	0.014-0.060	0.031-0.10	Stage-Discharge Rating Curve

Table 1. Summary of hydraulic model structure and input.

Hydraulic roughness was accounted for in the model with the Manning's *n*-value. Main channel Manning's *n*-values ranged from 0.010 in regular concrete-lined sections to 0.068 for natural sections with coarse bed material and irregular banks (Table 1). The upstream boundary condition in each of the models was set to critical depth, while the downstream boundary was typically determined by assuming normal depth conditions with an appropriate energy slope (Table 1). In the model for the Kinnickinnic River, the downstream boundary condition was set to an elevation of 579.5 feet (NGVD 29) to represent the water level in Lake Michigan. Because the geometry for the tributary to Villa Mann Creek was incorporated into the overall Villa Mann Creek model, the downstream water-surface elevation in the tributary reach was determined using an internal boundary condition based on the stage in the mainstem model at the confluence. The downstream boundary condition for S. 43rd Street Ditch was based on a stage-discharge rating curve. Overbank flow paths were defined at locations where high flows split from the main channel (**Table 2**). Bridge and culvert structures were modeled using the HEC-RAS Bridge Data Editor, while tunnel reaches were typically modeled using the "Cross-Section Lid" feature (**Table 3**).

3. UPDATED HYDRAULIC MODELS

Revised HEC-RAS models were developed to incorporate new topographic and bathymetric data collected by MMSD surveyors specifically for this project (**Appendix A**). The revised models better represent the existing channel geometry, and therefore, should provide improved estimates of existing hydraulic characteristics in the project reaches than the previous models.

3.1. Model Development

The following specific steps were taken to update the existing models:

1. Each of the models was geo-rectified to horizontally reference the model geometry (flow paths and cross sections) to the Wisconsin State Plane Coordinate System, South Zone, North American Datum of 1927. Geo-rectified models allow transfer of geospatial data to and from Geographic Information System (GIS) applications such as ArcGIS. The models were georectified using HEC-GeoRAS, a set of ArcGIS tools specifically designed to process geospatial data for use with HEC-RAS. HEC-GeoRAS requires a georectified station line for each separate model reach (including the main channel and any overbank or tributary flow paths) and cross-section lines. The station lines were developed using the digital terrain model (DTM) of the 2005 aerial photogrammetric mapping and associated aerial photography. The cross-section cut lines were typically obtained from SEWRPC, except when this information was not available, in which case the cut line locations were developed using the cross-section spacing and other information (building obstructions, roughness breaks, etc.) specified in the original hydraulic models.

2. The cross sections that were surveyed for this study (see Technical Memorandum: Surveying) were incorporated into the hydraulic models. These sections generally included the main channel portion of the cross section but did not include overbank geometry. At locations where the surveyed cross sections matched the location and orientation of the original model sections, the main channel portion of the original section was replaced with the surveyed cross sections. At locations where the survey section was located a short distance up- or downstream from the original model section, the original cross section was removed and replaced with the new survey section at the appropriate river station. Overbank geometry for the replaced cross sections were developed by cutting the section lines from the 2005 DTM using HEC-GeoRAS.

Table 2. Summary of overbank flow paths in the hydraulic models.

Model Reach	Location of Overbank Flow Path	Flow Breakout Station[1]	Flow Return Station[1]	Flow path Length (ft)	Number of Cross Sections
Kinnickinnic River	51st Street Bypass	37925	37082	800	3
Kinnickinnic River	Jackson Park Overflow	33567	30616	1715	6
Kinnickinnic River	Upstream Railroad Spur Overflow	23579	20714	1418	6
Kinnickinnic River	Downstream Railroad Spur Overflow	20824	17194	3039	18
Kinnickinnic River	S. 7th Street Overflow	15170	Comb.[2]	525	5
Kinnickinnic River	S. 6th St. Overflow	15057	Comb.[2]	345	4
Kinnickinnic River	Combined Overflow (6th St. and 7th St.)	6th & 7th[2]	14661	207	3
Wilson Park Creek	Airport Overflow	27903	19945	6585	8
Wilson Park Creek	S. Howell Ave. Overflow	19127	18427	695	5
Wilson Park Creek	S. 27th St Overflow	4593	3322	1510	8
Wilson Park Creek	W. Oklahoma Ave. Overflow	1633	DNR[3]	1389	35
S. 43rd St. Ditch	S. 43rd St. Overflow	3430	1075	2000	11
S. 43rd St. Ditch	Railroad Yard Overflow	530	DNR[3]	2080	4
Lyons Park Creek	S. 57th St. Overflow	4546	4354	184	3
Lyons Park Creek	W. Oklahoma Ave. Overflow	3664	1855	2087	8
Lyons Park Creek	W. Stack Dr. Overflow	1948	1855	84	2
Lyons Park Creek	58th St Overflow	1903	978	1212	8
Lyons Park Creek	W. Cleveland Ave. Overflow	939	118	926	6
Villa Mann Ck Tributary	I-43/I-894 Overflow	2653	1852	1154	4
Villa Mann Ck Tributary	S. 27th St. Tunnel Overflow	332	2860	1620	11

[1]Based on Tt-MEI Station Line.

[2]7th Street Overflow combines with 6th Street Overflow at Sta 14990 (upstream limit of combined overflow).

[3]Flow path does not return.

Table 3: Summary of bridge, culvert and tunnel structures included in the hydraulic models.					
Model Reach	Feature	RM	River Station* (ft)	Length (ft)	Model Method
Kinnickinnic River	Pedestrian Bridge at S. 51st St.	7.156	37797	5	Bridge
	S. 43rd St.	6.493	34326	65	Bridge
	Pedestrian Bridge	6.415	33919	3	Bridge
	Jackson Park Tunnel	6.041	31978	670	Culvert
	W. Kinnickinnic River Parkway (Jackson Park)	5.831	30870	69	Bridge
	W. Forest Home Avenue	5.671	30031	107	Bridge
	S. 35th Street	5.412	28669	85	Bridge
	Pedestrian Bridge	5.168	27383	9	Bridge
	W. Kinnickinnic River Parkway (Saint Lukes)	5.097	27018	57	Bridge
	S. 29th St.	4.984	26424	48	Bridge
	S. 27th St./US Hwy 41	4.862	25772	108	Bridge
	Union Pacific Railroad Spur	4.396	23323	19	Bridge
	S. 20th St.	4.291	22764	161	Culvert
	Abandoned Railroad Spur	3.933	20872	8	Bridge
	Union Pacific Railroad	3.915	20770	50	Bridge
	W. Cleveland Ave	3.762	19954	52	Bridge
	Pedestrian Bridge	3.622	19221	9	Bridge
	S. 16th St.	3.555	18866	72	Bridge
	S. 13th St.	3.3	17520	68	Bridge
	S. 9th Pl.	3.052	16208	55	Bridge
	S. 6th St.	2.792	14846	86	Bridge
	W. Chase Ave./State Hwy 38	2.387	12707	114	Bridge
	S. 1st St. (Upstream Bridge)	2.001	10650	97	Bridge
	W. Lincoln Ave.	1.947	10382	88	Bridge
	W. Becher St.	1.667	8902	88	Bridge
	S. 1st St. (Downstream Bridge)	1.422	7656	60	Bridge
	Canadian Pacific Railroad	1.306	7039	33	Bridge
	S. Kinnickinnic Ave./State Hwy 32	1.277	6896	66	Bridge
	Union Pacific Railroad	0.842	4590	31	Bridge
Wilson Park Creek	Edgerton Ditch Tunnel	5.97-5.62	31497-29649	1849	Lid
	S. Pennsylvania Avenue	5.51	29053	127	Culvert
	Lake Parkway Northbound	5.34	28193	48	Bridge
	Lake Parkway Southbound	5.327	28120	55	Bridge
	Chicago Pacific Railroad	5.3065	28002	136	Culvert
	Airport Service Road	4.935	26031	30	Bridge

Table 3: Summary of bridge, culvert and tunnel structures included in the hydraulic models.					
Model Reach	Feature	RM	River Station* (ft)	Length (ft)	Model Method
	Airport Tunnel	4.74-3.84	24993-20230	4763	Lid
	Howell/Layton Tunnel	3.636-3.50	19138-18400	738	Lid
	S. 5th St.	3.16	16617	50	Culvert
	S. 6th St.	3.02	15861	93	Culvert
	Canadian Pacific Railroad	2.56	13446	120	Culvert
	I-43/I-94	2.495	13094	145	Bridge
	S. 13th St.	2.4	12623	112	Culvert
	S. 20th St.	1.69	8952	114	Culvert
	W. Howard Ave.	1.29	6841	108	Culvert
	S. 27th St. Tunnel (Inlet)	0.8375	4337	226	Culvert
	S. 27th St. Tunnel (Middle)	0.7525	3758	578	Culvert
	W. Morgan Ave. Tunnel (Outlet)	0.685	3577	170	Culvert
	W. Lakefield Dr.	0.4825	2565	201	Culvert
	Euclid Avenue/Oklahoma Ave Tunnel	0.304-0.04	1629-229	1400	Lid
S. 43rd St. Ditch	W. Electric Avenue	0.955	4906	68	Bridge
	S. 43rd St. Tunnel	0.658-0.21	3413-1110	2417	Lid
	RR Yard Tunnel	0.10-0.001	500-16	500	Lid
Lyons Park Creek	S. 55th St.	1.17	6148	0	Culvert
	Lyons Park Pedestrian Bridge #1	1.068	5615	0	Bridge
	Lyons Park Pedestrian Bridge #1	0.964	5076	0	Bridge
	Lyons Park Pedestrian Bridge #1	0.898	4741	0	Bridge
	S. 57th St.	0.839	4426	0	Culvert
	Oklahoma Ave Tunnel (Lakefield - Bennett)	0.687-0.532	3657-2862	796	Lid
	W. Stack Dr.	0.35	1903	0	Culvert
	Pedestrian Bridge	0.188	1056	0	Bridge
	W. Cleveland Ave.	0.08	483	0	Culvert
Villa Mann Creek	W. Bolivar Avenue Culverts	0.3975	2109	124	Culvert
	W. Plainfield Avenue Culverts	0.2375	1277	95	Culvert
	S. 20th St. Culverts	0.0725	399	97	Culvert
Villa Mann Ck Tributary	Concrete Weir/Culvert Crossing	0.782	4080	16	Culvert
	Pedestrian Bridge	0.678	3537	10	Culvert
	W. Colony Dr.	0.6425	3330	48	Culvert
	I-43/I-894 Culvert	0.4875	2529	188	Culvert
	S. 27th St. Tunnel	0.256-0.0002	1320-24	1296	Lid

*Based on Tt-MEI Station Line

Appropriate roughness values (including horizontally variable *n*-values), ineffective flow areas, and blocked obstructions were used at all of the updated cross sections.

3. The hydrologic input to the models was updated using the revised hydrology that was developed using measured flow data and the HSPF model results (see Technical Memorandum: Hydrology). The revised hydrology was used to specify changes in flow along the various reaches for each modeled flow under existing and future (2020 land use) conditions (**Tables 4 and 5**).

4. The overbank flow paths in each of the models were originally developed for high flow conditions that result in unrealistic hydraulic conditions at low flows due to the HEC-RAS "optimization" (i.e., flow balancing) procedures. These procedures balance the water surface elevation or energy grade elevation at the upstream flow split to determine the appropriate distribution of discharge in the main channel and split flow path, and may cause artificially high water-surface elevations upstream from the flow split under low-flow conditions as the model forces a nominal amount of flow in the split flow path. To account for this, two separate scenarios were executed for each model and each hydrologic condition. The first model scenario was developed for high-flow conditions and includes the optimization of all overbank flow paths. This model was executed for all flows between the 1.5- and 100-year peak flows to determine the flow split (if any) at each location, which was used as input for the final model with only the main channel flow path.

In addition to the above general model updates, specific modifications to the models were made to better evaluate the hydraulic conditions over the range of flows that were evaluated for the sediment-transport analysis. In some cases, the ineffective flow areas were revised up- and downstream from the modeled bridge structures to better account for flow contraction and expansion. The Manning's *n*-values at many locations were adjusted to reflect observed roughness conditions based on information collected during the geomorphic field reconnaissance. In the Kinnickinnic River model, the cross-sectional geometry in the reach between S. 6th Street and the Interstate 94 Bridge was replaced with the design geometry for the proposed improvements in this area. This geometry was developed using the 50-percent design drawings (SEH, 2009). Because the geometry in this model did not include the weir for the USGS gage at 11th Street, the weir was inserted into the model using information collected during the field reconnaissance.

In the Lyons Park Creek model, the normal depth downstream boundary condition was replaced with a stage-discharge rating curve that was developed using the results from the Kinnickinnic River model, since the two models share a common cross section (i.e., the upstream cross section in the Kinnickinnic River model is the downstream cross section in the Lyons Park Creek model). To increase the computational resolution in the tributary to Villa Mann Creek and in the natural reach of Villa Mann Creek (upstream from the confluence with the tributary), 37 cross sections were added to these reaches using the HEC-RAS cross-section interpolation routine. The range of flows evaluated in the model for S. 43rd Street Ditch did not break out of the main channel into overbank flow paths at any location; thus, the overbank flow paths were removed from this model. Because the source of the rating curve used to establish the downstream boundary condition in the original model for this channel is unknown, and because the curve does not include the range of low flows considered in this study, the boundary condition was adjusted based on a normal depth assumption with a slope of 0.001, consistent with the average slope in the tunnel through the railroad yard in the downstream portion of this reach.

Table 4. Summary of existing conditions flows evaluated in the hydraulic models.

Channel:	**Kinnickinnic River**					**Wilson Park Creek**					**Lyons Park Creek**		**S. 43rd St. Ditch**		**Villa Mann Creek**			**Villa Mann Ck Trib**	
River Station:	*42219*	*36961*	*30152*	*20697*	*14996*	*32100*	*19713*	*17300*	*10072*	*3122*	*6861*	*1845*	*5528*	*4474*	*3791*	*3032*	*2046*	*4425*	*1603*
Profile	**Discharge (cfs)**																		
95% MDQ	0.2	0.4	0.8	3.0	3.1	0.1	0.6	0.9	1.1	1.3	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1
90% MDQ	0.3	0.5	1.0	3.4	3.6	0.2	0.7	1.0	1.3	1.5	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.1	0.1
70% MDQ	0.6	0.9	1.8	6.2	6.6	0.5	1.6	2.3	2.9	3.4	0.3	0.5	0.3	0.5	0.1	0.3	0.4	0.2	0.2
50% MDQ	0.8	1.3	2.5	8.6	9.0	0.7	2.3	3.5	4.4	5.2	0.5	0.6	0.5	0.7	0.2	0.5	0.6	0.2	0.4
30% MDQ	1.3	2.0	4.0	13.6	14.3	1.1	3.7	5.6	7.3	8.4	0.7	1.0	0.7	1.0	0.3	0.9	1.0	0.4	0.6
20% MDQ	1.9	2.8	5.8	20.2	21.1	1.6	5.2	8.4	10.9	12.5	1.0	1.4	1.1	1.6	0.5	1.3	1.6	0.5	0.9
10% MDQ	4.4	6.5	14.1	45.5	47.7	3.2	9.7	17.4	22.7	26.3	2.4	3.3	3.0	4.5	1.2	3.0	3.6	0.9	1.9
5% MDQ	9	13	28	86	89	6	16	31	41	48	5	6	6	9	2	6	7	2	3
2% MDQ	17	26	57	170	178	10	27	55	73	86	10	13	13	19	4	10	12	3	6
1% MDQ	28	42	91	263	276	14	38	78	107	124	16	21	20	30	6	15	18	4	9
0.5% MDQ	42	61	132	374	390	19	52	104	136	166	23	31	29	43	8	20	23	5	12
0.1% MDQ	76	112	247	666	716	35	98	186	250	295	42	57	50	74	13	34	40	11	21
0.05% MDQ	91	133	299	792	872	38	106	211	277	320	50	72	58	87	14	37	44	12	23
1.5-yr	448	557	934	2485	2574	143	570	1035	1361	1735	312	431	310	460	166	338	380	74	171
2-yr	580	720	1150	3080	3190	180	730	1300	1690	2150	400	550	350	520	200	410	480	90	210
5-yr	930	1160	1720	4480	4630	300	1130	1960	2440	3100	620	850	430	650	280	590	730	150	310
10-yr	1180	1460	2090	5360	5540	390	1380	2380	2890	3640	770	1060	490	730	330	700	880	180	370
25-yr	1480	1850	2560	6380	6590	510	1670	2890	3400	4230	960	1330	540	810	400	840	1050	220	440
50-yr	1730	2140	2910	7120	7350	610	1880	3260	3760	4620	1100	1520	570	860	450	930	1180	250	480
100-yr	1960	2450	3260	7800	8050	730	2080	3600	4070	4960	1240	1720	610	910	500	1030	1280	270	530

Table 5. Summary of future conditions (2020 PLU) flows evaluated in the hydraulic models.

Channel:	**Kinnickinnic River**					**Wilson Park Creek**					**Lyons Park Creek**		**S. 43rd St. Ditch**		**Villa Mann Creek**			**Villa Mann Ck Trib**	
River Station:	*42219*	*36961*	*30152*	*20697*	*14996*	*32100*	*19713*	*17300*	*10072*	*3122*	*6861*	*1845*	*5528*	*4474*	*3791*	*3032*	*2046*	*4425*	*1603*
Profile	**Discharge (cfs)**																		
95% MDQ	0.2	0.4	0.8	3.0	3.2	0.2	0.6	0.9	1.1	1.3	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1
90% MDQ	0.3	0.5	1.0	3.4	3.7	0.2	0.7	1.1	1.3	1.6	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.1	0.1
70% MDQ	0.6	0.9	1.8	6.3	6.7	0.5	1.6	2.3	3.0	3.5	0.3	0.5	0.3	0.5	0.1	0.3	0.4	0.2	0.2
50% MDQ	0.8	1.3	2.5	8.8	9.2	0.8	2.5	3.6	4.5	5.3	0.5	0.6	0.4	0.7	0.2	0.5	0.6	0.2	0.4
30% MDQ	1.3	2.0	4.0	13.9	14.5	1.2	3.9	5.8	7.4	8.7	0.7	1.0	0.7	1.0	0.3	0.9	1.0	0.4	0.6
20% MDQ	1.9	2.8	5.8	20.5	21.4	1.8	5.5	8.7	11.2	12.8	1.0	1.4	1.0	1.6	0.5	1.4	1.6	0.5	0.9
10% MDQ	4.4	6.5	14.2	46.2	48.4	3.5	10.2	18.0	23.3	26.9	2.4	3.3	2.9	4.5	1.2	3.1	3.6	0.9	1.9
5% MDQ	9	13	28	87	91	6	17	32	42	49	5	6	6	9	2	6	7	2	4
2% MDQ	17	26	57	173	180	11	29	56	75	88	10	13	12	19	4	11	12	3	6
1% MDQ	28	42	91	267	280	16	40	80	109	127	16	21	19	30	6	15	18	4	9
0.5% MDQ	42	61	132	380	396	21	54	107	140	170	23	31	28	43	8	20	24	5	12
0.1% MDQ	76	112	247	677	727	38	103	192	257	302	42	57	48	74	13	35	40	11	21
0.05% MDQ	92	133	299	805	885	41	111	218	285	328	50	72	56	87	14	37	45	12	24
1.5-yr	450	557	939	2527	2616	177	594	1075	1405	1777	315	433	300	470	169	347	389	76	178
2-yr	580	720	1160	3130	3230	220	760	1350	1740	2200	400	550	350	540	200	420	490	100	220
5-yr	930	1160	1730	4540	4690	350	1160	2010	2480	3130	620	860	440	680	280	600	730	150	320
10-yr	1180	1460	2100	5410	5590	450	1410	2430	2900	3670	770	1060	480	750	340	720	880	180	380
25-yr	1480	1850	2590	6420	6640	580	1710	2930	3360	4240	960	1330	540	840	400	840	1060	220	440
50-yr	1730	2150	2940	7150	7390	700	1920	3290	3670	4630	1100	1520	580	900	450	940	1180	250	490
100-yr	1960	2450	3300	7820	8070	820	2130	3620	3930	4960	1240	1720	610	950	500	1030	1290	270	530

3.2. Model Validation

The model was validated, to the extent possible, by comparing the predicted water-surface elevations to measured water-surface elevations at stream gages that are located in the various reaches. The USGS has taken 65 stream-gaging measurements at the Kinnickinnic River at S. 11th Street Gage, which is located about 100 feet upstream from the footbridge at S. 11th Street, since 1987 at discharges ranging from 3.7 cfs to 194 cfs for purposes of developing and re-calibrating the gage-rating curve. The water-surface elevations for these measurements were determined by adding the gage datum (588.9 feet NGVD29) to the reported outside gage height. Comparison of model results indicates very good agreement over the range of flows encompassed by the measurements (**Figure 2**).

Numerous other USGS stream gages exist along the modeled reaches (see Technical Memorandum: Hydrology). However, each of these gages reference a separate local datum that is not directly associated with known elevations (pers. comm., Mr. Steven Corsi, USGS). As such, validation of the hydraulic models using measurements at these gages was not possible.

3.3. Model Results

As discussed above, each of the models was executed over a range of discharges from baseflows through the 100-year flood peak under existing and future conditions hydrology. The flow distribution along the project reaches was established by adjusting the discharge to reflect tributary inflows based on the relationship developed in the hydrology analysis (see Technical Memorandum: Hydrology; Tables 4 and 5). The resulting predicted water-surface profiles indicate that significant backwater occurs upstream from many of the bridge structures at higher magnitude flood flows (**Figures 3 through 8**). The water-surface profiles also highlight the differences between super- and subcritical flow, especially where hydraulic jumps cause the water-surface to increase in the downstream direction for some distance. The hydraulic jumps often occur at transitions from concrete-lined to natural or rock-lined channels (i.e., Wilson Park Creek below S. 5th Street), upstream from backwater zones caused by bridge structures (e.g., the Kinnickinnic River above the S. 6th Street, S. 13th Street, and S. 16th Street Bridges), or at tunnel outlets (e.g. S. 43rd Street Ditch below S. 43rd Street Tunnel).

As expected, the model results indicate that hydraulic conditions (i.e., velocities, depths, main channel topwidths) vary considerably through the project reach based on the local slope, channel geometry, hydraulic roughness conditions, and downstream hydraulic controls (**Appendix B**). The results also indicate that the hydraulic conditions are very similar under the future conditions hydrology, since the increase in flow associated with 2020 PLU conditions is relatively small (see Technical Memorandum: Hydrology; **Appendix C**). The difference between the computed hydraulic conditions at most locations is due to a change in flow regime, where subcritical flow is predicted under one hydrologic condition and critical or supercritical flow is predicted under the other hydrologic condition.

To facilitate the sediment-transport analysis, subreach-averaged hydraulic conditions were developed from the model output using 47 subreaches that were identified based on a number of criteria, including drainage area, geomorphic setting (channel slope, bed material size, etc.), channel type (natural, rock-lined, or concrete-lined), and influence of infrastructure (**Table 6**).

Table 6. Summary of subreaches used to compute the subreach-averaged hydraulic conditions.

Stream or Channel	Subreach	Upstream Limit	Downstream Limit	Upstream Station*	Downstream Station*	Reach Length (ft)
Kinnickinnic River	KKR1	Lyons Park Creek	Upstream Limit of Rock Wall	42170	39620	2550
	KKR2	Upstream Limit of Rock Wall	Footbridge at S. 51st Street	39620	37800	1820
	KKR3	Footbridge at S. 51st Street	Downstream Limit of Riprap Bank Protection	37800	35800	2000
	KKR4	Downstream Limit of Riprap Bank Protection	GCS above S. 43rd Street Ditch Confluence	35800	33010	2790
	KKR5	GCS above S. 43rd Street Ditch Confluence	Kinnickinnic River Parkway Bridge in Jackson Park	33010	30860	2150
	KKR6	Kinnickinnic River Parkway Bridge in Jackson Park	Wilson Park Creek Confluence	30860	27070	3790
	KKR7	Wilson Park Creek Confluence	20th Street	27070	22770	4300
	KKR8	20th Street	16th Street	22770	18870	3900
	KKR9	16th Street	6th Street	18870	14850	4020
	KKR10	6th Street	Chase Ave	14850	12700	2150
	KKR11	Chase Ave	1st Street	12700	10650	2050
Wilson Park Creek	WPC1	S. Whitnall Ave	Upstream Limit of Edgerton Tunnel at S. Nicholson Ave.	32150	31500	650
	WPC1a	Upstream Limit of Edgerton Tunnel at S. Nicholson Ave.	Downstream Limit of Edgerton Tunnel at Delaware Ave.	31500	29640	1860
	WPC2	Downstream Limit of Edgerton Tunnel at Delaware Ave.	Northwestern RR Culvert at East Boundary of General Mitchell Airport	29640	28000	1640
	WPC3	Northwestern RR Culvert at East Boundary of General Mitchell Airport	Upstream Limit of Airport Tunnel	28000	25000	3000
	WPC3a	Upstream Limit of Airport Tunnel	Downstream Limit of Airport Tunnel	25000	20220	4780
	WPC4	Downstream Limit of Airport Tunnel	Confluence with Holmes Avenue Ditch	20220	17430	2790
	WPC5	Confluence with Holmes Avenue Ditch	Upstream Limit of Rock-lined Reach below S. 6th Street	17430	15700	1730
	WPC6	Upstream Limit of Rock-lined Reach below S. 6th Street	Downstream Limit of Rock-lined Reach Above Chicago Milwaukee Saint Paul and Pacific RR Bridge	15700	13600	2100
	WPC7	Downstream Limit of Rock-lined Reach Above Chicago Milwaukee Saint Paul and Pacific RR Bridge	Upstream Limit of Rock-lined Reach below S. 13th Street	13600	12470	1130
	WPC8	Upstream Limit of Rock-lined Reach below S. 13th Street	Confluence with Villa Mann Creek	12470	9900	2570
	WPC9	Confluence with Villa Mann Creek	S. 20th Street	9900	8950	950
	WPC10	S. 20th Street	W. Howard Ave	8950	6830	2120
	WPC11	W. Howard Ave	Upstream Limit of 27th/Morgan Enclosure	6830	4560	2270
	WPC11a	Upstream Limit of 27th/Morgan Enclosure	Downstream Limit of 27th/Morgan Enclosure	4560	3570	990
	WPC12	Downstream Limit of 27th/Morgan Enclosure	Upstream Limit of Oklahoma Enclosure at W. Euclid Ave.	3570	1650	1920
	WPC13	Upstream Limit of Oklahoma Enclosure at W. Euclid Ave.	Confluence with Kinnickinnic River	1650	0	1650
Lyons Park Creek	LPC1	W. Forest Home Ave.	S. 55th Street	7100	6150	950
	LPC2	S. 55th Street	Upstream Limit of S 57th St Enclosure	6150	4520	1630
	LPC3	Upstream Limit of S 57th St Enclosure	Upstream Limit of Oklahoma Tunnel at Lakefield Drive	4520	3650	870
	LPC3a	Upstream Limit of Oklahoma Tunnel at Lakefield Drive	Downstream Limit of Oklahoma Tunnel at Bennet Ave.	3650	2860	790
	LPC4	Downstream Limit of Oklahoma Tunnel at Bennet Ave.	Stack Drive	2860	1900	960
	LPC5	Stack Drive	Upstream Limit of Cleveland Tunnel	1900	620	1280
	LPC6	Upstream Limit of Cleveland Tunnel	Confluence with Kinnickinnic River	620	0	620
S. 43rd Street Ditch	43SD1	Downstream Limit of Enclosure	Confluence with Right Bank Tributary	5670	4580	1090
	43SD2	Confluence with Right Bank Tributary	Upstream Limit of S. 43rd St. Enclosure	4580	3410	1170
	43SD3	Upstream Limit of S. 43rd St. Enclosure	Downstream Limit of S. 43rd St. Enclosure	3410	1100	2310
	43SD4	Downstream Limit of S. 43rd St. Enclosure	Upstream Limit of RR Yard Enclosure	1100	500	600
	43SD5	Upstream Limit of RR Yard Enclosure	Tunnel Outlet at Confluence with KKR	500	0	500
Villa Mann Creek	VMC1	I-43 Culvert Outlet	Confluence with VMC Tributary	3780	3100	680
	VMC2	Confluence with VMC Tributary	W Bolivar Ave	3100	2100	1000
	VMC3	W Bolivar Ave	W Plainfield Ave	2100	1300	800
	VMC4	W Plainfield Ave	Confluence with Kinnickinnic River	1300	0	1300
Villa Mann Creek Tributary	VMCT1	Downstream Limit of Enclosure	W. Colony Drive	4430	3330	1100
	VMCT2	W. Colony Drive	I-43 Culvert	3330	2510	820
	VMCT3	I-43 Culvert	Upstream Limit of 27th Street Enclosure	2510	1310	1200
	VMCT4	Upstream Limit of 27th Street Enclosure	Confluence with Villa Mann Creek	1310	0	1310

*Based on Tt-MEI Station Line

The results in the Kinnickinnic River indicate that the average main channel hydraulic depth at the 2-year flood peak ranges from about 2 feet in Subreach KKR5 to about 6.6 feet in Subreach KKR10, with consistent depths of about 4 feet in the upstream, natural reaches and a general trend of increasing depth with increasing drainage area in the downstream portion of the reach (**Figure 9**). Main channel velocities are highest in the downstream concrete-lined reach (Subreach KKR9), but are also relatively high in the proposed project reach in Subreach KKR10 (**Figure 10**). The relatively high velocities in the concrete-lined reaches reflect the computed supercritical flow conditions. Main channel velocities are lowest in the natural reaches (Subreaches KKR1 through KKR4) and in the downstream reach at the lower discharges that are affected by water levels in Lake Michigan. The average main channel top width at the 2-year event is also relatively consistent (about 40 feet) through the natural reaches, and ranges from about 50 feet to nearly 75 feet in the concrete-lined reaches (**Figure 11**). The largest topwidths occur in Subreach KKR11, since this reach is located in the upstream portion of the Lake Michigan estuary.

In Wilson Park Creek, the results indicate a general trend of increasing hydraulic depth with increasing drainage area and discharge , with average depths at the 2-year event ranging from 1.8 feet in Subreach WPC1 to 8.4 feet in Subreach WPC11a (**Figure 12**). In the downstream two subreaches, lower hydraulic depths occur due to the increased gradient that results in supercritical flow. Main channel velocities vary along the reach, with relatively low velocities in the hydraulically rough natural and rock-lined reaches (Subreaches WPC1, WPC2, WPC6, WPC8 and WPC9), and significant variability in the concrete-lined and enclosed reaches due to changes in gradient and discharge (**Figure 13**). The largest relative topwidths also occur in the natural and rock-lined reaches (**Figure 14**).

The average hydraulic depth in Lyons Park Creek is somewhat less variable, from 1.7 feet in Subreach LPC6 to 3.0 feet in Subreach LPC2 ranging at the 2-year event (**Figure 15**). The lowest main channel velocities occur in the upstream natural reaches (3.5 to 4.6 fps at the 2-year event), and significantly increase in the concrete-lined and enclosed reaches (7.1 to 11.7 fps at the 2-year event; **Figure 16**). As expected, the largest top widths occur in the upstream natural reaches (about 38 feet at the 2-year event), while the smallest average topwidth occurs through the W. Oklahoma Avenue Tunnel (**Figure 17**).

Results from the S. 43rd Street Ditch model indicate average depths at the 2-year event ranging from 3.6 feet in Subreach 43SD2 to 5.1 feet in Subreach 43SD3 (**Figure 18**). The lowest velocities occur in the upstream subreach due to the relatively small drainage contribution, as well as the backwater effects from the W. Electric Avenue Bridge (**Figure 19**). At flood flows, the topwidths are controlled by the width of the tunnels in Subreaches 43SD3 and 43SD5, while the largest topwidths occur in the subreach upstream from S. 43rd Street (Subreach 43SD2; **Figure 20**).

Consistent with the other modeled reaches, the natural reaches of Villa Mann Creek have the largest hydraulic depths and the lowest velocities (**Figures 21 and 22**). Main channel velocities exceed 14 fps at flood flows in Subreach VMC2 due to the very steep channel gradient below the confluence with the tributary. The largest channel widths are caused by the backwater effects of West Plainfield Avenue in Subreach VMC3 (**Figure 23**). In the tributary to Villa Mann Creek, the significant backwater zone upstream from the S. 27th Street Tunnel results in large depths and topwidths and low velocities in Subreach VMCT3 (**Figures 24 through 26**). Upstream from the backwater zone in Subreaches VMCT1 and VMCT2, the relatively small drainage area for this tributary results in low depths (less than 2 feet at the 2-year event), low velocities (less than 5 fps at the 2-year event), and small topwidths (less than 20 feet at the 2-year event).

4. SUMMARY AND CONCLUSIONS

Previously developed hydraulic models for the project reaches were updated for this sediment-transport study using the Corps of Engineers HEC-RAS computer software (USACE, 2008), a one-dimensional (1-D) step-backwater program. The models were updated with cross-sectional geometry developed using topographic information from surveys conducted for this study by MMSD during the summer of 2009. The models were georectified to reference the Wisconsin State Plane Coordinate System, South Zone, North American Datum of 1927. Other minor updates to the models at some locations included modification to Manning's *n*-values, ineffective flow areas, and overbank topography and addition of interpolated cross sections. Hydrologic input to the model was based on results from the hydrologic analysis (see Technical Memorandum: Hydrology). Other model input (hydraulic roughness and downstream boundary conditions) were based on field observations and engineering judgment. The model results indicate that the hydraulic characteristics vary significantly along the project reaches, and are affected in several locations by infrastructure. The results also indicate that hydraulic characteristics are similar under existing and future (2020 Planned Land Use) hydrologic conditions because the flows do not change significantly.

5. REFERENCES

Short Elliott Hendrickson, Inc., 2009. Watercourse, Kinnickinnic River Flood Management, South 6th Street to Interstate 94 Bridge. Prepared for Milwaukee Metropolitan Sewerage District, Milwaukee, Wisconsin, September.

U.S. Army Corps of Engineers, 2008. HEC-RAS, River Analysis System, Users Manual, Version 4.0, Hydrologic Engineering Center, Davis, California.

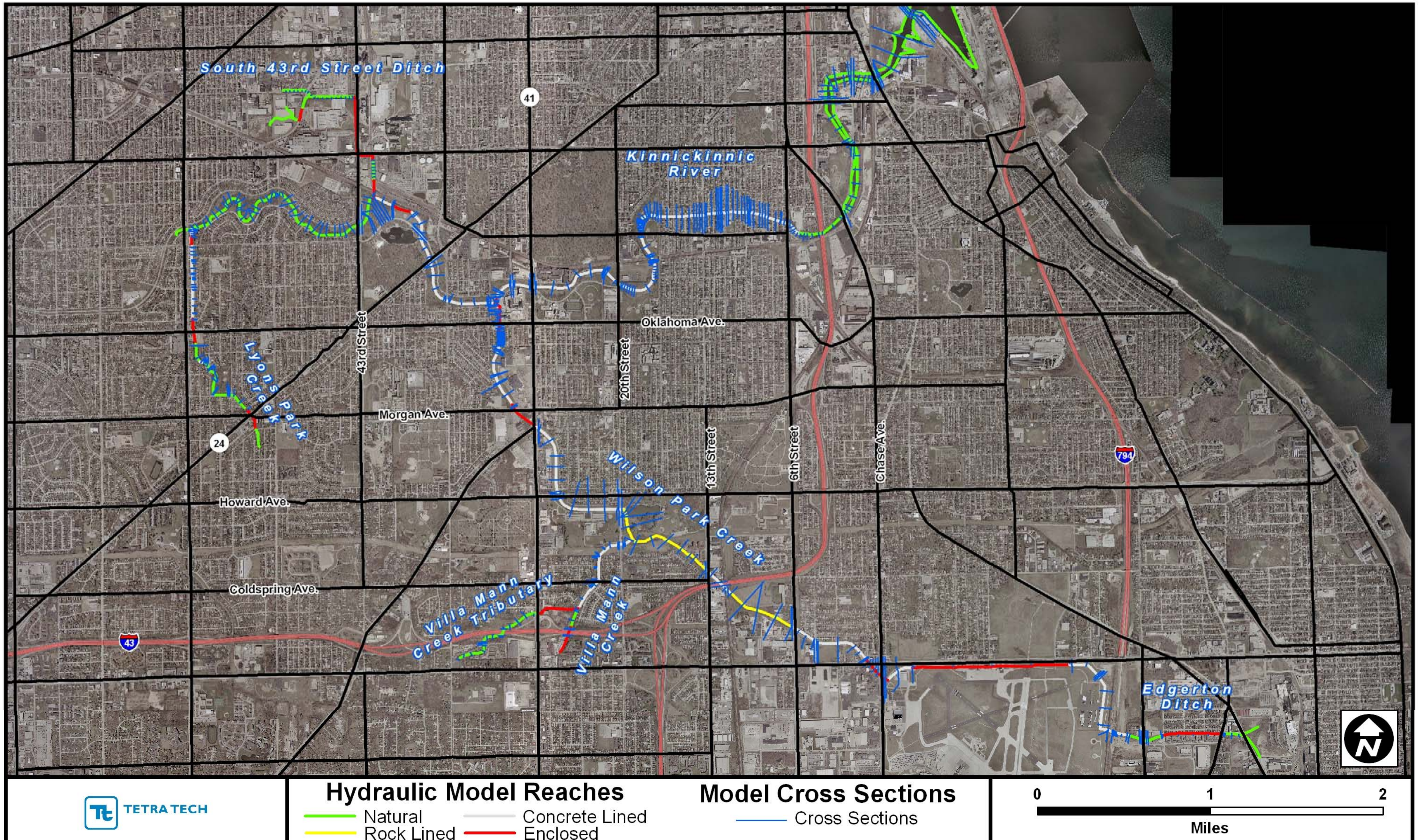


Figure 1. Aerial photograph showing the channel type (natural, rock-lined, concrete-lined, or enclosed) of the hydraulic model reaches.

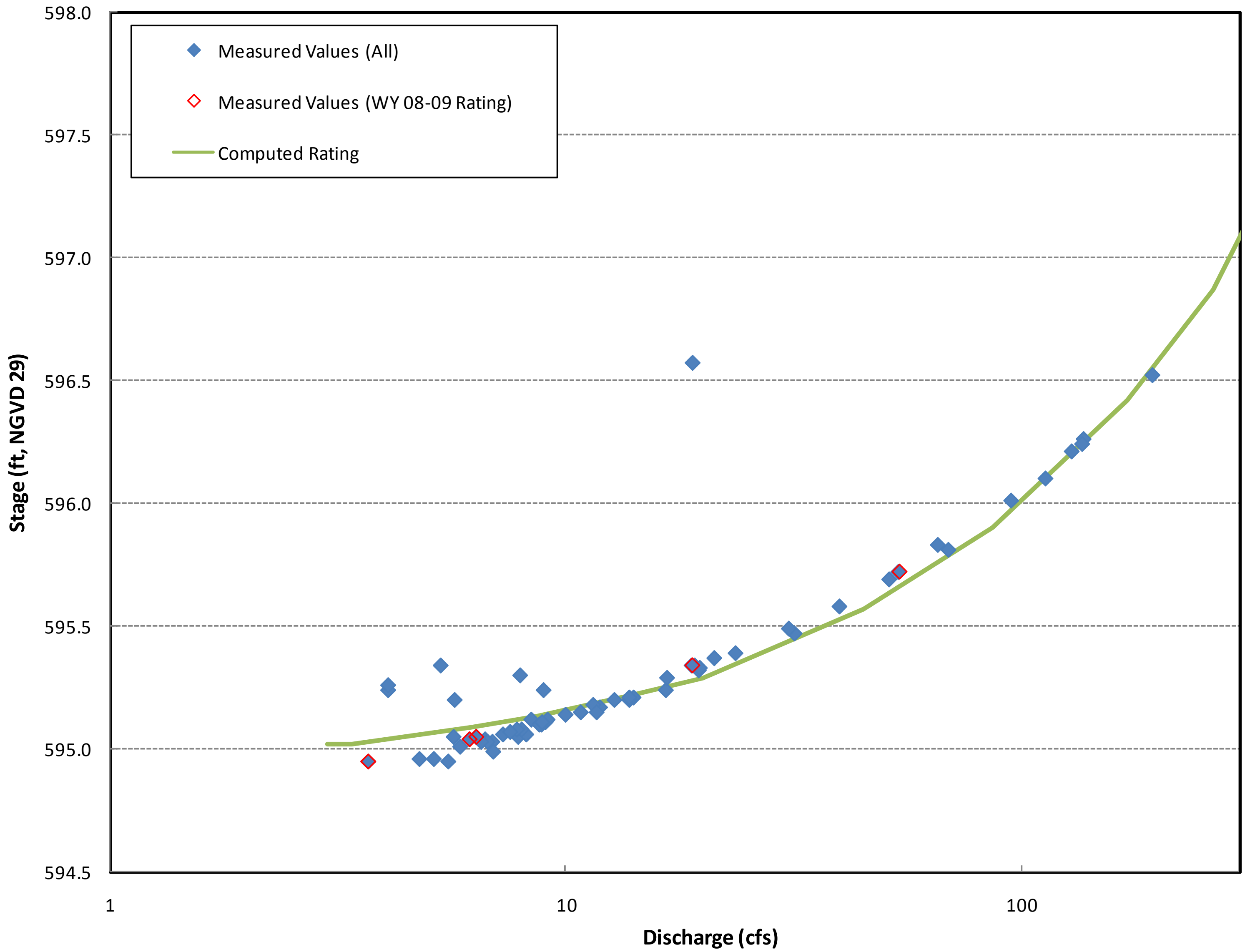


Figure 2. Comparison of measured and predicted water-surface elevations at the Kinnickinnic River at S. 11th Street gage.

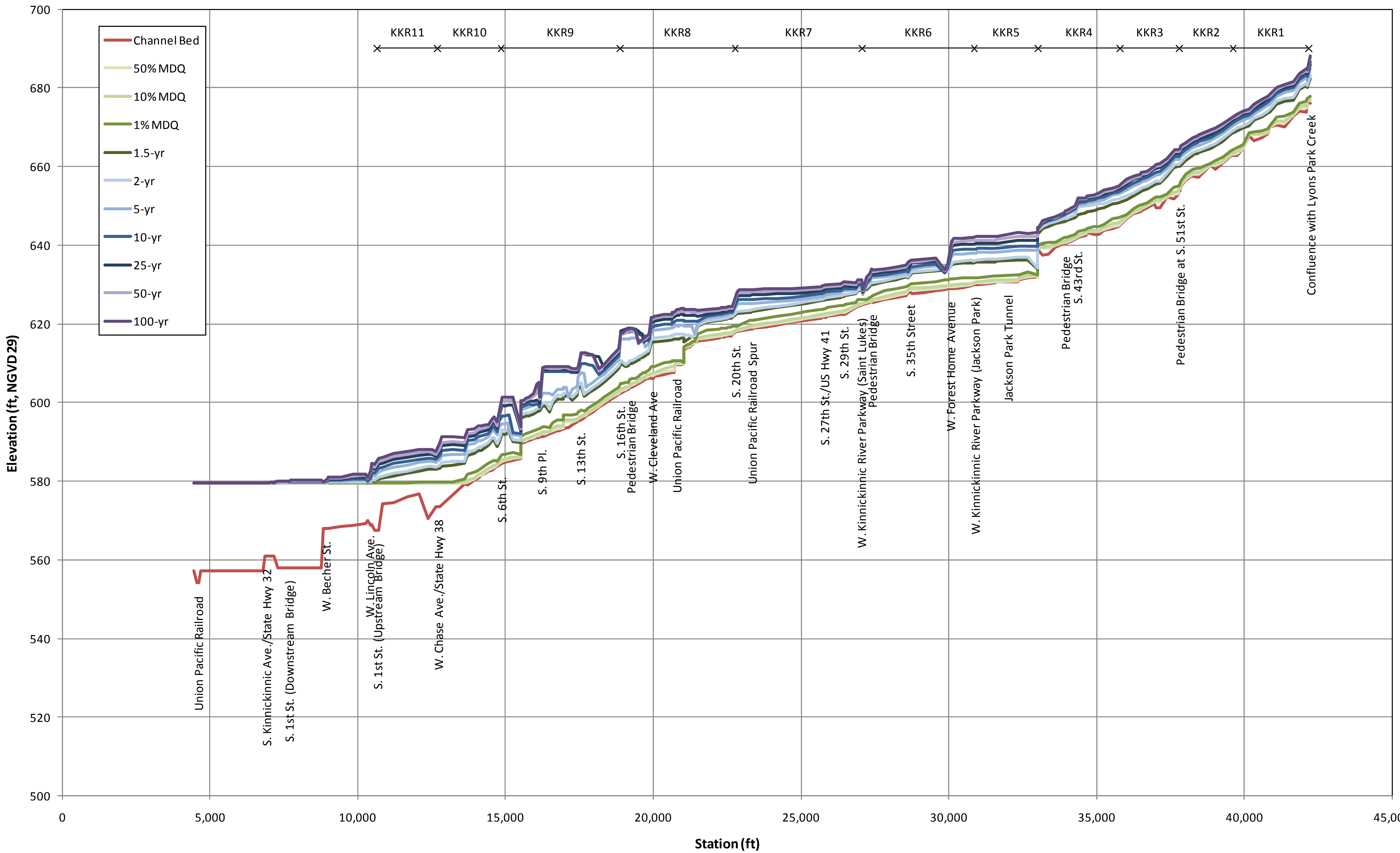


Figure 3. Computed water-surface profiles in the project reach of the Kinnickinnic River for a range of existing conditions flows up to the 100-year peak discharge.

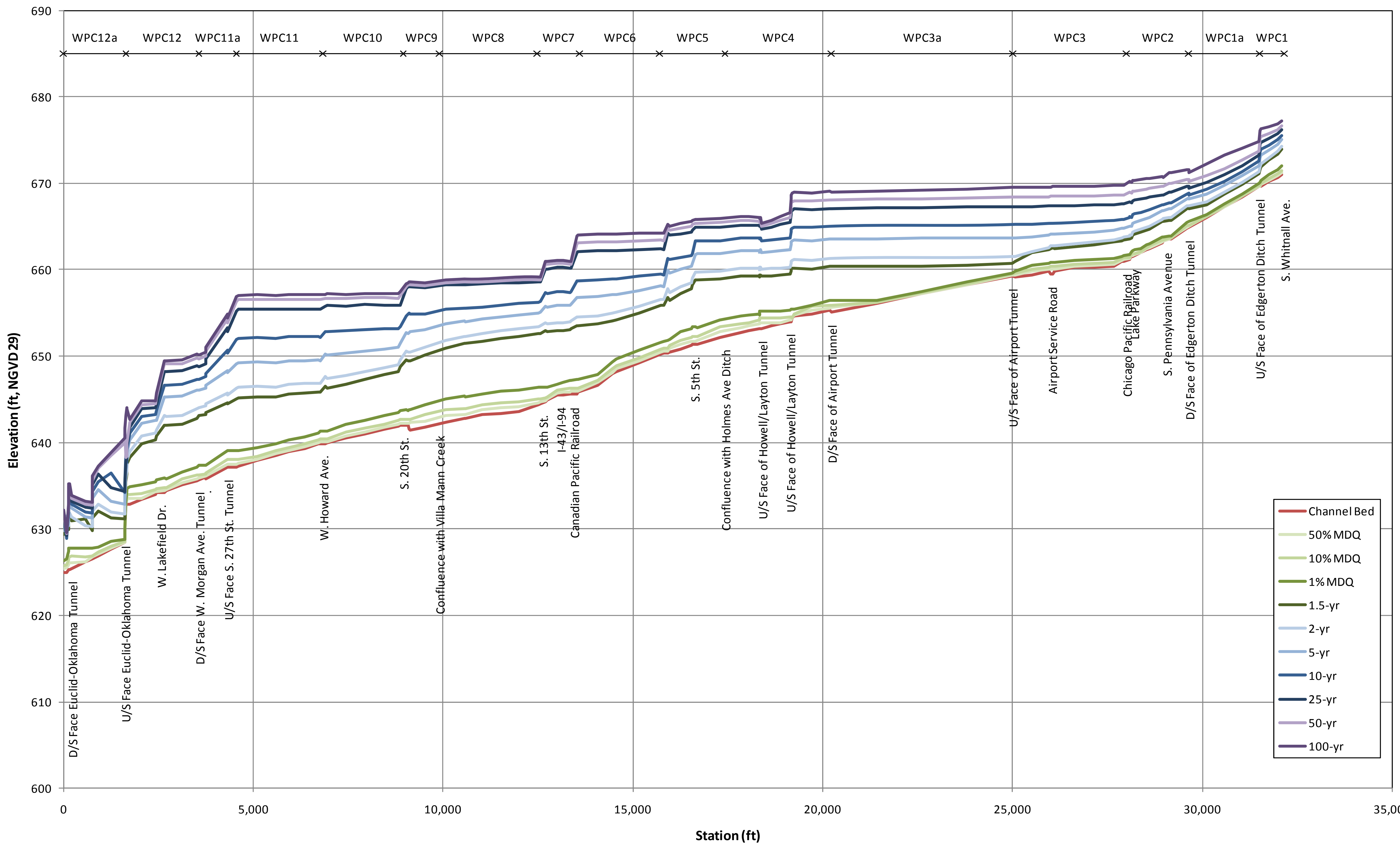


Figure 4. Computed water-surface profiles in the project reach of Wilson Park Creek for a range of existing conditions flows up to the 100-year peak discharge.

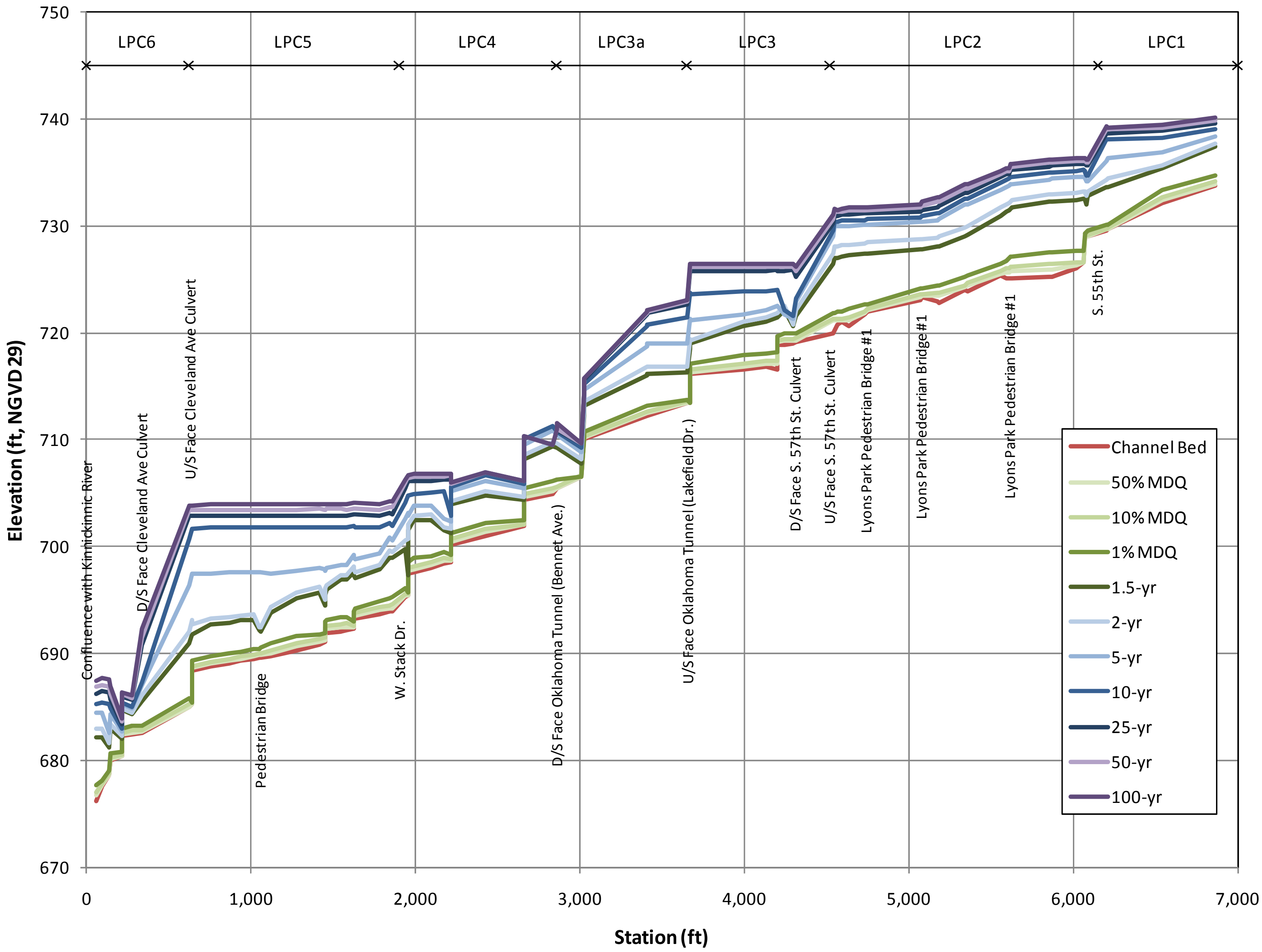


Figure 5. Computed water-surface profiles in the project reach of Lyons Park Creek for a range of existing conditions flows up to the 100-year peak discharge.

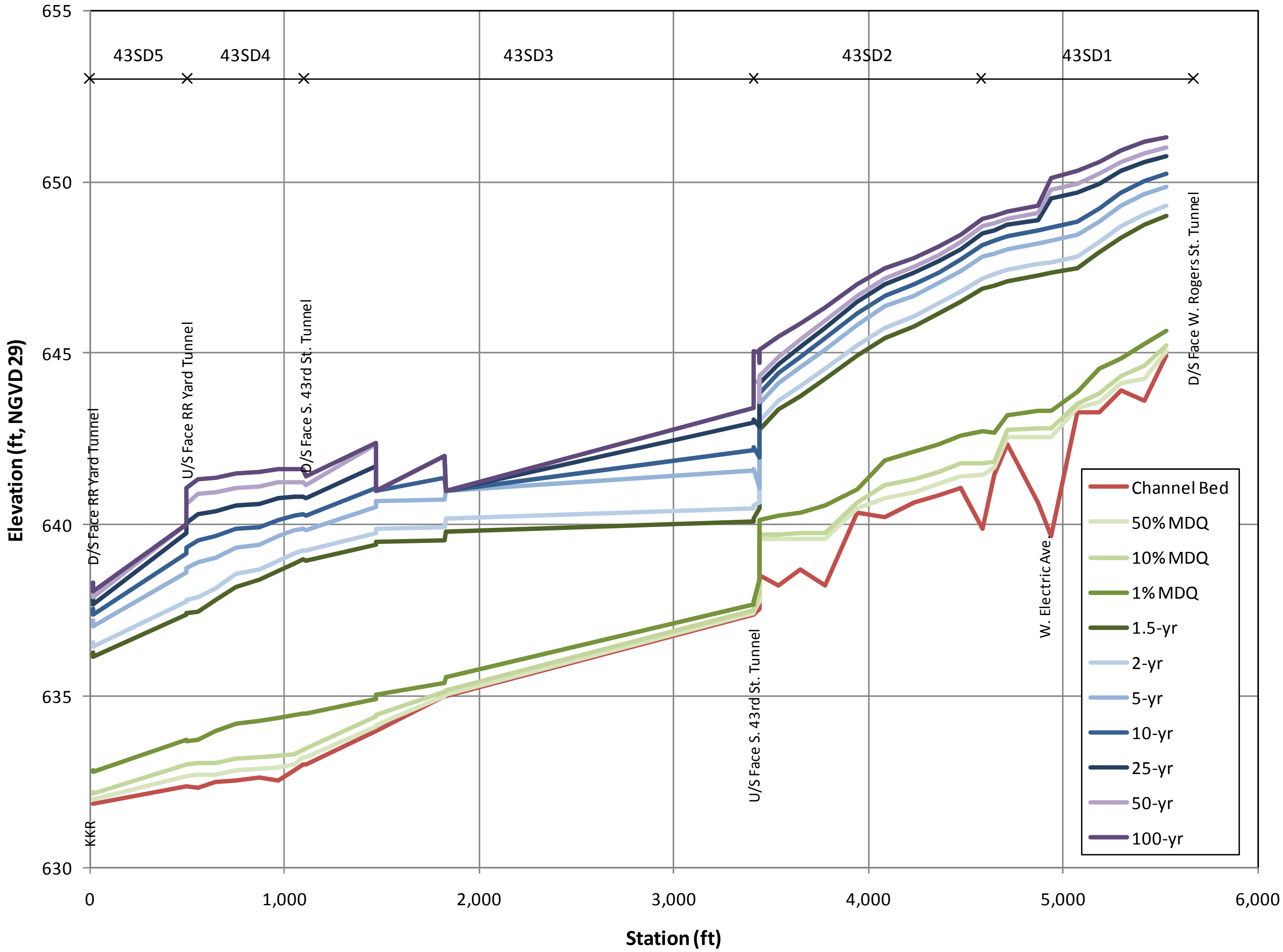


Figure 6. Computed water-surface profiles in the project reach of S. 43rd Street Ditch for a range of existing conditions flows up to the 100-year peak discharge.

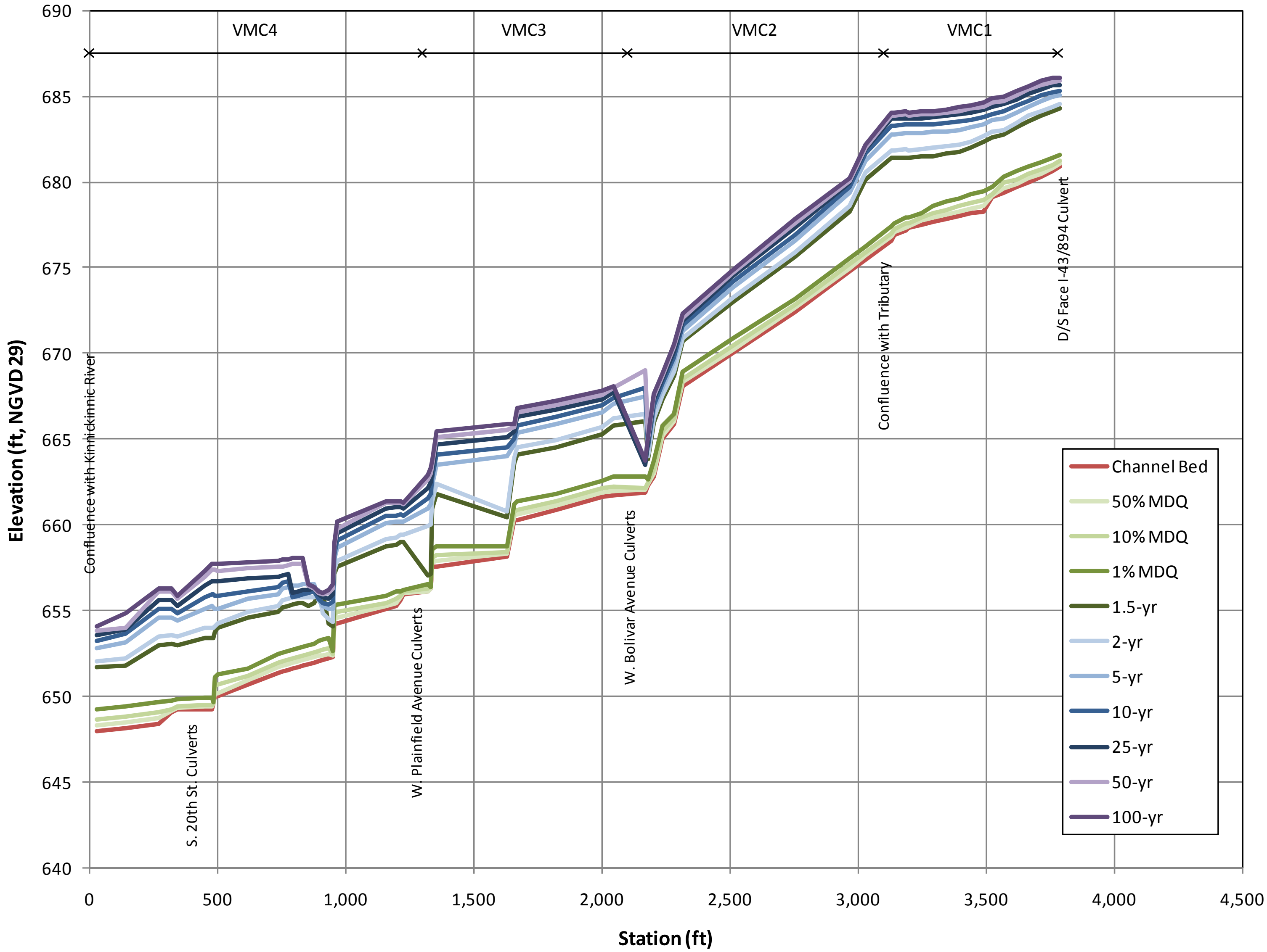


Figure 7. Computed water-surface profiles in the project reach of Villa Mann Creek for a range of existing conditions flows up to the 100-year peak discharge.

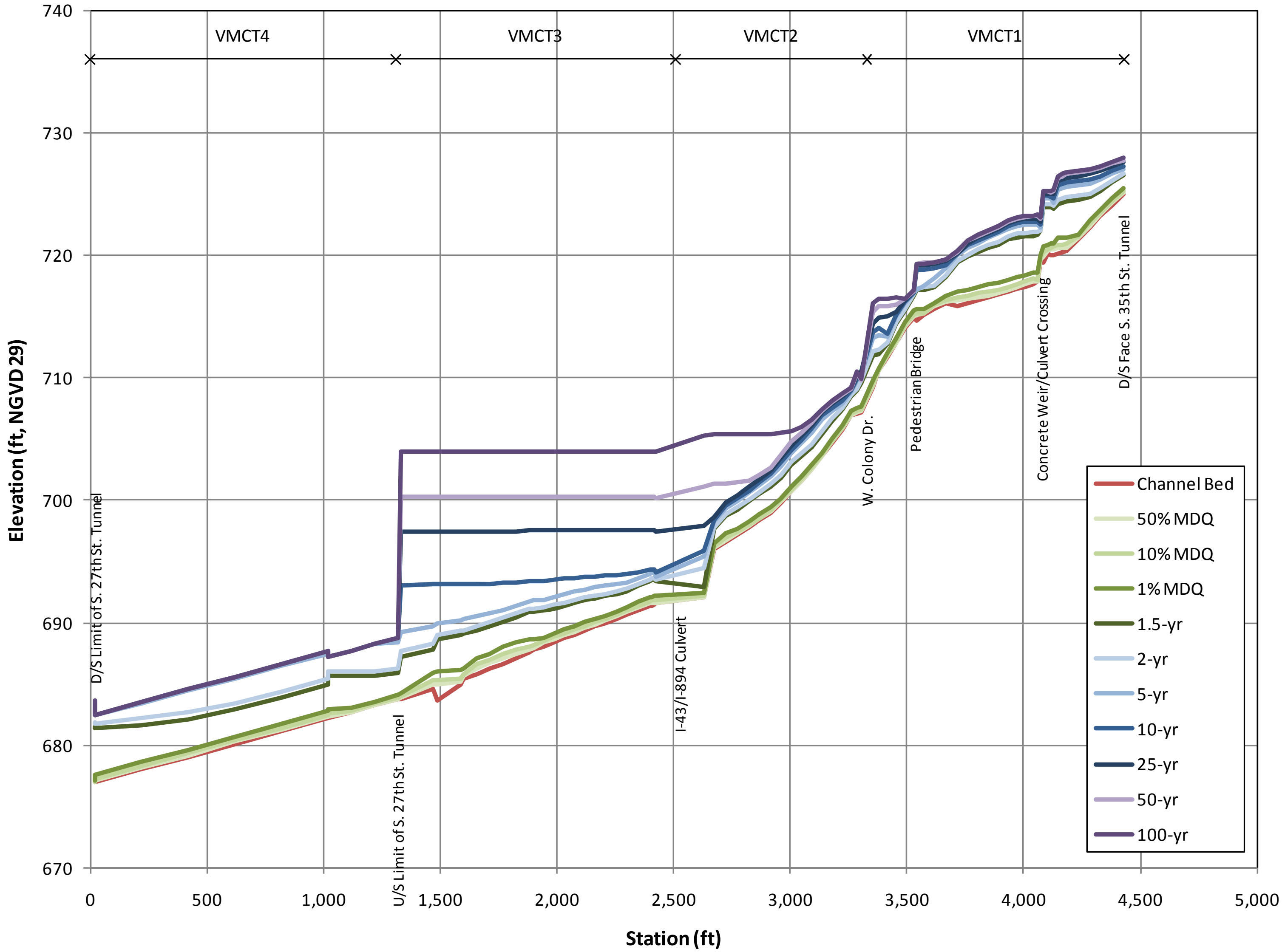


Figure 8. Computed water-surface profiles in the project reach of the tributary to Villa Mann Creek for a range of existing conditions flows up to the 100-year peak discharge.

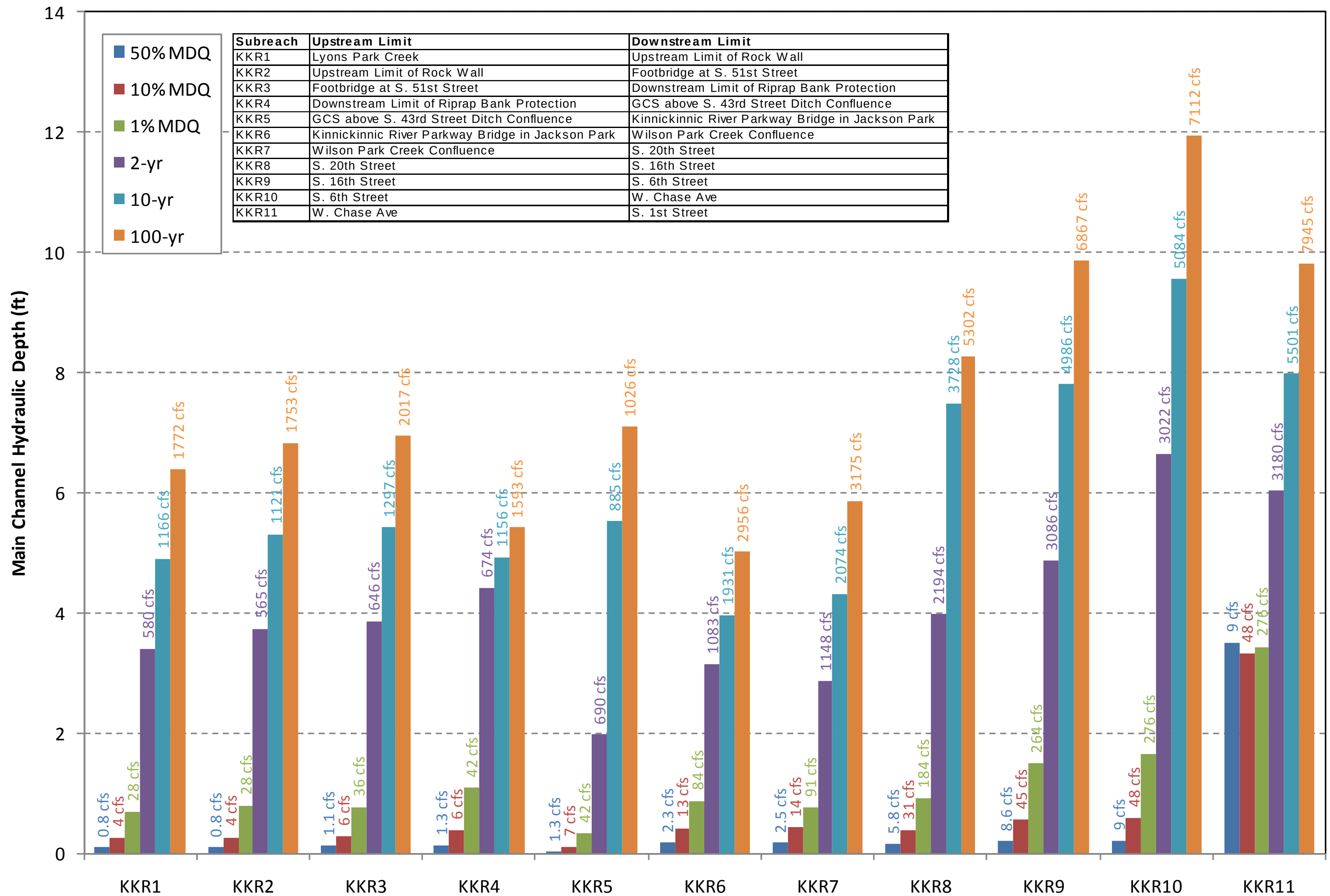
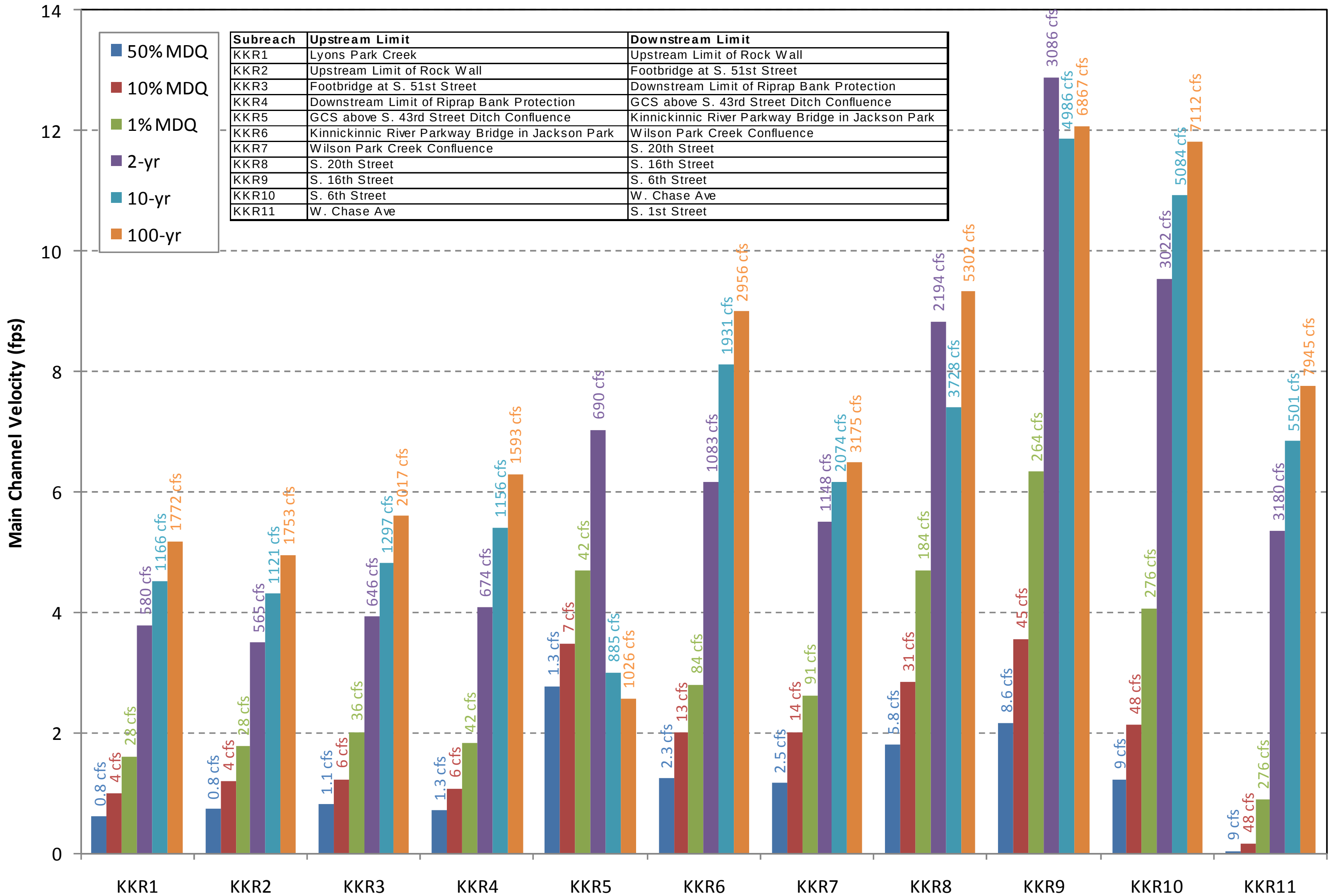


Figure 9. Subreach-averaged main channel hydraulic depth for the subreaches of the Kinnickinnic River at the 50-, 10-, and 1-percent mean daily flow exceedence levels and the 2-, 10-, and 100-year peak flows (existing conditions hydrology).



Subreach	Upstream Limit	Downstream Limit
KKR1	Lyons Park Creek	Upstream Limit of Rock Wall
KKR2	Upstream Limit of Rock Wall	Footbridge at S. 51st Street
KKR3	Footbridge at S. 51st Street	Downstream Limit of Riprap Bank Protection
KKR4	Downstream Limit of Riprap Bank Protection	GCS above S. 43rd Street Ditch Confluence
KKR5	GCS above S. 43rd Street Ditch Confluence	Kinnickinnic River Parkway Bridge in Jackson Park
KKR6	Kinnickinnic River Parkway Bridge in Jackson Park	Wilson Park Creek Confluence
KKR7	Wilson Park Creek Confluence	S. 20th Street
KKR8	S. 20th Street	S. 16th Street
KKR9	S. 16th Street	S. 6th Street
KKR10	S. 6th Street	W. Chase Ave
KKR11	W. Chase Ave	S. 1st Street

Figure 10. Subreach-averaged main channel velocity for the subreaches of the Kinnickinnic River at the 50-, 10-, and 1-percent mean daily flow exceedence levels and the 2-, 10-, and 100-year peak flows (existing conditions hydrology).

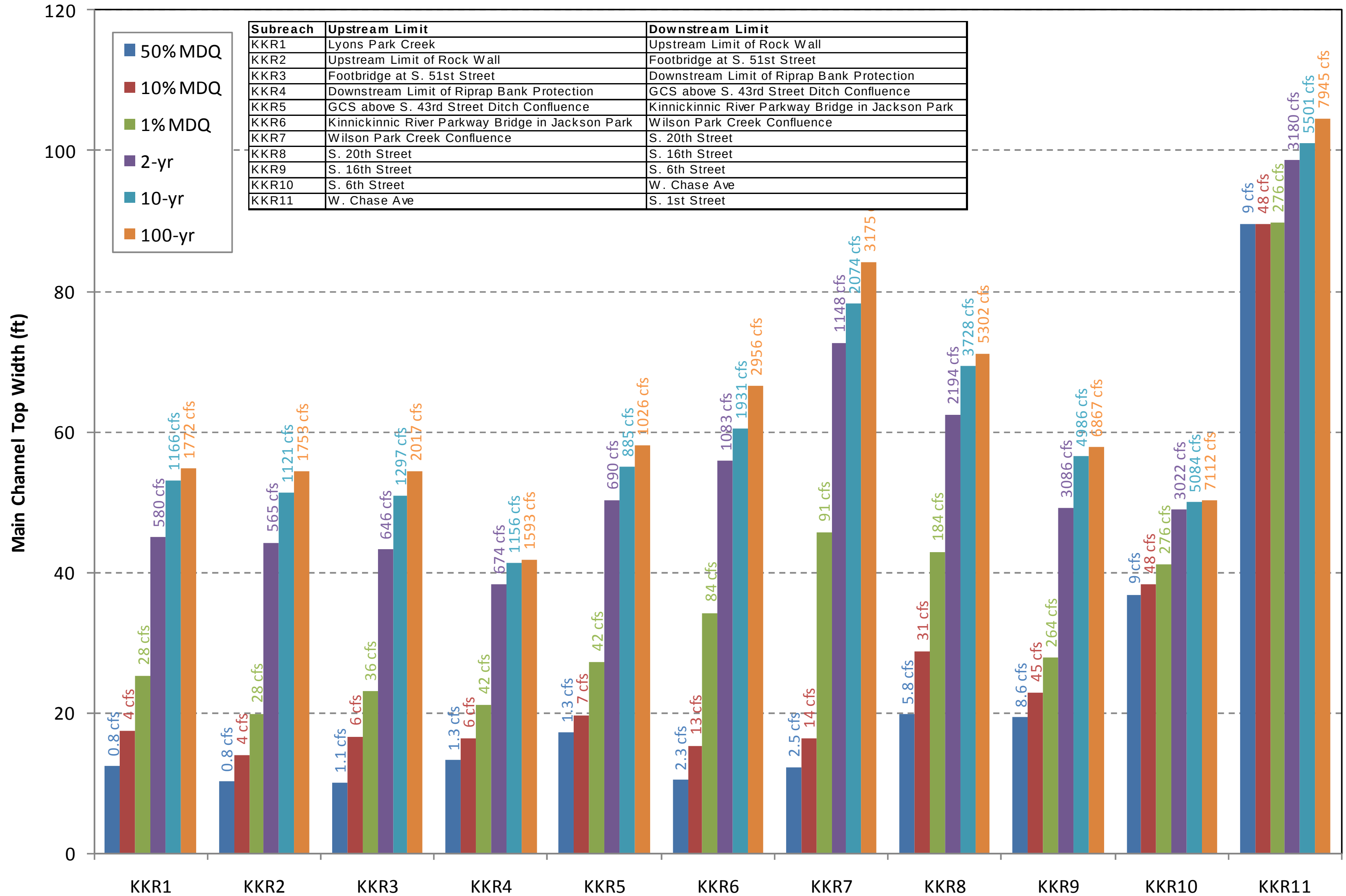
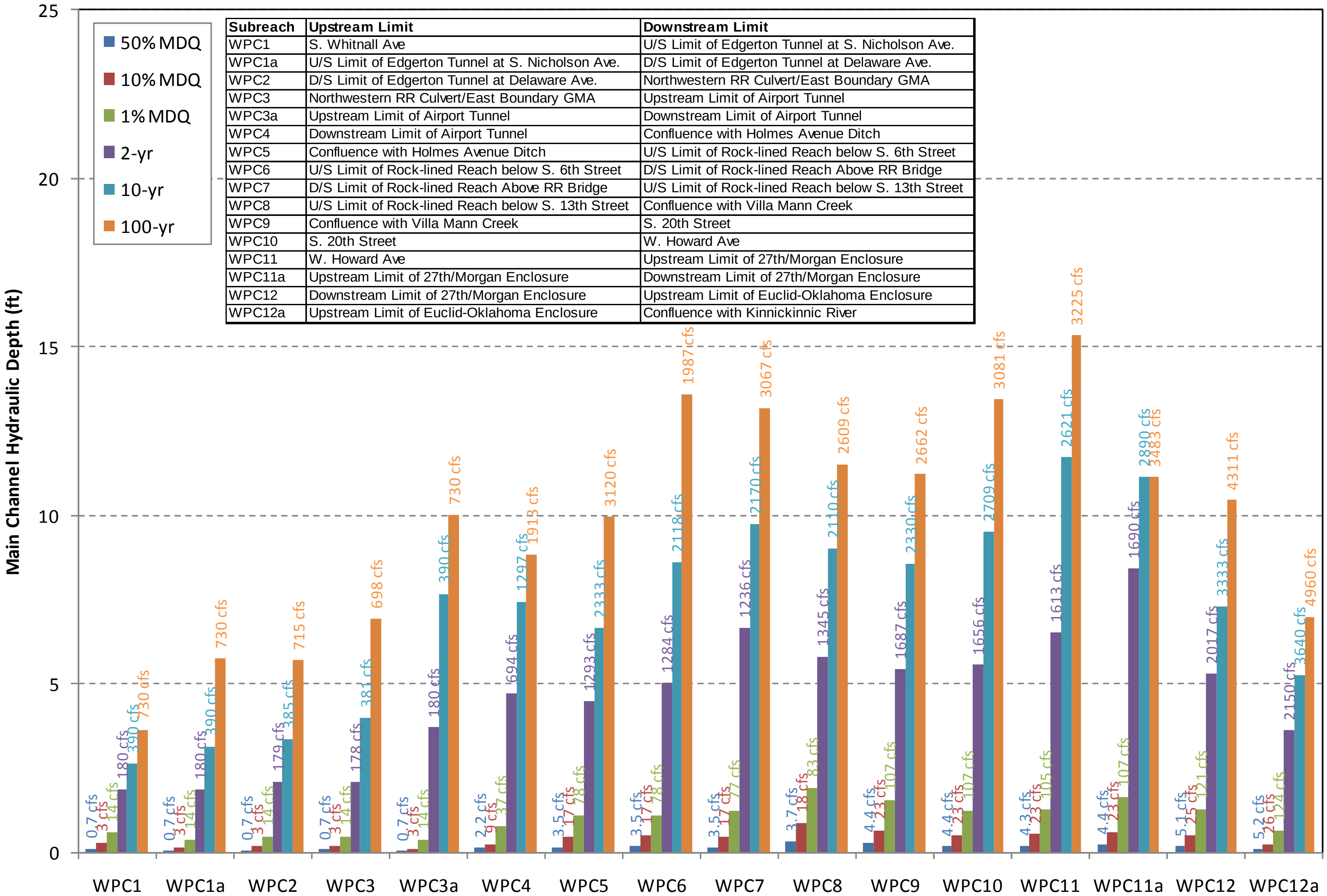
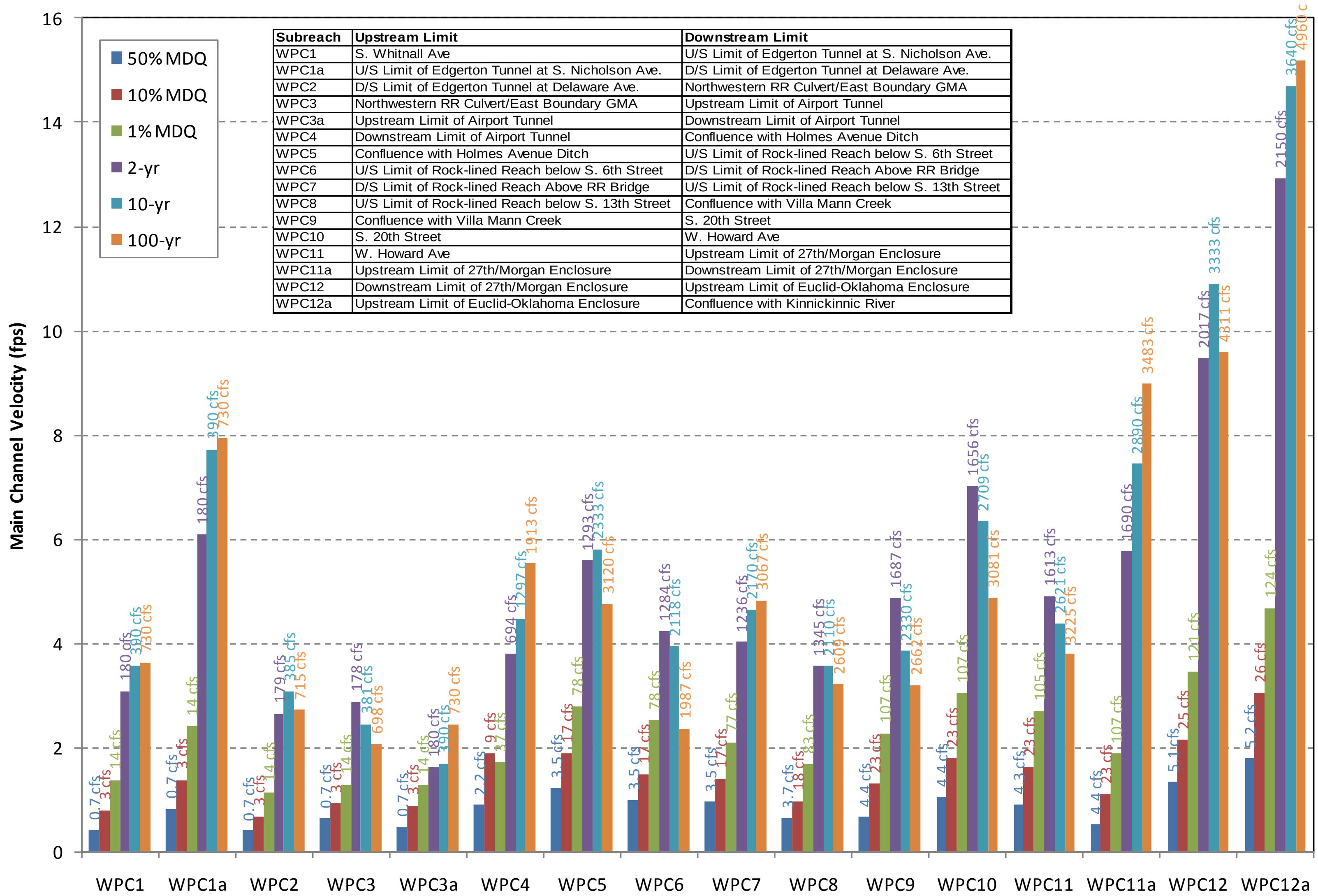


Figure 11. Subreach-averaged main channel topwidth for the subreaches of the Kinnickinnic River at the 50-, 10-, and 1-percent mean daily flow exceedence levels and the 2-, 10-, and 100-year peak flows (existing conditions hydrology).



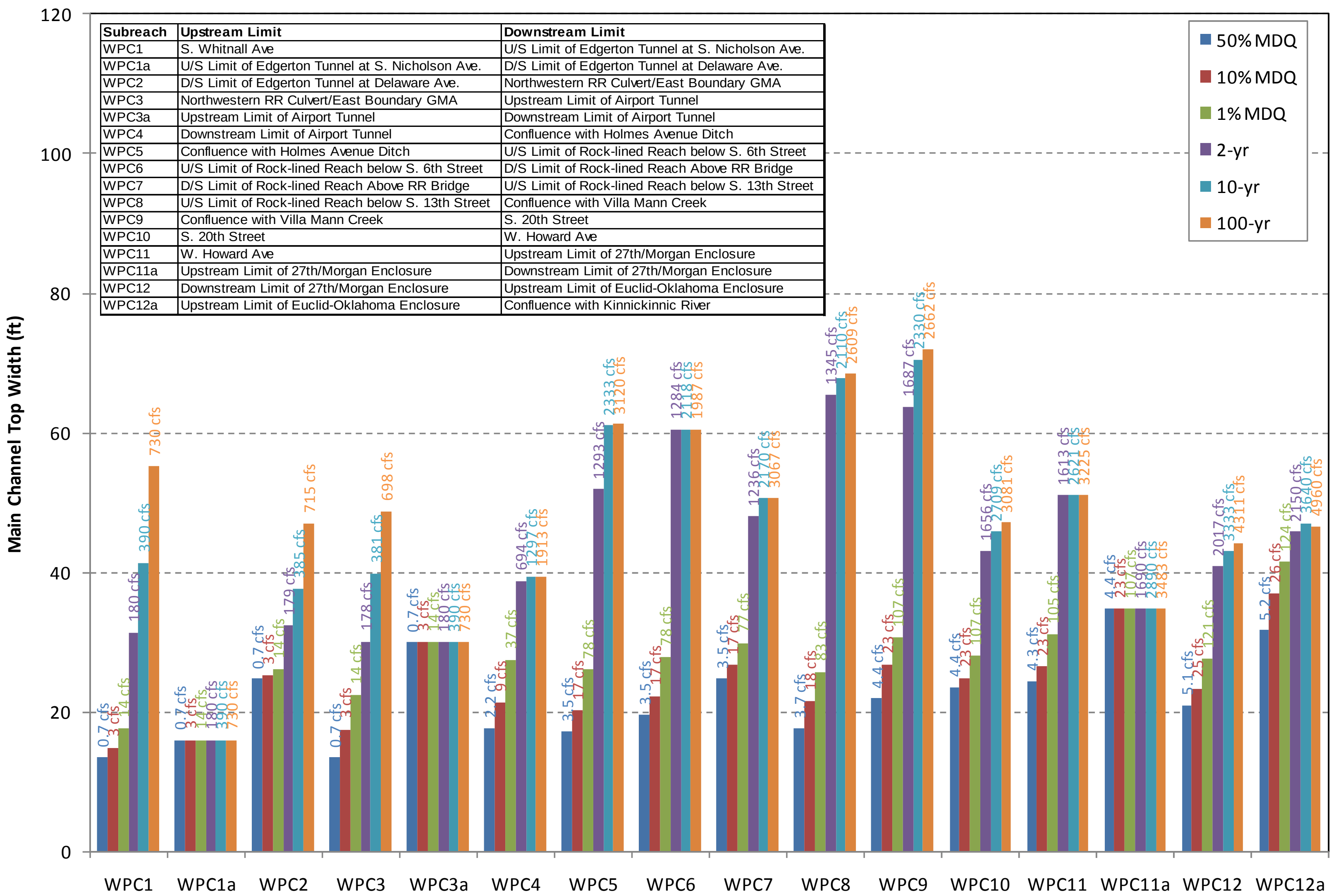
Subreach	Upstream Limit	Downstream Limit
WPC1	S. Whitnall Ave	U/S Limit of Edgerton Tunnel at S. Nicholson Ave.
WPC1a	U/S Limit of Edgerton Tunnel at S. Nicholson Ave.	D/S Limit of Edgerton Tunnel at Delaware Ave.
WPC2	D/S Limit of Edgerton Tunnel at Delaware Ave.	Northwestern RR Culvert/East Boundary GMA
WPC3	Northwestern RR Culvert/East Boundary GMA	Upstream Limit of Airport Tunnel
WPC3a	Upstream Limit of Airport Tunnel	Downstream Limit of Airport Tunnel
WPC4	Downstream Limit of Airport Tunnel	Confluence with Holmes Avenue Ditch
WPC5	Confluence with Holmes Avenue Ditch	U/S Limit of Rock-lined Reach below S. 6th Street
WPC6	U/S Limit of Rock-lined Reach below S. 6th Street	D/S Limit of Rock-lined Reach Above RR Bridge
WPC7	D/S Limit of Rock-lined Reach Above RR Bridge	U/S Limit of Rock-lined Reach below S. 13th Street
WPC8	U/S Limit of Rock-lined Reach below S. 13th Street	Confluence with Villa Mann Creek
WPC9	Confluence with Villa Mann Creek	S. 20th Street
WPC10	S. 20th Street	W. Howard Ave
WPC11	W. Howard Ave	Upstream Limit of 27th/Morgan Enclosure
WPC11a	Upstream Limit of 27th/Morgan Enclosure	Downstream Limit of 27th/Morgan Enclosure
WPC12	Downstream Limit of 27th/Morgan Enclosure	Upstream Limit of Euclid-Oklahoma Enclosure
WPC12a	Upstream Limit of Euclid-Oklahoma Enclosure	Confluence with Kinnickinnic River

Figure 12. Subreach-averaged main channel hydraulic depth for the subreaches of Wilson Park Creek at the 50-, 10-, and 1-percent mean daily flow exceedence levels and the 2-, 10-, and 100-year peak flows (existing conditions hydrology).



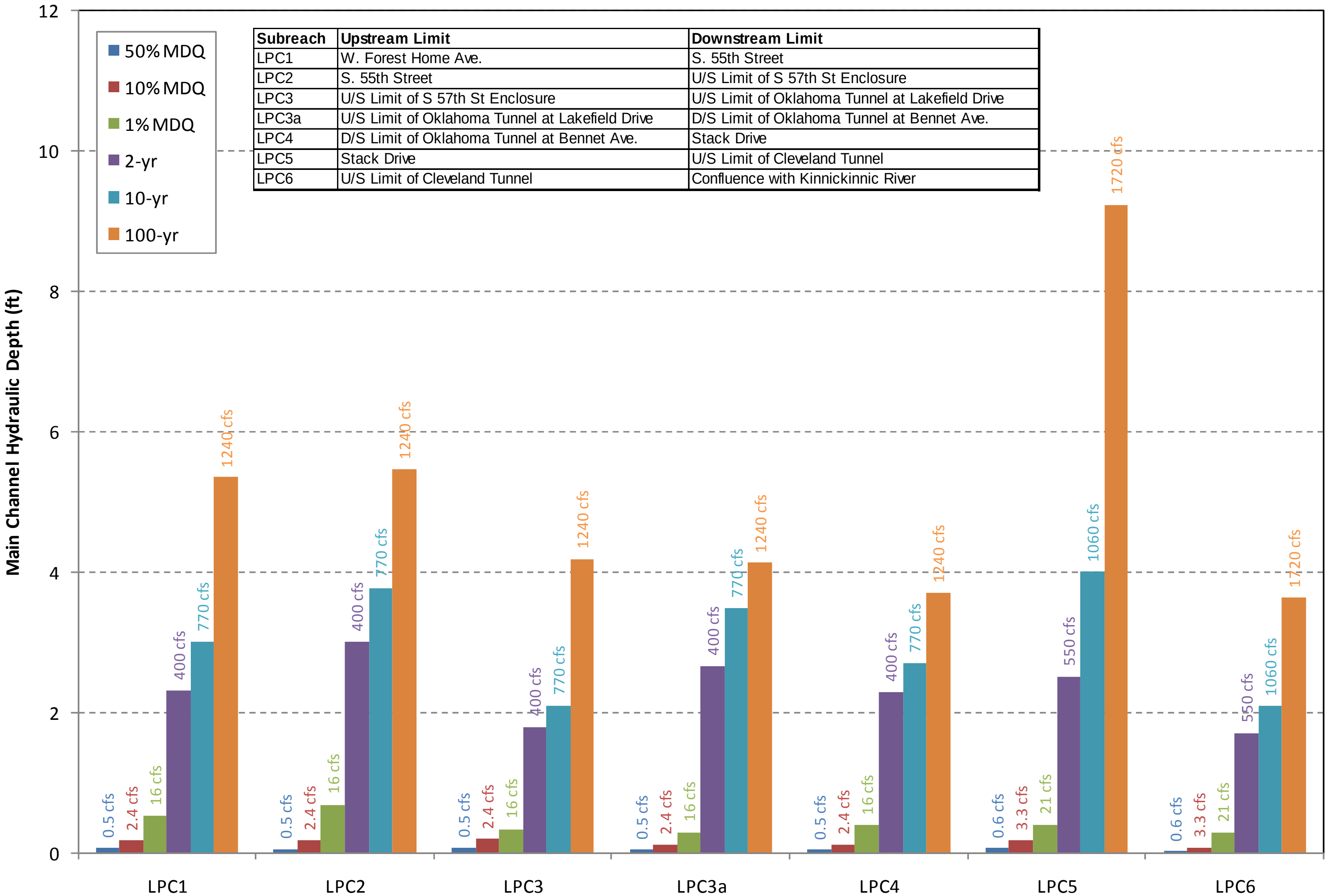
Subreach	Upstream Limit	Downstream Limit
WPC1	S. Whitnall Ave	U/S Limit of Edgerton Tunnel at S. Nicholson Ave.
WPC1a	U/S Limit of Edgerton Tunnel at S. Nicholson Ave.	D/S Limit of Edgerton Tunnel at Delaware Ave.
WPC2	D/S Limit of Edgerton Tunnel at Delaware Ave.	Northwestern RR Culvert/East Boundary GMA
WPC3	Northwestern RR Culvert/East Boundary GMA	Upstream Limit of Airport Tunnel
WPC3a	Upstream Limit of Airport Tunnel	Downstream Limit of Airport Tunnel
WPC4	Downstream Limit of Airport Tunnel	Confluence with Holmes Avenue Ditch
WPC5	Confluence with Holmes Avenue Ditch	U/S Limit of Rock-lined Reach below S. 6th Street
WPC6	U/S Limit of Rock-lined Reach below S. 6th Street	D/S Limit of Rock-lined Reach Above RR Bridge
WPC7	D/S Limit of Rock-lined Reach Above RR Bridge	U/S Limit of Rock-lined Reach below S. 13th Street
WPC8	U/S Limit of Rock-lined Reach below S. 13th Street	Confluence with Villa Mann Creek
WPC9	Confluence with Villa Mann Creek	S. 20th Street
WPC10	S. 20th Street	W. Howard Ave
WPC11	W. Howard Ave	Upstream Limit of 27th/Morgan Enclosure
WPC11a	Upstream Limit of 27th/Morgan Enclosure	Downstream Limit of 27th/Morgan Enclosure
WPC12	Downstream Limit of 27th/Morgan Enclosure	Upstream Limit of Euclid-Oklahoma Enclosure
WPC12a	Upstream Limit of Euclid-Oklahoma Enclosure	Confluence with Kinnickinnic River

Figure 13. Subreach-averaged main channel velocity for the subreaches of Wilson Park Creek at the 50-, 10-, and 1-percent mean daily flow exceedence levels and the 2-, 10-, and 100-year peak flows (existing conditions hydrology).



Subreach	Upstream Limit	Downstream Limit
WPC1	S. Whitnall Ave	U/S Limit of Edgerton Tunnel at S. Nicholson Ave.
WPC1a	U/S Limit of Edgerton Tunnel at S. Nicholson Ave.	D/S Limit of Edgerton Tunnel at Delaware Ave.
WPC2	D/S Limit of Edgerton Tunnel at Delaware Ave.	Northwestern RR Culvert/East Boundary GMA
WPC3	Northwestern RR Culvert/East Boundary GMA	Upstream Limit of Airport Tunnel
WPC3a	Upstream Limit of Airport Tunnel	Downstream Limit of Airport Tunnel
WPC4	Downstream Limit of Airport Tunnel	Confluence with Holmes Avenue Ditch
WPC5	Confluence with Holmes Avenue Ditch	U/S Limit of Rock-lined Reach below S. 6th Street
WPC6	U/S Limit of Rock-lined Reach below S. 6th Street	D/S Limit of Rock-lined Reach Above RR Bridge
WPC7	D/S Limit of Rock-lined Reach Above RR Bridge	U/S Limit of Rock-lined Reach below S. 13th Street
WPC8	U/S Limit of Rock-lined Reach below S. 13th Street	Confluence with Villa Mann Creek
WPC9	Confluence with Villa Mann Creek	S. 20th Street
WPC10	S. 20th Street	W. Howard Ave
WPC11	W. Howard Ave	Upstream Limit of 27th/Morgan Enclosure
WPC11a	Upstream Limit of 27th/Morgan Enclosure	Downstream Limit of 27th/Morgan Enclosure
WPC12	Downstream Limit of 27th/Morgan Enclosure	Upstream Limit of Euclid-Oklahoma Enclosure
WPC12a	Upstream Limit of Euclid-Oklahoma Enclosure	Confluence with Kinnickinnic River

Figure 14. Subreach-averaged main channel topwidth for the subreaches of Wilson Park Creek at the 50-, 10-, and 1-percent mean daily flow exceedence levels and the 2-, 10-, and 100-year peak flows (existing conditions hydrology).



Subreach	Upstream Limit	Downstream Limit
LPC1	W. Forest Home Ave.	S. 55th Street
LPC2	S. 55th Street	U/S Limit of S 57th St Enclosure
LPC3	U/S Limit of S 57th St Enclosure	U/S Limit of Oklahoma Tunnel at Lakefield Drive
LPC3a	U/S Limit of Oklahoma Tunnel at Lakefield Drive	D/S Limit of Oklahoma Tunnel at Bennet Ave.
LPC4	D/S Limit of Oklahoma Tunnel at Bennet Ave.	Stack Drive
LPC5	Stack Drive	U/S Limit of Cleveland Tunnel
LPC6	U/S Limit of Cleveland Tunnel	Confluence with Kinnickinnic River

Figure 15. Subreach-averaged main channel hydraulic depth for the subreaches of Lyons Park Creek at the 50-, 10-, and 1-percent mean daily flow exceedence levels and the 2-, 10-, and 100-year peak flows (existing conditions hydrology).

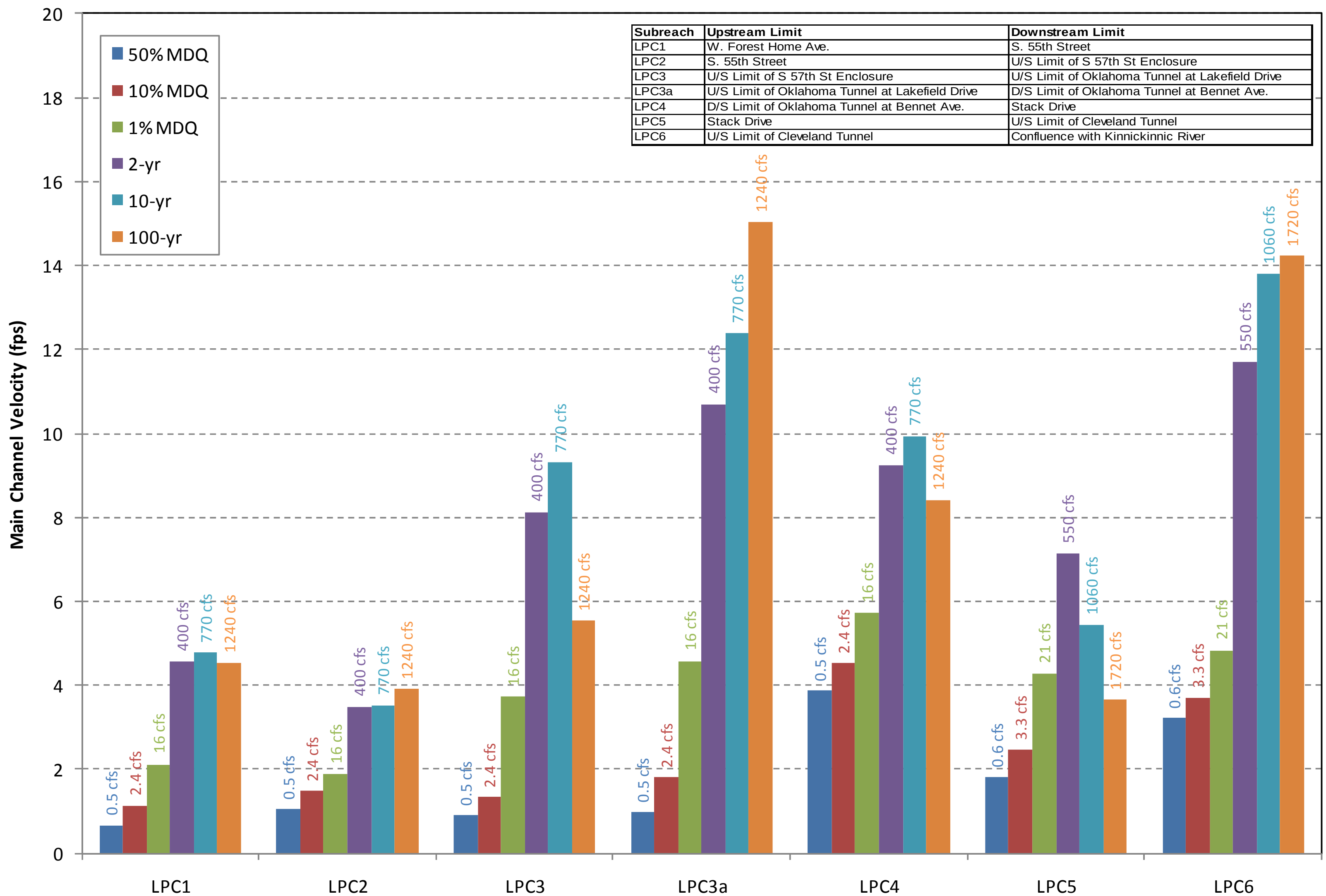


Figure 16. Subreach-averaged main channel velocity for the subreaches of Lyons Park Creek at the 50-, 10-, and 1-percent mean daily flow exceedence levels and the 2-, 10-, and 100-year peak flows (existing conditions hydrology).

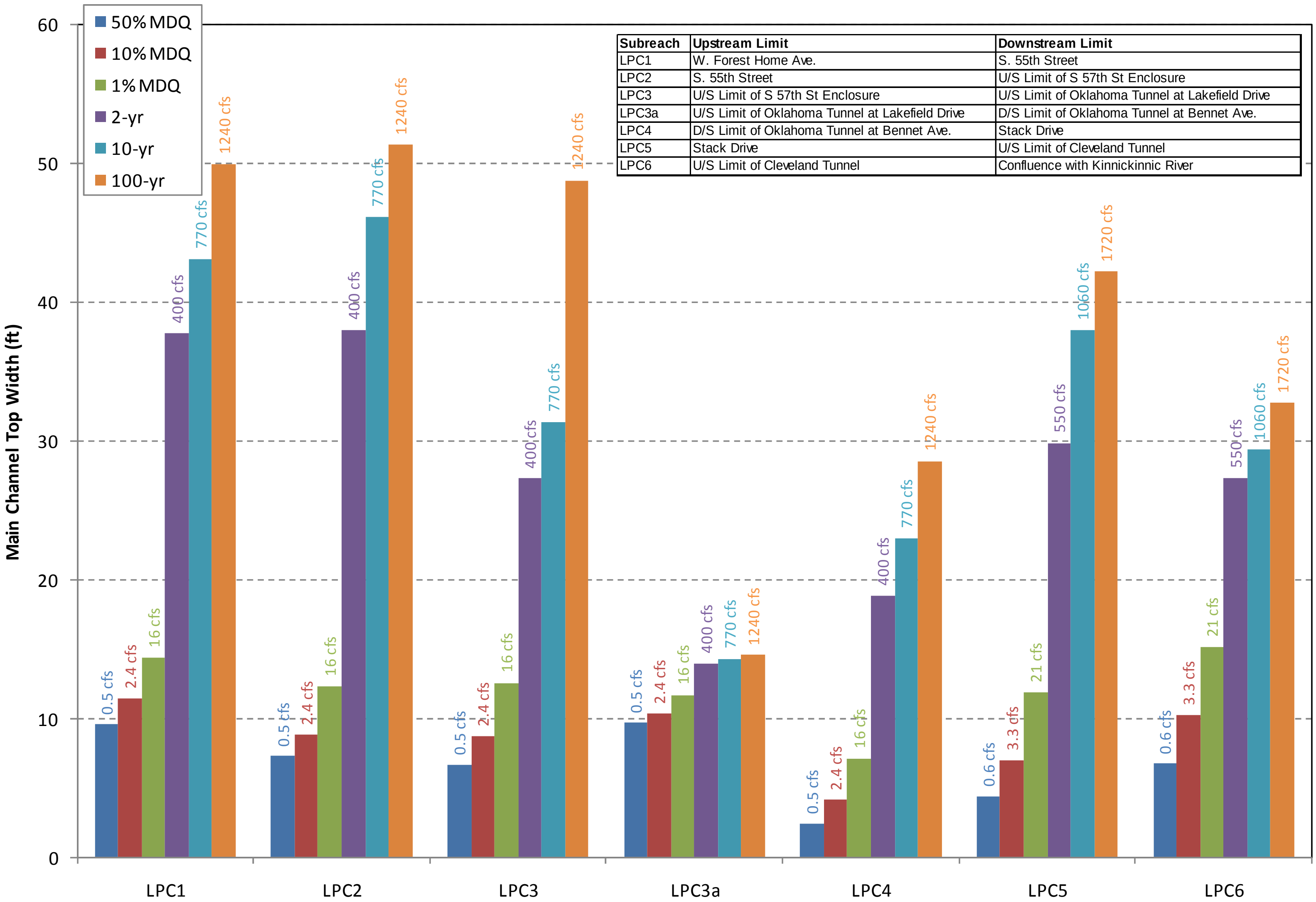
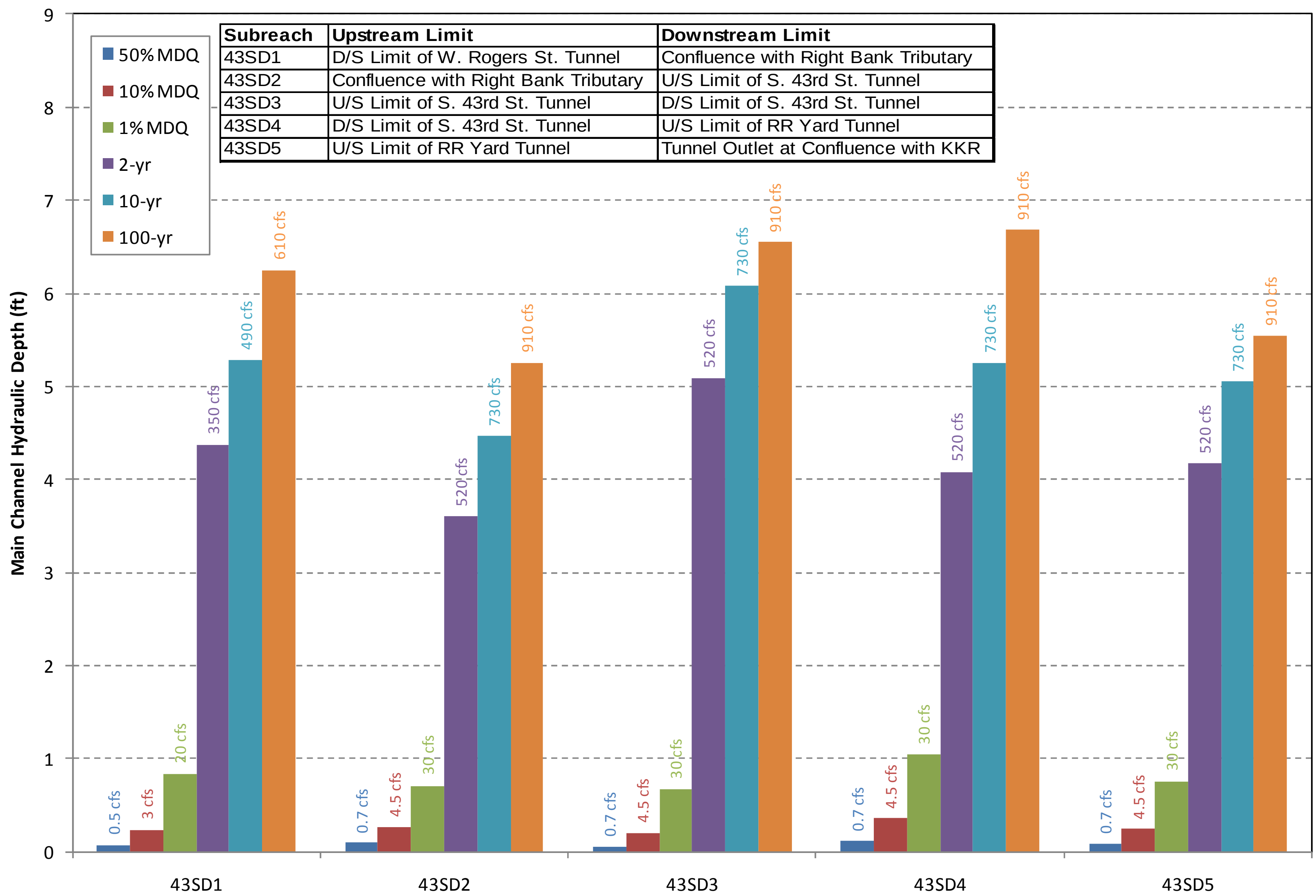
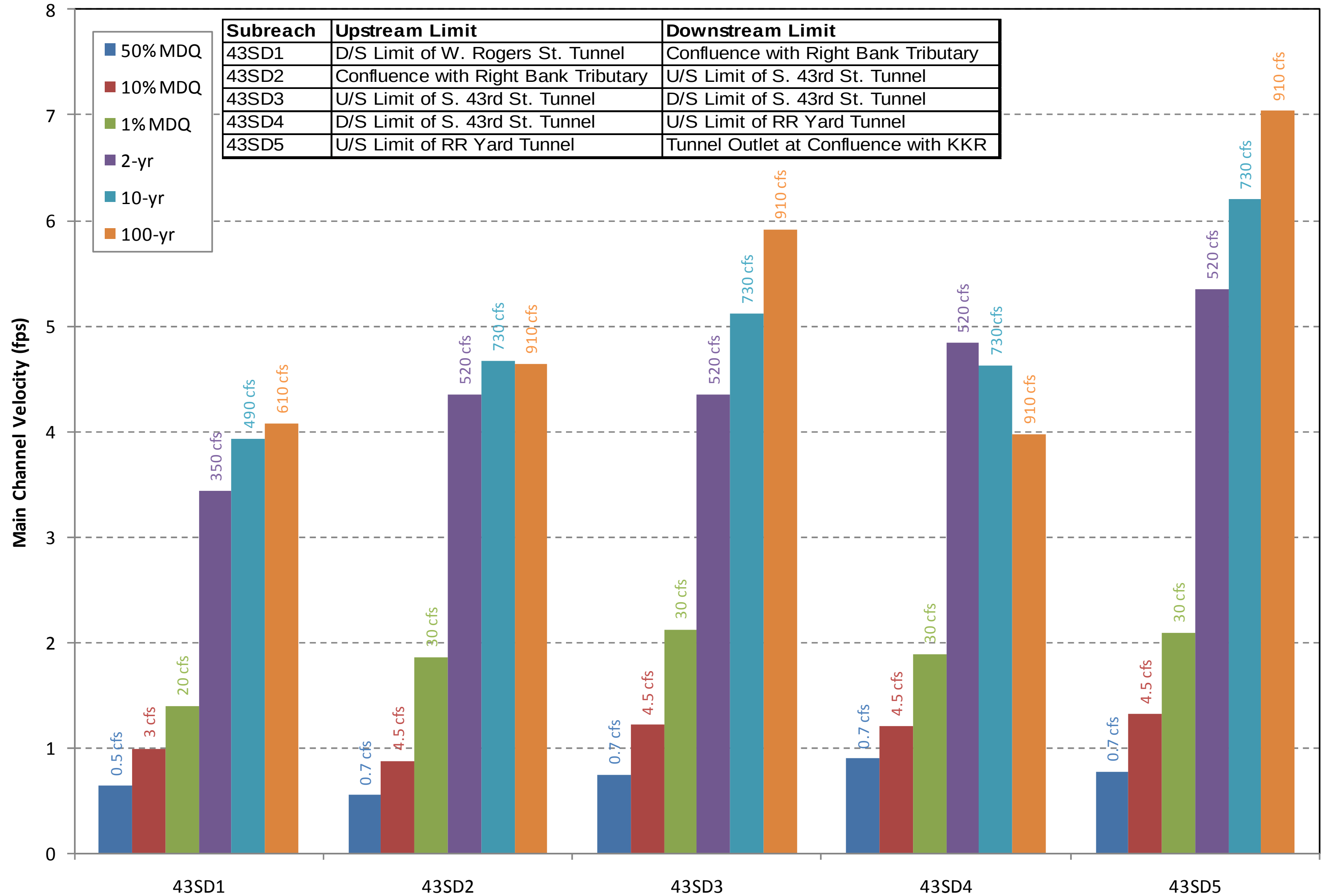


Figure 17. Subreach-averaged main channel topwidth for the subreaches of Lyons Park Creek at the 50-, 10-, and 1-percent mean daily flow exceedence levels and the 2-, 10-, and 100-year peak flows (existing conditions hydrology).



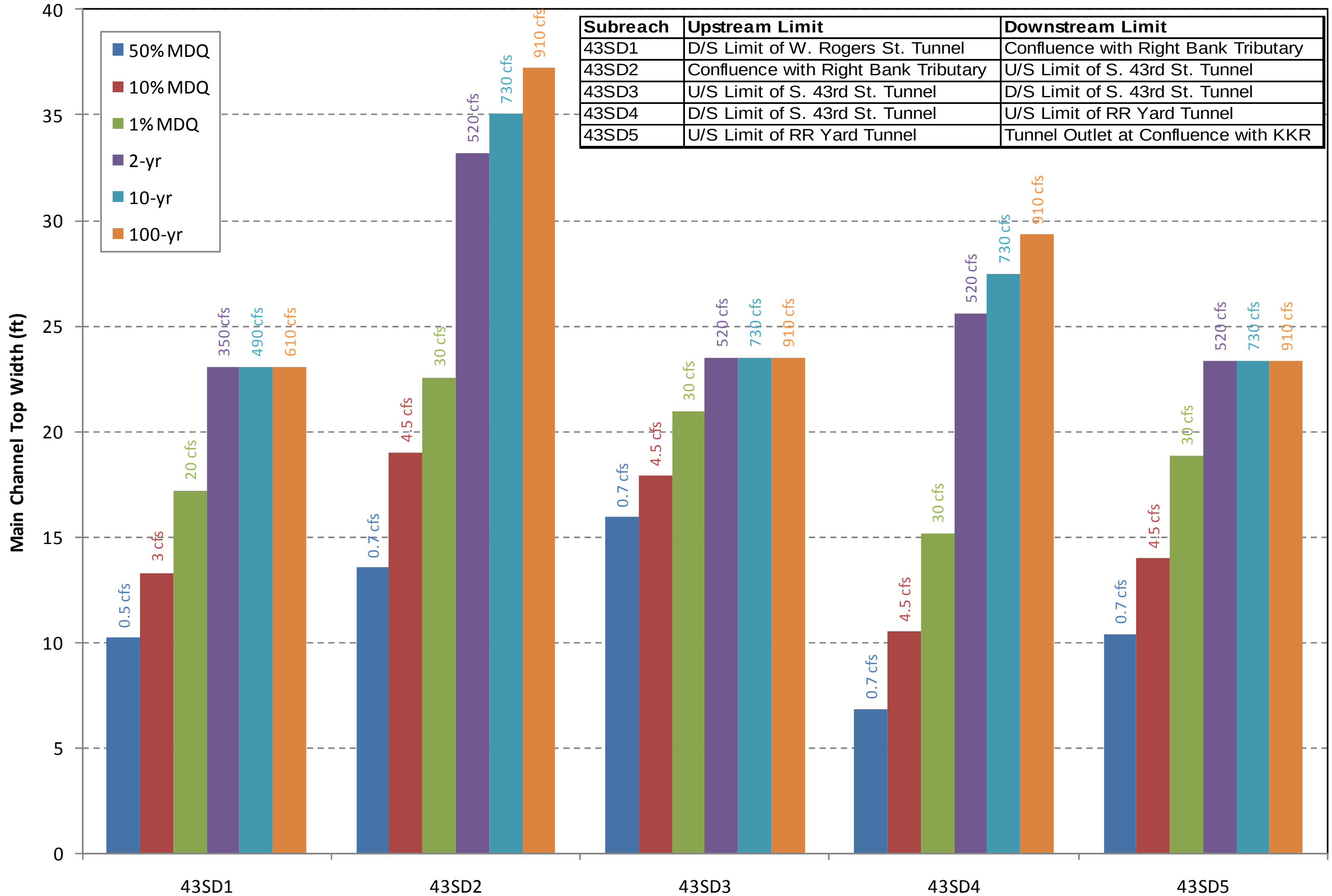
Subreach	Upstream Limit	Downstream Limit
43SD1	D/S Limit of W. Rogers St. Tunnel	Confluence with Right Bank Tributary
43SD2	Confluence with Right Bank Tributary	U/S Limit of S. 43rd St. Tunnel
43SD3	U/S Limit of S. 43rd St. Tunnel	D/S Limit of S. 43rd St. Tunnel
43SD4	D/S Limit of S. 43rd St. Tunnel	U/S Limit of RR Yard Tunnel
43SD5	U/S Limit of RR Yard Tunnel	Tunnel Outlet at Confluence with KKR

Figure 18. Subreach-averaged main channel hydraulic depth for the subreaches of South 43rd Street Ditch at the 50-, 10-, and 1-mean daily flow exceedence levels and the 2-, 10-, and 100-year peak flows (existing conditions hydrology).



Subreach	Upstream Limit	Downstream Limit
43SD1	D/S Limit of W. Rogers St. Tunnel	Confluence with Right Bank Tributary
43SD2	Confluence with Right Bank Tributary	U/S Limit of S. 43rd St. Tunnel
43SD3	U/S Limit of S. 43rd St. Tunnel	D/S Limit of S. 43rd St. Tunnel
43SD4	D/S Limit of S. 43rd St. Tunnel	U/S Limit of RR Yard Tunnel
43SD5	U/S Limit of RR Yard Tunnel	Tunnel Outlet at Confluence with KKR

Figure 19. Subreach-averaged main channel velocity for the subreaches of South 43rd Street Ditch at the 50-, 10-, and 1-percent mean daily flow exceedence levels and the 2-, 10-, and 100-year peak flows (existing conditions hydrology).



Subreach	Upstream Limit	Downstream Limit
43SD1	D/S Limit of W. Rogers St. Tunnel	Confluence with Right Bank Tributary
43SD2	Confluence with Right Bank Tributary	U/S Limit of S. 43rd St. Tunnel
43SD3	U/S Limit of S. 43rd St. Tunnel	D/S Limit of S. 43rd St. Tunnel
43SD4	D/S Limit of S. 43rd St. Tunnel	U/S Limit of RR Yard Tunnel
43SD5	U/S Limit of RR Yard Tunnel	Tunnel Outlet at Confluence with KKR

Figure 20. Subreach-averaged main channel topwidth for the subreaches of South 43rd Street Ditch at the 50-, 10-, and 1-percent mean daily flow exceedence levels and the 2-, 10-, and 100-year peak flows (existing conditions hydrology).

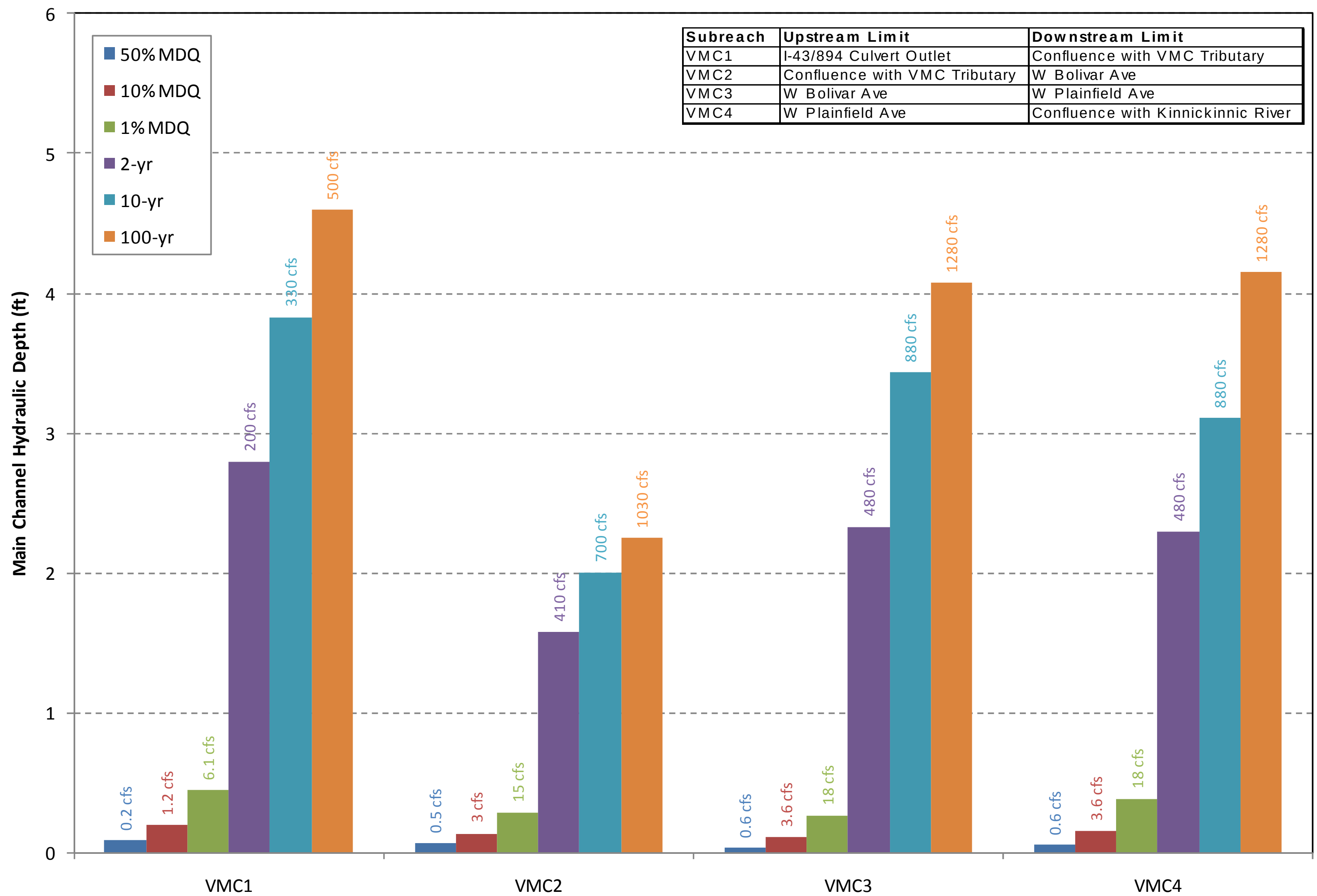


Figure 21. Subreach-averaged main channel hydraulic depth for the subreaches of Villa Mann Creek at the 50-, 10-, and 1-percent mean daily flow exceedence levels and the 2-,10-, and 100-year peak flows (existing conditions hydrology).

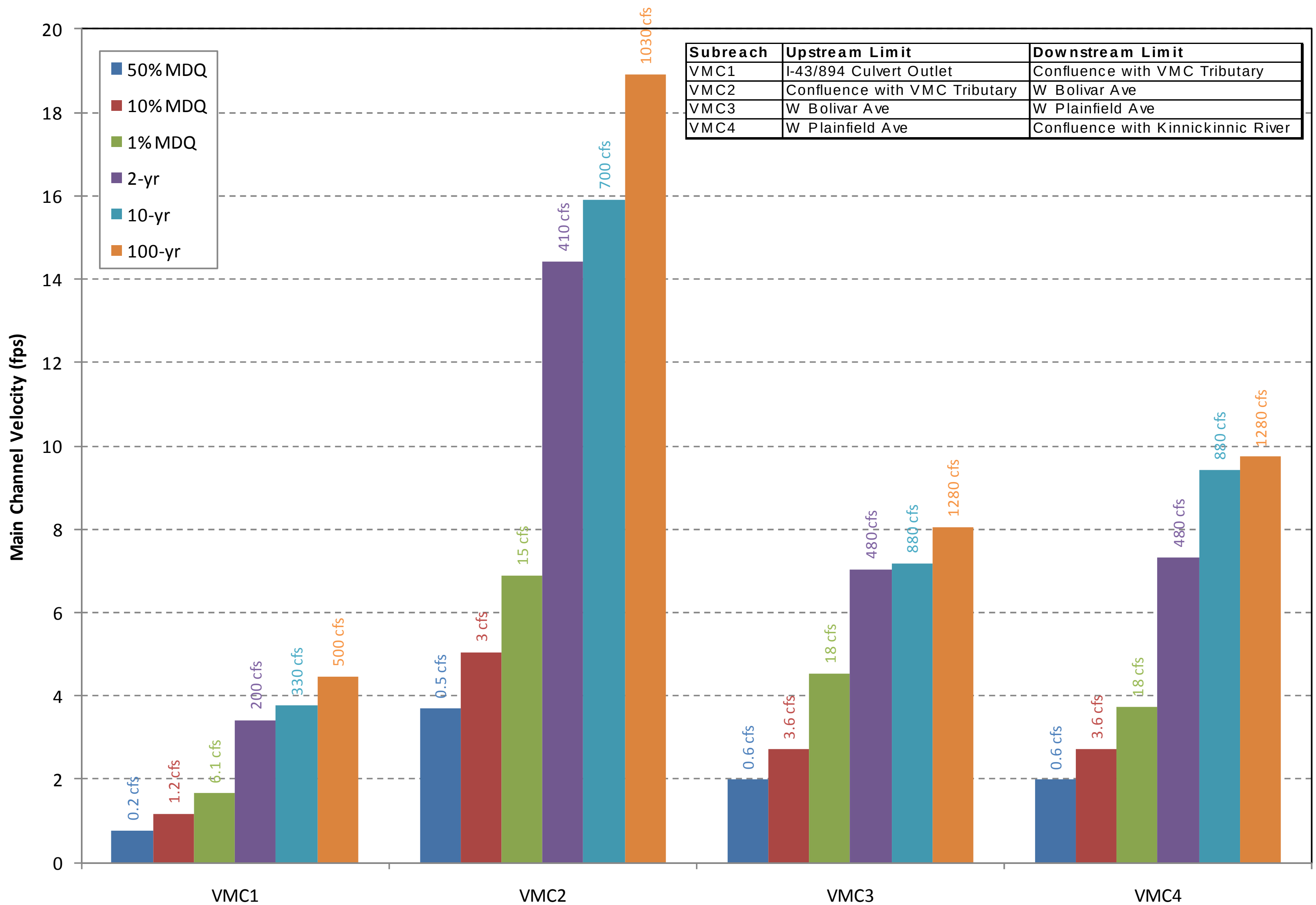


Figure 22. Subreach-averaged main channel velocity for the subreaches of Villa Mann Creek at the 50-, 10-, and 1-percent mean daily flow exceedence levels and the 2-, 10-, and 100-year peak flows (existing conditions hydrology).

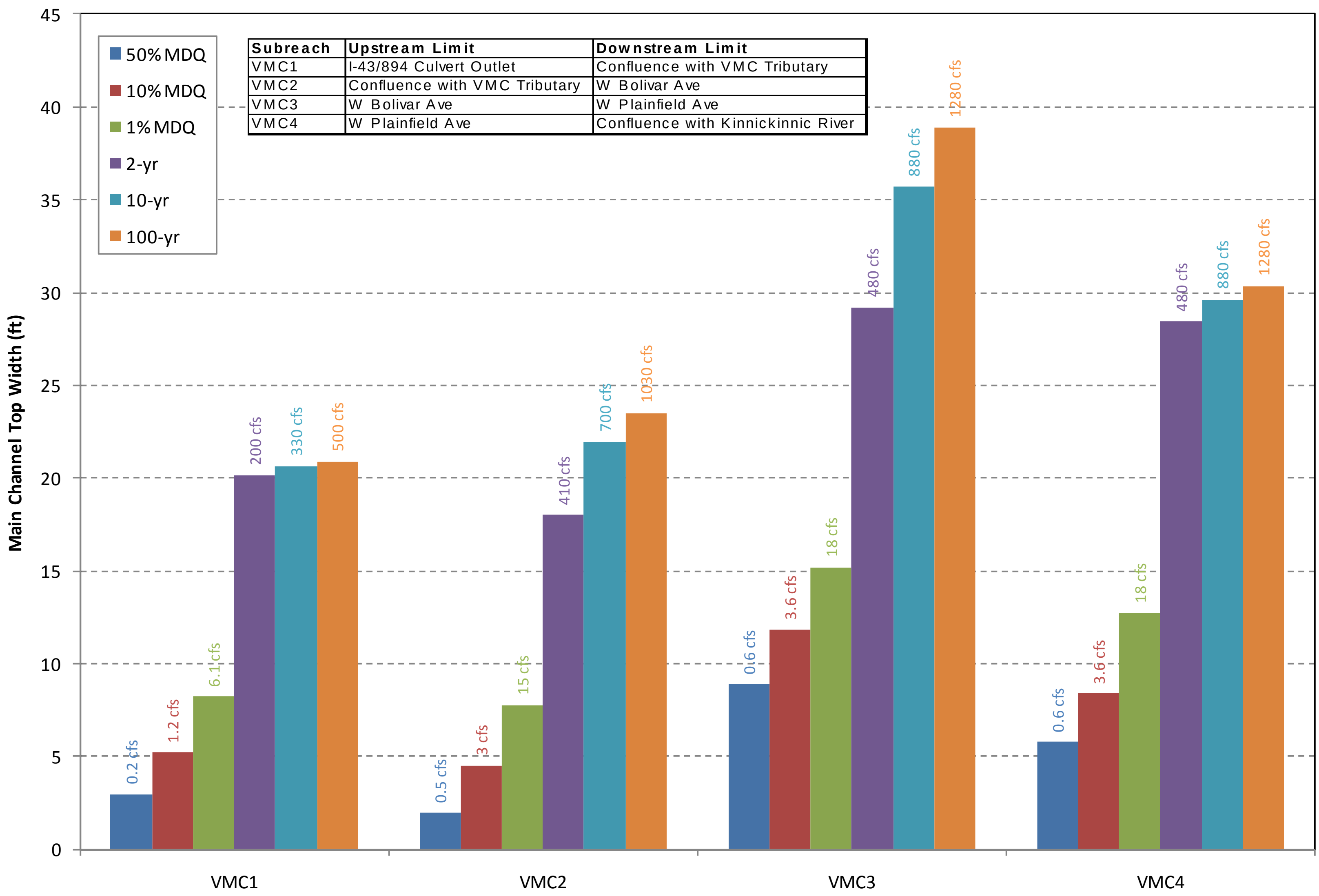
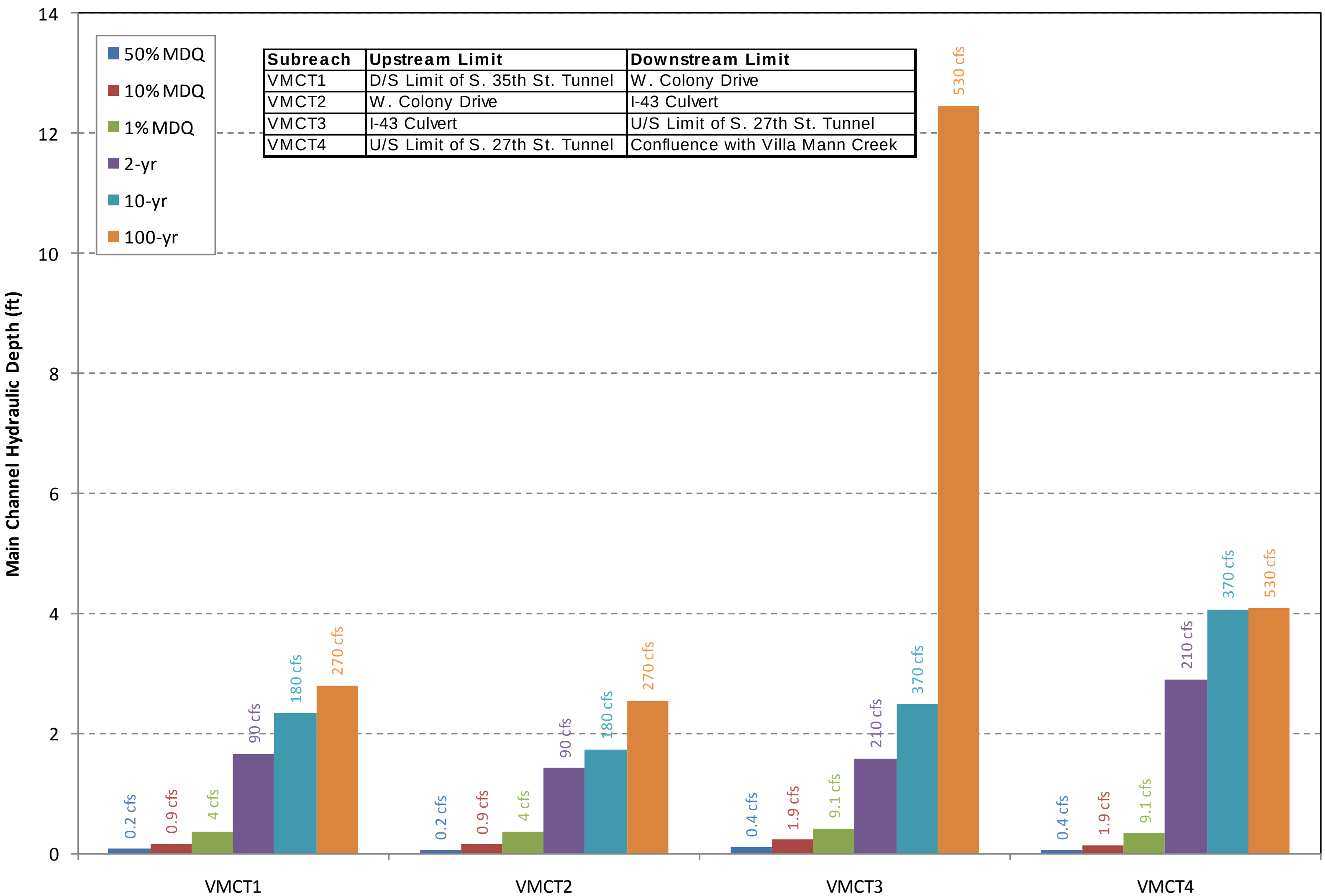
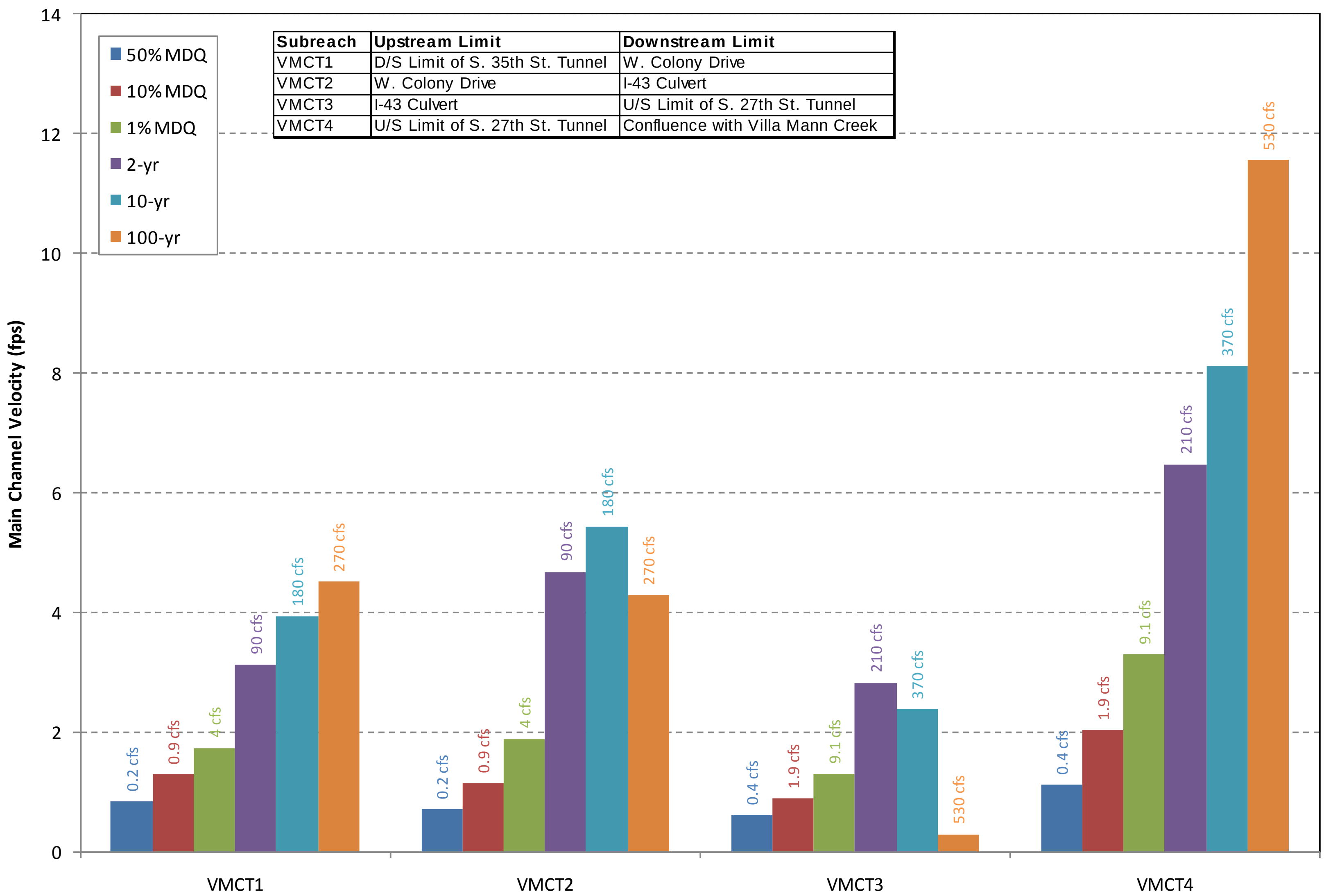


Figure 23. Subreach-averaged main channel topwidth for the subreaches of Villa Mann Creek at the 50-, 10-, and 1-percent mean daily flow exceedence levels and the 2-, 10-, and 100-year peak flows (existing conditions hydrology).



Subreach	Upstream Limit	Downstream Limit
VMCT1	D/S Limit of S. 35th St. Tunnel	W. Colony Drive
VMCT2	W. Colony Drive	I-43 Culvert
VMCT3	I-43 Culvert	U/S Limit of S. 27th St. Tunnel
VMCT4	U/S Limit of S. 27th St. Tunnel	Confluence with Villa Mann Creek

Figure 24. Subreach-averaged main channel hydraulic depth for the subreaches of the tributary to Villa Mann Creek at the 50-, 10-, and 1-percent mean daily flow exceedence levels and the 2-, 10-, and 100-year peak flows (existing conditions hydrology).



Subreach	Upstream Limit	Downstream Limit
VMCT1	D/S Limit of S. 35th St. Tunnel	W. Colony Drive
VMCT2	W. Colony Drive	I-43 Culvert
VMCT3	I-43 Culvert	U/S Limit of S. 27th St. Tunnel
VMCT4	U/S Limit of S. 27th St. Tunnel	Confluence with Villa Mann Creek

Figure 25. Subreach-averaged main channel velocity for the subreaches of the tributary to Villa Mann Creek at the 50-, 10-, and 1-percent mean daily flow exceedence levels and the 2-, 10-, and 100-year peak flows (existing conditions hydrology).

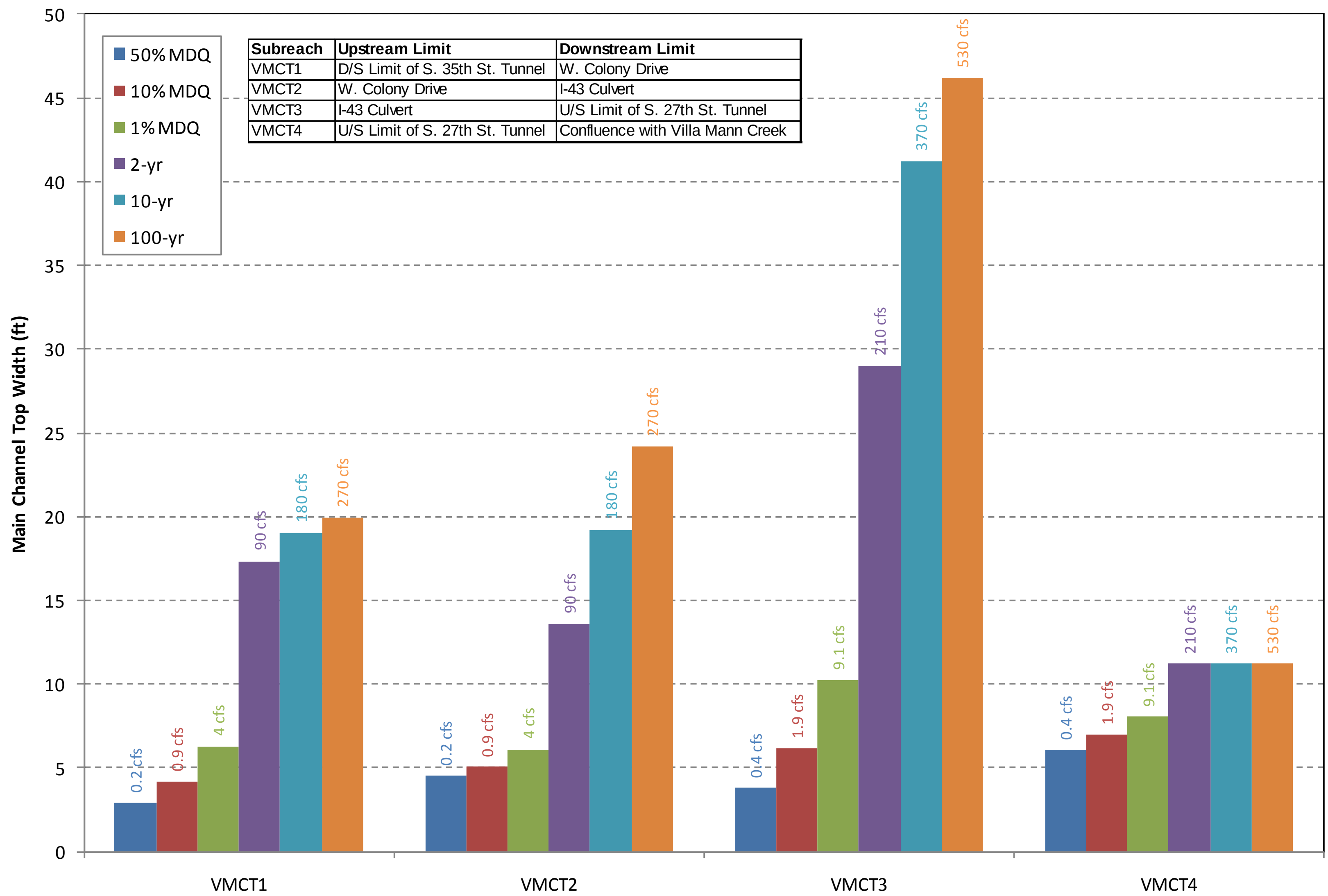
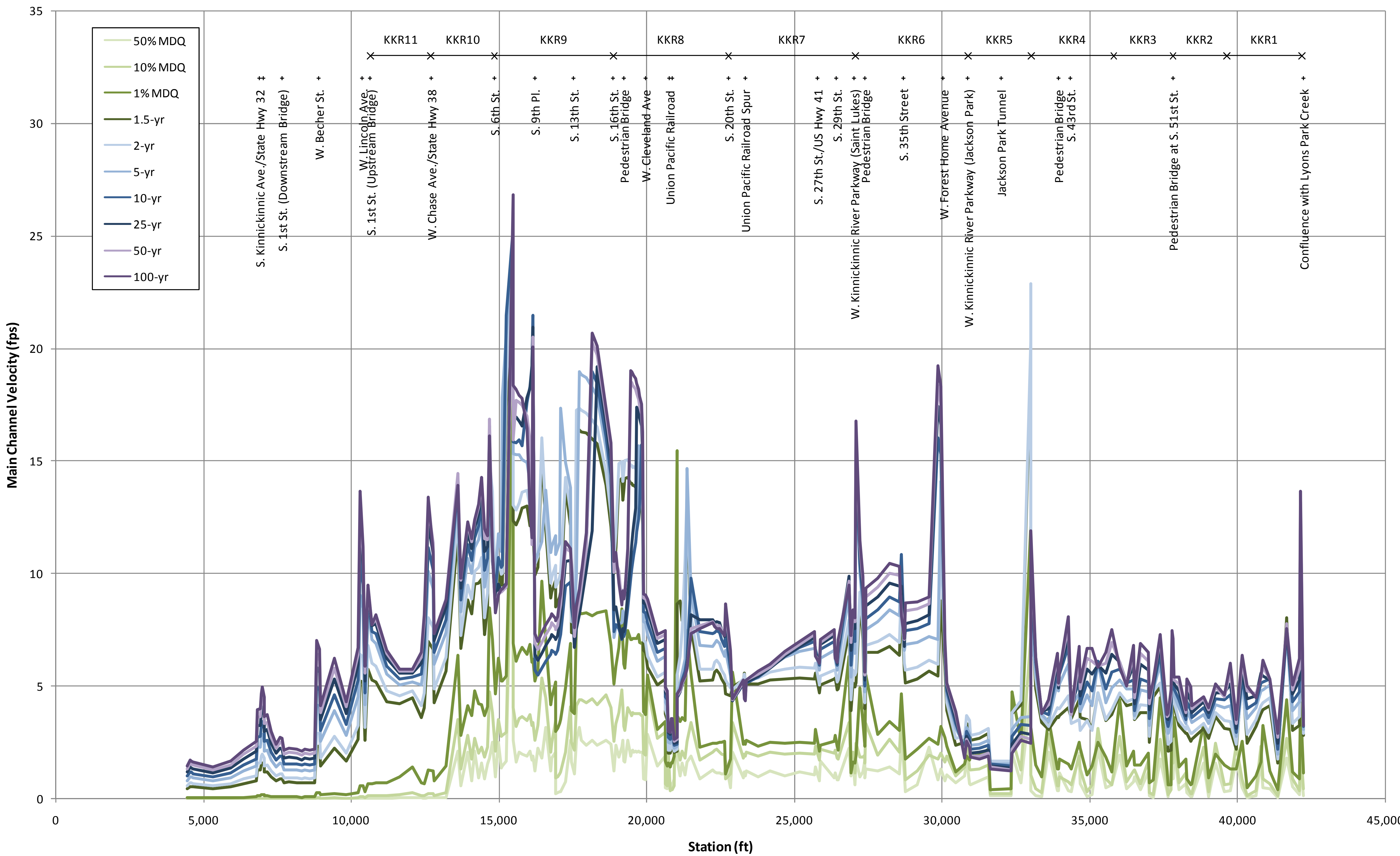


Figure 26. Subreach-averaged main channel topwidth for the subreaches of the tributary to Villa Mann Creek at the 50-, 10-, and 1-percent mean daily flow exceedence levels and the 2-, 10-, and 100-year peak flows (existing conditions hydrology).

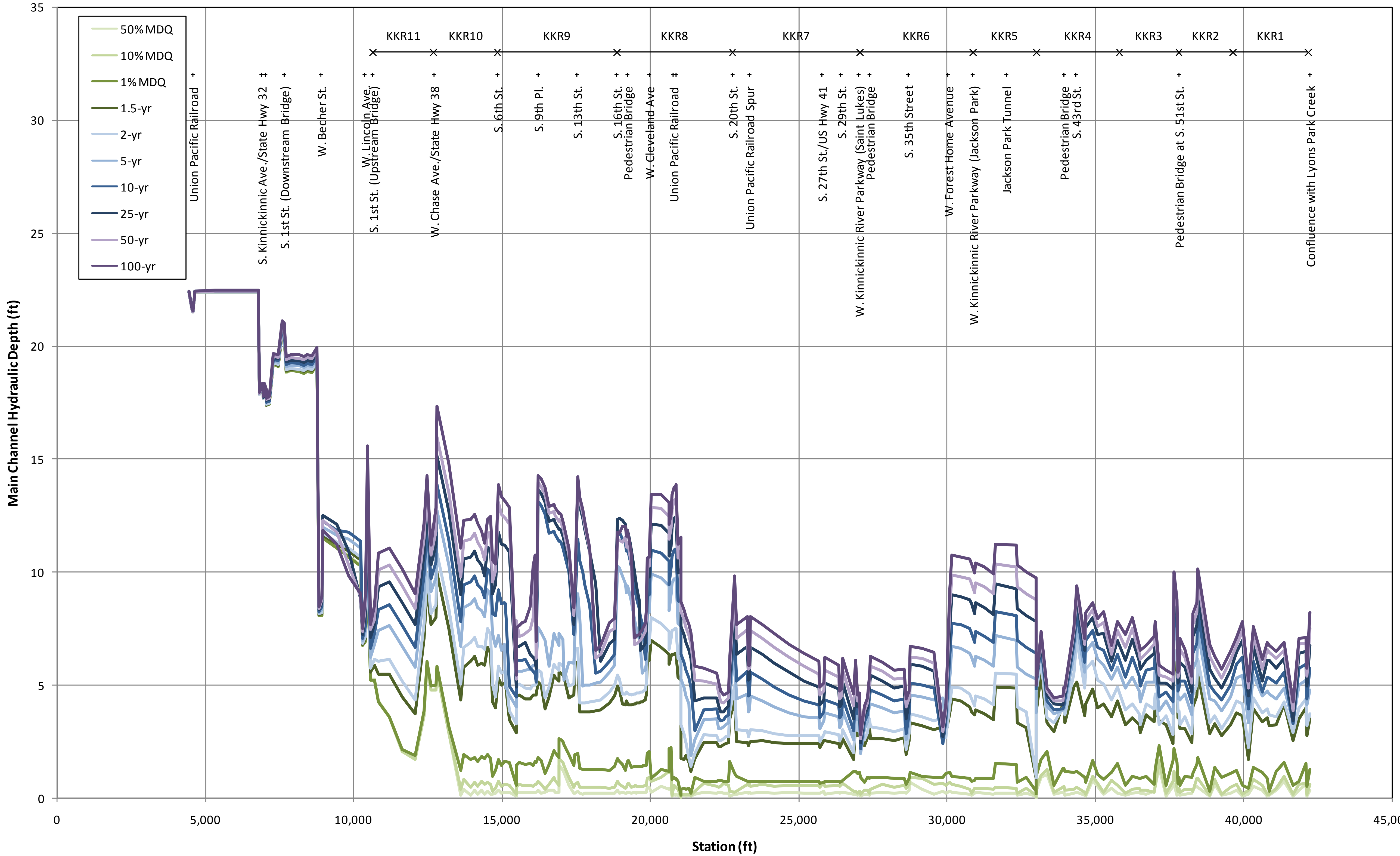
APPENDIX A

Hydraulic Models for the Kinnickinnic River, Wilson Park Creek, Lyons Park Creek, S. 43rd Street Ditch, Villa Mann Creek, and the Tributary to Villa Mann Creek (on CD)

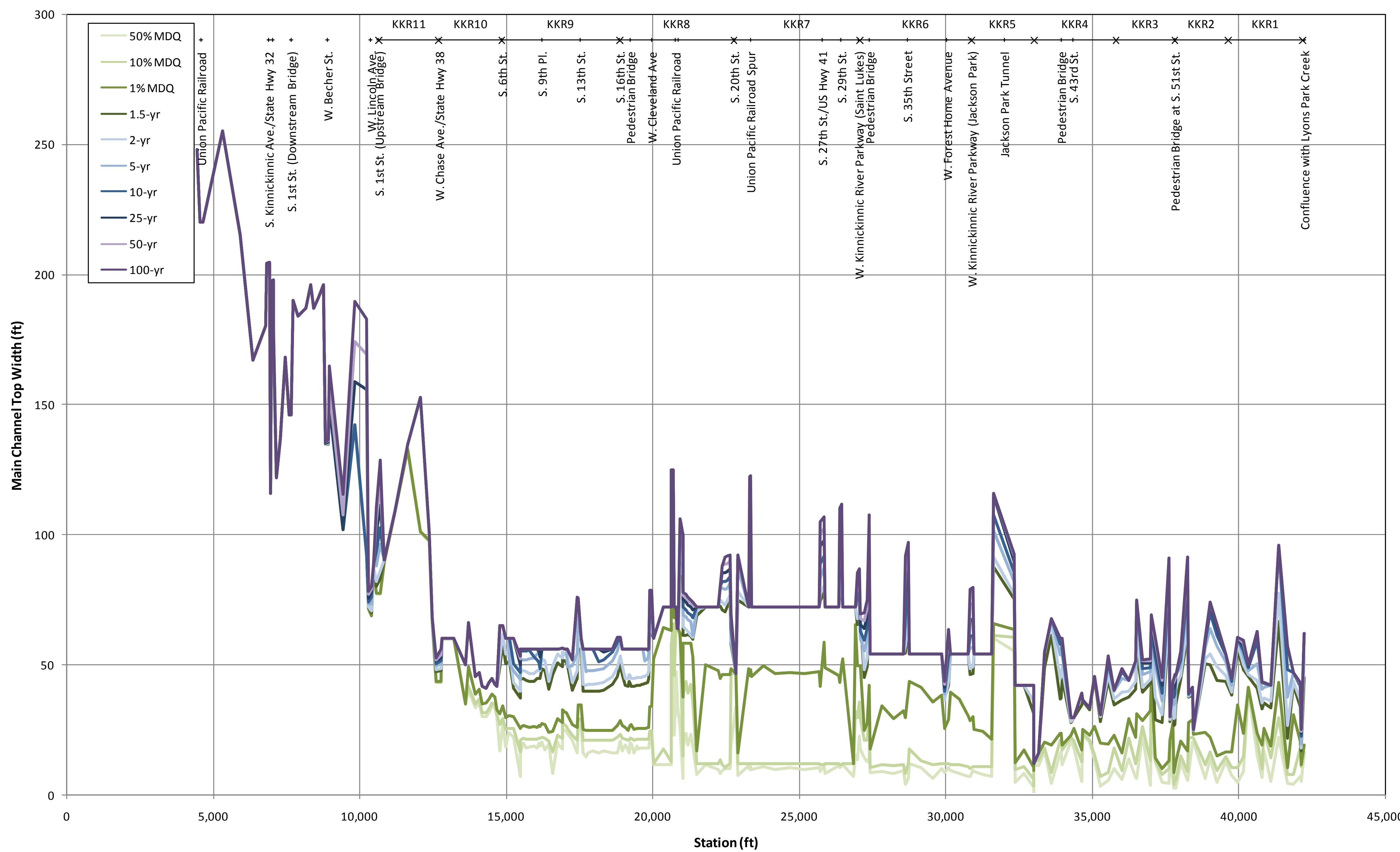
APPENDIX B
Profile Plots of Computed Main Channel Hydraulic Conditions (Velocity, Hydraulic Depth and Top Width) Under Existing Conditions Hydrology



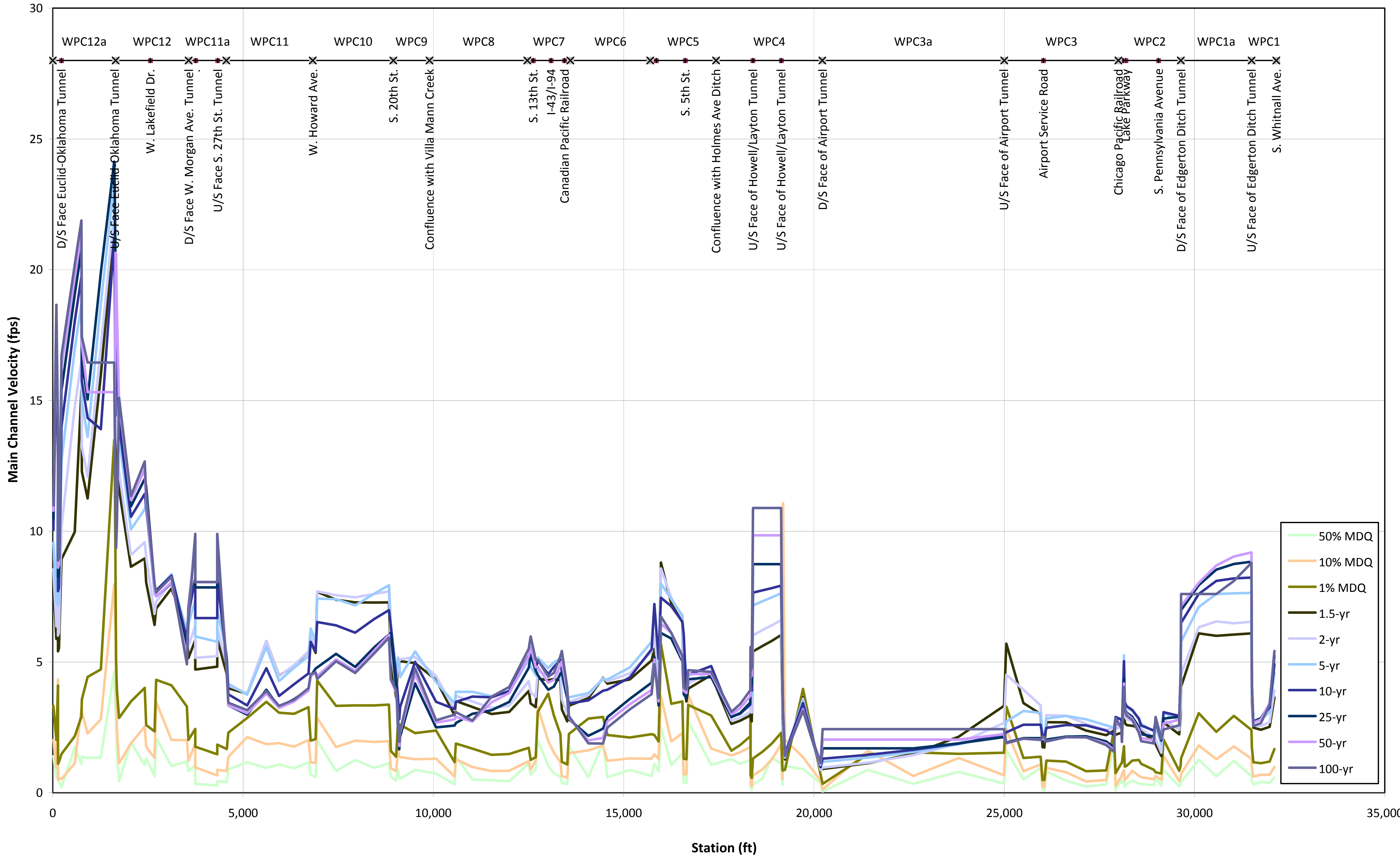
Computed main channel velocity in the Kinnickinnic River for selected existing conditions flows up to the 100-year peak discharge.



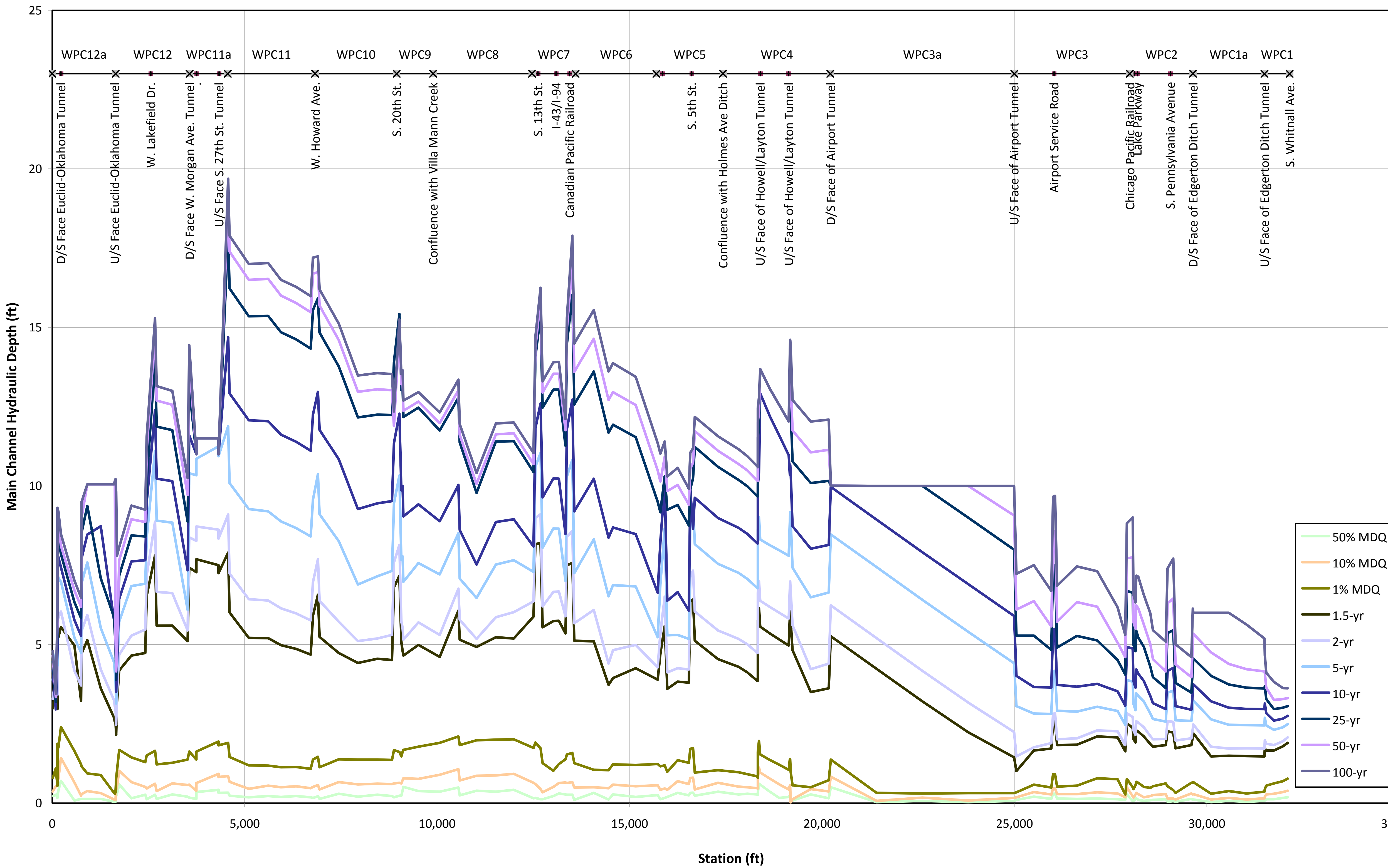
Computed main channel hydraulic depth in the Kinnickinnic River for selected existing conditions flows up to the 100-year peak discharge.



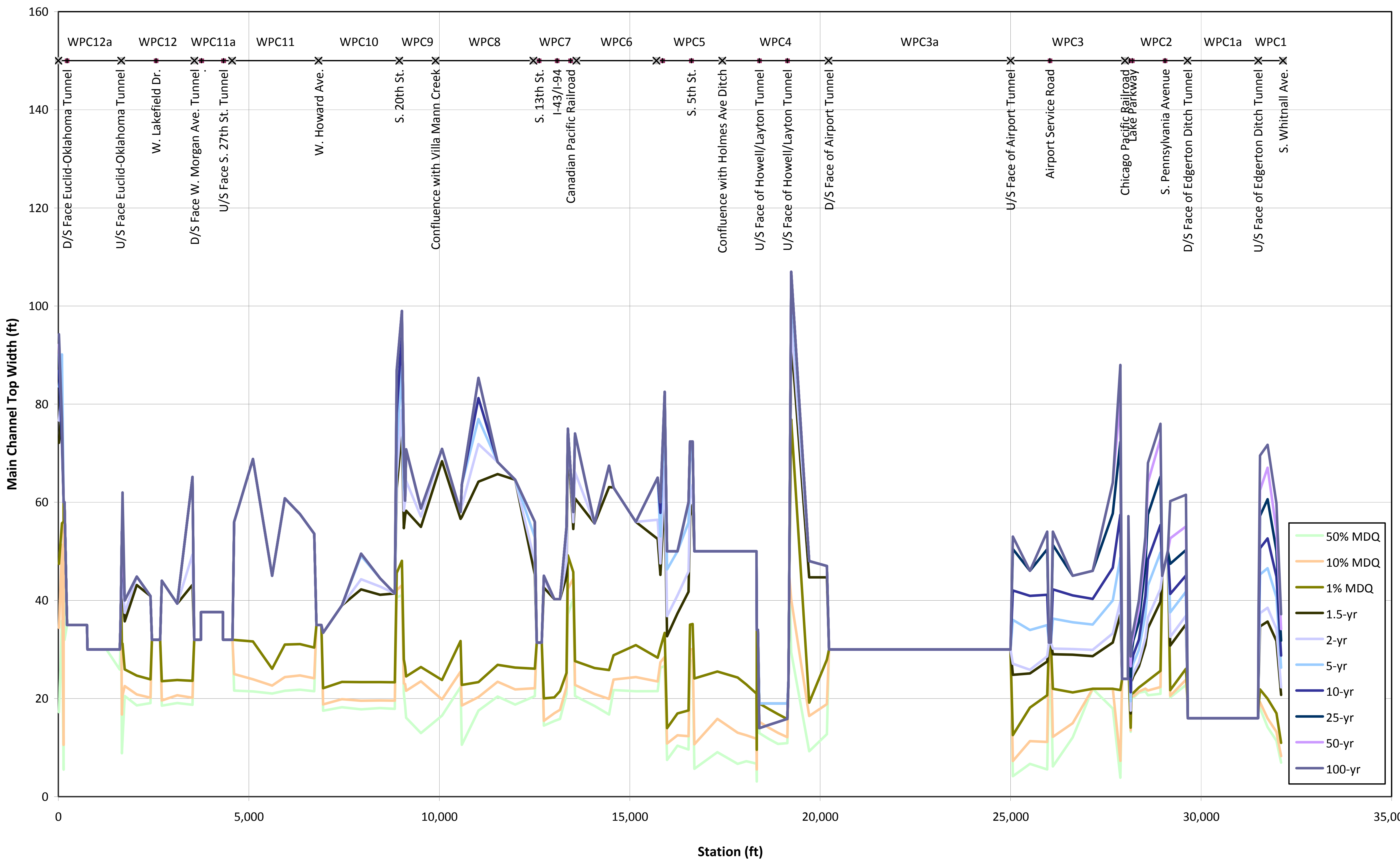
Computed main channel topwidth in the Kinnickinnic River for selected existing conditions flows up to the 100-year peak discharge.



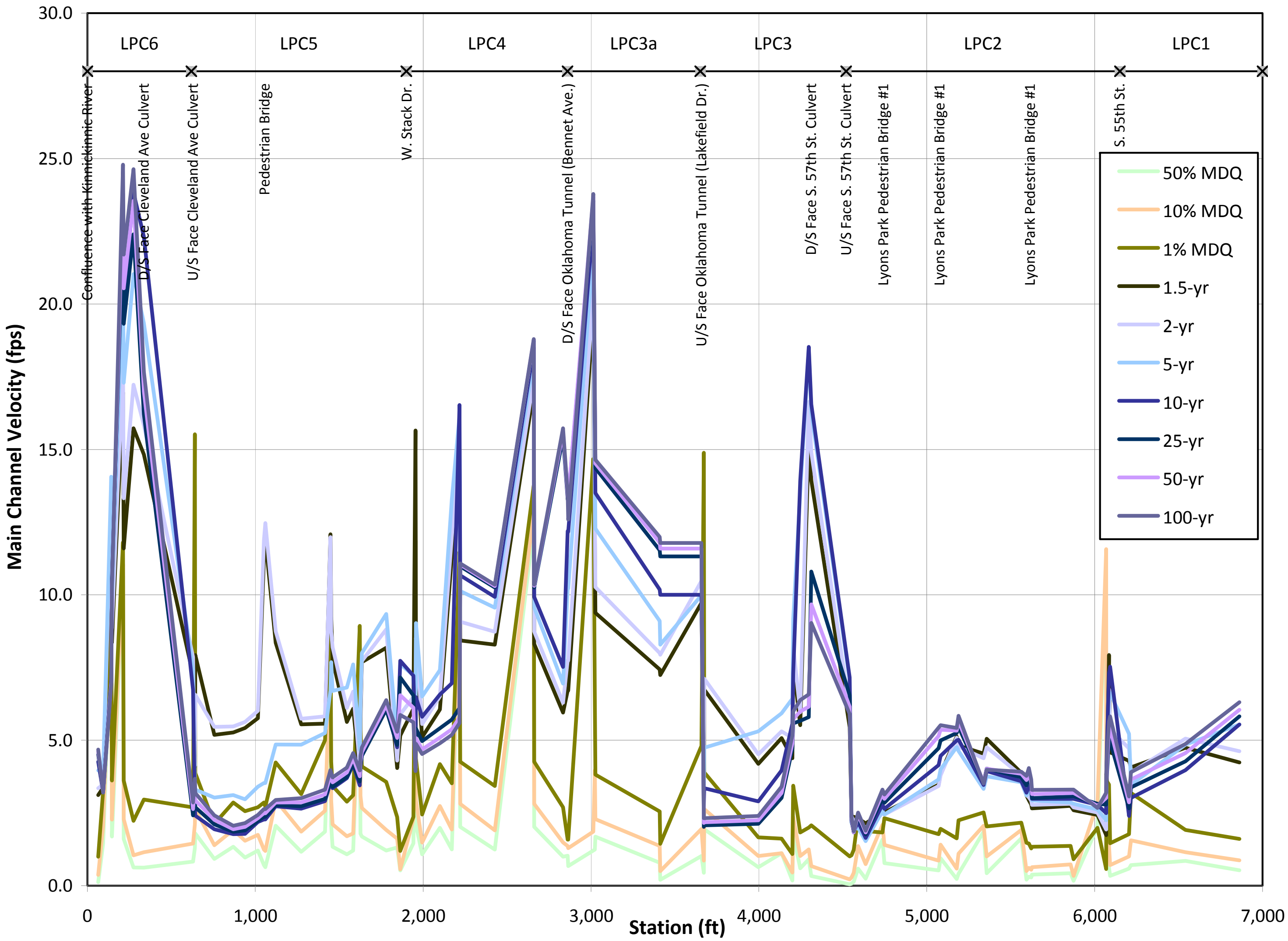
Computed main channel velocity in Wilson Park Creek River for selected existing conditions flows up to the 100-year peak discharge.



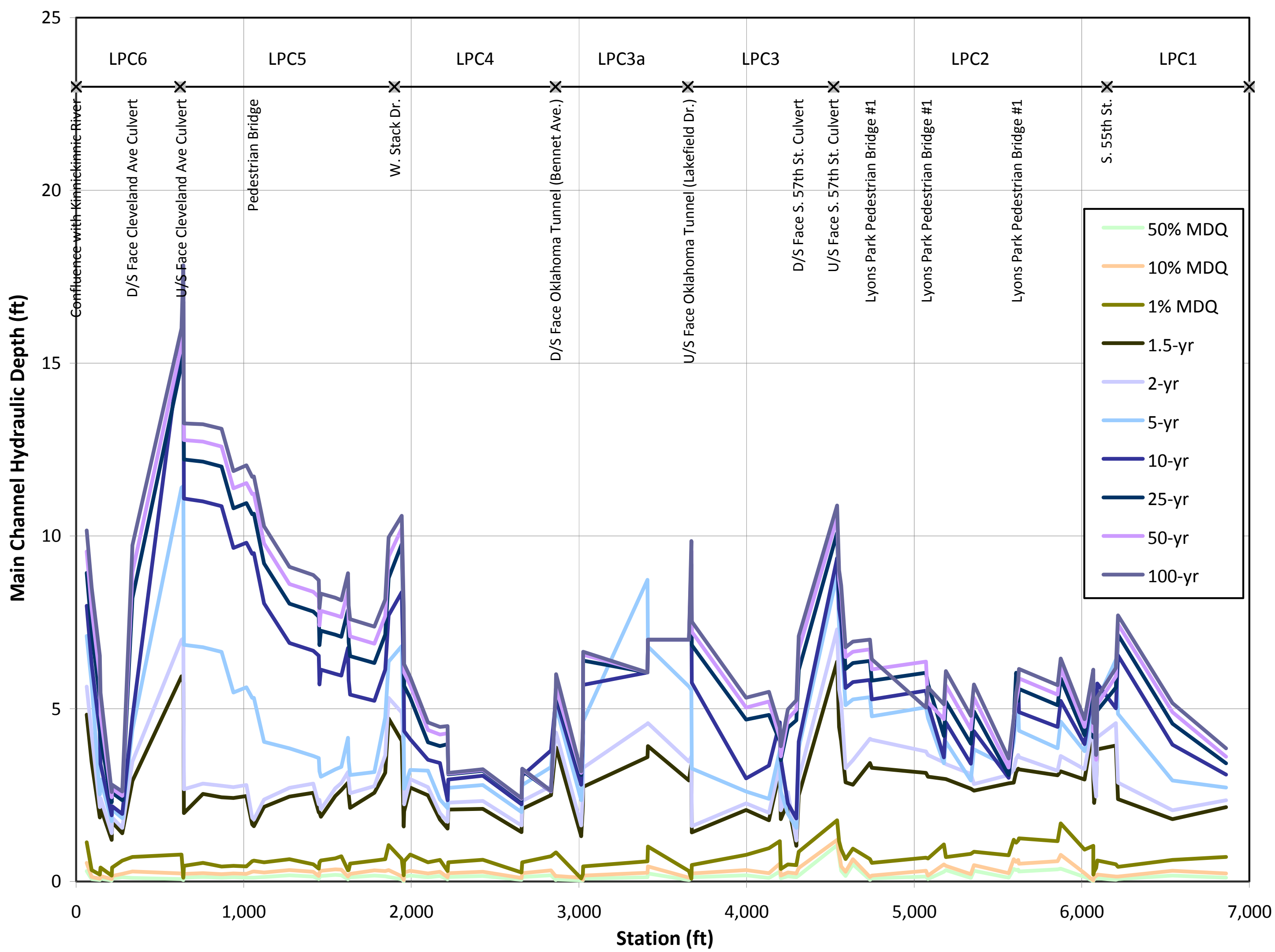
Computed main channel hydraulic depth in Wilson Park Creek River for selected existing conditions flows up to the 100-year peak discharge.



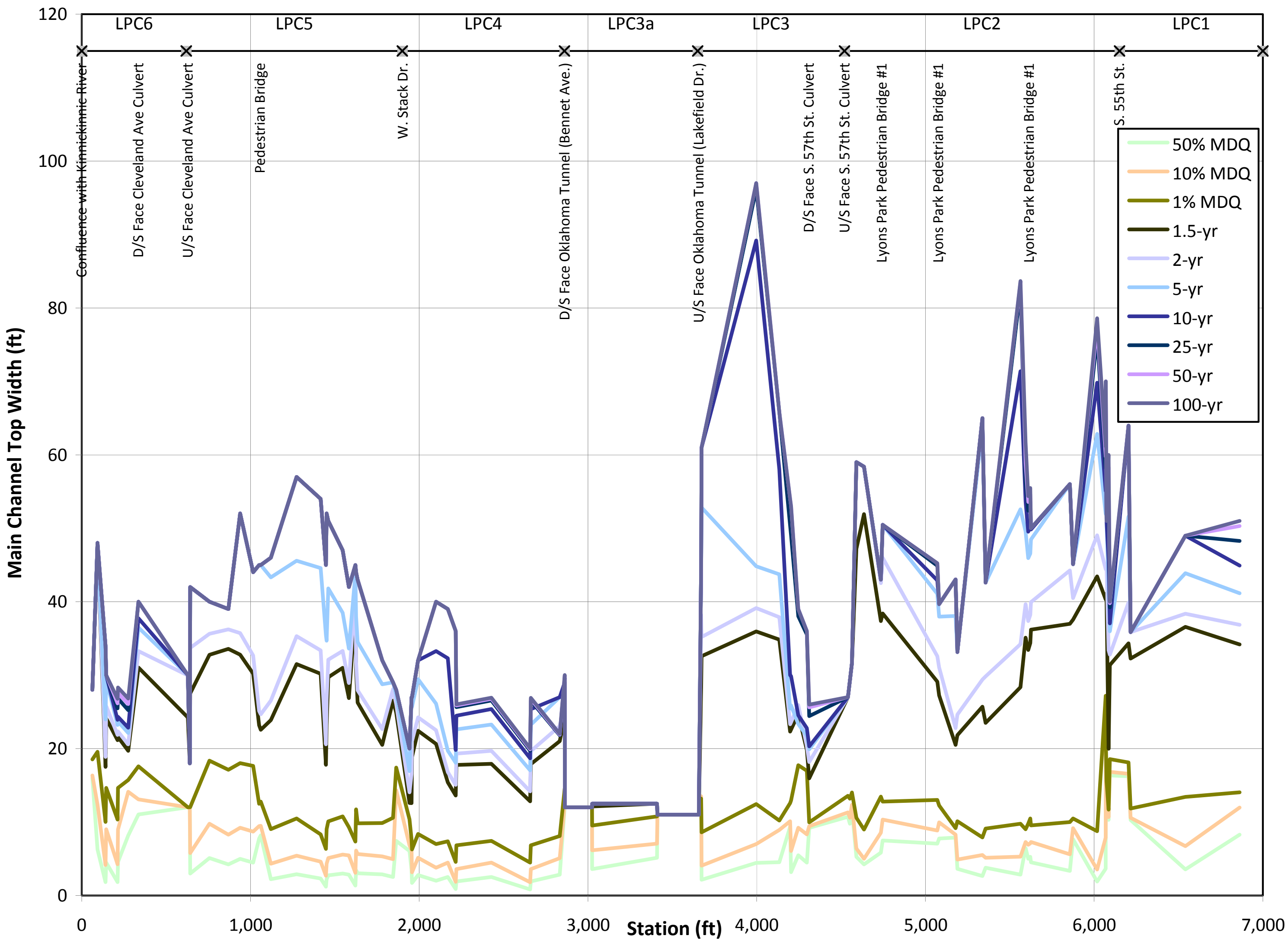
Computed main channel topwidth in Wilson Park Creek River for selected existing conditions flows up to the 100-year peak discharge.



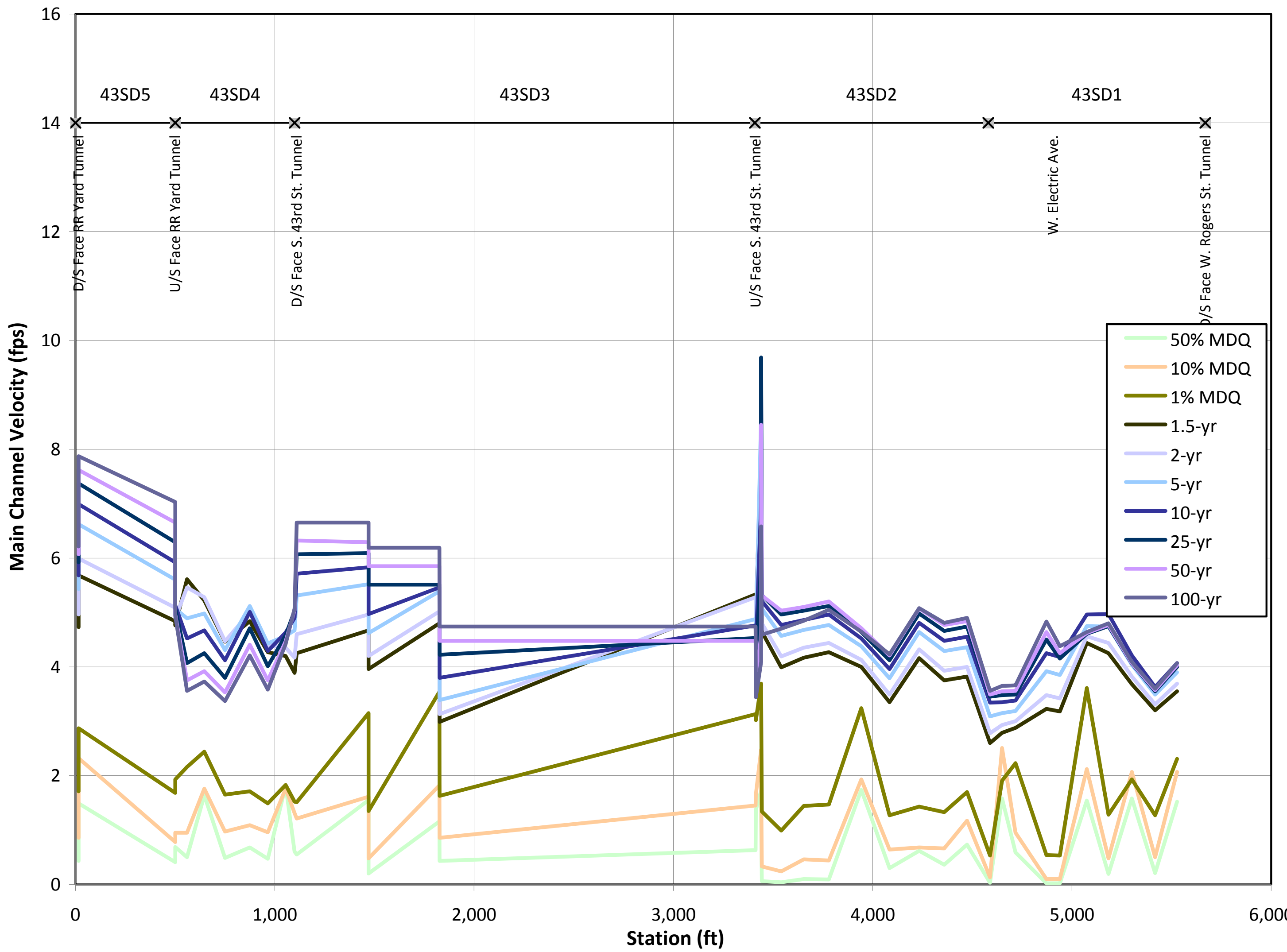
Computed main channel velocity in Lyons Park Creek River for selected existing conditions flows up to the 100-year peak discharge.



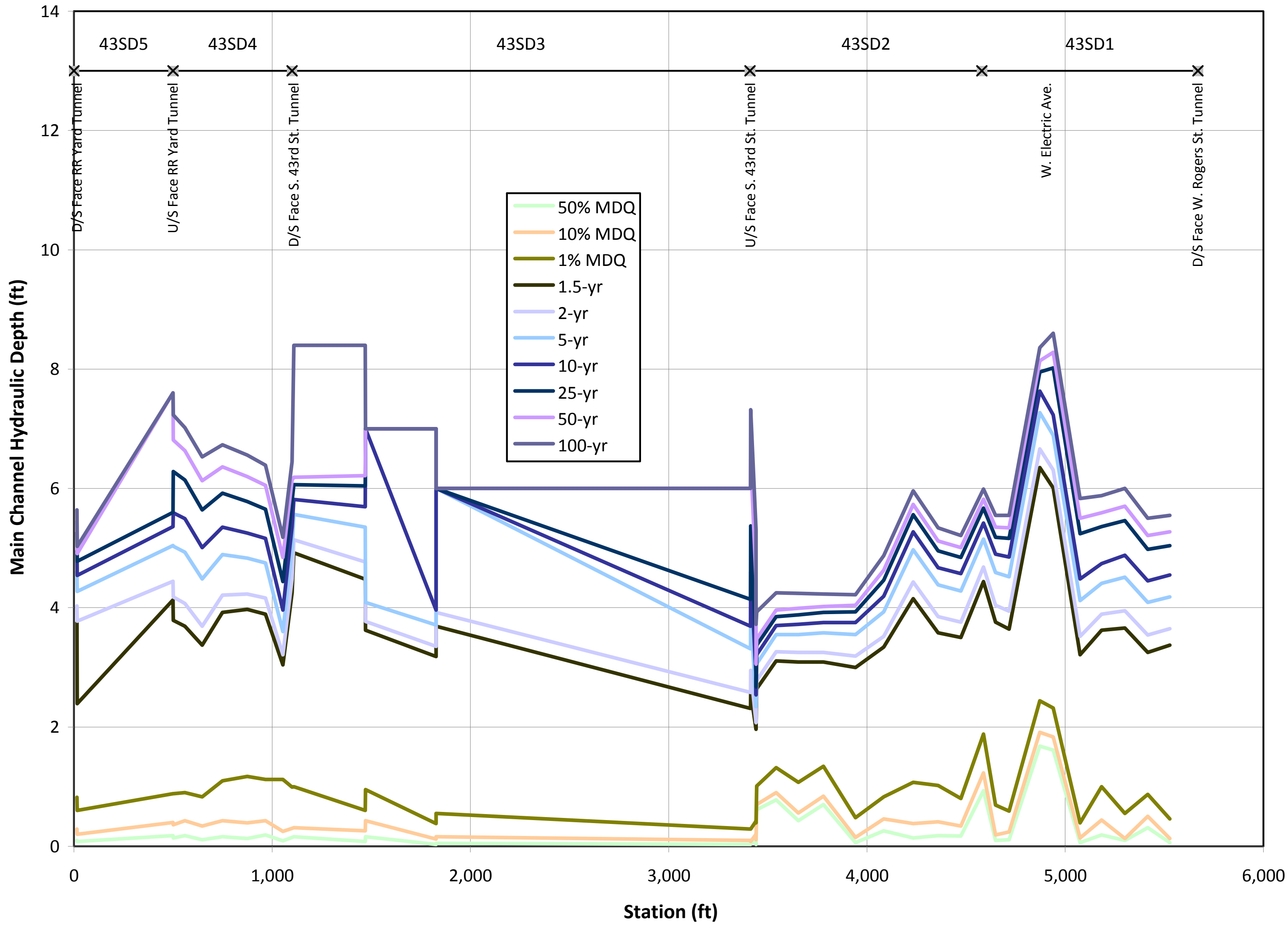
Computed main channel hydraulic depth in Lyons Park Creek River for selected existing conditions flows up to the 100-year peak discharge.



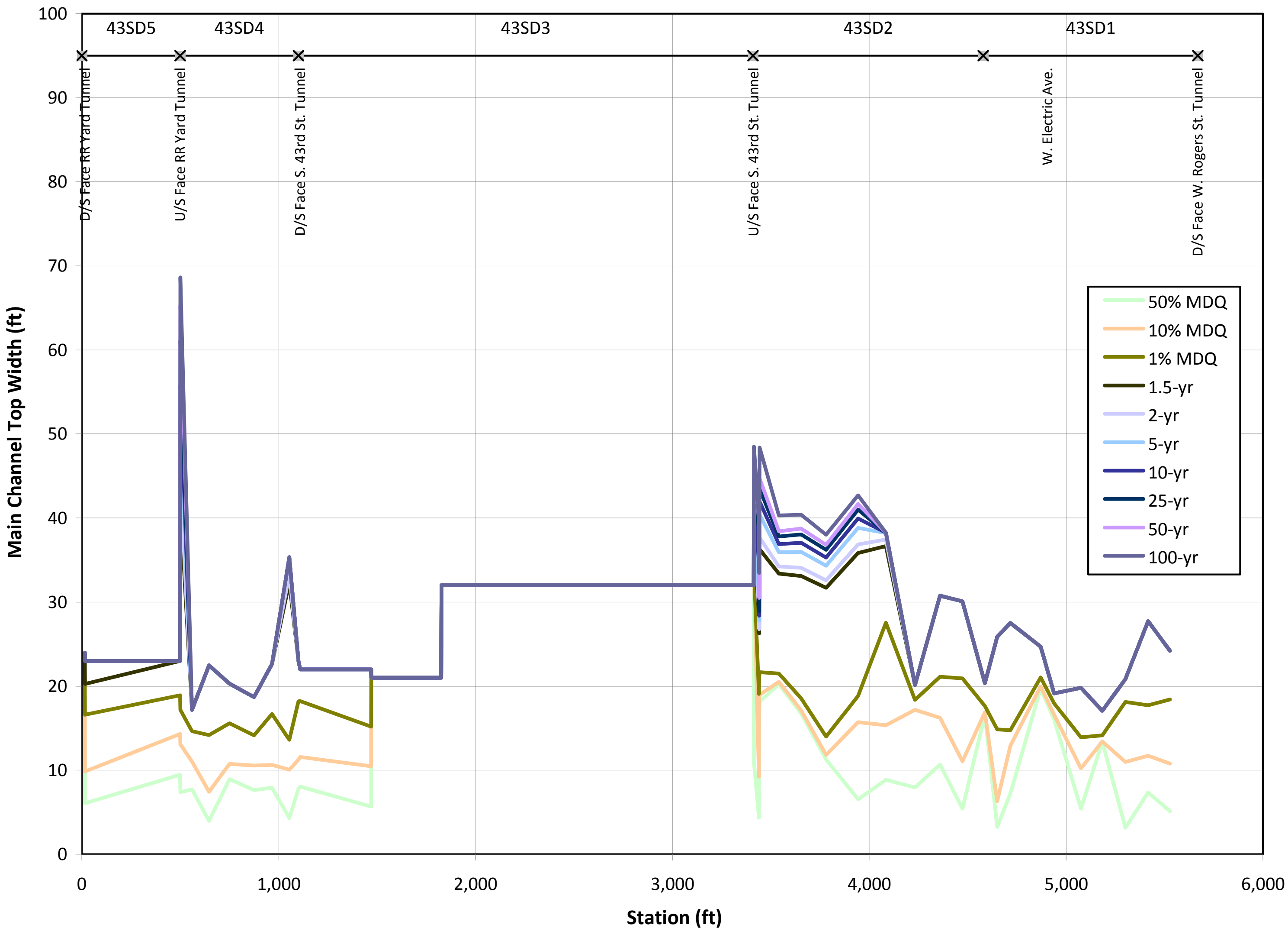
Computed main channel topwidth in Lyons Park Creek River for selected existing conditions flows up to the 100-year peak discharge.



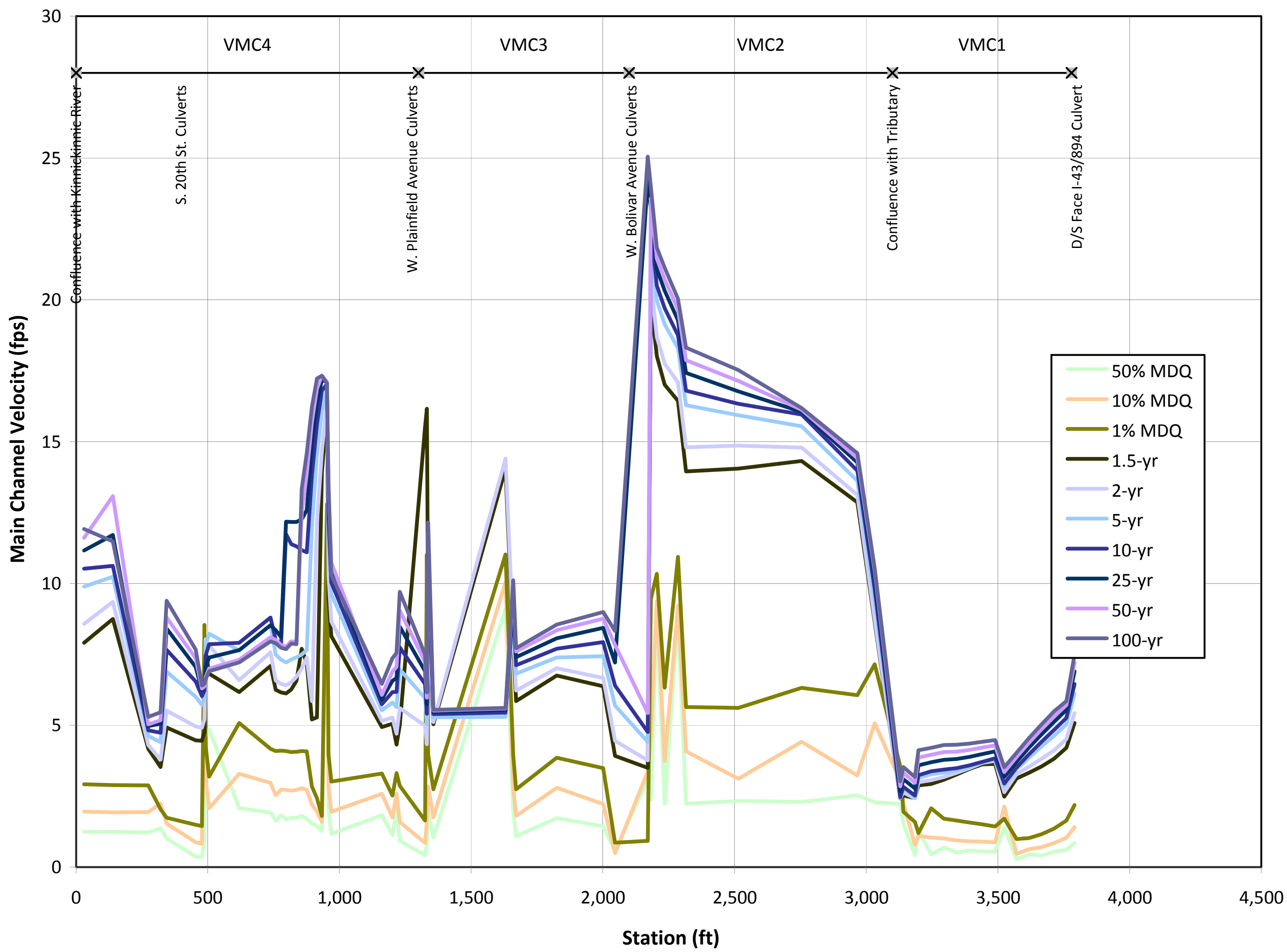
Computed main channel velocity in South 43rd Street Ditch River for selected existing conditions flows up to the 100-year peak discharge.



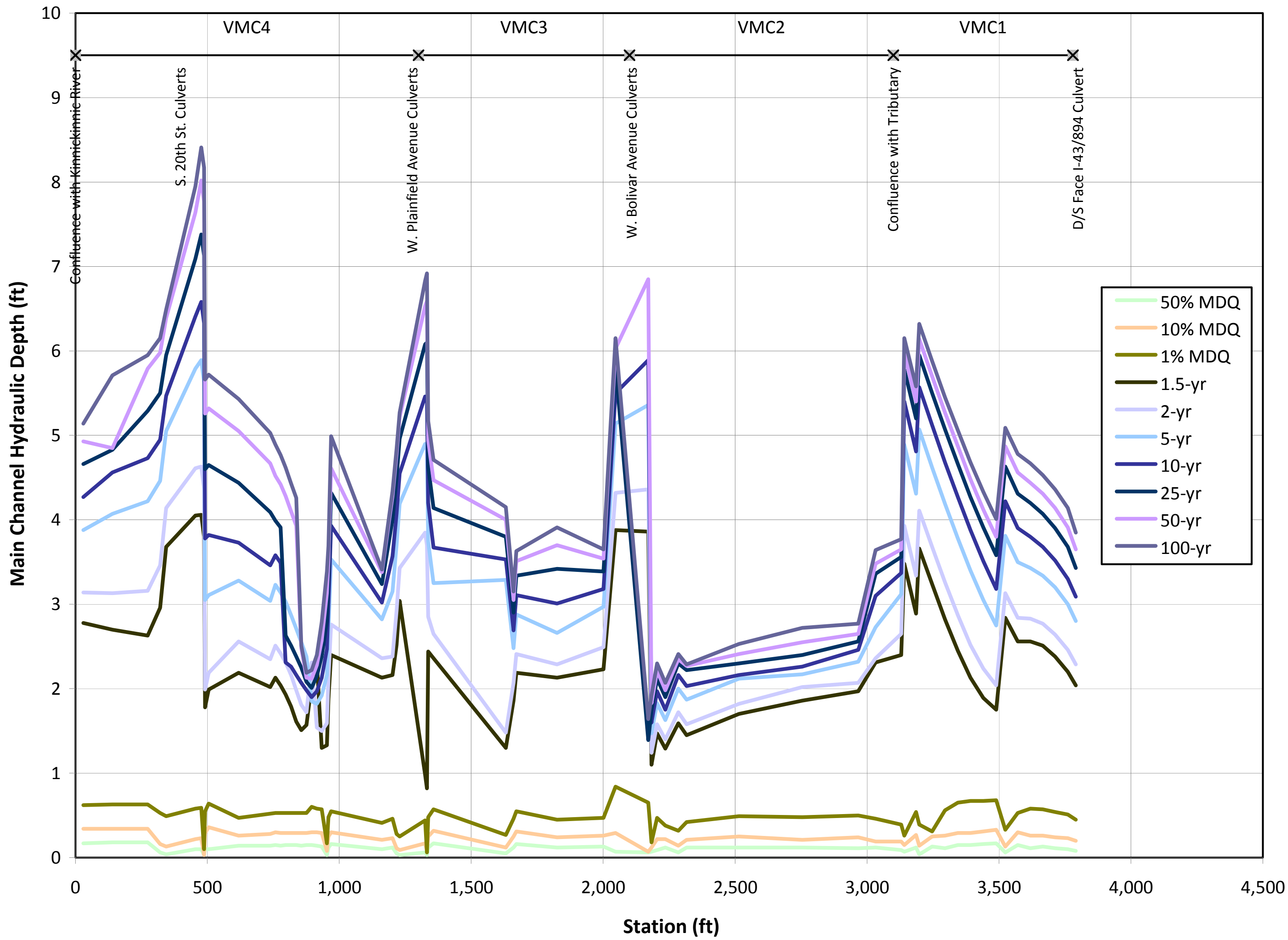
Computed main channel hydraulic depth in South 43rd Street Ditch River for selected existing conditions flows up to the 100-year peak discharge.



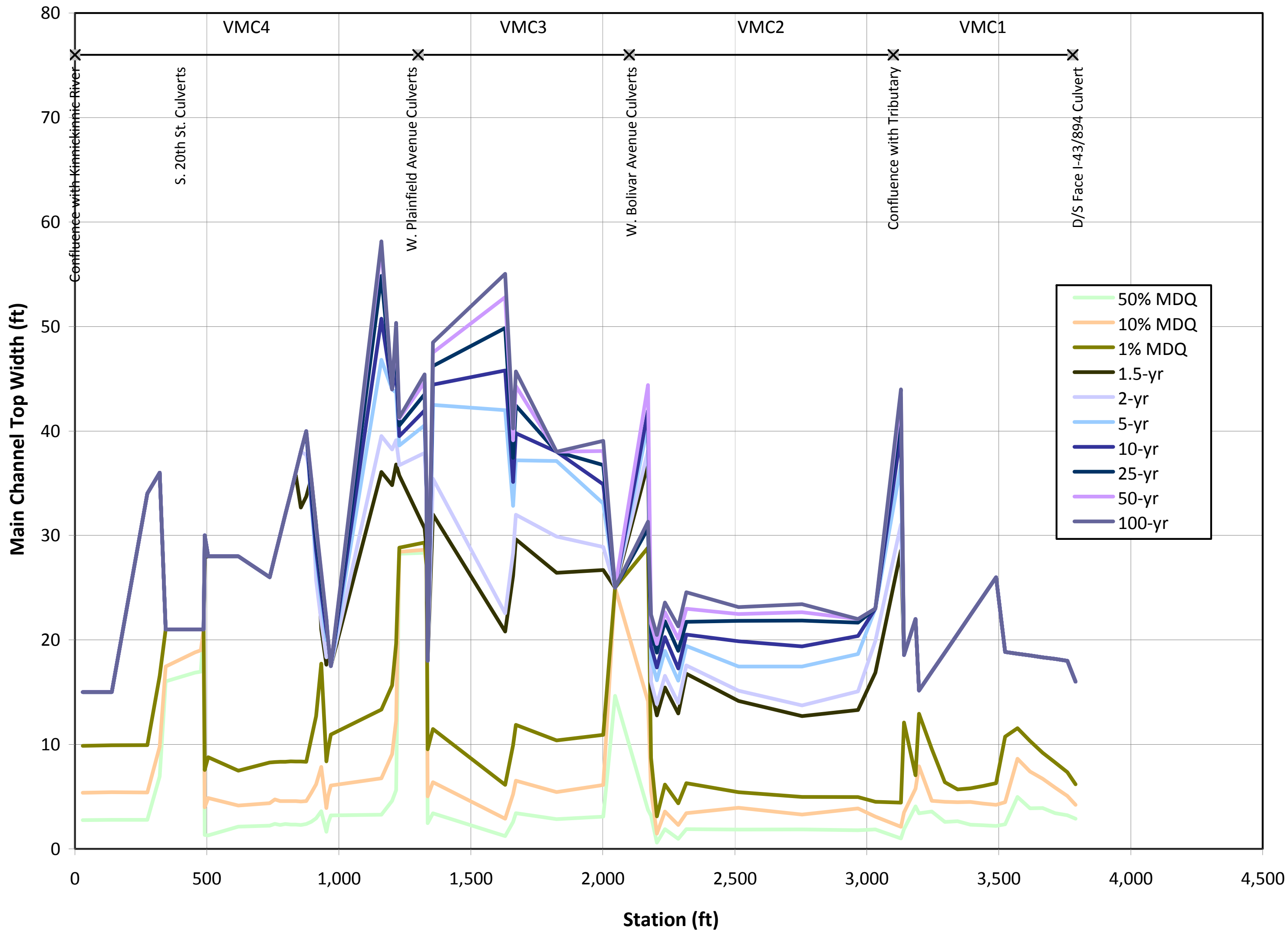
Computed main channel topwidth in South 43rd Street Ditch River for selected existing conditions flows up to the 100-year peak discharge.



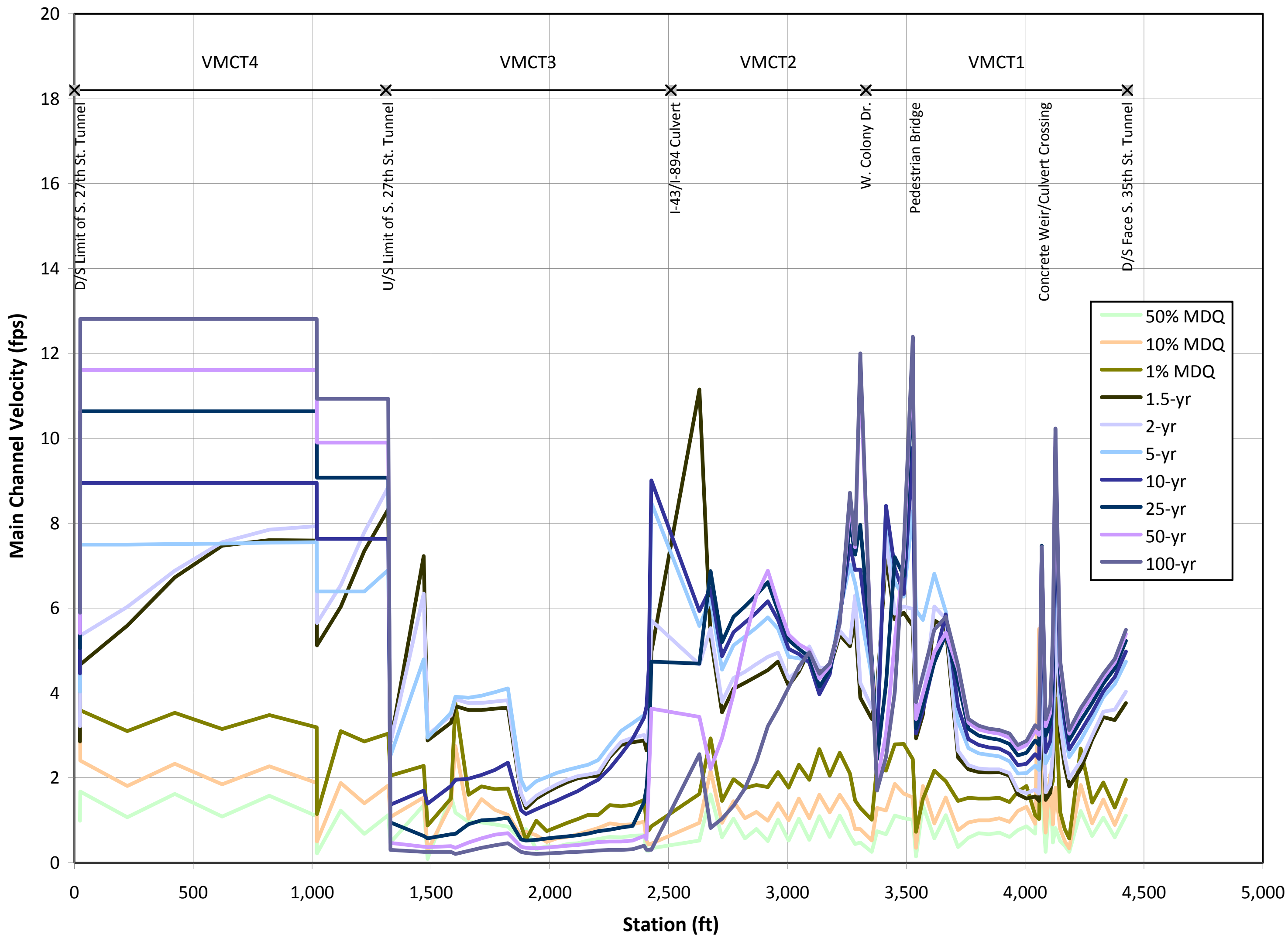
Computed main channel velocity in Villa Mann Creek River for selected existing conditions flows up to the 100-year peak discharge.



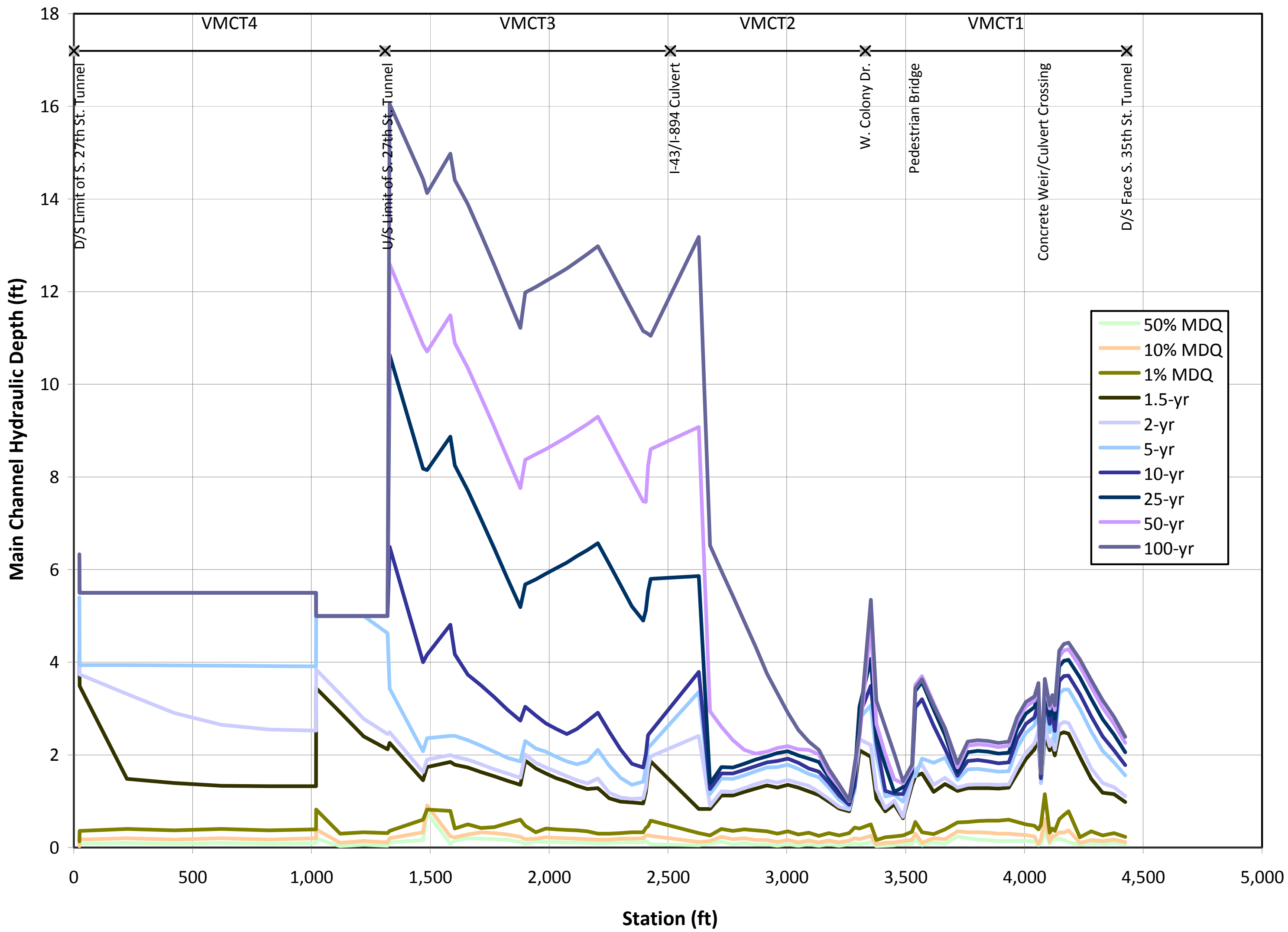
Computed main channel hydraulic depth in Villa Mann Creek River for selected existing conditions flows up to the 100-year peak discharge.



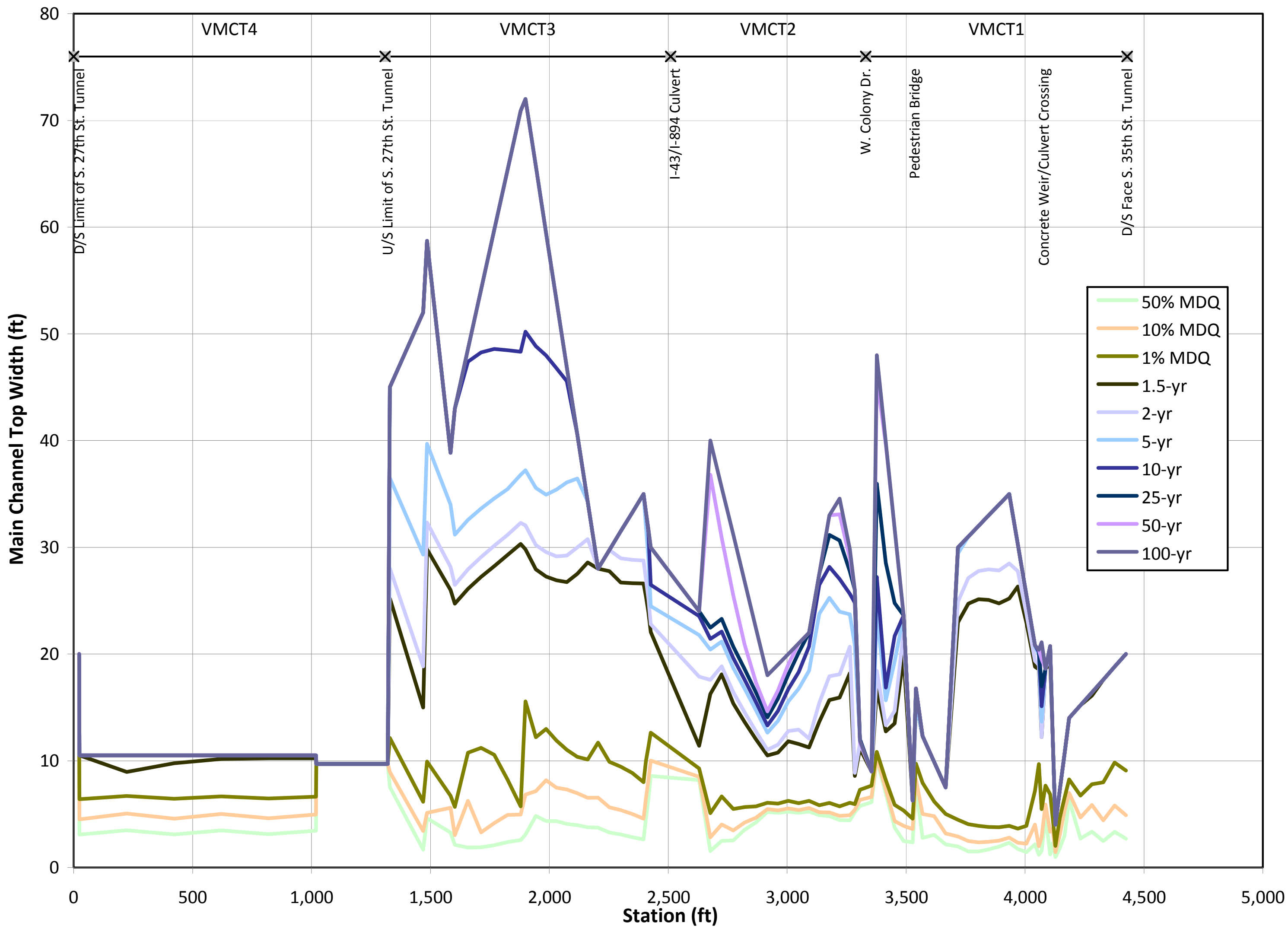
Computed main channel topwidth in Villa Mann Creek River for selected existing conditions flows up to the 100-year peak discharge.



Computed main channel velocity in the tributary to Villa Mann Creek River for selected existing conditions flows up to the 100-year peak discharge.

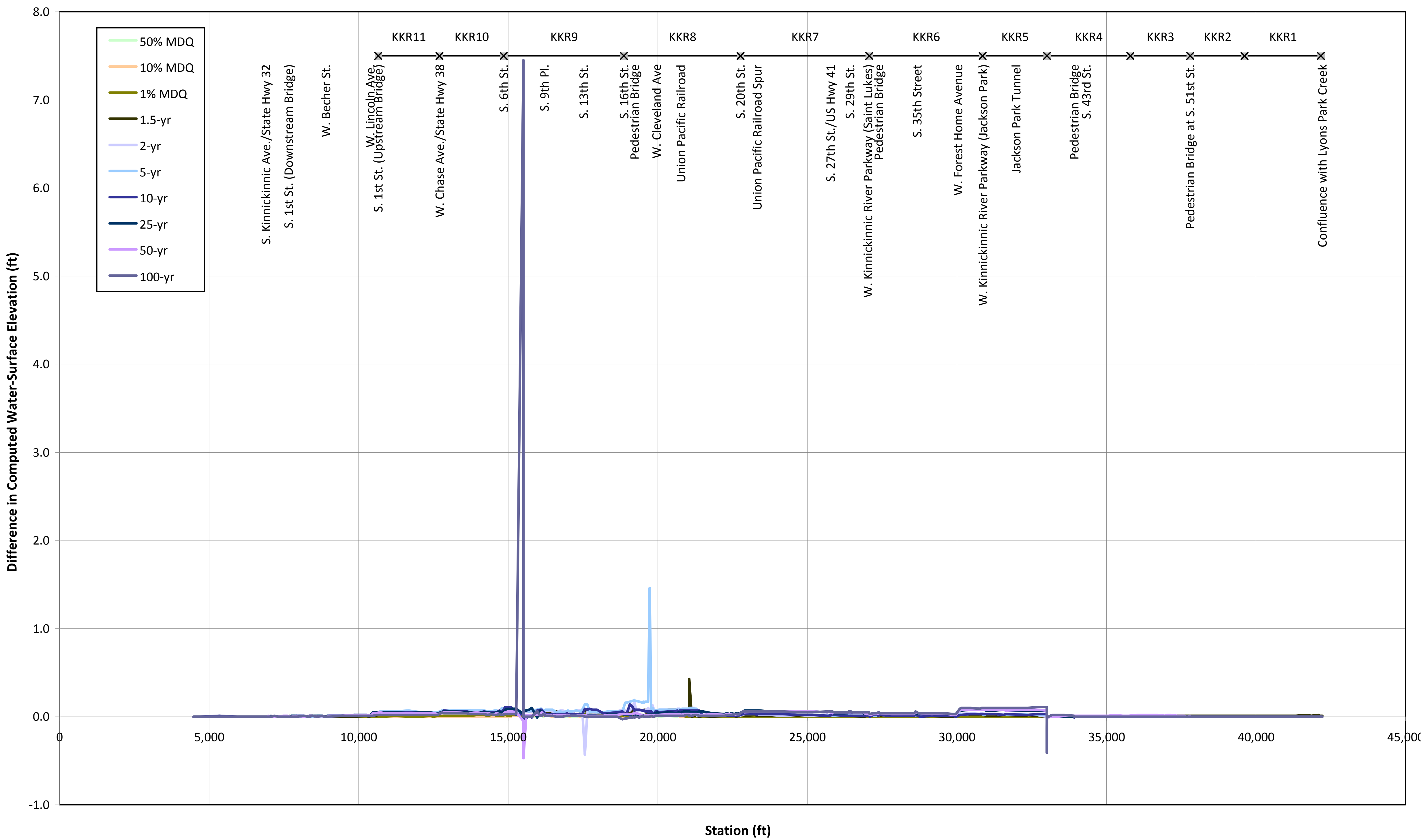


Computed main channel hydraulic depth in the tributary to Villa Mann Creek River for selected existing conditions flows up to the 100-year peak discharge.

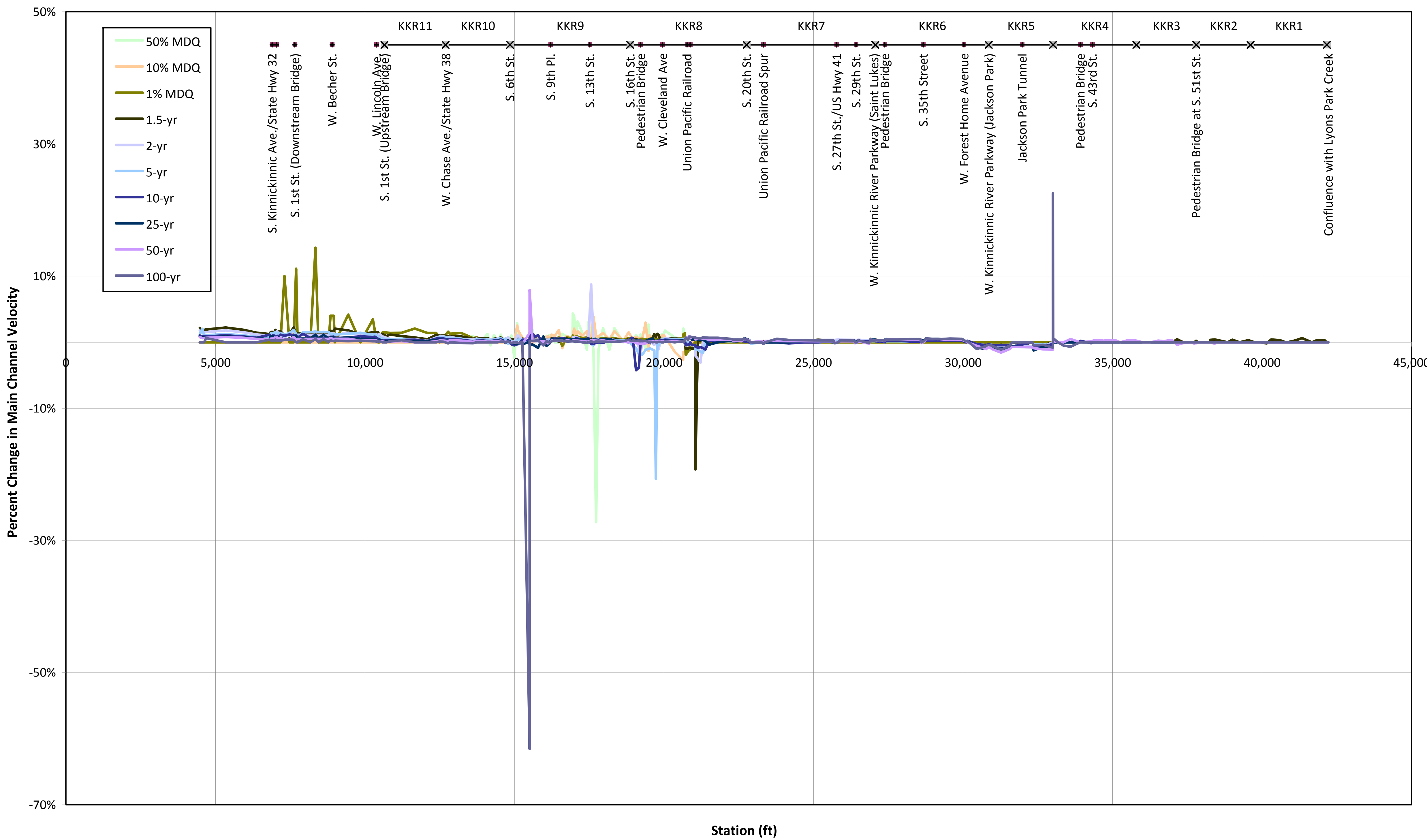


Computed main channel topwidth in the tributary to Villa Mann Creek River for selected existing conditions flows up to the 100-year peak discharge.

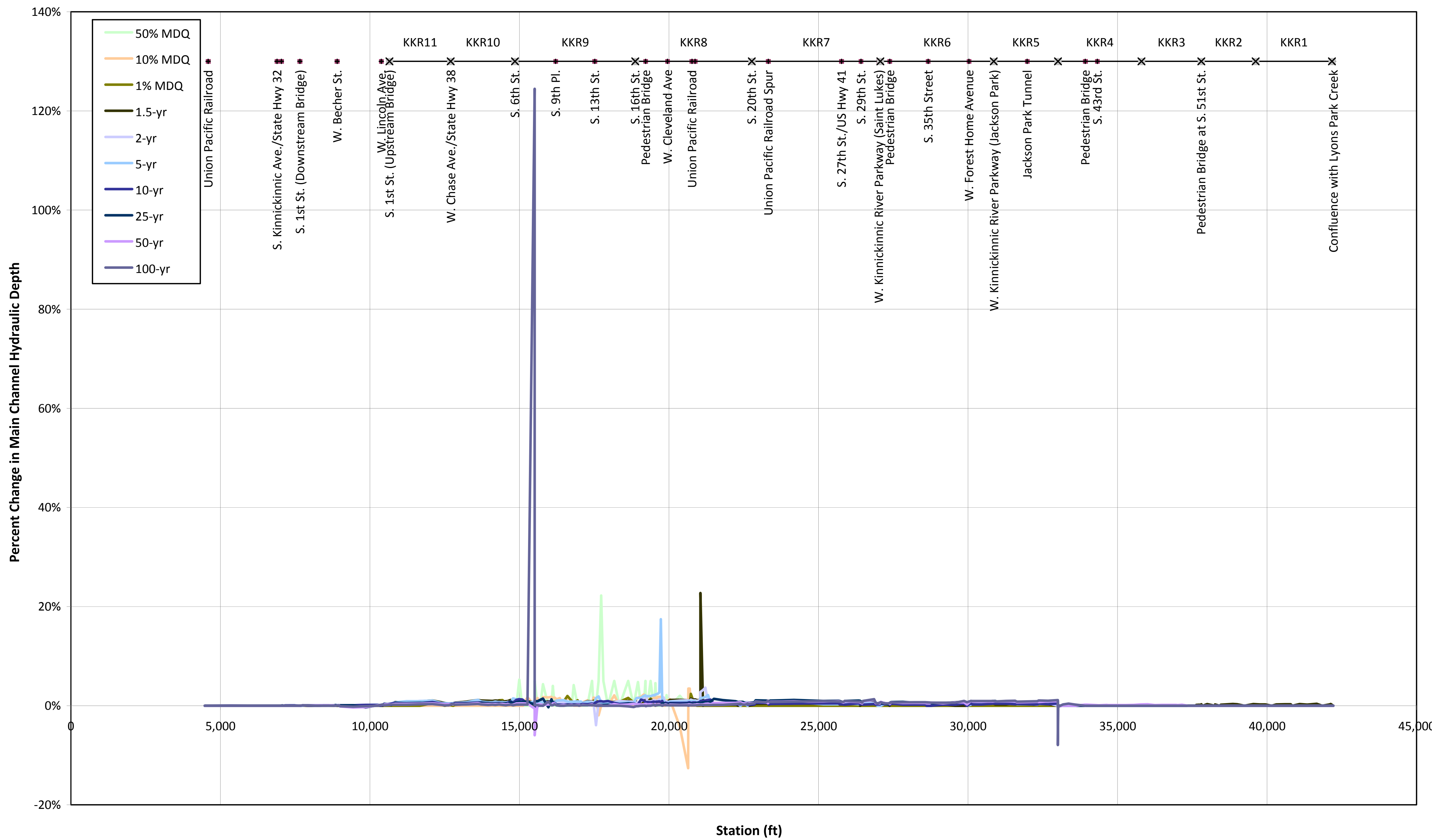
APPENDIX C
Profile Plots showing Change in Water-Surface Elevation and Percent Change in Computed Main Channel Hydraulic Conditions (Velocity, Hydraulic Depth, Top Width) between Existing and Future Conditions Hydrology



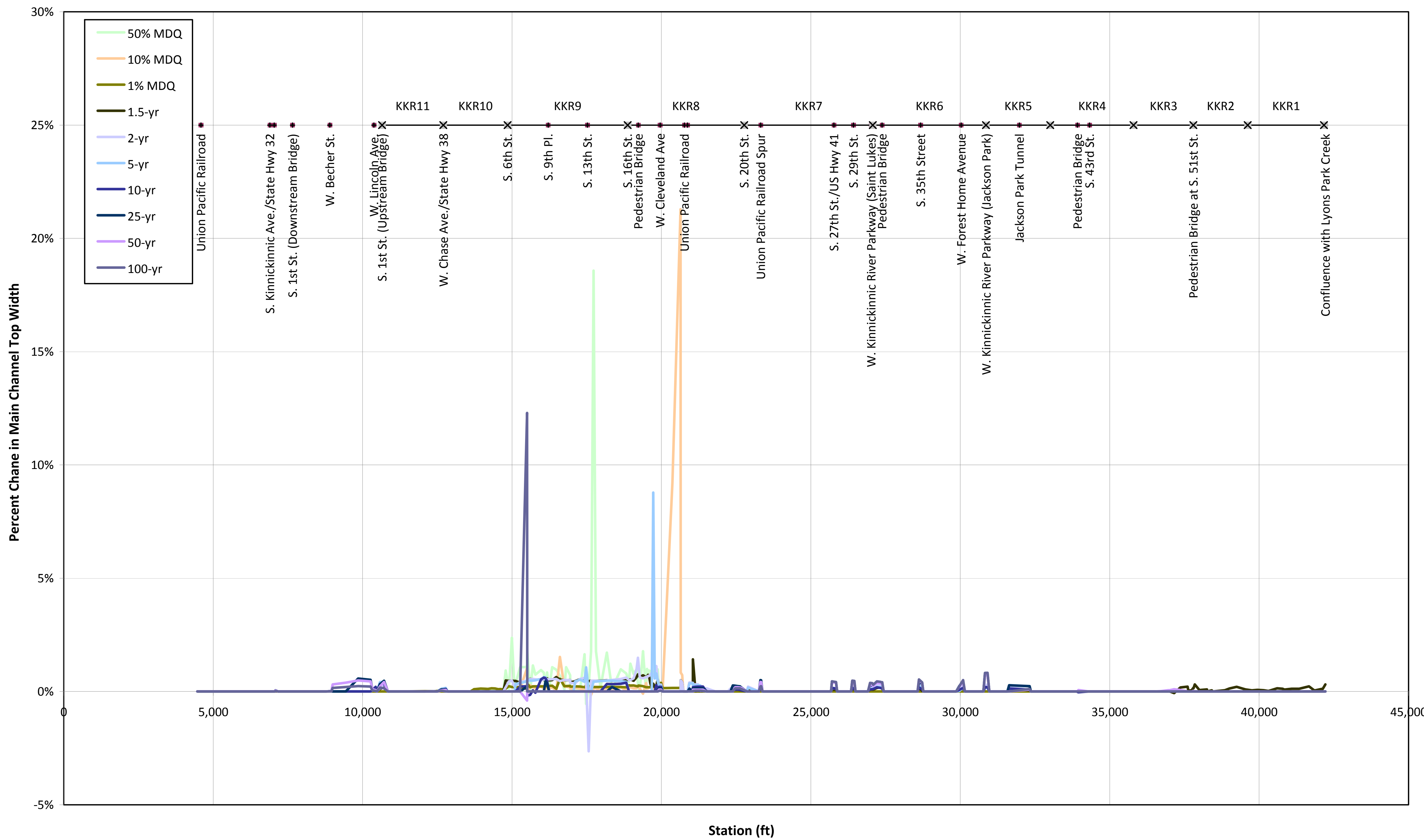
Computed change in water-surface elevation from existing to future conditions in the Kinnickinnic River for selected flows up to the 100-year peak discharge.



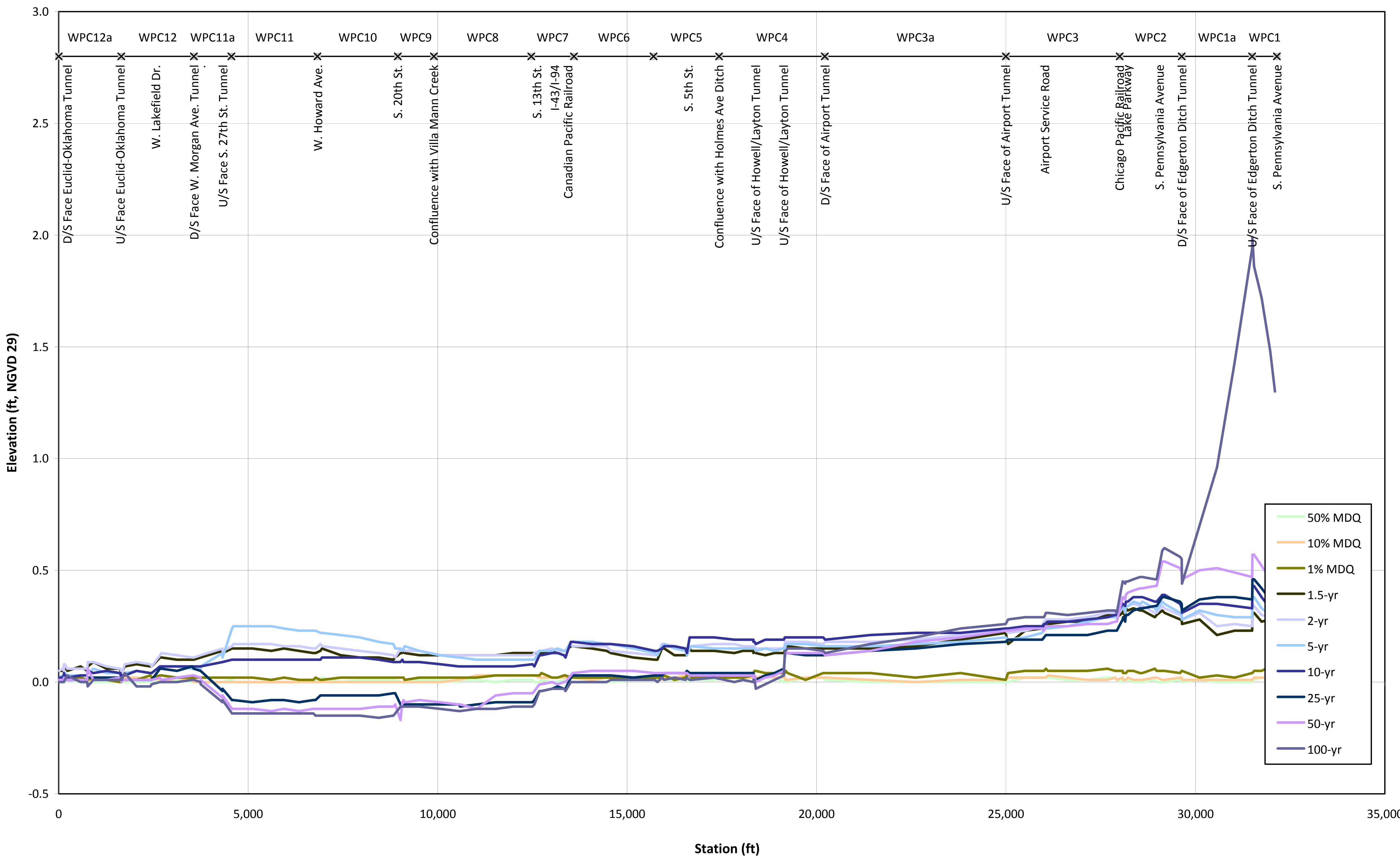
Computed percent change in main channel velocity from existing to future conditions in the Kinnickinnic River for selected flows up to the 100-year peak discharge.



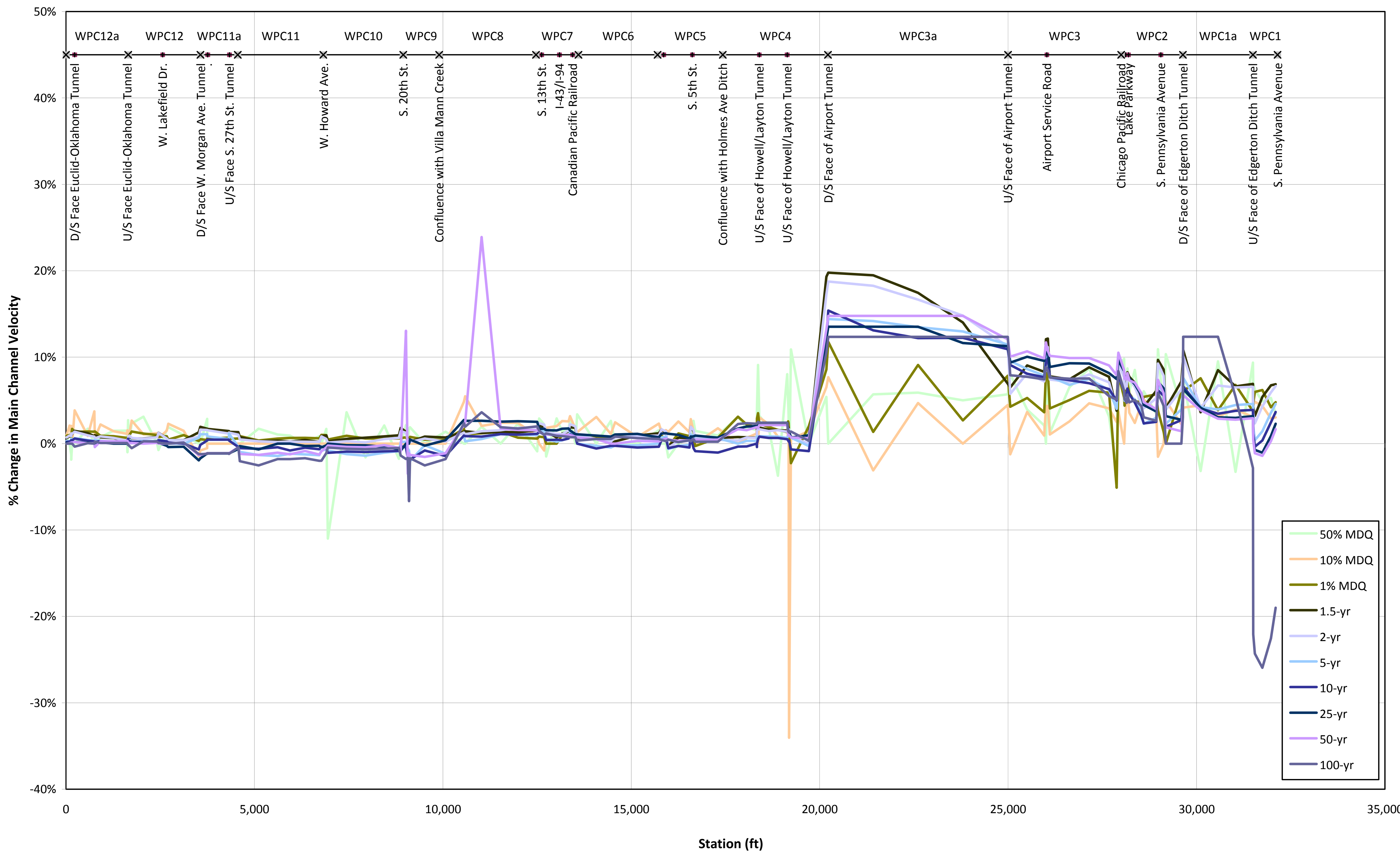
Computed percent change in main channel hydraulic depth from existing to future conditions in the Kinnickinnic River for selected flows up to the 100-year peak discharge.



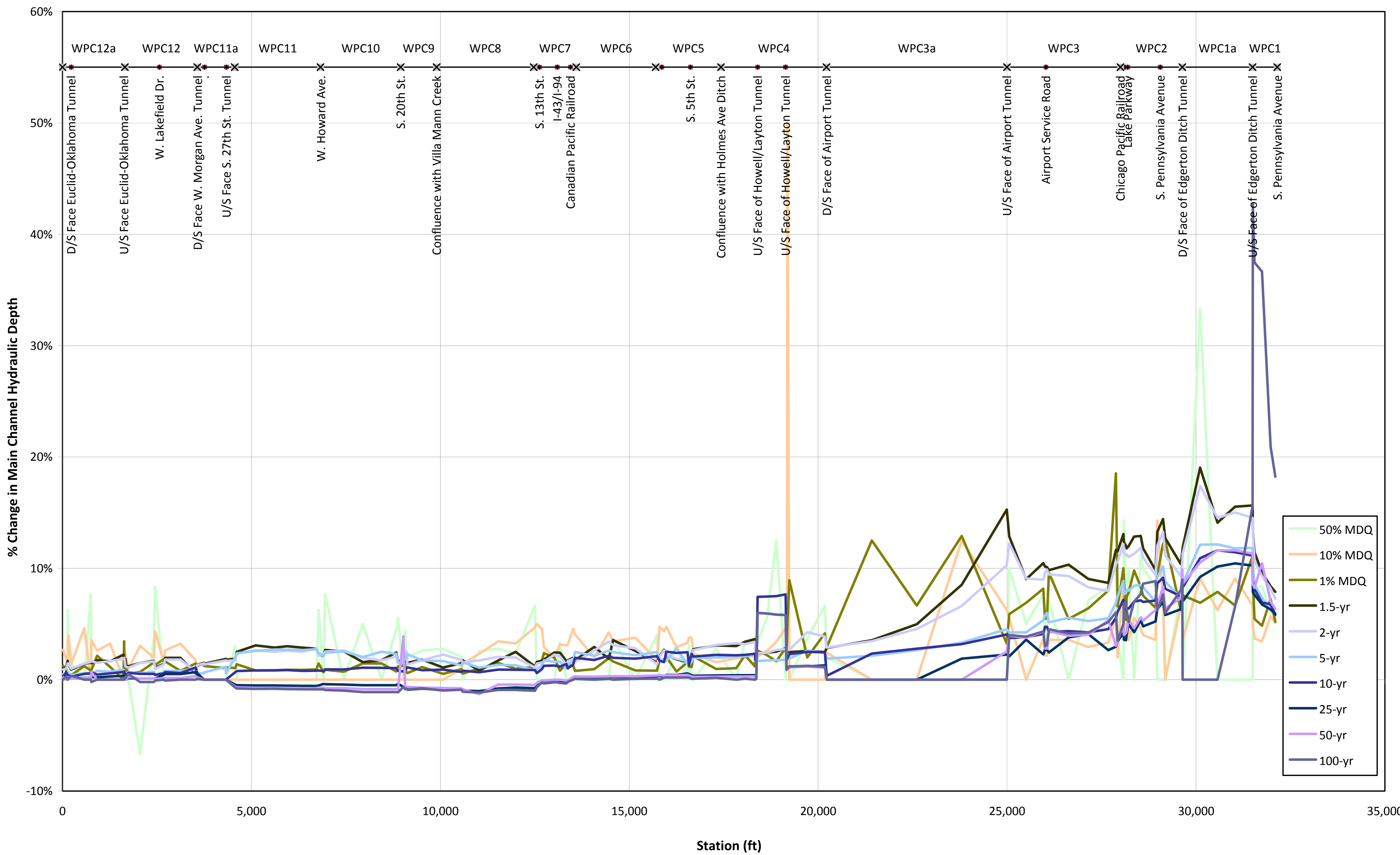
Computed percent change in main channel topwidth from existing to future conditions in the Kinnickinnic River for selected flows up to the 100-year peak discharge.



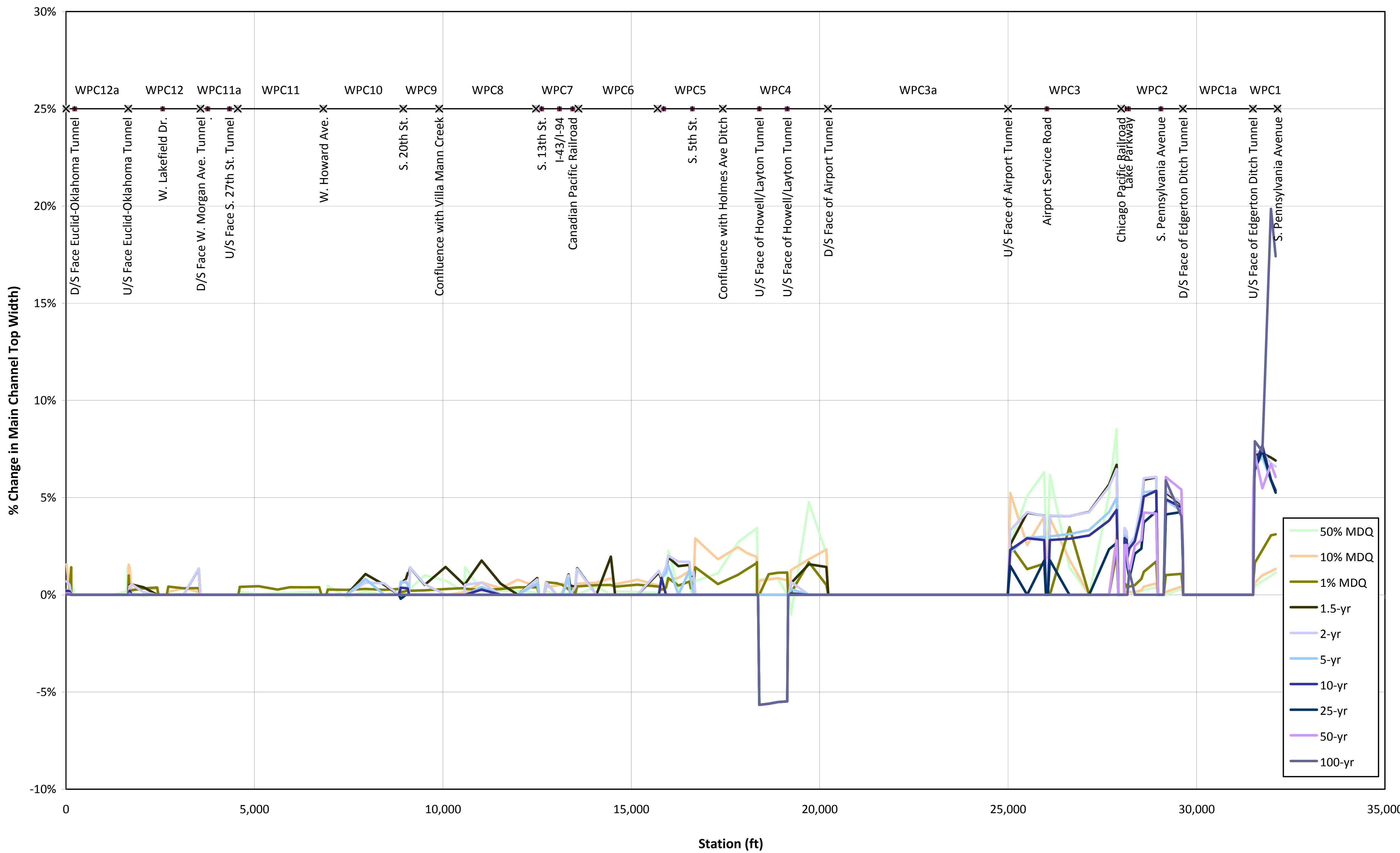
Computed change in water-surface elevation from existing to future conditions in Wilson Park Creek for selected flows up to the 100-year peak discharge.



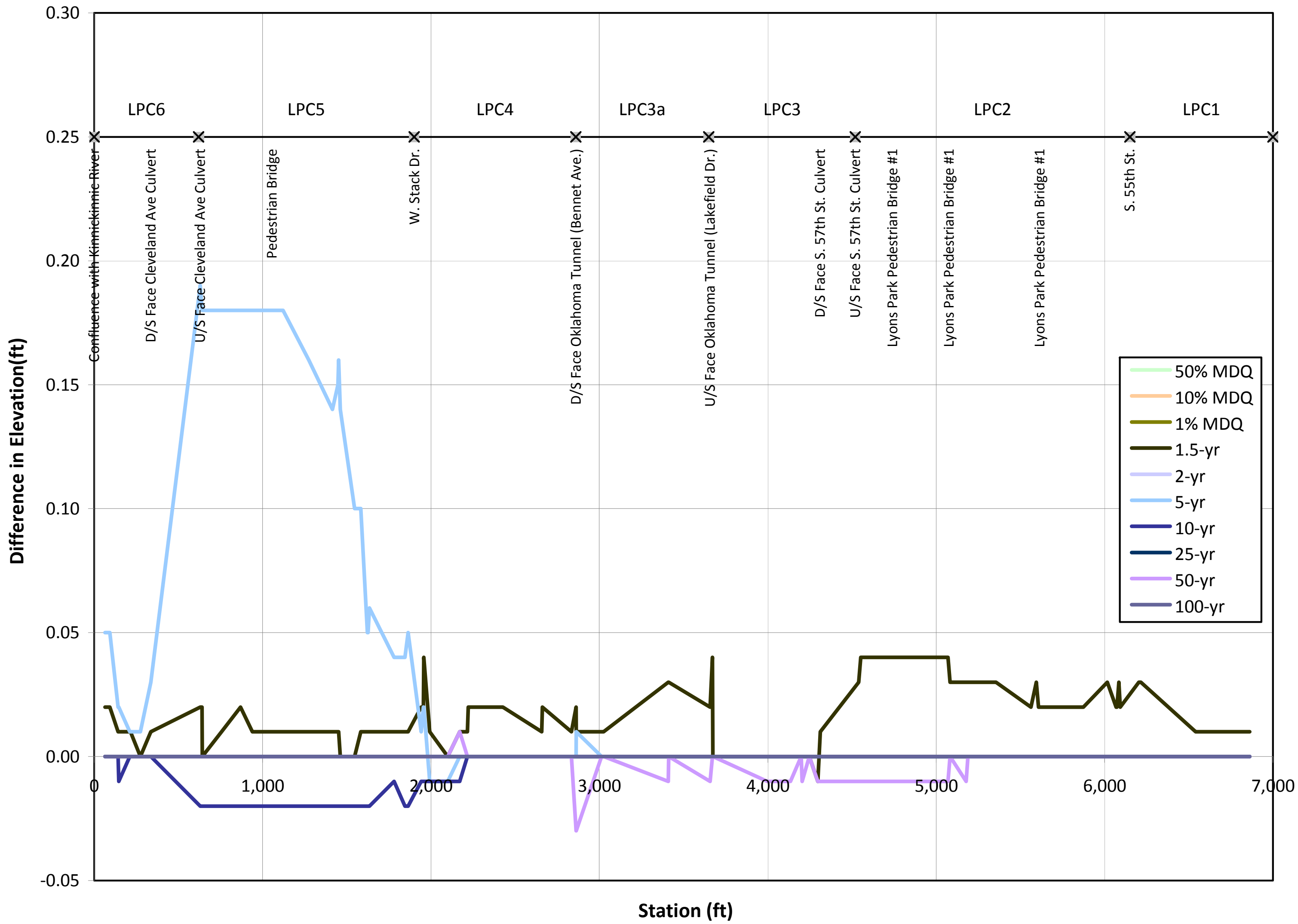
Computed percent change in main channel velocity from existing to future conditions in Wilson Park Creek for selected flows up to the 100-year peak discharge.



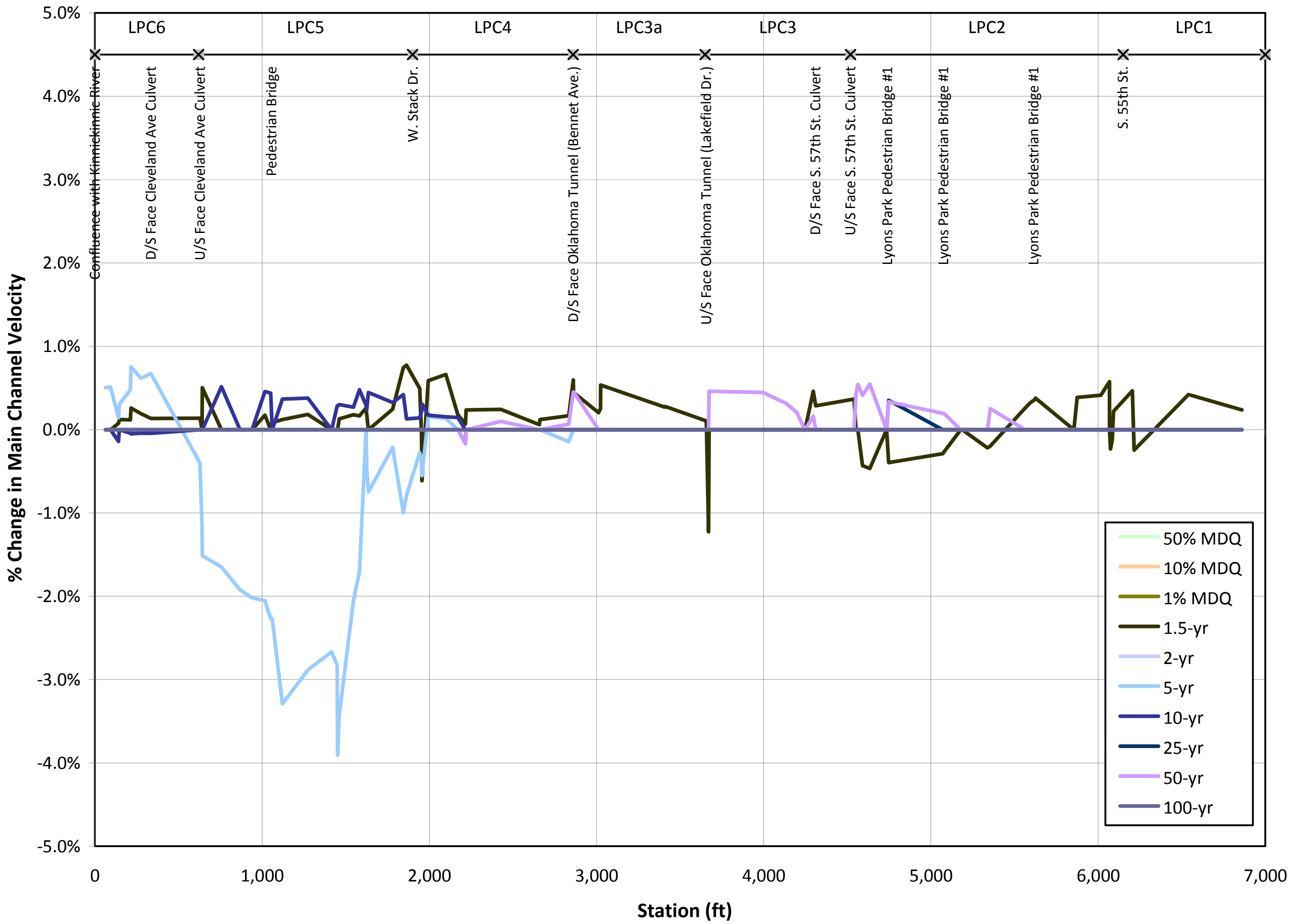
Computed percent change in main channel hydraulic depth from existing to future conditions in Wilson Park Creek for selected flows up to the 100-year peak discharge.



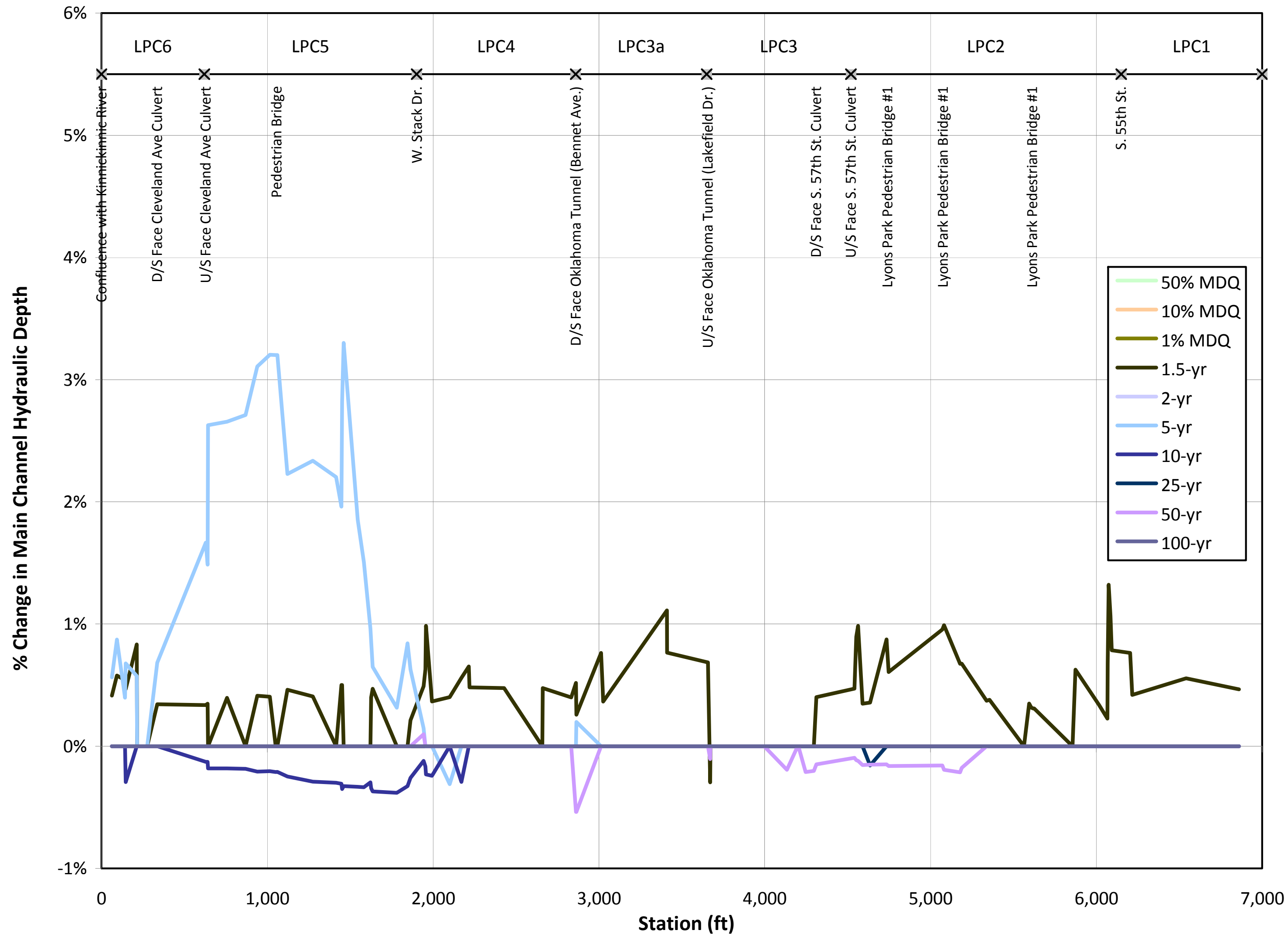
Computed percent change in main channel topwidth from existing to future conditions in Wilson Park Creek for selected flows up to the 100-year peak discharge.



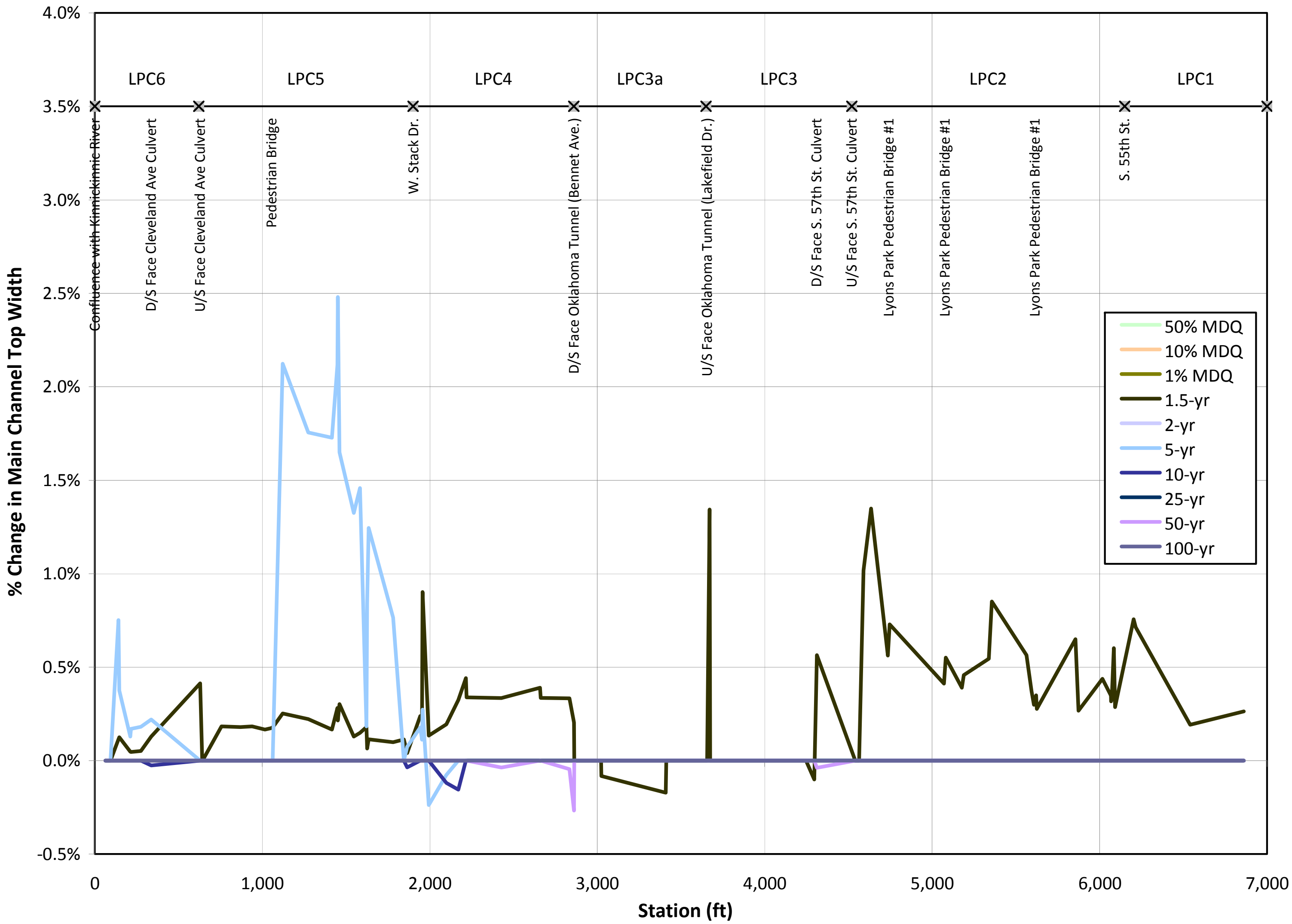
Computed change in water-surface elevation from existing to future conditions in Lyons Park Creek for selected flows up to the 100-year peak discharge.



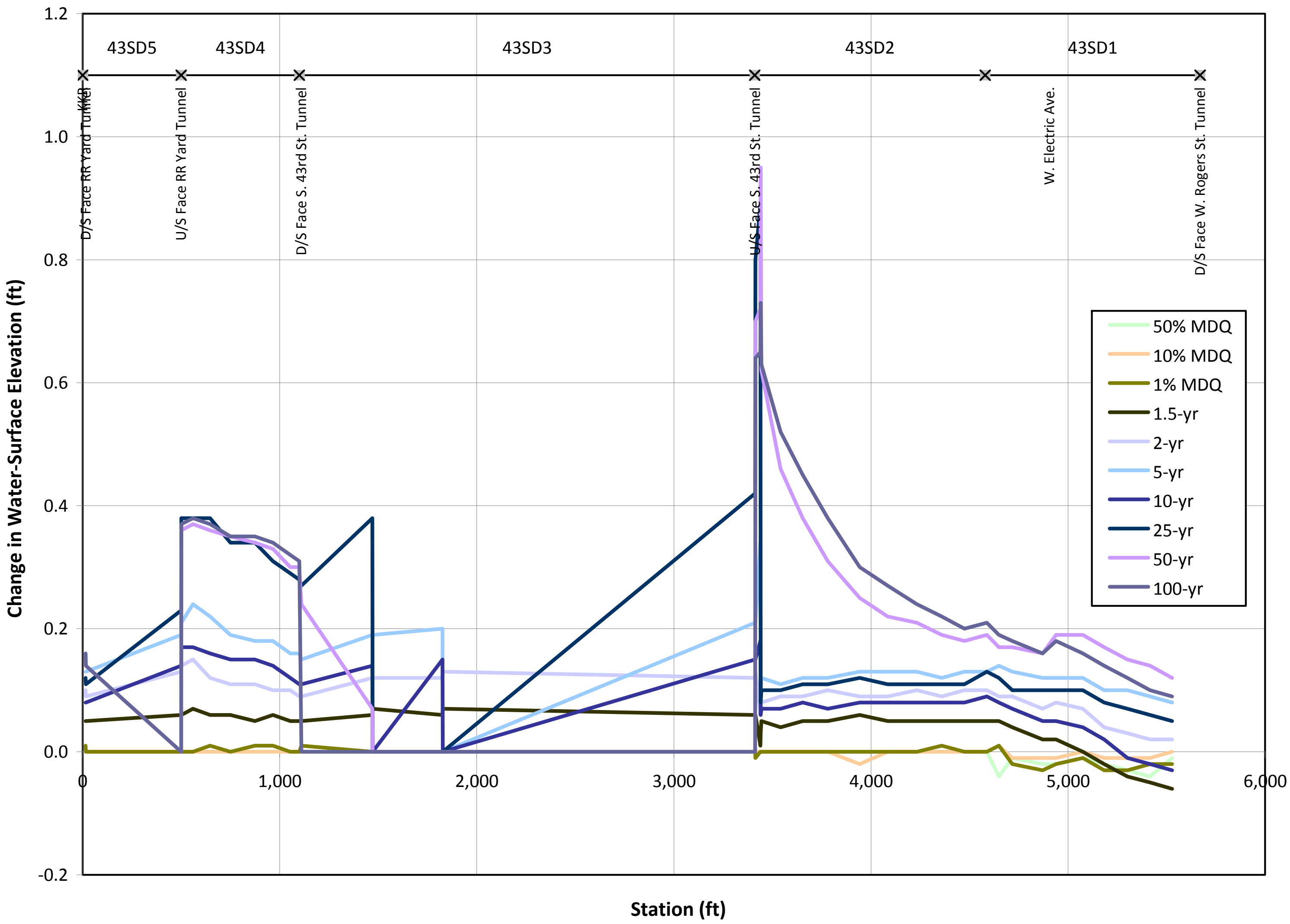
Computed percent change in main channel velocity from existing to future conditions in Lyons Park Creek for selected flows up to the 100-year peak discharge.



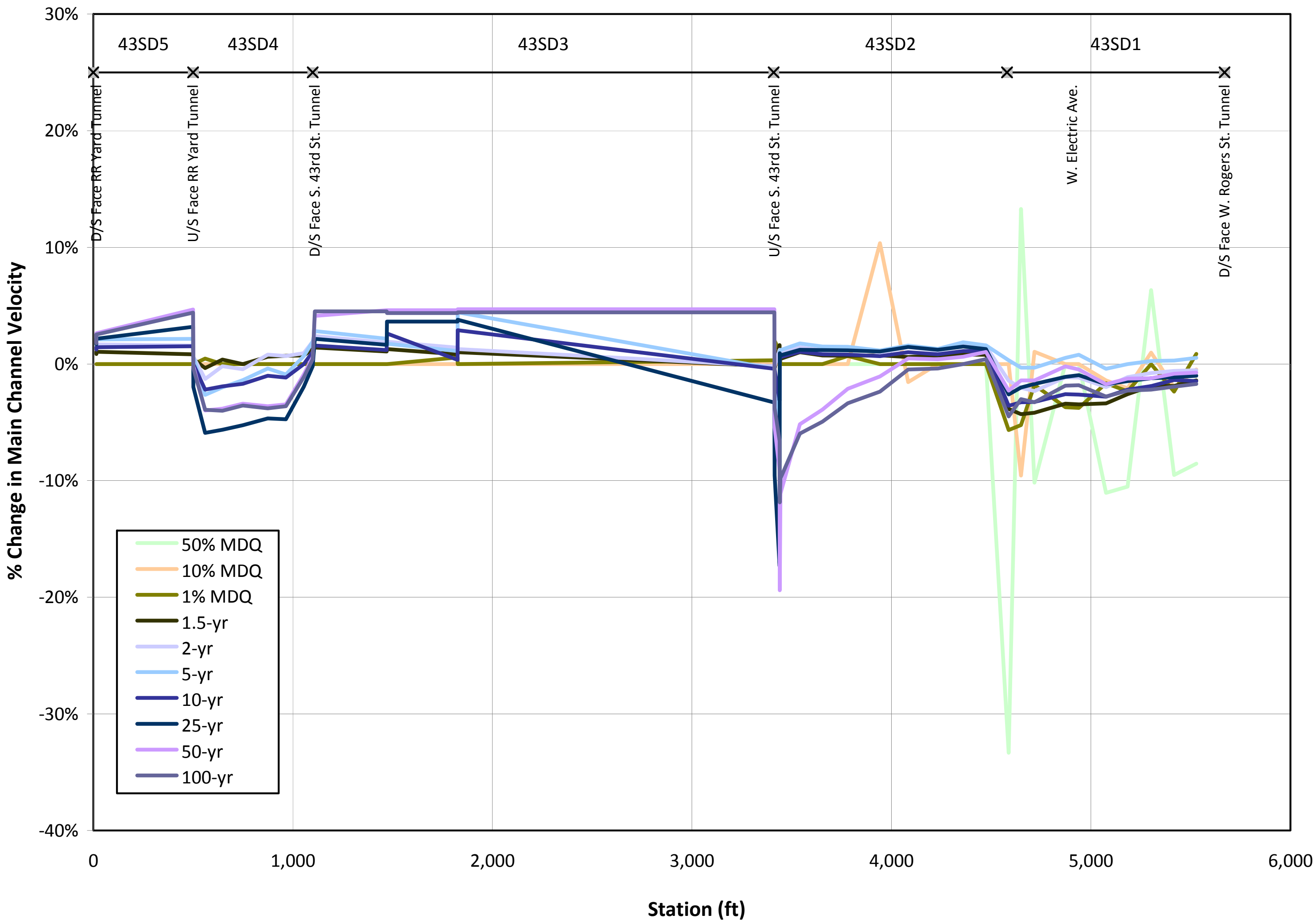
Computed percent change in main channel hydraulic depth from existing to future conditions in Lyons Park Creek for selected flows up to the 100-year peak discharge.



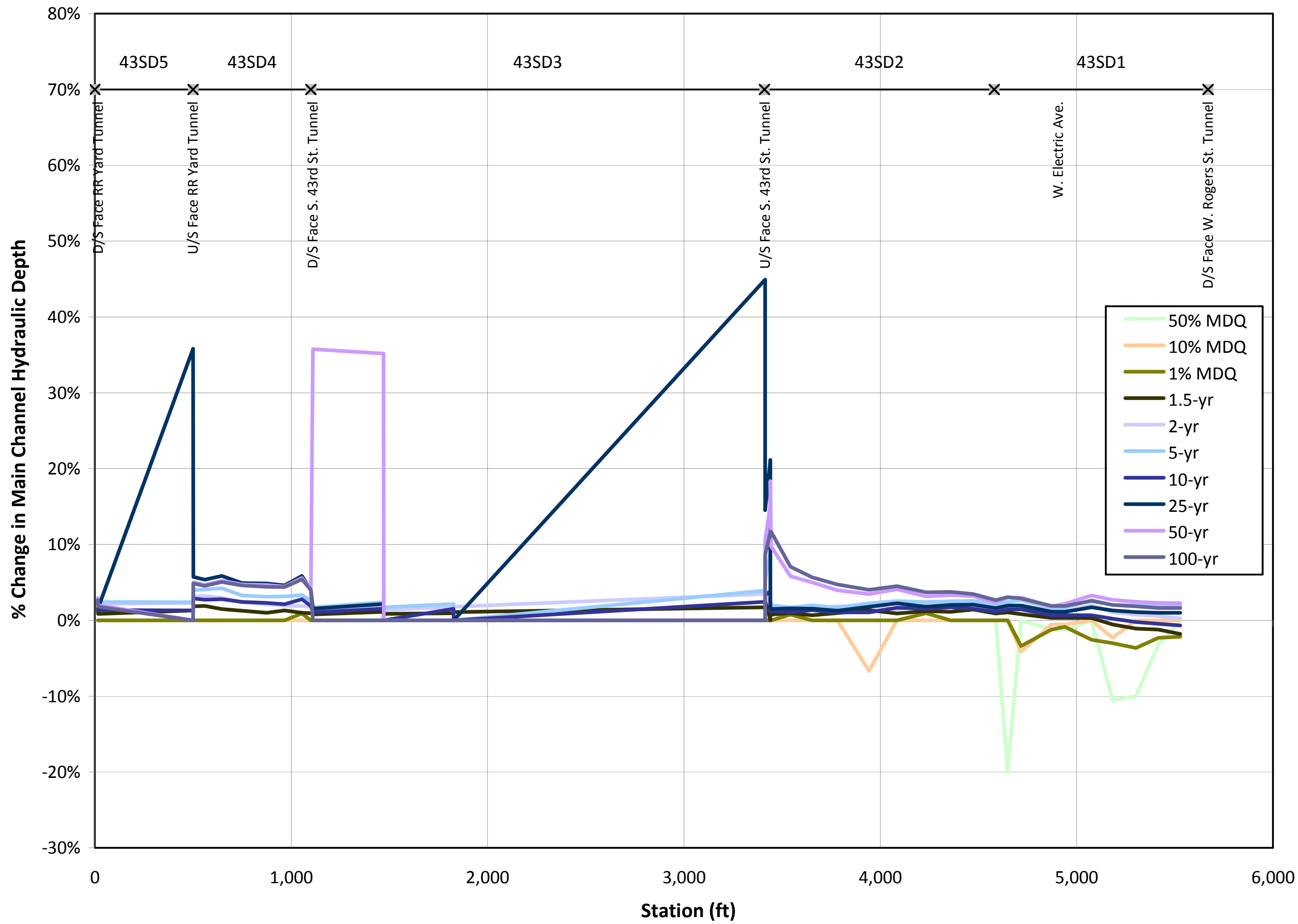
Computed percent change in main channel topwidth from existing to future conditions in Lyons Park Creek for selected flows up to the 100-year peak discharge.



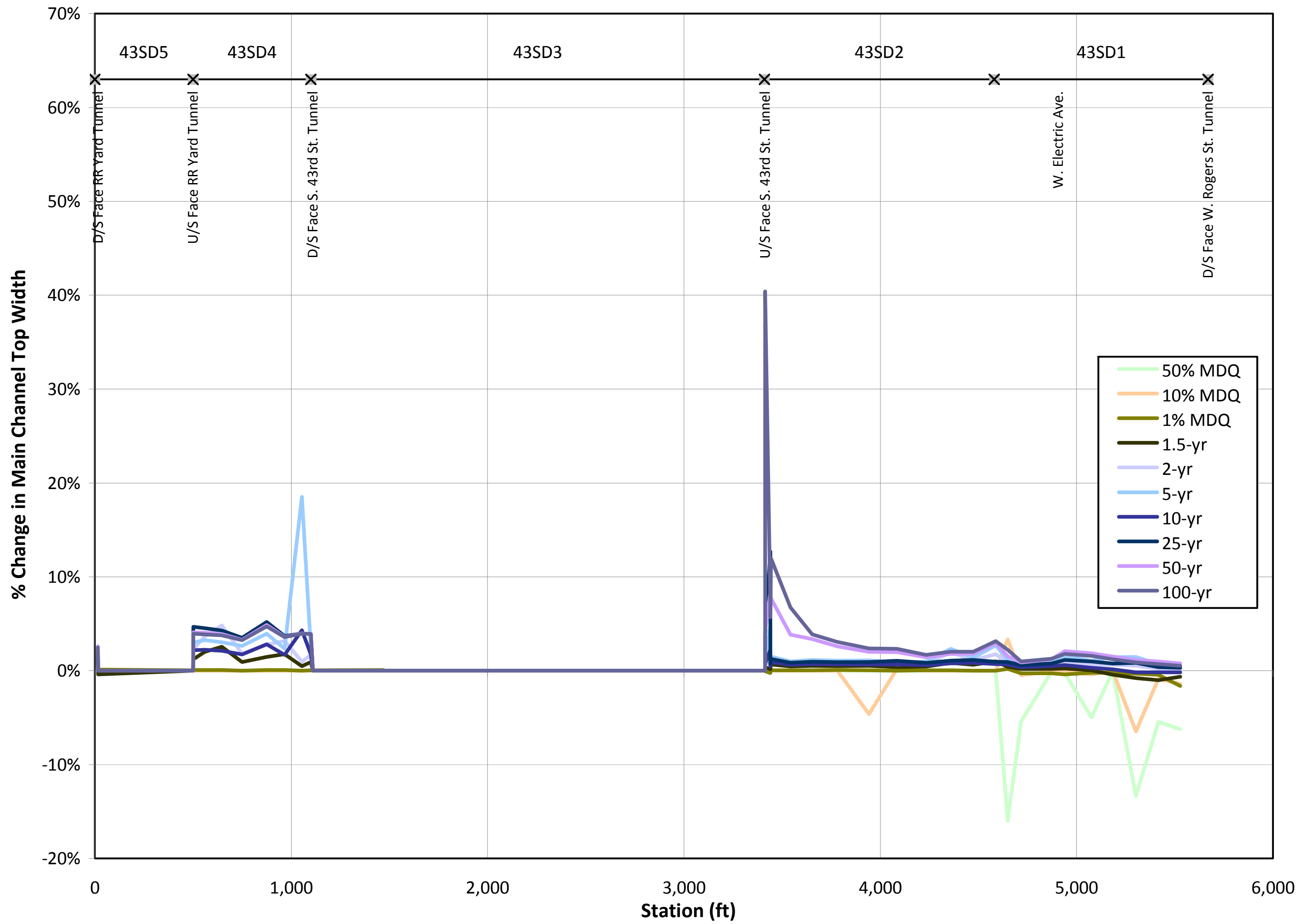
Computed change in water-surface elevation from existing to future conditions in South 43rd Street Ditch for selected flows up to the 100-year peak discharge.



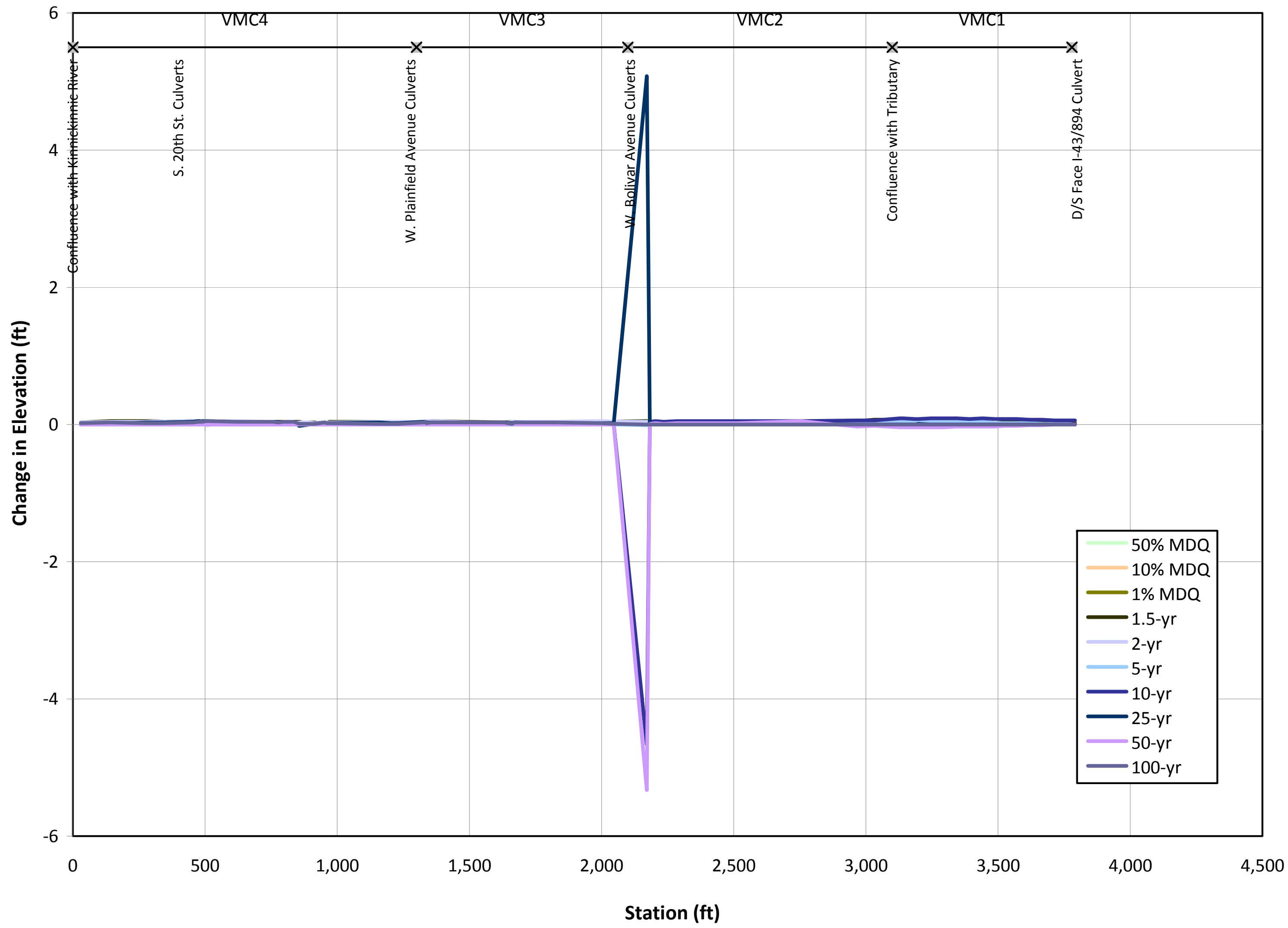
Computed percent change in main channel velocity from existing to future conditions in South 43rd Street Ditch for selected flows up to the 100-year peak discharge.



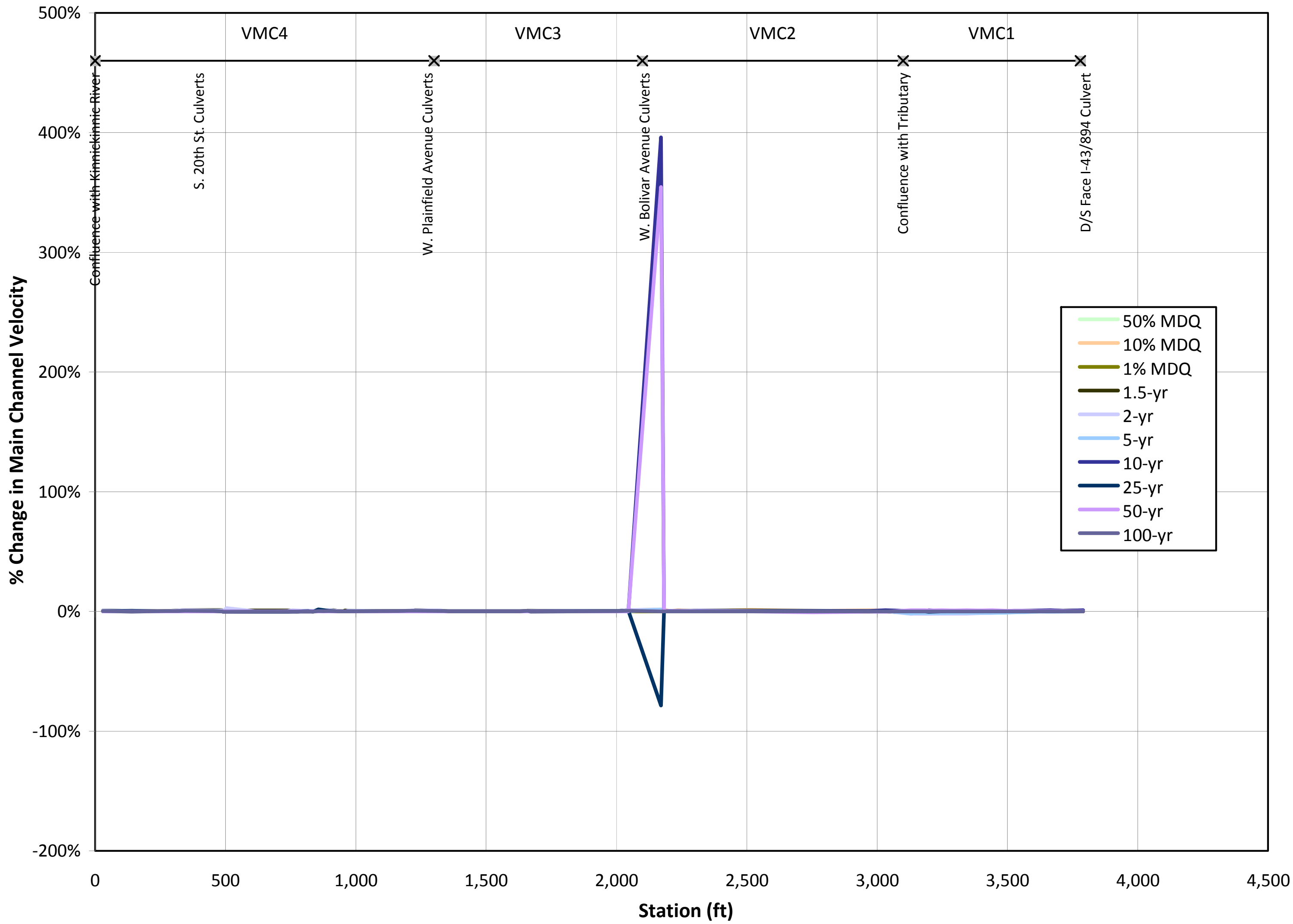
Computed percent change in main channel hydraulic depth from existing to future conditions in South 43rd Street Ditch for selected flows up to the 100-year peak discharge.



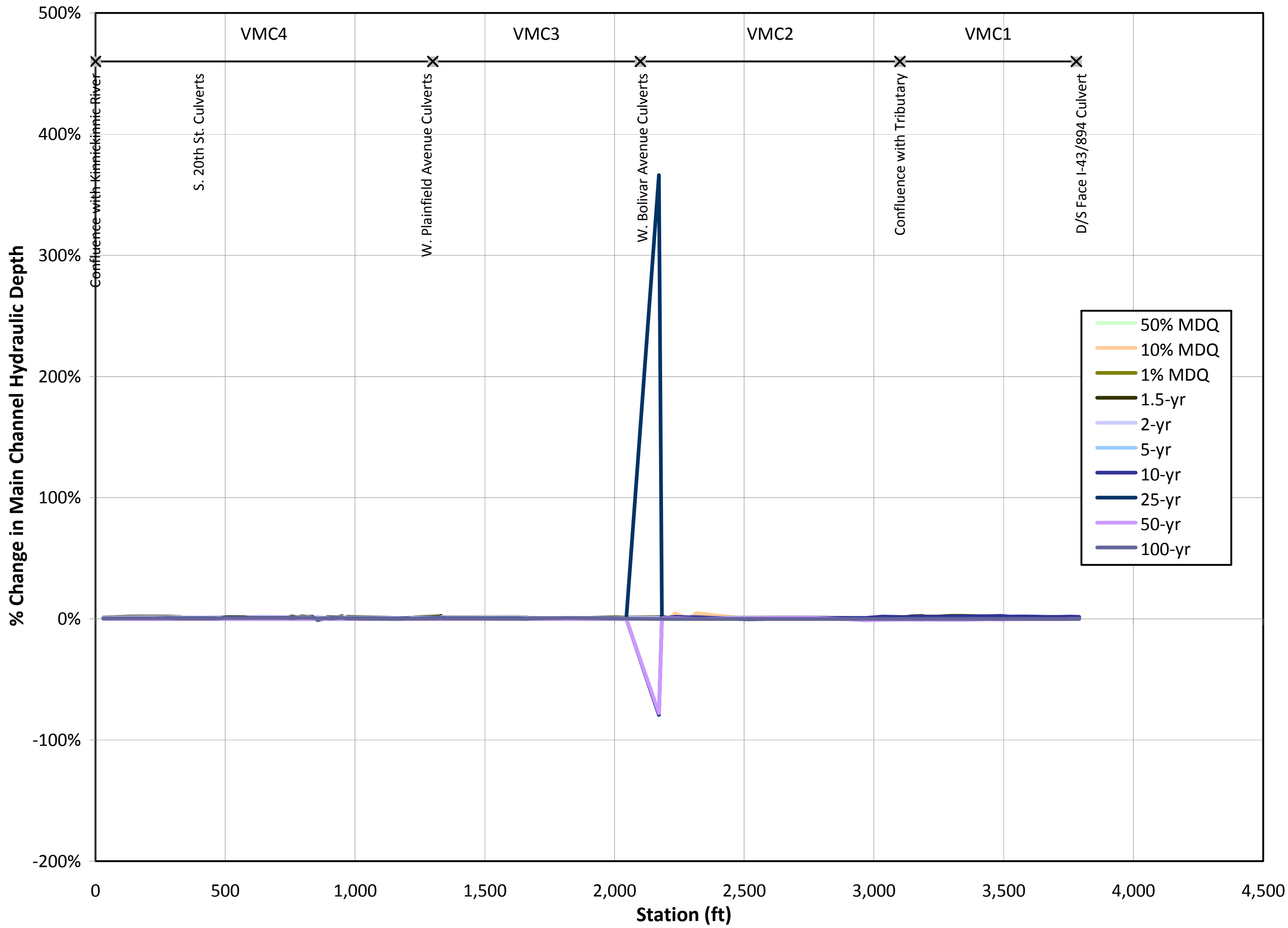
Computed percent change in main channel topwidth from existing to future conditions in South 43rd Street Ditch for selected flows up to the 100-year peak discharge.



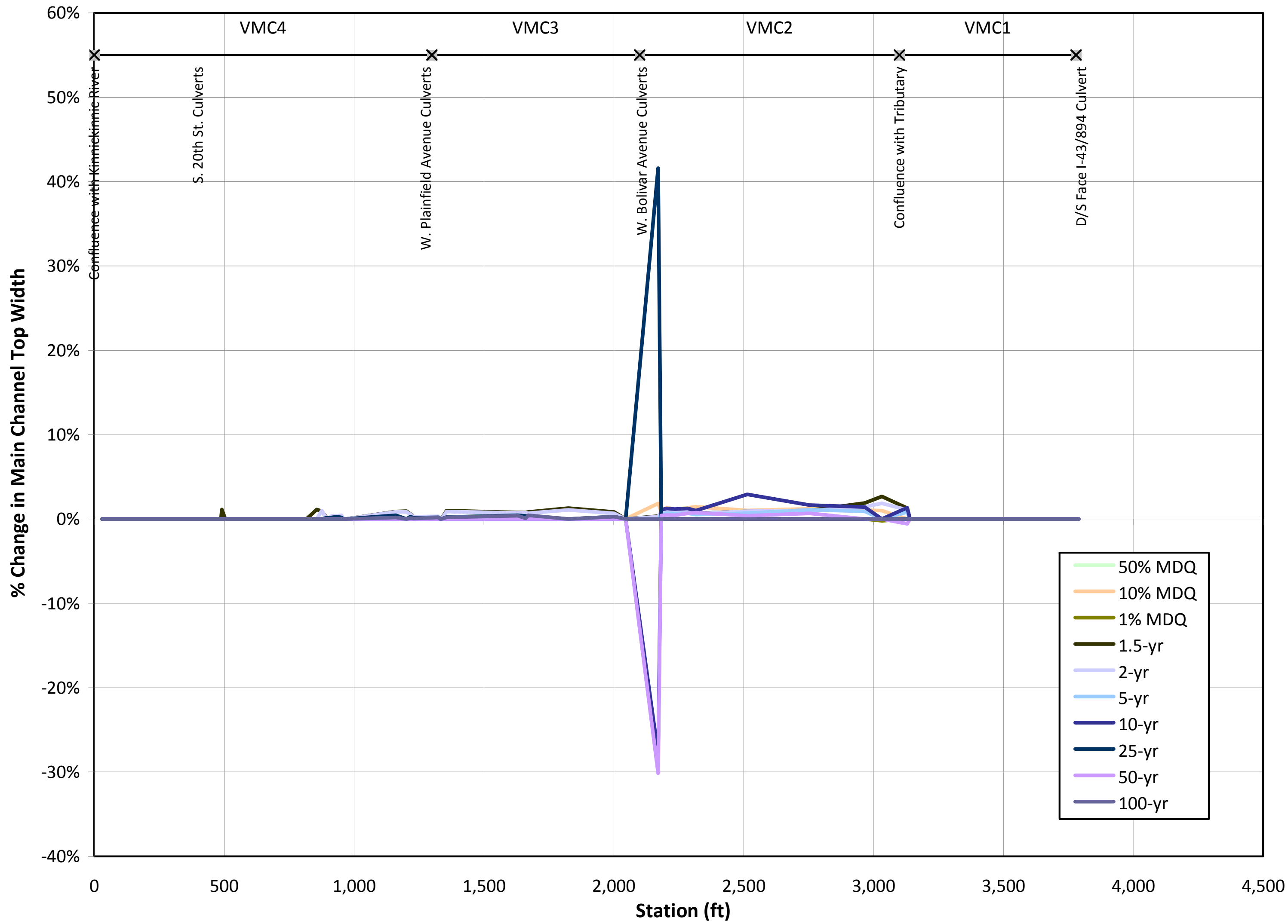
Computed change in water-surface elevation from existing to future conditions in Villa Mann Creek for selected flows up to the 100-year peak discharge.



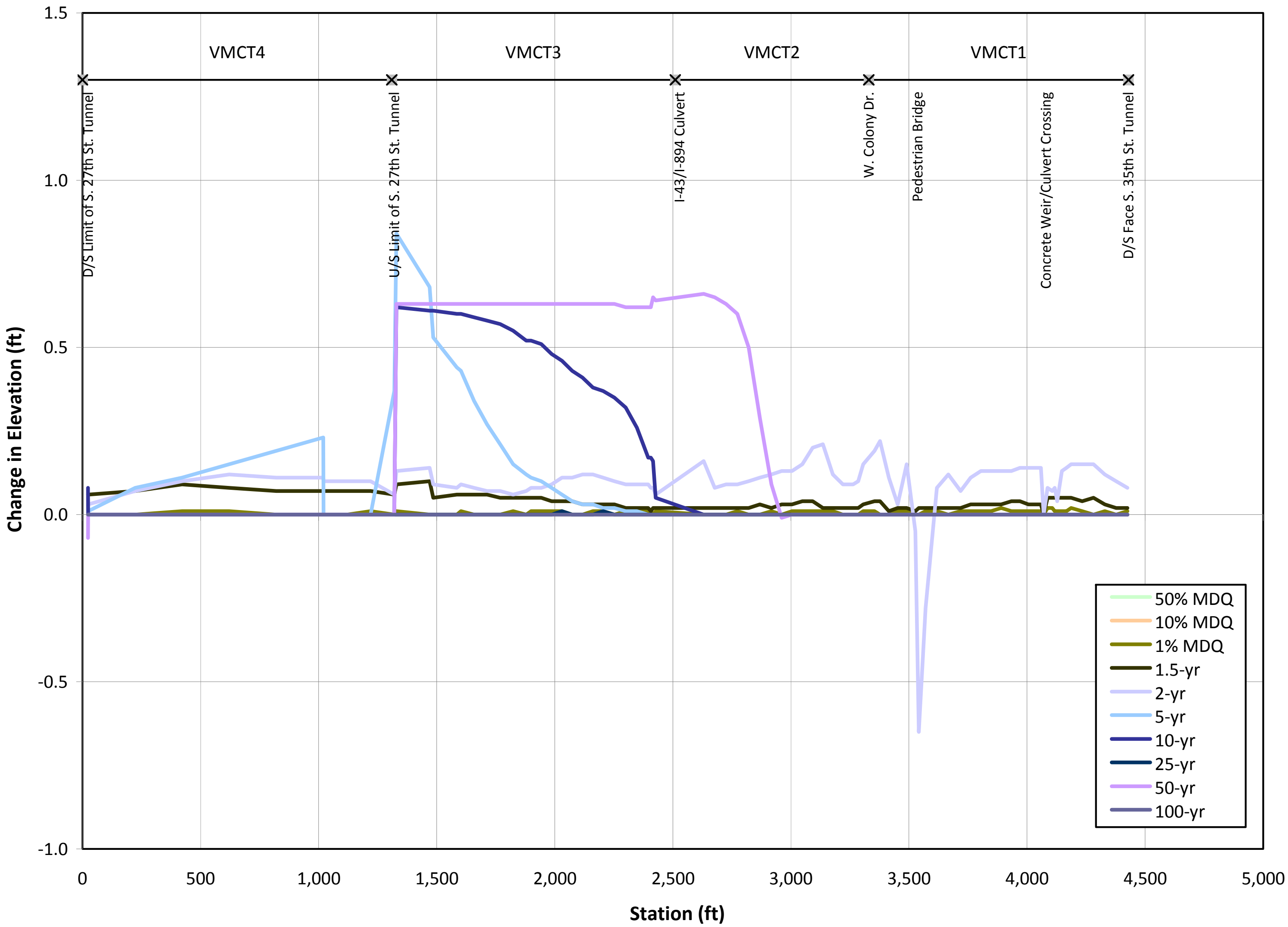
Computed percent change in main channel velocity from existing to future conditions in Villa Mann Creek for selected flows up to the 100-year peak discharge.



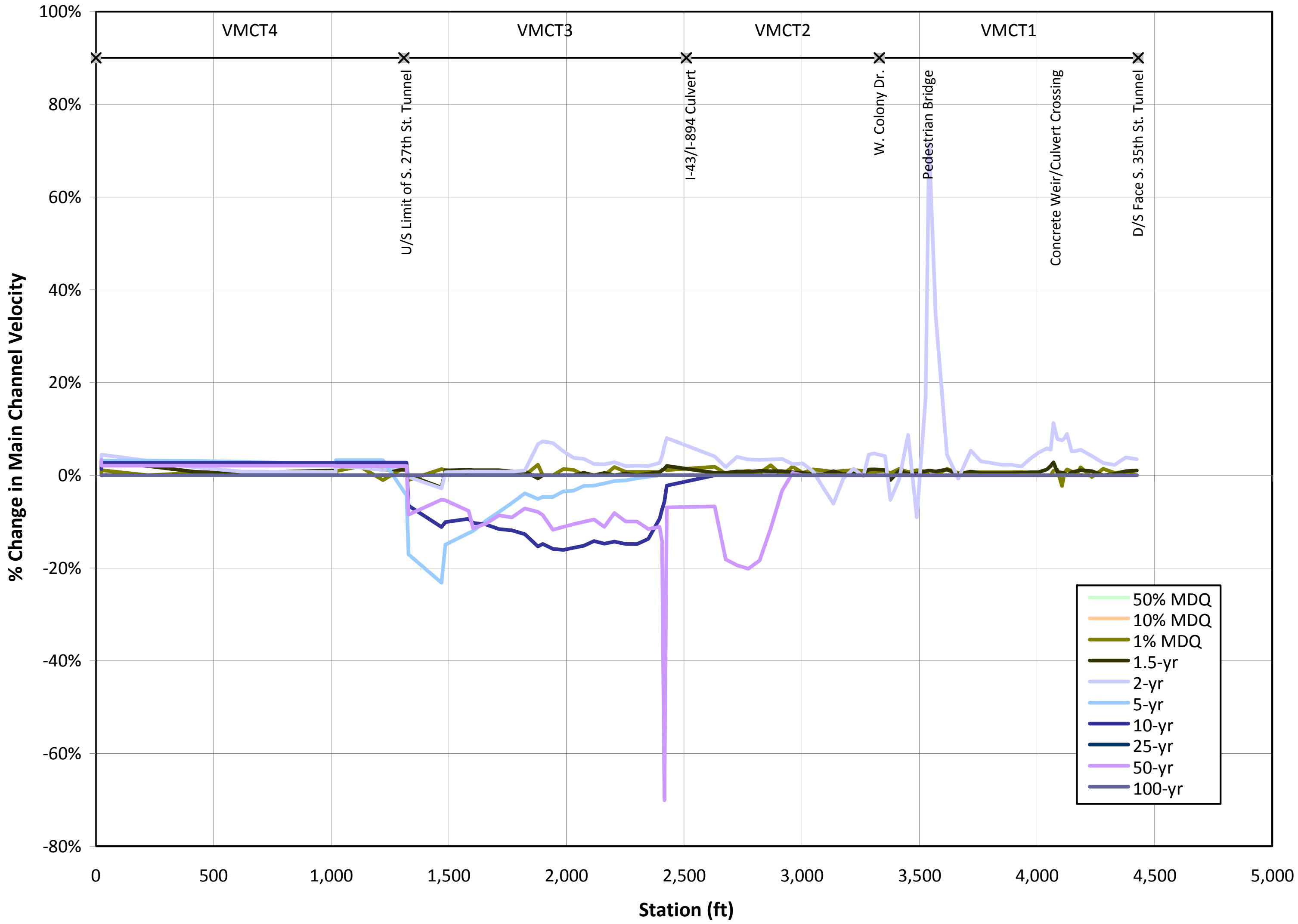
Computed percent change in main channel hydraulic depth from existing to future conditions in Villa Mann Creek for selected flows up to the 100-year peak discharge.



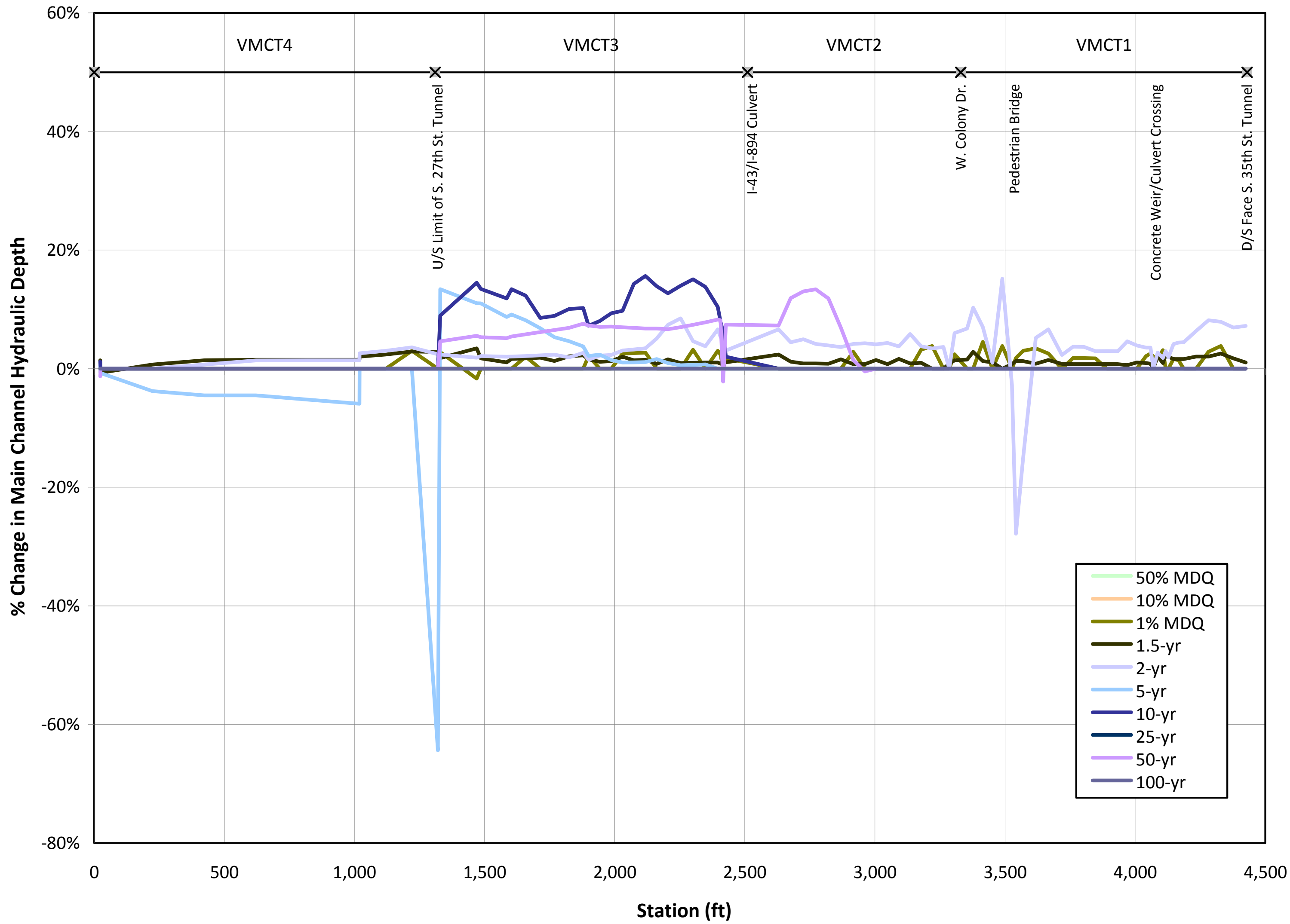
Computed percent change in main channel topwidth from existing to future conditions in Villa Mann Creek for selected flows up to the 100-year peak discharge.



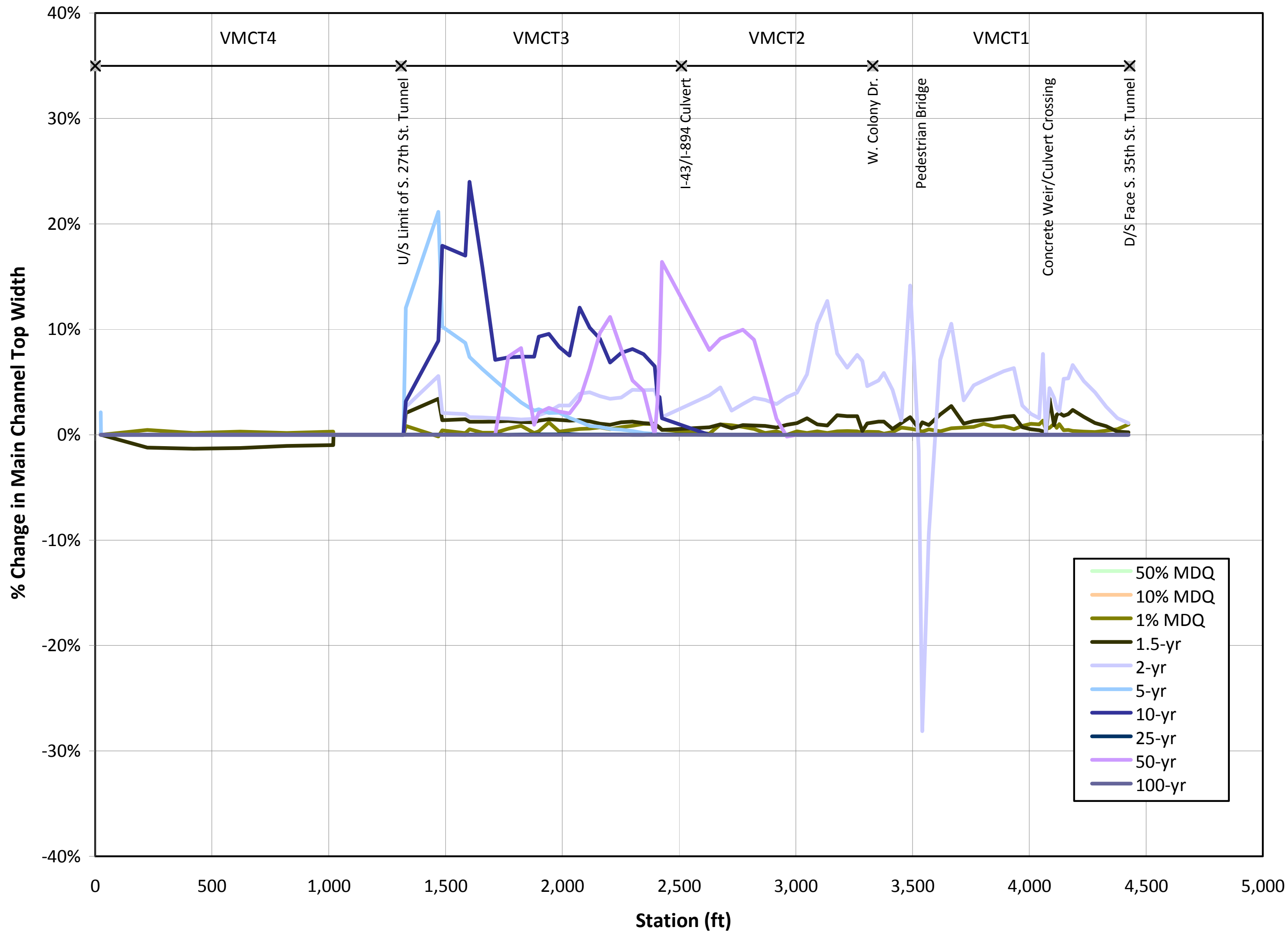
Computed change in water-surface elevation from existing to future conditions in the tributary to Villa Mann Creek for selected flows up to the 100-year peak discharge.



Computed percent change in main channel velocity from existing to future conditions in the tributary to Villa Mann Creek for selected flows up to the 100-year peak discharge.



Computed percent change in main channel hydraulic depth from existing to future conditions in the tributary to Villa Mann Creek for selected flows up to the 100-year peak discharge.



Computed percent change in main channel topwidth from existing to future conditions in the tributary to Villa Mann Creek for selected flows up to the 100-year peak discharge.