Calibration Results for 2003 Events

12 April 2005

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Methodology

The model of the lower Nooksack River has been calibrated to the 1990, 1995, and 2002 floods in a prior project. The occurrence of three significant floods in October-November of 2003, with additional observations of high-water marks (HWM's), presented additional opportunity to refine the model calibration with this new data. A model of this size and complexity always has large areas with no information on water levels in past floods. Adjustment of the model parameters is expected in those areas where new HWM's are found.

The goal of this recalibration was to maintain the results for the earlier flood events while properly reproducing the new data. From flood to flood some parts of the main channel of the Nooksack River may move laterally by many tens and sometimes hundreds of feet. These frequent channel movements have not been included in the current model. The channel geometry is in the position defined by the 1993 topographic maps of the river. However, the working hypothesis that the capacity of the main channel is effectively the same no matter what location it has, worked well previously, and has been maintained in the results presented herein.

The calibration process is as follows:

1. Estimate the tributary inflow hydrographs at the significant tributaries by using drainage-area ratios to adjust the observed record at Fishtrap Creek and at Anderson Creek. Fishtrap Creek is used for all tributaries downstream of the bridge at Everson and Anderson Creek is used for those tributaries upstream of this bridge.
2. Adjust and shift the hydrograph at Deming, as defined by the current rating curve used by the United States Geological Survey (USGS), to reproduce the hydrograph at Ferndale closely. The rating at Deming is poor and cannot be depended upon to provide flows that will reproduce Ferndale flows. Thus we first adjust the record at Deming to get a good approximation to the flows at Ferndale.
3. Compare the simulated maximum elevation with the observed elevation at each HWM. Make adjustments in an approximate order of priority as follows:
   - 3.0 Review the HWM relative to others from the same flood to see if it makes sense. Also check its location to make sure that the model as it now exists can represent the flow of water at that point. Several marks have been defined that were made by water enroute to the low point of the flood plain. These marks cannot be represented by the model until additional detail near the edges of the flood plain are added. Roads near the toe of levees as well as farm buildings near the toe of levees can yield useful HWM's but these can only be modeled if the geometric feature causing the water to pond is represented in the model.
   - 3.1 If the HWM is affected by a levee breech, make adjustments to the levee breach parameters to reduce the elevation difference.
   - 3.2 Review and adjust the roughness of the flow path for the HWM. This adjustment must be reasonable and care must be used to avoid unrealistic values.
   - 3.3 If the HWM is affected by a control surface, review the length, slope, and roughness of that surface to see if changes can be made to reduce the elevation difference. If the control surface elevation is based on the digital terrain model (DTM), then consider small shifts in elevation if other options are ineffective.

3.4 If the HWM is in the main channel, review and possibly shift the channel invert of the main channel to reduce the elevation difference.

3.5 Make additional adjustments to the flows at Deming.

The pattern followed is to make adjustments to the more uncertain values first. The details of a levee failure are most uncertain and surveyed control surfaces are the least uncertain. The roughness of a flow path in a flood plain is always of uncertain value given the complexity of the geometry which includes ditches, fence lines, roads, and so forth. The roughness and invert of the main channel of the Nooksack are also uncertain and are therefore one of the primary means of making adjustments.

As adjustments are made to improve the mimicry of the 2003 HWM's, each of the other events must be rerun and checked to ensure that prior results are maintained. In some cases this rule was not followed when the 2003 mark was deemed more reliable than marks from the 1995 or 1990 floods. Later surveys have benefitted from the Global Positioning System (GPS) so that marks can be located within a tolerance of a few feet. Some marks from the earlier survey are difficult to locate with precision in the model.

High-Water Mark Results

The results for the high-water marks are presented in chronological order with two tables for each event. The first table gives a brief description of each mark, its location in terms of the unsteady-flow model, and the elevation outcome. The second table gives a summary of the results in the first table.

High-water marks for 1990. There were 37 high-water marks used in the comparison. About 12 marks were not used. Some could not be placed on the ground with any precision. Several had values so much higher than simulated that they appeared to be in error. The results here are similar to those found in the previous report. Some marks have shifted but not enough to place them outside the tolerance used. Table 1–1 gives the details for each HWM used while Table 1–2 gives the summary of the results.

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TABLE 1–1: High-Water Mark Results: 1990 Event

High-Water Mark Description	Branch Number	Node	Observed Elevation (ft)	Simulated Elevation (ft.)	Difference Sim - Obs (ft)
Usgs Gage Deming	0	U4000	219.300	219.433	0.133
M-4 KCM NkskFldHstry p. 16	0	U4414	199.480	199.376	-0.104
HWM 61 Nugents Corners Brdg ups? M-9	0	D4062	156.000	156.592	0.592
M-6 KCM NkskFldHstry p. 16	0	D4840	156.470	155.881	-0.589
M-9 KCM NkskFldHstry p. 16	4068	406804	128.790	127.964	-0.826
M-9-7 KCM NkskFldHstry p.16	4069	406904	118.720	117.830	-0.890
Avr of 93.16,94.22. nr Emmrsn/Mssy cnr	0	D4606	93.700	92.908	-0.792
TP-A	0	D4608	91.740	91.607	-0.133
HWM 46 Mlk Prlr E Emmrsn Rd.	0	D4613	87.800	87.859	0.059
TP-C Rds Lane and Emmrsn Rd.	4622	462202	87.650	87.429	-0.221
M-11-5 Emmrsn Rd and Rds Lane	0	D4623	87.490	87.381	-0.109
HWM 44 Ups Everson Bridge M-12	0	D4141	84.480	84.114	-0.366
M-12-2 NkskFldHstry p16 R1 Blw EvrBrdg	0	U3402	84.560	82.628	-1.932
Log Cabin in park-	3403	340302	83.350	82.518	-0.832
M-12-3 R1 Nr StcknyIsld Rd Blw EvrsnBr	0	D3405	82.500	82.072	-0.428
Ups Evrsn MS utlty box	0	D4541	83.150	83.015	-0.135
M-13 on KCM map	3023	302302	77.550	77.735	0.185
HWM 40 Noon and Abbot in Nksk. M-14	3063	306302	68.910	69.259	0.349
HWM 38 Ron Bronsema gage	3081	308102	65.600	65.093	-0.507
Ron's estmt Nrthwd Rd(57.7 + 58.9)/2	0	D3862	58.300	57.380	-0.920
HWM 33 On Theil Rd	0	D3286	56.300	56.367	0.067
KCM pnt "M" NkskFldHstry p. 17	3511	351102	57.350	57.293	-0.057
HWM 31 Nr Hmptn/Nksk Av-"L"-KCM Doc	0	D3523	57.450	56.684	-0.766
HWM 30 Ups HngnRd Brdg-Nksk? M-15	0	U3129	57.000	57.088	0.088
HWM 28 Dns Guide Mrdn M-17	0	U2000	47.400	48.620	1.220
M-18 (flowpath unclear-MM,R1?)	2417	241702	40.600	40.864	0.264
HWM 26 Top step off Rvr Rd	2415	241501	40.600	41.172	0.572
KCM pnt "J" NkskFldHstry p. 17	2422	242202	40.810	40.437	-0.373
HWM 21 Dahlberg Rd	2474	247401	35.400	34.966	-0.434
HWM 18 nrly at HWM 17	2132	213202	33.600	33.999	0.399
HWM 15 Mark on milkhouse	0	D2168	33.800	33.066	-0.734
HWM 14 Ups I-5. Take Ed's mark.	0	D2195	33.300	32.742	-0.558
Usgs Gage Ferndale	0	D1010	28.200	27.758	-0.442
HWM 9 Pmp Hs nr Frndl WTP	1014	101403	26.500	26.341	-0.159
KCM pnt "I" NkskFldHstry p. 17	1215	121503	25.640	25.996	0.356
HWM 8 Hvndr Prk Offc Bldg	1222	122202	23.600	23.248	-0.352
HWM 1 Marietta Slough-avrg of 2 marks	0	U1310	12.000	12.424	0.424

The distribution of differences shows a bias to the low side. Some other events show a bias in the other direction. Consequently effort was not expended on trying to get a more centered result because doing so would have made another events HWM's fall outside the tolerance range of one foot from the surveyed level.

High-water marks for 1995. Only 16 marks were used for this event. About five marks were not

TABLE 1–2: High-Water Mark Mimicry Summary: 1990 Event

High-Water Mark Difference Range (ft)	Number of Differences	Proportion of Total Number	Cumulative Proportion
-5.00 to -1.00	1	0.03	0.03
-1.00 to -0.50	10	0.27	0.30
-0.50 to -0.25	6	0.16	0.46
-0.25 to -0.10	6	0.16	0.62
-0.10 to 0.00	1	0.03	0.65
0.00 to 0.10	3	0.08	0.73
0.10 to 0.25	2	0.05	0.78
0.25 to 0.50	5	0.14	0.92
0.50 to 1.00	2	0.05	0.97
1.00 to 5.00	1	0.03	1.00

used, some for being pre-peak and others for apparent errors in elevation that yielded differences too large to reduce without destroying the mimicry of other HWM's. Table 2–1 gives the details for the HWM's and Table 2–2 gives the summary of the results.

TABLE 2–1: High-Water Mark Results: 1995 Event

High-Water Mark Description	Branch Number	Node	Observed Elevation (ft)	Simulated Elevation (ft.)	Difference Sim - Obs (ft)
Usgs Gage Deming	0	U4000	219.000	218.813	-0.187
HWN 68 RB Deming Levee	4011	401103	203.500	202.364	-1.136
HWM 66 RB on levee. S. Wllms Rd	4026	402602	186.000	186.050	0.050
HWM 64 RB on levee. nr Mariotta Rd.	4039	403902	176.400	175.548	-0.852
HWM 42 LB on Nolte Rd nr peak	3022	302201	78.000	78.146	0.146
HWM 38 Ron Bronsema gage	3081	308102	66.600	65.883	-0.717
HWM 16 RB in over bank	2153	215301	31.500	31.777	0.277
HWM 10 nr Frndl WTP	1014	101402	25.400	25.446	0.046
HWM 5 ups Sltr Rd- pre-peak?	0	D1048	18.600	18.994	0.394
HWM 47 OvrQ Pth nr Emmrsn Rd	4615	461501	87.700	86.880	-0.820
HWM 48 MnSrt Evrsn-81.4 + 0.25	0	D4541	81.700	82.107	0.407
Apprx Mdln UtilityBx ups MnSrt(1)	0	D4541	83.000	82.107	-0.893
HWM 19 RghtFP-	2531	253102	34.700	32.473	-2.227
HWM 7 LftFP ups SltrRd	0	D1248	12.600	14.512	1.912
HWM 3 Rnbw Slgh LftFP	0	D1409	9.900	9.924	0.024
Usgs Gage Ferndale	0	D1010	26.660	26.833	0.173

The summary for this event shows a fairly uniform distribution of differences for the 16 marks used in the calibration check.

High-Water Marks for January 2002 event. This event was the first event that was surveyed when GPS readings were available. Also the Whatcom County staff were mobilized to collect marks soon after the event and the field survey for elevation followed without significant delay. No marks were excluded. Some marks included were inconsistent, that is, two marks appeared

TABLE 2–2: High-Water Mark Mimicry Summary: 1995 Event

High-Water Mark Difference Range (ft)	Number of Differences	Proportion of Total Number	Cumulative Proportion
-5.00 to -1.00	2	0.12	0.12
-1.00 to -0.50	4	0.25	0.37
-0.50 to -0.25	0	0.00	0.37
-0.25 to -0.10	1	0.06	0.43
-0.10 to 0.00	0	0.00	0.43
0.00 to 0.10	3	0.19	0.62
0.10 to 0.25	2	0.12	0.74
0.25 to 0.50	3	0.19	0.93
0.50 to 1.00	0	0.00	0.93
1.00 to 5.00	1	0.06	0.99

to be influenced by water levels that should have been close in elevation but the marks showed deviations that could not be supported by the simulation. We could not determine the source of the discrepancy. No topographical feature could be found to support the difference in elevation. Table 3–1 gives the details for the HWM results for the January 2002 event while Table 3–2 gives the summary.

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TABLE 3–1: High-Water Mark Results: Jan. 2002 Event

High-Water Mark Description	Branch Number	Node	Observed Elevation (ft)	Simulated Elevation (ft.)	Difference Sim - Obs (ft)
Usgs Gage Deming	0	U4000	218.000	217.804	-0.196
HWM 23-RB Nks on Dmng Dk	4011	401101	201.000	201.914	0.914
HWM 22-RB Nksk on lve bank	4038	403802	174.600	174.632	0.032
HWM 21-RB Nksk on bank	0	U4051	162.300	161.413	-0.887
HWM 20-RB undr NgntsCrnrBrdg	0	U4160	149.700	148.904	-0.796
HWM 19-RB Nksk .13 mi dns NgntsCrnrBrdg	4161	416102	147.700	147.830	0.130
HWM 18-RB Nksk @ RvrBrryPrjct	4069	406914	109.600	108.663	-0.937
HWM 17-RB Nksk VnDellnPrjt	4084	408401	99.200	98.676	-0.524
HWM 15-RB OvqPth on dk ups EvrsnBrdg	4630	463001	85.600	82.525	-3.075
HWM 14-RFP RvrsdMmrlPrk-StknyIslndRd	3003	300301	79.700	80.302	0.602
LB Nksk Noon-Abbot 3' blwbnk- bnkZ=71.5'	3063	306301	68.500	69.069	0.569
Ron Bronsema gage	3081	308102	65.400	65.584	0.184
RB Nksk Hnk Rnda's obs Frd Plndr Lnd	3118	311801	57.700	58.413	0.713
RB Nksk Hnk Rnda's obs Frd Plndr Lnd	3120	312001	57.700	58.202	0.502
Hannegan Gage 23 ft reading	0	D3129	57.100	57.479	0.379
HWM 1- Under GdMrdn Bridge RB	0	U2000	47.700	47.207	-0.493
HWM 2- RB Nksk on dike	2010	201001	43.600	44.329	0.729
HWM 10-RB Nksk end Hrksll Rd	2050	205001	35.900	35.442	-0.458
HWM 9- RB Nksk at EnglrFrm	2153	215301	27.500	28.359	0.859
HWM 7- RB Nksk at Vndr Ycht Prk	1003	100301	23.700	24.693	0.993
HWM 3- RB Nksk Nelda Sigurdson's land	1023	102302	21.000	20.788	-0.212
HWM 4- RB Nksk at end of Ryhrst Rd	1056	105601	17.000	16.518	-0.482
HWM 5- LFP Rttr Rd CL-LveBrk ups Qsrc	2250	225001	30.100	30.910	0.810
HWM 6- LFP ApplFrm-Rttr Rd Brk Qsrc	0	D2312	27.900	27.236	-0.664
HWM 13-RFP nr Hmptn Rd LB Kmm Crk	3867	386701	53.200	55.652	2.452
HWM 12-RFP Hmptn Rd RB of Kmm Crk	3520	352001	55.200	55.633	0.433
HWM 11-RFP Hnngn Rd LB of Kmm Crk	0	D3529	54.200	54.322	0.122
HWM 17A-RFP Hdwy Prprty	4889	488901	94.700	94.385	-0.315
HWM 16-RB Ups LgrwyDk wst EmmrsnRd	4618	461801	83.100	82.725	-0.375
HWM 8- LFP Hvndr Prk TlphnBldg	1223	122301	19.600	18.901	-0.699
HWM 24-RnbwSlgh FP on Frndl Rd	1402	140201	9.900	9.901	0.001
HWM 25-RnbwSlgh FP on MrnDrv	0	D1409	9.200	8.961	-0.239
USGS /Gage Ferndale.	0	D1010	23.000	23.399	0.399

The 33 marks showed a fairly uniform distribution of differences for this event.

High-Water Marks for the February 2002 event. This event had few marks since it followed closely on the January 2002 event. The Hannegan Gage result does not make sense with surrounding information. Perhaps the reading is in error. There seemed to be no way to reduce the simulated level there by 2.5 feet without destroying the mimicry at nearby marks in other events. Table 4–1 gives the details for this event and Table 4–2 gives the summary.

One of the marks was only marginally greater than the one foot difference so that we essentially mimicked two out of four marks in this event.

High-Water Marks for the October 2003 event. This flood was earlier in the season than most

TABLE 3–2: High-Water Mark Mimicry Summary: Jan. 2002 Event

High-Water Mark Difference Range (ft)	Number of Differences	Proportion of Total Number	Cumulative Proportion
-5.00 to -1.00	1	0.03	0.03
-1.00 to -0.50	6	0.18	0.21
-0.50 to -0.25	5	0.15	0.36
-0.25 to -0.10	3	0.09	0.45
-0.10 to 0.00	0	0.00	0.45
0.00 to 0.10	2	0.06	0.51
0.10 to 0.25	3	0.09	0.60
0.25 to 0.50	3	0.09	0.69
0.50 to 1.00	9	0.27	0.96
1.00 to 5.00	1	0.03	0.99

TABLE 4–1: High-Water Mark Results: Feb. 2002 Event

High-Water Mark Description	Branch Number	Node	Observed Elevation (ft)	Simulated Elevation (ft.)	Difference Sim - Obs (ft)
Usgs Gage Deming	0	U4000	215.900	216.906	1.006
Hannegan Gage 20.5 ft reading	0	D3129	54.600	57.032	2.432
HWM 1- Under GdMrdn Bridge RB	0	U2000	45.700	46.850	1.150
USGS Gage Ferndale.	0	D1010	23.600	24.020	0.420

TABLE 4–2: High-Water Mark Mimicry Summary: Feb. 2002 Event

High-Water Mark Difference Range (ft)	Number of Differences	Proportion of Total Number	Cumulative Proportion
-5.00 to -1.00	0	0.00	0.00
-1.00 to -0.50	0	0.00	0.00
-0.50 to -0.25	0	0.00	0.00
-0.25 to -0.10	0	0.00	0.00
-0.10 to 0.00	0	0.00	0.00
0.00 to 0.10	0	0.00	0.00
0.10 to 0.25	0	0.00	0.00
0.25 to 0.50	1	0.25	0.25
0.50 to 1.00	0	0.00	0.25
1.00 to 5.00	3	0.75	1.00

and was followed by another within a week. Thirty-four marks were retained and about 10 were not used. Of these 10, six marks could not be used because they reflected the local effect of topographic features not yet in the model. These were mostly near the edge of the left-hand flood plain in Reach 3. This reach, already the most complex of all in the Nooksack model, will require the addition of about five additional flow paths in the Scott Ditch drainage to represent the features that caused

these six marks. Several other marks were found to be in error. Mark 7 in Vander Yacht Park was at the top of a park bench back and was left there as the water receded. It was lower than the level at the USGS gage at Ferndale and could not possibly be correct being upstream of that gage. Mark 43 upstream of Slater Road is inconsistent with others downstream so it was not used. Mark 2 was retained and was downgraded by 0.5 feet because it was on the outside of a sharp bend. Also the efficiency of the flow over high ground on the left-hand bank downstream of this mark was reduced significantly to reflect the great distance between the main channel and the approximate point of overflow. The roughness of the channel was pushed to its maximum reasonable level to reach this adjusted mark that seemed to have validity based on visual reports of what was occurring at that location. Table 5–1 gives the details for the October 2003 event while Table 5–2 gives the summary.

The summary for the October 2003 event shows a bias to the high side with nearly one-half the marks being more than 0.5 feet above the surveyed elevation. However, changes to reduce those levels would have caused many marks in the 1990 event to go below the tolerance. Thus the bias was left as is. Any removal of the bias in the results for these two events will require using adjustments unique to these events. To do so, we would need to tie the adjustments to some quantitative aspect of each event and then include that same adjustment for all other events. At this time it is not apparent how to do that in any consistent manner.

TABLE 5–2: High-Water Mark Mimicry Summary: Oct. 2003 Event

High-Water Mark Difference Range (ft)	Number of Differences	Proportion of Total Number	Cumulative Proportion
-5.00 to -1.00	0	0.00	0.00
-1.00 to -0.50	3	0.09	0.09
-0.50 to -0.25	6	0.18	0.27
-0.25 to -0.10	2	0.06	0.33
-0.10 to 0.00	1	0.03	0.36
0.00 to 0.10	2	0.06	0.42
0.10 to 0.25	3	0.09	0.51
0.25 to 0.50	3	0.09	0.60
0.50 to 1.00	14	0.41	1.01
1.00 to 5.00	0	0.00	1.01

High-Water Marks for the November 2003 event. Not only were there two floods within a week in October of this year but there was also a flood in November! This flood had 20 high-water marks and all were used. Mark 11 may have been influenced by local topography because again no reasonable adjustment of the model parameters would reach this mark and maintain other marks within the elevation-difference tolerance. Table 6–1 gives the details for the November 2003 event and Table 6–2 gives the summary.

Note: This page is partially blank so that the following table falls on one page

TABLE 5–1: High-Water Mark Results: Oct. 2003 Event

High-Water Mark Description	Branch Number	Node	Observed Elevation (ft)	Simulated Elevation (ft.)	Difference Sim - Obs (ft)
Usgs Gage Deming	0	U4000	218.040	218.578	0.538
HWM 42-RB Nks on Dmng Dk	4007	400702	205.900	206.385	0.485
HWM 41-RB Nks on Dmng Dk	4008	400803	205.000	204.952	-0.048
HWM 23-RB Nks on Dmng Dk	4011	401101	202.800	202.597	-0.203
HWM 22-RB Nksk on lve bank	4038	403802	175.100	175.763	0.663
HWM 21-RB Nksk on bank	4050	405001	163.500	164.044	0.544
HWM 20-RB undr NgntsCrnrBrdg	0	U4160	149.100	149.874	0.774
HWM 40-RB Nksk	4068	406808	121.900	122.712	0.812
HWM 38-RB Nksk	4069	406902	120.900	120.447	-0.453
HWM 37-RB Nksk	4069	406905	115.200	116.040	0.840
HWM 18-RB Nksk @ RvrBrryPrjct	4069	406914	109.100	109.538	0.438
HWM 17-RB Nksk VnDellnPrjt	4084	408401	98.800	99.580	0.780
HWM 26 Fence Hadaway drvwy	4889	488901	96.600	96.673	0.073
HWM 28 Ups Massy Rd-ponded H2O	0	D4901	90.900	89.987	-0.913
HWM 32 Ups EvrsnMS-wst drvwy	0	D4541	81.300	81.060	-0.240
HWM 33 Ups EvrsnMS-staff gage	0	D4541	81.000	81.060	0.060
HWM 35a Ups Timon Road	3466	346601	61.600	62.153	0.553
HWM 35b Dns Timon Road	0	U3900	61.200	60.695	-0.505
Ron Bronsema gage	3081	308102	66.200	65.842	-0.358
Hannegan Gage 24 ft reading	0	D3129	58.100	57.727	-0.373
HWM 48 Lyndn Trtmnt Plnt	3536	353601	55.350	55.870	0.520
HWM 1- Under GdMrdn Bridge RB	0	U2000	48.400	47.913	-0.487
HWM 2- RB Nksk on dike	2016	201603	44.200	42.715	-0.985
HWM 8- LFP Hvndr Prk TlphnBldg	1223	122301	21.000	21.752	0.752
HWM 3- RB Nksk Nelda Sigurdson's land	1023	102302	22.400	21.949	-0.451
HWM 34-LB off Rrl Rd	1261	126101	12.400	12.581	0.181
HWM 36-Ups MrnDrv LFP	0	D1284	12.000	12.241	0.241
HWM 24-RnbwSlgh FP on Frndl Rd	1402	140201	10.900	10.452	-0.448
HWM 5- LFP Rttr Rd	2251	225101	32.200	32.683	0.483
HWM 10-RghtHnd FP	2451	245101	34.000	34.763	0.763
HWM 13-RFP nr Hmptn Rd LB Kmm Crk	3865	386501	56.000	56.892	0.892
HWM 12-RFP Hmptn and Nksk Av.	3523	352302	55.800	56.503	0.703
HWM 11-RFP Dns Hnngan Rd	0	D3530	55.900	56.005	0.105
USGS Gage Ferndale.	0	D1010	25.150	25.935	0.785

The elevation differences for this event were fairly uniformly distributed. All but two marks fell within the tolerance for elevation difference and one of those was just over the tolerance.

Conclusions of High-Water Mark Mimicry. The mimicry of the HWM's was good for all events, especially considering that these events span a period of approximately 13 years with various changes in the main channel of the Nooksack River. All of these marks were obtained with a fixed-bed for the channel. It is known that the bed is not fixed but there is no data on sediment transport nor on bed-level changes during floods to provide guidance in how to make reasonable adjustments to the geometry as a function of the flow. Such adjustments may be needed in the future but for

TABLE 6–1: High-Water Mark Results: Nov. 2003 Event

High-Water Mark Description	Branch Number	Node	Observed Elevation (ft)	Simulated Elevation (ft.)	Difference Sim - Obs (ft)
Usgs Gage Deming	0	U4000	216.400	217.312	0.912
HWM 20-RB undr NgntsCrnrBrdg	0	U4160	147.900	148.329	0.429
Ron Bronsema gage	3081	308102	64.800	65.485	0.685
Hannegan Gage 23 ft reading	0	D3129	57.100	57.423	0.323
HWM 1- Under GdMrdn Bridge RB	0	U2000	47.500	47.084	-0.416
HWM 6a ApelFrm Rd	2313	231302	24.600	24.252	-0.348
HWM 6b ApelFrm Rd	2313	231302	23.300	24.252	0.952
HWM 46 Barrett Rd	0	F2513	26.400	27.426	1.026
HWM 4-Ryhrst Rd Lv	1055	105503	16.500	16.746	0.246
HWM 8a RstRm Hvndr Prk	0	D1222	19.400	19.366	-0.034
HWM 8b OvrQ Pnt nr Hvndr Park	1021	102102	20.600	21.228	0.628
HWM 43-LFP Ups Sltr Rd	0	D1248	9.800	10.702	0.902
HWM 3- RB Nksk Nelda Sigurdson's land	1023	102302	20.800	20.791	-0.009
HWM 36-Ups MrnDrv LFP	0	D1284	9.700	9.067	-0.633
HWM 45- Dns MrnDrv	0	U1150	10.200	10.574	0.374
HWM 24-RnbwSlgh FP nr Frndl Rd	1404	140403	9.500	8.767	-0.733
HWM 5- LFP Rttr Rd	2251	225101	27.500	28.322	0.822
HWM 12-RFP Hmptn and Nksk Av.	3523	352302	55.200	55.432	0.232
HWM 11-RFP Dns Hnngan Rd	0	D3530	56.400	53.581	-2.819
USGS Gage Ferndale.	0	D1010	23.400	23.960	0.560

TABLE 6–2: High-Water Mark Mimicry Summary: Nov. 2003 Event

High-Water Mark Difference Range (ft)	Number of Differences	Proportion of Total Number	Cumulative Proportion
-5.00 to -1.00	1	0.05	0.05
-1.00 to -0.50	2	0.10	0.15
-0.50 to -0.25	2	0.10	0.25
-0.25 to -0.10	0	0.00	0.25
-0.10 to 0.00	2	0.10	0.35
0.00 to 0.10	0	0.00	0.35
0.10 to 0.25	2	0.10	0.45
0.25 to 0.50	3	0.15	0.60
0.50 to 1.00	7	0.35	0.95
1.00 to 5.00	1	0.05	1.00

the present the ability to obtain results such as these with a fixed-bed is sufficient evidence that the model is useful for flood-plain mapping and for making analyses of the effects caused by various management alternatives.

Fitting the HWM's from all events proved to be a major task. In some cases a careful balancing of differences was required to keep simulated levels within the tolerance of one foot of the observed mark. Repeated HWM's at or near the same location sometimes required this treatment. The

level for one event needed to be near the upper end of the range and the level at the same location for a different event needed to be near the lower end of the range. As more HWM's are defined as floods continue to occur, this task may prove impossible. At that time some marks may need to be discarded or some provision of channel changes in plan and invert elevation may need to be included in the model.

Results at Ferndale

The USGS stream gage at Ferndale played a pivotal role in the calibration. It is the only reliable measure of the flow in the lower Nooksack River. Deming is unreliable and the new gage at Cedarville has too short a record to be used and early signs are that it may have problems similar to those at Deming. The Ferndale gage was used as the calibration point for adjusting the flows at Deming. Thus we make comparisons between the observed and simulated flows at Ferndale both for the calibration events and for other events not used in the calibration. The results for flows are overall good, even for those events not used to calibrate. We also compare the water-surface elevations at this gage. These results are more variable with some events showing what appears to be a resistance to flow that varies with stage. The channel downstream of the Ferndale gage is a sand-bed channel, based on the sediment size, and is therefore subject to changes in bed forms and effective roughness as the flow varies. However, there have been no measurements in the river on which to base variation. The maximum stages for the major flood peaks are generally reproduced well because they were used in the calibration. Thus the hydraulic resistance in the model is keyed on the larger events. Documenting water levels for some minor events will be needed to refine the adjustment of the hydraulic resistance at lower flows. Adjustments could be made in the reach downstream of Ferndale to improve the results but adjustments elsewhere must have some observed data to serve as a basis.

Figure 1 is for the floods of 1990. Both events are included on the figure. The flows at Deming were adjusted to mimic both events but only the HWM's for the first event were used for additional calibration. Figure 2 is for the flood of 1995. Figure 3 is for the floods of 2002. The January event was the primary event used in the calibration. The February results are then a verification event. Finally, Figure 4 is for the events of 2003. There are three events in the figure and all were used to adjust the flows at Deming. The 1990 events and the 2003 events used a time-varying adjustment factor. The 1995 and 2002 events used a constant adjustment factor on the flow at Deming.

Comments on the results at Ferndale. The rising limb of the observed hydrograph at Ferndale has shown a consistent pattern of a reduction in the rate of flow increase near a flow of about 20,000 ft^3/s. The simulated rising limb sometimes shows a much smaller reduction in the rate of flow increase. This change in the rate of flow increase suggests that water is being stored at some point upstream. However, efforts to define where the storage needs to be increased in the model have so far proved futile. Changes have been made in the areas of major flood plain storage such as Scott Ditch, the Fishtrap Creek and Bertrand Creek area, and the flood plains in Reach 2. Nothing of significant effect has been found. There is the possibility that the change is caused by rating changes at Deming as the flow increases. Without an intermediate gage on the Nooksack giving a time history of flow and stage, it proves difficult to determine where this effect originates. One key might be to seek locations for HWM's in the flood-plain storage areas to check on the mimicry of the model in those locations. The new network of crest gages and high-level recording gages should help in this search. A flood in November 2004 was recorded by these devices but the event has not been modelled at this time.

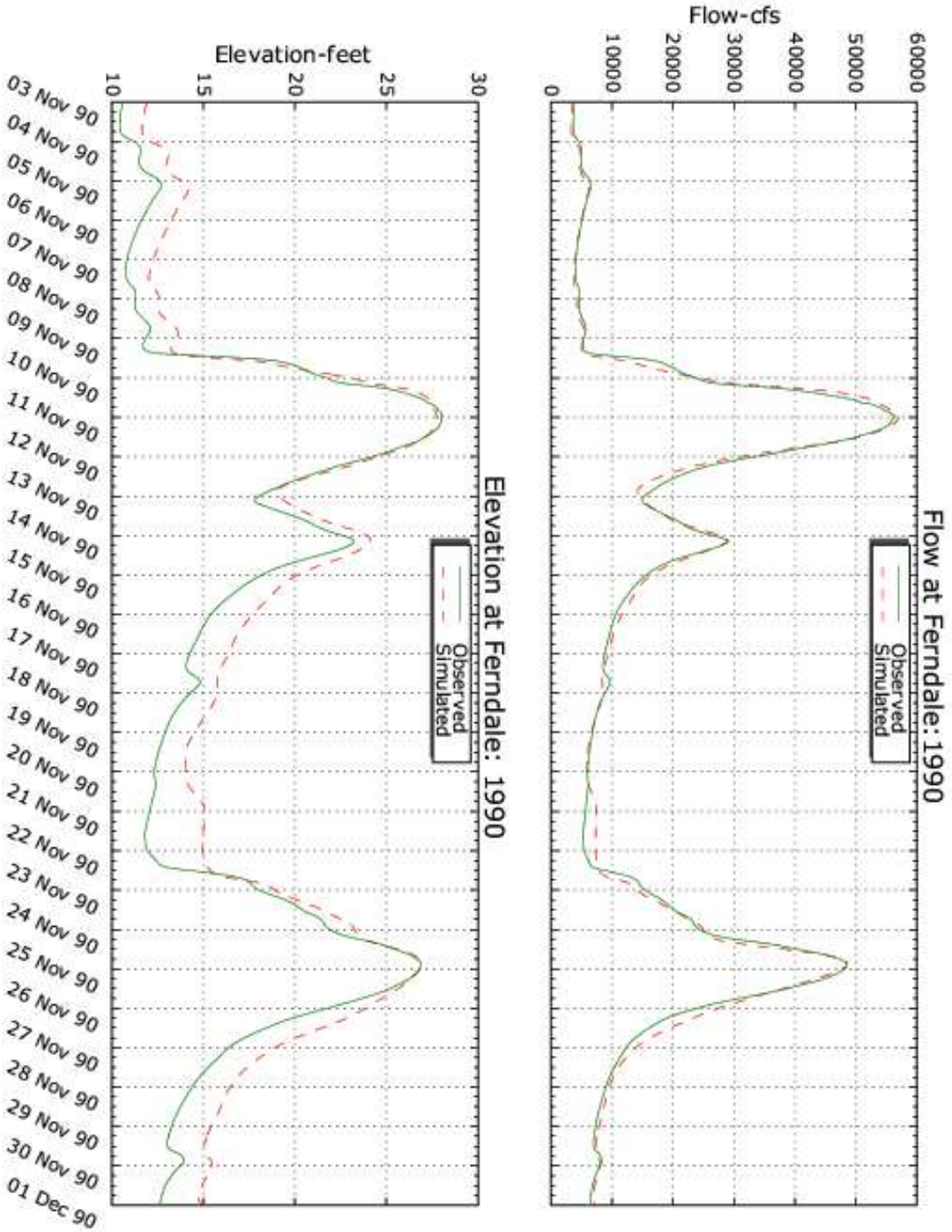

Figure 1: Flow and Elevation at Ferndale: 1990

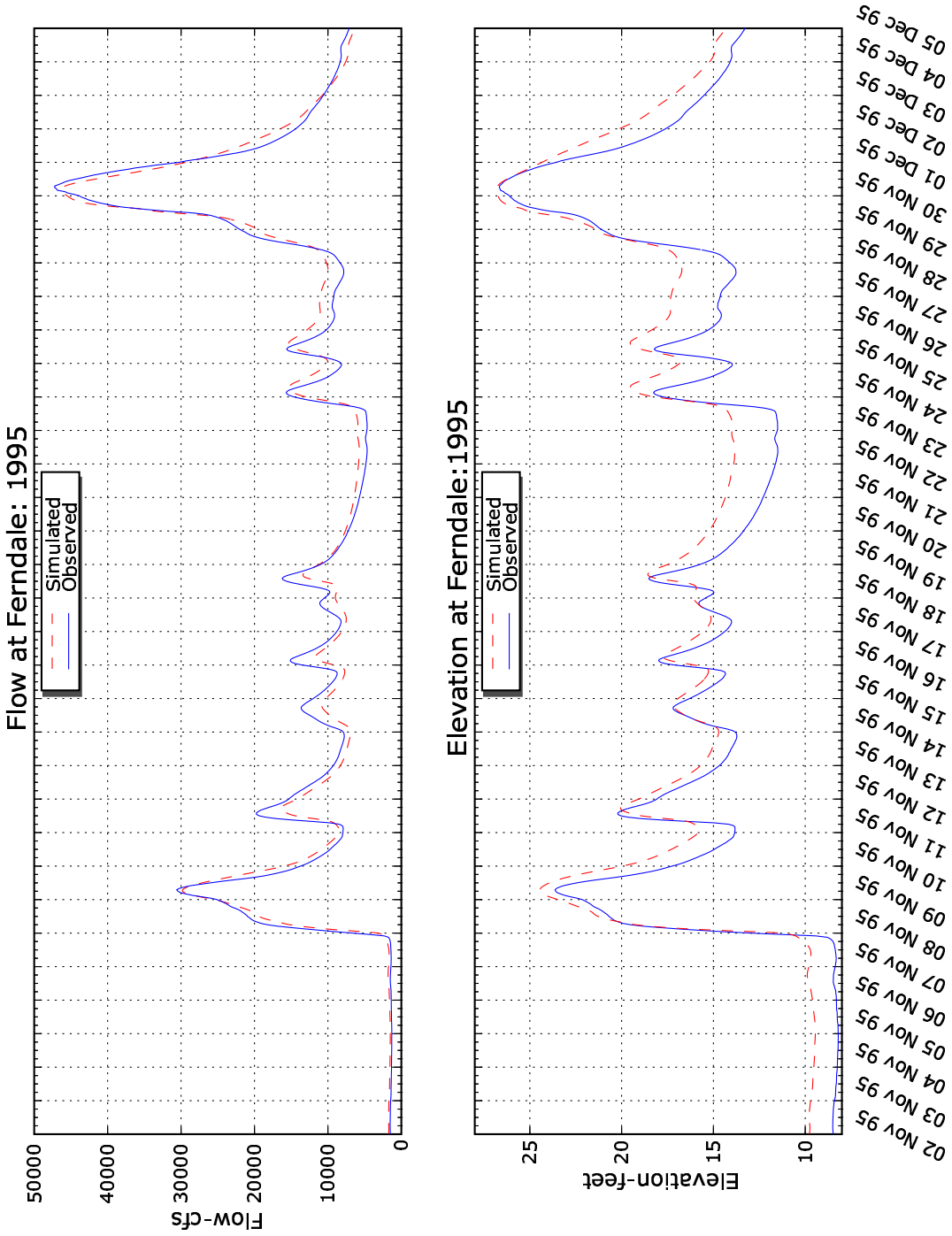

Figure 2: Flow and Elevationat Ferndale: 1995

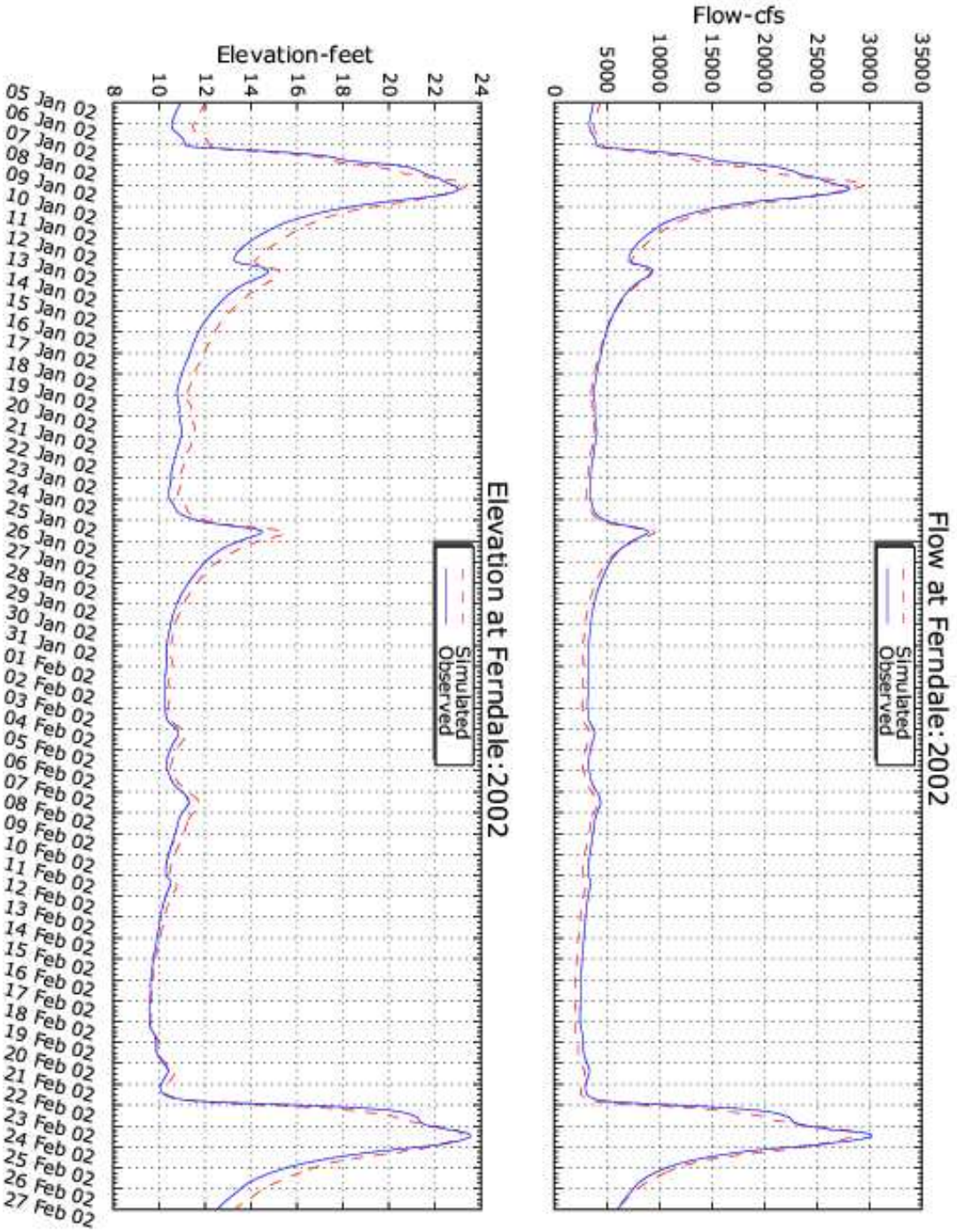

Figure 3: Flow and Elevation at Ferndale: 2002

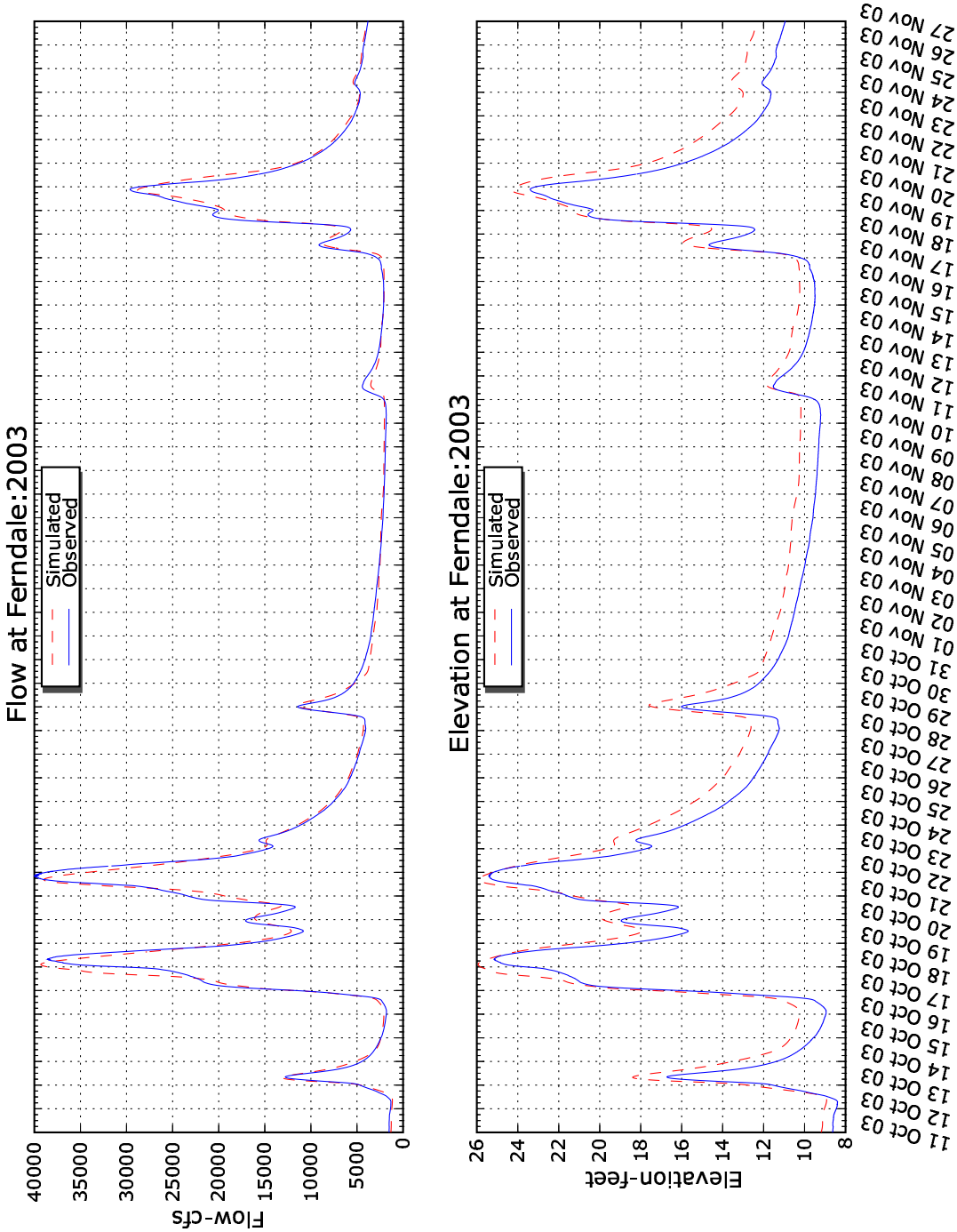

Figure 4: Flow and Elevation at Ferndale: 2003