Calibration of the 2010 FIS Model
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Introduction

The 2010 FIS (Flood Insurance Study) model of the lower Nooksack River is a major update and revision of the prior model for the lower Nooksack. The prior model was documented in a series of reports: "Lower Nooksack River Unsteady-Flow Model and Analysis of Initial Scenarios Near Everson", 6 February 2004; "Calibration Results For 2003 Events", 12 April 2005, "Flood Frequency Analysis at Deming, Ferndale and Everson", 12 April 2005; and "Analysis of Selected Scenarios", 11 July 2005. These reports provide much of the background for the current model of the lower Nooksack River. The major changes in the current model are:

1. The hydraulic geometry for cross sections was updated and extended using the Lidar survey obtained by the United States Geological Survey (USGS) in 2006. Some parts of Reach 5 were also revised using Lidar survey data from the Nooksack Indian Tribe based on flights made in 2009. The Lidar based information was merged with ground surveys from levees and from an extensive hydrographic survey of the main channel of the Nooksack, collected in 2006, to provide the DTM used for the ground surface. No hydrographic data was available for the prior model. In general Lidar yields somewhat better values for the ground surface than does photogrammetry. However, the Lidar survey suffered somewhat from not being made at the optimum leaf-off conditions. County staff spent much time reconciling the Lidar values with various ground surveys.
2. Much of the Scott Ditch drainage in Reach 3 was revised with several additional flowpaths to improve representation of the effect of various roads on flows over the banks of the Nooksack River.
3. In Reach 5, the portion of the model, developed for the City of Sumas in 1997, which was used east of the major north-south Burlington Northern railroad (BNRR), was deleted and replaced with a completely new delineation of flow paths and cross sections.
4. Flood events prior to 2003 were not used in the calibration with the exception of Reach 5. The 1990 event was used in Reaches 4 and 5 to aid in overflow calibration. Only this event has a large overflow at Everson Main Street and without that event, the calibration of the overflows near Everson failed to represent the 1990 overflow. The following flood events were used in the calibration of the Reach 1 to Reach 4 part of the model: October of 2003, November of 2004, November of 2006, and January of 2009. The November event in 2003 was used initially but was then deleted from the set of calibration events. This is discussed below in the section, "Calibration by Event". A shorthand reference to these events will consist of the year followed with no spaces by the first three letters of the month. For example, 2003oct refers to the flood, in this case, floods, occurring in October of 2003.
5. The current model has much more data for calibration than did the prior model. There are over 200 high-water marks, a time series of stage at the bridge in Everson for the later calibration events, and several time-series gages located throughout the floodplain, that yield stage above a pre-set elevation.

Sources of Flow Data

An attempt was made to use rainfall-runoff modeling to estimate the flows at the ungaged tributaries. However, it proved impossible to get a useful calibration. The rainfall data was quite limited for all events and in some cases was inconsistent with the stream flow at the gaged tributaries. Using rainfall-runoff modeling for tributary inflows will require adding several recording rain gages in the watershed. The long term recording gage at Blaine has apparently been discontinued. Some experimental rain gages exist near Fishtrap Creek but these proved to be of uncertain quality.

The major source of flow data was from the USGS gages in the watershed: Deming, Cedarville, Ferndale, Fishtrap Creek, and Anderson Creek. Reporting of flow data at Deming was discontinued in 2005, so data was only available for the earlier calibration events. Flow data from Squallicum Creek, managed by the City of Bellingham, was used in some of the later events, especially the major event in January of 2009. Tributaries that had no flow data upstream of Everson were based on Anderson Creek using drainage-area ratios. Tributaries downstream of Everson were based on Fishtrap Creek also using drainage-area ratios. More detail is given below for each of the calibration events.

The upstream boundary of the model is at Deming. Flows at Deming were used for the 2003oct and 2004nov events. After 2004, the only data published at Deming was the stage data. So for the 2006nov and 2009jan events, the flow series at Cedarville was time shifted and adjusted to serve as the boundary condition at Deming. Adjustments have always been used at Deming in order to reproduce the overflows at Everson Main Street (based on high water marks and some time-series of stage data) and the flows at Ferndale. The flows at Ferndale are the most reliable in the part of the stream system currently modeled. Consequently they have always served as the principal point of comparison.

Brief History of the Overflow Surface Near Everson

One of the challenges of building and calibrating a model of the lower Nooksack River upstream of a point between Lynden and Everson, is the movement of that reach of the River. Everson is near the downstream edge of a reach that acts like a large alluvial fan and the main channel of the Nooksack moves laterally from time to time, by many hundreds of feet in some locations. Downstream of Lynden, the lateral movement is strongly muted and is hardly noticed unless topographic maps are carefully compared. Lateral movement downstream of this point is virtually absent but the bed changes with the flow. No attempt has been made to model bed movement in either of the two models. The invert of the Nooksack was shifted in certain parts of the model to reach a calibration. As in the prior model, the largest shifts were adjacent to the overflow segment near Everson. Without an invert shift, the main channel of the Nooksack was unable to convey water at an elevation that would reproduce the observed overflow high-water marks and peak time-series stages at Everson Main Street.

The changes in the course of the main filaments of flow during floods has an effect on the banks of the Nooksack adjacent to and upstream of Everson. This is the area of the principal overflows to Sumas and British Columbia. Since the 1990 flood, some areas of the bank adjacent to the overflow segments have eroded. One area some distance upstream of the extension of Massey Road, is completely missing. It was not a principal overflow area but was a location where water would leave the Nooksack to the east, flow along an old depressed and mostly overgrown channel, and then would rejoin the Nooksack some hundreds of feet downstream. When the water-surface elevation in this auxiliary channel exceeded its right-hand bank elevation, overflow toward Massey Road would begin. This was at one time, the location of some of the earlier overflows during a large flood. This auxiliary channel is now gone and the Nooksack has direct access to the controlling overflow surface. Various other bank segments have been damaged and repaired since 1990. A concerted effort has been made to restore any part of the controlling overflow surface to its previous elevation based on surveys made of the surface in the early 2000's prior to any damage.

The recent history of the bank next to the controlling surface shows several cases of erosion and collapse. Here is a brief summary of the events involved and the complexity given to the definition of the overflow surface.

1. The 2003 floods began an "attack" on the bank near the upper end of the overflow strip adjacent to Emmerson Road and starting somewhat upstream of the extension of Massey Road. The 2004nov floods continued to damage the bank at this location. The control surface was not changed; however, the bank edge was moved closer to the control surface. The process of getting permits and funding for repairing the damage began then and in the summer of 2006, the restoration started.
2. In September 2006, the bank restoration was completed, restoring the surface to that established by the circa 2000 survey in the area. The 2006nov event then damaged about 250 feet or so of the upstream most part of the restoration. However, the overflow surface was not changed radically but probably dropped in elevation by about a foot. Part of the reason for the damage was the result of the shift in direction of the main channel flows. In 1993, for example, the topography shows the main channel parallel to the bank with its centerline about 350 feet away from the bank. The bank upstream of Massey Road had the main channel adjacent to it but flowing roughly parallel to it. The 2004 topographic map shows the main channel at the bank next to the overflow surface and essentially perpendicular to the bank just upstream of Massey Road.
3. During the repair of the damage caused by the 2006nov flood, local land owners asserted that there had been a small berm, buried deep in the vegetation, that had been taken away by the original restoration and now they were getting more water than they ever had before! The circa 2000 ground survey did not show any such berm but then the vegetation may have been thick enough to conceal it so the surveryors may have missed it. There is some evidence that the trace of the ground survey deviated around vegetation. Upon searching the area, some remnants of a small berm were found at the south boundary of the project.
4. Therefore, the repair added a small berm that appears to have raised the control surface by approximately 1 foot over about 250 feet.

Surveys have been made of the repaired restoration without and with the berm. The 2009 Lidar mapping of the area from the Nooksack Indian Tribe agrees closely with the elevations from these surveys.

We then have the following sequence of overflow surfaces:

1. From 1990 through the 2004nov flood, we used the overflow surface with the berm present. With the prior model we had no knowledge of the berm so it was not used in the modeling. It was used in the current model for these events.
2. The restoration project in the summer of 2006 removed the berm in the process of removing the vegetation. No one was looking for such a berm and it would be small in any case so no note of it was made.
3. The overflow surface for the 2006nov flood did not have the berm present. This is the flood that caused damage to the just completed restoration project.
4. The damaged restoration project was restored before the 2009jan flood and the berm was added. So the 2009jan event used the overflow surface with the berm present.

We must remember that the water leaving the Nooksack River adjacent to Everson must pass over both the controlling surface near the bank of the River and also over Emmerson Road and a smaller amount over Massey Road, before the water begins to flow toward Sumas and British Columbia. There is a shallow swale between the bank of the Nooksack and Emmerson Road and the Lagerway Dike and the old levee which antedates the Lagerway Dike by some decades. Only a portion of the water flowing over the banks of the Nooksack, flows over Emmerson Road, much of it continues downstream roughly parallel to the flows in the main channel of the Nooksack and then rejoins the flow in the Nooksack upstream of the highway bridge at Everson.

Overview of the Models

Overflows that cause damage in Sumas and British Columbia are infrequent so that most of the flood damage occurs along the lower Nooksack River. The Nooksack River was divided into numbered reaches in a project in the early 1990's and this set of names has been retained. Moving from Bellingham Bay upstream we have Reach 1 ending at the Interstate 5 (I-5) bridges, a short distance upstream of Ferndale. Reach 2 extends from the I-5 bridges to the Guide Meridian and its bridges over the Nooksack. Reach 3 then ends at the bridge at Everson, and finally, Reach 4 ends at the USGS stream gage a small distance upstream of Deming. The overflow corridor which takes water to Sumas and British Columbia, is designated as Reach 5. It begins at Everson Main Street and ends at the Southern BC railroad not far into British Columbia with the exception of the right-hand flood plain of the Sumas River. That flow path ends about 1900 feet downstream of the international border.

There are then three different models that can be selected: the model of Reaches 1 through 4, denoted as the R1R4 model; the model of Reach 5, denoted as the R5 model; and finally the model of all five reaches, denoted as the R1R5 model. The models can be selected by specifying a predefined scenario name when invoking the model system software, called FEQ.

Most of the calibration effort was expended on the R1R4 model because that is where most of the frequent problems occur, and because there are extensive sets of high-water marks and more recently, time-series records of stages above a given water-surface elevation. The overflow corridor has very little high-water mark data because there are few large events that cause significant flow in the corridor. Some of the events in the calibration set for the current model did have overflows that had a small set of high-water marks and there is one time-series of peak stage data also available. The stage and flow at the Huntingdon station was also available. As already mentioned above, the 1990 flood was used to aid in calibration of the R5 model.

The R1R5 model is just the joining of the R5 model to the R1R4 model at Everson Main Street. Test cases have been run of the R1R5 model comparing the results at Everson Main Street to the results obtained there when running the R1R4 model followed by the R5 model, using the simulated hydrograph at Everson Main Street as the upstream boundary condition for the R5 model. The model results for flow at Everson Main Street are nearly identical, with differences of a small fraction of one per cent, except at the very low flows. This shows that Everson Main Street is a controlling surface for the flow over it. This does not mean that it controls how much flows to Sumas and beyond. It only means that the flows over Everson Main Street are not affected by the tailwater levels at the upstream end of Reach 5.

In the final stages of calibrating all of the models, it was convenient to use the R1R5 model because it proved necessary to make some changes in Reach 4 to improve the mimicry of data in Reach 5. The R1R5 model created a summary of all of the high-water marks so that the effect of any change could be evaluated everywhere in one run. The combined model is such that it takes more time to run than the time taken to run both models in sequence. However, this increase was more than recovered in the ease with which all of the high-water marks could be compared.

Floods larger than the 1990 flood, for example, the current 100-year administrative flood, result in there being flow over Stickney Island Road on the right-hand bank of the Nooksack River just south of Everson. This water flows into the uppermost parts of Johnson Creek which is in Reach 5 of the model. However, there is a low divide between Reach 5 and Reach 3 on the western edge of the Reach 5 model. The now abandoned railroad fill going north out of Everson and on the western edge of the overflow corridor, is in effect a dam for this flow. There appears to be only one three-foot diameter culvert through this fill. Also the overflow corridor is filled with water when these overflows occur. Consequently a small flow of about 50 ft^3/s enters the upstream end of Reach 3. This flow increases to about 1,100 ft^3/s for the 500-year administrative event included as part of a flood insurance study (FIS). Consequently, the R1R5 model is much more convenient when the flows become large.

Table 1 summarizes some quantitative descriptors of model size and complexity comparing the prior and current R1R5 models:

TABLE 1: Prior and Current Model Item Counts

Item Name	Number in Prior Model	Number in Current Model
Branches	2204	3310
Exteror Nodes	8336	12792
Miles of Flowpath	150	180
Number of Equations	23,216	33,006
Potential Overflow Points	1287	2441

The size and complexity of the model has increased significantly.

Calibration Process

The calibration process has been outlined at some length in the report on the calibration of the 2003 event with the prior model. Suffice it to say that it involves many iterations of adjusting the flows at Deming, adjusting known failures or flood fights, if they are close to a high-water mark, as well as evaluating if a high-water mark is valid. The modeller must judge the relative uncertainty of different sources of information, that is, what sources are more reliable than others. For example, several high-water marks in Reach 1 did not make any sense with respect to what the model was simulating. Extensive checking showed that the geographic location given for the marks, that is, the State Plane Coordinate Easting and Northing, where completely in error and placed the marks nearly a mile from their true location.

Another problem that surfaced in the 2009jan event, was that the Fishtrap Creek record had extensive missing data near the peak of the flood because the gage was washed away by the high flows. This gap was not signalled by any special notation in the file from the USGS data base, so it was initially overlooked. More details on the 2009jan event are discussed below.

A final problem in calibration was a side effect of having multiple sources of information. This became an acute problem in the tributaries such as Scott Ditch and Johnson Creek. We had ground surveys for the structures on those flow paths but we did not have hydrography for the streams themselves. This could often lead to the invert of the stream channel, as defined by the Lidar survey, being several feet above the invert of the channel as shown by the ground survey. This problem was "solved" by inserting an estimated central channel that was sized to match the inverts as defined by the series of structures along these tributaries. Without doing that, it would be impossible to have the model run or make any sense whatever.

The other reality to remember is that high-water marks are relatively weak indicators of a calibration in a stream like the Nooksack, where we not only have uncertain upstream flows but also an uncertain channel invert. We also have an uncertain effective roughness for the flow surfaces. Past experience has shown that it is possible to compensate for error in flow by adjusting Manning's n or by shifting the channel invert. For example, in the middle 1990's working on the old Sumas model, trying to reach some estimate of the overflow at Everson Main Street (years prior to the unsteady flow modeling), I was able to represent at least three different flow levels with equivalent "goodness". The primary check on the modelling was the eventual volume of water delivered across the border. This was finally the criterion that led to the "acceptance" of one calibration as good enough.

A much stronger indicator of calibration is a time series of stage values and an even stronger indicator of calibration is a time series of both stage and flow. More of these were available for the current calibration than for any prior calibration.

Calibration Results by Event

For each event the results for high-water marks will be given first followed by results at various points of flow or stage time-series.

October 2003

This month had two floods with nearly the same maximum discharge with the second peak following the first by about 3.5 days. Consequently the high-water marks may be attributed to either flood because field checking was delayed until after the second flood. Also this flood shows the effect of channel invert elevations near Everson. The calibrated model shows a small overflow at Everson Main Street, with the second event's overflow slightly larger. However, only the first flood actually produced an overflow. This indicates that the first flood changed the effective flow cross section, such that the second flood did not cause an overflow. Reproducing this behavior with a fixed invert is probably not possible.

There where 38 high-water marks that appeared to be valid. The following two tables provide the results found at these marks. All but two marks fell within the desired tolerance of plus or minus one foot. The two marks shown in Table 2003–1 were both about two feet too low. HWM 31 at the base of a mailbox upstream of Emmerson Road, was affected by local topographic features not present in the model. The other mark, HWM49b was inside a barn and again it is presumed that local details affecting the actual flow, were not present in the model.

The location of each high-water mark is given by a brief description followed by an identification string following a colon that relates to a string associated with the mark in the full documentation of the mark. You will note that the string used to identify a mark varies from event to event. Each of the marks had an Easting and a Northing in the Washington North State Plane Coordinate System. It was then possible to identify fairly closely where the mark was on the ground. Each mark was assigned to a flowpath, the name given to a sequence of branches used by the software to compute the movement of water. Each flowpath in the model was denoted by a unique six-character string. The first two characters denote the reach. For example, "RA" denotes Reach 1. The next two characters are always "FL" denoting: "FlowLine". The final two characters then denote the particular flow line in the reach. The flowlines denoted here are used for computing distance along a flowpath. "MM" always denotes the flow line for the main channel of the Nooksack River. Generally the other flow lines begin with either "L", denoting to the left of the main channel, or "R", denoting to the right of the main channel. Reach 5 was complex enough that we exhausted the alphabet and deviated from that convention.

The station in the table gives the distance, in miles, from a reference point at or near the downstream end of the flowpath. The station can be negative and then denotes a location downstream of the reference point. In some cases the high-water mark was not in a stream channel but in an area that was represented by a level-pool reservoir in the model. In that case the station is left blank and the designation for the downstream node of the level-pool-reservoir appears in the flow-path axis column. There were other cases where the mark plotted on the map close to the boundary between flow paths. In some cases the initial assignment of the mark to a flowpath was changed by moving it a few feet.

The elevations in the table are based on the datum NAVD88. The precision of elevation in the table is higher than the actual precision of the result. However, the higher precision was retained as this is how the software presented the table. The higher precision is often needed in sorting out changes and the effect of adjustments to one or the other factor affecting the elevation of the water surface in the model. The final column gives the difference in the sense of simulated value less the observed value. Our goal was to have all high-water marks fall within one foot in absolute value of the observed high-water mark.

TABLE 2003–2: High-Water Mark Mimicry Summary: 2003oct Event

High-Water Mark Difference Range (ft)	Number of Differences	Proportion of Total Number	Cumulative Proportion
-5.00 to -1.00	2	0.05	0.05
-1.00 to -0.50	7	0.18	0.23
-0.50 to -0.25	7	0.18	0.41
-0.25 to -0.10	4	0.11	0.52
-0.10 to 0.00	1	0.03	0.55
0.00 to 0.10	3	0.08	0.63
0.10 to 0.25	3	0.08	0.71
0.25 to 0.50	4	0.11	0.82
0.50 to 1.00	7	0.18	1.00
1.00 to 5.00	0	0.00	1.00

Figure 2003–1 shows the results for flow at Ferndale. The same figure gives the flows at Deming, which were adjusted as needed for the calibration, and the unadjusted flows at Deming. It also shows the simulated flows at Everson Main Street, showing the two overflows when the evidence is that only the first flood of the event resulted in flow over Everson Main Street. However, there seems to be no way, using a fixed invert in the model, to have an overflow for the first event and to not have an overflow for the second event. Figure 2003-2 shows the elevation results at Ferndale, the key time-series of information in the lower Nooksack River. Finally, Figure 2003–3 gives the elevations at Deming.

November 2003

This event was initially in the set of calibration events. However, it was always an "outlier" in that its peak flow was the smallest of the set. The major problem was that several high-water marks in the left-hand flood plain in Reach 2, the Appel Farm land behind the Lattimore Dike, were always being over simulated by several feet. The marks appeared reliable. The changes required to bring the simulation of these high-water marks into range, destroyed the simulations in Reach 2 for all other calibration events. All of the background data was checked and no errors were found. This event followed the two larger events in October. Perhaps the invert in the Nooksack was much lower than was used in the model. We chose not to vary the invert from event to event for the simple reason that it would then become a problem to set the invert for administrative events. Before we can do the latter, we must develop some algorithm to vary the invert dynamically as the floods progress. That is not an easy task and will have to be reviewed and perhaps solved in the future. For the current effort we deleted this event from the calibration set.

Installation of Additional Gages

Whatcom County was in the midst of installing some additional gages in 2003 and 2004. The first flood with these gages operational was the November 2004 event. The USGS was contracted to install a stage recorder at the Everson Bridge to track the elevation of the Nooksack River there.

TABLE 2003–1: High-Water Mark Results: 2003oct Event

Rch.	High-Water Mark Description	Flow Path Axis	Station (mi.)	Obs. Elev. (ft.)	Sim. Elev. (ft.)	Diff. (ft.)
4	Usgs Gage Deming: Dmng	RDFLMM	36.6612	223.582	223.051	0.531
4	RB Nks on Dmng Dk: HWM 42	RDFLMM	35.6248	210.400	209.827	0.573
4	RB Nks on Dmng Dk: HWM 41	RDFLMM	35.5080	209.764	208.927	0.837
4	RB Nks on Dmng Dk: HWM 23	RDFLMM	35.2791	206.929	206.727	0.202
4	RB Nksk on lve bank: HWM 22	RDFLMM	33.0714	179.882	179.040	0.842
4	RB Nksk on bank: HWM 21	RDFLMM	31.9600	168.262	167.440	0.822
4	RB undr NgntsCrnrBrdg: HWM 20	RDFLMM	30.9998	153.416	153.047	0.369
4	RB Nksk: HWM 40	RDFLMM	28.6110	126.525	125.824	0.701
4	RB Nksk: HWM 37	RDFLMM	28.0652	119.857	119.117	0.740
4	RB Nksk at RvrBrryPrjct: HWM 18	RDFLMM	27.3041	113.075	113.011	0.064
4	RB Nksk VnDellnPrjt: HWM 17	RDFLMM	26.0269	102.112	102.701	-0.589
4	Fence Hadaway drvwy: HWM 26	RDFLMM	25.2760	99.778	100.498	-0.720
4	Tree FrnRD off Bisset: HWM 27	RDFLMM	24.9810	97.724	98.194	-0.470
4	Ups Mssy nr Emmerson Rd: HWM 30	RDFLMM	24.8794	96.369	96.994	-0.625
4	Ups EvrsnMS-wst drvwy: HWM 32	RDFLRB	0.0131	85.330	85.191	0.139
4	Ups EvrsnMS-staff gage: HWM 33	RDFLRB	0.0131	85.330	84.891	0.439
4	MlBx Base Ups Emmrsn Rd: HWM 31	RDFLRG	0.8914	93.634	95.594	-1.960
3	Ron Bronsema gage: RonB	RCFLMM	20.2145	70.176	70.107	0.069
3	Hannegan Gage 24 ft reading: Hnngn Rd	RCFLMM	18.1770	61.643	62.017	-0.374
3	RFP nr Hmptn Rd LB Kmm Crk: HWM 13	RCFLRB	4.0684	59.616	59.907	-0.291
3	RFP Dns Hnngan Rd: HWM 11	RCFLRB	2.0673	59.319	59.817	-0.498
3	Lyndn Trtmnt Plnt: HWM 48	RCFLRB	1.7802	59.257	59.271	-0.014
3	Polinder Rd: HWM 47	RCFLLG	2.3828	63.895	64.511	-0.616
3	Curb in Barn Shrmn Plndr Res: HWM 49b	RCFLLG	0.7970	52.450	54.424	-1.974
3	Tree Shrmn Plndr Res: HWM 49a	RCFLLG	0.7702	52.208	53.121	-0.913
3	RFP Hmptn and Nksk Av.: HWM 12	RCFLRC	0.6304	59.472	59.717	-0.245
3	Dns Timon Road: HWM 35b	RXFLMM	20.3932	64.763	65.107	-0.344
3	Ups Timon Road: HWM 35a	RCFLRL	0.5611	65.285	65.504	-0.219
2	Under GdMrdn Bridge RB: HWM 1	RBFLMM	15.4000	51.863	52.337	-0.474
2	RB Nksk on dike: HWM 2	RBFLMM	14.1827	47.299	48.150	-0.851
2	LFP Rttr Rd: HWM 5	RBFLLB	4.3072	36.597	36.160	0.438
2	RghtHnd FP: HWM 10	RBFLRB	4.1641	37.251	37.967	-0.716
1	USGS Gage Ferndale.: Frndl	RAFLMM	6.0328	29.265	29.367	-0.102
1	RB Nksk Nelda Sigurdson's land: HWM 3	RAFLMM	4.7243	26.192	26.363	-0.171
1	LFP Hvndr Prk TlphnBldg: HWM 8	RAFLLB	3.9995	25.062	24.963	0.099
1	LFP off Rural Avenue: HWM 34	RAFLLB	1.8636	16.731	16.367	0.364
1	Ups MrnDrv LFP: HWM 36	RAFLLB	0.6590	16.199	15.953	0.246
1	RnbwSlgh FP on Frndl Rd: HWM 24	RAFLRC	1.1726	14.530	14.853	-0.323

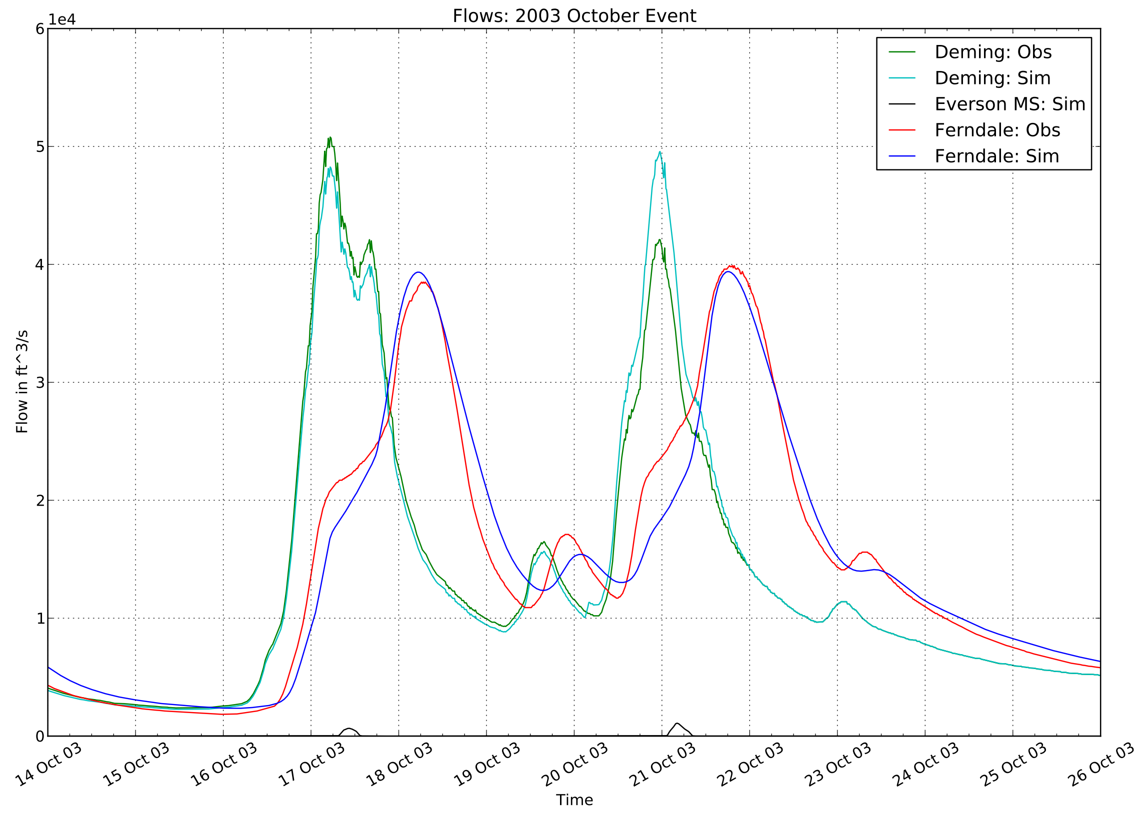

Figure 2003–1: Flows: 2003

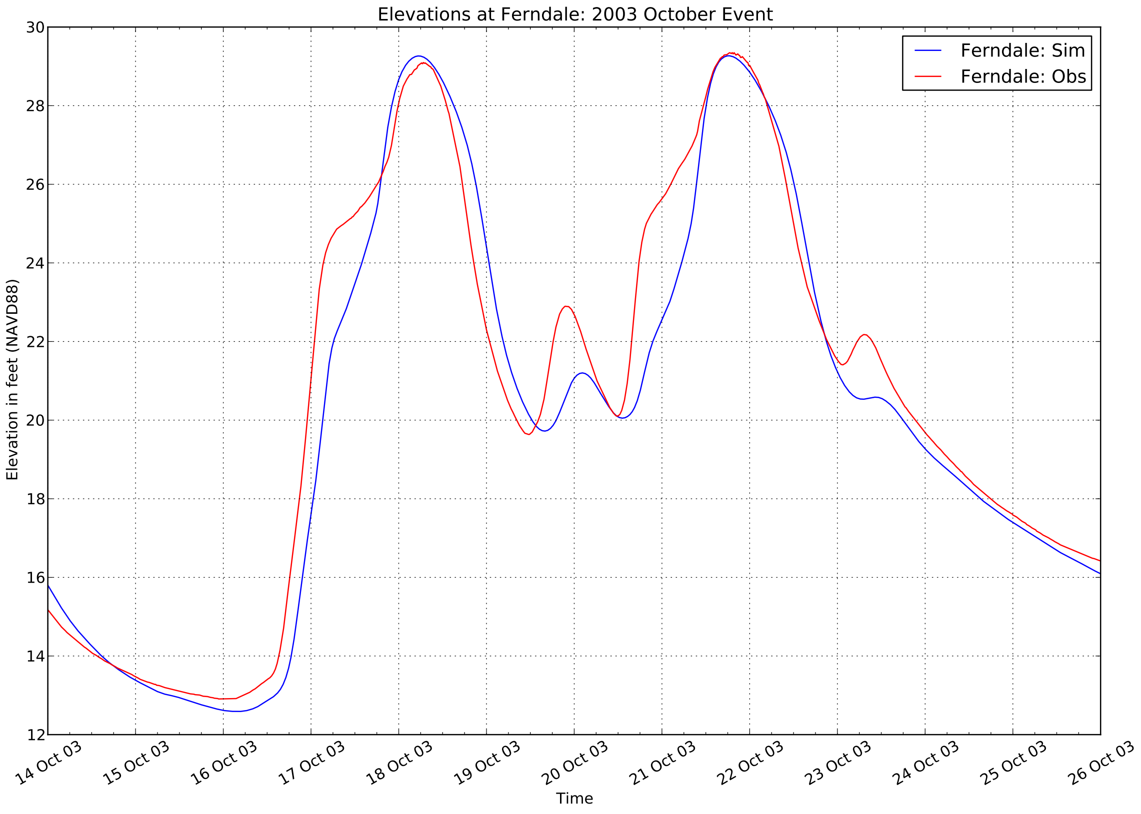

Figure 2003–2: Elevations at Ferndale: 2003

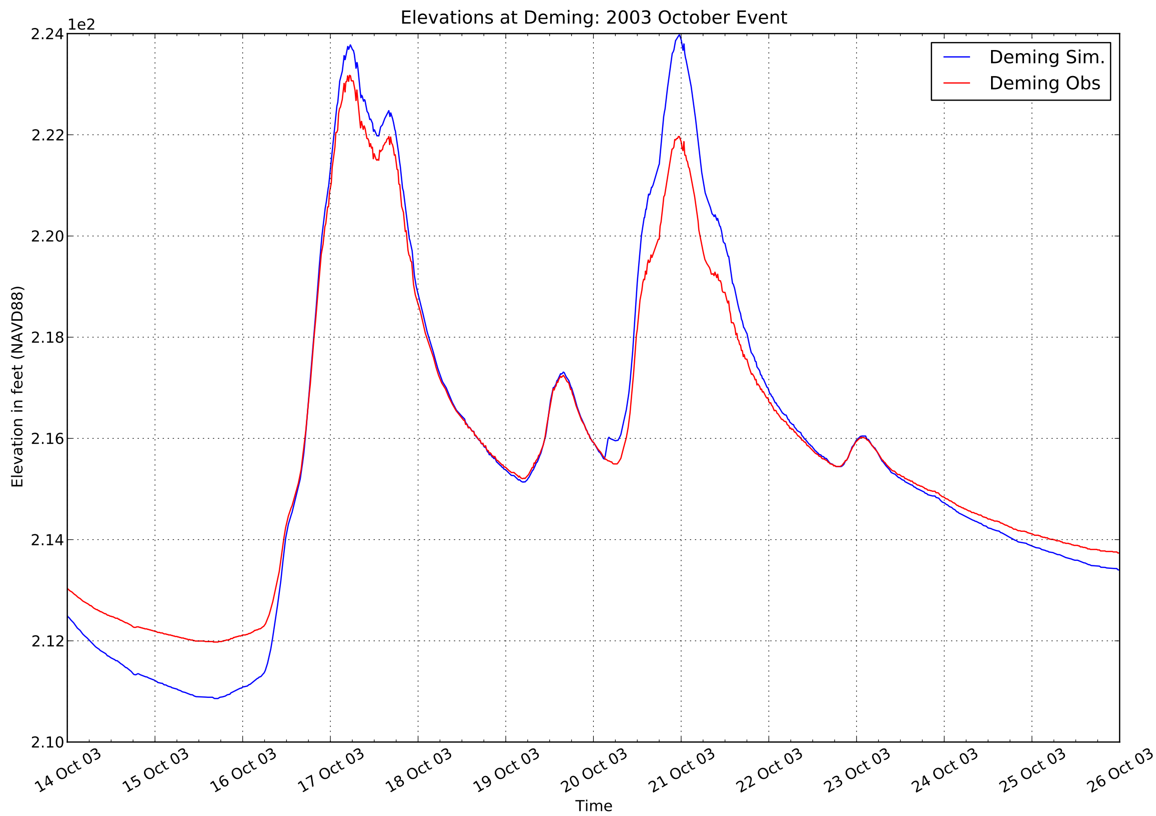

Figure 2003–3: Elevations at Deming: 2003

Two other gage types were installed at various other points in the lower Nooksack. The first, crest stage gages, are designed to measure the maximum water level, and the second, which I will call Time Series Gages (TSG's) are designed to start recording stage when the water rises above a preset level and to stop recording when it again falls below that level. The TSG's then give a short record of the peak stages at a given site.

One challenge with the TSG's was the data reduction depended on barometric pressure. In general a crest gage should be installed with the TSG to also give a point of calibration. This was not true in all cases, so some TSG records proved to be unusable because they had errors that could not be explained. As with all such equipment, failure is always an option, so that all gages do not report results for all events. Also vandalism is a sad fact of life with outdoor gage equipment of all types and so one gage was lost after yielding useful data for one event.

The crest stage gages are identified in the summary tables for high-water marks. The TSG's are also noted there. Table TSG-1 gives the locations of the gages that produced time-series that were used in the comparisons shown later in this report.

One other gage was installed at the south dry bridge on the Guide but it did not produce data that was valid for the events in the calibration set. This was an unfortunate failure because the flow through this bridge first flows upstream in the early parts of a flood and then reverses to downstream flow as the water in the left-hand flood plain rises in response to flows out of the Nooksack that occur upstream.

November 2004

This event, like those in October of 2003, had a small flow over Everson Main Street. There were 42 high-water marks that appeared to be valid. In this case there were some high-water marks

TABLE TSG–1: Locations of Time-Series Gages

Gage Id Number	Gage Description
1004	Slater Road – Downstream of Slater Road: Reach 1
1005	Appel Farm – About 800 feet upstream of Lattimore Dike: Reach 2
1007	Dahlberg – Downsream of Dahlberg Road: Reach 2
1009	Guide Nksk Bridge – Just ups on right bank of Nooksack: Reach 3
1011	in Scott Ditch – Just ups of Hannegan Road on Scott Ditch: Reach 3
1012	in Kamm Creek – Just ups of Nooksack Avenue: Reach 3
1017	Everson Main Street– Just ups of Main Street on right bank ups of culvert: Reach 4
1025	Johnson Street– On left bank of JC about 600' ups of the RR bridge: Reach 5

in Reach 5. These are shown at the end of the table. Tables 2004–1 and 2004–2 show the results. The 2004nov event was one of the easier events in the calibration set. It seemed to fit with the least difficulty and only one high-water mark fell outside the tolerance goal.

The following 13 figures present the time series results for this event. Figure 2004–1 shows the observed and simulated flows at Deming, Cedarville, Ferndale, and at Everson Main Street. The "observed" flow shown for Everson Main Street was computed from the time-series gage record there and the flow rating that has been used for Everson Main Street for both the prior and current models. It is based on a ground survey of the roadway and includes adjustments for some downstream blockage of flows by structures close to the street. The overflows are usually of modest duration so that no current meter measurements for the flows over Everson Main Street have ever been obtained. In addition, wading the flows of interest would be too dangerous.

The simulated flow at Deming is the observed flow as adjusted in the calibration to fit the model to the observations. In this case the flow claimed at Deming and at Cedarville was reduced in order to reproduce the various observations downstream. The peak flow at Ferndale was matched closely but the timing of the peak was early. The rapid offset in the rising limb of the observed flow at Ferndale has been called a "dog-leg" and appears in many of the flood hydrographs at Ferndale. This sudden change in the rate of increase of flow shows that additional storage is becoming effective at points upstream of Ferndale. Neither the prior nor the current model simulate this sudden shift well. In this flood event, there was also a small dogleg apparent at both Deming and Cedarville but it is much enhanced at Ferndale. More discussion of this dogleg and its simulation is given below in "Analysis of the Calibration". The overflow at Everson Main Street was simulated early and also with a peak greater than computed from the rating.

Figures 2004–2 through 2004–13 show comparisons of elevation at various locations in the modeled area. Figure 2004-2 shows the elevations at Ferndale. The low flows are under simulated, which is probably a result of using a fixed invert for all floods. However, the undersimulation is small. The largest differences in elevation appear on the rising limb, mainly due to the timing error and the lack of simulation of the dogleg. However, the overall shape is modeled reasonably well.

Figures 2004–3 and 2004–4 show elevation results at Deming and Cedarville respectively. Note that the multiplier on elevation values on the vertical axes appears at the top of the axis. For example, for Deming, the multiplier is "1e2" where the digit following the letter "e" denotes the power of ten. So in this case, the elevations are in the approximate range of 212 to 224 feet NAVD88. Considering that no effort was expended to calibrate to the shape of either the flow or the elevation data at Deming, the results shown in the figure are amazingly close. However, the receding limb at Cedarville shows quite a difference. No adjustment to the flow at Deming was able to correct this. For this event, the rating at Deming and Cedarville produced flows that did not fit well with

TABLE 2004–1: High-Water Mark Results: 2004nov Event

Rch.	High-Water Mark Description	Flow Path Axis	Station (mi.)	Obs. Elev. (ft.)	Sim. Elev. (ft.)	Diff. (ft.)
4	USGS Gage-TimeStageDem: USGS-Dem	RDFLMM	36.6612	223.674	223.470	0.204
4	USGS Gage-TimeStageCed: USGS-Ced	RDFLMM	31.0041	153.684	153.120	0.564
4	hwm lamppost - riverward flooding: 3-11-25-04	RDFLMM	25.4510	100.750	101.320	-0.570
4	hwm cnr 2885 Masssy - water out of Nooksack: 4-11-25-04	RDFLMM	24.8794	97.571	97.510	0.061
4	USGS Gage-TimeStageEverson: USGS-Evr	RDFLMM	23.5551	87.544	87.580	-0.036
4	hwm 6: 30 am nearing pk: 2-11-25-04	RDFLRB	0.0130	86.069	85.930	0.139
4	tree: culvert crossing: dirt rd: 24-11-25-04	RDFLRJ	1.5690	189.892	189.070	0.822
4	hwm 5am 11-25: 1-11-25-04	RDFLRG	0.8958	94.799	95.670	-0.871
4	Ups Emmerson Road: GN1016	RDFLRG	0.3796	90.768	90.850	-0.082
3	recorded by Lynden sewer staff: 29-11-25-04	RCFLRB	1.7560	59.951	59.830	0.121
3	Kamm Creek TSG Ups Nksk Ave Bridge: TSG1012	RCFLRC	0.6303	60.176	60.300	-0.124
3	Hannegan-Scott Ditch TSG 1011: TSG1011	RCFLLC	1.9903	52.965	52.600	0.365
3	Farm access Rd at jog in RCFLRL: GN1013	RCFLRL	1.3392	71.536	71.350	0.186
2	DryBridgeDitch at Guide: GN1010	RBFLLB	6.9399	51.728	50.940	0.788
2	ns Ritter Road: GN1006	RBFLLB	4.4643	36.819	36.680	0.139
2	Appel Farm tsg 800 ft ups LttmrDk: TSG1005	RBFLLB	2.5347	35.547	36.000	-0.453
2	hwm - pk nail in fence post: 17-11-25-04	RBFLLB	2.5275	35.547	35.830	-0.283
2	pk nail in rd and lath: 18-11-25-04	RBFLLB	0.3275	33.136	33.640	-0.504
2	Flynn Rd nr Fishtrap Levee: GN1008	RBFLRB	7.1951	44.886	45.040	-0.154
2	ppole 470274 159578 River Rd: 22-11-25-04	RBFLRB	6.0652	42.727	43.720	-0.993
2	Ups and across from CgrCrk Junc: TSG1007	RBFLRB	3.1830	36.510	37.500	-0.990
1	USGS Gage-TimeStageFerndale: USGS-Fern	RAFLMM	6.0328	29.642	29.770	-0.128
1	hwm - riverside of levee: 16-11-25-04	RAFLMM	4.9947	26.888	26.960	-0.072
1	hwm - cottonwd d/s o pipeline: 15-11-25-04	RAFLMM	4.9130	26.672	26.740	-0.068
1	hwm elec shed: 13-11-25-04	RAFLMM	4.8357	26.527	26.620	-0.093
1	hwm 15 in dia alder rivrside: 10-11-25-04	RAFLMM	4.4298	25.883	26.400	-0.517
1	hwm big cottonwood: 9-11-25-04	RAFLMM	4.2135	25.444	25.240	0.204
1	pk in alder tree riverward: 21-11-25-04	RAFLMM	4.0093	24.963	24.800	0.163
1	hwm top o arther bengen: 12-11-25-04	RAFLLB	3.9152	25.100	25.500	-0.400
1	hwm 6in dia ald fieldside: 11-11-25-04	RAFLLB	3.8588	24.856	24.810	0.046
1	2004 1995 1990 on file cabinet: 20-11-25-04	F1544		22.240	22.940	-0.700
1	hwm fieldward: 8-11-25-04	RAFLLB	3.4885	23.325	23.380	-0.055
1	Ups SltrRd 750 ft nr wst edg flding: 14-11-25-04	RAFLLB	2.8519	18.506	19.450	-0.944
1	Ups Slater twrd RHS of flwpth: 7-11-25-04	RAFLLB	2.6143	17.841	17.870	-0.029
1	paint on Slater Road: 19-11-25-04	RAFLLB	2.6032	17.840	17.840	-0.000
1	Dns Slater 120' left of twin culverts: 6-11-25-04	RAFLLB	2.5977	17.839	17.710	0.129
1	Ups Marine Drive-east of red barn: GN1000	RAFLLB	0.6577	16.451	16.630	-0.179
1	Ups Marine Drive-left side FrndlRd: GN1001	RAFLRC	0.9462	13.329	14.590	-1.261
5	hwm 215 evergreen: 5-11-25-04	REFLRG	2.0566	82.949	83.110	-0.161
5	Tom Road: GN1018	REFLRG	1.3250	75.938	75.580	0.358
5	Lindsay Road: GN1019	REFLRG	0.2744	72.314	71.530	0.784
5	Max stage Huntingdon Gage: BC-3	REFLSR	0.9207	35.236	35.010	0.226

TABLE 2004–2: High-Water Mark Mimicry Summary: 2004nov Event

High-Water Mark Difference Range (ft)	Number of Differences	Proportion of Total Number	Cumulative Proportion
-5.00 to -1.00	1	0.02	0.02
-1.00 to -0.50	8	0.19	0.21
-0.50 to -0.25	3	0.07	0.28
-0.25 to -0.10	5	0.12	0.40
-0.10 to 0.00	8	0.19	0.59
0.00 to 0.10	2	0.05	0.64
0.10 to 0.25	9	0.21	0.85
0.25 to 0.50	2	0.05	0.90
0.50 to 1.00	4	0.10	1.00
1.00 to 5.00	0	0.00	1.00

what occurred downstream.

Figure 2004–5 shows the elevations at the newly installed USGS stage record at Nooksack Bridge at Everson. Again the rise is somewhat early and the recession shows an excess but much reduced from that displayed at Cedarville. The maximum difference is about one foot, the tolerance limit used for high-water mark mimicry.

Figures 2004–6 through 2004–13 show results at the time-series gages that reported valid data for this event. Most of them show a rising limb that is too early and various results, a bit high or a bit low, on the peak. The Kamm Creek gage, available only for this event, shows perhaps the best mimicry. The Johnson Street gage shows a rather poor reproduction partly a consequence of the simulated overflow at Everson Main Street but also due to the lack of any data on the rainfall-induced flows. An approximate allocation of the flow record at the Huntingdon station was used as an estimate but refinement of a small overflow will require much better data than that.

The recession of the stage record at the Appel Farm site was used to solve an unknown at Lattimore Dike. The ground survey for structures reports two culvert barrels, with one directly above the other. The outlet of the lower barrel was completely buried in sand at the time of the survey. However, the upstream end of the culvert could be measured. The unknown was the state of this culvert during a high flow event. Would the high head upstream be able to dislodge the plug of sand in the barrel? It is also possible that the culvert was cleared after the survey but before the flood. However, it was also completely blocked during an earlier field inspection of the structure.

The initial assumption was that it would not but the time-series gage recession showed otherwise. With only the upper barrel active, the drain time for this detention basin, because that is what it is during a flood, was days too long. Activating the lower barrel resulted, with some minor adjustments, in mimicking the recession of this event closely. Subsequent recessions for other events were then mimicked closely. This among many other insights shows that progress in modeling often depends not on increased refinement in the model structure or the solution methodology, but in just having sufficient measured data from past floods.

November 2006

This event had two precursor peaks just days before the flood peak occurred. This event also had one of the larger overflows at Everson Main Street in the calibration set. There were 57 high-water marks that appeared to be valid. The high-water mark results are given Tables 2006–1 and 2006–2.

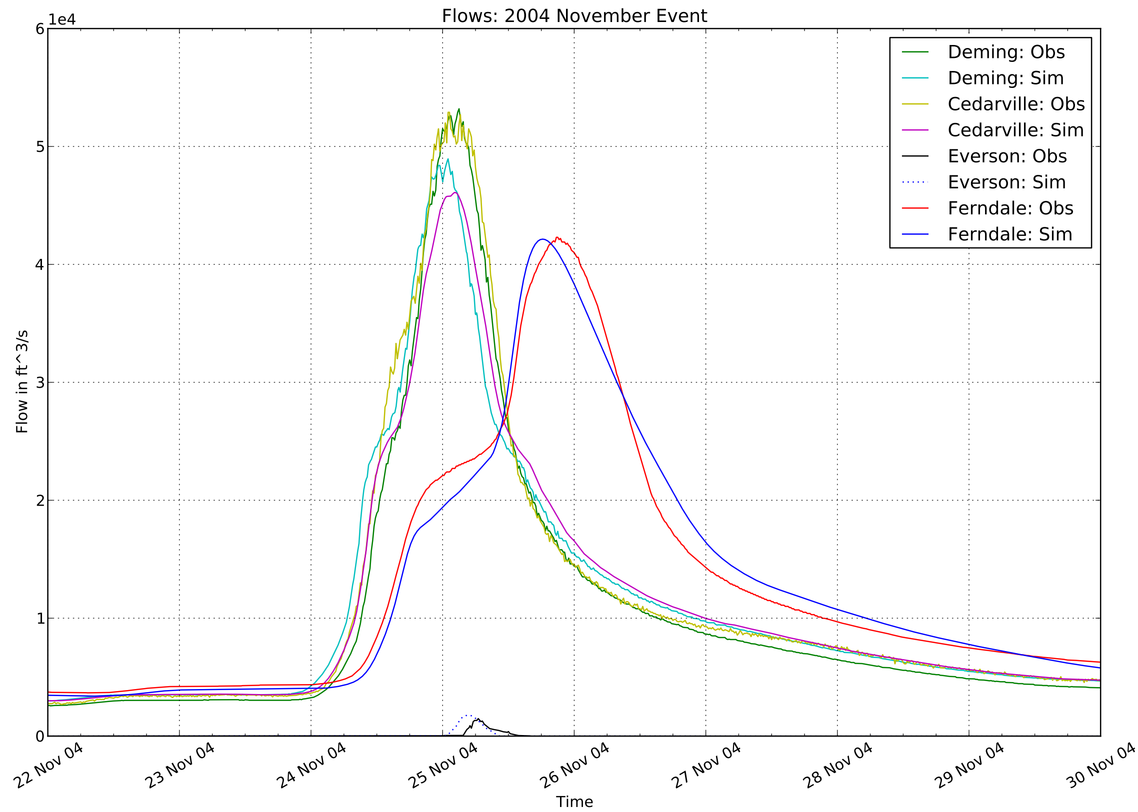

Figure 2004–1: Flows: 2004

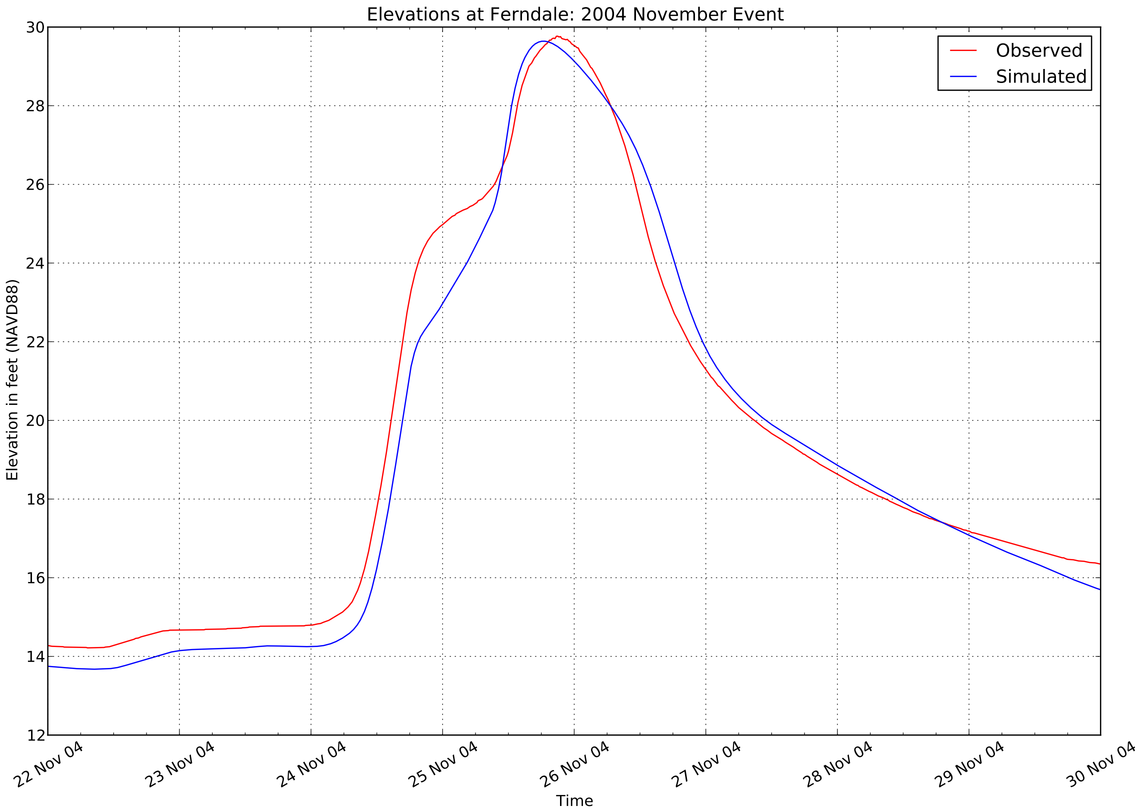

Figure 2004–2: Elevations at Ferndale: 2004

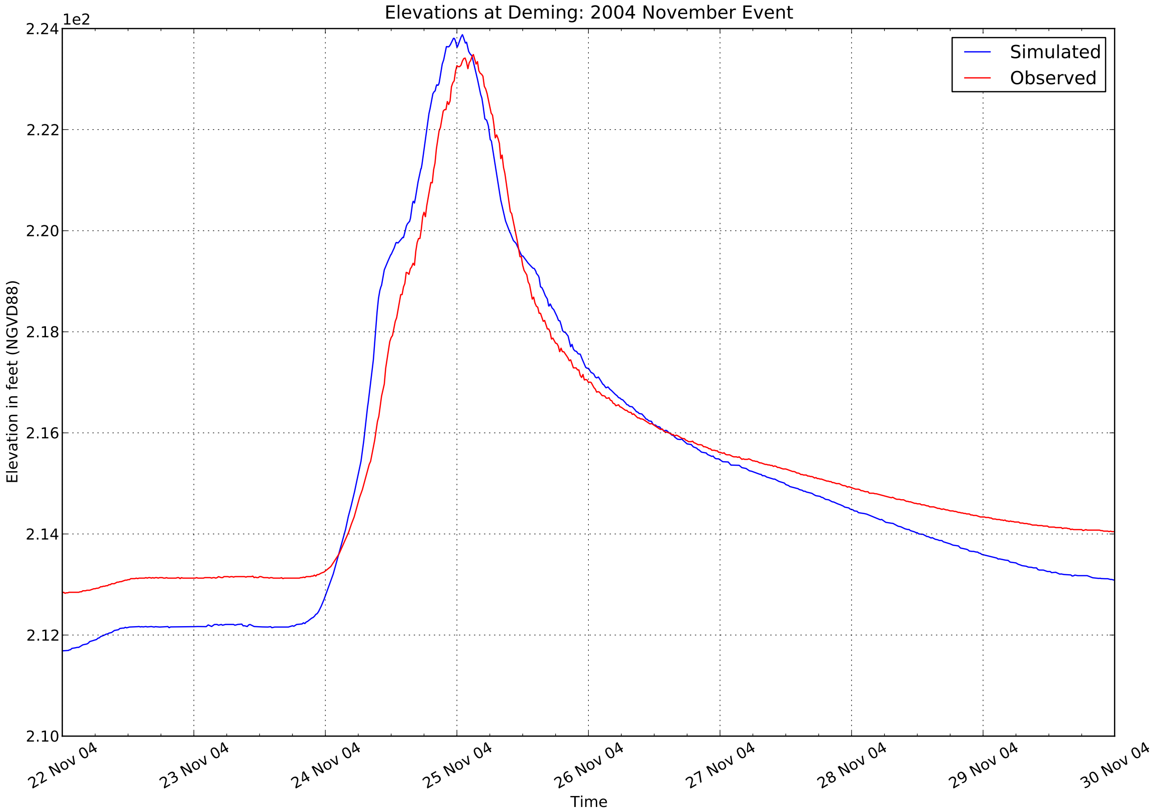

Figure 2004–3: Elevations at Deming: 2004

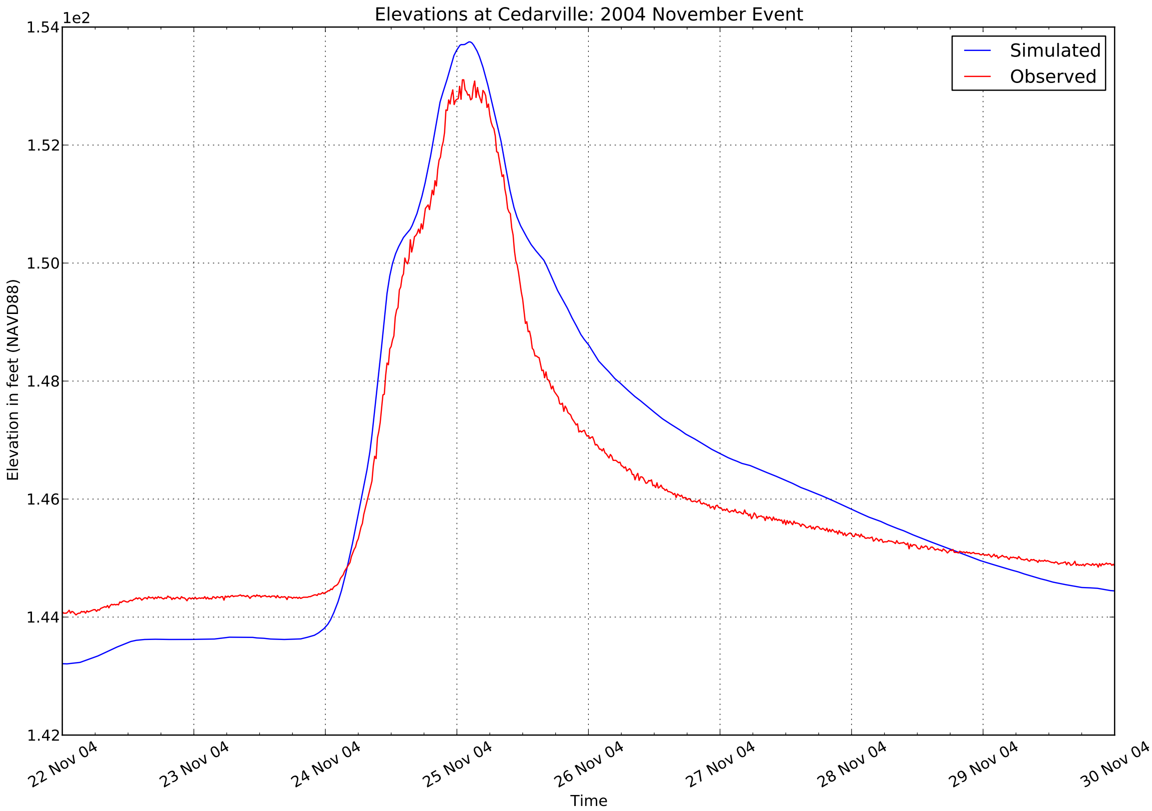

Figure 2004–4: Elevations at Cedarville: 2004

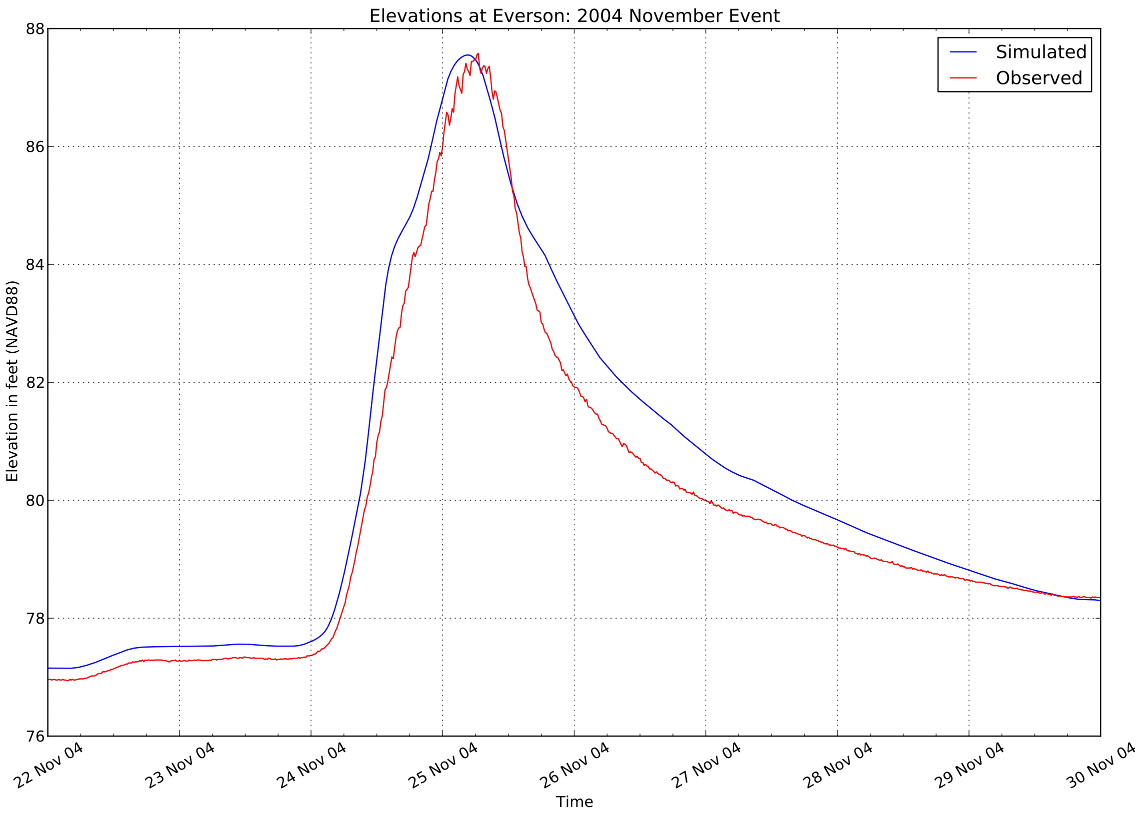

Figure 2004–5: Elevations at Everson: 2004

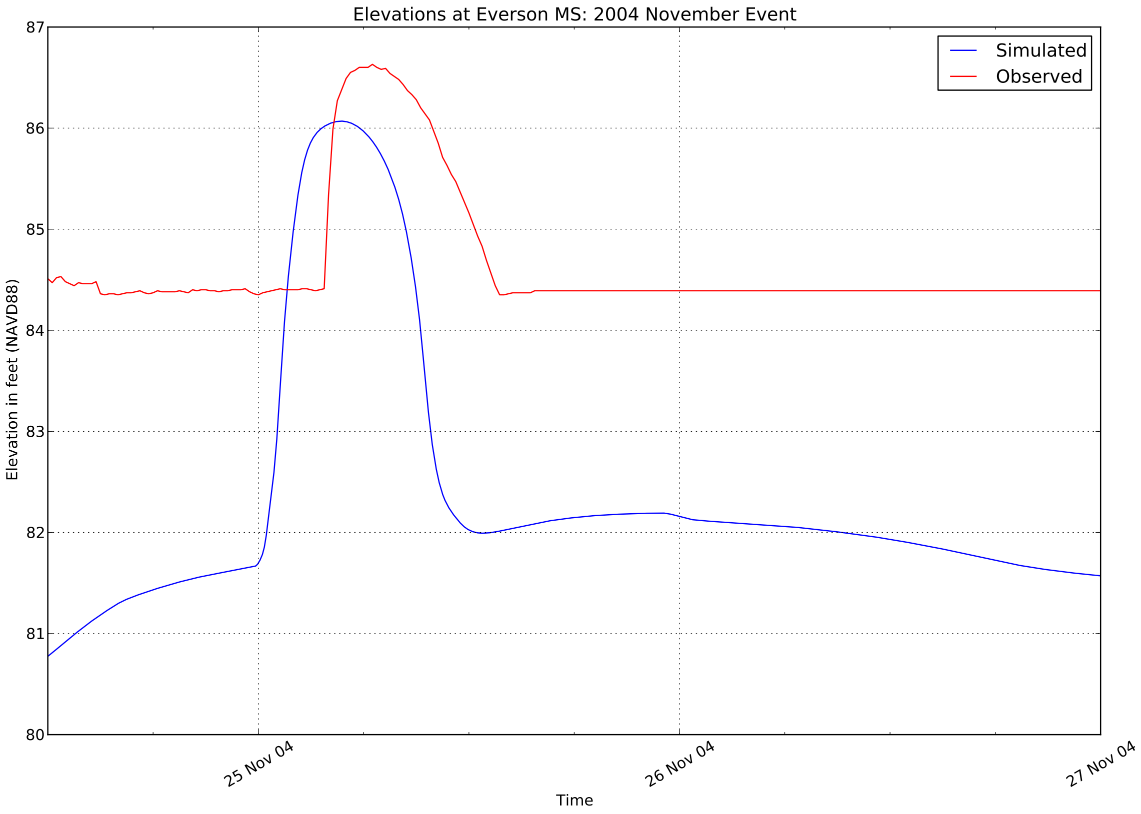

Figure 2004–6: Elevations at Everson Main Street: 2004

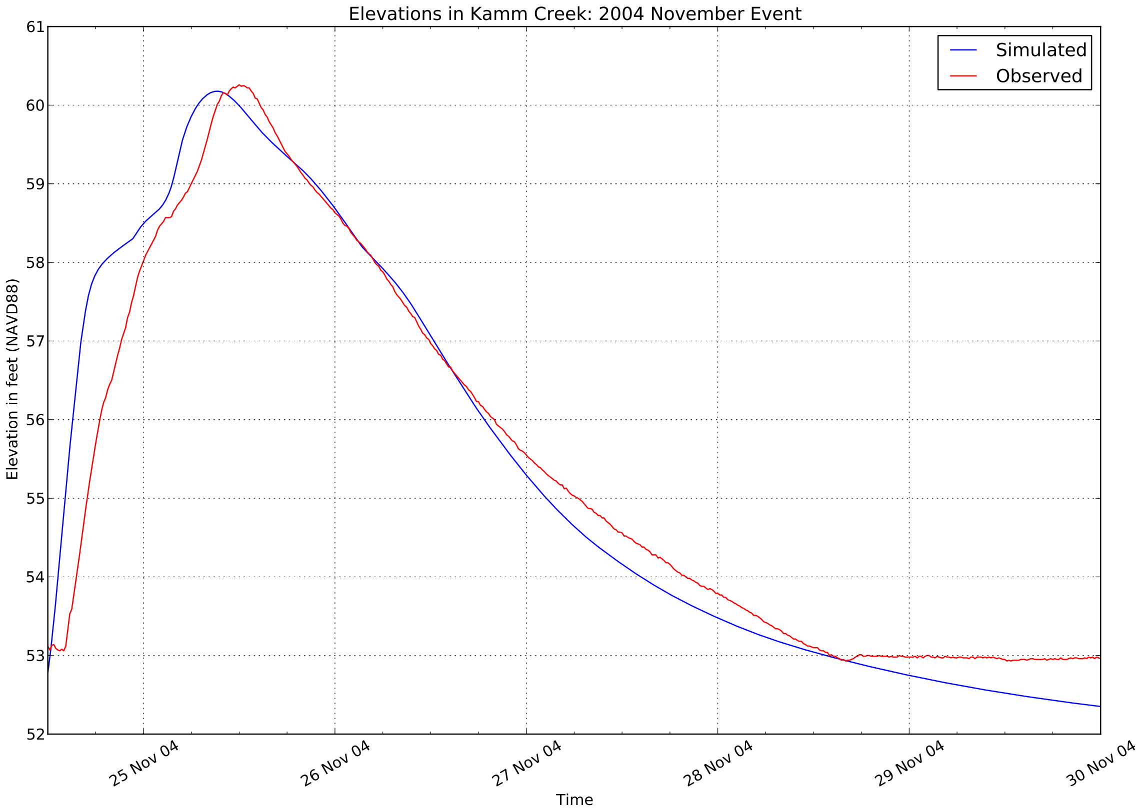

Figure 2004–7: Elevations in Kamm Creek: 2004

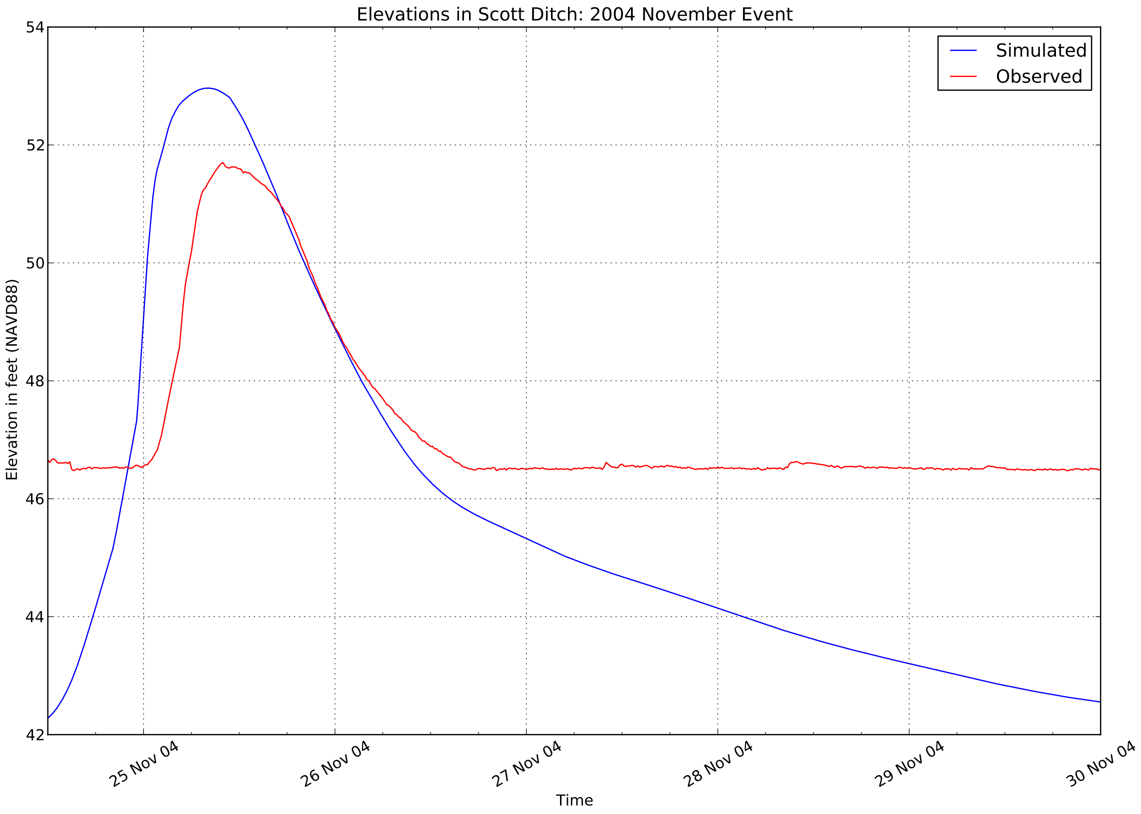

Figure 2004–8: Elevations in Scott Ditch: 2004

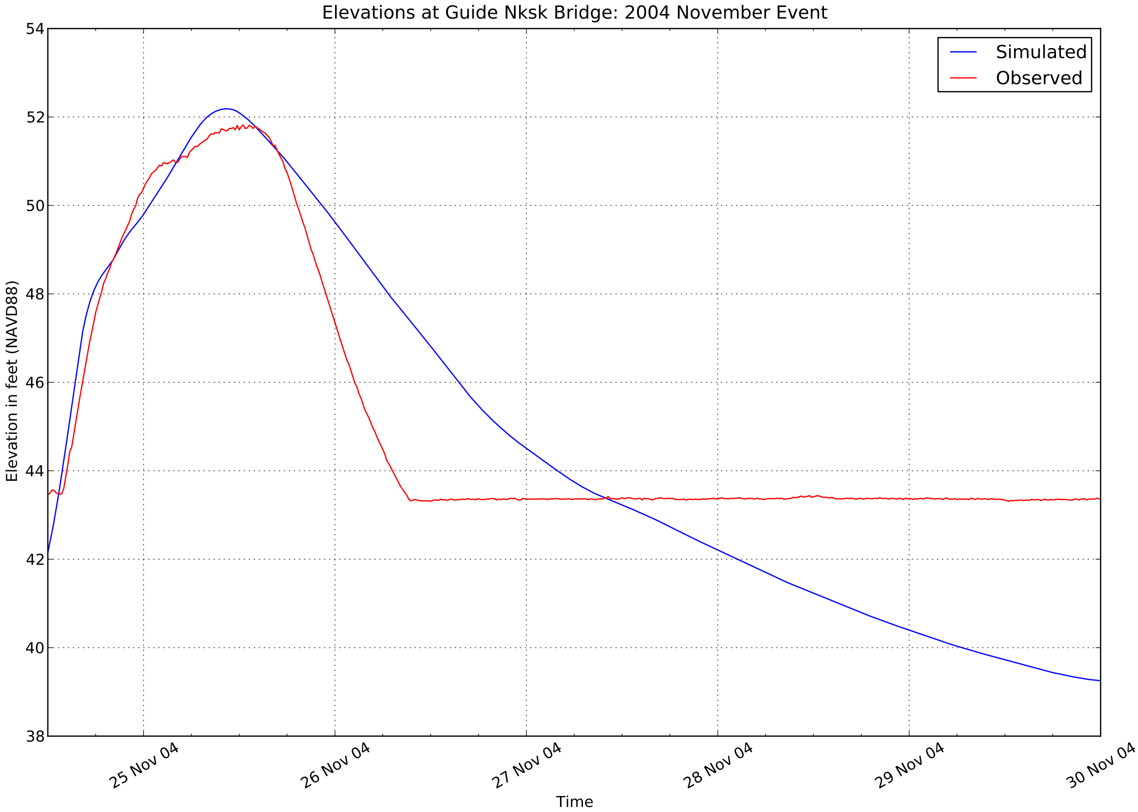

Figure 2004–9: Elevations at Guide Nooksack Bridge: 2004

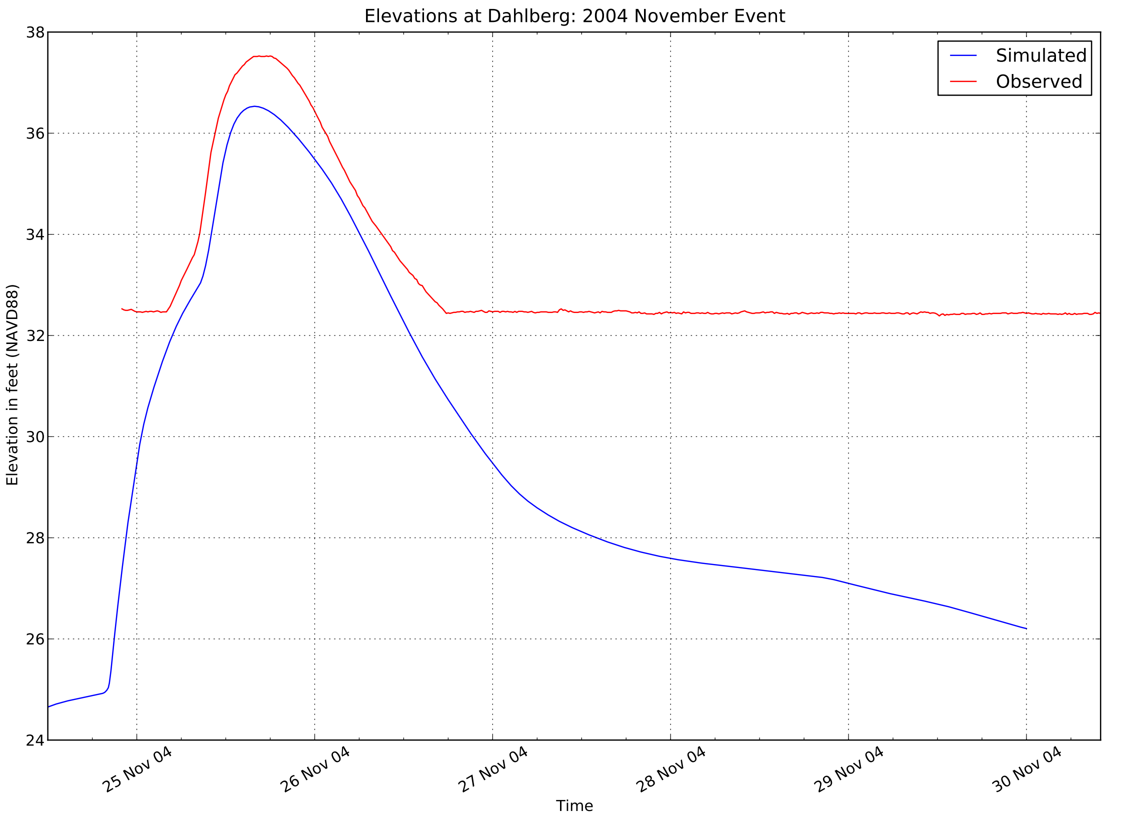

Figure 2004–10: Elevations at Dahlberg: 2004

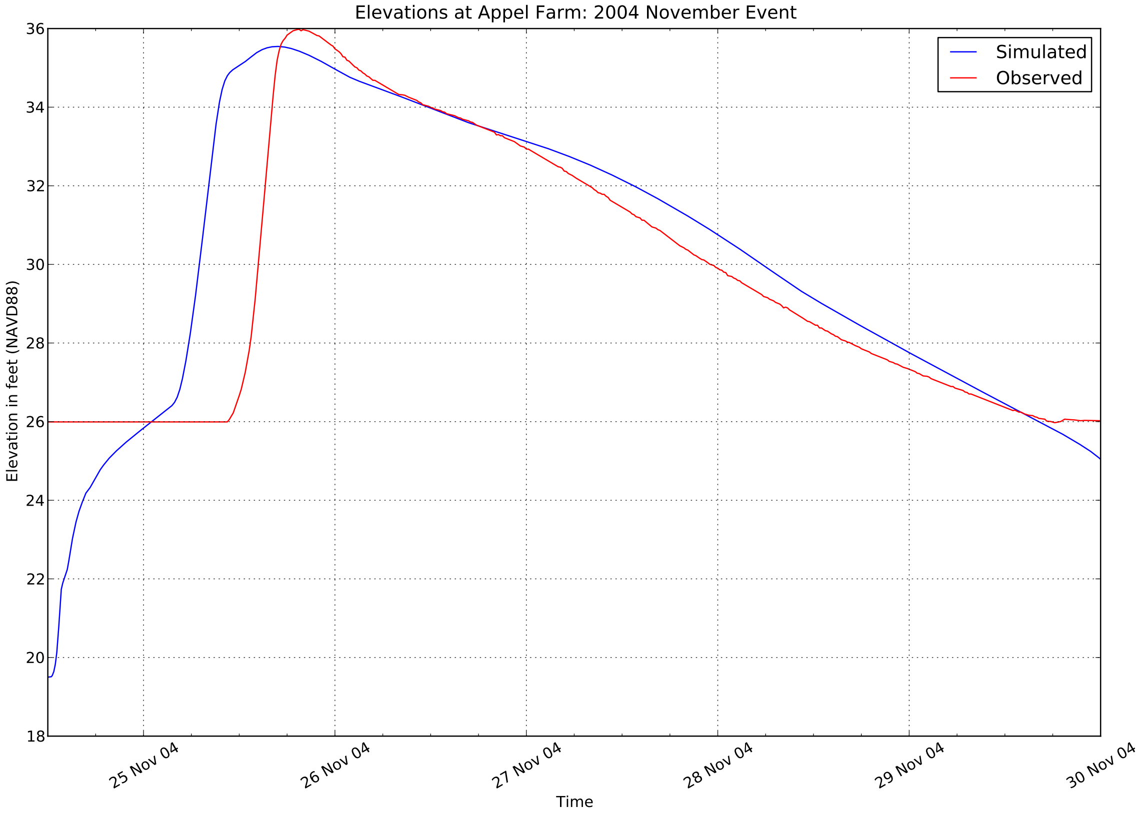

Figure 2004–11: Elevations at Appel Farm: 2004

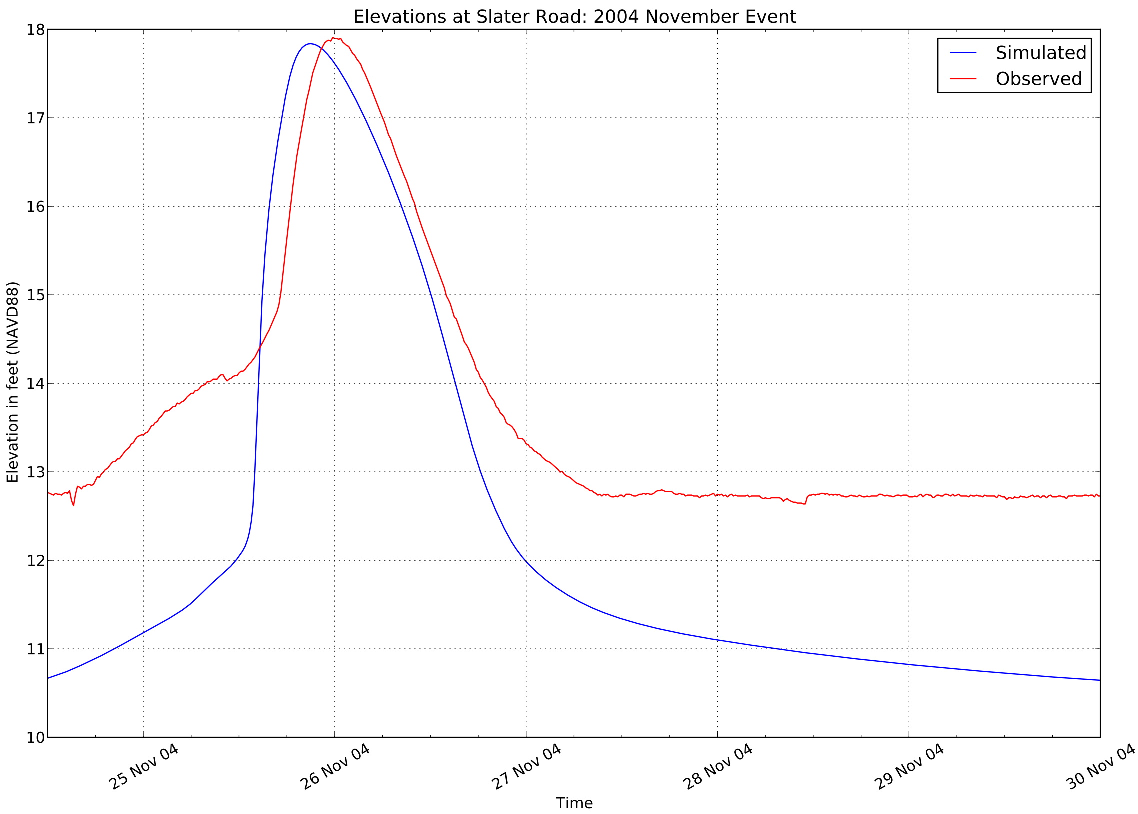

Figure 2004–12: Elevations at Slater Road: 2004

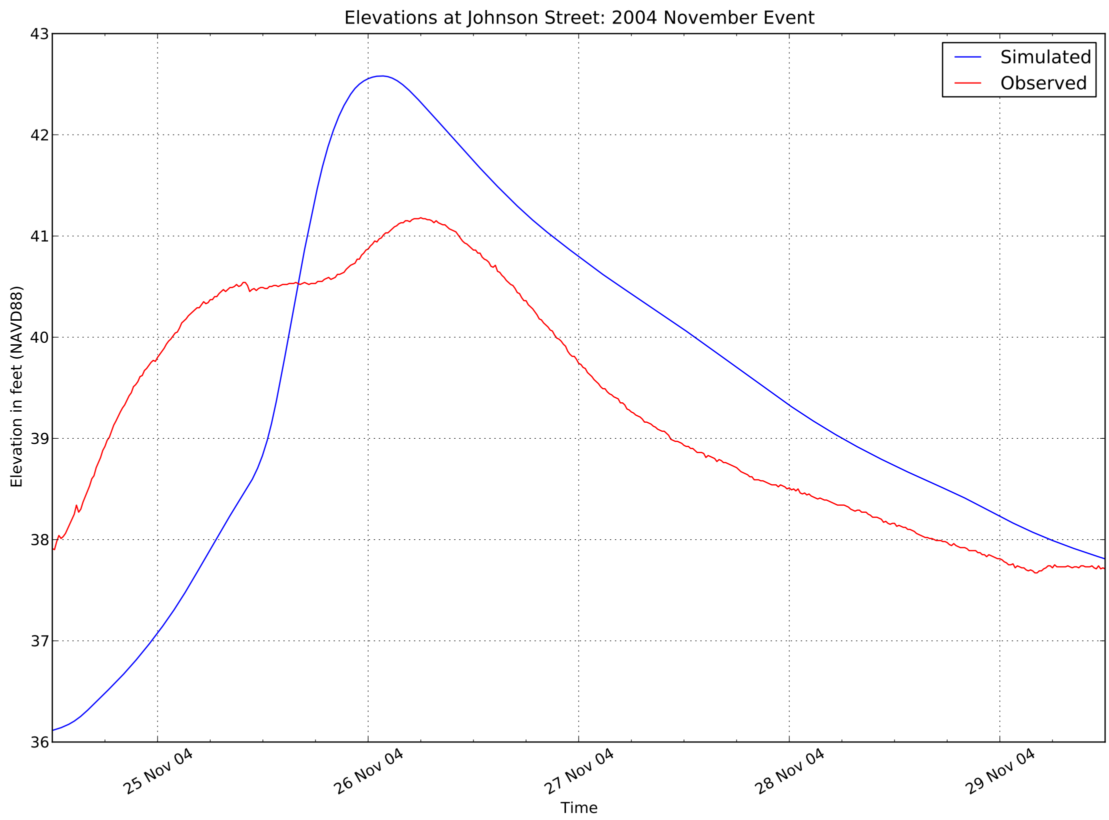

Figure 2004–13: Elevations at Johnson Street: 2004

This event caused major problems in calibration with two high-water marks in the left-hand flood plain upstream of Everson Road. This was the only event with high-water marks in that flood plain. Initial calibrations always showed these marks under simulated by 2 feet or more. It took many iterations and experiments to create a pattern that would get close to these marks and would also do well with the other events. The difficulty was getting the level of the Nooksack to agree with the stage record at the Everson Nooksack bridge and to also produce overflows that were "close enough" at Everson Main Street. This led to a major review of some of the overflow surfaces and also of the levee crest on the left-hand flood plain, across from the overflow segment that tends to produce most of the overflows. Nooksack invert level changes were also made.

After many iterations and blind ends, a refinement in the overflow connections upstream of the extension of Massey Road finally provided a major key to fitting the model to the four calibration events. What proved to be the case was a subtle distortion of flow overland to upstream of Massey Road. The initial configuration was such that the flow of water, as modeled, did not submerge the critical control on the flow surface near the bank. However, adding more detail to the flow division that takes place at the corner of Emmerson-Massey Road showed that the critical control was submerged by the water flowing overland to the somewhat distant low point upstream of Massey Road. With this refinement and some adjustments to the overflow surface for the 2006nov event, the model was able to reproduce overflows at Everson Main Street but was putting too much water into the left-hand flood plain.

A review of the major points of overflow into the left-hand flood plain, showed that they were just downstream of a right-angled bend in the levee crest. Also the current main flow filament in the Nooksack had a right-angled bend. Furthermore, there was a remnant island of ground not far streamward from the levee, that had ground elevations just slightly lower than the crest of the

TABLE 2006–1: High-Water Mark Results: 2006nov Event

Rch.	High-Water Mark Description	Flow Path Axis	Station (mi.)	Obs. Elev. (ft.)	Sim. Elev. (ft.)	Diff. (ft.)
4	USGS Deming Gage: USGS-Dem	RDFLMM	36.6612	223.768	224.240	-0.472
4	R4-10u/sot: 7-11-06-06	RDFLMM	36.0571	215.811	216.080	-0.269
4	Hwmr4-9d/send of ot: 6-11-06-06	RDFLMM	36.0287	215.555	216.550	-0.995
4	Hwmr4-6: 24-11-06-06	RDFLMM	34.2530	193.882	194.230	-0.348
4	Hwm: 3-11-06-06	RDFLMM	34.0367	191.427	191.160	0.267
4	Hwm: 4-11-06-06	RDFLMM	33.4552	183.707	184.100	-0.393
4	rch4-2hwm15 ft sth pk-tree: 30-11-06-06	RDFLMM	32.7547	178.653	178.460	0.193
4	hwm2x2stake: 32-11-06-06	RDFLMM	32.4446	174.448	175.300	-0.852
4	USGSCedarvilleGage: USGS-Ced	RDFLMM	31.0041	153.802	153.560	0.242
4	Hwm dbrsln: 2-11-06-06	RDFLMM	29.3200	135.350	135.620	-0.270
4	R4-14 pk fnc pst 8 frm cnr: 9-11-06-06	RDFLMM	25.2312	100.115	100.960	-0.845
4	Hwmr4-14: 10-11-06-06	RDFLMM	25.1010	99.247	99.910	-0.663
4	R4-15 pk in 10in alder: 11-11-06-06	RDFLMM	25.0100	98.361	99.190	-0.829
4	R4-16: 12-11-06-06	RDFLMM	24.9367	98.087	98.970	-0.883
4	USGS Everson Gage: USGS-Evr	RDFLMM	23.5507	87.549	87.830	-0.281
4	Hwmr 4-18: 14-11-06-06	RDFLLB	0.1963	88.319	88.220	0.099
4	R4-19: 15-11-06-06	RDFLLB	0.0503	88.189	87.930	0.259
4	Upstrm MssyRd: GN1015	RDFLRS	0.7205	95.617	95.530	0.087
4	Evrsn Mn Strt: TSG1017	RDFLRB	0.0133	86.286	86.600	-0.314
4	R4-17+611-04 hwm: 13-11-06-06	RDFLRG	0.8897	95.727	96.040	-0.313
4	Ups Emmerson Road: GN1016	RDFLRG	0.3787	90.850	90.820	0.030
4	hwmrr4-11fencepost: 8-11-06-06	RDFLRJ	3.1268	210.648	211.730	-1.082
4	hwm7 scour on rd wtr 3ft: 25-11-06-06	RDFLRJ	1.5697	189.936	189.350	0.586
4	HWM on fnc-pst: 34-11-06-06	RDFLRJ	1.3866	187.675	187.100	0.575
4	HWMr4-8 pk in cdr: 33-11-06-06	RDFLRJ	0.9350	181.440	181.760	-0.320
4	Hwm(Sande): 5-11-06-06	RDFLRJ	0.2274	172.307	171.060	1.247
3	Ron Bronsema gage: RonB	RCFLMM	20.2145	70.222	70.200	0.022
3	Hnngn-ScttDtch: TSG1011	RCFLLC	1.9903	53.000	52.600	0.400
3	Frm accss Rd at jog in RCFLRL: GN1013	RCFLRL	1.3394	71.572	71.130	0.442

levee. Consequently flow over the left-hand levee would be reduced by at least two effects: first, being on the inside of a right-angled bend in the main flow, and, second, being in the "shadow" of the island. Consequently, the crest of the levee was increased downstream of the right-angled bend by a fraction of a foot. This then reduced the flow to the left-hand flood plain and brought the two high-water marks closer to their observed level.

The two key high-water marks were: 14-11-06-06 and 15-11-06-06. One of these marks was in an open-side shed and was field checked and the survey notes reviewed. Also its level made sense with the local topography as defined by the Lidar-based contour map. So, there is no reason to believe that the marks were in error.

From the process of fitting the model to these marks we can see that several changes in future documentation of overflow-producing floods need to be made:

1. The work with the prior model established that the profile of Emmerson Road and any small berms placed to protect buildings on the upstream side of Emmerson Road, were a primary

TABLE 2006–1: High-Water Mark Results: 2006nov Event-concluded

Rch.	High-Water Mark Description	Flow Path Axis	Station (mi.)	Obs. Elev. (ft.)	Sim. Elev. (ft.)	Diff. (ft.)
2	TB Gud Brdg HWM: 39-11-06-06	RBFLMM	15.4000	52.274	52.570	-0.296
2	TB HWM RR110706A: 26-11-06-06	RBFLMM	15.1912	51.932	51.430	0.502
2	TB Old Gud hwma: 37-11-06-06	RBFLMM	14.7734	51.350	50.680	0.670
2	TB Old Gud hwmb: 38-11-06-06	RBFLMM	14.7546	51.297	50.560	0.737
2	TB HSM RR 110706b: 27-11-06-06	RBFLMM	14.6655	50.839	50.000	0.839
2	TB RR HWM3: 42-11-06-06	RBFLMM	14.1727	47.792	48.560	-0.768
2	Dns Rttr Rd: GN1006	RBFLLB	4.4588	35.004	34.270	0.734
2	TB Rttr hwm: 36-11-06-06	RBFLLB	4.3377	35.004	33.870	1.134
2	TB Prds hwmc: 49-11-06-06	RBFLLB	0.8582	32.589	33.290	-0.701
2	TB Prds hwmb: 48-11-06-06	RBFLLB	0.6968	32.416	32.890	-0.474
2	TB Prds hwma: 47-11-06-06	RBFLLB	0.4181	32.283	32.560	-0.277
2	Flynn Rdn FshtrpCrkLv: GN1008	RBFLRB	7.1932	44.955	45.910	-0.955
2	TB RR HWMA Jst upstrm Fsh Trp Crk Lv: 40-11-06-06	RBFLRB	5.9402	42.732	43.350	-0.618
2	UpsandacrossfromCgrCrkJunc: TSG1007	RBFLRB	3.1830	36.268	37.100	-0.832
2	TB RR HWMB: 41-11-06-06	RBFLRD	0.2802	42.699	42.410	0.289
1	USGS Frndl Gg: USGS-Fern	RAFLMM	6.0328	29.064	29.020	0.044
1	TB Hvndr Prk hwm: 50-11-06-06	RAFLLB	3.9939	24.748	24.520	0.228
1	TB Sltr hwm atUps edg Rd: 45-11-06-06	RAFLLB	2.6100	17.026	16.380	0.646
1	Dns edg Sltr Rd: TSG1004	RAFLLB	2.6017	17.025	16.330	0.695
1	TB Sltr Mddl Rd?: 46-11-06-06	RAFLLB	2.6068	17.026	16.280	0.746
1	Ups MrnDrv-est rd brn: GN1000	RAFLLB	0.6577	15.958	15.510	0.448
1	Ups Mrn Drv nr est edg fldd area: 43-11-06-06	RAFLLB	0.6577	15.958	15.410	0.548
1	Sth MrnDrv lv wth snd bgs 1805MrnDrv: 44-11-06-06	RAFLLB	0.2245	13.023	13.400	-0.377
1	Dns edg Mrn Drv 300 Est Rnbw Slgh: 35-11-06-06	RAFLRC	0.9288	12.649	13.680	-1.031
5	Tm Rd: GN1018	REFLRG	1.3250	76.067	76.490	-0.423
5	Lndsy Rd: GN1019	REFLRG	0.2744	72.581	72.850	-0.269
5	Jhnsn St wst BNRR: TSG1025	REFLMM	1.5395	42.917	42.050	0.867
5	Mx stg Hntngdn Gg: BC-3	REFLSR	0.9207	34.216	33.680	0.536

influence on the quantity of flow that would be diverted to the overflow corridor. Recall that much of the water flowing over the banks of the Nooksack River DOES NOT flow to the overflow corridor. Instead it flows roughly parallel to the Nooksack and then rejoins the Nooksack River a short distance upstream of the bridge at Everson. Whatcom County has established time-series gages and crest-stage gages in this area to better track what water levels a flood produces.

TABLE 2006–2: High-Water Mark Mimicry Summary: 2006nov Event

High-Water Mark Difference Range (ft)	Number of Differences	Proportion of Total Number	Cumulative Proportion
-5.00 to -1.00	2	0.04	0.04
-1.00 to -0.50	11	0.19	0.23
-0.50 to -0.25	15	0.26	0.49
-0.25 to -0.10	0	0.00	0.49
-0.10 to 0.00	0	0.00	0.49
0.00 to 0.10	5	0.09	0.58
0.10 to 0.25	3	0.05	0.63
0.25 to 0.50	6	0.11	0.74
0.50 to 1.00	13	0.23	0.97
1.00 to 5.00	2	0.04	1.00

2. The calibration for the 2006nov event, the only event to have reliable high-water marks in the left-hand flood plain upstream of Everson Road, established that the crest elevation of the levee on that side of the river as well as its effectiveness, also have a strong influence on how much water flows over the right-hand bank near Everson. The flow over the left-hand levee is complicated by the bend in the river that is currently present. Raising that levee to improve protection to the left-hand flood plain, will increase, to some degree, the flow over the right-hand bank of the Nooksack and also the flow over Emmerson Road. It is strongly recommended that at least a crest-stage gage be established somewhere near the downstream end of this flow path, so that we get a value of the water-surface elevation upstream of Everson Road. It would be better if a time- series gage could also be established there. We would then have time series of elevations at the three points of flow past Everson: in the Nooksack main channel, over Everson Main Street, and through the large arch culvert Everson Road, and for a really large event, flow over Everson Road into the upper end of the Scott Ditch flow paths in the left-hand flood plain of Reach 3.

Even with all the complications imposed by this event, only four out of the 57 high-water marks fall outside of the tolerance. However, none of them are far outside.

The results for time-series data are shown in Figures 2006–1 through 2006–11. Recall that for this event, the USGS ceased publishing records of flow at Deming, in part because the cableway was no longer safe, but also, because Cedarville was available some miles downstream. The boundary condition required at Deming was then constructed by shifting the flow record at Cedarville in both time and flow as required to create flows at Deming that made sense of what occurred downstream. Therefore, the observed flow shown for Deming is just the time-shifted record at Cedarville. The simulated flow shown for Deming is the flow sequence that was used for the boundary condition and shows the effect of adjustments made in flow. As is clear from the figure, Cedarville appeared to show a flow that was much too large, at least near the peak. Note that the adjustment of the flows at Deming varied depending on the flow at Deming so that the change in the flow used varied with the flow given by the time-shifted Cedarville flows taken as Deming observed.

This event had two modest flood peaks that preceded the main peak. The flow adjustments made in this flow range were much smaller than for the main peak. However, at Ferndale the mimicry of the early peaks was rather poor, in part from the sparse data coverage of tributary inflows that would have had a greater influence on these peaks. As in the prior events, the peak flow is closely simulated because that was one of the calibration values. The observed rising limb again shows the dogleg and the simulation shows a much muted reproduction of it. At Everson Main Street the simulated peak is low and early. A major problem in modeling the overflow at Everson Main Street is the large rate of change of flow with upstream water-surface elevation. A small difference in elevation can yield a large difference in peak flow.

Figure 2006-2 shows the elevation results at Ferndale. The dogleg deficiency again appears as do various differences in timing. However, the overflow shape is generally reproduced and the recession limb shape is mimicked well.

Figures 2006–3 and 2006–4 show results at Deming and Cedarville respectively. The results at Deming are considerably in error at the lower flows but the general shape of the main rise is reproduced well, albeit with an offset in timing. However, the timing at Deming was set to better match the timing at Cedarville. This effort results in a consistent but small over simulation of elevations at Cedarville but with timing that is quite close.

The good timing results at Cedarville carry over to the elevation sequence at Everson for this event, as shown in Figure 2006–5. The precursor peaks are poorly mimicked but the main peak is represented well with a recession that follows the observed data closely.

Figures 2006–6 through 2006–11 again show results at the time-series gages reporting valid data. The result at Everson Main Street is too early and a bit too narrow, but the difference in the peak elevation is reasonable.

The rise is generally too early but the peak elevation varies from too high to too low at the remaining locations. The recession at the Appel Farm gage is reasonably close, given that the outlet capacity was refined using the 2004nov flood. In this case, the flows at Everson Main Street were larger than in the 2004nov event, and the results at Johnson Street are somewhat improved.

January 2009

This event has the highest peak at Ferndale among all other events in the calibration set. It also proved to be the most difficult in calibration. There were several reasons for this difficulty:

1. In the press of time, the records from the USGS for Fishtrap Creek and Anderson Creek were quickly scanned for indicators of missing data. However, it turned out that the extracted data did not have any special flags for periods with missing data! It was only after concluding that there HAD to be additional water from upstream, that a large gap, in the Fishtrap Creek record was detected, right near the peak of the flood. Investigation with the USGS revealed that the gage itself was destroyed but a high-water mark near the peak had been found. Therefore an approximate hydrograph, obtained by extension from the existing rating curve, was used to create a first approximation to the flows in the missing period. This estimated period was then adjusted to better match the record of flow and elevation at Ferndale.
2. There were many anecdotal accounts that the downstream portion of the watershed and especially that portion downstream of Ferndale had received unusually heavy rainfall onto several inches of icy snow on top of frozen ground. However, there were no quantitative flow records found from the USGS near that part of the Nooksack. The extensive efforts to calibrate Reach 1, using Ferndale as the upstream boundary revealed an approximate shortfall of about 10,000 ft^3/s in the left-hand flood plain. For this event, there were three well established and consistent high-water marks at and near Slater Road in the left-hand flood plain. There were also three well established and consistent high-water marks at and near Marine Drive. All efforts to reach either set of high-water marks failed, falling 2 or more feet below both sets of marks with the tributary flows in hand. A check with the 100-year levels in the left-hand flood plain obtained using the prior model showed that the current high-water marks were somewhat higher. Of course, we had essentially no high-water marks in the left-hand flood plain for the prior model so it was not well calibrated there, especially for the 1990 flood.
3. Much time and effort was expended in exploring a Manning's n for the main channel that

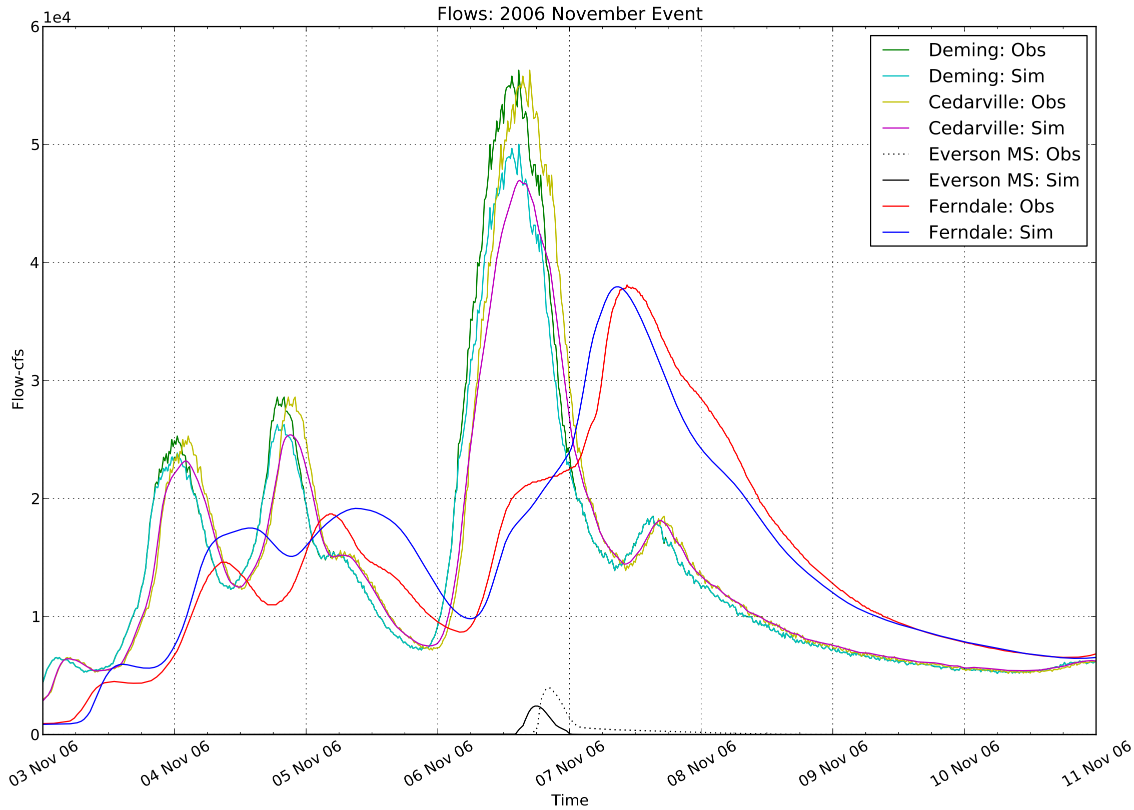

Figure 2006–1: Flows: 2006

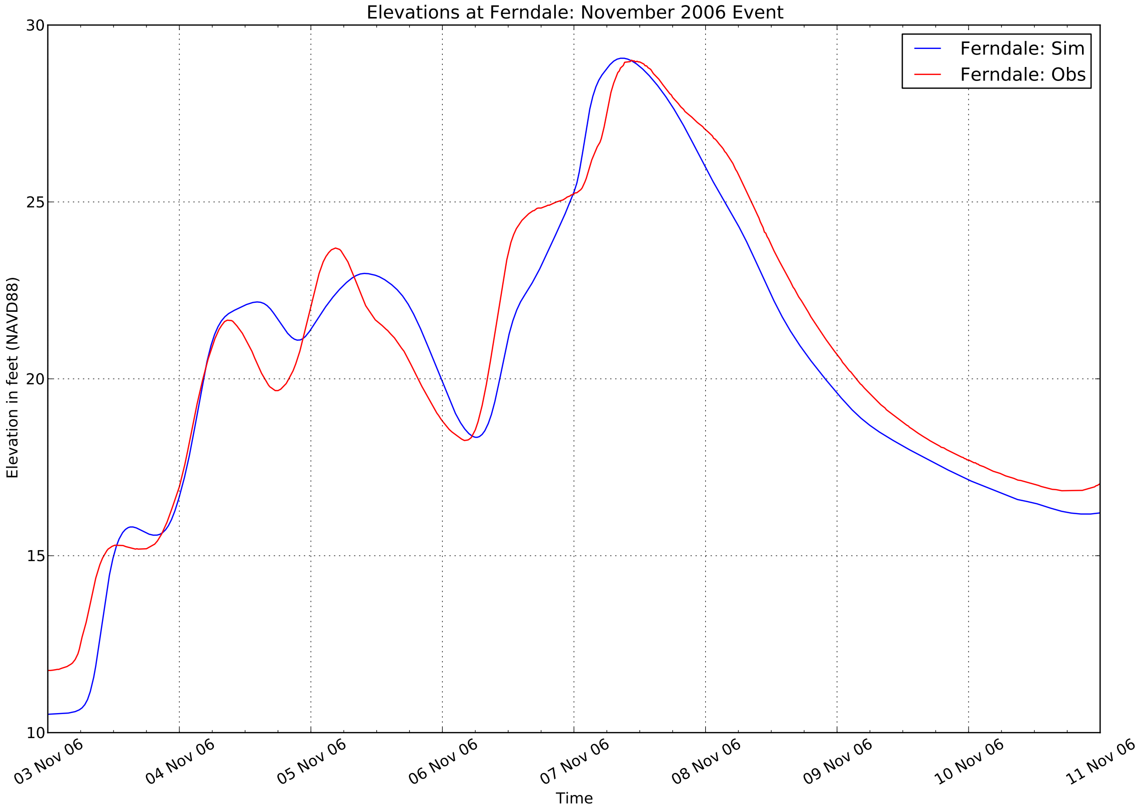

Figure 2006–2: Elevations at Ferndale: 2006

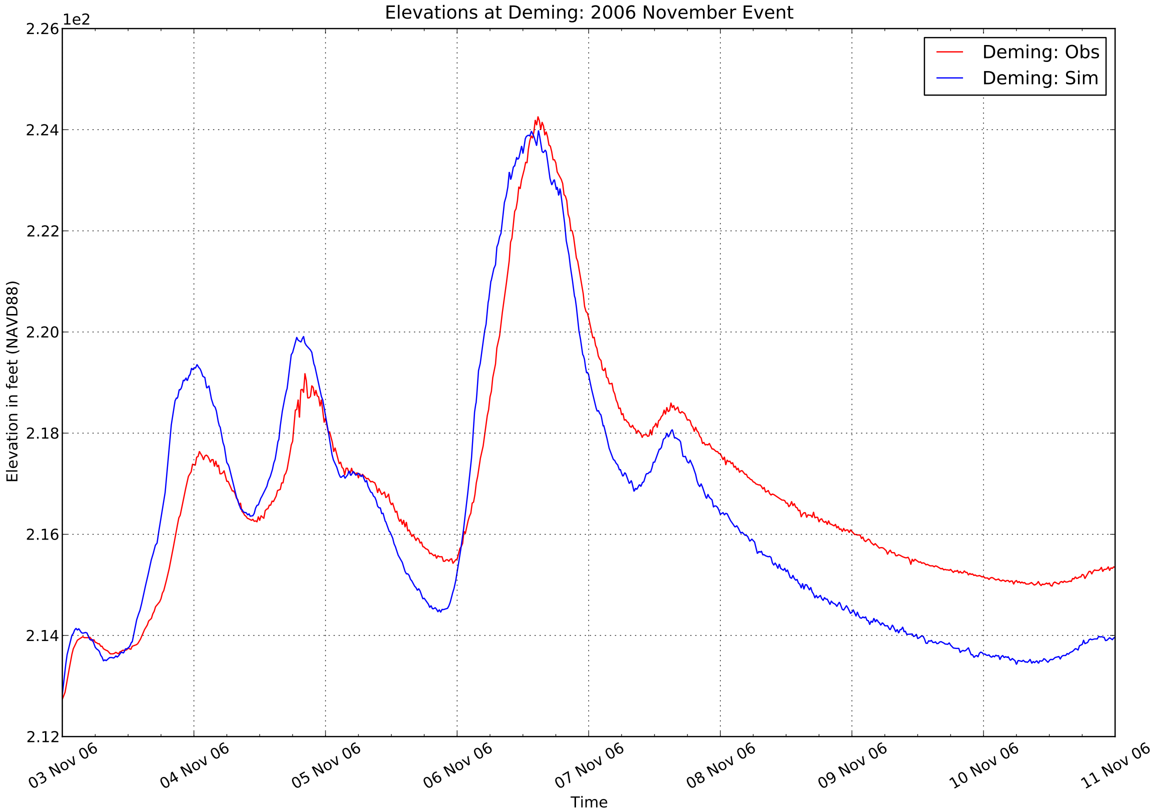

Figure 2006–3: Elevations at Deming: 2006

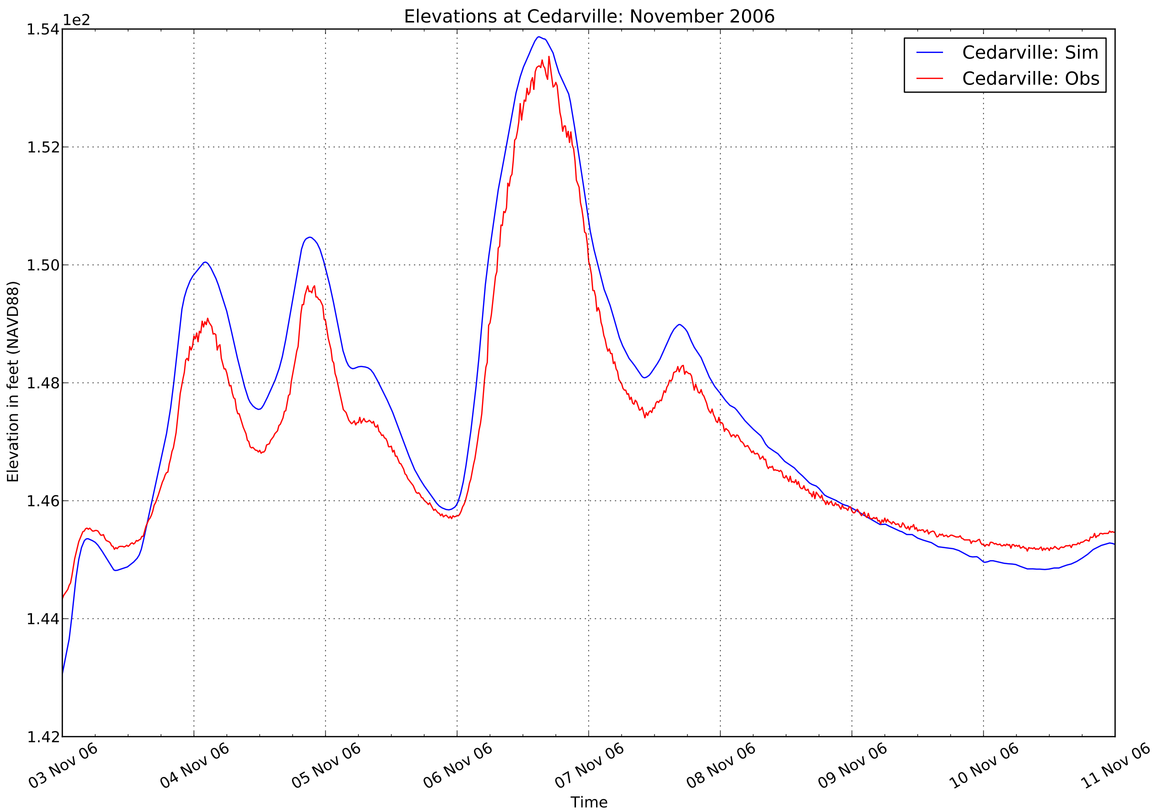

Figure 2006–4: Elevations at Cedarville: 2006

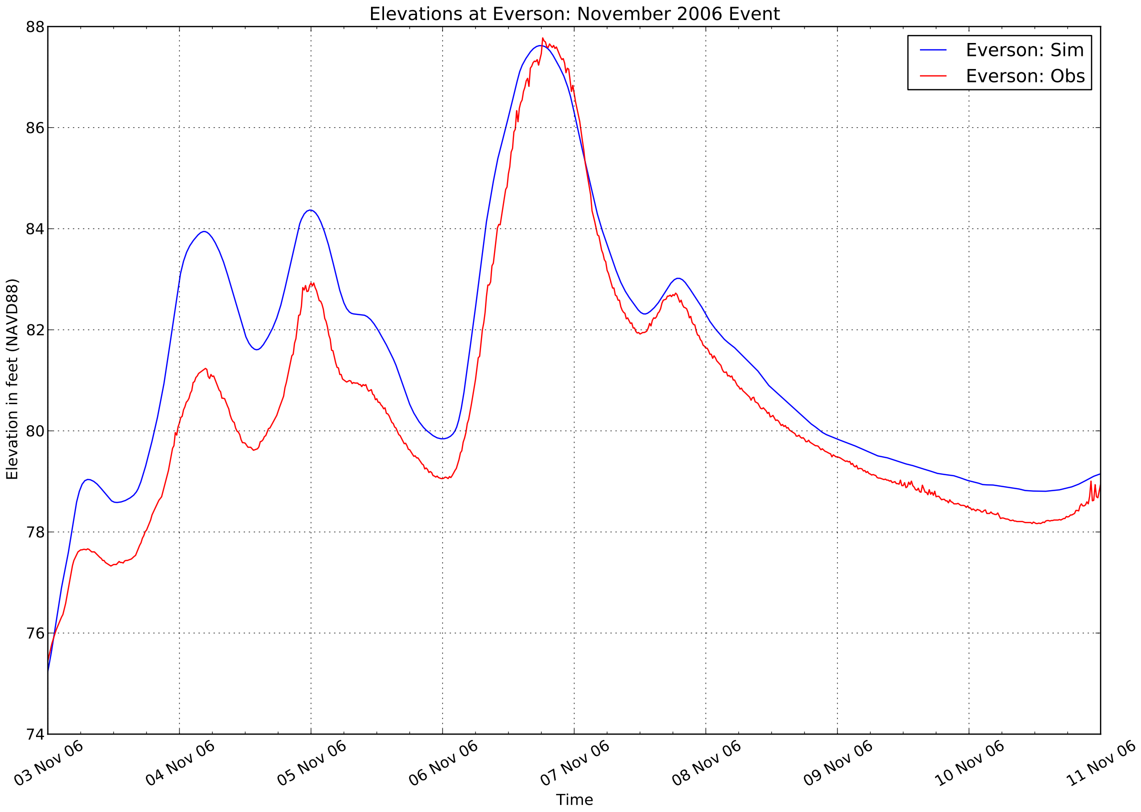

Figure 2006–5: Elevations at Everson: 2006

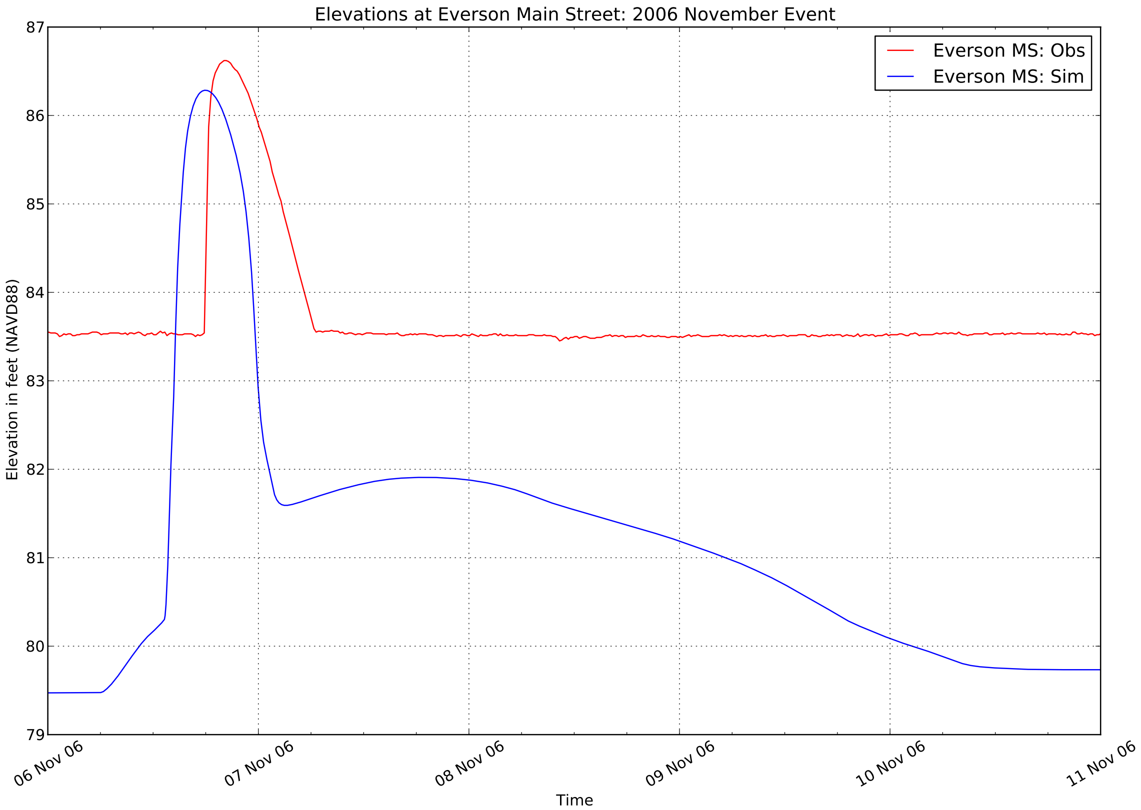

Figure 2006–6: Elevations at Everson Main Street: 2006

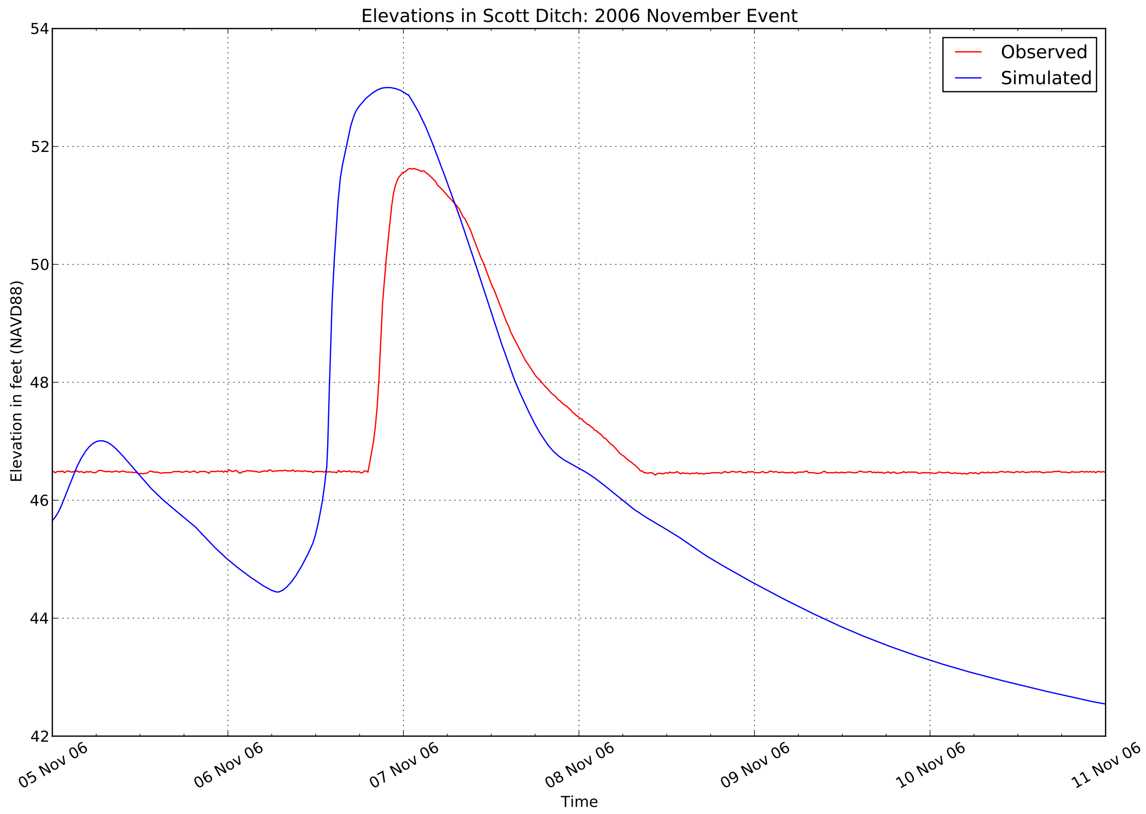

Figure 2006–7: Elevations in Scott Ditch: 2006

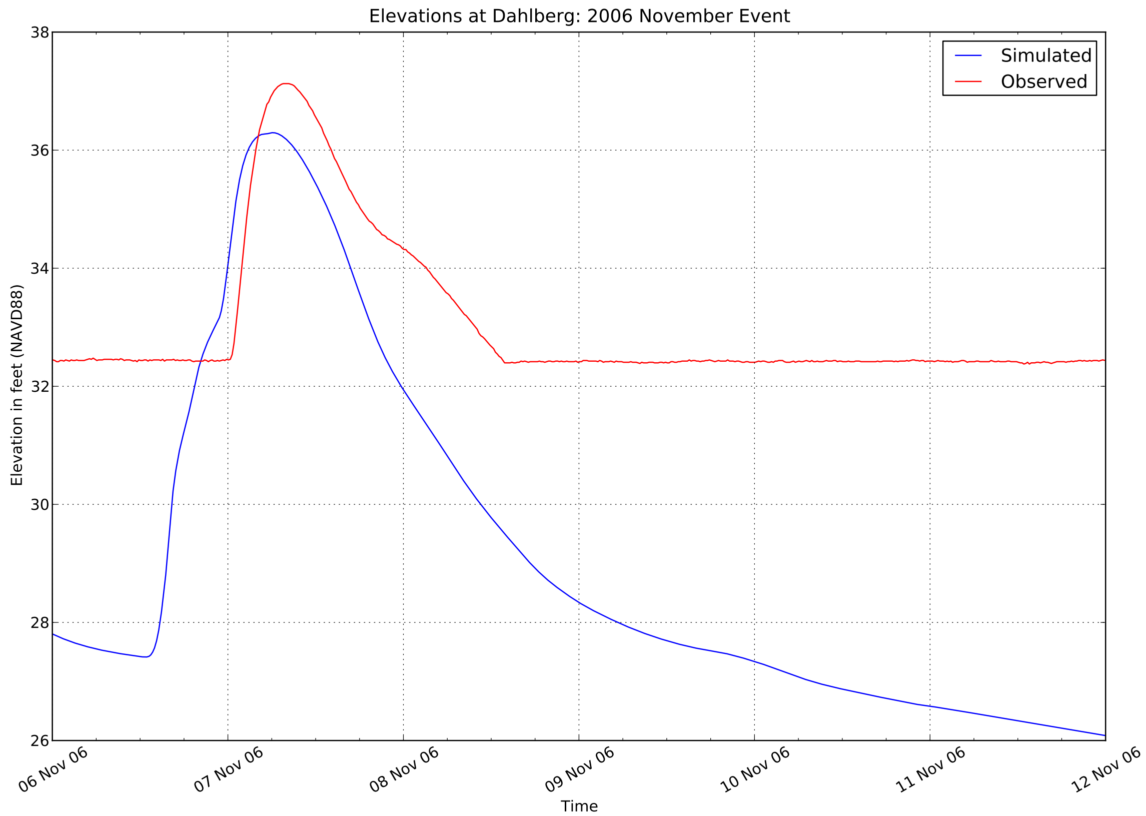

Figure 2006–8: Elevations at Dahlberg: 2006

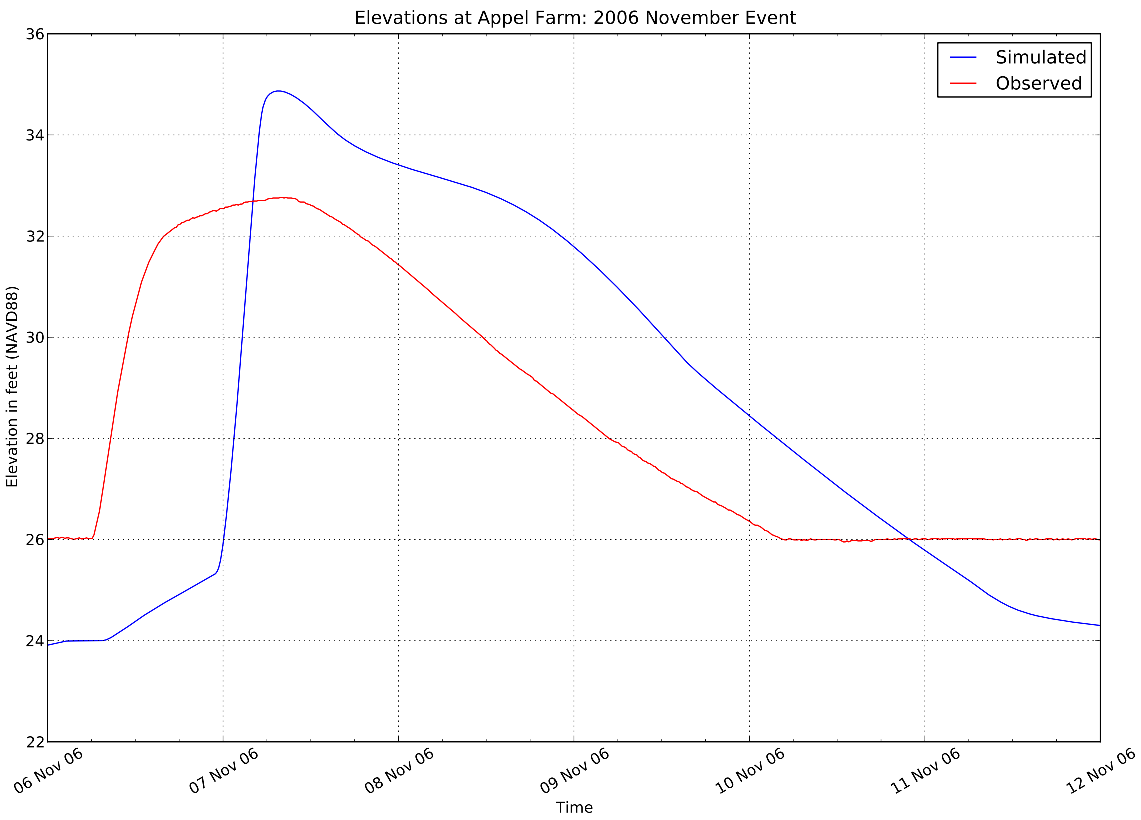

Figure 2006–9: Elevations at Appel Farm: 2006

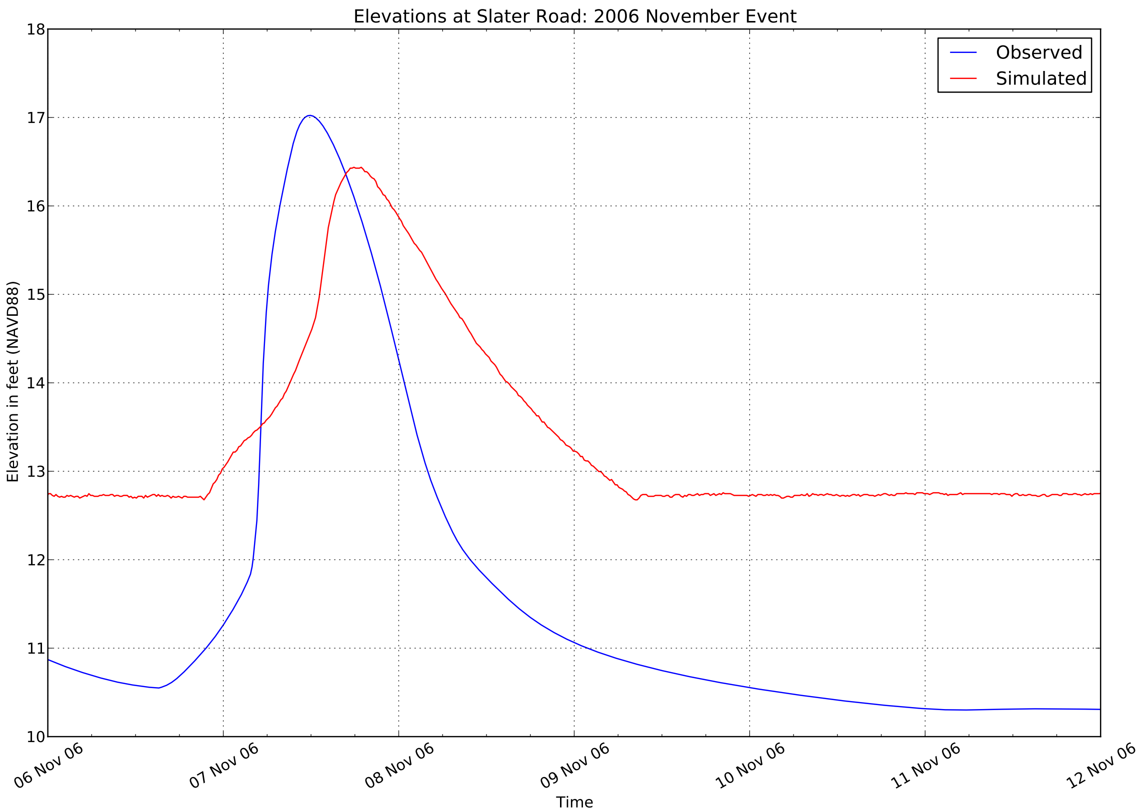

Figure 2006–10: Elevations at Slater Road: 2006

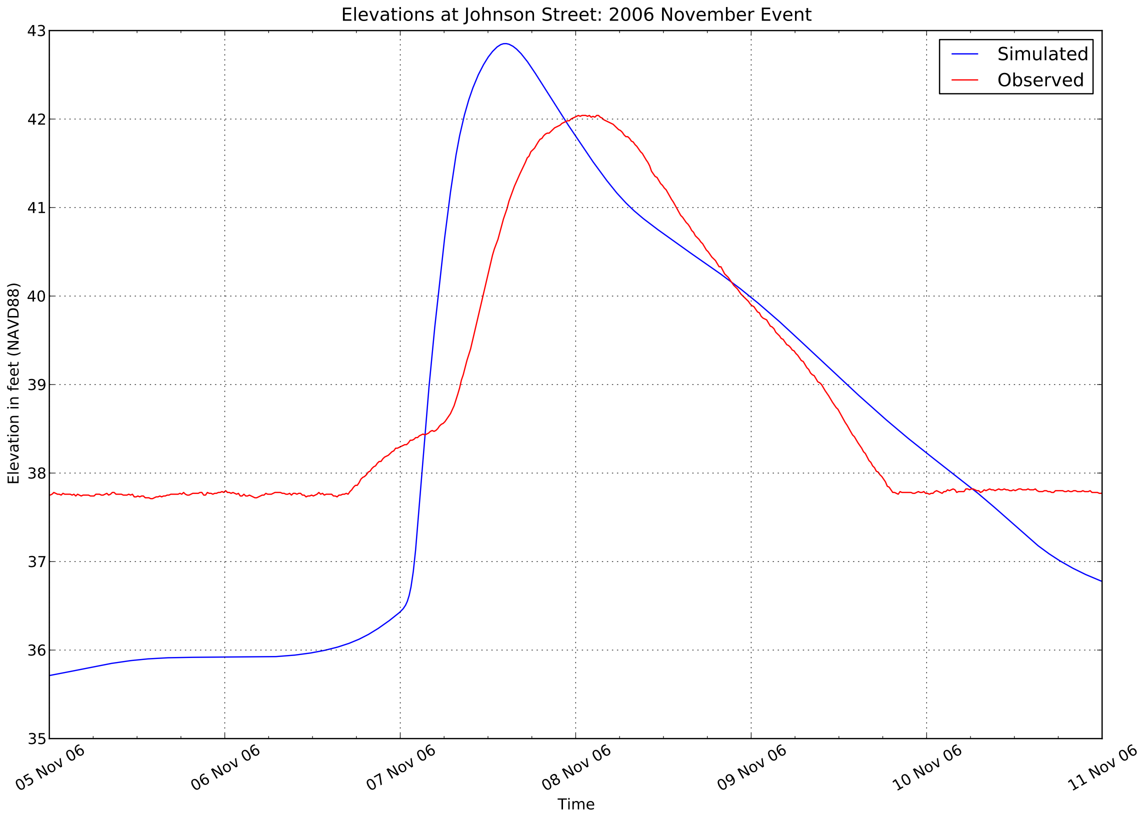

Figure 2006–11: Elevations at Johnson Street: 2006

varied with water-surface elevation. Also the potential effect of water temperature on bed forms was also reviewed. The Nooksack basin had just experienced a December of below normal temperature and the ground was frozen and there had been some ice on the Nooksack at various points, including Ferndale. However, none of these effects could account for the shortfall in flow in the left-hand flood plain.

4. Another option that was explored was a debris jam on the Nooksack bridge and also the Silver Creek bridge on Marine Drive. There were small amounts of debris reported but even a gross over estimate of its effects could not produce the high-water marks at Marine Drive and had essentially no effect at Slater Road.
5. As is usual, the breakthrough came via finding additional flow data! The discovery was made by Bob Elliot, then of NHC, while working on a contract for the City of Bellingham. Bellingham had installed its own gage on Squallicum Creek, just over the divide from the Nooksack in 2006. They had a rough rating over a control structure and the stage record from the 2009jan event was available and had resulted in large flows, far larger in its stage than in anyones memory. The same was said for parts of Silver Creek as well. Thus this record was transfered, adjusted upward as required and finally we began to get reasonably close to the six well established and consistent high-water marks in the left-hand flood plain between Slater Road and Marine Drive.

The Squallicum Creek record was also used in the 2006nov event for the tributaries in Reach 1 and the downstream end of Reach 2.

There were 76 valid high-water marks for this event, possibly the most for any event on the Nooksack River. The results are given in Tables 2009–1 and 2009–2.

Once the flow deficiency was rectified and the problems with the 2006nov event were essentially

TABLE 2009–1: High-Water Mark Results: 2009jan Event

Rch.	High-Water Mark Description	Flow Path Axis	Station (mi.)	Obs. Elev. (ft.)	Sim. Elev. (ft.)	Diff. (ft.)
4	No notes: pdp 63	RDFLMM	36.0582	215.394	214.500	0.894
4	USGS Cedarville Gage: USGS-Ced	RDFLMM	31.0041	153.273	152.630	0.643
4	USGS Everson Gage: USGS-Evr	RDFLMM	23.5507	87.162	87.350	-0.188
4	Ups EvrsnMS: TSG1017	RDFLRB	0.0133	85.296	85.350	-0.054
4	Emmerson Crest gage 1016: 1016	RDFLRG	0.3729	90.358	90.800	-0.442
4	Upstrm Massey Rd: GN1015	RDFLRS	0.7205	95.109	95.200	-0.091
3	Dns Evrsn-Dbrs bs tree RB Nksk: r31346	RCFLMM	23.4383	86.719	86.400	0.319
3	Dns Eversn N Nolte Rd nr start Rd: r30145	RCFLMM	23.0489	84.069	84.000	0.069
3	Slt Ln insd Lv AbbtRd and wst NoonRd: r30443	RCFLMM	20.7321	72.398	72.600	-0.202
3	Ron Bronsema gage: RonB	RCFLMM	20.2145	70.157	70.500	-0.343
3	Frmabl Lve-edg Frd Polinder Farm: r30739	RCFLMM	19.4339	68.149	67.700	0.449
3	Insd lve-tree-dns cntct lve toe and Hmptn Rd: r30954	RCFLMM	18.5340	64.147	64.700	-0.553
3	End snlg SndBg Rw N PlndrRdandW HnngnRd.: r31837	RCFLMM	17.9475	60.129	60.800	-0.671
3	InsdLve on Nksk BlsymaandPlndr Rd: r31636	RCFLMM	17.0043	56.129	56.900	-0.771
3	SiltLn Trnk BC Ave Lyndn: r32655	RCFLMM	16.9297	55.814	56.400	-0.586
3	Ups GdMrdnRd RB In trees silt on trunk: r32557	RCFLMM	15.4990	52.024	52.600	-0.576
3	Nrth NlteRd Silt on TrTrnk E FrmStd: r30244	RCFLLB	4.4505	72.719	73.500	-0.781
3	Ups Noon Rd. Dbrs Ln on Grss/bshs: r30342	RCFLLC	4.1371	66.820	67.300	-0.480
3	Dbrs ln ups ThielRd nr Scott Ditch: r30641	RCFLLC	3.0625	59.690	59.100	0.590
3	Hannegan-Scott Ditch TSG 1011: TSG1011	RCFLLC	1.9903	52.939	52.600	0.339
3	DbrsLn Dns Bylsma well N WsrLkRd: r31534	RCFLLE	1.0243	52.277	51.800	0.477
3	Dbrs Ln Bshs/Grss ups GdMrdnRd at Bbe Rd: r32233	RCFLLE	0.0553	52.057	51.100	0.957
3	DbrsLn WEdg Blsma @Plndr. Nr Tn Mn Trctr: r31735	RCFLLG	0.5606	52.356	51.800	0.556
3	Dbrs Ln at FgLn on ThielRd bit S AbbtRd: r30540	RCFLLM	1.7594	58.593	57.900	0.693
3	Dns HnngnRd just Nrth Nksk Brdg-slt on pst: r30838	RCFLRB	2.0671	59.886	60.400	-0.514
3	DbrsLn Bshs/Grss S Lyndn. Gln Blnkr's Grvl Drvwy: r31956	RCFLRB	0.7263	47.416	48.800	-1.384
3	Kamm Creek TSG Ups Hnngn Rd Brdg: TSGXXXX	RCFLRC	0.6303	60.046	60.900	-0.854
3	Farm access Rd at jog in RCFLRL: GN1013	RCFLRL	1.3394	71.315	71.200	0.115
3	S Timon Rd@frm nxt to Nksk. Nr Ron Brnsma Farm: r31251	RCFLRL	0.4029	65.144	65.800	-0.656
3	Ups Stkny Islnd Rdmdwy : r31450	RCFLRS	0.3815	75.667	75.800	-0.133
3	Edg Nrthwd Rd north RR. In LPRE: r31053	F3519		60.670	61.400	-0.730

resolved, this event came in well, considering how it appeared early in the calibration effort. Only one high-water mark out of the 76 valid high-water marks fell outside the tolerance.

The time-series results for this flood show how this event differed from all others in the calibration set. The peak was quite prolonged and the volume of flow was larger. In this event a considerable reduction in the peak at Deming was required. The tributary flows downstream of Everson were estimated from the record at Fishtrap Creek. In this event the record at Fishtrap Creek, near to and following the peak flow, was estimated. The larger than usual adjustment at Deming may have been a result of an overestimate of the missing flows at Fishtrap Creek. As in many large floods, resolution of this uncertainty is not possible.

The dogleg at Ferndale is muted in the observed series compared to earlier events. The simulated hydrograph at Ferndale barely hints at a dogleg as well and the peak is too early.

TABLE 2009–1: High-Water Mark Results: 2009jan Event-concluded

Rch.	High-Water Mark Description	Flow Path Axis	Station (mi.)	Obs. Elev. (ft.)	Sim. Elev. (ft.)	Diff. (ft.)
2	Ext Old GdMrdn dns GdMrdn-dbrsLn edg GrvlRd: r32332	RBFLMM	14.7548	50.927	50.800	0.127
2	W Flynn Rd and Rvr Rd inside lvee: jnt26 29	RBFLMM	14.6506	50.406	50.400	0.006
2	Slty Ln trunk RvrRd smwht dns Flynn Rd: r32758	RBFLMM	14.5735	49.520	50.400	-0.880
2	ApplFrm Rd N and E LttmrDk-dbrs Bshs/Grss: r32431	RBFLLB	2.5511	37.433	37.500	-0.067
2	Appel Farm:TSG1005	RBFLLB	2.5347	37.433	37.700	-0.267
2	Ups PrdsRd SltyLn trunk: r32830	RBFLLB	0.8588	36.292	35.900	0.392
2	Dns FlynnRdN 1st FrmStd N Rvr Rd: r32059	RBFLRB	6.9670	43.183	44.100	-0.917
2	Harksell Rd-silt line on Road: jnt23 26	RBFLRB	4.1061	39.115	40.100	-0.985
2	Dahlberg-ups and across from CgrCrk Junc: TSG1007	RBFLRB	3.1830	37.950	38.700	-0.750
2	1705 Trigg Rd. PwrPl. Flow N-¿S: jnt22 25	RBFLRB	1.8339	37.064	37.300	-0.236
2	100' dns Flynn Rd in Fshtrp Grss/dbrs line: jnt25 28	RBFLRD	1.7912	44.078	43.200	0.878
2	Ups Flynn RdPndng Nrth Fshtrp: r32160	RBFLRH	1.3606	42.004	42.500	-0.496
2	Flynn Rd. Pndng Nrth Fshtrp: jnt24 27	RBFLRH	1.1258	42.003	42.300	-0.297
1	USGS strm gage:USGS-Fern	RAFLMM	6.0328	31.331	31.340	-0.009
1	PUD 1 water intake on rb Nksk: jnt13 18	RAFLMM	5.5998	29.983	29.900	0.083
1	Nksk RB south Frndl WTP strctrs: jnt14 19	RAFLMM	5.4987	29.405	28.600	0.805
1	Abt 550 ft ups Lmm Rvr Clvrt-Nksk rght bnk: jnt21 17	RAFLMM	4.7151	27.388	27.700	-0.312
1	Abt 135 ft dns RAXSAD-lft-hnd fld pln: jnt31 22	RAFLLB	4.0991	27.630	27.400	0.230
1	Abt 135 ft dns RAXSAC in lft-hnd fld pln: jnt30 23	RAFLLB	4.0594	27.535	27.400	0.135
1	Abt 250 ft dns RAXSAC in lft-hnd fld pln: jnt29 24	RAFLLB	4.0130	27.409	27.200	0.209
1	Abt 65 ft ups RAXSAZ in lft-hnd fld pln: jnt32 21	RAFLLB	3.6515	25.838	25.900	-0.062
1	Abt 165 ft ups RAXSBJ and 265 ft dns 21: jnt33 20	RAFLLB	3.5882	25.603	25.300	0.303
1	110 ft ups Sltr Road nr rght edg flow path: jnt15 12	RAFLLB	2.6332	20.240	21.100	-0.860
1	73 ft ups Sltr Road abt 140 ft est 12: jnt18 13	RAFLLB	2.6164	20.185	21.100	-0.915
1	27 ft ups Sltr Road btwn 12 and 13: jnt16 14	RAFLLB	2.6090	20.179	21.000	-0.821
1	Abt 25 ft dns Sltr Rd to lft edg flw pth: jnt19 16	RAFLLB	2.6042	20.179	20.200	-0.021
1	Just dns CL Sltr Rd-nr rght edg flw pth: jnt17 15	RAFLLB	2.6035	20.179	21.100	-0.921
1	At intrsctn Cntry and Rrl ups MrnDrv: jnt2 3	RAFLLB	0.6625	17.742	18.000	-0.258
1	Ups MrnDrv abt 310 ft wst Slvr Crk Brdg: jnt4 4	RAFLLB	0.6599	17.740	17.900	-0.160
1	Ups MrnDrv-est red brn: GN1000	RAFLLB	0.6577	17.738	18.100	-0.362
1	Ups MrnDrv-lft side FrndlRd: GN1001	RAFLRC	0.9462	15.803	16.600	-0.797
1	Ups MrnDrv just wst Ferndale Road: jnt5 5	RAFLRC	0.9335	15.785	16.300	-0.515
1	Ups MrnDrv abt 80 ft est Rnbw Slgh: jnt6 6	RAFLRC	0.9298	15.778	15.700	0.078
1	Dns side S-lv: 64	RAFLRE	1.0856	15.536	15.300	0.236
1	Dns side S-lv: 65	RAFLRE	1.0222	15.441	15.400	0.041
1	Dns side S-lv: 68	RAFLRE	0.9576	15.369	14.900	0.469
1	Dbrs on Rd. Assign to RAFLRH ups end: jnt7 7	RAFLRH	0.2211	12.191	12.900	-0.709
1	Dlta side MrnDrv on hs-50 ft dns RAXSBP: jnt282	RAFLLH	0.0925	16.055	15.800	0.255
1	Dns side S-lv: 67	RAFLRO	0.0348	15.349	15.000	0.349
1	Avrg jnt12 and jnt8: 11 and 8 in LRLPRCD: aver99	F1981		10.698	11.500	-0.802
1	Avrg jnt9 and 10: 9 and 10 in LRLPRFG: aver98	F1983		9.346	8.550	0.796
1	Lummi Rvr Fld pln in LRLPRED: GN1002	F1982		9.350	8.900	0.450
5	Johnson St wst BNRR: TSG1025	REFLMM	1.5395	42.949	43.400	-0.451
5	Max stage Huntingdon Gage:BC-3	REFLSR	0.9207	36.473	36.560	-0.087

TABLE 2009–2: High-Water Mark Mimicry Summary: 2009jan Event

High-Water Mark Difference Range (ft)	Number of Differences	Proportion of Total Number	Cumulative Proportion
-5.00 to -1.00	1	0.01	0.01
-1.00 to -0.50	22	0.29	-.30
-0.50 to -0.25	10	0.13	0.43
-0.25 to -0.10	5	0.07	0.50
-0.10 to 0.00	7	0.09	0.59
0.00 to 0.10	5	0.07	0.66
0.10 to 0.25	6	0.08	0.74
0.25 to 0.50	10	0.13	0.87
0.50 to 1.00	9	0.12	1.00
1.00 to 5.00	0	0.00	1.00

The reproduction of the elevation results at Ferndale, as shown in Figure 2009-2, is quite good, with the lower flows again showing the larger differences. This is believed to be primarily the effect of using a fixed invert for all events.

Figure 2009-3, giving the results for elevations at Cedarville, shows a pattern similar to that at Ferndale with greater differences near the peak of the flood.

The results at Everson for this event, are the best in the entire calibration set. Even the lower flows show differences of about 0.5 foot, which is excellent, given the nature of this stream.

The stage reproduction at Everson Main Street starts well but cannot sustain the long flat peak that the time-series gage record shows for this site. Reproducing such a long flat peak will require a long flat peak in the Nooksack, much flatter than is now simulated.

The elevation results at the remaining time-series gages are depicted in Figures 2009–6 through 2009–10. The results at the Guide are quite good and show that the elevations sequence in the main channel was reproduced well. The remaining sites in the R1R4 model show the characteristic early rise with various highs and lows for the peaks. Again, the recession limb at the Appel Farm site is reproduced well, at least on average. The Johnson Street site, again does not do well. The local runoff probably differed markedly from that allocated from the Sumas River flows at Huntingdon.

November 1990 Flood in Reach 5

The overflows at Everson Main Street in the set of calibration events were too small to calibrate the new model in Reach 5. In order to provide a calibration the 1990 flood was used. The overflow was as calculated from the prior model. There have been only small changes in Reach 5 so that the 1990 flood would be a good basis. In any case, without doing so, it would be impossible to calibrate the current model in Reach 5.

There were 27 high-water marks in reach 5 that were used. One of them, S-8, in the north part of Sumas, appeared to be slightly below ground level, based on the new Lidar-based contour map. However, we came within the one-foot tolerance, so it was retained. Mark S-1 did not appear to make sense, being lower than another mark downstream, at least as the flow paths were defined. So it was reset to the elevation downstream. This may indicate that the flow paths are not correct or it may just indicate an invalid high-water mark. At this time, there is no way to decide. The documentation of the 1990 marks is sparse or does not exist.

All but 2 out of the 27 marks fell within the tolerance, which given the nature of Reach 5, the lack of any time-series data at Everson Main Street, and the limited number of marks, appears to be about as good as we will be able to attain.

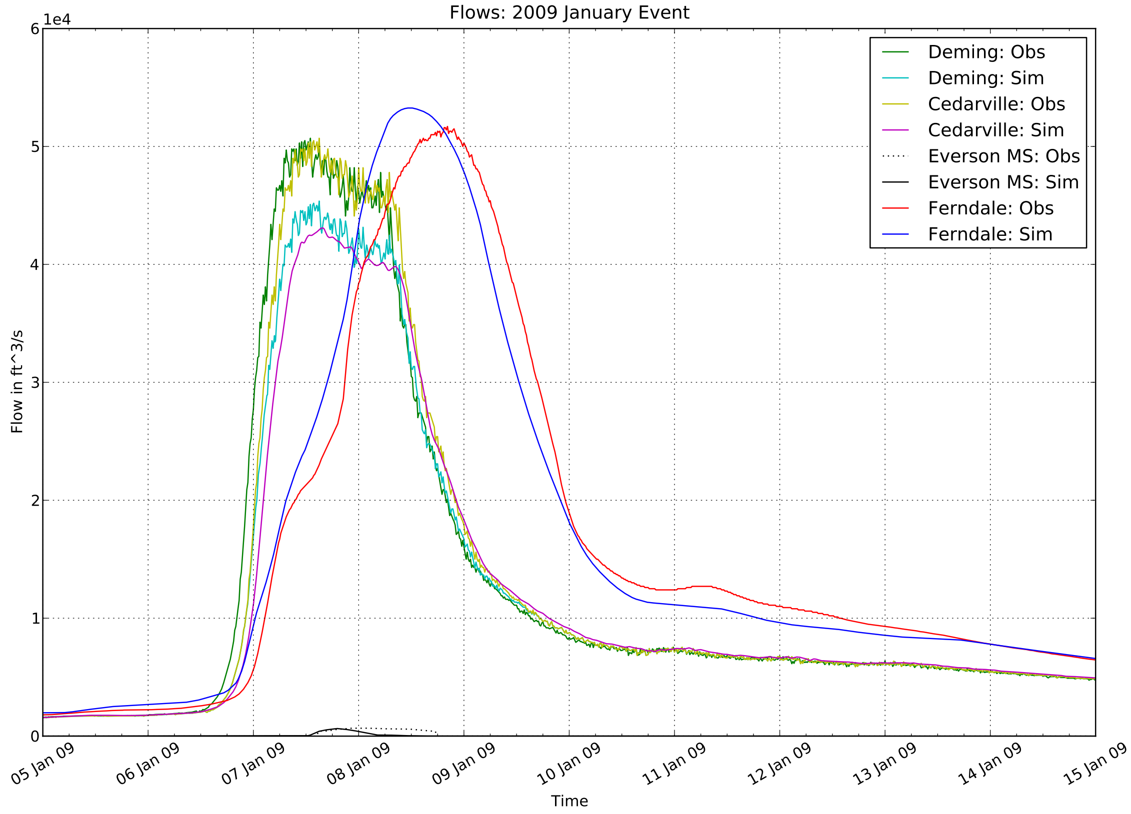

Figure 2009–1: Flows: 2009

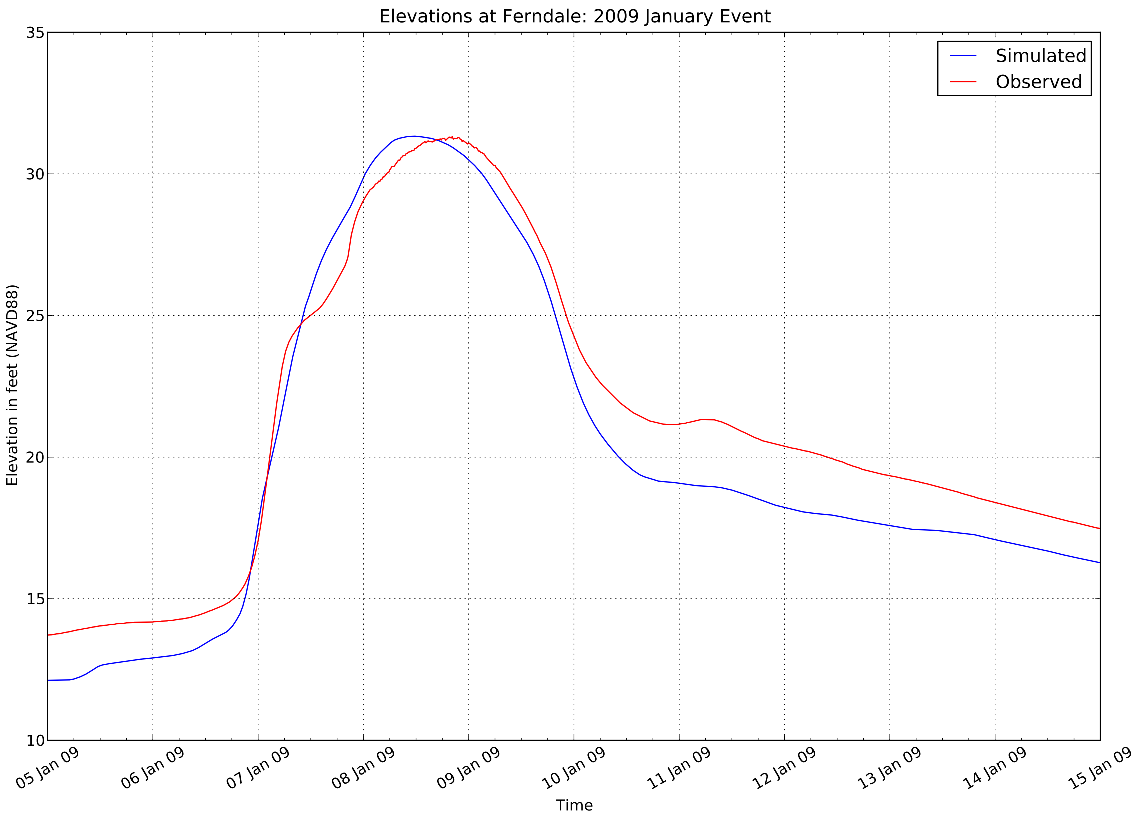

Figure 2009–2: Elevations at Ferndale: 2009

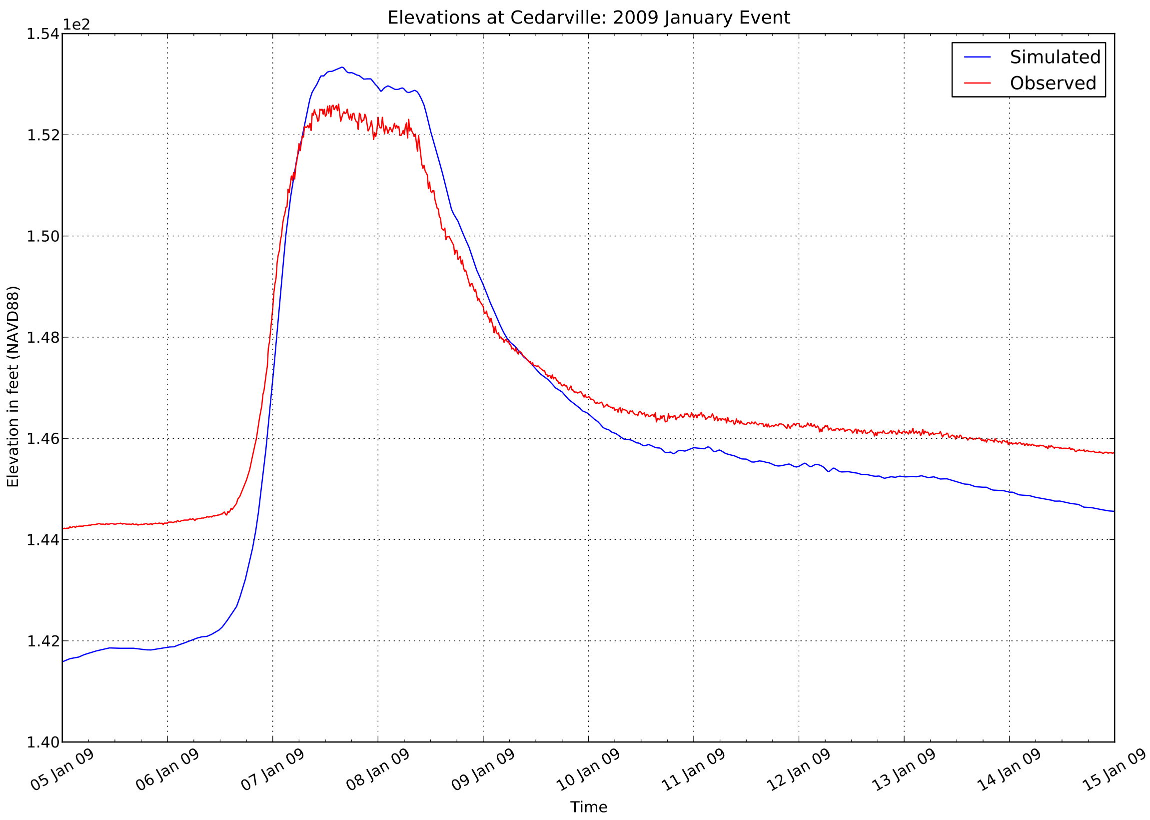

Figure 2009–3: Elevations at Cedarville: 2009

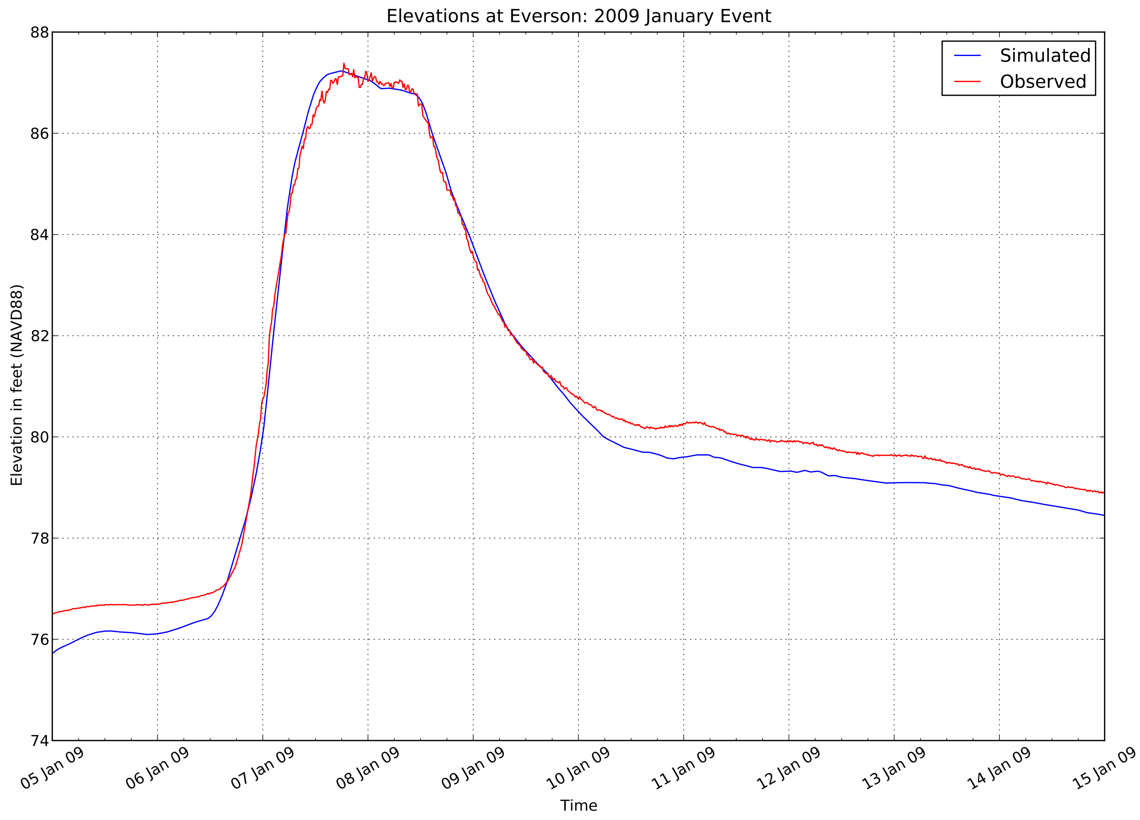

Figure 2009–4: Elevations at Everson: 2009

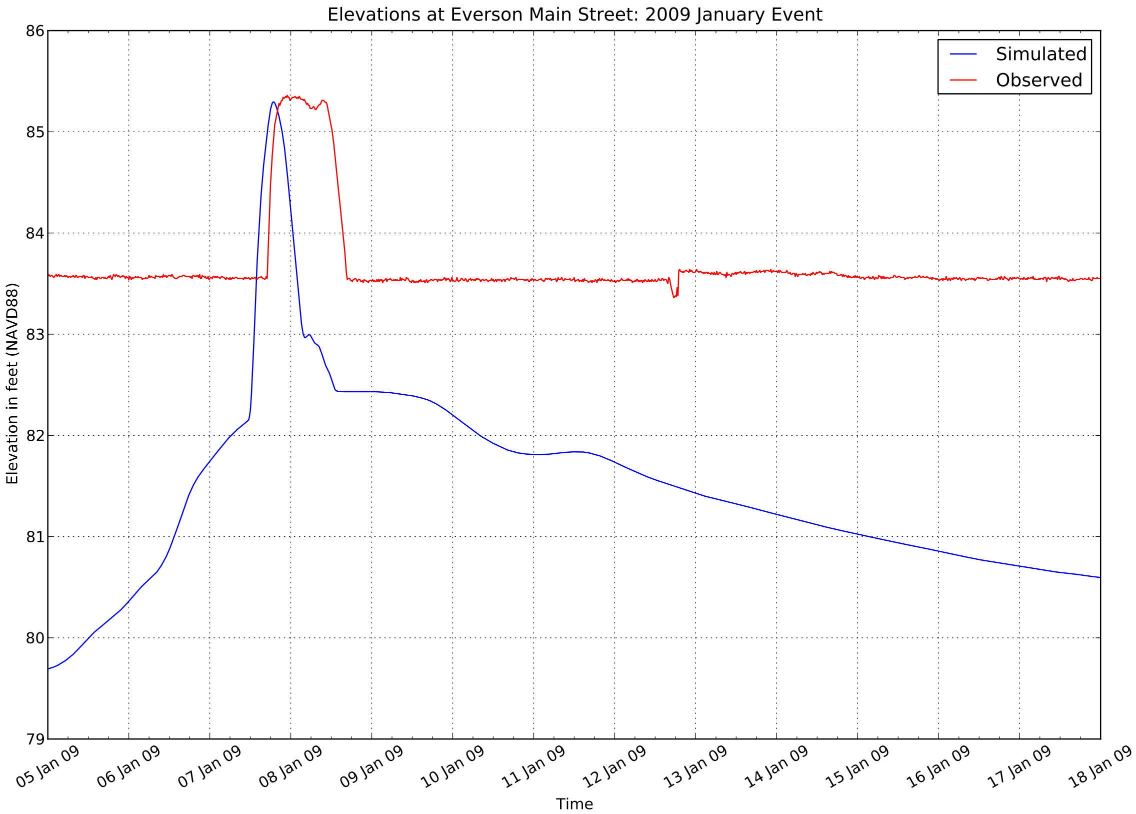

Figure 2009–5: Elevations at Everson Main Street: 2009

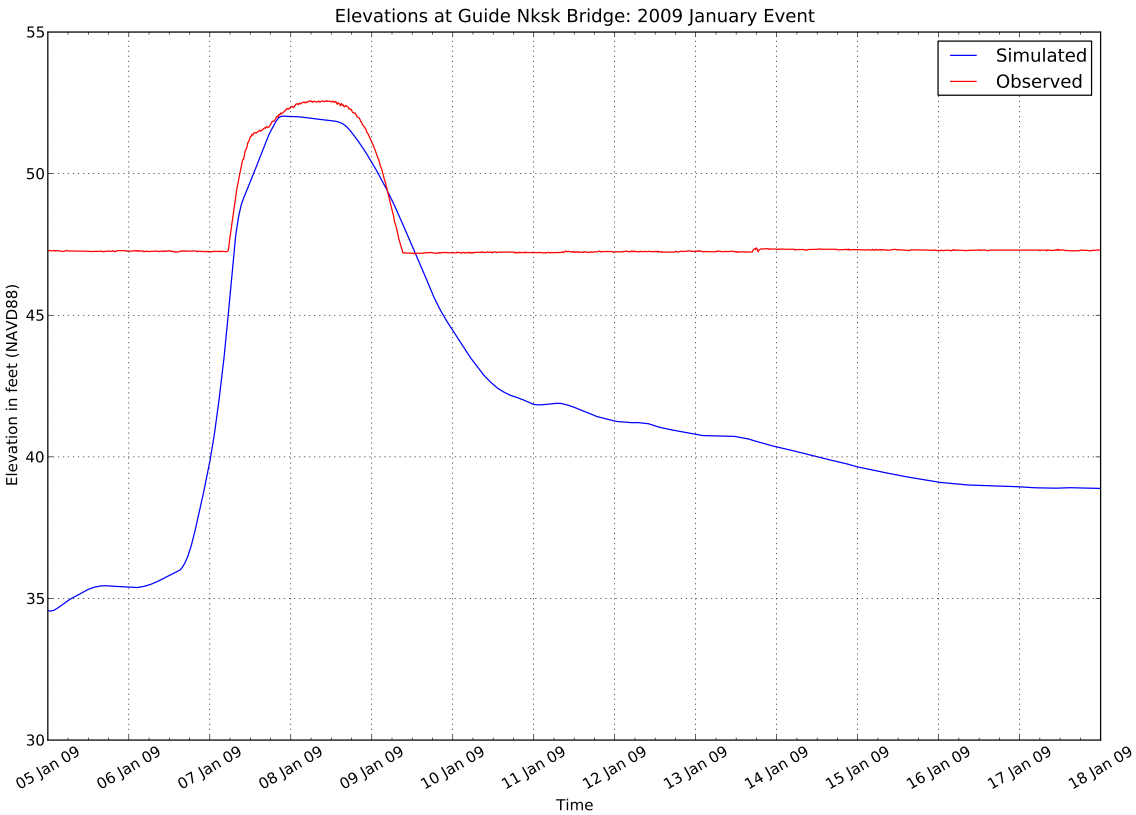

Figure 2009–6: Elevations at Guide Nooksack Bridge: 2009

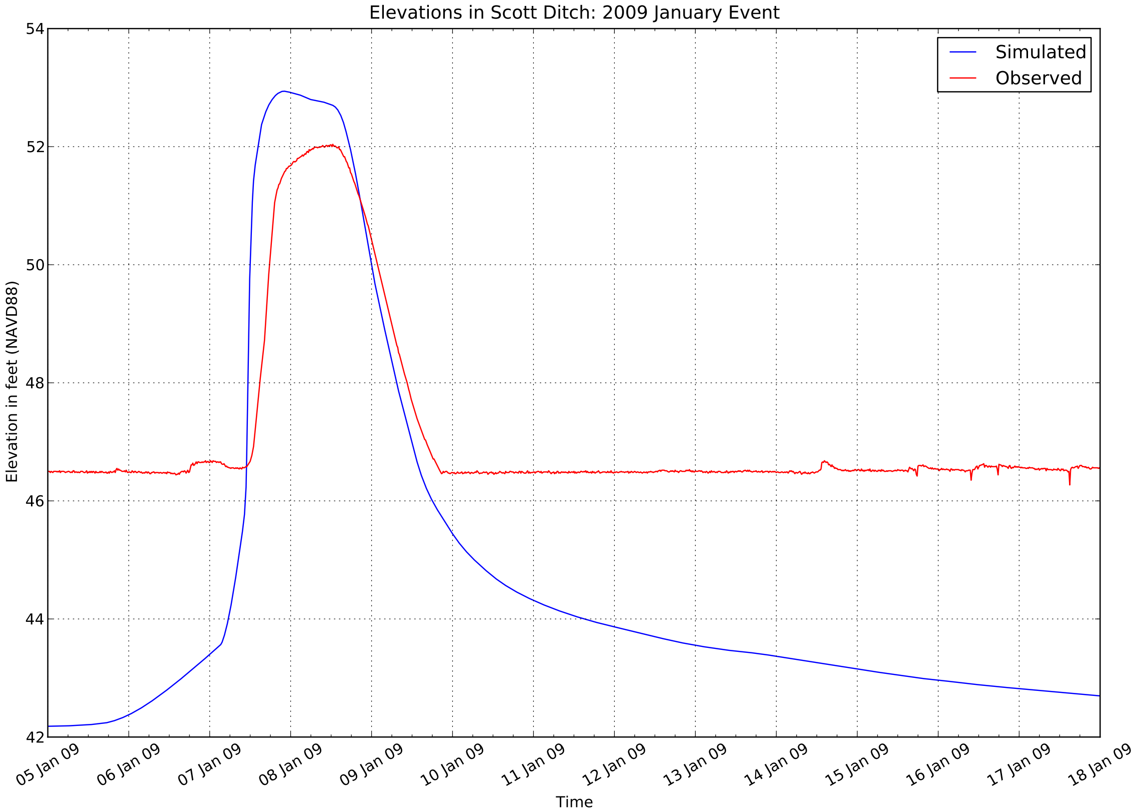

Figure 2009–7: Elevations in Scott Ditch: 2009

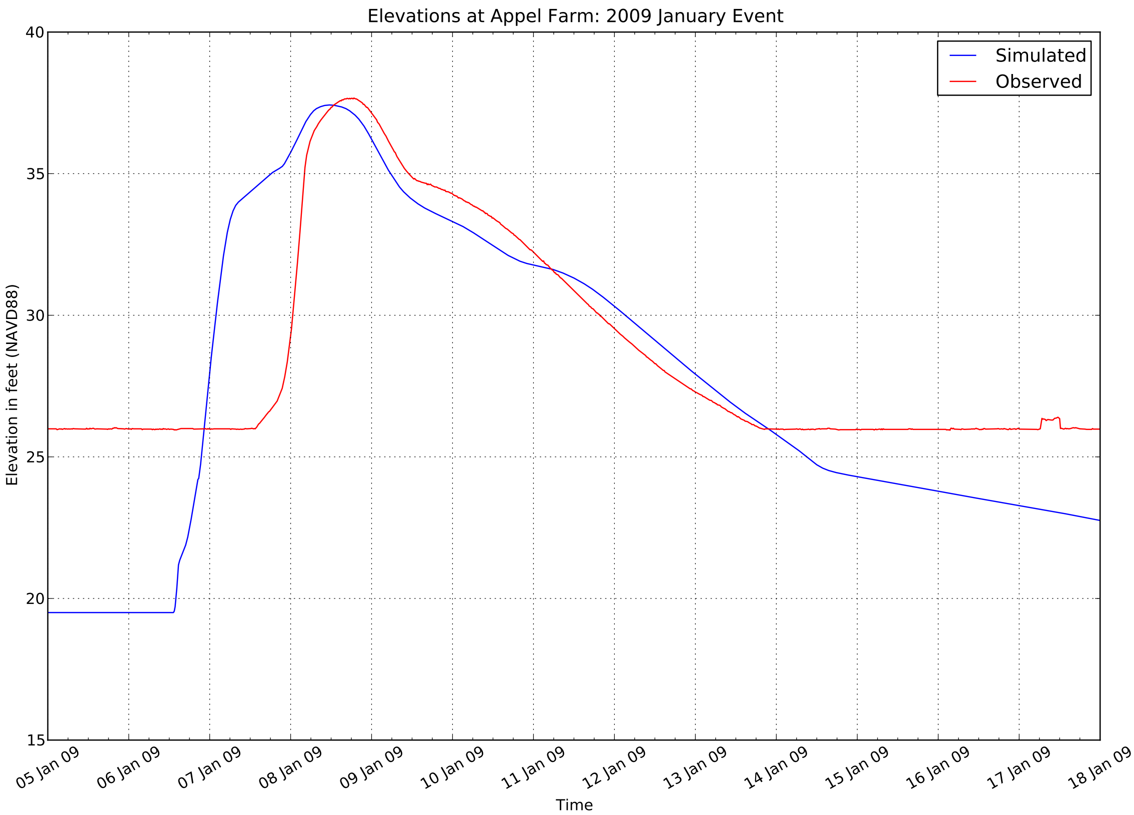

Figure 2009–8: Elevations at Appel Farm: 2009

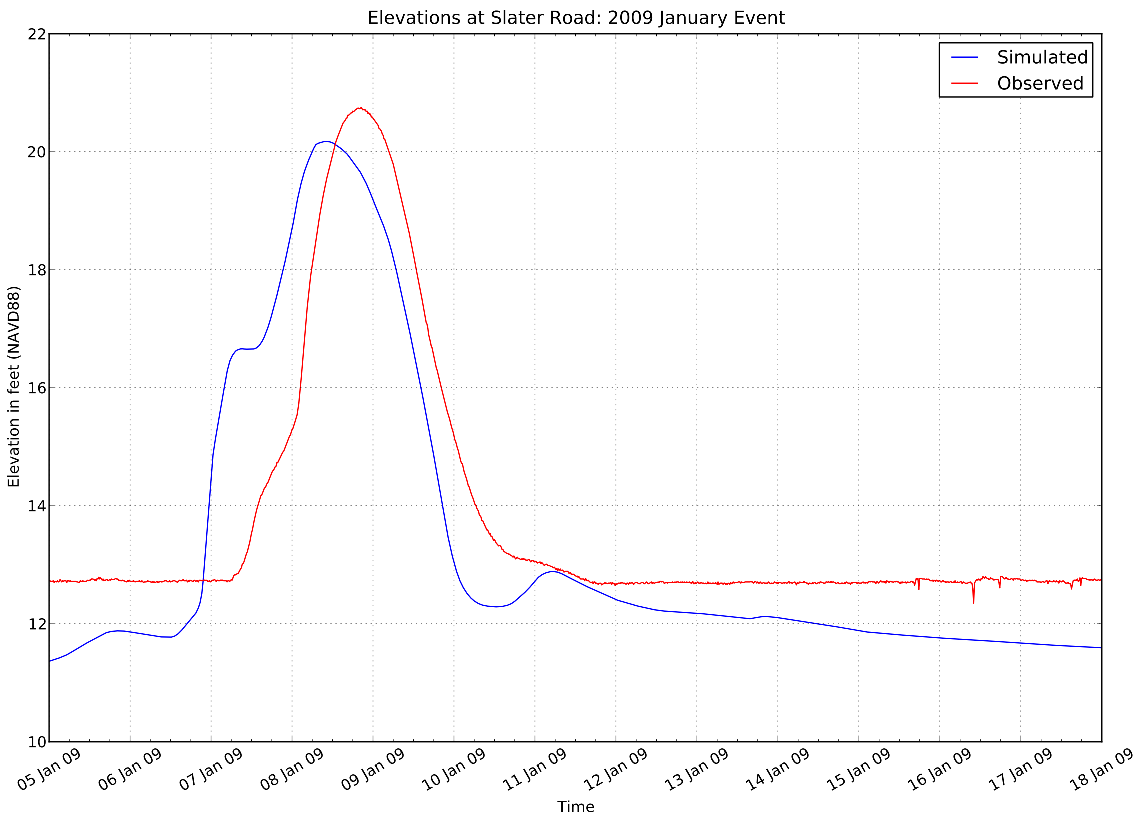

Figure 2009–9: Elevations at Slater Road: 2009

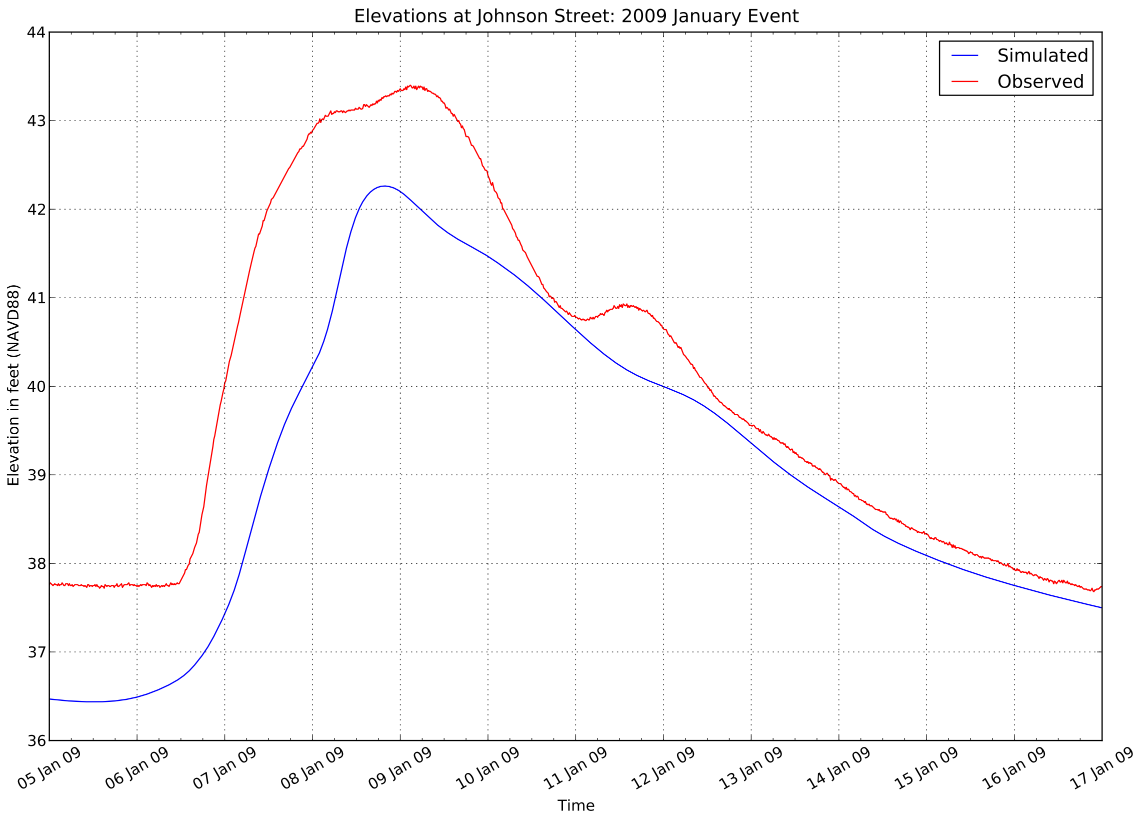

Figure 2009–10: Elevations at Johnson Street: 2009

TABLE 1990–1: High-Water Mark Results: 1990 Flood in Reach 5

Rch.	High-Water Mark Description	Flow Path Axis	Station (mi.)	Obs. Elev. (ft.)	Sim. Elev. (ft.)	Diff. (ft.)
5	in sw Sumas (Reset to S-14): S-1	REFLST	0.6440	44.878	44.480	0.398
5	s Sumas: S-14	REFLST	0.5346	43.561	44.480	-0.919
5	in sw Sumas: S-4	REFLST	0.5225	43.404	44.080	-0.676
5	far se Sumas: S-13	REFLST	0.3800	42.201	42.880	-0.679
5	far se Sumas: S-12	REFLST	0.3028	42.160	42.580	-0.420
5	wst of BNRR Sumas: S-2	REFLLF	0.2240	47.182	47.380	-0.198
5	wst of BNRR Sumas: S-3	REFLLF	0.1449	47.173	47.380	-0.207
5	wst of BNRR Sumas: S-5	REFLLF	0.0761	47.162	47.480	-0.318
5	nrth Sumas(Blw grnd): S-8	REFLLR	0.5020	41.922	41.280	0.642
5	far ne Sumas: S-15	REFLLR	0.2836	39.920	40.580	-0.660
5	10.84m B. C.: BC-1	REFLLR	0.1968	39.259	39.440	-0.181
5	nw Sumas: S-7	REFLLP	1.0092	44.341	44.280	0.061
5	cntrl Sumas: S-6	REFLLP	0.8896	43.673	44.680	-1.007
5	se Sumas: S-11	REFLLP	0.7435	42.048	42.780	-0.732
5	ne Sumas: S-9	REFLLP	0.6595	41.274	42.380	-1.106
5	est Sumas: S-10	REFLLP	0.6412	40.911	41.680	-0.769
5	9.37m B. C.: BC-2	REFLLP	0.1975	35.302	34.620	0.682
5	Max stage Hntngdn Gage: BC-3	REFLSR	0.9207	36.885	37.016	-0.131
5	Tp utlty bx at Shuksan and EvrGrn: JG-3	REFLRG	2.0562	84.114	84.620	-0.506
5	Pnt R nr Evrgrn Wy and VnBrn: HWM 49	REFLRG	1.9848	83.453	83.560	-0.107
5	Nr barn at long clvrt: HWM 51	REFLMM	10.0157	73.304	74.130	-0.826
5	Tp stp at Jim Glass house: JG-1	REFLMM	9.4676	71.958	72.280	-0.322
5	Md stn in Jim Glass barn: JG-2	REFLMM	9.4592	71.954	72.420	-0.466
5	Sth Bdgr Rd in Trb 1of1 on shed: HWM 52	REFLRM	0.7543	69.228	69.590	-0.362
5	Mark on mlkhs sth Clrbrk Rd: HWM 53	REFLRO	0.3159	61.505	62.310	-0.805
5	Nw of Clrbrk and Nksk Rd-in LPRD: UNK 1	F5603		59.625	60.280	-0.655
5	bttm step on frnt porch-in LPRE: HWM 54	F5604		59.684	60.580	-0.896

The only time series data available for the 1990 flood in Reach 5 was the stream gage record at Huntingdon. One problem with this gage is that it is only partially affected by the overflows. It has a significant influence from the flows in the Sumas River, which it was designed to measure. Figures 1990–1 and 1990–2 show the calibration results at Huntingdon. The natural flows at Huntingdon were based on the rainfall-runoff modeling effort from the University of British Columbia, the same source as used for the prior model of Reach 5.

The reproduction of high-water marks and the mimicry at Huntingdon is similar to that obtained with the prior model. Until we get additional data from subsequent large floods, there is little more that can be done to calibrate Reach 5.

Summary of the Calibration

The calibration to the four events plus the addition of the 1990 flows in Reach 5, proved to be a challenging task. The time-series gages have revealed some problems in timing of the flows over the banks and levees into the flood plains of the Nooksack. The high-water mark results are similar to those obtained with the prior model and with the prior calibration events. The problem with the

TABLE 1990–2: 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	2	0.07	0.07
-1.00 to -0.50	11	0.41	0.48
-0.50 to -0.25	5	0.19	0.67
-0.25 to -0.10	5	0.19	0.86
-0.10 to 0.00	0	0.00	0.86
0.00 to 0.10	1	0.04	0.90
0.10 to 0.25	0	0.00	0.90
0.25 to 0.50	1	0.04	0.94
0.50 to 1.00	2	0.07	1.00
1.00 to 5.00	0	0.00	1.00

dog-leg on the rising limb of the flood hydrographs at Ferndale persists but the following Analysis of Calibration will provide more detail on its source and the means to improving its reproduction in the simulated flood hydrographs.

As with all models, the results can only be an approximation to what we currently understand and have measured in the stream system. The lack of modeling the dogleg does distort the remainder of the hydrograph. The simulated floods at Ferndale are a bit too early and tend to be too high. Thus we compensate with other parameters to reduce the peaks somewhat to better mimic what was observed. This is of course, a distortion of what we adjust. Such overlap is ubiquitous in models of this complexity. A change in Manning's n can compensate, in part, for having an invert elevation that might not be quite correct. It is not even clear that there is a well defined invert during the larger floods. There is probably a layer of sediment of various sizes being moved near the bottom of the flow with a density that increases as the current "invert" is approached. However, the cross section for our fixed-bed approximation, must have an invert, so we provide a fixed value, based on multiple calibration runs.

The goal of the model is to provide estimates of the maximum water-surface elevations attained under various proposed conditions, only one of which, is for the Flood Insurance Study underway for the Lower Nooksack River. The current calibration is adequate for that purpose. Given all the other uncertainties, it is also adequate for flood forecasting on the main Nooksack River channel but would tend to predict times of arrival some hours earlier on the flood plains.

This does not mean, however, that the model is "done". A model of this complexity and of a river that is constantly changing, is never done in the sense that no more needs to be improved. It does, however, attain a state where it is "good enough" for the tasks at hand. Any application must, never the less, always keep in mind, the possible short comings of the model as it now exists. This may be disconcerting to some, but it is the reality for any model constructed with any modeling system. It is just the "the way it is"!

Analysis of the Calibration

Many insights to the modeling of the lower Nooksack River were gleaned from the long process of calibration. Also some important information on the topography near Everson became available too late to be included in the current model. I take up the dogleg first, since it has occupied large amounts of research over the last number of years.

The dogleg on the rising limb of the hydrograph at Ferndale appears on essentially every flood

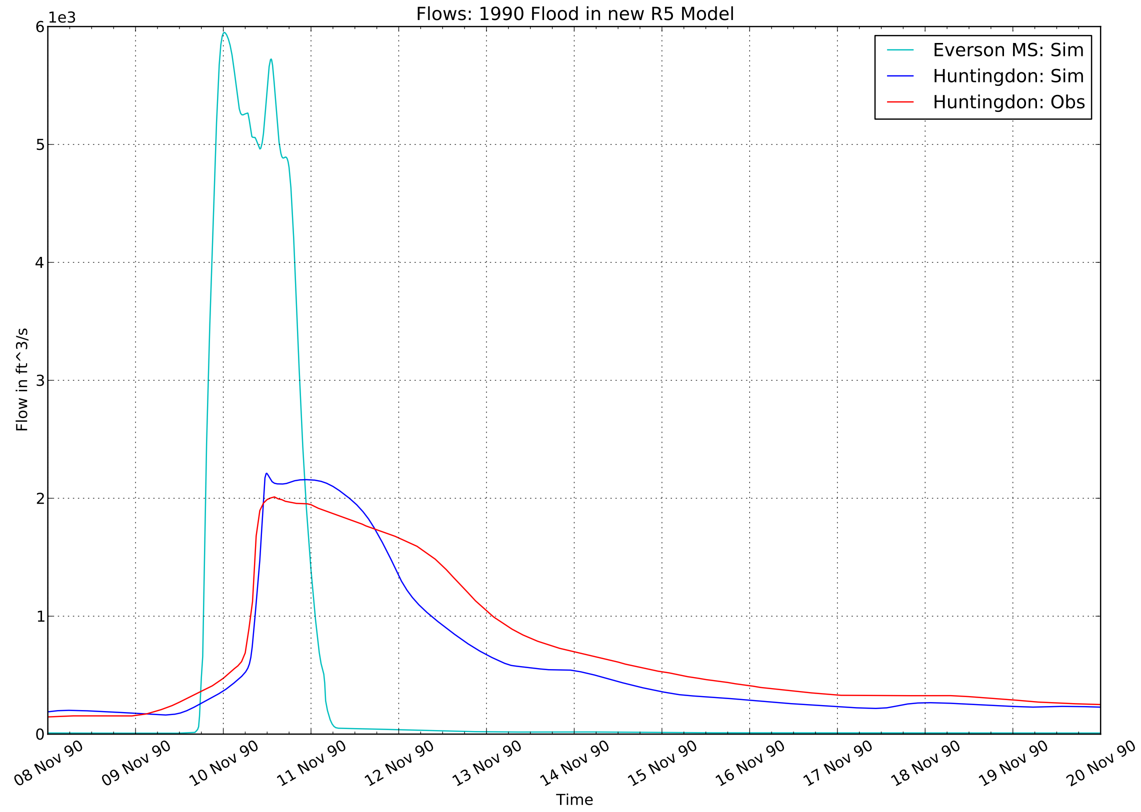

Figure 1990–1: Flows in new R5 Model: 1990

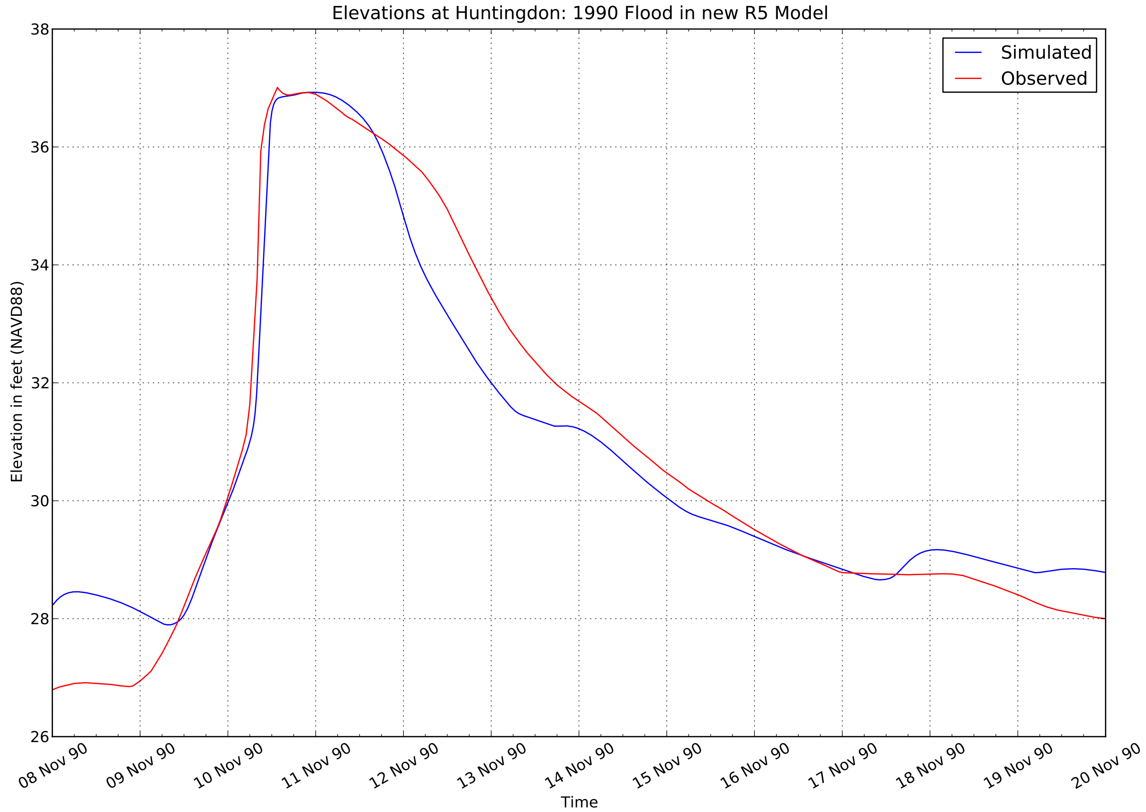

Figure 1990–2: Elevations in new R5 Model: 1990 hydrograph in any of the calibration events used in this modeling effort. Also, neither the current nor the prior model did more than provide a greatly muted dogleg at Ferndale. It was Yarslov Schmuck, who commented in one of the early meetings on the prior model, that it revealed storage somewhere that was not in the model. This observation resulted in a "hunt" for the missing storage. Much effort was expended in experiments with the model exploring where such storage might be overlooked. Backflows occur early in any flood event at various points in the Lower Nooksack River. Kamm Creek, Scott Ditch, Bertrand Creek, Fishtrap Creek, Ten Mile Creek, and various other points are possibilities. However, none of these alone or in aggregate had enough missing volume to account for the dogleg. At one point it appeared that the storage behind the Lattimore Dike in Reach 2 provided much of the dogleg. But closer study proved that to be false. A rough analysis of the shift in the rising-limb of the hydrograph at Ferndale suggests that there is about 10,000 $Acre-feet$ or about 12 millions $m^3$of storage "missing" in the model. The back flows into the afore-mentioned areas could not come close to that volume! There most then be some other lack in the current model that prevents mimicry of the dogleg.

The time-series gage results, not available until the calibration of the current model, provided another tool to help find the cause of the dogleg at Ferndale. Nearly every such gage in the flood plain showed that the model had flows some hours too early. These gages being too early suggested that the model was initiating overflows too early as the water levels in the Nooksack River increased during a flood. As an exploratory experiment, the invert of the Nooksack from downstream of Everson to the I-5 bridges was shifted downward by differing amounts to see what effect that would have on the timing at the time-series gages.

The difference in the time of rise did get reduced, to approximately what we have now in the model. It had been far larger prior to the shift. A major side-effect of this shift was that the dogleg at Ferndale had an excellent simulation for its early part–the best ever to date. However, the later part of the dogleg was still not mimicked. Also, several key high-water marks in the flood plain were moved outside the tolerance. As these high-water marks were again moved into tolerance, by reducing the invert shift nearby, the simulation of the dogleg also deteriorated. Thus honoring the high-water marks, with the current model, removed the improved mimicry of the dogleg.

In addition to this, some work on the overflow near Everson, upstream of the extension of Massey Road, showed how sensitive overflows could be to how flows over the bank of the Nooksack are represented. In this case, adding additional detail to the overflow, to include the effect of a local ring levee around some structures southwest of the corner between Emmerson and Massey Roads, resulted in an improved representation of the flows over Massey Road. This flow had always been too high for most of the overflows.

Flows out of the Nooksack River to the flood plain occur in two ways in the current model: there are flows over an identifiable levee, and where a levee is lacking, there are flows over high ground near or at the bank of the main channel. The flow over a levee is modeled as flow over an embankment shaped weir. There are two regimes of flow over such an embankment: flows that are free of the effect of tailwater elevation and flows that are affected by the tailwater elevation. The first regime is called "free flow" and the second is called "submerged flow". Flow over an embankment-shaped weir is unaffected by tailwater until the water surface downstream matches a level upstream given by about 70 percent of the head there. The head is the difference in upstream water-surface elevation and the crest elevation of the levee. Consequently most flows over levees in the model will be free flow, until the flood plain is filled to nearly match the level in the Nooksack River.

Flows over the ground surface, where no levee is present, are modeled differently. The model assumed that a short segment of horizontal channel, on the order of 50 to 100 feet long, would represent the resistance to flow near the river. Again such overflows have two regimes: free and submerged. In this case the submergence begins when the depth of flow from the tailwater, which might be in a flowpath some hundreds of feet away, and 5 to 10 feet lower, reaches the critical depth at the downstream end of this horizontal channel. Based on the experience near Everson, many of these segments will be at free flow in the model throughout the overflow event because the destination flow path is substantially lower than is the overflow surface.

The assumption made in the prior model for the flows over the bank without any levee was the simplest one that could be made. As a general rule, there is no reason to be more complicated than needed in building a model, until evidence suggests that such complexity will be repaid by an improved result. Thirty-five years of experience in unsteady-flow modeling in natural channels has revealed, among many other things, that it is a pitfall to spend great amounts of time on refinements before you have evidence that they are needed. Every refinement becomes a time sink and in modeling, these sinks can grow rapidly. For example, the current model has more than 2,000 points of potential overflow, many of these are over banks that have no identifiable levee. Each point of overflow can represent, on microscopic examination, a complex flow problem. So it is wise to use the simplest possible representation that, at the time, represents the major aspects of the overflow.

What does this all have to do with lack of simulation of the dogleg at Ferndale? Much, because all of these observations, taken together, show that the model does not have a missing volume, but it is filling the space in some parts of the flood plains, too early in the flood. That is what the invert shift revealed. The downward shift in invert, delayed the filling of the flood plain. Thus when the higher flows arrived, there was still volume left to be filled in the flood plain, and so the mimicry of the dogleg was improved. However, only the early part was improved. The later part was not improved, because there are many points of overflow, from the main channel, where no levees are present. Some of these or perhaps many of these are flowing at free flow when they should be flowing at submerged flow, at a greatly reduced rate. The volume that appeared to be missing, was present in the system, but by being filled too early, was no longer able to affect the subsequent flows as had occurred in the natural system.

How can we determine which points of overflow need to be modeled with greater attention to local topographic details? That will require a careful review of how the water leaving the channel reaches the lower part of the flowpath in the flood plain. A good place to begin is wherever the invert shift distorted the high-water marks. As with anything on a model of this size, the best approach to solving the problem is to extract additional data from the DTM in a form that can be adapted to have software compute what is happening. This will require the creation of a new form of overflow in the software that computes these flows. A short segment of horizontal channel will no longer be adequate. The flow over the banks and toward the low point of the receiving flow path, will need to be modeled using a surface that approximates the surface near the bank.

We already have such approximations in the form of the cross sections used to define the flow capacity of the various flowpaths that make up the model. In some cases, where the current cross sections are more distant from each other, one or more additional cross sections may need to be inserted. However, most of the required data is in hand. What is required is a much more adequate representation of the movement of water out of the Nooksack River into its flood plains where ever there is no well defined levee.

Another consistent observation from the calibration effort, was that the model could not represent the duration of overflow at Everson Main Street and still honor the elevations from the time-series gage. To increase the duration meant that the water levels in the Nooksack adjacent to the overflow surfaces near Everson would have to be higher. When that was done, two problems occurred. First, the flows to the left-hand flood plain in the 2006nov event, the only event with high-water marks there, became much too large. Second, the peak flow at Everson Main Street and some of the high-water marks near Emmerson Road were over simulated. No solution to this impasse was found.

However, late in the calibration effort, the Nooksack Tribe provided the results of a Lidar-based DTM from Everson upstream, including the overflow surfaces near Everson. This DTM revealed details not seen before in some brush in the overflow strip next to the Nooksack River. A vestigial bank, some feet high was clearly shown as present in that area. The pressures for the FIS study, now on long-term hold as FEMA reviews certain past procedures, precluded using this information. This new information would revise the several flowpaths currently used to represent the overflow strip.

It is unknown if this additional detail will solve the overflow duration impasse. However, in this case, the only way to find out, is to refine the model using the latest verified data. The ground features shown on the Lidar-based contour map need to be field verified, but Whatcom County staff do report finding such a bank on a field inspection trip.

Improvement in the representation of the flows out of the Nooksack River upstream of Everson could also result in improving the duration of simulated overflows at Everson Main Street. There are many such points of overflow because there are extensive reaches of the river without levees in Reach 4.

Clearly the data from the time-series gages was a major key to sorting out the source for the dogleg on the hydrograph at Ferndale. The record at the Appel Farm also helped solve the unknown state of the "buried" culvert under Lattimore Dike. These gages must be maintained and improved by making sure that each one has a crest-stage gage by it and also by seeking high-water marks near it, just in case the crest-stage gage fails. Spiders and their webs can cause many problems with crest-stage gages, as well as with the time-series gages, so additional high-water marks are needed, should the other gages fail to provide a valid record of stage.

Conclusions

The current model, even with its known shortcomings, is adequate for representing the maximum elevations attained for a given set of flows at the model boundaries. The time of arrival of the high water in the flood plain will tend to be too early but that has only a second-order effect on the maximum elevations. As always, care must be used when making changes to the model, mistakes are easy to make, and sometimes hard to find, unless the mistake causes the model to fail to complete an analysis run.

The model has proved to be quite robust during the calibration. That is, failures to complete a run where infrequent, and generally occurred only in the early parts of running a new event. There will always be parts of the model that need some adjustment for each new event, as the sequence of flows differs for each.

Recommendations for the Future

Here is a list of recommendations, based on the above results, and discussion:

1. Refinement of the overflow surfaces near Everson, using the Nooksack Tribe Lidar results, should be given priority. The new Lidar data shows topographic patterns that could affect the flow division between return to the Nooksack River or flow over Emmerson Road. Here-to-fore these features where deeply embedded in various forms of vegatal cover, masking the detials.
2. A new time-series gage should be installed, with a crest-stage gage, in the left-hand flood plain, upstream of Everson Road. Also, high-water marks should be sought near there for every flood with or without an overflow. Current time-series gage network should be retained and if possible a new gage should be installed at the south Guide Dry bridge.
3. The levee across from the overflow surface near Everson should be monitored for natural or artificial changes, with the same priority as now used for the overflow surfaces near Everson.

4. Refinement of the computations of the flows out of the Nooksack when no levee is present, should be given consideration. This currently appears to be the best way to improve the timing of the model in the flood plains and at Ferndale. This might also improve the mimicry of overflow duration at Everson Main Street. The simple assumption of a short segment of horizontal channel to provide a control for the flow over the bank where levees are absent fails to reflect the true rate at which water moves from the main channel and into the flood plain. The simple assumption used now mutes the effect of tailwater so that the flows out of the Nooksack River are too large early in the flood so that the modeling of the later higher flows has too little storage remaining on the floodplain to mimic the early rising limb of the hydrograph at Ferndale, which we have called the "dogleg".
5. Relaxing the fixed-bed assumption needs attention as well. As always, the simplest reasonable representation should be used first. All of the complexities of sediment transport need not be added. The data for doing so is completely lacking in the Nooksack River in any case! I am currently contemplating the following approach to this task:
   - 5.1 Take the low flow invert as defined by the hydrographic survey, perhaps with some adjustments found by calibrating to some low flow event.
   - 5.2 Establish a range of movement of the invert along the flow path. The current invert shifts would be used as a guide.
   - 5.3 Create a system of function tables that can interpolate for any invert level between the two limits defined in items 5.1 and 5.2. These three steps are relatively straightforward.
   - 5.4 Establish a target invert level that varies with flow. That is, what level would be obtained if the flow were held constant for a protracted time period. This does not mean that this invert would actually occur when the flow reaches the given level, only that the invert would move toward this "desired" level.
   - 5.5 The rate at which the invert moves toward the desired level defined by the current flow rate would depend on the past history of the flows at that point. This is the part that is not clear but some form of time-weighted average of the stream power per unit length at the point might be a good starting point. Stream power per unit length is the product of the flow rate and the slope of the local energy grade line. It provides an estimate of the "power" available at that point and at that time. The greater the average power, the more rapidly the invert moves towards its "desired" level.

Much trial and error and experimentation would be required, but it does seem possible to devise a system that would enable modeling of the dual peaks in October of 2003, with the first producing overflow at Everson Main Street, but the second, nearly equivalent peak, coming a few days later, did not produce an overflow there. Apparently the invert did not have time to "recover" to its pre-event state in the short time between major flood peaks. This might also bring the 2003nov event into a reasonable range as well.