From: Scott Boettcher
To: scottb@sbgh-partners.com
Subject: FW: Doty Gage
Date: Wednesday, May 18, 2016 5:31:12 AM

Scott;

Actually, the situation with the Doty gage is just the opposite. The gage was washed out by the flood so there is no data for the peak of the December 2007 event. Therefore the USGS did what is called an "Indirect Discharge Measurement" where they estimate the peak flow at a location based on high water marks and channel properties and estimated the flow as about 63,100 cfs. We looked at the same high water mark data and on the basis of our hydraulic modeling and analysis we concluded that 63,000 cfs was too high and that the peak flow was likely closer to 52,600 cfs or less. We also did a preliminary hydrologic analysis which supported a lower peak discharge (maybe even quite a bit lower than 52,600 cfs). For all the work we have done for the Flood Authority we are using our estimate of the peak flow for December 2007, which results in a slightly lower estimate of the 100-year event (35,000 cfs versus 37,000 cfs).

Attached is our memorandum that describes our review and analysis related to the USGS' estimate of the December 2007 flood peak. I've also included a copy of the USGS' summary of the indirect discharge measurement. I don't have any pictures of the flood at the gage site but there is a great video showing flows just downstream at the Elk Creek Bridge - see https://www.youtube.com/watch?v=CUDGgwNpXNE

When you are out at the site you can go back to the gage (see attached picture) and think about what it looked like with water up to the level of the gage house. If you are on the bank look downstream about 250 feet and across the river and you should be able to see a huge concrete block which was part of the gage that was wiped out in 2007. The water level in 2007 reached the back room (river side) of the owners house which is just south of the creamery and was well up the side of the building that sits on the river bank right by the gage. Water did not come over the bank by the creamery.

Larry

MEMORANDUM

Date: January 31, 2014
To: H&H Technical Committee
From: Larry Karpack, Watershed Science & Engineering (WSE)
Cc: Bob Montgomery, Anchor QEA
Re: Chehalis Basin Strategy: Reducing Flood Damage and Enhancing Aquatic Species - Peer Review of December 2007 Peak and Hydrograph at Doty Gaging Station

Introduction

The USGS gage on the Chehalis River near Doty was inoperable during portions of the December 2007 flood event and the peak stage observed during the 2007 flood was more than 10 feet higher than any previously recorded stage at this site. No direct measurements of streamflow were made during the flood event. Therefore, the USGS prepared an indirect discharge computation of the flood peak for this event and used that computation to update their stage-discharge rating curve, to estimate the peak discharge for that flood event, and to compute the flood event volume through graphical infilling of the flood hydrograph. Several stakeholders have questioned the accuracy of the USGS's peak flow estimate and previous analyses indicate that the overall event runoff volume may be too high. In addition, Lewis County staff believes that a log and debris dam may have formed and subsequently broke just downstream from Pe Ell. The potential effects of a dam break flood on the observed peak discharge at the gage site need to be evaluated. A thorough review of the peak flow estimate and flow hydrograph is needed to improve confidence in the data and address these concerns. This work addresses Task 1.3.2 Peer Review of December 2007 Peak and Hydrograph at Doty Gaging Station.

In conducting this peer review WSE staff met with the USGS on September 4, 2013 to discuss their observations during the December 2007 flood, to obtain relevant data, and to ask about the USGS' streamflow gaging in the basin. Data provided by the USGS included survey data, high water mark information, flow data, a summary of the December 3, 2007 indirect discharge measurement, and anecdotal information about the flood. WSE staff met again with the USGS on November 22, 2013 to share the preliminary results of our analysis and to ask follow up questions regarding USGS gaging in the Chehalis basin.

Background and Data Review

The Chehalis River basin is located in southwest Washington, encompassing a drainage area of approximately 2,100 square miles. The river rises in the Willapa Hills and runs generally east, then north, and then west to its mouth at Grays Harbor. Elevations range from over 3,000 feet in the headwaters above Pe Ell to sea level at the mouth. Major tributaries to the Chehalis River include the South Fork Chehalis, Newaukum, Skookumchuck, Black, Satsop, and Wynoochee Rivers. The upper Chehalis River, upstream of Pe Ell, encompasses steep, mountainous terrain, with steep channel slopes and very narrow floodplains. Mean annual precipitation in the upper watershed ranges from more than 120 inches per year in the Willapa Hills to less than 45 inches per year near the Twin Cities of Chehalis and Centralia.

The December 2007 event was a classic atmospheric river (pineapple express) type event with a fairly narrow path of extreme rainfall. The highest rainfall center was concentrated in the Willapa Hills in the Upper Chehalis River Basin (main stem and South Fork). There was very little low level snow immediately prior to the event although additional snow may have fallen during the early part of the storm. The 2007 storm set records for 24-

hour precipitation in the upper basin, even though the heaviest precipitation actually occurred over about 12 hours or less at many locations. The resulting flood is the largest in the historic record at Grand Mound (84 years), Porter (65 years), Doty (74 years), and the South Fork Chehalis (73 years aggregate record). It is the third largest storm in the 74 year record on the Newaukum River. The USGS estimate of the peak discharge on the Chehalis River near Doty (63,100 cfs) is more than double the next highest flood in the 74 year record (28,900 cfs in 1996) and was approximately 67% greater than the current estimate of the 100-year flood. In contrast, at Grand Mound the USGS estimated flow was only about 6% higher than the next highest event (1996).

The USGS has operated a gaging station near Doty continuously since 1939. Unfortunately the gage was inoperable during a significant portion of the December 2007 flood event (see Figure 1). As shown in Figure 1 the gage also showed a sudden rise and quick fall between 9 AM and 11 AM when it ceased operation. Based on their post event analysis the USGS believes that flow at the Doty gage peaked at about 1 PM, at a stage of 31.36 feet gage (335.86 feet NAVD). The timing and water surface elevation of the peak were confirmed to WSE by the owners of the Willapa Hills Cheese and sheep dairy who live on the property near the gage. The USGS believes the rapid rise and fall in the water surface elevations shown in the gage record may have been caused by logs catching on the measurement cableway causing water to temporarily back up until the cableway failed. The residents did not observe this rise and fall in water levels indicating that it might have been caused by a problem with the gage as it was failing rather than actual water level fluctuations. Although it is not possible to confirm either theory the USGS noted that the surveyed high water mark at the gage site is still about 1 foot higher than the highest stage recorded prior to the failure, even with the large fluctuations.

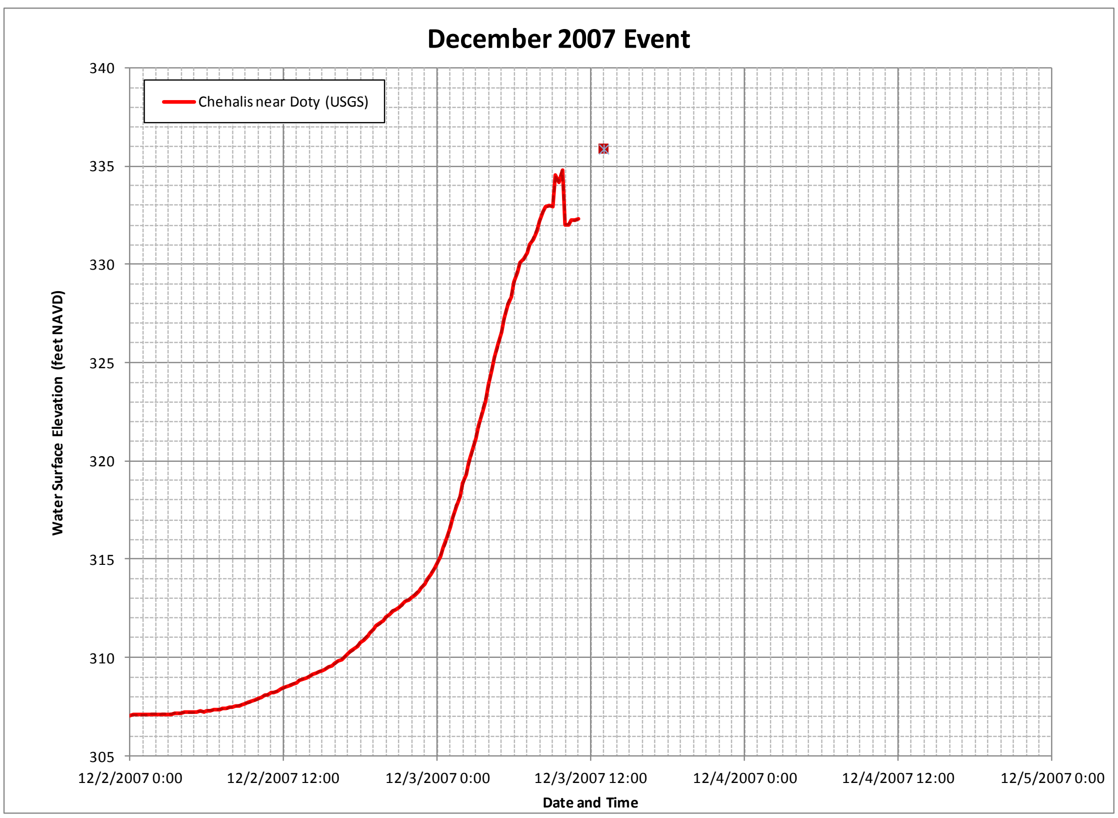

Figure 1: USGS observed water surface elevations for Chehalis River near Doty

Following the December 2007 flood the USGS visited the gage site, set and surveyed numerous high water marks, surveyed 4 river cross sections, and used these data to compute an indirect discharge measurement using the Slope-Area method. In simple terms the slope area method uses observed high water and cross section data to determine the slope and area of flow. The flow velocity is then determined from the water surface slope using Manning's equation and the flow is then computed as the product of area times velocity. Implicit in the computation of velocity is an assumption of the Manning's "n" (roughness) of the measurement cross sections. The USGS assumed a Manning's n value of 0.040 for the Doty slope-area computation. Based on their work the USGS estimated the peak discharge for the December 2007 flood to be 63,100 cfs with an uncertainty of plus or minus 15% (± 9,465 cfs).

Using the indirect peak discharge the USGS updated and extended their rating curve for the Doty gage and used the new rating curve to recompute flows up until the time at which the gage failed. Figure 2 shows the USGS estimated flows using the original rating curve, in place at the time of the December 2007 flood event, and the final (updated and extended) rating curve. The USGS also created a hydrograph for the flood and used that hydrograph to estimate mean daily flows for the event (as shown in Figure 2).

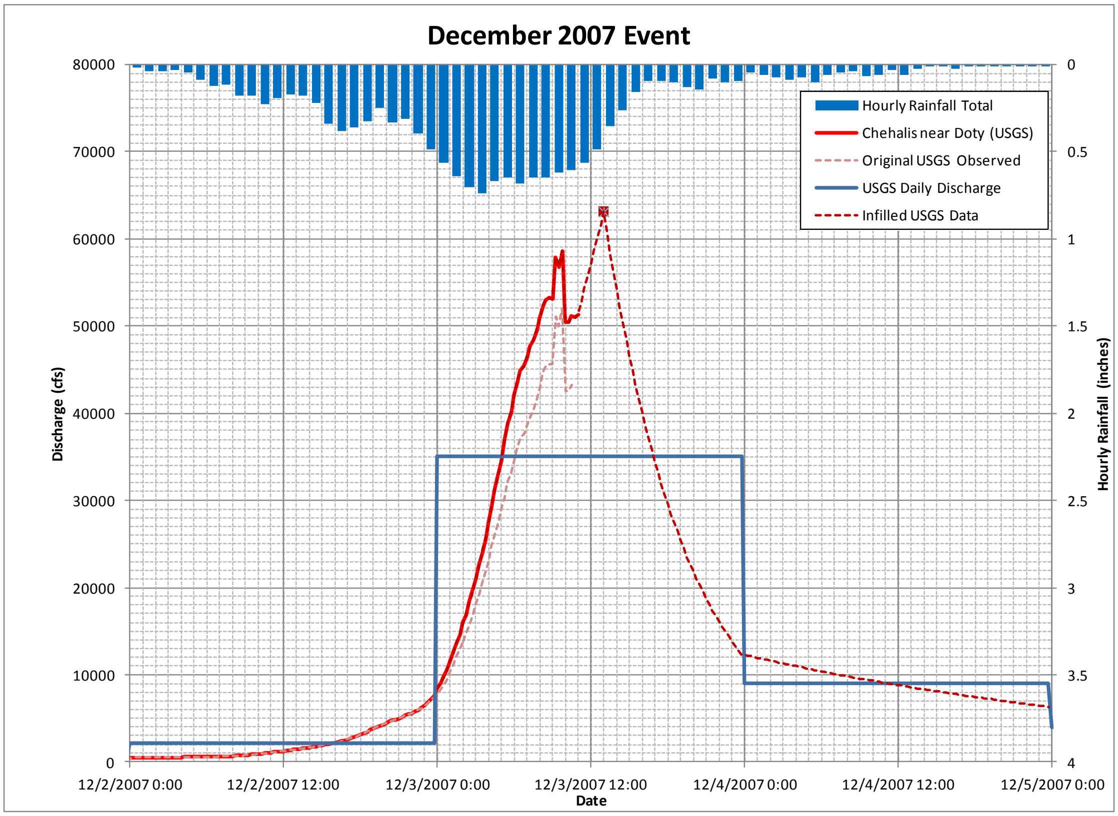

Figure 2: USGS estimated flows for Chehalis River near Doty

Analysis and Conclusions

Peak Discharge

Watershed Science and Engineering (WSE) obtained the USGS' Indirect Discharge Measurement summary for the Doty gage and the data used to produce this computation. WSE also obtained numerous high water marks for the December 2007 flood from Lewis County. WSE is in the process of updating the HEC-RAS hydraulic model of the Chehalis River. This process consists of updating the model geometry to use new surveyed channel cross section data and recent LiDAR based floodplain elevation data. The model will then be calibrated to observed high water marks and used to evaluate flooding throughout the basin. For the current work WSE updated and calibrated the portion of the Chehalis River model upstream of the confluence with the South Fork

Chehalis River. The model was then used to evaluate various assumptions of Manning's n values and flow rates at the Doty gage site.

Using the HEC-RAS model with a Manning's n value of 0.050 (the same value that was used in the recent FEMA study) WSE estimated the peak discharge for the December 2007 flood event to be about 52,600 cfs. This flow and Manning's n value combination provided good calibration results for high water marks throughout the upper Chehalis River (see Figure 3). The one exception is the reach immediately downstream of Pe Ell where a debris jam was reported. This reach is discussed in greater detail in the following section.

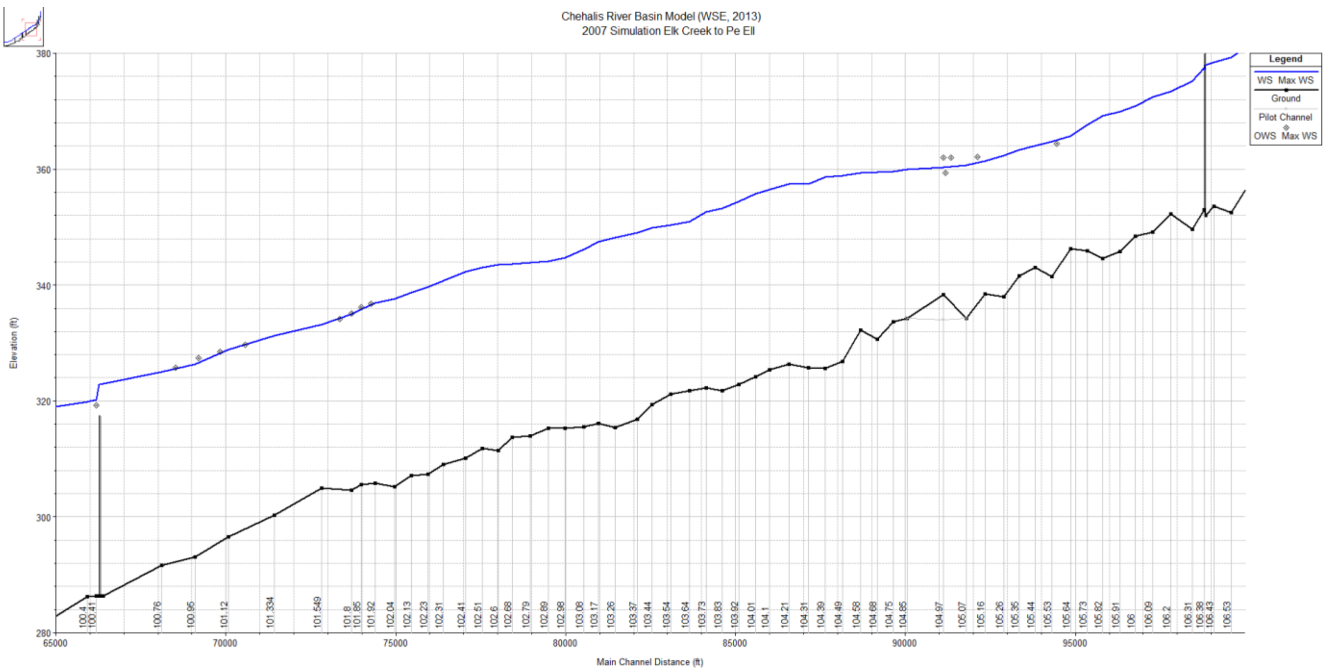

Figure 3: HEC-RAS Model Profile and Observed High Water Marks for December 2007 Flood Event

In addition to estimating the peak discharge for the December 2007 flood WSE also compared a rating curve generated with the HEC-RAS model to the USGS rating curves. Figure 4 shows the HEC-RAS model stage-discharge rating curve compared to Rating 17.1, which was in effect during the 2007 flood, and Rating 18, which was developed after the flood using the USGS peak flow estimate. As seen in Figure 4 the model rating curve matches very well with USGS Rating 17.1 but not so well with Rating 18. In fact, as reported by the USGS, the peak flow for this event estimated by WSE (52,600 cfs) is essentially the same as the flow that would be derived from a straight line extension of Rating 17.1 (52,300 cfs).

It should be noted that the most significant factor controlling the peak discharge determination is the selection of Manning's n. WSE feels that a Manning's n of 0.050 is appropriate for the channel near the Doty gage during extremely high flows. Factors affecting this include channel bed material, channel slope, flow depth, bank vegetation, form roughness due to changes in channel geometry, turbulence, entrained sediment, and the effects of the large amount of woody debris carried by the flow. Considering all of these factors we believe that 0.050 is an appropriate value. However, given that the n value needs to be assumed (it cannot be calculated given the available data) we believe that the uncertainty around the peak flow estimate due to the selection of Manning's n may be as high as 20%. Furthermore, there is also uncertainty due to other factors such as the variability in observed high water marks of one foot or more, the effect that wave action may have had on setting high water marks, the effect that logs in the flow may have had on conveyance capacity, and uncertainties due to the use of a relatively limited set of cross sections to represent the channel geometry. Given all of these factors we recommend that the peak flow for the December 2007 flood event be stated as 52,600 cfs plus or minus 25% (as compared to the USGS estimate of 63,100 cfs plus or minus 15%).

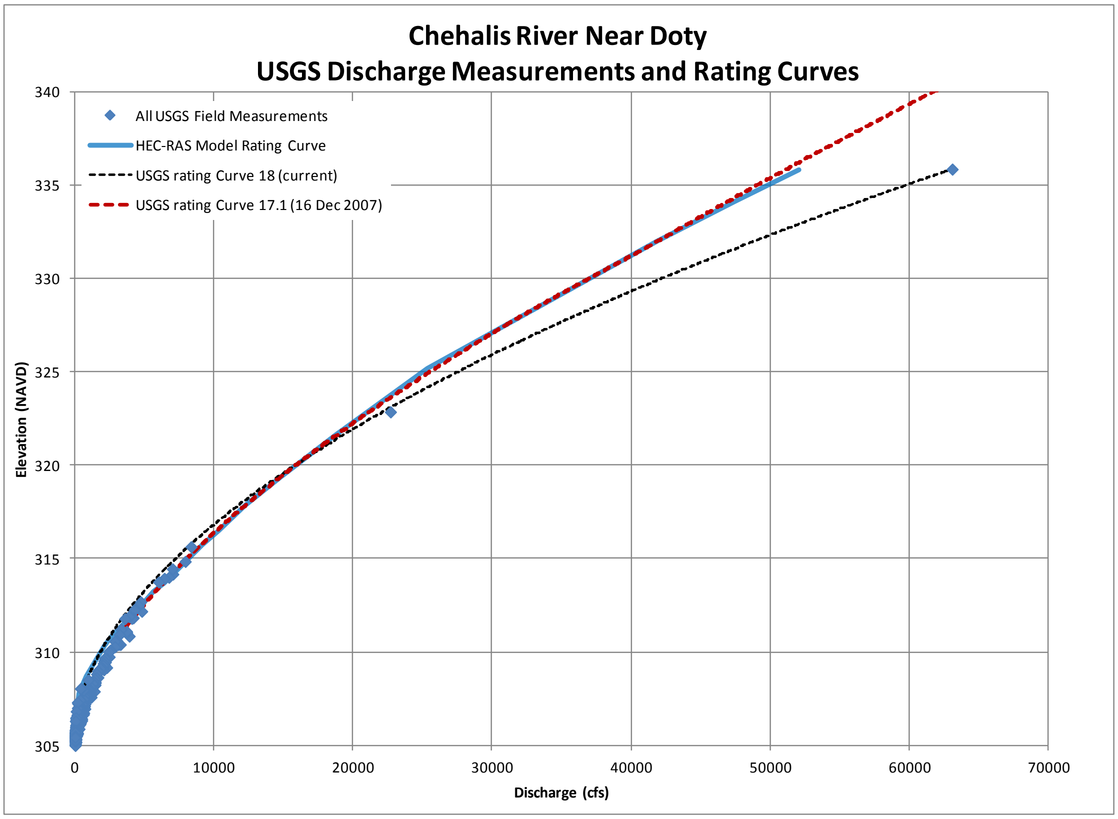

Figure 4: HEC-RAS Model Profile and Observed High Water Marks for December 2007 Flood Event

Dam Break

As noted above the updated HEC-RAS model compares well to all observed high water marks in the upper Chehalis with the exception of three marks just downstream of Pe Ell. These high water marks were collected by the USGS at the request of Lewis County to document the presence and effect of a log jam that had formed at that location. Because the baseline HEC-RAS model is not set up to include debris jams the observed high water levels downstream of Pe Ell could not be matched. For this reason a second model geometry was created incorporating a debris jam at the location identified by the County. This model was then run to determine what impact the debris jam would have had on water levels and flooding, and also to evaluate the potential downstream effects on flow of the subsequent failure of the jam. Based on these analyses the debris jam could have ponded an additional 170 acre feet of water and resulted in a dam break peak release of about 2,000 cfs if it occurred coincident with the event peak. This release would have been attenuated as it moved downstream but could have resulted in about an 800 cfs increase in the observed peak at the Doty gage, had the dam break coincided with the event peak (which is a reasonable assumption but not certain).

Event Runoff Volume

In addition to reviewing the USGS peak discharge estimate for the 2007 flood WSE also reviewed the estimated event runoff volume as determined from the USGS mean daily discharge estimates. At the time WSE began our work the USGS published mean daily discharge at Doty for December 3, 2007 was 55,000 cfs. Based on a basin area of 113 square miles to the gage site this would correspond to 18.1 inches of runoff over the basin for that day. Using the original USGS data the total runoff from December 3 through December 6 would have been over 32 inches or more than double the event rainfall (as will be described below). Furthermore it would not have been possible to create a hydrograph that would have matched the 15-minute gage data through the time of failure (11 AM) and still resulted in a mean daily discharge of 55,000 cfs on December 3rd. After reviewing this information the USGS revised their estimates of the mean daily discharges for this event as shown in Table 1, resulting in total runoff from December 3 through December 6 of 16.5 inches.

Table 1: USGS mean daily discharge data for Chehalis River near Doty

DATE	ORIGINAL USGS ESTIMATED DISCHARGE		REVISED USGS ESTIMATED DISCHARGE	
	MEAN DAILY	INCHES	MEAN DAILY	INCHES
12-03-2007	55,000 cfs	18.1 inches	35,000 cfs	11.5 inches
12-04-2007	25,000 cfs	8.2 inches	9,000 cfs	3.0 inches
12-05-2007	12,500 cfs	4.1 inches	4,000 cfs	1.3 inches
12-06-2007	6,000 cfs	2.0 inches	2,200 cfs	0.7 inches

Additional Supporting Information

As described above WSE believes that the peak discharge for the December 2007 flood event was not as high as estimated by the USGS. However, the difference in estimated peak discharge depends on the assumption of Manning's n value that is used. Given the fact that Manning's n cannot be directly measured, and direct measurements of the actual discharge are not available, additional information was sought to support WSE's peak discharge estimate. WSE has detailed radar based precipitation data for the December 2007 event, which were developed for a previous project. These data show that the spatially averaged total rainfall over the basin between December 1 and December 4 2007 was 16.0 inches (ranging from a high of about 26 inches in the highest elevations to about 12 inches at some lower locations). Using these rainfall data a simple HEC-1 rainfall runoff model was created for the basin. The model was configured with 3 sub-basins corresponding to Thrash Creek (the area with the highest rainfall), the proposed dam site, and the Doty gage. The hydrologic model was then calibrated to the extent possible to match the observed USGS flow estimates through the point when the gage became inoperable as shown in Figure 5.

Because detailed precipitation data is not available for any other large flood events the hydrologic model could not be calibrated or validated to any other events. This is never the preferred situation. However, this is the situation we are in and in lieu of any other data to support the peak discharge estimates the preliminary hydrologic model was used to provide insight into the peak discharge estimate. Assuming that losses to infiltration (groundwater), interception, and evapotranspiration were negligible through the peak of the flood the model computed peak discharge estimate for the 2007 event was 46,200 cfs. To attain the peak discharge estimated by WSE for the event (52,600 cfs) would have required approximately 13% more rainfall than observed, which is certainly not out of the question either through measurement error or due to snowmelt contributions (see Figure 6). To attain the USGS estimated peak discharge of 63,100 would have required 37% more rainfall than observed which does not appear to be reasonable.

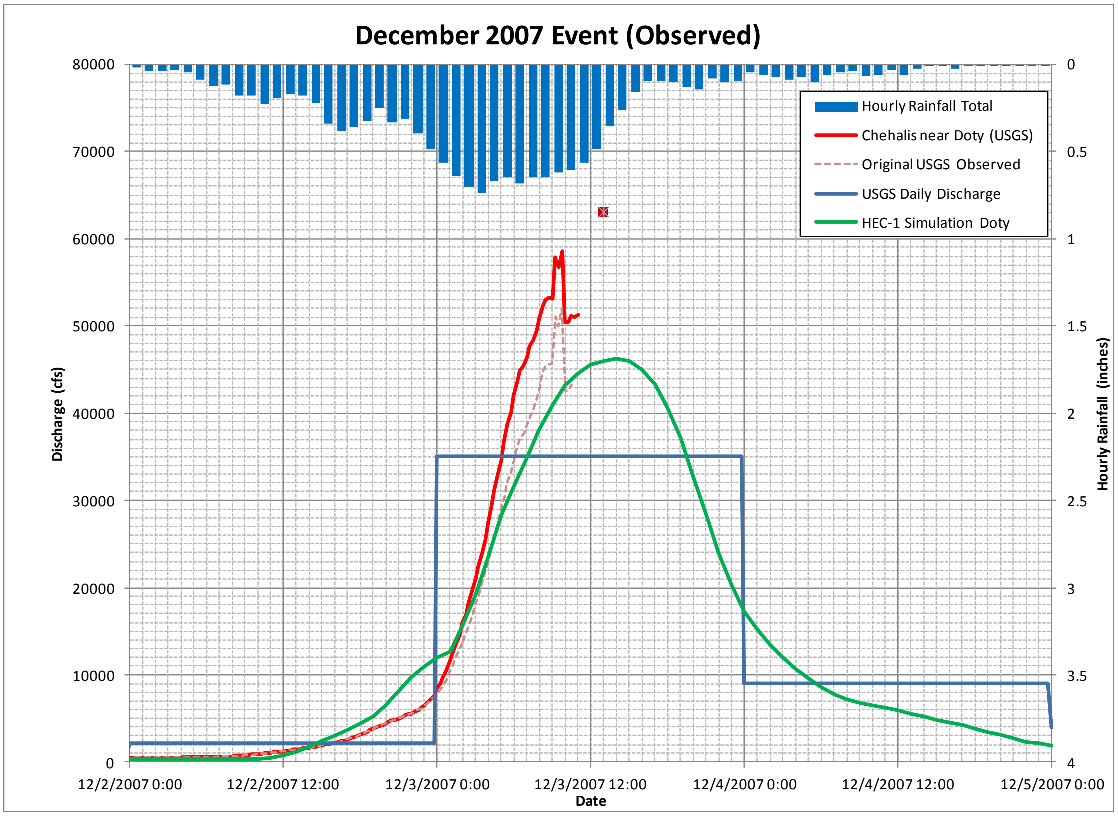

Figure 5: Observed Data and Hydrologic Model Results Using Observed Rainfall

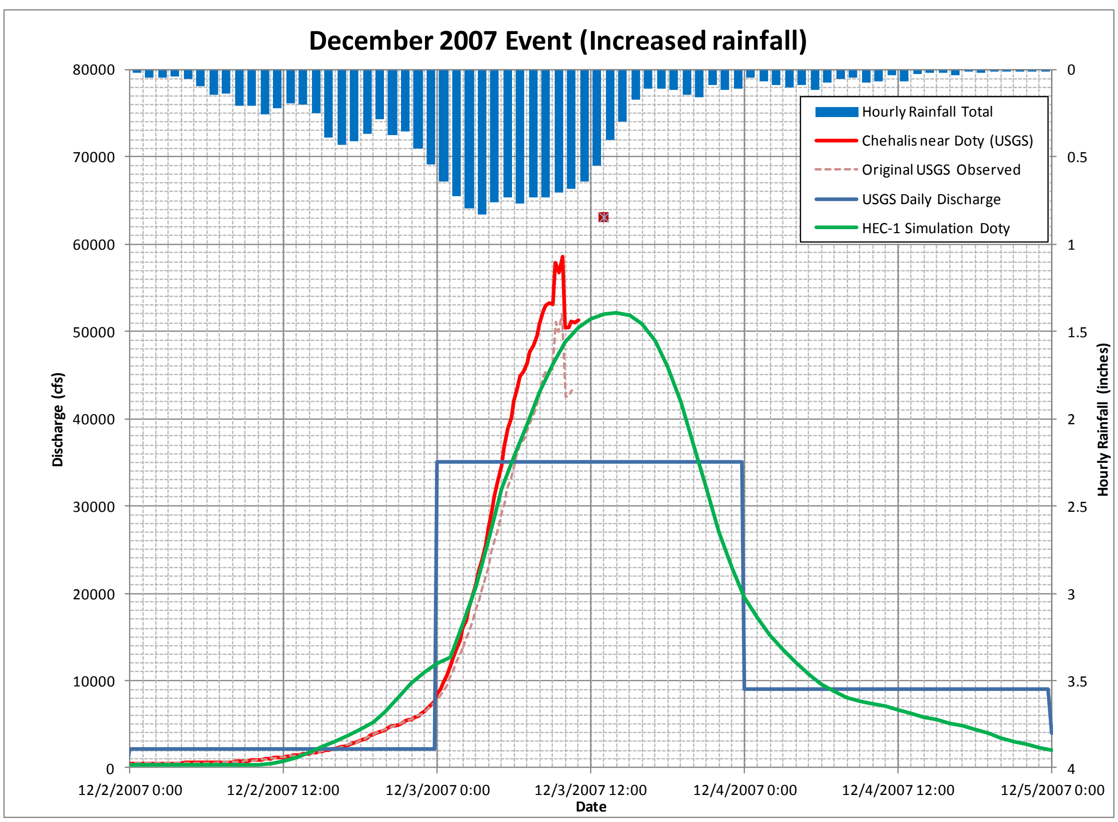

Figure 6: Observed Data and Hydrologic Model Results Using Rainfall Increased by 13%

Given these analyses the rainfall data and hydrologic modeling appear to support a lower estimate of the peak flow. The modeling also supports the revised mean daily discharge estimates produced by the USGS, or even lower values. The event runoff volume using the hydrologic model without any increase in rainfall is about 14 inches while the runoff using the rainfall increased by 13% is about 15.8 inches (which matches the revised USGS mean daily discharges, see Table 1).

Effect of Revised Flow Estimates on Flood Frequency

As described above, WSE believes that the best estimate of the peak discharge at the Doty gage during the December 2007 flood is 52,600 cfs, approximately 15% lower than the USGS' estimate. WSE also determined that the mean daily discharges originally published by the USGS were unreasonable, and the USGS subsequently revised these. The next question to be addressed was what difference the revised discharges would have on flow frequency at the Doty gage. To address this question WSE recomputed peak flow frequency results using the revised, reduced value for the December 2007 event. The results of this analysis are summarized in Table 2. The first two results columns in Table 2 (columns 3 and 4) show the previously computed flood frequency quantiles from the FEMA study (column 3) and the Flood Authority modeling (column 4). Columns 5 and 6 show these two sets of data recomputed using the adjusted value of 52,600 cfs for the December 2007 flood. As seen in Table 2 the 15% reduction in discharge for the December 2007 event results in about a 5% reduction in the 100-year discharge at the Doty gage.

Table 2: Revised Flood Frequency Quantiles for Chehalis River near Doty

PERCENT CHANCE EXCEEDENCE	RETURN PERIOD (YEARS)	USGS DOTY GAGE COMPUTED FREQUENCY CURVE - FLOW (CFS)			
		ALL OBSERVED USGS DATA		DEC 2007 EVENT SET TO 52,600 CFS	
		1940 - 2012	WITH HISTORIC PERIOD	1940 - 2012	WITH HISTORIC PERIOD
0.2	500	59,000	54,000	54,000	50,000
0.5	200	47,000	43,000	43,000	41,000
1	**100**	**39,000**	**37,000**	**37,000**	**35,000**
2	50	32,000	30,000	31,000	29,000
4	25	26,000	25,000	25,000	24,000
10	10	20,000	19,000	19,000	19,000
20	5	15,000	15,000	15,000	15,000
50	2	9,900	9,900	10,000	9,900
99	1.01	4,300	4,400	4,300	4,300

Notes: [1] All frequency analyses based on the methods of Bulletin 17B of the Hydrology Subcommittee, Interagency Advisory Committee on Water Data, Revised September 1981
[2] Frequency analyses conducted using US Army Corps of Engineers HEC-SSP Software

Using the USGS' revised mean daily discharge estimates WSE also recomputed the flood flow frequency data at the Doty gage for other durations. These data are needed to develop hydrographs for input to the hydraulic modeling. Flood frequency analyses were conducted for the period of record (Water year 1940 – 2013) using the US Army Corps of Engineers HEC-SSP Software and the methods of Bulletin 17B. Table 3 shows the results of these analyses.

Table 3: Flood Frequency Quantiles for Chehalis River near Doty for Extended Durations

PERCENT CHANCE EXCEEDENCE	RETURN PERIOD (YEARS)	USGS DOTY GAGE COMPUTED FREQUENCY CURVE - FLOW (CFS)				
		1-DAY	3-DAYS	7-DAYS	15-DAYS	30-DAYS
0.2	500	33,200	16,300	8,400	4,800	3,700
1	100	23,100	12,500	7100	4,400	3,300
4	25	16,400	9,600	6,000	3,900	3,000
10	10	12,600	7,900	5,200	3,600	2,700
20	5	10,100	6,700	4,600	3,200	2,400
50	2	7,000	5,000	3,600	2,600	1,900

Summary and Recommendations

Based on the analyses described herein WSE believes that the peak discharge estimate made by the USGS for the Chehalis River near Doty for the December 2007 flood event is somewhat high. WSE's analyses indicate the peak discharge for that event was probably closer to 52,600 cfs although there is still a great deal of uncertainty surrounding this value. However, even though we believe that the actual peak discharge in this event was approximately 15% less than the value reported by the USGS, reducing the value would only have a small effect on flood flow quantiles (about 5% for the 100-year flow). The peak flow quantiles recommended for use in the current project are shown in the far right column of Table 2. The recommended 100-year flow is 35,000 cfs which is 5% lower than the value used in the 2012 modeling for the Flood Authority and about 10% lower than the value used in the 2010 FEMA study.

A more significant result of WSE's work was to highlight concerns with the mean daily discharges estimated by the USGS. The USGS has since revised their estimated mean daily discharges for this event, reducing these by an average of about 50%. The revised USGS mean daily discharges have been used to recompute multi-day flood frequency analyses as shown in Table 3. A refined hydrograph for Doty for the December 2007 event has also been developed for use in the hydraulic model calibration (see Figure 7). The statistical hydrologic analysis used for the Chehalis River HEC-RAS hydraulic model will also be updated to reflect the new data shown in Table 3 and Figure 7.

It should be noted that the recommended changes to the flood hydrograph for the December 2007 event may not have a significant impact on simulated water surface elevations and inundation limits in the hydraulic model. The reason for this is that the hydraulic model will be calibrated to observed high water marks (HWMs) from recent flood events, including December 2007, and thus some or all of the reduction in estimated discharges will be offset by adjustments to the hydraulic model (e.g. increased roughness values) to match the high water marks. Ultimately the hydraulic model for the December 2007 calibration event should show similar results to the previous calibration runs and the simulations of the 100-year flood may be slightly lower (or higher) than the previous runs depending on whether the change in discharge or any required change in the model roughness has greater effect.

One further note - the work reported herein was done specifically for the Chehalis River Basin Flood Hazard Mitigation project under the direction and guidance of a Hydrologic and Hydraulic Technical Committee. These analyses may be useful in the future for other purposes such as updating FEMA floodplain mapping but any use for other purposes (e.g. FEMA) would need to be reviewed and approved by the appropriate agency.

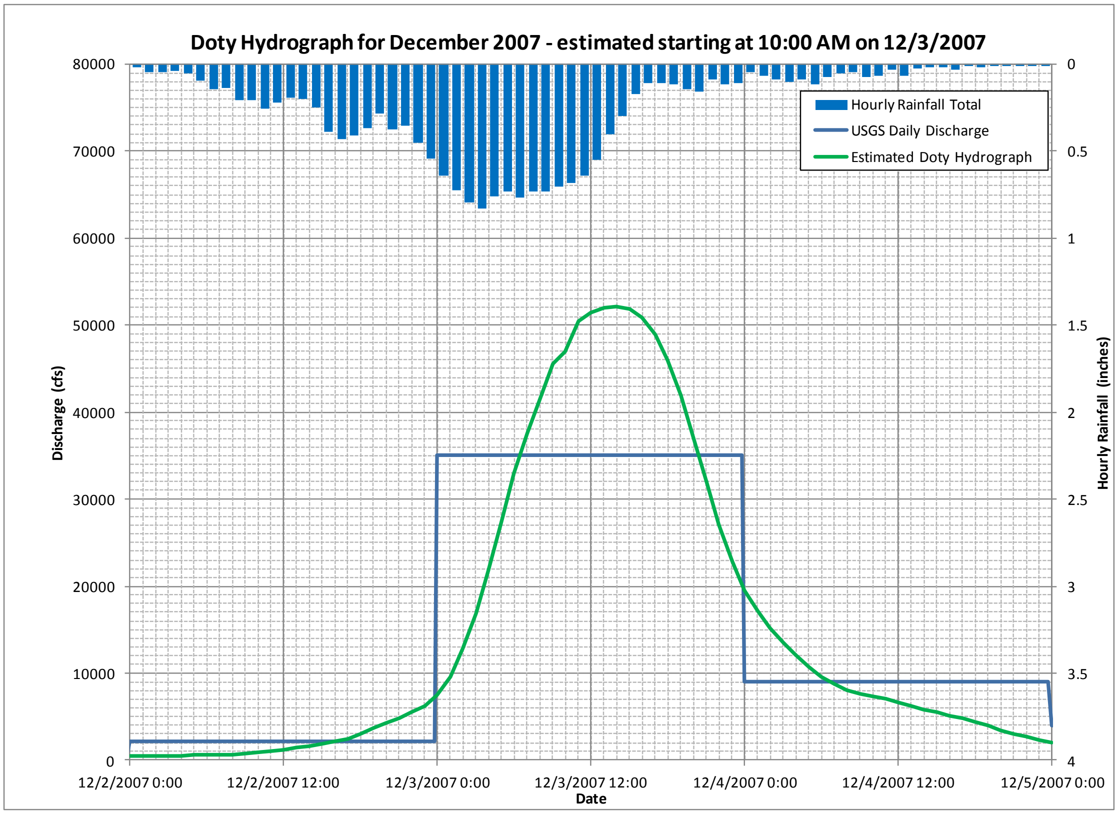

Figure 7: Recreated Hydrograph for Doty Gage for December 2007 Flood Event

INDIRECT MEASUREMENT SUMMARY

CHEHALIS RIVER NEAR DOTY, WASH.
CHEHALIS RIVER BASIN
STATION NUMBER 12020000

FLOOD OF DECEMBER 3, 2007

TYPE OF MEASUREMENT.--4 section slope area.

LOCATION OF SITE.--Lat 46º37’02”, long 123º16’38”, in NE 1/4, NW 1/4, sec 14, T.13N., R.5W, Lewis County, at gaging station, 1.6 mi. upstream from Elk Creek and 1.3 mi. south of Doty on the Willipa Hills Sheep Dairy (fig 1).

SURVEY OF SITE.--Highwater marks (HWMs) and cross sections were surveyed by USGS employees Mark Mastin, Pete Laird, Morgan Keys and Cameron Marshall December 11-13, 2007. The survey was made at an arbitrary datum and later corrected to gage datum using a correction value of –83.65 ft based on RM10, a brass tablet in a concrete pad at the entrance to the gage house. Gage datum is 301.1 ft above NGVD of 1929 (river-profile survey). Elevations determined from shots on RM10 at different control points varied by 0.02 ft and computed elevations for the middle and upper outside gages varied by 0.03 ft from the observed gage plate elevation. The base for setting up the survey instrument was flood-deposited mud which did not provide an ideal, stable medium for accurate surveying. Backsight readings at control points provide a measure of error and the points were within 0.183 ft in the horizontal and 0.059 ft. in the vertical. A Topcon 211D (5-second accuracy, serial number LG1893) divisions) was used for the survey.

A hand-held Garmen map 76 GPS unit was used to acquire latitude and longitude readings on two of the survey control hubs with a reported accuracy of 9.0 to 9.7 ft. The horizontal coordinates were computed in feet with an abitrary starting point and magnetic north azimuth. The coordinates were rotated and translated to units of meters in UTM zone 10, NAD27 using the GPS-determined azmuth and location so that the points could be overlain on a digital raster graphic of the 7.5-minute quadrangle of the site (fig. 1). See Excel file “chehalis_doty_rotate&translate.xls” for the coordinates.

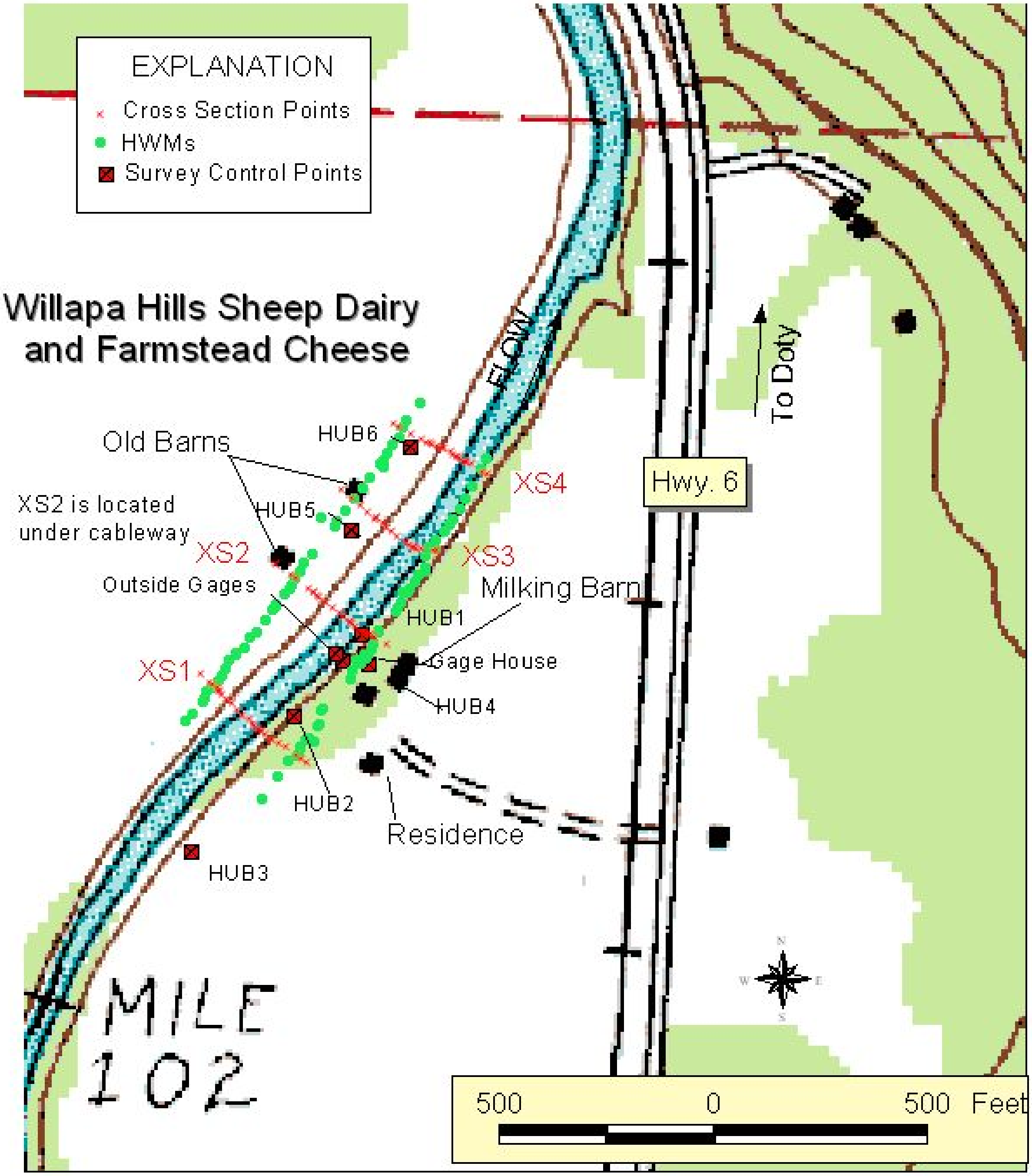

Figure 1. Location of survey in the vicinity of the Chehalis River near Doty, WA (Sta. No. 12020000) streamgage.

DISCHARGE AND GAGE-HEIGHT.—63,100 ft^3/s was the computed peak discharge for this indirect measurement; no gage height record was available at the peak and the peak exceeded the highest CSG. The gage height record showed a sudden rise and quick fall before becoming inoperable (fig. 2), which may have coincided with the time when the cableway began to catch trees until it gave way. HWMs indicate that the stage at the peak was higher than this temporary surge. An excellent seed line on the door of the gage house at 31.36 ft is used for the peak gage height. It is within 0.23 ft of several excellent HWMs just upstream and downstream from the gage house.

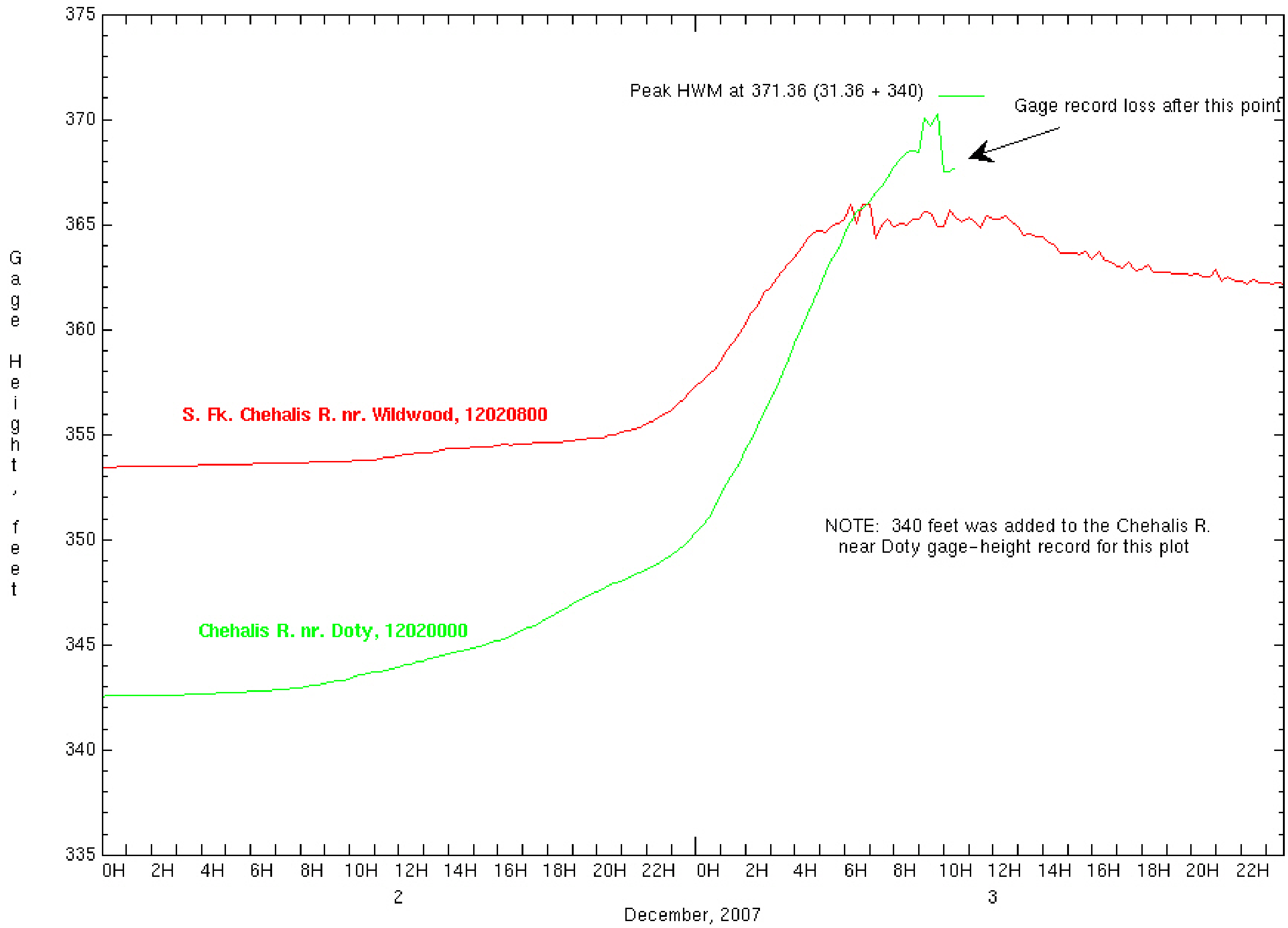

Figure 2. Gage-height record for December 2-3, 2007, at the Chehalis River near Doty and South Fork Chehalis River near Wildwood stream gages, Washington.

DRAINAGE AREA.--113 mi^2

UNIT DISCHARGE.—558 ft^3/s per mi^2

NATURE OF FLOOD.--Flood was caused by heavy rainfall augmented with snowmelt from existing snow on the ground prior to the rainfall. Francis, a National Weather Service (NWS) station located 11 miles southeast of the gage, reported a 3-day storm total of 14.1 inches of precipitation, a maximum 24-hour total of 9.7 inches, and a maximum 6-hour total of 3.2 inches. The 100-year, 24-hour precipitation total at Francis is just under 8.0 inches and the Willipa Hills (upper drainage area for the Chehalis River) 100-year, 24-hour precipitation total exceeds 10 inches as estimated from an isopluvial map by Miller, Frederick, and Tracey(1973). A USGS-operated tipping bucket rain gage at the South Fork Chehalis River near Wildwood gage, 14 miles to the southeast, reported a 3-day storm total of 12.53 inches of precipitation, a maximum 24-hour total of 9.29 inches, and a maximum 6-hour total of 4.00 inches. The property owner at the gage site reported that there was no snow at the gage before the storm, but there were eight inches of snow in the hills, which was gone after the storm. The property owner also stated that the river was completely filled with floating trees near the time of the peak.

FIELD CONDITIONS.--The highwater marks covered a reach beginning about 300 feet upstream of the gage and ending about 550 feet downstream of the gage. The reach is straight with a very steep left bank upstream of the cableway (about 150 feet below the gage) and a very steep right bank below the cableway. A low terrace exists on the right bank above the cableway and on the left bank below the cableway. The flood inundated the terrace but was barely contained within the upper banks, except for a small area near the owners residence that overflowed the upper bank. Some flow in this overflow was connected to a small drainage that drains to the river on the right bank below the cableway. It was difficult to determine if the flow was going from the drainage to the overflow area or vice versa over a flat channel about 20 feet wide. In any case, the flow was thought to be minimal or insignificant compared to the main flow—perhaps a few cubic feet per second at the peak—and was not included in the calculations. The steep banks were vegetated with a mature fir and cedar trees and brush. The lower terraces were mostly grass with occasional maple or groups of alder trees. Upstream of the cableway the right-lower terrace was recently planted with fir trees about 2-3 feet high. The main channel streambed is gravel-sand-bedrock in the upper two cross sections and mud to a depth of about 1 foot in the lower cross sections. Several large debris piles were found in the channel. One pile on the left main-channel bank included the right-bank cableway anchor block that was transported during the flood and remained connected to the cable.

The highwater marks were generally fair to excellent quality small debris and mud lines. Many photographs were taken of the reach. Four cross sections were surveyed beginning with XS1 at the upper end, XS2 at the cableway and XS3 and XS4 downstream. Total reach length is 737 ft.

COMPUTATIONS.-- A previous indirect measurement done in 1972 at the same location used main channel n values that averaged 0.040 and overbank n values of 0.040. The four cross sections were subdivided at the lower terrace top of bank. n values of 0.040 were used for the indirect measuement described herein.

SAM, version 2.1, an Excel program (test version) written by Jon Hortness, USGS, was used to manipulate the survey data to compile an input file for the Slope Area Computation (SAC) program v. 97.01 that was used to make the computations. Eliminating the results from XS3 to XS4, a very short reach, the values for the other possible combinations of reaches between cross sections range from 60,500 to 70,400 ft^3/s for the computations with the 0.040 n value for the main and side channels. Using an n value of 0.035 for the main and side channels for the reach from XS1 to XS4 provides a peak discharge of 67,300 ft^3/s, and using an n value of 0.040 for the same reach, provides a peak discharge of the result is 63,100 ft^3/s, or 6.2 percent less. The results using for the n value of 0.040 for the main and subdivided channels are shown below:

DISCHARGE COMPUTATIONS

	dH,fall (ft)	Reach length (ft)	Discharge (cfs)	Spread (%)	HF (ft)	CX	RC	RX	ER
XS1 - XS2	0.94	311.	68217.	0	0.595	1.000	0.579	0.000	#
XS2 - XS3	0.83	228.	70449.	0	0.519	1.000	0.599	0.000	#
XS3 - XS4	0.74	198.	53169.	0	0.301	1.000	1.462	0.000	#
XS1 - XS3	1.77	539.	69237.	0	1.115	1.000	0.588	0.000	#
XS2 - XS4	1.57	426.	60495.	0	0.772	1.000	1.034	0.000	#
XS1 - XS4	2.51	737.	63070.	0	1.348	1.000	0.862	0.000	@#

Definitions:

Spread, the percent difference between discharge computed with no expansion loss (k=0) and discharge computed with full expansion loss (k=1.0), divided by the discharge computed with full expansion loss

HF, friction head- HF = sum of Q*Q*L/(K1*K2) over subreaches; Q, discharge; L, reach length; K1, upstream section conveyance; K2, downstream section conveyance

CX, the computed discharge divided by the discharge computed with no expansion loss (k=0)

RC, velocity head change in contracting section divided by friction head

RX, velocity head change in expanding section divided by friction head

ER, warnings, *-fall <' 0.5ft, @-conveyance ratio exceeded, #-reach too short error, 1-negative or 0 fall

******, terms that can not be computed because' of strong expansion in reach

CROSS SECTION PROPERTIES

I.D. XS4 | Velocity head 3.24ft | Discharge 63070.cfs

Ref.distance 975.ft | Q/K 0.0024 | Alpha 1.065

Sub area no.	Water surface el.(ft)	n	Area (sq.ft)	Top width (ft)	Wetted perimeter (ft)	Hydraulic radius (ft)	Conveyance x 0.001 (cfs)	%	Vel. (fps)	F
1	29.77	0.040	606.5	58.1	61.1	9.93	104.397	8.	8.5	0.46
2	29.77	0.040	3900.2	155.2	168.5	23.14	1179.820	92.	14.9	0.52
Total	29.77	---	4507.	213.	230.	19.63	1284.220	100.	14.0	0.54

CROSS SECTION PROPERTIES

I.D. XS3 | Velocity head 2.62ft | Discharge 63070.cfs

Ref.distance 777.ft | Q/K 0.0019 | Alpha 1.048

Sub area no.	Water surface el.(ft)	n	Area (sq.ft)	Top width (ft)	Wetted perimeter (ft)	Hydraulic radius (ft)	Conveyance x 0.001 (cfs)	%	Vel. (fps)	F
1	30.51	0.040	415.3	43.7	46.8	8.87	66.285	5.	6.9	0.40
2	30.51	0.040	4556.0	178.9	195.6	23.29	1384.140	95.	13.2	0.46
Total	30.51	---	4971.	223.	242.	20.51	1450.420	100.	12.7	0.47

I.D. XS2 | Velocity head 2.37ft | Discharge 63070.cfs

Ref.distance 549.ft | Q/K 0.0018 | Alpha 1.047

Sub area no.	Water surface el.(ft)	n	Area (sq.ft)	Top width (ft)	Wetted perimeter (ft)	Hydraulic radius (ft)	Conveyance x 0.001 (cfs)	%	Vel. (fps)	F
1	31.34	0.040	4563.0	183.8	197.4	23.12	1379.330	92.	12.7	0.45
2	31.34	0.040	659.9	53.0	58.2	11.33	123.992	8.	7.9	0.39
Total	31.34	---	5223.	237.	256.	20.43	1503.320	100.	12.1	0.45

I.D. XS1 | Velocity head 2.08ft | Discharge 63070.cfs

Ref.distance 238.ft | Q/K 0.0015 | Alpha 1.087

Sub area no.	Water surface el.(ft)	n	Area (sq.ft)	Top width (ft)	Wetted perimeter (ft)	Hydraulic radius (ft)	Conveyance x 0.001 (cfs)	%	Vel. (fps)	F
1	32.28	0.040	4265.6	155.3	174.9	24.39	1336.250	83.	12.2	0.41
2	32.28	0.040	1420.2	113.0	116.3	12.21	280.469	17.	7.7	0.38
Total	32.28	---	5686.	268.	291.	19.52	1616.720	100.	11.1	0.42

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Definitions:
  n, Manning's coefficient of roughness    Q/K = discharge/conveyance
  F, Froude number F = Ki*Q/(K*A sqrt(g*(Ai/TWi)); Q, discharge; A, total cross-
      section area; g, acceleration of gravity; Ai, sub-section area; TWi, sub-
      section top width
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EVALUATION.--The reliability of the computed value of 63,100 ft^3/s is considered fair. The reach is straight and the profiles are fairly well defined despite some spread in elevations found in marks located near one another. The HWMs were generally fair to excellent. The marks were surveyed about a week after the flood had passed. Eliminating the short reach from XS3 to XS4, the final result is 11.6 percent less than the highest value and 4.1 percent greater than the lowest value. The question of whether to use the n value estimated in the field versus a higher value estimated for this analysis and the previous analysis results in a difference of 6.2 percent.

PREVIOUS COMPUTATIONS.--A four section slope-area computation was made for the flood of 1/20/72 by J.R. Williams, M.B. Miles, and R. J. Longfield. Discharge was computed at 22,700 ft^3/s at a gage height of 18.25 ft.

REMARKS.--The flood described in this summary is the peak of record for this gage site. The gage has been in place continuously since 1939. The previous peak of record was 28,900 ft^3/s on February 8, 1996 at a gage height of 20.37 ft. On a log-Pearson Type III distribution exceedance plot of annual peak flows at this station (fig. 3), the peak is less than a 0.2 percent annual exceedance flood (500-year flood). The measurement plots 20.6 percent to the right of a straight-line extension of the current rating. The discharge estimated from the current rating with a straight-line extension is 52,300 ft^3/s (fig. 4).

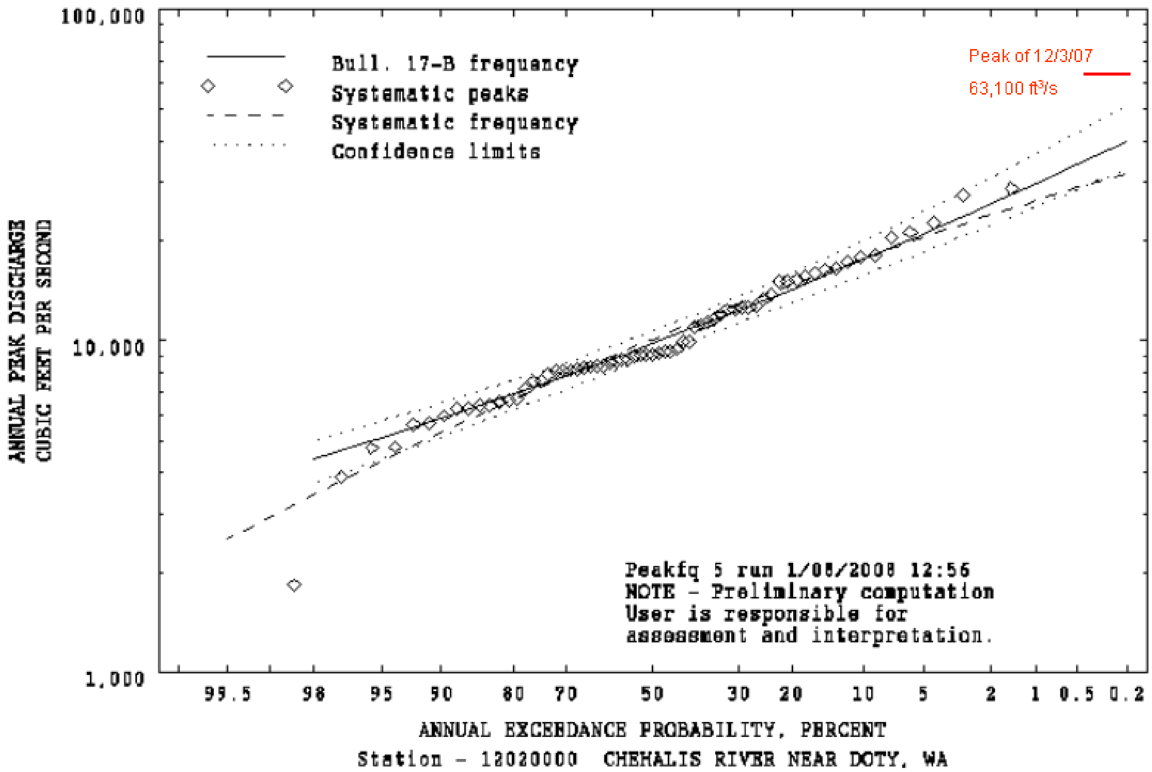

Figure 3. Annual exeedance probability plot of annual peaks at Chehalis River near Doty, Washington for water years 1940 through 2006. (The plot was generated using the PKFQWin program, version 5.2.0.)

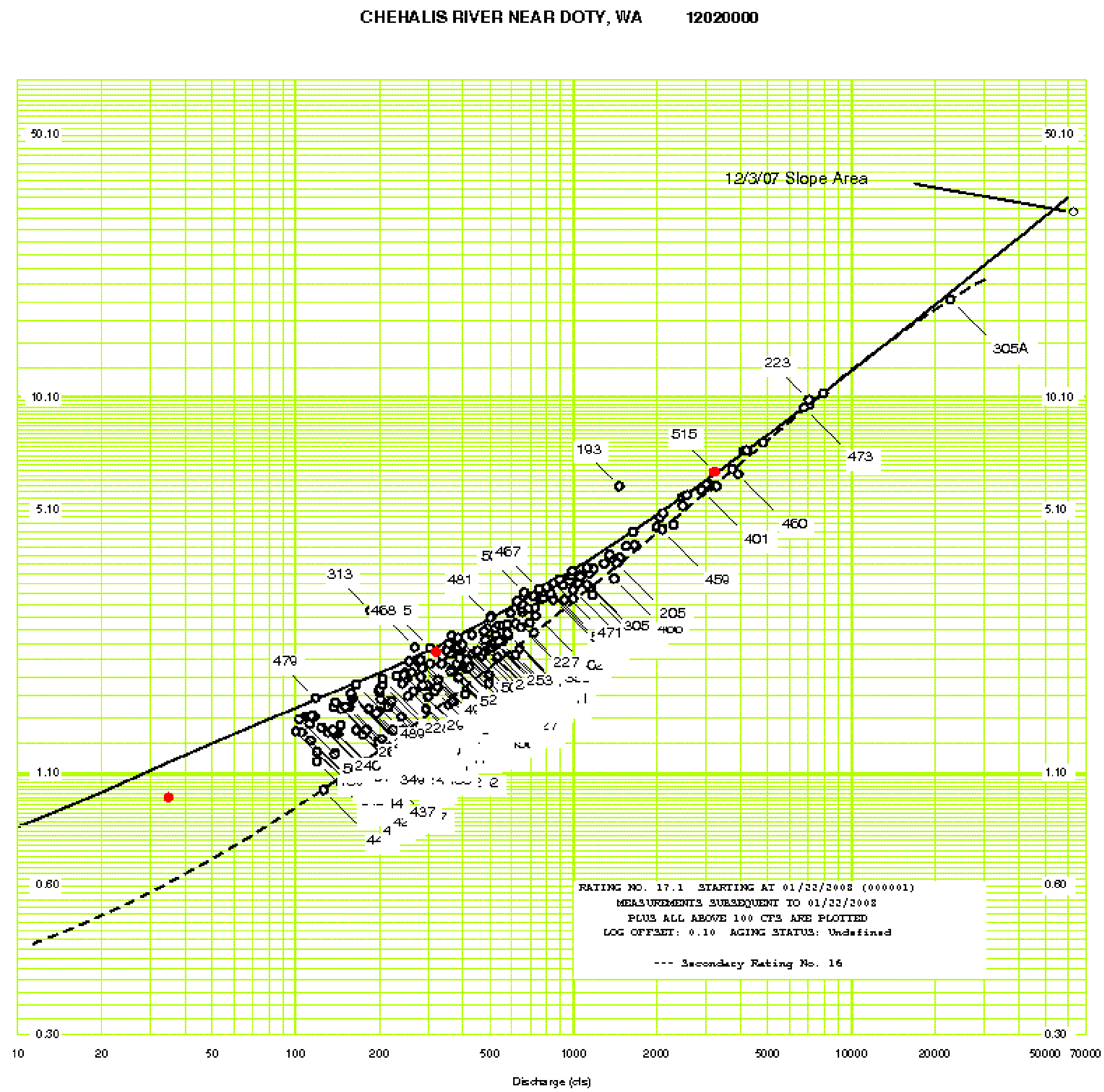

Figure 4.—Stage-discharge rating plot for ratings no. 16 and 17 (current rating) for Chehalis River near Doty, WA, with the 12/3/07 slope-area measurement plotted. Water year 2008 current-meter measurements are shown with red dots.

REFERENCES CITED.--

Miller, J.F., Federick, R. H., and Tracey R.J., 1973, Precipitation-frequency atlas of the Western United States, Volume IX—Washington: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, NOAA Atlas 2, p. 43

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1/3/08

Analysis revised by Mark Mastin
1/18/08