Low Low Water in Puget Sound vs. Mean Sea Level

What do the flood event gauge readings at Sedro-Woolley really mean?

When you make the adjustment of 8.93 feet to the published values and then subtract the impacts of upstream dam storage it is very possible that the 1990, 1995, 2003 flood events mirror the 1906, 1917 and 1921 flood events.

Larry Kunzler
July 18, 2010

In drafting the historical chapter of past flood control/reduction efforts I reviewed the over 80 plus studies dating back to 1875. In 1928 the Corps published the following table

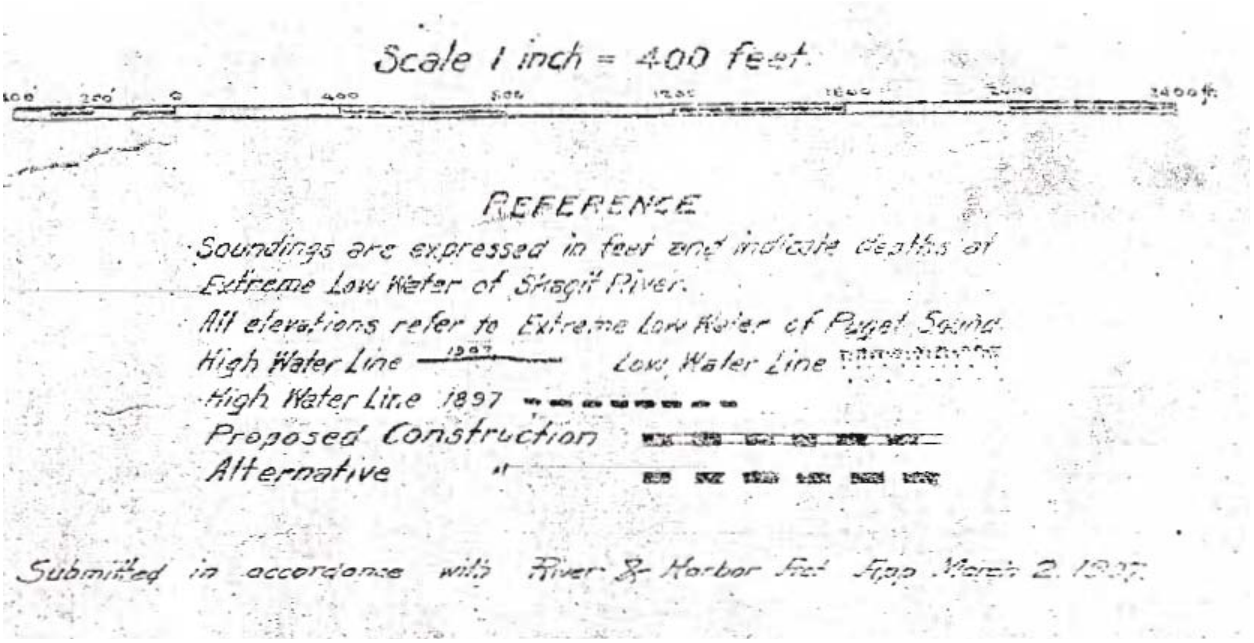
38. Flood heights and discharges at Sedro-Woolley (25 miles above the mouth, drainage area 2,970 square miles) were as follows:

Date	Gauge Height[1]		Discharge	Run-off	Accuracy
			Cubic feet	*Second feet per square*	
			per second	*mile*	*Per cent*
About 1815……..	63.5	33.5	400,000	134	15
About 1856……..	60.0	30.0	350,000	101	15
Nov. 16, 1896……..	54.8	24.8	185,000	62	15
Nov. 19, 1897……..	54.9	24.9	190,000	64	15
Nov. 16, 1906……..	54.7	24.7	180,000	61	15
Nov. 30, 1909……..	56.5	26.5	220,000	74	10
Dec. 30, 1917……..	54.1	24.1	195,000	66	10
Dec. 13, 1921……..	54.3	24.3	210,000	71	10

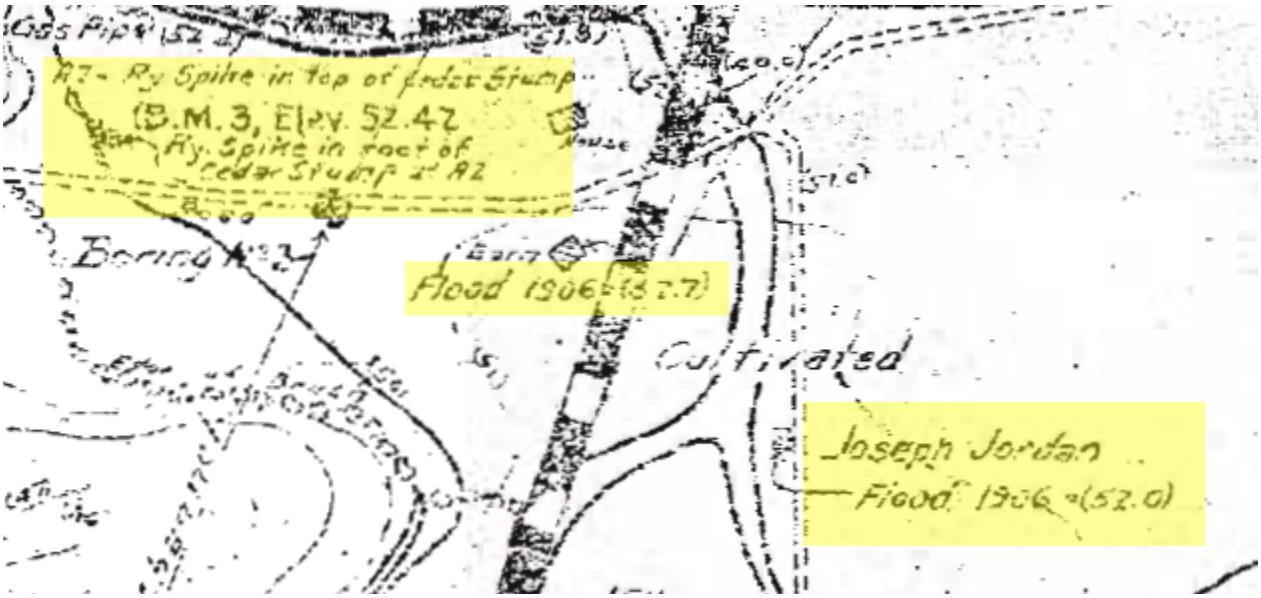
[1]Zero of gauge set at elevation of extreme low water in Puget Sound
(***Source***: USACE Preliminary Examination of Skagit River May 9, 1928)

The figures published are the same figures that Stewart used in his 1923 "Draft" report except that the Corps added 30 feet to Stewarts gage readings but those were based on Low Low Water in Puget Sound. I had no idea what Low Low Water meant and had always been led to believe that all the gage readings we currently use are based on Mean Sea Level.

Later I was reviewing a copy of the Corps of Engineers Survey map they published on March 2, 1907 (See **USACE Survey Map of the Skagit River in the Sterling Area**). The map is a wonderful piece of history showing the location of the river in the Sterling area below Sedro-Woolley as it existed in 1907. The significance of the map is unparalleled in our discussions on the Skagit River hydrology. First, in the bottom right hand corner the legend indicates that "All elevations refer to Extreme Low Water of Puget Sound", the same verbiage used by the Corps in 1928.



The map shows us the flood elevations of the 1906 flood event and was published just 16 weeks, 4 months after the 1906 flood event which according to Mr. Stewart's report, allegedly carried 180,000 cfs at Sedro-Woolley. This is the closest thing to an actual gauge reading since the gauge was installed at Concrete in 1924.



The above locations are approximately 2,890 feet below the Northern Pacific Railroad Bridge crossing.

According to USGS (Mr. Stewart) the:

6. November 16, 1906: Flood exceeded the 1897 flood in the diked districts on the delta, because of the dikes. In all other sections of the river the flood of 1906 was lower than that of 1897.

(***Source***: 1961 USGS WSP 1527, Stewart/Bodhaine Report page 2)

So the levees were having an impact on flood elevations in the lower valley as early as 1906. So what were the Low Low Water elevations based on? Again we turn to our good friends at USGS. In 1961 they published the following table:

28. *Skagit River near Sedro Woolley, Wash.*

Location.—Lat 48°29'05", long 122°14'30", in NW¼ sec. 36, T. 35 N., R. 4 E., at Northern Pacific Railway bridge, three-quarters of a mile downstream from entrance to Beatty Slough, and 1½ miles south of Sedro Woolley.

Drainage area.—3,000 sq mi, approximately, of which 400 sq mi is in Canada.

Gage.—Staff or chain gages. Datum of gage is extreme low sea level in Puget Sound (levels by Corps of Engineers), which is 8.93 ft below mean sea level, unadjusted.

Stage-discharge relation.—Defined by current-meter measurements below 91,000 cfs and extended by logarithmic plotting.

Remarks.—Flow in Beatty's slough is included in this record.

Annual peak stages and discharges of Skagit River near Sedro Woolley, Wash.

Water year	Date	Gage height (feet)	Discharge (cfs)
1815		63.5	400,000
1856		60.0	300,000
1897	Nov. 16, 1896	54.8	185,000
1898	Nov. 19, 1897	54.9	190,000
1907	Nov. 16, 1906	54.7	180,000
1908	June 11, 1908	47.8	48,200
1909	Nov. 18, 1908	52.0	97,000
1910	Nov. 30, 1909	56.5	220,000
1911	Nov. 21, 1910	52.1	114,000
1912	Nov. 19, 1911	48.4	66,600
1913	June 3, 1913	48.4	70,800
1914	Jan. 7, 1914	49.6	104,000
1915	Apr. 3, 1915	48.4	67,800
1916	June 18, 1916	46.5	75,800
1917	June 16, 1917	44.4	60,400
1918	Dec. 30, 1917	54.1	195,000
1919	Dec. 4, 1918	47.0	80,200
1922	Dec. 13, 1921	54.3	210,000
1923	Dec. 23, 1922	45.2	71,000

(Source: 1961 USGS WSP 1527, Stewart/Bodhaine Report page 52)

The most important information above is that it shows us the difference between Low Low Water in Puget Sound and Mean Sea Level. *"Datum of the gauge is extreme low sea level in Puget Sound (levels by Corps of Engineers) which is **8.93 feet** below mean sea level, unadjusted."* Important to realize at this point is that the discharges and gauge elevations published by USGS in 1961 with the exception of the discharge of the 1856 flood are exactly the same as those published by the Corps in 1928 referenced above:

Skagit River near Sedro-Woolley, Wash.
[Gaging station 28, page 52.]

Date of flood	*Elevation (feet)*	*Discharge (cfs)*
1815	63.5	400,000
1856	60.0	300,000
November 16, 1896	54.8	185,000
November 19, 1897	54.9	190,000
November 16, 1906	54.7	180,000
November 30, 1909	56.5	220,000
December 30, 1917	54.1	195,000
December 13, 1921	54.3	210,000

(***Source***: USGS WSP 1527, 1961)

What this means is that in order to reach mean sea level you have to subtract 8.93 from the published elevation/gauge readings which results in the following:

Skagit River near Sedro-Woolley, Wash
Minus 8.93 feet Extreme Low Water to get to Mean Sea Level

1815	54.7	400,000
1856	51.1	300,000
November 16, 1896	45.9	185,000
November 19, 1897	46.0	190,000
November 16, 1906	45.8	180,000
November 30, 1909	47.6	220,000
December 30, 1917	45.2	195,000
December 13, 1921	45.4	210,000

Now admittedly, as previously mentioned, the downstream levees play a significant role on the reported gauge readings. Over the years as the levees have been raised and strengthen that impact would be more pronounced. However, over the years there has been another major influence on the flood flows at Sedro-Woolley. That influence would be the storage capacity behind the Upper Baker and Ross Dams. Using Corps of Engineer information contained in the Feasibility Scoping Meeting Read-Ahead Report dated August 2009 (See Appendix A) the figures reported for Sedro-Woolley would be approximately as follows:

Skagit River near Sedro-Woolley, Wash

Minus Approx. 3 feet Due to Ross/Upper Baker Dam Storage or roughly 50,000 cfs[1]

1815	51.7	350,000
1856	48.1	250,000
November 16, 1896	42.9	135,000
November 19, 1897	43.0	140,000
November 16, 1906	42.8	130,000
November 30, 1909	44.6	170,000
December 30, 1917	42.2	145,000
December 13, 1921	42.4	160,000

The 2003 flood event registered 42.02 (Mean Sea Level) on the Sedro-Woolley gage. In 2006 it registered 42.2. Using as a rule of thumb a 6 foot difference between the SW and MV gage due to the levee impacts on artificial overbank storage that would mean that during the 1990 and 1995 flood events the SW gage would have read very close to 42+ feet.

[1] Source: USACE Feasibility Scoping Meeting Read-Ahead Report August 2009

APPENDIX A

- **Flood of 1995.** Flows on the Skagit River reached 160,000 cfs at Concrete and 141,000 cfs at Mount Vernon during the November 28-30, 1995 flood. Concrete was above zero damage stage for four days and above major damage (90,000 cfs) for one and a half days. Mount Vernon was above zero damage stage for approximately 4 days and above major damage for approximately 3 days. As a result of the reservoir regulation and sandbagging efforts, levees at Mount Vernon and Fir Island were able to withstand the flood without failing. Runoff stored at Ross and Upper Baker was estimated to have reduced flood levels by about 5 feet and 2 feet at Concrete and Mount Vernon, respectively.

Future changes to the study area hydrology (for example, due to climate change or future development) have not been modeled or incorporated into the analysis for the study.

Table 5-2. Peak Flows

Recurrence	Unregulated Concrete	Regulated Concrete	Unregulated Sedro-Woolley	Regulated Sedro-Woolley	Unregulated Mount Vernon	Regulated Mount Vernon
2-year	72,900	72,900	78,100	78,100	75,700	75,700
5-year	119,400	93,900	124,300	99,400	116,500	97,300
10-year	156,000	120,400	160,600	125,100	142,700	117,400
25-year	205,300	158,000	210,300	163,400	199,400	146,000
50-year	248,100	192,100	252,000	198,500	233,700	190,900
75-year	276,500	215,500	280,200	222,600	257,000	212,400
100-year	297,100	235,400	298,600	242,000	273,900	230,100
250-year	372,200	320,200	368,100	319,800	334,000	289,800
500-year	437,000	386,900	429,900	380,800	396,700	346,400