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1 Hydrology of the Eklutna River

1.1 Watershed Description and Historical Development

The Eklutna watershed lies northeast of Anchorage. The drainage basin is approximately 171 mi^2 in size above the Old Glenn Highway. The watershed extends from the Eklutna Glacier in the Chugach Mountains, to the Knik Arm of Cook Inlet, approximately 27 miles northwest of the glacier. The topography of the area is very rugged, with elevation ranges from near sea level to over 8,000 feet. The upper end of the watershed contains several glaciers, including the Eklutna Glacier. These glaciers constitute over 6 square miles of the watershed. The Eklutna Glacier is the longest, almost 7 miles long. Downstream of the Eklutna Glacier the watershed consists of a steep-sided glaciated valley with widths varying from between 2 miles at elevation 4,800 feet to about 400 feet at elevation 1,000 feet. Eklutna Lake covers most of this valley.

The lake is 6.5 miles long and 1.2 miles wide with an average depth of 120 feet. The lake was formed when a recessional terminal moraine of the Eklutna Glacier dammed the valley. Water levels of Eklutna Lake are regulated by the Eklutna Purchasers Association that operates the Eklutna Hydroelectric Project. The Hydroelectric project draws water from Eklutna Lake via an underwater lake tap. In addition to the lake tap an earth filled dam with an uncontrolled spillway was constructed at the outlet of the lake to increase the amount of water storage available. This dam and water diversion eliminate outflow into the Eklutna River under normal conditions in most years. Diversion of water from the lake began in 1955. The dam was damaged during the 1964 earthquake and subsequently rebuilt with a higher crest elevation of 871 feet, thereby increasing the storage capacity for the hydroelectric project.

Prior to the current Eklutna Hydroelectric project an older dam existed at the outlet of Eklutna Lake that was constructed in conjunction with the Lower Eklutna River Dam in 1929. This original dam consisted of interlocking wood timbers and pilings that could be flash boarded to increase lake storage. This dam and gate system was used to buffer outflow from the lake and to provide in stream flow throughout the winter for the hydroelectric project on the Lower River. Current water rights allow the Eklutna Purchasers to regulate lake water levels between the water intake invert elevation of 793 feet and the dam crest elevation of 871 feet for power generation and water supply. This essentially eliminates flow in the Eklutna River in all but extreme circumstances. The lake water surface elevation varies on an annual basis with the maximum elevation recorded of 877 ft on September 25, 1995 and a minimum elevation of 814.2 ft on June 1, 1962. Based on a review of existing data, the Eklutna Lake dam has been overtopped seven times since the dam was raised in 1964.

Figure 1 **Ek**lutna Diversion Dam **and Lower Eklutna River Canyon (ca. 1930-32, Hodges)**

Below the dam on Eklutna Lake, the Eklutna River flows through a deep gorge cut through glacial drift and, in places, bedrock. The depth of this gorge varies between 50 feet and 500 feet before the river converges with Thunderbird Creek. Approximately 1 mile upstream of the convergence with Thunderbird Creek, the flow of Eklutna River is partially blocked by an old diversion dam built around 1930. This dam was used to divert water for power generation by Anchorage Light and Power, but now the area behind the dam is full of sediment, and water flows over the dam. This dam is a 61 ft high concrete arch diversion dam which provided additional head for the hydroelectric turbines. The water intake for turbines was located near the top of the concrete arch dam. The project typically operated with a full pool behind the dam with only a small portion of the flow (less than 140 cfs) routed through the diversion tunnel with the remainder of the natural flow going over the crest of the dam. The crest of this older dam was sized to pass 6,000 cfs over the dam (Figure 1). The average August flows on Eklutna River between 1930 and 1946 were 1251 cfs (USGS 1947). Thus, the average August flows minus the water routed through the diversion tunnel indicates that, on average, approximately 1100 ft^3/s flowed over the dam; providing significant flows in the lower Eklutna River.

Downstream of the confluence with Thunderbird Creek the slope of Eklutna River lessens and the river leaves the canyon. As the river passes underneath the Old Glen Highway, its floodplain begins to widen until, at its mouth, a large alluvial fan has formed. Prior to construction of dams along the Eklutna River this alluvial fan was a depositional zone with a braided channel form. Lateral shifting of the river was unconfined until 1916 when the railroad was constructed.

In 1916 the Alaska Railroad (AKRR) constructed a trestle across the alluvial fan with two 'wingwalls' that ran up river to confine flow to the trestled portion of the crossing. Figure 2 shows the trestle crossing shortly after construction in 1916. In 1917 three bridges with a span of 56 feet each were constructed across the main channel of the river. The rest of the trestle portion of track was filled in, confining flow to these three bridge spans.

Figure 2 Photo of the Eklutna River Crossing Aug. 1916 (A.E.C. G25)

The bed material at the AKRR crossing was classified as 'glacial boulders and loose material in layers'. In 1927 the river had two main channels as it passed under the three- span railroad bridge. One channel was 70 ft across with a depth of 2 feet and the second channel was 40 feet across with a depth of 2.5 feet. In 1927 the three bridges were removed and a single 80 feet span bridge was installed, this bridge is still currently in service. Ground survey information from April 1917 and June 1927 indicate that the river and flood plain beneath the 3 bridges aggraded approximately 4 feet on average over this 11 year time period.

In addition to the railroad bridge, there are two additional bridges on the lower Eklutna River. The Old Glenn highway crosses the stream near the downstream end of the Eklutna canyon. The New Glen Highway bridge was constructed in 1978 and crosses the river downstream from the Old Glenn Bridge. Other development that has occurred within the lower Eklutna River system has been primarily the mining of gravel. Gravel has been extracted at various times along both the Northern and Southern flanks of the river. The most notable gravel mining operation was downstream of the AKRR crossing between the years of 1970 and 1984. The area mined was approximately 150 acres (based on aerial photograph measurements). Figure 3 shows the maximum extents of the gravel mining operation and the location of the historical centerline of the lower Eklutna River. Several other smaller areas upstream of the railroad crossing on the North side of the river have been mined periodically for gravel. A large 40 acre gravel operation is currently mining material on the North Side of the River between the New Glenn Highway and the Alaska Railroad.

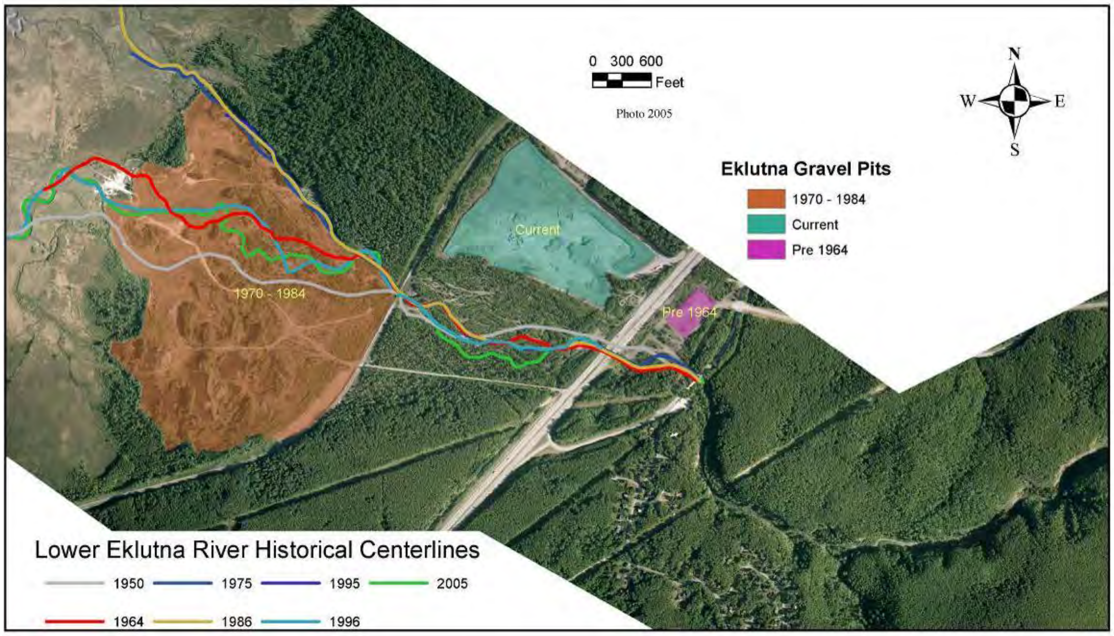

Figure 3 Lower Eklutna River Gravel Mining and Historical Stream Centerlines

1.2 Hydrology Past and Present

The hydrology of the Eklutna River basin has dramatically changed with the construction of the Eklutna Lake Hydroelectric Facility. This project essentially eliminates outflow from the Eklutna Lake into the Eklutna River. Only during extreme events does water overtop the Eklutna Lake dam and flow into the river.

During normal conditions with no outflow from Eklutna Lake, the watershed has an effective area of 49 sq. miles at the Old Glenn Highway Bridge. The Eklutna watershed below the Lake dam is 19 sq. miles and the Thunderbird Creek watershed is 30 sq miles. The lower Eklutna River and Thunderbird creek receive water primarily from snowmelt and rainfall, and secondarily from ground water, depending on the season. Eklutna Lake receives water primarily from snowmelt and glacier melt, with approximately 80 percent of the total runoff into the lake occurring between June and September.

1.2.1 Hydrologic Analysis

Table 1 below shows the location and dates of USGS collected stream flow and stage data within the Eklutna Watershed.

Table 1 USGS Stage and Discharge Measurements

Site No.	Site	Start	Stop	Length	Measurement
15280000	Eklutna Creek nr Lake Outlet	1946-10-01	1962-09-30	16 Years	Stage/Discharge
15277600	East Fork Eklutna Creek	1960-06-01	1988-12-31	6 Years[1]	Discharge
15277800	West Fork Eklutna Creek	1960-06-01	1988-12-31	6 Years[1]	Discharge
15278000	Eklutna Lake	1983-06-22	Present	25 Years	Stage
15280200	Eklutna River @ Glenn Highway	2002-05-01	2007-09-30	5 Years	Stage/Discharge

[1]Record is not continuous

The lower Eklutna River and Thunderbird Creeks have steep, mountainous headwaters that contribute to flashy – quickly rising and declining- peak stream flows. Figure 4 shows the continuous stream flow record for the Eklutna River at the Old Glenn Highway Bridge between May 2002 and September 2007 with average daily and yearly (water year) peak discharge values.

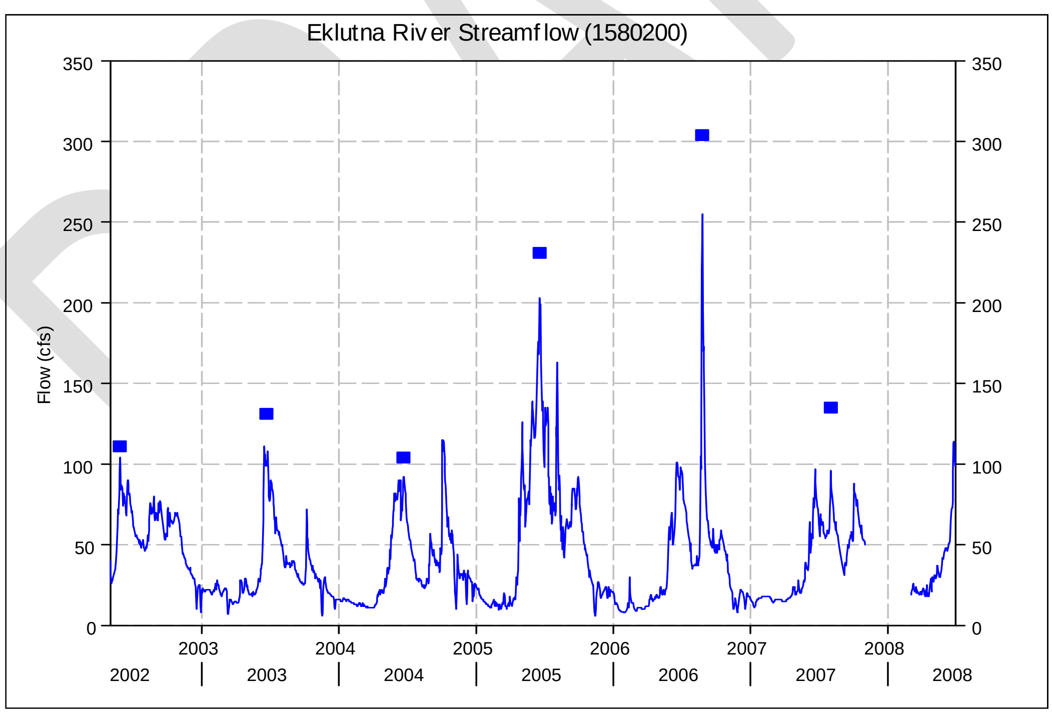

Figure 4 Continuous Stream Flow Record for Eklutna River @ Old Glenn Highway Bridge

The annual hydrograph is dominated by a spring snowmelt peak that occurs in mid June and flashy late summer peak flows**.** Note that during this period of record the Dam at Eklutna Lake was not overtopped. The average annual mean flow for this period of record was 39 cfs, ranging from a low of 33 cfs for 2003 to a high of 56 cfs for 2002. Average monthly flows range from a peak of 101 cfs during the month of June to a low of 16 cfs during the month February. It is assumed that fish migration will primarily occur between the months of May through the end of September, with out migration occurring during the early portion of the window and upstream migration occurring throughout this time window.

1.2.1.1 Frequency Analysis

Frequency analysis of a series of annual peak-stream flow data produces estimates of peak-stream flow frequency and magnitude, reported as T-year discharges. T is a recurrence interval, or the numbers of years during which the discharge is expected to be exceeded once, and is the reciprocal of the annual exceedance probability (AEP). For example, every year the 50-year peak stream flow, or 50-year flood, has a 1 in 50, or 2 percent, chance of being exceeded.

Initial estimates for peak stream flow on the Lower Eklutna River were performed using a log-Pearson Type III analysis of the systematic record combined with regional peak flow regression equations developed for Alaska (Curran and others, 2003). The program HEC-SSP was used for the station analysis with a weighted skew coefficient based on the regional generalized skew and the skew calculated for the station. Results from this analysis are shown in Table 2. It must be noted that this analysis assumes that there is no discharge from Eklutna Lake. Discharge from Eklutna Lakes is discussed in section 1.2.2.

Weighting the gaging station peak stream flow estimate with a regional equation based estimate can reduce the uncertainties in stream flow estimates for gaging stations with short periods of record (Interagency Advisory Committee on Water Data, 1982). The Eklutna River gaging station, with a short period of record, benefits from incorporating regional hydrology into the frequency estimates.

Table 2 Peak Stream flow for Lower Eklutna River (Assumes no overtopping of Eklutna Lake)

Recurrence Interval (year)	Estimated from Stream flow Data			Estimated from Regional Equations				Weighted Estimate
	Peak Stream flow (cfs)	Confidence Limits		Peak Stream flow (cfs)	Confidence Limits		Equivalent Years of Record	Peak Stream flow (cfs)
		5 %	95 %		5 %	95 %		
2	148	103	204	589	300	1150	1	180
5	219	163	376	909	492	1680	2.4	328
10	277	202	585	1150	629	2110	3.8	481
25	367	251	1011	1480	793	2760	5.6	719
50	445	289	1496	1740	904	3340	6.6	908
100	536	330	2178	2000	1000	3990	7.4	1109
200	640	373	3131	2280	1090	4760	8	1322

This analysis and the stream flow record indicates that the Eklutna watershed exhibits stream flow characteristics similar to a small steep mountainous watersheds; however, careful consideration of extreme flows influenced by overtopping of the Eklutna Lake dam must also be considered.

1.2.1.2 Historic Average Annual Flows

In addition to the recent Eklutna River stream flow record, two previous records exist that provide some insight into stream flow conditions prior to any development within the Eklutna Basin. The USGS operated a stream gaging station on the Upper Eklutna River just below the outlet of the lake between 1946 and 1962. The second record is a 1947 USGS report (Johnson) that presents monthly stream flow data passing the lower Eklutna River dam compiled from measured flow through the lower dam power house and flow over the lower dam crest from 1930 through 1946.

Using a relationship between lake outflows and flow past the lower dam developed by Johnson (1947) the various records were adjusted to approximate average annual flows from the Eklutna watershed at the Old

Glenn Highway. The recent 2002 through 2007 gage record was adjusted based on contributing area to estimate an average annual flow of 24 cfs from the Thunderbird Watershed. The recent estimated average annual flow from Thunderbird watershed was added to the historic estimates of average flow from the Eklutna watershed to estimate total flow at the Old Glenn Highway.

Table 3 below provides a summary of discharge data for Eklutna River, measured between 1930 and 1952 compared to the more recent record.

Table 3 Comparison of Average Annual Flows at the Old Glenn Highway Bridge

	Average Annual Steamflow (cfs)	Minimum Annual Stream flow (cfs)	Maximum Annual Stream flow (cfs)	Jun–Sep Avg (cfs)	Oct-May Avg (cfs)
Current (2002 -2007)[1]	39	33	56	59	17
Historic (1930-1952)[2]	402	251	513	880	121

[1] **Zero discharge from Eklutna Lake during this period**

[2] This compiled record represents un-regulated flows for Eklutna River.

In addition to comparing annual monthly flows in tabular form; Figure 5 below provides a graphical depiction of the impact that the dam at Eklutna Lake has had on stream flow in the lower Eklutna River. These flow duration curves show a dramatic reduction in discharge in the Eklutna River.

One significant impact of this flow regime change is the reduction of stream power available for sediment transport. It has been estimated based on operations of the original lower Eklutna Dam that 300,000 cubic yards of sediment was deposited annually upstream from the lower dam (Lesondak, 2002). This material accumulated behind the lower dam and was occasionally sluiced out through a sluice gate at the base of this concrete arch dam.

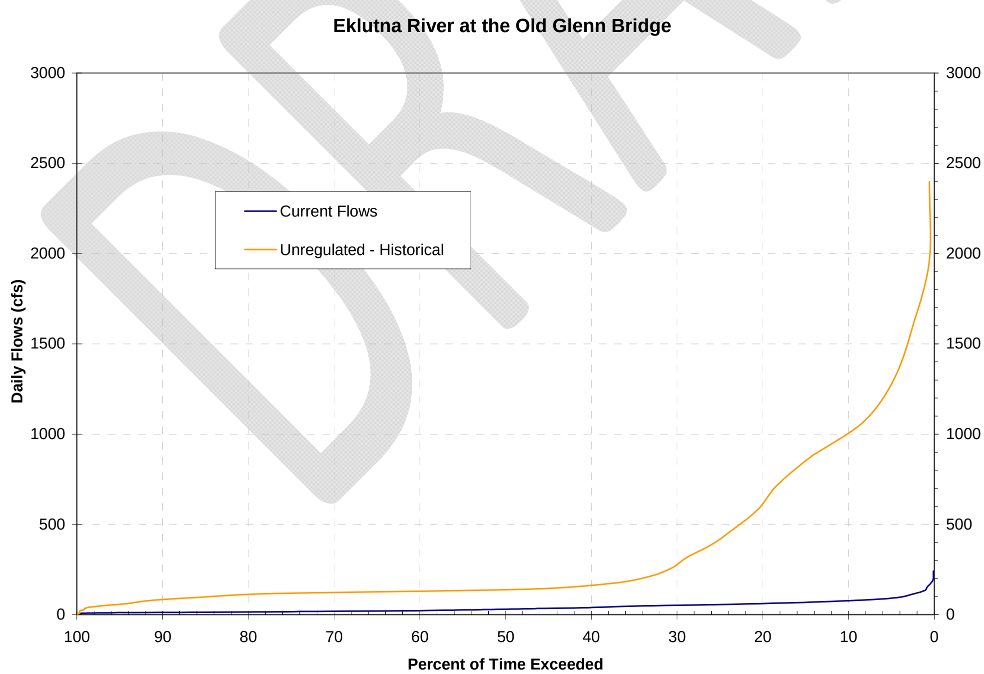

Figure 5 Comparison of Flows Before and After Dam Construction

The flood of record along the lower Eklutna River, since the lake was dammed in 1955, occurred around September 21, 1995. The stream was un-gaged during this period. Eklutna lake stage crested at 877.62 on September 25th with an estimated peak flow of approximately 1000 cfs over the upper dam. Nearby watersheds of Peters Creek and Eagle River peaked at discharges of 5,000 cfs and 14,000 cfs respectively on the 21st of September (USGS). These correspond to a recurrence interval of approximately 200 years (0.5% AEP). Flow over the Eklutna Lake dam on the 21st of September had not peaked yet and was approximately 300 cfs based on the average daily lake stage recorded.

The 200 year recurrence interval flood within the Eklutna watershed below the dam (and including Thunderbird Creek) would be approximately 1,300 cfs. Combining flows from the lower Eklutna Watershed with the estimated 300 cfs over the spillway results in an estimated peak discharge of 1600 cfs in Eklutna Creek below the old Glenn Highway.

A 1967 Bureau of Reclamation report provides the spillway design discharge over the Eklutna Lake Dam of 3,315 cfs. This is the calculated discharge from the Probable Maximum Flood and is well beyond a reasonable design return interval for the Lower Eklutna River.

1.2.2 Routing of Extreme Lake Flows

Examining historical records from a variety of sources indicate that the dam at Eklutna Lake is overtopped periodically and that these flows are likely the critical flows that any project on the lower Eklutna River will need to sustain. The lake provides storage for the Eklutna Hydroelectric Project. The lake has a storage capacity of 191,807 acre feet between the hydroelectric project intake at elevation 814 ft. and the upper end of effective storage elevation of 876 ft. The crest of the spillway at the Eklutna Lake dam is 871 ft. This is considered the volume of active storage available for power generation. Two seasons characterize the lake and water levels. During the summer season the lake is open and inflow is much greater than the outflows drawn for hydroelectric generation and the Anchorage Municipal water supply. Lakes levels rise during the summer due to the high inflow from snowmelt, glacier melt and rainfall. During the winter inflows are essentially eliminated and the lake level drops as the outflows remain nearly constant. Typical annual average lake outflows are 388 (cfs) for the hydroelectric project (1966-1988) and 45 (cfs) for municipal water supply.

Since the Eklutna Dam was re-built after the 1964 earthquake it has overtopped an estimated eight times or approximately once every six years. These events occur during the late summer and early fall when lake levels are at their highest. Table 4 shows the estimated dates of overtopping and the estimated peak outflow based on recorded observations and the spillway rating curve. Overtopping events general peak quickly and then extend for several weeks before lake levels drop below the crest of the spillway.

Table 4 Overtopping and Estimated Peak Outflow

Event Dates[1]		Event Peak			Source
Outflow Start	Outflow End	Outflow	Lake Stage[5]	Date	
1964	1964	784 cfs [4]	-	3 Aug 1964	USGS
Sep 1967	Oct 1967	-	-	-	CH2MHill, 1981
Sep 1968	Oct 1968	-	-	-	CH2MHill, 1981
Aug 1977	Oct 1977	-	-	-	CH2MHill, 1981
5 Sep 1989	7 Oct 1989	150 cfs [2]	873.71	13 Sep 1989	USGS
12 Sep 1990	27 Sep 1990	70 cfs [2]	872.31	16 Sep 1990	USGS
21 Sep 1995	20 Oct 1995	1,000 cfs [2]	877.62 [3]	25 Sep 1995	USGS
19 Aug 1997	31 Oct 1997	480 cfs [2]	875.51	10 Sep 1997	USGS

Notes:
[1] Data from 1981-1988 are not included.
[2] Based on Spillway Rating Curve, CH2MHILL, 1981
[3] Verified by the USGS on Sept 27th 1995
[4] Unknown if this was the peak outflow for 1964.

In order to adequately establish extreme flows on the lower Eklutna River the watershed was modeled using HEC-HMS to include affects from both the storage of Eklutna Lake and diversion of water for hydroelectric power and municipal use. Figure 6 shows the Eklutna Watershed model used to simulate flows.

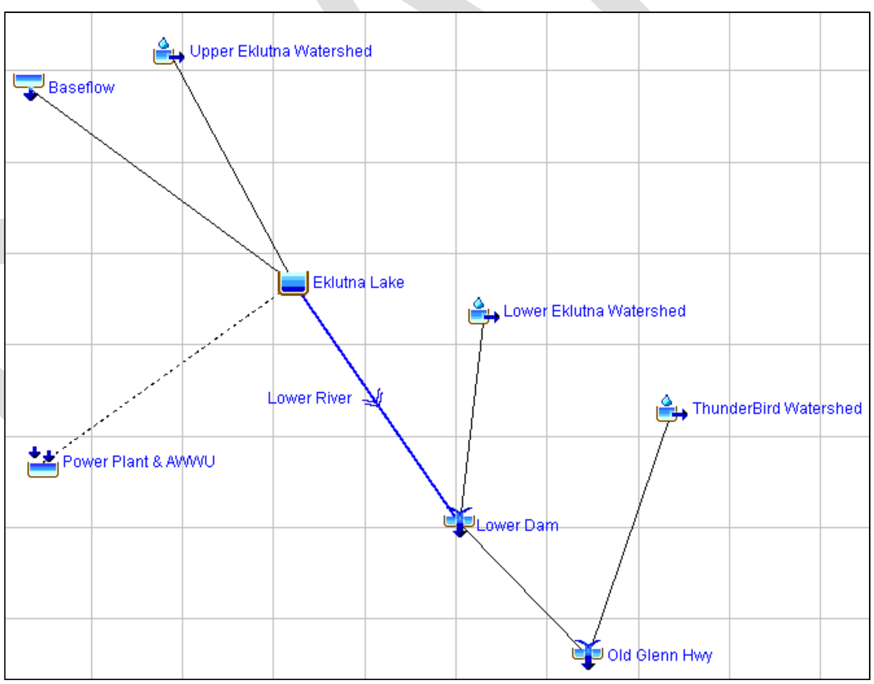

Figure 6 Eklutna Watershed Hydrologic Model.

Hydrologic input to the lake is broken down into two components, the first component is baseflow. This represents inflow into the lake as a result of glacier runoff. Baseflow was simulated as a linearly decreasing hydrograph that begins at 800 cfs recedes at 350 cfs per month. This approximates the average monthly inflows that occur between August and September (USGS, 1992) when an overtopping event is likely. To simulate the 100 year hydrograph due to rainfall into Eklutna Lake a standard SCS storm with a depth equal to the 24hr 100 year return interval (TP 47) was routed through the watershed using the Snyder Unit Hydrograph and a constant rate for precipitation losses. The 100 year inflow from rainfall into the lake was also estimated by utilizing USGS regional regression equations. The resulting SCS modeled hydrograph has a peak flow of approximately 10,500 cfs and is within the 90% confidence limits of regional regression estimate for the Upper Eklutna basin. This same procedure was performed for both the lower Eklutna watershed and the Thunderbird Creek watershed; however the peaking coefficients of these two watersheds were adjusted so that the 100 year hydrograph matched the previously calculated value of 1109 cfs using the weighted regional regression equations. This adjustment was performed based on the additional stream gaging data and a higher confidence in the calculated 100 year peak stream flows in the lower Eklutna Watershed.

Storage within the lake was modeled using the elevation-storage relationship from the USGS 1992 study. Diversion from Eklutna Lake was estimated at a constant 700 cfs. This includes water for both the hydroelectric plant and municipal water use. All model runs were arbitrarily started on September 1st. Initial model runs were performed with the lake stage at the crest of the spillway as a conservative estimate of the initial conditions prior to rainfall and also the lake stage well below the elevation of the spillway. That later case simulates the 100 yr flood with zero discharge from the lake. The hydrograph from these two simulations are shown in Figure 7.

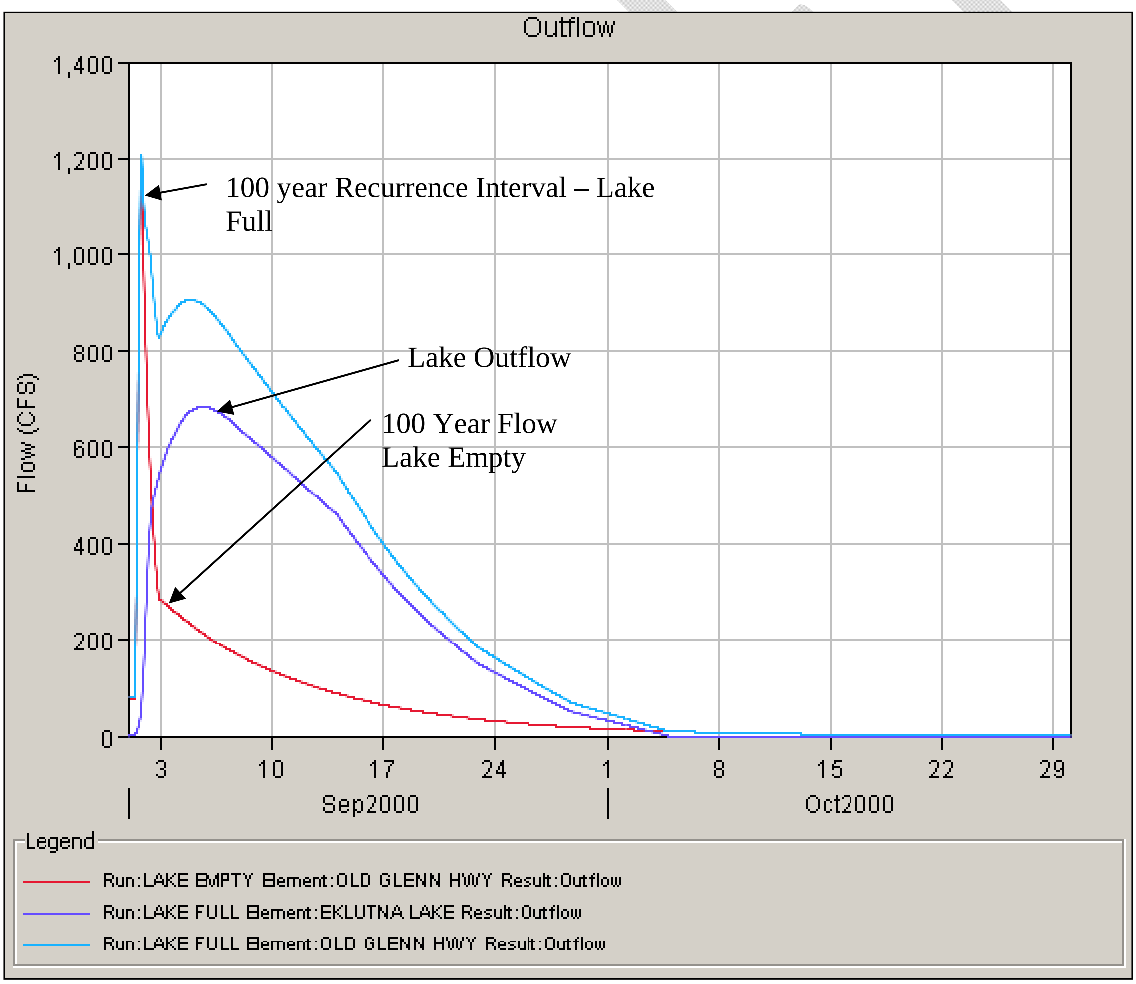

Figure 7 **Hydrologic Model Output**

Examination of the computed hydrographs reveals several key considerations for any project constructed along the lower Eklutna River:

Eklutna Lake attenuates peak flows: The calculated 100 year flood, assuming the lake is full, is 1210 cfs as compared to 5360 cfs using regional flood frequency equations without considering the impact of the dam and routing of flows through the lake. Regional flood frequency curves that do not include reservoir routing are not an appropriate method for estimating peak flows below Eklutna Lake.

Peak flows from Eklutna Lake are delayed and do not coincide with peak flows from the Lower Eklutna Watershed and Thunderbird Creek.

High flows have a long duration. Peak flows that result from overtopping of the Eklutna Lake dam have a long duration and large runoff volume. In the example above, flows remained above 255 cfs for 20 days. The highest daily average flow during the recent period of record (2002-2007) was 255 cfs.

Lake stages from the hydrologic model output were visually compared against actual measured stages during the September 1995 overtopping event (Figure 8). Flows on nearby Eagle River and Peterson Creek were both estimated to exceed the 100 year return interval for this September 1995 storm. The graph indicates that the model reasonable matches the general shape and timing for lake stages during peak flows. Both the measured and model lake stages show a delay to peak stage on the order of one week with the overtopping event lasting several weeks. The peak modeled stage is lower than the measured stage. Modeling a lower stage is likely due to rainfall occuring beyond the modeled 24 hour storm. Peak lakes stages will be a result of longer duration rain events. The modeled lake stage recedes at a slower rate than the rate measured during the 1995 event. This could be due to withdraws that exceed the estimate of 700 cfs in the model, or baseflow into the lake was overestimated. Future work could further refine this watershed model should the need arise. The current model provides an adequate understanding of the timing and magnitude of peak flows along the lower Eklutna Watershed.

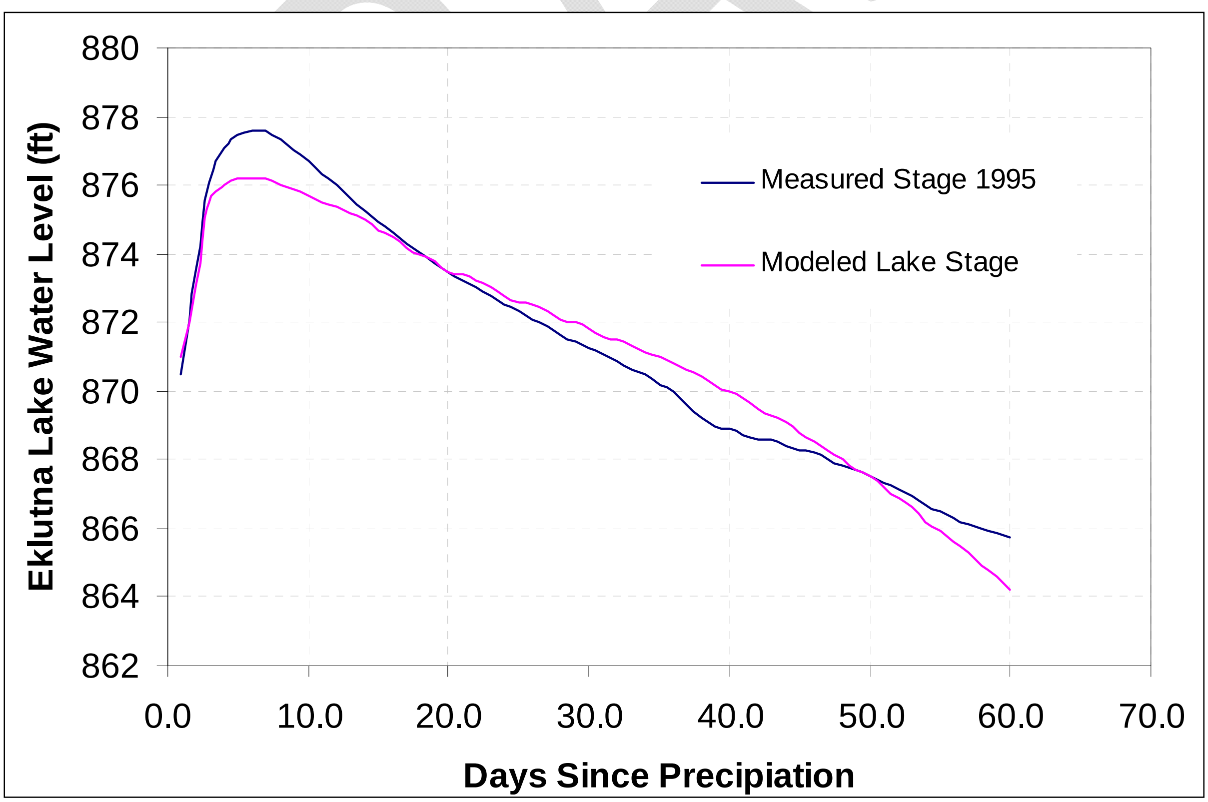

Figure 8 **Model 100 Year Lake Level and Measured Lake Levels, Sept 1995 Flood Event**

1.2.3 Low Flows and Estimation of Channel Forming Discharge

In order to design a stream restoration project with long-term stability which is sustainable without the need for maintenance, it is necessary to evaluate the full range of flows that will affect the channel. These include both low and high flow analysis to provide for fish passage. The channel forming discharge or the discharge that if maintained indefinitely would produce the same channel geometry as the natural long-term hydrograph.

The gaged record (15280200) was examined for low flow durations based on the average daily flow record for the period each year between June 1st and October 1st. Low flow data are presented in Table 5. This table shows that during each year the average low 7 day summer flows ranged from 24 to 51 cfs. The lowest flows recorded during this period were during the month of August 2004. The minimum daily average flow was 23 cfs with the minimum 7 day average flow being 24 cfs ending on the 25th of August 2004. Based on this information the hydraulic design criteria for fish passage will be evaluated for the low flow condition of 24cfs.

Table 5 Average Minimum Discharge (June 1 - October 1)

Year	Lowest Mean Average Daily Flow (cfs)		
	1 Day	7 Day	30 Day
2003	25	26	30
2004	23	24	26
2005	42	51	59
2006	35	37	41
2007	31	34	42

The channel forming discharge is often estimated by one of three methods:

- A discharge based on statistical return intervals
- The effective discharge which, over time, does the most work and transports the most sediment.
- The natural bankfull channel discharge

Discharge Based on Statistical Return Intervals

The discharge based on statistical return intervals was discussed in 1.2.1.1 of this report. In summary, the 2, 5 10, 25, 50, 100, and 200 year intervals were weighted and calculated using the HEC-SSP program. The frequency analysis assumed that there was no discharge from Eklutna Lake.

Effective Discharge

The effective discharge is defined as the mean of the discharge increment that transports the largest fraction of the annual sediment load over a period of years. It is calculated by integrating the flow-duration curve and a bed-material-sediment rating curve. In order to develop the bed-material-sediment rating curve suspended sediment and bed load measurements were performed five times at a variety of discharges. The bed load data measured for each discharge were combined with the portion of suspended sediment that was also considered bed material resulting in the total bed material for each measured discharge. It was assumed that the wash load portion of the suspended sediment samples consisted of all particles with sizes less than 0.0625". On average approximately 85% of the suspended sediment load was considered wash load. The measured bed material transported during these five discharges is shown in Figure 9. Curves generated for the East Fork and West Fork of Eklutna River (USGS, 1992) are also shown on the figure. Sediment load functions are often represented as a power function:

$$Q_s=aQ^b$$

The bed material sediment load function for the lower Eklutna River was estimated to be $Qs=1E\text{-}03*Q^2$. This function was fit graphically to the measured data (Figure 9). In order to validate the higher end of this curve the function was applied to daily flows measured by the USGS, adjusted for the lower dam, for the years 1947 through 1954. The resulting average volume of transported sediment during these years was 207,000 cubic yards (assuming a density of 100 lbs/cy). This agrees well with the anecdotal estimates of approximately 300,000 cubic yards of material sluiced through the concrete arch dam annually (Lesondak, 2002). These estimates are generally not considered precise but do provide an approximate value for the quantity of transported sediment on a daily basis.

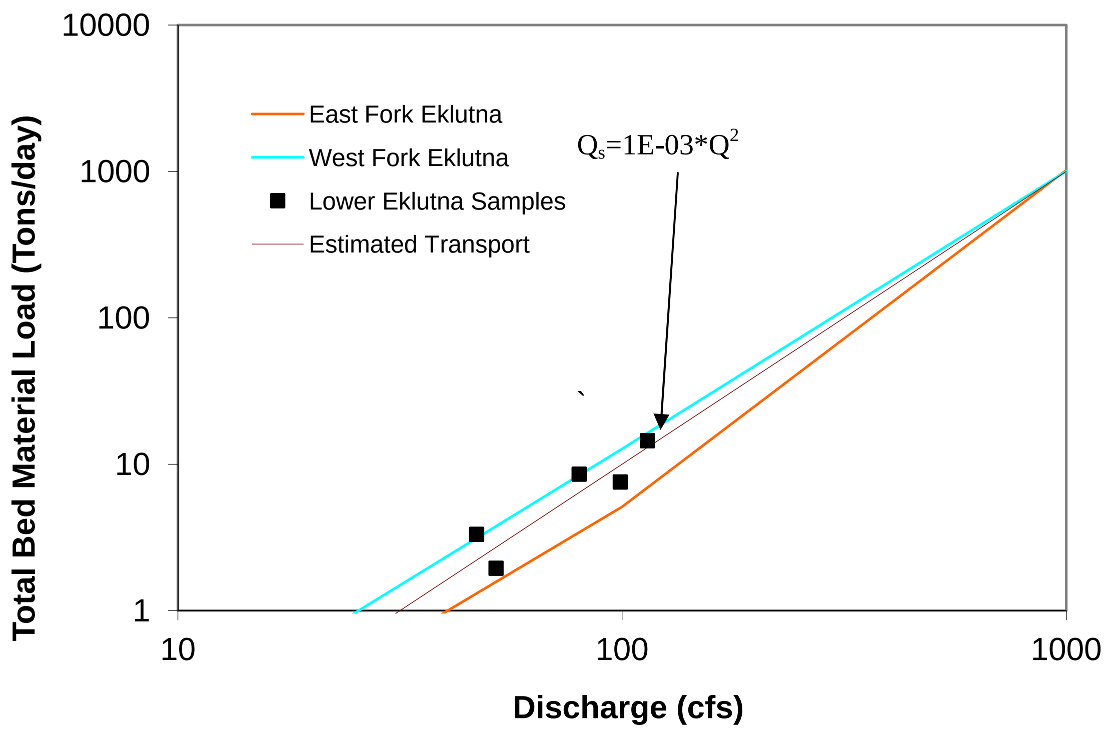

Figure 9 **Bed Material Load and Discharge for the Lower Eklutna River**

A flow duration curve and the bed-material-sediment rating curve were integrated to produce a sediment load histogram that displays sediment load as a function of discharge for the period of record. This histogram peaks at 80 cfs which is the calculated effective discharge (Figure 10).

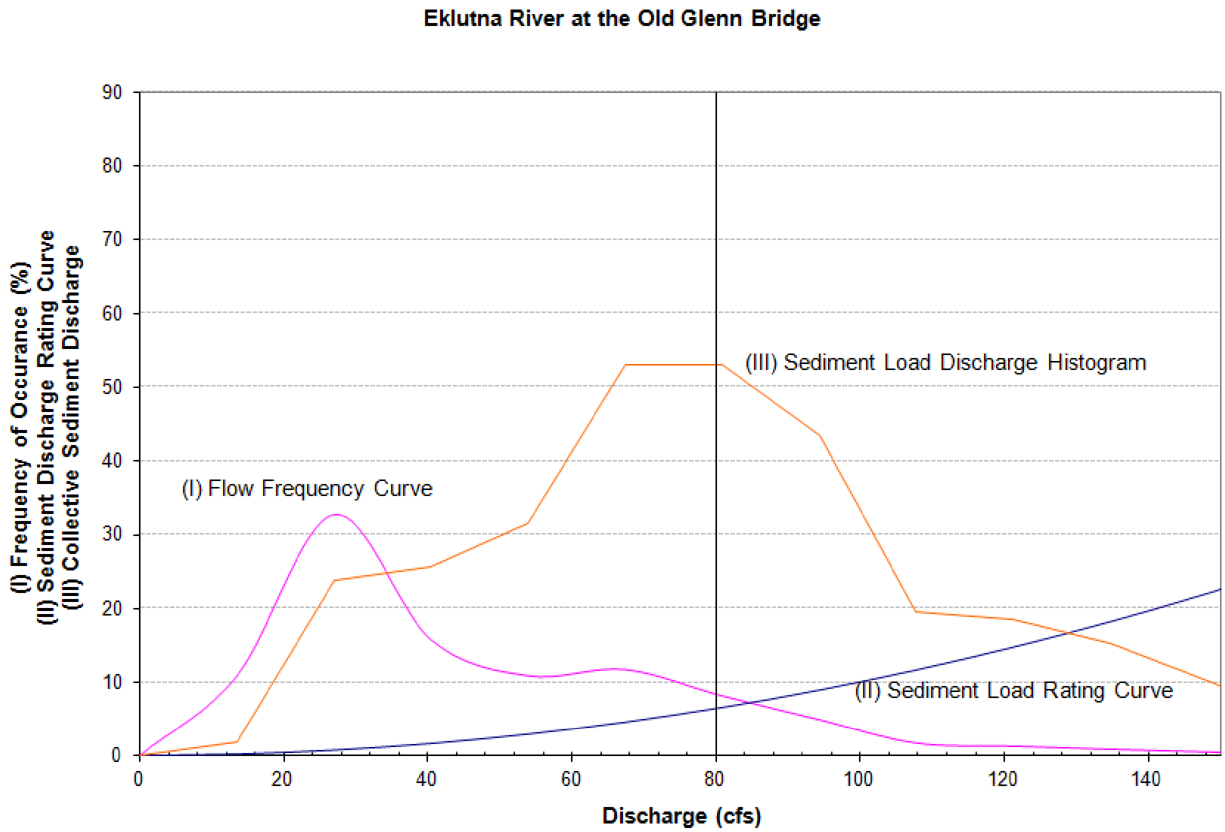

Figure 10 Eklutna River Derivation of Effective Discharge

Natural Bankfull Channel Discharge

In general, bankfull discharge in stable channels is often assumed to correspond to an annual flood recurrence interval of approximately 1 to 2.5 years with the mean typically of 1.5 years. Based on the previous return interval analysis the 1.5 year discharge is approximately 130 cfs.

1.2.4 Hydraulic Analysis of Extreme Flows

A water surface profile for the 100 year without project condition was computed for this study using HEC-RAS version 4.0. HEC-RAS is a one-dimensional modeling system that computes water-surface profiles for gradually varied flow by solving the one-dimensional energy equation and for rapidly varied flow by solving the momentum equation. The water surface profile was calculated for steady flow conditions. Input parameters for the streadyflow analysis in HEC-RAS include geometric and elevation data for the channel and bridges and roughness coefficients for channel and overbank areas.

The results of the 100-year, without project condition, water surface profile averaged 3 feet depths in the main channel, with varying depths in the over-bank channels. Without project condition, the floodwaters were free to spread out to the extents of the levees, except where flows were restricted through the New Glenn Highway and AKRR bridges. An example of the wide area where floodwaters could collect during a 100-year event is shown in Figure 11.

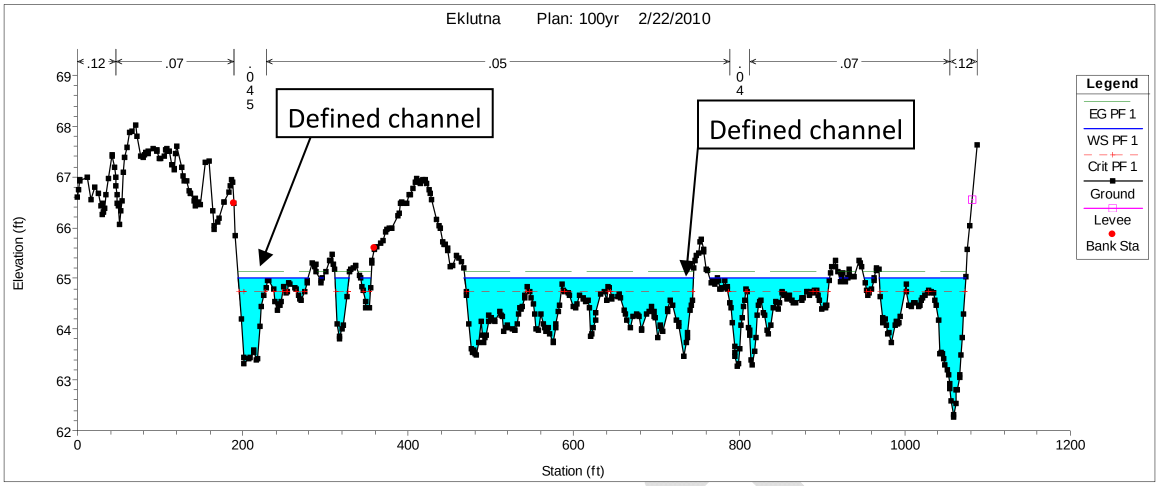

Figure 11 HEC-RAS Cross-Section, between New Glenn Highway and AKRR bridges

2 Geomorphology and Sediment Analysis

2.1 Historical Changes

The Lower Eklutna River has gone through three distinct sediment-discharge regimes in the past 100 years. In addition to changes in the sediment-discharge regime a substantial change in the base elevation occurred below the Alaska Railroad crossing as a result of gravel mining.

Analysis of long-term changes in a river's morphology can be achieved qualitatively with the aid of the relationship proposed by Lane (1995):

$$QS \sim Q_t d_{50}$$

In which:

Q = water discharge

S = energy slope

Q_t = total sediment discharge

d_{50} = median sediment size.

As one or more of these variables change either naturally or artificially the system responds by adjusting one or more of the other variables to seek a new equilibrium.

2.1.1 Before Construction along the Lower River

The first sediment-discharge regime was the natural regime that existed during the early 1900's prior to any construction along the lower river. The Lower Eklutna River had high daily discharges during the summer with high sediment loads resulting in a braided and aggrading lower river. This flow regime was responsible for the formation of the alluvial fan that dominates the lower Eklutna River as it exits the upper canyon. Historical photos show a wide braided river with multiple channels that was aggrading over time. Examination of 1928 As-built drawings of the Alaska Railroad crossing shows that the river aggraded across this crossing between the years 1916 and 1927. During this period the railroad crossing consisted of three 56 feet bridge spans. In 1927 these three spans were replaced with a single 80 feet span. The stream bed material on this drawing was described as 'glacial boulders and loose material in layers.' The deposition of sediment can be explained by Lane's relationship above, as the river slope decreases on the left side of the equation the total sediment discharge on the right side decreases in response. As the river exited the canyon and the slope decreased (left side of equation) sediment was deposited to reduce the right side of Lane's relationship. It is unclear why the new bridge was installed just 11 years after construction of the first three bridges but it was likely in response to the aggrading river. Replacing the three bridge span with a single bridge would decrease the width to depth ratio for this area increasing the amount of sediment that is transported underneath the bridge. The Eklutna River in 1918 (looking downstream from the railroad) is shown in Figure 13. The Eklutna River in 1917 (looking at the railroad crossing before the construction of the 3-span bridge) is shown in Figure 13.

Figure 12 Eklutna River in 1918 after construction of the 3 – span bridge

Figure 13 Eklutna River 1917 (prior to construction of the 3-span bridge**)**

2.1.2 Subsequent to Construction of Lower Dam

The second sediment-discharge regime was subsequent to construction of the Lower Dam on the Eklutna River. The lower dam operated with a pool behind it throughout the year, slowing the water and accumulating sediment throughout the year. It has been reported that it filled up each year with sediment, an approximate volume of 300,000 cubic yards. With the dam in operation the total sediment discharge downstream was significantly reduced. The river responded to a lack of sediment downstream of the lower dam by entraining sediment, resulting in overall degradation below the lower dam. Shallow bedrock from the lower dam to the entrance of the canyon limited the available sediment supply; the first opportunity to entrain sediment was on the alluvial fan upstream of the Railroad tracks. Figure 14 shows a Lidar Survey of the lower Eklutna River (June 2007). Flood containment berms constructed by the Alaska Railroad can be seen on either side of Eklutna River upstream of the railroad crossing. Relic channels can be seen crossing the southern berm. The 60-65' contour band shows obvious degradation of the area between the two berms when compared to the alluvial fan elevations to the North and South of the Flood Containment berms.

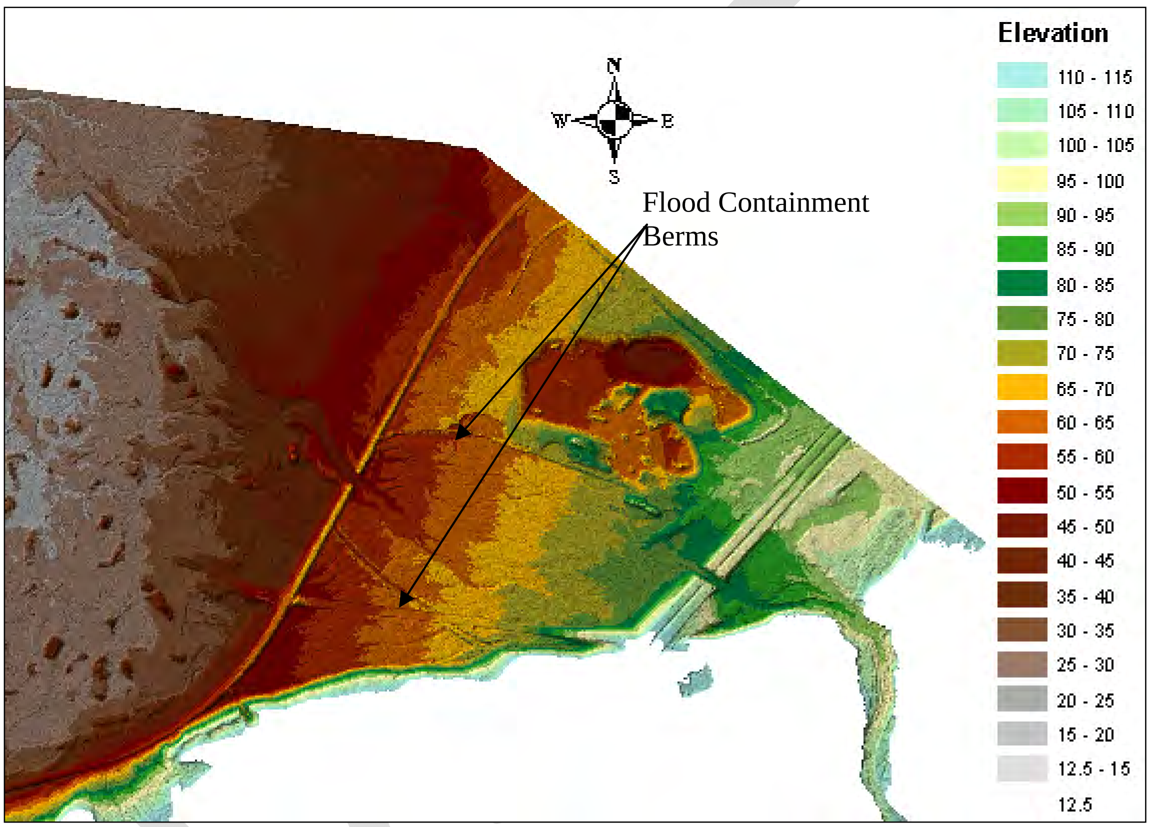

Figure 14 Lower Eklutna River Lidar Image showing original Alaska Railroad Berms

2.1.3 After the Upper Dam put into Service

The third and current sediment discharge regime began in 1955 when the dam at Eklutna Lake went into operation. This dam effectively eliminates discharge from the lake in all but extreme events, reducing the average annual discharge in the lower Eklutna River by 90%, with a corresponding reduction in total sediment discharge. The current relationship between slope, discharge, sediment discharge and median grain diameter is significantly different than the undisturbed Eklutna River. Given this altered condition any restoration measures need to bring the lower Eklutna River closer conditions that would exist in an undisturbed river with similar river morphology. Key differences between the geomorphology of the today and the historic undisturbed lower Eklutna River are summarized in Table 6.

Table 6 Geomorphic comparison of the lower Eklutna River

Geomorphic Characterization	Original Eklutna River	Current 'Stable' Eklutna River

Channel Pattern	Multiple Thread	Single Thread
Sinuosity	Very Low	Moderate (> 1.2)
Channel Material	Cobbles with Boulders	Gravel with cobbles
Width/Depth Ratio	Very High	Moderate
Stream Type (Rosgen)	D3 – Debris Fan	C3

Investigations by Leopold and Wolman (1957) showed that the relationships between discharge and channel slope can define thresholds for indicating which rivers tend to be braided or meandering, as shown in Figure 15. Rivers that are near the threshold line may exhibit segments that transitions between the two platforms. Changes in discharge along the lower Eklutna River have changed the regime from a braided system towards more of a meandering system.

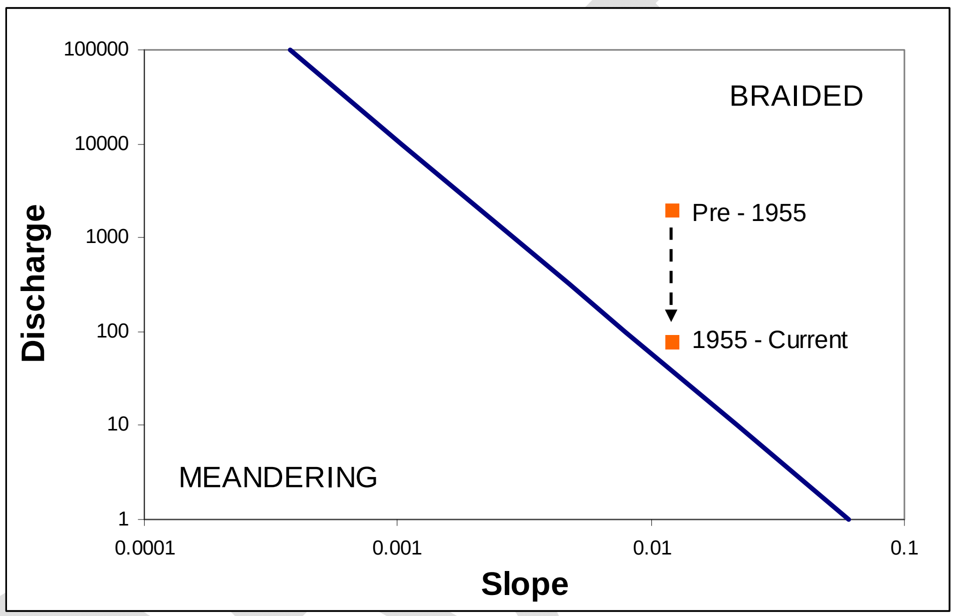

Figure 15 Leopold and Wolman's (1957) Relationship Between Channel Patterns.

In addition to changes in sediment and discharge relationship, the Lower Eklutna River has undergone a significant base elevation change due to mining of gravel below the Alaska Railroad tracks. Examination of aerial photographs and Lidar data show that the perched diversion channel, as seen in 1975 aerial photographs (Figure 16), constructed during active gravel mining dramatically changed course during a fall 1995 flood event. The area outlined in red is highlights an area of significant change in the lower river as a result of this flood event. Eroding into the area actively mined which lowered the thalweg downstream of the Alaska Railroad by an estimated five feet.

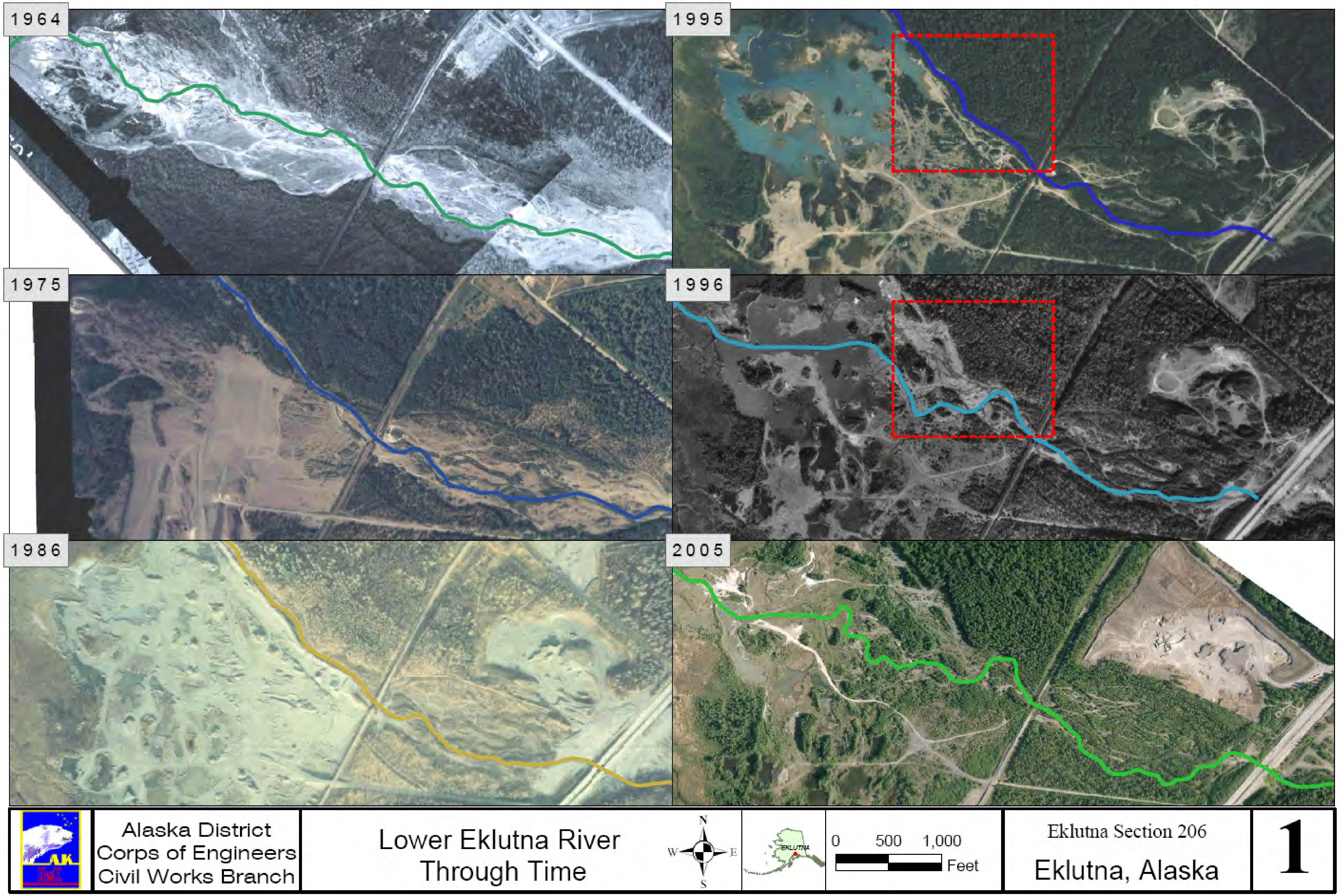

Figure 16 **Eklutna River through Time**

2.2 Sediment Distribution

A sediment investigation was conducted in May 2004 to characterize the material present in the Eklutna River channel bottom. Samples were collected at several cross-section locations above the Old Glenn Highway, above and below the New Glenn Highway and below the AKRR crossing. The sieve analyses resulted in the distribution shown in Figure 17.

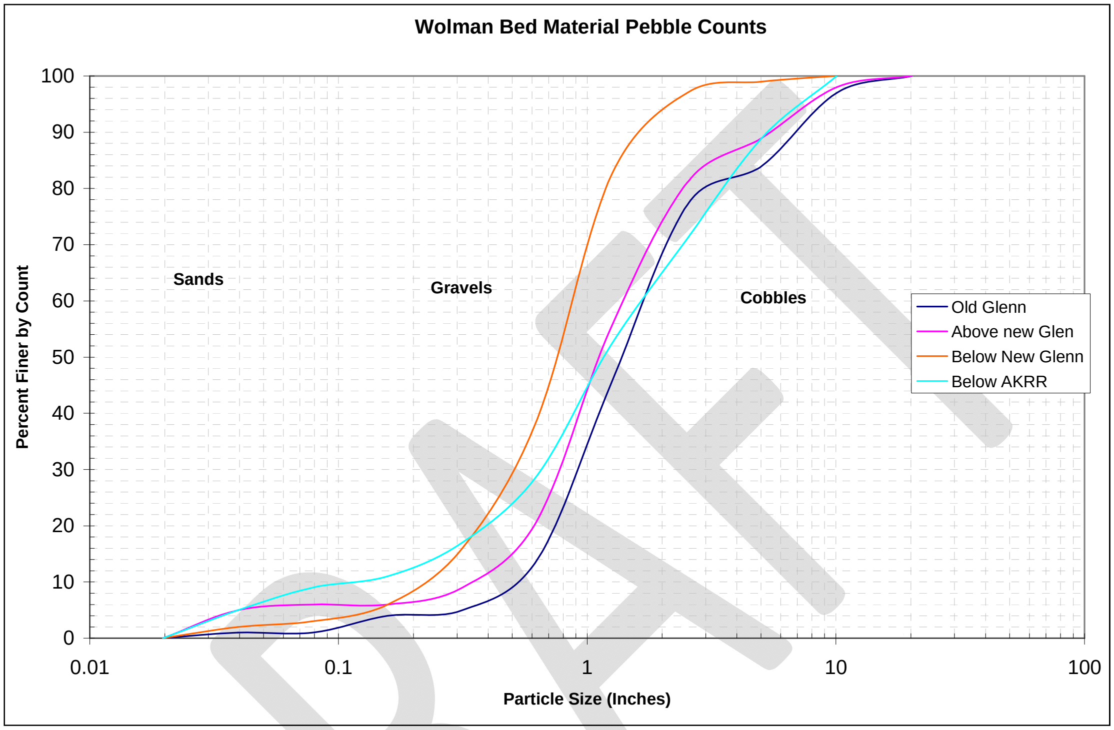

Figure 17 Wolman Bed Material Pebble Counts

The stream bed sediment distribution, using the percent finer by count, was determined from the Wolman chart and is summarized in Table 7. The D_{84}, D_{50} and D_{16} values represent the grain size where 84, 50 and 16 percent of the sample (by weight) passes the given size classes. As expected, the distribution of material is mostly gravels and cobbles.

Table 7 Sediment Distribution

Location	D_{84}	D_{50}	D_{16}
Above Old Glenn Highway	5.0	1.5	0.7
Above New Glenn Highway	3.0	1.2	0.5
Below New Glenn Highway	1.2	0.7	0.3
Below AKRR Crossing	4.0	1.2	0.3

2.3 Riverbed Slope

The Eklutna River slope averages 0.015 feet per foot upstream of the New Glenn Highway and downstream of the AKRR bridge crossings. A significant flattening of the river slope occurs between the New Glenn Highway and AKRR bridges (see Figure 18).

Braided rivers have a complex, transient morphology characterized by flows that diverge and converge around major assemblages of emergent bars and vegetated islands. The splitting and re-joining of flow paths around channel deposits results in a very dynamic rate of channel activity relative to other types of channels. As a consequence, bar migration, avulsions, and abandonment can all occur within a single flood event and, on small braided channels, significant channel change has been observed daily (Goff and Ashmore, 1994; Lane et al., 1995). Observed changes are also episodic, even at constant discharge, as sediment is delivered downstream in pulses (Nicholas et al., 1995). Refer to Figure 16 for Eklutna River changes through time.

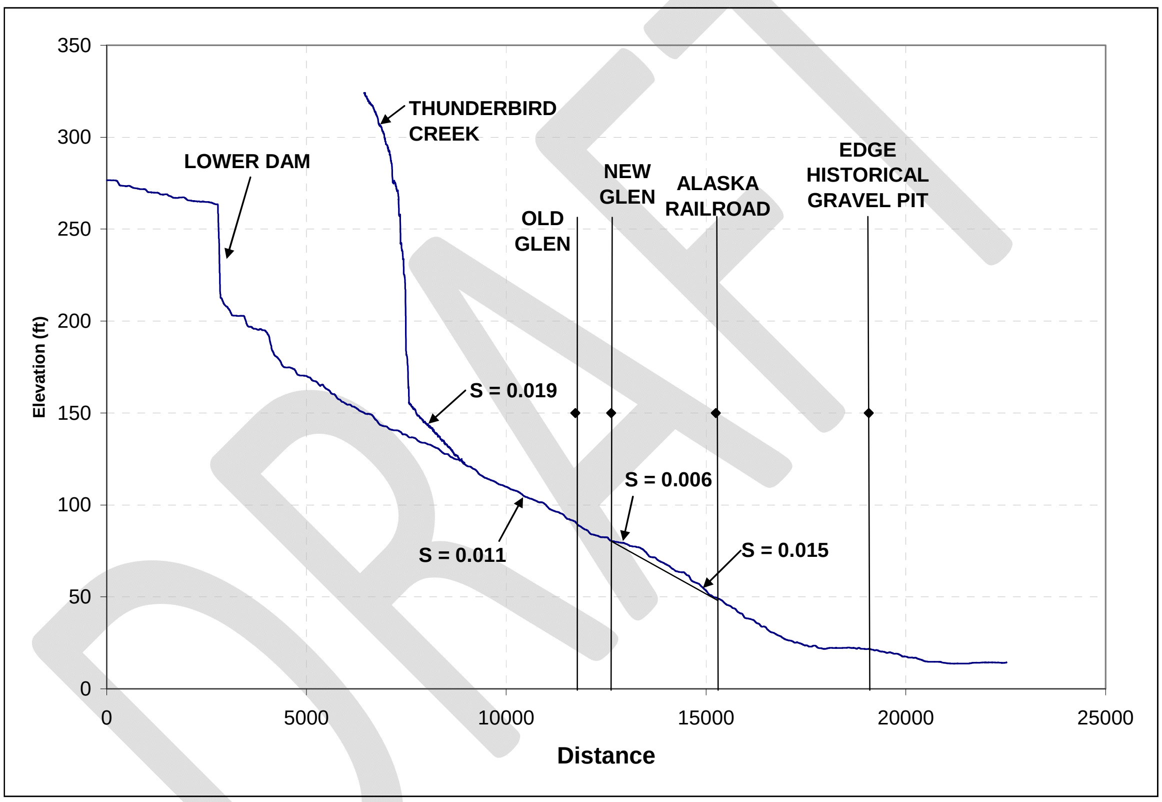

Figure 18 **Eklutna River Slope Profile**

Flows at most times of the year are not strong enough to move the large gravel sediment throughout the system or to flush the silt out of the bed material. Silt is trapped behind the lower dam and ….

2.4 Aufeis Conditions

Aufeis forms by upwelling of river water behind ground water discharge. As the winter progresses, the normal river ice cover thickens and approaches the river bed in shallow reaches. The possible paths of icing feed water that cause the aufeis at the AKRR crossing are shown in Figure 19 (CRREL, Carey, 1973).

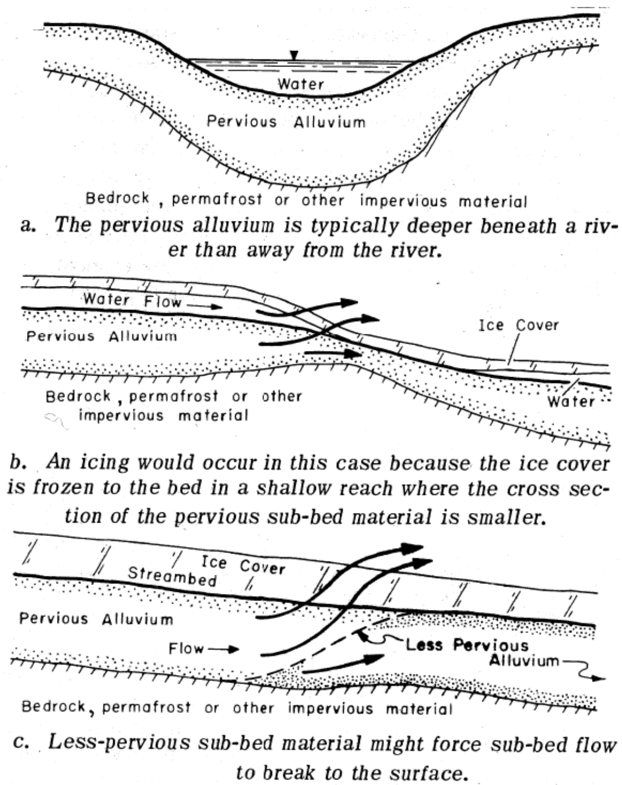

Figure 19 Possible Paths of Icing Feed Water

In the case of the Ekluna River, the aufeis and normal river ice disconnects the river upstream from the AKRR with the river below the AKRR. Very few areas of open water exist during the winter with a majority of the stream channel frozen completely to the ground. An example of aufeis upstream of the AKRR crossing is shown in Figure 20. It is unlikely that these conditions could be altered to provide connectivity between the areas above and below the AKRR crossing.

Figure 20 Aufeis upstream from Alaska Railroad Crossing

3 Suitability for Habitat Enhancement Project

The suitability of the Eklutna River for a habitat enhancement project may be determined by discussing five key responses to imposed change. Those responses include sensitivity to disturbance, recovery potential, sediment supply, streambank erosion potential, and vegetation controlling influence. The Eklutna River can be categorized with three different stream types based on the reach location. A summary of the stream types is presented in Table 8.

Table 8 Eklutna River under Project Conditions

Reach	Stream Type[1]	Sensitivity to Disturbance	Recovery Potential	Sediment Supply	Streambank erosion potential	Vegetation controlling influence
Upstream New Glenn bridge	C4	Very high	Good	High	Very high	Very high
Between AKRR & New Glenn bridges	D4	Very high	Poor	Very high	Very high	Moderate
Downstream AKRR bridge	C3	Moderate	Good	Moderate	Moderate	Very high
[1] Rosgen, 1994						

The reaches upstream of the New Glenn bridge and downstream of the AKKRR bridge may be improved by the addition carefully located measures (i.e, large woody debris, boulder clusters, and cross-vanes) that would be used to create a riparian corridor. The reach between the AKRR and New Glenn bridge crossings is in the poorest condition. The addition of a riparian corridor would be of some help, but would be most effective after stabilizing the channel.

4 Discarded Measures

4.1 Off Channel Overwinter Pools

Off-channel spawning and rearing areas are intended to provide winter and summer refuge for juvenile fish. Three typical types of habitat within a river floodplain are overflow channels, percolation-fed channels and wall-based channels (P.N. Peterson and L.M. Reid). Overflow channels are very active and prone to frequent flooding. Percolation channels are protected somewhat from flood flows and have the benefit of providing winter and summer refuge for juvenile fish. Wall-based channels sit high on the floodplain and are protected from flood flows and are mainly developed for overwintering habitat. Overflow channels are flood swales that are directly connected to main river channel during high flows. Periodic floods through these channels can help maintain their productivity. Percolation-fed channels are supplied by water that percolates as groundwater from the river.

Off channel overwinter pools were initially considered downstream of the Alaska Railroad considered but eliminated from consideration based on several geomorphic aspects of the system. The three primary challenges for artificially created overwinter ponds downstream of the Alaska Railroad are:

- Lack of surface water during the winter months. Several field investigations during the winter months have failed to detect significant winter flows downstream of the Alaska Railroad crossing. Extensive aufeis formation upstream of the railroad also indicates that little or no surface water passes through the Alaska Railroad Bridge during the winter months (see Figure 20).

- Monitoring wells installed in this area indicate that the Stream is perched just below the Railroad Crossing until the stream reaches the area of tidal influence.
- Dissolved oxygen is adequate during the summer months in the five wells installed; however the wells in areas where ground water could be a potential source of dissolved oxygen have not been sampled during the critical winter months. The general trend showed a higher dissolved oxygen levels in summer that decrease in the fall.

This lower section of Eklutna River is the depositional zone that is characterized by continuous channel migration as the river aggrades over time. A surface hydrologic connection from off channel overwintering ponds to the main stream channel would be difficult to maintain as the channel constantly shifts in response to deposition of sediment.

One site upstream of the New Glenn Highway has been identified as one location for an off-channel overwintering pool. The Eklutna channel is stable in this area increasing the chances of success. The off channel pool would be on the order of 3000 sq feet and excavated so that during low flow conditions the pools are approximately six feet deep. A channel on the downstream end of the pool would connect to the River and provide for fish passage into the off channel pool.

4.2 Large in-line Overwinter Pond

One measure considered was a large in-line overwinter pond between the New Glenn Highway and the Alaska Railroad Crossing. This measure was eliminated due to possible adverse impacts downstream from the large pond. A large in-line pond would be an effective sediment trap, altering the natural discharge-sediment transport regime downstream of the pond and would likely lead to a degradation of spawning habitat, possible degradation of the stream channel. Spawning gravels in streams are typically mobilized every two to four years. As gravels are mobilized downstream from the in-line pond there will be a lack of gravel to replenish these areas.

5 Habitat Enhancement Measures

5.1 Large Woody Debris

The POWTEC assessment of Eklutna River described the section of river below the Alaska Railroad tracks as areas that are suitable for spawning improvements. Large woody debris (LWD) is proposed along an approximately 1000’ length of stream to facilitate the development of small pools and increase the overall instream shelter available in this section of the river. Gravel mining removed all of the trees that would have been natural feeder sources for LWD. In order to minimize disturbance in this section pieces of Large Woody Debris would be placed unanchored on the stream banks and extending into the natural channel. Similar river restoration projects have targeted a value of 60 pieces of LWD per 1000’ of stream channel (Resurrection River, 2006). A British Columbia study reported that a healthy stream should have greater than 3 pieces of LWD per channel segment equal to the bank full channel width for 2nd and 3rd order streams. This equats approximately 85 pieces of LWD per 1000 ft of stream channel for the lower Eklutna River (assuming a bank full width of 35 feet). The value of additional large woody debris has been demonstrated by a stream condition survey along Chester Creek showing a positive correlation between captured salmonids and a Large Woody Debris Index value measured for each 100 m sampled reach (Figure 21). Pieces of large woody debris measured along Chester creek ranged from a low of 6 pieces to a high of 81 pieces per 1000 ft. The target value for the lower Eklutna River will be 80 pieces per 1000 ft.

The stream length downstream from the railroad bridge that could benefit from additional LWD is 2500 ft; therefore a total of 200 pieces of Large Woody Debris would be placed. Each piece of

LWD will measure a minimum of 12 inches in diameter with a length of at least forty five feet. The pieces would be placed throughout this reach in areas that are easily accessible with a large concentration of LWD being placed towards the upstream end of this reach. The LWD would also be placed strategically to deter ORV traffic from crossing and travelling adjacent to the lower Eklutna River. It is expected that some redistribution of the LWD would occur during the next out of bank flood along this reach. Several studies have shown that properly sized LWD will likely remained in place or only move slightly with a majority of the placed LWD remaining within the designated reach.

LWD along the lower Eklutna river would be placed along the banks in this section. To minimize disruption to the existing stream bank the LWD will not be keyed into the stream bank. These structures will act as small deflectors creating small pools of backwater that can also provide fish resting areas. They will also provide additional submerge shelter. In addition to LWD placed in the active, LWD will be place outside of the active channel as part of the riparian corridor enhancement in areas where the stream is likely to migrate. These clusters of LWD will serve two purposes the first will be as a future source of wood debris, feeding the stream as each cluster is encroached upon. The second purpose of these off channel LWD clusters will be to prevent or direct off road vehicle use away from the stream. An estimated 100 additional pieces of large woody debris will be placed outside of the active channel.

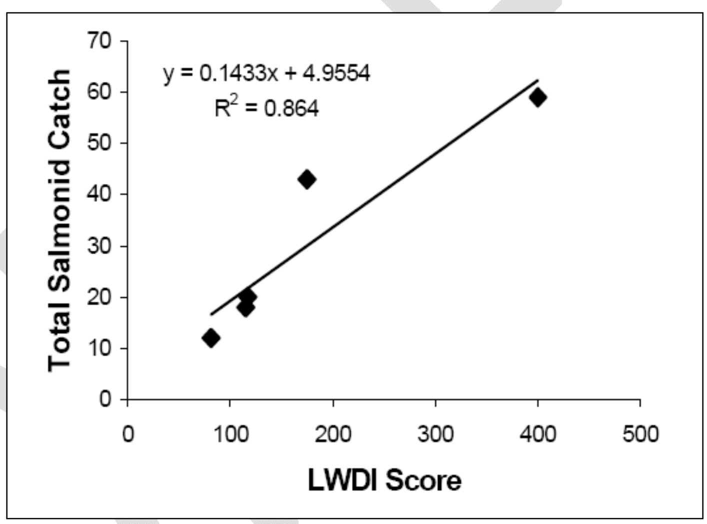

Figure 21 LWDI vs. Salmonid Catch (Davis and Muhlberg, 2001)

5.2 Boulder Clusters

In addition to the placement of LWD below the Alaska Railroad tracks boulders will be placed in a cluster just downstream of the bridge in a section that provides easy construction access. Boulders and boulder clusters are a very common method of fish habitat improvement to provide instream cover, resting areas and small scour pools. The small pools are created by the increased water velocities around the boulders.

5.3 Cross-Vane

The cross vane structure is designed to create instream holding water, increase the stream depth by decreasing the width to depth ratio, increase or maintain sediment transport capacity and provide a natural sorting of gravel in the upwelling downstream of the structure. The POWTEC report identifies a long stretch of river with a small amount of holding area between the New Glenn Highway and the confluence of Thunderbird Creek and Eklutna River. A series of Cross-

Vanes are proposed for this lower section between the New Glenn Highway and the mouth of Eklutna Canyon. These structures will consist of a bolder weir that is shaped like a 'V' with the point oriented in the upstream direction. As water flows downriver and over the structure it is re-directed towards the centerline of the river creating a deeper scour pool in the center with holding areas towards the stream banks. The series of cross veins will be spaced at a typical naturally occurring interval of five to seven bankfull widths.

5.4 Riparian Corridor

This measure will consist of identifying a riparian corridor for the lower Eklutna River. It will be up to the landowner to strictly enforce an off road free buffer on either side of the River in this section. Since the construction of the Upper Dam and reduction in discharge through this section of the river vegetation has taken root within the riparian zone of this stream, but so has off road vehicle traffic. Reducing and or eliminating off road vehicle traffic that crosses and runs adjacent to the river will allow vegetation to continue to grow. This provides valuable cover and in the future will be a source for naturally occurring wooding debris in this lower section of river. As part of the Riparian corridor a low water crossing has been designed and should be installed at a location that meets both the user's requirements and has adequate real estate right of way. The low water crossing will concentrate streams crossing to a single location that is hardened to prevent bank erosion. This low water crossing will consist of a geo-cell structure backfilled with cobble size material. The upstream and downstream edges of the crossing will be armored with large stone keyed into the stream bed.

5.5 Constructed Stream Channel

A stream channel may be constructed between the New Glenn Highway and the AKRR bridge crossings. This new stream channel will allow for a deeper bankfull average depth and provide a single channel for flows. The proposed stream characteristics are presented in Table 9.

Table 9 Constructed Stream Channel Characteristics

New Glenn Highway to AKRR Bridge		
	Existing	Proposed
Effective Discharge	80 cfs	
Valley Length	2130 feet	
Valley Slope	0.0145 ft/ft	
Valley Width	800 ft	
Elevation Drop	30.85 ft	
Channel Length	2550 ft	2380 ft
Channel Type	Braided	Single
Channel Slope	0.007 – 0.013	0.012
Rosgen Channel Type	D-4	C-4
Bankfull Width Avg	40 ft ++	30 ft
Bankfull Ave. Depth	1.0	1.5
Sinuosity	1.20	1.12
Entrenchment Ratio	20	27
D50 & Ds50	0.75	
Avg. Bed Shear Stress		
Critical Dimensionless Shear Stress	0.0586[1]	

[1]Andrews, Rosgen and Leopold et al. 1983

A proposed alignment for the constructed stream channel is shown in Figure 22. This alignment will provide stability for the channel as flows pass between the New Glenn Highway and the AKRR crossing.

Approximately 588 cubic yards of existing material will be excavated along the alignment and 60 cubic yards of fill material would be added to create the stream channel. A typical constructed stream channel cross section is shown in Figure 23.

Figure 22 Constructed Stream Channel Alignment

AutoCAD ones?

Figure 23 Typical Constructed Stream Cross Section

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