Memorandum

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TO: Mark Wilgus, Jeff Burkey, Curt Crawford, Dale Nelson
COMPANY/AGENCY: King County Water and Land Resources Division
FROM: Peter Brooks and David Hartley
SUBJECT: Juanita Creek- Relationship of Roughness, Gravel Size, and Disturbance Flows

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Introduction

A combination of data obtained from field measurements, hydraulic model computations, and the literature were utilized to develop gravel disturbance metrics on Juanita Creek. These metrics include selection of an appropriate Shield's parameter to predict incipient motion of gravel material, estimation of the threshold discharge (Q_c) at which existing and proposed median grain size (D_{50}) will mobilize, and the development of an approximate relationship between Q_c and Manning's n values. These metrics were evaluated at Sites 107, 105, 203 that represent lower, mid, and upper Juanita Creek, respectively.

Shield's Parameter

Incipient particle motion was evaluated using a standard Shield's analysis that relies on the selection of Shield's parameter (τ^*_c). Shield's parameters are commonly cited as ranging from 0.045 to as low as 0.03 for engineering applications (USACE, 1995), but wider variations have been observed in natural settings (Buffington and Montgomery, 1997). Wilcock et al (2009) suggest the influence of sand on the surface can reduce standard values by a factor of four, resulting in enhanced gravel transport for a given discharge.

Findings obtained from field measurements, including pebble counts and bedload sampling conducted on Juanita Creek, are inconclusive but do suggest that the results of Wilcock et al (2009) are valid to some degree.

As such NHC employed a methodology for selecting the Shield's parameter based on conditions observed in the reach of interest. If the sand component observed in the bed was less than approximately 10%, a standard Shield's parameter of 0.045 was implemented. If the surface sand content was observed to be greater than 10% a "modified Wilcock" value of 0.0225, or half the standard value, was selected as the Shield's parameter. Here, a factor four reduction was deemed too drastic considering the inherent uncertainties associated with computations as well as measurements.

Shear Partioning

NHC partitioned the bed shear stress into two components, total shear stress (τ_t) and grain shear stress (τ_g), and then derived the following relation:

$$\frac{\tau_g}{\tau_t} \propto \frac{f_g}{f_t} \qquad (1)$$

Here, f_g and f_t are the Darcy friction factors associated with grain and total roughness, respectively. Grain roughness, fg, can be computed using the following empirical relation (Henderson, 1966):

$$f_g = 0.113\left(\frac{D_{84}}{R}\right)^{\frac{1}{3}} \qquad (2)$$

In this relation R is the hydraulic radius of the channel (in feet) and D_{84} is the particle diameter (in feet) that exceeds 84 percent of the particles sampled. Combining the Manning's and Darcy equations, total roughness, f_t, can be computed using the following equation:

$$f_t = 8g\left(\frac{n_t}{1.49R^{\frac{1}{6}}}\right)^2 \qquad (3)$$

Here, g is gravitational acceleration and n_t is the total Manning's roughness value, i.e. the value used to represent channel roughness in the HEC-RAS model. Relations 1-3 allow for the estimation of bed shear stress associated with incipient motion, τ_g, using results computed by HEC-RAS, i.e. τ_t, and sediment characteristics of the respective study reach.

Gravel Disturbance Metrics

From a simplified hydraulic standpoint, there are effectively two possible ways to reduce the disturbance frequency of a given gravel size in a stream channel: 1) increase the overall roughness of the channel, i.e. the *total* Manning's roughness (n_T); or 2) coarsening of the gravel bed, i.e. increase the effective D_{50} particle size.

Figures 1-3 illustrate the impacts varying the total Manning's roughness coefficient, along each reach, on computed grains shear stress (τ_g) over a range of discharges. Threshold shear stress (τ_c) computed for several grain sizes of interest, including existing condition D_{50} values at each reach, as well as those observed as suitable spawning gravels for Coho salmon, are plotted for reference. Kondolf and Wolman (1993) report Coho spawning grain size data from 11 different sites. A median spawning gravel size of 16.5 mm was measured, with lower and upper quartiles of 11 and 31 mm, respectively.

Lower Juanita Creek (Site 107)

- Existing total Manning's roughness values, n_T, on lower Juanita Creek likely range between 0.035 and 0.040.
- Existing D_{50} particle sizes are relatively small (11.7 mm)
- Based on observed surface sand content incipient motion was assumed to be reduced, i.e. a 'modified Wilcock' values for the Shield's stress (τ^*_c) for this reach was set to 0.023.
- Backwater influences created by the Juanita Creek Drive culvert reduced the computed bed shear stress at discharges exceeding the 1.01 to 1.25-year frequencies, thus the range discharges exceeding this level are not plotted on Figure 1.

The two upper τ_g profiles in Figure 1, computed for likely existing n_T values of 0.035 and 0.040, lie well above the existing particle τ_c threshold (0.09 psf), thus illustrating the likely mobility of these particles during low-frequency events (less than 50% of the 1.01-year flow, 56 cfs). Note: At the lowest discharge evaluated (10% of the 2-year flow, 21) HEC-RAS defaulted to critical depth for the 0.040 τ_g profile at one of the cross-sections evaluated and resulted in computation of an excessively high, and likely unrepresentative, τ_g value. As such, the data point on Figure 1 was omitted.

Incremental increases to the total channel roughness (n_T) results in a decrease of the τ_g profiles, but the existing D_{50} particle is still computed as being mobile up to an n_T of approximately 0.048.

When values of total channel roughness (n_T) begin to exceed 0.048, the threshold discharge to initiate motion begins to increase. For example, the existing D_{50} particle is mobilized at the 1.01-year flow (112 cfs) for an n_T value of approximately 0.054.

Increasing the total channel roughness also increases the influence of the backwater at lower discharges, thus resulting in a decrease of particle mobility. For an n_T value of 0.060, at no discharge will the existing D_{50} be computed as mobile. In other words, backwater conditions are compounded by friction losses within the channel and essentially 'choke' the channel. Under such conditions sediment aggradation could be expected, as well as potentially negative flood impacts.

An increase in threshold discharge (Q_c) can also be achieved by coarsening the channel bed. Were the median particle diameter of the bed material be increased from the existing D_{50} value of 11.7 mm to approximately 27 mm, the Qc could increase to just less than the 1.01-year flow (112 cfs).

Manipulation of both channel roughness and surface grain size distribution may be a suitable option to reduce disturbance frequency. Figure 1 indicates a modest increase in total channel roughness from the existing value of approximately 0.035-0.040 to 0.045, combined with coarsening of the surface grain size distribution to achieve a D_{50} of 14-18 mm would increase the threshold discharge from a negligibly small value to approximately the 1.01-year flow. This may be a suitable option if excessive roughening of the channel becomes a concern with regards to flooding. From a spawning gravel standpoint the current D_{50} value of 11.7 mm does fall within the range observed for Coho salmon, but on the lower end. Increasing this value slightly through selective gravel augmentation may yield benefits to in-stream habitat.

Middle Juanita Creek (Site 105)

- Existing total Manning's roughness values, n_T, on middle Juanita Creek likely range between 0.036 and 0.040.
- Existing D_{50} particle sizes are relatively large (39.5 mm)
- Based on limited observed surface sand content, the Shields parameter for incipient motion was assumed to be standard value of 0.045.
- Backwater influences do not exist at this site (at least in HEC-RAS model)

The grain shear stress (τ_g) profiles in Figure 2 resemble those expected in a reach without backwater influences, i.e. the computed value of τ_g increases with discharge.

The two upper τ_g profiles in Figure 2, computed for likely existing n_T values of 0.036 and 0.040, indicated the threshold discharge for existing conditions at Site 105 is approximately a 100-year flow (290 cfs).

The surface substrate at Site 105 is armored with generally coarse gravel and cobbles and the channel is relatively confined between 3-4 ft high banks. The armored condition at this site implies that this site is supply-limited, but it may be more accurate to characterize it as a transport-reach where material from upstream is transported though with little deposition occurring.

The measured existing D_{50} grain size of 39.5 mm actually exceeds the maximum D_{50} value for Coho spawning of 33 mm, reported by Kondolf and Wolman (1993).

Due to the coarseness of the existing bed material, manipulation of the channel roughness and surface grain size distribution would not result in the benefit of reducing disturbance frequency at this site.

Increasing the channel roughness may actually help capture smaller gravel transported from upstream, and effectively reduce the surface grain size distribution, possibly into the range preferred by Coho.

Upper Juanita Creek (Site 203)

- Existing total Manning's roughness values, n_T, on upper Juanita Creek likely range between 0.035 and 0.040.
- Existing D_{50} particle sizes are relatively small (15.3 mm)
- Based on observed surface sand content, the Shields parameter for incipient motion was assumed to be reduced, i.e. a ' modified Wilcock'. The selected Shield's stress (τ^*_c) for reach was set to 0.023.
- Backwater influences created by the 108th Ave NE culvert reduced the computed bed shear stress at discharges exceeding the 2- to 50-year frequencies, thus the range discharges exceeding this level are not plotted on Figure 3.

The two upper τ_g profiles in Figure 3, computed for likely existing n_T values of 0.035 and 0.040, indicated the threshold discharge for existing conditions at Site 203 is between the 1.01-yr flow (21 cfs) and the 1.25-year flow (36 cfs).

Site hydraulic and sediment transport measurements were collected on March 9, 2011 at Site 203. Measured discharge ranged from approximately 12 to 40 cfs (~ 1.5-yr flow at peak) during the visit. A Manning's n value of 0.036 was calculated from velocity and water surface slope measurements. Gravel particles were collected by the sediment trap with largest being in the 22 mm size class. These measured values agree well with computed values shown in Figure 3.

When the value of total channel roughness (n_T) is 0.050, the threshold discharge to initiate motion increases to approximately the 2-year flow (~48 cfs). At n_T values greater than 0.050 backwater influences, similar to those previously discussed on lower Juanita Creek (Site 107), begin to occur and result in decreased particle mobility.

References

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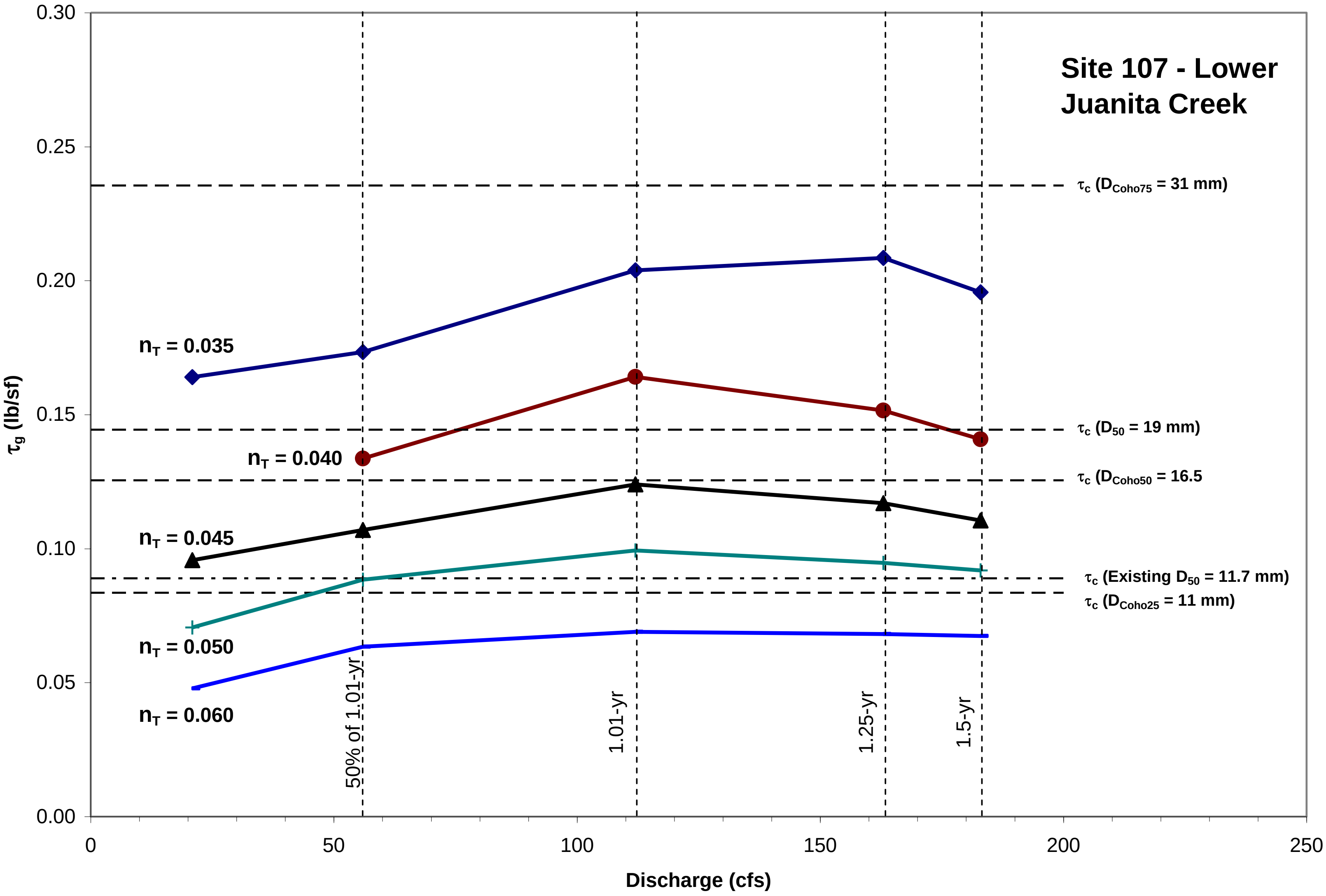

Figure 1. Grain shear stress (τ_g) as a function of discharge for varying values of total channel roughness (n_T) at Site 107, Lower Juanita Creek.

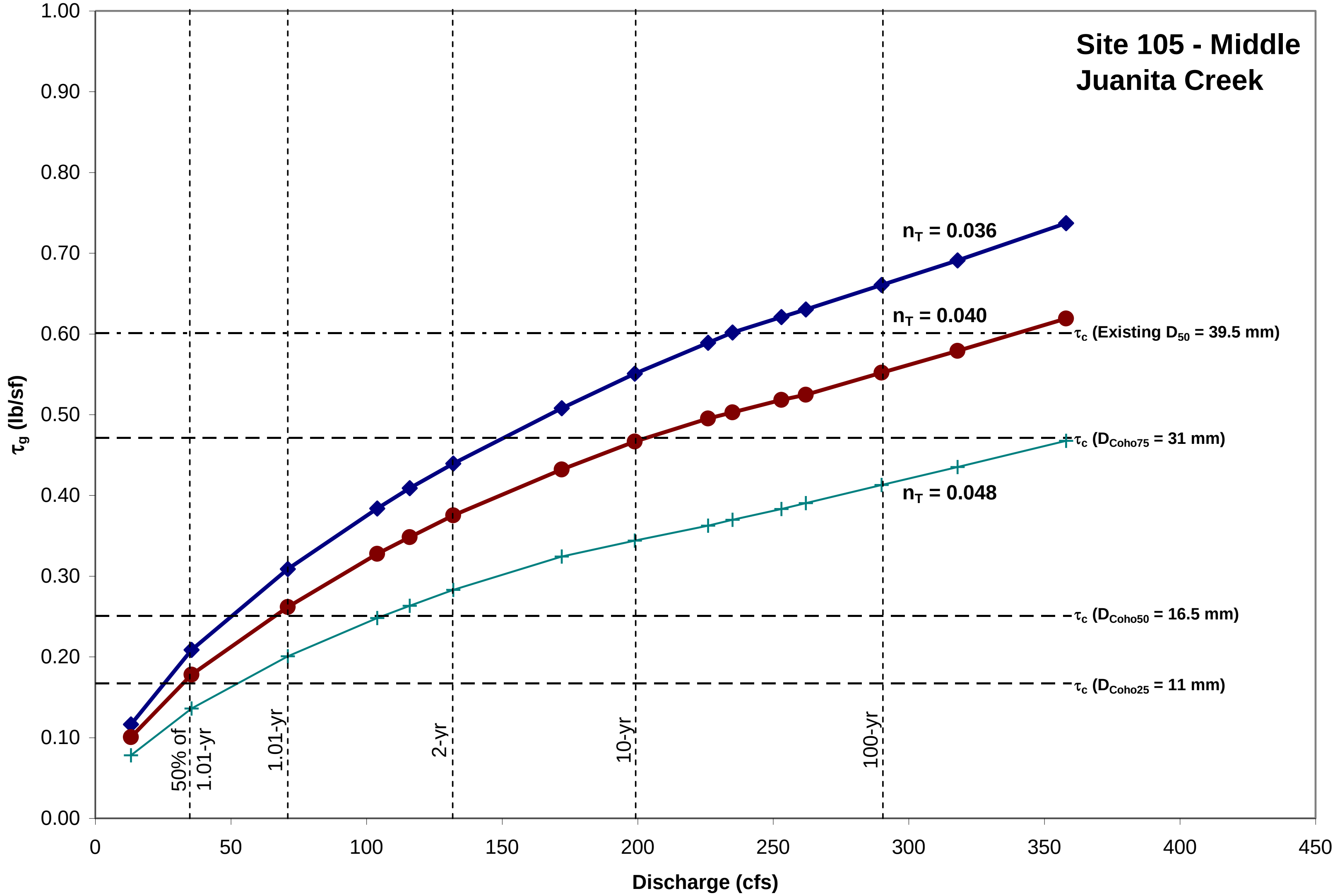

Figure 2. Grain shear stress (τ_g) as a function of discharge for varying values of total channel roughness (n_T) at Site 105, Middle Juanita Creek.

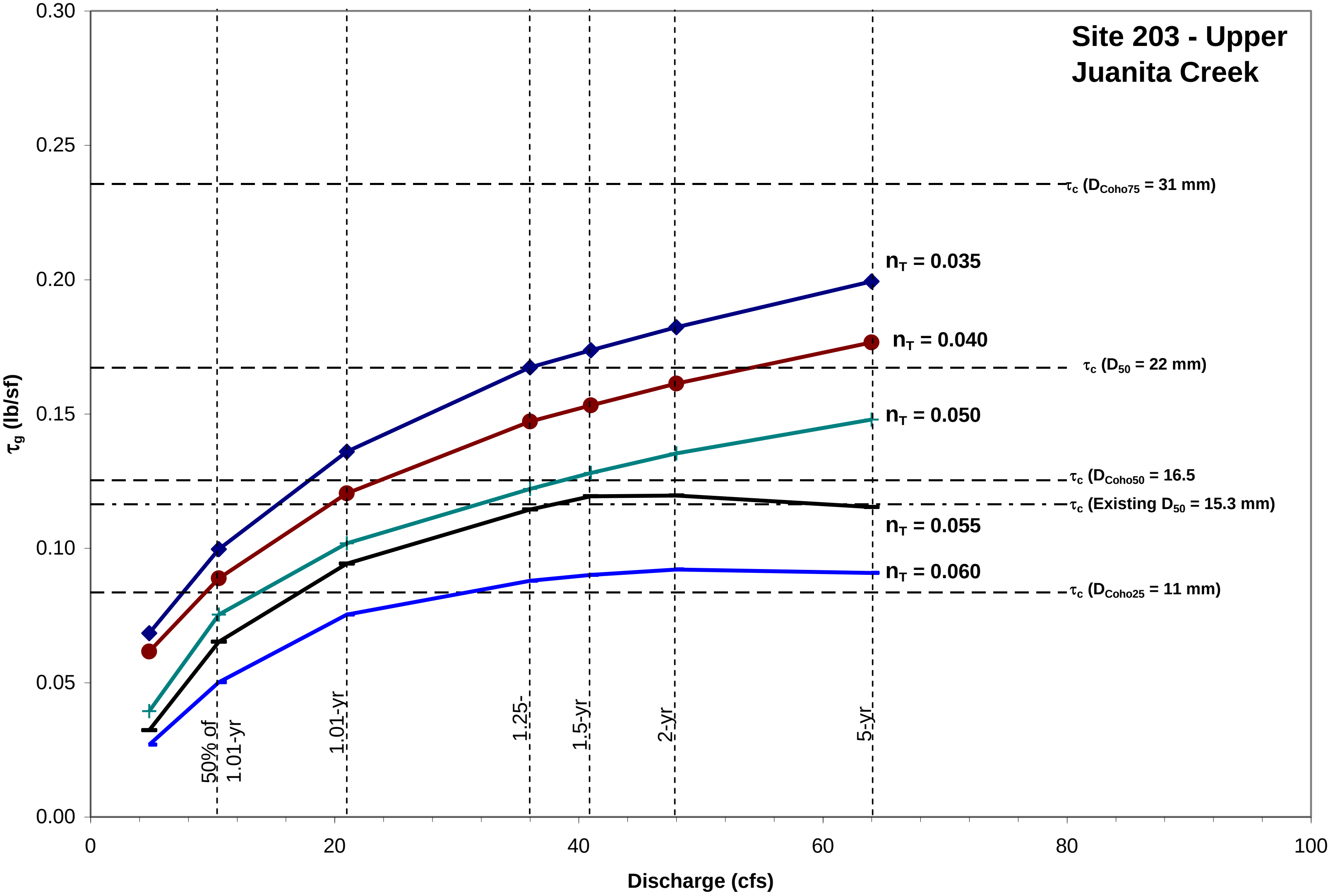

Figure 3. Grain shear stress (τ_g) as a function of discharge for varying values of total channel roughness (n_T) at Site 203, Upper Juanita Creek.