Appendix H
Excess Transport Capacity Analysis

The availability and abundance of gravel or small cobble-sized material in the Tucannon River plays a large role in the geomorphic processes that force bedforms, complexity, and connectivity. Through on-site assessment, it is clear that the reaches with ample gravel to small cobble-sized material, available throughout the reach, form pools at instream wood locations more easily, access the floodplain more frequently, and develop complex side channels and split flows. The individual project area assessments in the assessment show that many of these areas are associated with river avulsions or migrations shortly upstream, providing a potential source of these gravel-sized materials. However, for other reaches, as is often the case with confined and incised systems, the supply of material can become "locked" in the floodplain and is no longer accessed on a regular basis. The materials remaining in the channel bottom often represent lag deposits and collectively form an armor layer that resists pool formation and temporary sediment storage and facilitates high energy flows through the reach. When this happens, a feedback loop of confinement and incision propagates and can extend downstream over time. Without human intervention or a large natural change, such as a large tree falling into the river and capturing additional wood and sediment, the dominant channel bed material becomes resistant to regularly occurring geomorphic change. With less frequent geomorphic change, the floodplain and the smaller material stored therein are accessed and mobilized less frequently, contributing to this feedback loop. The process of confinement often continues until a threshold and possibly catastrophic flow breaks the cycle.

One solution to this cycle is to provide another source of material that is sized to be frequently mobilized. This material can quickly cause localized geomorphic change, which in turn will release material "locked" in the floodplain and jumpstart the process of sediment transport and minor avulsions or migrations. For this reason, gravel augmentation is one of the restoration actions recommended in this assessment. However, to make decisions on the placement and amount of this restoration action, it is important to understand how the transport capacity of a reach might be different from other reaches in the basin. The following Excess Transport Capacity analysis establishes a basin-wide trend in transport capacity based on the modeled shear stress and uses this trend to identify reaches of the basin where shear stress and transport capacity differ from the expectations for the basin. While this method does not determine what the transport capacity of a reach is, it can tell us something about how the reach is different from other similar reaches in this basin, and provide enough clues for better recommendations for gravel augmentation and sediment transport continuity in general.

Analysis Overview

Shear stress has historically been used as a metric for gauging the bedload sediment transport capacity and potential for geomorphic change in a reach. Many commonly used transport models either use shear stress as a direct input or are indirectly related to shear stress (Wilcock 2001). For a full sediment transport model and detailed transport capacity information, the material size for each reach is usually required. Due to the large scale and scope of assessing the entire Tucannon River basin, this analysis does not include sediment size information. However, using shear stress information collected with a HEC-RAS one-dimensional (1D) model, trends and patterns for the basin can be determined and, taken over the whole basin, some information about the trends and patterns of the transport capacity in the basin can be inferred.

Shear stress (measured in pounds per foot*second [lb/ft^2]), is calculated in HEC-RAS as a product of shear stress and velocity and is used as a primary factor in many bedload transport equations (USACE 2016) and was chosen for this assessment as a representation of the bedload transport capacity of a reach. The 2-year event was chosen as the flow used for this analysis because it is the return flow in which geomorphic changes due to restoration efforts in this basin are expected to occur. Based on experience in the Tucannon River basin, this flow is known to mobilize the gravel and small cobbles most relevant to geomorphic change in the basin. Additionally, particular focus was placed on the 2-year flow event because it occurs more frequently than the 5-year flow event, and in reaches with process-based restoration efforts, immediate geomorphic response is desirable. Due to the selection of this flow for this model, it was necessary to use the results of the 1D HEC-RAS model for this analysis.

For this method, shear stress is defined as a product of friction slope and hydraulic radius and the unit weight of water. HEC-RAS directly outputs the variable shear stress in the form of two variables: total shear stress and channel shear stress. This analysis and the associated prioritization focus on channel shear stress, which gives a better indication of the bedload transport capacity than total shear stress because vegetation and largely ineffective flow prevent most bedload transport on the floodplain.

Examining shear stress at a single cross section can display some statistical noise because the exact location of the cross sections may not fully capture the slope and confinement of the channel. Additionally, the shear stress at a single cross section represents only the channel configuration at that exact location and may vary quite a bit over the length of a project area. Because the distances between cross sections is not constant, a length-weighted averaging method was required to determine a single shear stress value for each project area. This shear stress value will be referred to as the modeled shear stress for the purposes of this analysis.

These modeled shear stress values are only rough indicators of sediment transport, and these values only become useful when used to examine how they compare to large basin-wide trends. One of the primary factors that contributes to a reach naturally having higher transport capacity is the average energy slope. Reaches that are steeper, such as those generally seen in the upper portions of the basin, will naturally have more capacity for sediment transport regardless of external factors. Energy grade elevation is a HEC-RAS output that can be calculated for every cross section. The average grade slope was calculated for each project area, accounting for each cross section in a similar averaging method used for the modeled shear stress. The detailed mechanisms of the shear stress averaging calculation are discussed in more detail in the Detailed Instructions for Performing this Analysis section below.

The regression equation shown in Equation H-1 was developed to describe the relationship of the energy grade slope on the average shear stress for each project area. The power regression curve has a moderately good correlation, with an R^2 value of 0.538.

Equation H-1

$$\tau_p = 10.86\, {S_{EG}}^{0.488}$$

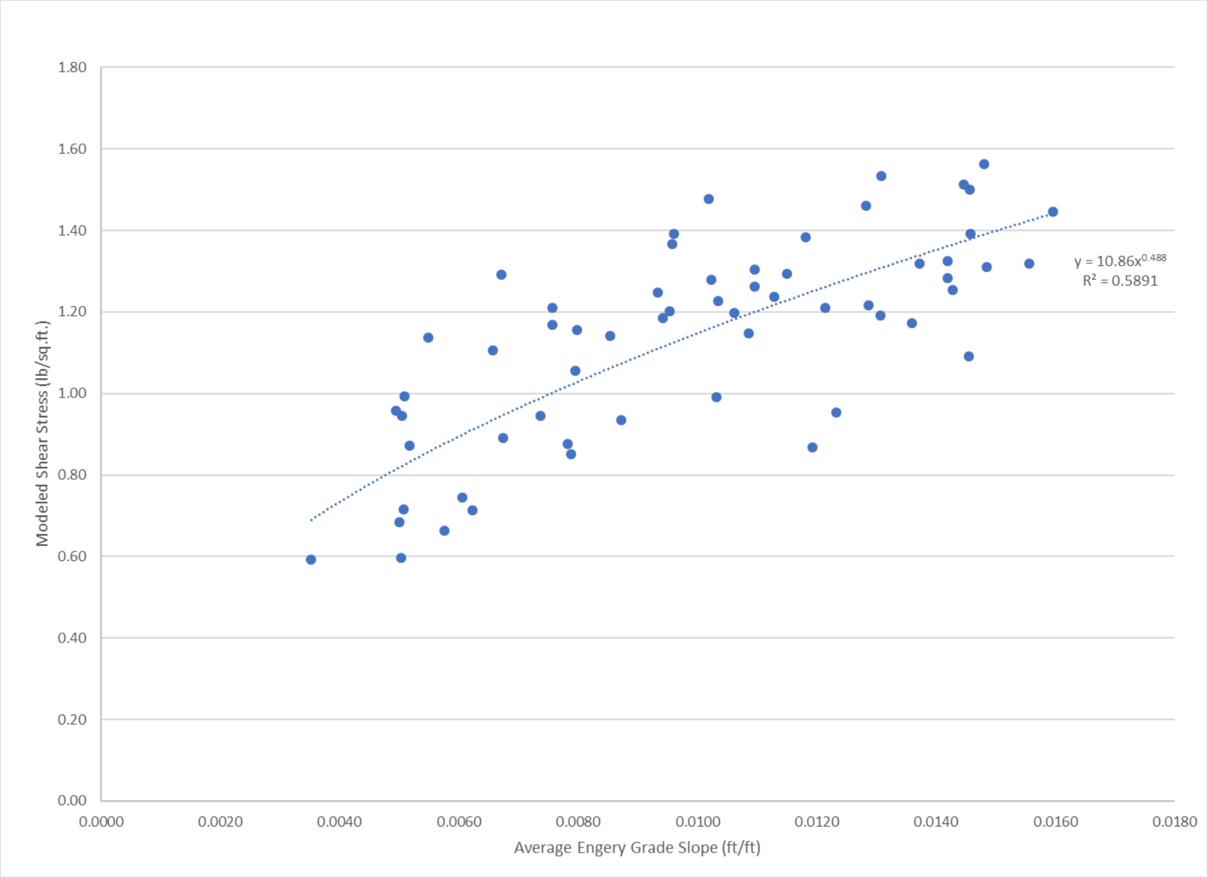
where:

τ_p = predicted shear stress

S_{EG} = slope of the energy grade line

Figure H-1 shows the regression curve and how it relates the average energy grade slope and shear stress for each project area. There are several plain outliers to this trend, as well as many other project areas that are significantly higher than the regression average. These outliers and high values are the project areas that have much more transport capacity than would be expected of a project area in the Tucannon River basin with similar slopes. With this information, restoration actions that will account for this high transport capacity can be recommended for individual project areas, and basin-wide trends can be established for basin-wide actions such as gravel augmentation. These recommendations and how they affect individual project areas can be found in the Project Area Cut Sheets in Appendix J.

Figure H-1
Modeled Shear Stress vs. Energy Grade Slope



Aside from graphically seeing how the outliers occur to this trend, numerical values for excess transport capacity were determined that describe the variance from this trend. Equation H-1 is used to determine a shear stress value for each project area, predicted by the energy grade slopes and the relationship described in this regression equation. This value is referred to as the predicted shear stress for this assessment. By differencing the modeled shear stress and the predicted shear stress, the variance from the regression equation can be determined as shown in Equation H-2. This is the value referred to as the Excess Transport Capacity metric for this analysis and will be the value used in the assessment to indicate projects where restoration actions targeting sediment transport might be implemented. For a full list of the values of the modeled shear stress, predicted shear stress, energy grade slopes, and excess transport capacity, see Table H-3 at the end of this appendix.

Equation H-2

$$\mathrm{ETC} = \tau_m - \tau_p$$

where:
ETC = excess transport capacity
τ_m = modeled shear stress
τ_p = predicted shear stress

Bedload Transport Trends and Patterns

This section briefly describes some of the basin-wide trends and findings from the Excess Transport Capacity analysis. A more detailed breakdown of how this analysis applies to individual project areas is discussed in the Project Area Cut Sheets in Appendix J. This section references figures that are provided at the end of this appendix.

Because the Excess Transport Capacity metric factors out slope though the regression equation in Equation H-1, the correlation with position in the basin seen in most of the other analysis results is not seen in the plot of excess transport capacity across the basin in Figure H-3. A basin-wide trend would be expected in a measure of just the transport capacity of individual project areas, but because this analysis result measures excess transport capacity, a basin-wide trend is not expected. However, small-scale trends are apparent and identifying these smaller trends is the strength of this analysis.

First, it should be noted that almost all project areas known to be highly confined will show high excess transport capacity. Examples include: Project Area 4, located behind the Camp Wooten levee; Project Area 13, which is currently confined by Rainbow Lake; Project Areas 21 and 22, which are both leveed and confined; Project Areas 37 and 38, which are both incised and confined; and many others. Table H-1 shows typical ranges of excess transport capacity and how those ranges have been incorporated into the prioritization. Channel confinement is a classic way of increasing the transport capacity in a reach. Straightening meanders, removing overbank flows and storage area, and decreasing roughness and complexity are all effects of channel confinement and causes of increased sediment transport. The reaches that will likely have a larger bed sediment size and be resistant to geomorphic change are exactly the type of reaches that need to be addressed with restoration strategies that are catered to reducing excess transport capacity.

Additionally, there are two distinct groupings evident in Figure H-3. Project Areas 8 to 12 all show less transport capacity than would be expected of their slopes. It is highly likely this is directly tied to the Tucannon Hatchery Dam, located at the downstream end of Project Area 12, which acts as a grade control structure and barrier for sediment transport, forcing a depositional area in Project Area 12 and upstream. Many of these reaches have also been noted as having high complexity and larger than normal floodplain areas.

The second grouping of project areas with similar excess transport capacity values is Project Areas 20 to 27, which all have high excess transport capacity values. Many of these project areas are highly leveed and confined, likely contributing to the high excess transport capacity. This is a long stretch of the river to have higher than usual transport capacities, which likely has a negative effect on the complexity and connectivity of these reaches.

Finally, when compared to the other metrics of this assessment, Excess Transport Capacity shows a moderate correlation to many of the complexity metrics. In particular, Excess Transport Capacity seems to be negatively correlated with low-flow complexity with a variance of 0.351, which is one of the highest correlations between any of the metrics. As discussed previously, complexity and transport capacity are closely tied fluvial processes. Without adequate available sediment, as is often the case in places with high excess transport capacities, the geomorphic changes that force complexity cannot form, causing more confinement and incision. It is also interesting that the Excess Transport Capacity metric shows no correlation at all with the Connectivity metric with r2 values of 0 for all three analysis results of Channel Aggradation, Encroachment Removal, and Total Floodplain Potential. Because these connectivity values are indicators of potential for additional connection, this lack of correlation indicates that project areas with abnormally high transport capacity might not have a lot of potential floodplain area to be connected.

Scoring for Prioritization

In order to fit analysis results into the prioritization process, each project area is ranked, classified, and scored in each of the three prioritization metrics (Complexity, Connectivity, and Excess Transport Capacity). Project areas are ranked in the Connectivity metric from best to worst based on the Excess Transport Capacity scores. Each project area then has a rank for the Excess Transport Capacity prioritization metric and can be classified and scored according to the classification and scoring systems outlined in Table H-1.

Similar to the Connectivity metric classifications, projects that rank highly in Excess Transport Capacity indicate that these are the project areas where the balance of sediment transport to slope is out of the ordinary. Therefore, project areas that rank high in the Excess Transport Capacity metric are those where efforts to balance sediment transport and allow more in-channel sediment deposition should be focused. The percentile rank where the classes change for the Excess Transport Capacity metric were chosen based on distinctive threshold values where the actual transport capacity score is much different from those ranked directly around it. Additionally, below 50%

already indicates that the project area is at or below the transport capacity for the reach and will not require any restoration focused on restoring sediment transport balance.

Table H-1
Excess Transport Capacity

Percentile Rank	Class	Class Score	Metric Score Threshold[1]	Class Conceptualization
90th to Top	1	5	0.247	These project areas have extremely high transport capacity for their slopes compared to what is typical in the basin, and restoration efforts. These project areas should be a primary target for restoration actions focused on sediment transport balance.
70th to 90th	2	3	0.126	Project areas in this class have significantly higher transport capacity than other project areas in this assessment. These project areas should be a secondary target for restoration actions focused on sediment transport balance.
50th to 70th	3	1	0.00	Project areas in this class have only slightly higher transport capacity than would be expected, and sediment transport balance restoration actions should only be targeted when other restoration actions are already considered for the project area.
Bottom to 50th	4	0	N/A	Projects areas in this class have a normal or less amount of transport capacity based on their slopes.

Notes:

1. This is the score that defines the lower limit for the corresponding classification for this metric. These data can be used to track progression of project areas and compare to how they would rank according to the levels of this assessment, as new restoration projects are completed and new data become available.

Detailed Instructions for Performing this Analysis

Part of the purpose of this assessment is to define repeatable and data-driven methods for assessing project areas and how they have progressed in relation to their goals. This section provides the detailed steps taken to perform the Excess Transport Capacity analysis of the Tucannon River so that these analyses can be repeated in the future for additional analyses and evaluation of progress. Table H-2 provides the data that will need to be collected to reassess the project areas for excess transport capacity.

Table H-2
Raw Data Needed to Perform Excess Transport Capacity Analysis

Data Needed	Used For	Source
Topography Digital Elevation Model	1D hydraulic modeling	LiDAR, preferably blue-green and 0.5-meter horizontal accuracy or greater
Hydrology	Flows used in hydraulic modeling	Hydrologic gage data[1]
Cross sectional shear stress and energy grade elevation	Modeled shear stress	1D hydraulic modeling results
Project area delineations	Calculation of the average model results per project area	Project area shapefiles from this assessment

Notes:

1. See Appendix C for a description of gage locations on the Tucannon River and methods used to interpret those data.

The following instructions will assume the user has adequate GIS and HEC-RAS modeling knowledge and access to the same data sources as those produced in this report.

Examining shear stress at a single cross section can display some statistical noise because the exact location of the cross sections may not fully capture the slope and confinement of the channel. Additionally, the shear stress at a single cross section represents only the channel configuration at that exact location and may vary quite a bit over the length of a project area. The simple solution to this is to take the average of the shear stresses at all cross sections in the project area. However, because the cross sections represent the shear stress at a given point, an averaging technique shown in Equation H-3 has been applied to each project area. Every pair of cross sections represents a length of channel between these two cross sections, so the shear stress over this length can be more accurately represented as the average of the upstream cross section and the downstream cross section, referred to here as the Reach Average Shear Stress. To find the average for a project area, each reach between a pair of cross sections in the project area were then averaged, and because not all cross sections are spaced evenly, these were weighted by length of each cross-sectional reach.

Equation H-3

$$\tau_{a,b} = \sum_{a-1}^{b} (\tau_i + \tau_{i+1})\, L_{i,i+1} \Bigg/ \sum_{a-1}^{b} L_{i,i+1}$$

where:

$\tau_{a,b}$ = length weighted, reach average, shear stress of the project area *a,b*

i = cross sections of the basin, where i=0 is the most downstream cross section in the basin and i=n is the most upstream cross section in the basin

τ_i = shear stress at cross section i

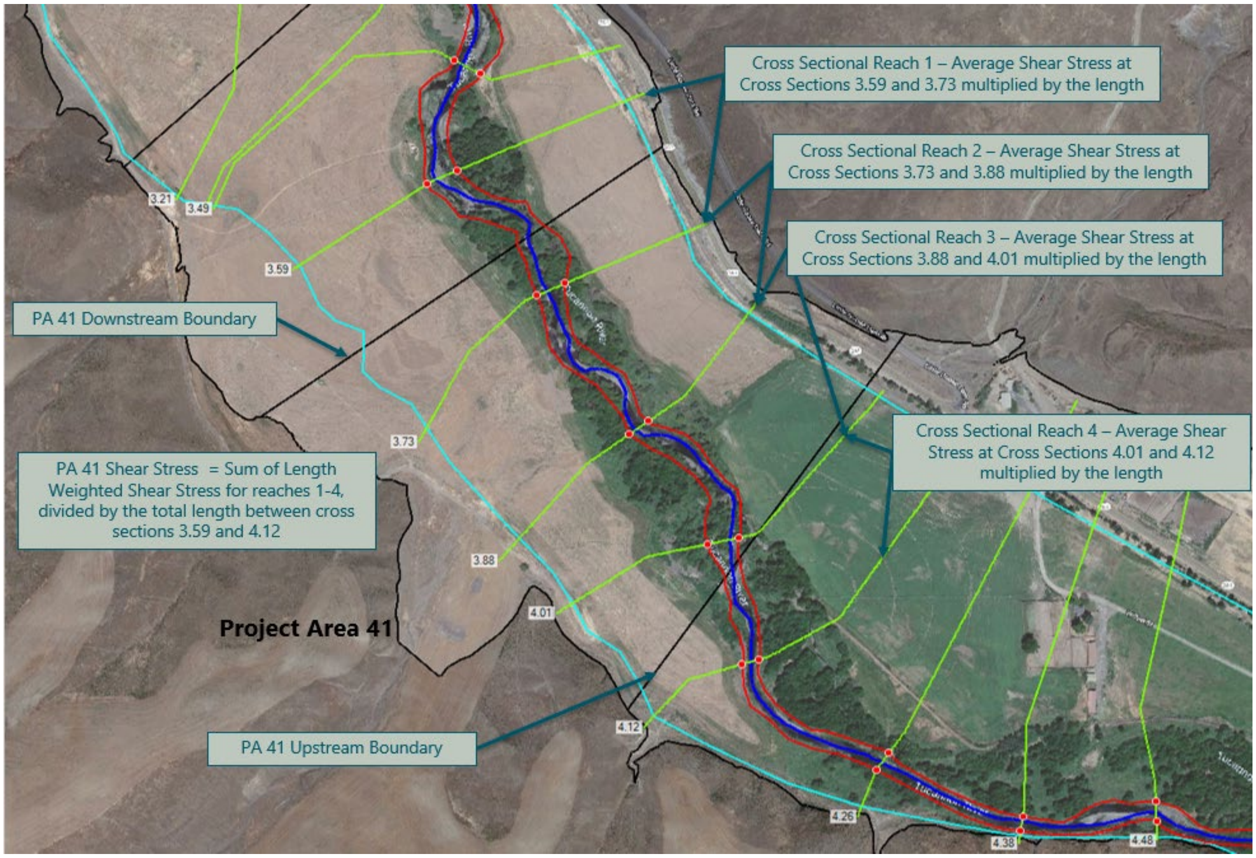
$L_{i,i+1}$ = river length of the reach between cross sections i and $i+1$

a = most downstream cross section of the project area

b = most upstream cross section of the project area

Finally, each project area takes the average from the first cross section downstream of the downstream project boundary to the cross section that exists just upstream of the upstream project boundary. This is necessary to account for all area in a project area because cross sections and project boundaries do not often coincide exactly and some portion of the first and cross-sectional reach would be excluded from the analysis. This has the effect of slightly more of the river length being factored into each project area average. However, since the upstream and downstream conditions do have some effect on the transport capacity of the reach, this possibly serves to make this reach estimate of shear stress more accurate. The final result is a model result-based shear stress value for each project area, which will be referred to as the modeled shear stress. This process of calculation is visually described in Figure H-2 for Project Area 41.

Figure H-2
Project Area 41: Calculation of Length Weighted Reach Average Shear Stress



The average energy grade slope was calculated using the same array of cross sections, all of those that fall within the project area, as well as the cross sections immediately upstream and downstream. The energy grade elevation at each cross section at the upstream and downstream ends of the project area was differenced and divided by the total length to determine the energy grade slope for the project area.

Using the regression equation in Equation H-4, predicted shear stresses were found for each cross section. For an explanation of the source of the regression equation, see the Analysis Overview section and Figure H-1. Finally, predicted shear was subtracted from modeled shear to find the excess transport capacity shown in Equation H-5. Table H-3 lists the energy grade slope, modeled shear stress, predicted shear stress, and excess transport capacity for each project area.

Equation H-4

$$\tau_p = 10.86\, {S_{EG}}^{0.488}$$

where:

τ_p = predicted shear stress

S_{EG} = slope of the energy grade line

Equation H-5

$$\mathrm{ETC} = \tau_m - \tau_p$$

where:

ETC = excess transport capacity

τ_m = modeled shear stress

τ_p = predicted shear stress

References

USACE, 2016. *HEC-RAS River Analysis System Hydraulic Reference Manual*. Version 5.0. CPD-69. February 2016. Available at: https://www.hec.usace.army.mil/software/hec-ras/documentation/HEC-RAS%205.0%20Reference%20Manual.pdf.

Wilcock, P.R., 2001. Toward a practical method for estimating sediment-transport rates in gravel-bed rivers. *Earth Surface Processes and Landforms* 26(13): 1395-1408.

Tables

Table H-3
Excess Transport Capacity Analysis Results

Project Area	River Length (mile)	Cross-Sectional Reach Count	Average EGL Slope	Modeled Shear Stress (lb/ft s)	Predicted Shear Stress	Excess Transport Capacity
1.10	0.55	15.00	0.0148	1.56	1.387	0.176
1.20	0.39	11.00	0.0145	1.51	1.371	0.142
2.00	0.64	19.00	0.0143	1.25	1.362	-0.109
3.10	0.37	12.00	0.0160	1.45	1.437	0.009
3.20	1.44	26.00	0.0142	1.28	1.359	-0.075
4.00	0.24	4.00	0.0131	1.53	1.307	0.226
5.00	0.45	7.00	0.0142	1.33	1.359	-0.034
6.00	0.74	13.00	0.0146	1.39	1.376	0.016
7.00	0.45	5.00	0.0146	1.50	1.376	0.124
8.00	0.45	9.00	0.0136	1.17	1.331	-0.159
9.00	0.40	6.00	0.0137	1.32	1.337	-0.019
10.10	0.47	7.00	0.0148	1.31	1.388	-0.078
10.20	0.72	12.00	0.0121	1.21	1.261	-0.051
10.30	0.41	13.00	0.0156	1.32	1.420	-0.101
11.10	0.75	13.00	0.0131	1.19	1.306	-0.115
11.20	0.96	15.00	0.0119	0.87	1.250	-0.382
12.00	0.65	10.00	0.0146	1.09	1.375	-0.283
13.00	0.77	13.00	0.0128	1.46	1.294	0.166
14.10	0.61	10.00	0.0123	0.95	1.270	-0.316
14.20	0.82	11.00	0.0110	1.30	1.200	0.104
14.30	0.72	11.00	0.0109	1.15	1.195	-0.048
15.10	0.38	7.00	0.0129	1.22	1.296	-0.081
15.20	0.42	5.00	0.0115	1.29	1.228	0.065
16.00	1.39	15.00	0.0110	1.26	1.201	0.062
17.10	0.34	4.00	0.0103	1.23	1.167	0.059
17.20	0.31	6.00	0.0103	0.99	1.166	-0.174
18.10	1.08	15.00	0.0113	1.24	1.217	0.021
18.20	0.78	10.00	0.0102	1.28	1.162	0.117
19.00	0.56	9.00	0.0106	1.20	1.182	0.015
20.00	0.44	6.00	0.0118	1.38	1.244	0.139
21.00	1.05	13.00	0.0102	1.48	1.159	0.317
22.00	1.08	15.00	0.0096	1.37	1.125	0.241
23.00	1.05	11.00	0.0093	1.25	1.112	0.136
24.00	0.76	10.00	0.0095	1.20	1.123	0.080
25.00	0.54	6.00	0.0096	1.39	1.127	0.265
26.00	2.99	43.00	0.0094	1.19	1.116	0.070
27.00	1.05	13.00	0.0080	1.06	1.030	0.027
28.10	0.87	12.00	0.0087	0.93	1.076	-0.141
28.20	1.17	16.00	0.0079	0.85	1.025	-0.173
28.30	1.16	15.00	0.0085	1.14	1.065	0.077
29.00	1.12	15.00	0.0076	1.17	1.005	0.164
30.00	1.01	12.00	0.0078	0.88	1.021	-0.145
31.00	1.49	18.00	0.0074	0.95	0.993	-0.047
32.10	0.79	8.00	0.0067	1.29	0.949	0.343

Table H-3
Excess Transport Capacity Analysis Results

Project Area	River Length (mile)	Cross-Sectional Reach Count	Average EGL Slope	Modeled Shear Stress (lb/ft s)	Predicted Shear Stress	Excess Transport Capacity
32.20	0.69	8.00	0.0080	1.16	1.031	0.124
33.00	1.22	14.00	0.0066	1.11	0.940	0.166
34.10	1.14	13.00	0.0061	0.74	0.904	-0.159
34.20	0.78	10.00	0.0062	0.71	0.916	-0.202
35.00	0.66	12.00	0.0051	0.72	0.830	-0.114
36.00	1.73	22.00	0.0058	0.66	0.882	-0.218
37.00	1.10	14.00	0.0051	0.99	0.831	0.163
38.00	2.97	32.00	0.0052	0.87	0.838	0.034
39.10	0.10	1.00	0.0050	0.95	0.827	0.118
39.20	0.63	4.00	0.0055	1.14	0.862	0.276
40.00	0.28	6.00	0.0076	1.21	1.006	0.074
41.00	0.35	4.00	0.0067	0.89	0.951	-0.060
42.00	0.33	4.00	0.0050	0.68	0.824	-0.140
43.00	0.43	4.00	0.0050	0.60	0.827	-0.231
44.00	0.43	4.00	0.0049	0.96	0.819	0.138
45.00	0.52	6.00	0.0035	0.59	0.697	-0.105

Figures

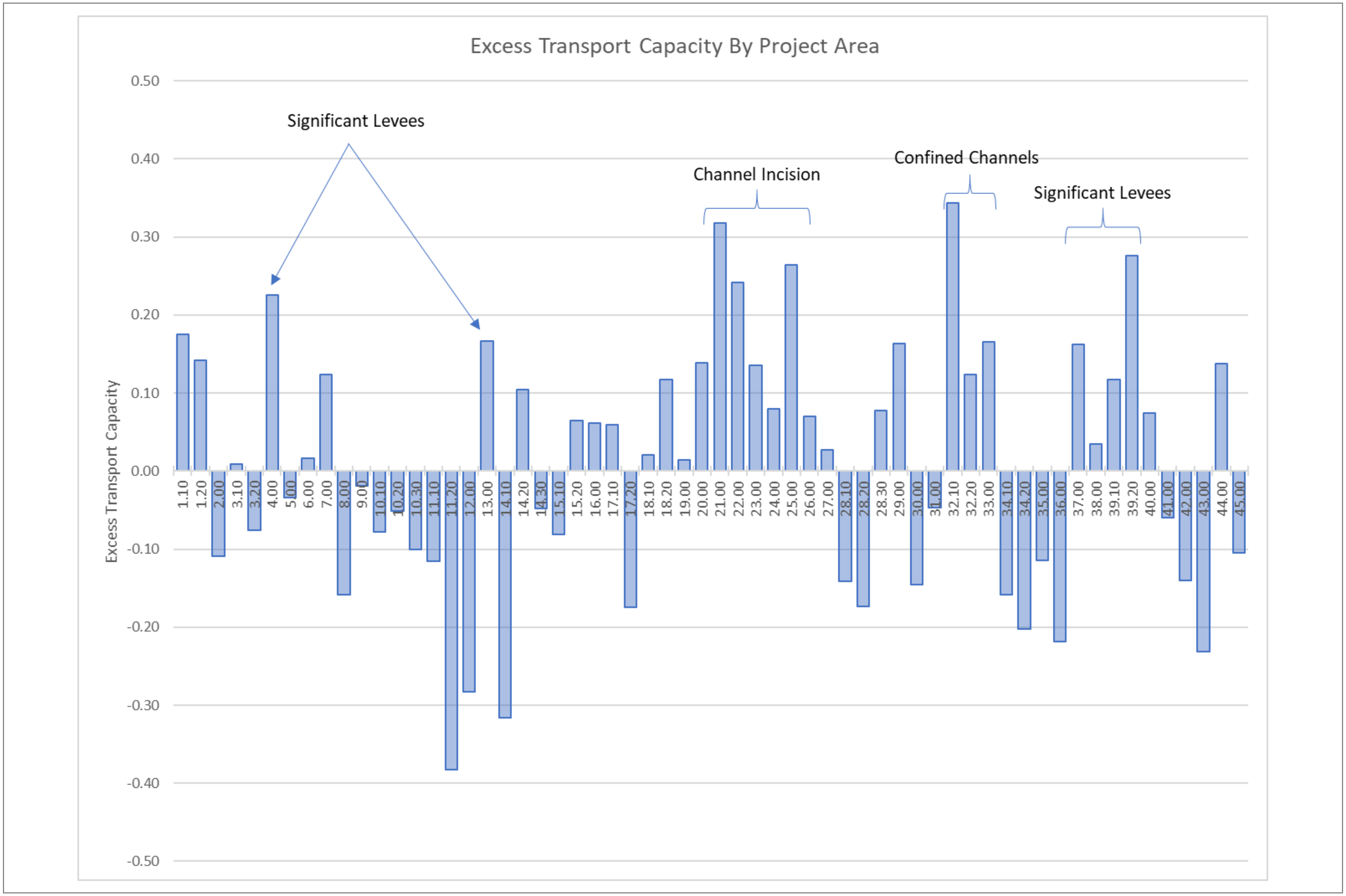


Figure H-3
Excess Transport Capacity