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Technical Memorandum

Date:	April 18th, 2025
To:	Kris Fischer, CTUIR Liz Eastman, NPT
From:	AJ Jones, P.E. W2r Brenda Fasse, EIT. W2r
Project:	Tucannon River Big Four – Floodplain Restoration Project
Subject:	BOR Risk Assessment for Large Wood Design

BOR Risk Assessment

The method for the reach-scale risk assessment follows the guidance outlined in Step 4 of the Large Woody Material (LWM) Risk-Based Design Guidelines (Reclamation 2014). This evaluation includes assessing Public Safety Risks and Property Damage Risks associated with the placement of LWM in the project reach. Direct outcomes of this risk assessment approach include recommendations on log-jam design, safety factors for stability, and design floods. The risk assessment made use of general information, professional judgement, and information about reach user characteristics provided by the Project Sponsor, CTUIR, and coordination with the NPT and WDFW.

1 Public Safety Risk Matrix

The Public Safety Risk matrix plots two major categories: the structure characteristics of each LWM structure versus the user characteristics for the project area (Reclamation 2014). Each category has a number of factors that are associated with the risk of that characteristic summarized below. The project design team assigned each factor a rating from 0 to 10, which represent low to high levels of public safety risk. For each category, the rating assigned to each factor is summed and then averaged. The average for each category is plotted on the matrix to determine the overall risk to the public of the LWM structure (Figure 1).

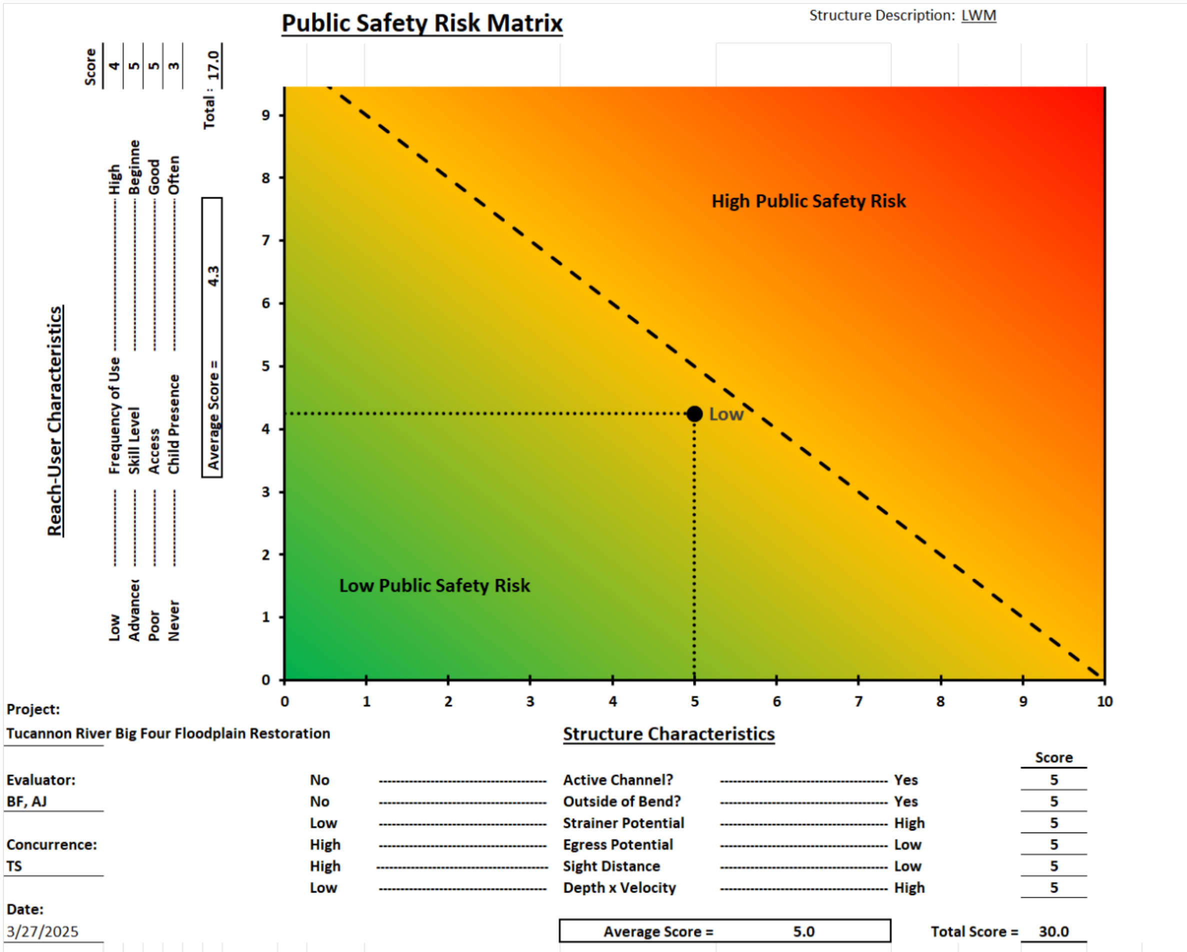

Figure 1 Public Safety Risk Matrix (Reclamation 2014).

1.1 Reach User-Characteristics

The reach user-characteristics are plotted on the Y-axis of Figure 1 and include the following four factors for developing an average categorical risk:

- Frequency of use – This factor rates the level of use that can be expected in the project area by floating, swimming, or other in-river activities. A reach of river that is frequently used by the public would have a higher rating.
- Skill Level – This factor rates the level of skill and knowledge of the river reach that is anticipated by the recreationists using the system. A reach that is frequently used by individuals with proper safety equipment and training would receive a lower risk rating than one that is frequented by low-skilled inner-tube recreationists.
- Access – This factor rates the risk of public safety related to accessibility to the project reach—specifically, LWM structure. The easier the access, the higher the risk.
- Child Presence – This factor rates the risk of the project reach for the presence of children, who are prone to investigating or climbing on LWM structures. A reach that that has easy access for children, or is near children camps or parks, has a higher risk.

The rating evaluation for the reach-user characteristics are summarized in Table 1.

Table 1 Reach-User Characteristic Ratings.

Reach-User Characteristics	Rating	Notes
Frequency of Use	4	The area surrounding the project reach is used by local visitors during the summer months for fishing, and recreational activities, but direct use of the creek through the project reach is minimal. The reach will primarily be used fly-fishers. A search of the American Whitewater database revealed no documentation on rafting or kayaking routes on Tucannon River.
Skill Level	5	Rafting is not likely to occur. Fishing will mostly be fly fishing by skilled anglers.
Access	5	The reach is readily accessible by USFS roads, but further away far from major population centers.
Child Presence	3	This reach has limited child presence.
Average	4.3	Reach is primarily used by fishers and hikers. Low overall use by children and suitability as a floatable river make public safety risk low to moderate.

1.2 Structure Characteristics

The structure characteristics include the following six factors for developing an average categorical risk:

- Active Channel – This factor rates the uncertainty of physical channel migration. The magnitude of risk is higher in anticipation of dynamic channel movement.
- Outside of bend – This factor rates the location of the LWM structure design inside or outside of a bend. A person is more likely to be forced into a structure on the outside of a bend; therefore, a higher risk rating is associated with a structure located on the outside of a bend.
- Strainer potential – This factor rates the potential for a structure to pin or entrap a person. The more voids or protrusions a structure has, the higher the risk of entrapping an individual.
- Egress potential – This factor rates the ease of avoiding the LWM structure by floating or swimming around the structure. Structures that protrude into the channel or cause the recreationist to be pushed into deep, quick stream currents have higher ratings.
- Sight distance – This factor rates the ability for recreationist to see the structure from upstream and have enough time to divert away from the structure. Length of approach, slope, width, and stream velocity should all be considered when analyzing risk for this factor. An LWM structure located downstream of a bend in a narrow channel would have a higher risk rating.
- Depth x velocity – This factor rates channel approach velocity and depth to assess the safety of standing and moving, or walking away and around, the structure. A lower rating is applied to stream systems with lower depths and velocities where recreationists can easily avoid a structure.

At this design stage, LWM structure-specific risks were not assessed and all scores were assumed to be 5.

Based on the above, the overall public safety risk category is ranked as low to moderate.

2 Property Damage Risk Matrix

The Property Damage Risk matrix evaluates property damage risk potential for all structures within a project reach by weighing the property/project characteristics and stream potential against each other factors (Reclamation 2014). A rating of 0 to 10 is assigned to each of the factors associated with the two property damage risk categories. The average for each category is then plotted on the property damage matrix to determine the overall risk of the LWM structure (Figure 2).

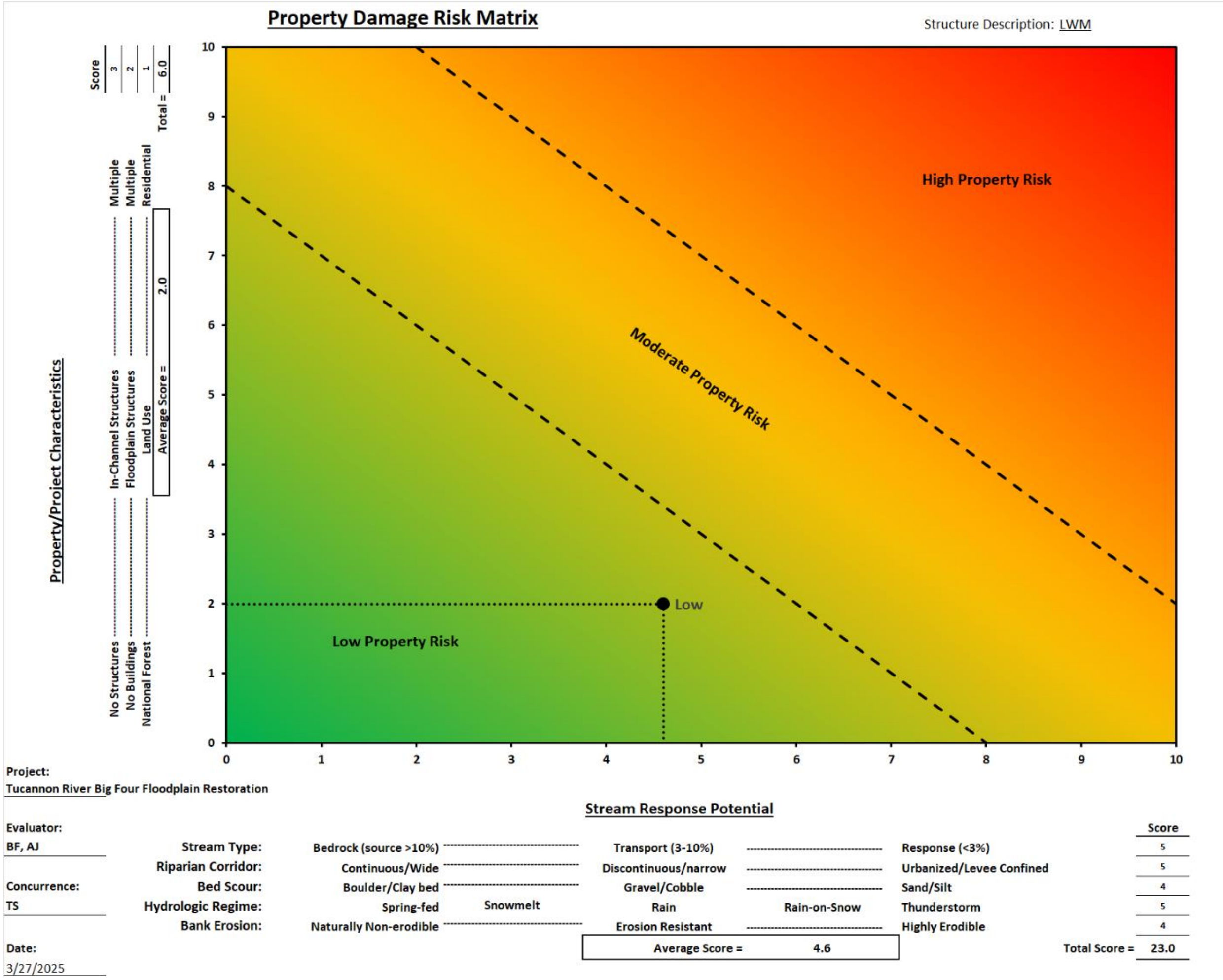

Figure 2 Property Damage Risk Matrix (Reclamation 2014).

2.1 Stream Response Potential

The property/project characteristics are plotted on the X-axis of Figure 2, and include the following five factors for developing an average categorical risk:

- Stream type – This factor rates the stream's sensitivity to change based on the stream type and slope within a project reach. A project located in a response reach within an alluvial channel may have high sensitivity and receive a high stream type rating.
- Riparian corridor – This factor rates the project reach's ability to absorb disturbances through natural riparian resiliency without causing harm to habitat or property. A project located in a reach with a wide riparian corridor would be rated low compared to a stream with a relatively narrow riparian corridor.
- Bed scour potential – This factor rates the project reach's physical susceptibility to bed changes based on channel material composition. Streams with highly erodible material such as sand or loose gravel may be susceptible to great disturbance and therefore have a higher rating.

- Bank erosion potential – This factor rates the project reach's physical susceptibility to bank erosion based on bank material composition. Channels with banks composed of highly erodible material such as sand or loose gravel are associated with a higher risk rating.
- Dominant Hydrologic Regime – This factor rates the stream's temporal hydrologic variability. Stream systems with evidence of high variability in their hydrograph have a much greater potential for system response and hence a relatively lower channel stability. Higher hydrograph variability equates to higher risk potential.

The evaluation of the five stream response factors for the project reach is provided in Table 2 with notes describing the rational for each rating.

Table 2 Stream response potential ratings

Stream Response Potential	Rating	Notes
Stream Type	5	The reach is located within an alluvial channel with bedrock outcrops and a moderate slope (1.3%). Although the reach is considered a response reach, it has many characteristics of a transport reach and has a moderate sensitivity to change.
Riparian Corridor	5	The School Fire in 2005 severely burned the riparian area in the downstream half of the project area and the riparian cover has not fully recovered. In areas where the floodplain has been disconnected there are problems with invasive vegetation establishment. The riparian cover is expected to improve with the project response.
Bed Scour Potential	4	The reach is dominated by coarse gravel to cobble-sized sediment. The reach is alluvial in nature and contains bedrock outcrops (RM 42.8) that act as a natural grade control which limits overall bed scour and incision potential through the project reach. Additionally, the bed is already somewhat incised, decreasing potential for active rapid incision.
Dominant Hydrologic Regime	5	Snow-melt dominated hydrologic regime with relatively moderate variability in peak flows.
Bank Erosion Potential	4	Bank erosion processes are active but very slow. Historical aerials indicate relatively slow rates of channel migration and bank erosion. The well-established riparian corridor also reduces bank erosion potential.
Average	4.6	The average stream response potential risk is low to moderate.

2.2 Property/Project Characteristics

The property/project characteristics are plotted on the Y-axis of Figure 2, and include the following three factors for developing an average categorical risk:

- In-channel structures – This factor rates the risk of LWM based on the proximity and vulnerability of in channel structures such as bridges, piers, docks, pumps, fish screens, and other features in the channel.
- Floodplain structures – This factor weighs the vulnerability and type of structures within the 100-year floodplain. Projects that have multiple structures within the 100-year floodplain may be rated high.

- Land use – This factor is used to determine the damage potential based on land use. Natural land uses may receive a lower rating than farm land or rural residence based on the judgement of the design team.

The evaluation of the three property/project characteristic factors is provided in Table 3 with notes describing the rational for each rating.

Plotting of average scores on Figure 2 reveals a low property risk category.

Table 3 Property/Project Characteristics

Property/Project Characteristics	Rating	Notes
In-Channel Structures	3	There are no bridges within the project reach. A dispersed campground sits outside of the project area. There is potential for overhead powerline relocation. The project elements are design to not increase flood risk to infrastructure adjacent to the project reach. A bridge is located multiple miles downstream of the project area with large segments of unconfined channel and floodplain between, and therefore it has low potential of being impacted by the project elements. The Beaver-Watson lake intake is below the project, and is the closest in channel structure to protect under current lake configurations.
Floodplain Structures	2	The project reach has no structures within the geomorphic floodplain.
Land Use	1	The project reach is within undeveloped WDFW private lands used for recreation and fishing. These uses mimic those of national forest land.
Average	2.0	The average property risk is low.

3 Risk-Based LWM Design Recommendations

The identified low categories of public safety and property risks have associated recommendations of design flood and factor of safety (FOS) listed in Table 4.

Table 4 LWM risk-based design recommendations (Reclamation, 2014). Yellow highlighting calls-out the project reach.

Public Safety Risk	Property Damage Risk	Stability Design Flow Criteria	FOS Sliding	FOS Buoyancy	FOS Rotation & Overturning
High	High	100-year	1.75	2.0	1.75
High	Moderate	50-year	1.5	1.75	1.5
High	Low	25-year	1.5	1.75	1.5
Low	High	100-year	1.75	2.0	1.75
Low	Moderate	25-year	1.5	1.75	1.5
Low	Low	10-year	1.25	1.5	1.25

Appendix C

Wood Habitat Structure Stability Calculations

WHS Type #1 Large Apex Jam

Buoyancy Calculations

Project: Tucannon Big Four Floodplain Restoration - Large Apex Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

Spreadsheet Description

- The spreadsheet below is used to calculate the Factor of Safety against Buoyant uplift of the LWM

Assumptions:

1) The LWM structure behaves as a single structure under the design load and will not experience any shearing at joints
2) The LWM structure will be submerged during the design event.
3) Negative buoyancy is uplift, positive numbers equals downward.
4) Ballast material remains intact and is not scoured out.
5) The uplift due to racking material is evenly dividing among all layers.

Input (Cells Requiring Input from Structure Detail)
Input (Cells requiring Input from Hydraulic Model)
Input (Cells automatically populated from Input to Interface Tab)
Input (Cells requiring input from a dropdown list)
Output (Cells automatically updated are this color)
Output (Cells automatically updated with previously calculated values are this color)

FBD and Equations:

$$FOS_b = \frac{F_{LWMd} + F_{boulders} + F_{soil} + F_{piles-e}}{|F_{LWMs} + F_L|}$$ **Equation 18**

FOS_b = buoyancy factor of safety

Tucannon Big Four Floodplain Restoration has a "LOW" Public Safety Risk Factor and a "MODERATE" Property Damage Risk Factor. The Design buoyancy factor of safety (FOS_b) for this structure is 1.75 per Table 4 "*Minimum Recommended Factors of Safety*".

Table 4. Minimum recommended factors of safety.

Public Safety Risk	Property Damage Risk	Stability Design Flow Criteria	$FOS_{sliding}$	$FOS_{buoyancy}$	$FOS_{rotation}$ $FOS_{overturning}$
High	High	100-year	1.75	2.0	1.75
High	Moderate	50-year	1.5	1.75	1.5
High	Low	25-year	1.5	1.75	1.5
Low	High	100-year	1.75	2.0	1.75
Low	Moderate	25-year	1.5	1.75	1.5
Low	Low	10-year	1.25	1.5	1.25

1. Large Wood Material Force - Dry (F_{LWMd})

$$F_{LWMd} = V_{LWMd} * \gamma_{wood}$$ **Equation 3**

V_{LWMd} = volume of dry large wood material

Comment: Assumed to be zero because structure assumed to be submerged during design event.

2. Boulder Ballast Force ($F_{boulder}$)

$N_{bouldersub}$			Number of submerged boulders (from design)
$d_{bouldersub}$	1.5	ft	Effective diameter of submerged boulder (ft, from spec)
$\gamma_{boulder}$	146	lb/ft^3	unit weight of boulders (Table 5)
γ_{water}	62.4	lb/ft^3	unit weight of water
$F_{bouldersub}$		lb	Eqn. 6
$N_{boulderdry}$			Number of dry boulders (from detail)
$d_{boulderdry}$	3	ft	Effective diameter of dry boulder (ft, from spec)
$F_{boulderdry}$		lb	Eqn. 7
$F_{boulder}$		**lb**	**Eqn. 5**

Comment: The intent is design without the use of boulders so it is assumed no boulders are used.

$$F_{boulder} = F_{bouldersub} + F_{boulderdry}$$ **Equation 5**

$$F_{bouldersub} = N_{bouldersub} * \frac{\pi}{6} * d_{bouldersub}^3 * (\gamma_{boulder} - \gamma_w)$$ **Equation 6**

$N_{bouldersub}$ = number of submerged boulders
$d_{bouldersub}$ = effective diameter of submerged boulders
$\gamma_{boulder}$ = unit weight of boulders

$$F_{boulderdry} = N_{boulderdry} * \frac{\pi}{6} * d_{boulderdry}^3 * \gamma_{boulder}$$ **Equation 7**

$N_{boulderdry}$ = number of unsubmerged boulders
$d_{boulderdry}$ = effective diameter of unsubmerged boulders

Buoyancy Calculations

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Latest Revision: 4/2/2025

3. Soil Backfill Force (F_{soil})

$N_{logssub1}$	3		Number of Type 1 buried logs (from detail)
L_{eb1}	30	ft	Average embedded length of Type 1 logs (from detail)
d_{bole1}	1.5	ft	Average diameter of Type 1 logs (from detail)
$h_{soilsub1}$		ft	Average height of submerged soil above Type 1 log (from detail)
$V_{soilsub1}$		ft^3	Volume of submerged soil above Type 1 log (from detail)
$h_{soildry1}$		ft	Average height of dry soil above Type 1 log (from detail)
$V_{soildry1}$		ft^3	Volume of dry soil above Type 1 log (from detail)
$N_{logssub2}$	1		Number of Type 2 buried logs (from detail)
L_{eb2}	25	ft	Average embedded length of Type 2 logs (from detail)
d_{bole2}	1	ft	Average diameter of Type 2 logs (from detail)
$h_{soilsub2}$		ft	Average height of submerged soil above Type 2 log (from detail)
$V_{soilsub2}$		ft^3	Volume of submerged soil above Type 2 log (from detail)
$h_{soildry2}$		ft	Average height of dry soil above Type 2 log (from detail)
$V_{soildry2}$		ft^3	Volume of dry soil above Type 2 log (from detail)
$N_{logssub3}$	7		Number of Type 3 buried logs (from detail)
L_{eb3}	27	ft	Average embedded length of Type 3 logs (from detail)
d_{bole3}	2	ft	Average diameter of Type 3 logs (from detail)
$h_{soilsub3}$	5	ft	Average height of submerged soil above Type 3 log (from detail)
$V_{soilsub3}$	1,890	ft^3	Volume of submerged soil above Type 3 log (from detail)
$h_{soildry3}$		ft	Average height of dry soil above Type 3 log (from detail)
$V_{soildry3}$		ft^3	Volume of dry soil above Type 3 log (from detail)
γ_{soil}	120	lb/ft^3	Specific Gravity of bank/backfill material (Table 5)
γ_{water}	62.4	lb/ft^3	Unit weight of water
SG_{rock}	2.64		Specific Gravity of Rock (Using unit weight of bedrock from Table 5)
e	0.37		Eqn. 14
γ_{sat}	137	lb/ft^3	Eqn. 13
γ'_{soil}	74.5	lb/ft^3	Eqn. 12
F_{soil}	**140,891**	**lb**	**Eqn. 8**

$$F_{soil} = \sum_i^n V_{soilsub_i} * \gamma'_{soil} + V_{soildry_i} * \gamma_{soil}$$ **Equation 8**

$$V_{soilsub_i} = L_{eb_i} d_{bole_i} h_{soilsub_i}$$ **Equation 9**

$V_{soilsubi}$ = volume of submerged soil above log i
L_{ebi} = embedded length of log i
d_{bolei} = bole diameter of log i
$h_{soilsubi}$ = height of submerged soil above log i

$$V_{soildry_i} = L_{eb_i} d_{bole_i} h_{soildry_i}$$ ***Equation 10***

$V_{soildryi}$ = volume of dry soil above log i
$h_{soildryi}$ = height of dry soil above log i

$$\gamma_{soil} = (99.2 + 18.6 * \log(d_{50}))$$ **Equation 11**

d_{50} = median grain size in millimeters

$$\gamma'_{soil} = \gamma_{sat} - \gamma_w$$ **Equation 12**

$$\gamma_{sat} = \frac{(SG_{rock} + e) * \gamma_w}{1 + e}$$ **Equation 13**

$$e = \frac{SG_{rock} * \gamma_w}{\gamma_{soil}} - 1$$ **Equation 14**

Buoyancy Calculations

Project: Tucannon Big Four Floodplain Restoration - Large Apex Jam
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Latest Revision: 4/2/2025

4. Pile Skin Friction

N_{piles}	8		Number of piles (Design)
d_{piles}	1	ft	Diameter of piles (Design)
L_{piles}	12	ft	Embedded length of piles (Design)
k_s	1		Coefficient of lateral earth pressure (0.5 to 1.5 depending on soil and density)
Placement Method	Excavated		Method of pile placement
Placement Multiplier	0.25		See RBDG (P. 52)
Pile Placement Location	Bed		Bed or Bank
ϕ_{soil}	0.66	rad	Internal angle of friction of soils (Table 5)
γ_{soil}	126	lb/ft^3	Specific Weight of Soil
e	0.31		Eqn. 14
γ_{sat}	141	lb/ft^3	Eqn. 13
γ_{water}	62.4	lb/ft^3	Unit weight of water
σ'	939	lb/ft^2	Eqn 16
γ_{wood}	33	lb/ft^3	Unit weight of wood
$F_{piles\text{-}v}$	**32,972**	**lb**	**Eqn 15**

$$F_{piles-v} = N_{piles} * \pi * d_{piles} * L_{piles}(k_s * \tan\frac{2}{3}\phi * \sigma' + \frac{d_{piles}}{4} * (\gamma_{wood} - \gamma_w))$$

Equation 15

N_{piles} = number of piles
d_{piles} = diameter of piles
L_{piles} = embedded length of piles
k_s = coefficient of lateral earth pressure (0.5 to 1.5 depending on soil and density)
ϕ = internal angle of friction of soils

$$\sigma' = L_{piles} * (\gamma_{sat} - \gamma_w)$$

Equation 16

$$\gamma_{sat} = \frac{(SG_{rock} + e) * \gamma_w}{1 + e}$$

Equation 13

$$e = \frac{SG_{rock} * \gamma_w}{\gamma_{soil}} - 1$$

Equation 14

Assumptions:
*** k_s = 1**
**** This calculation is based on the assumption that piles are driven or vibrated into place. If piles are drilled or excavated, the associated coefficicient of lateral earth pressures shall be approx. 50% and 25% of the driven value, respectively.**
***** For use in buoyancy calculations, piles must be mechanically fastened.**
****** Top 2' of pile embedment disregarded for calculation to account for vortex shedding.**

Buoyancy Calculations

Project: Tucannon Big Four Floodplain Restoration - Large Apex Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

5. Large Wood Material Force - Submerged (F_{LWMs})

$$F_{LWMs} = V_{LWMs} * (\gamma_{wood} - \gamma_w)$$ Equation 2

V_{LWMs} = volume of submerged large wood material
γ_{wood} = unit weight of wood
γ_w = unit weight of water

$N_{logssub1}$	3		Number of log type 1 (from detail)
L_{log1}	30	ft	Length of log type 1 (from detail)
d_{bole1}	1.5	ft	Diameter of log type 1 (from detail)
d_{rw1}		ft	Diameter of rootwad of log type 1 (from detail)
V_{LWMs1}	159	ft^3	Volume of LWM1
$N_{logssub2}$	30		Number of log type 2 (from detail)
L_{eb2}	20	ft	Length of log type 2 (from detail)
d_{bole2}	1	ft	Diameter of log type 2 (from detail)
d_{rw2}		ft	Diameter of rootwad of log type 2 (from detail)
V_{LWMs2}	471	ft^3	Volume of LWM2
$N_{logssub3}$	7		Number of log type 3 (from detail)
L_{eb3}	40	ft	Length of log type 3 (from detail)
d_{bole3}	2	ft	Diameter of log type 3 (from detail)
d_{rw3}	5.00	ft	Diameter of rootwad of log type 3 (from detail)
V_{LWMs3}	1,063	ft^3	Volume of LWM3
V_{LWMs}	1,693	ft^3	Volume of LWM
γ_{wood}	33.0	lb/ft^3	Unit weight of logs
γ_w	62.4	lb/ft^3	Unit weight of water
F_{LWMs}	**-49,780**	**lb**	**Eqn. 3**

Volume of Rootwad

National Large Wood Manual. 2016

Equation 6-4 (p. 6-38)

$V_{rw} = \pi * t_k * w_k^2 / 3$

$\pi*(2d_{bole}) * (1/2d_{rw})^2 / 3$

t_k = Thickness of rootwad measured in direction parallel to trunk

= 4 times the radius of the log ($4r_k$ or

w_k =

Radius of rootwad

= 2.5 times the radius of the log ($2.5r_k$ or $1.25d_{bole}$) or 1/2 d_{rw} specified

6. Lift Forces (F_L)

$$F_L = -\frac{C_L * A_{LWM} * \gamma_w * U_o^2}{2*g}$$ Equation 4

C_L = lift coefficient
A_{LWM} = area of large woody material perpendicular to flow
u_u = upstream channel velocity at design event
g = acceleration due to gravity

C_L	0.45		Lift Coefficient
A_{LWM}	150	ft^2	Calc'd in Drag Forces
γ_w	62.4	lb/ft^3	Unit weight of water
U_o	9.0	ft/s	upstream velocity (from model)
g	32.2	ft/s^2	Unit weight of water
F_L	**-5,298**	**lb**	**Eqn. 4**

Comment: Lift forces neglected per Section 6.4.2 of BOR Risk Based Design Guidelines

Factor of Safety

FOS_b =	$(F_{LMDd} + F_{boulders} + F_{soil} + F_{piles-v}) / (F_{LWMs} + F_L)$		
F_{LWMd}		lb	Assumed Zero
$F_{boulder}$		lb	
F_{soil}	140,891	lb	
$F_{piles-v}$	32,972	lb	
F_{LWMs}	-49,780	lb	
F_L	-5,298	lb	
FOS_b	**3.16**		**STABLE FOR BUOYANCY**

Summary Comments:

Overturning Calculations

Project:	Tucannon Big Four Floodplain Restoration - Large Apex Jam	**Analyst:**	BF
Project Number:	20230017	**Calculations Checked By:**	AJ
		Latest Revision:	4/2/2025

Spreadsheet Description

Purpose: The spreadsheet below is used to calculate the Factor of Safety against vertical overturning.

Assumptions:
1) The LWM structure behaves as a single structure under the design load.
2) The effect of soil in back of the structure is negligible.
3) The structure will be submerged during the design event
4) This LWM structure experiences the largest loads. All LWM structures on site will be designed based on this LWM structure's loadings

Input (Cells Requiring Input from Structure Detail)
Input (Cells requiring Input from Hydraulic Model)
Input (Cells requiring input from a dropdown list)
Input (Cells automatically populated from Input to Interface Tab)
Output (Cells automatically updated are this color)
Output (Cells automatically updated with previously calculated values are this color)

FBD and Equations:

$$FOS_{overturn} = \frac{MR_{overturn}}{MD_{overturn}}$$ **Equation 49**

Tucannon Big Four Floodplain Restoration has a "LOW" Public Safety Risk Factor and a "MODERATE" Property Damage Risk Factor. The Design Overturn Factor of Safety ($FOS_{overturn}$) for this structure is 1.5 per Table 4 "Minimum Recommended Factors of Safety".

Table 4. Minimum recommended factors of safety.

Public Safety Risk	Property Damage Risk	Stability Design Flow Criteria	$FOS_{sliding}$	$FOS_{buoyancy}$	$FOS_{rotation}$ $FOS_{overturning}$
High	High	100-year	1.75	2.0	1.75
High	Moderate	50-year	1.5	1.75	1.5
High	Low	25-year	1.5	1.75	1.5
Low	High	100-year	1.75	2.0	1.75
Low	Moderate	25-year	1.5	1.75	1.5
Low	Low	10-year	1.25	1.5	1.25

1. Resistance to Overturn ($MR_{rotation}$ and $MD_{rotation}$)

Driving:

F_i	28,160	lb	Impact Forces (Calc'd in Sliding)
F_d	17,659	lb	Drag Forces (Calc'd in Sliding)
F_{hu}		lb	Upstream Hydrostatic Forces (Calc'd in Sliding)
F_L	-5,298	lb	Lift Forces (Assumed Zero in Buoyancy Calcs)
Y_u	5	ft	Upstream water elevation from model
d_{ubury}	6	ft	Depth at upstream side of structure from channel bottom to point of rotation measured perp to flow
L_s	40	ft	Length of structure parallel to flow
$MD_{overturn}$	**671,766**	**lb*ft**	**Eqn 46**

$$MD_{overturn} = F_i * (Y_u + d_{bury}) + F_d * \left(\frac{Y_u}{2} + d_{bury}\right) + F_{hu} * \left(\frac{Y_u}{3} + du_{bury}\right) + |F_L| * L_s$$

Equation 46

du_{bury} = depth at the upstream side of the structure from channel bottom to point of rotation measured perpendicular to flow
Ls = length of structure measured parallel to flow

$$MR_{overturn} = |F_{hd}| * \left(\frac{Y_d}{2} + dd_{bury}\right) + |F_{passive}| * (dd_{bury}) + (F_b - F_L - F_{piles-v}) * \frac{L_s}{2} + \sum_i^n F_{pile-v_i} * Lpv_i$$ **Equation 47**

$$F_{pile-v_i} = \frac{F_{piles-v}}{N_{piles}}$$ **Equation 48**

L_{pvi} = distance from pile 'i' to the point of rotation measured parallel to flow

$$FOS_{overturn} = \frac{MR_{overturn}}{MD_{overturn}}$$ **Equation 49**

Resisting:

F_{hd}		lb	Downstream Hydrostatic Forces (Calc'd in Sliding)
$F_{passive}$	-15,786	lb	Passive Forces (Calc'd in Sliding)
F_b	118,786	lb	Buoyancy Forces (Calc'd in Sliding)
F_{pile-v}	32,972	lb	Lateral Resistance from Piles (Calc'd in Sliding)
Y_d	2.2	ft	Downstream water elevation
d_{dbury}	6	ft	Depth at downstream side of structure from channel bottom to point of rotation measured perp to flow
N_{piles}	8		Number of Piles (Design)
L_{pvi}	30	ft	Distance from pile to the point of rotation measured parallel to flow.
$F_{pile-vi}$		lb	Eqn 48
$MR_{overturn}$	**1,916,941**	**lb*ft**	**Eqn 47**

Factor of Safety

$FOS_{overturnon}$ = $MR_{overturn}$ / $MD_{overturn}$			
$MD_{overturn}$	671,766	lb	
$MR_{overturn}$	1,916,941	lb	
$FOS_{overturn}$	**2.85**		**STABLE FOR OVERTURN**

Rotation Calculations

Project: Tucannon Big Four Floodplain Restoration - Large Apex Jam
Project Number: 20230017

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

Spreadsheet Description

Purpose: The spreadsheet below is used to calculate the Factor of Safety against LWM structure horizontal rotation.

Assumptions:
1) The LWM structue behaves as a single structure under the design load.
2) The effect of soil in back of the structure is negligible.
3) The structure will be submerged during the design event
4) This LWM structure experiences the largest loads. All LWM structures on site will be designed based on this LWM structure's loadings

Input (Cells Requiring Input from Structure Detail)
Input (Cells requiring Input from Hydraulic Model)
Input (Cells requiring input from a dropdown list)
Input (Cells automatically populated from Input to Interface Tab)
Output (Cells that are automatically updated are this color)
Output (Cells that are automatically updated with previously calculated values are this color)

FBD and Equations:

$$FOS_{rotation} = \frac{MR_{rotation}}{MD_{rotation}}$$ **Equation 45**

Table 4. Minimum recommended factors of safety.

Public Safety Risk	Property Damage Risk	Stability Design Flow Criteria	$FOS_{sliding}$	$FOS_{bouyancy}$	$FOS_{rotation}$ $FOS_{overturning}$
High	High	100-year	1.75	2.0	1.75
High	Moderate	50-year	1.5	1.75	1.5
High	Low	25-year	1.5	1.75	1.5
Low	High	100-year	1.75	2.0	1.75
Low	Moderate	25-year	1.5	1.75	1.5
Low	Low	10-year	1.25	1.5	1.25

Tucannon Big Four Floodplain Restoration has a "LOW" Public Safety Risk Factor and a "MODERATE" Property Damage Risk Factor. The Design Rotation Factor of Safety ($FOS_{rotation}$) for this structure is 1.5 per Table 4 "Minimum Recommended Factors of Safety".

1. Resistance to Rotation ($MR_{rotation}$ and $MD_{rotation}$)

$$MD_{rotation} = (F_i + F_d + F_{hu}) * (\frac{L_{sp}+L_{ebp}}{2})$$ **Equation 42**

L_{sp} = *length of wood structure from tip to point of rotation measured perpendicular to flow*
L_{ebp} = *embedded length of wood structure measured perpendicular to flow*

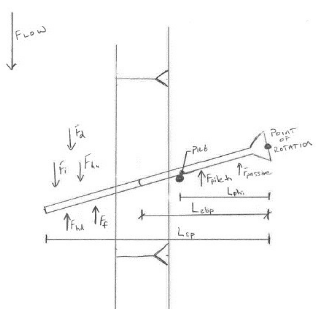
$$MR_{rotation} = \left| F_{hd} * \left(\frac{L_{sp} + L_{ebp}}{2}\right) + F_{passive} * \frac{L_{ebp}}{2} + F_f * \frac{L_{sp}}{2} + \sum_{i}^{n} F_{pile-h_i} * L_{ph_i} \right|$$ **Equation 43**

$$F_{pile-h_i} = \frac{F_{piles-h}}{N_{piles}}$$ **Equation 44**

L_{phi} = *distance from pile 'i' to the point of rotation measured perpendicular to flow*

Driving:

L_{sp}	1	ft	Length of wood structure from tip to point of rotation measured perpendicular to flow
L_{ebp}	1	ft	Embedded length of wood structure measured perp. to flow
F_i	28,160	lb	Impact Forces (Calc'd in Sliding)
F_d	17,659	lb	Drag Forces (Calc'd in Sliding)
F_{hu}		lb	Upstream Hydrostatic Forces (Calc'd in Sliding)
$MD_{rotation}$	**45,819**	**lb*ft**	**Eqn 42**



Resisting:

F_{hd}		lb	Downstream Hydrostatic Forces (Calc'd in Sliding)
$F_{passive}$	-15,786	lb	Passive Forces (Calc'd in Sliding)
F_f	-67,045	lb	Friction Forces (Calc'd in Sliding)
F_{pile-h}	-30,800	lb	Lateral Resistance from Piles (Calc'd in Sliding)
$F_{pile-hi}$	-3,850	lb	Lateral Resistance from Piles (Calc'd in Sliding)
N_{piles}	8		Number of Piles (Design)
L_{phi}	5	ft	Distance from pile to the point of rotation measured perp. to flow.
$MR_{rotation}$	**195,414**	**lb*ft**	**Eqn 43**

Factor of Safety

$FOS_{rotation}$ =	*$MR_{rotation}$ / $MD_{rotation}$*		
$MD_{rotation}$	45,819	lb	
$MR_{rotation}$	195,414	lb	
$FOS_{rotation}$	**4.26**		**STABLE FOR ROTATION**

Recalculate with single log

Summary Comments:

Sliding Calculations

Project: Tucannon Big Four Floodplain Restoration - Large Apex Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

Spreadsheet Description

Purpose: The spreadsheet below is used to calculate the Factor of Safety against LWM sliding.

Assumptions:
1) The LWM structure behaves as a single structure under the design load and will not experience any shearing at joints.
2) The effect of soil in back of the structure is negligible.
3) The structure will be submerged during the design event.
4) Channel velocity (V_c) taken from hydraulic model.
5) This LWM structure experiences the largest loads. All LWM structures on site will be designed based on this LWM structure's loadings.

Input (Cells Requiring Input from Structure Detail)
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Output (Cells automatically updated are this color)
Output (Cells automatically updated with previously calculated values are this color)

FBD and Equations:

$$FOS_{sliding} = \frac{|F_{hd}+F_f+F_{piles-h}+F_{passive}|}{F_d+F_{hu}+F_l}$$ Equation 41

Tucannon Big Four Floodplain Restoration has a "LOW" Public Safety Risk Factor and a "MODERATE" Property Damage Risk Factor. The Design Sliding Factor of Safety ($FOS_{sliding}$) for this structure is 1.5 per Table 4 "Minimum Recommended Factors of Safety".

Table 4. Minimum recommended factors of safety.

Public Safety Risk	Property Damage Risk	Stability Design Flow Criteria	$FOS_{sliding}$	$FOS_{bouyancy}$	$FOS_{rotation}$ $FOS_{overturning}$
High	High	100-year	1.75	2.0	1.75
High	Moderate	50-year	1.5	1.75	1.5
High	Low	25-year	1.5	1.75	1.5
Low	High	100-year	1.75	2.0	1.75
Low	Moderate	25-year	1.5	1.75	1.5
Low	Low	10-year	1.25	1.5	1.25

1. Drag Force (F_d)

Y_u	5.00	ft	Upstream water depth
hdebris	6	ft	Debris height (incl. accumulation)
wdebris	25	ft	Debris width (incl. accumulation)
Debris Shape	Rectangle		
A_{LWM}	150	ft^2	Wetted area of LWM
γ_{water}	62.40	lb/ft^3	Unit weight of water
v_c	9.00	ft/s	Velocity from Model
g	32.20	ft/s^2	Acceleration due to gravity
A_b	150.00	ft^2	Debris area
$w_{channel}$	100	ft	Channel width
c_d	1.50		NLWM Worst Case
F_d	17659	lb	Eqn 19

$$F_d = \frac{C_D * A_{LWM} * \gamma_w * U_c^2}{2 * g}$$ Equation 19

$F_d = drag\ force$
$C_d = drag\ coefficient$
A_{LWM} = area of wetted debris based on the upstream water surface elevation projected normal to flow direction and the potential drift accumulation
$\gamma_w = unit\ weight\ of\ water$
$U_c = velocity\ in\ contracted\ section$
$g = acceleration\ due\ to\ gravity$

Cd can be assumed 0.9 when fully submerged, 1.5 when WSEL withi

$$C_{d-applied} = \frac{C_d}{(1-B)^2}$$ C_d is typically estimated as 1.0 Equation 27

Sliding Calculations

Project: Tucannon Big Four Floodplain Restoration - Large Apex Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

3. Impact Force (F_i)

L_{debris}	40	ft	Length of debris member (Design)
$d_{boledebris}$	2	ft	Bole diameter of debris member (Design)
$d_{rwdebris}$	5	ft	Rootwad diameter of debris member (Design)
V_{debris}	152	ft^3	Volume of debris
γ_{wood}	33	lb/ft^3	Unit weight of wood
w_{debris}	5,011	lb	weight of debris
g	32.2	ft/s^2	Acceleration due to gravity
$V_{channel}$	9.0	ft/s	Velocity from Model
Δt	0.03	sec	Impact Interval (0.03 sec recommended)
C_i	0.6		Coefficient of importance (from Table 6)
C_o	0.8		Coefficient of orientation
C_d	1		Figure 11 (need water depth from model)
Degree of Screening or Sheltering Upstream	No upstream screening, flow path wider than 30'		ASCE 7-05
C_b	1		ASCE 7-05
R_{max}	0.8		Response ratio for impulsive loads
F_i	**28,160**	**lb**	**Eqn 30**

$$F_i = \frac{\pi w_{debris} * V_{channel} * C_i * C_o * C_d * C_b * R_{max}}{2 * g * \Delta t} \quad \textbf{Equation 30}$$

F_i = impact force

w_{debris} = weight of debris

g = acceleration constant due to gravity

$V_{channel}$ = water velocity in channel

Δt = time from initial velocity to zero velocity

C_i = coefficient of importance

C_o = coefficient of orientation = 0.8

C_d = coefficient of depth

C_b = coefficient of blockage

R_{max} = response ratio for impulsive loads = 0.8

Assumption:

***Largest impact force would be generated by structure being struck by floating large key member. For impact calculation, assuming 18" diameter, 40' long member with rootwad impacts structure.**
****See Section 6.3.3 of LWM RBDG (P. 44) for debris loading sizing.**

4. Friction Force (F_f)

ϕ_{bed}	0.66	radians	Calculated for streambed material (small cobble)
μ_{bed}	0.78		Eqn 32
F_{LWMd}		lb	Buoyancy Calcs
$F_{boulder}$		lb	Buoyancy Calcs
F_{soil}	140891	lb	Buoyancy Calcs
$F_{piles-v}$	32972	lb	Buoyancy Calcs
F_{LWMs}	-49780	lb	Buoyancy Calcs
F_L	-5298	lb	Buoyancy Calcs
F_b	118,786	lb	Eqn 17
F_f	**-67,045**	**lb**	**Eqn 31**

$$F_f = -\mu_{bed} * (F_b - F_{piles-v}) \quad \text{Equation 31}$$

F_f = force due to frictional resistance

$F_b - F_{piles-v} > 0$

$$\mu_{bed} = \tan \phi \quad \text{Equation 32}$$

$$F_b = F_{LWMs} + F_{LWMd} + F_L + F_{boulder} + F_{soil} + F_{piles-v} \quad \textit{Equation 17}$$

Note:
***If buoyancy forces are less than vertical pile forces (Fb-Fpiles-v<0), then friction force = 0.**

Sliding Calculations

Project: Tucannon Big Four Floodplain Restoration - Large Apex Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

5. Passive Forces ($F_{passive}$)

Φ_{bank}	0.63	radians	Calculated for bank material (very course gravel)
K_p	3.85		Eqn 34
γ_{water}	62.4	lb/ft^3	Unit weight of water
γ_{soil}	120	lb/ft^3	Unit weight of soil
γ_{sat}	137	lb/ft^3	Previously calculated for buoyancy calcs
$N_{logssub1}$	3		Number of log type 1 (from detail)
Orientation$_1$**	Perpendicular		Perpendicular or Parallel to flow
L_{eb1}	30	ft	Length of log type 1 (from detail)
d_{bole1}	1.5	ft	Diameter of log type 1 (from detail)
D_{sub1}		ft	Depth of submerged soil above log 1
D_{dry1}		ft	Depth of dry soil above log 1
σ_{v1}		lb/ft^2	
$\sigma_{v1}*L_{eb1}*\gamma_{soil}$		lb	
$N_{logssub2}$	1		Number of log type 2 (from detail)
Orientation$_2$**	Perpendicular		Perpendicular or Parallel to flow
L_{eb2}	25	ft	Length of log type 2 (from detail)
d_{bole2}	1	ft	Diameter of log type 2 (from detail)
D_{sub2}		ft	Depth of submerged soil above log 2
D_{dry2}		ft	Depth of dry soil above log 2
σ_{v2}		lb/ft^2	
$\sigma_{v2}*L_{eb2}*\gamma_{soil}$		lb	
$N_{logssub3}$	7		Number of log type 3(from detail)
Orientation$_3$**	Parallel		Perpendicular or Parallel to flow
L_{eb3}	27	ft	Length of log type 3 (from detail)
d_{bole3}	2	ft	Diameter of log type 3 (from detail)
D_{sub3}	5	ft	Depth of submerged soil above log 3
D_{dry3}		ft	Depth of dry soil above log 3
σ_{v3}	373	lb/ft^2	
$\sigma_{v3}*L_{eb3}*\gamma_{soil}$	8,197	lb	
$F_{passive}$	**-15,786**	**lb**	**Eqn 31**

**** Eqns 33 through 35 represent the case where passive forces act along the length of a log perpendicular to flow. If log is parallel to flow,**

$$F_{passive} = -0.5 * K_p * \sum_i^n \sigma_{v_i} * L_{em_i} * d_{log_i}$$ Equ

$$K_p = \frac{1+\sin\emptyset}{1-\sin\emptyset}$$ Equ

$$\sigma_{v_i} = D_{sub_i} * (\gamma_{sat} - \gamma_{water}) + D_{dry_i} * \gamma_{soil}$$ Equ

D_{subi} = depth of submerged soil above log i
D_{dryi} = depth of dry soil above log i
L_{emi} = embedded length of log i
d_{logi} = diameter of log i

Sliding Calculations

Project: Tucannon Big Four Floodplain Restoration - Large Apex Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

6. Lateral Resistance from Piles ($F_{piles-h}$)

N_{piles}	8		Number of piles (Design)
d_{piles}	1	ft	Diameter of piles (Design)
L_{piles}	12	ft	Embedded length of piles below scour (Design)
Placement Method	Excavated		Method of pile placement
Placement Multiplier	0.25		See RBDG (P. 52)
Pile Placement Location	Bed		Bed or Bank
γ_{water}	62.4	lb/ft^3	Unit weight of water
γ_{soil}	126	lb/ft^3	Unit weight of soil
γ_e	63.6	lb/ft^3	Eqn 37
ϕ_{soil}	0.66	radians	Calculated for material pile is located
K_p	4.20		Eqn 38
h_{load}**	3	ft	Height above scour depth load is applied
$F_{piles-h}$	**-30,800**	**lb**	**Eqn 15**

*** Top 2' of pile embedment disregarded for calculation to account for vortex shedding.**
**** Analysis also assumes that the resultant force is located at half of the flow depth on the upstream side of the LWM structure to produce a conservative moment on the pile.**

$$F_{piles-h} = -N_{piles} * \frac{L_{pile}^3 * \frac{1}{2} * \gamma_e * d_{pile} * K_p}{h_{load} + L_{pile}}$$ Equation 36

N_{piles} = number of piles
L_{pile} = length of pile embedded below potential scour depth

$$\gamma_e = \gamma_s - \gamma_w$$ effective unit weight of soil — Equation 37

γ_s = dry unit weight of the soil

γ_w = unit weight of the soil
d_{pile} = diameter of the pile
h_{load} = height above the potential scour depth the load is applied

$$K_p = \frac{1+\sin\emptyset}{1-\sin\emptyset}$$ Equation 38

Factor of Safety

$FOS_{sliding}$ =	*$(F_{hd} + F_f + F_{piles-h} + F_{passive}) / (F_d + F_{hu} + F_i)$*		
F_d	17,659	lb	
F_{hu}		lb	
F_{hd}		lb	
F_i	28,160	lb	
F_f	-67,045	lb	
$F_{passive}$	-15,786	lb	
$F_{piles-h}$	-30,800	lb	
$FOS_{sliding}$	**2.48**		**STABLE FOR SLIDING**

Summary Comments:

Appendix C

Wood Habitat Structure Stability Calculations

WHS Type #2 Medium Apex Jam

Buoyancy Calculations

Project:	Tucannon Big Four Floodplain Restoration - Medium Apex Jam	**Analyst:**	BF
Project No.:	20230017	**Calculations Checked By:**	AJ
		Latest Revision:	4/2/2025

Spreadsheet Description

- The spreadsheet below is used to calculate the Factor of Safety against Buoyant uplift of the LWM

Assumptions:

1) The LWM structure behaves as a single structure under the design load and will not experience any shearing at joints
2) The LWM structure will be submerged during the design event.
3) Negative buoyancy is uplift, positive numbers equals downward.
4) Ballast material remains intact and is not scoured out.
5) The uplift due to racking material is evenly dividing among all layers.

Input (Cells Requiring Input from Structure Detail)
Input (Cells requiring Input from Hydraulic Model)
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Output (Cells automatically updated are this color)
Output (Cells automatically updated with previously calculated values are this

FBD and Equations:

$$FOS_b = \frac{F_{LWMd} + F_{boulders} + F_{soil} + F_{piles-e}}{|F_{LWMs} + F_L|}$$ **Equation 18**

FOS_b = buoyancy factor of safety

Tucannon Big Four Floodplain Restoration has a "LOW" Public Safety Risk Factor and a "MODERATE" Property Damage Risk Factor. The Design buoyancy factor of safety (FOS_b) for this structure is 1.75 per Table 4 "*Minimum Recommended Factors of Safety*".

Table 4. Minimum recommended factors of safety.

Public Safety Risk	Property Damage Risk	Stability Design Flow Criteria	$FOS_{sliding}$	$FOS_{buoyancy}$	$FOS_{rotation}$ $FOS_{overturning}$
High	High	100-year	1.75	2.0	1.75
High	Moderate	50-year	1.5	1.75	1.5
High	Low	25-year	1.5	1.75	1.5
Low	High	100-year	1.75	2.0	1.75
Low	Moderate	25-year	1.5	1.75	1.5
Low	Low	10-year	1.25	1.5	1.25

1. Large Wood Material Force - Dry (F_{LWMd})

$$F_{LWMd} = V_{LWMd} * \gamma_{wood}$$ **Equation 3**

V_{LWMd} = volume of dry large wood material

Comment: Assumed to be zero because structure assumed to be submerged during design event.

2. Boulder Ballast Force ($F_{boulder}$)

$N_{bouldersub}$			Number of submerged boulders (from design)
$d_{bouldersub}$		ft	Effective diameter of submerged boulder (ft, from spec)
$\gamma_{boulder}$	146	lb/ft^3	unit weight of boulders (Table 5)
γ_{water}	62.4	lb/ft^3	unit weight of water
$F_{bouldersub}$		lb	Eqn. 6
$N_{boulderdry}$			Number of dry boulders (from detail)
$d_{boulderdry}$		ft	Effective diameter of dry boulder (ft, from spec)
$F_{boulderdry}$		lb	Eqn. 7
$F_{boulder}$		**lb**	**Eqn. 5**

$$F_{boulder} = F_{bouldersub} + F_{boulderdry}$$ **Equation 5**

$$F_{bouldersub} = N_{bouldersub} * \frac{\pi}{6} * d^3_{bouldersub} * (\gamma_{boulder} - \gamma_w)$$ **Equation 6**

$N_{bouldersub}$ = number of submerged boulders
$d_{bouldersub}$ = effective diameter of submerged boulders
$\gamma_{boulder}$ = unit weight of boulders

$$F_{boulderdry} = N_{boulderdry} * \frac{\pi}{6} * d^3_{boulderdry} * \gamma_{boulder}$$ **Equation 7**

$N_{boulderdry}$ = number of unsubmerged boulders
$d_{boulderdry}$ = effective diameter of unsubmerged boulders

Comment: The intent is design without the use of boulders so it is assumed no boulders are used.

Buoyancy Calculations

Project: Tucannon Big Four Floodplain Restoration - Medium Apex Jam
Project No.: 20230017

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

3. Soil Backfill Force (F_{soil})

$N_{logssub1}$	3		Number of Type 1 buried logs (from detail)
L_{eb1}	20	ft	Average embedded length of Type 1 logs (from detail)
d_{bole1}	1	ft	Average diameter of Type 1 logs (from detail)
$h_{soilsub1}$		ft	Average height of submerged soil above Type 1 log (from detail)
$V_{soilsub1}$		ft^3	Volume of submerged soil above Type 1 log (from detail)
$h_{soildry1}$		ft	Average height of dry soil above Type 1 log (from detail)
$V_{soildry1}$		ft^3	Volume of dry soil above Type 1 log (from detail)
$N_{logssub2}$	5		Number of Type 2 buried logs (from detail)
L_{eb2}	27	ft	Average embedded length of Type 2 logs (from detail)
d_{bole2}	1.5	ft	Average diameter of Type 2 logs (from detail)
$h_{soilsub2}$	3	ft	Average height of submerged soil above Type 2 log (from detail)
$V_{soilsub2}$	608	ft^3	Volume of submerged soil above Type 2 log (from detail)
$h_{soildry2}$		ft	Average height of dry soil above Type 2 log (from detail)
$V_{soildry2}$		ft^3	Volume of dry soil above Type 2 log (from detail)
$N_{logssub3}$	4		Number of Type 3 buried logs (from detail)
L_{eb3}	15	ft	Average embedded length of Type 3 logs (from detail)
d_{bole3}	0.5	ft	Average diameter of Type 3 logs (from detail)
$h_{soilsub3}$		ft	Average height of submerged soil above Type 3 log (from detail)
$V_{soilsub3}$		ft^3	Volume of submerged soil above Type 3 log (from detail)
$h_{soildry3}$		ft	Average height of dry soil above Type 3 log (from detail)
$V_{soildry3}$		ft^3	Volume of dry soil above Type 3 log (from detail)
γ_{soil}	120	lb/ft^3	Specific Gravity of bank/backfill material (Table 5)
γ_{water}	62.4	lb/ft^3	Unit weight of water
SG_{rock}	2.64		Specific Gravity of Rock (Using unit weight of bedrock from Table 5)
e	0.37		Eqn. 14
γ_{sat}	137	lb/ft^3	Eqn. 13
γ'_{soil}	74.5	lb/ft^3	Eqn. 12
F_{soil}	**45,286**	**lb**	**Eqn. 8**

$$F_{soil} = \sum_i^n V_{soilsub_i} * \gamma'_{soil} + V_{soildry_i} * \gamma_{soil}$$ **Equation 8**

$$V_{soilsub_i} = L_{eb_i} d_{bole_i} h_{soilsub_i}$$ **Equation 9**

$V_{soilsubi}$ = volume of submerged soil above log i
L_{ebi} = embedded length of log i
d_{bolei} = bole diameter of log i
$h_{soilsubi}$ = height of submerged soil above log i

$$V_{soildry_i} = L_{eb_i} d_{bole_i} h_{soildry_i}$$ ***Equation 10***

$V_{soildryi}$ = volume of dry soil above log i
$h_{soildryi}$ = height of dry soil above log i

$$\gamma_{soil} = (99.2 + 18.6 * \log(d_{50}))$$ **Equation 11**

d_{50} = median grain size in millimeters

$$\gamma'_{soil} = \gamma_{sat} - \gamma_w$$ **Equation 12**

$$\gamma_{sat} = \frac{(SG_{rock} + e) * \gamma_w}{1 + e}$$ **Equation 13**

$$e = \frac{SG_{rock} * \gamma_w}{\gamma_{soil}} - 1$$ **Equation 14**

Buoyancy Calculations

Project: Tucannon Big Four Floodplain Restoration - Medium Apex Jam
Project No.: 20230017

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

4. Pier Log Friction

$$F_{piles-v} = N_{piles} * \pi * d_{piles} * L_{piles}(k_s * \tan\frac{2}{3}\emptyset * \sigma' + \frac{d_{piles}}{4} * (\gamma_{wood} - \gamma_w))$$ **Equation 15**

N_{piles} = number of piles
d_{piles} = diameter of piles
L_{piles} = embedded length of piles
k_s = coefficient of lateral earth pressure (0.5 to 1.5 depending on soil and density)
ϕ = internal angle of friction of soils

$$\sigma' = L_{piles} * (\gamma_{sat} - \gamma_w)$$ **Equation 16**

N_{piles}	6		Number of piles (Design)
d_{piles}	1	ft	Diameter of piles (Design)
L_{piles}	12	ft	Embedded length of piles (Design)
k_s	1		Coefficient of lateral earth pressure (0.5 to 1.5 depending on soil and density)
Placement Method	Excavated		Method of pile placement
Placement Multiplier	0.25		See RBDG (P. 52)
Pile Placement Location	Bank		Bed or Bank
ϕ_{soil}	0.63	rad	Internal angle of friction of soils (Table 5)
γ_{soil}	120	lb/ft^3	Specific Weight of Soil
e	0.37		Eqn. 14
γ_{sat}	137	lb/ft^3	Eqn. 13
γ_{water}	62.4	lb/ft^3	Unit weight of water
σ'	895	lb/ft^2	Eqn 16
γ_{wood}	33	lb/ft^3	Unit weight of wood
$F_{piles-v}$	**22,106**	**lb**	**Eqn 15**

$$\gamma_{sat} = \frac{(SG_{rock} + e) * \gamma_w}{1 + e}$$ **Equation 13**

$$e = \frac{SG_{rock} * \gamma_w}{\gamma_{soil}} - 1$$ **Equation 14**

Assumptions:
*** k_s = 1**
**** This calculation is based on the assumption that piles are driven or vibrated into place. If piles are drilled or excavated, the associated coefficicient of lateral earth pressures shall be approx. 50% and 25% of the driven value, respectively.**
***** For use in buoyancy calculations, piles must be mechanically fastened.**
****** Top 2' of pile embedment disregarded for calculation to account for vortex shedding.**

5. Large Wood Material Force - Submerged (F_{LWMs})

$$F_{LWMs} = V_{LWMs} * (\gamma_{wood} - \gamma_w)$$ **Equation 2**

V_{LWMs} = volume of submerged large wood material
γ_{wood} = unit weight of wood
γ_w = unit weight of water

$N_{logssub1}$	3		Number of log type 1 (from detail)
L_{log1}	20	ft	Length of log type 1 (from detail)
d_{bole1}	1	ft	Diameter of log type 1 (from detail)
d_{rw1}		ft	Diameter of rootwad of log type 1 (from detail)
V_{LWMs1}	47	ft^3	Volume of LWM1
$N_{logssub2}$	5		Number of log type 2 (from detail)
L_{eb2}	27	ft	Length of log type 2 (from detail)
d_{bole2}	1.5	ft	Diameter of log type 2 (from detail)
d_{rw2}	3.75	ft	Diameter of rootwad of log type 2 (from detail)
V_{LWMs2}	294	ft^3	Volume of LWM2
$N_{logssub3}$	6		Number of log type 3 (from detail)
L_{eb3}	12	ft	Length of log type 3 (from detail)
d_{bole3}	1	ft	Diameter of log type 3 (from detail)

Volume of Rootwad

National Large Wood Manual. 2016
Equation 6-4 (p. 6-38)

$V_{rw} = \pi * t_k * w_k^2 / 3$
$\pi * (2d_{bole}) * (1/2d_{rw})^2 / 3$

t_k = Thickness of rootwad measured in direction parallel to trunk
= 4 times the radius of the log ($4r_k$ or

w_k =
Radius of rootwad

Buoyancy Calculations

Project: Tucannon Big Four Floodplain Restoration - Medium Apex Jam
Project No.: 20230017

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

d_{rw3}		ft	Diameter of rootwad of log type 3 (from detail)
V_{LWMs3}	57	ft^3	Volume of LWM3
V_{LWMs}	397	ft^3	Volume of LWM
γ_{wood}	33.0	lb/ft^3	Unit weight of logs
γ_w	62.4	lb/ft^3	Unit weight of water
F_{LWMs}	**-11,685**	**lb**	**Eqn. 3**

= 2.5 times the radius of the log ($2.5r_k$ or $1.25d_{bole}$) or 1/2 d_{rw} specified

6. Lift Forces (F_L)

$$F_L = -\frac{C_L * A_{LWM} * \gamma_w * U_o^2}{2 * g} \quad \text{Equation 4}$$

C_L = lift coefficient
A_{LWM} = area of large woody material perpendicular to flow
u_u = upstream channel velocity at design event
g = acceleration due to gravity

C_L	0.45		Lift Coefficient
A_{LWM}	75	ft^2	Calc'd in Drag Forces
γ_w	62.4	lb/ft^3	Unit weight of water
U_o	7.0	ft/s	upstream velocity (from model)
g	32.2	ft/s^2	Unit weight of water
F_L	**-1,602**	**lb**	**Eqn. 4**

Comment: Lift forces neglected per Section 6.4.2 of BOR Risk Based Design Guidelines

Factor of Safety

FOS_b =	$(F_{LMDd} + F_{boulders} + F_{soil} + F_{piles\text{-}v}) / (F_{LWMs} + F_L)$		
F_{LWMd}		lb	Assumed Zero
$F_{boulder}$		lb	
F_{soil}	45,286	lb	
$F_{piles\text{-}v}$	22,106	lb	
F_{LWMs}	-11,685	lb	
F_L	-1,602	lb	
FOS_b	**5.07**		**STABLE FOR BUOYANCY**

Summary Comments:

Overturning Calculations

Project: Tucannon Big Four Floodplain Restoration - Medium Apex Jam
Project Number: 20230017

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

Spreadsheet Description

Purpose: The spreadsheet below is used to calculate the Factor of Safety against vertical overturning.

Assumptions:
1) The LWM structure behaves as a single structure under the design load.
2) The effect of soil in back of the structure is negligible.
3) The structure will be submerged during the design event
4) This LWM structure experiences the largest loads. All LWM structures on site will be designed based on this LWM structure's loadings

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FBD and Equations:

$$FOS_{overturn} = \frac{MR_{overturn}}{MD_{overturn}}$$ **Equation 49**

Tucannon Big Four Floodplain Restoration has a "LOW" Public Safety Risk Factor and a "MODERATE" Property Damage Risk Factor. The Design Overturn Factor of Safety ($FOS_{overturn}$) for this structure is 1.5 per Table 4 "Minimum Recommended Factors of Safety".

Table 4. Minimum recommended factors of safety.

Public Safety Risk	Property Damage Risk	Stability Design Flow Criteria	$FOS_{sliding}$	$FOS_{buoyancy}$	$FOS_{rotation}$ $FOS_{overturning}$
High	High	100-year	1.75	2.0	1.75
High	Moderate	50-year	1.5	1.75	1.5
High	Low	25-year	1.5	1.75	1.5
Low	High	100-year	1.75	2.0	1.75
Low	Moderate	25-year	1.5	1.75	1.5
Low	Low	10-year	1.25	1.5	1.25

$$MD_{overturn} = F_i * (Y_u + d_{bury}) + F_d * \left(\frac{Y_u}{2} + d_{bury}\right) + F_{hu} * \left(\frac{Y_u}{3} + du_{bury}\right) + |F_L| * L_s$$

Equation 46

du_{bury} = *depth at the upstream side of the structure from channel bottom to point of rotation measured perpendicular to flow*
Ls = *length of structure measured parallel to flow*

$$MR_{overturn} = |F_{hd}| * \left(\frac{Y_d}{2} + dd_{bury}\right) + |F_{passive}| * (dd_{bury}) + (F_b - F_L - F_{piles-v}) * \frac{L_s}{2} + \sum_i^n F_{pile-v_i} * Lpv_i$$ **Equation 47**

$$F_{pile-v_i} = \frac{F_{piles-v}}{N_{piles}}$$ **Equation 48**

L_{pvi} = *distance from pile 'i' to the point of rotation measured parallel to flow*

$$FOS_{overturn} = \frac{MR_{overturn}}{MD_{overturn}}$$ **Equation 49**

1. Resistance to Overturn ($MR_{rotation}$ and $MD_{rotation}$)

Driving:

F_i	7,073	lb	Impact Forces (Calc'd in Sliding)
F_d	5,341	lb	Drag Forces (Calc'd in Sliding)
F_{hu}		lb	Upstream Hydrostatic Forces (Calc'd in Sliding)
F_L	-1,602	lb	Lift Forces (Assumed Zero in Buoyancy Calcs)
Y_u	5	ft	Upstream water elevation from model
d_{ubury}		ft	Depth at upstream side of structure from channel bottom to point of rotation measured perp to flow
L_s	40	ft	Length of structure parallel to flow
$MD_{overturn}$	**112,815**	**lb*ft**	**Eqn 46**

Resisting:

F_{hd}		lb	Downstream Hydrostatic Forces (Calc'd in Sliding)
$F_{passive}$	-3,806	lb	Passive Forces (Calc'd in Sliding)
F_b	54,105	lb	Buoyancy Forces (Calc'd in Sliding)
F_{pile-v}	22,106	lb	Lateral Resistance from Piles (Calc'd in Sliding)
Y_d	2.93	ft	Downstream water elevation
d_{dbury}		ft	Depth at downstream side of structure from channel bottom to point of rotation measured perp to flow
N_{piles}	6		Number of Piles (Design)
L_{pvi}	7	ft	Distance from pile to the point of rotation measured parallel to flow.
$F_{pile-vi}$		lb	Eqn 48
$MR_{overturn}$	**672,020**	**lb*ft**	**Eqn 47**

Factor of Safety

$FOS_{overturnon}$ = $MR_{overturn}$ / $MD_{overturn}$			
$MD_{overturn}$	112,815	lb	
$MR_{overturn}$	672,020	lb	
$FOS_{overturn}$	**5.96**		**STABLE FOR OVERTURN**

Rotation Calculations

Project: Tucannon Big Four Floodplain Restoration - Medium Apex Jam
Project Number: 20230017

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

Spreadsheet Description

Purpose: The spreadsheet below is used to calculate the Factor of Safety against LWM structure horizontal rotation.

Assumptions:
1) The LWM structue behaves as a single structure under the design load.
2) The effect of soil in back of the structure is negligible.
3) The structure will be submerged during the design event
4) This LWM structure experiences the largest loads. All LWM structures on site will be designed based on this LWM structure's loadings

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Output (Cells that are automatically updated with previously calculated values are this color)

FBD and Equations:

$$FOS_{rotation} = \frac{MR_{rotation}}{MD_{rotation}} \quad \textbf{Equation 45}$$

Table 4. Minimum recommended factors of safety.

Public Safety Risk	Property Damage Risk	Stability Design Flow Criteria	$FOS_{sliding}$	$FOS_{buoyancy}$	$FOS_{rotation}$ $FOS_{overturning}$
High	High	100-year	1.75	2.0	1.75
High	Moderate	50-year	1.5	1.75	1.5
High	Low	25-year	1.5	1.75	1.5
Low	High	100-year	1.75	2.0	1.75
Low	Moderate	25-year	1.5	1.75	1.5
Low	Low	10-year	1.25	1.5	1.25

Tucannon Big Four Floodplain Restoration has a "LOW" Public Safety Risk Factor and a "MODERATE" Property Damage Risk Factor. The Design Rotation Factor of Safety ($FOS_{rotation}$) for this structure is 1.5 per Table 4 "Minimum Recommended Factors of Safety".

1. Resistance to Rotation ($MR_{rotation}$ and $MD_{rotation}$)

$$MD_{rotation} = (F_i + F_d + F_{hu}) * (\frac{L_{sp}+L_{ebp}}{2}) \quad \textbf{Equation 42}$$

L_{sp} = *length of wood structure from tip to point of rotation measured perpendicular to flow*

L_{ebp} = *embedded length of wood structure measured perpendicular to flow*

$$MR_{rotation} = \left| F_{hd} * \left(\frac{L_{sp}+L_{ebp}}{2}\right) + F_{passive} * \frac{L_{ebp}}{2} + F_f * \frac{L_{sp}}{2} + \sum_i^n F_{pile-h_i} * L_{ph_i} \right| \quad \textbf{Equation 43}$$

$$F_{pile-h_i} = \frac{F_{piles-h}}{N_{piles}} \quad \textbf{Equation 44}$$

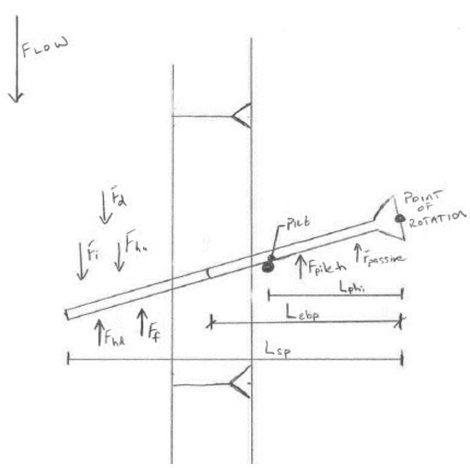
L_{phi} = *distance from pile 'i' to the point of rotation measured perpendicular to flow*

Driving:

L_{sp}	13	ft	Length of wood structure from tip to point of rotation measured perpendicular to flow
L_{ebp}	7	ft	Embedded length of wood structure measured perp. to flow
F_i	7,073	lb	Impact Forces (Calc'd in Sliding)
F_d	5,341	lb	Drag Forces (Calc'd in Sliding)
F_{hu}		lb	Upstream Hydrostatic Forces (Calc'd in Sliding)
$MD_{rotation}$	**124,146**	**lb*ft**	**Eqn 42**

Resisting:

F_{hd}		lb	Downstream Hydrostatic Forces (Calc'd in Sliding)
$F_{passive}$	-3,806	lb	Passive Forces (Calc'd in Sliding)
F_f	-25,000	lb	Friction Forces (Calc'd in Sliding)
F_{pile-h}	-23,896	lb	Lateral Resistance from Piles (Calc'd in Sliding)
$F_{pile-hi}$	-3,983	lb	Lateral Resistance from Piles (Calc'd in Sliding)
N_{piles}	6		Number of Piles (Design)
L_{phi}	25	ft	Distance from pile to the point of rotation measured perp. to flow.
$MR_{rotation}$	**773,227**	**lb*ft**	**Eqn 43**



Factor of Safety

$FOS_{rotation}$ =	$MR_{rotation}$ / $MD_{rotation}$		
$MD_{rotation}$	124,146	lb	
$MR_{rotation}$	773,227	lb	
$FOS_{rotation}$	**6.23**		**STABLE FOR ROTATION**

Summary Comments:

Sliding Calculations

Project: Tucannon Big Four Floodplain Restoration - Medium Apex Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

Spreadsheet Description

Purpose: The spreadsheet below is used to calculate the Factor of Safety against LWM sliding.

Assumptions:
1) The LWM structure behaves as a single structure under the design load and will not experience any shearing at joints.
2) The effect of soil in back of the structure is negligible.
3) The structure will be submerged during the design event.
4) Channel velocity (V_c) taken from hydraulic model.
5) This LWM structure experiences the largest loads. All LWM structures on site will be designed based on this LWM structure's loadings.

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FBD and Equations:

$$FOS_{sliding} = \frac{|F_{hd}+F_f+F_{piles-h}+F_{passive}|}{F_d+F_{hu}+F_l} \quad \text{Equation 41}$$

Tucannon Big Four Floodplain Restoration has a "LOW" Public Safety Risk Factor and a "MODERATE" Property Damage Risk Factor. The Design Sliding Factor of Safety ($FOS_{sliding}$) for this structure is 1.5 per Table 4 "Minimum Recommended Factors of Safety".

Table 4. Minimum recommended factors of safety.

Public Safety Risk	Property Damage Risk	Stability Design Flow Criteria	$FOS_{sliding}$	$FOS_{bouyancy}$	$FOS_{rotation}$ $FOS_{overturning}$
High	High	100-year	1.75	2.0	1.75
High	Moderate	50-year	1.5	1.75	1.5
High	Low	25-year	1.5	1.75	1.5
Low	High	100-year	1.75	2.0	1.75
Low	Moderate	25-year	1.5	1.75	1.5
Low	Low	10-year	1.25	1.5	1.25

1. Drag Force (F_d)

Y_u	5.00	ft	Upstream water depth
hdebris	5	ft	Debris height (incl. accumulation)
wdebris	15	ft	Debris width (incl. accumulation)
Debris Shape	Rectangle		
A_{LWM}	75	ft^2	Wetted area of LWM
γ_{water}	62.40	lb/ft^3	Unit weight of water
v_c	7.00	ft/s	Velocity from Model
g	32.20	ft/s^2	Acceleration due to gravity
A_b	75.00	ft^2	Debris area
$w_{channel}$	100	ft	Channel width
c_d	1.50		NLWM Worst Case
F_d	5341	lb	Eqn 19

$$F_d = \frac{C_D * A_{LWM} * \gamma_w * U_c^2}{2 * g} \quad \text{Equation 19}$$

F_d = drag force
C_d = drag coefficient
A_{LWM} = area of wetted debris based on the upstream water surface elevation projected normal to flow direction and the potential drift accumulation
γ_w = unit weight of water
U_c = velocity in contracted section
g = acceleration due to gravity

Cd can be assumed 0.9 when fully submerged, 1.5 when WSEL withi

$$C_{d-applied} = \frac{C_d}{(1-B)^2}$$

C_d is typically estimated as 1.0 Equation 27

Sliding Calculations

Project: Tucannon Big Four Floodplain Restoration - Medium Apex Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

3. Impact Force (F_i)

L_{debris}	40	ft	Length of debris member (Design)
$d_{boledebris}$	1.5	ft	Bole diameter of debris member (Design)
$d_{rwdebris}$	3.75	ft	Rootwad diameter of debris member (Design)
V_{debris}	82	ft^3	Volume of debris
γ_{wood}	33	lb/ft^3	Unit weight of wood
w_{debris}	2,697	lb	weight of debris
g	32.2	ft/s^2	Acceleration due to gravity
$V_{channel}$	7.0	ft/s	Velocity from Model
Δt	0.03	sec	Impact Interval (0.03 sec recommended)
C_i	0.6		Coefficient of importance (from Table 6)
C_o	0.8		Coefficient of orientation
C_d	1		Figure 11 (need water depth from model)
Degree of Screening or Sheltering Upstream	Limited upstream screening, flow path 20' wide		ASCE 7-05
C_b	0.6		ASCE 7-05
R_{max}	0.8		Response ratio for impulsive loads
F_i	**7,073**	**lb**	**Eqn 30**

$$F_i = \frac{\pi w_{debris} * V_{channel} * C_i * C_o * C_d * C_b * R_{max}}{2 * g * \Delta t}$$ **Equation 30**

F_i = impact force

w_{debris} = weight of debris

g = acceleration constant due to gravity

$V_{channel}$ = water velocity in channel

Δt = time from initial velocity to zero velocity

C_i = coefficient of importance

C_o = coefficient of orientation = 0.8

C_d = coefficient of depth

C_b = coefficient of blockage

R_{max} = response ratio for impulsive loads = 0.8

Assumption:

***Largest impact force would be generated by structure being struck by floating large key member. For impact calculation, assuming 18" diameter, 40' long member with rootwad impacts structure.**
****See Section 6.3.3 of LWM RBDG (P. 44) for debris loading sizing.**

4. Friction Force (F_f)

ϕ_{bed}	0.66	radians	Calculated for streambed material (small cobble)
μ_{bed}	0.78		Eqn 32
F_{LWMd}		lb	Buoyancy Calcs
$F_{boulder}$		lb	Buoyancy Calcs
F_{soil}	45286	lb	Buoyancy Calcs
$F_{piles-v}$	22106	lb	Buoyancy Calcs
F_{LWMs}	-11685	lb	Buoyancy Calcs
F_L	-1602	lb	Buoyancy Calcs
F_b	54,105	lb	Eqn 17
F_f	**-25,000**	**lb**	**Eqn 31**

$$F_f = -\mu_{bed} * (F_b - F_{piles-v})$$ Equation 31

F_f = force due to frictional resistance

$F_b - F_{piles-v} > 0$

$$\mu_{bed} = \tan \emptyset$$ Equation 32

$$F_b = F_{LWMs} + F_{LWMd} + F_L + F_{boulder} + F_{soil} + F_{piles-v}$$ *Equation 17*

Note:
***If buoyancy forces are less than vertical pile forces (Fb-Fpiles-v<0), then friction force = 0.**

Sliding Calculations

Project: Tucannon Big Four Floodplain Restoration - Medium Apex Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

5. Passive Forces ($F_{passive}$)

ϕ_{bank}	0.63	radians	Calculated for bank material (very course gravel)
K_p	3.85		Eqn 34
γ_{water}	62.4	lb/ft^3	Unit weight of water
γ_{soil}	120	lb/ft^3	Unit weight of soil
γ_{sat}	137	lb/ft^3	Previously calculated for buoyancy calcs
$N_{logssub1}$	3		Number of log type 1 (from detail)
Orientation$_1$**	Perpendicular		Perpendicular or Parallel to flow
L_{eb1}	20	ft	Length of log type 1 (from detail)
d_{bole1}	1	ft	Diameter of log type 1 (from detail)
D_{sub1}		ft	Depth of submerged soil above log 1
D_{dry1}		ft	Depth of dry soil above log 1
σ_{v1}		lb/ft^2	
$\sigma_{v1}*L_{eb1}*\gamma_{soil}$		lb	
$N_{logssub2}$	5		Number of log type 2 (from detail)
Orientation$_2$**	Parallel		Perpendicular or Parallel to flow
L_{eb2}	27	ft	Length of log type 2 (from detail)
d_{bole2}	1.5	ft	Diameter of log type 2 (from detail)
D_{sub2}	3	ft	Depth of submerged soil above log 2
D_{dry2}		ft	Depth of dry soil above log 2
σ_{v2}	224	lb/ft^2	
$\sigma_{v2}*L_{eb2}*\gamma_{soil}$	1,976	lb	
$N_{logssub3}$	4		Number of log type 3(from detail)
Orientation$_3$**	Perpendicular		Perpendicular or Parallel to flow
L_{eb3}	15	ft	Length of log type 3 (from detail)
d_{bole3}	0.5	ft	Diameter of log type 3 (from detail)
D_{sub3}		ft	Depth of submerged soil above log 3
D_{dry3}		ft	Depth of dry soil above log 3
σ_{v3}		lb/ft^2	
$\sigma_{v3}*L_{eb3}*\gamma_{soil}$		lb	
$F_{passive}$	**-3,806**	**lb**	**Eqn 31**

3.85184

** Eqns 33 through 35 represent the case where passive forces act

$$F_{passive} = -0.5 * K_p * \sum_i^n \sigma_{v_i} * L_{em_i} * d_{log_i}$$ Equ

$$K_p = \frac{1+\sin\phi}{1-\sin\phi}$$ Equ

$$\sigma_{v_i} = D_{sub_i} * (\gamma_{sat} - \gamma_{water}) + D_{dry_i} * \gamma_{soil}$$ Equ

D_{subi} = depth of submerged soil above log i
D_{dryi} = depth of dry soil above log i
L_{emi} = embedded length of log i
d_{logi} = diameter of log i

Sliding Calculations

Project: Tucannon Big Four Floodplain Restoration - Medium Apex Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

6. Lateral Resistance from Piles ($F_{piles\text{-}h}$)

$$F_{piles-h} = -N_{piles} * \frac{L_{pile}^{3} * \frac{1}{2} * \gamma_e * d_{pile} * K_p}{h_{load} + L_{pile}}$$ Equation 36

N_{piles} = number of piles
L_{pile} = length of pile embedded below potential scour depth

$$\gamma_e = \gamma_s - \gamma_w$$ effective unit weight of soil — Equation 37

γ_s = dry unit weight of the soil

γ_w = unit weight of the soil
d_{pile} = diameter of the pile
h_{load} = height above the potential scour depth the load is applied

$$K_p = \frac{1+\sin\phi}{1-\sin\phi}$$ Equation 38

N_{piles}	6		Number of piles (Design)
d_{piles}	1	ft	Diameter of piles (Design)
L_{piles}	12	ft	Embedded length of piles below scour (Design)
Placement Method	Excavated		Method of pile placement
Placement Multiplier	0.25		See RBDG (P. 52)
Pile Placement Location	Bed		Bed or Bank
γ_{water}	62.4	lb/ft^3	Unit weight of water
γ_{soil}	126	lb/ft^3	Unit weight of soil
γ_e	63.6	lb/ft^3	Eqn 37
ϕ_{soil}	0.66	radians	Calculated for material pile is located
K_p	4.20		Eqn 38
h_{load}**	2.5	ft	Height above scour depth load is applied
$F_{piles\text{-}h}$	**-23,896**	**lb**	**Eqn 15**

*** Top 2' of pile embedment disregarded for calculation to account for vortex shedding.**
**** Analysis also assumes that the resultant force is located at half of the flow depth on the upstream side of the LWM structure to produce a conservative moment on the pile.**

Factor of Safety

$FOS_{sliding}$ =	$(F_{hd} + F_f + F_{piles\text{-}h} + F_{passive}) / (F_d + F_{hu} + F_i)$		
F_d	5,341	lb	
F_{hu}		lb	
F_{hd}		lb	
F_i	7,073	lb	
F_f	-25,000	lb	
$F_{passive}$	-3,806	lb	
$F_{piles\text{-}h}$	-23,896	lb	
$FOS_{sliding}$	**4.25**		**STABLE FOR SLIDING**

Summary Comments:

Appendix C

Wood Habitat Structure Stability Calculations

WHS Type #3 Margin Jam

Buoyancy Calculations

Project: Tucannon Big Four Floodplain Restoration - Margin Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

Spreadsheet Description

- The spreadsheet below is used to calculate the Factor of Safety against Buoyant uplift of the LWM

Assumptions:

1) The LWM structure behaves as a single structure under the design load and will not experience any shearing at joints
2) The LWM structure will be submerged during the design event.
3) Negative buoyancy is uplift, positive numbers equals downward.
4) Ballast material remains intact and is not scoured out.
5) The uplift due to racking material is evenly dividing among all layers.

Input (Cells Requiring Input from Structure Detail)
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FBD and Equations:

$$FOS_b = \frac{F_{LWMd} + F_{boulders} + F_{soil} + F_{piles-e}}{|F_{LWMs} + F_L|}$$ **Equation 18**

FOS_b = *buoyancy factor of safety*

Tucannon Big Four Floodplain Restoration has a "LOW" Public Safety Risk Factor and a "MODERATE" Property Damage Risk Factor. The Design buoyancy factor of safety (FOS_b) for this structure is 1.75 per Table 4 "*Minimum Recommended Factors of Safety*".

Table 4. Minimum recommended factors of safety.

Public Safety Risk	Property Damage Risk	Stability Design Flow Criteria	$FOS_{sliding}$	$FOS_{buoyancy}$	$FOS_{rotation}$ $FOS_{overturning}$
High	High	100-year	1.75	2.0	1.75
High	Moderate	50-year	1.5	1.75	1.5
High	Low	25-year	1.5	1.75	1.5
Low	High	100-year	1.75	2.0	1.75
Low	Moderate	25-year	1.5	1.75	1.5
Low	Low	10-year	1.25	1.5	1.25

1. Large Wood Material Force - Dry (F_{LWMd})

$$F_{LWMd} = V_{LWMd} * \gamma_{wood}$$ **Equation 3**

V_{LWMd} = *volume of dry large wood material*

Comment: Assumed to be zero because structure assumed to be submerged during design event.

2. Boulder Ballast Force ($F_{boulder}$)

$N_{bouldersub}$			Number of submerged boulders (from design)
$d_{bouldersub}$		ft	Effective diameter of submerged boulder (ft, from spec)
$\gamma_{boulder}$	146	lb/ft^3	unit weight of boulders (Table 5)
γ_{water}	62.4	lb/ft^3	unit weight of water
$F_{bouldersub}$		lb	Eqn. 6
$N_{boulderdry}$			Number of dry boulders (from detail)
$d_{boulderdry}$		ft	Effective diameter of dry boulder (ft, from spec)
$F_{boulderdry}$		lb	Eqn. 7
$F_{boulder}$		**lb**	**Eqn. 5**

$$F_{boulder} = F_{bouldersub} + F_{boulderdry}$$ **Equation 5**

$$F_{bouldersub} = N_{bouldersub} * \frac{\pi}{6} * d_{bouldersub}^3 * (\gamma_{boulder} - \gamma_w)$$ **Equation 6**

$N_{bouldersub}$ = *number of submerged boulders*
$d_{bouldersub}$ = *effective diameter of submerged boulders*
$\gamma_{boulder}$ = *unit weight of boulders*

$$F_{boulderdry} = N_{boulderdry} * \frac{\pi}{6} * d_{boulderdry}^3 * \gamma_{boulder}$$ **Equation 7**

$N_{boulderdry}$ = *number of unsubmerged boulders*
$d_{boulderdry}$ = *effective diameter of unsubmerged boulders*

Comment: The intent is design without the use of boulders so it is assumed no boulders are used.

Buoyancy Calculations

Project: Tucannon Big Four Floodplain Restoration - Margin Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

3. Soil Backfill Force (F_{soil})

$N_{logssub1}$	2		Number of Type 1 buried logs (from detail)
L_{eb1}	27	ft	Average embedded length of Type 1 logs (from detail)
d_{bole1}	1.5	ft	Average diameter of Type 1 logs (from detail)
$h_{soilsub1}$	3	ft	Average height of submerged soil above Type 1 log (from detail)
$V_{soilsub1}$	243	ft^3	Volume of submerged soil above Type 1 log (from detail)
$h_{soildry1}$		ft	Average height of dry soil above Type 1 log (from detail)
$V_{soildry1}$		ft^3	Volume of dry soil above Type 1 log (from detail)
$N_{logssub2}$	4		Number of Type 2 buried logs (from detail)
L_{eb2}	15	ft	Average embedded length of Type 2 logs (from detail)
d_{bole2}	0.5	ft	Average diameter of Type 2 logs (from detail)
$h_{soilsub2}$		ft	Average height of submerged soil above Type 2 log (from detail)
$V_{soilsub2}$		ft^3	Volume of submerged soil above Type 2 log (from detail)
$h_{soildry2}$		ft	Average height of dry soil above Type 2 log (from detail)
$V_{soildry2}$		ft^3	Volume of dry soil above Type 2 log (from detail)
$N_{logssub3}$			Number of Type 3 buried logs (from detail)
L_{eb3}		ft	Average embedded length of Type 3 logs (from detail)
d_{bole3}		ft	Average diameter of Type 3 logs (from detail)
$h_{soilsub3}$		ft	Average height of submerged soil above Type 3 log (from detail)
$V_{soilsub3}$		ft^3	Volume of submerged soil above Type 3 log (from detail)
$h_{soildry3}$		ft	Average height of dry soil above Type 3 log (from detail)
$V_{soildry3}$		ft^3	Volume of dry soil above Type 3 log (from detail)
γ_{soil}	120	lb/ft^3	Specific Gravity of bank/backfill material (Table 5)
γ_{water}	62.4	lb/ft^3	Unit weight of water
SG_{rock}	2.64		Specific Gravity of Rock (Using unit weight of bedrock from Table 5)
e	0.37		Eqn. 14
γ_{sat}	137	lb/ft^3	Eqn. 13
γ'_{soil}	74.5	lb/ft^3	Eqn. 12
F_{soil}	**18,115**	**lb**	**Eqn. 8**

$$F_{soil} = \sum_i^n V_{soilsub_i} * \gamma'_{soil} + V_{soildry_i} * \gamma_{soil}$$ **Equation 8**

$$V_{soilsub_i} = L_{eb_i} d_{bole_i} h_{soilsub_i}$$ **Equation 9**

$V_{soilsubi}$ = volume of submerged soil above log i
L_{ebi} = embedded length of log i
d_{bolei} = bole diameter of log i
$h_{soilsubi}$ = height of submerged soil above log i

$$V_{soildry_i} = L_{eb_i} d_{bole_i} h_{soildry_i}$$ ***Equation 10***

$V_{soildryi}$ = volume of dry soil above log i
$h_{soildryi}$ = height of dry soil above log i

$$\gamma_{soil} = (99.2 + 18.6 * \log(d_{50}))$$ **Equation 11**

d_{50} = median grain size in millimeters

$$\gamma'_{soil} = \gamma_{sat} - \gamma_w$$ **Equation 12**

$$\gamma_{sat} = \frac{(SG_{rock} + e) * \gamma_w}{1 + e}$$ **Equation 13**

$$e = \frac{SG_{rock} * \gamma_w}{\gamma_{soil}} - 1$$ **Equation 14**

Buoyancy Calculations

Project: Tucannon Big Four Floodplain Restoration - Margin Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

4. Pile Skin Friction

N_{piles}			Number of piles (Design)
d_{piles}		ft	Diameter of piles (Design)
L_{piles}		ft	Embedded length of piles (Design)
k_s	1		Coefficient of lateral earth pressure (0.5 to 1.5 depending on soil and density)
Placement Method	Driven or Vibrated		Method of pile placement
Placement Multiplier	1		See RBDG (P. 52)
Pile Placement Location	Bank		Bed or Bank
ϕ_{soil}	0.63	rad	Internal angle of friction of soils (Table 5)
γ_{soil}	120	lb/ft^3	Specific Weight of Soil
e	0.37		Eqn. 14
γ_{sat}	137	lb/ft^3	Eqn. 13
γ_{water}	62.4	lb/ft^3	Unit weight of water
σ'		lb/ft^2	Eqn 16
γ_{wood}	33	lb/ft^3	Unit weight of wood
$F_{piles-v}$		**lb**	**Eqn 15**

$$F_{piles-v} = N_{piles} * \pi * d_{piles} * L_{piles}(k_s * \tan\frac{2}{3}\emptyset * \sigma' + \frac{d_{piles}}{4} * (\gamma_{wood} - \gamma_w))$$

Equation 15

N_{piles} = number of piles
d_{piles} = diameter of piles
L_{piles} = embedded length of piles
k_s = coefficient of lateral earth pressure (0.5 to 1.5 depending on soil and density)
ϕ = internal angle of friction of soils

$$\sigma' = L_{piles} * (\gamma_{sat} - \gamma_w)$$

Equation 16

$$\gamma_{sat} = \frac{(SG_{rock} + e) * \gamma_w}{1 + e}$$

Equation 13

$$e = \frac{SG_{rock} * \gamma_w}{\gamma_{soil}} - 1$$

Equation 14

Assumptions:
*** k_s = 1**
**** This calculation is based on the assumption that piles are driven or vibrated into place. If piles are drilled or excavated, the associated coefficicient of lateral earth pressures shall be approx. 50% and 25% of the driven value, respectively.**
***** For use in buoyancy calculations, piles must be mechanically fastened.**
****** Top 2' of pile embedment disregarded for calculation to account for vortex shedding.**

5. Large Wood Material Force - Submerged (F_{LWMs})

$$F_{LWMs} = V_{LWMs} * (\gamma_{wood} - \gamma_w)$$

Equation 2

V_{LWMs} = volume of submerged large wood material
γ_{wood} = unit weight of wood
γ_w = unit weight of water

$N_{logssub1}$	4		Number of log type 1 (from detail)
L_{log1}	40	ft	Length of log type 1 (from detail)
d_{bole1}	1.5	ft	Diameter of log type 1 (from detail)
d_{rw1}	4	ft	Diameter of rootwad of log type 1 (from detail)
V_{LWMs1}	327	ft^3	Volume of LWM1
$N_{logssub2}$			Number of log type 2 (from detail)
L_{eb2}		ft	Length of log type 2 (from detail)
d_{bole2}		ft	Diameter of log type 2 (from detail)
d_{rw2}		ft	Diameter of rootwad of log type 2 (from detail)
V_{LWMs2}		ft^3	Volume of LWM2
$N_{logssub3}$	4		Number of log type 3 (from detail)
L_{eb3}	15	ft	Length of log type 3 (from detail)
d_{bole3}	0.5	ft	Diameter of log type 3 (from detail)

Volume of Rootwad

National Large Wood Manual. 2016
Equation 6-4 (p. 6-38)

$V_{rw} = \pi * t_k * w_k^2 / 3$
$\pi * (2d_{bole}) * (1/2 d_{rw})^2 / 3$

t_k = Thickness of rootwad measured in direction parallel to trunk
= 4 times the radius of the log ($4r_k$ or $2*d_{bole}$)

w_k =
Radius of rootwad

Buoyancy Calculations

Project: Tucannon Big Four Floodplain Restoration - Margin Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

d_{rw3}		ft	Diameter of rootwad of log type 3 (from detail)
V_{LWMs3}	12	ft^3	Volume of LWM3
V_{LWMs}	339	ft^3	Volume of LWM
γ_{wood}	33.0	lb/ft^3	Unit weight of logs
γ_w	62.4	lb/ft^3	Unit weight of water
F_{LWMs}	**-9,958**	**lb**	**Eqn. 3**

= 2.5 times the radius of the log ($2.5r_k$ or $1.25d_{bole}$) or 1/2 d_{rw} specified

6. Lift Forces (F_L)

$$F_L = -\frac{C_L * A_{LWM} * \gamma_w * U_o^2}{2 * g} \quad \text{Equation 4}$$

C_L = *lift coefficient*
A_{LWM} = *area of large woody material perpendicular to flow*
u_u = *upstream channel velocity at design event*
g = *acceleration due to gravity*

C_L	0.45		Lift Coefficient
A_{LWM}	20	ft^2	Calc'd in Drag Forces
γ_w	62.4	lb/ft^3	Unit weight of water
U_o	6.0	ft/s	upstream velocity (from model)
g	32.2	ft/s^2	Unit weight of water
F_L	**-314**	**lb**	**Eqn. 4**

Comment: Lift forces neglected per Section 6.4.2 of BOR Risk Based Design Guidelines

Factor of Safety

FOS_b =	$(F_{LMDd} + F_{boulders} + F_{soil} + F_{piles\text{-}v}) / (F_{LWMs} + F_L)$		
F_{LWMd}		lb	Assumed Zero
$F_{boulder}$		lb	
F_{soil}	18,115	lb	
$F_{piles\text{-}v}$		lb	
F_{LWMs}	-9,958	lb	
F_L	-314	lb	
FOS_b	**1.76**		**STABLE FOR BUOYANCY**

Summary Comments:

Overturning Calculations

Project:	Tucannon Big Four Floodplain Restoration - Margin Jam	**Analyst:**	BF
Project Number:	20230017	**Calculations Checked By:**	AJ
		Latest Revision:	4/2/2025

Spreadsheet Description

Purpose: The spreadsheet below is used to calculate the Factor of Safety against vertical overturning.

Assumptions:
1) The LWM structure behaves as a single structure under the design load.
2) The effect of soil in back of the structure is negligible.
3) The structure will be submerged during the design event
4) This LWM structure experiences the largest loads. All LWM structures on site will be designed based on this LWM structure's loadings

Input (Cells Requiring Input from Structure Detail)
Input (Cells requiring Input from Hydraulic Model)
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Output (Cells automatically updated are this color)
Output (Cells automatically updated with previously calculated values are this color)

FBD and Equations:

$$FOS_{overturn} = \frac{MR_{overturn}}{MD_{overturn}}$$ **Equation 49**

Tucannon Big Four Floodplain Restoration has a "LOW" Public Safety Risk Factor and a "MODERATE" Property Damage Risk Factor. The Design Overturn Factor of Safety ($FOS_{overturn}$) for this structure is 1.5 per Table 4 "Minimum Recommended Factors of Safety".

Table 4. Minimum recommended factors of safety.

Public Safety Risk	Property Damage Risk	Stability Design Flow Criteria	$FOS_{sliding}$	$FOS_{buoyancy}$	$FOS_{rotation}$ $FOS_{overturning}$
High	High	100-year	1.75	2.0	1.75
High	Moderate	50-year	1.5	1.75	1.5
High	Low	25-year	1.5	1.75	1.5
Low	High	100-year	1.75	2.0	1.75
Low	Moderate	25-year	1.5	1.75	1.5
Low	Low	10-year	1.25	1.5	1.25

$$MD_{overturn} = F_i * (Y_u + d_{bury}) + F_d * \left(\frac{Y_u}{2} + d_{bury}\right) + F_{hu} * \left(\frac{Y_u}{3} + du_{bury}\right) + |F_L| * L_s$$

Equation 46

du_{bury} = depth at the upstream side of the structure from channel bottom to point of rotation measured perpendicular to flow
Ls = length of structure measured parallel to flow

$$MR_{overturn} = |F_{hd}| * \left(\frac{Y_d}{2} + dd_{bury}\right) + |F_{passive}| * (dd_{bury}) + (F_b - F_L - F_{piles-v}) * \frac{L_s}{2} + \sum_i^n F_{pile-v_i} * Lpv_i$$ **Equation 47**

$$F_{pile-v_i} = \frac{F_{piles-v}}{N_{piles}}$$ **Equation 48**

L_{pvi} = distance from pile 'i' to the point of rotation measured parallel to flow

$$FOS_{overturn} = \frac{MR_{overturn}}{MD_{overturn}}$$ **Equation 49**

1. Resistance to Overturn ($MR_{rotation}$ and $MD_{rotation}$)

Driving:

F_i	5,632	lb	Impact Forces (Calc'd in Sliding)
F_d	3,924	lb	Drag Forces (Calc'd in Sliding)
F_{hu}		lb	Upstream Hydrostatic Forces (Calc'd in Sliding)
F_L	-314	lb	Lift Forces (Assumed Zero in Buoyancy Calcs)
Y_u	3	ft	Upstream water elevation from model
d_{ubury}	2	ft	Depth at upstream side of structure from channel bottom to point of rotation measured perp to flow
L_s	13	ft	Length of structure parallel to flow
$MD_{overturn}$	**45,976**	**lb*ft**	**Eqn 46**

Resisting:

F_{hd}		lb	Downstream Hydrostatic Forces (Calc'd in Sliding)
$F_{passive}$	-34,887	lb	Passive Forces (Calc'd in Sliding)
F_b	7,843	lb	Buoyancy Forces (Calc'd in Sliding)
F_{pile-v}		lb	Lateral Resistance from Piles (Calc'd in Sliding)
Y_d	2.35	ft	Downstream water elevation
d_{dbury}	4.5	ft	Depth at downstream side of structure from channel bottom to point of rotation measured perp to flow
N_{piles}	1		Number of Piles (Design)
L_{pvi}	27	ft	Distance from pile to the point of rotation measured parallel to flow.
$F_{pile-vi}$		lb	Eqn 48
$MR_{overturn}$	**210,011**	**lb*ft**	**Eqn 47**

Factor of Safety

$FOS_{overturnon}$ = $MR_{overturn}$ / $MD_{overturn}$			
$MD_{overturn}$	45,976	lb	
$MR_{overturn}$	210,011	lb	
$FOS_{overturn}$	**4.57**		**STABLE FOR OVERTURN**

Rotation Calculations

Project:	Tucannon Big Four Floodplain Restoration - Margin Jam
Project Number:	20230017

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

Spreadsheet Description

Purpose: The spreadsheet below is used to calculate the Factor of Safety against LWM structure horizontal rotation.

Assumptions:
1) The LWM structue behaves as a single structure under the design load.
2) The effect of soil in back of the structure is negligible.
3) The structure will be submerged during the design event
4) This LWM structure experiences the largest loads. All LWM structures on site will be designed based on this LWM structure's loadings

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Output (Cells that are automatically updated with previously calculated values are this color)

FBD and Equations:

$$FOS_{rotation} = \frac{MR_{rotation}}{MD_{rotation}}$$ **Equation 45**

Tucannon Big Four Floodplain Restoration has a "LOW" Public Safety Risk Factor and a "MODERATE" Property Damage Risk Factor. The Design Rotation Factor of Safety ($FOS_{rotation}$) for this structure is 1.5 per Table 4 "Minimum Recommended Factors of Safety".

Table 4. Minimum recommended factors of safety.

Public Safety Risk	Property Damage Risk	Stability Design Flow Criteria	$FOS_{sliding}$	$FOS_{buoyancy}$	$FOS_{rotation}$ $FOS_{overturning}$
High	High	100-year	1.75	2.0	1.75
High	Moderate	50-year	1.5	1.75	1.5
High	Low	25-year	1.5	1.75	1.5
Low	High	100-year	1.75	2.0	1.75
Low	Moderate	25-year	1.5	1.75	1.5
Low	Low	10-year	1.25	1.5	1.25

1. Resistance to Rotation ($MR_{rotation}$ and $MD_{rotation}$)

$$MD_{rotation} = (F_i + F_d + F_{hu}) * \left(\frac{L_{sp} + L_{ebp}}{2}\right)$$ **Equation 42**

L_{sp} = *length of wood structure from tip to point of rotation measured perpendicular to flow*
L_{ebp} = *embedded length of wood structure measured perpendicular to flow*

$$MR_{rotation} = \left| F_{hd} * \left(\frac{L_{sp} + L_{ebp}}{2}\right) + F_{passive} * \frac{L_{ebp}}{2} + F_f * \frac{L_{sp}}{2} + \sum_{i}^{n} F_{pile-h_i} * L_{ph_i} \right|$$ **Equation 43**

$$F_{pile-h_i} = \frac{F_{piles-h}}{N_{piles}}$$ **Equation 44**

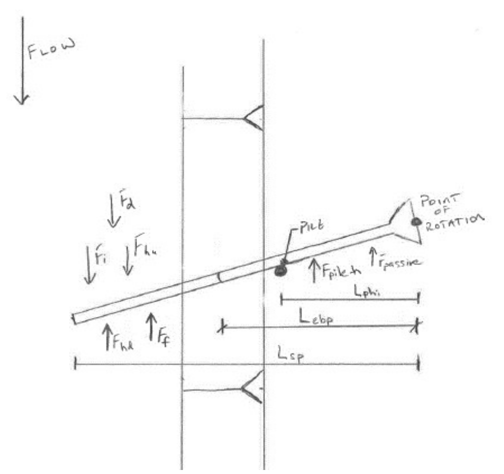
L_{phi} = *distance from pile 'i' to the point of rotation measured perpendicular to flow*

Driving:

L_{sp}	40	ft	Length of wood structure from tip to point of rotation measured perpendicular to flow
L_{ebp}	27	ft	Embedded length of wood structure measured perp. to flow
F_i	5,632	lb	Impact Forces (Calc'd in Sliding)
F_d	3,924	lb	Drag Forces (Calc'd in Sliding)
F_{hu}		lb	Upstream Hydrostatic Forces (Calc'd in Sliding)
$MD_{rotation}$	**320,131**	**lb*ft**	**Eqn 42**

Resisting:

F_{hd}		lb	Downstream Hydrostatic Forces (Calc'd in Sliding)
$F_{passive}$	-34,887	lb	Passive Forces (Calc'd in Sliding)
F_f	-6,127	lb	Friction Forces (Calc'd in Sliding)
F_{pile-h}		lb	Lateral Resistance from Piles (Calc'd in Sliding)
$F_{pile-hi}$		lb	Lateral Resistance from Piles (Calc'd in Sliding)
N_{piles}			Number of Piles (Design)
L_{phi}	27	ft	Distance from pile to the point of rotation measured perp. to flow.
$MR_{rotation}$	**593,525**	**lb*ft**	**Eqn 43**



Factor of Safety

$FOS_{rotation}$ =	*$MR_{rotation}$ / $MD_{rotation}$*		
$MD_{rotation}$	320,131	lb	
$MR_{rotation}$	593,525	lb	
$FOS_{rotation}$	**1.85**		**STABLE FOR ROTATION**

Summary Comments:

Sliding Calculations

Project:	Tucannon Big Four Floodplain Restoration - Margin Jam	**Analyst:**	BF
Project No.:	20230017.1	**Calculations Checked By:**	AJ
		Latest Revision:	4/2/2025

Spreadsheet Description

Purpose: The spreadsheet below is used to calculate the Factor of Safety against LWM sliding.

Assumptions:
1) The LWM structure behaves as a single structure under the design load and will not experience any shearing at joints.
2) The effect of soil in back of the structure is negligible.
3) The structure will be submerged during the design event.
4) Channel velocity (V_c) taken from hydraulic model.
5) This LWM structure experiences the largest loads. All LWM structures on site will be designed based on this LWM structure's loadings.

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Output (Cells automatically updated are this color)
Output (Cells automatically updated with previously calculated values are this color)

FBD and Equations:

$$FOS_{sliding} = \frac{|F_{hd}+F_f+F_{piles-h}+F_{passive}|}{F_d+F_{hu}+F_l}$$ Equation 41

Tucannon Big Four Floodplain Restoration has a "LOW" Public Safety Risk Factor and a "MODERATE" Property Damage Risk Factor. The Design Sliding Factor of Safety ($FOS_{sliding}$) for this structure is 1.5 per Table 4 "Minimum Recommended Factors of Safety".

Table 4. Minimum recommended factors of safety.

Public Safety Risk	Property Damage Risk	Stability Design Flow Criteria	$FOS_{sliding}$	$FOS_{bouyancy}$	$FOS_{rotation}$ $FOS_{overturning}$
High	High	100-year	1.75	2.0	1.75
High	Moderate	50-year	1.5	1.75	1.5
High	Low	25-year	1.5	1.75	1.5
Low	High	100-year	1.75	2.0	1.75
Low	Moderate	25-year	1.5	1.75	1.5
Low	Low	10-year	1.25	1.5	1.25

1. Drag Force (F_d)

Y_u	3.00	ft	Upstream water depth
hdebris	5	ft	Debris height (incl. accumulation)
wdebris	15	ft	Debris width (incl. accumulation)
Debris Shape	Triangle		
A_{LWM}	75	ft^2	Wetted area of LWM
γ_{water}	62.40	lb/ft^3	Unit weight of water
v_c	6.00	ft/s	Velocity from Model
g	32.20	ft/s^2	Acceleration due to gravity
A_b	75.00	ft^2	Debris area
$w_{channel}$	75	ft	Channel width
c_d	1.50		NLWM Worst Case
F_d	3924	lb	Eqn 19

$$F_d = \frac{C_D \cdot A_{LWM} \cdot \gamma_w \cdot U_c^2}{2 \cdot g}$$ Equation 19

F_d = drag force
C_d = drag coefficient
A_{LWM} = area of wetted debris based on the upstream water surface elevation projected normal to flow direction and the potential drift accumulation
γ_w = unit weight of water
U_c = velocity in contracted section
g = acceleration due to gravity

Cd can be assumed 0.9 when fully submerged, 1.5 when WSEL withi

$$C_{d-applied} = \frac{C_d}{(1-B)^2}$$ C_d is typically estimated as 1.0 Equation 27

Sliding Calculations

Project: Tucannon Big Four Floodplain Restoration - Margin Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

3. Impact Force (F_i)

L_{debris}	40	ft	Length of debris member (Design)
$d_{boledebris}$	2	ft	Bole diameter of debris member (Design)
$d_{rwdebris}$	5	ft	Rootwad diameter of debris member (Design)
V_{debris}	152	ft^3	Volume of debris
γ_{wood}	33	lb/ft^3	Unit weight of wood
w_{debris}	5,011	lb	weight of debris
g	32.2	ft/s^2	Acceleration due to gravity
$V_{channel}$	6.0	ft/s	Velocity from Model
Δt	0.03	sec	Impact Interval (0.03 sec recommended)
C_i	0.6		Coefficient of importance (from Table 6)
C_o	0.8		Coefficient of orientation
C_d	0.5		Figure 11 (need water depth from model)
Degree of Screening or Sheltering Upstream	Limited upstream screening, flow path 20' wide		ASCE 7-05
C_b	0.6		ASCE 7-05
R_{max}	0.8		Response ratio for impulsive loads
F_i	**5,632**	**lb**	**Eqn 30**

$$F_i = \frac{\pi w_{debris} * V_{channel} * C_i * C_o * C_d * C_b * R_{max}}{2 * g * \Delta t}$$ **Equation 30**

F_i = impact force

w_{debris} = weight of debris

g = acceleration constant due to gravity

$V_{channel}$ = water velocity in channel

Δt = time from initial velocity to zero velocity

C_i = coefficient of importance

C_o = coefficient of orientation = 0.8

C_d = coefficient of depth

C_b = coefficient of blockage

R_{max} = response ratio for impulsive loads = 0.8

Assumption:

***Largest impact force would be generated by structure being struck by floating large key member. For impact calculation, assuming 18" diameter, 30' long member with rootwad impacts structure.**
****See Section 6.3.3 of LWM RBDG (P. 44) for debris loading sizing.**

4. Friction Force (F_f)

ϕ_{bed}	0.66	radians	Calculated for streambed material (small cobble)
μ_{bed}	0.78		Eqn 32
F_{LWMd}		lb	Buoyancy Calcs
$F_{boulder}$		lb	Buoyancy Calcs
F_{soil}	18115	lb	Buoyancy Calcs
$F_{piles-v}$		lb	Buoyancy Calcs
F_{LWMs}	-9958	lb	Buoyancy Calcs
F_L	-314	lb	Buoyancy Calcs
F_b	7,843	lb	Eqn 17
F_f	**-6,127**	**lb**	**Eqn 31**

$$F_f = -\mu_{bed} * (F_b - F_{piles-v})$$ Equation 31

F_f = force due to frictional resistance

F_b-$F_{piles-v}$ >0

$$\mu_{bed} = \tan \emptyset$$ Equation 32

$$F_b = F_{LWMs} + F_{LWMd} + F_L + F_{boulder} + F_{soil} + F_{piles-v}$$ *Equation 17*

Note:
***If buoyancy forces are less than vertical pile forces (Fb-Fpiles-v<0), then friction force = 0.**

Sliding Calculations

Project: Tucannon Big Four Floodplain Restoration - Margin Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

5. Passive Forces ($F_{passive}$)

ϕ_{bank}	0.63	radians	Calculated for bank material (very course gravel)
K_p	3.85		Eqn 34
γ_{water}	62.4	lb/ft^3	Unit weight of water
γ_{soil}	120	lb/ft^3	Unit weight of soil
γ_{sat}	137	lb/ft^3	Previously calculated for buoyancy calcs
$N_{logssub1}$	2		Number of log type 1 (from detail)
$Orientation_1$**	Perpendicular		Perpendicular or Parallel to flow
L_{eb1}	27	ft	Length of log type 1 (from detail)
d_{bole1}	1.5	ft	Diameter of log type 1 (from detail)
D_{sub1}	3	ft	Depth of submerged soil above log 1
D_{dry1}		ft	Depth of dry soil above log 1
σ_{v1}	224	lb/ft^2	
$\sigma_{v1}*L_{eb1}*\gamma_{soil}$	18,115	lb	
$N_{logssub2}$	4		Number of log type 2 (from detail)
$Orientation_2$**	Perpendicular		Perpendicular or Parallel to flow
L_{eb2}	15	ft	Length of log type 2 (from detail)
d_{bole2}	0.5	ft	Diameter of log type 2 (from detail)
D_{sub2}		ft	Depth of submerged soil above log 2
D_{dry2}		ft	Depth of dry soil above log 2
σ_{v2}		lb/ft^2	
$\sigma_{v2}*L_{eb2}*\gamma_{soil}$		lb	
$N_{logssub3}$	2		Number of log type 3(from detail)
$Orientation_3$**	Parallel		Perpendicular or Parallel to flow
L_{eb3}	27	ft	Length of log type 3 (from detail)
d_{bole3}	1.5	ft	Diameter of log type 3 (from detail)
D_{sub3}		ft	Depth of submerged soil above log 3
D_{dry3}		ft	Depth of dry soil above log 3
σ_{v3}		lb/ft^2	
$\sigma_{v3}*L_{eb3}*\gamma_{soil}$		lb	
$F_{passive}$	**-34,887**	**lb**	**Eqn 31**

3.85184

** Eqns 33 through 35 represent the case where passive forces act

$$F_{passive} = -0.5 * K_p * \sum_i^n \sigma_{v_i} * L_{em_i} * d_{log_i}$$ Equ

$$K_p = \frac{1+\sin\phi}{1-\sin\phi}$$ Equ

$$\sigma_{v_i} = D_{sub_i} * (\gamma_{sat} - \gamma_{water}) + D_{dry_i} * \gamma_{soil}$$ Equ

D_{subi} = depth of submerged soil above log i
D_{dryi} = depth of dry soil above log i
L_{emi} = embedded length of log i
d_{logi} = diameter of log i

Sliding Calculations

Project: Tucannon Big Four Floodplain Restoration - Margin Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

6. Lateral Resistance from Piles ($F_{piles\text{-}h}$)

N_{piles}			Number of piles (Design)
d_{piles}		ft	Diameter of piles (Design)
L_{piles}		ft	Embedded length of piles below scour (Design)
Placement Method	Excavated		Method of pile placement
Placement Multiplier	0.25		See RBDG (P. 52)
Pile Placement Location	Bank		Bed or Bank
γ_{water}	62.4	lb/ft^3	Unit weight of water
γ_{soil}	120	lb/ft^3	Unit weight of soil
γ_e	57.6	lb/ft^3	Eqn 37
ϕ_{soil}	0.63	radians	Calculated for material pile is located
K_p	3.85		Eqn 38
h_{load}**	2.5	ft	Height above scour depth load is applied
$F_{piles\text{-}h}$		**lb**	**Eqn 15**

*** Top 2' of pile embedment disregarded for calculation to account for vortex shedding.**
**** Analysis also assumes that the resultant force is located at half of the flow depth on the upstream side of the LWM structure to produce a conservative moment on the pile.**

$$F_{piles-h} = -N_{piles} * \frac{L_{pile}^2 * \frac{1}{2} * \gamma_e * d_{pile} * K_p}{h_{load} + L_{pile}} \quad \text{Equation 36}$$

N_{piles} = number of piles
L_{pile} = length of pile embedded below potential scour depth

$$\gamma_e = \gamma_s - \gamma_w \qquad \textit{effective unit weight of soil} \quad \text{Equation 37}$$

γ_s = dry unit weight of the soil

γ_w = unit weight of the soil
d_{pile} = diameter of the pile
h_{load} = height above the potential scour depth the load is applied

$$K_p = \frac{1+\sin\phi}{1-\sin\phi} \quad \text{Equation 38}$$

Factor of Safety

$FOS_{sliding}$ =	*$(F_{hd} + F_f + F_{piles\text{-}h} + F_{passive}) / (F_d + F_{hu} + F_i)$*		
F_d	3,924	lb	
F_{hu}		lb	
F_{hd}		lb	
F_i	5,632	lb	
F_f	-6,127	lb	
$F_{passive}$	-34,887	lb	
$F_{piles\text{-}h}$		lb	
$FOS_{sliding}$	**4.29**		**STABLE FOR SLIDING**

Summary Comments:

Appendix C

Wood Habitat Structure Stability Calculations

WHS Type #4 Channel Spanning Jam w/ Salvaged Trees

Buoyancy Calculations

Project: Tucannon Big Four Floodplain Restoration - Channel Spanning Jam w/ Salvaged Trees
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

Spreadsheet Description

- The spreadsheet below is used to calculate the Factor of Safety against Buoyant uplift of the LWM

Assumptions:

1) The LWM structure behaves as a single structure under the design load and will not experience any shearing at joints
2) The LWM structure will be submerged during the design event.
3) Negative buoyancy is uplift, positive numbers equals downward.
4) Ballast material remains intact and is not scoured out.
5) The uplift due to racking material is evenly dividing among all layers.

Input (Cells Requiring Input from Structure Detail)
Input (Cells requiring Input from Hydraulic Model)
Input (Cells automatically populated from Input to Interface Tab)
Input (Cells requiring input from a dropdown list)
Output (Cells automatically updated are this color)
Output (Cells automatically updated with previously calculated values are this color)

FBD and Equations:

$$FOS_b = \frac{F_{LWMd} + F_{boulders} + F_{soil} + F_{piles-e}}{|F_{LWMs} + F_L|}$$ **Equation 18**

FOS_b = *buoyancy factor of safety*

Tucannon Big Four Floodplain Restoration has a "LOW" Public Safety Risk Factor and a "MODERATE" Property Damage Risk Factor. The Design buoyancy factor of safety (FOS_b) for this structure is 1.75 per Table 4 "*Minimum Recommended Factors of Safety*".

Table 4. Minimum recommended factors of safety.

Public Safety Risk	Property Damage Risk	Stability Design Flow Criteria	$FOS_{sliding}$	$FOS_{buoyancy}$	$FOS_{rotation}$ $FOS_{overturning}$
High	High	100-year	1.75	2.0	1.75
High	Moderate	50-year	1.5	1.75	1.5
High	Low	25-year	1.5	1.75	1.5
Low	High	100-year	1.75	2.0	1.75
Low	Moderate	25-year	1.5	1.75	1.5
Low	Low	10-year	1.25	1.5	1.25

1. Large Wood Material Force - Dry (F_{LWMd})

$$F_{LWMd} = V_{LWMd} * \gamma_{wood}$$ **Equation 3**

V_{LWMd} = *volume of dry large wood material*

Comment: Assumed to be zero because structure assumed to be submerged during design event.

2. Boulder Ballast Force ($F_{boulder}$)

$N_{bouldersub}$			Number of submerged boulders (from design)
$d_{bouldersub}$	2.5	ft	Effective diameter of submerged boulder (ft, from spec)
$\gamma_{boulder}$	146	lb/ft^3	unit weight of boulders (Table 5)
γ_{water}	62.4	lb/ft^3	unit weight of water
$F_{bouldersub}$		lb	Eqn. 6
$N_{boulderdry}$			Number of dry boulders (from detail)
$d_{boulderdry}$	2.5	ft	Effective diameter of dry boulder (ft, from spec)
$F_{boulderdry}$		lb	Eqn. 7
$F_{boulder}$		**lb**	**Eqn. 5**

$$F_{boulder} = F_{bouldersub} + F_{boulderdry}$$ **Equation 5**

$$F_{bouldersub} = N_{bouldersub} * \frac{\pi}{6} * d_{bouldersub}^3 * (\gamma_{boulder} - \gamma_w)$$ **Equation 6**

$N_{bouldersub}$ = *number of submerged boulders*
$d_{bouldersub}$ = *effective diameter of submerged boulders*
$\gamma_{boulder}$ = *unit weight of boulders*

$$F_{boulderdry} = N_{boulderdry} * \frac{\pi}{6} * d_{boulderdry}^3 * \gamma_{boulder}$$ **Equation 7**

$N_{boulderdry}$ = *number of unsubmerged boulders*
$d_{boulderdry}$ = *effective diameter of unsubmerged boulders*

Comment: The intent is design without the use of boulders so it is assumed no boulders are used.

Buoyancy Calculations

Project: Tucannon Big Four Floodplain Restoration - Channel Spanning Jam w/ Salvaged Trees
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

3. Soil Backfill Force (F_{soil})

$N_{logssub1}$	6		Number of Type 1 buried logs (from detail)
L_{eb1}	27	ft	Average embedded length of Type 1 logs (from detail)
d_{bole1}	1.5	ft	Average diameter of Type 1 logs (from detail)
$h_{soilsub1}$	3	ft	Average height of submerged soil above Type 1 log (from detail)
$V_{soilsub1}$	729	ft^3	Volume of submerged soil above Type 1 log (from detail)
$h_{soildry1}$		ft	Average height of dry soil above Type 1 log (from detail)
$V_{soildry1}$		ft^3	Volume of dry soil above Type 1 log (from detail)
$N_{logssub2}$	4		Number of Type 2 buried logs (from detail)
L_{eb2}	13.3	ft	Average embedded length of Type 2 logs (from detail)
d_{bole2}	0.8	ft	Average diameter of Type 2 logs (from detail)
$h_{soilsub2}$	5.75	ft	Average height of submerged soil above Type 2 log (from detail)
$V_{soilsub2}$	245	ft^3	Volume of submerged soil above Type 2 log (from detail)
$h_{soildry2}$		ft	Average height of dry soil above Type 2 log (from detail)
$V_{soildry2}$		ft^3	Volume of dry soil above Type 2 log (from detail)
$N_{logssub3}$			Number of Type 3 buried logs (from detail)
L_{eb3}		ft	Average embedded length of Type 3 logs (from detail)
d_{bole3}		ft	Average diameter of Type 3 logs (from detail)
$h_{soilsub3}$		ft	Average height of submerged soil above Type 3 log (from detail)
$V_{soilsub3}$		ft^3	Volume of submerged soil above Type 3 log (from detail)
$h_{soildry3}$		ft	Average height of dry soil above Type 3 log (from detail)
$V_{soildry3}$		ft^3	Volume of dry soil above Type 3 log (from detail)
γ_{soil}	120	lb/ft^3	Specific Gravity of bank/backfill material (Table 5)
γ_{water}	62.4	lb/ft^3	Unit weight of water
SG_{rock}	2.64		Specific Gravity of Rock (Using unit weight of bedrock from Table 5)
e	0.37		Eqn. 14
γ_{sat}	137	lb/ft^3	Eqn. 13
γ'_{soil}	74.5	lb/ft^3	Eqn. 12
F_{soil}	**72,586**	**lb**	**Eqn. 8**

$$F_{soil} = \sum_i^n V_{soilsub_i} * \gamma'_{soil} + V_{soildry_i} * \gamma_{soil}$$ **Equation 8**

$$V_{soilsub_i} = L_{eb_i} d_{bole_i} h_{soilsub_i}$$ **Equation 9**

$V_{soilsubi}$ = volume of submerged soil above log i
L_{ebi} = embedded length of log i
d_{bolei} = bole diameter of log i
$h_{soilsubi}$ = height of submerged soil above log i

$$V_{soildry_i} = L_{eb_i} d_{bole_i} h_{soildry_i}$$ ***Equation 10***

$V_{soildryi}$ = volume of dry soil above log i
$h_{soildryi}$ = height of dry soil above log i

$$\gamma_{soil} = (99.2 + 18.6 * \log(d_{50}))$$ **Equation 11**

d_{50} = median grain size in millimeters

$$\gamma'_{soil} = \gamma_{sat} - \gamma_w$$ **Equation 12**

$$\gamma_{sat} = \frac{(SG_{rock} + e) * \gamma_w}{1 + e}$$ **Equation 13**

$$e = \frac{SG_{rock} * \gamma_w}{\gamma_{soil}} - 1$$ **Equation 14**

Buoyancy Calculations

Project: Tucannon Big Four Floodplain Restoration - Channel Spanning Jam w/ Salvaged Trees
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

4. Pier Log Friction

N_{piles}			Number of piles (Design)
d_{piles}		ft	Diameter of piles (Design)
L_{piles}		ft	Embedded length of piles (Design)
k_s	1		Coefficient of lateral earth pressure (0.5 to 1.5 depending on soil and density)
Placement Method	Excavated		Method of pile placement
Placement Multiplier	0.25		See RBDG (P. 52)
Pile Placement Location	Bed		Bed or Bank
ϕ_{soil}	0.66	rad	Internal angle of friction of soils (Table 5)
γ_{soil}	126	lb/ft^3	Specific Weight of Soil
e	0.31		Eqn. 14
γ_{sat}	141	lb/ft^3	Eqn. 13
γ_{water}	62.4	lb/ft^3	Unit weight of water
σ'		lb/ft^2	Eqn 16
γ_{wood}	33	lb/ft^3	Unit weight of wood
$F_{piles-v}$		**lb**	**Eqn 15**

$$F_{piles-v} = N_{piles} * \pi * d_{piles} * L_{piles}(k_s * \tan\frac{2}{3}\phi * \sigma' + \frac{d_{piles}}{4} * (\gamma_{wood} - \gamma_w))$$ Equation 15

N_{piles} = number of piles
d_{piles} = diameter of piles
L_{piles} = embedded length of piles
k_s = coefficient of lateral earth pressure (0.5 to 1.5 depending on soil and density)
ϕ = internal angle of friction of soils

$$\sigma' = L_{piles} * (\gamma_{sat} - \gamma_w)$$ Equation 16

$$\gamma_{sat} = \frac{(SG_{rock} + e) * \gamma_w}{1 + e}$$ Equation 13

$$e = \frac{SG_{rock} * \gamma_w}{\gamma_{soil}} - 1$$ Equation 14

Assumptions:
*** k_s = 1**
**** This calculation is based on the assumption that piles are driven or vibrated into place. If piles are drilled or excavated, the associated coefficicient of lateral earth pressures shall be approx. 50% and 25% of the driven value, respectively.**
***** For use in buoyancy calculations, piles must be mechanically fastened.**
****** Top 2' of pile embedment disregarded for calculation to account for vortex shedding.**

5. Large Wood Material Force - Submerged (F_{LWMs})

$$F_{LWMs} = V_{LWMs} * (\gamma_{wood} - \gamma_w)$$ Equation 2

V_{LWMs} = volume of submerged large wood material
γ_{wood} = unit weight of wood
γ_w = unit weight of water

$N_{logssub1}$	6		Number of log type 1 (from detail)
L_{log1}	40	ft	Length of log type 1 (from detail)
d_{bole1}	1.5	ft	Diameter of log type 1 (from detail)
d_{rw1}	4	ft	Diameter of rootwad of log type 1 (from detail)
V_{LWMs1}	490	ft^3	Volume of LWM1
$N_{logssub2}$	2		Number of log type 2 (from detail)
L_{eb2}	60	ft	Length of log type 2 (from detail)
d_{bole2}	1.5	ft	Diameter of log type 2 (from detail)
d_{rw2}	4	ft	Diameter of rootwad of log type 2 (from detail)
V_{LWMs2}	234	ft^3	Volume of LWM2
$N_{logssub3}$	1		Number of log type 3 (from detail)
L_{eb3}	40	ft	Length of log type 3 (from detail)
d_{bole3}	1.5	ft	Diameter of log type 3 (from detail)

Volume of Rootwad

National Large Wood Manual. 2016
Equation 6-4 (p. 6-38)

V_{rw} = $\pi * t_k * w_k^2 / 3$
$\pi * (2d_{bole}) * (1/2d_{rw})^2 / 3$

t_k = Thickness of rootwad measured in direction parallel to trunk
= 4 times the radius of the log ($4r_k$ or

w_k =
Radius of rootwad

Buoyancy Calculations

Project: Tucannon Big Four Floodplain Restoration - Channel Spanning Jam w/ Salvaged Trees
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Analyst: BF
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= 2.5 times the radius of the log ($2.5r_k$ or $1.25d_{bole}$) or 1/2 d_{rw} specified

d_{rw3}		ft	Diameter of rootwad of log type 3 (from detail)
V_{LWMs3}	71	ft^3	Volume of LWM3
V_{LWMs}	795	ft^3	Volume of LWM
γ_{wood}	33.0	lb/ft^3	Unit weight of logs
γ_w	62.4	lb/ft^3	Unit weight of water
F_{LWMs}	**-23,379**	**lb**	**Eqn. 3**

6. Lift Forces (F_L)

$$F_L = -\frac{C_L * A_{LWM} * \gamma_w * U_o^2}{2 * g}$$ **Equation 4**

C_L = lift coefficient
A_{LWM} = area of large woody material perpendicular to flow
u_u = upstream channel velocity at design event
g = acceleration due to gravity

C_L	0.45		Lift Coefficient
A_{LWM}	420	ft^2	Calc'd in Drag Forces
γ_w	62.4	lb/ft^3	Unit weight of water
U_o	8.3	ft/s	upstream velocity (from model)
g	32.2	ft/s^2	Unit weight of water
F_L	**-12,464**	**lb**	**Eqn. 4**

Comment: Lift forces neglected per Section 6.4.2 of BOR Risk Based Design Guidelines

Factor of Safety

FOS_b =	*$(F_{LMDd} + F_{boulders} + F_{soil} + F_{piles\text{-}v}) / (F_{LWMs} + F_L)$*		
F_{LWMd}		lb	Assumed Zero
$F_{boulder}$		lb	
F_{soil}	72,586	lb	
$F_{piles\text{-}v}$		lb	
F_{LWMs}	-23,379	lb	
F_L	-12,464	lb	
FOS_b	**2.03**		**STABLE FOR BUOYANCY**

Summary Comments:

Overturning Calculations

Project: Tucannon Big Four Floodplain Restoration - Channel Spanning Jam w/ Salvaged Trees
Project Number: 20230017

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

Spreadsheet Description

Purpose: The spreadsheet below is used to calculate the Factor of Safety against vertical overturning.

Assumptions:
1) The LWM structure behaves as a single structure under the design load.
2) The effect of soil in back of the structure is negligible.
3) The structure will be submerged during the design event
4) This LWM structure experiences the largest loads. All LWM structures on site will be designed based on this LWM structure's loadings

Input (Cells Requiring Input from Structure Detail)
Input (Cells requiring Input from Hydraulic Model)
Input (Cells requiring input from a dropdown list)
Input (Cells automatically populated from Input to Interface Tab)
Output (Cells automatically updated are this color)
Output (Cells automatically updated with previously calculated values are this color)

FBD and Equations:

$$FOS_{overturn} = \frac{MR_{overturn}}{MD_{overturn}}$$ **Equation 49**

Tucannon Big Four Floodplain Restoration has a "LOW" Public Safety Risk Factor and a "MODERATE" Property Damage Risk Factor. The Design Overturn Factor of Safety ($FOS_{overturn}$) for this structure is 1.5 per Table 4 "Minimum Recommended Factors of Safety".

Table 4. Minimum recommended factors of safety.

Public Safety Risk	Property Damage Risk	Stability Design Flow Criteria	$FOS_{sliding}$	$FOS_{buoyancy}$	$FOS_{rotation}$ $FOS_{overturning}$
High	High	100-year	1.75	2.0	1.75
High	Moderate	50-year	1.5	1.75	1.5
High	Low	25-year	1.5	1.75	1.5
Low	High	100-year	1.75	2.0	1.75
Low	Moderate	25-year	1.5	1.75	1.5
Low	Low	10-year	1.25	1.5	1.25

1. Resistance to Overturn ($MR_{rotation}$ and $MD_{rotation}$)

Driving:

F_i	15,488	lb	Impact Forces (Calc'd in Sliding)
F_d	41,548	lb	Drag Forces (Calc'd in Sliding)
F_{hu}		lb	Upstream Hydrostatic Forces (Calc'd in Sliding)
F_L	-12,464	lb	Lift Forces (Assumed Zero in Buoyancy Calcs)
Y_u	7	ft	Upstream water elevation from model
d_{ubury}	6	ft	Depth at upstream side of structure from channel bottom to point of rotation measured perp to flow
L_s	40	ft	Length of structure parallel to flow
$MD_{overturn}$	**1,094,617**	**lb*ft**	**Eqn 46**

$$MD_{overturn} = F_i * (Y_u + d_{bury}) + F_d * \left(\frac{Y_u}{2} + d_{bury}\right) + F_{hu} * \left(\frac{Y_u}{3} + du_{bury}\right) + |F_L| * L_s$$

Equation 46

du_{bury} = depth at the upstream side of the structure from channel bottom to point of rotation measured perpendicular to flow
Ls = length of structure measured parallel to flow

$$MR_{overturn} = |F_{hd}| * \left(\frac{Y_d}{2} + dd_{bury}\right) + |F_{passive}| * (dd_{bury}) + (F_b - F_L - F_{piles-v}) * \frac{L_s}{2} + \sum_i^n F_{pile-v_i} * Lpv_i$$ **Equation 47**

$$F_{pile-v_i} = \frac{F_{piles-v}}{N_{piles}}$$ **Equation 48**

L_{pvi} = distance from pile 'i' to the point of rotation measured parallel to flow

$$FOS_{overturn} = \frac{MR_{overturn}}{MD_{overturn}}$$ **Equation 49**

Resisting:

F_{hd}		lb	Downstream Hydrostatic Forces (Calc'd in Sliding)
$F_{passive}$	-139,796	lb	Passive Forces (Calc'd in Sliding)
F_b	36,743	lb	Buoyancy Forces (Calc'd in Sliding)
F_{pile-v}	-6,161	lb	Lateral Resistance from Piles (Calc'd in Sliding)
Y_d	5.92	ft	Downstream water elevation
d_{dbury}	6	ft	Depth at downstream side of structure from channel bottom to point of rotation measured perp to flow
N_{piles}	10		Number of Piles (Design)
L_{pvi}	40	ft	Distance from pile to the point of rotation measured parallel to flow.
$F_{pile-vi}$	616	lb	Eqn 48
$MR_{overturn}$	**2,192,568**	**lb*ft**	**Eqn 47**

Factor of Safety

$FOS_{overturnon}$ =	$MR_{overturn}$ / $MD_{overturn}$		
$MD_{overturn}$	1,094,617	lb	
$MR_{overturn}$	2,192,568	lb	
$FOS_{overturn}$	**2.00**		**STABLE FOR OVERTURN**

Rotation Calculations

Project: Tucannon Big Four Floodplain Restoration - Channel Spanning Jam w/ Salvaged Trees
Project Number: 20230017

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

Spreadsheet Description

Purpose: The spreadsheet below is used to calculate the Factor of Safety against LWM structure horizontal rotation.

Assumptions:
1) The LWM structue behaves as a single structure under the design load.
2) The effect of soil in back of the structure is negligible.
3) The structure will be submerged during the design event
4) This LWM structure experiences the largest loads. All LWM structures on site will be designed based on this LWM structure's loadings

Input (Cells Requiring Input from Structure Detail)
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FBD and Equations:

$$FOS_{rotation} = \frac{MR_{rotation}}{MD_{rotation}}$$ **Equation 45**

Table 4. Minimum recommended factors of safety.

Public Safety Risk	Property Damage Risk	Stability Design Flow Criteria	$FOS_{sliding}$	$FOS_{buoyancy}$	$FOS_{rotation}$ $FOS_{overturning}$
High	High	100-year	1.75	2.0	1.75
High	Moderate	50-year	1.5	1.75	1.5
High	Low	25-year	1.5	1.75	1.5
Low	High	100-year	1.75	2.0	1.75
Low	Moderate	25-year	1.5	1.75	1.5
Low	Low	10-year	1.25	1.5	1.25

Tucannon Big Four Floodplain Restoration has a "LOW" Public Safety Risk Factor and a "MODERATE" Property Damage Risk Factor. The Design Rotation Factor of Safety ($FOS_{rotation}$) for this structure is 1.5 per Table 4 "Minimum Recommended Factors of Safety".

1. Resistance to Rotation ($MR_{rotation}$ and $MD_{rotation}$)

$$MD_{rotation} = (F_i + F_d + F_{hu}) * \left(\frac{L_{sp}+L_{ebp}}{2}\right)$$ **Equation 42**

L_{sp} = *length of wood structure from tip to point of rotation measured perpendicular to flow*
L_{ebp} = *embedded length of wood structure measured perpendicular to flow*

$$MR_{rotation} = \left| F_{hd} * \left(\frac{L_{sp}+L_{ebp}}{2}\right) + F_{passive} * \frac{L_{ebp}}{2} + F_f * \frac{L_{sp}}{2} + \sum_i^n F_{pile-h_i} * L_{ph_i} \right|$$ **Equation 43**

$$F_{pile-h_i} = \frac{F_{piles-h}}{N_{piles}}$$ **Equation 44**

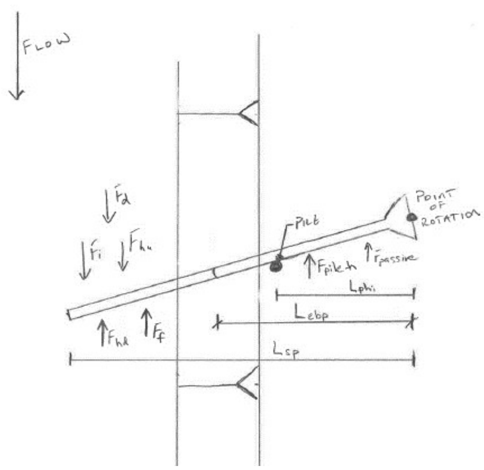
L_{phi} = *distance from pile 'i' to the point of rotation measured perpendicular to flow*

Driving:

L_{sp}	5	ft	Length of wood structure from tip to point of rotation measured perpendicular to flow
L_{ebp}	10	ft	Embedded length of wood structure measured perp. to flow
F_i	15,488	lb	Impact Forces (Calc'd in Sliding)
F_d	41,548	lb	Drag Forces (Calc'd in Sliding)
F_{hu}		lb	Upstream Hydrostatic Forces (Calc'd in Sliding)
$MD_{rotation}$	**427,766**	**lb*ft**	**Eqn 42**

Resisting:

F_{hd}		lb	Downstream Hydrostatic Forces (Calc'd in Sliding)
$F_{passive}$	-139,796	lb	Passive Forces (Calc'd in Sliding)
F_f	-28,707	lb	Friction Forces (Calc'd in Sliding)
F_{pile-h}	-6,161	lb	Lateral Resistance from Piles (Calc'd in Sliding)
$F_{pile-hi}$	-616	lb	Lateral Resistance from Piles (Calc'd in Sliding)
N_{piles}	10		Number of Piles (Design)
L_{phi}	5	ft	Distance from pile to the point of rotation measured perp. to flow.
$MR_{rotation}$	**801,549**	**lb*ft**	**Eqn 43**



Factor of Safety

$FOS_{rotation}$ =	$MR_{rotation}$ / $MD_{rotation}$		
$MD_{rotation}$	427,766	lb	
$MR_{rotation}$	801,549	lb	
$FOS_{rotation}$	**1.87**		**STABLE FOR ROTATION**

Summary Comments:

Sliding Calculations

Project: Tucannon Big Four Floodplain Restoration - Channel Spanning Jam w/ Salvaged Trees
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

Spreadsheet Description

Purpose: The spreadsheet below is used to calculate the Factor of Safety against LWM sliding.

Assumptions:
1) The LWM structure behaves as a single structure under the design load and will not experience any shearing at joints.
2) The effect of soil in back of the structure is negligible.
3) The structure will be submerged during the design event.
4) Channel velocity (V_c) taken from hydraulic model.
5) This LWM structure experiences the largest loads. All LWM structures on site will be designed based on this LWM structure's loadings.

Input (Cells Requiring Input from Structure Detail)
Input (Cells requiring Input from Hydraulic Model)
Input (Cells requiring input from a dropdown list)
Input (Cells automatically populated from Input to Interface Tab)
Output (Cells automatically updated are this color)
Output (Cells automatically updated with previously calculated values are this color)

FBD and Equations:

$$FOS_{sliding} = \frac{|F_{hd}+F_f+F_{piles-h}+F_{passive}|}{F_d+F_{hu}+F_l}$$ Equation 41

Tucannon Big Four Floodplain Restoration has a "LOW" Public Safety Risk Factor and a "MODERATE" Property Damage Risk Factor. The Design Sliding Factor of Safety ($FOS_{sliding}$) for this structure is 1.5 per Table 4 "Minimum Recommended Factors of Safety".

Table 4. Minimum recommended factors of safety.

Public Safety Risk	Property Damage Risk	Stability Design Flow Criteria	$FOS_{sliding}$	$FOS_{bouyancy}$	$FOS_{rotation}$ $FOS_{overturning}$
High	High	100-year	1.75	2.0	1.75
High	Moderate	50-year	1.5	1.75	1.5
High	Low	25-year	1.5	1.75	1.5
Low	High	100-year	1.75	2.0	1.75
Low	Moderate	25-year	1.5	1.75	1.5
Low	Low	10-year	1.25	1.5	1.25

1. Drag Force (F_d)

Y_u	7.00	ft	Upstream water depth
hdebris	5	ft	Debris height (incl. accumulation)
wdebris	60	ft	Debris width (incl. accumulation)
Debris Shape	Rectangle		
A_{LWM}	420	ft^2	Wetted area of LWM
γ_{water}	62.40	lb/ft^3	Unit weight of water
v_c	8.25	ft/s	Velocity from Model
g	32.20	ft/s^2	Acceleration due to gravity
A_b	420.00	ft^2	Debris area
$w_{channel}$	50	ft	Channel width
c_d	1.50		NLWM Worst Case
F_d	41548	lb	Eqn 19

$$F_d = \frac{C_D * A_{LWM} * \gamma_w * U_c^2}{2 * g}$$ Equation 19

F_d = *drag force*
C_d = *drag coefficient*
A_{LWM} = *area of wetted debris based on the upstream water surface elevation projected normal to flow direction and the potential drift accumulation*
γ_w = *unit weight of water*
U_c = *velocity in contracted section*
g = *acceleration due to gravity*

Cd can be assumed 0.9 when fully submerged, 1.5 when WSEL withi

$$C_{d-applied} = \frac{C_d}{(1-B)^2}$$ C_d is typically estimated as 1.0 Equation 27

Sliding Calculations

Project: Tucannon Big Four Floodplain Restoration - Channel Spanning Jam w/ Salvaged Trees
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

3. Impact Force (F_i)

L_{debris}	40	ft	Length of debris member (Design)
$d_{boledebris}$	2	ft	Bole diameter of debris member (Design)
$d_{rwdebris}$	5	ft	Rootwad diameter of debris member (Design)
V_{debris}	152	ft^3	Volume of debris
γ_{wood}	33	lb/ft^3	Unit weight of wood
w_{debris}	5,011	lb	weight of debris
g	32.2	ft/s^2	Acceleration due to gravity
$V_{channel}$	8.3	ft/s	Velocity from Model
Δt	0.03	sec	Impact Interval (0.03 sec recommended)
C_i	0.6		Coefficient of importance (from Table 6)
C_o	0.8		Coefficient of orientation
C_d	1		Figure 11 (need water depth from model)
Degree of Screening or Sheltering Upstream	Limited upstream screening, flow path 20' wide		ASCE 7-05
C_b	0.6		ASCE 7-05
R_{max}	0.8		Response ratio for impulsive loads
F_i	**15,488**	**lb**	**Eqn 30**

$$F_i = \frac{\pi w_{debris} * V_{channel} * C_i * C_o * C_d * C_b * R_{max}}{2 * g * \Delta t}$$ **Equation 30**

F_i = impact force

w_{debris} = weight of debris

g = acceleration constant due to gravity

$V_{channel}$ = water velocity in channel

Δt = time from initial velocity to zero velocity

C_i = coefficient of importance

C_o = coefficient of orientation = 0.8

C_d = coefficient of depth

C_b = coefficient of blockage

R_{max} = response ratio for impulsive loads = 0.8

Assumption:

***Largest impact force would be generated by structure being struck by floating large key member. For impact calculation, assuming 18" diameter, 30' long member with rootwad impacts structure.**
****See Section 6.3.3 of LWM RBDG (P. 44) for debris loading sizing.**

4. Friction Force (F_f)

ϕ_{bed}	0.66	radians	Calculated for streambed material (small cobble)
μ_{bed}	0.78		Eqn 32
F_{LWMd}		lb	Buoyancy Calcs
$F_{boulder}$		lb	Buoyancy Calcs
F_{soil}	72586	lb	Buoyancy Calcs
$F_{piles-v}$		lb	Buoyancy Calcs
F_{LWMs}	-23379	lb	Buoyancy Calcs
F_L	-12464	lb	Buoyancy Calcs
F_b	36,743	lb	Eqn 17
F_f	**-28,707**	**lb**	**Eqn 31**

$$F_f = -\mu_{bed} * (F_b - F_{piles-v})$$ Equation 31

F_f = force due to frictional resistance

F_b-$F_{piles-v}$ >0

$$\mu_{bed} = \tan \emptyset$$ Equation 32

$$F_b = F_{LWMs} + F_{LWMd} + F_L + F_{boulder} + F_{soil} + F_{piles-v}$$ ***Equation 17***

Note:
***If buoyancy forces are less than vertical pile forces (Fb-Fpiles-v<0), then friction force = 0.**

Sliding Calculations

Project: Tucannon Big Four Floodplain Restoration - Channel Spanning Jam w/ Salvaged Trees
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5. Passive Forces ($F_{passive}$)

ϕ_{bank}	0.63	radians	Calculated for bank material (very course gravel)
K_p	3.85		Eqn 34
γ_{water}	62.4	lb/ft^3	Unit weight of water
γ_{soil}	120	lb/ft^3	Unit weight of soil
γ_{sat}	137	lb/ft^3	Previously calculated for buoyancy calcs
$N_{logssub1}$	6		Number of log type 1 (from detail)
Orientation$_1$**	Perpendicular		Perpendicular or Parallel to flow
L_{eb1}	27	ft	Length of log type 1 (from detail)
d_{bole1}	1.5	ft	Diameter of log type 1 (from detail)
D_{sub1}	3	ft	Depth of submerged soil above log 1
D_{dry1}		ft	Depth of dry soil above log 1
σ_{v1}	224	lb/ft^2	
$\sigma_{v1}*L_{eb1}*\gamma_{soil}$	54,344	lb	
$N_{logssub2}$	4		Number of log type 2 (from detail)
Orientation$_2$**	Perpendicular		Perpendicular or Parallel to flow
L_{eb2}	13.3	ft	Length of log type 2 (from detail)
d_{bole2}	0.8	ft	Diameter of log type 2 (from detail)
D_{sub2}	5.75	ft	Depth of submerged soil above log 2
D_{dry2}		ft	Depth of dry soil above log 2
σ_{v2}	429	lb/ft^2	
$\sigma_{v2}*L_{eb2}*\gamma_{soil}$	18,243	lb	
$N_{logssub3}$	2		Number of log type 3(from detail)
Orientation$_3$**	Perpendicular		Perpendicular or Parallel to flow
L_{eb3}		ft	Length of log type 3 (from detail)
d_{bole3}		ft	Diameter of log type 3 (from detail)
D_{sub3}		ft	Depth of submerged soil above log 3
D_{dry3}		ft	Depth of dry soil above log 3
σ_{v3}		lb/ft^2	
$\sigma_{v3}*L_{eb3}*\gamma_{soil}$		lb	
$F_{passive}$	**-139,796**	**lb**	**Eqn 31**

3.85184

** Eqns 33 through 35 represent the case where passive forces act

$$F_{passive} = -0.5 * K_p * \sum_i^n \sigma_{v_i} * L_{em_i} * d_{log_i}$$ Equ

$$K_p = \frac{1+\sin\phi}{1-\sin\phi}$$ Equ

$$\sigma_{v_i} = D_{sub_i} * (\gamma_{sat} - \gamma_{water}) + D_{dry_i} * \gamma_{soil}$$ Equ

D_{subi} = depth of submerged soil above log i
D_{dryi} = depth of dry soil above log i
L_{emi} = embedded length of log i
d_{logi} = diameter of log i

Sliding Calculations

Project: Tucannon Big Four Floodplain Restoration - Channel Spanning Jam w/ Salvaged Trees
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6. Lateral Resistance from Piles ($F_{piles\text{-}h}$)

N_{piles}	10		Number of piles (Design)
d_{piles}	0.8	ft	Diameter of piles (Design)
L_{piles}	5.75	ft	Embedded length of piles below scour (Design)
Placement Method	Excavated		Method of pile placement
Placement Multiplier	0.25		See RBDG (P. 52)
Pile Placement Location	Bed		Bed or Bank
γ_{water}	62.4	lb/ft^3	Unit weight of water
γ_{soil}	126	lb/ft^3	Unit weight of soil
γ_e	63.6	lb/ft^3	Eqn 37
ϕ_{soil}	0.66	radians	Calculated for material pile is located
K_p	4.20		Eqn 38
h_{load}**	2.5	ft	Height above scour depth load is applied
$F_{piles\text{-}h}$	**-6,161**	**lb**	**Eqn 15**

$$F_{piles-h} = -N_{piles} * \frac{L_{pile}^3 * \frac{1}{2} * \gamma_e * d_{pile} * K_p}{h_{load} + L_{pile}} \quad \text{Equation 36}$$

N_{piles} = number of piles
L_{pile} = length of pile embedded below potential scour depth

$$\gamma_e = \gamma_s - \gamma_w \quad \textit{effective unit weight of soil} \quad \text{Equation 37}$$

γ_s = dry unit weight of the soil

γ_w = unit weight of the soil
d_{pile} = diameter of the pile
h_{load} = height above the potential scour depth the load is applied

$$K_p = \frac{1+\sin\phi}{1-\sin\phi} \quad \text{Equation 38}$$

*** Top 2' of pile embedment disregarded for calculation to account for vortex shedding.**
**** Analysis also assumes that the resultant force is located at half of the flow depth on the upstream side of the LWM structure to produce a conservative moment on the pile.**

Factor of Safety

$FOS_{sliding}$ =	*$(F_{hd} + F_f + F_{piles\text{-}h} + F_{passive}) / (F_d + F_{hu} + F_i)$*		
F_d	41,548	lb	
F_{hu}		lb	
F_{hd}		lb	
F_i	15,488	lb	
F_f	-28,707	lb	
$F_{passive}$	-139,796	lb	
$F_{piles\text{-}h}$	-6,161	lb	
$FOS_{sliding}$	**3.06**		**STABLE FOR SLIDING**

Summary Comments:

Appendix C

Wood Habitat Structure Stability Calculations

WHS Type #5 Channel Spanning Jam

Buoyancy Calculations

Project: Tucannon Big Four Floodplain Restoration - Channel Spanning Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

Spreadsheet Description

- The spreadsheet below is used to calculate the Factor of Safety against Buoyant uplift of the LWM

Assumptions:

1) The LWM structure behaves as a single structure under the design load and will not experience any shearing at joints
2) The LWM structure will be submerged during the design event.
3) Negative buoyancy is uplift, positive numbers equals downward.
4) Ballast material remains intact and is not scoured out.
5) The uplift due to racking material is evenly dividing among all layers.

Input (Cells Requiring Input from Structure Detail)
Input (Cells requiring Input from Hydraulic Model)
Input (Cells automatically populated from Input to Interface Tab)
Input (Cells requiring input from a dropdown list)
Output (Cells automatically updated are this color)
Output (Cells automatically updated with previously calculated values are this color)

FBD and Equations:

$$FOS_b = \frac{F_{LWMd} + F_{boulders} + F_{soil} + F_{piles-e}}{|F_{LWMs} + F_L|}$$ **Equation 18**

FOS_b = *buoyancy factor of safety*

Tucannon Big Four Floodplain Restoration has a "LOW" Public Safety Risk Factor and a "MODERATE" Property Damage Risk Factor. The Design buoyancy factor of safety (FOS_b) for this structure is 1.75 per Table 4 "*Minimum Recommended Factors of Safety*".

Table 4. Minimum recommended factors of safety.

Public Safety Risk	Property Damage Risk	Stability Design Flow Criteria	$FOS_{sliding}$	$FOS_{buoyancy}$	$FOS_{rotation}$ $FOS_{overturning}$
High	High	100-year	1.75	2.0	1.75
High	Moderate	50-year	1.5	1.75	1.5
High	Low	25-year	1.5	1.75	1.5
Low	High	100-year	1.75	2.0	1.75
Low	Moderate	25-year	1.5	1.75	1.5
Low	Low	10-year	1.25	1.5	1.25

1. Large Wood Material Force - Dry (F_{LWMd})

$$F_{LWMd} = V_{LWMd} * \gamma_{wood}$$ **Equation 3**

V_{LWMd} = *volume of dry large wood material*

Comment: Assumed to be zero because structure assumed to be submerged during design event.

2. Boulder Ballast Force ($F_{boulder}$)

$N_{bouldersub}$			Number of submerged boulders (from design)
$d_{bouldersub}$	2.5	ft	Effective diameter of submerged boulder (ft, from spec)
$\gamma_{boulder}$	146	lb/ft^3	unit weight of boulders (Table 5)
γ_{water}	62.4	lb/ft^3	unit weight of water
$F_{bouldersub}$		lb	Eqn. 6
$N_{boulderdry}$			Number of dry boulders (from detail)
$d_{boulderdry}$	2.5	ft	Effective diameter of dry boulder (ft, from spec)
$F_{boulderdry}$		lb	Eqn. 7
$F_{boulder}$		**lb**	**Eqn. 5**

$$F_{boulder} = F_{bouldersub} + F_{boulderdry}$$ **Equation 5**

$$F_{bouldersub} = N_{bouldersub} * \frac{\pi}{6} * d^3_{bouldersub} * (\gamma_{boulder} - \gamma_w)$$ **Equation 6**

$N_{bouldersub}$ = *number of submerged boulders*
$d_{bouldersub}$ = *effective diameter of submerged boulders*
$\gamma_{boulder}$ = *unit weight of boulders*

$$F_{boulderdry} = N_{boulderdry} * \frac{\pi}{6} * d^3_{boulderdry} * \gamma_{boulder}$$ **Equation 7**

$N_{boulderdry}$ = *number of unsubmerged boulders*
$d_{boulderdry}$ = *effective diameter of unsubmerged boulders*

Comment: The intent is design without the use of boulders so it is assumed no boulders are used.

Buoyancy Calculations

Project:	Tucannon Big Four Floodplain Restoration - Channel Spanning Jam	**Analyst:**	BF
Project No.:	20230017.1	**Calculations Checked By:**	AJ
		Latest Revision:	4/2/2025

3. Soil Backfill Force (F_{soil})

$N_{logssub1}$	3		Number of Type 1 buried logs (from detail)
L_{eb1}	27	ft	Average embedded length of Type 1 logs (from detail)
d_{bole1}	1	ft	Average diameter of Type 1 logs (from detail)
$h_{soilsub1}$	3	ft	Average height of submerged soil above Type 1 log (from detail)
$V_{soilsub1}$	243	ft^3	Volume of submerged soil above Type 1 log (from detail)
$h_{soildry1}$		ft	Average height of dry soil above Type 1 log (from detail)
$V_{soildry1}$		ft^3	Volume of dry soil above Type 1 log (from detail)
$N_{logssub2}$	1		Number of Type 2 buried logs (from detail)
L_{eb2}	13.3	ft	Average embedded length of Type 2 logs (from detail)
d_{bole2}	2	ft	Average diameter of Type 2 logs (from detail)
$h_{soilsub2}$	2	ft	Average height of submerged soil above Type 2 log (from detail)
$V_{soilsub2}$	53	ft^3	Volume of submerged soil above Type 2 log (from detail)
$h_{soildry2}$		ft	Average height of dry soil above Type 2 log (from detail)
$V_{soildry2}$		ft^3	Volume of dry soil above Type 2 log (from detail)
$N_{logssub3}$	4		Number of Type 3 buried logs (from detail)
L_{eb3}	13	ft	Average embedded length of Type 3 logs (from detail)
d_{bole3}	1	ft	Average diameter of Type 3 logs (from detail)
$h_{soilsub3}$	2	ft	Average height of submerged soil above Type 3 log (from detail)
$V_{soilsub3}$	104	ft^3	Volume of submerged soil above Type 3 log (from detail)
$h_{soildry3}$		ft	Average height of dry soil above Type 3 log (from detail)
$V_{soildry3}$		ft^3	Volume of dry soil above Type 3 log (from detail)
γ_{soil}	120	lb/ft^3	Specific Gravity of bank/backfill material (Table 5)
γ_{water}	62.4	lb/ft^3	Unit weight of water
SG_{rock}	2.64		Specific Gravity of Rock (Using unit weight of bedrock from Table 5)
e	0.37		Eqn. 14
γ_{sat}	137	lb/ft^3	Eqn. 13
γ'_{soil}	74.5	lb/ft^3	Eqn. 12
F_{soil}	**29,833**	**lb**	**Eqn. 8**

$$F_{soil} = \sum_i^n V_{soilsub_i} * \gamma'_{soil} + V_{soildry_i} * \gamma_{soil}$$ **Equation 8**

$$V_{soilsub_i} = L_{eb_i} d_{bole_i} h_{soilsub_i}$$ **Equation 9**

$V_{soilsubi}$ = volume of submerged soil above log i
L_{ebi} = embedded length of log i
d_{bolei} = bole diameter of log i
$h_{soilsubi}$ = height of submerged soil above log i

$$V_{soildry_i} = L_{eb_i} d_{bole_i} h_{soildry_i}$$ ***Equation 10***

$V_{soildryi}$ = volume of dry soil above log i
$h_{soildryi}$ = height of dry soil above log i

$$\gamma_{soil} = (99.2 + 18.6 * \log(d_{50}))$$ **Equation 11**

d_{50} = median grain size in millimeters

$$\gamma'_{soil} = \gamma_{sat} - \gamma_w$$ **Equation 12**

$$\gamma_{sat} = \frac{(SG_{rock} + e) * \gamma_w}{1 + e}$$ **Equation 13**

$$e = \frac{SG_{rock} * \gamma_w}{\gamma_{soil}} - 1$$ **Equation 14**

Buoyancy Calculations

Project: Tucannon Big Four Floodplain Restoration - Channel Spanning Jam
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Calculations Checked By: AJ
Latest Revision: 4/2/2025

4. Pier Log Friction

N_{piles}			Number of piles (Design)
d_{piles}	1	ft	Diameter of piles (Design)
L_{piles}	5.75	ft	Embedded length of piles (Design)
k_s	1		Coefficient of lateral earth pressure (0.5 to 1.5 depending on soil and density)
Placement Method	Excavated		Method of pile placement
Placement Multiplier	0.25		See RBDG (P. 52)
Pile Placement Location	Bed		Bed or Bank
ϕ_{soil}	0.66	rad	Internal angle of friction of soils (Table 5)
γ_{soil}	126	lb/ft^3	Specific Weight of Soil
e	0.31		Eqn. 14
γ_{sat}	141	lb/ft^3	Eqn. 13
γ_{water}	62.4	lb/ft^3	Unit weight of water
σ'	450	lb/ft^2	Eqn 16
γ_{wood}	33	lb/ft^3	Unit weight of wood
$F_{piles-v}$		**lb**	**Eqn 15**

$$F_{piles-v} = N_{piles} * \pi * d_{piles} * L_{piles}(k_s * \tan\frac{2}{3}\phi * \sigma' + \frac{d_{piles}}{4} * (\gamma_{wood} - \gamma_w))$$

Equation 15

N_{piles} = number of piles
d_{piles} = diameter of piles
L_{piles} = embedded length of piles
k_s = coefficient of lateral earth pressure (0.5 to 1.5 depending on soil and density)
ϕ = internal angle of friction of soils

$$\sigma' = L_{piles} * (\gamma_{sat} - \gamma_w)$$

Equation 16

$$\gamma_{sat} = \frac{(SG_{rock} + e) * \gamma_w}{1+e}$$

Equation 13

$$e = \frac{SG_{rock} * \gamma_w}{\gamma_{soil}} - 1$$

Equation 14

Assumptions:
*** k_s = 1**
**** This calculation is based on the assumption that piles are driven or vibrated into place. If piles are drilled or excavated, the associated coefficicient of lateral earth pressures shall be approx. 50% and 25% of the driven value, respectively.**
***** For use in buoyancy calculations, piles must be mechanically fastened.**
****** Top 2' of pile embedment disregarded for calculation to account for vortex shedding.**

5. Large Wood Material Force - Submerged (F_{LWMs})

$$F_{LWMs} = V_{LWMs} * (\gamma_{wood} - \gamma_w)$$

Equation 2

V_{LWMs} = volume of submerged large wood material
γ_{wood} = unit weight of wood
γ_w = unit weight of water

$N_{logssub1}$	3		Number of log type 1 (from detail)
L_{log1}	27	ft	Length of log type 1 (from detail)
d_{bole1}	1	ft	Diameter of log type 1 (from detail)
d_{rw1}	2.50	ft	Diameter of rootwad of log type 1 (from detail)
V_{LWMs1}	73	ft^3	Volume of LWM1
$N_{logssub2}$	1		Number of log type 2 (from detail)
L_{eb2}	13.3	ft	Length of log type 2 (from detail)
d_{bole2}	2	ft	Diameter of log type 2 (from detail)
d_{rw2}		ft	Diameter of rootwad of log type 2 (from detail)
V_{LWMs2}	42	ft^3	Volume of LWM2
$N_{logssub3}$	4		Number of log type 3 (from detail)
L_{eb3}	13	ft	Length of log type 3 (from detail)
d_{bole3}	1	ft	Diameter of log type 3 (from detail)

Volume of Rootwad

National Large Wood Manual. 2016

Equation 6-4 (p. 6-38)

$V_{rw} = \pi * t_k * w_k^2 / 3$

$\pi * (2d_{bole}) * (1/2d_{rw})^2 / 3$

t_k = Thickness of rootwad measured in direction parallel to trunk

= 4 times the radius of the log ($4r_k$ or

w_k =

Radius of rootwad

Buoyancy Calculations

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d_{rw3}		ft	Diameter of rootwad of log type 3 (from detail)
V_{LWMs3}	41	ft^3	Volume of LWM3
V_{LWMs}	156	ft^3	Volume of LWM
γ_{wood}	33.0	lb/ft^3	Unit weight of logs
γ_w	62.4	lb/ft^3	Unit weight of water
F_{LWMs}	**-4,588**	**lb**	**Eqn. 3**

= 2.5 times the radius of the log ($2.5r_k$ or $1.25d_{bole}$) or 1/2 d_{rw} specified

6. Lift Forces (F_L)

$$F_L = -\frac{C_L * A_{LWM} * \gamma_w * U_o^2}{2 * g}$$ **Equation 4**

C_L = *lift coefficient*
A_{LWM} = *area of large woody material perpendicular to flow*
u_u = *upstream channel velocity at design event*
g = *acceleration due to gravity*

C_L	0.45		Lift Coefficient
A_{LWM}	225	ft^2	Calc'd in Drag Forces
γ_w	62.4	lb/ft^3	Unit weight of water
U_o	7.0	ft/s	upstream velocity (from model)
g	32.2	ft/s^2	Unit weight of water
F_L	**-4,807**	**lb**	**Eqn. 4**

Comment: Lift forces neglected per Section 6.4.2 of BOR Risk Based Design Guidelines

Factor of Safety

FOS_b =	$(F_{LMDd} + F_{boulders} + F_{soil} + F_{piles\text{-}v}) / (F_{LWMs} + F_L)$		
F_{LWMd}		lb	Assumed Zero
$F_{boulder}$		lb	
F_{soil}	29,833	lb	
$F_{piles\text{-}v}$		lb	
F_{LWMs}	-4,588	lb	
F_L	-4,807	lb	
FOS_b	**3.18**		**STABLE FOR BUOYANCY**

Summary Comments:

Overturning Calculations

Project: Tucannon Big Four Floodplain Restoration - Channel Spanning Jam
Project Number: 20230017

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

Spreadsheet Description

Purpose: The spreadsheet below is used to calculate the Factor of Safety against vertical overturning.

Assumptions:
1) The LWM structure behaves as a single structure under the design load.
2) The effect of soil in back of the structure is negligible.
3) The structure will be submerged during the design event
4) This LWM structure experiences the largest loads. All LWM structures on site will be designed based on this LWM structure's loadings

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FBD and Equations:

$$FOS_{overturn} = \frac{MR_{overturn}}{MD_{overturn}}$$ **Equation 49**

Tucannon Big Four Floodplain Restoration has a "LOW" Public Safety Risk Factor and a "MODERATE" Property Damage Risk Factor. The Design Overturn Factor of Safety ($FOS_{overturn}$) for this structure is 1.5 per Table 4 "Minimum Recommended Factors of Safety".

Table 4. Minimum recommended factors of safety.

Public Safety Risk	Property Damage Risk	Stability Design Flow Criteria	$FOS_{sliding}$	$FOS_{buoyancy}$	$FOS_{rotation}$ $FOS_{overturning}$
High	High	100-year	1.75	2.0	1.75
High	Moderate	50-year	1.5	1.75	1.5
High	Low	25-year	1.5	1.75	1.5
Low	High	100-year	1.75	2.0	1.75
Low	Moderate	25-year	1.5	1.75	1.5
Low	Low	10-year	1.25	1.5	1.25

$$MD_{overturn} = F_i * (Y_u + d_{bury}) + F_d * \left(\frac{Y_u}{2} + d_{bury}\right) + F_{hu} * \left(\frac{Y_u}{3} + du_{bury}\right) + |F_L| * L_s$$ **Equation 46**

du_{bury} = depth at the upstream side of the structure from channel bottom to point of rotation measured perpendicular to flow
Ls = length of structure measured parallel to flow

$$MR_{overturn} = |F_{hd}| * \left(\frac{Y_d}{2} + dd_{bury}\right) + |F_{passive}| * (dd_{bury}) + (F_b - F_L - F_{piles-v}) * \frac{L_s}{2} + \sum_i^n F_{pile-v_i} * Lpv_i$$ **Equation 47**

$$F_{pile-v_i} = \frac{F_{piles-v}}{N_{piles}}$$ **Equation 48**

L_{pvi} = distance from pile 'i' to the point of rotation measured parallel to flow

$$FOS_{overturn} = \frac{MR_{overturn}}{MD_{overturn}}$$ **Equation 49**

1. Resistance to Overturn ($MR_{rotation}$ and $MD_{rotation}$)

Driving:

F_i	13,141	lb	Impact Forces (Calc'd in Sliding)
F_d	16,024	lb	Drag Forces (Calc'd in Sliding)
F_{hu}		lb	Upstream Hydrostatic Forces (Calc'd in Sliding)
F_L	-4,807	lb	Lift Forces (Assumed Zero in Buoyancy Calcs)
Y_u	7.5	ft	Upstream water elevation from model
d_{ubury}	6	ft	Depth at upstream side of structure from channel bottom to point of rotation measured perp to flow
L_s	40	ft	Length of structure parallel to flow
$MD_{overturn}$	**525,926**	**lb*ft**	**Eqn 46**

Resisting:

F_{hd}		lb	Downstream Hydrostatic Forces (Calc'd in Sliding)
$F_{passive}$	-50,720	lb	Passive Forces (Calc'd in Sliding)
F_b	20,438	lb	Buoyancy Forces (Calc'd in Sliding)
F_{pile-v}		lb	Lateral Resistance from Piles (Calc'd in Sliding)
Y_d	6.2	ft	Downstream water elevation
d_{dbury}	6	ft	Depth at downstream side of structure from channel bottom to point of rotation measured perp to flow
N_{piles}	3		Number of Piles (Design)
L_{pvi}	40	ft	Distance from pile to the point of rotation measured parallel to flow.
$F_{pile-vi}$		lb	Eqn 48
$MR_{overturn}$	**809,222**	**lb*ft**	**Eqn 47**

Factor of Safety

$FOS_{overturnon}$ = $MR_{overturn}$ / $MD_{overturn}$			
$MD_{overturn}$	525,926	lb	
$MR_{overturn}$	809,222	lb	
$FOS_{overturn}$	**1.54**		**STABLE FOR OVERTURN**

Rotation Calculations

Project: Tucannon Big Four Floodplain Restoration - Channel Spanning Jam
Project Number: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

Spreadsheet Description

Purpose: The spreadsheet below is used to calculate the Factor of Safety against LWM structure horizontal rotation.

Assumptions:
1) The LWM structue behaves as a single structure under the design load.
2) The effect of soil in back of the structure is negligible.
3) The structure will be submerged during the design event
4) This LWM structure experiences the largest loads. All LWM structures on site will be designed based on this LWM structure's loadings

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Output (Cells that are automatically updated with previously calculated values are this color)

FBD and Equations:

$$FOS_{rotation} = \frac{MR_{rotation}}{MD_{rotation}}$$ **Equation 45**

Tucannon Big Four Floodplain Restoration has a "LOW" Public Safety Risk Factor and a "MODERATE" Property Damage Risk Factor. The Design Rotation Factor of Safety ($FOS_{rotation}$) for this structure is 1.5 per Table 4 "Minimum Recommended Factors of Safety".

Table 4. Minimum recommended factors of safety.

Public Safety Risk	Property Damage Risk	Stability Design Flow Criteria	$FOS_{sliding}$	$FOS_{buoyancy}$	$FOS_{rotation}$ $FOS_{overturning}$
High	High	100-year	1.75	2.0	1.75
High	Moderate	50-year	1.5	1.75	1.5
High	Low	25-year	1.5	1.75	1.5
Low	High	100-year	1.75	2.0	1.75
Low	Moderate	25-year	1.5	1.75	1.5
Low	Low	10-year	1.25	1.5	1.25

1. Resistance to Rotation ($MR_{rotation}$ and $MD_{rotation}$)

$$MD_{rotation} = (F_i + F_d + F_{hu}) * \left(\frac{L_{sp}+L_{ebp}}{2}\right)$$ **Equation 42**

L_{sp} = length of wood structure from tip to point of rotation measured perpendicular to flow

L_{ebp} = embedded length of wood structure measured perpendicular to flow

$$MR_{rotation} = \left| F_{hd} * \left(\frac{L_{sp}+L_{ebp}}{2}\right) + F_{passive} * \frac{L_{ebp}}{2} + F_f * \frac{L_{sp}}{2} + \sum_{i}^{n} F_{pile-h_i} * L_{ph_i} \right|$$ **Equation 43**

$$F_{pile-h_i} = \frac{F_{piles-h}}{N_{piles}}$$ **Equation 44**

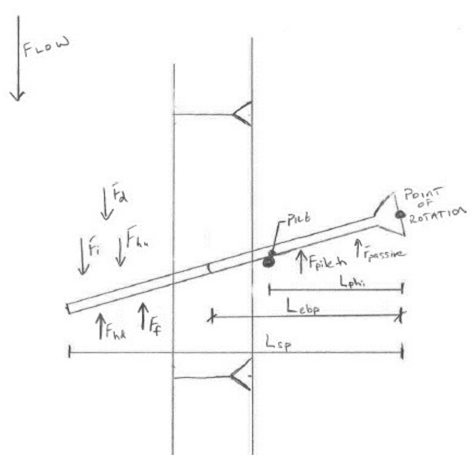
L_{phi} = distance from pile 'i' to the point of rotation measured perpendicular to flow

Driving:

L_{sp}	15	ft	Length of wood structure from tip to point of rotation measured perpendicular to flow
L_{ebp}	27	ft	Embedded length of wood structure measured perp. to flow
F_i	13,141	lb	Impact Forces (Calc'd in Sliding)
F_d	16,024	lb	Drag Forces (Calc'd in Sliding)
F_{hu}		lb	Upstream Hydrostatic Forces (Calc'd in Sliding)
$MD_{rotation}$	**612,467**	**lb*ft**	**Eqn 42**

Resisting:

F_{hd}		lb	Downstream Hydrostatic Forces (Calc'd in Sliding)
$F_{passive}$	-50,720	lb	Passive Forces (Calc'd in Sliding)
F_f	-15,968	lb	Friction Forces (Calc'd in Sliding)
F_{pile-h}	-5,391	lb	Lateral Resistance from Piles (Calc'd in Sliding)
$F_{pile-hi}$	-770	lb	Lateral Resistance from Piles (Calc'd in Sliding)
N_{piles}	7		Number of Piles (Design)
L_{phi}	27	ft	Distance from pile to the point of rotation measured perp. to flow.
$MR_{rotation}$	**950,034**	**lb*ft**	**Eqn 43**



Factor of Safety

$FOS_{rotation}$ =	$MR_{rotation}$ / $MD_{rotation}$		
$MD_{rotation}$	612,467	lb	
$MR_{rotation}$	950,034	lb	
$FOS_{rotation}$	**1.55**		**STABLE FOR ROTATION**

Summary Comments:
drag and impact forces assumed to be acting in the center of the log, so the length from here to the point of rotation is shorter than the overall length of the log. (20 feet versus 40 feet).

Sliding Calculations

Project:	Tucannon Big Four Floodplain Restoration - Channel Spanning Jam	**Analyst:**	BF
Project No.:	20230017.1	**Calculations Checked By:**	AJ
		Latest Revision:	4/2/2025

Spreadsheet Description

Purpose: The spreadsheet below is used to calculate the Factor of Safety against LWM sliding.

Assumptions:
1) The LWM structure behaves as a single structure under the design load and will not experience any shearing at joints.
2) The effect of soil in back of the structure is negligible.
3) The structure will be submerged during the design event.
4) Channel velocity (V_c) taken from hydraulic model.
5) This LWM structure experiences the largest loads. All LWM structures on site will be designed based on this LWM structure's loadings.

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FBD and Equations:

$$FOS_{sliding} = \frac{|F_{hd}+F_f+F_{piles-h}+F_{passive}|}{F_d+F_{hu}+F_l} \quad \text{Equation 41}$$

Tucannon Big Four Floodplain Restoration has a "LOW" Public Safety Risk Factor and a "MODERATE" Property Damage Risk Factor. The Design Sliding Factor of Safety ($FOS_{sliding}$) for this structure is 1.5 per Table 4 "Minimum Recommended Factors of Safety".

Table 4. Minimum recommended factors of safety.

Public Safety Risk	Property Damage Risk	Stability Design Flow Criteria	$FOS_{sliding}$	$FOS_{bouyancy}$	$FOS_{rotation}$ $FOS_{overturning}$
High	High	100-year	1.75	2.0	1.75
High	Moderate	50-year	1.5	1.75	1.5
High	Low	25-year	1.5	1.75	1.5
Low	High	100-year	1.75	2.0	1.75
Low	Moderate	25-year	1.5	1.75	1.5
Low	Low	10-year	1.25	1.5	1.25

1. Drag Force (F_d)

Y_u	7.50	ft	Upstream water depth
hdebris	5	ft	Debris height (incl. accumulation)
wdebris	15	ft	Debris width (incl. accumulation)
Debris Shape	Rectangle		
A_{LWM}	225	ft^2	Wetted area of LWM
γ_{water}	62.40	lb/ft^3	Unit weight of water
v_c	7.00	ft/s	Velocity from Model
g	32.20	ft/s^2	Acceleration due to gravity
A_b	225.00	ft^2	Debris area
$w_{channel}$	75	ft	Channel width
c_d	1.50		NLWM Worst Case
F_d	16024	lb	Eqn 19

$$F_d = \frac{C_D * A_{LWM} * \gamma_w * U_c^2}{2 * g} \quad \text{Equation 19}$$

$F_d = drag\ force$
$C_d = drag\ coefficient$
A_{LWM} = *area of wetted debris based on the upstream water surface elevation projected normal to flow direction and the potential drift accumulation*
$\gamma_w = unit\ weight\ of\ water$
$U_c = velocity\ in\ contracted\ section$
$g = acceleration\ due\ to\ gravity$

Cd can be assumed 0.9 when fully submerged, 1.5 when WSEL withi

$$C_{d-applied} = \frac{C_d}{(1-B)^2}$$ C_d is typically estimated as 1.0 Equation 27

Sliding Calculations

Project: Tucannon Big Four Floodplain Restoration - Channel Spanning Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

3. Impact Force (F_i)

L_{debris}	40	ft	Length of debris member (Design)
$d_{boledebris}$	2	ft	Bole diameter of debris member (Design)
$d_{rwdebris}$	5	ft	Rootwad diameter of debris member (Design)
V_{debris}	152	ft^3	Volume of debris
γ_{wood}	33	lb/ft^3	Unit weight of wood
w_{debris}	5,011	lb	weight of debris
g	32.2	ft/s^2	Acceleration due to gravity
$V_{channel}$	7.0	ft/s	Velocity from Model
Δt	0.03	sec	Impact Interval (0.03 sec recommended)
C_i	0.6		Coefficient of importance (from Table 6)
C_o	0.8		Coefficient of orientation
C_d	1		Figure 11 (need water depth from model)
Degree of Screening or Sheltering Upstream	Limited upstream screening, flow path 20' wide		ASCE 7-05
C_b	0.6		ASCE 7-05
R_{max}	0.8		Response ratio for impulsive loads
F_i	**13,141**	**lb**	**Eqn 30**

$$F_i = \frac{\pi w_{debris} * V_{channel} * C_i * C_o * C_d * C_b * R_{max}}{2 * g * \Delta t}$$ **Equation 30**

F_i = impact force

w_{debris} = weight of debris

g = acceleration constant due to gravity

$V_{channel}$ = water velocity in channel

Δt = time from initial velocity to zero velocity

C_i = coefficient of importance

C_o = coefficient of orientation = 0.8

C_d = coefficient of depth

C_b = coefficient of blockage

R_{max} = response ratio for impulsive loads = 0.8

Assumption:

***Largest impact force would be generated by structure being struck by floating large key member. For impact calculation, assuming 18" diameter, 30' long member with rootwad impacts structure.**
****See Section 6.3.3 of LWM RBDG (P. 44) for debris loading sizing.**

4. Friction Force (F_f)

ϕ_{bed}	0.66	radians	Calculated for streambed material (small cobble)
μ_{bed}	0.78		Eqn 32
F_{LWMd}		lb	Buoyancy Calcs
$F_{boulder}$		lb	Buoyancy Calcs
F_{soil}	29833	lb	Buoyancy Calcs
$F_{piles-v}$		lb	Buoyancy Calcs
F_{LWMs}	-4588	lb	Buoyancy Calcs
F_L	-4807	lb	Buoyancy Calcs
F_b	20,438	lb	Eqn 17
F_f	**-15,968**	**lb**	**Eqn 31**

$$F_f = -\mu_{bed} * (F_b - F_{piles-v})$$ Equation 31

F_f = force due to frictional resistance

$F_b - F_{piles-v} > 0$

$$\mu_{bed} = \tan \emptyset$$ Equation 32

$$F_b = F_{LWMs} + F_{LWMd} + F_L + F_{boulder} + F_{soil} + F_{piles-v}$$ *Equation 17*

Note:
***If buoyancy forces are less than vertical pile forces (Fb-Fpiles-v<0), then friction force = 0.**

Sliding Calculations

Project: Tucannon Big Four Floodplain Restoration - Channel Spanning Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

5. Passive Forces ($F_{passive}$)

ϕ_{bank}	0.63	radians	Calculated for bank material (very course gravel)	
K_p	3.85		Eqn 34	3.85184
γ_{water}	62.4	lb/ft^3	Unit weight of water	
γ_{soil}	120	lb/ft^3	Unit weight of soil	
γ_{sat}	137	lb/ft^3	Previously calculated for buoyancy calcs	
$N_{logssub1}$	3		Number of log type 1 (from detail)	
$Orientation_1$**	Perpendicular		Perpendicular or Parallel to flow	
L_{eb1}	27	ft	Length of log type 1 (from detail)	
d_{bole1}	1	ft	Diameter of log type 1 (from detail)	
D_{sub1}	3	ft	Depth of submerged soil above log 1	
D_{dry1}		ft	Depth of dry soil above log 1	
σ_{v1}	224	lb/ft^2		
$\sigma_{v1} * L_{eb1} * \gamma_{soil}$	18,115	lb		
$N_{logssub2}$	1		Number of log type 2 (from detail)	
$Orientation_2$**	Parallel		Perpendicular or Parallel to flow	
L_{eb2}	13.3	ft	Length of log type 2 (from detail)	
d_{bole2}	2	ft	Diameter of log type 2 (from detail)	
D_{sub2}	2	ft	Depth of submerged soil above log 2	
D_{dry2}		ft	Depth of dry soil above log 2	
σ_{v2}	149	lb/ft^2		
$\sigma_{v2} * L_{eb2} * \gamma_{soil}$	468	lb		
$N_{logssub3}$	4		Number of log type 3(from detail)	
$Orientation_3$**	Perpendicular		Perpendicular or Parallel to flow	
L_{eb3}	13	ft	Length of log type 3 (from detail)	
d_{bole3}	1	ft	Diameter of log type 3 (from detail)	
D_{sub3}	2	ft	Depth of submerged soil above log 3	
D_{dry3}		ft	Depth of dry soil above log 3	
σ_{v3}	149	lb/ft^2		
$\sigma_{v3} * L_{eb3} * \gamma_{soil}$	7,753	lb		
$F_{passive}$	**-50,720**	**lb**	**Eqn 31**	

** Eqns 33 through 35 represent the case where passive forces act

$$F_{passive} = -0.5 * K_p * \sum_i^n \sigma_{v_i} * L_{em_i} * d_{log_i}$$ Equ

$$K_p = \frac{1+\sin\emptyset}{1-\sin\emptyset}$$ Equ

$$\sigma_{v_i} = D_{sub_i} * (\gamma_{sat} - \gamma_{water}) + D_{dry_i} * \gamma_{soil}$$ Equ

D_{subi} = depth of submerged soil above log i
D_{dryi} = depth of dry soil above log i
L_{emi} = embedded length of log i
d_{logi} = diameter of log i

Sliding Calculations

Project: Tucannon Big Four Floodplain Restoration - Channel Spanning Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

6. Lateral Resistance from Piles ($F_{piles-h}$)

N_{piles}	7		Number of piles (Design)
d_{piles}	1	ft	Diameter of piles (Design)
L_{piles}	5.75	ft	Embedded length of piles below scour (Design)
Placement Method	Excavated		Method of pile placement
Placement Multiplier	0.25		See RBDG (P. 52)
Pile Placement Location	Bed		Bed or Bank
γ_{water}	62.4	lb/ft^3	Unit weight of water
γ_{soil}	126	lb/ft^3	Unit weight of soil
γ_e	63.6	lb/ft^3	Eqn 37
ϕ_{soil}	0.66	radians	Calculated for material pile is located
K_p	4.20		Eqn 38
h_{load}**	2.5	ft	Height above scour depth load is applied
$F_{piles-h}$	**-5,391**	**lb**	**Eqn 15**

$$F_{piles-h} = -N_{piles} * \frac{L_{pile}^3 * \frac{1}{2} * \gamma_e * d_{pile} * K_p}{h_{load} + L_{pile}} \quad \text{Equation 36}$$

N_{piles} = number of piles
L_{pile} = length of pile embedded below potential scour depth

$$\gamma_e = \gamma_s - \gamma_w \quad \text{effective unit weight of soil} \quad \text{Equation 37}$$

γ_s = dry unit weight of the soil

γ_w = unit weight of the soil
d_{pile} = diameter of the pile
h_{load} = height above the potential scour depth the load is applied

$$K_p = \frac{1+\sin\phi}{1-\sin\phi} \quad \text{Equation 38}$$

*** Top 2' of pile embedment disregarded for calculation to account for vortex shedding.**
**** Analysis also assumes that the resultant force is located at half of the flow depth on the upstream side of the LWM structure to produce a conservative moment on the pile.**

Factor of Safety

$FOS_{sliding}$ =	*$(F_{hd} + F_f + F_{piles-h} + F_{passive}) / (F_d + F_{hu} + F_i)$*		
F_d	16,024	lb	
F_{hu}		lb	
F_{hd}		lb	
F_i	13,141	lb	
F_f	-15,968	lb	
$F_{passive}$	-50,720	lb	
$F_{piles-h}$	-5,391	lb	
$FOS_{sliding}$	**2.47**		**STABLE FOR SLIDING**

Summary Comments:

Appendix C

Wood Habitat Structure Stability Calculations

WHS Type #6 Strainer Jam

Buoyancy Calculations

Project: Tucannon Big Four Floodplain Restoration - Strainer Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

Spreadsheet Description

- The spreadsheet below is used to calculate the Factor of Safety against Buoyant uplift of the LWM

Assumptions:

1) The LWM structure behaves as a single structure under the design load and will not experience any shearing at joints
2) The LWM structure will be submerged during the design event.
3) Negative buoyancy is uplift, positive numbers equals downward.
4) Ballast material remains intact and is not scoured out.
5) The uplift due to racking material is evenly dividing among all layers.

Input (Cells Requiring Input from Structure Detail)
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FBD and Equations:

$$FOS_b = \frac{F_{LWMd} + F_{boulders} + F_{soil} + F_{piles-e}}{|F_{LWMs} + F_L|}$$ **Equation 18**

FOS_b = *buoyancy factor of safety*

Table 4. Minimum recommended factors of safety.

Public Safety Risk	Property Damage Risk	Stability Design Flow Criteria	$FOS_{sliding}$	$FOS_{buoyancy}$	$FOS_{rotation}$ $FOS_{overturning}$
High	High	100-year	1.75	2.0	1.75
High	Moderate	50-year	1.5	1.75	1.5
High	Low	25-year	1.5	1.75	1.5
Low	High	100-year	1.75	2.0	1.75
Low	Moderate	25-year	1.5	1.75	1.5
Low	Low	10-year	1.25	1.5	1.25

Tucannon Big Four Floodplain Restoration has a "LOW" Public Safety Risk Factor and a "MODERATE" Property Damage Risk Factor. The Design buoyancy factor of safety (FOS_b) for this structure is 1.75 per Table 4 "*Minimum Recommended Factors of Safety*".

1. Large Wood Material Force - Dry (F_{LWMd})

$$F_{LWMd} = V_{LWMd} * \gamma_{wood}$$ **Equation 3**

V_{LWMd} = *volume of dry large wood material*

Comment: Assumed to be zero because structure assumed to be submerged during design event.

2. Boulder Ballast Force ($F_{boulder}$)

$N_{bouldersub}$			Number of submerged boulders (from design)
$d_{bouldersub}$	2.5	ft	Effective diameter of submerged boulder (ft, from spec)
$\gamma_{boulder}$	146	lb/ft^3	unit weight of boulders (Table 5)
γ_{water}	62.4	lb/ft^3	unit weight of water
$F_{bouldersub}$		lb	Eqn. 6
$N_{boulderdry}$			Number of dry boulders (from detail)
$d_{boulderdry}$	2.5	ft	Effective diameter of dry boulder (ft, from spec)
$F_{boulderdry}$		lb	Eqn. 7
$F_{boulder}$		**lb**	**Eqn. 5**

Comment: The intent is design without the use of boulders so it is assumed no boulders are used.

$$F_{boulder} = F_{bouldersub} + F_{boulderdry}$$ **Equation 5**

$$F_{bouldersub} = N_{bouldersub} * \frac{\pi}{6} * d^3_{bouldersub} * (\gamma_{boulder} - \gamma_w)$$ **Equation 6**

$N_{bouldersub}$ = *number of submerged boulders*
$d_{bouldersub}$ = *effective diameter of submerged boulders*
$\gamma_{boulder}$ = *unit weight of boulders*

$$F_{boulderdry} = N_{boulderdry} * \frac{\pi}{6} * d^3_{boulderdry} * \gamma_{boulder}$$ **Equation 7**

$N_{boulderdry}$ = *number of unsubmerged boulders*
$d_{boulderdry}$ = *effective diameter of unsubmerged boulders*

Buoyancy Calculations

Project: Tucannon Big Four Floodplain Restoration - Strainer Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

3. Soil Backfill Force (F_{soil})

$N_{logssub1}$	6		Number of Type 1 buried logs (from detail)
L_{eb1}	27	ft	Average embedded length of Type 1 logs (from detail)
d_{bole1}	1	ft	Average diameter of Type 1 logs (from detail)
$h_{soilsub1}$	3	ft	Average height of submerged soil above Type 1 log (from detail)
$V_{soilsub1}$	486	ft^3	Volume of submerged soil above Type 1 log (from detail)
$h_{soildry1}$		ft	Average height of dry soil above Type 1 log (from detail)
$V_{soildry1}$		ft^3	Volume of dry soil above Type 1 log (from detail)
$N_{logssub2}$	11		Number of Type 2 buried logs (from detail)
L_{eb2}	10	ft	Average embedded length of Type 2 logs (from detail)
d_{bole2}	1	ft	Average diameter of Type 2 logs (from detail)
$h_{soilsub2}$	5.75	ft	Average height of submerged soil above Type 2 log (from detail)
$V_{soilsub2}$	633	ft^3	Volume of submerged soil above Type 2 log (from detail)
$h_{soildry2}$		ft	Average height of dry soil above Type 2 log (from detail)
$V_{soildry2}$		ft^3	Volume of dry soil above Type 2 log (from detail)
$N_{logssub3}$	2		Number of Type 3 buried logs (from detail)
L_{eb3}	13	ft	Average embedded length of Type 3 logs (from detail)
d_{bole3}	1.75	ft	Average diameter of Type 3 logs (from detail)
$h_{soilsub3}$	2	ft	Average height of submerged soil above Type 3 log (from detail)
$V_{soilsub3}$	91	ft^3	Volume of submerged soil above Type 3 log (from detail)
$h_{soildry3}$		ft	Average height of dry soil above Type 3 log (from detail)
$V_{soildry3}$		ft^3	Volume of dry soil above Type 3 log (from detail)
γ_{soil}	137	lb/ft^3	Specific Gravity of bank/backfill material (Table 5)
γ_{water}	62.4	lb/ft^3	Unit weight of water
SG_{rock}	2.64		Specific Gravity of Rock (Using unit weight of bedrock from Table 5)
e	0.20		Eqn. 14
γ_{sat}	148	lb/ft^3	Eqn. 13
γ'_{soil}	85.1	lb/ft^3	Eqn. 12
F_{soil}	**102,936**	**lb**	**Eqn. 8**

$$F_{soil} = \sum_i^n V_{soilsub_i} * \gamma'_{soil} + V_{soildry_i} * \gamma_{soil}$$ **Equation 8**

$$V_{soilsub_i} = L_{eb_i} d_{bole_i} h_{soilsub_i}$$ **Equation 9**

$V_{soilsubi}$ = volume of submerged soil above log i
L_{ebi} = embedded length of log i
d_{bolei} = bole diameter of log i
$h_{soilsubi}$ = height of submerged soil above log i

$$V_{soildry_i} = L_{eb_i} d_{bole_i} h_{soildry_i}$$ ***Equation 10***

$V_{soildryi}$ = volume of dry soil above log i
$h_{soildryi}$ = height of dry soil above log i

$$\gamma_{soil} = (99.2 + 18.6 * \log(d_{50}))$$ **Equation 11**

d_{50} = median grain size in millimeters

$$\gamma'_{soil} = \gamma_{sat} - \gamma_w$$ **Equation 12**

$$\gamma_{sat} = \frac{(SG_{rock} + e) * \gamma_w}{1 + e}$$ **Equation 13**

$$e = \frac{SG_{rock} * \gamma_w}{\gamma_{soil}} - 1$$ **Equation 14**

Buoyancy Calculations

Project: Tucannon Big Four Floodplain Restoration - Strainer Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

4. Pier Log Friction

N_{piles}			Number of piles (Design)
d_{piles}	1	ft	Diameter of piles (Design)
L_{piles}	13	ft	Embedded length of piles (Design)
k_s	1		Coefficient of lateral earth pressure (0.5 to 1.5 depending on soil and density)
Placement Method	Excavated		Method of pile placement
Placement Multiplier	0.25		See RBDG (P. 52)
Pile Placement Location	Bed		Bed or Bank
ϕ_{soil}	0.72	rad	Internal angle of friction of soils (Table 5)
γ_{soil}	137	lb/ft^3	Specific Weight of Soil
e	0.20		Eqn. 14
γ_{sat}	148	lb/ft^3	Eqn. 13
γ_{water}	62.4	lb/ft^3	Unit weight of water
σ'	1,106	lb/ft^2	Eqn 16
γ_{wood}	33	lb/ft^3	Unit weight of wood
$F_{piles-v}$		**lb**	**Eqn 15**

$$F_{piles-v} = N_{piles} * \pi * d_{piles} * L_{piles}(k_s * \tan\frac{2}{3}\phi * \sigma' + \frac{d_{piles}}{4} * (\gamma_{wood} - \gamma_w))$$

Equation 15

N_{piles} = number of piles
d_{piles} = diameter of piles
L_{piles} = embedded length of piles
k_s = coefficient of lateral earth pressure (0.5 to 1.5 depending on soil and density)
ϕ = internal angle of friction of soils

$$\sigma' = L_{piles} * (\gamma_{sat} - \gamma_w)$$

Equation 16

$$\gamma_{sat} = \frac{(SG_{rock} + e) * \gamma_w}{1+e}$$

Equation 13

$$e = \frac{SG_{rock} * \gamma_w}{\gamma_{soil}} - 1$$

Equation 14

Assumptions:
$* k_s = 1$
**** This calculation is based on the assumption that piles are driven or vibrated into place. If piles are drilled or excavated, the associated coefficicient of lateral earth pressures shall be approx. 50% and 25% of the driven value, respectively.**
***** For use in buoyancy calculations, piles must be mechanically fastened.**
****** Top 2' of pile embedment disregarded for calculation to account for vortex shedding.**

5. Large Wood Material Force - Submerged (F_{LWMs})

$$F_{LWMs} = V_{LWMs} * (\gamma_{wood} - \gamma_w)$$

Equation 2

V_{LWMs} = volume of submerged large wood material
γ_{wood} = unit weight of wood
γ_w = unit weight of water

$N_{logssub1}$	6		Number of log type 1 (from detail)
L_{log1}	27	ft	Length of log type 1 (from detail)
d_{bole1}	1	ft	Diameter of log type 1 (from detail)
d_{rw1}	2.50	ft	Diameter of rootwad of log type 1 (from detail)
V_{LWMs1}	147	ft^3	Volume of LWM1
$N_{logssub2}$	1		Number of log type 2 (from detail)
L_{eb2}	40	ft	Length of log type 2 (from detail)
d_{bole2}	2	ft	Diameter of log type 2 (from detail)
d_{rw2}	5.00	ft	Diameter of rootwad of log type 2 (from detail)
V_{LWMs2}	152	ft^3	Volume of LWM2
$N_{logssub3}$	1		Number of log type 3 (from detail)
L_{eb3}	40	ft	Length of log type 3 (from detail)
d_{bole3}	2	ft	Diameter of log type 3 (from detail)

Volume of Rootwad

National Large Wood Manual. 2016

Equation 6-4 (p. 6-38)

$V_{rw} = \pi * t_k * w_k^2 / 3$

$\pi * (2d_{bole}) * (1/2 d_{rw})^2 / 3$

t_k = Thickness of rootwad measured in direction parallel to trunk

= 4 times the radius of the log ($4r_k$ or

w_k =

Radius of rootwad

Buoyancy Calculations

Project: Tucannon Big Four Floodplain Restoration - Strainer Jam
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Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

d_{rw3}		ft	Diameter of rootwad of log type 3 (from detail)
V_{LWMs3}	126	ft^3	Volume of LWM3
V_{LWMs}	424	ft^3	Volume of LWM
γ_{wood}	33.0	lb/ft^3	Unit weight of logs
γ_{w}	62.4	lb/ft^3	Unit weight of water
F_{LWMs}	**-12,477**	**lb**	**Eqn. 3**

= 2.5 times the radius of the log ($2.5r_k$ or $1.25d_{bole}$) or 1/2 d_{rw} specified

6. Lift Forces (F_L)

$$F_L = -\frac{C_L * A_{LWM} * \gamma_w * U_o^2}{2 * g}$$ **Equation 4**

C_L = lift coefficient
A_{LWM} = area of large woody material perpendicular to flow
u_u = upstream channel velocity at design event
g = acceleration due to gravity

C_L	0.45		Lift Coefficient
A_{LWM}	120	ft^2	Calc'd in Drag Forces
γ_w	62.4	lb/ft^3	Unit weight of water
U_o	12.0	ft/s	upstream velocity (from model)
g	32.2	ft/s^2	Unit weight of water
F_L	**-7,535**	**lb**	**Eqn. 4**

Comment: Lift forces neglected per Section 6.4.2 of BOR Risk Based Design Guidelines

Factor of Safety

FOS_b =	$(F_{LMDd} + F_{boulders} + F_{soil} + F_{piles\text{-}v}) / (F_{LWMs} + F_L)$		
F_{LWMd}		lb	Assumed Zero
$F_{boulder}$		lb	
F_{soil}	102,936	lb	
$F_{piles\text{-}v}$		lb	
F_{LWMs}	-12,477	lb	
F_L	-7,535	lb	
FOS_b	**5.14**		**STABLE FOR BUOYANCY**

Summary Comments:

Overturning Calculations

Project: Tucannon Big Four Floodplain Restoration - Strainer Jam
Project Number: 20230017

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

Spreadsheet Description

Purpose: The spreadsheet below is used to calculate the Factor of Safety against vertical overturning.

Assumptions:
1) The LWM structure behaves as a single structure under the design load.
2) The effect of soil in back of the structure is negligible.
3) The structure will be submerged during the design event
4) This LWM structure experiences the largest loads. All LWM structures on site will be designed based on this LWM structure's loadings

Input (Cells Requiring Input from Structure Detail)
Input (Cells requiring Input from Hydraulic Model)
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Output (Cells automatically updated are this color)
Output (Cells automatically updated with previously calculated values are this color)

FBD and Equations:

$$FOS_{overturn} = \frac{MR_{overturn}}{MD_{overturn}}$$ **Equation 49**

Tucannon Big Four Floodplain Restoration has a "LOW" Public Safety Risk Factor and a "MODERATE" Property Damage Risk Factor. The Design Overturn Factor of Safety ($FOS_{overturn}$) for this structure is 1.5 per Table 4 "Minimum Recommended Factors of Safety".

Table 4. Minimum recommended factors of safety.

Public Safety Risk	Property Damage Risk	Stability Design Flow Criteria	$FOS_{sliding}$	$FOS_{buoyancy}$	$FOS_{rotation}$ $FOS_{overturning}$
High	High	100-year	1.75	2.0	1.75
High	Moderate	50-year	1.5	1.75	1.5
High	Low	25-year	1.5	1.75	1.5
Low	High	100-year	1.75	2.0	1.75
Low	Moderate	25-year	1.5	1.75	1.5
Low	Low	10-year	1.25	1.5	1.25

1. Resistance to Overturn ($MR_{rotation}$ and $MD_{rotation}$)

$$MD_{overturn} = F_i * (Y_u + d_{bury}) + F_d * \left(\frac{Y_u}{2} + d_{bury}\right) + F_{hu} * \left(\frac{Y_u}{3} + du_{bury}\right) + |F_L| * L_s$$

Equation 46

du_{bury} = depth at the upstream side of the structure from channel bottom to point of rotation measured perpendicular to flow
Ls = length of structure measured parallel to flow

$$MR_{overturn} = |F_{hd}| * \left(\frac{Y_d}{2} + dd_{bury}\right) + |F_{passive}| * (dd_{bury}) + (F_b - F_L - F_{piles-v}) * \frac{L_s}{2} + \sum_i^n F_{pile-v_i} * Lpv_i$$ **Equation 47**

$$F_{pile-v_i} = \frac{F_{piles-v}}{N_{piles}}$$ **Equation 48**

L_{pvi} = distance from pile 'i' to the point of rotation measured parallel to flow

$$FOS_{overturn} = \frac{MR_{overturn}}{MD_{overturn}}$$ **Equation 49**

Driving:

F_i	22,528	lb	Impact Forces (Calc'd in Sliding)
F_d	25,115	lb	Drag Forces (Calc'd in Sliding)
F_{hu}		lb	Upstream Hydrostatic Forces (Calc'd in Sliding)
F_L	-7,535	lb	Lift Forces (Assumed Zero in Buoyancy Calcs)
Y_u	6.75	ft	Upstream water elevation from model
d_{ubury}	3	ft	Depth at upstream side of structure from channel bottom to point of rotation measured perp to flow
L_s	40	ft	Length of structure parallel to flow
$MD_{overturn}$	**681,134**	**lb*ft**	**Eqn 46**

Resisting:

F_{hd}		lb	Downstream Hydrostatic Forces (Calc'd in Sliding)
$F_{passive}$	-231,142	lb	Passive Forces (Calc'd in Sliding)
F_b	82,925	lb	Buoyancy Forces (Calc'd in Sliding)
F_{pile-v}		lb	Lateral Resistance from Piles (Calc'd in Sliding)
Y_d	5.35	ft	Downstream water elevation
d_{dbury}	3	ft	Depth at downstream side of structure from channel bottom to point of rotation measured perp to flow
N_{piles}	9		Number of Piles (Design)
L_{pvi}	27	ft	Distance from pile to the point of rotation measured parallel to flow.
$F_{pile-vi}$		lb	Eqn 48
$MR_{overturn}$	**2,502,607**	**lb*ft**	**Eqn 47**

Factor of Safety

$FOS_{overturnon}$ =	*$MR_{overturn}$ / $MD_{overturn}$*		
$MD_{overturn}$	681,134	lb	
$MR_{overturn}$	2,502,607	lb	
$FOS_{overturn}$	**3.67**		**STABLE FOR OVERTURN**

Rotation Calculations

Project: Tucannon Big Four Floodplain Restoration - Strainer Jam
Project Number: 20230017

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

Spreadsheet Description

Purpose: The spreadsheet below is used to calculate the Factor of Safety against LWM structure horizontal rotation.

Assumptions:
1) The LWM structue behaves as a single structure under the design load.
2) The effect of soil in back of the structure is negligible.
3) The structure will be submerged during the design event
4) This LWM structure experiences the largest loads. All LWM structures on site will be designed based on this LWM structure's loadings

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Output (Cells that are automatically updated with previously calculated values are this color)

FBD and Equations:

$$FOS_{rotation} = \frac{MR_{rotation}}{MD_{rotation}}$$ **Equation 45**

Tucannon Big Four Floodplain Restoration has a "LOW" Public Safety Risk Factor and a "MODERATE" Property Damage Risk Factor. The Design Rotation Factor of Safety ($FOS_{rotation}$) for this structure is 1.5 per Table 4 "Minimum Recommended Factors of Safety".

Table 4. Minimum recommended factors of safety.

Public Safety Risk	Property Damage Risk	Stability Design Flow Criteria	$FOS_{sliding}$	$FOS_{buoyancy}$	$FOS_{rotation}$ $FOS_{overturning}$
High	High	100-year	1.75	2.0	1.75
High	Moderate	50-year	1.5	1.75	1.5
High	Low	25-year	1.5	1.75	1.5
Low	High	100-year	1.75	2.0	1.75
Low	Moderate	25-year	1.5	1.75	1.5
Low	Low	10-year	1.25	1.5	1.25

1. Resistance to Rotation ($MR_{rotation}$ and $MD_{rotation}$)

$$MD_{rotation} = (F_i + F_d + F_{hu}) * \left(\frac{L_{sp}+L_{ebp}}{2}\right)$$ **Equation 42**

L_{sp} = length of wood structure from tip to point of rotation measured perpendicular to flow
L_{ebp} = embedded length of wood structure measured perpendicular to flow

$$MR_{rotation} = \left| F_{hd} * \left(\frac{L_{sp}+L_{ebp}}{2}\right) + F_{passive} * \frac{L_{ebp}}{2} + F_f * \frac{L_{sp}}{2} + \sum_{i}^{n} F_{pile-h_i} * L_{ph_i} \right|$$ **Equation 43**

$$F_{pile-h_i} = \frac{F_{piles-h}}{N_{piles}}$$ **Equation 44**

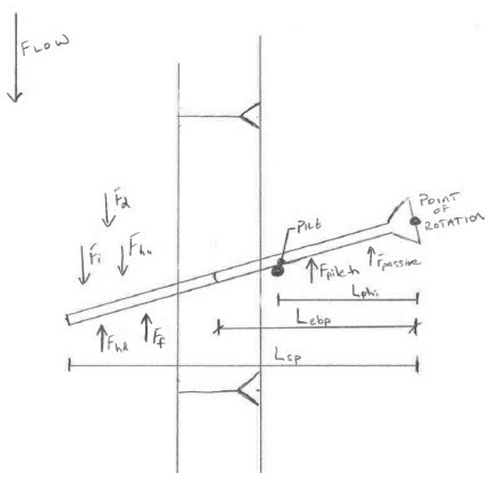
L_{phi} = distance from pile 'i' to the point of rotation measured perpendicular to flow

Driving:

L_{sp}	40	ft	Length of wood structure from tip to point of rotation measured perpendicular to flow
L_{ebp}		ft	Embedded length of wood structure measured perp. to flow
F_i	22,528	lb	Impact Forces (Calc'd in Sliding)
F_d	25,115	lb	Drag Forces (Calc'd in Sliding)
F_{hu}		lb	Upstream Hydrostatic Forces (Calc'd in Sliding)
$MD_{rotation}$	**952,855**	**lb*ft**	**Eqn 42**

Resisting:

F_{hd}		lb	Downstream Hydrostatic Forces (Calc'd in Sliding)
$F_{passive}$	-231,142	lb	Passive Forces (Calc'd in Sliding)
F_f	-72,085	lb	Friction Forces (Calc'd in Sliding)
F_{pile-h}	-70,005	lb	Lateral Resistance from Piles (Calc'd in Sliding)
$F_{pile-hi}$	-6,364	lb	Lateral Resistance from Piles (Calc'd in Sliding)
N_{piles}	11		Number of Piles (Design)
L_{phi}	25	ft	Distance from pile to the point of rotation measured perp. to flow.
$MR_{rotation}$	**3,191,841**	**lb*ft**	**Eqn 43**



Factor of Safety

$FOS_{rotation}$ =	*$MR_{rotation}$ / $MD_{rotation}$*		
$MD_{rotation}$	952,855	lb	
$MR_{rotation}$	3,191,841	lb	
$FOS_{rotation}$	**3.35**		**STABLE FOR ROTATION**

Summary Comments:

Sliding Calculations

Project: Tucannon Big Four Floodplain Restoration - Strainer Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

Spreadsheet Description

Purpose: The spreadsheet below is used to calculate the Factor of Safety against LWM sliding.

Assumptions:
1) The LWM structure behaves as a single structure under the design load and will not experience any shearing at joints.
2) The effect of soil in back of the structure is negligible.
3) The structure will be submerged during the design event.
4) Channel velocity (V_c) taken from hydraulic model.
5) This LWM structure experiences the largest loads. All LWM structures on site will be designed based on this LWM structure's loadings.

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Output (Cells automatically updated are this color)
Output (Cells automatically updated with previously calculated values are this color)

FBD and Equations:

$$FOS_{sliding} = \frac{|F_{hd}+F_f+F_{piles-h}+F_{passive}|}{F_d+F_{hu}+F_l}$$ Equation 41

Tucannon Big Four Floodplain Restoration has a "LOW" Public Safety Risk Factor and a "MODERATE" Property Damage Risk Factor. The Design Sliding Factor of Safety ($FOS_{sliding}$) for this structure is 1.5 per Table 4 "Minimum Recommended Factors of Safety".

Table 4. Minimum recommended factors of safety.

Public Safety Risk	Property Damage Risk	Stability Design Flow Criteria	$FOS_{sliding}$	$FOS_{bouyancy}$	$FOS_{rotation}$ $FOS_{overturning}$
High	High	100-year	1.75	2.0	1.75
High	Moderate	50-year	1.5	1.75	1.5
High	Low	25-year	1.5	1.75	1.5
Low	High	100-year	1.75	2.0	1.75
Low	Moderate	25-year	1.5	1.75	1.5
Low	Low	10-year	1.25	1.5	1.25

1. Drag Force (F_d)

Y_u	6.75	ft	Upstream water depth
hdebris	5	ft	Debris height (incl. accumulation)
wdebris	15	ft	Debris width (incl. accumulation)
Debris Shape	Rectangle		
A_{LWM}	120	ft^2	Wetted area of LWM
γ_{water}	62.40	lb/ft^3	Unit weight of water
v_c	12.00	ft/s	Velocity from Model
g	32.20	ft/s^2	Acceleration due to gravity
A_b	120.00	ft^2	Debris area
$w_{channel}$	60	ft	Channel width
c_d	1.50		NLWM Worst Case
F_d	25115	lb	Eqn 19

$$F_d = \frac{C_D * A_{LWM} * \gamma_w * U_c^2}{2 * g}$$ Equation 19

F_d = drag force
C_d = drag coefficient
A_{LWM} = area of wetted debris based on the upstream water surface elevation projected normal to flow direction and the potential drift accumulation
γ_w = unit weight of water
U_c = velocity in contracted section
g = acceleration due to gravity

Cd can be assumed 0.9 when fully submerged, 1.5 when WSEL withi

$$C_{d-applied} = \frac{C_d}{(1-B)^2}$$ C_d is typically estimated as 1.0 Equation 27

Sliding Calculations

Project: Tucannon Big Four Floodplain Restoration - Strainer Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

3. Impact Force (F_i)

L_{debris}	40	ft	Length of debris member (Design)
$d_{boledebris}$	2	ft	Bole diameter of debris member (Design)
$d_{rwdebris}$	5	ft	Rootwad diameter of debris member (Design)
V_{debris}	152	ft^3	Volume of debris
γ_{wood}	33	lb/ft^3	Unit weight of wood
w_{debris}	5,011	lb	weight of debris
g	32.2	ft/s^2	Acceleration due to gravity
$V_{channel}$	12.0	ft/s	Velocity from Model
Δt	0.03	sec	Impact Interval (0.03 sec recommended)
C_i	0.6		Coefficient of importance (from Table 6)
C_o	0.8		Coefficient of orientation
C_d	1		Figure 11 (need water depth from model)
Degree of Screening or Sheltering Upstream	Limited upstream screening, flow path 20' wide		ASCE 7-05
C_b	0.6		ASCE 7-05
R_{max}	0.8		Response ratio for impulsive loads
F_i	**22,528**	**lb**	**Eqn 30**

$$F_i = \frac{\pi w_{debris} * V_{channel} * C_i * C_o * C_d * C_b * R_{max}}{2 * g * \Delta t}$$ **Equation 30**

F_i = impact force

w_{debris} = weight of debris

g = acceleration constant due to gravity

$V_{channel}$ = water velocity in channel

Δt = time from initial velocity to zero velocity

C_i = coefficient of importance

C_o = coefficient of orientation = 0.8

C_d = coefficient of depth

C_b = coefficient of blockage

R_{max} = response ratio for impulsive loads = 0.8

Assumption:

***Largest impact force would be generated by structure being struck by floating large key member. For impact calculation, assuming 18" diameter, 30' long member with rootwad impacts structure.**
****See Section 6.3.3 of LWM RBDG (P. 44) for debris loading sizing.**

4. Friction Force (F_f)

ϕ_{bed}	0.72	radians	Calculated for streambed material (small cobble)
μ_{bed}	0.87		Eqn 32
F_{LWMd}		lb	Buoyancy Calcs
$F_{boulder}$		lb	Buoyancy Calcs
F_{soil}	102936	lb	Buoyancy Calcs
$F_{piles-v}$		lb	Buoyancy Calcs
F_{LWMs}	-12477	lb	Buoyancy Calcs
F_L	-7535	lb	Buoyancy Calcs
F_b	82,925	lb	Eqn 17
F_f	**-72,085**	**lb**	**Eqn 31**

$$F_f = -\mu_{bed} * (F_b - F_{piles-v})$$ Equation 31

F_f = force due to frictional resistance

$F_b - F_{piles-v} > 0$

$$\mu_{bed} = \tan \emptyset$$ Equation 32

$$F_b = F_{LWMs} + F_{LWMd} + F_L + F_{boulder} + F_{soil} + F_{piles-v}$$ ***Equation 17***

Note:
***If buoyancy forces are less than vertical pile forces (Fb-Fpiles-v<0), then friction force = 0.**

Sliding Calculations

Project: Tucannon Big Four Floodplain Restoration - Strainer Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

5. Passive Forces ($F_{passive}$)

Φ_{bank}	0.72	radians	Calculated for bank material (very course gravel)	
K_p	4.81		Eqn 34	4.81495131
γ_{water}	62.4	lb/ft^3	Unit weight of water	
γ_{soil}	137	lb/ft^3	Unit weight of soil	
γ_{sat}	148	lb/ft^3	Previously calculated for buoyancy calcs	
$N_{logssub1}$	6		Number of log type 1 (from detail)	
$Orientation_1$**	Perpendicular		Perpendicular or Parallel to flow	
L_{eb1}	27	ft	Length of log type 1 (from detail)	
d_{bole1}	1	ft	Diameter of log type 1 (from detail)	
D_{sub1}	3	ft	Depth of submerged soil above log 1	
D_{dry1}		ft	Depth of dry soil above log 1	
σ_{v1}	255	lb/ft^2		
$\sigma_{v1}*L_{eb1}*\gamma_{soil}$	41,362	lb		
$N_{logssub2}$	11		Number of log type 2 (from detail)	
$Orientation_2$**	Perpendicular		Perpendicular or Parallel to flow	
L_{eb2}	10	ft	Length of log type 2 (from detail)	
d_{bole2}	1	ft	Diameter of log type 2 (from detail)	
D_{sub2}	5.75	ft	Depth of submerged soil above log 2	
D_{dry2}		ft	Depth of dry soil above log 2	
σ_{v2}	489	lb/ft^2		
$\sigma_{v2}*L_{eb2}*\gamma_{soil}$	53,830	lb		
$N_{logssub3}$	2		Number of log type 3(from detail)	
$Orientation_3$**	Parallel		Perpendicular or Parallel to flow	
L_{eb3}	13	ft	Length of log type 3 (from detail)	
d_{bole3}	1.75	ft	Diameter of log type 3 (from detail)	
D_{sub3}	2	ft	Depth of submerged soil above log 3	
D_{dry3}		ft	Depth of dry soil above log 3	
σ_{v3}	170	lb/ft^2		
$\sigma_{v3}*L_{eb3}*\gamma_{soil}$	819	lb		
$F_{passive}$	**-231,142**	**lb**	**Eqn 31**	

**** Eqns 33 through 35 represent the case where passive forces act**

$$F_{passive} = -0.5 * K_p * \sum_i^n \sigma_{v_i} * L_{em_i} * d_{log_i}$$ Equ

$$K_p = \frac{1+\sin\emptyset}{1-\sin\emptyset}$$ Equ

$$\sigma_{v_i} = D_{sub_i} * (\gamma_{sat} - \gamma_{water}) + D_{dry_i} * \gamma_{soil}$$ Equ

D_{subi} = depth of submerged soil above log i
D_{dryi} = depth of dry soil above log i
L_{emi} = embedded length of log i
d_{logi} = diameter of log i

Sliding Calculations

Project: Tucannon Big Four Floodplain Restoration - Strainer Jam
Project No.: 20230017.1

Analyst: BF
Calculations Checked By: AJ
Latest Revision: 4/2/2025

6. Lateral Resistance from Piles ($F_{piles\text{-}h}$)

$$F_{piles-h} = -N_{piles} * \frac{L_{pile}^3 * \frac{1}{2} * \gamma_e * d_{pile} * K_p}{h_{load} + L_{pile}} \quad \text{Equation 36}$$

N_{piles} = number of piles
L_{pile} = length of pile embedded below potential scour depth

$$\gamma_e = \gamma_s - \gamma_w \quad \text{effective unit weight of soil} \quad \text{Equation 37}$$

γ_s = dry unit weight of the soil

N_{piles}	11		Number of piles (Design)
d_{piles}	1	ft	Diameter of piles (Design)
L_{piles}	13	ft	Embedded length of piles below scour (Design)
Placement Method	Excavated		Method of pile placement
Placement Multiplier	0.25		See RBDG (P. 52)
Pile Placement Location	Bed		Bed or Bank
γ_{water}	62.4	lb/ft^3	Unit weight of water
γ_{soil}	137	lb/ft^3	Unit weight of soil
γ_e	74.6	lb/ft^3	Eqn 37
ϕ_{soil}	0.72	radians	Calculated for material pile is located
K_p	4.81		Eqn 38
h_{load}**	2.5	ft	Height above scour depth load is applied
$F_{piles\text{-}h}$	**-70,005**	**lb**	**Eqn 15**

γ_w = unit weight of the soil
d_{pile} = diameter of the pile
h_{load} = height above the potential scour depth the load is applied

$$K_p = \frac{1+\sin\phi}{1-\sin\phi} \quad \text{Equation 38}$$

*** Top 2' of pile embedment disregarded for calculation to account for vortex shedding.**

**** Analysis also assumes that the resultant force is located at half of the flow depth on the upstream side of the LWM structure to produce a conservative moment on the pile.**

Factor of Safety

$FOS_{sliding}$ =	$(F_{hd} + F_f + F_{piles\text{-}h} + F_{passive}) / (F_d + F_{hu} + F_i)$		
F_d	25,115	lb	
F_{hu}		lb	
F_{hd}		lb	
F_i	22,528	lb	
F_f	-72,085	lb	
$F_{passive}$	-231,142	lb	
$F_{piles\text{-}h}$	-70,005	lb	
$FOS_{sliding}$	**7.83**		**STABLE FOR SLIDING**

Summary Comments: