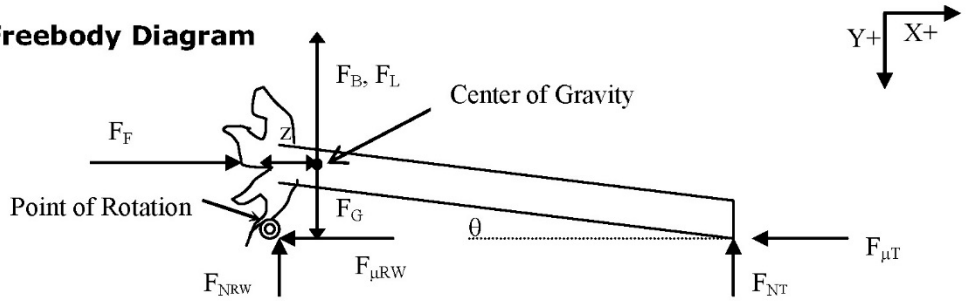
Appendix **D**

Large Wood Stability Analysis

Figure 1: Freebody Diagram



Required Calculations

Force Balance / Momentum

$\Sigma Fy = 0$, $F_F (\sin \theta) + F_G = F_B + F_L + F_{NT} + F_{NRW}$

$\Sigma Fx = 0$, $F_F (\cos \theta) = F_{\mu RW} + F_{\mu T}$

$\Sigma Mo = 0$, $F_{NT} (L_T \cos\theta + z) + F_B z + F_L z = (F_G + B_R) z + F_F (2/3\ d_w)$

Geometric Calculations and Forces

$\mu_{BED} = \tan \phi$

$\theta = \tan^{-1} ((\frac{1}{2} D_{RW})/(L_T))$

$z = (\frac{1}{2} D_{RW}) \sin \theta$

$\forall_{RW} = (\pi (D_{RW})^2)/4) L_{RW} (1-\eta_P)$

$\forall_T = (\pi (D_T/2)^2) L_T$

$\forall_{Tsub} = (d_w/\sin\theta)(\pi r^2)$

$A_{Rwsub} = (A_{RW})(P_{sub})$

$\forall_{Rwsub} = A_{RWsub} L_{RW}$

$F_G = (\forall_T + \forall_{RW}) \rho_T$

$F_B = (\forall_{Tsub} + \forall_{RWsub}) \rho_w$

STOP, CHECK FS_B →

$FS_B = F_G/F_B$

If $FS_B < 1.5$, add required ballast (B_R) to obtain $FS_B = 1.5$ before continuing calculations

$FS_B = (F_G + B_R)/F_B$

$B_R = ((FS_B)(F_B)) - F_G$

$F_F = (v^2/2g) A_{RWsub} \rho_w C_D$

$F_L = (v^2/2g) (\forall_T + \forall_{RW}) \rho_w C_L$

Sum of Moments and Factors of Safety

1. ΣFy, $F_F (\sin \theta) + (F_G + B_R) = F_B + F_L + F_{NT} + F_{NRW}$
2. ΣMo, $F_{NT} (L_T \cos\theta + z) + F_B z + F_L z = (F_G + B_R) z + F_F (2/3\ d_w)$

Solve Equation 2. for F_{NT}, substitute into Equation 1. Solve for F_{NRW}

3. $F_{\mu T} = F_{NT} \mu_{BED}$
4. $F_{\mu RW} = F_{NRW} \mu_{BED}$

$FS_M = (F_{\mu T} + F_{\mu RW}) / (F_F (\cos \theta))$

$FS_B = ((F_G + B_R) + F_F (\sin \theta)) / (F_B + F_L)$

Notation and Constants

F_B	=	force due to buoyancy		
F_G	=	force due to gravity		
F_F	=	force due to flow		
F_μ	=	force due to friction between LW and bed		
F_L	=	force due to lift		
F_N	=	force normal to LW at the tip and the rootwad		

Subscripts T and RW refer to the tree and rootwad respectively

ρ_T	=	density of the tree	See Table 2	
ρ_W	=	density of water	=	62.4 #/ft^3
S_g	=	Specific Gravity		
		Water	=	1.0
		Rock (average for quartz)	=	2.65
g	=	acceleration due to gravity	=	32.2 ft/s^2
B_R	=	ballast required (submerged weight)	=	#
v	=	velocity of flowing water	=	ft/s
d_w	=	depth of water	=	ft
η_P	=	porosity		
θ	=	angle from rootwad face to vertical	=	degrees
ϕ	=	internal angle of friction for bed material (*See Table 1*)	=	degrees
μ_{BED}	=	coefficient of friction for bed material		
z	=	distance in the x direction from the center of gravity to the point of interest	=	ft
L_T	=	length of the tree	=	ft
D_T	=	diameter of the tree	=	ft
L_{RW}	=	thickness of the rootwad	=	ft
D_{RW}	=	diameter of the rootwad	=	ft
$\forall$	=	volume	=	ft^3
A	=	area	=	ft^2
P_{sub}	=	proportion submerged (from Figure 2)		

Subscripts T, RW, and BD refer to tree, rootwad, and boulder respectively. *Subscript SUB refers to the submerged values.*

C_D	=	coefficient of fluid drag		
		C_{DT}	=	0.3
		C_{DRW}	=	1.2
		C_{DBD}	=	0.2
C_L	=	coefficient of lift for large roughness element	=	0.18
FS_B	=	factor of safety – buoyancy		
FS_M	=	factor of safety -- momentum		

C_D and C_L values derived from: D'Aoust and Millar, 1999

Smith River Estuary Backwater Habitat Enhancement Design Project
Large Wood Stability Analysis - Final Design

Structure ID	Station	Structure component ID	Total pieces of wood (#)	Log length (ft)	Log width (ft)	Tree with rootwad	Tree volume (ft^3)	Total volume (ft^3)	% submerged	Force gravity (lbs)	Force boyancy (lbs)	Ballast from partial burial (lbs)	Log flow acting area (ft^2)	Approximate flow velocity (ft/s)	Force of lift from flow (lbs)	Force of flow (lbs)	Weight of boulder required to counteract buoyancy & lift (tons) FS_B=1.5	Normal force (without burial ballast) (lbs)	Resistance force from partial burial (lbs)	Factor of safety for momentum (FS_M=2 min)	Governing factor of safety	Final weight of boulder required for FS_B=1.5 min & $FS_{M=2}$ min (tons)	Factor of safety for bouyancy & lift (FS_B=1.5 min)
A	100	A1	8	25	2	No	79	79	100%	2645	4898	2000	50	2	55	58	2.2	468	2000	41.1	Bouyancy/ Lift	2.2	1.5
	100	A2		30	2	No	94	94	100%	3175	5878	3200	60	2	66	70	2.0	-236	3200	43.0	Bouyancy/ Lift	2.0	1.5
	120	A3		30	2	No	94	94	100%	3175	5878	2000	60	2	66	70	3.0	961	2000	40.2	Bouyancy/ Lift	3.0	1.5
	120	A4		35	2	No	110	110	100%	3704	6858	3500	70	2	77	81	2.6	-42	3500	42.5	Bouyancy/ Lift	2.6	1.5
	140	A5		35	2	No	110	110	100%	3704	6858	3500	70	2	77	81	2.6	-42	3500	42.5	Bouyancy/ Lift	2.6	1.5
	140	A6		35	2	No	110	110	100%	3704	6858	3200	70	2	77	81	2.8	257	3200	41.9	Bouyancy/ Lift	2.8	1.5
	160	A7		35	2	No	110	110	100%	3704	6858	3500	70	2	77	81	2.6	-42	3500	42.5	Bouyancy/ Lift	2.6	1.5
	160	A8		30	2	No	94	94	100%	3175	5878	3000	60	2	66	70	2.2	-36	3000	42.5	Bouyancy/ Lift	2.2	1.5
B	80	B1	6	40	2	No	126	126	100%	4233	7837	1000	80	2	88	93	5.4	2943	1000	37.3	Bouyancy/ Lift	5.4	1.5
	120	B2		40	2	No	126	126	100%	4233	7837	1000	80	2	88	93	5.4	2943	1000	37.3	Bouyancy/ Lift	5.4	1.5
	150	B3		40	2	No	126	126	100%	4233	7837	1000	80	2	88	93	5.4	2943	1000	37.3	Bouyancy/ Lift	5.4	1.5
	75	B4		40	1.75	No	96	96	100%	3241	6001	0	70	2	67	81	4.7	3017	0	31.1	Bouyancy/ Lift	4.7	1.5
	120	B5		40	1.75	No	96	96	100%	3241	6001	0	70	2	67	81	4.7	3017	0	31.1	Bouyancy/ Lift	4.7	1.5
	150	B6		40	1.75	No	96	96	100%	3241	6001	0	70	2	67	81	4.7	3017	0	31.1	Bouyancy/ Lift	4.7	1.5