CT – Chip Trees

SLT – Small Log Trees (<=80 ft3)

LLT – Large Log Trees (>80 ft3)

SL – Small Trees (<=80 ft3)

ALT – All Log Trees

Removals, trees/acre

$$RemovalsST = RemovalsCT + RemovalsSLT \tag{1}$$

$$RemovalsALT = RemovalsSLT + RemovalsLLT \tag{2}$$

$$Removals = RemovalsCT + RemovalsSLT + RemovalsLLT \tag{3}$$

Volume Per Acre, ft3/acre

$$VolPerAcreCT = RemovalsCT \times TreeVolCT \tag{4}$$

$$VolPerAcreSLT = RemovalsSLT \times TreeVolSLT \tag{5}$$

$$VolPerAcreLLT = RemovalsLLT \times TreeVolLLT \tag{6}$$

$$VolPerAcreST = VolPerAcreCT \times TreeVolSLT \tag{7}$$

$$VolPerAcreALT = VolPerAcreSLT \times TreeVolLLT \tag{8}$$

$$VolPerAcre = VolPerAcreCT + VolPerAcreSLT \times TreeVolLLT \tag{9}$$

Tree Volume, *ft3/tree*

$$TreeVolST = \frac{VolPerAcreST}{RemovalsST} \tag{10}$$

$$TreeVolALT = \frac{VolPerAcreALT}{RemovalsALT} \tag{11}$$

$$TreeVolST = \frac{VolPerAcre}{Removals} \tag{12}$$

Other Assumptions

$$MaxManualTreeVol, ft3 = 150 \tag{13}$$

$$MaxMechTreeVol, ft3 = 80 \tag{14}$$

$$MoistureContentFraction, wet\ basis = 0.50 \tag{15}$$

$$LogLength, ft = 32 \tag{16}$$

$$LoadWeight, green\ tons\ (logs) = 25 \tag{17}$$

$$LoadWeight, green\ tons\ (chips) = 25 \tag{18}$$

$$CTLTrailSpacing, ft = 50 \tag{19}$$

$$HardwoodCostPremium, fraction = 0.20 \tag{20}$$

$$ResidueRecoveryFraction\ for\ WT\ systems = 0.80 \tag{21}$$

$$ResidueRecoveryFraction\ for\ CTL = 0.50 \tag{22}$$

Calculated Intermediates

DBH

DBH – Diameter at Breast Height, in

$$DBHCT = \sqrt{\frac{TreeVolCT + 3.675}{0.216}} \tag{23}$$

$$DBHSLT = \sqrt{\frac{TreeVolSL + 3.675}{0.216}} \tag{24}$$

$$DBHLLT = \sqrt{\frac{TreeVolLLT + 3.675}{0.216}} \tag{25}$$

$$DBHST = \sqrt{\frac{RemovalsCT \times DBHCT^2 + RemovalsSLT \times DBHSLT^2}{RemovalsST}} \tag{26}$$

$$DBHALT = \sqrt{\frac{RemovalsSLT \times DBHSLT^2 + RemovalsLLT \times DBHLLT^2}{RemovalsALT}} \tag{27}$$

$$DBH = \sqrt{\frac{RemovalsCT \times DBHCT^2 + RemovalsALT \times DBHALT^2}{Removals}} \tag{28}$$

Tree Height

$$HeightCT = -20 + 24 \times \sqrt{DBHCT} \tag{29}$$

$$HeightSLT == -20 + 24 \times \sqrt{DBHSLT} \tag{30}$$

$$HeightLLT == -20 + 24 \times \sqrt{DBHLLT} \tag{31}$$

$$HeightST = \frac{RemovalsCT \times HeightCT + RemovalsSLT \times HeightSLT}{RemovalsST} \tag{32}$$

$$HeightALT = \frac{RemovalsSLT \times HeightSLT + RemovalsLLT \times HeightLLT}{RemovalsALT} \tag{33}$$

$$Height = \frac{RemovalsCT \times HeightCT + RemovalsALT \times HeightALT}{Removals} \tag{34}$$

Wood Density

If the wood density for chip trees, small log trees or large log trees is not specified by users, then it is 50 lb/ft3 by default.

$$\begin{aligned} &WoodDensityST \\ &= \frac{WoodDensityCT \times VolPerAcreCT + WoodDensitySLT \times VolPerAcreSLT}{VolPerAcreST} \end{aligned} \tag{35}$$

$$WoodDensityALT = \frac{WoodDensitySLT \times VolPerAcreSLT + WoodDensityLLT \times VolPerAcreLLT}{VolPerAcreALT} \quad (36)$$

$$WoodDensity = \frac{WoodDensityCT \times VolPerAcreCT + WoodDensityALT \times VolPerAcreALT}{VolPerAcre} \quad (37)$$

Hardwood Fraction

If the hardwood fraction for chip trees, small log trees or large log trees is not specified by users, then it is 0 by default.

$$HdwdFractionST = \frac{HdwdFractionCT \times VolPerAcreCT + HdwdFractionSLT \times VolPerAcreSLT}{VolPerAcreST} \quad (38)$$

$$HdwdFractionALT = \frac{HdwdFractionSLT \times VolPerAcreSLT + HdwdFractionLLT \times VolPerAcreLLT}{VolPerAcreALT} \quad (39)$$

$$HdwdFraction = \frac{HdwdFractionCT \times VolPerAcreCT + HdwdFractionALT \times VolPerAcreALT}{VolPerAcre} \quad (40)$$

Butt Diameter

$$ButtDiamSLT = DBHSLT + 3 \quad (41)$$

$$ButtDiamST = DBHST + 3 \quad (42)$$

Logs Per Tree

Logs per chip tree was assumed as 1.

$$LogsPerTreeCT = 1 \quad (43)$$

$$LogsPerTreeSLT = -0.43 + 0.678 \times \sqrt{DBHSLT} \quad (44)$$

$$LogsPerTreeLLT = -0.43 + 0.678 \times \sqrt{DBHLLT} \quad (45)$$

$$LogsPerTreeST = \frac{LogsPerTreeCT \times RemovalsCT + LogsPerTreeSLT \times RemovalsSLT}{RemovalsST} \quad (46)$$

$$LogsPerTreeALT = \frac{LogsPerTreeSLT \times RemovalsSLT + LogsPerTreeLLT \times RemovalsLLT}{RemovalsALT} \quad (47)$$

$$LogsPerTree = \frac{LogsPerTreeCT \times RemovalsCT + LogsPerTreeALT \times RemovalsALT}{Removals} \quad (48)$$

Log Volume

$$LogVolST = \frac{TreeVolST}{LogsPerTreeST} \quad (49)$$

$$LogVolALT = \frac{TreeVolALT}{LogsPerTreeALT} \quad (50)$$

$$LogVol = \frac{TreeVol}{LogsPerTree} \tag{51}$$

CTL Logs Per Tree

The minimum for CTLLogsPerTree is 1.

$$CTLLogsPerTreeCT = 2 \times (-0.43 + 0.678 \times \sqrt{DBHCT}) \tag{52}$$

$$CTLLogsPerTree = 2 \times (-0.43 + 0.678 \times \sqrt{DBHST}) \tag{53}$$

CTL Log Volume

$$CTLLogVolCT = \frac{TreeVolCT}{CTLLogPerTreeCT} \tag{54}$$

$$CTLLogVol = \frac{TreeVolST}{CTLLogsPerTree} \tag{55}$$

BFperCF

$$BFperCF = 5 \tag{56}$$

Bole Weight

$$BoleWtCT = \frac{WoodDensityCT \times VolPerAcreCT}{2000} \tag{57}$$

$$BoleWtSLT = \frac{WoodDensitySLT \times VolPerAcreSLT}{2000} \tag{58}$$

$$BoleWtLLT = \frac{WoodDensityLLT \times VolPerAcreLLT}{2000} \tag{59}$$

$$BoleWtST = BoleWtCT + BoleWtSLT \tag{60}$$

$$BoleWtALT = BoleWtSLT + BoleWtLLT \tag{61}$$

$$BoleWt = BoleWtCT + BoleWtALT \tag{62}$$

Residue Weight

RF – Residue Fraction

$$ResidueCT = UserSpecRFCT \times BoleWtCT \tag{63}$$

$$ResidueSLT = UserSpecRFSLT \times BoleWtSLT \tag{64}$$

$$ResidueLLT = UserSpecRFLLT \times BoleWtLLT \tag{65}$$

$$ResidueST = ResidueCT \times ResidueSLT \tag{66}$$

$$ResidueALT = ResidueSLT \times ResidueLLT \tag{67}$$

$$Residue = ResidueCT \times ResidueALT \tag{68}$$

Manual Machine Size

The maximum of ManualMachineSize is 1.

$$ManualMachineSizeALT = \frac{TreeVolALT}{MaxManualTreeVol} \tag{69}$$

$$ManualMachineSize = \frac{TreeVol}{MaxManualTreeVol} \quad (70)$$

Mechanized Machine Size

The maximum of MechMachineSize is 1.

$$MechMachineSize = \frac{TreeVolST}{MaxMechTreeVol} \quad (71)$$

Chipper Size

The maximum of ChipperSize is 1.

$$ChipperSize = \frac{TreeVolCT}{MaxMechTreeVol} \quad (72)$$

NonSelfLevelCabDummy

$$NonSelfLevelCabDummy_{slope<15} = 1 \quad (73)$$

$$NonSelfLevelCabDummy_{15<slope<35} = 1.75 - 0.05 \times Slope \quad (74)$$

$$NonSelfLevelCabDummy_{slope>35} = 0 \quad (75)$$

CSlopeFB&Harv (Mellgren 90)

$$CSlopeFB_{Harv} = 0.00015 \times Slope^2$$
$$+ 0.00359 \times NonSelfLevelCabDummy \times Slope \quad (76)$$

CRemovalsFB&Harv (Mellgren 90)

$$CRemovalsFB_{Harv}$$
$$= 0.66 - 0.001193 \times RemovalsST \times 2.47$$
$$+ 5.357 \times 10^{-7} \times (RemovalsST \times 2.47)^2 \quad (77)$$

CSlopeSkidForwLoadSize (Mellgren 90)

$$CSlopeForwLoadSize = 1 - 0.000127 \times Slope^2 \quad (78)$$

Chardwood

$$CHardwoodCT = 1 + HdwdCostPremium \times HdwdFractionCT \quad (79)$$

$$CHardwoodSLT = 1 + HdwdCostPremium \times HdwdFractionSLT \quad (80)$$

$$CHardwoodLLT = 1 + HdwdCostPremium \times HdwdFractionLLT \quad (81)$$

$$CHardwoodST = 1 + HdwdCostPremium \times HdwdFractionST \quad (82)$$

$$CHardwoodALT = 1 + HdwdCostPremium \times HdwdFractionALT \quad (83)$$

$$CHardwood = 1 + HdwdCostPremium \times HdwdFraction \quad (84)$$

System Product Summary

Amounts Recovered Per Acre

ResidueRecoveredPrimary – WT residue recovered as part of primary product, GT/ac

ResidueRecoveredOptional – Optional residue recovered, GT/ac

$$BoleVolCCF = \frac{VolPerAcre}{100} \quad (85)$$

$$ResidueRecoveredPrimary = ResidueRecovFracWT \times ResidueCT \qquad (86)$$

$$PrimaryProduct = BoleWt + ResidueRecoveredPrimary \qquad (87)$$

$$ResidueRecoveredOptional$$
$$= ResidueRecovFracWT \times (ResidueSLT + ResidueLLT) \qquad (88)$$

$$TotalPrimaryAndOptional$$
$$= PrimaryProduct + ResidueRecoveredOptional \qquad (89)$$

Amounts Unrecovered and Left within the Stand Per Acre

GroundFuel – Activity fuels (residues) on the ground, GT/ac

$$GroundFuel = ResidueLLT + ResidueST \times (1 - ResidueRecovFracWT) \qquad (90)$$

ResidueLLT not times 1-ResidueRecovFracWT?

Amounts Unrecovered and Left at the Landing

PiledFuel – Piled activity fuels (residues), GT/ac

$$PiledFuel = ResidueSLT \times ResidueRecovFracWT \qquad (91)$$

No CT and LLT residue Piled? Assume all ResidueLLT left within the stand?

TotalResidues

$$TotalResidues = ResidueRecoveredPrimary$$
$$+ ResidueRecoveredOptional + ResidueUncutTrees \qquad (92)$$
$$+ GroundFuel + PiledFuel$$

System Cost Elements

For Primary Products (boles & WT residues), $/CCF of material treated by the activity

Fell&Bunch: trees <=80 cf	12.70
Manual Fell, Limb, Buck: all trees	
Manual Fell, Limb, Buck: all log trees	
Manual Fell, Limb, Buck: trees >80cf	12.78
Manual Fell: trees <=80 cf	
Manual Fell: chip trees	
Harvest: trees <=80 cf	
Skid Bunched: all trees	35.42
Skid Unbunched: all trees	
Forward: trees <=80 cf	
Yard Unbunched: all trees	
Yard CTL: trees <=80 cf	
Process: log trees <=80 cf	8.18
Load: log trees	7.78
Load CTL: log trees <=80 cf	
Chip: chip whole trees	7.76
Chip: chip tree boles	
Chip CTL: chip tree boles	
Primary Product Move-In Costs, $/CCF	79.06

For Optional Residues, $/GT of additional residue recovered

$$Chip\ Loose\ Residues: from \log trees \leq 80\ cf$$

$$= CostChipLooseRes \times CollectionOption \times InLimits1 \tag{93}$$

$$Residue\ MoveIn\ Costs, \frac{\$}{GT}$$

$$= 0 \times CalcMoveIn \times CalcResidues \times InLimits1 \tag{94}$$

What is the point of residue move-in costs?

For All Products, $/ac

$$ChipLooseResiduesFromLogTreesLess80cf$$
$$= CostChipLooseRes \times CalcResidues \tag{95}$$
$$\times ResidueRecoveredOptional \times InLimits1$$

$$FellAndBunchTreesLess80cf$$
$$= \frac{CostFellBunch \times VolPerAcreST \times InLimits1}{100} \tag{96}$$

$$ManualFellLimbBuckTreesLarger80cf$$
$$= CostManFLBLLT \times VolPerAcreLLT/100 \times InLimits1 \tag{97}$$

$$SkidBunchedAllTrees = CostSkidBun \times VolPerAcre/100 \times InLimits1 \tag{98}$$

$$ProcessLogTreesLess80cf$$
$$= CostProcess \times VolPerAcreSLT/100 \times InLimits1 \tag{99}$$

$$LoadLogTrees = CostLoad \times VolPerAcreALT/100 \times InLimits1 \tag{100}$$

$$ChipWholeTrees = CostChipWT \times VolPerAcreCT/100 \times InLimits1 \tag{101}$$

$$Stump2TruckPrimaryProductWithoutMovein\ (Mech\ WT)$$
$$= FellAndBunchTreesLess80cf$$
$$+ ManualFellLimbBuckTreesLarger80cf \tag{102}$$
$$+ SkidBunchedAllTrees + ProcessLogTreesLess80cf$$
$$+ LoadLogTrees + ChipWholeTrees$$

$$Movein4PrimaryProduct$$
$$= MoveInCosts!\,G39 \times CalcMoveIn \times BoleVolCCF \tag{103}$$
$$\times InLimits1$$

$$OntoTruck4ResiduesWoMovein\ (Mech\ WT)$$
$$= ChipLooseResiduesFromLogTreesLess80cf \tag{104}$$

$$Movein4Residues$$
$$= 0 \times CalcMoveIn \times CalcResidues \tag{105}$$
$$\times ResidueRecoveredOptional \times InLimits1$$

System Cost Summaries

$$TotalPerAcre = Stump2Truck4PrimaryProductWithoutMovein$$
$$+ Movein4PrimaryProduct \tag{106}$$
$$+ OntoTruck4ResiduesWoMovein + Movein4Residues$$

$$TotalPerBoleCCF = \frac{TotalPerAcre}{BoleVolCCF} \tag{107}$$

$$TotalPerGT = \frac{TotalPerAcre}{TotalPrimaryProductsAndOptionalResidues} \tag{108}$$

Limits

$$MaximumLLTperAcre = none \tag{109}$$

$$MaxLLTasPercentALT = none \tag{110}$$

$$ExceededMaxLLT = 0 \tag{111}$$

$$AvgTreeSizeLimit4Chipping = 80 \tag{112}$$

$$AvgTreeSizeLimit4Processing = 80 \tag{113}$$

$$AvgTreeSizeLimit4ManualFellLimbBuck = 250 \tag{114}$$

$$AvgTreeSizeLimit4loading = 250 \tag{115}$$

$$AvgTreeSize4GrappleSkiddingOfBunchedTrees = 250 \tag{116}$$

$$ExceededMaxTreeVol = IF(OR(TreeVolCT$$
$$> AvgTreeSizeLimit4Chipping, TreeVolSLT$$
$$> AvgTreeSizeLimit4Processing, TreeVolLLT$$
$$> AvgTreeSizeLimit4ManualFellLimbBuck, TreeVolALT \tag{117}$$
$$> AvgTreeSizeLimit4loading, TreeVol$$
$$> AvgTreeSize4GrappleSkidding),1,0)$$

$$SkiddingLimit(Slope, \%) = 40 \tag{118}$$

$$ExceededMaxSkidSlope = IF(Slope > SkiddingLimit, 1,0) \tag{119}$$

$$YardingDistLimit = 0 \tag{120}$$

$$ExceededMaxYardingDist = 0 \tag{121}$$

$$InLimits1 = IF(OR(ExceededMaxLLT = 1, ExceededMaxTreeVol$$
$$= 1, ExceededMaxSkidSlope \tag{122}$$
$$= 1, ExceededMaxYardingDist = 1), NA(),1)$$