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The HIGHLEAD Program: Locating and Designing Highlead Harvest Units by Using Digital Terrain Models.

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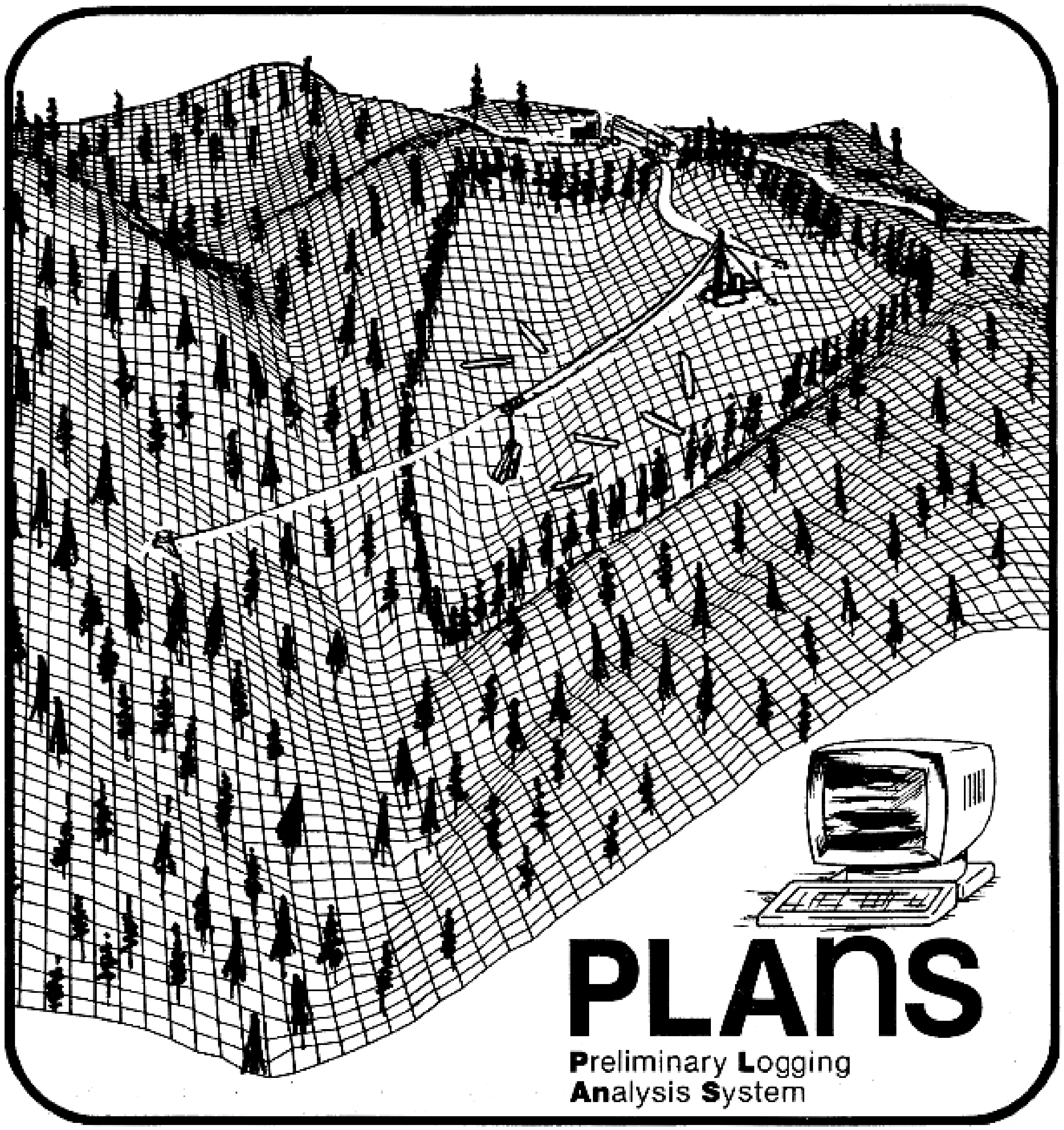

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Abstract

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PLANS, a software package for integrated timber-harvest planning, uses digital terrain models to provide the topographic data needed to fit harvest and transportation designs to specific terrain. HIGHLEAD, an integral program in the PLANS package, is used to design the timber-harvest units to be yarded by highlead systems. It solves for the yarding limits of direct mainline pull to the top of the tower by assuming that the angle of pull must be equal to or greater than the slope of the ground. The ground is sampled through a system of 18 uniformly spaced corridor profiles that radiate from user-selected landing locations and that are extrapolated from the digital terrain model. HIGHLEAD permits the planner to reduce the yarding coverage by shortening yarding distance on individual corridors or by deleting portions of the yarding circle. Conversely, the planner can try to extend the yarding distance on individual corridors by tightlining. The algorithm for tightlining is explained as are limitations of the analysis and interpretations on the maximum, safe log load for highlead systems. A guide giving detailed operating instructions for the program is available from the authors.

Keywords: Timber harvest planning, computer programs/programming, logging operations analysis/design, road building (forest/logging).

Contents

Introduction

Highlead is the harvesting system most frequently used in the Pacific Northwest, yet little information helpful to timber-harvest planners has been published on the physical limitations of the system. The lack of analytical procedures cannot be explained by an indifference on the part of loggers to the physical layout of the highlead harvesting unit. Cable loggers appreciate that lift (deflection) is needed not only for skyline logging but also for highlead; however, some aspects of high lead yarding make it troublesome to analyze. Interactions between the logs hooked to the highlead system and the terrain make a mathematical model providing a single, correct solution for the log-moving capacity of the system impossible, especially in borderline cases; yet the predominate role of highlead yarding makes a valid process for designing highlead units important. A program providing such a process is included in the PLANS (preliminary logging analysis system package (Twito and others 1987b). The HIGHLEAD program ascertains the physical limits of boundaries for units yardable with highlead cable systems. During preliminary planning of harvest activities, a planner using this program can rapidly solve and compare alternative highlead harvesting patterns. The program includes options for extending highlead yarding distance through a tightlining technique. The capacity of the HIGHLEAD program for rapid analyses is partly the result of using stored digital terrain models (DTMs). 'These models, also used by other PLANS design and analysis programs, can be produced by digitizing topographic maps (Twito and others 1987a). PLANS was developed by the Forest Engineering Systems group of the Pacific Northwest Research Station, USDA Forest Service.

Background

The highlead system is both the most widely used and one of the simplest (fig. 1) cable yarding systems in the United States (Studier and Binkley 1974). Unlike skyline cable systems, highlead systems have limited lifting capacity. Logs are generally pulled along the ground and occasionally attain partial suspension while being yarded with the highlead system. Under favorable conditions (fig. 2), a limited amount of lift to overcome ground obstacles can be generated by "tightlining." Tightlining is holding tension in the haulback line while pulling the turn of logs toward the landing with the mainline. Because of the increased stress this places on the system, tightlining can cause safety problems, accelerate wear of equipment, and slow production. For these reasons, the planner should try to layout settings that minimize the need for tightlining. When irregular terrain and difficult topography make this impossible, analyzing tightlining is desirable to ensure that its use will allow yarding without overloading the highlead system.

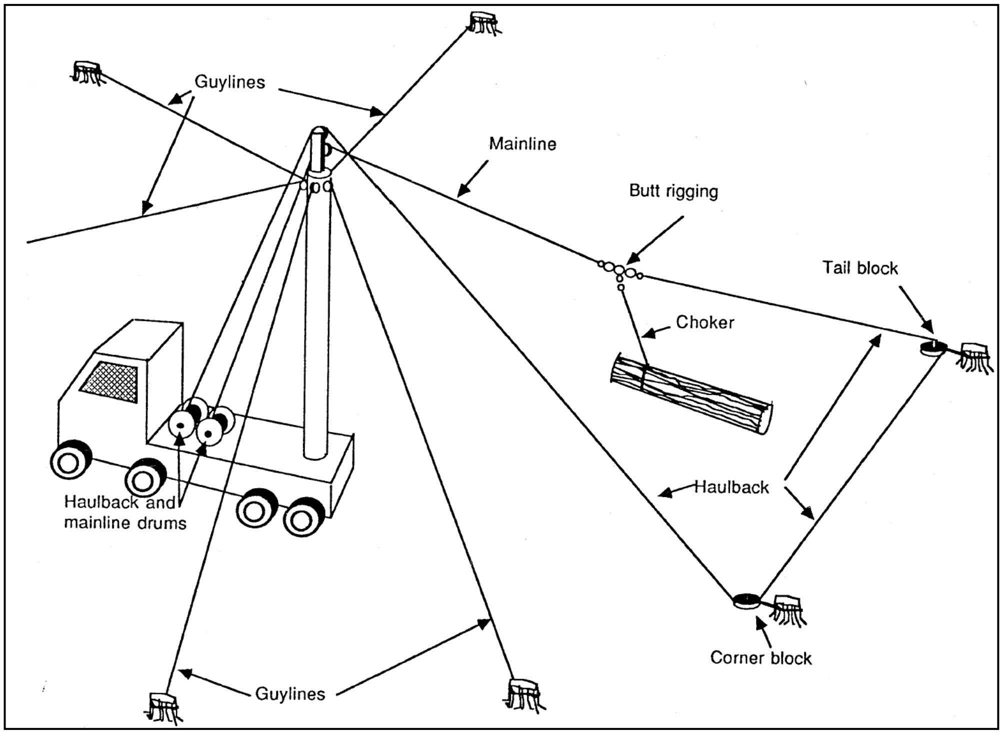

Figure 1—Highlead logging system.

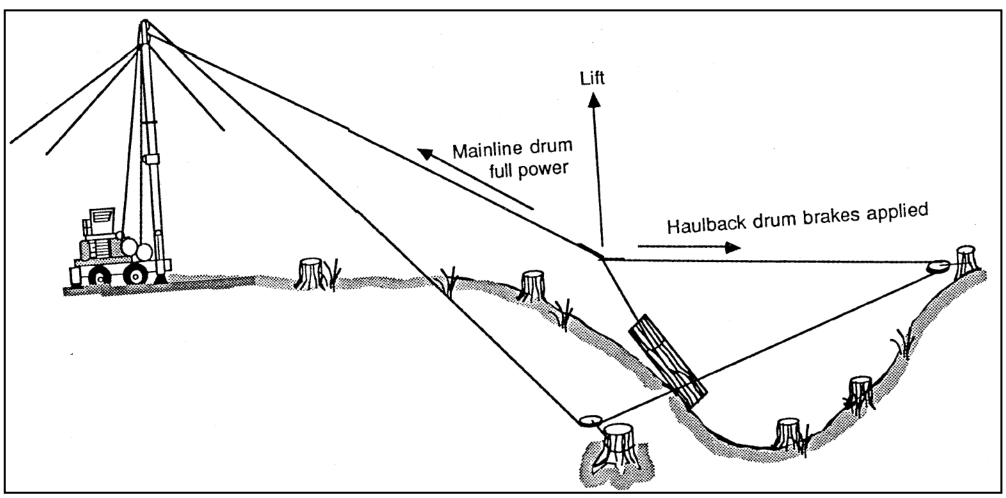

Figure 2—Tightlining logs with a highlead system.

When laying out the boundary of a highlead setting, the planner should not allow the ground to obstruct the line of sight between any point on the setting and the mainline block (Kline 1961, Pearce 1960). Although many authors have presented this general rule for planners to follow (Conway 1976, Kline 1961, Liley 1983, Pearce 1960, Studier and Binkley 1974, Wellburn 1975), few have presented analytical methods for designing highlead units.

Previous Analyses of the Highlead System

Dykstra (1976) describes a computer program for analyzing options in cable logging; it includes algorithms to determine the yarding capacity of a highlead system in terms of payload[1] and yarding distance. The program constructs ground profiles of highlead corridors by using terrain data extracted from a DTM. Dykstra's analysis of highlead payload is unique in the literature, but he does caution that the analysis is only an initial effort developed because no other analysis was available to meet his immediate research needs. He states that a more rigorous procedure should be developed for estimating highlead load capacity and that his program, as presented, should be considered experimental.

Reutebuch and Evison (1984) developed a computer program that determines maximum yarding reach and occurrences of blind lead along a highlead corridor; they did not attempt an analysis of load capacity. Their program constructs ground profiles of highlead corridors from field survey data, from data derived by digitizing single corridors drawn on a topographic map, or from a DTM.

Both of the computer programs mentioned above use a "line-of-sight" algorithm to determine occurrences of blind lead. Dykstra defines blind lead as occurring when the line of sight between the tailblock and top of the tower is obscured by the ground line of the corridor profile. Reutebuch and Evison use a more conservative definition of blind lead, however; they define it as occurring whenever the line of sight between a ground point along a highlead profile and the top oft the highlead tower is obscured by the ground line. The HIGHLEAD program uses a blind lead algorithm slightly different from the "line-of-sight" approach; it is more conservative and realistic than that of either Dykstra or Reutebuch and Evison and is unique in providing an analytical basis for extending the yarding limits via tightlining.

The HIGHLEAD Program

The HIGHLEAD computer program was developed to provide an operational tool to help the planner rapidly develop and evaluate highlead setting boundaries. The program was developed on a Hewlett Packard 9020 computer in the HP BASIC 2.0 language.[2] Besides the microcomputer, a printer, a graphics plotter, and a digitizer tablet are required to execute the program.

The PLANS DTM

To use the HIGHLEAD program, the planner must first obtain a topographic map of the project area and build a DTM of the project area. The MAP program (Twito and others 1987a) is used to build the DTM. For MAP, the topographic map with the project area delineated on it is taped to the digitizer, and each contour line within the area is traced with the digitizer cursor. From these contour data, the MAP program generates a gridded DTM of the project area and stores it for use with a variety of PLANS programs, including HIGHLEAD.

[1] The maximum weight of logs that can be safely transported to the landing in one yarding cycle.

[2] Use of a trade name does not imply endorsement or approval of any product by the USDA Forest Service to the exclusion of others that may be suitable.

Preliminary Highlead Setting Design Using DTMs

In a typical run of the HIGHLEAD program, the topographic map of the project area, with the boundary of DTM coverage marked on it, is taped to the digitizer tablet, and the DTM is loaded into the computer. Next, the height of the highlead tower, the height of the tailhold, and the maximum yarding distance for the highlead system are entered. The planner then marks the location of likely highlead landings on the map. The digitizer cursor is positioned over one of the likely landings, and its position (the x-y coordinates) is sent to the computer. The program automatically extracts ground profiles for each of 18 evenly spaced yarding corridors radiating from the landing (fig. 3).

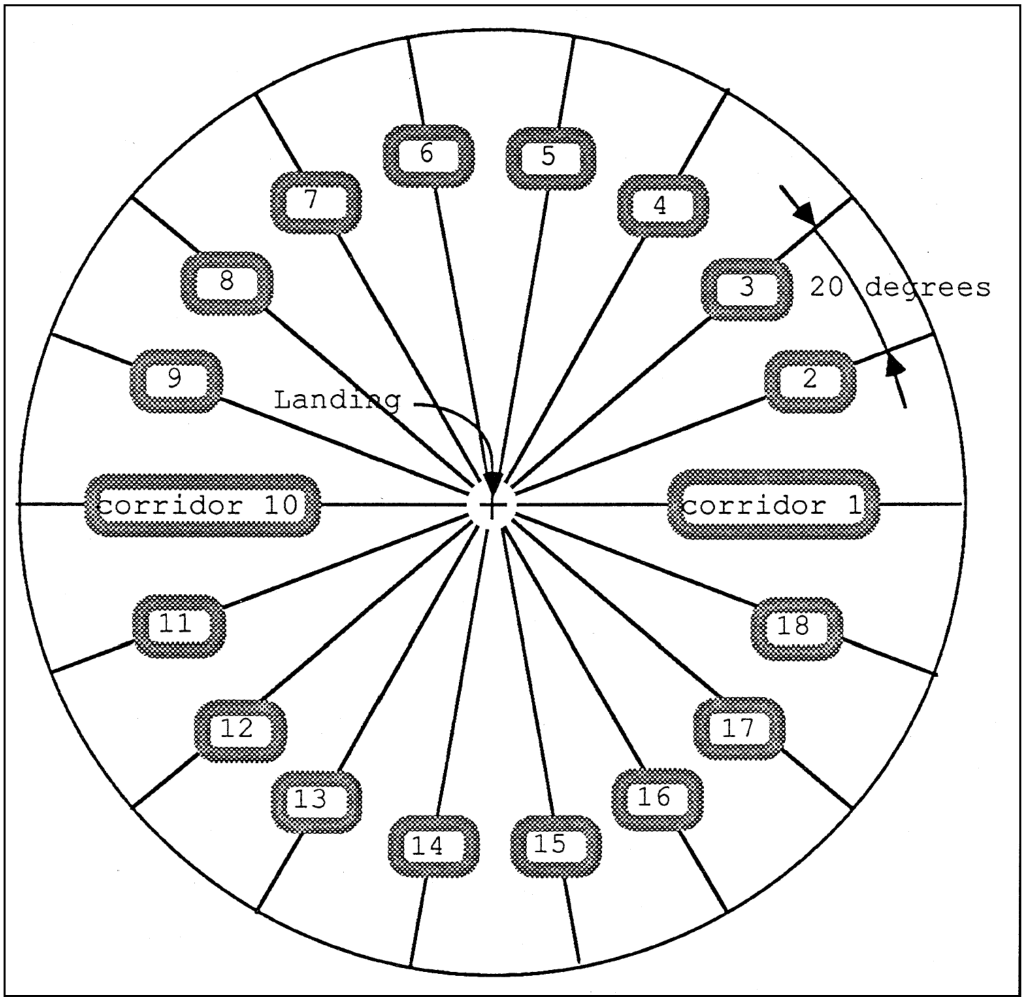

Figure 3—Layout of the highlead unit used in the HIGHLEAD program.

For each of the 18 corridors, the HIGHLEAD program computes the maximum yarding distance over which the yarding equipment can operate without exceeding the line capacity of the yarder and without yarding in a blind lead situation.

A plan-view plot of the area that can be yarded to the landing is displayed on the terminal screen (fig. 4). Next, the planner may choose to modify the yarding boundary by changing the yarding distance for individual corridors or by deleting any of the 18 corridors from the setting.

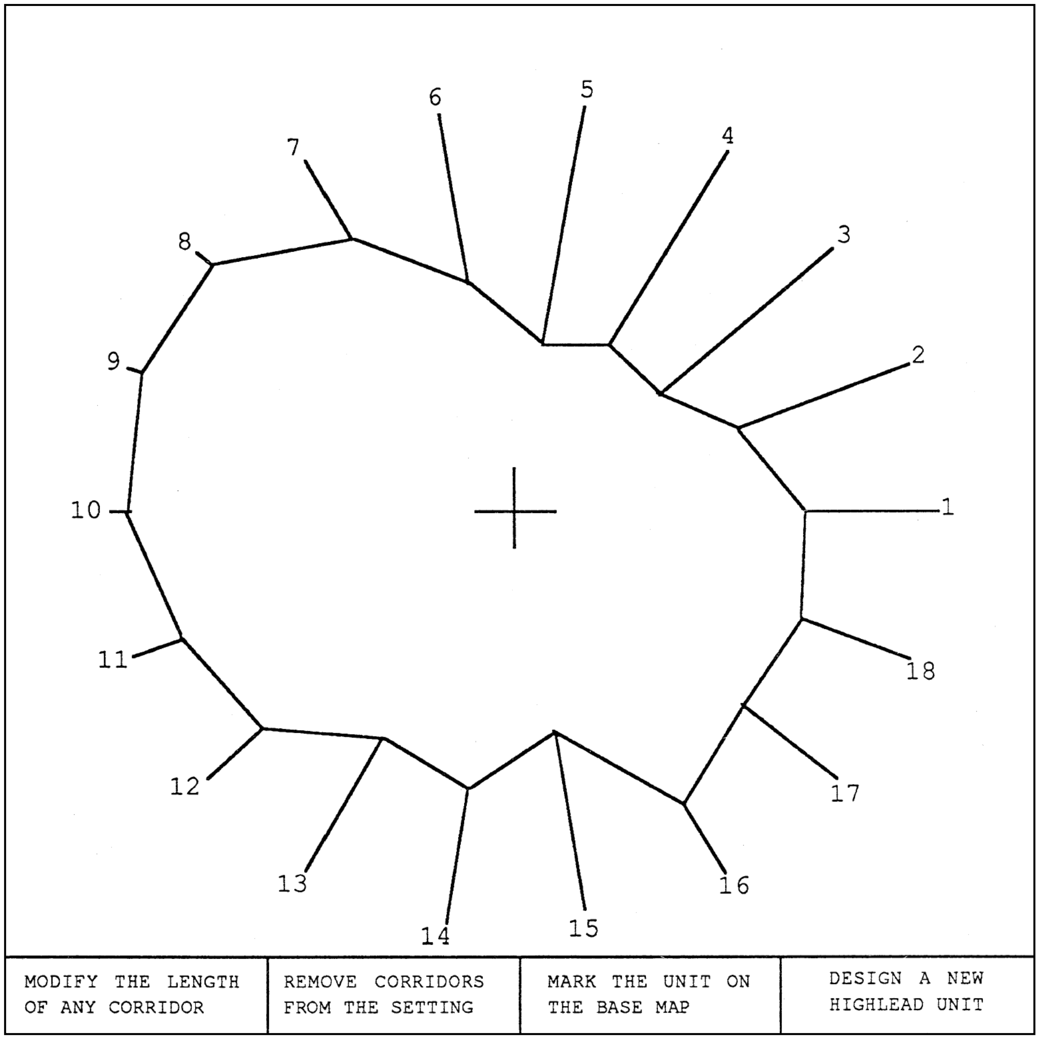

Figure 4—Highlead harvest unit plotted from the HIGHLEAD program.

Changing the yarding distance for a selected corridor--The planner can modify the yarding distance corridor by corridor. The number of the corridor to be modified is entered, and its profile is plotted immediately on the computer screen. The position of the tower and the initial yarding limit are shown on this profile. If the planner wants to extend this limit by tightlining, the location of the tailblock must first be established by setting a cursor on the terrain point selected for the tailblock. The analysis proceeds, and the yarding limit possible with tightlining is shown on the profile with a message explaining why tightlining could not be extended beyond the limit shown.

A planner may, on some corridors, plan for the highlead system not to yard to its maximum reach[3] and, consequently, will adjust the yarding limit of those corridors

[3] Some planners, depending on their objective, are concerned only with establishing access to the timber and do not wish to detail their plan to the point of deciding which of several landings that provide yarding access to the timber should be used. If a planner wishes to forecast the harvesting costs for a plan and use an analytical program like SIMYAR to predict yarding costs, then the harvest boundaries should be delineated as correctly as possible to ensure an accurate analysis.

inward. This shortening of yarding distance is done by moving a pointer on the terminal screen to a constrained yarding limit selected at a position on the corridor profile that is inside the maximum yarding limit shown by the program.

Deleting yarding corridors—The planner may not want the highlead harvest unit to extend around a full 3600 circle. The planner may delete those corridors encompassing terrain not to be included in the setting by typing in the numbers of the corridors to be removed.

Transferring the designed highlead harvest unit to the plan—When the design of a unit is completed, HIGHLEAD can produce a map-scale plot of the unit (fig. 5). This plotted drawing can be traced onto the topographic map or to an overlay keyed to the map (with the aid of digitized transfer points marked 1 and 2) to provide a permanent record of the unit design. Both the initial boundary established by direct mainline pull and the boundary resulting from any user modifications are shown on the plot with the acreage included in each boundary, the average slope of the unit, and the average yarding distance.

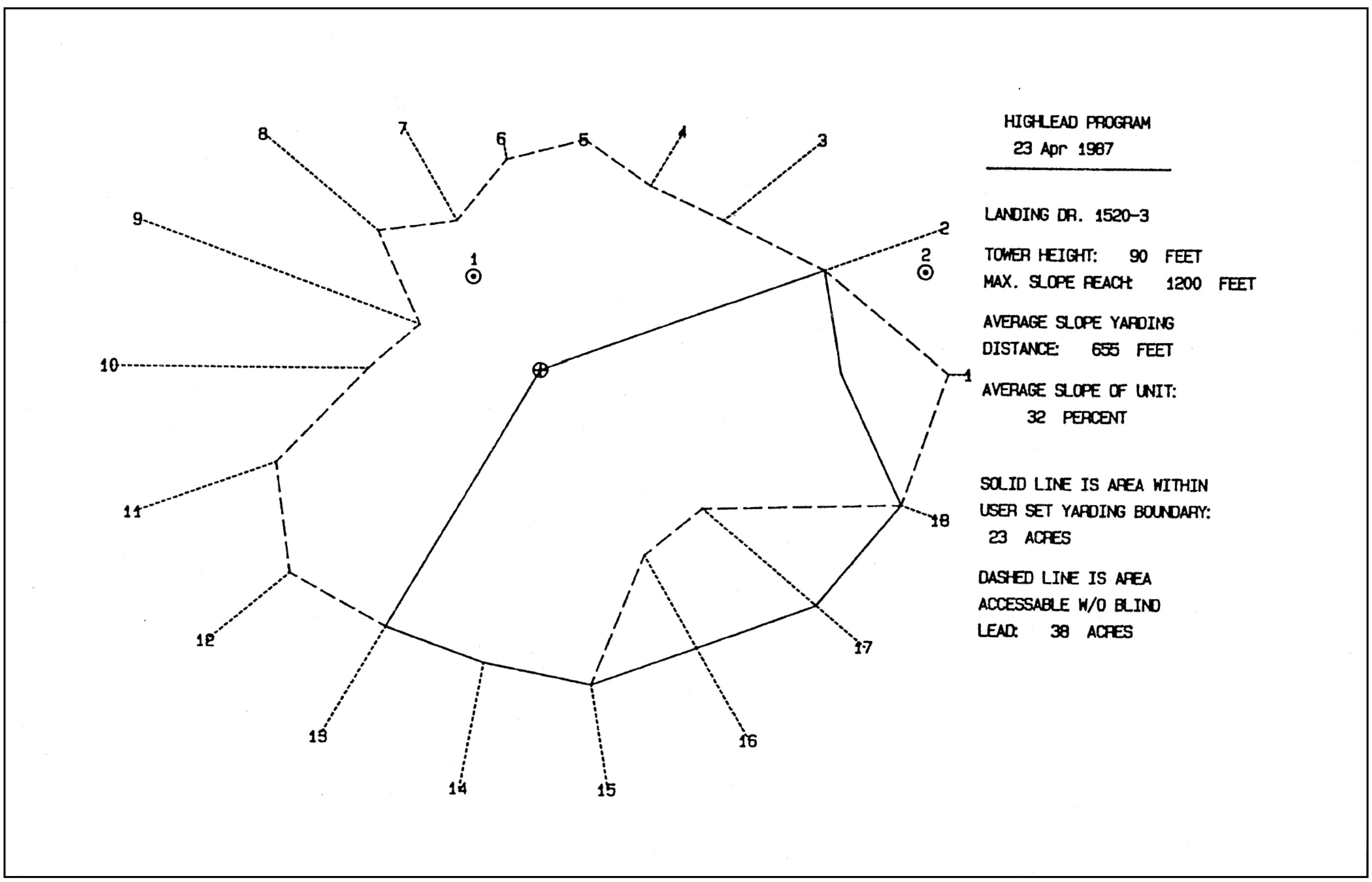

Figure 5—Final design of a highlead harvest-unit for transfer to the timber-harvest plan

Analytical Description of the HIGHLEAD Program

The HIGHLEAD program calculates and shows the distance out from the landing accessible for yarding; this is the yarding limit. A point on the topographic map is picked as a promising landing location. When this point is digitized, a network of 18 evenly spaced yarding corridors radiating out from the yarder are plotted in plan-view; each corridor subtends a 20° arc. This defines the initial yarding limit of the setting.

Direct Yarding Limit

This initial yarding limit shows the area from which logs can be pulled directly to the landing by the mainline without the lead angle having to be improved via tightlining. The pull of the mainline is not obstructed by any intervening ground and tends to pull logs across or over the ground rather than into it. Terrain outside the area of direct mainline pull is either in a blind lead area or beyond the maximum reach of the yarding system.

A terrain profile for each corridor is divided (horizontally) into 20 evenly spaced sections comprised of elevations calculated from the DTM for 21 evenly spaced terrain points. The sequence of checking for ground obstructions begins at the terrain point nearest the tower and progresses outward to the maximum reach (limited by mainline length) specified for the setting. If, for example, the maximum yarding reach of a system is specified to be 1 ,000 feet, the resulting terrain points are 50 feet apart (that is, 1000 +20=50). If the terrain point 50 feet out from the tower does not result in a blind lead situation, the next terrain at 100 feet is checked and so forth. When a blind lead situation occurs, the yarding limit is set at the previous terrain point. If no blind lead problems occur in a corridor, the yarding limit is not reached and extends the full length of the mainline reach.

Blind Lead Algorithm

Blind lead has been defined as a condition on those portions of highlead settings where a straight line between a log and the top of the highlead tower intersects the ground. It can be approximated, after the timber is cut, as areas inside the harvest unit where the tower cannot be seen. The HIGHLEAD program calculates the blind lead point in a slightly more conservative manner (fig. 6).

The initial test for highlead feasibility requires that the angle of pull (A_p) be equal to or greater than the angle of the ground (A_G). The A_p of the choker must be at least parallel to the ground or provide a pull that lifts the hooked end of the log from the ground. If the angle is less, the log will be pulled into the ground and a blind lead situation will result. The analysis for highlead yarding used in the HIGHLEAD program assumes that the chokers are fixed to the log at a point 3 feet above the ground. This makes the analysis slightly more conservative because the angle from that point to the head block on the tower is slightly lower than if the chokers were fixed at the ground line.

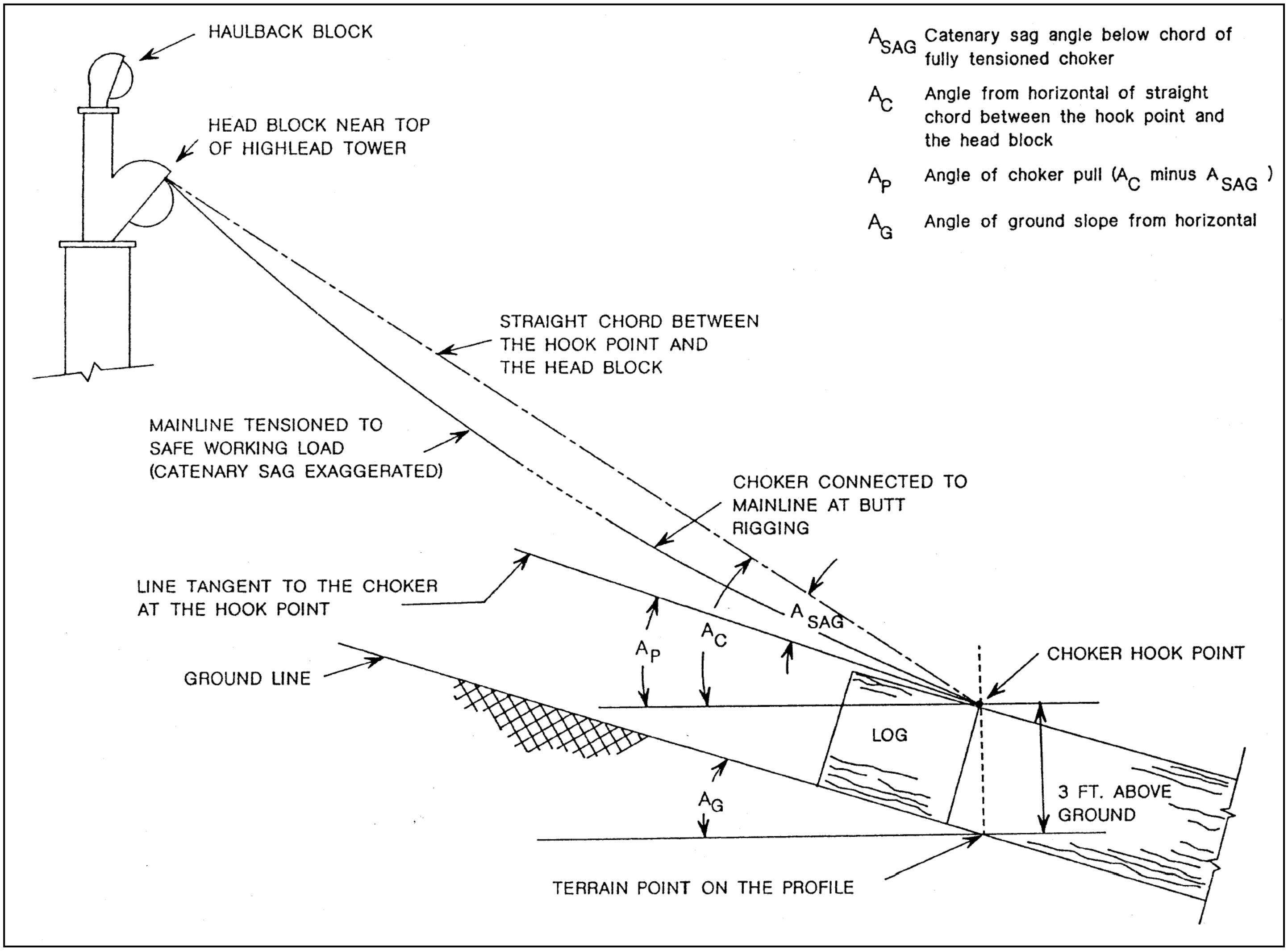

Figure 6—Angles used for determining the yarding limit from direct mainline pull.

Catenary Correction for the Mainline

The vertical angle measured from the choker hook point to the mainline block is corrected in this analysis for the slope, or sag angle, of a tensioned wire rope. This sag angle, described and measured by catenary equations, brings the analysis closer to reality. It is shown as ASAG on figure 6, where the magnitude of ASAG is exaggerated for clarity. Fully tensioned wire ropes approximate straight lines (rigid links) more closely than figure 6 would indicate. The amount of sag for a wire rope tensioned to a safe working load (that is, one-third of predicted breaking strength of extra-improved plow steel) is dependent solely on the horizontal distance from the log to the tower. Solving for the catenary sag angles of a number of different line sizes and spans shows that when the lines are assumed fully tensioned, the angle does not change with line size or slope but only with horizontal distance. The method we used to solve these sag angles required iterative solutions of the transcendental catenary equations presented by Carson (1977). The resulting ASAG can be expressed simply as 0.00155° per foot of horizontal span distance, or 1.55° at a 1,000-foot horizontal span. This constant is used in the HIGHLEAD program and speeds the analysis considerably.

The correction of 0.00155° per foot is not trivial. Its effect can be duplicated by using the standard "line-of-sight" algorithm but shortening the highlead tower to an equivalent adjusted height. If this were done, the tower would have to be shortened from its actual height by over 27 feet at a yarding distance of 1,000 feet, and by over 13 feet at a yarding distance of 500 feet.

Analysis of Tightlining

Once the initial yarding limits are calculated for 18 corridors, the planner may try extending the yarding distance into areas of blind lead by tightlining. The purpose of tightlining is to lift the butt rigging high enough that logs can be skidded to the landing without plowing into or hanging up on the ground. Tightlining analysis in the HIGHLEAD program tests the shape of the ground profile to see if the criteria assumed necessary for successful tightlining can be met. Figure 7 outlines this tightlining algorithm.

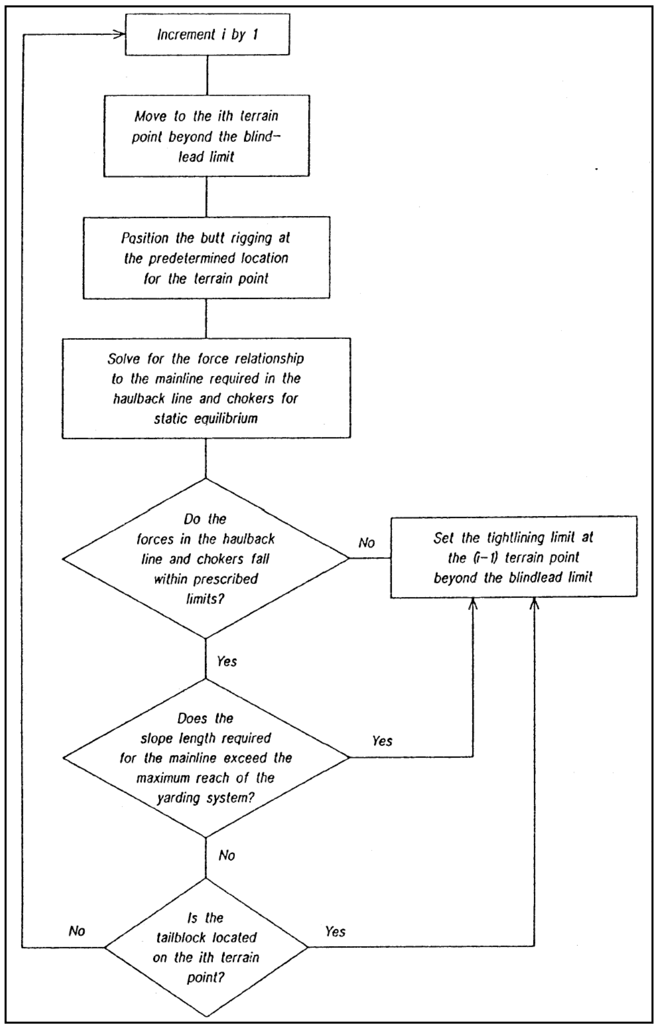

Figure 7—Flowchart of the tightlining algorithm.

In general, the algorithm is based on simple, rational assumptions. The results from a force-balance analysis of the three tensioned cables that join at the butt rigging are used to determine whether too much tension is required in the haulback line to hold the butt rigging where the chokers can pull on the logs with sufficient lift to move the load. The details on this assumption follow.

The butt-rigging position establishes the direction of pull on the log. If the butt rigging is close to or on the ground, insufficient upward pull is exerted from the chokers to initiate log movement. A solution for tightlining requires that a specific and critical position of the butt rigging (where the chokers, the mainline, and the haulback line meet), a necessary prerequisite to log movement, be determined. This butt-rigging position depends on the shape of the profile, the log weight, the coefficient of static friction between the log and the ground, and the tension in the various lines. Because log movement can typically occur at many combinations of lead and choker tension, many solutions for tightlining are possible. The tightlining algorithm used in HIGHLEAD does not solve for specific conditions; it only checks whether or not tightlining will succeed. A key assumption in this algorithm is that the butt rigging must be positioned high enough off the ground for its lead to provide a direction of choker pull slightly higher than the slope of the ground. This position is the lowest point the butt rigging can occupy if tightlining is to succeed (fig. 8).

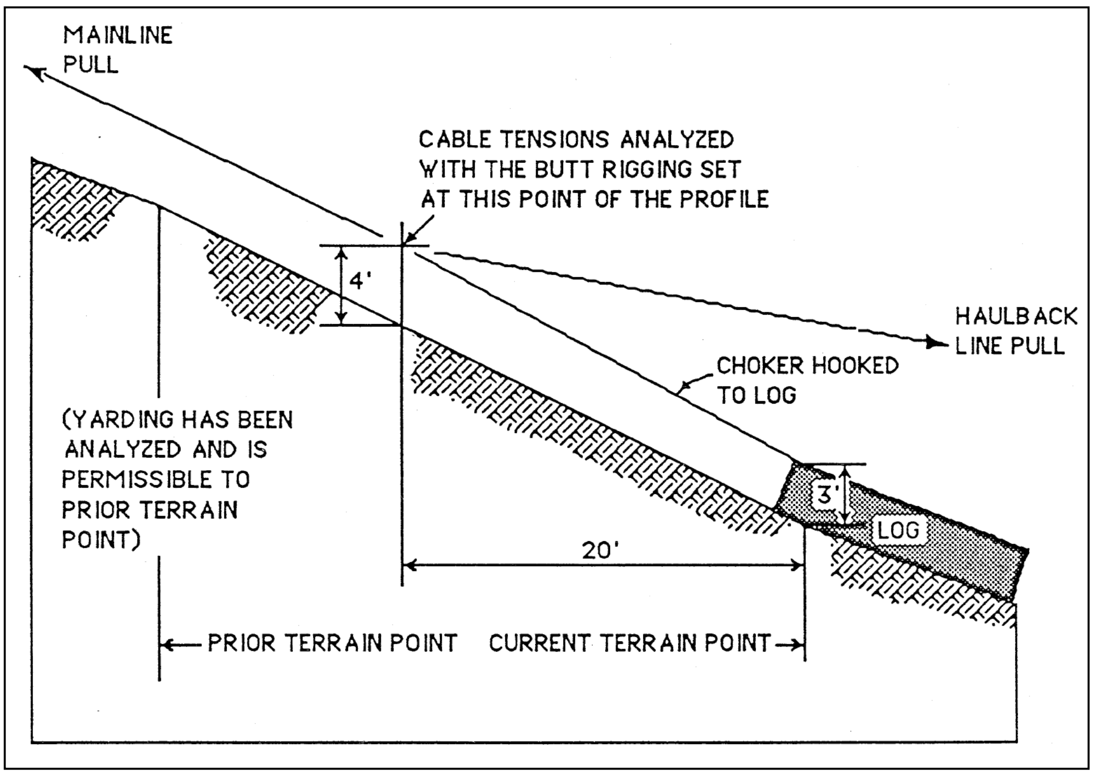

Figure 8—Position where the butt rigging is initially set when wire rope tensions and the feasibility of increasing the yarding reach by tightlining are analyzed.

The position assigned to the butt rigging is 4 feet off the ground and 20 feet ahead of the log,[4] which results in a near-minimal upward pull angle for the chokers that allows skidding (moving) the logs. It also provides a discrete location needed for solving the forces in the working lines.

[4] This position permits a reasonably effective upward pull to be exerted on the log(s) by the chokers 30 feet long (a reasonable choke length for highlead yarding) hooked to a large-diameter log 3 feet (fig. 8) above the ground.

Higher tension in the chokers is required to move the logs when the butt rigging is 4 feet above the ground than when the butt rigging is higher. It is convenient, however, to set a butt-rigging position that is at or near the minimum limit of yarding operability. When generous deflection in the profile permits lifting the butt rigging to positions higher than 4 feet, tightlining becomes easier and success more probable. These results do not conflict with the tightlining algorithm because the algorithm's line-tension criteria are most easily met when the deflection is great. The deflection for the highlead span is greatest when the butt rigging is only 4 feet off the ground. The algorithm will therefore approve tightlining when the deflection is ample. Log movement may begin with low choker tension and at a butt-rigging position higher than 4 feet off the ground, but this would tend to occur because the most efficient angle of choker lead (where minimum pull through the chokers will overcome the forces resisting log movement) is generally when the butt rigging is higher than 4 feet off the ground (see fig. 9).

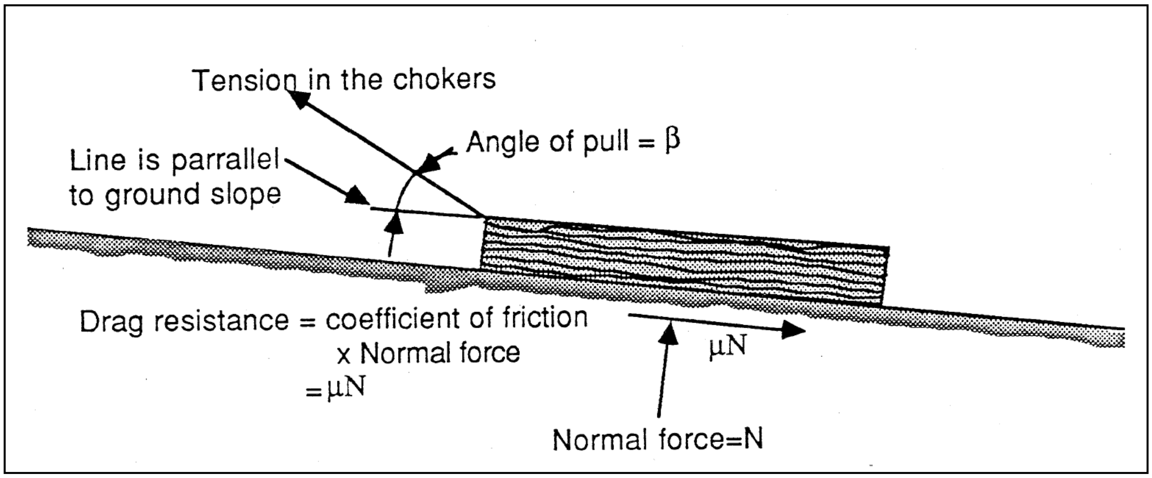

Figure 9—The most efficient angle is the angle of pull whereby a minimum tension in the chokers is required to move the log. This angle is expressed by β = Arc TAN μ.

When the coefficient of friction between logs and the ground is between 0.5 and 1.0, the optimum β angle will range between 26.6° and 45°. If log movement does not occur when the butt rigging is higher than 4 feet, the tension on the mainline can be increased. This will pull the butt rigging to a lower position, which is unfavorable to log movement, but will put a higher tension in the chokers, which is favorable to log movement. In many instances, the increased tension in the chokers will more than compensate for the less effective pulling angle. Therefore this algorithm, which uses a fixed position of the butt rigging, should not negate any feasible tightlining opportunities. Conversely, when the butt rigging cannot be held as high as the assumed point because of poor deflection, the haulback and choker tensions will not meet the criteria of this tightlining algorithm. Even though this 4-foot-high position of the butt rigging might rarely occur, it provides a convenient and reliable method for the analysis of tightlining when it is combined with checks on line tension.

With the butt-rigging position set, the line of action of the force vectors in each of the working lines can be established. The mainline pulls from the butt rigging to the headblock on the tower. The haulback line pulls from the butt rigging to the tailblock. The drop line, or choker, pulls from the butt rigging to the log. The mainline is assumed fully tensioned, and the analysis is based on the relation between the tensions required in the other two lines and the mainline. Three main assumptions govern the tightlining analysis.

1. Tension in the haulback line cannot exceed one-half of the mainline tension. This is based on highlead yarding generally being done with a mainline about twice as strong as the haulback line. A typical West Coast highlead yarder will spool a 1-1/4-inch mainline, which has a safe working strength of 53,300 pounds, and a 7/8-inch haulback, which has a safe working strength of 26,500 pounds. The haulback, in this case, has a safe working strength and a cross-sectional area slightly less than one-half of the mainline. Although other combinations of main and haulback line can be used, the implied two-to-one force ratio is a reasonable planning guideline; the mainline does the real work of pulling the logs in, and the haulback is generally needed only to pull the mainline, butt rigging, and chokers out into the harvest unit. Even when the haulback line must be tensioned during tightlining, it is not practical to allow the tension in the haulback to equal the tension in the mainline. If the horizontal component of the tension in the mainline does not **exceed** the horizontal component of the tension in the haulback, no tension will be available in the chokers for hauling in (yarding) logs.

2. Tension in the drop line (choker) must be at least one-half of the mainline tension. This assumption, a corollary of the first, ensures that at least half of the pull from the mainline is transmitted into the chokers to pull the log towards the landing. The reasons for limiting the haulback tension to less than one-half of the mainline tension also apply to requiring the dropline tension to be at least one-half of the mainline tension.

3. Tension is the only force permitted in the lines. This assumption provides a necessary restraint on the analysis. Wire ropes can act only as tensile structural members. Any force-balance solution meeting the requirements of static equilibrium by assigning a compressive force in a wire rope is automatically rejected.

Two additional assumptions control tightlining analysis but do not relate to line tensions.

4. The yarding limit for tightlining cannot move as far out as the tailblock, but is limited to the terrain point immediately in front of the tailblock. This assumption is necessitated by the tightlining algorithm. If the force vectors to be analyzed for the tightlining solution are established with the log at the same terrain point as the tailblock, the spatial arrangement invalidates the algorithm because the log and the tailblock cannot occupy the same space. Harvest planners should be aware that restricting the yarding limit resulting from tightlining to the terrain point in front of the tailblock will not necessarily constrain the highlead system from yarding up to the tailblock.

5. The yarding limit for tightlining cannot be set at a slope distance from the tower that is beyond the reach of the highlead mainline. This final assumption provides a way to ensure that the yarding limit will not be set at a point beyond the reach of the mainline. The initial direct-yarding-limit analysis encompassed a circle with a horizontal radius set equal to the maximum slope-yarding distance of the system. The tightlining analysis restricts reach in blind lead areas by imposing a slope-distance constraint on the reach of the mainline.

Examples of Tightlining

Designing to increase yarding distance through tightlining is done profile by profile. The planner chooses the profile to be examined for tightlining and then must choose a location and rigging height for the tailblock on the profile. This location should be selected to take advantage of whatever lift the terrain permits. With these inputs, the tightlining analysis proceeds automatically. It begins one terrain point beyond the terrain point labeled as the yarding limit, based on direct mainline pull; this is the first terrain point where the blind lead situation occurred. The routine analyzes that terrain point for tightlining operations. If tightlining criteria are met at that terrain point, the analysis moves one more terrain point out from the yarder and repeats the analysis for the new point. The example in figure 10 shows tightlining analysis at a point where tightlining meets the criteria of the algorithm.

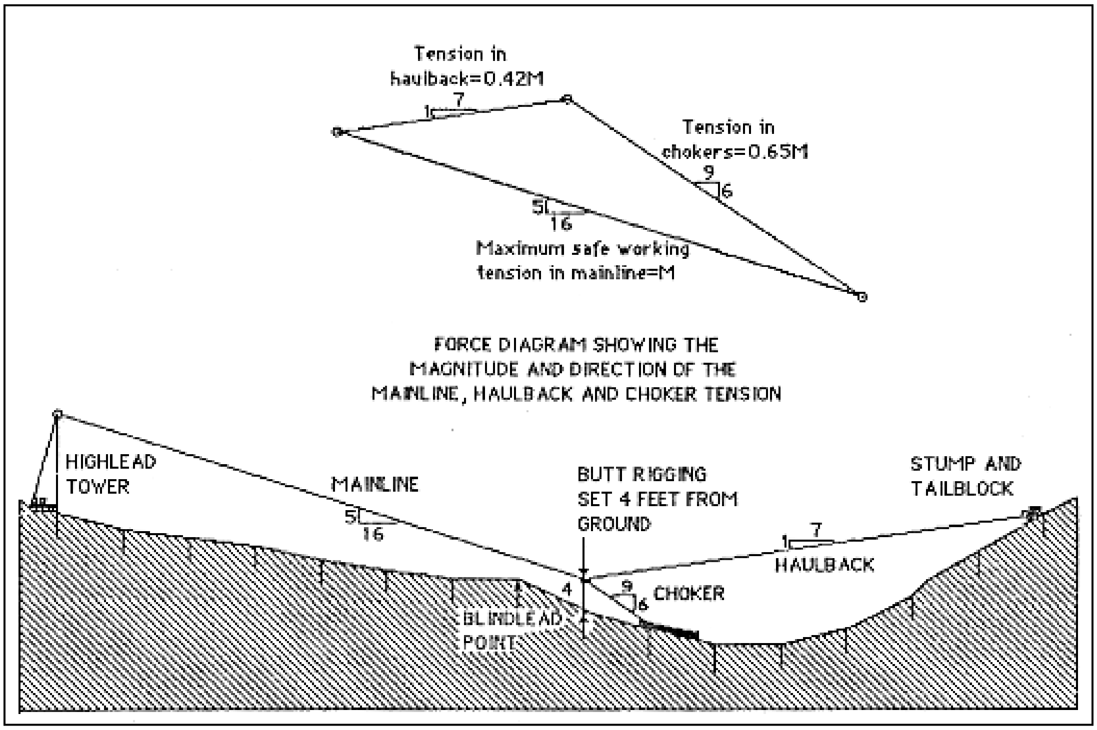

Figure 10—Profile of a situation where tightlining meets the choker and haulback tension requirements of the algorithm.

The force diagram above the profile indicates that the haulback tension is less than half (42 percent) and the choker tension is greater than half (65 percent) of the mainline tension, as required. This analysis continues until a terrain point is encountered where one or more of the five criteria are not satisfied. When this point is encountered, a message is printed at the last terrain point meeting the tightlining criteria. The message indicates how far along the profile tightlining is feasible and indicates which criteria were violated beyond the displayed yarding limit.

Figure 11 shows where tightlining cannot extend the yarding limit beyond the blind lead point. Here the haulback line is overstressed (at 58 percent of mainline tension). Sufficient tension for yarding can pass from the mainline to the chokers, so only the overstressed haulback prevents tightlining success. In this situation, the blind lead point

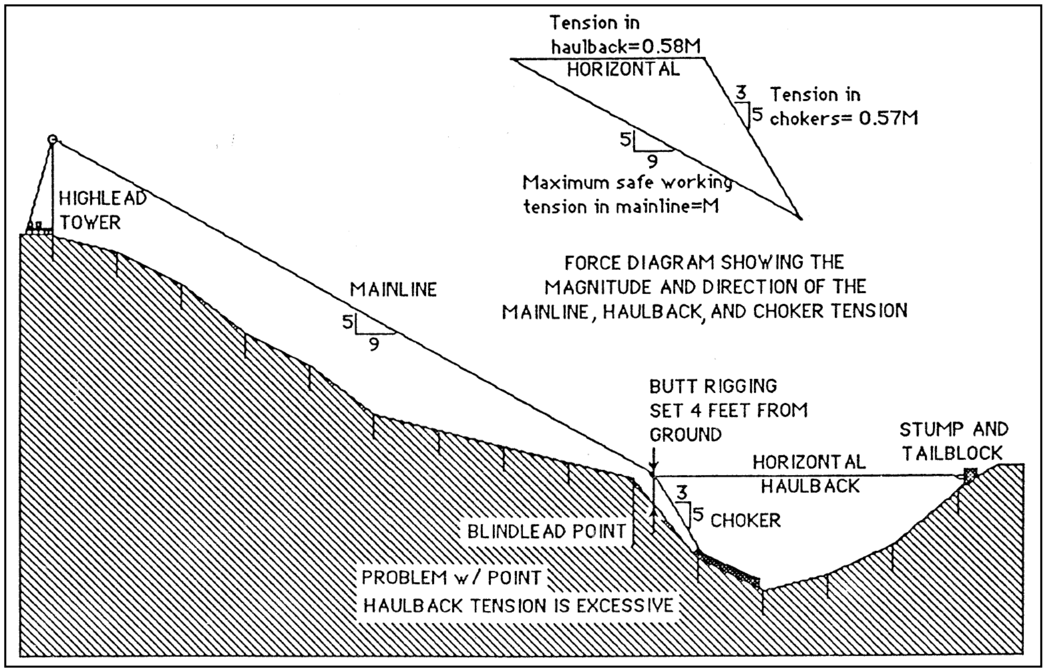

Figure 11—Profile of a situation where the haulback tension is too high to meet the requirements of the tightlining algorithm.

(called the "direct mainline pull yarding limit on the program's output) is also the yarding limit with tightlining, which shows that tightlining cannot increase yarding reach on this profile.

Tightlining under the conditions shown in figure 12 is difficult to impossible. Here the haulback line is overstressed, and the chokers are understressed.

Planners using HIGHLEAD learn to recognize whether tightlining will or will not work. Straight or convex ground profiles, which are poor for skyline yarding, provide little possibility for successful tightlining. The situation above (fig. 12) typifies a tug of war between the haulback and mainline, where too little (42 percent) of the mainline's tension passes into the drop line and too much (61 percent) into the haulback line.

Figure 13 shows a situation in which the tail block is positioned on the profile at a point where lift through tightlining is impossible. When the algorithm can solve the force system only by assigning negative tension to either the chokers or the haulback, a message indicating that no lift is possible from tightlining is displayed. Negative tension, as defined here, is compression-a force impossible to develop in wire ropes.

These tightlining examples plotted in profile view show and emphasize that lift (deflection) is as important for highlead yarding as for skyline systems.

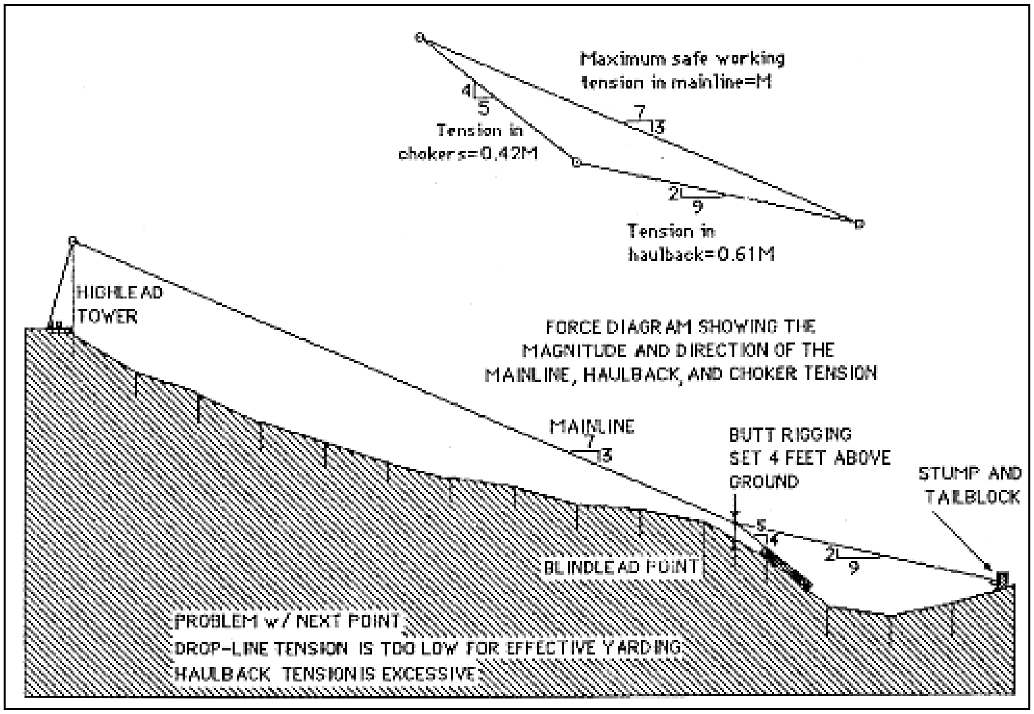

Figure 12—Profile of a situation where the haul back tension is too high and the choker tension is too low to meet the requirements of the tightlining algorithm.

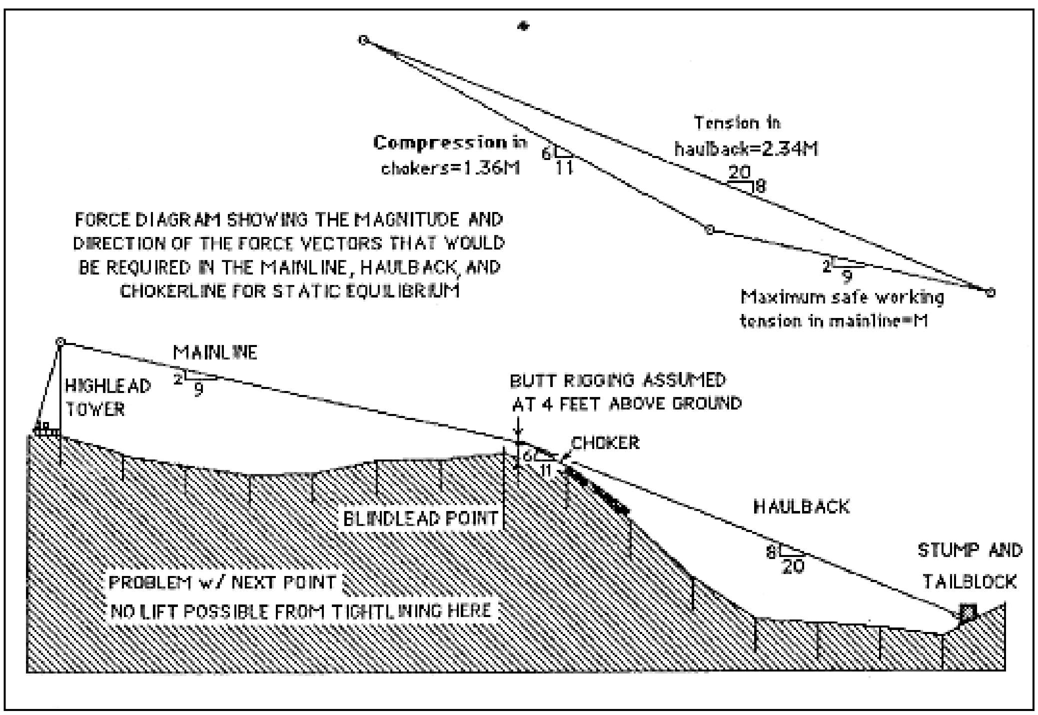

Figure 13—Profile of a situation where tightlining is impossible because the algorithm solved the force triangle by assigning a compressive force to one of the cables.

Limitations

Smoothed, uniform ground profiles extracted from the DTM may not analytically restrict yarding to the extent representative of actual ground conditions and therefore could limit the usefulness of the HIGHLEAD program. In actual field conditions, short adverse pitches, dips, rocks, stump butt swells, and terrain irregularities typically occur to impede log movement but are conspicuously missing from extracted profiles. These irregularities can become major obstructions for highlead yarding, yet accounting for them on timber-harvest plans in a way that is both analytically correct and practical is difficult.

The yarding system can be strained and possibly overtaxed if, when log movement begins, the log is pulled immediately into an obstruction. When the log is already moving with sufficient velocity, it may be able to push through and obliterate potential obstructions. Past logging often shows where skidded logs have pushed or plowed through obstructions. Such skidtracks develop a trough that permits easier passage of the next logs. Because all potential obstructions do not cause hangups, the field irregularities in the analyses can be partially ignored.

Payload

The HIGHLEAD program does not produce a payload analysis for the yarding corridors of the designed harvest unit. This makes the program inconsistent with other cable-logging design programs for skyline yarding systems, which usually include a payload analysis. One reason for ignoring payload calculations in the HIGHLEAD algorithm is that payload for highlead depends on the coefficient of friction between the log and the ground, which in turn depends on several variables beyond the level of complexity needed for area planning. Furthermore, maximum physical payload for highlead yarders is generally so ample that the actual payload hooked is seldom limited. Other factors, such as the number of chokers, the number of logs within reach of the chokers, and log size, will normally limit the log turn to a weight less than maximum physical payload. The yarding limit determined by the mainline pull angle is therefore the most critical variable in planning highlead harvest units.

Maximum physical payload for highlead yarding can be approximated by assuming a coefficient of log-drag friction, which will range between 0.5 and 1.0 for logs with bark on bare ground; it will differ with log species and diameter, soil texture and moisture content, and slope (Henshaw 1977). If a conservatively high coefficient of log-drag friction of 1.0 is assumed, and it is also assumed that the logs are on level ground (where slope[5] does not affect the payload) and the choker pull is parallel to the ground slope, then when the pull in the choker exceeds the log weight log movement will begin. Once movement begins, the magnitude of the log-drag force will be reduced because the resistance from kinetic (moving) friction is lower than resistance from static (stationary) friction. This will, in turn, permit a higher proportion of the choker tension to increase the acceleration of the log toward the yarder. The safe working tension of the mainline is roughly equivalent to the highlead payload on level ground. The highlead payload should be multiplied by the reciprocal of the sine plus the cosine of the ground-slope angle when the yarding is being done uphill (for example, the payload is 71 percent of the safe tension in the mainline on 100-percent ground slopes).

[5] Whether the log is yarded uphill or downhill has a considerable effect on the tension required. For example, on a 80-percent slope with a coefficient of friction of 1.0, a 1,406-pound force is needed to begin moving a 1,000-pound log uphill. Yarding it downhill would only take a 156-pound force.

A nominal and realistic payload must be assigned to evaluate cable-yarding costs in SIMYAR, the yarding-simulation program in PLANS. Payload is constrained by the pull exerted through the mainline drum. Theoretically, the mainline in the HIGHLEAD can be any diameter, but from a practical standpoint it is usually between 3/4 and 1-3/8 inches; the haulback is about one-half of the weight and strength of the mainline. Table 1 lists payloads for HIGHLEAD based on mainline size and pull. The program assumes these payloads are being yarded uphill on 1 DO-percent slopes and the accelerating force from mainline pull is 1,000 pounds greater than the forces resisting log movement. For tightlining, the HIGHLEAD algorithm requires that at least one-half of the tension from the mainline be transmitted to the chokers; therefore, the payloads for tightlining are based on a choker tension one-half that of the direct mainline tension.

Table 1--Maximum highlead payloads for various combinations of main and haulback lines assuming that (1) the mainlines will be stressed to their safe working tension, (2) the coefficient of log-drag friction is 1.0, (3) the logs will be yarded up a 100-percent slope, (4) the extra pull exerted through the mainline exceeds the resisting forces by 1,000 pounds, and (5) the choker pull exerted via tightlining is limited to one-half of the choker pull attained by direct highlead yarding

			Maximum highlead payload	
Mainline diameter	Haulback diameter	Ratio of mainline to haulback weight	Direct highlead pull	Tightlining
------- *Inches* -------			---------- *Kips* ---------	
1-3/8	1	1.89:1	44.5	21.9
1-1/4	7/8	2.04:1	37.0	18.1
1-1/8	3/4	2.25:1	29.9	14.6
1	3/4	1.78:1	23.7	11.5
7/8	5/8	1.97:1	18.0	8.7
3/4	1/2	2.26:1	13.2	6.2

Tightlining

Many loggers prefer to rig highlead yarders as a running skyline (referred to as a "Grabinsky") to yard areas where direct highlead yarding is difficult because of poor lift. This system (see fig.14) is superior to tightlining with conventional highlead rigging on corridors where lift is needed because the haulback line is twice as effective in supplying lift to the butt rigging. This improvement in lift does not further reduce the effectiveness of the mainline for moving the logs to the landing because the additional lift is supplied totally by the haulback line. The analysis with HIGHLEAD does not, however, address this preferred system.

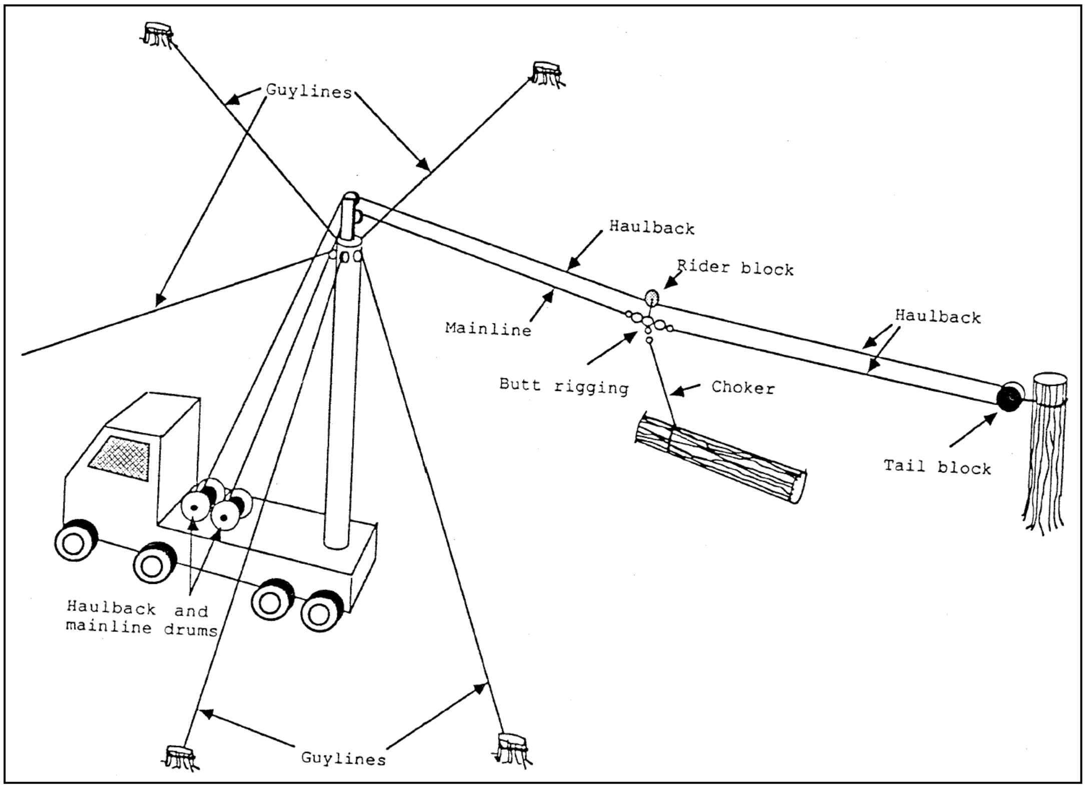

Figure 14—Highlead yarder rigged as a Grabinsky skyline.

For the planner wishing to make exact harvest unit designs that take into account the differences between the operating limits of tightlining and Grabinsky yarding, we recommend analyzing the Grabinsky access limits by using the running skyline option (SKYTOWER; Twito and others in press) in the PLANS program. Entering a small carriage clearance (4 to 6 feet) and payload[6] (1 to 3 kips) will approximate Grabinsky requirements.

[6] The actual highlead payload would be heavier than this; with highlead yarding, the log is not suspended from the carriage as in skyline systems but is fully supported by the ground.

We recommend using the HIGHLEAD tightlining option to determine which areas of the harvest unit cannot be accessed by direct highlead pull but relying on the Grabinsky skyline to ensure that yarding can be accomplished. Any unit requiring a high percentage of its area to be tightlined should, in fact, be yarded by a Grabinsky, which is easier on the equipment and the site than are conventional highlead tightlining operations.

Another skyline option often used to alleviate blind lead problems is the shotgun (flyer) method. This option, even though often used with highlead yarders, is definitely a skyline system that can also be analyzed with SKYTOWER. When the yarding is uphill with the skyline slopes sufficient to permit outhaul of the carriage by gravity and good anchoring available, this option should be considered.

Conclusions

Cable loggers know that, whether they use a skyline or highlead system, the ability to operate depends on the ability to lift the logs. Most of the effort for assuring that needed lift is available has been expended in analyzing of skyline yarding systems, even though highlead is the predominant yarding system in the Pacific Northwest. This HIGHLEAD program, although not the first addressing this subject, is a pioneer in analyzing how the coverage can be extended via tightlining. The program works quickly and conveniently by using DTM data to arrive at highlead settings well adjusted to the topography.

Metric Equivalents

1 inch = 2.54 centimeters

1 foot = 0.3048 meter

1 pound = 0.4536 kilogram

1 kip = 453.59 kilograms

-

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Operating Instructions and Worked Examples

An appendix to this report containing step-by-step operating instructions for the HIGHLEAD program is available from the Pacific Northwest Research Station. A copy of this appendix can be obtained by photocopying this page, filling in the necessary information, and sending it to:

USDA Forest Service
Pacific Northwest Research Station
Forestry Sciences Lab
Forest Engineering Systems 4043
Roosevelt Way NE
Seattle, WA 98105

(206) 442-7814

This appendix includes an example of designing highlead harvest units and demonstrates many of the options and manipulations available.

If you wish to receive the PLANS program set--which includes HIGHLEAD--stored on diskettes, send five 5-1/4-inch double-sided, double-density, flexible mini discs.

Please send supplementary material for the HIGHLEAD program to:

NAME ______________________________

ADDRESS ______________________________

____

CITY ______________________________

STATE & ZIP CODE ______________________________

Twito, Roger H.; Reutebuch, Stephen E.; McGaughey, Robert J. 1988. The HIGHLEAD program: locating and designing highlead harvest units by using digital terrain models. Gen. Tech. Rep. PNW-GTR-206. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 21 p.

PLANS, a software package for integrated timber-harvest planning, uses digital terrain models to provide the topographic data needed to fit harvest and transportation designs to specific terrain. HIGHLEAD, an integral program in the PLANS package, is used to design the timber-harvest units to be yarded by highlead systems. It solves for the yarding limits of direct mainline pull to the top of the tower by assuming that the angle of pull must be equal to or higher than the slope of the ground. The ground is sampled through a system of 18 uniformly spaced corridor profiles that radiate from user-selected landing locations and that are extrapolated from the digital terrain model. HIGHLEAD permits the planner to reduce the. yarding coverage by shortening yarding distance on individual corridors or by deleting portions of the yarding circle. Conversely, the planner can try to extend the yarding distance on individual corridors by tightlining. The algorithm for tightlining is explained as are limitations of the analysis and interpretations on the maximum, safe tog load for highlead systems. A guide giving detailed operating instructions for the program is available from the authors.

Keywords: Timber harvest planning, computer programs/programing, logging operations analysis/design, road building (forest/logging).

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HIGHLEAD Program—Users Instructions

EXAMPLE 1: ESTABLISHING THE SETTING BOUNDARY FOR A HIGHLEAD UNIT.

The planner wants to determine the area that can be highlead logged uphill to landing 3 by using a yarder with a 90-foot tower and a maximum reach of 1,200 feet.

Firmly tape figure 1 to the digitizer tablet, and tape a sheet of clear acetate film over the map. Carefully mark the corners of the DTM unit on the overlay. Use this clear overlay as a scratch pad during development of the logging plan.

To access the HIGHLEAD program, the planner must type:

LOAD "PLANS/BEGIN:CS80,5", 1 (followed by the EXECUTE key)

The following list of steps must then be executed to analyze the setting. The inputs and outputs for this example (example 1) are given. Slightly different results are expected with each run of this example because of slight distortions in the map and differences in positioning the digitizer cursor.

All prompts printed on the terminal screen have been capitalized in the following examples.

PLANS

PRELIMINARY LOGGING ANALYSIS SYSTEM

Please choose one of the following eight plans programs:

1. SKYMOBILE . . . . Analyze skyline payloads and spans for individual profiles
2. SKYTOWER . . . . Analyze payloads and spans for large central landings
3. HIGHLEAD . . . . Analyze direct pull and tightlining limits for highlead
4. ROUTES . . . . Project trial grade lines and calculate % sideslopes
5. SLOPE . . . . Plot overlay maps for areas of specified slope, aspect, etc.
6. VISUAL . . . . View a terrain model in perspective from desired viewpoint
7. SIMYAR . . . . Simulate yarding activities to estimate yarding cost
8. MAP . . . . Digitize contour lines to create a digital terrain model

ENTER A 1 THROUGH 8 TO MATCH YOUR CHOICE.

Keyboard Input: 3

comment: All keyboard inputs are completed by pressing the RETURN key.

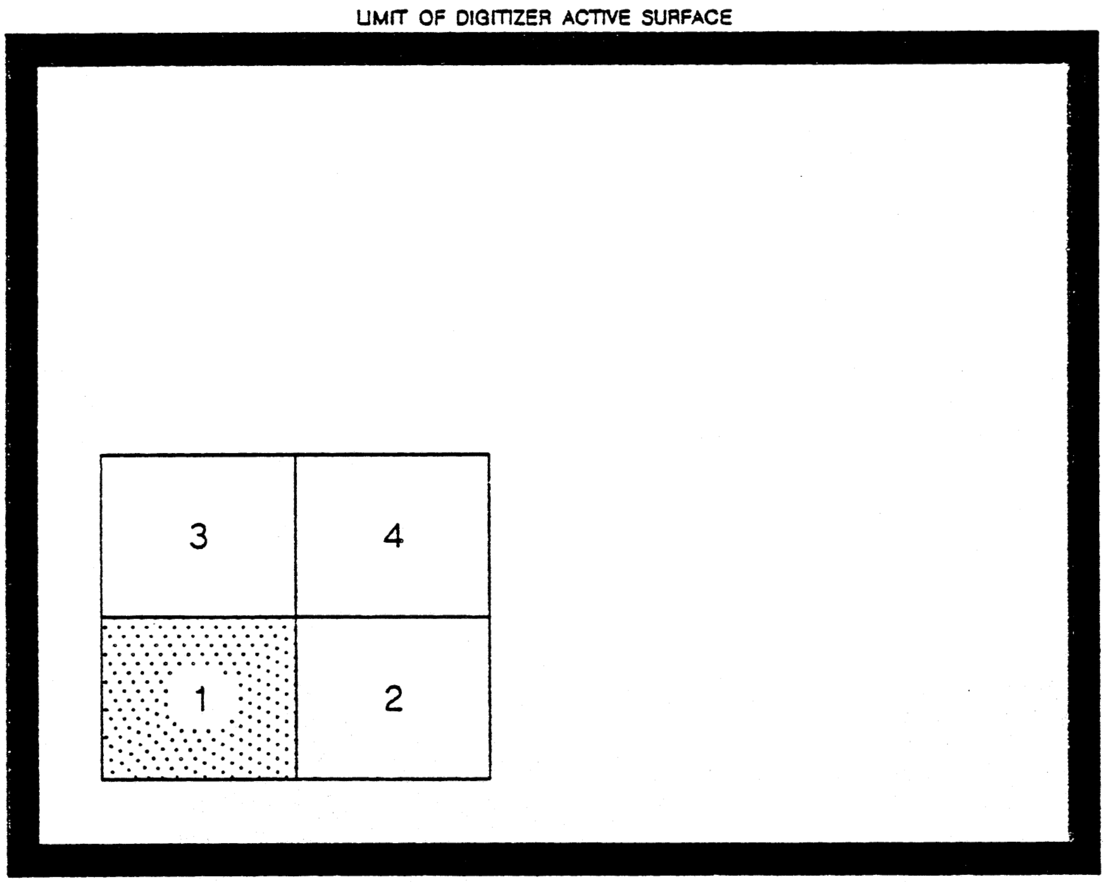
▪▪▪▪▪▪▪▪

Step 1-2
ENTER THE DATA FILE NAME FOR THE DESIRED DTM UNIT.

Keyboard input: EXAMPLE_DTM1

....

Step 1-3



THE SHADED DTM UNIT IS EXAMPLE_DTM1 --- SELECT THE DESIRED LOADING OPTION

LOAD ALL DTM UNITS	LOAD ONLY THE SHADED DTM UNIT	

Softkey input: LOAD ONLY THE SHADED DTM

comment: In this example, the terrain data for only the shaded DTM unit is loaded.

....

Step 1-4

DIGITIZE THE LOWER LEFT CORNER OF THE DTM UNIT.

DIGITIZE THE LOWER RIGHT CORNER OF THE DTM UNIT.

Digitizer input: Center the cursor over the lower left corner of the DTM unit and press any cursor key.

Center the cursor over the lower right corner of the DTM unit and press any cursor key.

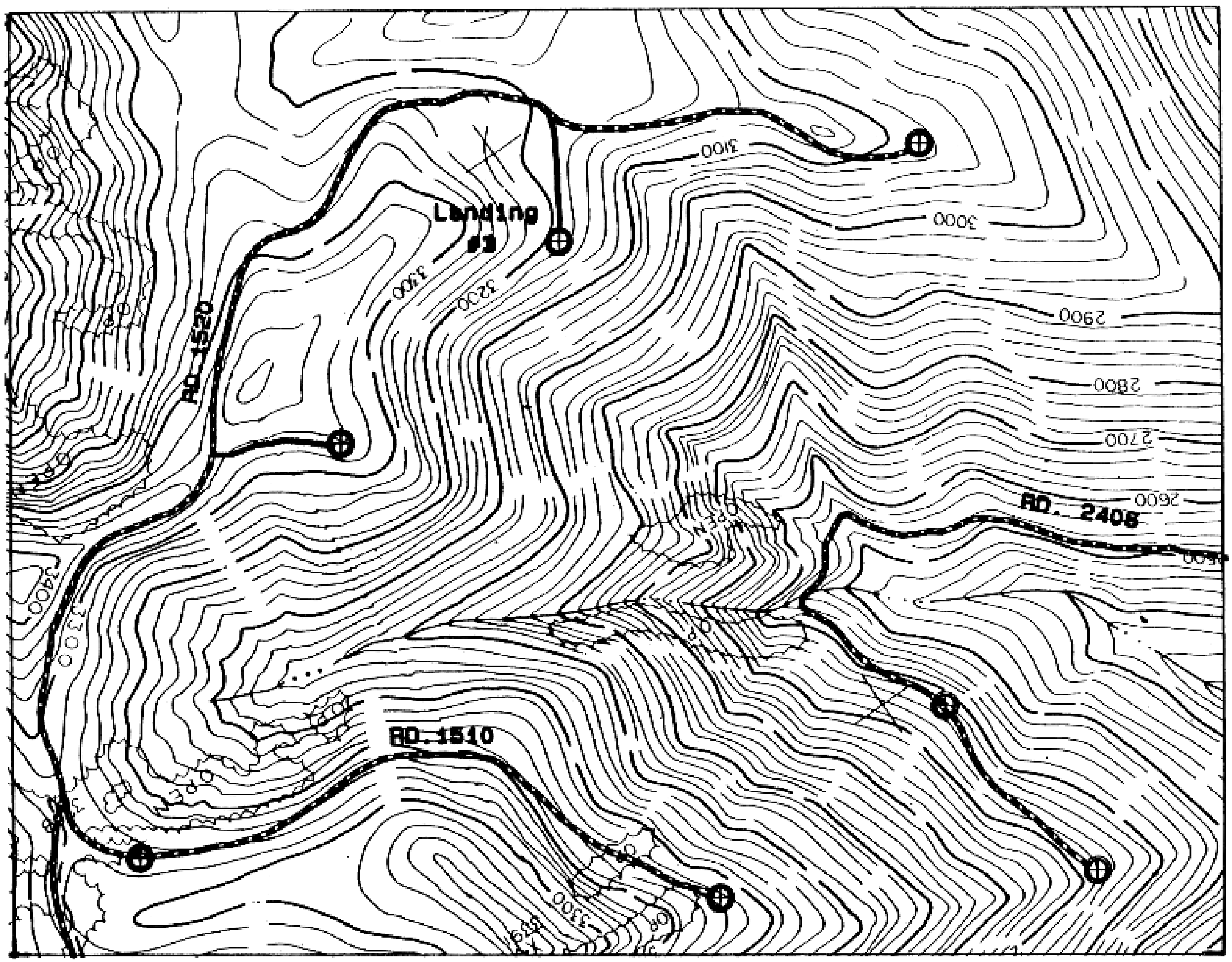


Figure 1. Map for HIGHLEAD examples.

Step 1-5

HOW TALL IS THE TOWER (FT) ?

Keyboard input: 90

Step 1-6

HOW HIGH ABOVE THE GROUND WILL THE TAILBLOCK BE RIGGED (FT) ?

Keyboard input: **2**

comment: The tailblock will usually be rigged to a stump.

Step 1-7

WHAT IS THE MAXIMUM SLOPE YARDING DISTANCE (FT)?

Keyboard input: 1200

Step 1-8

WHAT IS THE LANDING NAME OR NUMBER (UP TO 15 CHARACTERS) ?

Keyboard input: RD. 1520-3

Step 1-9

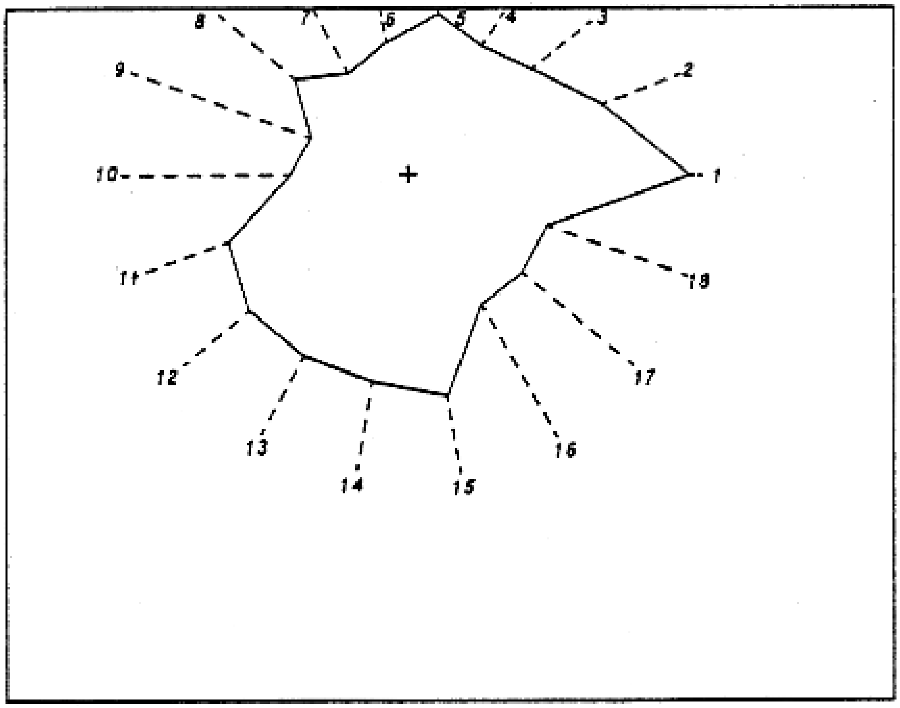
DIGITIZE LANDING RD. 1520-3

Digitizer input: Center the cursor over landing 3 and press any cursor key.

▪▪▪▪▪▪▪▪

Step 1-10

DISTANCE FROM DIGITIZER CURSOR TO LANDING: 432 FEET



MODIFY THE LENGTH OF ANY CORRIDOR	*REMOVE CORRIDORS FROM THE SETTING*	*MARK THE UNIT ON THE BASE MAP*	*DESIGN A NEW HIGHLEAD UNIT*

comment: The relative position of the digitizer cursor within the map area is represented by the small flashing cross on the screen. As the planner moves the cursor, the distance from the current cursor location and the digitized landing location is displayed.

The planner should slide the yarding corridor template (distributed with the PLANS program disks) under the acetate overlay and carefully center it over the digitized landing. The template can then be properly aligned with the aid of the digitizer cursor. Move the digitizer cursor until the small flashing cursor is centered over corridor 1 on the terminal screen. Rotate the template until corridor 1 on the template is directly under the digitizer cursor crosshair.

After properly aligning the template, the planner can position the cursor at desired tailholds or yarding limits and note the distance along each corridor to such points.

MODIFY THE LENGTH OF ANY CORRIDOR	*REMOVE CORRIDORS FROM THE SETTING*	*MARK THE UNIT ON THE BASE MAP*	*DESIGN A NEW HIGHLEAD UNIT*

Softkey input: REMOVE CORRIDORS FROM THE SETTING

comment: The planner does not want the area defined by corridors 3 through 12 to be yarded to landing 3.

....

Step 1-11

FIRST CORRIDOR YOU WANT TO REMOVE (1-18)? (PRESS RETURN WHEN DONE)

Keyboard input: 3

....

Step 1-12

LAST CORRIDOR YOU WANT TO REMOVE (1-18) ? (PRESS RETURN TO REMOVE ONLY #3)

Keyboard input: 12

comment: Corridors 3 through 12 are removed in a counter-clockwise direction starting with corridor 3 and
finishing with corridor 128

....

Step 1-13

FIRST CORRIDOR YOU WANT TO REMOVE (1-18) ? (PRESS RETURN WHEN DONE)

Keyboard input: RETURN

comment: Pressing the RETURN key without typing a number signals the program that you are done removing corridors.

....

Step 1-14

MODIFY THE LENGTH OF ANY CORRIDOR	REMOVE CORRIDORS FROM THE SETTING	MARK THE UNIT ON THE BASE MAP	DESIGN A NEW HIGHLEAD UNIT

Softkey input: MODIFY THE LENGTH OF ANY CORRIDOR

....

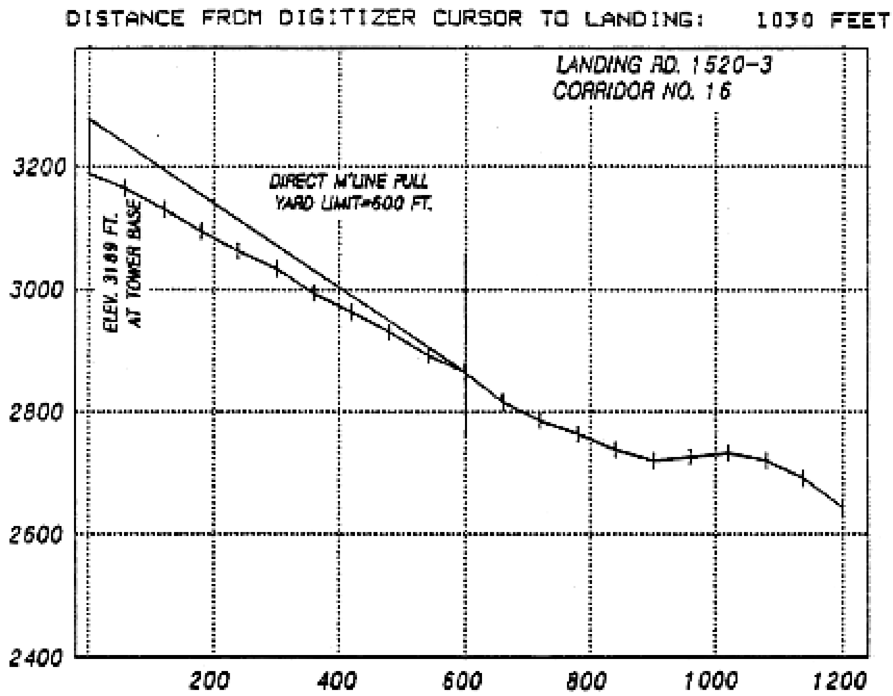
Step 1-15

WHICH CORRIDOR WOULD YOU LIKE TO ANALYZE (1-18)? (PRESS RETURN WHEN DONE)

Keyboard input: 16

....

Step 1-16



EXTEND REACH BY TIGHTLINING	SET SHORTER YARDING LIMIT	HARD COPY		DONE WITH PROFILE

Softkey input: EXTEND REACH BY TIGHTLINING

....

Step 1-17

POSITION THE VERTICAL LINE USING THE ⇐OR⇒THEN PRESS TAILBLOCK

TAIL BLOCK	

Digitizer input: Move the digitizer cursor along corridor 16 until it is about 1,000 feet from the landing.

***Keyboard arrow keys:** Use the screen cursor-positioning arrows* at *the top of the keyboard to move the flashing, vertical line left until it is directly over the small flashing cross. The vertical line moves in smaller steps when the SHIFT key is held down.*

Softkey input: TAILBLOCK

▪▪▪▪▪▪▪▪

Step 1-18

WANT TO CHANGE THE TAILBLOCK HEIGHT?

	YES		NO	

Softkey input: NO

▪▪▪▪▪▪▪▪

Step 1-19

	SET SHORTER YARDING LIMIT	HARD COPY		DONE WITH PROFILE

Softkey input: HARD COPY

comment: The profile plot of corridor 16 is produced on the printer as shown in figure 2.

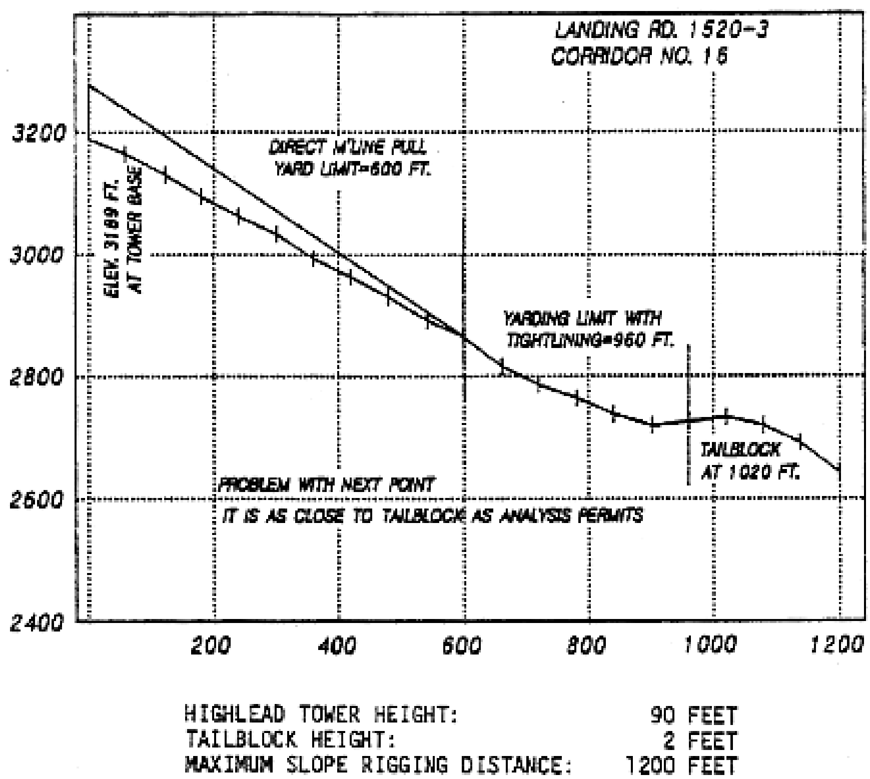


Figure — Profile plot of corridor 16.

....

Step 1-20

	SET SHORTER YARDING LIMIT	HARD COPY		DONE WITH PROFILE

Softkey input: DONE WITH PROFILE

....

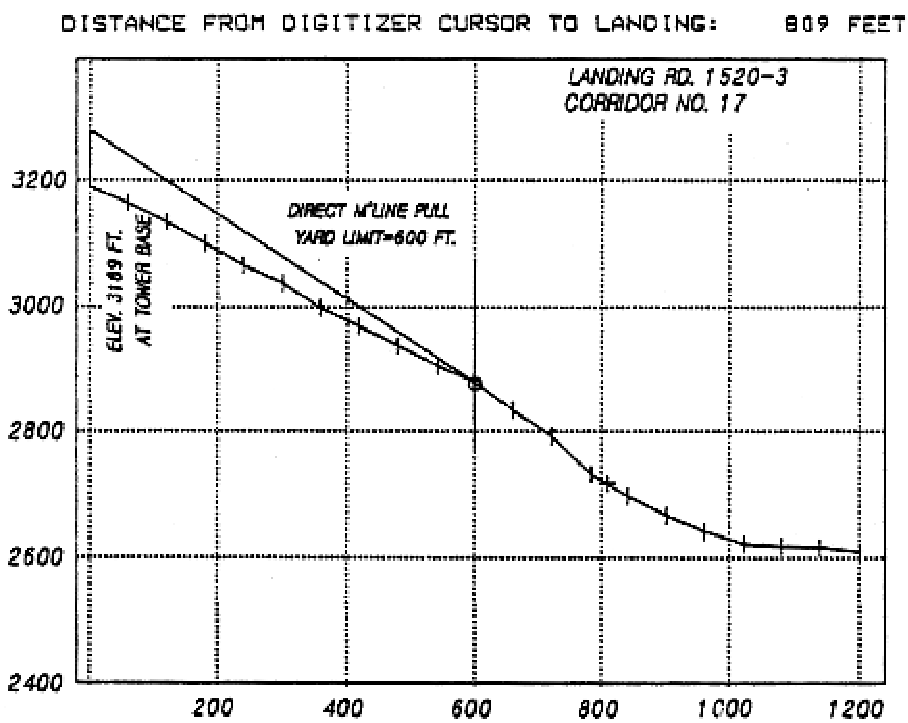
Step 1-21

WHICH CORRIDOR WOULD YOU LIKE TO ANALYZE (1-18) ? (PRESS RETURN WHEN DONE)

Keyboard input: 17

....

Step 1-22



EXTEND REACH BY TIGHTLINING	SET SHORTER YARDING LIMIT	HARD COPY		DONE WITH PROFILE

Softkey input: EXTEND REACH BY TIGHTLINING

....

Step 1-23

POSITION THE VERTICAL LINE USING THE ⇐OR⇒THEN PRESS TAILBLOCK

TAIL BLOCK	

Keyboard arrow keys: ***Use the screen cursor-positioning arrows at the top of the keyboard to move the flashing vertical line left to a point about 1,150 feet from the tower.***

Softkey input: TAILBLOCK

....

Step 1-24

WANT TO CHANGE THE TAILBLOCK HEIGHT?

	YES		NO	

Softkey input: YES

comment: The tailblock will be rigged 20 feet above the ground on a tree rather than on a stump.

....

Step 1-25

HOW HIGH ABOVE THE GROUND WILL THE TAILBLOCK BE RIGGED (FT) ?

Keyboard input: 20

....

Step 1-26

	SET SHORTER YARDING LIMIT	HARD COPY		DONE WITH PROFILE

Softkey input: DONE WITH PROFILE

....

Step 1-27

WHICH CORRIDOR WOULD YOU LIKE TO ANALYZE (1-18) ? (PRESS RETURN WHEN DONE)

Keyboard input: **18**

Step 1-28

EXTEND REACH BY TIGHTLINING	SET SHORTER YARDING LIMIT	HARD COPY		DONE WITH PROFILE

Softkey input: EXTEND REACH BY TIGHTLINING

▪▪▪▪▪▪▪▪

Step 1-29

POSITION THE VERTICAL LINE USING THE ⇐OR⇒THEN PRESS TAILBLOCK

TAIL BLOCK	

Keyboard arrow keys: Use the screen cursor-positioning arrows to move the vertical line left to a point about 1,000 feet from the tower.

Softkey input: TAILBLOCK

▪▪▪▪▪▪▪▪

Step 1-30

WANT TO CHANGE THE TAILBLOCK HEIGHT?

	YES		NO	

Softkey input: NO

▪▪▪▪▪▪▪▪

Step 1-31

	SET SHORTER YARDING LIMIT	HARD COPY		DONE WITH PROFILE

Softkey Input: DONE WITH PROFILE

▪▪▪▪▪▪▪▪

Step 1-32

WHICH CORRIDOR WOULD YOU LIKE TO ANALYZE (1-18) ? (PRESS RETURN WHEN DONE)

Keyboard input: 1

▪▪▪▪▪▪▪▪

Step 1-33

EXTEND REACH BY TIGHTLINING	SET SHORTER YARDING LIMIT	HARD COPY		DONE WITH PROFILE

Softkey input: SET SHORTER YARDING LIMIT

comment: The yarding limit will be moved in to better match the limits of corridors 2 and 18.

▪▪▪▪▪▪▪▪

Step 1-34

POSITION THE VERTICAL LINE USING THE ⇐OR⇒THEN PRESS YARDING LIMIT

YARDING LIMIT	

Keyboard arrow keys: ***Use the screen cursor-positioning arrows to move the vertical line left to a point about 850 feet from the left end of the profile.***

Softkey Input: YARDING LIMIT

▪▪▪▪▪▪▪▪

Step 1-35

	SET SHORTER YARDING LIMIT	HARD COPY		DONE WITH PROFILE

Softkey input: DONE WITH PROFILE

▪▪▪▪▪▪▪▪

Step 1-36

WHICH CORRIDOR WOULD YOU LIKE TO ANALYZE (1-18) ? (PRESS RETURN WHEN DONE)

Keyboard input: RETURN

comment: The RETURN key is pressed without typing a number to signal the program that the planner has completed the setting design.

▪▪▪▪▪▪▪▪

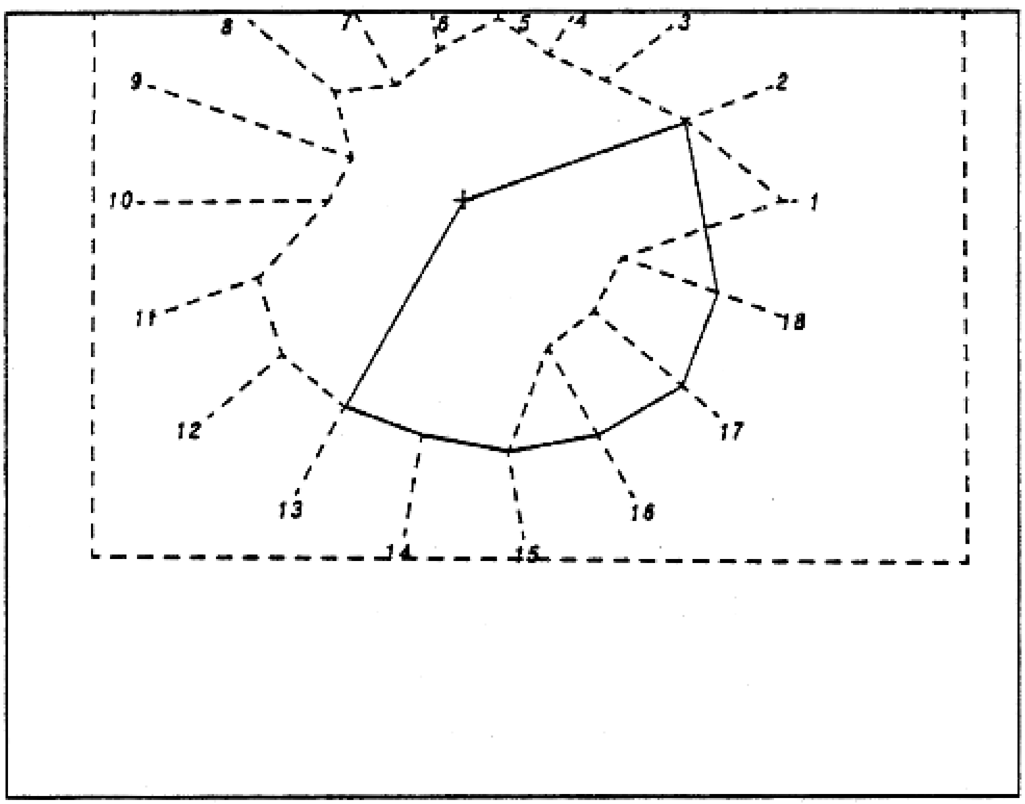
Step 1-37

MODIFY THE LENGTH OF ANY CORRIDOR	REMOVE CORRIDORS FROM THE SETTING	MARK THE UNIT ON THE BASE MAP	DESIGN A NEW HIGHLEAD UNIT

Softkey Input: MARK THE UNIT ON THE BASE MAP

....

Step 1-38



MARK AND DIGITIZE 2 REFERENCE POINTS WITHIN THE DASHED RECTANGLE

comment: The planner should mark two points on the map overlay that will be used to correctly align the plot of
the setting boundary.

Digitizer input: Center the cursor over each reference point and press any cursor key.

....

Step 1-39

LOAD PAPER IN THE PLOTTER--PAPER SIZE AT LEAST 9.7 BY 6.0--THEN PRESS RETURN

comment: The paper must be a minimum size of 9.7 by 6.0 inches. In this case, an 8-1/2- by 11-inch piece is acceptable.

....

▪▪▪▪▪▪▪▪

Step 1-40

ALIGN THE REFERENCE POINTS ON THE PLOT WITH THOSE YOU MARKED ON THE BASE MAP, THEN TRACE THE DESIGN ONTO THE BASE MAP. WHEN YOU ARE ALL DONE, PRESS ALL DONE.

I CAN'T FIND THE REFERENCE POINTS		ALL DONE

Softkey input: ALL DONE

comment:: The planner should remove the setting plot shown in figure 3 from the plotter and transfer the boundary to the map. A summary of the setting attributes (fig. 4) is printed on the printer.

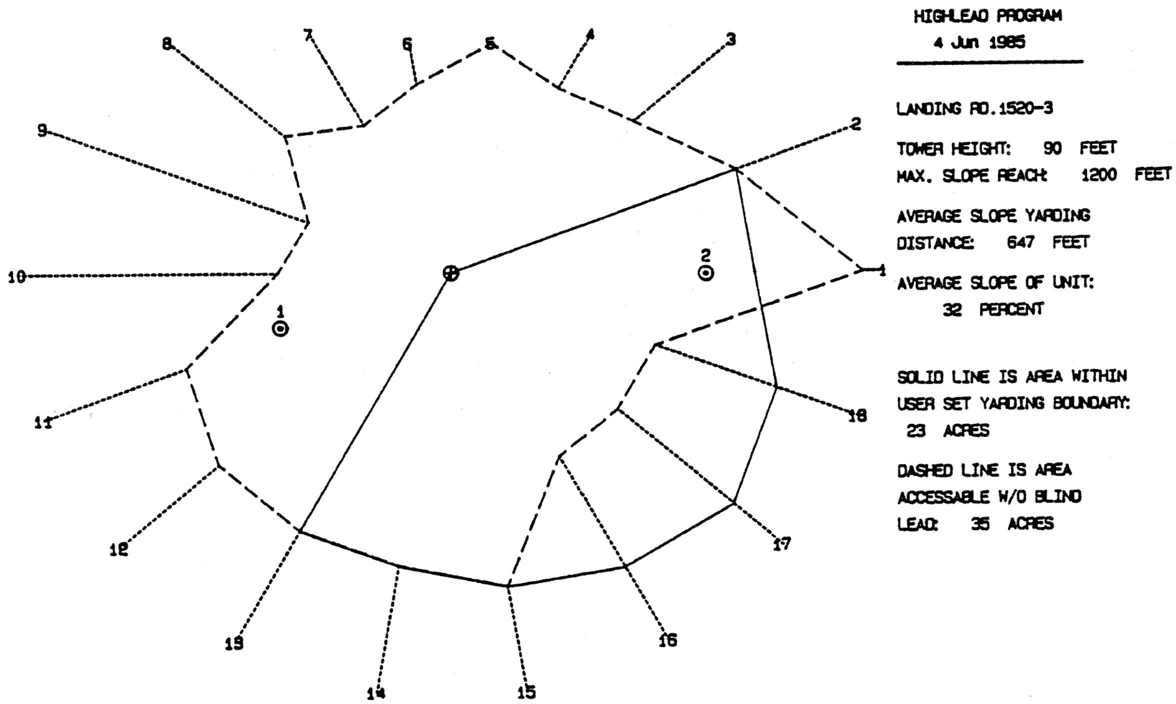


Figure 3— Plan view of the high lead setting.

```
LANDING: RD.1520-3

  TOWER HEIGHT:                              90 FEET
  MAX. SLOPE YARDING DIST:                 1200 FEET

  AVE. SLOPE YARDING DIST:                  647 FEET
  AVE. GROUND SLOPE:                         32 PERCENT

  HIGHLEAD UNIT AREA:                        23 ACRES
```

CORRIDOR NUMBER	TAILBLOCK HEIGHT (FEET)	HORIZONTAL YARDING LIMIT (FEET)	BLIND LEAD OCCURS AT (FEET)
1	2	840	----
2	2	840	----
3(DELETED)	--	----	----
4(DELETED)	--	----	----
5(DELETED)	--	----	----
6(DELETED)	--	----	----
7(DELETED)	--	----	----
8(DELETED)	--	----	----
9(DELETED)	--	----	----
10(DELETED)	--	----	----
11(DELETED)	--	----	----
12(DELETED)	--	----	----
13	2	840	----
14	2	840	----
15	2	900	----
16	2	960	600
17	20	1020	600
18	2	960	600

Figure 4— Highlead setting summary.

Step 1-41

MODIFY THE LENGTH OF ANY CORRIDOR	REMOVE CORRIDORS FROM THE SETTING	MARK THE UNIT ON THE BASE MAP	DESIGN A NEW HIGHLEAD UNIT

Softkey input: DESIGN A NEW HIGHLEAD UNIT

Step 1-42

DESIGN HIGHLEAD UNIT WITH THE SAME SYSTEM		DESIGN HIGHLEAD UNIT BUT CHANGE SYSTEM		GO TO A DIFFERENT PLANS PROGRAM

Softkey input: GO TO A DIFFERENT PLANS PROGRAM

Step 1-43

SELECT THE DESIRED PLANS PROGRAM

SKYMOBILE	SKYTOWER	HIGHLEAD	ROUTES	SLOPE	VISUAL	SIMYAR	NEXT MENU

comment: The planner can branch to any of the programs in the PLANS package by pressing the appropriate softkey.