Stand Level Setting Design

Biological Legacies in Clayoquot Sound

Dean Rae Berg and Peter Schiess

Back

Clayoquot Sound Symposium
Ahousat, Flores Island, British Columbia
***March* 6, 7, 8 1996**

Dean Rae Berg
Independent Forest Contractor-15806 60th Ave. W., Edmonds, WA 98026
Peter Schiess
Professor-Forest Engineering, University of Washington, Box 352100, Seattle, WA 98195-2100

Stand Level Setting Design for Biological Legacies in Clayoquot Sound

14 figures
20 tables

1. INTRODUCTION

1.1. Problem Statement

Conventional planning has been from the top down with target levels assigned from the harvest base using financial goals or past harvest level. Local managers are directed to determine the units to be cut and technicians often determine boundary, shape, access, and design of the cutting unit. In the past this process has been driven by volume rather than value. Cutting units are selected until targets are met, usually the easiest settings first. This reduces the number of units that are suitably reviewed for proper cable deflection, payloads, and local environmental and habitat impacts. Proper analysis requires spending time on long-term planning and analytical unit design based on technical, economic, and ecological considerations. These jobs are often assigned to the lowest job category qualified, typically competent technicians (Dyson 1990, Schiess et al. 1988).

Although value is at the center of long-term planning, few procedures use value as criteria for selection of harvest alternatives. This is a symptom of a discontinuity between strategic and tactical plans (Dimancescu 1992). Strategic plans are typically not at the site level and are often nullified by tactical plans because of improper use--even lack--of analytical tools and personnel (Dyson 1990, Schiess et al. 1988, Depta 1984).

Placement of harvest settings in the landscape must consider the condition of other stands in the vicinity besides the value of the timber being harvested (Franklin and Forman 1987). Ecological consideration is based on observed declines in habitats and species threats to water quality (CSE 1995, Swanson and Franklin 1992, Franklin 1992, Swanson and Berg 1991).

As research merges with operations our collective wisdom about forest harvest and management improves at a rapid rate; forest management in this context becomes powerful research (Walters 1986). Silviculture and harvesting technology are viewed as a critical elements in forest operations designed for ecological maintenance and habitat recovery (Berg and Schiess *in prep*, Cullen and Schiess 1992, Schiess et al 1988, Depta 1984, Ruth and Silen 1950, Toumey and Korstian 1934, Simpson 1900).

1.2. Forest Engineering Design

The primary function of forest management has historically been to plan for the growth and harvest of timber in a manner that ensured a continuous supply of wood products. There might have been some specific technical aspect of a rather difficult nature, however, the various components of a larger process were dealt with in an isolationists and linear fashion. Recently, forest management has grown to include the planning for sustained supply of multiple forest resources including such diverse resources as water quality, wildlife, recreation and visual landscapes (Naiman et al 1992, Alexander 1989).

There are spatial and temporal issues that further complicate the management planning process in addition to the diverse and often competing range of resources that must be managed. Forest managers are now faced with complex systems where they have to consider ecological/biological resources, physical, social/regulatory to technical resources (Franklin 1992, Oliver et al. 1992). In this transition to a holistic planning approach no adequate effort has been undertaken to critically review the design process, including the ecological and social domains (Dimancescu 1992).

Design in the engineering disciplines is a well established process. Engineering design as defined by the American Board Engineering and Technology (ABET), the organization that evaluates and accredits engineering curricula in the United States, is as follows:

> ***Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing, and evaluation***

Engineering design is not a single, isolated act or action, rather it is a process. In the context of natural resources the design process can also be extended to biological or ecological systems. Engineering design in this context outlines a process which includes ecological as well as the more traditional components of resource extraction as road design, setting or cut-block design.

The elements of engineering design, as well as ecological design, may consist of the following elements:

1. Recognition of need / problem definition
2. identification of goals and objectives, functional requirements and constraints (FR & C)
3. collection of information or defining the design parameters
4. conceptualization of design solutions
5. Evaluations
6. Communication of design/implementation

In the past, engineering design addressed only economic and technical aspects of setting or cut-block layout . This report introduces the concepts of silvicultural engineering as a design process that accomplishes retention of biological legacy and social values while safely and efficiently producing logs from the forest.

2. Cut-block and Structural Retention Design An Ecological Engineering Design Process

2.1. Recognition of need / problem definition

Rising wages in the 1970's in British Columbia encouraged a move to mechanized yarding operations to reduce costs. By the mid 1980's the machine of choice was grapple yarders that resulted in dense road network. Clear-cutting combined with the dense road network resulted in increased visual impact, reduced forest productivity and damaged aquatic ecosystems. Forest designers now considers the harvest from different view points.

Contemporary harvest planning in the Clayoquot Sound combined with the high timber values at stake demand detailed plans developed by specialists capable of combining engineering design principles (e.g., Skyline profile analysis after Cullen and Schiess 1992) and ecological design principles (e.g., Biological legacies after Franklin 1992 and Oliver et al. 1992).

In the context of Clayouquot Sound the recognition of need is best summarized in The Clayoquot Sound Land Use Decision - Background Report (April 1993)

> "Clayoquot Sound has been the focus of intense public debate about land use and resource development. The controversy has centered around the issues of forest wilderness, protection of ecosystems, visual aesthetics, tourism and large scale industrial forest operations."

Changing attitudes about the ecological values and knowledge about sustainable forestry are now impacting harvesting decisions and operations to a significant degree (Birch and Johnson 1992, Weigand and Burdett 1992). Social considerations, aesthetics, a new understanding of ecosystem functions all result in additional demands which alter the traditional hierarchy of logging and production variables (Keegan et al. 1995, Kimmins 1995).

2.2. Functional Requirements and Constraints

As a result of those intense, public debate the provincial government appointed the Scientific Panel for Sustainable Forest Practices in Clayoquot Sound (CSSP 1995). The panel (CSSP 1995) provided background information for this report and addresses the issues involved with sustainable forestry in Clayoquot Sound. They (CSSP 1995) recommend managing for biodiversity in the Clayoqout Sound. The primary themes of the panel's final report state:

- Maintain biological diversity inherent to old growth forests
- Create managed forests that retain near-natural levels of biological diversity, structural diversity, and ecological function;
- Maintain viable populations of all indigenous species
- Sustain the species, populations, and the processes associated with late successional forest stands and structures.
- Maintain the quality and productivity of aquatic environments;
- Protect regions important to the heritage of the ***Nuu-Chah-Nulth*** people

- Create settings that are aesthetically acceptable to recreationalists

These alternatives include retention of live dominant and codominant trees in both aggregates (patches) and dispersed as individual trees depending on the operational limits of these sites.

Harvest plans are in accordance with the British Columbia Forest Practices Code (MOF 1995), and the recommendations of the Clayoquot Sound Scientific Panel (CSSP, 1995) and emphasize the concept of retention of biological legacies—those structural elements from the primary forest (Old Growth) that potentially maintaining some forest function (e.g., habitat islands, undisturbed forest floor, early recovery to late seral forest structure).

According to the *Scientific Panel* (CSSP 1995) the variable-retention system provides permanent retention after the harvest of various forest "structures" or habitat elements (Perry 1994). Additionally, the forest structures are maintained and meet the following specific ecological objectives:

- to provide, immediately after harvest, habitat important to survival of organisms and processes that would otherwise be lost from the harvested area either temporarily or permanently.
- to maintain remnant structural features and organisms from previous stands for the health of future stands.
- to improve "connectivity" between cutting units and forest areas by facilitating the movement of organisms through cut areas.

The silvicultural system incorporates principles of ecological sustainabilty. First, there should be no net loss of ecosystem resilience and long-tern site productivity. The meandering aggregates are an example of connecting retention islands and allow for structural and genetic diversity. The reliance on aggregates facilitates the persistence of soil micro-organism community structure in those patches, such as micro arthropods and mycorhizae.

Second, it is important to retain the forest structure, function and composition. An example used here is the retention of no-work zones around large decadent cedar snags. These aggregates can be connected to existing forest and help continue the structural characteristics of the native forests. Retaining structure offers at least three important functions. Structure offers refuge to some organisms following harvest and innoculum for the surrounding new forest. Structure enriches the new forest allowing the early development of late-seral forest conditions. Retention within the harvest unit offers some connectivity across the cut-over area between uncut forest.

Finally, it is the persistence and endurance of structure that is important when maintaining forest functions. The pattern of retention can mimic the action of natural disturbance. Islands of full retention are present in these designs. These islands in combination with snag clumps (no-work zones) contain remnant structure that has an important role in ecological recovery and maintenance of biological legacies (Franklin et al 1996, Swanson and Berg 1990, Franklin 1989).

2.3. Design Elements

Design elements can be thought of as the physical, focial, ecological characteristics of an area (cut block) that, when continued represent the planned setting of cut block. Examples would be slope form, hydrography, stability zones, cultual characteristics of an area in question.

Collection of information can be grouped into various design parameters or elements under several, broad categories such as:

Biological design elements
Ecological design elements
Physical design elements
Technical design elements
Social/cultural design elements
Regulatory design elements

Examples of the various design elements and their considerations presented in the following sections.

2.3.1. Biological Design Elements

Growth and Yield - The retention of overstory trees does have an influence on the developing forest. This is most apparent in the regeneration of coastal conifers. These highly productivity forests range up to 6.4m^3/ha/year of growth (e.g., annual increment). All of the primary species are shade tolerant and will survive but as retention level increases, development toward projected targets is delayed (MOF 1994).

Stand inventory data are important elements in developing tree dimensions and related log weights information, data which is crucial in determining appropriate payload design data. appropriate payload determination will affect skyline deflection, yarder selection and landing locations.

Pests, Pathogens, and Disturbance - Fungal pathogens are persistent following harvest (Arnott et al. 1995). Root rot and mistletoe infections are of concern in terms of both the survival and quality of the new forest. Proper selection of residual trees can partially reduce the negative influences. Wind-throw is the dominant disturbance vector and creates a range of patch sizes from single tree gaps (ca. 1 -1.5 ha) to blowdown on slopes of hundreds of hectares (personal observation of the authors). Fire is and occasional event with surface and crown fires of moderate to high intensity. Return interval of high intensity fire is 3-5 centuries and affects areas of 50-500 ha. (Parminter 1992). There are numerous research efforts in the Clayoquot Region focusing on the role of biotic and abiotic disturbance that will be crucial to future silvicultural design.

2.3.2. Physical Design Elements

The geomorphic template of the landscape dictates many design decisions. The fluvial network of streams are the backbone of basin hydrology and are influenced by activity on the adjacent slopes. This is where the stability zones are identified based upon steepness of slopes, parent geology, and soils.

Soil disturbance - Compaction, scalping, and erosion of soil are all of critical concern in Clayoquot Sound because of the potential negative impact to site productivity and salmon spawning. Road building has been a major contributor of sediment while logging can trigger shallow seated slope failures as well (CSSP 1995, Collins et al 1995). Excessive soil compaction reduces site productivity.

Rain on Snow is of concern at mid-elevation settings and is partially addressed at the landscape level by limiting the rate of harvest. The cumulative effects of the peak run-off can be softened by retention of trees or patches of trees with healthy root systems (e.g., dominant and co-dominant canopy classes) within the managed forest matrix.

2.3.3. Technical Design Elements

Better deflection line analysis (e.g., full suspension feasibility) is necessary to cable logging planning in Clayoquot region setting design to reduce logging related slope failures. This includes feasibility of harvest systems that minimize the use of mid-slope roads. Elements include skyline system (live, standing or running), landing location, tower height, cable diameter, tail-hold anchors and height, and payload. Those elements in combination with the topography determine suspension capabilities and with it the silvicultural systems that may be utilized in a particular deflection zone.

2.3.4. Technical (Equipment) Design Elements - Process to Identify System

Topography and soils, and silvicultural system used, are in most cases the primary design elements that determine initial equipment selection. Initial equipment selection follows a hierarchy of variables or a decision matrix:

Topography/soil
(Physical Design elements)

Silvicultural system
(Ecological Design Elements)

Suspension requirement (full/partial)
based on management objectives
(e.g. soil/erosion)
(Technical Design Elements)

Timber characteristics
(log size/volume per area)
(Biological Design Elements)

Yarding distance/direction

(Technical Design Elements)

With current technology and the current regulatory environment in the Clayoquot Regions, ground-based equipment is typically excluded from slopes in excess of 30 to 40 percent slope. Silvicultural system (e.g., clear-cut, STR, selection) may further restrict use of certain systems. Stand characteristics (e.g., volume per log, volume per area) impact production and cost. There is an inverse relationship of harvest unit costs (dollars/m3 harvested) and log size or timber volume per area. A lower bound, or timber volume per area extracted is necessary for the system to be profitable. Profitability calculations can include other, indirect and non-monetary costs such as avoided soil damage, improved aesthetics, habitat restoration. For example current cable thinning operations in Washington and Oregon require about 90 to 120 m^3 per hectare removal minimum. Such volume requirements are a function of commodities values and can therefore change.

In areas of silvicultural retention, log control during the yarding cycle is of paramount importance, both in regards to residual tree damage, ground disturbance and yarding productivity. Unit design is driven by the retention plan. Full suspension zones allow for dispersed and variable density retention because of the flexibility in log control. Partial Suspension zones imply that patch cutting or wedges are the preferred retention pattern. Log control is effected by:

- Height of skyline above ground a function of payload and topography
- Lateral inhaul distances
- Ability to maneuver/reposition carriage during lateral inhaul
- Length of logs

Corridors that are not in the fall line of the slope (or perpendicular to the contours) result in cross-slope or sidehill yarding. Experience elsewhere has shown that under such situations log control becomes difficult for partially suspended logs during the inhaul. The trailing end of the log, dragging along the ground tends to swing towards the fall line, away and downhill from the skyline corridor. This action results in added ground disturbance, and in the case of partial cut regimes, results in wider corridors and higher damage to the residual stand. Differences of as little as three degrees between the fall line and corridor orientation caused the trailing end of the log to swing downhill resulting in increased ground disturbance and residual tree damage. In such situation full suspension may be required in order to keep corridor width, ground disturbance and residual tree damage within acceptable levels.

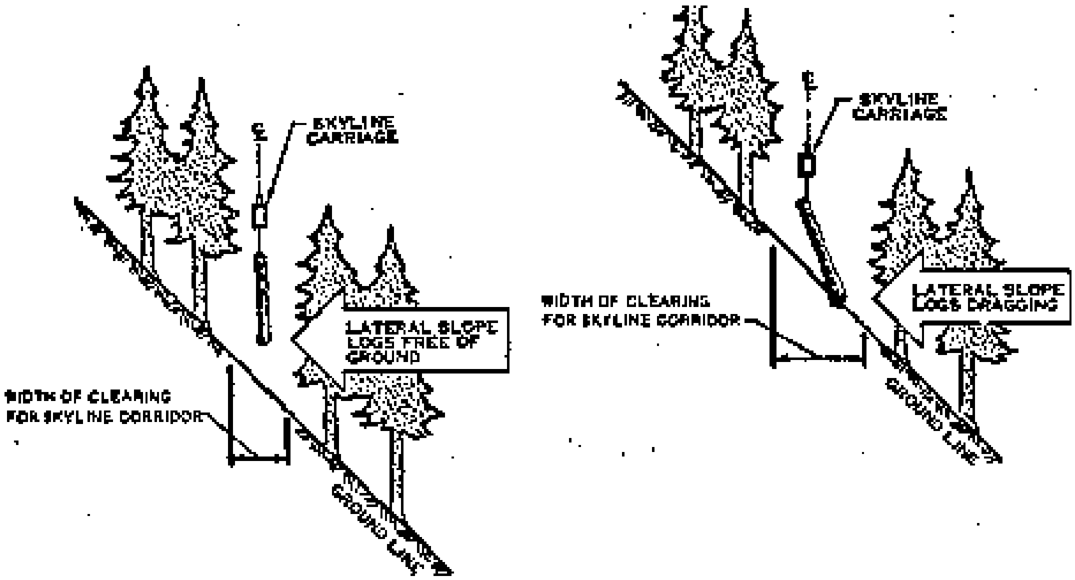


Figure 1. Corridor width as a function of log suspension. Dragging (or partially suspended logs are difficult to control, particular in downhill yarding situation resulting in wider corridors and increased operational delays. (Studier and Binkley, 1976)

Current experience with lateral inhaul of large logs in residual stands is limited. Experience from some trials in the US and Central Europe indicate the following. The ideal carriage position during the lateral inhaul cycle must be high, ideally more than 20 meters above ground. Such a position provides an appropriate upward lift to break the log loose from its bed with minimal resistance (or minimal resistance) from dragging. Repositioning the carriage during this yarding cycle is important for improving lateral movement and reducing damage to residual trees or regeneration.

During lateral inhaul two situations can occur at the end of this cycle which may be the result of carriage height, log length and lateral inhaul angle (the angle between skyline corridor and orientation of lateral inhaul corridor). 1. Log turns are completely within the main corridor, either fully suspended or the dragging end within the corridor limits; when the inhaul cycle starts, the log turn moves without further swinging. 2. Log turns do not clear the corridor limits at the end of the lateral inhaul (some potion of the logs are still within the forest stand at some angle to the corridor direction). When the inhaul cycle starts the turn may pivot around residual trees resulting in damage and potential hangups

For high carriage positions the lead angle of the lateral inhaul can be perpendicular to the skyline. The lower the skyline the sharper the lead of the log has to be in order to keep operation and residual tree damage to acceptable levels.

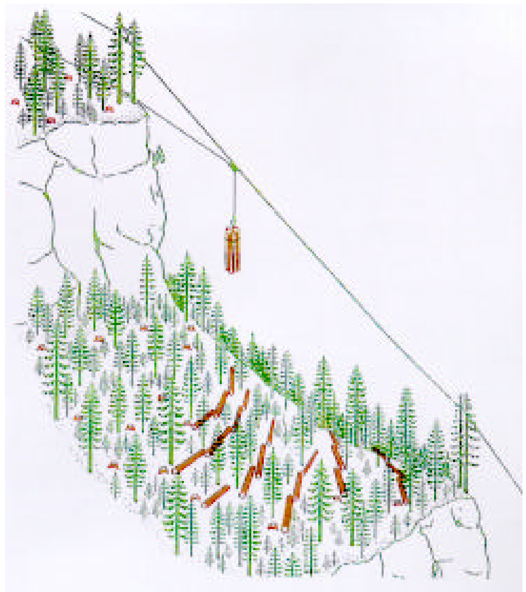


Figure 2. Falling pattern and log arrangement in residual timber stands and high skyline location to assist with lateral yarding into the corridor.

Falling patterns obviously are important for the lateral yarding cycle. In retention systems, various falling patterns have been developed from herring bone patterns to falling parallel to the contours. Herring bone patterns (or chevron pattern) require precise location of skyline corridors since they form the spine of the pattern. Because of the importance of the corridor location in relation to the felled trees fallers have to be informed of the corridor locations. The disadvantage of this approach is the limited flexibility of changing corridor locations once falling has started. Another is the increased lateral yarding distance for sharp lead angles which can be more than the corridor spacing. Falling progress, pattern and corridor location represent a linked system. Its advantages are easier movements of logs into the main corridor.

Where corridor locations cannot be marked prior to the begin of falling activities, or where corridor locations may change after falling activities have started falling timber parallel to contours should be the preferred options. Falling pattern and corridor locations are independent, allowing for more operational flexibility. Log length, skyline height in the corridor and ability to reposition carriage during the lateral inhaul become important parameters in such situations. Log lengths of 8 - 10 metres have proven to be acceptable in Central Europe under uneven-aged silvicultural systems in combination with standing skyline systems.

2.3.4. Social/Cultural Design Elements

Social design elements may include visual elements such as viewsheds from certain areas, visited by tourists or recreationists. Depending on flexibility from other design elements stand edges can be feathered to reduce stark contrast from cut areas to retained forest stands. If properly used, a high degree of coincidence with other design elements is possible such as stream buffer requirements or cable suspension requirements.

Cultural elements may include culturally modified trees (CMT). Those elements conceivably can be combined with other design elements such as riparian areas or safety zones.

2.3.5. Regulatory Design Elements

Regulatory design elements may either deal with water quality/protection issues (MOF 1993) or worker safety issues. For example the no-work zones around snags can be used in conjunction with providing additional ecological retention zones to minimize open areas in combination with technical requirements based on cable deflection requirements

The area reserved for a snag in a no-work zone is significant. A 50 metre snag will require approximately a square hectare (0.78 ha; 75 metre snag, 1.7 ha), based on regulations requiring the radius of a no-work zone equal to one and a half times the height of the snag.

A key to the harvest systems and numerous silvicultural options is the awareness of safety. The use of parallel contour patches, protects workers in steep terrain from falling and rolling debris by creating physical barriers.

3 FLOW OF PLANNING

The design process centers first on identifying the spatially fixed design elements. Most of the design elements discussed in the previous section have spatially constraining features. Examples are zones of slope instabilities. The design engineers has no flexibility in moving the location of such zones in response to other design considerations such as allowing partial retention in this particular area (a technical/equipment design element) which may result in locally high ground disturbances triggering slope failures.

3.1. Spatially fixed design elements

- physical design elements (slope stability, erosion, topography)
- biological design elements (stand data/timber data)
- cultural design elements (historic sites and uses, CMT)
- regulatory design elements (stream buffer requirements)
- ecological design elements (wetlands, wildlife trees)

The physical design elements result in a characterization of the planning areas based on topography and slope stability. Based on steepness (30 % slope) an initial determination is made as to cable system or ground system zones. The resulting map identifies areas which require cable system and payload analysis and areas where ground systems could be used.

Next, based on soil and geology, sensitive zones are identified with marginal slope stability. The marginal stability zones would have a minimum retention of 50 to 60 percent in a dispersed fashion as opposed to aggregated retention to fully utilize the root system as a stabilizing element in the soils. Regulatory requirements identify the various retention zones along streams

3.2. Spatially flexible design elements

In the next step, spatially flexible design elements are identified and mapped:

- technical design elements (equipment selection, deflection zones, full/partial)
- visual design elements (aesthetics)
- silvicultural design elements (retention patterns)
- regulatory (snag retention-no-work zones)

Typically this may start with identification of important snags/wildlife trees which may require no-work zones. Based on the particular location and impact on other design elements (such as skyline corridor) they can be eliminated, provided, of course that adequate numbers of such biological legacies exist elsewhere in the planning unit.

Next yarding opportunities are identified based on cable suspension. Zones of full suspension offer the most opportunities for silvicultural design such as high levels of retention in a uniformly dispersed pattern. Zones of partial suspension are more restrictive in that aggregated retention or low level of retention are more appropriate.

It is in these overlapping zones where the engineer and ecologist can now enter into a meaningful dialogue which ultimately will result in a superior design that satisfies both engineering principles as well as ecological and other principles. It is now possible for the engineer to indicate to the ecologist that in the areas of partial cable suspension there are some technical limitations to certain silvicultural prescriptions. For example, in areas of partial suspensions, patch cuts are the preferred system form the engineer's point of view. It allows for better system operations (less potential for hangups). Other forms of retention might still be possible but could result in a sub-optimal design. In areas of full cable suspension, there is more flexibility in regards to dispersed retention. If the ecologist has some severe concerns, then a different landing location or cable system might be used to address them.

Conflicting designs become apparent such as partial suspension across a highly sensitive and unstable portion of the planning area. The remedy is changing the technical specification such that full suspension is achieved, or considering moving the identified area into full retention especially if other design elements conflict with partial suspension requirements. Aggregate areas are located strategically to create wildlife passages through the areas of harvest, as well as, to maximize efficiency in yarding. No single harvest area will be greater than 4 hectares and in critical corridors more trees will be retained. In areas of full yarding suspension, more trees can be left with less concern about breakage or damage to standing and harvested trees. The areas of relatively higher visual impact have a higher retention than the areas of less visibility.

Design solutions are then tested against visual design requirements and economic feasibility and costs. Aerial views of the proposed residual stand structure are used for design discussion. Prescribing logging systems with STR involves two principal costs: Foregone or deferred timber revenue and decrease in unit revenues because of increased unit harvesting costs ($/Mbf). Presently, there are replicated experimental efforts in the PNW that will someday yield limited significant results (e.g., DEMO, ; MASS, Arnott et al. 1995; Coates). Meanwhile, resources are at risk while we guess about design considerations.

The design process results in the spatial arrangement and interaction of the design elements. These are the zones of ecological engineering opportunities. It is here that the forest engineer and the ecologist can interact to produce designs that satisfy ecological and engineering design principles for the cut-block in question.

3.3. Design Tools - Biological, Physical and Regulatory Analysis

The starting point is to develop and display relevant information such as topography, slope stability zones, timber stand characteristics and stream inventories. As part of the design process a number of tools are utilized. Most of the initial information is stored in a GIS data base which serves as a central data manager. It allows for the display, manipulation and overlay of various information. This approach is used to create the various design zones based on spatially fixed design elements and spatially flexible design elements.

Output is usually in map format that show streams with regulatory buffer requirements, slope stability zones, timber type maps, visibility zones and other relevant ecological and/or cultural concerns. Most of this information is created within the GIS software tool either through analysis and overlay or creating the information by importing it into the database through digitizing or other means.

3.3.1. Technical Analysis

3.3.1.1. Payload Estimation

Next, stand data are used to determine payloads based on log dimensions and number of logs in the stand (Appendix 1). It is critical for the design to determine a reasonable design payload, based on the timber resource, used to prescribe proper equipment. (e.g., DBH of 60% of the diameter distribution). Decisions may include:

1. Cut sub-optimal log length
2. Limit yarding of difficult, low value, legacy trees
3. Process large logs prior to yarding to meet payload constraints

The appropriate design payload may be selected relative to the estimated mean payload weight. This decision involves a balance between an over designed system for a small volume of large logs or an under-designed system incapable of removing valuable timber.

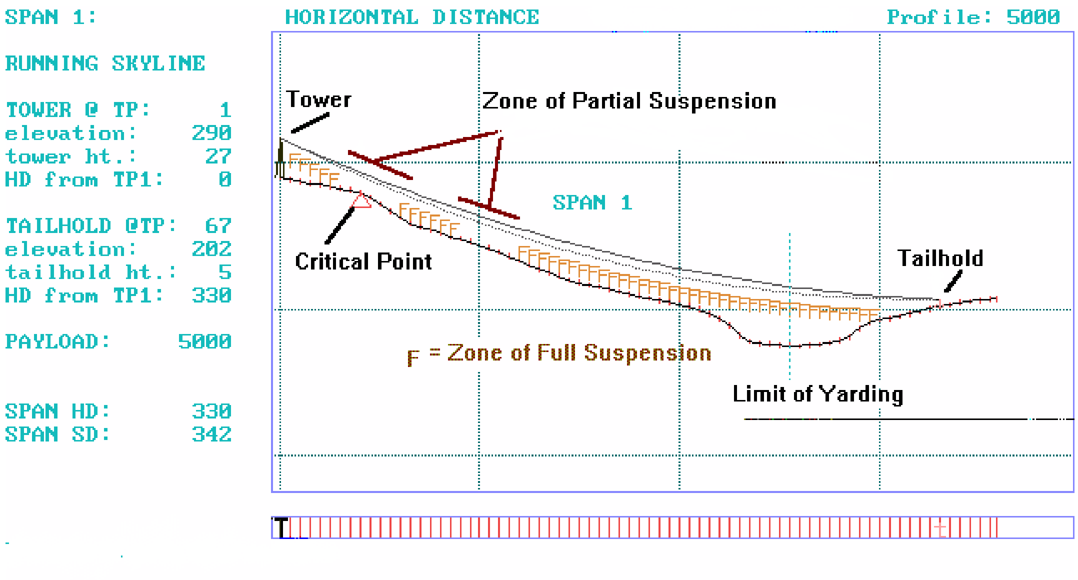
FORSEE (USDA Forest Service) estimates payloads from stand data and requires form class, form class height, bucking rules, tree species densities, and utilization parameters. Scribner-Westside volume rule is used; FORSEE estimates the number, size, volume, and weight of logs per tree for a pre-determined payload, as well as a limited design payload. Payload estimates from FORSEE are used as input to HELIPACE (helicopter yarding) and PLANS (Skyline yarding).

3.3.1.2. Logging Systems Analysis

The technical design utilizes PLANS, a cable analysis software based on digital elevation models (DEM) (Twito et al. 1987). PLANS is a set of computer programs that allows the design engineer to analyze large areas. PLANS uses a digital elevation model (DEM) to provide topographic data needed for harvest unit design and transportation system development. PLANS can quickly extract ground profiles, slope and aspect information., and general land form characteristics during the development of a harvest plan. The interface to the DEM employs an on-screen contour map generated from the DEM data

Skyline corridors are evaluated along with various other data, such as the yarder specifications (tower and tail-hold height, cable diameters), and type of system (i.e. running, standing, or live skyline systems). Each yarding corridors is now examined to see that log suspension is achievable for the design payload (Figure 3). In case full or partial suspension is lacking, other yarder and tail-hold locations are investigated until they resolve the problem. Technical design solutions from PLANS are then exported into the GIS data base for overlay with other design considerations such as wildlife retention trees (no-work zones). to evaluate the constraints of stream buffers, no-work zones, and various silvicultural prescriptions.

Figure 3 Profile of a single deflection line from the PLANS program. The verticle green line is the established limit of yarding. The blue triangle denotes the critical point--that point at which the logs are not able to fly clear of the surface. The descriptions of the setup are given, here in metric units.



3.3.1.3. Visual Analysis

Visual impacts of the harvest system are displayed at both stand level (1-5 hectares) and watershed level (5000-50,000 ha;CSSP 1995) . The two steep sites (Deer bay and Rolling Stone) are in areas with visual quality concerns. Scenes from UTOOLS of proposed designs are from multiple view points and may be determined by demand. Aerial views of the proposed residual stand structure are used for design discussion. UTOOLS illustrates stand characteristics for the overall harvest while SVS shows specific stand-level harvest ideas.

Stand Visualization System SVS is a visual stand simulation program developed by Robert Magauhey USDA Forest Service Region 6 that provides visual representation of specific stand characteristics. SVS produces an image of the stand showing 1-4 hectares. Representation of specific stand characteristics and harvest ideas provides, for the harvest planner, a powerful communication tool. SVS is used in this report to illustrate harvest patterns, no-work zones, cable corridors, riparian management zones, and specific retention patterns (Figure 4a,b,c,d). One can manipulate the level and pattern distribution of retention, crown width and ratio, and species distribution. SVS can place a single tree in a specific location, useful for representing Culturally Modified Trees and no-work zones. Cable corridors were simulated in SVS with widths of five and ten meters. If cable heights are not above or below crown height, partial trimming of branches could be done.

SVS represents tabular and graphical summaries of stand information and produces overhead, profile and perspective angles. Information presented is before and after visual effects, crown cover, and stand density using graphic using images depicting stand conditions. Input is from a stand table calculated from cruise data. This information consists of tree DBH, height, crown ratio, crown radius, status (live or dead), plant class, crown class and number of similar trees. Tabular representations of stand characteristics may also be obtained through the use of SVS. Before and after harvest conditions regarding DBH, species, height and crown cover can tabulated in the form of histograms (Figure 5 a,b,c).

Figure 4 (a,b,c,d) Examples of the output from SVS. Clump retention around a hazard tree or snag (a) based on the criteria for a "No-Work" zone. Outer edges beyond the regulatory boundary could be feathered to improve the visual quality.

Corridors cut through aggregated retention can be represented visually (b) and offered to cutters for a target structure to be achieved. The stand can then be presented (c) based on the decision to limit yarding corridor width to 5 metres.

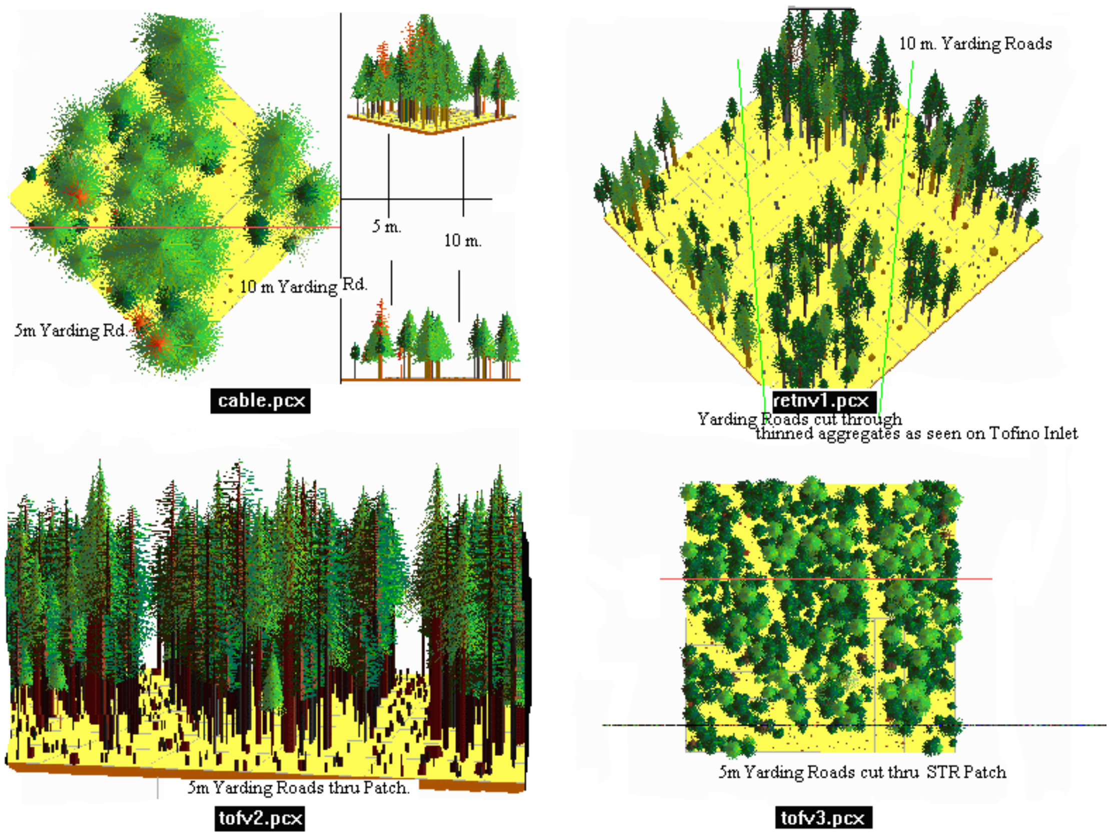


Figure 5 (a,b,c). Tabular out put from SVS about stand conditions. Post harvest stand structure based on species (a), diameter (b), and height (c) distributions.

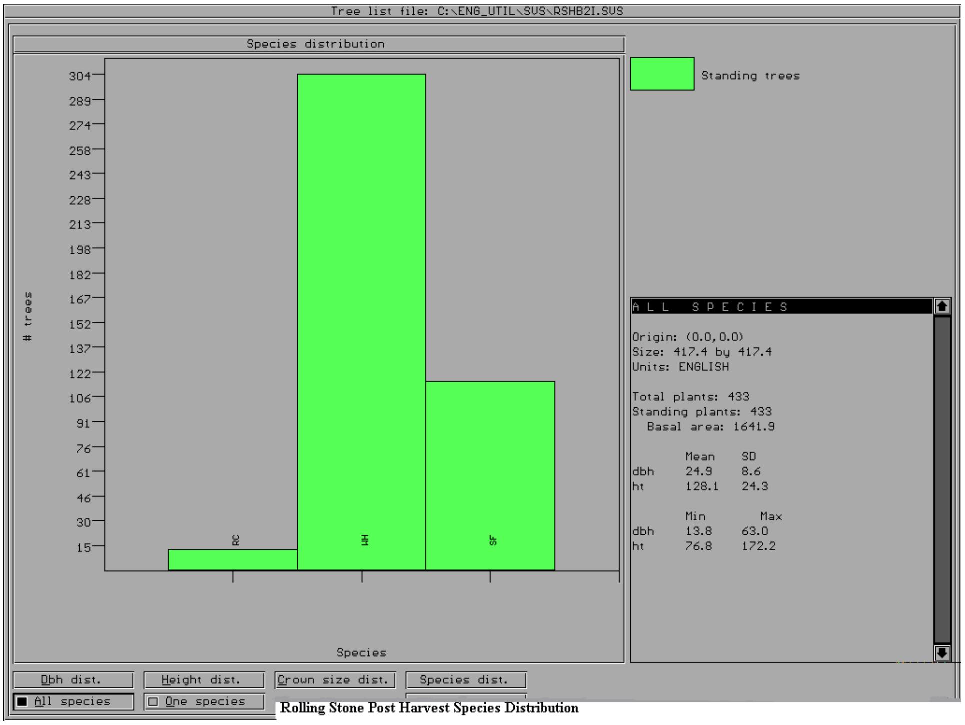


Figure 5a

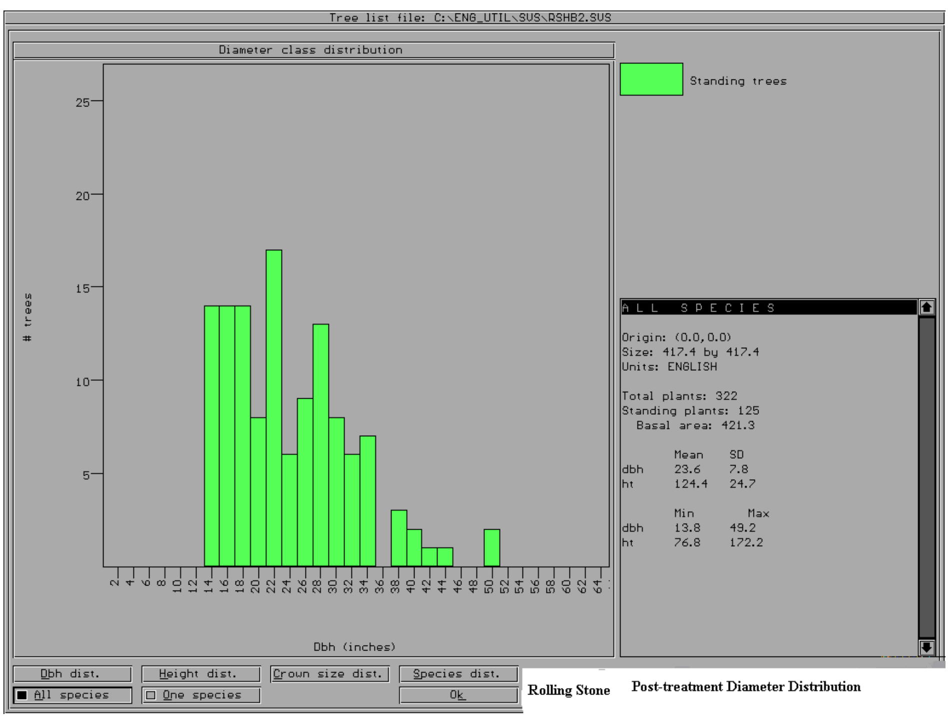


Figure 5b

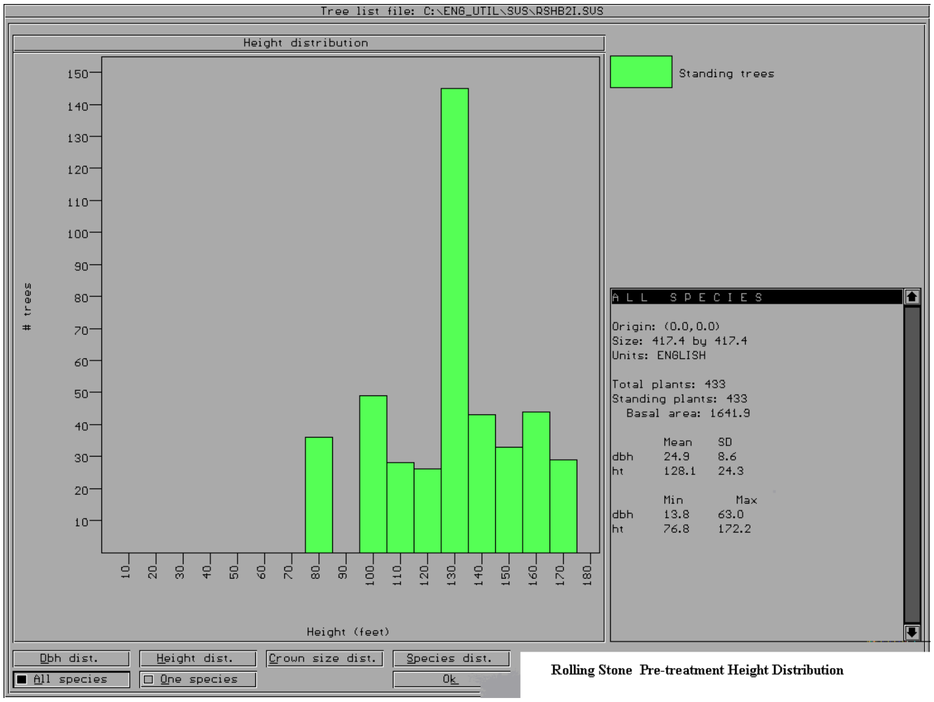

Tree list file: C:\ENG_UTIL\SUS\RSHB2I.SUS
Height distribution
Standing trees
trees
Height (feet)
ALL SPECIES
Origin: (0.0,0.0)
Size: 417.4 by 417.4
Units: ENGLISH
Total plants: 433
Standing plants: 433
Basal area: 1641.9
Mean SD
dbh 24.9 8.6
ht 128.1 24.3
Min Max
dbh 13.8 63.0
ht 76.8 172.2
Dbh dist.
Height dist.
Crown size dist.
Species dist.
All species
One species
Ok
Rolling Stone Pre-treatment Height Distribution

Figure 5c

UTOOLS is geographic analysis software developed by Robert Magauhey USDA Forest Service Region 6 that provides a flexible visualization framework for spatial analyses to address proposed harvesting plan. UTOOLS uses spatial data from Borland Paradox databases (overlay operations involve combinations of map layers and attributes done with Paradox queries). UTOOLS displays important data residing in the database (e.g., vegetation polygon numbers, stream and road identifiers and slope / aspect numbers corresponding to the elevations). Data is from either GIS (e.g.,Arc/Info) or PLANS in the form of a MOSS file converted into raster format. All database operations are executed in the database program (e.g., Borland PARADOX). The results of the UTOOLS analysis shows the unit before and after the harvest plan is cut.

Raster maps can be accessed in the UMAP program. Digital Eerrain Models DEMs from GIS (Arc/Info) are imported to UTOOLS and stored in the elevation section of the database. DEMs are manipulated and reconfigured with any user defined pixel size for use in UVIEW that displays landscape views. Another database is created for displaying the structure of a tree stand. The database relates stand data (DBH, H, TPA, etc.) and the vegetation polygons. With the two databases and the reconfigured DTM, UVIEW allows the user freedom to create any view desired from any angle, elevation or distance.

UTOOLS provides the audience with a visual story of the unit. The overall goal provides a before harvest look at the unit landscape in a view that displays much of the surrounding area and the unit. Once the existing visual quality of the area is established, images showing yarding corridors, clear-cuts and silvicultural retention zones are constructed from critical vantage points These vantage points are determined by the public views of interest of the harvested area. Areas of high visibility from ground level are considered critical viewpoints. Other views were constructed to offer visualization of forest practices that could be initiated upon the unit. UTOOLS is listed below:

1. Project data assembled
   - I) Exporting map layer from the local GIS
   - II) Exporting attribute data

2. The GIS map layers are gridded and converted to a Paradox spatial database with the program UCELL5. Spatial databases contained a record for each pixel or grid cell on the ground, and a field for each map layer. The pixel cell size was 10 meter.

3. Attribute data that describe GIS polygons (e.g. canopy closure, species, stand structure, etc.) are imported to Paradox and added to the spatial database using relational queries.

4. Elevation data was added to the spatial database by processing the USGS digital elevation data with the programs IMPRIDEM and ADDELEV.

5. A terrain model, required by UVIEW for 3D viewing, is built by running the program EXTELVE.

6. UCELL5 program was used to added map layers to the spatial database, like slope , streams and roads.

7. UVIEW gives a realistic 3D landscape images with vegetation. These map images were saved to PCX files and output to a printer.

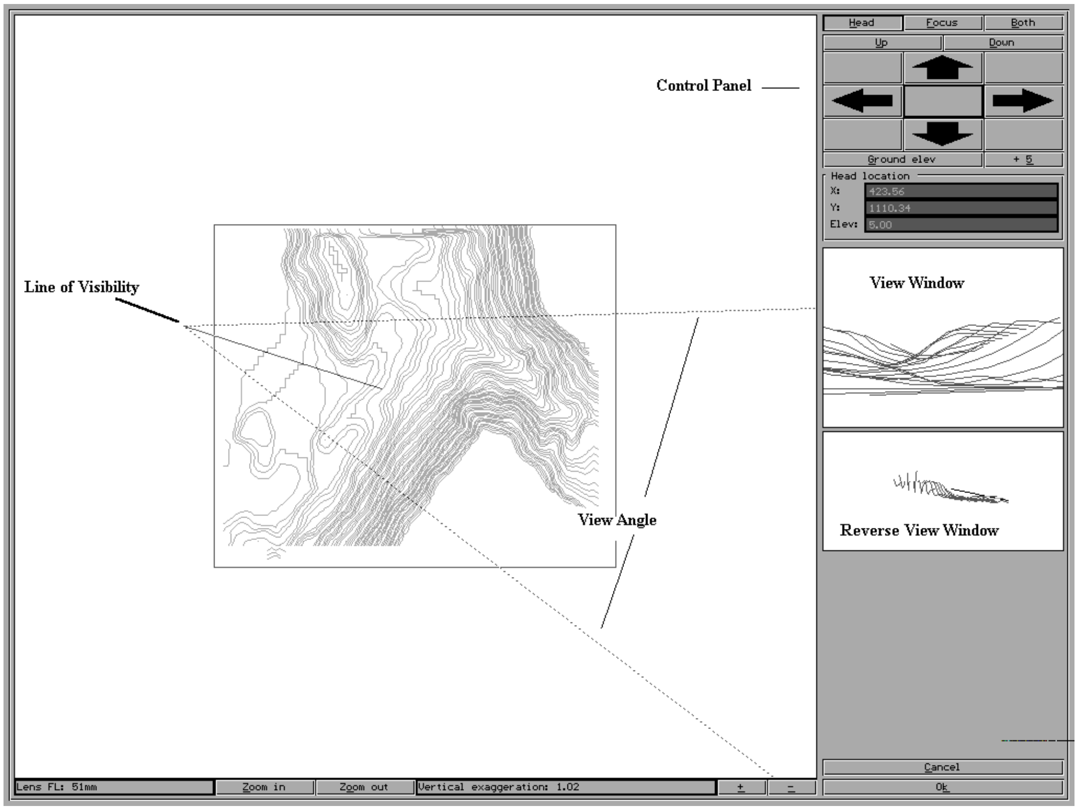
3.3.1.4. Visual Impact

The line of visibility is the imaginary line that dictates if the unit can be seen from a person standing at sea-level or higher (5m). For example, a person positioned within the Line of Visibility and on the shoreline would be unable to see the unit because of the trees that will block their view. The further one travels from the line of visibility the greater the possibility to see the unit. The unit boundary was not denoted on the images because each image is focused on the unit. The plan view printouts show the unit boundary and location of the Lines of Visibility (Figure 6). Images display windows on the side for:

1) A 3-D representation of the view
2) The line of sight delineated, pointing at the hillside.

Each image provides information on the name of the retention plan and view elevation. Additional information on descriptions of the retention strategies are presented in the Silvicultural section of the report.

Figure 6. The output for Utools is controlled by the view points and can incorporate the critical lines of visibility.



3.4. Economics

The economic analysis is based on information from FERIC reports (Forrester 1995, Sauder and Nagy 1977) as determined by the yarder type and system (Appendix 2). Baseline information comes from corridor area (taking into account the feathering pattern of the lateral yarding).

3.5. General Time Tables

Several harvest plans were developed using computer programs that determine technical feasibility (e.g., amount of suspension, length or corridors, location of corridors). For feasible plans, silvicultural prescriptions, production estimates, and aesthetic quality evaluations were produced. A final plan was chosen and developed more fully in the areas of aesthetic quality, economic feasibility, silvicultural feasibility, and ease of operation.

Week 1 Review Available Information
- Forest Practice Regulations
- Clayoquot Sound Scientific Panel recommendations
- Maps Provided
  - Familiarization with Software Tools
  - PLANS,UTOOLS, SVS, FORSEE/HELIPACE
  - Produce Arc/Info Map overlaying coverages impacting design
  - Create Stand Table
  - Information Search for Production/Costs associated with Harvest Methods
- FERIC Reports
- Forest Service Engineering Notes

Week 2 Preliminary Harvest Planning
- Software Analysis
- Production/Costs for Initial Plan
  - Develop Harvest and Production/Cost Estimates
  - Develop Alternative Yarding Systems (including Production/Costs)
  - Report on Proposed Alternatives

Week 3 Finalize Design
  - Report of Final Design

Week 4 Products
  - Harvest System Details
  - Payload Analysis & Production/Costs
  - PLANS Harvest Diagrams
  - SVS Plots & Stand Tables
  - UTOOLS Displays
  - Arc/Info Harvest Design Maps
  - Incorporate Products into Final Report

4. INVENTORY

4.1. Harvest Unit Description

Physical Characteristics The sites are described based on synoptic survey of the site and landform inventory as supplied by the committee. We judge the validity based on recent aerial photography of the sites. The digital elvation model is the base map for planning. Streams classification follows the CSSP and Forest Code.

Stand Summary (Appendix 1) contains basic tree data from the cruise data and derived quantities. Stand Visual Simulator (SVS) creates stand tables that depict stand structure. Claymore Consulting determined a basic stand summary. Software (HELIPACE, FORSEE, and SVS) is used for analysis for production estimates. The stocking information provides calculated quantities such as Total Weight (gross), Avg. Volume/tree, and Avg. Weight/tree ; Avg green densities (fir = 637 kg/m^3, hemlock = 782 kg/m^3, cedar = 533 kg/m^3 (Nielson et al. 1985), used for of payload estimation (piece size and piece distribution on ground).

4.2. Log Size Distribution

Log count for a given weight can also be thought of as a population curve similar to an inverse exponential curve. The distribution of the population is found by averaging the log weights produced in FORSEE. For random selection of logs, a random number generator is used in place of probability. Equation 1 can used to estimate a single log weight.

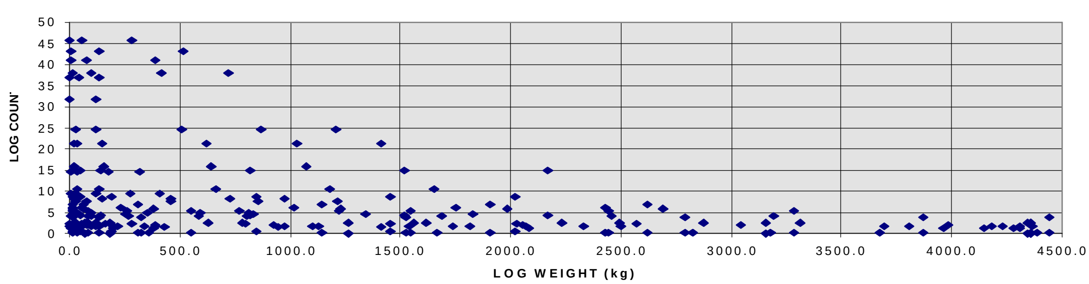


Figure 7. The estimated Log Weight = Mean Log Weight x 1n(I-Probability) (1) of a 10 metre log distribution for Tofino Inlet inventory.

Weight Distribution Informatio n The number of logs selected from the random log estimator corresponds with the number of chokers. The total weight of the number of randomly selected logs estimates a single payload weight. An example of this process is illustrated in Table 2**.** This mean payload weight can be compared to Figure 6 to verify the design payload for the stand.

Table 2. Tofino Inlet design payload for 10 metre logs (in kilograms).

FORSEE LOG TABLE		LOG BREAKDOWN		FOUR CHOKERS			THREE CHOKERS		
IND. LOG WT.	LOG COUNT								
1.7	1.9	**MEAN LOG WEIGHT**	**1138**	**MEAN**	**4489**	**PAYLOAD**	**MEAN**	**3391**	**PAYLOAD**
136.4	1.9	Standard Error	187	**STDEV**	2226		**STDEV.**	1939	
39.6	1.9	Median	483	**STDERROR**	74		**STD ERROR**	65	
1.7	37	Standard Deviation	1345						
136.4	37								
39.6	37								
3.4	2.3			3795			1700		
285.1	2.3			361			3347		
57.2	2.3			697			460	5506	
3.4	45.6			1751	6605				
285.1	45.6						139		
57.2	45.6			1485			1033		
4.9	2.1			149			3740	4912	
389.7	2.1			2130					
78.3	2.1			367	4130		105		
4.9	41						690		
389.7	41			660			531	1326	
78.3	41			4180					
47.5	0.4			1354			981		
2017.4	0.4			2897	9092		871		
1453.1	0.4						994	2846	
845.1	0.4			1059					
189.0	0.4			2335			177		
17.0	0.4			1699			634		
47.5	8.7			1702	6795		51	861	
2017.4	8.7								
1453.1	8.7			1334			7		
845.1	8.7			390			1474		
189.0	8.7			1330			1963	3444	
17.0	8.7			273	3327				

The table has several parts. The left hand column is the distribution of log weights estimated from the inventory and using FORSEE to project a distribution. The Second column indicates the reliabiltiy of the weight estimation. The last columns are for payloads using either three or four chokers off of a skyline. The sets of four numbers are random samples from the distribution derived in the first column. This is an indication of
expected turns sixe compared to design payload. A target of 60% of the cummulative log weight distribution assures that the yarder will be at close to capacity most of the time.

The following is a description of the quantities used for payload definition.

NET VOL - Net volume was taken directly from the stand data for hemlock and balsam but was taken as 70 % of the gross volume for cedar. This was done considering the likelihood of more defect being yarded in than was listed for net volume of cedar in the cruise.

VOL/TREE - This is the net volume divided by the number of merchantable trees/acre. This is the net volume of the tree after being topped and bucked in the field.

WGT/TREE - This is the net volume/tree multiplied by the density of the particular species using the same values as in section 2.2. This is the net weight of the tree after being topped and bucked in the field.

CUM % OF WGT/TREE - This value was found by taking the percentage of the total stand volume within a species - DBH class and tracking it as a cumulative sum. Prior to calculating this value, the data was ranked from the smallest weight/tree to the largest weight/tree.

MAX & MIN WGT/TREE - Simply the maximum and minimum values in the distribution of wgt/tree.

MAX & MIN LOG WGT - These values were found by taking the max and min values of wgt/tree and dividing by the number of logs/tree. The number of logs per tree was given as 2.78 and did not differentiate between the two stand types.

AVG VOL/TREE - Found by taking the total net volume of all trees and dividing by the merchantable trees/hectare.

AVG VOL/LOG - Found by taking the avg vol/tree and dividing by 2.78, the number of logs/tree.

PERCENT (%) OF VOL by Species (CEDAR, HEMLOCK, AND BALSAM) - These values are the amount of volume within a species as a percentage of the total volume.

AVG WGT/LOG - This average is a weighted average and is weighted for each species by taking the percentage of the total volume, multiplying this by the average vol/log, and then by multiplying the value for the species density. The sum of this value for all species is then the avg wgt/log.

A decision was made to select the appropriate design payload relative to the estimated mean payload weight. This decision involves a balance between an over-designed system for a small volume of large logs or an under-designed system incapable of removing valuable timber.

4.3. Log Values

Log value was determined by using data provided by Claymore Consulting. Their estimates of the volume/hectare within a log grade were used and determined for the entire area. These numbers were adjusted from total volumes given by the Claymore data based on the area prescribed for retention in the plans. Log volume was used to estimate wood value using Log Lines, Jan 96, Puget Sound Region prices (Arbor-Pacific 1996), converted to Canadian dollars($1.32 US to $1.00 Canadian)).

Cedar logs were given the value of camprun for # 1 Premium logs and # 1 Lumber. Utility and pulp logs were valued as whitewoods. Both balsam and hemlock were valued the same, as whitewoods, #1 Premium logs at $153/m3 and # 1 Lumber logs at $139/m3. Utility log grades and chipper logs were considered chip & saw logs or pulp.

4.4. Economics

Production Estimation

The density of each tree species for the unit is known from the cruise information and from this the volume of timber in each corridor has been calculated. The value of each species is known (Arbor-Pacific 1996) and the gross timber value per corridor can be calculated. A flat rate reduction (percent) based on the level of retention was used to calculate the net value of that timber. There was a general cost associated with ownership ($91.35 / hour).

Yarding time

Production estimates developed from the data in FERIC reports TR-112 (Forrester 1995), TR-19 (Sauder and Nagy 1977), and Howard and Coultish (1993). The estimation of corridor length and width from the PLANS provides the area in square meters is and added to the lateral yarding area (calculated in the same fashion). The volume per species per corridor was then calculated from the area and the known density of trees per unit area. The number of turns was calculated by dividing the total volume per corridor by the turn weight. The yarding time per turn was extrapolated from the literature. Total time to harvest the corridors finally related to cost.

Additional time was associated with the rigging of tailspars, yarder down time, pre-rigging, and loading & bucking. The time related to tailspar rigging was from Forrester (1995), adjusted to fit our situation, was a function of both the height of the tailspar and the number tailspars. This, combined with the yarding time as described above, provided the yarding subtotal.

Yarder down time incorporates the time necessary to rig all the components to yard the next corridor, related to the number of guylines required on the particular yarder. To minimize the yarder down time, it was decided to have two men pre-rig the next corridor to be yarded when the change time is predicted to be long. Two men could pre-rig two corridors per 8 hour shift. Loading & bucking time is based on the volume of timber to be harvested.

Machine specifications provided are those typically used by the equipment. Additional operational costs include the cost of timber left behind but also increased operating costs associated with the harvest system required. On the other hand there the avoided cost of restoration (e.g., stream/fish damage, hillsope failure), however intangible at this time, allows for active operations at some level of production.

Total productive machine hours for each setting was determined from summing the road change times and the yarding cycle times.

Mechanical Delay Hours (MDH) for the systems in the FERIC report ranged from 7-11 % of the SMH, depending on which system was used. This figure was rounded off to 10% and used as the MDH value for all settings in this unit.

Non-mechanical delay hours (NDH) associated with the FERIC reports were 12 % and 13 % with the choker rigged systems and only 3 % of the SMH for the grapple system.

Felling Costs, adjusted for local conditions and retention are:

	Cost
Area felled with no retention	\$9.04/ m^3
Area felled at 30 % retention	\$8.81/ m^3

Loading Costs consider that the loader would be on site throughout the entire yarding time. Costs are calculated for the entire SMH period needed for the tower and includes bucking (chaser) costs.

Ownership and Operating Costs are from Sauder and Nagy (1975) and Forrester (1995) for the Madill 009 highlead tower and for the Cypress 1825C hydraulic loader. Using a standard format developed by FERIC, costs include all equipment, all materials, all wages, and bucking costs adjusted to reflect the situation prescribed in the Clayoquot Region. The data associated with owning and operating costs are shown in Appendix 2.

4.5. Environmental Impacts

Critical issues for the Clayoqout Sound are soil distrubance, slope stability, riparian and terrestrial habitats, and visual quality. Skyline systems produce the smallest degree of soil disturbance. There is concern for dragging logs on some of the skyline paths because soil disturbance may result. Riparian Management Zone (RMZ) will filter most of the sediment unless there is a direct source entering stream such as a culvert, ditch, road or another captive stream.

Two of the designs cross a fish bearing streams, however they do not carry logs into the riparian area, only the cable line will be in the RMZ. The line being in the system may cause some damage, depending the number and spacing of the cable lines. If the lines are close together and numerous then there will be a negative impact. The critical question for crossing of the stream is the amount of exposed area in the riparian buffer. The total amount of area exposed for the Wyssen system is 4m (the width for each corridor is about 1ft). If the area where the lines cross is moderately dense canopy, minimal damage to the riparian trees may occur (e.g. pruning). The impact of these systems on the riparian area is minimal, mostly from lines crossing the stream. Cables will be laid in the stream and then pulled up nthrough the crown and will remain until the corridor is completed. The amount of oil entering the stream from the nine lines is probably minimal, however they should not be kept in the stream longer than a day. As a safe guard, harvesting could be scheduled in spring and summer when flows are high and thus minimize contamination of salmon eggs.

When considering the environmental impacts, the other species inhabiting the area is also considered. Species of concern will have the riparian area, operable linkages, aggregates of timber and narrow clear-cut sections as a refuge.

5. SITE LEVEL ANALYSIS

5.1. Site 1 Kennedy Flats - Grice Bay

5.1.1. Site Characteristics

Kennedy Flats is flat, wet and susceptible to disturbances with several streams, which are habitat to salmon. The lack of deflection and the site fisheries sensitivity makes this unit difficult to harvest. The Kennedy Flats region is not a critical viewshed. Therefore the visual presentation of the harvest is not of paramount importance.

There are primarily western hemlock and balsam fir dispersed around islands of isolated large, decadent red cedar trees. The majority of the volume is from the cedar. The cedars contain up to 50% defect. Constraints were topography, streams, and the stand itself with occasional large cedar and heavy log weights.

5.1.2. Constraints

The stand is pole size hemlock and balsam fir with occasional remnant large cedars. The odd cedar will have log weights that will be on the extreme end of the payload distribution. Streamsides are steepp with highly variable flood levels. Destabilization of the banks will deliver sediment. Salmon habitat is extensive and the concerns are for potential loss of spawning sites, buried redd sites, and loss of rearing pools. There are numerous wet sites on the unit that present significant regeneration challenges.

5.1.3. Silvicultural Prescriptions

The silvicultural design considered the nearby salmon habitat, visual impact, biological diversity, and feasibility of implementation. Designs considered included partial cuts. With helicopter logging ,retention patterns is flexible. The only concern is the reduced productivity due to a complicated retention pattern. Strategically located and designed structural retention is capable of conserving all components of fine-scale heterogeneity (Elm) and maintaining optimum productivity (pieces/hour).

Conservation of ground vegetation the forest floor is another notable characteristic from this silvicultural design. Ground skidding and light temporary road building will likely degrade site conditions and could deliver sediment to nearby streams. The subsurface water flow is

The optimal pattern mimics more of a natural landscape with few geometric shapes governing the pattern of retained timber. This variable retention to achieved goals of biodiversity, feasibility and a decreased visual impact. Selection of trees in 30%-60% retention patches have two main requirements: diameter is >12.5 cm and single tree selection system. The single tree selection system is defined as an uneven-aged silvicultural system which new age classes are created by the removal of individual trees of all size classes, more or less uniformly throughout the stand (**Forest Practices Code, BC**).

Another silvicultural system examined is partial cut with variable retention. 100% retention being snags or riparian areas. The 30-60% retention was chosen on the basis of visual impact. The partial cut options are not selected on the basis of feasibility of harvesting and are not favorable for biological diversity. With partial cut, the goal of preserving the diversity is decreased because the entire area is disturbed, therefore the likelihood of diversity of species surviving decreases. Windfall is another factor which would cause concern for this system; the remaining trees are highly susceptible to windfall.

5.1.4. Selected Harvest Plan

Conventional ground based harvesting is inappropriate for the Kennedy Flats site because strict environmental codes, flat terrain, and wet soil conditions. Conventional options for harvest on this site are too damaging to the environment or too expensive. Highlead, skidder, multispan yarding were evaluated. The helicopter was the final choice for the harvest system.

The preferred harvest plan is via helicopter. This unit should be harvested with another unit within a 2 mile radius is being helicopter yarded. This plan provides several advantages in relation to the retention patterns, environmental considerations, compared to the use of other yarding operations. The feasibility of implementing stand structure goals is improved with a helicopter. The helicopter is not impeded by cable roads that require navigation through the contour patches.

- The plan of retention is independent of the yarding operation.
- Using this plan, we can reduce road construction, maintenance, and preserve aesthetic quality of site.
- The material that is economically unfit for removal will be left for strategic reserve retention.

The design creates aggregated retention islands centered on the safe cedars. Ground skidding is avoided to protect both nearby salmon habitat and the site productivity. Large woody debris loading on the ground limits the effectiveness of ground-based mechanized systems because of obstructions. A series of temporary roads off the mainline with irregular shaped skyline yarding corridors were designed for limited lateral yarding. This system would require that the area below the skyline be clear to avoid hang-ups during yarding.

5.1.5. Economics

The costs reported in Table 3 are Can$ for MBF. A conversion rate of 222 MBF per m3 was used to convert the costs/MBF to costs/m3. Total helicopter yarding costs (stump-to-truck) are $54/m3. This compares favorably to a local estimates of $65/m3. However, this rate is substantially higher than traditional grapple yarding costs of around $11./m3 and also significantly higher than a skyline tower setting would require.
The feasibility of implementing stand structure goals is improved with a helicopter. The helicopter is not impeded by cable roads that require navigation through the

contour patches. Reduced road construction, maintainance is somewhat offset by the size of a safe log landing zone for helicopters. But the low road density preserves aesthetic quality of the site. All trees and material unfit for removal are left for woody debris recruitment. With helicopter logging, retention patterns are flexible. The only concern is the reduced productivity due to a complicated retention pattern. Strategically located and designed structural retention is capable of conserving all components of fine-scale heterogeneity (Elm 1994) and maintaining optimum productivity (pieces/hour).

Table 3 Summary for Sale: Take 85% of Volume (Note: figures in English units)

Unit	Alt	Acres	Landing	AYD	Net MBF/Day	Work Days	Net MBF	Net Cost/MBF	Mean Load
1	3	62	KL	1344	230.2-230.2	6.8-6.8	1566.8	136-149	16921-16921

Aircraft S-64

Cost Recapitulation

	---------- Extended Cost	--------	Cost/Net MBF	--
Yarding	161951.97	170529.50	103.36	108.84
Falling	44113.02	44113.02	28.15	28.15
Loading	6331.04	18993.11	4.04	12.12
	0.00	0.00	0.00	0.00
Move In/Out				
Aircraft	8400.00	8400.00	5.36	5.36
Ground	2211.00	4136.00	1.41	2.64
TOTAL	223007.02	246171.62	142.33	157.12

5.1.6. Environmental Impacts

For this report the soil disturbance and riparian area damage are minimal.
The environmental considerations; canopy structure, soil disturbance, and stand composition still require some study. One concern is the amount of soil disturbed by the landing for helicopter logging of aproximately 0.3 hectare. Windfall is another factor which would cause concern for this system; the remaining trees are highly susceptible to windfall. Tree selection should favor leaving the well developed crowns and roots of stand dominants.

Other species inhabiting the area are also important when considering the environmental impacts. Species of concern will have the riparian area, operable linkages, aggregates of timber with snags, and narrow uncut sections as a refuge. Overall, the impacts from the planned harvest on Kennedy Flats will be insignificant.

5.1.7. Other options considered

Conventional ground based harvesting is inappropriate for the Kennedy Flats site because strict environmental codes, flat terrain with wet soil conditions, salmon habitat and the site productivity. Conventional ground based harvest options for this site are damaging to the environment and expensive (e.g., highlead, skidder). Large woody debris loading (from historic wind events) on the ground limits the effectiveness of ground-based mechanized systems because of obstructions. A series of temporary roads off the mainline with irregular shaped skyline yarding corridors were designed for limited lateral yarding (Figure 8 a,b,c.). This system would require that the area below the skyline be clear to avoid hang-ups during yarding.

Live running skyline using a Madil 009 tower yarder with estimated payload of 5000 kg is desired. From two diferent settings we use a 27M tower with 10m chokers. The 2270 kg carriage is recommended. Because of large span distance for the first setting, an intermediate span with a 26m supporting tower is needed. For the second setting, 26m tailholds are used for the first two corridors, and a 20m tailhold for the third corridor. For a 427M mobile tower, maximum slope rigging distance, a minimum required ground clearance of 5M is necessary.

The yarder impact is minimal considering the following factors: the yarder is in a stand of timber and will make one trip in and out. However to establish a suitable landing location based on terrain limitations, a road must be constructed on less than suitable base. A Riparian Management Zone, RMZ, will filter most of the sediment from the mainline unless there is a direct source entering stream such as a culvert, ditch, road or another stream. The soil erosion may increase by using a road crossing.

Potential drawbacks

- This system requires long rigging time.
- There may not be tree spars tall enough to accomodate a 26m tailhold.
- This layout crosses a stream.

The partial cut options are not selected on the basis of feasibility of harvesting and are not favorable for biological diversity. The resulting landscape pattern is not as visually appealing because of stark edges. The aggregate patches are more natural. With partial cut, the goal of preserving the diversity is decreased because the entire area is disturbed, therefore the likelihood of diversity of species surviving decreases. Contour patch pattern without variable retention has most of the benefits, whereas the preferred option considers the density of the transition zone. The spans used for this analysis are presented in Appendix 3.

5.1.7. Visual Quality

The images for Kennedy Flats were basic, due to the flat topography of the area and the small amount of disturbance associated with harvesting. Views were taken form an aerial point of view but lack the real texture of the landscape. This technique was chosen to amplify the contrast between pre- and post- stand densities of the unit. Images contain the area of the harvesting practice. Unit boundary is not delineated because the goal was to display the differences between the before-and -after-look of the area. Because of the heavy flight traffic to the nearby Tofino International Airport, the visual quality of the retention pattern will be judged by passengers destined for the region (Figure 9 a, b)

Stand structures based on the harvest prescriptions (Figure 10 a,b) illustrate the effect of canopy removal. The general stand structure will include no-work zones around large redcedar trees, dispersed retention and contour patches along the tops of all the streambanks.

Figure 8(a,b) The landscape or aerial view of the Kennedy Flats both before and after harvest cutting. For landscapes with such little relief the visualization has less impact.

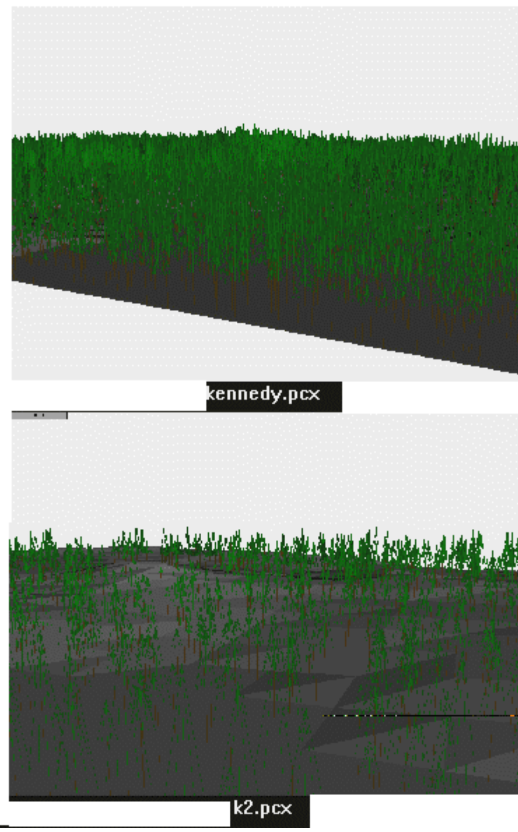
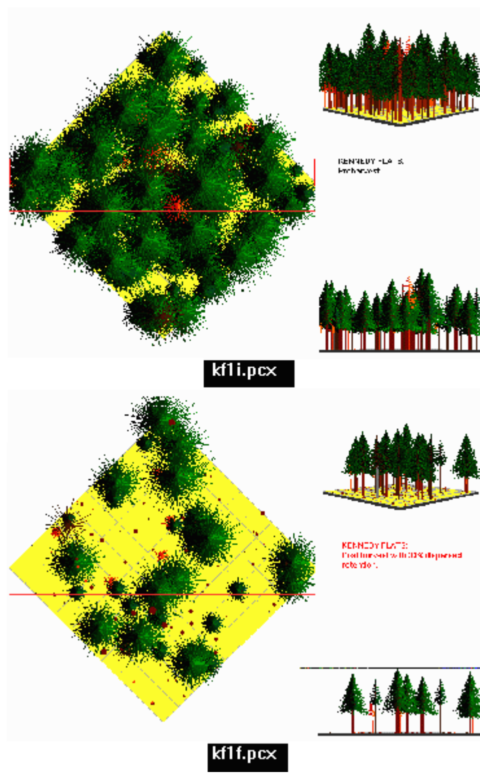


Figure 9 (a,b,c), Views of the stand both before and after cutting from SVS software based on the inventory data.



5.1.8. Payload Estimation

A design payload of 5000 kg is sufficient for removing most timber.

Table 4. Design payload for Kennedy Flats for 10 metre logs. Weights are in lbs (1 lb=0.45 k).

INDIVID. LOG WT.	LOG COUNT	*LOG BREAKDOWN*		PAYLOAD WITH FOUR CHOKERS			PAYLOAD WITH THREE CHOKERS		
247.5	**81.0**								
4120.3	8.6	**MEAN LOG WEIGHT**	**1925**	**MEAN**	**7677**	**payload weight**	**MEAN**	**5640**	**payload weight**
2413.3	8.6	Standard Error	153.619	**STDEV**	3795		**STDEV.**	3271	
595.8	8.6	Median	1020.05	**STD ERROR**	126		**STD ERROR**	109	
28.7	8.6								
4513	7.2	Standard Deviation	2161.61						
3255.1	7.2	Sample Variance	4672564						
1913.7	7.2								
450.9	7.2								
37.6	7.2	Range	10200.4						
5155.8	9.7	Minimum	13.1						
3718.6	9.7	Maximum	10213.5						
2186.3	9.7								
523.5	9.7								
34.7	9.7	Confidence Level(95.0%)	302.949						
273.5	83.1								
543	77.5								
209.8	77.5								
784.5	49.3								
232.2	49.3								
77.4	49.3								
1122.3	34.3								
290.2	34.3								
50.8	34.3								
1289.9	27.6								
703.5	27.6								
126.8	27.6								
1633.2	32								
904.9	32								
177	32								
1963.5	9								
1220.5	9								

Table 5. LOG VALUE — KENNEDY FLATS

CEDAR

LOG GRADE	% OF TOTAL LOGS	VOL HARVESTED	$$/m3	TOTAL $$
# 1 PREMIUM	0.0	0	174	0
# 1 LUMBER	0.0	0	174	0
# 2 SAWLOG	36.5	1332	167	222082
# 3 SAWLOG	25.9	945	162	153385
# 4 SAWLOG	5.5	201	163	32795
# 5 UTILITY	13.0	474	52	24652
# 6 UTILITY	1.9	69	52	3603
# 6 CHIPPER	17.2	628	90	56338
	TOTAL	**3649**		**492855**

HEMLOCK

LOG GRADE	% OF TOTAL LOGS	VOL HARVESTED	$$/m3	TOTAL $$
# 1 PREMIUM	0.0	0	153	0
# 1 LUMBER	0.0	0	139	0
# 2 SAWLOG	8.1	446	113	50513
# 3 SAWLOG	17.9	985	89	87550
# 4 SAWLOG	57.6	3168	83	264118
# 5 UTILITY	14.0	770	52	40015
# 6 UTILITY	2.5	138	52	7146
# 6 CHIPPER	0.0	0	90	0
	TOTAL	**5506**		**449342**

BALSAM Fir

LOG GRADE	% OF TOTAL LOGS	VOL HARVESTED	$$/m3	TOTAL $$
# 1 PREMIUM	0.0	0	153	0
# 1 LUMBER	0.0	0	139	0
# 2 SAWLOG	22.7	319	113	36200
# 3 SAWLOG	35.4	498	89	44276
# 4 SAWLOG	18.0	253	83	21106
# 5 UTILITY	23.9	336	52	17469
# 6 UTILITY	0.0	0	52	0
# 6 CHIPPER	0.0	0	90	0
	TOTAL	**1406**		**119051**
			TOTAL $$ ALL SPECIES	**1061248**

5.1.9. Evaluation

The variable retention patterns will satisfiy many of the Scientific Panels recommendations for maintaining ecological function. The persistence of structure and compostion is well supported by a number of habitat islands (centered on large, old redcedars) and irregular boundaries. The snags retained serve as cavity nesting sites. Much of the forest floor will remain untouched except for the falling impacts.

The harvest system is expensive but minimizes risk to salmonids by flying logs to a central helicopter landing off site. The log transportation should be on well built roads with ample provisions for drainage (e.g., culverts, fords) to minimize sedimentation.

5.2. Site 2 Rolling Stone - Fortune Channel

5.2.1. Characteristics

Rolling Stone is a dissected landscape that requires wide riparian buffers to protect steep stream banks. Many small, localized slumps occur across the harvestable areas. In the central-upper portion of the unit are several small local slope failures. These failures are a natural occurrence assumed to be triggered by shallow soils on a steep slope. Because of these failures, extra consideration was paid to attempt to protect the steeper slopes throughout the unit. The unit boundary in the northwest is along a type S-5 stream and continues as a tributary to Rolling Stone Creek. Large cedars present primarily in the riparian areas have strong bank and erosion control influence. Sedimentation is of great concern.

The southern boundary is a prominent ridge that increases in elevation from west to east. The top of the unit runs north to south and is below the top of a north-south ridge outside of the unit. A road divides the unit; above the road there are small local failures present. To the West is a previous clear-cut.

5.2.2. Constraints

Highly erodable soils cover most of the area. Streams are characterized by steep riparian banks. These combine to create a potential risk to salmonids.
Snags for cavity dependent wildlife are critical to maintain
Visibility from the north and west

5.2.3. Stand Summary

The cruise data shows the unit is divided in to two sections. One stand is primarily western hemlock and balsam fir (HB). This unit accounts for approximately one-third of the twenty-five hectare harvest unit. The lower elevations are comprised of large cedar and hemlock and account for the majority of the setting area. The second stand is redcedar and western hemlock (CH). The hemlock-balsam section is large healthy trees with few snags. In the CH, old growth cedars both live and snags are sparsely scattered. These large, decadent trees serve as centers of habitat islands.

5.2.4. Silvicultural Prescription

Retention plans for this unit are based on steep areas with consideration for timber quality. The goal was to remove trees of high value, while still leaving areas which include large old growth cedar for wildlife, and balsam and hemlock for diversity. Aggregates are used to protect locally unstable areas. Dispersed retention is not used. Harvesting methods in this area consist of small clearcut areas, aggregates at the northern end, and pockets of 30% retention.

5.2.5. Preferred Harvest and Retention System

Harvest system decisions were based on an optimum balance between economical efficiency and environmental considerations. The unique characteristics of the Rolling Stone unit made many options impossible. PLANS analysis narrowed the alternatives to three harvest plans, one was favored.

PLANS analysis used a live running skyline configuration (Appendix 3). A standing skyline was tested but the output was not sufficient. PLANS produced the profiles for each corridor. Given the estimated payload and tower and tailhold heights, PLANS returned the maximum span. Through the process, yarders and their corresponding settings were selected based on their capacity for yarding distance, cable diameter, load capacity and deflection. Profiles were manually adjusted, tail holds raised, yarding limits set until the final unit boundaries, including tailhold and yarding limit locations were satifactory. Information given from PLANS is illustrated in Table 6.

The preferred system uses the 90’ Madill 099 tower. This large tower provides maximum deflection on the convex slope. A 1” skyline is used on the upper two landings (B & C), and a 1 1/4 “ skyline is used on the lower landing below the center road. The 1” skyline maximum span was 700 meters The 1” skyline was needed in the upper settings to reach across streams for tailholds. Longer lines created additional deflection. In the lower setting, hanging across the stream for great distances was not necessary, therefore distance was not a factor and the use of a heavier cable allowed for increased deflection. With the 1 1/4” the maximum span was 365 m. The carriage was a clamping carriage equipped with four chokers. The four choker system was chosen over the three chokers for increased production since a majority of the logs being harvested are of smaller size and weight. The expected crew size (8) for this operation is an operator, hooktender, four choker setters, and a chaser.

Table 6. Stand average setting information.

Setting	AYD	Avg.Chord Slope	Avg. Payload	Covered Area	Area Harvest
A	119 m	35 %	4882 kgs	6.14 ha	4.86
B	109 m	23 %	4977 kgs	6.39 ha	4.20
C	230 m	39 %	5000 kgs	12.96 ha	

<u>SETTING A</u> , the central landing, requires a small spur road to be built off the center road. This landing is almost all uphill yarding and will require a few corridors to tailhold across the riparian area. This unit is bound by riparian areas on two sides and a clear-cut at the west end. This unit has shorter yarding distance and heavier cable to improve deflection. The design payload for this area is 4400 kg. Slightly lighter payload was used because of the convex sloping and the stand tables.

<u>SETTING B</u> is a smaller setting with the landing in the center of the main road. This setting is bound by the riparian area to the north and setting C to the East. This is a radial setting with yarding in all directions, for shorter distances. A payload of 5000 kg was selected. This setting has short yarding distances, uphill, downhill and sidehill.

<u>SETTING C</u> covers the largest area of (12.96 hectares) and will have the maximum amount of retention. According to the design 25 to 30 % of the trees will be left in either aggregate patches or no-work-zones. It will be necessary to hang through the riparian area, but yarding limits are set well before the buffer. This deflection allows to reach the larger logs. This setting requires a road to be built to the proposed

landing. From the proposed landing most of the yarding will be uphill; with a limited amount of sidehill and downhill yarding. Most yarding will be short distances and full suspension. A payload design of 5000 kg was used.

The road needed to reach this landing will need to be approximately .88 km long at an 18% grade with a stretch out of the landing at 4%. If, upon field review the location of this road is not possible it is recommended that the upper portion of the unit be left. The unit can later be added to an additional nearby unit for possible helicopter logging. Given a rough estimate of $85,000/ km The overall cost of the road will be $74,800.

The layout consists of two tower landings North (below) the road; one above off of an extension of a designed road above the unit. The proposed 0.87 km road is built to use the long reach ability of a tower setting, with an average road spacing of 600 metres.

Log Weight Distribution Setting A was designed primarily for the cedar/hemlock stand and therefore the payload used in the design was slightly lower at 4400 kgs. The payload for settings B and C were based on a four choker carriage. The average log weight for the hemlock/balsam stand was 1235 kgs. Using four chokers the total combined weight would be 5000 kgs. The maximum log weight for that section was 5415 kgs. For most of the corridors, although a 5000 kg payload was specified, they will be able to haul the max log weight as a single log. For the cedar/hemlock stand the average was 725 kgs, so for four chokers the total would be 3000 kgs. The maximum weight was 8992 kgs.

Payload Estimation

Hemlock and balsam are both shade tolerant, hence, a large number of smaller trees that make up a significant portion of the harvested volume. The hemlock are of the highest market value and serve as the strongest source of tailholds.

5.2.6. Other Options Considered

<u>ALL GRAPPLE</u> yarder option used the Madill 144; a 70' swing yarder equipped with a radio controlled grapple weighing 2260 kg, a 1000 kg single log grapple was also tested. Because the longer yarding spans and the convex slope, grapple visibility would be a problem. The radio controlled carriage allows the operator to pick up logs over the crest of the hill in both uphill and downhill yarding. The yarder was equipped with 1" diameter cable. The grapple system had a maximum span of 275 yds. Upon evaluation of the profiles, logs could only be hauled as single logs with the grapple and the system could only retrieve the smaller logs. Most of the logs greater than 70% of the average would have to be specially bucked to make weight. A total of seven landings would be needed as a minimum. Excessive yarding corridors would have been needed in order to reach the timber due to the lack of lateral yarding. The expected crew size for this system is an operator, a utility person, and a hooktender. It was decided that the silvicultural impact of all of the yarding corridors and the lack of flexibility in leave patch options made an all grapple system impractical.

The grapple yarder, although quicker in cycle times, did not give adequate deflection in most of the settings. An extra 20’ of lift from the tower would allow for greater distances of reach and longer full-suspension areas.

GRAPPLE-TOWER COMBINATION SYSTEM was designed with a 90’ tower used on setting C and another tower placed at the base of the unit to the northwest, in the old clear-cut. Both of these settings were designed with the same specs as previously described. The swing yarder would be driven down the center road to yard both sides of the road. Economically, this option seemed the most effective. However, it also required a great deal of downhill yarding. The yarding design invited damage to ground, live, and harvested trees. With the combination plan, the environmental impact far outweighs the financial benefits. With the downhill yarding, and inability to get full suspension, the cycle times would be much greater than the production equations estimate.

Harvesting Concerns

Because of necessary deflection some tailhold will reach up to 15 meters in height. To support the 5000+ kg payload the ideal tree would be a hemlock of approximately 65 cm (~ 77cm DBH) at point of rigging. If such a tree could not be located a straight healthy cedar of 70+cm at point of rigging could be used as an alternative. It is essential that the soundness of the tree be verified before it is used as a tailhold and should be guyed so that the majority of the load is transferred as a compression force along the tree in order to avoid breakage. The additional time required to guy the taller tailholds was factored into the time production equations. Although tall tailholds are not preferred, the necessity for maximized deflection is reason enough to raise the tailhold to decrease any soil disturbance.

The yarding system designed cannot support such a weight in most cases. The decision needs to be made in the field whether the tree can be bucked into shorter lengths and dragged into the landing. Numerous large, redcedar snags are left behind for wildlife and require no-work-zones otherwise they can be cut and left as LWD recruitment.

This report examines three different running skyline systems, a swing yarder with chokers, a swing yarder with grapple, and a tower yarder with chokers. One of the systems contained in the FERIC report matched the system designed for the Rolling Stone unit (Tower yarder with chokers). The FERIC element times were applied to tower yarder with chokers to Rolling Stone at setting A, B, and C (Table 7 a,b,c). FERIC times for road changes were not used and are considered later, separate of the yarding cycle. The AYD was 81 meters in the FERIC study.

Table 7a. <u>Setting A</u> Yarding Cycle Changes --Tower Yarder w/chokers

ACTIVITY	FERIC (Mar95)	Rolling Stone	Reason for Changes
Outhaul	0.33 min.	0.51 min.	Value is proportional with the distance change of AYD between FERIC and Rolling Stone
Hookup	3.32 min.	8.32 min.	Chart in (cable thinning handout) showed the time changes for lateral outhaul and inhaul with lateral yarding distance. The value for the LYD_{avg} of Rolling Stone for this setting was then added to FERIC report hookup time
Inhaul	0.66 min.	1.03 min.	Value is proportional with the distance change of AYD between FERIC and Rolling Stone
Deck	0.29 min.	0.39 min.	Increased due to more chokers used in Rolling Stone unit (0.10 min./log)
Unhook	0.98 min.	1.31 min.	Increased due to more chokers used in Rolling Stone unit (0.33 min./choker)
Road change	0.44 min.	--	Considered separate
Delay	0.37 min.	0.37 min.	No changes made
Total Cycle Time	**6.39 min.**	**11.93 min.**	

Table 7b. <u>Setting B</u> Yarding Cycle Changes -- Tower Yarder w/chokers

ACTIVITY	FERIC (Mar95)	Rolling Stone	Reason for Changes
Outhaul	0.33 min.	0.45 min.	Value is proportional with the distance change of AYD between FERIC and Rolling Stone
Hookup	3.32 min.	8.32 min.	Chart in (cable thinning handout) showed the time changes for lateral outhaul and inhaul with lateral yarding distance. The value for the LYD_{avg} of Rolling Stone for this setting was then added to FERIC report hookup time
Inhaul	0.66 min.	0.90 min.	Value is proportional with the distance change of AYD between FERIC and Rolling Stone
Deck	0.29 min.	0.39 min.	Increased due to more chokers used in Rolling Stone unit (0.10 min./log)
Unhook	0.98 min.	1.31 min.	Increased due to more chokers used in Rolling Stone unit (0.33 min./choker)
Road change	0.44 min.	--	Considered separate
Delay	0.37 min.	0.37 min.	No changes made
Total Cycle Time	**6.39 min.**	**11.74 min.**	

Table 7c. <u>Setting C</u> Yarding Cycle Changes -- Tower Yarder w/chokers

ACTIVITY	FERIC (Mar95)	Rolling Stone	Reason for Changes
Outhaul	0.33 min.	0.99 min.	Value is proportional with the distance change of AYD between FERIC and Rolling Stone
Hookup	3.32 min.	8.32 min.	Chart in (cable thinning handout) showed the time changes for lateral outhaul and inhaul with lateral yarding distance. The value for the LYD_{avg} of Rolling Stone for this setting was then added to FERIC report hookup time
Inhaul	0.66 min.	1.98 min.	Value is proportional with the distance change of AYD between FERIC and Rolling Stone
Deck	0.29 min.	0.39 min.	Increased due to more chokers used in Rolling Stone unit (0.10 min./log)

Unhook	0.98 min.	1.31 min.	Increased due to more chokers used in Rolling Stone unit (0.33 min./choker)
Road change	0.44 min.	--	Considered separate
Delay	0.37 min.	0.37 min.	No changes made
Total Cycle Time	**6.39 min.**	**13.36 min.**	

Road change time was considered separately from the road change time estimated in the FERIC report because of the dramatic increase in time associated with the retention of trees. For the Rolling Stone harvest unit the following estimates were used to calculate total road change time on a given setting:

Type of Road Change	Assumed Time Requirements
Retention between corridors	four hrs / change
No retention between corridors	one hr / change

The area was broken down for each setting into two silvicultural categories. These two categories were area cut, and area cut at 70 % for each stand type. From this information the area cut at 70 % was reduced to an area cut (7/10 of total area cut at 70 %) and added to the area cut to get a total area within each stand type that was cut and yarded to a given landing. This area was then multiplied by the number of trees/hectare and by the number of logs/tree to get the number of logs to be yarded to each landing (Table 8). For production analysis on the Rolling Stone unit the values with the choker systems were increased to 15 % and increased to 7 % for the grapple system. This reflects some of the organizational difficulties that are present in yarding sites with retention.

Table 8. Stand Harvest Area by Setting

	[Units]	SETTING A	SETTING B	SETTING C
AREA OF C-H STAND CUT	HA	3.63	3.06	5.07
AREA OF C-H STAND CUT AT 70%	HA	1.18	1.14	0.00
AREA OF H-B STAND CUT	HA	0.00	1.05	4.91
AREA OF H-B STAND CUT AT 70%	HA	0.00	0.00	0.00
ADJ AREA OF C-H STAND CUT	HA	4.45	3.86	5.07
ADJ AREA OF H-B STAND CUT	HA	0.00	1.05	4.91
# OF TREES CUT IN C-H STAND		1258.96	1091.47	1432.94
# OF TREES CUT IN H-B STAND		0.00	244.20	1140.58
# OF LOGS YARDED IN C-H STAND		3499.90	3034.28	3983.59
# OF LOGS YARDED IN H-B STAND		0.00	678.89	3170.80
VOL OF LOGS YARDED IN C-H STAND	M^3	4130	3580	4701
VOL OF LOGS YARDED IN H-B STAND	M^3		1147	5359
TOTAL LOGS YARDED		**3499.90**	**3713.16**	**7154.39**
TOTAL VOL OF LOGS YARDED	$\mathbf{M^3}$	**4130**	**4727**	**10060**

Data from production estimates for each setting based on the two different yarding systems is presented below (Tables 9 a, b). The number of grapple yarding corridors was assumed to be three times the amount necessary for yarding with chokers over the same area. This assumption was made to reflect the inability to lateral yard with the grapple system.

Table 9 a. Production for Yarding with Chokers at Setting A, B, and C

Activity or Variable	Setting A	Setting B	Setting C
Total # of logs in setting	3499.90	3713.16	7154.39
# of logs/turn	3.3	3.3	3.3
# of turns required	1061	1125	2168
Yarding Time for setting	12658	13208	28964
Road Change Time	1980	4320	1680
Total, or PMH	244.0	292.1	510.7
MDH	32.5	39.0	68.1
NDH	48.8	58.4	102.1
Scheduled machine hrs. (SMH)	325.3	389.5	680.9
# days to yard setting (8 hr shift)	40.7	48.7	85.1
Vol (m^3)/PMH	16.9	16.2	19.7
Vol (m^3)/SMH	12.7	12.1	14.8

Table 9b. Production for Grapple Yarding at Setting A, B, and C

Activity or Variable	Setting A	Setting B	Setting C
Total # of logs in setting	3499.90	3713.16	7154.39
# of logs/turn	1.3	1.3	1.3
# of turns required	2692	2856	5503
Yarding Time for setting (min.)	9278	9482	28065
Road Change Time	5940	12960	5400
Total, or PMH	253.6	374.0	557.8
MDH	30.6	45.1	67.2
NDH	21.4	31.5	47.0
Scheduled machine hrs. (SMH)	305.5	450.6	672.0
# days to yard setting (8 hr shift)	38.2	56.3	84.0
Vol (m^3)/PMH	16.3	12.6	18.0
Vol (m^3)/SMH	13.5	10.5	15.0

Table 10. LOG VALUE ROLLING STONE

CEDAR

LOG GRADE	% OF TOTAL LOGS	VOL HARVESTED	$$/m3	TOTAL $$
# 1 PREMIUM	4.5	287	174	49870
# 1 LUMBER	1.7	108	174	18840
# 2 SAWLOG	45.7	2911	167	485421
# 3 SAWLOG	28.8	1835	162	297753
# 4 SAWLOG	2.5	159	163	26024
# 5 UTILITY	3.7	236	52	12249
# 6 UTILITY	0.8	51	52	2648
# 6 CHIPPER	12.7	809	90	72620
	TOTAL	**6396**		**965425**

HEMLOCK

LOG GRADE	% OF TOTAL LOGS	VOL HARVESTED	$$/m3	TOTAL $$
# 1 PREMIUM	7.4	711	153	108600
# 1 LUMBER	9.0	864	139	120074
# 2 SAWLOG	31.7	3044	113	345109
# 3 SAWLOG	14.1	1354	89	120394
# 4 SAWLOG	19.8	1901	83	158498
# 5 UTILITY	11.5	1104	52	57382
# 6 UTILITY	0.8	77	52	3992
# 6 CHIPPER	5.6	538	90	48264
	TOTAL	**9592**		**962313**

BALSAM fir

LOG GRADE	% OF TOTAL LOGS	VOL HARVESTED	$$/m3	TOTAL $$
# 1 PREMIUM	6.6	162	153	24769
# 1 LUMBER	0.0	0	139	0
# 2 SAWLOG	31.8	781	113	88529
# 3 SAWLOG	34.7	852	89	75767
# 4 SAWLOG	17.2	422	83	35209
# 5 UTILITY	7.8	192	52	9953
# 6 UTILITY	0.6	15	52	766
# 6 CHIPPER	1.3	32	90	2865
	TOTAL	**2455**		**237857**
			TOTAL $$ ALL SPECIES	**2165596**

FELLING COSTS

$9.04/m^3 x 18828.09 m^3 = $170206
$8.81/m^3 x 2153.10 m^3 = $18969
TOTAL = $189175

OWNERSHIP AND OPERATING COSTS (INCLUDING LOADING)

Choker system $335.96/h x 1395.7 = $468899 = $24.8/m^3
Loader $170.55/h x 1395.7 = $238037 = $12.6/m^3
Grapple system $231.55/h x 1428.1 = $330677 = $17.5/m^3
Loader $170.55/h x 1428.1 = $243562 = $12.9/m^3

Tower/Choker system	Log Value		$2165596
	Costs	Ownership and Operating	- $ 468899
		Loader	- $ 238037
		Felling	- $ 189175
		Road	- $ 74800
			Net $1,194,685
Grapple system		Log Value	$2165596
	Costs	Ownership and Operating	- $ 330677
		Loader	- $ 243562
		Felling	- $ 189175
		Road	- $ 74800
			Net $1,327,382

5.2.7. Visual Stand Representations

The results of the UTOOLS analysis show the unit before and after the harvest (Figure 10 a,b). From the straight west perspective, the unit is visible for the most part and the retention areas are prominent. There are few straight line or geometric boundaries because of the dispersion of retention. The unit itself has a visual partial retention layout for a harvest area to meet visual quality objectives.

SVS leave tree plans including dispersed areas and sections of the aggregate patches. Within this stand, a diverse four acre area was chosen for depiction by SVS. Cedars in this area tend to have splits in the trunk creating complex crowns. Crown ratios were increased to reflect this trend to create the effect of a wide, multi-top canopy tree retention patterns (Figure 11 a,b,c).

Figure 10 (a,b). Landscape view from the northwest before (a) and after (b) harvest. This design was modified at the symposium by adjusting the level of retention from 35 % up to 50% by eliminating several yarding corridors and extending the boundary of designed aggregates.

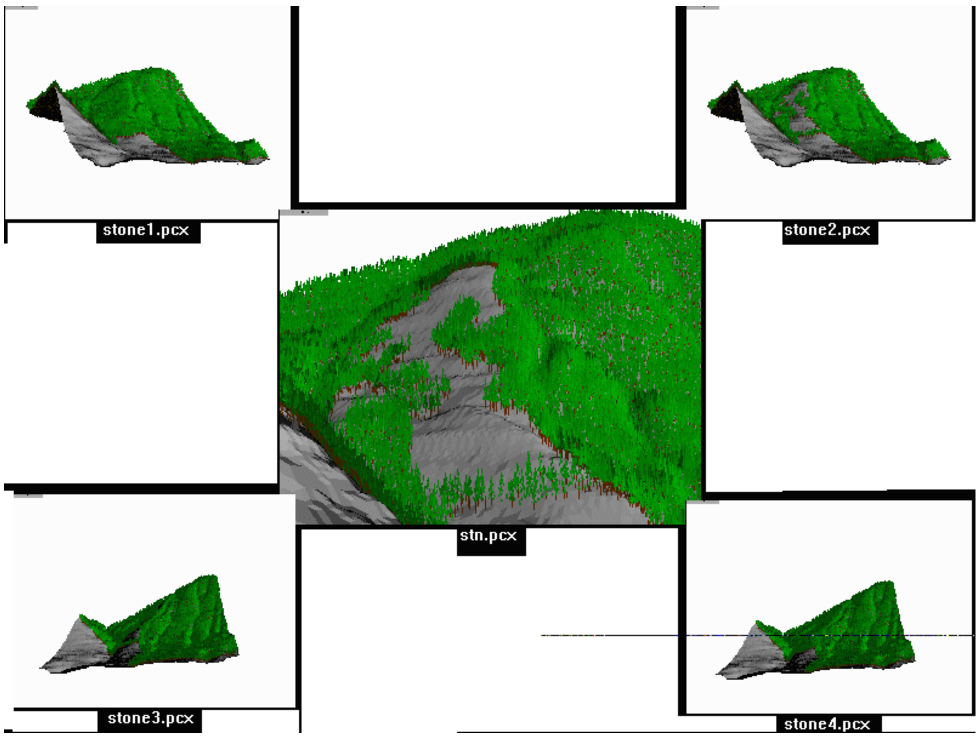
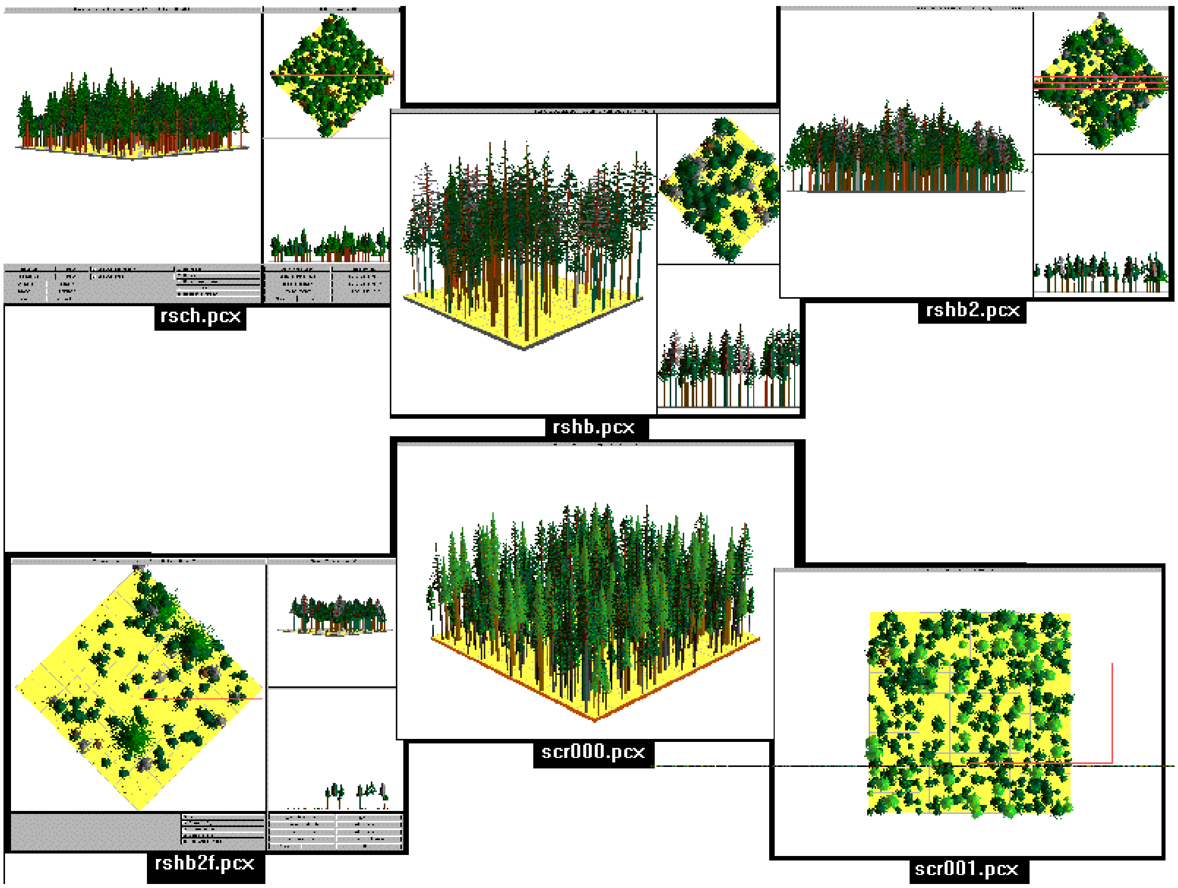


Figure 11 (a,b,c). Pre-harvest depiction of western hemlock-balsam fir timber type (a). Southeastern corner representation of aggregate retention in the western hemlock-balsam fir timber type (b). Post havest depiction of both 30% retentiona and clearcut areas in the redcedar-balsam fir stand type (c).



5.2.8. Evaluation

Our recommendation is for tower yarding for environmental reasons given the high level of STR.. The tower yarder will allow for less ground damage and easier yarding, lower log damage, and fewer yarding hang-ups Overall the tower yarder gives the flexibility and the deflection needed in this particular stand.

Silvicultural goals are met by openings throughout the canopy. Islands of full and partial retention are well connected across the site. Full 50 metre regulatory buffers are left on the streams to protect the steep gully walls and limit erosion potential to downstream salmon habitat.

Large aggregates on the southwestern boundary offer protection to small, headwall tributaries scattered across the central portion of the site. Partial retention on the west end soften the stark clearcut boundary and offers some connection between streams. This retention pattern meets many of the goals of the Scientific Panel while providing a safe working environment.

All these factors result in the retention and harvest plan as illustrated in the site maps. The areas harvested are listed in Table 7, and categorized according to stand type and retention percentages.

Table 11. Stand Harvest Area Summary

	[Units]	HEM/BAL STAND	CED/HEM STAND	TOTALS
AREA CUT	HA	5.96	12.94	18.90
AREA CUT AT 70%	HA	0.00	2.33	2.33
AREA NOT CUT	HA	2.25	2.22	4.46
TOTALS	HA	8.20	17.49	25.69
AREA CUT	%	72.63	74.00	73.57
AREA CUT AT 70%	%	0.00	13.31	9.06
AREA NOT CUT	%	27.37	12.69	17.38
AREA CUT IN AREA CUT AT 70%	HA	0.00	1.63	1.63
AREA NOT CUT IN AREA CUT AT 70%	HA	0.00	0.70	0.70
TOTALS	HA	0.00	2.33	2.33
ADJ AREA CUT	HA	5.96	14.57	20.53
ADJ AREA NOT CUT	HA	2.25	2.92	5.16
TOTALS	HA	8.20	17.49	25.69
ADJ AREA CUT	%	72.63	83.32	79.90
ADJ AREA NOT CUT	%	27.37	16.68	20.10

5.3. Site 3 Deer Bay -Tofino Inlet

5.3.1. Characteristics

The steep slopes are comprised of large colluvium (talus) that has developed large dimension redcedar and hemlock stands. There are a number of springs that emerge from the steep talus. The site is bounded by salmon bearing waters. Heritage trees have been positively identified in the lower riparian stands and near the northern corner of the unit.

5.3.2. Constraints

Shallow, coarse soils on steep slope with high susceptibilty to failure. Windthrow potential because of soils and topographic position. Visually sensitive slopes are evaluated within the context of a existing modified landscape.

5.3.3. Silvicultural Prescription

The silvicultural design used for Tofino Inlet on the Clayoqout Sound resulted from a comparison of patterns and retention. Other factors considered were visual impact, biological diversity, and feasibility of implementation. Five designs were considered including a wedge, two contour patch cuts, and two partial cuts. Visually, the wedge system is not adequate, due to its straight edges, triangular corners, large size, high color and texture contrast and notched skyline.

The preferred STR pattern mimics a natural landscape and distrubance with no geometric shapes governing the pattern of retained timber. This option uses contour patches with variable retention to achieve goals of biodiversity, feasibility and a decreased visual impact is seen as the best option from a visual stand point. Selection of trees in the 30%-60% patches has two main requirements: diameter is >12.5 cm and uses single tree selection system. defined as an uneven-aged silvicultural system, which creates new age classes are by removal of individual trees of all size classes, more or less uniformly throughout the stand **(Forest Practices Code, BC 1995**). All cable roads can pass through the contour patches. The patches were designed for no lateral yarding through retention on side slopes. When walking through a late seral stand, one of the noticeable aspects is the change of stand density. This is noticeable via the transition from the meadow patches to the stand of timber. This STR system varies the density as the distance from the meadows (openings) increases, achieving a natural transition zone. Because the visual quality is of great concern, retention is arranged to minimize visual impacts.

100% retention around large snags (no-work zones) or riparian areas as conservation or . The 30-60% retention was chosen on the basis of visual impact. The areas of high visual impact have a higher retention than the areas less visibility. The partial cut options were not selected on the basis of feasibility and biological diversity. With partial cut, the goal of preserving the diversity is decreased because the entire area is disturbed. Windfall is another factor which would cause concern for this system; the geomorphic position on the slope puts residual trees at risk. Contour patch pattern has most of the benefits of the chosen option but without variable retention.

The resulting landscape pattern not as visually appealing Dispersed retention is eliminated because of shallow, unstable rooting and vulnerability to wind throw. Aggregates are used to buffer streams and wildlife trees.

5.3.3.1. Setting Design and Retention

The proposal design does not utilize the currently existing mid slope road. It has one objective to demonstrate the power of cable systems planning which ulitimately would result in a low road density. The prevalent design fulfills that requirement.

The planning tools are so powerful that local engineers could redesign in order to utilize the midslope road. It certainly will result in shorter yarding distances and, hence, lower costs with greater detrimental impact to streams.

The preferred plan for harvest on the Tofino Inlet plot incorporates a Wyssen sled with multiple tail holds. The sled itself will be brought in on a truck and trailer to the end of the existing road just outside the north end of the unit. The sled will then be unloaded and dragged up the hill under its own power to the final destination. From this location a strawline will be run for the 1st corridor, while a 5 meter head spar is rigged. To increase productive time two men will be allotted to pre-rig the next corridor to be harvested. Each of the corridors will incorporate a stump, or multiple stumps when necessary, for a tail hold.

The operation itself will be a downhill yarding operation with areas of retention both within the corridors, as well as outside them. Some lateral yarding will be incorporated, however, the self contained line in the carriage will allow non-patterned felling. The logs will be yarded down the hill side, fully suspended, to the lower road and decked there. These logs can be loaded out when the tailhold is changed.

The lateral yarding in each of the corridors will be limited by the terrain. The corridors with a majority of their area being sidehill logged, or close to it, will have the vast majority of there lateral load coming from the downhill side of the corridor. The distance of lateral yarding will increase when this occurs. All of the lateral inhaul will commence in a fashion that will allow the logs to be brought in as close to perpendicular to the contour lines as possible.

5.3.3.2. Payload Estimation

Log count for a given weight is shown in Table 8, for 10m and 14m logs.
Design payload estimating incorporates cruise information, local bucking rules and statistical analysis. The stand table is provided in (Appendix 1).

For The Wyssen system, two cable diameters were evaluated using PLANS. The 1 3/8” skyline was insufficient to provide necessary deflection and payload. 1 7/8” skyline provided adequate deflection for full suspension, for a payload of approximately 7000 kg. PLANS results for profiles are shown in Appendix 3. The design payload of this weight is an example of an over designed system with weight almost double the weight of the heaviest 10 and 14 meter logs. However, the specifications given for the Wyssen sled include a skyline of 1 7/8” EIPS cable. A smaller diameter cable could provide a properly determined design payload, however, the 1 7/8” EIPS skyline was choosen to eliminate complications of exchanging cables and reduce set up costs.

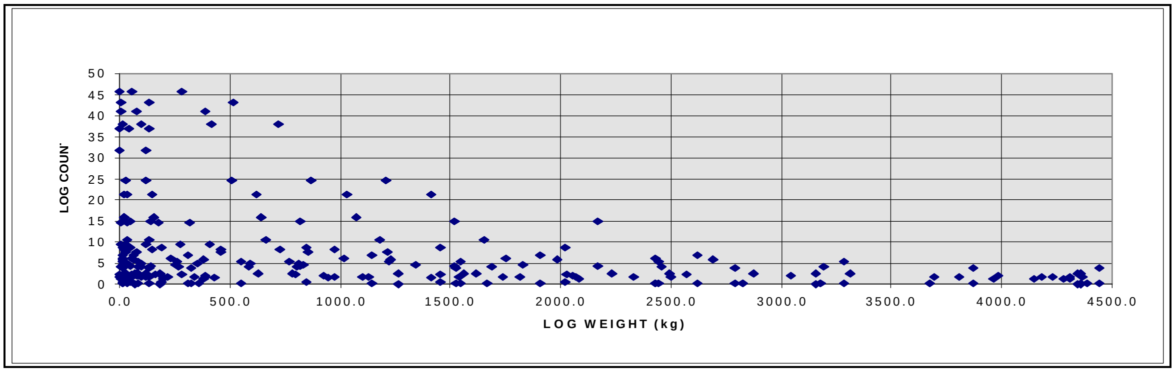


Figure 12.   Tofino Inlet distribution of 10 metre logs.

Table 12. Tofino Inlet Design payload for 10 metre logs, units are kilograms.

FORSEE LOG TABLE		LOG BREAKDOWN		FOUR CHOKERS			THREE CHOKERS		
IND. LOG WT.	LOG COUNT								
1.7	1.9	**MEAN LOG WEIGHT**	**1138**	**MEAN**	**4489**	**PAYLOAD**	**MEAN**	**3391**	**PAYLOAD**
136.4	1.9	Standard Error	187	**STDEV**	2226		**STDEV.**	1939	
39.6	1.9	Median	483	**STD ERROR**	74		**STD ERROR**	65	
1.7	37	Standard Deviation	1345						
136.4	37								
39.6	37								
3.4	2.3			3795			1700		
285.1	2.3			361			3347		
57.2	2.3			697			460	5506	
3.4	45.6			1751	6605				
285.1	45.6						139		
57.2	45.6			1485			1033		
4.9	2.1			149			3740	4912	
389.7	2.1			2130					
78.3	2.1			367	4130		105		
4.9	41						690		
389.7	41			660			531	1326	
78.3	41			4180					
47.5	0.4			1354			981		
2017.4	0.4			2897	9092		871		
1453.1	0.4						994	2846	
845.1	0.4			1059					
189.0	0.4			2335			177		
17.0	0.4			1699			634		
47.5	8.7			1702	6795		51	861	
2017.4	8.7								
1453.1	8.7			1334			7		
845.1	8.7			390			1474		
189.0	8.7			1330			1963	3444	
17.0	8.7			273	3327				

Table 13. Yarder specifications for the Wyssen sled

Yarder Information

System type	Standing Skyline
Tower height (m)	5
Talihold height (m)	1
Carriage weight (kg)	2270
Height to logs fly clear (m)	15
Skyline diameter (inches)	1 7/8
Mainline diameter (inches)	3/4
Haulback diameter (inches)	0

Table 14. Summary of yarding costs.
Wyssen sled with chokers

Operation	**Hours**	**Cost** ($ / hour)	**Total Cost** ($)	**Cost** ($/m^3)
Yarding	5397	243.56	1314512	26.92
Backspar rigging	36	54.15	1949	0.039
Mobile backspar			0	0
Yarding subtotal			1,316,461	
Yarder down time	72	109.29	7868	
Pre-rig time (2 men)	36	35.52	1278	
Felling			803719	16.46
Loading & bucking	673	193.45	130378	2.67
Total production costs			$2,259,707	
	Volume harvested	48,828.66m^3		

To calculate the net value of the timber, the costs associated with harvesting are subtracted from the gross timber value.The final gross timber value under the corridors, the net value under the corridors, and the net profit from the harvest are shown below.

Gross timber value under the corridors	$6,748,514 (Can$)
Net timber value under the corridors	$3,374,257 (Can.$)
Total profit from the harvest	$953,647 (Can.$)

Information regarding locations of each corridor, corridor length, width, lateral yarding distance, and other details can be found in the maps of the area.

5.3.3.3. Environmental Impacts

The amount of soil disturbed by the Wyssen sled is minimal considering the following factors. The sled is in a stand of timber and will make one trip up and down the hill at a short distance; the sled slides on the ground and doesn’t churn up soil as a tractor would, and little compaction will result. There is concern about dragging payload on some of the paths for the skyline because of soil disturbance.

This plan provides several advantages in relation to the retention patterns, environmental considerations, and use of other yarding equipment to lower the cost of the operation. The first three corridors will be used to our advantage to feather, and eliminate, the geometric clearcut edge of the site (south side). This plan decommissions the upper road to help eliminate the chance of failure and improve the aesthetic quality of the site. The material we out of reach of the sled corridors can be yarded with either a grapple yarder, a swing yarder with chokers, or forwarding all of the material within reach to the road. Any material that cannot be reached with the previous methods would be left as clumped retention.

Stability of the steep southeast hill is a critical issue- a slump occurred on the northeast corner of the unit. Slope hydrology and the loss of root strength as stumps and large roots decay are a consideration for monitoring. The effects from root strength are usually delayed by about 10 years after the decay of roots, causing long term problems for the area. The STR prescriptions decrease the risk for mass failure by leaving contour aggregates on the steep southeast slope. The Wyssen sled reduces impact on slope stability.

5.3.4. Economics

Economic analysis is based on a Wyssen sled with 2 chokers. The baseline information comes from the length and width of each corridor in question. From this information the area of that corridor is calculated and added to the lateral yarding area (taking into account the feathering pattern of the lateral yarding). The density of each tree species for the unit is known from the cruise information and from this we have calculated the volume of timber in each corridor. The value of each species is used to compute timber value per corridor can be calculated.

Corridor length, width, and lateral yarding distance were used to determine the total area. From the length of the corridor the yarding time per turn, the number of turns, and the weight per turn were evaluated for the system

With total yarding time known, the cost of yarding the area (costs per hour) were estimated from the FERIC report TR-112 (Forrester 1995). In addition, a cost for rigging the backspar was estimated using the same source (each change was estimated to take 4 hours).

5.3.4.2. Potential drawbacks:

The sled is limited in this downhill configuration to the distance gravity will carry the carriage. Because of this, there are some areas within the stand that may be out of reach. An alternative to solve this problem would be to push a road to the area we want to put the sled and use a yarding tower. This would allow a mainline, and in so doing allow for all of the timber under each of the corridors to be within reach.

5.3.4.3. Other Options Considered

5.3.4.3.1. The 24m mobile tower takes the material below the upper road. The idea behind this operation is that a 20m tailhold would be rigged and used throughout the operation as a common tailhold. In doing this the time to change corridors would be lower than if multiple tailholds were used. The other benefit of this operation comes from its visual aspect; all of the corridors are perpendicular, or close to perpendicular, to the vital view sheds which in so doing blocks the public view of the operation. The logs would be yarded down to the lower road and decked there for future pick-up. The yarder would be moved along the road to each of the subsequent corridor locations.

Table 15. Specifications for 24m tower with a central tailspar

System type	Standing skyline
Tower height (m)	24
Talihold height (m)	20
Carriage weight (kg)	2270
Height to logs fly clear (m)	15
Skyline diameter (inches)	1 1/8
Mainline diameter (inches)	3/4
Haulback diameter (inches)	0

Table 16. Costs for 24 metre mobile tower with central tail spar.

Operation	Hours	Cost ($ / hour)		Total cost ($)	Cost ($ / ^3)
Yarding	1525	227.23		346549.6	0.9327
Backspar rigging	10	54.15		541.5	0.017
Mobile backspar				0	0
Yarding subtotal				34,7091.1	
Yarder down time	40	109.29		4371.6	
Pre-rig time (2 men)	16	35.52	5	68.32	
Felling				521756.7	
16.46		Loading & bucking 437		193.45	
84638.61	2.67				
Total production costs				$958,426.4	

Volume harvested 31,698.46m^3

Potential drawbacks:

- Every corridor crosses a salmon bearing stream and the surrounding RMZ
- The tower has 4 guylines to be rigged every time it must be moved increasing the yarder down time

- Because its necessity, the upper spur road will not be available for decommissioning, and therefore poses a potential hazard due to failure
- This operation doesn't appear to be as economically sound as our primary plan

5.3.4.3.2.

The 27.4m central tower covers a large area of the upper region of the unit. The tower is centrally located with multiple tailholds; all of which are 1m. The corridors are once again strung perpendicular to the vital view sheds. The logs would be yarded to the upper spur road and cold decked for future loading.

Table 17: Yarder specifications for 27.4m tower with multiple tailholds

Yarder Information

System type	Running skyline
Tower height (m)	27.4
Talihold height (m)	1
Carriage weight (kg)	2200
Height to logs fly clear (m)	15
Skyline diameter (inches)	0
Mainline diameter (inches)	1
Hulback diameter (inches)	3/4

Table 18. Costs for 27.4m tower with multiple tailholds

Operation	Hours	Cost ($ / hour)	Total Cost ($)	Cost ($ / ^3)
Yarding	1282	227.23	291300.6	29.8
Backspar rigging	24	54.15	1299.6	0.133
Mobile backspar			0	0
Yarding subtotal			292,600.2	
Yarder down time	24	109.29	2622.96	
Pre-rig time (2 men)	24	35.52	852.48	
Felling			160744.2	16.46
Loading & bucking	134	193.45	26075.7	2.67
Total production costs			$482,895.6	
	Volume harvested	9765.75m^3		

Potential drawbacks:

- Every corridor crosses a salmon bearing stream and the surrounding RMZ
- Because of its necessity, the upper spur road will not be available for decommissioning, and therefore poses a potential hazard due to failure
- This operation doesn't appear to be as economically sound as our primary plan

5.3.4.3.3.
30m tower takes the material in the unit from one landing. The operation is rigged off the main road in the lower section of the unit. All of the yarding would be downhill and requires full suspension. The logs would be decked at the landing where they would be loaded in the future.

Table 19. Yarder specifications for 30m tower centrally located

Yarder Information	
System type	Standing skyline
Tower height (m)	30
Talihold height (m)	15
Carriage weight (kg)	2270
Height to logs fly clear (m)	13
Skyline diameter (inches)	1 3/8
Mainline diameter (inches)	1 1/4
Haulback diameter (inches)	0

Table 20. Costs for 30m tower centrally located

Operation	**Hours**	**Cost** ($ / hour)	**Total Cost** ($)	**Cost** ($ / ^3)
Yarding	976	243.56	23,915.8	15.6
Backspar rigging	36	54.15	1949.4	0.12
Mobile backspar			0	0
Yarding subtotal			239,865.2	
Yarder down time	72	109.29	7868.88	
Pre-rig time (2 men)	36	35.52	1278.72	
Felling			249,965.00	16.46
Loading & bucking	209	193.45	40,548.96	2.67
Total production costs			$539,526.80	
Volume harvested	15186.21m^3			

Potential drawbacks:

- Full suspension requires 15m tailholds for all of the corridors
- Corridors are parallel to the critical viewsheds.

5.3.5. Visual Quality
Images were taken from two critical viewpoints and two elevation heights.
Both viewpoints were focused towards the unit from the water, from either the Northwest and the Southwest direction (Figure13 a,b). The elevations were positioned to duplicate the view of an individual from the water surface. For maximum clarity of the unit, an elevation of 5m was chosen and an elevation of 400m was chosen to receive aerial views of the unit (Figure 13 c,d,e).

SVS communicates specific harvest patterns, the general stand structure, a no-work zone, a fan of 5m corridors, and an example of parallel contour patches with 5m corridors (Figure 14 a,b,c). The technically feasible five meter corridors reduce visual impact. The parallel contour example illustrates possible orientation of corridors with strategically located leave areas

Figure 13 (a,b,c). Lines of visibility used for Tofino Inlet-Deer Bay (a,b) and the results from the southwest at 5 metres above sea level.

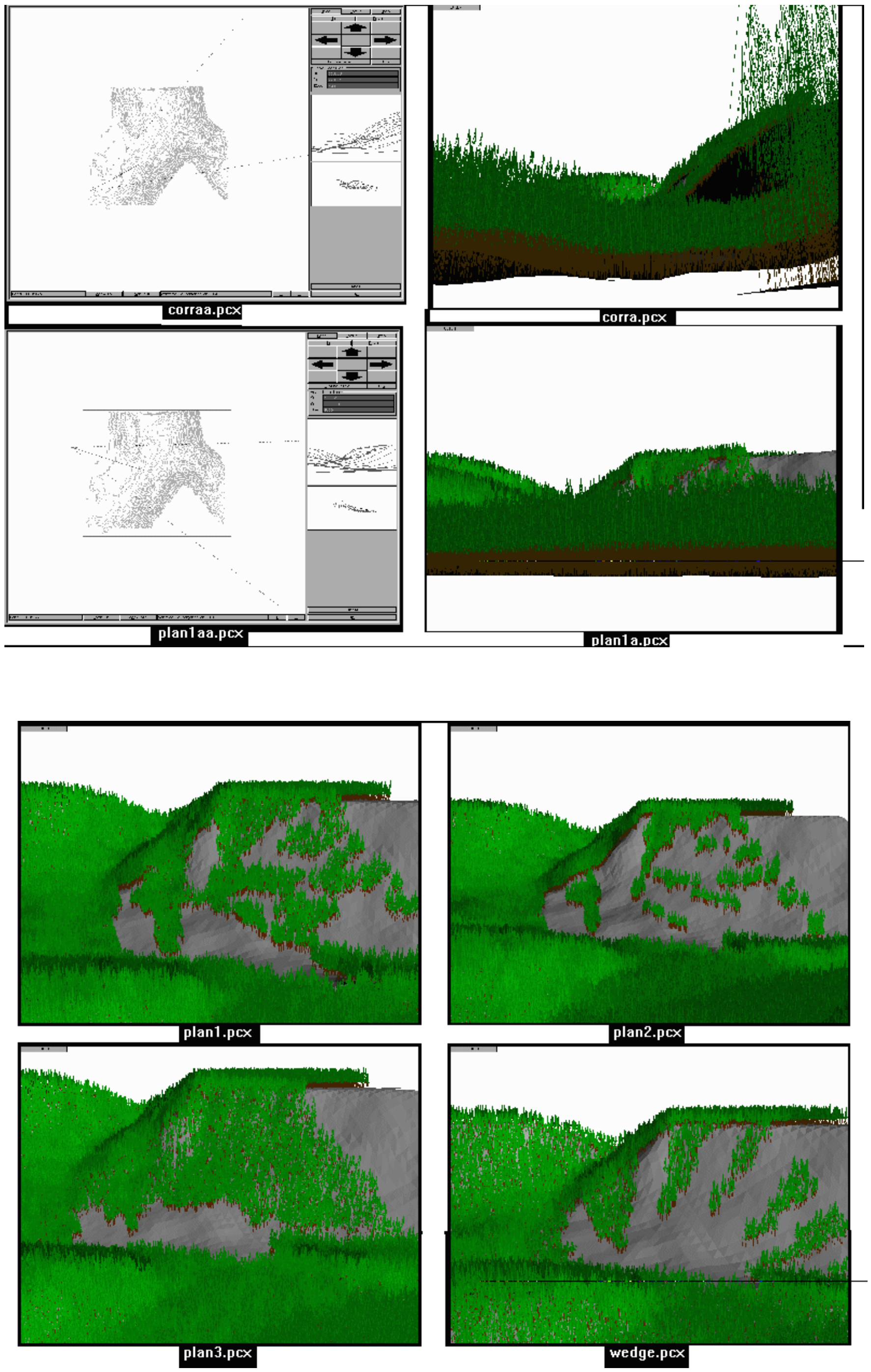
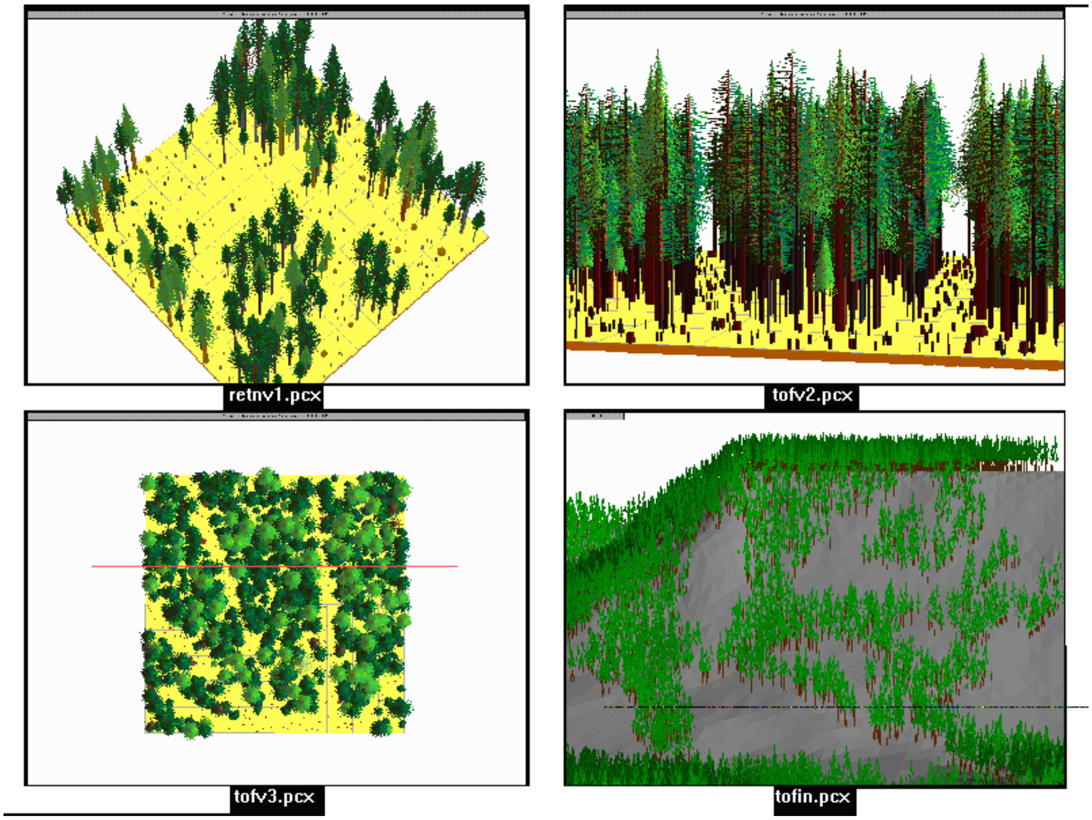


Figure 14. SVS output based on the inventory at Tofino Inlet. including stand structure and retention areas with corridors



5.3.6. Evaluation
We designed a feasible harvest system for Tofino Inlet, using an approach to project organization for harvest system design. Overall, the impacts from the planned harvest on the Tofino unit will be insignificant.

This plan provides several advantages in relation to the retention patterns, environmental considerations, and use of other yarding equipment to lower the cost of the operation:

- The first three corridors will be used to our advantage to feather, and eliminate, the geometric edge of the site (south side).
- Using this plan we can also decommission the upper road to help eliminate the chance of failure and also to better the aesthetic quality of the site.
- The material we cannot reach with the sled corridors can be yarded with either a grapple yarder, a swing boom yarder with chokers, or by simply forwarding all of the material within reach to the road. Any material that cannot be reached with the previous methods would be left as clumped retention .

If the area where the lines cross is moderately dense canopy, minimal damage to the riparian trees may occur (e.g. pruning). The impact of these systems on the riparian area is minimal, mostly from lines crossing the stream. Cables will be laid in the stream and then pulled up nthrough the crown and will remain until the corridor is completed. The amount of oil entering the stream from the nine lines is probably minimal, however they should not be kept in the stream longer than a day. As a safe guard, harvesting could be scheduled in spring and summer when flows are high and thus minimize contamination of salmon eggs.

When considering the environmental impacts, the other species inhabiting the area is also considered. Species of concern will have the riparian area, operable linkages, aggregates of timber as a refuge. Critical issues for the Clayoqout Sound are soil disturbance, slope stability, riparian and terrestrial habitats, and visual quality. Riparian Management Zone (RMZ) will filter most of the sediment unless there is a direct source entering stream such as a culvert, ditch, road or another stream. The total amount of area exposed for the Wyssen system is 4m (the width for each corridor is about 1ft).

Stability of the steep southeast hill is a critical issue-a slump occurred on the northeast corner of the unit. Slope hydrology and the loss of root strength as stumps and large roots decay are a consideration for monitoring. The effects from root strength are usually delayed by about 10 years after the decay of roots, causing long term problems for the area. The STR prescriptions decrease the risk for mass failure by leaving contour aggregates on the steep southeast slope. The Wyssen sled reduces impact on slope stability.

The awareness of worker safety is central to all harvest systems and STR options. The use of parallel contour patches protect workers in steep terrain from falling and rolling debris by creating physical barriers. Our designs provide opportunities to minmize the use of mid-slope roads and reduces maintenance and construction costs.

6. CONCLUSIONS

This report includes a complete harvest system, based on constraints and functional requirements. It is the presentation of a process as much as it is a design solution. It is a developed approach to project management for harvest system design. The design approach involved gathering stand and terrain information for harvest systems and silvicultural approaches. Analyzing each system with specific STR prescriptions for adherence to ecological principles, technical feasibility, production, visual impact and economic feasibility was repeated for the numerous combinations to give an unbiased result.

The process was initiated to design a harvest system that incorporates technical feasibility based on terrain and economics, visual impact based on view sheds, and environmental, societal impact based on local history, biodiversity, and potential harvest impact. Technology increases group productivity, efficiency and product quality using programs such as PLANS, FORSEE, UTOOLS, SVS, and ARC-INFO.

It will be more efficient planning of well designed harvest operations that yield the greatest benefit--both culturally and economically. There are several ways to improve productivity; increase the flow of materials to the workers, increase the quality of the labor, and improve efficiency of use of material and labor (Riggs et al. 1979). If the variables that make work more efficient are identified then design can make use of them to improve production (Taguchi et al. 1989). Likewise, our means of value appraisal includes very little information about setting layout and design (Berg and Schiess *submitted*). For example, if the trade-offs between the amount of sidehill yarding and yarding distance were known, setting designs could describe boundaries that offered the highest utility to loggers.

Management of Clayoquot Sound Forests is a political situation because the defensible solution combines functional requirements of numerous disciplines into definable design criteria. The technical application here offers design suggestions that first maintain the biological legacy of these magnificent, productive forests safely and feasibly, then provides for the cultural, recreation, jobs, aesthetics, and ecologically designed development.

The process provides the landowner with the range of consequences of choosing specific management alternatives, with preferred alternatives that demonstrate the utility to public and private land managers.

ACKNOWLEDGMENTS

We wish to thank senior class forest engineers at the College of Forest Resources, University of Washington, for their valuable assistance: Dave Carlson, Matt Walsh, Robin McKennon, Kristen Stohr, Joseph Cho,Vahid Khastou, Mark Davis, Julie Garrison, Weikko Jaross, Reed Moss, Jeff Paschall, Leon Serachan. Tim Brown has offer suggestions about faller safety. Kathryn Jeanne Young-Berg of Wild@heart provided crucial support. Robert MaGauhey has generously offered his personal insights on the tools he has developed: UTOOLS, SVS. PLANS, HEILPACE, and FORSEE

BIBLIOGRAPHY

Alexander,T.G. 1989. Timber management, traditional forestry, and multiple use stewardship: The case of the Intermountain Region. Jour. For.Vol.33, No. 1.pp 21-34

Arbor-Pacific. 1996. LOG LINES January 1996- Price reporting service for the Pacific Northwest. Mount Vernon, Washington.

Arnott, J.T., W.J.Beese, A.K.Mitchel, and J.Peterson. 1995. Montane Alternative Silvicultural Systems (MASS). Forestry Canada and British Columbia Ministry of Forests Joint Publication. FRDA Report No..238. 122 pp.

Berg, Dean Rae, and Peter Schiess. (submitted). Forest Harvest Setting Design Evaluation Incorporating Loggers' Preference. Jour. For. Vol. 94 No. 7 pp (July)

Birch, K.R., and K.N. Johnson. 1992. Stand level wood-production costs of leaving live, mature trees at regeneration harvest in coastal Douglas-fir stands. W. Jour. Appl. For. Vol. 7(3):65-68

Centre for the Study of the Environment (CSE). 1995. *Status and Future of Salmon in Western Oregon and northern California. Santa Barbara, CA*

Clayoquot Sound Scientific Panel (CSSP). 1995. *Sustainable Ecosystem Management in Clayoquot Sound: Planning and Practice.* Cortex Consultants, Victoria, British Columbia. Canada. 295 pp.

Collins, B.D., T.J.Beechie, L.E.Benda, P.M.Kennard, C.N.Veldhuisen, V.S.Anderson, and D.R.Berg. 1994. Salmonid habitat and watershed assessment and restoration plan for Deer Creek, North Cascades of Washington. Report to Stilliguamish Indian Tribe and Washington Department of Ecology. 232 pp.

Cullen, J., and P.Schiess. 1992. Integrated computer aided timber harvest planning system. in Proceedings of the International Mountain Logging Symposium. Seattle, Washington. pp.

Depta, D.J. 1984. Integrated forest planning systems at Weyerhaeuser Company. *in* Proceedings IUFRO Symposium on Forest Management Planning and Managerial Economics. Forest Management Laboratory. Tokyo, Japan.

Dimancescu, D. 1992. The Seamless Enterprise: Making Cross Functional Management Work. Harper Business, Harper-Collins Publishers, Inc. New York.Dyson, R.G. 1990. *Strategic Planning* . John Wiley and Sons. New York.

Elm, Taylor James. 1994 Managing Forests for Structural Diversity: Principles, Regulatory constraints, and application. Master of Science thesis. Simon Fraser University. Vancouver, British Columbia.

FEMAT 1993. Forest Ecosystem Management: An Ecological, Economic, and Social Assessment. Interagency SEIS team. Portland, OR.

Forrester, P.D. 1995. Evaluation of three cable yarding systems in a coastal old-growth forest. Forest Engineering Research Institute of Canada Technical Report No. TR-112 Dec., P.Q., Canada.

Franklin, J.F. 1992. Scientific basis for new perspectives in forests and streams. in New Perspectives for Watershed Management: Balancing Long-Term sustainability with Cumulative Environmental Change. R.J.Naiman University of Washington. 25-72 pp. Springer-Verlag. New York.

Franklin, J.F., and R.T.T.Forman. 1987. Creating landscape patterns by forest cutting: ecological consequences and principles. Landscape Ecology 1:5-18.

Franklin, J.F., D.R. Berg, D. Thornburg, and J. Tappenier. 1996 (in press). Alternative silvicultural approaches to timber harvest: Variable Retention Harvest System. In Forestry fot the Twenty First Century, K. Kohm (ed.). Island Press. Washington D.C. pp

Howard, A.F., and L.E. Coultish. 1993. Production equations for tower yarding in coastal British Columbia. For. Eng. Vol 4(2):19-25

Keegan, C.E, C.E.Fielder, and F.J. Stewart. 1995. Cost of timber harvest under traditional and "New Forestry" silvicultural prescriptions. WJAF 10(1) pp 36-42 Kimmins, J.P. 1987, *Forest Ecology* , Macmillan Publishing Company. 257 pp

Kimmins, J.P. 1995. *Balancing Act* . University of British Columbia Press. Vancouver B.C. Canada.

Krag, R.K., E.A.Sauder, and G.V.Wellburn. 1986. A foreset engineering analysis of landslide areas on Queen Charlotte Island, British Columbia. British Columbia Ministry of ForestsLand Mgmt. Report No..43 (August 1986)

Mac Arthur, R.H., and E.O.Wilson. 1967. *The Theory of Island Biogeography* Princeton University Press. Princeton, New Jersey.

Ministry of Forest. 1993.Coastal Fisheries / Forestry Guideline Manual.

Ministry of Forest. 1994. A field guide for site identification and interpretation for the Vancouver forest region. British Columbia Ministry of Forest Land Mgmt. Report No. 28.

Ministry of Forest. 1995. Forest Practices Code of British Columbia: Silvicultural Systems Guidebook. Province of British Columbia

Mitsch, W.J., and S.E. Jorgensen. 1989. *Ecological Engineering* . Wiley and Sons, Inc. New York. 472 pgs.

Naiman, R.J.,T.J.Beechie, L.E.Benda, D.R.Berg and others. 1992. Fundamental elements of ecologically watersheds in the Pacific Northwest coastal ecoregion. in New Perspectives for Watershed Management: Balancing Long-Term sustainability with Cumulative Environmental Change. R.J.Naiman University of Washington. pp.127-188 Springer-Verlag. New York.

Nielson, R.W., J.Dobie, and D.M. Wright. 1985. Conversion factors for the forest products industry in western Canada. Forintek Canada Corp. Western Laboratory, Vancouover B.C.

Oliver, C.D., D.R. Berg, D.R. Larsen, K.L. O'Hara. 1992. Integrating management tools, ecological knowledge, and silviculture. in New Perspectives for Watershed Management: Balancing Long-Term sustainability with Cumulative Environmental Change. R.J.Naiman University of Washington. Pp 361-382. Springer-Verlag. New York.

Parminter, J. 1992. Typical historic patterns of wildfire disturbance by biogeoclimatic zone: map addendum. After Old growth forests: problem analysis. British Columbia Ministry of Forests. 1990. 104 pp.

Perry, D.A. 1994. *Forest Ecosystems* . Johns Hopkins University Press. Baltimore, Maryland. 649p.

Riggs J.L., L.L. Bethel, F.S. Atwater, G.H.E. Smith, H.A. Stackman. 1979. Industrial Organization and Management. McGraw-Hill Co. New York

Ruth, R.H. and R.R. Silen. 1950. Suggestions for getting more forestry in the logging plan. Research note 72. USDA Forest Service. PNW Forest and Range Experiment Station. Portland, OR

Sauder, B.J. and M.M. Nagy. 1977. Coast Logging: Highland Versus Long-Reach Alternatives. Forest Engineering Research Institute of Canada Technical Report No. TR-19 Dec., P.Q., Canada.

Sauder, E.A., and G.V. Wellburn. 1987. Studies of yarding operations on sensitive terrain, Queen Charlotte Islands. B.C. Land Management Report No. 52. Ministry of Forests. Victoria, B.C.

Schiess, P., and J.Cullen, and S.Brown. 1988. Long-term timber sales planning. In Proceedings of the International Mountain Logging Symposium. Portland, OR. pp. 82-86

Simpson, John. 1900. *The New Forestry or the Continental System Adapted to British Woodlands and Game Preservation.* Pawson & Brailsford. Sheffield, England.

Studier, D.D., and V.W.Binkley. 1974. *Cable Logging Systems* . USDA Forest Service. Portland, OR

Swanson, F.J., and D.R. Berg. 1991. Ecological roots of new approaches to forestry. Forest Perspectives. Vol.1 No.3 pp 6-8

Swanson, F.J., and J.F.Franklin. 1992. New forestry principles from ecosystem analysis of Pacific Northwest forests. Ecol. Apps. 2:(3) 262-274

Taguchi, G, E.A. Elsayed, and T.C. Hsiang. 1989. *Quality Engineering in Production Systems*. McGraw-Hill. New York.

Toumey and Korstian. 1937. *Foundations of Silviculture Upon and Ecological* Basis. John Wiley & Sons. New York

Twito, R.H., S.E. Reutebuch, R.J. McGaughey, C.N. Mann. 1987. Preliminary logging analysis system (PLANS): overview. PNW-GTR-199. 24 p. Pacific Northwest Forest and Range Experiment Station, Portland, OR

Walters, C. 1986. *Adaptive Management of Renewable Resources*. Macmillan Publishing Co. New York.

Weigand, J., and L. Burdett. 1992. Economic implications for Management of structural retention units on the Blue River Ranger District, Willamette National Forest. Research Note PNW-RN 510 USDA Forest Service Pacific Northwest Forest Research Station. Portland, Oregon.

Zeilke, Ken. 1993. Environmental Forestry: Plum Creek Timber Company's Approach to Forest Management: A Case Study. Government of Canada, Province of British Columbia. 19 pp.

Man will occasionally stumble over the truth but most times he will pick himself and carry on.

Winston Churchill

APPENDIX 1: Stand Summaries

APPENDIX 2a: Data for ownership and operating costs and Machine Costs

APPENDIX 2b: Ownership and operating costs

APPENDIX 2c: Operating costs

APPENDIX 3: Maps with Data from PLANS - Cut-block site maps

Kennedy Flats Skyline Analysis

Yarder Description

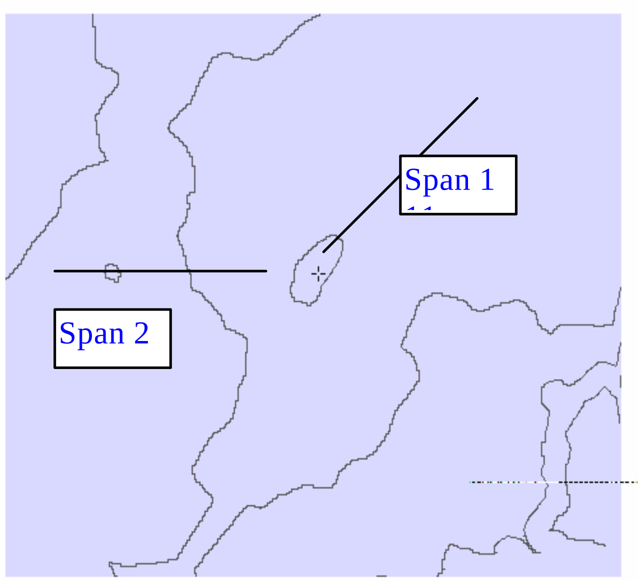
Type of skyline system: RUNNING skyline; Thunderbird TMY-90

Maximum slope rigging distance (feet)	2000
Desired payload (pounds)	9000
Minimum required ground clearance (feet)	2
Carriage height when logs fly clear (feet)	50
Carriage weight (pounds)	3000
Tower height (feet)	90
Tailhold height (feet)	45
Allowable haulback tension (pounds)	53300
Haulback line weight (pounds/feet)	2.89
Mainline or combined main and slackpulling line weight (pounds/feet)	1.42

Tower:

Located at terrain point	1
Elevation (feet)	55
Horizontal distance from terrain point 1 (feet)	0

Yarding Limits: No analysis conducted within 50 feet of the tailhold.

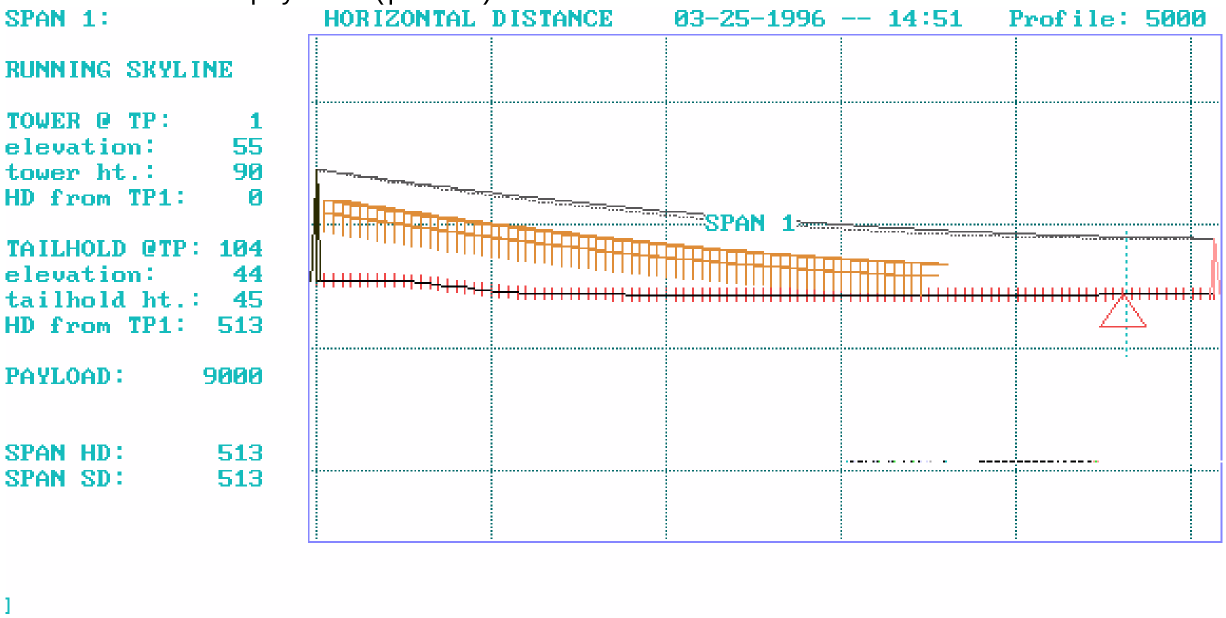


Analysis Results

Span 1

Tailhold:

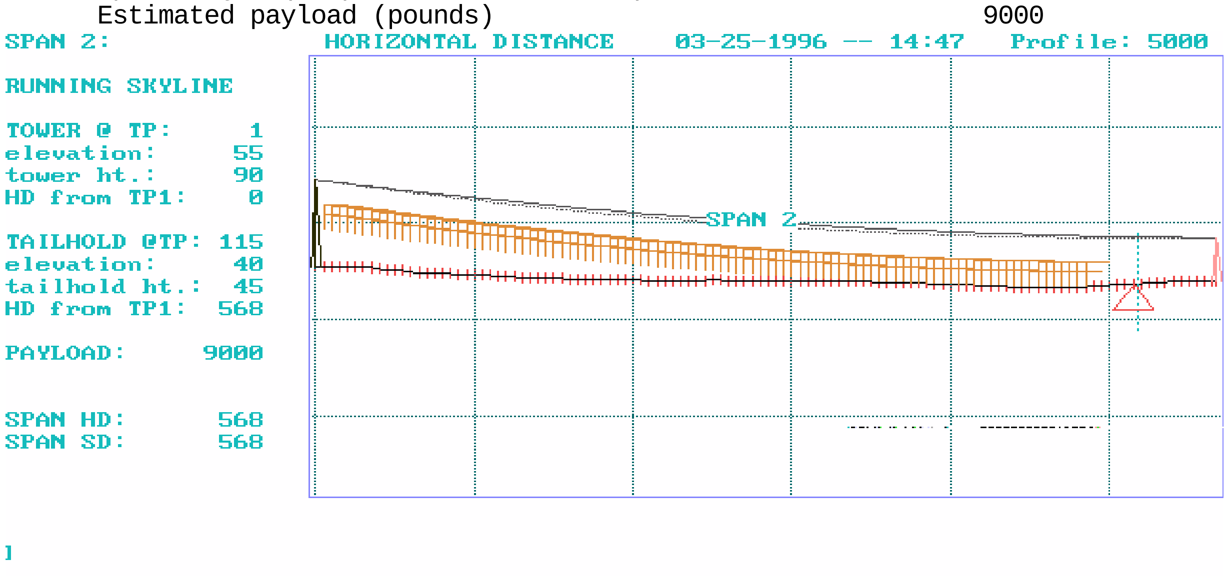
Located at terrain point	104
Elevation (feet)	44
Horizontal distance from terrain point 1 (feet)	513
Span length (horizontal distance in feet)	513
Span length (slope distance in feet)	513
Estimated payload (pounds)	9000



Span 2

Tailhold:

Located at terrain point	109
Elevation (feet)	40
Horizontal distance from terrain point 1 (feet)	537
Span length (horizontal distance in feet)	537
Span length (slope distance in feet)	537
Estimated payload (pounds)	9000



Tofino Inlet-Deer Bay Skyline Analysis

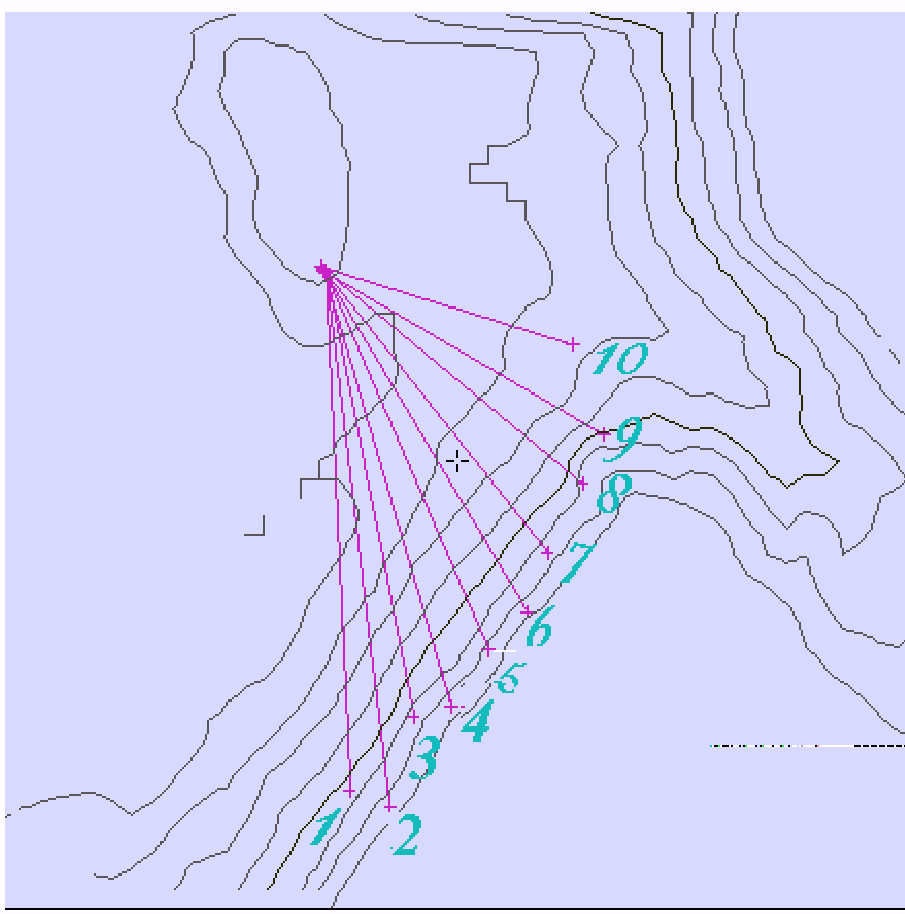
PLANS --- SKYMOBIL Version: 2.10
Yarder Description
Type of skyline system: Live skyline; Wyssen Sled

Maximum slope rigging distance (meters)	2200
Desired payload (kilograms)	6818
Minimum required ground clearance (meters)	5
Carriage height when logs fly clear (meters)	15
Carriage weight (kilograms)	2270
Tower height (meters)	5
Tailhold height (meters)	1
Allowable haulback tension (kilograms)	52594
Haulback line weight (kilograms/meters)	9.66
Mainline or combined main and slackpulling line weight (kilograms/meters)	1.54

Yarding Limits: No analysis conducted within 15 meters of the tailhold.

Tower - common for all cable spans

Located at terrain point	1
Elevation (meters)	86
Horizontal distance from terrain point 1 (meters)	0

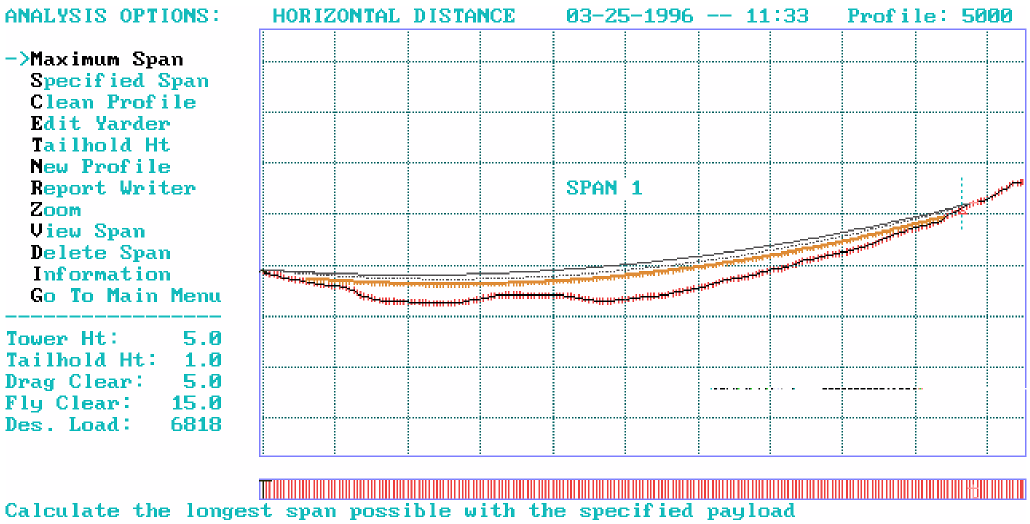


Analysis Results

Span : 1

Tailhold:

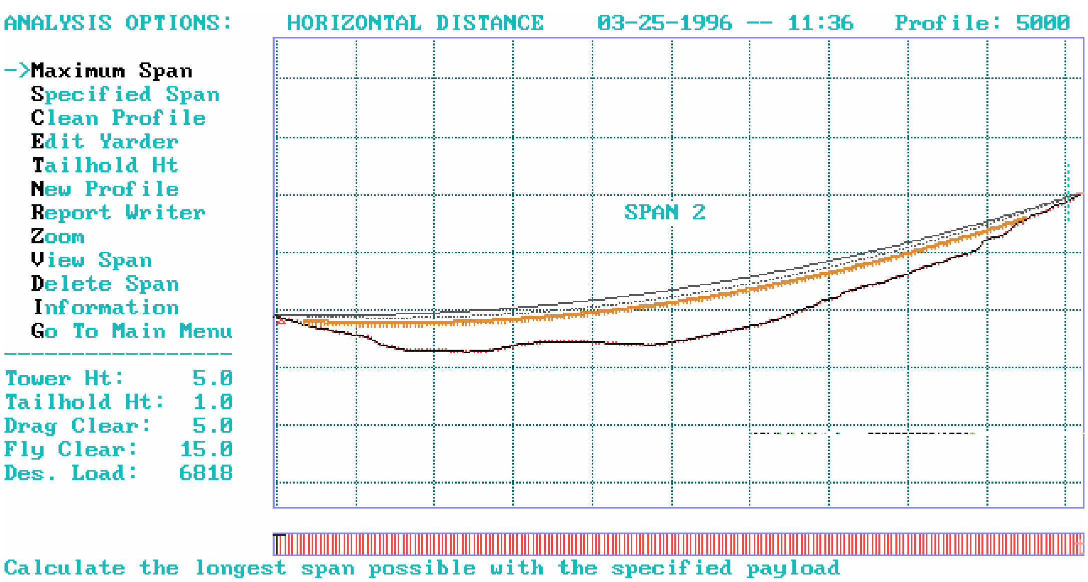
Located at terrain point	197
Elevation (meters)	221
Horizontal distance from terrain point 1 (meters)	980
Span length (horizontal distance in meters)	980
Span length (slope distance in meters)	989
Estimated payload (kilograms)	6818



Span 2

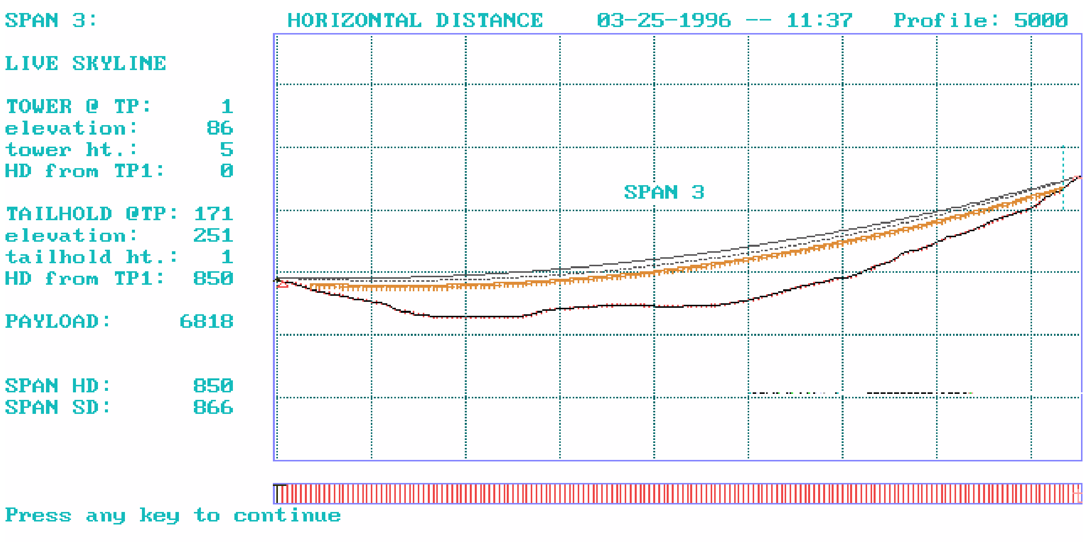
Tailhold:

Located at terrain point	205
Elevation (meters)	301
Horizontal distance from terrain point 1 (meters)	1019
Span length (horizontal distance in meters)	1019
Span length (slope distance in meters)	1041
Estimated payload (kilograms)	6818



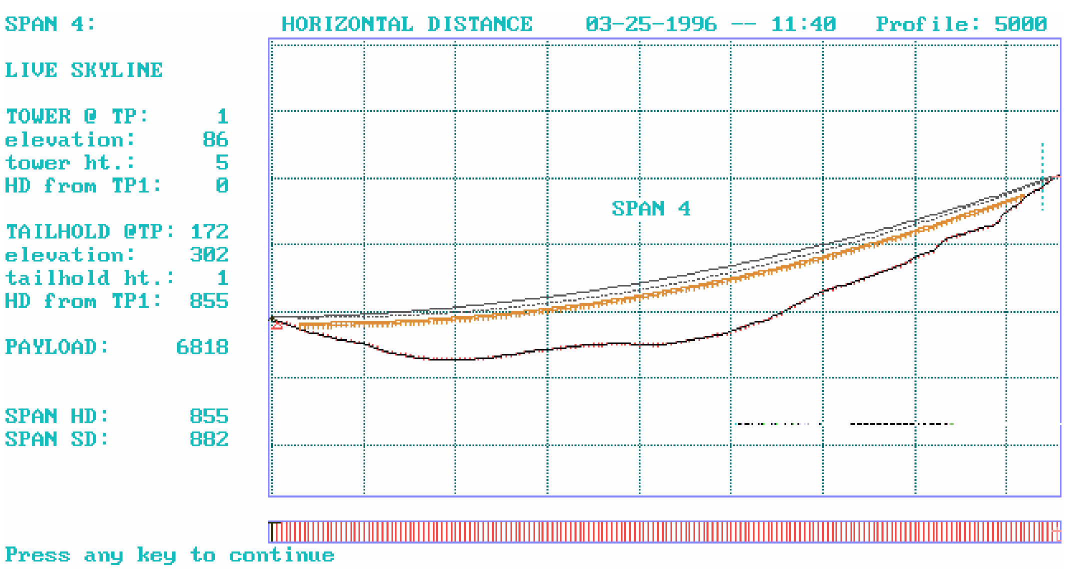
Span 3
Tailhold:

Located at terrain point	173
Elevation (meters)	260
Horizontal distance from terrain point 1 (meters)	860
Span length (horizontal distance in meters)	860
Span length (slope distance in meters)	877
Estimated payload (kilograms)	6818



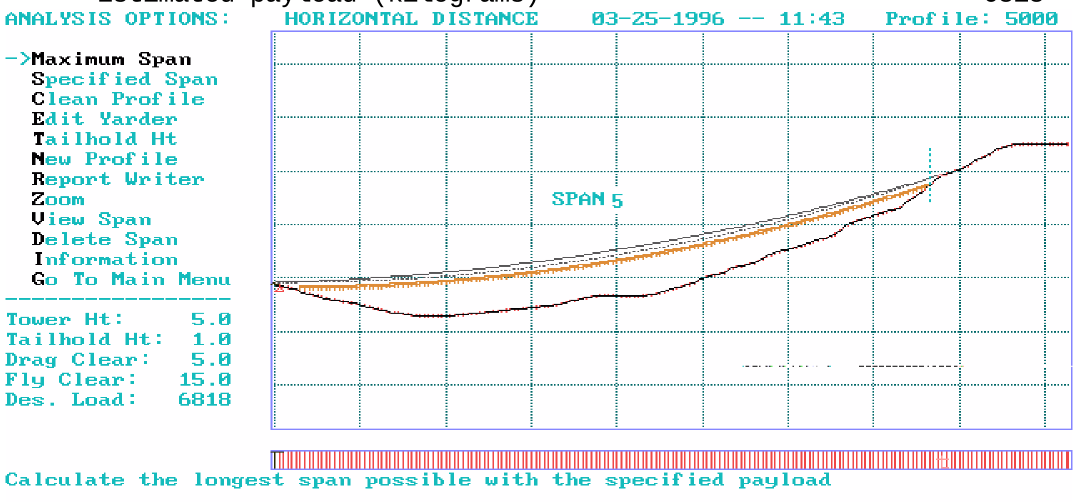
Span 4
Tailhold:

Located at terrain point	172
Elevation (meters)	302
Horizontal distance from terrain point 1 (meters)	855
Span length (horizontal distance in meters)	855
Span length (slope distance in meters)	882
Estimated payload (kilograms)	6818



Span 5
Tailhold:

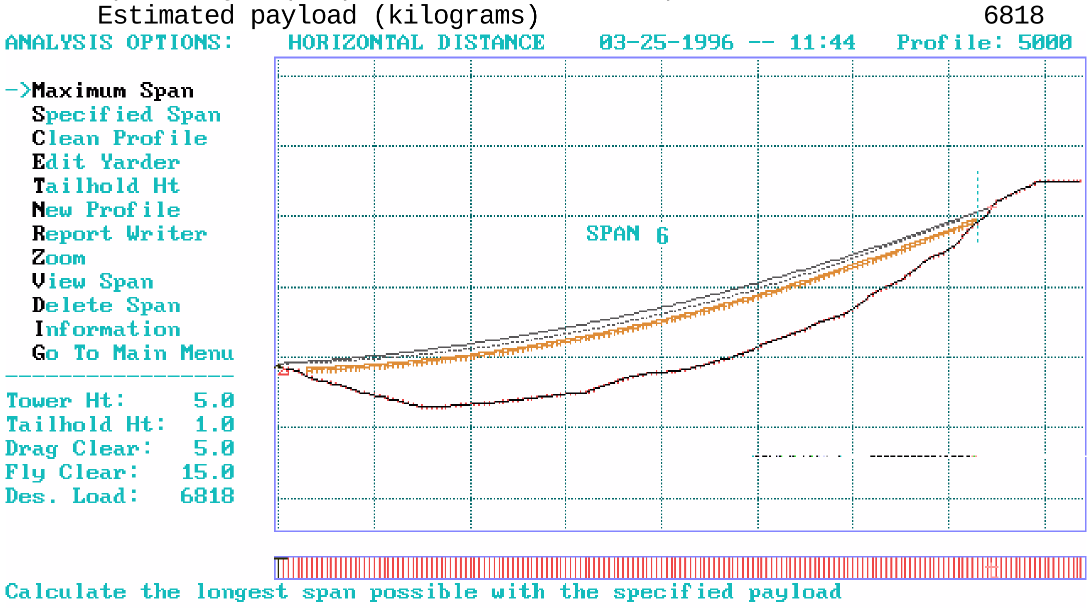
Located at terrain point	157
Elevation (meters)	291
Horizontal distance from terrain point 1 (meters)	780
Span length (horizontal distance in meters)	780
Span length (slope distance in meters)	806
Estimated payload (kilograms)	6818



Span 6

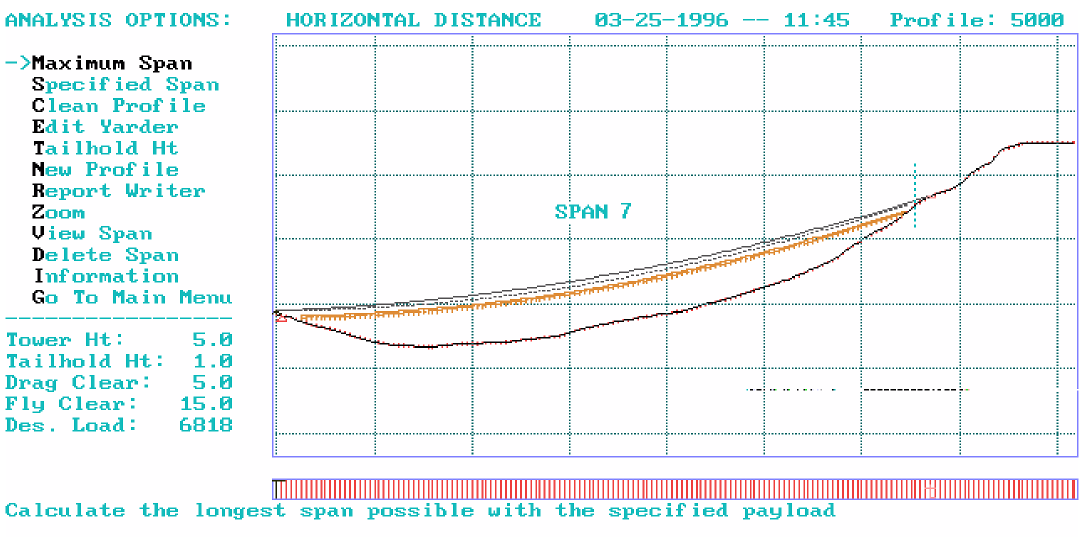
Tailhold:

Located at terrain point	150
Elevation (meters)	313
Horizontal distance from terrain point 1 (meters)	745
Span length (horizontal distance in meters)	745
Span length (slope distance in meters)	779
Estimated payload (kilograms)	6818



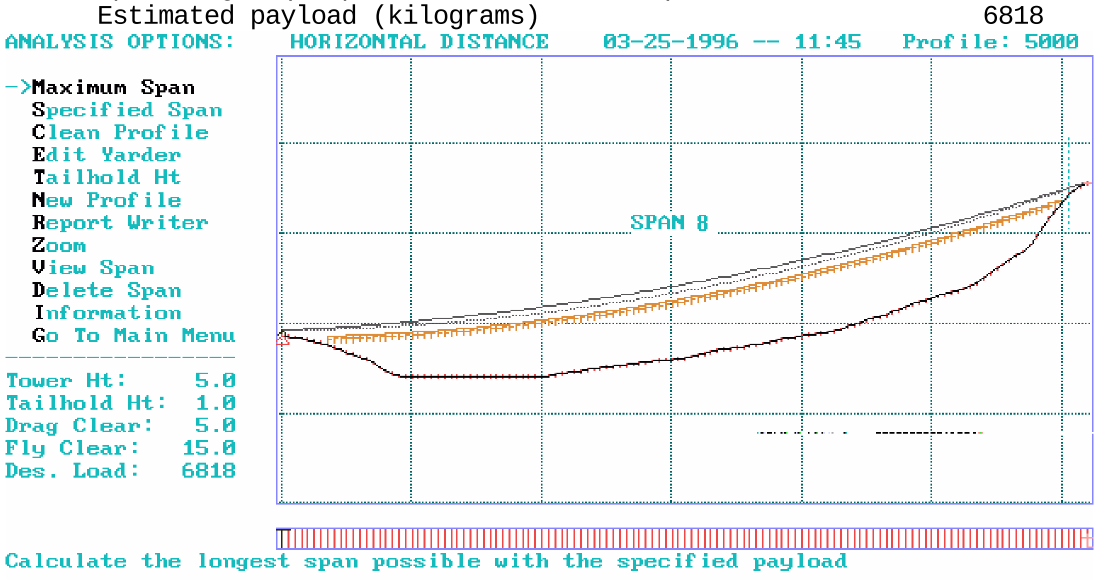
Span 7
Tailhold:

Located at terrain point	135
Elevation (meters)	266
Horizontal distance from terrain point 1 (meters)	670
Span length (horizontal distance in meters)	670
Span length (slope distance in meters)	694
Estimated payload (kilograms)	6818



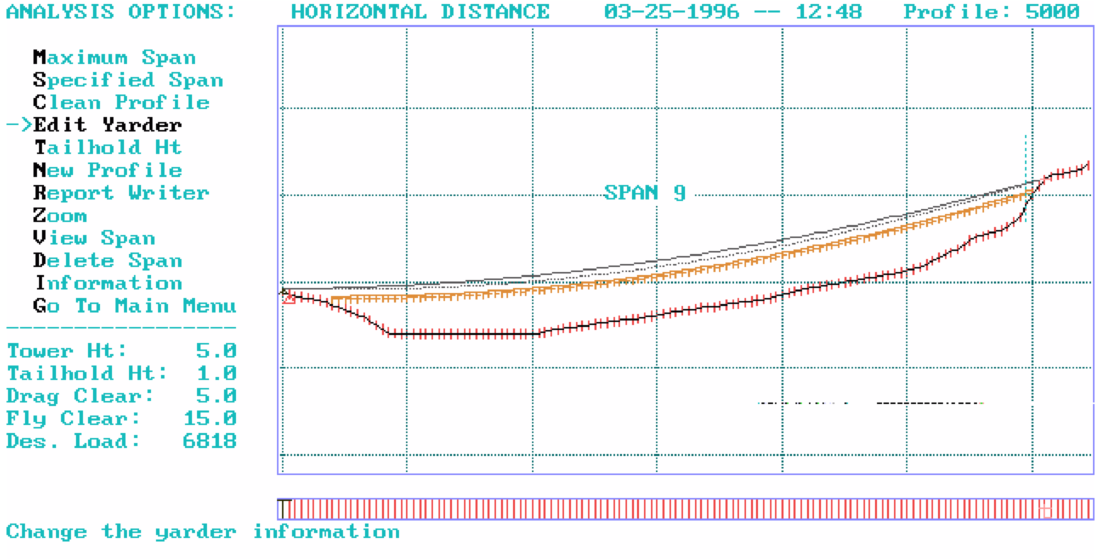
Span 8
Tailhold:

Located at terrain point	126
Elevation (meters)	255
Horizontal distance from terrain point 1 (meters)	620
Span length (horizontal distance in meters)	620
Span length (slope distance in meters)	643
Estimated payload (kilograms)	6818



Span 9
Tailhold:

Located at terrain point 123
Elevation (meters) 218
Horizontal distance from terrain point 1 (meters) 610
Span length (horizontal distance in meters) 610
Span length (slope distance in meters) 624
Estimated payload (kilograms) 6818



Span 10
Tailhold:

Located at terrain point 100
Elevation (meters) 109
Horizontal distance from terrain point 1 (meters) 495
Span length (horizontal distance in meters) 495
Span length (slope distance in meters) 495
Estimated payload (kilograms) 6818