1. As for the total stand a given site has a fixed productive capacity, or maximum final yield.

2. In all stands, all live stems eventually become merchantable. Nevertheless merchantable volume never equals total volume because of the wood lost in the stumps and tops.

3. Stand tending treatments increase the proportion of total stand volume which is merchantable, and reduce the age at which all live stems become merchantable.

4. Unlike total stand volume, spacing treatments can produce an equal or greater merchantable stand volume than an untreated stand, over a considerable part of the rotation. Eventually the merchantable volume in the spaced and unspaced stands will converge.

5. Spacing and fertilization treatments reduce the age at which a stand reaches harvestable size.

6. In the first years after treatment it is reasonable to expect the effects on merchantable volume of spacing and fertilization combined to exceed the sum of the separate treatment effects. Later, this "synergistic" effect should diminish.

Operational conditions are quite different from those in which research is conducted. Many naturally regenerated stands on cutover areas have irregular stocking due to clumping or deciduous stand components. Planting and spacing both improve the stem distribution. Market conditions affect the actual recovery during harvesting so the bigger the average diameter, the higher the recovery is likely to be.

In operational conditions, treatments are constrained by cost and physical output targets. Research plots are specially selected to have very even stocking and all treatments are very carefully and uniformly applied.

The effect of operational conditions on the yield of treated versus natural stands are discussed in the next section of the report.

OPERATIONAL CONDITIONS

The responses to intensive treatments which are captured in the merchantable part of the stand are different from total stand responses. Similarly, responses in operational conditions are different from those found in research conditions. Mitchell and Cameron (1985) suggest that research plots produce yields in excess of what can be achieved operationally because microsite, irregular spacing, environmental conditions and other factors are not as carefully controlled in the operational environment as they are in research installations. Research plots are often treated, altered or abandoned if damaged by pests, weather, or other agents. Mitchell and Cameron (1985) identify three reasons for differences between potential (research plot) yields and operational yields. These are, site occupancy, chronic losses and productive potential.

Site occupancy refers to the effect of rock outcrops, small marshes, and other openings that create unproductive areas. Understocking associated with low regeneration density, clumping, brush competition, and mortality from insects, diseases and other pests has a similar impact. Overstocked stands, on the other hand, can carry high volumes for short periods, but are unstable and prone to snow and ice damage.

Chronic losses caused by insects, pests and diseases can reduce volume growth without killing trees.

Productive potential means that some areas may be relatively more productive than others, relative to top height. This concept is incorporated into the British Forest Management Tables (Bradley et al. 1971) as "Production Classes". The authors state that "factors which influence Production Class tend to be macro-climatical rather than specific to individual stands." Genetic makeup could also contribute to differences in the productive potential.

For coastal Douglas-fir Mitchell and Cameron estimate the difference between potential and actual total yield to be 20% in stands 40 metres in height. This difference can be minimized by forestry practices like site preparation, planting, brushing and weeding, spacing and thinning, fertilization and pest management.

The biggest difference between actual and potential total yields will be found in naturally regenerated second growth stands. The smallest difference will be found in intensively managed plantations. In this sense, in operational conditions, forestry practices result in a yield "gain". For example, if forestry practices result in a yield equal to 90% of potential versus 80% in natural stands, then a 12.5% gain (10/80) has been achieved.

This whole question of potential versus actual yields has tremendous practical significance. Unfortunately, so little information is available that it must be classified as a "gray area". Field foresters have an intuitive feel that their forestry practices do narrow the gap between potential and actual yields. No one appears to have any "hard" information on this subject. The consultants' suggest it is high time to find out more about potential versus actual yields.

In the following paragraphs the effects of some common forestry practices on closing the gap between actual and potential yields are outlined.

PLANTING

Planting provides good regular stocking. A well planted stand reduces the reduction from potential yield in naturally regenerated stands caused by low density, clumping or from snow and ice damage in overstocked stands. Planting also provides the opportunity to gain from genetically improved stock, and reduces loss of yield by reducing the regeneration delay.

BRUSHING AND WEEDING

Brushing and weeding preserves good site occupancy. Reductions to potential yield from brush competition are prevented. In severe cases, brushing and weeding may mean the difference between no yield at all and a healthy commercial stand.

SPACING AND THINNING

Spacing and thinning provides more regular stocking thereby lessening the reduction from potential yield due to poor site occupancy. At the same time rotations are reduced because the merchantable proportion of total stand volume is increased in younger stands.

FERTILIZATION

Fertilization directly increases yield and shortens rotations by increasing the merchantable proportion of total stand volume in younger stands.

CONCLUSIONS ABOUT OPERATIONAL CONDITIONS

There are several conclusions to be made about applying forestry practices in operational versus research conditions.

1. Operational conditions are different from research conditions.

2. Actual yields in operational conditions are less than the potential yields represented by research plots due to incomplete site occupancy, chronic losses and variations in productive potential for the same site index.

3. Natural regeneration of cut-over land will capture the lowest proportion of the potential yield.

4. Forestry tending practices result in improved yields over natural regeneration by capturing a higher proportion of the potential yield.

5. Knowledge of the difference between actual yields in operational conditions and the potential yields of research plots is very weak.

This completes the trail from growth and yield theory to operational conditions. The next and final section of this survey provides some conclusions relating total stand production, merchantable stand production and production under operational conditions.

GENERAL CONCLUSIONS

For the range of densities encountered under operational conditions in even-aged stands:

1. A given site has a fixed potential yield because it provides just so much soil moisture, soil nutrients, carbon dioxide and sunlight for plant growth.

2. Spacing or a low initial density does not increase the fixed potential yield of a site. Therefore, spacing of a low initial density does not increase potential total stand volume. In fact a spaced stand carries a smaller total volume/ha than an untreated or high density stand for a considerable period. Eventually the total volume of the spaced stand catches up to the untreated stand. In operational conditions the spaced stand volume may eventually exceed the unspaced stand.

3. In terms of merchantable volume, a spaced or low initial density stand may not carry a reduced volume/ha and may carry an increased merchantable volume/ha for a considerable period. Eventually the merchantable volume of the untreated or high density stand will catch up to the spaced or low density stand.

4. A spaced or low density stand will reach a harvestable size more quickly. If harvesting occurs as soon as the stand is big enough, then spaced and low initial density stands may yield a higher merchantable volume than high density stands. An example will illustrate this for a rotation using stand diameter.

Suppose a natural Douglas-fir stand takes 85 years after logging to reach 40 cm stand dbh, and is then logged to yield a merchantable volume of 750 m^3/ha. The mean annual increment (merchantable) is 8.8 m^3. Suppose a plantation on the same site takes only 65 years after logging to reach 40 cm dbh and is logged, yielding 621 m^3/ha merchantable volume. The M.A.I. for the plantation is 9.6 m^3. In terms of merchantable volume and a technical rotation determined by size, in this hypothetical example, the plantation will give a 9% increase in production. However, both MAI's using the dbh rotation may be less than the biological maximum (culmination) MAI.

5. Fertilization does raise the productive capacity of a site and, like spacing shortens the time to merchantable size.

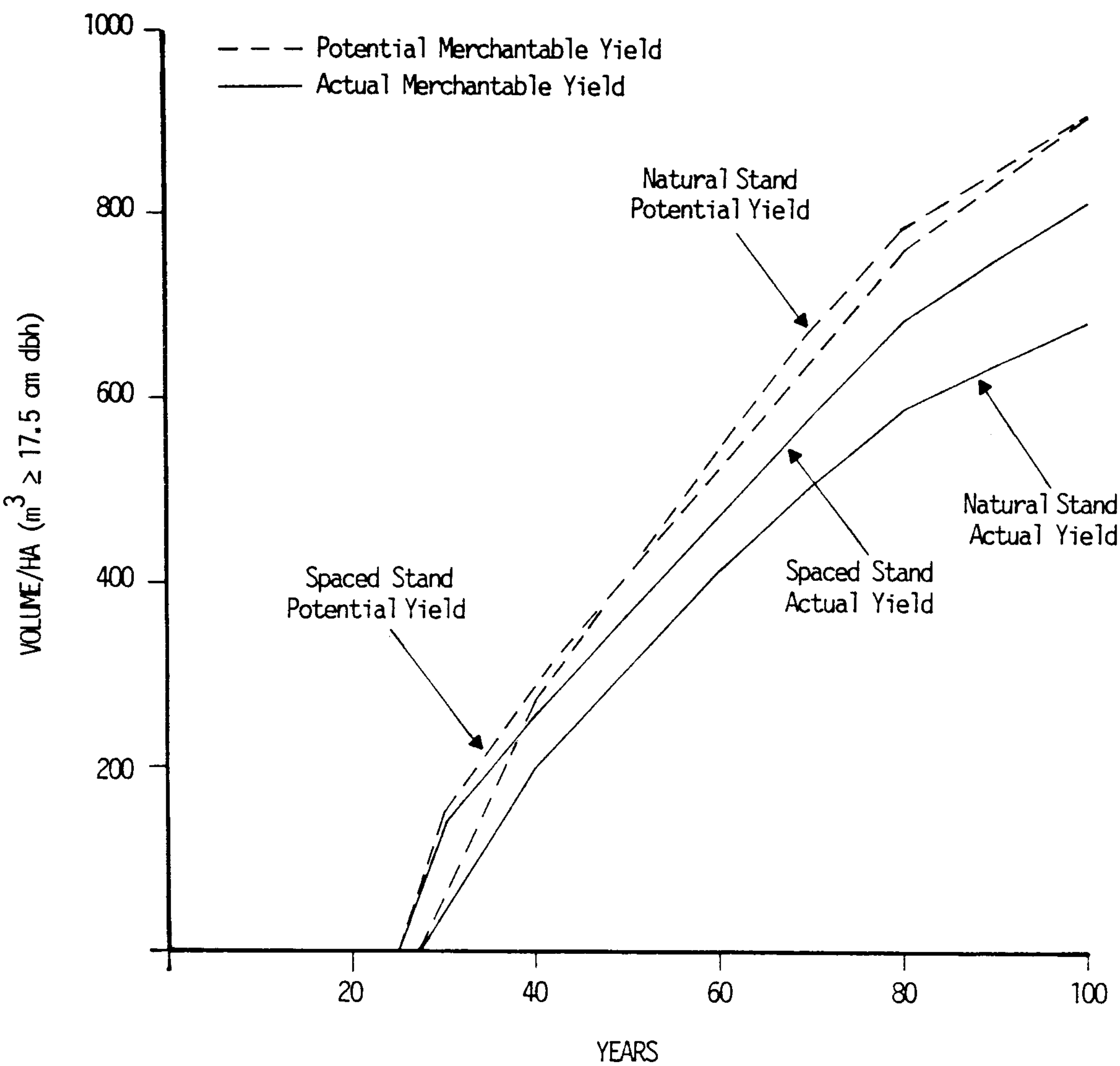
6. A desirable initial stand density, or spacing treatment, is one which results in a stand at harvest which has a relative density index (RDI) between 0.4 and 0.55 at rotation age. This stand will have the largest dbh possible, have minimized mortality, yet will be fully stocked and as close as possible to the potential yield for that rotation age.

7. In terms of merchantable stand volume and short second growth rotations applying treatments under operational conditions can produce yield gains over naturally regenerated stands. Information on these gains is very weak and should be improved by some field research. Figure 10 gives an example for spaced coastal Douglas-fir stands. At 100 years after stand establishment the natural and the spaced stand have the same potential yield in terms of

merchantable volume. In operational conditions both stands produce less than the potential but the actual yield of the spaced stand is expected to be 16% greater than the natural stand at 100 years. Although the dbh is not shown in Figure 10, at 100 years the dbh of the natural stand is expected to be 39.0 cm while the spaced stand dbh is expected to be 45.4 cm.

Figure 10: Coastal Douglas-fir SI 30

Potential and Actual (Operational) Merchantable Yields in a Natural and a Spaced Stand



II. IMPACT OF INTENSIVE FORESTRY PRACTICES IN B.C.

DESCRIPTION OF THE YIELD TABLES

Second growth yield tables were constructed for coastal Douglas-fir, western hemlock, mixtures of western hemlock and amabalis fir, and interior spruce, lodgepole pine and wet belt Douglas-fir. All of these yield tables should be considered to be preliminary.

Each yield table shows volume per hectare, diameter at breast height and stems per hectare. Volumes are in cubic metres per hectare, diameters are in centimetres. For lodgepole pine only, trees 12.5 cm or greater in diameter are included in the tables. For all other species, trees 17.5 cm or greater are included. For all species the table volumes represent the wood between a 30 cm stump and a 10 cm top.

The tables were prepared for good and medium sites only. The site class boundaries followed were those used by the B.C. Ministry of Forests and Lands. These boundaries are not consistent between species. Table 2 shows the Ministry's site class boundaries using a 50 year total age reference.

Table 2. 50 Year Total Age Site Class Boundaries

Species	Site Class Lower Boundary (m at 50 years) Good	Medium
COAST		
Douglas-fir	31.8	22.7
Hemlock	27.0	18.7
INTERIOR		
Spruce	16.0	12.2
Lodgepole pine	19.5	15.1
Douglas-fir	19.9	15.4

In preparing the yield tables the following site index curves were used for each species:

- Coastal Douglas-fir: Bruce (1981)
- Interior Douglas-fir: Monserud (1985)
- Hemlock: Wiley (1978)
- Balsam: B.C. Ministry of Forests and Lands (1979)
- White spruce: Goudie (1984)
- Lodgepole pine: Goudie (1984a)

Table 3 shows the total age site index representing good and medium sites for each species according to Ministry of Forests site class boundaries.

Table 3. Total Age Site Index for Good and Medium Sites

Species	Good	Medium
COAST		
Douglas-fir	36	27
Hemlock	31	23
Balsam	28	21
INTERIOR		
Spruce	18	14
Lodgepole pine	22	17
Douglas-fir	22	18

The yield tables were based on or developed from the results from three stand simulation models. Douglas-fir and hemlock tables were based on PAKSTAND, a stand model developed by the consultant. Spruce and lodgepole pine tables were based on TASS, as reported by Goudie and Mitchell (1986) and Goudie (1984b). The spruce tables for spaced stands were influenced by the results from TASS for unthinned stands. TASS is the stand model used by the B.C. Ministry of Forests. The yield tables for mixed hemlock/balsam stands were influenced by the SPS model developed by Applied Biometrics Inc., Spokane.

For each species, statistics for the merchantable part of the stand were modified to represent operational conditions. A set of operational adjustment factors were developed to allow for production losses caused by irregular stocking, insects, diseases and other factors described earlier in the report. No allowances for decay waste and breakage have been made in the yield tables. The operational adjustment factors are shown in Table 4 below:

Table 4. Operational Adjustment Factors

	Douglas-fir	Hemlock	Spruce	Pine
Natural	0.75	0.80	0.80	0.85
Planted	0.90	0.90	0.90	0.90
Spaced	0.90	0.90	0.90	0.90
Spaced and Fertilized	0.90	-	-	-

The complete set of yield tables is presented in Appendix 1.

EFFECT OF PRACTICES ON NET STAND VALUES

INTRODUCTION

In order to illustrate the effect of operational yields in relation to the intensive forestry practices on a financial basis the consultants programmed their forest investment model with information reflecting current conditions (i.e. costs and prices) and calculated the expected returns on the application of a practice as if it were an investment. The assumptions and the costs and prices used are detailed in Appendix 2. It is important to note that different assumptions and more specific and/or precise costs and prices can change the values discussed. Attention should be focused on the general principles and situation rather than on the specifics of any one example. For instance, spacing a regime may or may not be attractive because of the costs involved. It may also be attractive or not attractive depending on whether a premium market value is attributed to larger diameter trees.

The analysis is based on market derived values for the general current situation. It mainly follows the Faustmann principles or assumptions, and the decision criterion is basically the net present value generated by application of a practice or treatment on one hectare of forest for a maximum of one rotation.

VALUES IN RELATION TO PRINCIPLES

In Section I the principles were established that relate the physical responses to the practices in question. These responses are inherent in the yield curves presented in Appendix 1. The objective of this section is to illustrate, using the differences between yield curves or deviation from curves, what the physical response is in terms of net present value in light of the application of a practice or treatment. The practices being considered are:

1. brushing and weeding
2. conifer release
3. juvenile spacing
4. fertilization.

Brushing and Weeding, or Conifer Release

These practices remove competing vegetation and thus allow the more rapid development of the forest stand. This effect is minor but positive, and is not covered in this analysis. The major concern addressed in this study is where brush prevents the establishment of a "normal" forest stand, either natural or planted. In this situation a drastic deviation from the normal natural stand yield curve or the normal planted stand yield curve can occur. In essence, we have an inadequately stocked regime and are losing the total physical response on part of a productive site. While yield curves are currently not available for the seriously understocked situations the discussions in Section I can indicate the general physical result. We can, however, explore what the values would be from losing the entire one hectare of forest (or half, or three-quarters) by deviating from our normal curve on the basis that it applies to only some portion of the one hectare. This assumption may not be unrealistic as brush take-over does frequently occur in patches.

Juvenile Spacing

This practice can correct for drastic overstocking and hence reduce a long term competitive mortality situation. If the stand is drastically overstocked (stagnating), considerable mortality over an extremely long rotation is required to obtain a final crop which may or may not have an acceptable stem diameter size. Spacing in this situation is, in essence, rescuing the stand from a rotation length that is not acceptable from an investment point of view, or rescuing the stand from not attaining merchantable sized stems within a reasonable rotation or investment period.

Spacing stands that are fully stocked or moderately overstocked can best be described as an enhancement procedure where steady future growth on fewer stems provides a more valuable stem. Where long rotations are considered, total volume will be similar to the unspaced stand but will be based on fewer large stems (provided adequate or minimum stem numbers are maintained to fully utilize the site). Investments in enhancement spacing are really being directed at stem size. If volume is not to be lost, rotations must be long. If rotations are short, volume must be sacrificed to obtain the desired stem size.

What is important, and what has not been documented to date, is that operational yield curves depending on species and site and initial stocking density vary to great extremes while fulfilling the above conditions. To date, for second growth stands, we have not had adequate definitions of "understocked", "fully stocked" and "over stocked". Hence, when we consider spacing as a treatment we may not be in the enhancement mode as discussed above, but are really applying our treatment to inadequately stocked or excessively stocked stands. This phenomenon is expressed in the yield curves developed by the consultant. Coastal Douglas fir, for instance, established at 2800 stems per hectare (natural stand) experiences competitive mortality at a very early age. Spacing this stand at 15 or 20 years of age increases volume within 10 years and the relative difference in volume, i.e. convergence, does not occur until after some 120 years. In this situation, from an investment viewpoint, spacing becomes an attractive practice provided the cost is appropriate. Note also that the investment situation is not as dependent on a larger stem requiring a value premium. At the other extreme, note that white spruce (natural stand) established at 2500 stems per hectare does not experience significant competitive mortality until some 100 years of age. Spacing this stand significantly increases stem diameter but drastically curtails volume. Convergence does not occur until after 120 years. In this situation spacing from an investment point of view would not be appropriate unless a very large premium in value was associated with large stems.

Paramount to the whole issue of spacing is what level of stocking is it being applied to, and then will it meet stem size objectives?

Fertilization

This practice provides a transient growth response, and at the end of the growth period the fertilized stand is in a position to yield higher total and merchantable volumes than the unfertilized stand at the end of the rotation. The effect, in terms of increased diameter, is most noticeable in stands that are just fully stocked. When fertilization is combined with spacing, the age at which a stand reaches harvestable size is decreased even farther. Spacing and fertilizing can be a very effective practice where a premium value for larger stems exists.