Implications of proposed parking lot development for wind loading and resistance of trees, MacMillan Park, Vancouver Island.

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Introduction

Problem statement

This project was initiated by Bill Zinovich of BC Parks. The objectives are to:

1. assess how a proposed parking lot south of MacMillan Park will increase the susceptibility of trees adjacent to the parking lot and within the park to windthrow.
2. recommend actions to reduce the potential for windthrow within the proposed parking lot and in the adjacent park.

Context

The proposed parking lot is immediately south of MacMillan Park on land recently acquired from Weyerhaeuser Corporation. The Park is 157 ha in area and lies on a floodplain and lower slopes within the Cameron Valley. At this location, the Cameron Valley narrows and changes direction from north-south to east-west. The area is well known for high winds with routine westerly summer Qualicums generated by air temperature differences between the east and west coasts of Vancouver Island, and periodic extreme winter winds from the south and west associated with the passage of Pacific low pressure systems and resulting fronts. The constricted topography funnels winds from the south and west. The stand in Cathedral Grove is dominated by very large old Douglas-fir in 300 and 800 year age cohorts. Many of these trees reach 70m in height. Rooting is generally restricted by a water table, although in the sorted soils of the floodplain, rooting often exceeds 1.5m. Rooting and bole strength is compromised in many trees by *Phellinus weirii* (laminated root rot) or *Phaeoleus schweinitzii* (brown cubical butt rot). The tops of the trees are flagged to the west and there is much evidence of wind caused branch loss, indicating that these trees are acclimated to routine wind loads.

There has been a history of windthrow in the Cameron Valley. The area proposed for the parking lot is within a stand that initiated after clearcut salvage of a natural windthrow patch in 1958. Windthrow events initiating from old windthrow salvage areas along the south park boundary on the east side of the main Cameron River channel caused 8.6 ha of damage within the park in the winter of 1990-91. An additional 24.7 ha of moderate damage and 12.0 ha of heavy damage occurred on January 1, 1997. This event also caused considerable damage in old growth stands east of Cameron Lake and in second growth stands on the lowlands on the east side of Vancouver Island. In my 1998 report, I concluded that future wind events of the magnitude of the January 1, 1997 event are likely (30-40 year return period) and will cause further extension of the damage to the north and east. The stand to the west of the highway experienced minimal damage in the 1990-91 and 1997 events.

Project Approach

In preparing this report, I have reviewed results of recent windthrow modeling and wind tunnel studies. I have evaluated the incremental effects of the parking lot using two modeling approaches. I have inspected the site of the proposed parking lot and adjacent stands in the field. Time and budget were insufficient to conduct a detailed analysis of wind flow in the Cameron Valley or the effects of the proposed parking lot.

Limitations of windthrow risk assessment

Windthrow has deterministic and stochastic components. The latter results from variability in wind speed and turbulence, the complex interaction of wind, terrain and canopies, and the variability in anchorage as soil properties change with soil moisture. Mechanistic and empirical modeling approaches have been developed to predict the likelihood and severity of damage. At best these results are probabilistic. Our recent work suggests a high degree of consistency in variables selected in empirical models, however, local validation is necessary.

Methods

Empirical windthrow risk model

We have recently completed a GIS-based empirical model for Weyerhaeuser's West Island Timberlands. This operating area extends from the west coast to central Vancouver Island. MacMillan Park directly abuts the operating area. To build the model we selected six 1:20,000 NTS mapsheets representative of the range of conditions. Weyerhaeuser supplied 1:15000 scale colour aerial photographs, digital orthophotographs, forest cover, ecosystem and logging history layers. We obtained TRIM topographic data from the BC MRSM. BC Hydro provided their wind resource map data. The flow of wind over terrain in response to synoptic weather conditions is simulated for key days from the climate record using numerical modeling techniques. The mean wind speed is represented at 1km grid resolution. Wind roses are represented at 5km grid resolution. Using stereo-photo pairs, we map and estimate crown closure loss to windthrow around cutblock edges and within-block reserves for all areas harvested within 10 years before the photographs were taken. Using custom scripts, we calculate distance limited topographic exposure from the digital elevation models. Each cutblock and within-block reserve is buffered with a 25m deep buffer. Each buffer is divided into 25m long segments. For the centroid of each segment, we determine the distance across the opening (fetch) in each of the 8 cardinal directions. We calculate boundary orientation from the coordinates of adjacent segments. Data from each map layer is extracted for each segment centroid. The resulting database is imported into SAS statistical software. The frequency of damage for levels of class variables is analyzed. After accounting for spatial correlation, segments are randomly assigned to 3 datasets. For each dataset a family of logistic regression models is fit and tested against the other 2 datasets. Since logistic models predict the probability of an event. It is necessary to determine a threshold value of wind damage in a boundary segment. This threshold was based on two variables, the percentage of segment area within a windthrow polygon, and the percentage canopy loss. Models were fit for a low severity threshold (= 30% segment area loss, = 20% canopy loss; minimum detectable level with aerial photographs), and a high severity threshold (= 90% segment area loss, = 50 % canopy loss). The logistic models are 70-75% accurate at predicting the outcome of individual boundary segments.

ForestGALEs

The UK Forestry Commission has developed a deterministic windthrow risk model based on the mechanics of windthrow. ForestGALES calculates the critical wind speed necessary to cause overturning or stem breakage, and the probability of this wind occurring. The model was developed for uniform plantations. Critical turning moment equations were empirically determined in tree winching studies. Drag equations were empirically determined in wind tunnel studies. The wind regime for the United Kingdom was determined using tatter flags. Wind behaviour in canopies was determined using field and wind tunnel experiments. A number of BC species including Sitka spruce and Douglas-fir are represented in the model, however, the model is not completely validated for the UK and is unvalidated for BC. The effect of opening size on the probability of critical wind is useful for the purpose of this report.

Wind tunnel

Dr. Michael Novak of the Department of Forest Sciences at UBC has completed field and wind tunnel studies of the effect of opening length and width on wind loading. He has also studied the effect of opening length in a field study at the Sicamous Creek study site in South Central BC.

Edge modification

There have been several studies on the effects of edge modification in Coastal BC. The most comprehensive was by Chuck Rowan of the BC Ministry of Forests. Wind exposed cutblock boundaries at 14 locations on Vancouver Island and the Queen Charlotte Islands were divided into 50-70m long and 20-30m deep treatment units. These treatment units were randomly assigned to control (untreated), crown modification or edge thinning treatments. Treatments were completed prior to the first winter winds after harvesting of the adjacent cutblock was completed. All overstory trees were tagged and measured prior to treatment and then remeasured each summer for several years. The treated stands included young mature (1906 windthrow origin), mature and old growth stands.

Data sources

Forest cover data immediately adjacent to MacMillan Park, and topographic and mean wind data within and adjacent to the Park was available in the GIS dataset prepared for the WIT study. Ecosystem and administrative layers for the Park were provided by Bill Zinovich of BC Parks, along with a digital version of an early parking lot layout and a paper version of a more recent layout. I visited the study site on December 18, 2003 and inspected the area of the proposed parking lot, the Weyerhaeuser private land immediately to the south and the Park immediately to the north. I also refer to weather and ecosystem data collected for the preparation of my January 1998 report on the January 1, 1997 windthrow event and refer to the observations and conclusions contained in that report.

Application of models in project

The data for the 1958 stand and for the high volume old growth stand was entered into the logistic regression models for low and high damage severity thresholds. The effects of varying opening size on probability of damage was evaluated by varying the score (fetch) and direx (number of cardinal directions with > 100m of fetch) variables. For comparison, base and worst case scenarios were also modeled. Since we have no data for wind damage in unharvested stands, the base scenario (minimal change in wind exposure) is a north facing boundary on an opening less than 100m wide. The worst case scenario (maximum change in wind exposure) would be a south facing boundary on a clearcut more than 10 tree lengths wide. As a test for the model predictions, the actual percentage of segments with at least the threshold level of damage was also tallied using the WIT dataset restricted to segments with attributes similar to those of the 1958 and high volume old growth stands.

ForestGALES was under stand and soil conditions like the 1958 stand (height 32.5, DBH 34, 3.3m spacing, notched planting, average drainage, gleysol). The model was initially run for Sitka spruce since it is better represented than other species in the datasets underlying the ForestGALES equations. The model was then re-run for Douglas-fir and for western hemlock with the same stand and soil conditions. For these two species the model provides a warning that this combination of conditions is not represented in the underlying database.

Results

Stand conditions

The stand, site and opening data conditions obtained from the GIS are summarized in Table 1. The proposed parking lot is within a second growth stand that initiated in 1958. The stand immediately to the west of this is labeled as a medium volume second growth stand. This stand type appears to extend into the park to the north of the 1958 stand. Further to the west of the 1958 stand and is a high volume old growth stand that may be more representative of the stand conditions nearer to the core trail area of the park. Length of parking lot measured from north boundary to corner in access road to south. The GIS variables were used in the empirical model. The length of the parking lot and the second growth stand data was used in ForestGALES.

Table 1. Summary of variables obtained from GIS dataset.

Variable	Source	Value
Composition of 2nd growth stand	Forest Cover	Deciduous
Height of 2nd growth stand	"	-
Age of 2nd growth stand	"	42 years
Site Index of 2nd growth stand	"	34
Volume of 2nd growth stand	"	-
Composition of medium vol OG stand	Forest Cover	Hemlock, Douglas-fir
Height of medium vol OG stand	"	-
Age of medium vol OG stand	"	204
Site Index of medium vol OG stand	"	27
Volume of medium vol OG stand	"	726
Composition of high vol OG stand	Forest Cover	Douglas-fir
Height of high vol OG stand	"	-
Age of high vol OG stand	"	329
Site Index of high vol OG stand	"	40
Volume of high vol OG stand	"	1709
Topex limited to 3000m	DEM, TRIM	100
Modelled mean wind speed	BC Hydro	4.9 m/s
Length of parking lot north to south	Paper map	190m
Length from north end to road corner	"	265m
Width of parking lot	"	100m
Length of salvage opening to south	Orthophoto	560m
Directional fetch within parking lot	Paper map	S=265 SE=72 SW=93
Combined Fetch (SCORE)		430
Number of directions with > 100m (DIREX)		1

The stand and site conditions observed during the field inspection of the proposed parking lot and adjacent stands are summarized in Table 2. A number of uprooted and broken trees were observed in this stand. In most cases there was evidence of structural root erosion due to Phellinus weirii or heartwood decay due to Phaoleous schweinitzii. Phellinus damage was distributed throughout the stand, but several larger gaps were observed. The presence of these diseases in the old growth stand within MacMillan Park is well known, but it was surprising how well advanced they were in this very vigorous second growth stand. There was also some windthrow of trees with sound root systems that were restricted by a water table.

Table 2. Summary of variables obtained from field inspection.

Variable	Value
Composition of 2nd Growth	hemlock (30) grand fir (30) Douglas-fir (20) big leaf maple (10) red alder (5) redcedar (5)
Height of 2nd growth	33 m
Diameter of 2nd growth	35 cm
Height of OG	65-70 m
Top of sub-canopy in OG	35m
Soils	sorted, silts-sands
Rooting depth	variable, 40-150cm

There were two long, narrow areas of windthrow salvage to the west of the proposed parking area. Both ran north from the access road. The first was approximately 60m east of the gate on the access road. This area was approximately 25m wide and ran for approximately 320m at a bearing of 030°. The second area was approximately 20m east of the point where the south spur road leaves the access road. This area was approximately 15m wide and ran for 150m at a bearing of 005°. Presumably these areas were to salvage timber damaged in the 1997 event. No new windthrow was observed along the side or end of these gaps. In contrast, approximately 20% of the large overstory Douglas-fir retained in the area of partial salvage at the north end of the 1997 salvage opening south of the access road have been windthrown since the completion of salvage. There is a 70m tall dead Douglas-fir at the junction of the south spur road and the access road. While this tree is ribboned as a wildlife tree, it has Phaoleous schweinitzii conks at the base and leans to the north over the road.

Empirical model

The results of the empirical model are summarized in Table 3. The model calculates the probability of damage for a 25m long, 25m deep section of the boundary at the north end of the parking lot. The model was run for conditions in the 1958 stand, for conditions in the medium volume old growth stand, and again for conditions in the high volume old growth stand. Results reflect the average outcome for stands with similar properties in the WIT dataset.

Table 3. Empirical model results for second growth and old growth.

Scenario	Probability of damage to boundary
Low Severity Threshold	
2^{nd} Growth, north facing (base case)	0.04
2^{nd} Growth, south facing no gap (base case)	0.16 (0.23 n=792 2^{nd} all vrs180)
2^{nd} Growth, parking lot	0.21 (0.23)
2^{nd} Growth, parking lot plus salvage opening	0.23 (0.27)
2^{nd} Growth, full exposure	0.58
Med vol OG, north facing (base case)	0.05
Med vol OG, south facing no gap (base case)	0.19
Med vol OG, parking lot	0.24
Med vol OG, parking lot plus salvage opening	0.27
Med vol OG, full exposure	0.63
High vol OG, north facing (base case)	0.10
High vol OG, south facing no gap (base case)	0.32
High vol OG, parking lot	0.40
High vol OG, parking lot plus salvage opening	0.43 (0.48 n=82 OG all vrs180)
High vol OG, full exposure	0.78
High Severity Threshold	
2^{nd} Growth, north facing (base case)	0.01
2^{nd} Growth, south facing no gap (base case)	0.08 (0.07 n=792)
2^{nd} Growth, parking lot	0.10 (0.09)
2^{nd} Growth, parking lot plus salvage opening	0.10 (0.10)
2^{nd} Growth, full exposure	0.21
Med vol OG, north facing (base case)	0.01
Med vol OG, south facing no gap (base case)	0.8
Med vol OG, parking lot	0.11
Med vol OG, parking lot plus salvage opening	0.11
Med vol OG, full exposure	0.28
High vol OG, north facing (base case)	0.02
High vol OG, south facing no gap (base case)	0.15
High vol OG, parking lot	0.19
High vol OG, parking lot plus salvage opening	0.19 (0.19 n=82)
High vol OG, full exposure	0.36

ForestGALES

The results of the ForestGALES runs for the second growth stand are summarized in Table 5. The result is given in critical wind speed, the above canopy wind speed needed to cause uprooting (Turn) or stem breakage (Break). Note that Sitka spruce (Ss) is intermediate in windfirmness between western hemlock (Hw) and Douglas-fir (Fd). Gap length is the length of the opening in the wind direction in meters.

Table 5. ForestGALES results for second growth in critical wind speed (km/h).

Gap length	Ss Turn	Ss Break	Fd Turn	Fd Break	Hw Turn	Hw Break
0	78	71	86	91	68	60
25	54	49	61	65	48	43
50	52	47	58	62	46	42
100	49	45	57	60	45	40
200	48	43	55	58	43	39
300	47	43	54	58	43	39

Wind Tunnel

The results of Novak et al. and of Gardiner et al. (Figures 1 and 2) both indicate that once openings are longer than 5 tree lengths, there is little shelter from the stand to windward. However, the results of these studies are quite different for gaps less than 5 tree lengths long. The Gardiner wind tunnel study indicates a minimal sheltering effect. While the Novak wind tunnel and field studies indicate a significant sheltering effect. This may reflect lower crown density in Gardiner's model forest. Given the similarity between Novak's wind tunnel and field results, I am inclined to put more weight on Novak's findings. Furthermore, in our WIT study the percentage of segments damaged was 12, 20, 25 and 37% for gaps of 20, 100, 180 and 300m respectively. ForestGALES uses equations from Gardiner's study and therefore shows a large initial decrease in critical wind speed as a gap develops, followed by a very gradual decrease as the gap widens. I believe that this change is too abrupt and does not properly reflect the shelter that occurs in gaps of several tree lengths.

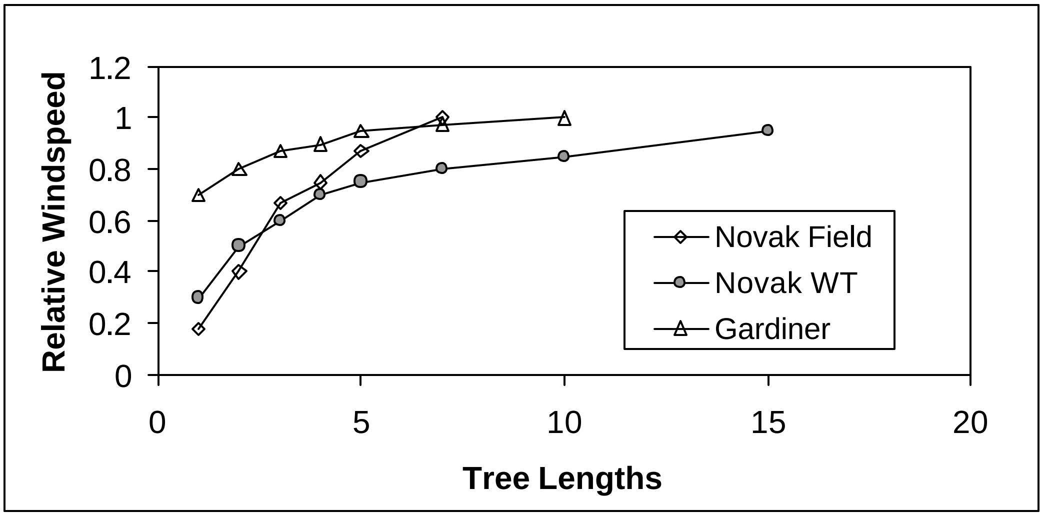

Figure 1. Effect of opening length on relative wind speed.

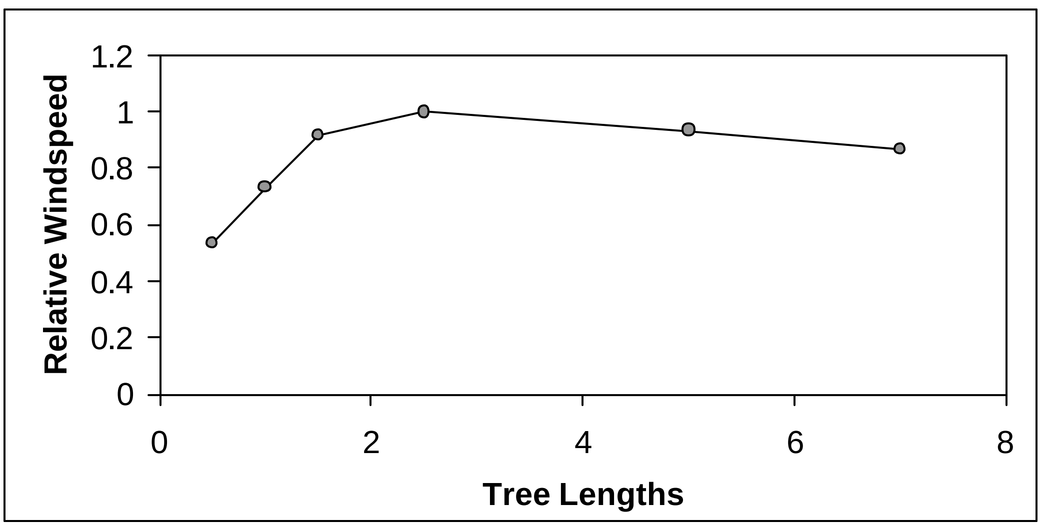

Figure 2. Effect of opening width (cross wind direction) on relative wind speed.

Discussion

Effect of proposed opening on susceptibility

The empirical model results indicate that in openings on southwestern Vancouver Island with attributes that are generally similar to those of at the north end of the proposed parking lot the probability of damage (low severity threshold) from endemic winds is 21%. This is an increase of 17% from the north facing base-case, but still represents a substantial reduction from the probability for a fully exposed boundary. For the medium volume old growth stand adjacent to the parking lot, the probability of damage 24%. If the parking lot abutted a high volume old growth stand such as that to the south, the probability of damage would be 40%. For the high severity threshold, the probabilities are 10%, 11% and 19% for the second growth, medium volume old growth and high volume old growth respectively.

Effects of varying opening size

Wind loading on windward facing boundaries varies with opening size. The empirical results indicate that with a parking lot that is 190m from south to north and 100m from east to west, the probability of damage (low severity threshold) to a south facing boundary increases from 16% for a minimal gap to 21% for the proposed opening. If the parking lot opening merges with the salvage opening to the south, then the probability of damage increases to 23%. Equivalent values for the medium volume old growth are 19, 24 and 27%. For the high volume old growth they are 32, 40 and 43%. There is a high degree of consistency between the logistic model predictions and the actual percentage of segments damaged in the subsets of the WIT dataset with conditions similar to the second growth and high volume old growth type.

Qualifications for MacMillan Park situation

The values for mean wind speed and topex used in the empirical model are those obtained for the vicinity of the proposed parking lot from the GIS layers. Both values are close to the averages for these values in the WIT dataset and represent locations with moderate wind speed and moderate topographic exposure. The wind regime in this valley gap is somewhat unusual and may not correlate as well with these two variables as in other locations in WIT. At the present time it is not possible to evaluate the correlation between actual and predicted wind regime in the Cameron Valley. The WIT model is based on cutblock boundaries with up to 10 years of wind exposure (1990-2000). The model is intended to represent the probability of damage due to endemic winds. Under extreme winds damage patterns and severity are likely to differ. The empirical model predicts a probability of severe damage of 36% in the high volume old growth with full boundary exposure. Given the extent and severity of the 1990-91 and 1997 damage along the south boundary to the east, this prediction clearly underestimates the probability of damage from catastrophic winds. On the other hand, it may over-estimate the probability of damage in the vicinity of the parking lot since the second growth stand is 30m lower than the top of the adjacent canopy, and since the old growth stand to the north has been exposed since the gap was created by windthrow in the 1950's. While Phellinus weirii is common in coastal second growth, the root disease incidence in the 1958 stand is likely more severe than average in the second growth stands in

WIT. If this is the case, then the model would under-predict the likelihood of damage.

Effect of parking lot on wind loading of trees within the park

It is not possible to provide a detailed answer to this question with the resources available in this project. We have no equivalent scenarios in our WIT dataset and ForestGALES is not sophisticated enough to evaluate this complex scenario. The question could be evaluated using wind tunnel experiments, but this would be a long and expensive undertaking. I will therefore take a diagnostic approach. The parking lot is within an opening that was created within the 1950's during a natural windthrow event and subsequent salvage. The trees and stands to the north of this opening would have acclimated through failure and growth following that event. The opening has now regenerated to a dense 33m tall second growth stand that is still 30m shorter than the top of the canopy in the surrounding old growth stands. Given the long term presence of this opening and the large height differential with adjacent stands, I do not expect that the parking lot opening will produce a large change in wind loading on the old growth stands within the park to the lee. In the context of the much larger openings to the south and east of the park, the change in wind loading due to the parking lot is very low. I do expect damage in the stand in the immediate vicinity of the opening. I do not expect this damage to extend 75m to the park boundary due to endemic events.

Recommendations

Consequences

There are a number of potential consequences should trees along the boundary of the parking lot or trees left within islands in the parking lot uproot or break due to wind. These include loss of overstory, change in visual quality, obstruction of trails and access roads, damage to structures such as fences or signs, damage to vehicles, and injury to workers or visitors. These consequences should be considered in making prescriptive decisions.

Opening size and configuration

Keeping the opening short and narrow is a good way to reduce wind loading on the north boundary and on trees to the north of the opening. It is advisable to retain the large treed island proposed at the south end of the parking lot since this reduces the length of the opening. It is also advisable to work with the adjacent land owner to retain the overstory Douglas-fir between the access road and the salvage opening to the south. Similarly, it is also advisable to retain the strip of trees between the parking lot and the narrow north running salvage strip to the west.

Crown modification

In the study by Chuck Rowan, crown modification was found to reduce windthrow by 40% compared to untreated controls. Trees along the northwest, north and northeast boundaries of the parking lot will have higher wind exposure following harvesting. It is therefore recommended that they be treated. Removing 30% of the crown area (or mass) will reduce turning moments by approximately 40%. I would recommend that crown modification extend 20m into the stand edge. Spiral pruning maintains the crown shape and reduces potential for decay entry. An arborist can advise on the best manner of crown modification for these trees. Trees in retained parking lot islands and the trees between the parking lot and the salvage strip to the west will be exposed to winds from several directions. I suggest that these trees also be treated. If the parking lot is to be felled in the winter months it is critical that these treatments be completed prior to the first winds. Practically, this means that they should be treated before the parking lot is felled. This may raise safety issues with the falling crew since there may be suspended overhead branches. I suggest that you consult with the WCB on the best way to proceed. Crown modification treatments are only partially effective, therefore, some incremental damage in the zone around the parking lot should be expected.

Protection of tree roots

Trees are more sensitive to root disturbance than to crown disturbance. Where the structural roots are damaged during excavation, the trees should be removed. The roots of trees in small internal islands in the parking lot will be affected by deposition of ballast and surfacing material and by changes in aeration and drainage. I suggest that you consult an arborist to determine the minimum island size for viable tree retention. The presence of Phellinus and Phaeoleous scwheinitzii complicates matters. It is hard to detect the degree to which Phellinus has undermined root integrity in standing trees. I am also not sure how crown modification will affect the progression of the disease. An experienced arborist should be consulted on these issues.

Access management

Failure of decayed branches or boles in this location is possible under any wind conditions. Precautionary signage should be posted at park entry points. High use areas such as the parking lot, access and trail areas should be routinely inspected for hazardous trees. A park closure plan should be implemented when wind speeds exceed 40km/h or if damage commences. Because of the 'Qualicum' wind effect, winds of this speed can occur in any season including the peak summer visitor months on warm sunny afternoons. Meteorological offices should be able to provide advance warning of synoptic conditions under which high winds are likely. Gates and signage at park entry points should indicate when and why the park is closed. It would be a good idea to inspect for suspended debris after damaging winds prior to re-opening the park. Since freshly exposed trees are particularly vulnerable, these practices are very important during the first year after the parking lot is opened.

Conclusion

Creating an opening in the 1958 stand to locate a parking lot south of MacMillan Park will increase the probability of damage along the boundary of the opening. Some wind damage in the vicinity of the parking lot is likely. The likelihood and severity of damage can be lowered by modifying the crowns of trees around the north end of the opening and trees within island or strip reserves. Given the history of this opening and the height differential between the second growth stand and the adjacent old growth stands, the incremental wind loading due to the proposed opening on the old growth stands within the park to the north is expected to be small. As noted in my 1998 report, the areas of moderate and severe damage that developed during the 1990-91 and 1997 catastrophic wind events will expand during future extreme wind events. Within this context, the incremental effect of the proposed parking lot is small.

References

Appendices

Colour photo of GIS layers over orthophoto base
Photos taken on December 18, 2003 visit