The Feasibility of Applying Air Photo Interpretation to the Locating, Analyzing and Development of Wind Power Sites

by

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Abstract: If wind power is to become a viable energy alternative, a rapid and reliable cost effective methodology must be established, whereby large areas can be surveyed for windy sites and those sites can be evaluated. Based primarily on locating wind deformed vegetation, this paper establishes the feasibility of using air photo reconnaissance for the locating, analyzing, and preliminary site development of wind energy conversion systems (WECS).

Regarding the long range concerns of any potential wind power site development, this paper also draws attention to the value of locating: (1) associated geographical features for siting, designing and construction, (2) certain people with local experience of wind and climate, and (3) potential land use development conflicts.

1.0 Introduction

1.1 Problem

There is urgent need to develop alternative sources of energy. To develop wind power, the resource must be located and assessed. An expedient method of analyzing large areas to locate best sites for wind power development is needed.

Several natural features record evidence of wind, such as snow drifts, sand dunes, trees and others. Trees are being used by the Wind Power Study Group at Oregon State University, to determine such wind characteristics as prevailing direction, mean annual speed and the occurrence of severe winds and ice loads. The relationship between tree crown deformations and local mean wind velocity has been calibrated and validated with Douglas-fir (Pseudotsuga menziesii) and Ponderosa pine (Pinus ponderosa) (Hewson and Wade, 1978). Persistant winds also deform other trees in the genera Pinus, Tsuga, Juniperus, Abias, Picea, and Quercas. The research is being conducted for the U.S. Department of Energy under the title: "Vegetation as an Indicator of High Wind Velocity."

Local and regional assessments of wind power potential and subsequent development may be expedited by establishing a remote sensing methodology, whereby wind deformed trees and other eolian features may be located and analyzed.

1.2 Purpose

The purpose of this research paper is to report on the feasibility of using air photo reconnaissance to locate and analyze wind deformed trees and related eolian features. Another related purpose is to establish a methodology for planning, gathering and using air photos for local wind resource analysis.

2.0 Methods

2.1 Review

Since the need for this research was initiated by the work of Wade, Hewson and Baker, an analysis of their studies is prerequisite. Their method of finding and analyzing sites of wind deformed trees includes on site measurements and photography. Some of the features of interest seem noticeable, perhaps measurable, from the air under certain conditions of the trees, the sites, and the air photos.

2.2 Site Targetting and Photo Aquisition

A search for existing air photographs was begun to illustrate their feasible use for locating wind deformed vegetation. Existing photos were sought for two reasons: (1) to determine their accessibility and general value, and (2) minimum budget requirements. Several related activities are required.

The first activity is to inventory the factors of air photo interpretation that may be required. These include:

1) The kinds of air photo evidence that may show a relationship between local winds and local vegetation.
2) The regional, areal, local, and site conditions which create these relationships.
3) The requirements of the air photo reconnaissance, and

4) The required interpretation skills.

Another activity, that of actual site investigations, begins by plotting three coinciding elements on different scales of thematic (theme) maps. These elements, in order, include:

1) wind - i.e., probable surface wind flow patterns,
2) terrain - i.e., the topographic features of the region, area, and site that may accelerate, deflect, or otherwise influence local winds, and
3) vegetation - i.e., possible distributions of useful vegetation species.

Promising sites, with possible useful evidence, are pinpointed by moving from small scale to large scale maps.

Another activity, once target sites are determined, is to locate which agencies or private interests are likely to have useful air photo coverage of the sites. Several different interests may have air photos of any one site, such as the U. S. Forest Service, State Forest Service, County planning office, Army Corps of Engineers, or the private owner of the site, such as a timber company. Where existing useful photos are made available, a study file of photos can be compiled through loans, purchases, photography, and occasionally by photostatic copying. Gathering the study file of air photos is a major activity, itself.

2.3 Electronic Image Enhancement

There are many potential problems in gathering and using existing air photos. A partial remedy prompts yet another research activity: electronic image processing of available routine air photos. This processing can include density slicing, color enhancing, digital processing, and scale variations. These processes are used to detect image features that are not readily apparent to the eye due to degrees of detail, scale, pattern distributions or grey tonal value.

To research the complete feasibility of applying electronic image processing, an air reconnaissance mission is required to provide imagery that is more controlled than that provided by the study file described above. A flight was planned over several sites in the Columbia Gorge area and was flown by the Oregon Army National Guard. The imagery can provide records of the study sites under comparable conditions of: solar reflectivity, sun angle, season, ground cover, time of day, site development, film type, film processing, scale intervals, and imagery history. These controlled conditions are requisites before the electronic enhancement experiments can be verified for future use.

3.0 Analysis

3.1 Statistical Background

For over 150 years, many studies have referred to tree deformation as an indicator of prevailing winds (Davies, 1814; Jefferson, 1904; Lawrence, 1939; Putnum, 1948; Thomas, 1958; Sekiquti, 1951; Misawa, 1954; Holroyd, 1970; Hewson et al., 1977, 1978, 1979; Wade and Hewson, 1978). Trees may provide valuable information of wind direction, mean wind velocity, wind regularity, seasonality of winds, hazardous wind and icing, and local wind sheer. These factors are critical to potential siting of wind power turbines.

Using trees, three indices of wind power potential for a given area have been developed by Hewson *et al.* (1977), based on the earlier work of Putnum (1948). These indices have related the mean annual wind speed to tree deformation at more than 60 locations in the Pacific Northwest using two widely distributed conifers: *Pseudotsuga menziesii* (Douglas fir) and *Pinus ponderosa* (Ponderosa pine). The three indices are: (1) the Griggs-Putnum Index - a qualitative rating scale based on the apparent external deformation of tree crowns (Figures 1 and 2); (2) the Deformation Ratio - a quantitative index that measures the regularity of crown assymetry and stem deflection of trees (Figures 3 and 4); and (3) the Compression Ratio - a quantitative anatomical measurement of compression wood thickness on leeward side of trees compared to the windward side (Figure 5). These indices were calibrated and validated at 23 locations which have from one to three years of continuous wind data.

The reliability of these indicators seems very strong. The regression equation correlation coefficient (r), the coefficient of determination (r^2) and the number of data points (n) are given in Figure 6 (Hewson *et al.*, 1977; Wade and Hewson, 1978, 1979). The relationship between mean wind speed and the indices is shown in Figures 2 and 4. These indices were validated on an independent data set. Mean prediction errors for each index are also given in Figure 6.

The indices of tree deformation are calibrated against several wind characteristics including mean annual wind speed, mean growing season wind speed, mean non-growing season wind speed, and percent of winds from the prevailing direction. Hewson *et al.* (1977) found that the trees they studied do not deform in winds < 4 m/s (< 9 m.p.h.). Likewise, the trees do not deform (except for breakage) in short period severe winds. Also, the more constant the prevailing wind direction and wind speed, the greater is the possible deformation. Potential wind turbines are designed to rely on the same character of winds that is recorded by wind deformed Ponderosa pines and Douglas firs. Consequently, the location of such trees is of great interest to the siting of wind power development.

The Griggs-Putnum index is the easiest to adapt to air photo reconnaissance of local wind power assessment. The other two indices are valuable for cross reference field checking. The Deformation Ratio is designed for crown profile photogrammetry (on grade), while the Compression Ratio is designed for laboratory measurement of core samples.

3.2 Preplanning

Wind deformed vegetation is a site specific phenomenon which is affected by characteristics of vegetation, terrain, wind patterns, and land use. Analysis must include regional, area, and site considerations. Thus, different scales of analysis are required. Direct detection of wind deformed tree crowns is feasible, so far, only on large scale photos.

Access to a library of thematic (theme) maps, air photos, and other remote sensing imagery of varied scales becomes essential. Photostatic copies of air photos may be adequate and may even enhance some air photo evidence (Figure 16). Since regional features influence local features, it is most effective to first plot possible study sites with a collection of small scale thematic maps, prior to pinpointing photo targets on large scale detailed maps. Likely areas are best noted on small scale shaded relief maps of the entire region (e.g., on a 1:500,000 U.S.G.S. shaded relief map of Oregon, Figure 7, or 1:500,000 aeronautical charts by the U.S. Department of Commerce, available at flight planning offices of most airports). The latter type of map proves most helpful for many reasons. (1) They prove more accurate for the purposes of this research, and (2) provide valuable associative evidence (e.g., lowest level visual flightpaths are mapped, which may coincide with regional and local surface wind factors). (3) Many potential land use conflict areas such as wilderness areas, wildlife refuges, and other natural preserves are indicated. Aeronautical charts locate the boundaries, and give the flight regulations over these and all domestic areas. (4) If any air photo missions are subsequently required, these maps (if current) must be used by pilots for the reasons indicated. (5) Power grids are illustrated, and (6) if anemometry is desired, tallest local structures are indicated.

A larger scale map then must be used to locate more specific areas such as ridges or valley reaches (e.g., 1:250,000 U.S.G.S. topographic map, "The Dalles," Figure 8). After the corresponding elements are plotted on different scaled thematic maps of terrain, wind patterns and vegetation distributions, actual photo targets are best plotted on the largest scale topographic maps available (e.g., on a 1:24,000 U.S.G.S., 7 1/2 minute series).

Most available vegetation thematic maps prove to be either obsolete, or too small a scale to be completely useful. However, high level infrared photos or Landsat color composites can provide vegetation information (as will be discussed later). These photos are indirectly available through most local resource managing agencies. If this imagery is not available, other small scale air photos or timber survey maps may be useful, if current.

The emphasis on preliminary planning with maps, or on small scale stereo air photos is a matter of availability, costs, quality, current accuracy, and interpretation skills.

3.3 Large Scale Air Photos

3.3.1 Air photo interpretation of wind deformed vegetation generally requires photos of a scale larger than 1:8,000. This scale requires lower level reconnaissance flights and photos of smaller areas than what are routinely made by resource agencies. For example: forest management agencies usually have photos at a 1:24,000 scale, whereas county planning agencies usually have photos at a 1:12,000 scale. However, some management or planning problems may require low level vertical or oblique air photography over specific sites. Examples of such needs include forest records of fire damaged trees, and Department of Transportation records of snow removal.

The vast majority of 'agency' air photos require vertical camera shots for stereo viewing, mapping, and photogrammetric purposes. However, tree crown deformations are not so apparent from directly overhead as they are in oblique profile views or in tree shadows. In vertical photos, the trees toward the edges of the photo are seen more from the side than from above. Parallax distortion also increases from the center of the photo to the photo edges. This parallax distortion can obscure any pattern of deformed tree crown shapes. This parallax distortion increases with low level photos, and if the terrain is irregular. The majority of photo targets for this research are located in mountainous areas and require low level flights. In the case of study sites in the Columbia Gorge, local terrain features rise to elevations that exceed the required flight altitudes. The combined extremes of low flight requirements and radical slopes cause such parallax distortion that stereo viewing is found impractical, if not impossible. Stereo viewing may prove useful in more level terrain; but is probably not necessary at the required scale.

3.3.2 For the purposes of wind prospecting, the air photo interpreter must be aware of the many possible influences on the shaping, and on the apparent image of tree crowns. Categorically, these influences are listed in Figure 18.

Although these influences can compound each other (and the list is not comprehensive), most of these possible influences can be accounted for through careful air photo interpretation. If not, local management records can be checked and field checking may be required.

The strongest single influence of wind deformation - exposure -

needs elaboration. Trees that are at the edge of community stands act as wind breaks for the rest of the stand (homogeneous or other-wise). They are more likely to be wind deformed than specimens that are protected (e.g., Douglas-fir and mixed Douglas-fir stands). If a tree stands significantly taller than its surrounding community, it is probably a minority species for the given site. Densities within some communities are so spaced to allow adequate wind exposure of a majority of specimens, especially in older communities (e.g., climax Mountain Hemlock) and in more arid regions (e.g., Ponderosa Pine). In either case, if crown asymmetry is similar in a number of contiguous specimens with similar exposure, and if other possible influences are accounted for as described above, this qualitative evi-dence of wind deformed vegetation can be assessed with the Griggs-Putnam index, Figures 1, 2, 12, and 14 (these figures are further analyzed in Section 3.6).

For the purposes of local wind prospecting, it appears more cost and time effective to rely upon hand held oblique photos, as illustrated, which can reveal both tree profiles and tree shadows (Figures 12 and 14), even if some field checking is required.

3.3.3 If existing agency air photos reveal wind deformed vegetation, it is purely coincidental. To find such photos takes considerable time on the part of the researcher and the cooperating agency. This also requires knowing the appropriate agencies and their reasons for making air photo surveys. But there are some obvious possibilities. For example: transportation corridors usually follow routes that are a combination of least resistance and shortest distance between places. Surface winds generally do the same. When these routes are similar, it is possible to find wind deformed vegetation or other eolian features, if they exist, in the photographic records of different agencies or other interested parties that are concerned with the development, management or use of transportation corridors (e.g., Department of Transportation, barge and gas line companies, railroads, utilities; Figure 13). In some cases, features are altered by the development interests that collect the air photos, which may preclude field checking. For example, most Army Corps of Engineers air photos in the Columbia Gorge were taken prior to or during the construction of the present hydro-electric and navigation facilities, which have changed stream characteristics and the associated distributions of vegetation. In another example, vegetation is frequently removed by the highway construction that is based on that department's air photo files. On the other hand, these same photos provide historic records where current vegetation or other eolian features are presently lacking, due to recent land use or natural changes. These photos can prove very useful.

3.4 Small Scale Air Photos

3.4.1 As mentioned earlier, wind deformed vegetation is a result of regional factors. Although individual wind deformed tree corwns may not be resolvable in higher level photos of smaller scales than 1:8,000, the smaller scale images can reveal associations of eolian evidence and area or regional factors. These area or regional factors may be directly observable especially with false color infrared films. High level infrared photos can determine such botanical factors as the distribution of individual species types, or stresses such as water depletion which may be due to surface winds. Distributions of douglas fir, Ponderosa Pine, Oregon Oak, Black Cottonwood, cherry orchards, grass pasture, wheat, rabbit brush, and sage are observable in Figures 10, 13, 15, and 17.

The association of regional and area terrain features such as ridges, valleys, and plains are important. The proximity, magnitude, and association of terrain features which influence local surface winds must be determined. Small scale, regional or area wide air photos are invaluable for accounting for these associations.

Perceiving the association of these botanical and geomorphic features on high level photos has proven very reliable and helps in plotting searches for lower level, large scale air photos, and site targetting. Likewise, high level photos are very useful for the pre-flight planning of subsequent air photo reconnaissance flights, if they are required.

3.4.2 High level photos can provide valuable associative evidence of local surface winds. Some of this evidence is temporal and transitory, such as local orographic cloud formations and waves. But, when these features are regularly and predictably apparent through time in random photos, the consistency of regional and local winds can be qualitatively established. (Such evidence led to the low level oblique photos included in this report.) Some examples include the regularly apparent wave reaches in the mid-Columbia River Gorge region beginning between Shellrock Mountain (Oregon) and Wind Mountain (Washington) and extending east for at least two miles to Viento State Park (Oregon) (Figure 11). A similar wave pattern is regularly visible at the east end of the Gorge (Figure 16). Another example is the orographic cumulus cloud concentrations that commonly appear along a north-south axis which runs through Augsburger Mountain (Washington), which happens to be the principal axis of the Cascades. These necessarily indicate regional temperature and pressure gradients which may provide useful diurnal surface wind flows (Figure 9). A third example is in the deflation areas and dunal streaks apparent across the flood plains north of The Dalles, Oregon (Figure 15). These types of eolian evidence are easily visible in small scale air photos, and provide associative evidence of where to make closer, larger scale inspections for quantifiable evidence, such as tree crowns.

3.4.3 Regional and local land use and resource management interests may be identified in high level photos. These interests may provide additional sources of lower level photos. This process provided many of the photos in this report. In this same manner, people may be located who can corroborate air photo evidence by their first hand field experience. For example: valuable knowledge from barge captains, highway patrolmen and state forestry rangers confirmed the air photo evidence of the winds in the Gorge mentioned above (Figure 13). Extended regions that are illustrated in high level imagery can possibly be analyzed effectively with the qualitative and quantitative techniques offered by electronic image processing. The feasibility of electronic image enhancement was preceived in this research, but the limits of the available photo quality and hardware did not allow the general application of these techniques.

3.5 Wind Power Site Development

3.5.1 Air photo interpretation is a widely used activity of land use planners and resource developers. Any large scale wind turbine development will be based on several economic factors including: site stability, site ownership, site access, proximity of support facilities, and the proximity of existing power grids for cost-effective tie-ins. Initial use of air photos of potential wind power sites can prove invaluable in alerting "would be" developers to these and other problems or potentials in the vicinity.

3.5.2 Probably the greatest influence on site development for large scale wind turbines will be the politics of land use planning. Any large scale development will require an Environmental Impact Assessment, and compatability of adjacent land uses must be established. Gathering and using existing air photos helps alert the developers of wind power sites in a couple of ways. Not only are physical relationships of adjacent land use activities usually observable on air photographs, but the activity of gathering existing photos necessarily introduces the developer to the people and agencies that have land use management concerns in the area.

3.6 Study Sample

Figures to illustrate the relation of processes described here are arranged together at the back of the paper to make step-by-step comparisons easier. Figures 1 - 6 illustrate the statistical reliability of using the apparent shaping of some trees to assess local mean annual winds. Figures 7 and 8 illustrate preplanning with different scales of maps before seeking air photographs of likely trees or other eolean features.

Figures 9 - 17 illustrate the use of different scales of air photos and different scales of various associative evidence to narrow in on specific sites of wind deformed trees, other eolian features, or related site development issues. The photos came from a number of sources, as indicated. Figures 12 and 14 record wind deformed trees. Figure 12 is used to illustrate some of the problems to avoid, while Figure 14 is a best case sample.

The trees in these figures are located on the Oregon side of the Columbia Gorge at Shellrock Mountain and Viento State Park. They range from 0 to 50 feet above the river and are from 10 to 120 feet tall. Based on the Griggs-Putnum Index, local winds are predominantly from the west at a mean velocity ($\overline{V}$) of 4 to 7 meters per second (m/s). The reliability of this assessment is verified by comparing local anemometer data gathered by Hewson, Wade and Baker at nearby Augsburger Mountain (2000 ft. elevation).

The apparent lack of structural damage to the trees indicates that sudden gusting and winter icing probably does not present a local problem to wind turbine siting. The apparent proximity of power lines is a promising site asset, but the apparently unstable slope of one site and the heavily committed adjacent land uses apparent at the other site probably restrict large scale wind power development on the photographed sites. But the photographs do establish that there is a wind resource in the area that has industry potential.

Figures 15-17 illustrate other examples of possible associative evidence and photo acquisition techniques. All the photos and maps illustrated here were being used in an office situation. Consequently, some apparent symbols in the figures have no bearing on the discussion here.

Figure 18 lists many of the possible influences on tree crown shapes. The air photo interpreter must be aware of these geographical and ecological possibilities in order to avoid misinterpretations.

4.0 Conclusions

4.1 Air Photo Interpretation

Air photography has been used for wind prospecting purposes. Many eolean features are descernable in air photography. Wind deformed trees have been located and analyzed with air photos to qualitatively establish local wind characteristics that are important to any cost-effective development of local wind resources. For wind prospecting purposes, this air photography requires many pre-planning considerations.

For the purpose of local wind prospecting, it seems most effective and economical to rely on the least sophisticated of air photography. After careful planning with available maps, high level air photos, and local knowledge of wind conditions, local surveys are best accomplished with common hand-held 35 mm camera equipment, high speed film and a locally chartered plane.

Flight paths should be planned that are perpendicular to the suspected prevailing surface wind directions, and keeping low camera angles records greatest visibility of deformed tree crowns. Such flight paths can show how wide the local mean surface wind field may be and where it is strongest. Repeated parallel flights can reveal how long the field is.

For large area surveys (regional, national) the more technical image processing and direct small scale interpretations of wind deformed vegetation may prove valuable, and should be persued. Small scale imagery can illustrate other eolian features; and can provide invaluable associative information for locating wind deformed vegetation.

4.2 Proposed Research

Additional research is proposed. It has been shown that different scales of imagery reveal different kinds and areas of evidence of surface winds. A hierarchical procedural model should be established that illustrates the feasible use relationship between all remotely sensed imagery and all generically eolian features. This model should show the relationships of:

1. quality of evidence;
2. quantifiability of evidence;
3. scale of evidence;
4. distribution of evidence;
5. kinds of appropriate useful imagery;
6. scale of imagery;
7. limits and quality of imagery;
8. processing and interpretation procedures of imagery;
9. relative dollar and time costs of imagery, imagery acqusition and imagery interpretation; and

10. accessibility.

Different kinds of qualitative eolian evidence may be spread over large areas. This model would indicate the scale requirements needed to preceive a quantifiable character for different kinds of qualitative evidence. Such a model would also aid in a systematic search: (1) through the association of different kinds of regional, area, or local qualitative evidence, and (2) through different scales of imagery to achieve a quantifiable local indicator of wind resources. It has been suggested by other sources that the present research accomplishes this general application of remote sensing to wind prospecting. However, the research reported here has been generally limited to the feasibility of using air photos to locate wind deformed tree crowns of Douglas-fir and Ponderosa pine.

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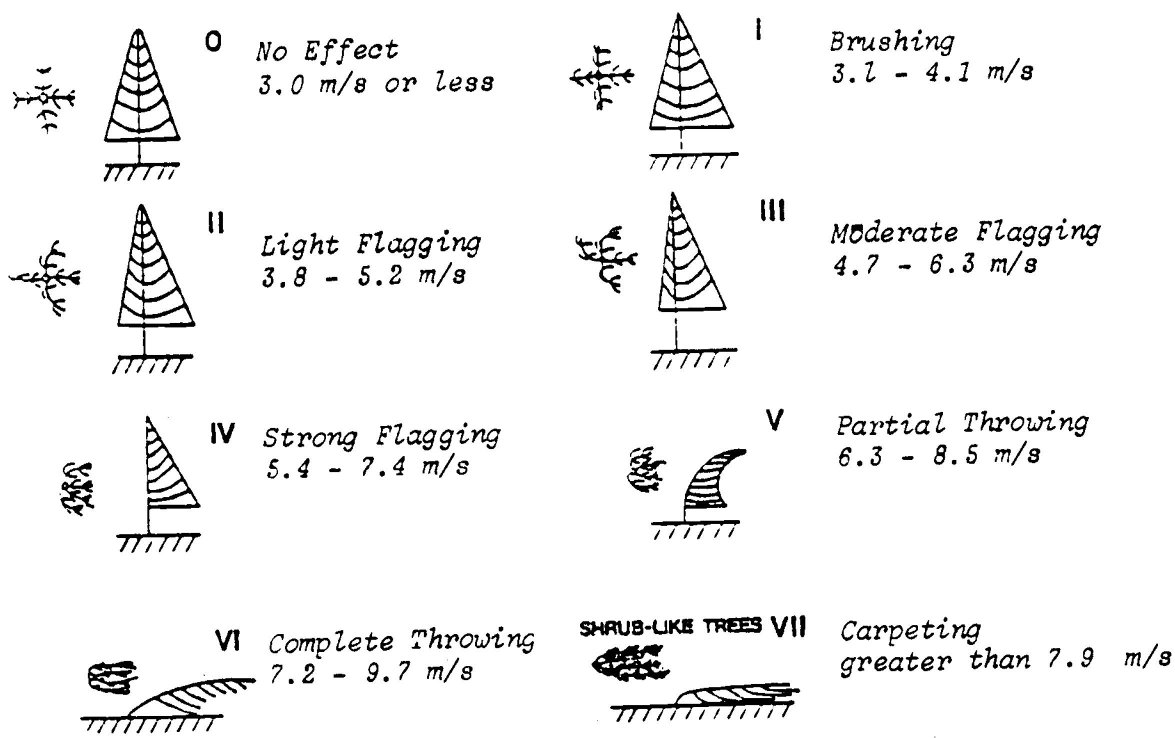

Figure 1. The Griggs-Putnam Index. The 8 classifications illustrate degrees of tree crown deformation (top and profile views) and the range of mean annual wind speeds that create that degree of asymmetry. (Courtesy: Hewson and Wade)

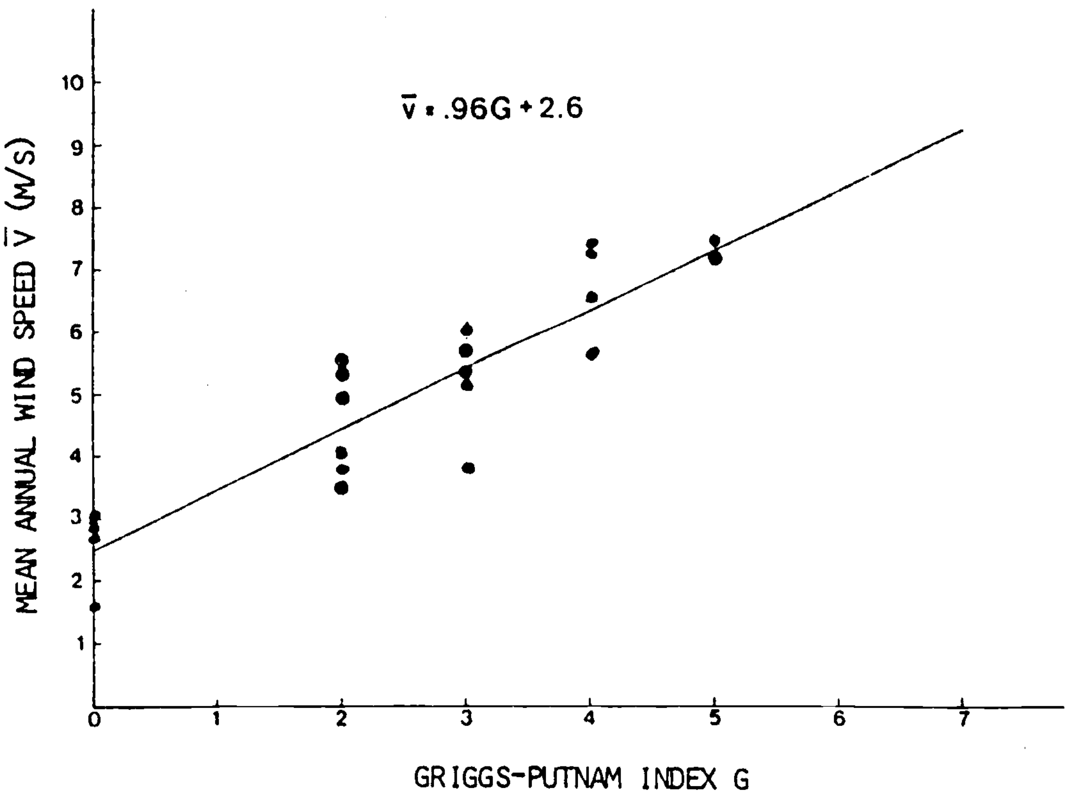

Figure 2. Graph of Griggs-Putnum Index Equation and regression showing the relationship of class numbers to mean annual wind speed. (Courtesy: Hewson and Wade)

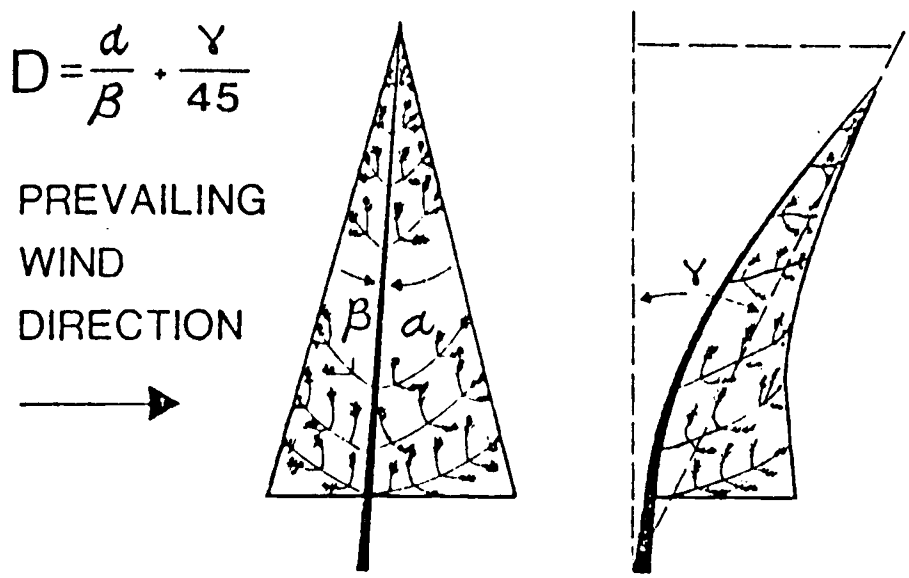

Figure 3. The Deformation Ratio. This ratio measures the degree of wind induced crown asymmetry and tree trunk deflection. The ratio of α and β has a minimum value of 1 and a maximum value of 5.

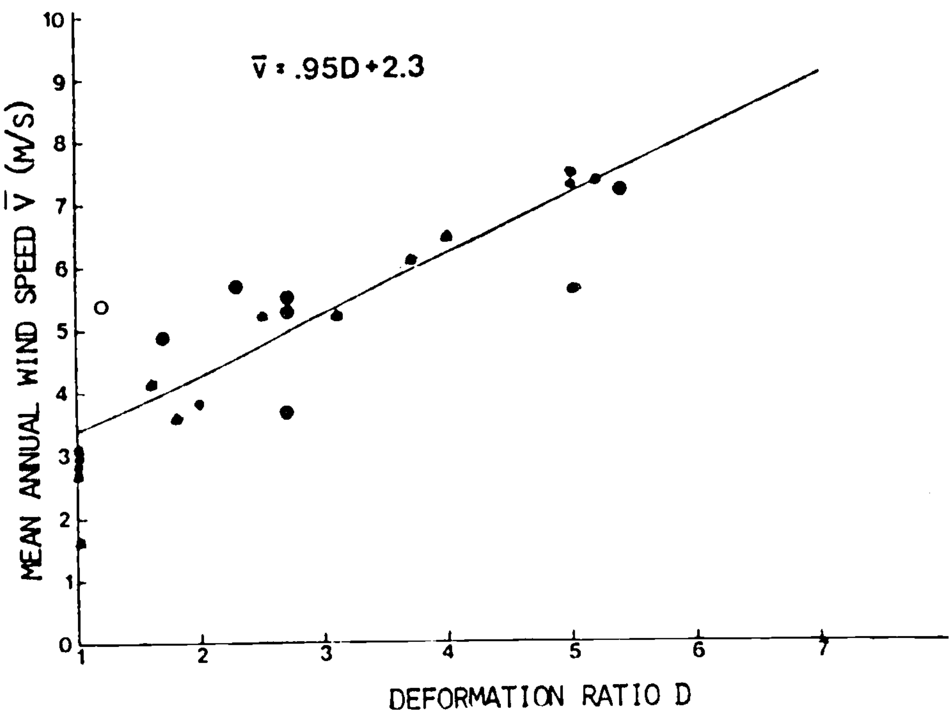

Figure 4. Graph of Deformation Ratio Equation, showing relationship to mean annual wind velocity. (Courtesy: Hewson and Wade)

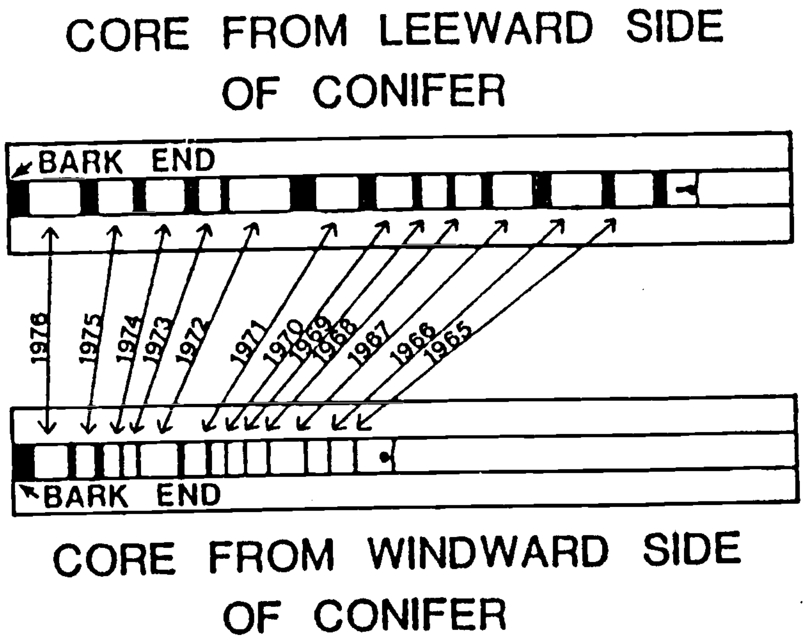

Figure 5. Compression Ratio. Core samples from the windward and leeward side of the tree are mounted and cross-dated as shown above. Note that in conifers there is more growth on the leeward side of trees that grow in windy locations. (Courtesy: Hewson and Wade)

Index	Correlation Coefficient r	Mean Prediction Error (%)	Number of Data Points
G	0.91	15	23
D	0.87	18	23
C	0.82	20	21
	Average Error	18	

Figure 6. Table of Statistical Validations of Indices.
"G" = Griggs-Putnum Index
"D" = Deformation Ratio
"C" = Compression Ratio
(Courtesy: Hewson and Wade)

Figure 7. Regional plotting of topographically most-likely windy areas are best plotted on a small scale shaded relief map such as on this U. S. G. S. 1:500,000 scale map of Oregon. The wind prospector must be prepared to notice a variety of site associative evidence depending on local land use, vegetation cover, season of imagery, climate, and recent weather. Associative evidence may include wind deformed vegetation, sand dunes, deflation pits, snow drifts, snow fences, wind breaks, tumble weeds, smoke plumes, waves, beaches, etc. The Columbia Gorge is indicated between the arrow and row of dots.

Figure 8. A closer look at the Columbia Gorge on a 1:250,000 scale U. S. G. S. topographic map allows more specific plotting of probable sites. The numbers are sites that seem of most promising exposure. They are more closely analyzed in following photos. Arrows are prevailing wind directions found on maps, which are corroborated in photos.

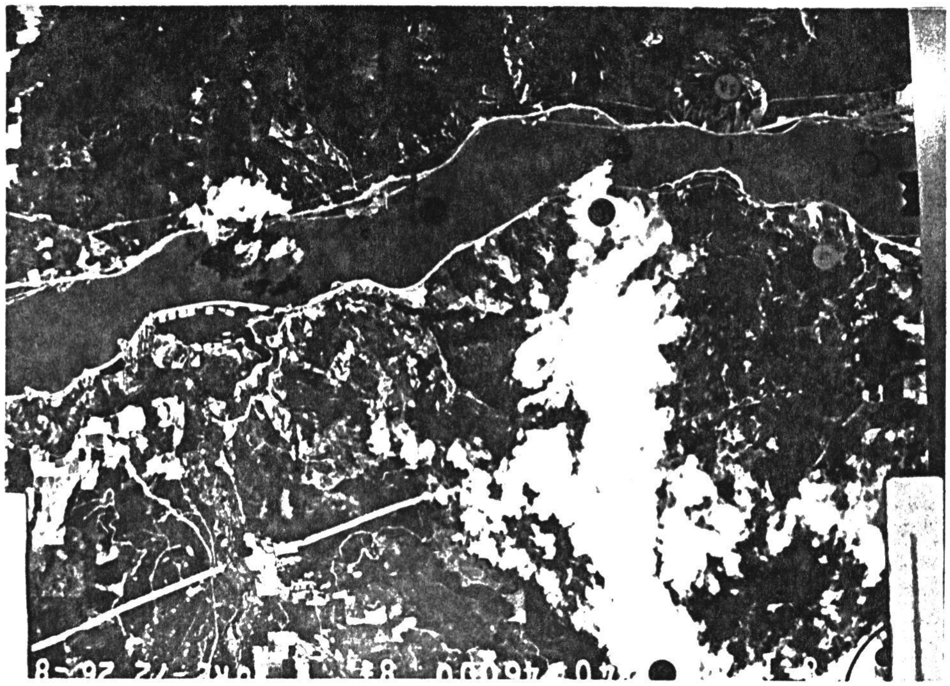

Figure 9. Associative geographical evidence of possible local surface wind accelerations are apparent in a 1: 63,360 scale air photo of the central area of the Columbia Gorge (courtesy: Oregon Department of Forestry). A Venturi effect seems to occur between the yellow dots (Shellrock Mtn., OR, and Wind Mtn., WA). An accented wave pattern is usually evident in summer imagery between the green dots; orographic cloud accumulations usually appear between the blue dots. Red dots are study sites. Figures 10 through 14 are closer, larger scale inspections of study sites.

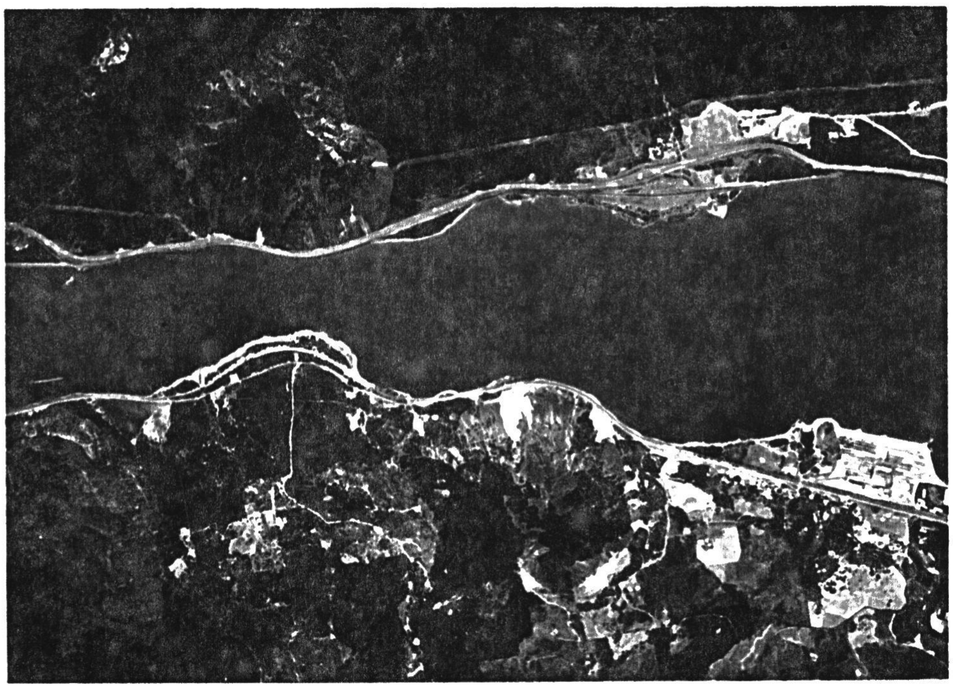

Figure 10. Recent location of vegetation within the area pictured in Figure 4 is apparent on a lower level 1: 32,500 scale false color infrared photo. (Courtesy: ERSAL, Oregon State University, NASA flight 75-127)

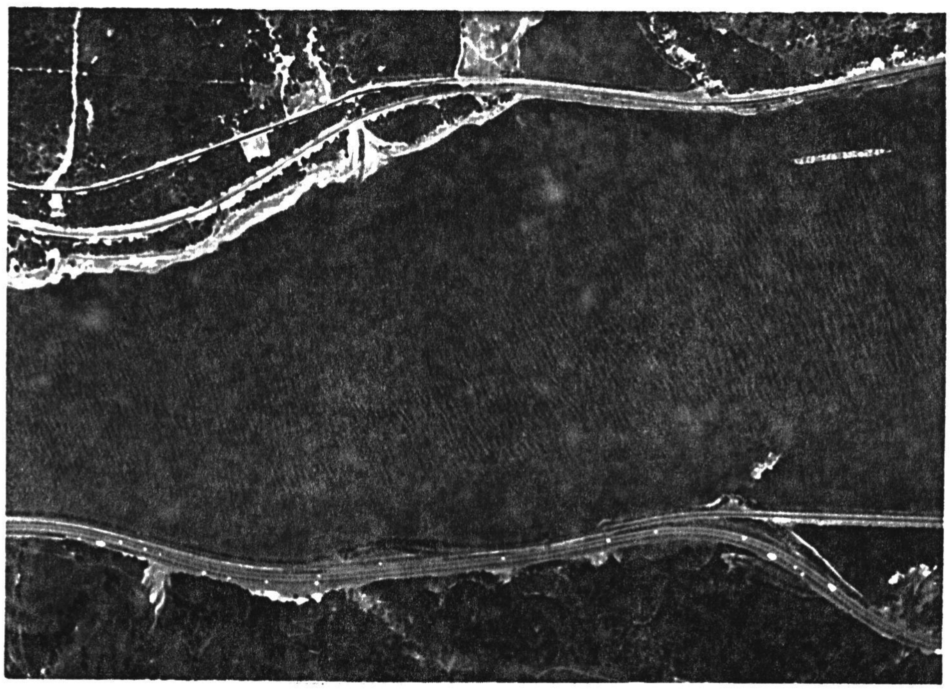

Figure 11. The usual summer wave patterns are clearly evident in this closer magnified view of an area of Figures 3 and 4. Wave length is approximately 40 yards, compared to the log raft in upper right, indicating strong winds. (Courtesy: ERSAL, Oregon State University, NASA flight 75-127)

Figure 12. Wind deformed Douglas-fir trees on Shellrock Mtn., Oregon, are indicated by arrow in upper right on a hand held oblique photo (courtesy: Oregon Department of Transportation). Assessment of local mean annual wind speeds, based on this photo and the Griggs-Putnam Index is not reliable since trees are immature, photo is of poor quality, and flagging is close to the same direction as camera and flight angles. The arrow in lower left indicates typical wave direction and points toward Viento State Park, in the distance.

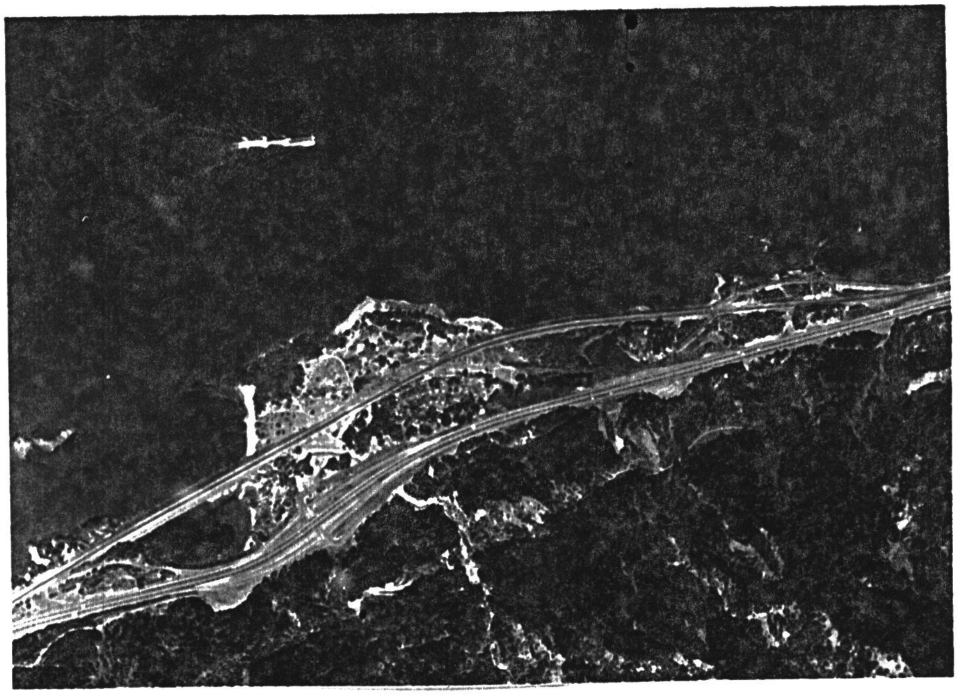

Figure 13. A high elevation infrared photo shows the locations of Douglas-fir trees (dark purple) including some on a well exposed point on the south (bottom) shore (Viento State Park, Oregon). Local land use and management interests that are shown include: barge traffic, railroad, highway, power lines, waterway, forest, and state park. (Courtesy: ERSAL, Oregon State University, NASA flight 75-127)

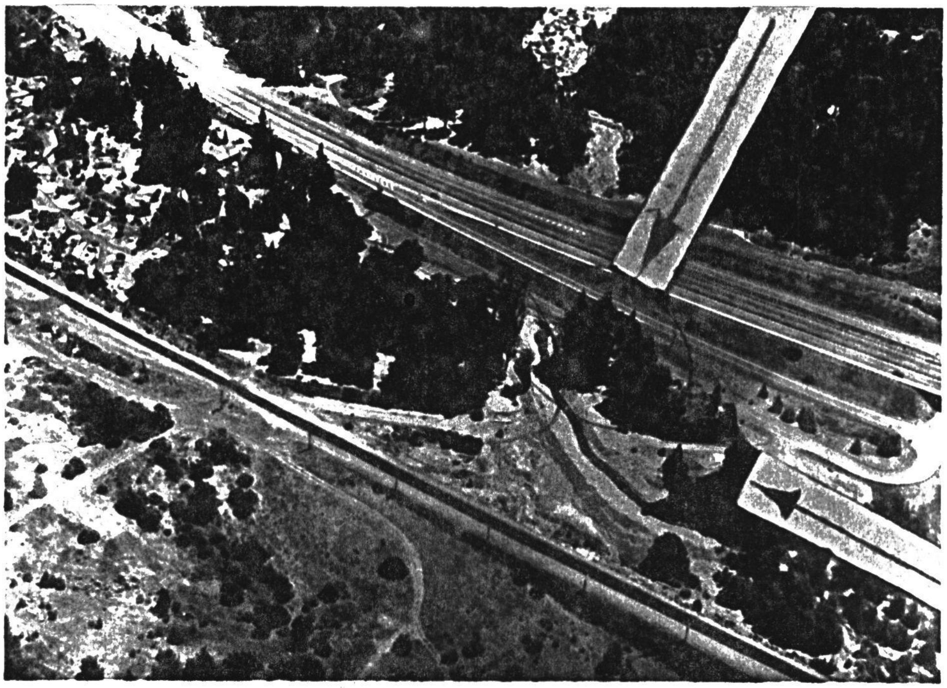

Figure 14. Wind caused tree crown deformation is evident in a low level hand-held oblique photo of the same trees at Viento State Park indicated in Figure 7. Using the Griggs-Putnam Index, classes 3-4 are apparent, which indicate local westerly winds with a mean annual velocity of 4.7 - 7.4 m/s. There is no evidence of storm or ice damage. (Courtesy: Oregon Department of Transportation)

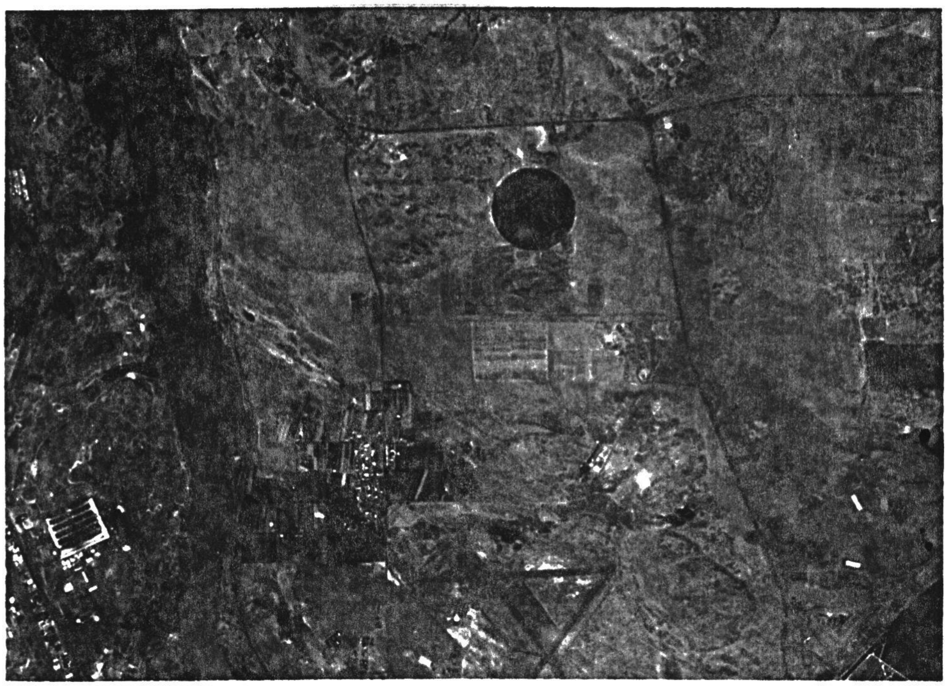

Figure 15. Wave patterns and dunal streaks are apparent north of Dallesport, WA, in a detail look at a 1:32,500 scale false color infrared photo. They are caused by persistant winds at the east end of the Columbia Gorge. (Courtesy: ERSAL, Oregon State University, NASA flight 75-127)

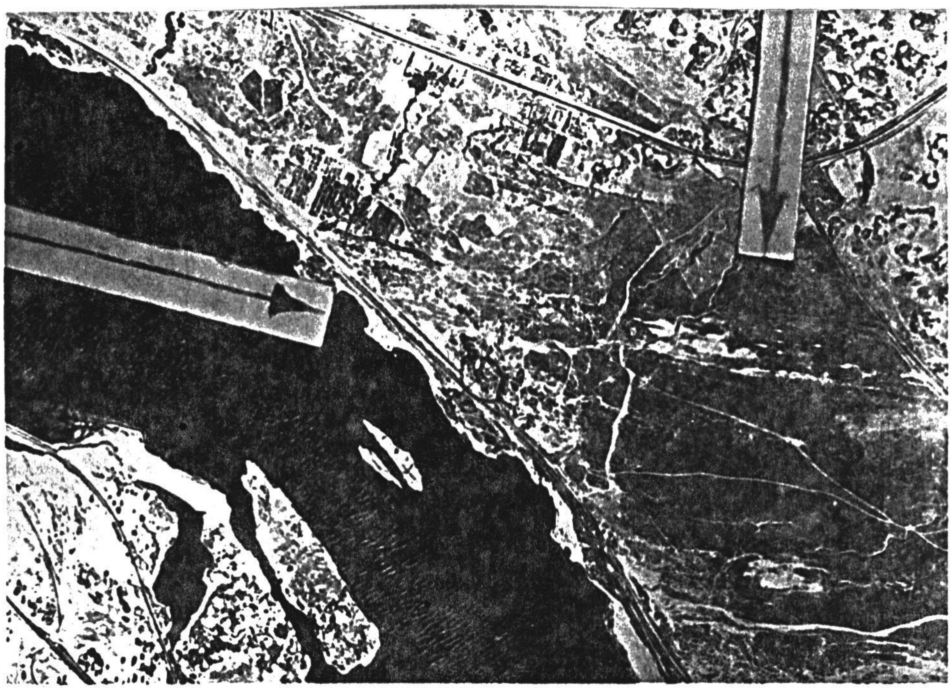

Figure 16. Photostatic copies of air photos may enhance some kinds of photo evidence (same as in Photo #9) as here with a photo from early 1940's (courtesy: Bonneville Power Administration). Historic photos may establish the reliability of temporal or transitory evidence.

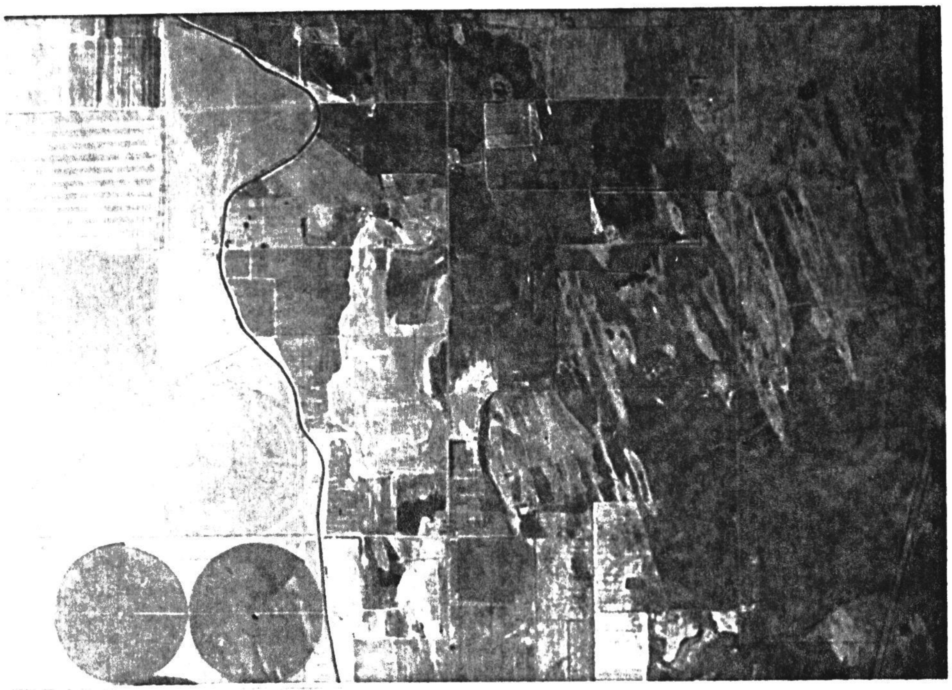

Figure 17. Vegetation distribution is sometimes indirectly dictated by eolian causes. Eolian soil depositions are frequently evident in crop development in eastern Oregon and Washington. (Courtesy: ERSAL, Oregon State University, NASA flight 75-127)

1. re. ecological and botanical influences -

   a. phototaxic propensity
   b. community density, age, competition, and succession
   c. maturity
   d. normal morphology
   e. normal distributions
   f. seasonal phenology

2. re. site -

   a. exposure
   b. roughness and slope of terrain
   c. adjacent land forms (also regional)
   d. elevation

3. re. site history -

   a. fire
   b. ice
   c. sand
   d. salt spray
   e. landslide
   f. slumping terrain
   g. soil creep
   h. avalanche
   i. earthquake
   j. lightning
   k. drought
   l. flood
   m. disease
   n. logging or other pruning

4. re. climate -

   a. season length and intensity's
   b. seasonal wind directions, regularity, intensity, humidity, and temperature
   c. snow
   d. temperature extremes
   e. available moisture
   f. frost

continued . . .

Figure 18. List of possible influences on tree morphology.

Figure 18. continued

5. re. air photo timing and reconnaissance mission -

   a. sun angle
   b. light intensity
   c. shadow contrast
   d. flight angle
   e. flight elevation
   f. parallax
   g. camera angle
   h. film type
   i. concurrent surface breezes