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**Geographic Image Modelling of
Environmental Degradation Associated with
Acid Mine Drainage - Kam-Kotia Mine
Tailings.**

by

Nicholas A. Walsworth

A thesis submitted to the faculty of Graduate Studies
and Research in partial fulfilment of requirements for
the degree of Master in Geography
(Master of Arts)

Carleton University,
Ottawa, Ontario.
January, 1998

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acceptance of the thesis

**Geographic Image Modelling of
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submitted by
Nicholas A. Walsworth, B.Sc., B.A.
in partial fulfillment of the requirements for
the degree of Master of Arts

Thesis Supervisor

Chair, Department of Geography

Carleton University
January 1998.

ABSTRACT

A planar cellular transition model was proposed as a predictive methodology for modelling tree canopy dynamics along a chemical contamination gradient associated with mine tailings at the Kamiskotia, Ontario.

Raster model transitions were developed as a function of both proximity to the tailings and neighbourhood class configurations. Inputs to the model consisted of scanned registered archival photography, which had been segmented to identify tree crown apexes showing changes over a 45 year interval. Tone and density of the tree crown apexes were used to separate coniferous/understorey classes occurring as openings within the mature aspen canopy.

Significant temporal trends were established utilizing the Mann-Krendall statistic which indicated forest degradation nearer the tailings and within mature canopy areas showing less homogeneity.

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CHAPTER 1: INTRODUCTION

Long term environmental monitoring of industrial facilities has proven to be an expensive proposition for regulators. The difficulties in maintaining continuity in sampling and the frequent requirement to extrapolate from local to regional scale often make monitoring analysis expensive and difficult to apply. The resulting accumulation of extraneous data can both obscure the initial objective and reduce communicative effectiveness of an individual analysis. Recognizing these limitations, remotely sensed imagery is often applied in association with sampling as a more practical means of relating data to a regional context. Aerial photography has been utilized to record landscape conditions since the 1940 s, offering the potential of an extended historical sequence of environmental change at medium scales (1:10,000 - 1:70,000). Government mapping programs such as the Ontario Forest Resource Inventory (FRI) provide an existing temporal database at sub-metre resolutions and in stereo, both useful for drainage and forest analysis.

Landscape change is an aggregate description of a multitude of environmental processes. Both natural successional change and contaminant induced change may exhibit spatial characteristics in remotely sensed imagery. Spatial processes may be divided into local processes such as inter-tree competition for light, or regional processes, such as climatic change. Generally, the division between natural and

contaminant associated change is unclear but is generally more easily identified for point source pollution. For example, a gradual succession of lower-order forest types characterized by thinning canopy may be texturally evident within multi-temporal imagery. Temporally integrated, these images may display spatial trends and feature associations indicative of a pollution gradient, or ecological process. This visualization of change on forest images is the conceptual basis for this study.

1.1) Acid Mine Drainage and Resource Development

Acid drainage is a serious environmental problem associated with mining activities, as well as a legislative problem since many mines are developed on leased Crown Lands. Potential environmental consequences of acid mine drainage (A.M.D.) include heavy metal contamination of biological systems, and inevitably forest degradation. A.M.D. is generated from the oxidation of sulphide minerals which, when exposed to oxygen and water, produces acidic pore water and harmful concentrations of sulphate, iron, and heavy metals. Mined waste rock and tailings which have been discarded due to low ore grade, or waste slurry from the crushing and concentrating process in the mill, are principal sources of A.M.D. Depending upon the mining situation and ore grades, the majority of the mined rock is accumulated as waste. The amount of acid mine drainage produced is dependent on the concentration of sulphide within the waste rock and on the climate and catchment area

physiography. In wet climates with large catchment areas large flow rates can exist in streams draining tailings piles. For example, at the Sullivan Mine, British Columbia, 6000 L/min of flow was measured from 239 hectares of tailings (Kuit, 1980). Rates and concentrations of A.M.D. production are dependent on the aggregate particle surface area available for oxidation and involve factors such as particle size, void inter-connectivity, shape, pore pressure and saturation. Generally, the finer the particle size the greater the reaction surface and the higher the acid production. The run-off will continue long after mine closure. To alleviate this inherent problem many mines use waste rock as aggregate in backfill concrete after areas have been mined out. However, only a portion of the original material can be replaced, and the finer tailings are generally not used. Approximately 12,000 ha of tailings have been estimated to be unrehabilitated in Canada (Béchar, 1993).

Unlike renewable land resource activities such as agriculture and forestry in which there is clearly a vested economic interest in maintaining land viability into the future, mineral deposits are finite resources with a limited production life. The temptation, therefore, is to maximize profits at the expense of nature. Short-sighted economically-driven development has led to the irreversible degradation of the local environment surrounding many former mine sites. Legislation has attempted to control emissions

from mining by incorporating requirements of rehabilitation after closure. Public planning processes consider development through environmental review, in which risks are assessed and mitigating measures recommended. It has proven to be difficult, however, to refuse approval for mining development since it can be lucrative for small communities. Development refusal may be viewed as the application of a double standard when companies have already invested both time and money in regional exploration programs, often encouraged by the very governments exercising their right of refusal. In order to assess whether development is "appropriate", environmental reviews are generally undertaken utilizing a cost-benefit analysis in which all the economic, societal and environmental concerns are brought forward and assessed in an attempt to find an optimal compromise. This requires projecting the consequences of mining activities based on current knowledge utilizing past development as the model. The Kam-Kotia site in Timmins, Ontario, is a good example of poor implementation of acceptable practices and serves as a monument to the need for environmental controls. For the geographer the site provides a laboratory illustrating the catastrophic effects of acid mine drainage and associated spatial changes. Use of archival photographic record provides a baseline from which change may be assessed.

1.2) Objectives

The aim of this study was to develop a geographic modelling methodology describing temporal forest changes and to determine the feasibility of using archival aerial photography as inputs to the model. The developed model has been applied to forest changes associated with chemical contamination and mechanical deterioration from wind effects near the Kam-Kotia Mine site, Timmins, Ontario.

The following research objectives were set:

- survey the extent of tailings diffusion and associated forest degradation at the site;
- using temporal archival photographic analysis evaluate the environmental changes which have occurred over the period of tailings deposition to the present;
- demonstrate how automated image recognition of tree crowns and a descriptive temporal model can be integrated to characterize forest change;
- show how the integration of neighbourhood tree locality measures can be used to delineate forest type classes and enhance a temporal transition model of forest change;
- evaluate the suitability of employing measures of proximity to a pollution source for the diagnosis of change.

At the root of this study is the belief that morphological law as derived from measurements of image structure may provide a first diagnostic of processes acting within the physical landscape, and that these measurements, with sufficient temporal training, may be encapsulated in a predictive representation of environmental change.

1.3) Thesis Structure

This thesis presents the development of a modelling methodology for portrayal of forest change. Because intermediate results were required before continuing to subsequent stages of model development, evaluation of each stage of the model is presented with its associated methodology in order to preserve continuity. Chapter 2 of the text begins with a description of the chemistry and the problems associated with the generation of acid mine drainage. A brief summary of remote sensing and its role in ecology follows, highlighting temporal modelling mechanisms and geographic models in particular. The geography of the study site is then introduced in Chapter 3 and previous studies of the area are summarized in Chapter 4. Chapter 5 elaborates upon the study approach and some initial requirements. The remaining text is divided into three methodological sections describing the development of the temporal modelling sequence (Figure 1-1). Chapter 6, Section 1 is a field description of geographic processes involved in tailings spread which leads to the conclusion that

Figure 1-1 Three procedural areas of study

individual trees are suitable objects for analysis of associated forest degradation. Chapter 6, Section 2 is a comparison of two airborne imagery-based, automated, tree-stem recognition methods. Chapter 6, Section 3 uses the derived tree-stem images for four temporal dates to assess landscape changes. Temporal image comparisons are made between individual trees and also between aggregate tree counts. Trends are compared at differing distances from the tailings as well as using a neighbourhood model. The final chapter of the thesis summarizes the proposed model, results obtained and discusses recommendations for further work.

CHAPTER 2: BACKGROUND - Acid Mine Drainage and Methods for Modelling of Environmental Impacts Using Remote Sensing

This chapter provides a background discussion of the three underlying concepts involved in the research; acid mine chemistry (2.1), vegetation response to contamination (2.2) and remote sensing for the evaluation of vegetation change in acid mine environments (2.3). Further discussion is involved with techniques of interpreting remote sensing imagery (2.4) and methods for image modelling (2.5) which are relevant to the research.

2.1) Acid Mine Chemistry and Degradation Processes

Acid generation is directly related to the oxidation of sulphide such as pyrite, FeS_2 . The reactions are similar to those occurring within car batteries and used for the leaching of metals. Occurring in two parts, metal sulphide is first converted to sulphate according to either of the following reactions:

or, for saturated conditions

The ferrous iron (Fe^{2+}) is then oxidized to (Fe^{3+}):

Oxidation occurs in the unsaturated zone in which oxygen is available from the atmosphere as opposed to the saturated zone where oxygen diffusion is retarded. The reactions are

catalyzed by iron oxidizing bacteria at pH values lower than 4.5, increasing rates to 10^6 times that of straight chemical oxidation (Singer and Stumm, 1970) and are believed to thrive within water films coating sulphide mineral grain boundaries. The ferric ions and dilute sulphuric acid produced by oxidation liberate metallic ions such as Cd, Co and Ni generating ferrous iron and sulphur (Rossi, 1990). Metal concentrations are dependent on the composition of the raw material available for oxidation within the tailings and iron partitioning between an aqueous and a hydroxide precipitate. Ferrous iron (Fe^{2+}) is found in solution at pH less than 6 and ferric iron is found in solution at pH less than 3. Commonly, water within tailings can range in pH between 2 and 4, contains a mix of dissolved metals and characterized by an elevated conductivity due to increases in ionic species. Rates of reaction and oxidation are dependent on surface areas of tailing particles, structure and composition of the sulphide minerals, rate of oxygen transport to the reaction site particle surface, residence time of percolating water, temperature, and the vitality of biological growth of iron-oxidizing bacteria (*Thiobassilus ferro-oxidans*) (Béchar, 1993).

Pollution effects of A.M.D. are complex but can be categorized as a result of metal toxicity, acidity, changes in sedimentation or water processes, and salinization. Contamination spreads via ground water and run-off, its advance dependent on the hydraulic conductivity and

surrounding substrate buffering capacities. Elevated sulphate and iron concentrations will precede the acid front until the buffering capacity of the substrate is superseded. Outflow will contaminate local streams impacting upon shellfish and fry (Kelly, 1988). Local wells also may become contaminated. The infiltration of metals becomes cumulative within living organisms and communities. Environmental degradation can be assessed at differing levels within the biological system including;

- (1) population-level effects either through senescence or avoidance,
- (2) community-level effects such as decreases in diversity,
- (3) system level impacts using indicators such as decreased litter.

2.2) Vegetation Response to Acid Mine Contamination

Metals such as nickel, copper, chromium, cobalt and lead may cause stunted plant growth, localized absence of certain species, and reduced vegetation cover. In less severe conditions, chlorosis and early senescence of local vegetation becomes apparent. Chang and Collins (1983) reported retarded development of chlorophyll at concentrations of as low as 100 parts per million nickel, copper and zinc metals in forest soil.

Plant nutrients bound within clays and chelating compounds in the soil are leached by acidity and replaced by metals from the mine tailings. Bacterial and detritivore activity

may decrease, changing the circulation of nutrients in the system and litter.

The cumulative effects of high soil acidity and metal content may also be morphologically evident through branch dieback, thinning crowns, early senescence, or a prominence of disease such as fungal attack causing an overall density decline of sensitive species.

If individual tree deaths are not replaced by regrowth, forest structural changes may occur. It is this response to stress which is studied in this thesis. In areas of extreme impact, vegetation may become denuded. Soils then become subject to erosion and re-deposition thereby modifying hydrological patterns, especially during spring run-off. The tailings themselves, which typically have a large amount of mobile silts and sands, may be mobilized with surficial flow and mass movement resulting in clogged waterways, decreased light transmittance through the water column, and increased siltation which may be harmful to benthic organisms. Denudation of vegetation cover can also increase direct evaporation rates, causing the formation of salts and progressive salinization. Large amounts of sulphate and iron hydroxide are products of the chemical process and can form crusting upon the surface, which in turn may be mobilized by wind, and deposited on surrounding vegetation, leading to leaf-surface burning. Crystals may also form upon organic materials, cementing their surfaces in a similar manner to

petrification.

2.3) Conceptual Basis for Analysis of Environmental Degradation using Remote Sensing

Geographic mapping studies attempt to describe aspects of the physical landscape; understanding is undertaken through deriving relationships between mappable features and modelling them to validate an hypothesis. Newell and Simon (1976) encapsulated "knowledge" in terms of a physical symbol hypothesis in which the representation of knowledge is undertaken through symbols which can be linked forming symbol structures. In addition to these dynamic structures, a collection of processes is utilized to create, modify, reproduce or destroy these symbol expressions in an evolving representation of symbol structures. This is a natural language or object-oriented computer-based representation, but this idea is not radically new to geographers (Bunge, 1962). For example, as a part of map communication, cartographers have had a long history of employing perceptual symbology taking advantage of graphical constructs to produce meaning.

Image interpretation similarly attempts to recognize image symbology that is representative of natural process. Visual image interpretation comprises three stages: detection of features; identification of features; and assessment of the significance of features (Lloyd, 1994). Detection is necessarily a ground generalization process, because not all

ground features will be detectable on the imagery. This may be due to scale, in that features are either too small or too large; objects may have poor tonal or colour contrast or are blurred; they may also be obscured by shadow or atmospheric conditions.

Satellite remotely sensed observation now provides the opportunity to monitor the biosphere at regional and global scales. Intermediate-large scale measures allow regional to local themes to be examined using airborne images. Before multispectral scanners were introduced aerial photography was the primary source of imagery and therefore provides a longer archival record. The spatial extent of tailings deposits and their spectral differences from the surrounding landscape favour the use of aerial imagery for recognition of environmental stress (Fenstermaker, 1990). To the extent that archival imagery exists, the temporal context of regional variations may be available.

2.4) Image Segmentation

Visual image interpretation is based on feature identification, which is then assessed by its contextual significance. Graphic elements such as size, shape, shadow, tone, colour, texture, pattern and situation, are all considered during interpretation. The methodology of extracting objects or classes of objects from imagery is called segmentation.

Haralick and Shapiro (1985) outlined several segmentation techniques in a summary article which, although not directly applied to tree delineation, shows how methods are frequently a hybridization of techniques. Their classification of segmentation methods is outlined next.

i) Measurement Space-Guided Spatial Clustering

The simplest technique is *Measurement Space-Guided Spatial Clustering* (M.S.G.S.C.) in which, with single band data, clusters can be interpreted directly as the intervals between valleys within a histogram of the image pixel values. A classified segmented image can then be created through assigning the cluster classes via unique pixel grey tones. Although histogram modes and peaks may not be well developed, the prime disadvantage of segmenting solely in measurement space is that there is no spatial continuity control, since it depends entirely on grey tones. An enhancement to this process is to create masks of connected pixel groups iteratively derived from the clustering and in turn these small area masks can be merged to adjacent clusters (Ohlander, 1975).

The advantage of M.S.G.S.C. is that it avoids poor region merges, but unfortunately, it does not produce contiguous regions. To lessen the noise, grey tones are frequently smoothed, simplifying the image (Goldberg et al., 1984; Nagao and Matsuyama, 1979). A number of spatially specific threshold scenarios have at various times been proposed.

Chow and Kaneko (1972) used local areas to generate the histogram while others have produced masks favouring high contrast edges using Laplacian magnitude or "busyness" (% pixels having a high neighbourhood threshold). The theoretical basis for these approaches is that the histogram, generated from the high contrast mask, will have equal numbers of pixels from the background and the foreground object and hence should serve to enhance cluster separability (Weszka et al., 1978). Panda and Rosenfeld (1978) transformed an image into two-dimensional space consisting of grey-tone intensity and gradient magnitude. High gradients were considered likely at an edge between regions which, through projection, could form a decision boundary separating foreground and background low-gradient elements.

ii) Region Growing Segmentation Techniques

"Region Growing" algorithms, in contrast to those described previously, are spatially explicit. The simplest, the *Single Linkage Region Growing Method* (S.L.R.G.M.) takes the form of linking neighbouring pixels with "similar" properties so that segments are sets of like pixel chains. "Similarity" in its simplest form is an absolute difference between grey tone intensities below a certain threshold, or a difference normalized with the paired differences for the entire area. Although simple in theory, the major limitation of this technique in practice is that it takes only one aberrant link to merge regions (Bryant, 1979; Asano and Yokoya,

1981).

Hybrid Linkage Growing Methods (H.L.G.M.) assign a pixel a "property vector" based upon its $K \times K$ neighbourhood (Reed and Wechsler, 1990). Pixels are similar if their neighbourhoods are similar, thus enhancing performance in noisy data. Links between similar pixel-neighbourhood arcs are created if each pixel is in the other's shared neighbour list and the number of shared neighbours is great enough. If regions are assumed to have normal distributions of grey tones a t-test can be used to pair neighbour regions (Yakimovsky, 1976). Jarvis and Patwick (1973) used a measure of similarity as a measure of association between the pixel and the $K \times K$ neighbourhood (eq 2-1).

$$\begin{aligned} \text{Similarity} = & W_1 (A_{\text{pixel}} - B_{\text{pixel}})^2 \\ & + W_2 (A_{\text{pixel}} - \text{avg}B_{(K \times K)})^2 \\ & + W_3 (B_{\text{pixel}} - \text{avg}A_{(K \times K)})^2 \end{aligned}$$

Eq. 2-1

Roberts and Sobel operators have been applied in growing algorithms to close gaps between segments (Haralick and Dinstein, 1975). Other edge detection techniques have also been used to create segment enclosures which can be filled to form regions (Perkins, 1980; Pavlidis and Liow, 1990). Haralick (1980) suggested fitting a plane to the neighbourhood, or on either side of a pixel, and testing to determine if the slope was zero or if the coefficients of

fit were similar; if this was not the situation an edge was assumed. Woodcock et al. (1983) used this slope facet model to segment rugged forest landscapes.

In this manner regions may be merged based upon the property vector. Pong et al. (1984) used this formulation in an iterative manner updating the property vector with each merge and stopping the sequence when the variance of the combined region was exceeded.

An alternative to the above techniques, employed by *Centroid Linkage Region Growing* (C.L.R.G.), is to compare a pixel to the mean and standard deviation of a completed segment so that it may be incorporated within the segment if it is similar or within a new segment if it is not. If two adjoining segments are similar they can also be merged (Pavlidis, 1972). The strength of centroid linkage is its ability to place boundaries on weak gradients since it depends upon a difference between the pixel and the mean of a neighbouring region to declare a boundary. However, it lacks the spatial fidelity that single-linkage growing demonstrates. Hybrid Linkage Combination Techniques combine both single linkage and centroid linkage techniques by limiting centroid linkage to non-edge pixels having distinct boundaries (Haralick and Shapiro, 1985).

iii) Spatial Clustering Techniques

Spatial Clustering is an attempt to combine clustering in

measurement space with region growing or spatial linkage techniques. Haralick and Kelly (1969) used histogram peaks as seeds, combining both spatial and measurement region growing clustering away from these peaks. An alternative algorithm is to apply differing measurement intervals iteratively so that a generated segment maximizes its coincidence with a border defined by an edge operator (Milgram, 1979). Instead of only utilizing edge geometry, gradient-guided segmentation can direct segmentation towards an edge. For example, Minor and Sklansky (1981) counted the number of distinct directions in a 3 x 3 neighbourhood and defined the following rules: if the number was high, it indicated the pixel was interior to the segment and region growing could continue; if the number was low, as for high gradients and limited directions, processing would cease.

Spatial clustering may also be applied within an aggregated pyramid structure in which parent-child links between aggregated layers are formed through association of a pixel to its closest parent. Segmentation in this instance is accomplished by backtracking through these parent-child links (Burt et al., 1981). This methodology is similar to *Split and Merge Methods* which consecutively divide an image until each portion is tested as being homogeneous. Tests of homogeneity use measures such as sample variance and range. Segments, however, tend to be blocky and artificial, and adjacent segments frequently need additional merges (Horwitz and Pavlidis, 1976; Chen and Palidis, 1980).

Shadow and texture are strong image elements of forested areas. Individual tree crowns seldom portray sharply defined edges or uniform tones. Such image characteristics favour the application of region-growing segmentation, with surficial image highs acting as the seeds from which to initiate growth. Laplacian filters may not be appropriate for delineating tree edges, but may highlight high tonal contrasts found between illuminated and shadowed portions of crowns.

2.5) Temporal Modelling using Remote Sensing

Recognition of change is the fundamental requirement for undertaking modelling. One may argue that most environmental measures can only convey meaning through comparison to standards, which frequently are "average" measures of "health" for the region or similar habitat. The variance between the control and the sample is an indication of difference from which change can frequently be inferred. In remote sensing a popular example of such work is the use of calibrated sensors to detect red-edge (670nm-800nm) spectral shifts in the identification of stressed vegetation that exhibits chlorosis and/or cell deterioration (Chang and Collins, 1983). Another popular spectral technique is the combination of spectral bands, often in some form of ratio, which have been effective in mapping vegetation characteristics, including vegetation stress, particularly if spectral responses in different bands have an inverse relationship. This is the situation for the red and infrared

bands in that chlorophyll absorbs red light while mesophyll tissue strongly reflects in the infrared. Thus the IR/R ratio for healthy vegetation is high, whereas stressed vegetation and bare soil will show smaller values. Clearly, use of such measures in quantitative modelling requires care in minimizing external factors such as leaf orientation and atmospheric variation since different bands are not affected uniformly.

For local environmental change, differences can be recognized through a relative measure with a comparable control area rather than an absolute quantitative measure. The control sample area is usually selected to be representative of a pre-existing environment located nearby but assumed, or known to be, unaffected by the stress mechanism(s). Associated with this logic is the assumption that natural variance is proportional to distance, so there is an inherent trade-off in placing a control sample close to the disturbance yet not so close as to be impacted by it. Obviously, if the goal of any study is to delineate the area of impact, a difficulty arises when a necessary model input and the study goal are one and the same. Frequently, measures of landscape autocorrelation or semivariance are used to assess natural background variations towards which aberrant areas may be contrasted.

To alleviate difficulties in defining locality, or when studying more pervasive changes, temporal comparisons are

needed, thereby replacing auto- with cross-correlation comparisons. This is the situation with many climate/vegetation studies. For remote-sensing studies, this involves imaging the same geographic area through time. In simplistic terms temporal imagery measures radiance change, which should imply changes within the landscape if data are calibrated (Singh and Harrison, 1985). The principal difficulty in this approach is that the largest differences are often caused by the sensor or differing illumination conditions, outweighing the subtle measures of environmental changes. Another important consideration in such temporal analysis is the sampling interval. Transition calculations are limited to comparison within the selected time interval, so that the change continuum is reduced to instantaneous snapshots. Clearly, where appropriate, natural cycles such as seasonal, diurnal, tidal and a host of others must also be considered.

2.5.1) Change Representation

Portrayal of change can be undertaken through animation which can display imagery sequentially. An alternative is to store temporal topology, similar to HHCodes found within ArcInfo (Langran, 1993). Both methods portray change but they do not address quantification of it. Tobler (1979) outlined five model categories for understanding change (Figure 2-1). Lower categories start with a model in which changes are random, such that local states are not related to previous states. Higher categories show measures

Figure 2-1 Five temporal geographic models (Tobler, 1979)

of predictability encapsulated into a function dependent upon a singular or a sequential set of previously existing coincident or neighbouring attributes. This function describes the propagation of states between instances of time. Model V represents the approach taken in this research: local forest structural change through time is assumed to be a function of pre-existing conditions within the immediate neighbourhood, and of some causal mechanisms.

The simplest accepted method of examining spatial change is to overlay maps of differing time periods. This is used to construct temporal difference images or temporal ratio images (Avery and Berlin, 1985). Problems arise when multiple coverages are incorporated since the added layers often make results difficult to interpret.

Graphs are also often employed to illustrate changes, either by applying the graph directly or as "symbolic glyphs" indicative of trends (Monmonier, 1990). Often trends and not rates are required for interpretation; for these applications, the Mann-Kendall trend statistic is useful. It may be used with ranked data for which a positive or negative difference direction is calculated for all unique pairs (later minus earlier) (Varekamp et al, 1996). Each of these change layers can then be summed to form a critical value which can be compared to a look-up table to determine if the trend is significant (Gilbert, 1987). Alternatively, other statistics can represent change. Many workers use an

initial hypothesis and apply the model spatially so that predicted values and residuals from regression may be considered. More advanced methods may undertake principal component analysis to reduce data redundancy. Standardized principal components can also be used directly for integrating time-series data. This technique has most frequently been a method of data compression, through undertaking a linear transformation between bands or temporal images to create a new uncorrelated set of bands ranked in terms of the amount of variance explained in the original data (Davis, 1986). The first component is often indicative of a characteristic value, whereas the remaining principal components are representative of successively decreasing changes (Eastman and Funk, 1993). The principal components have been attributed to seasonal, atmospheric, and successional differences but still there are no comprehensive methods of interpreting the change components.

- Ⓐ Primary input image containing attributes being modelled.
- Ⓑ Associated input image containing attributes used in the modelling but not transformed.
- Ⓒ Roving neighbourhood window - here consisting of a 3 x 3 kernel travelling through each of the images synchronously row by row successively so that the window is moved through all the available input cells.
- Ⓓ The transition rule propagates the state of the input cell as a function of its associate and input image neighbours.
- Ⓔ At the end of a cycle/iteration the output image becomes the input image for the next generation.

Figure 2-2 General cellular automata schematic.

2.5.2) Discussion of Transition Models

The most common methodology utilized in building mathematical transition models of natural phenomena has been the differential equation describing change as a function of position and time. Some of the most popular transitional models in geography consist of thermodynamic and gravitational equations, which describe natural distribution patterns such as the nebula effect associated with diffusion systems. These equations are continuous and vary smoothly. In contrast, raster models do not represent space as a continuum but instead as a discrete structure consisting of an array of cells characterized by a finite number of states and time steps. Raster modelling is a technique by which attributes associated with a cell may change over time. Although physical space is thought of as being continuous, this does not necessarily infer that differential equations are superior models. Frequently, the researcher is more concerned with patterns of relativistic behaviour, for example, whether the landscape has been degraded and where, rather than precise amounts. Cell-space models make the discreteness explicit in a digital computer model and may therefore be interpreted to be a more realistic view of the computational world.

Tobler's (1979) five model categories have already been introduced as a means for understanding change (Figure 2-1). The following discussion will outline an example of a

functionally dependent model with the introduction of Markov chains as a predictive methodology in deriving landscape change. The discussion will proceed to illustrate traditional Markovian modelling limitations when considering geographic applications, and introduce the automata approach as an alternative for this study (Figure 2-2). Interspersed are relevant considerations and decisions regarding implementation details for modelling the environmental degradation at mine sites. Lastly, as part of the theory section, a tailings centred diffusion approach will be discussed as a means of defining the tailings propagation edge, and more importantly offering a geographical benchmark from which to assess forest structural change.

i) Markov Chains

Markov chains as a particular raster model are an accepted means of modelling stochastic ecological changes (Viovy and Saint, 1994). For example, Hall et al. (1991) used multi-year Landsat imagery as a means of estimating transition frequencies between states and later used it as an input for a predictive model. The temporal imagery was obtained in successive years at similar times of day and growing season. The predicted percentages of land classes were then assessed by comparison with known percentages for selected dates.

This methodology, applied to imagery, consists of radiometrically and geometrically registering temporal images ($g_{i,j}^t$) so that a state transition matrix (T) for a

time interval $(t \rightarrow t+1)$ describing change is obtained. The matrix is square and contains non-negative entries corresponding to the transitional probabilities, so that all rows sum to 1. Assuming

the transition is steady-state, a prediction may

be made by the power method (Eq. 2.2). The power method (x) in

effect can dilate, contract, or reverse the direction of propagation, offering a means of extrapolating temporally irregular data coverage to create a continuous image sequence of landscape proportions through time. Figure 2-3 shows that the tree coverage percentage for an archival

image is approximately 30% spruce, 20% poplar and 50% other.

Comparing this image to an image of the same area 5 years later shows changes portrayed in a transition matrix corresponding to the transition area divided by the initial class area. This transition matrix quantifies the probability a certain class transition will occur. Substituting the transition matrix (T) and the initial area percentages (X^{1988}) and using a power factor of two, the 1998 landscape composition can be predicted.

$$(g_{ij}^t)^x = (T_{(t \rightarrow t+1)})^x g_{ij}^t$$

where x indicates the number
of intervals to be extrapolated.

Eq. 2.2 Stochastic Model
(Tobler, 1979)

Predictive Example		
1988 Class %	Transition matrix 1993	to extrapolate to 1998 $Z^{1998} = X^{1988} T^2$
30% Spruce	$T = \begin{Bmatrix} 0.8 & 0.1 & 0.1 \\ 0.1 & 0.7 & 0.2 \\ 0 & 0.1 & 0.9 \end{Bmatrix}_{1988}^{1998}$	which produces a composition of {23, 23.2, 53.8}
20% Poplar		
50% Other		

Figure 2-3. Markov Landscape Example

When considering a number of image combinations, temporal error-correcting methodologies may enhance creation of a smooth behavioural dynamic having similarities to Tobler's historical model (Figure 2-1). Obviously there are problems with the steady-state assumption, in that only minor changes would seem validly addressed and hence would appear ill-applied to catastrophic behaviour as is evident at mine sites where tailings are disposed of in the surrounding environment at high rates. For this reason, such transformations are only envisaged to be applicable to forest damage proximal to tailings after the tailings have essentially reached their final spatial extent.

In application, transitional modelling can be undertaken either on a pixel or patch-based transition, differing only in estimation of contagion and amount of edge (Flamm & Turner, 1994). It is important to determine which scale is appropriate for description of the involved changes, and which will reflect the desired behaviour (De Cola 1994). This is a much-researched study topic, an example being the multitude of fractal studies in the literature, yet, derivation of a specific means for discovering appropriate scale has not been determined. For the purpose of this study, it is believed that the individual tree level should be the appropriate scale of analysis to understand the environmental degradation associated with acid mine drainage. Trees and tree clumps are both sensitive to heavy-metal contamination and are visibly interpretable within

1:15,840 photography (Figure 2-4), allowing changes to be quantified using archival photography. From an ecological standpoint it is not enough simply to model individual trees, but additionally, the spatial inter-relationship between entities (trees) needs to be

Figure 2-4 Closeup image scan showing tree crowns.

quantified in order to achieve accurate description of change that incorporates components of both inter-tree competitive growth and the broad contamination effects.

ii) Geographic Model - Automata

Hagerstrand (1967) coined the term neighbourhood effect while studying diffusion in order to explain the ordered transfer/dispersal of information between adjacent nodes. This description of geographic locality is a defining feature of cellular-space models. In raster systems this is termed a cell neighbourhood. A cell's neighbourhood is usually characteristic of the model consisting of the cell and cells nearest to it geometrically. For example in a square-celled lattice the simplest definition is to include cells in a box surrounding the central cell - a Queen's case neighbourhood.

The consideration of context is the crux of any geographical model as viewed by Tobler (1979). Turner (1987, 1988)

extended transition models to become spatially explicit using four or eight nearest neighbours to influence probabilities. Obviously, direct application must address problems associated with maintaining spatial contiguity. This is due to the probabilistic nature of the transitions in that the whole neighbourhood region defines a class, and consequently derived neighbour elements may not correspond. Figure 2-5 shows an example of this in which two adjacent Rook's case neighbourhoods, each having predefined neighbourhood transitions, result in overlapping elements that are in disagreement. Decision rules to minimize these

Figure 2-5 Continuity problems with neighbour block transitions.

conflicts may be implemented or simply the central cell can be modelled alone. In the latter, the resulting spatially explicit model is identical to that in Tobler's Model V, otherwise known as a cellular automata model.

Cellular automata are characterized by a system of interacting cells displaying aggregate behaviour (Equation 2.3) as follows:

$$g_{ij}^{t+\Delta t} = F(g_{ij}^t, n_{ij})$$

Eq. 2.3 Geographic Model

- 1) $G = \Sigma g$, the cellular space consists of a 1,2, or 3 dimensional matrix of cells,
- 2) at any instant in time a cell can have one of a set of local discrete states, g_{ij}^t .
- 3) at every time step, the state of each cell is updated according to the transition rule F , which acts upon the target cell as a function of the neighbouring cells, n_{ij} . (Tobler, 1979)

In a parallel-processing computing environment the cell space of an automatum could be likened to a series of synchronously activated machines modifying a target cell as a function of inputs from its neighbouring states. In a serial (Figure 2-2) computational environment the neighbourhood may be viewed as a floating template that is transposed across space so that it is centred upon every individual cell of concern during one generation of the model run. Such implementations mimic this synchronous update behaviour through storing outputs until the full raster has been traversed, at which point it is updated in bulk. The full sequence is referred to as an iteration which for real-world models may correspond to a specific time interval so that the iterative cycling and updating of

attributes in space potentially mimic natural behaviour such as diffusion, competitive growth, etc. Cellular automata are also spatially explicit, considering space as a function of neighbours and they can be probabilistic, encompassing stochastic description.

Transition Function

The transition rule defines how a cell at a time t will change as a function of its neighbours. Figure 2-6 shows a landuse example of a transition rule encoding an urban transition of agricultural land when surrounded by incompatible landuse types. Since position of the surrounding neighbours is not necessarily important, the rule can be generalized, thus lowering the number of possible neighbour permutations.

Figure 2-6 Transition rule for a landuse example (Tobler 1979).

Modelling may be achieved in two differing ways:

- Forward approach, for which the transformation rules are given and the aim is to understand pattern development.

- Backward approach, in which patterns are given and the aim is to determine the transformation rules.

Forward, Deterministic Rules

Much of the work in automata has focussed upon development of deterministic rule sets (Toffoli and Margolus, 1987), each transition rule set displaying characteristic transition behaviours. The most famous, the "Game of Life" rule set depends upon the number of neighbours and the central value displaying dynamic patterns comparable to bacterial growth/death cycles (Gardner, 1971). Toffoli and Margolus (1987) classified these transformations based upon counting rules as a model of competitive growth. An extension of these non-directional rules are voting rules, in which a simple majority of states will determine an evolutionary outcome. In a binary context this may be represented by a simple majority in a nine-cell sum (3x3 Queen's-case neighbourhood). The cumulative spatial effect is a consolidation of areas, with boundary areas frequently forming convoluted edges representative of small variations in the majority. The textural effect is similar to those found within metallic ores generated by annealing processes. A variation of this is the fuzzy anneal, in which a marginal majority is employed which tends to be more adaptive and able to consolidate over a larger range of configurations (Toffoli and Margolis, 1987). Sato and Iwasa (1993) used deterministic directional automata to simulate wave-regeneration forest rings within subalpine areas as a

neighbour function of tree height and wind exposure.

Automata have been applied to modelling turbulent flow using an hexagonal lattice, with particles interacting through vector momentum (Wayner, 1988). In a geographic application, runoff and flooding can be modelled in this way (Walsworth, 1994). An analogy is to consider the raster model as a pyramid of champagne glasses; once a glass is filled it will overflow into the surrounding glasses below. In a raster terrain model, each cell may be likened to a glass - with one important difference - namely that flow is not fixed but a function of the slope and direction of terrain. The water model algorithm distributes flows by way of a water budget approach in which each cell has its inputs and outputs.

Backward, Non-Deterministic Rules

Unlike the previous forward methodologies, backward automata focus upon prediction through the comparison of states between individual time steps, and iterating the model for relatively few generations rather than thousands. In implementation they are similar to Markovian methods in which individual classes or signatures are transitionally modelled with the aid of a square probability matrix (Hall, 1988; Harbaugh & Bonham-Carter, 1970). The automata transition matrix tabulates probabilities of change within the central cell as a function of the cell and its neighbourhood. The introduction of the cell neighbourhood has the effect of raising the total number of input

transitions for a binary problem from 2 to 25 for a rook case neighbourhood, or $[\text{states}]^{\text{neighbours}}$ combinations. Negating the consideration of cell positions would reduce the number of combinations to 10. Zhou and Liebold (1995) derived a model for gypsy-moth outbreaks using the backward method showing that defoliation was highly correlated between successive years, and that consideration of neighbours improved the prediction of the model over that of straight cell-cell comparisons.

Transition Interval

Any transition derived, however, is dependent upon the sampling density and the ability to resolve the periodicity of the change, a consideration that is usually limited by data inputs. This limitation can be demonstrated through using the fuzzy-anneal rule described earlier. This rule is a binary deterministic rule determining a marginal majority within the neighbourhood. If the transitional probabilities between the initial image and later image iterations are calculated, the result will not uncover the original rule but an averaged probabilistic form of it, dependent upon the developmental sequence. Table 2-1 shows the comparison of probabilities of change between two classes $\{0,1\}$ dependent upon the sum of the Queen's-case neighbourhood. The first sequence shows the deterministic rule for one iteration, and the second sequence the calculated transition, for the same image, which has undergone five iterations. The fact that the general shape of the distribution remains approximately

the same may indicate that similar transitions derived from natural landscape image changes may be indicative of an annealing.

Table 2-1. Comparison of annealing transition probabilities between an example initial image consisting of two classes (0,1) and iterations 1 and 5. Note the apparent smoothing of transition probabilities.

	Trans	Probabilities as a Function of Number of Neighbours								
# Neighbours		0	1	2	3	4	5	6	7	8
Original Fuzzy Anneal Rule	p(0,1)	0	0	0	1	0	1	1	1	1
	p(1,0)	1	1	1	0	1	0	0	0	0
Calc. for 5th Generation	p(0,1)	0	0.15	0.16	0.31	0.70	0.62	0.80	1	1
	p(1,0)	1	0.75	0.65	0.61	0.55	0.21	0.09	0.07	0

The advantage of deterministic application is that the model can be discrete within its transitions such that space is not degraded into a random probabilistic sample as is found within stochastic modelling.

Aggregate Behaviour

The consideration of spatial neighbourhood conceptually maintains continuity of structure in the form of edge and contiguity (Phipps, 1989). This characteristic is a necessity for modelling phenomena such as disease spread, forest blowdown, and competitive growth (Bitterlich et al., 1993). Cellular Automata models have been used extensively to model dynamics portraying chaotic and other non-linear behaviours, although this atomistic approach has been criticized in lacking an appreciation of system integrity.

Much research has focused upon "bridging the gap between dis-aggregate and aggregate description" (Ziegler, 1976) in an attempt to unravel the intertwined issues of spatial complexity and complication (Coullelis, 1985). Wolfram (1984) has conjectured that automata are the simplest systems capable of self-organizing behaviour. Various studies have utilized forward transformational automata undergoing a large set of iterations in order to understand pattern development. This study, however, will approach modelling by way of backward modelling in which the aim is to estimate the transformation rules to forest-pattern development.

(iii) Definition of the tailings edge

An interesting challenge is to develop spatial relationships of transitions and a more rigorous understanding of natural process, so that meaning can be derived from the stochastic behaviour (Sato and Iwasa, 1993). In this respect, probability counts incorporated into the transition cellular matrix can be collected with reference to a number of relationships qualifying forest parameters, such as tree type, crown size, density, orientation, soil contamination gradients and proximity to the tailings. The relationship of tree dynamics to the propagation of the tailings edge is considered the most relevant in terms of image modelling, but, to be useful, it requires definition by way of physical landscape processes. For acid mine drainage, it would appear, the integration of terrain and the proportions of

dead-tree population counts would be appropriate for statistically deriving the location of the tailings edge. The problem, however, is that the tailings edge may not necessarily be distinct. The vegetation type and density may exhibit a spatial gradient at the limit of the mine tailings and beyond. Recognizing this fact, a fuzzy edge definition is derived utilizing a Bayesian-data driven methodology used for mineral exploration (Appendix 2) (Bonham-Carter, 1994). Instead of mineral deposits, dead trees are utilized. In this context the statistic can be interpreted as: the ratio of dead trees that fall on a pattern (distance buffer from the tailings) to the total number of trees, compared to the ratio of pattern area to the map total area. Practically, if more dead trees fall on the map pattern than would be expected due to chance, then the pattern may be indicative of degradation. Utilizing this theory for the temporal sequence in relationship to the diffusion patterns provides a graphical estimate of the tailings edge progression (Appendix 2).

2.6 Summary

Remotely sensed imagery appeared suitable for survey of the acid drainage and associated forest structural changes at the Kam-Kotia Mine. Image modelling consists of recognizing change followed by its interpretation. The discussion above outlined several automatic techniques for segmenting imagery into identifiable features and for recognizing forest stress. A region-growing routine was proposed as a suitable

methodology. Once features are identified, tracking of changes spatially and through time may uncover functional relationships, which can then be implemented within a model. A model integrating local neighbour relations and distance from a contamination source is a combination that could describe change at the Kam-Kotia Mine site.

CHAPTER 3: STUDY AREA

The Kam-Kotia Mine is an abandoned zinc and copper deposit located in Northern Ontario 40 kilometres north-west of Timmins (Figure 3-1). The mine site is located overlooking the community of Kamiskotia which is composed of a number of cottages, permanent houses and summer homes, surrounding Kamiskotia Lake. The mine site is situated on a small hill consisting of Archean metavolcanics. Buildings formerly on the site have been removed so that only the foundations remain perched on the edge of a steep-sided open pit approximately 20 metres in depth. Surrounding the mine shaft are numerous large rock piles and three tailings areas, a southern tailings which extends to near the edge of Kamiskotia Lake in the bottom of Figure 3-1 and to the north impounded and unimpounded tailings areas.

3.1) Mine History

Underground exploration at this location started in 1926 and consisted of two 49m shafts and 183m of drifting, but was abandoned in 1928 (Gledhill, 1928). During 1943-44 the shafts were pumped out and a 53m by 38m pit was mined for the war effort by War Time Metal Corp. under the management of Hollinger Mines Ltd. (Berry, 1944). Kam-Kotia Mines Ltd. was formed in the 1950's and operations shifted to underground workings, during which time the mill capacity increased from 800 to 1800 metric tonnes a day. With the addition of copper-zinc ore from the Jamieson Township Deposit 1.6 miles to the S.E., by 1968 output reached a

Figure 3-1 Location map and the KamKotia Mine site

maximum of 2700 metric tonnes a day (Pickering, 1991). Between 1954 and 1961, 0.1 to 0.3 million metric tonnes of waste were discharged to the south of the mill; subsequent to 1961 waste was discharged to the north (Gibson, 1976). Approximately 3.0 million metric tonnes were deposited between 1962 and 1967 in the swampy area north of the mill (M.O.E., 1976). As a result of the Ontario Water Resources Commission (1967) recommendations, major impoundments were constructed over the following two years, during which time tailings corresponding to approximately 1.2 to 1.6 million metric tonnes of waste material were temporarily pumped into the abandoned pit (Kilborn Ltd., 1983). These later mining stages were characterized by the highest milling rates with the waste being deposited in the northern impounded area. Mining operations were closed on December 1972 (G.T.C., 1984). Two years later Cominco and Kam-Kotia Mines Ltd. formed the new company of Robinson Mines Ltd. with transferred ownership of both mine and mining rights. Robinson Mines undertook some reserve exploration to maintain ownership but let a portion of the claims lapse.

Following the dominant topographic drainage, the unconfined tailings sprawl to the northeast, having both escaped the dam through breaching and from having been deposited before its construction. By 1976, the government, concerned about the poor maintenance of the containment dams at the abandoned tailings sites, attempted to negotiate with the company the undertaking of remedial measures - with no

success (Gibson, 1976). This resulted in the issuance of a control order by M.O.E. and an unsuccessful Environmental Appeal on the part of Robinson. A survey of ownership in 1978, however, showed that the Province through the Ministry of Natural Resources Land Management of Crown Lands held ownership of 70% of affected lands whilst Robinson held only 30%. The Environmental Hearing Board determined that Robinson could not be held liable for any site rehabilitation under the Environmental Protection Act since under the terms of the act any responsible party is defined as one having charge, management or control over the property. The costly mistake borne by the taxpayer was that the Ministry allowed the claims formerly held by Robinson to lapse, thus negating any corporate liability for cleanup.

3.2) Geography

Topographically, most of the area surrounding the mine site is relatively flat. Slopes in the area are small, ranging from 0.002 to 0.005 N.E (OMNR, 1991). Soils are glacial and post-glacial sand and silt. To the northwest of the impounded tailings, an esker of glacial sands forms a broad topographic ridge. Excepting this ridge, the area surrounding the mine is of low relief and drainage is poor, forming swampy areas and meandering streams which eventually drain into the Kamiskotia River to the north and east via northerly and a south-easterly creeks.

The three tailings areas total an area of approximately 303

hectares. The largest, of 168 ha, corresponds to the unconfined north-eastern tailings (1991 MNR Photo). The northern impounded tailings is cradled between the esker and a containment dam to the northeast. The dam is visible in Figure 3-1 as a straight line dividing the impounded and N.E. unimpounded tailings. It is approximately 7m high, is constructed of waste rock, runs from the waste pile north of the pit for about 300m north where it contacts the esker. Tailings, which have now dried, were filled into this area as well as into the former open pit when operations were predominantly underground. Tailings are composed of fine silts and sands with oxide rich crusts forming on the surface when dry. Tailings depths decrease to the north from their deepest point in the confined area of approximately 5.8 m (G.T.C., 1983). Below the tailings is about half a metre of fine sand below which is clay. In some areas a hard pan exists. Surface oxidation on the tailings varies in depth from 5 to 20 cm and is above the average water table of 30-60cm below the surface. Dryer oxidized tailings areas are crusted with iron-sulphate-hydroxide crust. The upper surface of the silty clays is weak and appears to be cavitied. It has been postulated that degradation of the silty clay zone has taken place due to acidic leachate between the upper sands and the clay which has undergone ionic replacement, the dissolution of the clay making it less compact and corroded (Kilborn, 1983). The northern tailings areas and leachate flowing from the waste rock dumps have inhibited plant growth due to high acidity and

metal content. Many dead stumps and trunks litter the tailings. Outflow drainage from the unimpounded tailings collects in northern and southeastern seeps. The northern seep has westerly and easterly branches which merge approximately 750m north of the tailings. The broad, nearly rectangular forested area between these stream branches and areas along the remaining section of the northern seep comprise Carleton University's long-term study area (Lévesque and King, 1995). Existing trees consist of mature trembling aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), white birch (*Betula papyrifera*), and jack pine (*Pinus banksiana*) on well-drained sites with an understorey of balsam fir (*Abies balsamifera*) and spruce (Sw - *Picea glauca*, Sb - *Picea mariana*). In wet areas, black spruce (*Picea mariana*), alder (*Alnus* var.) and cedar (*Thuja occidentalis*) occur whereas in intermediate less-wet areas there is a mix. Interspersed throughout the area are fallen trees, mostly the result of blowdown.

Much of the area east of Kamiskotia Lake to the Mattagami River was burned in the 1850 s. The western side of the lake was devastated by a 1911 fire with the character of regrowth still distinguishable 33 years later (Berry, 1944). Recent fires have not affected the area but large spruce and pine were most likely lumbered, because the Feldman Timber Company built a saw mill in 1942 at the mouth of the Little Kamiskotia River to supply lumber for the mine.

CHAPTER 4:

PREVIOUS RESEARCH AT THE KAM-KOTIA MINE SITE

The Ministry of Northern Development and Mines in association with the Ministry of Environment and Natural Resources, starting in the early 1980 s, each commissioned a number of studies and collection of environmental parameters measuring contamination of water flows, wind blown tailings dust, and ground water chemistry in the area. A major assessment was undertaken between 1982-1984 by Kilborn Engineering (1983) and GTC Geologic Testing Consultants (1984) which consisted of a site survey, drilling, waste material assessment and modelling of differing remediation alternatives to control or eliminate contaminated seepage from the tailings.

The major concern to ministry officials was the southern tailings which are seeping into the Little Kamiskotia River 200m east of Highway#576. The southern tailings are clearly visible from the road at this point. The Kilborn report contracted by the government reported that the initial damage to the southern area was the result of a spill from a 6" outflow pipe from the mill and of leachate from crushed sulphide-rich waste rock piles. The cumulative effect was contamination of the area with Zn, Cu, Fe and arsenic at levels 20 times the 1978 regulated levels. Trees and ground vegetation had been killed and contamination has accumulated in the Little Kamiskotia River (Gibson, 1976). Due to the direction of the river flow it has not spread into

Kamiskotia Lake. Following the recommendations of the report, the Ministry dug a seepage ditch to collect effluent along the western side of this tailings, re-routing it away from the roadside community. Most wells in the area are naturally protected by a dense clay layer and are thought to be safe as infiltration downward would be limited.

It is estimated that half of the 3 million tonnes of tailings deposited between 1962 and 1967 were discharged into the north-east unconfined tailings (Kilborn, 1983). Follow-up work conducted by GTC found the following contamination relationships. Salts had concentrations of 2000 to 4000 ppm showing increased conductivity measures in the upper oxidation zone due to evaporation and due to secondary enrichment at the edge of the water table. Generally there is a correlation between lower pH values and higher salt concentrations. Salt enrichment is coincident with drainage paths, presumably since they represent where the water table is closest to the surface. Heavy metal concentrations showed an enrichment along a secondary zone below the oxidation layer but did not appear to percolate into the sand layer (Kilborn, 1983). This is due to the high carbonate contents within the sands and lower solubility of metals at higher pH. Fe and pH contours place the central high in the middle of the containment dike. Concentration of metal contaminants such as nickel were quite low, while arsenic was high at 2,000ppm to 5,000ppm, its source probably being arsenopyrite (M.N.D.M., 1995). In

piezometer water samples, copper, lead and cadmium were up to double the M.O.E. Provincial water quality objectives (0.05 mg/l Cu, 0.25 mg/l Pb, 0.002 mg/l Cd) (Kilborn, 1983).

4.1) Remediation and Estimation of Acid Runoff

Liming is the conventional treatment process in which A.M.D. is collected and neutralized. Lime is added to raise the pH and then aerated to accelerate metal oxidation and precipitation. The neutral metal-free water can then be pumped out leaving the hydroxide sludge. The sludge is stored in ponds and may represent volumes of many times the treated water (Béchar, 1993). In the long term such treatments are not viable. An advantage of liming is that Cd, Ni, and Pb should be caught up in the iron precipitation process.

G.T.C. estimated that the sands composing the aquifer, having a carbonate content of 7.5%, acted as a buffer to the acidic water. The calculation of the sand-buffering capacity and acid-generation rates by GTC stated that sufficient buffering capacity existed in the surrounding sands if drainage was evenly distributed along the contamination front. Due to the focal nature of water flow, this condition was not satisfied and required computer modelling to mimic reaction and flow in a geographic domain. The result predicted increases of 500% of sulphate discharge into the Kamiskotia River in 30 years.

The remediation proposal for the unconfined tailings was to restrict water leaving the area, thus creating localized settling ponds to remove the fines. Additionally, revegetation testing was undertaken by Laurentian University. Other rehabilitation measures under consideration by the Ministry were constructed wetlands to include oxidizing ponds to precipitate iron, and ponds which neutralize acidity, with Sphagnum moss and cattails to recover metals. Micro-organism treatments have also been proposed, including running leachate through straw, hay, or peat compost to be processed by sulphate-reducing bacteria (Béchar, 1993). Efforts are still experimental and frequently require large amounts of capital to implement on site.

4.2) Image Studies

As a part of the Ontario Ministry of Natural Resources (O.M.N.R.) assessment of remedial processes, Mussakowski and Chan (1993) compiled a sequence of archival aerial photographs showing the catastrophic spread of the tailings damage and proposed a drainage model for understanding this change. Rates of spread have clearly slowed since the closure of the mine in the early 1970 s. Future change, however, will likely be characterized by more subtle and gradual landscape differences. In this respect, an airborne remote-sensing research program designed by King (1995) has been implemented to evaluate forest canopy and tree crown stress related to processes induced by the tailings.

Lévesque and King (1995) found a distinct soil metal gradient with decreasing concentrations away from the tailings. Some metals, particularly Fe and Al, are at toxic levels in the forest soil near the tailings.

Lévesque and King (1996), using semi-variogram analysis of 0.5m - 1m resolution airborne digital-camera imagery, found significant correlations between semivariogram range and forest canopy measures such as crown size, tree height and canopy closure. In 0.25m imagery crown closure was significantly related to semivariogram range. Seed and King (1997) have found significant relations of Leaf Area Index (L.A.I.) and basal area with the proportion of shadow in airborne imagery. Dominant tree ring counts made by E.Seed (1996) for trembling aspen cores previously sampled by J. Lévesque in the 1993 field season show that the average age is 76 ± 12 years old. Plotting the number of rings per core length showed a slight decrease away from the tailings but was not significant since results were highly variable and observations were probably more influenced by stem density at each site.

CHAPTER 5: REQUIREMENTS FOR TEMPORAL CHANGE MODELLING

5.1) Study Approach

The study was divided into three components consisting of field observation, image interpretation and temporal analysis. Field work sought to uncover degradation indicators recognizable both in the field and in aerial photography. Field observations were intended to aid in recognition of physical processes that could be useful for interpretation of derived transitions. Previous researchers chose to link canopy measures and radiometric characteristics for interpretation of degradation (Lévesque and King, 1996). For temporal studies utilizing archival photography, a physical model employing a tree segmentation technique was thought to be more suitable. Modelling individual trees was more ecologically transparent and allowed inferences of aggregate forest structural change from any imbalances between tree death and regrowth.

Manual photo interpretation to identify and catalog individual trees proved to be tedious and required rigorous testing through repetition. Since the modelling routines required a fairly large sample size it was considered best to test and implement an automated digital routine. This required digital conversion and estimation of an appropriate scale for analysis. Matching images was also a requirement for determining temporal transitions. Lastly, the temporal technique adopted was not common within commercial modelling

packages, so programming was required.

5.2) Data and Products

Maps

A number of maps cover the area, the most recent being the 1980, 1:20,000 Ontario Base Map series. A map of geologic exploration cutlines was obtained from Falconbridge Inc. of Timmins and the 1980 Forest Resource Inventory Map covering Robb and Jamieson Townships was obtained from the O.M.N.R. Detailed maps of well positions and 1m contours were also made available from the M.N.D.M. in Timmins who are currently coordinating environmental work on the property.

Photographs

A number of scanned aerial photographs (1:15,840 to 1:70,000) were obtained from the O.M.N.R. (Appendix 1). Scan densities had already been varied depending upon the scale in order to approximate a 5m ground pixel size which had been initially selected. However, upon determining that better resolution was required (section 6.2.3), diapositives of the area were obtained and the entire image set scanned at 0.4m pixel resolution. Only the better quality images were used for the temporal modelling. Four black and white photographs were selected including, three 1:15,840 photos from 1949, 1961, 1979, and one 1:20,000 photo from 1991.

5.3) Equipment Requirements

The research was carried out using PCI Inc. Image Analysis Software, Corel Draw and Idrisi raster GIS software. For the creation of the modelling modules, Borland C was used. Field equipment included a pH meter, topographic survey levelling equipment (Kern), and associated survey gear.

CHAPTER 6: METHODOLOGY AND RESULTS BY ACTIVITY

Remote sensing image modelling studies consist of standard activities of image acquisition, image pre-processing, enhancement and classification of features, error assessment and interpretation. This study similarly adopts this sequence in an attempt to understand temporal changes associated with effects of the tailings propagation. Methods and results are presented together in chapters describing field work, image interpretation and temporal neighbourhood model development. Each section builds upon previous work and attempts to correct or improve upon deficiencies found in previous sections.

SECTION 6.1: FIELD DESCRIPTION OF THE TAILINGS EDGE

Field work was undertaken to develop an understanding of the layout of the Kam-Kotia tailings area and to qualitatively describe the A.M.D. environment in an attempt to infer the causes of any perceived change. Much of the geographic description has already been introduced in Chapter 5 but it will be expanded upon here based upon specific findings of this research. The second objective of the field research was to develop and compare tailings-centred diffusion versus a forest dieback approach to modelling of change.

6.1.1) Field Methods

The site was visited both in late summer and spring of 1995 and 1996. The methods on each occasion consisted of walking

transects, determining the tailings edge through visual assessment, noting topographic control and tree dieback and relating these various observations to changes observed in the archival imagery. Soil profiles were determined for both the tailings and surrounding areas. Water colour was noted and pH was measured in open pools around the edges of the tailings as an indicator of contamination. Drainage directions were also inferred from mineral and debris trains. The flow path and acidity with the addition of substrate type were established as the parameters required for development of a tailings-centred drainage model. Dead wood counts and terrain profiles were sampled along the transect cut lines on both the tailings and within the forested area at 20m stations to about 400 metres away from the tailings edge. These line locations are shown later in Figure 6.3. Dead wood counts, both fallen and standing, were taken from a swath approximately 20 metres either side of the line (visual distance) recording height class, type and orientation. Size classes were limited to either 'large' or 'intermediate', the distinction being whether the tree was deemed to be part of the upper canopy (large) and hence viewable from the air or intermediate in canopy position. Levelling for terrain profiling was undertaken using a piezometer located near the north eastern seep as a datum set at 10m. The 24+00N and 29+00 tie lines were used to close measures between lines.

Figure 6-1: The northern tailings showing photograph sites and text description locations.

Photo 1: Drainage on the tailings and cattail remnants.

Photo 2: Tailings impoundment wall.

Photo 4: Liquification and collapse of saturated tailing silts.

< Photo 3: Iron hydroxide crusting on the tailings surface.

6.1.2) Results and Discussion of Field Activities

i) Tailings and Drainage Characteristics

Figure 6-1 shows the location and view direction of the photographs. The unimpounded tailings are characterized by almost total defoliation of larger trees (photo 1). Near the tailings margins algae grow in trapped puddles on the tailings surface, cattails grow in some less acidic streams, small birch and pine shrubs cling to life on mats of dead sticks, moss or lichen.

The unconfined tailings shallowly grade downward away from a high located near the south central part of the confinement wall (photo 2). The tailings edge against the forest accumulates water in pools. Evaporation rates are fairly high with the tailings cover having a moderate capillary tension due to their moderately fine grain size but poor water retention ability. When dry, the tailings surface is characterized by polygonal desiccation cracking, iron oxide and salt crusts and flakes in some areas of high water table (photo 3). In other areas, particularly on the south eastern edge of the impounded tailings where grain sizes are larger and sediments both thicker and dryer, wind re-mobilizes loose sand grains forming sand strips and rippled surfaces.

The flat exposed tailings not only offer little shelter from winds but also thermal differences between the tailings surface and its surroundings cause strong thermal convection

Photo 5: Steep sided erosion and slumping in the Northern Seep

Photo 6: Area of shallow slope inflection having large amounts of debris and some regeneration

Photo 7: Sulphate cones crystalized on dead bullrush stems.

Photo 8: Silt buildup behind an old beaver dam.

Photo 9: An example of tree growth on a debris mat.

evident from the many wind vortices that cross the tailings lifting dust. During the spring, snow on the tailings melts more quickly than in the surrounding forest, due to its predisposition to flooding, and lack of sun sheltering which facilitates direct solar heating of the snow and is enhanced by a lower albedo caused by fine oxide dust contamination. Also during wet spring conditions, water saturation within the silts creates a loss in strength producing slumping and flow (photo 4). Stream cut channels are common, especially within the main seeps to the north along which slumping is evident (photo 5).

Throughout the area, poles, twigs and logs litter the surface in various stages of decay, some appearing almost petrified due to the bleaching and the infiltration of sulphates (photo 6). A rare phenomenon is found near the tailings wall in which 2-3cm high twigs, probably bases of bull-rush stems, are crystal encrusted, apparently acting as wicks through which sulphate-rich water rises and then evaporates forming crystal cones (Photo 7). Generally, the litter on the tailings consists of downed tree trunks which interrupt the sheet flow drainage, redirecting flows, and causing braided micro-channels, terracing from silt deposition, and streams with high sediment transport and bank erosion (Leopold and Wolman, 1957). The braids empty into two main meandering streams flowing northwards which eventually merge and empty into the Kamiskotia River. In some areas logs have been collected in debris abutments

presumably from movement caused by high spring floods. Similarly, wood chips and branches have moved with water flow, collecting in bunches, particularly nearer the tailings margins, where they form platforms upon which small (< 1m) shrubs grow shallow root systems (Photo 9). Twigs and logs are also commonly buried due to the high sediment flow rates. Water flowing over the logs forms miniature water falls eroding lee side silts and creating extended cut channels. Old beaver dams in the northern seep similarly show these formations of downstream ponds and cuts. The southern seep, outside the research study area, still has occupied beaver dams reportedly causing flooding (Butler, 1996). In the northern seep all dams have broken, forming deep channel creeks cutting through the silts previously accumulated by the dams (Photo 8). Photograph 8 shows such a dam behind which upstream silts had accumulated to the approximate level of the dam indicating relatively high erosional rates. Many of these old dams, although with holes, appear almost cemented in place, perhaps due to petrification or perhaps due to the decomposition of organic debris within the dam causing precipitation of iron hydroxide through de-oxygenation and filtering (Eq.6-1),

Cellulose strands have been observed to collect within long standing acid pools, and may, in combination with iron

hydroxide, have cementing properties.

ii) Tailings Edge

Archival air photography shows that the northern unimpounded tailings have been deposited in what was once a low wet spruce bog area rimmed by mixed and spruce-dominated forests. The tailings edge has remained relatively stable since 1972. A descriptive orientation of the unconfined tailings proceeding clockwise from the northern end of the impoundment wall around to the mine rock pile on the southern edge of the impoundment is shown in Figure 6-1, referenced to 1979 archival imagery .

Along the length of the containment wall, there is evidence of leakage with wet areas occurring at its base. This is probably caused by the combination of elevation differences and loading which has raised the water table. The fact that the wall was built from waste rock with no lining upon earlier tailings only enhances the likelihood of leakage.

The north impounded tailings next to the impoundment wall appear to be relatively shallow at their northern edge. Cat-tails grow here probably because of the surrounding sandy soils, as described earlier, which may produce some buffering capacity. A hole in the impoundment wall has occurred near its northern end, contributing to the outwash of material from the impounded tailings into the unimpounded tailings area 7m below (A). It is unclear if the unimpounded

tailings area immediately north of this point had been affected before the breakage, potentially having been locally isolated from the acid drainage. The outwash from the breakage has deposited a thin tailings over the northern portion of the unimpounded area covering the regional beige sands and has formed a small easterly flowing stream channel. Locally, some trees have survived, being isolated upon small mounds, although they typically appear burnt. Unlike the majority of poles found on the tailings, they still have branches, indicating that dam breakage probably occurred in the last ten years. This is confirmed by the archival air photography. Approximately 200m down stream, debris lessens due to the area originally being more flat and open.

Drainage to areas north comes predominantly from the esker/glacial outwash plain to the northwest which joins the tailings runoff in a small creek along the northern edge of the tailings and then flows into the northern seep (B). To control drainage and limit water flow onto the unimpounded tailings the M.N.D.M. proposed a rerouting of drainage for the area but none was yet evident near the tailings (Fergusen and Rietzel, 1994). Trees along the northwestern edge of the unconfined tailings are principally black spruce and small white birch.

Approaching the western branch of the northern seep, jack pine increase in numbers amongst the spruce. The area north

of the seep bed is recovering from forestry carried out in the late 80's and early 90's, and is characterized by small dense poplars and replanted pine. The area west of the seep is a mixed forest area containing large trembling aspen, balsam poplar, black spruce, and some jack pine. The 1983 and later air photography (Figure 6-1) show that some of this area had been logged. A former road crossing the swamp is also evident.

Separating the northern seep drainage into a northern area and an easterly area, a spruce point juts into the tailings, its end being mostly dead poles occupying a shallow flexure which acts as the division between watersheds (C). To the east of this division surface water either flows to the eastern branch of the northern seep or as ground water through the central spruce bog. The tailings edge is characterized by a shallow northerly concavity (D) along which the edge and forested areas more distant from the tailings are characterized by seasonally wet black spruce-cedar-alder bog, in contrast to the predominantly mixed aspen forests at its margins. This bog area penetrates about 400m incising an irregular, somewhat triangular chunk out of the rectangular forested area between the two creeks. This is presumably the forest type which existed previous to much of the tailings deposition, however, progressively lower density of trunks towards the tailings centre indicate the central portion of the tailings was probably mostly open bog. The whole area is prone to saturation in the spring

with the creation of numerous ponds. Soils are organic silty clay indicative of poor aeration. The tailings surface tends to be hummocky with larger trees, typically white birch, occupying isolated dryer areas.

The northern unconfined tailings boundary along this central bog is not well defined due to little variation in elevation as well as variable occurrence of trees and grasses amongst the debris (D). This is particularly prevalent along a broad barely distinguishable elongated ridge jutting into the tailings (photo 6) shown in Figure 6-1 (D). This particular inflection in slope is distinguishable in that much of the growth is new, representing a margin zone upon which life, although stunted and deformed, may prevail until growth necessitates anchoring roots into the tailings. More centrally located within the eastern portion of the unimpounded tailings are more pronounced vegetation "islands" which maintain their vitality because of their elevation above the tailings (F).

To the east is the north eastern corner of the northern unimpounded tailings from which the eastern channel of the northern seep drains. Transects L92E and L93E (see Figure 6-3) between which the Lévesque and King (1993, 1996) long term test sites are located meet the tailings in this area (E). The area is characterized by large trembling aspen and an understorey of balsam fir and aspen shoots. The area near the tailings shows signs of transition with leaning aspen

and a recent clearing created from tree blow-down.

The eastern portion of the tailings is characterized by a set of individual treed "islands" of varying size crossing the tailings at an angle (F). North-east of the largest island two drainage streams merge. The northerly flowing stream follows the eastern edge of the tailings and has cattails growing in it, as opposed to the easterly flowing channel which is the main central channel for the tailings. The water in each stream did not differ significantly, both being pH 2.2. The south eastern edge of the tailings is characterized by stagnant water pools and bog, with a mix of spruce, while on the tailings small abnormal birch survive. The south eastern corner is composed of a number of recent and older beaver dammed ponds (G). Water is not oxide rich but is rich in black organics. Some of these waters drain to the southeastern seep. Soft wet conditions of spring made passage through this area difficult, pools do remain throughout most of the summer. Generally the southern edge back to the waste rock dump is composed of bog, spruce forest, and large amounts of debris.

iii) Measurement of Acidity

Acidity within various pools was measured using a standard pH meter and litmus paper. The pH meter readings commonly showed poor stability even when being calibrated. Acidity showed ranges between 2.5 to 3.1, the highest being at the waste dump and the lowest around the beaver ponds. The poor

stability of measurements did not allow determination that acidity of surface runoff was a function of the amount of mixing and drainage path. Consideration of modelling surface water pH by flow path, distance, and substrate was thought not to be viable.

iv) Measurement of Topography

Elevation was measured along line 91E on the unconfined tailings. The profile crossed the "treed islands" near the eastern tailings edge (Shown in Figure 6-2). Regressing the elevations indicated an apparent slope of 0.7 degrees along the line, which is probably indicative of the maximum slope for this area since it parallels a stream. Plotting residuals and comparing them to cover types indicated that the surviving trees were on higher ground, while dead poles occurred at intermediate elevations (Figure 6-2). This pattern is the result of tree aversion to the wet conditions that existed previous to the tailings deposition and followed by subsequent acid mine drainage.

Figure 6-3 shows an averaged surface sampled at a 100m square interval using the elevations obtained along the transects. Average slope for the area displayed is about 0.3 to 0.4 degrees falling to the north-east. This is about half the previously stated slope for L91E which is indicative of slopes found along drainage seeps. Apart from the dominant drainage directions, the contours show that the central

Figure 6-2 "Islands" A qualitative correlation of vegetation and drainage. Below grade are the tailings and dead spruce poles. Above grade are the surviving, although stressed, large aspen and black spruce. (see Figure 6-3 for location)

Figure 6-3 Elevation contours (red) showing a shallow NE gradient with very low gradients within the central bog.
 Note: poor drainage = black spruce, good drainage = mixed forest.

spruce/cedar swamp is fairly flat and hence suffers from poor drainage. Surrounding the swamp, deciduous forest underlain by sandy soils shows higher slopes and better drainage. Many of the controls to drainage are below the resolution of the contouring and closure errors of 30cm. For example, a slight confining lip exists around the edge of the tailings. This lip may have formed from erosion and degradation of organic material causing soil deflation. However, observations show that root soil coverage thicknesses are similar for tailings poles and living conifers along the margin, indicating that the denuded surface is probably fairly similar to the pre-tailings surface elevation. The marked difference is that depressions have been infilled with tailings. Similarly, there is a gradual incline toward the east confining the eastern portion of the swamp but this also is below the resolution of the contouring.

v) Dead Wood Inventory Along Transects

Dead wood counts were collected along the transects (L85E, L86E, L89E, L90E) within the forest as possible indicators of stress (Figure 6-4). Trends indicated an increase of dead wood nearer the tailings edge. The counts were taken in 20m intervals and about 20m on either side of the line. Since comparison with the aerial photography was desired, counts were limited to medium sized and larger trees which would potentially be visible from the air. Types of dead wood included: poles, fallen, leaning, broken upper half,

Dead Tree Counts - Kamiskotia Field Work 1996

Figure 6-4 Dead tree counts with distance from the tailings edge for four traverse lines.

Green curve is the terrain profile (residual from regression)

Contrast = $Wt+ - Wt-$

$Wt+ = \ln((\text{Cum. \# Dead} / \text{Total Dead}) / (\text{Cum. Surface Dist.} / \text{Total Surface Dist.}))$

$Wt- = \ln((\text{Reverse Cum. \# Dead} / \text{Total Dead}) / (\text{Reverse Cum. Surface Dist.} / \text{Total Surface Dist.}))$

uprooted and partially uprooted trees in varying modes of decay.

To cover all the transects and not introduce variability between transects, counts were taken from the transect and so were affected on occasion by dense ground cover. Transects 85 and 86 represent primarily a mixed forest while transects 89 and 90 are in the central spruce bog. Raw dead tree counts displayed in Figure 6-4 by the blue histogram show variability between stations, the initial stations in all transects showing relatively large counts as compared to typical counts below 10 trunks/station, excepting transect 85 which has counts approximately half the others. The topographic trends are illustrated by a residual plot (green) calculated by subtracting elevation values from a best fit straight line [$\text{elev} = a + b(\text{dist})$] offset to make all values positive. Average apparent slopes along the transects are between -0.20 to -0.47 with inflections approximately at the midpoints. Comparison of the topography and dead counts shows little relationship excepting those lows corresponding to the tailings edge. Contrasts were calculated cumulatively using dead counts and the cumulative area under the positively adjusted terrain profile. Positive contrasts are an indication of an association between dead trees and the tailings. In all situations except transect L90E, contrasts (red) show positive local peaks within 200m to 250m distances, indicative that more dead wood occurs proximal to the tailings than might be expected due to chance. Transect

L90E does not show this behaviour due to an uprooted swath of birch trees occurring in the central portion of the line.

It was not the sampling goal to establish causes (if any) of the degradation but simply to establish the spatial pattern. Spatial relationships may reflect a host of processes such as wind blow-down due to poor sheltering, poor rooting substrate, disease, water flow changes as well as acid drainage and wind blown contaminants. Another consideration is differing rates of decomposition between species. Alban (1993) quotes density decreases of 40-73% for an 11-17 year period for two mixed wood sites in New Hampshire. Rates were species dependent, being greatest for aspen followed by spruce and red pine and lastly jack pine. Clearly the tailings effects, if present, are superimposed upon the natural spatial transition from open-bog to spruce-bog to mixed forest. Hopefully, the selected transects, which are approximately homogeneous in forest class and terrain over their length, minimized these previously mentioned extraneous factors. Due to the difficulty of qualifying extraneous effects, deadwood counts should be viewed only as a qualitative indication of degradation from the tailings.

Such research, either on the ground or from the air, could be undertaken at periodic intervals and changes observed. Samples could be further broken into species, stand composition and age, so that responses could be compared to

changing environmental conditions. This appears to be the direction of future research in the area (King,1997)

6.1.3) Field Description and Modelling Scenarios

Change studies may either be implemented through process or through derivation of empirical relationships. The first attempts to implement theory derived from study on the ground and then applies it regionally to form a graphical representation. This is usually implemented in equation form and parameters corresponding to all the relevant variables within the regional area must be included. Usually, factors are applied to compensate for differing substrate, thermal gradients, bed thicknesses and so on. The finite element analysis and acid buffering calculations done by GTC (1984) are an example of such work. Any result is dependent upon the combined consideration of weighting and accuracy of the parameters, thematic coverage, block sample sizes, and the transferability of the model equations to the particular system. This is one of the criticisms of technology, as models are applied in black box fashion without consideration for local distinctiveness. Similarly, this could be a criticism of implementations deriving image change, an example being the preponderance of studies which define a sample area by the area for which imagery could be acquired. Image change methods do provide benefits of being measurement rather than theoretically-oriented, implicitly incorporating spatial differences and scales of change. Consequently, graphic change is readily transparent with the

difficulty being interpreting the graphical changes.

In this image application model, change can be portrayed as tailings spread in which either a line or a zone in a fuzzy function model progressively diffuses via edge movement. Tailings degradation within the archival photographs has been contiguous to previously denuded areas, and from observation, dependent upon surface flow of acid-rich waters. Recognizing that the tailings-front movement has slowed over time implies that different processes may become evident and more subtle changes may be exhibited. Adoption of a degradation function based on distance from the tailings denudation edge allows for modelling of contamination movement into the forest and slow degradation of forest or individual tree-crown structure. Vegetation centred modelling was favoured since images of suitable scale were all originally obtained by the O.M.N.R. for forestry inventory purposes and, as such, the bare tailings were typically over-exposed and less useful for analysis.

Two alternatives for modelling vegetation degradation and regrowth were considered:

- a) modelling individual tree statistics such as crown area, perimeter, crown texture, and
- b) modelling tree population estimates.

The former requires delineation of tree edges. This was considered problematic due to variable shadow, contrast, and original photographic scale problems. The latter population

model avoids these problems and allows the modelling methodology to be simplified to evaluation of specific characteristics of trees represented by points. It therefore was selected for subsequent research on temporal modelling.

SECTION 6.2:

DIGITAL CONVERSION OF AIR PHOTOGRAPHY AND TREE DELINEATION

Tree population counts have been selected as the preferred methodology for delineating landscape degradation. This potentially formulates a linkage between ground measures and aerial measures through the use of a common discrete unit. Through use of temporal tree matching and tree spatial distribution densities a model of change can be developed. Manual interpretation of imagery can be effective, but it is complex and subjective. Manual tree delineation is also impractical due to the large number of trees.

6.2.1) Goal

The goal of this portion of the research was to develop an automated tree-counting algorithm in order to extract a tree population sample. The sample was classified and later used for degradation assessment. The methodology utilized the concepts outlined previously in the segmentation background (2.4), and was assessed further for accuracy of representation of tree populations.

The discussion in this section describes two automated tree apex counting methodologies. Subsection 6.2.2 introduces the two differing techniques. Subsection 6.2.3 shows the calculation of suitable scanning scales for undertaking analysis. Subsection 6.2.4 outlines testing methodologies for assessing the accuracy of the tree-counting techniques

utilizing a number of synthetic images of known population and by comparison to manual counts. Subsection 6.2.5 describes the results of these tests. Subsection 6.2.6 presents the results of applying the counting methodologies to the study images, and discusses the effects of resolution and tree distribution as functions of brightness and distance from the tailings.

6.2.2) Adopted Tree Population Estimate Methodology

The use of black-white aerial photography places certain constraints upon interpretation thereby limiting identification of tree apexes and requiring certain assumptions to be made. In a mature forest setting within a maximum packing configuration, tree image shapes are assumed to be approximately oval. Tree apexes are also assumed to be well illuminated and relatively brighter while edges are diffusely illuminated or in shadow. Gougeon (1995) outlined an automated shadow-following tree-delineation program. A valley-following routine traces the shadows between tree crowns and eventually forms polygons by keeping track of topology. This research has adopted a similar approach but favoured delineation away from peak centres instead of working from shadows up onto crowns. Two primary techniques were implemented and compared; a high-pass filter and a double-aspect technique. Both take advantage of brighter tones being coincident with the centre of the tree crown. However, they are subject to variable tree morphology such that apical lobes may be misinterpreted as individual

crowns. Although it was not a goal of this study to delineate tree crowns but just to count them, experimentation with edge delineation became a consideration since many crowns exhibited multiple lobes which had to be merged for development of true population counts.

i) High-pass filter for apex detection

High-pass filters accentuate areas of rapid change of high frequency data within a window. A popular configuration is the Laplacian filter (Figure 6-5). Darker areas will be negative and brighter

areas positive, each with greater magnitude as the differences between the central cell and its surroundings differ.

0	1	0		1	1	1
1	-4	1	or	1	-8	1
0	1	0		1	1	1

Figure 6-5 Window configuration of a Laplacian high-pass filter.

Determination of peaks requires definition of a positive threshold which, in the model, was set visually after it was run.

ii) Double Aspect Method

Tree apical centres were estimated by assuming that the crowns were characterized by a conical morphology within the grey tones of the imagery. The apexes of these features were defined by using a double calculation of the surficial aspects for each of the four directional pairs (two using the pixel orthogonal direction approximately N-S, E-W, and two diagonal approximately, NW-SE, NE-SW). The four

resulting images consisted of ridge and gully trend lines (Figure 6-6). The intersection of the ridges and gullies corresponded to local peaks and lows. Partial outer tree perimeters were estimated through combining (union) all the gully lines. This did not produce a polygon image but it did provide a partial delineation of edges. To fill in the edge boundaries, it was decided to allocate the areas surrounding the peaks as a function of proximity and brightness, using the edges as boundary fences to any allocation process. This process consisted of inverting the grey tone images so that light areas had low values and the dark high, ranging between 0 and 255. Gully edge areas were then assigned a high value creating a partial surface boundary edge.

The Idrisi "cost" function was then applied to smooth the surfaces into a grey-tone weighted proximity buffer or isodapane surrounding the centroid. The "cost" function works by assigning every pixel the minimum cumulative cell traversal sum away from a set of points. In this example, the set of points are the tree apex centroids. The areas then became capable of allocation forming a Thiessen like division of space. Removing the gully pixels and normalizing the cost surfaces in relation to the maximum value for each polygon produced a proximity surface pixel ranking between a central peak and the shadow edge, in effect forming a bowl whose isodapane rings were ranked thresholds. Implementing this sequence required dividing the images into 200 by 200 pixel regions due to the limitations of some of the

Figure 6-6: Double Aspect Methodology showing the sequence for derivation of tree apices and the creation of the cost surface based upon brightness and proximity to the apex.

allocation and cross-tabulation functions in Idrisi. The resulting distribution required some amalgamation of points since multiple peaks occurred in some single crowns (Figure 6-6). Two methodologies were used as a means of aggregation. The first method consisted of running the apex finding routines upon multiple filtered input images. Filtering had the effect of generalizing, shifting and flattening small perturbations, so that the combination of apexes from these successively filtered (mean of a 3x3 roving window) images would make a dense cloud of stem points which could then be replaced with a single centroid. This methodology also allowed the flat topped peaks, found in overexposed areas, to be assigned centroids. Flat top peaks showed a depression of perimeter values coincident with smoothing. The second amalgamation method followed the rationale that if multiple points occupied a single tree crown there would be a relatively small distance between them and they would share a side, where, using a bowl analogy, the ridge separating the two adjacent areas would be relatively small. Continuing the bowl analogy, if each bowl is filled, the liquids would merge at relatively lower fill volumes than those areas segregated by deep shadow. This algorithm was implemented by assigning a minimum rank threshold percentage (10%) followed by a unique grouping of contiguous areas (Figure 6-6). Tree centres were then amalgamated and finally replaced with a unique centroid. The Idrisi code is summarized in Appendix 3.

6.2.3) Image Data, Resolution, and Scan Size Limitations

As previously described, the Kam-Kotia archival image sequence dated from 1949 and had been obtained from the O.M.N.R. and from Natural Resources Canada in print format and in diapositive format (Appendix 1). Digital conversion of these images allowed for enhancement, georeferencing, and matching between image dates. Conversion was undertaken using a Kodak Megaplug 1.4 digital camera producing a 1300 x 1000 pixel size image of a maximum of 256 grey levels. Image scales ranged from 1:15,840 to 1:70,000. The use of a macro lens in combination with a height adjustable mount allowed the images to be scanned at a consistent scale despite varying photographic scales. Scans were collected from the entire black and white dataset and georeferenced even though it was expected that only the higher quality imagery would be required for further temporal modelling.

Preliminary analysis, using the historical scan sequence created by Mussakowski and Chan (1993), showed that a 5m ground pixel size would be too large for delineation of trees approximating the size of small conifers. In order to derive any separability, pixel sizes must be no more than half the size of the smallest object imaged, in this case 2.5m. Also, surface measures over the grey-scale image were to be the base of the proposed methodologies and since most surface measurement routines use a minimum 3 by 3 cell window, it was assumed that any surface slope would require approximately three measures or approximately five pixels

per slope in order to portray a trend. Thus the largest scan pixel size required was 0.5m. In addition, images would need to be matched and georeferenced, both of which required resampling using a low-order bilinear technique.

Consequently, scan scales smaller than 0.5 m were assumed to be the most practical and appropriate.

The study area, situated between the creeks on a 1:15,840 image, was approximately 7cm(wide) x 6cm(high). The scan dimensions using the Megaplug Camera are 1300p(w) x 1000(h), so the smallest ground resolution obtainable for the whole area was 0.9 m. Line-pair resolution for black and white film imagery is 50 lp/mm for low contrast to 100 lp/mm for higher contrast film (Lillesand and Kiefer, 1994). Equation 6-2 shows the conversion of this line-pair resolution to pixel resolution for the F.R.I. 1:15,840 scale.

Pixel Res. = Photo scale / line pair resol. * equiv. diagonal

Low Contrast Photography:

15,840 / 50 lp/mm * (2.828pixel/(lp)) = 896mm = 0.89m

Similarly for high contrast photography

100 lp/mm produces a 0.458m ground pixel resolution.

Eq 6-2: Line-pair resolution to pixel resolution conversion.

Scanning the area at a resolution smaller than 0.5m required dividing the image into 9 separate (2.56cm (width) x 2cm

(height)) rectangular sections, equivalent to 405.5m (width) by 316.8m (height) each. With a 10 percent edge overlap this produced images covering 486.6m (width) by 380.2m (height) and a pixel resolution of 0.38m. The scan scale exceeded the calculated maximum resolution for high contrast imagery. This resolution showed individual dead poles on the tailings as well as texture within intermediate-sized crowns.

A six by six reference grid corresponding to half the rectangular section size was created, (202m width by 158m high each), such that each rectangular section scan image had nine grid line intersections. This allowed scanning of each of the temporal images with a grid underlay, once at low resolution (~1.5m) and each of the nine rectangular sections with high-resolution (0.38m pixel). The low-resolution images were geographically matched and the high resolution images were inserted using the grid intersections. Registration in this manner used recognizable temporally stable features rather than attempting matching at the tree level which for some of the poorer quality images proved to be difficult. The result was nine sub-images of nine dates (Appendix 1) all registered to 1m rms. This error should not affect image matching and is less than errors associated with off nadir distortion. In the process of image registration, the transformation resample the ground pixel size was increased to 0.47m.

From the nine dates of imagery, four images (1946, 1964,

1979, 1991) were selected for detailed analysis. They were selected to represent time periods of significant change as well as the two end points, the initial pre-mine and recent conditions. In addition, the larger scale imagery was used since many individual trees could be identified and visually matched. This eliminated problems in comparing images of vastly differing scales for tree level changes.

The images showed misregistration due either to poor reference features as on the 1946 images, or to view angle differences which added height displacement not modelled by a smooth convolution. The maximum error for height displacement is about 10 pixels. Another concern is differing illumination. Image comparison between dates will require flexibility to address these difficulties.

6.2.4) Testing Tree Apex Counting Methods

The tree apices interpreted from the two recognition methods were tested both against a synthetic dataset in which differing noise levels were applied, and against the manually interpreted sub-windows of the image set. Each test was assessed for its tree-count estimate, errors of omission and errors of commission. Manual tests additionally assessed the threshold brightness at which apices became visually recognizable. Thresholds varied between images. Image comparisons were also made using apex brightnesses greater than those thresholds, as they exhibited less background shadow noise. Despite this noise, the automated methods do

have potential for the counting smaller trees in shadow, albeit at reduced accuracy, whereas a manual interpreter would generally not attempt to identify such trees.

The Synthetic Image Set

i) Without Noise

A number of synthetic images were created to test the two tree-counting methods. This was undertaken using a two-class image derived from a random image which had been run a number of times through a 3x3 modal filter forming an annealed surface. Figure 6-19, in Section 6.3.2, shows the development of clumps having a random distribution and formed from taking the marginal majority class in the nine-cell window. The larger area class was assigned to the large crown/low density class whereas the remaining areas were assigned to the small crown/high density class. A random point generation program was written which used this raster class map to place apex centroids (Appendix 2). The program increased the image size by five in each direction forming an approximate maximum density of one tree for every 5x5 pixels. For the small tree class a centroid could be placed anywhere within the 25 cell square whereas for the large/low density tree class a similar placement routine was adopted but was implemented randomly for approximately every 6th hit forming an average density of 1 apex for every 150 pixels. The resulting random point image was converted to raster form and a conical surface was formed to mimic a treed surface. This was undertaken through outward dilation from

these point cells followed by grey tone inversion. The image was then stretched to occupy a range between 50 and 200 approximating the grey-level range of the imagery. This resulted in an image whose peaks were flat and broad, which when densely packed had ill-defined edges. This base image is referred to as the "smooth" image (Figures 6-7 and 6-8). To make the model more realistic shadow was then added. Shadows were calculated using the Idrisi hill shading module, which, by applying an azimuth angle and a zenith angle, calculated the illumination via the cosine of the incidence angle (Bonham-Carter, 1994).

ii) With Noise

Noise was added to the "smooth" image using a normal random variance within a variable range provided with Corel Draw. An extension of the shadowing was the creation of the "rough" image (Figure 6-8), which attempted to add texture to the shadow image model. This was accomplished by replacing the smooth dilation away from the points with an uneven but constantly decreasing dilation formed using a cost surface over a random image and then shadowing. The result proved to be a fairly mottled image with many smaller peaks.

iii) Evaluation of Accuracy of Tree Apex Counting Methods

Apex delineation testing was conducted using raw apical counts with no post-processing merges of closely spaced multiple peaks. This short cut had the advantage of

increasing comparability, illustrating the validity of adopting a surface-modelling-based procedure whilst eliminating the time-consuming customized generalization steps. The accuracies of the tree-apex-counting methodologies were compared in their ability to identify a tree polygon correctly whether a unique centroid is placed within the polygon or not. A tree polygon was defined as the inner six tenths of the contoured dilated surface, but in order to limit random hits within the tests, an 8 pixel radius and a 5 pixel radius were utilized for large and small tree classes respectively. Polygons were utilized to compensate for errors associated with crown flatness.

Method for Manual Count Comparison

A 100 by 100 pixel window was taken from each of the scanned photographs. Trees were then interpreted manually from the contrast enhanced images (Figures 6-10 a,b,c,d - sub-images i,ii). Both the double aspect and the high-pass tree delineation methods were applied to the raw imagery and visually compared to manual determinations (v). Comparisons were based upon a 10 class brightness scale. This was undertaken through classification of the original grey tone images into 10 classes (linear scale), then extracting the brightest class value for each tree, and producing classified points. It should be noted that compiled-count comparisons were only for the double-aspect methodology. This was partly due to being unable to determine readily a mutually comparable high-pass filter cutoff threshold and

hence high-pass results became portrayed as a colour range (sub-images iii). The high-pass method also tended to highlight edges and produce the brightest values on small strong peaks as opposed to broader bright areas.

Figure 6-7 Synthetic image profiles

Tree Apex Derivation Testing Using Synthetic Image Set

Figure 6-8 Effect of shadow and texture upon tree counts. Blue polygons indicate omissions. Points outside polygons are indicative of commissions. Polygons may have multiple centroids, or centroids may overlap boundaries; assessed by the multiple and misses statistic. Note * Base Image for Figures 6-9

$$\text{Tree Peak Error\%} = (\text{Correctly ID} / \text{Total Polygons}) \times 100$$

$$\text{Multiples and Misses\%} = ((\# \text{ of Centroids} - \text{Correctly ID}) / \text{Correctly ID}) \times 100$$

If (+) Centroids > Identified polygons, If (-) Centroid < Identified polygons (overlap)

Tree Apex Derivation Testing Using a Synthetic Image Set Effects of Random Noise Variance

Figure 6-9 Tree Apex Derivation Testing using a Synthetic Data Set with Variance Added.

6.2.5) Results of Tree Apex Testing

i) Synthetic Testing with and without noise

Results in Figures 6-8 and 6-9 show the effects of noise upon the apex delineation with blue polygons indicative of tree counting omissions. The high-pass filter methodology proved to be the most consistent over the variance range but the double-aspect methodology performed better with random-noise values similar to that found within the photography (var = 30). Trends showed that the double-aspect method improved greatly when some variance was added to the imagery whereas the high-pass method proved susceptible to added variance. The relative improvement of the double aspect method was primarily due to the replacement of flat domal apexes characterized by sharp but non-intersecting aspect contacts with diffuse directional-aspect contacts which have a greater potential for intersection. In all situations, addition of noise or high frequencies had the effect of broadening derived peaks as evidenced by larger points. Another factor is that the highpass filter was expected to degrade as trees became larger since it is a measure of contrast which would be maximized on smaller trees.

A second statistical tally subtracted the number of recognized polygons from the number of unique spatially interpreted groups. Multiple counts show more than one derived apex per tree polygon whereas misses are apexes outside a tree polygon. The multiple/misses result, if positive, would be indicative of more multiples than misses

and if negative, of more misses than multiples. The double-aspect method showed negative results associated with image noise for this calculation. Centroid overlap is a probable interpretation for these results and may be evidence of degradation of subtle divisions between trees within high-density clumps (Figure 6-7). The high-pass method indicated variability in both finding trees and in the multiple/miss statistic due in all probability to its innate sensitivity to the application of random noise to small solitary peaks. Both techniques showed degradation of their recognition abilities from image overexposure and noise. The combination of overexposure and noise, however, does not compound any errors.

The remaining test qualified shadow effects through the application of Idrisi's surface shading to original smooth conical images. Plots G and H in Figure 6-7 and portrayed in the 2nd and 3rd columns of Figure 6-8, show shadow image effects of added shadows, illustrating a displacement of the maximum illumination centre toward surfaces incident to the illumination ray, in this example to the west (left). A secondary effect of shading was an overall increase in contrast with profiles showing a replacement of conical shapes with boxed profiles and poor apical development. Similarly, interpreted tree centres were displaced toward the illumination source, in many situations becoming compromised due to displacement out of the immediate polygon.

The "rough" image in Figure 6-8 showed that many small peaks were added as the result of the combination of the developed irregular conical surfaces and their enhancement with low angle illumination. For this reason, count comparisons between the "rough" image and the original counts were probably not valid and indicated that the interpretation of tree cones solely by grey tone can be hindered by increased contrast and differing illumination.

In summary, results of apex identification were derived from a limited set of tests; to develop trend measures would require multiple tests at each variance since they are random. The other concern is qualifying the role of tree density. Despite these limitations it appears for images of similar tree density and fairly high noise, the accuracy of tree counting techniques between 80-90% but may be further affected by shadow effects. Shadow effects are image dependent having a positive effect on counts for highly textured clumped crowns, or a negative effect caused through shadows obscuring smaller interstitial trees.

ii) Results Comparison with Manual Counts

Visual comparison between automated and manual counts showed good agreement. The double-aspect technique found small peaks in the shadows (lower third of the histogram - coloured blue in Figure 6-10a,b,c,d subimage iv) which were below the highpass threshold and also not manually identifiable. Any implementation should probably rank the

peaks according to brightness or digital number (DN) class (subimages v).

Along the bottom rows of Figure 6-10, both the "cost" surface and the "cost" threshold delineation method have been portrayed. Automated polygon outlines were defined by thresholds derived from manual tracings and averaged for all polygons of similar apical brightness. Typically, a 60% cost threshold produces fairly good results but optimally this threshold may be defined from external methodologies.

Exploration of methods for optimizing tree delineation was not pursued further as the double-aspect technique had been shown to be reasonably accurate with the synthetic data set. It was felt that this technique was adequate for temporal modelling.

The most striking observation along the temporal data sequence was found to be a significant increase of derived stem counts from 1946 to 1990 despite similar spatial scales and comparable dynamic ranges (Figure 6-12). This can be attributed to better illumination, particularly within the 1979 image, less blur, greater contrast due to better film fidelity, and improved resolution of the later photography. In the 1979 and 1990 images, middle to understorey trees become recognizable. Unfortunately, noise also increased with sensitivity and resolution, thus false identification of individual trees in the more recent imagery was greater than in older imagery. This created a dilemma for the

understanding of temporal changes in individual tree stems.

Figure 6-10a: Tree Delineation Comparisons Between Manual and Digital Surface Methods for a 1946 Distal Reference Image

i) Manual Digitization

ii) Manual Polygons

i,ii) Manual tree interpretations: boundaries have been delineated with the aid of contrast enhancement and are shown with and without source photography.

iii) Aspect Peaks vs High-Pass Filter Image

iv) Pk Classes Over 100 x 100 Image

v) Peak Numbers. Auto vs Manual

0 :	-----	
1 :	23	0
2 :	15	0
3 :	12	11
4 :	17	17
5 :	17	16
6 :	13	12
7 :	7	7
8 :	4	4
9 :	1	1
10 :	0	0

iii) Comparison of the Double Aspect Method points (white) and high pass (mixed color groups) shows good coincidence, with the D.A.M. finding additional information within the shadows. High Pass colours reflect differing grey tone frequency intensities above a cutoff determined through maximizing the number of unique groups.

iv) Double aspect peaks have been assigned a value within a ten class range derived from the original image peak brightness.

v) Manual and DAM peak counts comparisons show that manual recognition decreases below a certain brightness intensity.

vi) Cost Surface Away From Peaks

vii) Computer Delineation

Manual Interp. DN class vs Cst Av

0 :	47+-26
1 :	none
2 :	none
3 :	71+-33
4 :	35+-20
5 :	42+-19
6 :	50+-21
7 :	51+-21
8 :	46+-22
9 :	44+-21
10 :	65+-18

vi) Cumulative cell traversal "cost surface" values away from apex centres with colour brightness indicative of increased value.

vii) Average costs extracted from manually interpreted polygons of similar brightness. Illustrating that perimeters cannot be applied in this manner and that a 60% threshold is a reasonable approximation.

Figure 6-10b: Tree Delineation Comparisons Between Manual and Digital Surface Methods for a 1961 Distal Reference Image

i) Manual Digitization

ii) Manual Polygons

i,ii) Manual tree interpretations: boundaries have been delineated with the aid of contrast enhancement and are shown with and without source photography.

iii) Aspect Peaks vs High-Pass Filter Image

iv) Pk Classes Over 100 x 100 Image

v) Peak Numbers. Auto vs Manual

0	:	-----
1	:	0 0
2	:	0 0
3	:	24 1
4	:	31 26
5	:	33 33
6	:	22 22
7	:	12 12
8	:	2 2
9	:	0 0
10	:	0 0

iii) Comparison of the Double Aspect Method points (white) and high pass (mixed color groups) shows good coincidence, with the D.A.M. finding additional information within the shadows. High Pass colours reflect differing grey tone frequency intensities above a cutoff determined through maximizing the number of unique groups.

iv) Double aspect peaks have been assigned a value within a ten class range derived from the original image peak brightness.

v) Comparison of Manual and DAM peak counts show that manual recognition decreases below a certain brightness intensity.

vi) Cost Surface Away From Peaks

vii) Computer Delineation

Manual Interp. DN class vs Cst Av

0	:	48+-25
1	:	none
2	:	44+-27
3	:	44+-20
4	:	49+-19
5	:	44+-18
6	:	46+-23
7	:	47+-20
8	:	56+-21
9	:	52+-15
10	:	72+-16

vi) Cumulative cell traversal 'cost surface' values away from apex centres with colour brightness indicative of increased value.

vii) Average costs extracted from manually interpreted polygons of similar brightness. Illustrating that perimeters cannot be applied in this manner and that a 60% threshold is a reasonable approximation.

Figure 6-10c: Tree Delineation Comparisons Between Manual and Digital Surface Methods for a 1979 Distal Reference Image

i) Manual Digitization

ii) Manual Polygons

i,ii) Manual tree interpretations: boundaries have been delineated with the aid of contrast enhancement and are shown with and without source photography.

iii) Aspect Peaks vs High-Pass Filter Image

iv) Pk Classes Over 100 x 100 Image

v) Peak Numbers. Auto vs Manual

0 :	-----
1 :	0 0
2 :	10 0
3 :	21 2
4 :	28 25
5 :	29 29
6 :	46 45
7 :	27 25
8 :	11 11
9 :	1 1
10 :	0 0

iii) Comparison of the Double Aspect Method points (white) and high pass (mixed color groups) shows good coincidence, with the D.A.M. finding additional information within the shadows. High Pass colours reflect differing grey tone frequency intensities above a cutoff determined through maximizing the number of unique groups.

iv) Double aspect peaks have been assigned a value within a ten class range derived from the original image peak brightness.

v) Comparison of Manual and DAM peak counts show that manual recognition decreases below a certain brightness intensity.

vi) Cost Surface Away From Peaks

vii) Computer Delineation

Manual Interp. DN class vs Cst Av

0 :	48+-25
1 :	none
2 :	34+-14
3 :	45+-21
4 :	47+-18
5 :	44+-19
6 :	48+-19
7 :	51+-18
8 :	51+-20
9 :	46+-16
10 :	52+-16

vi) Cumulative cell traversal "cost surface" values away from apex centres with colour brightness indicative of increased value.

vii) Average costs extracted from manually interpreted polygons of similar brightness. Illustrating that perimeters cannot be applied in this manner and that a 60% threshold is a reasonable approximation.

i) Manual Digitization

ii) Manual Polygons

i,ii) Manual tree interpretations: boundaries have been delineated with the aid of contrast enhancement and are shown with and without source photography.

iii) Aspect Peaks vs High-Pass Filter Image

iv) Pk Classes Over 100 x 100 Image

Peak Numbers. Auto vs Manual		
0	:	-----
1	:	0 0
2	:	49 0
3	:	68 1
4	:	27 5
5	:	33 31
6	:	28 27
7	:	38 36
8	:	19 19
9	:	4 3
10	:	1 1

iii) Comparison of the Double Aspect Method points (white) and high pass (mixed color groups) shows good coincidence, with the D.A.M. finding additional information within the shadows. High Pass colours reflect differing grey tone frequency intensities above a cutoff determined through maximizing the number of unique groups.

iv) Double aspect peaks have been assigned a value within a ten class range derived from the original image peak brightness.

v) Comparison of Manual and DAM peak counts show that manual recognition decreases below a certain brightness intensity.

vi) Cost Surface Away From Peaks

vii) Computer Delineation

v) Manual Interp. DN class vs Cst Av		
0	:	47+-26
1	:	none
2	:	none
3	:	71+-33
4	:	35+-20
5	:	42+-19
6	:	50+-21
7	:	51+-21
8	:	46+-22
9	:	44+-21
10	:	65+-18

vi) Cumulative cell traversal "cost surface" values away from apex centres with colour brightness indicative of increased value.

vii) Average costs extracted from manually interpreted polygons of similar brightness. Illustrating that perimeters cannot be applied in this manner and that a 60% threshold is a reasonable approximation.

6.2.6) Application Of Counting Technique To The Study Area

A rectangular area for study was selected located between the branch of the northern seep and the central spruce bog area (Figure 6-3). The four higher resolution image dates used previously were again utilized. The image sizes were 800 x 400 pixels, the bottom edge of the area being proximal to the tailings. The area also represents a longitudinal contact between spruce found in wet areas and the mature aspen found in well drained areas. Transitions of this contact might be indicative of changing environmental controls as Lévesque and King (1995) showed the existence of a soil metal contamination gradient away from the tailings.

Comparison of tree counts for the two techniques showed that the double-aspect method consistently produced higher counts than the high-pass filter method. Table 6-8 shows the stem counts for the two techniques. Counts include trees apexes within shadows. Double-aspect counts have been merged at a 10% threshold.

Table 6-1. Stem counts for the two methods.

Image Date	Double Aspect	Max High-pass Count	High-pass Thresh	Thresh count
1946	3570	3202	2	3202
1961	6138	3896	1 or 2	3441/3896
1979	7722	4917	3	4543
1991	9436	5956	3	3642

High-pass groups were tallied at differing threshold

cutoffs, the adopted thresholds representing a maximization of unique centroids. Figure 6-11 shows the number of unique apex groups as a function of a high-pass frequency threshold. Adopting a single threshold proved difficult since images suffered from contrast differences. An example was with the 1961 image in Figure 6-12 in which a central tight circular mass of medium sized poplars was not highlighted with a higher threshold yet the lower threshold caused other larger tree clumps to merge into a single unit. The high-pass procedure showed difficulty in highlighting subtle details such as trees in shadow. The procedure did, however, show broad delineation of tree types in the 1979 imagery. The results for the 1961 imagery highlighted spruce to the east and a thin discontinuous strand crossing through the central portion of the image up its eastern side and back along the upper edge (Figure 6-12). In the 1991 image conifers similarly showed high contrast as measured by the high-pass filter but unfortunately most are obscured within shadows. In contrast, the 1946 image showed that conifers have lower contrast measures as compared to the aspen, the flatness in tone probably being the result of poorer film quality.

Effects of Resolution on Tree Counts

Counts increased with later imagery due to increases in tonal resolution and quality such that individual crowns and stems became more distinct, allowing mid-height trees to be imaged in the shadows. To determine the extent of the

Figure 6-11: The variation of unique highpass spatial groups with cutoff threshold.

Figure 6-12: High-Pass Filter Crown/Stem Delineation

1991

Conifers are high contrast but mostly in shadow.

1979

Conifers high contrast, aspen low.

1961

Conifers high contrast, aspen low.

1946

Aspen high frequency, conifers low.

Legend
0 1 2 3 4 5 6

influence of the varied resolution and contrast on tree counts the images were iteratively smoothed using a mean filter and peaks were determined using the double-aspect technique (Figure 6-13, Table 6-2). In all instances, peak numbers decreased and fewer differences were evident with each iteration as the smaller peaks followed by larger peaks were smoothed with the loss of image definition. The rate of image change was highest for the latest 1991 image.

Unfortunately, the curves cannot simply be extrapolated to form a correction factor since rates are not linear nor similar. This is indicative that differing combinations of causes were involved, the obvious ones being image geometry, view angle and shadow.

To further assess the effects of resolution on the tree counting methodology, tree counts and airborne colour infrared digital camera images were obtained from E. Seed, who has studied LAI along the north western seep (Seed and King, 1997). The image apex counting methods were applied to the infrared channel of the imagery in plots of 20m square. This imagery differed from the air photography in both resolution of 0.25m pixels vs. 0.47m and texture blockiness as the digital camera imagery had good tonal dynamic ranges within crowns compared to the blurred and over-exposed photography. Results showed that the apex identification methodology resulted in over-estimation of tree counts, due to the frequent delineation of branches and stem clumps (multiple apexes identified for single crowns)

Figure 6-13: Double aspect peak counts as a function of smoothing with a low pass filter.

Figure 6-14: Automated tree/stem counts using 0.25m infrared Kodak CIR digital camera images of plots located near the W. Branch of the Northern Seep (E.Seed 1997). Stem and internal crown clumps were highlighted producing poor comparison to ground counts and showing that counts are resolution dependent.

(Figure 6-14). To a lesser degree, this also appeared to be the case with later images within the temporal photography sequence. In both cases, it also appeared to be beyond the ability of the technique to merge internal crown peaks without merging small dense tree groups.

Therefore, for clarity, the techniques have been referred to as a stem delineating method since short of making use of stereo pairs branch lobes appeared difficult to distinguish from small trees. Segmentation can be varied by; increasing the cost threshold generalization which would increase the number of merges, or by changing the "cost" surface through manipulating weights applied to grey tone images. For example should initial results show merging between clumps and few of the desired merges within clumps, the traversal/distance weight would be too low and would require increase to encourage local merges. Normalizing the cost surface followed by generalization was an attempt to merge asymmetric polygons in which apexes are off-centre and thought to be representative of prominent stems within a larger crown. However, the technique does not address the separability between apexes which should probably consist of an additional apex merging prior to normalization. Resolution of imagery may also be reduced by decreasing variations in grey tones and reducing apex counts. Low-pass filters have a similar effect and have been utilized for their noise reduction capability. Perhaps lower resolution could enhance comparability between image dates where branch

effects and loss of intermediate trees is minimized. Any solution will probably be image specific, consequently, using airborne colour infrared photography and ground counts to establish a calibration factor may not be appropriate when applied to other imagery. An alternative approach is to observe changes in distribution and relative rates of change. For example, the distribution of trees as a function of distance from the tailings may be informative.

In summary, it was difficult to conduct a rigorous accuracy assessment of the capabilities of both apex delineation techniques since ground information was not available. for all dates. Many current remote sensing studies use calibrated sensors so that image characteristics are correctable with gain and offset adjustments; without calibration, image matching must be based on the use of pseudo-invariant (stable) regions such as water, rock, quarries and roofs. Little work appears to have directly addressed the criteria for selecting "stable" areas within vegetated landscapes, so at best, uncalibrated temporal comparison can be no more than a relative measure of landscape change.

Double-Aspect Count Variations with Distance and Tone

Assuming that trees having large rounded crowns and high crown closure have higher reflectance, and that deciduous trees produce lighter film tone than coniferous trees, the apexes were given values corresponding to the brightness

values from the underlying crowns, similar to that done for manual count comparisons in Section 6.2.4. Figure 6-15 shows the brightness values assigned to the tree polygons. The brighter classes are associated with larger poplars while darker points are associated with spruce or balsam fir, usually in the understory. Figure 6-16 shows the tree count histograms at different brightness thresholds and is plotted as a function of distance from the present tailings. The blue area and colours below represent the whole tree apex population, successively lower curves include crowns above a certain brightness class indicated in the legend. Although trends appeared relatively flat for the total counts for all image dates, brighter trees were proportionately more numerous farther from the tailings. This phenomenon was found to become more pronounced within later images perhaps being indicative of degradation.

Referring back to the image test comparison of peaks and manual counts, perhaps these manual recognition thresholds could be of assistance in a relative conversion. These threshold values, displayed in Table 6-2, qualitatively define the brightness intensity at which an observer can recognize a tree for each image date. Taking values greater than this cutoff, hopefully, removes less well defined crowns within shadow, and concentrates upon larger tree count distributions which are less likely to be affected by differing sun illumination. The technique may also artificially maintain continuity through limiting the

addition of trees that were not resolvable at earlier image dates.

Table 6-2 Double-aspect thresholds from manual interpreted deciduous signatures.

Image Date	% Peak counts remaining after adopting the brightness threshold	Equivalent Brightness Curve
1946	65%	49>3
1961	81%	61>1
1979	66%	79>3 or 4
1991	47%	91>3

Adopting these thresholds seemed to support the decrease in apex brightness nearer the tailings, perhaps being the result of more open crowns and increased micro-shadow within them. It may be indicative of degradation but as discussed previously, it may be due to the varied image quality of the four photos. Entwined with the tonal observations were potential effects from image geometry such as, off-nadir angles. Geometry may have created increased relative sizes and brightness of trees located further from the tailings, but its effect is still uncertain and probably not significant due to the small study window. For clarification, the study area was within the inner northern quarter ($< 10^\circ$ to the NE and NNW, respectively) of the 1961 and 1979 images but was in the outer quarter ($> 20^\circ$ off-nadir to the SSE and North, respectively) of the 1946 and 1991 images. Visual comparison of the near and off-nadir brightness counts show little indication of brightness

Figure 6-15: Tree polygon edges defined at the 60% cost threshold with assigned brightness classes.

Figure 6-16: Double Aspect Point Apex Count Variation with Brightness Class and Distance

changes as a result of geometric effects. Total cumulative stem counts appeared equally distributed or even slightly decreased away from the tailings, the inference being that smaller darker stems, and no doubt noise within the shadows, remained in the absence of larger bright areas. This led to an interesting consideration of forest degradation, in that, depending on scale, one should actually expect increases in stem counts and texture measures within a degraded forest in which the unifying spatial properties of larger trees have been diminished due to damage or death. King (1997) has found that stem density does in fact decrease significantly ($\alpha=0.01$) with increasing distance from the tailings as trees become larger and L.A.I. increases. This appeared to be true for high resolution imagery as compared to lower resolution images in which finer differences evened out. This might be the case with the 1946 imagery which appeared not to have sensed understorey characteristics.

6.2.7) Summary of Stem Counting Applications

Visual comparison of stem delineation showed that the double-aspect and the high-pass filter methods each produced an estimate of tree numbers based upon local tonal peaks. The techniques utilized this ability to identify conical peaks which, if minor, are assumed to be stem lobes and were merged to form trees. This differs from gully following techniques, proposed by Gougeon (1995), in which areas are divided based upon edge intensity. The advantage of accumulating areas as opposed to tracing them is that

topology need not be considered. Limitations of not having true tree numbers associated with the stem delineation techniques were accepted and the study moved on to consideration of problems associated with archival photographic temporal comparisons.

SECTION 6.3:

TRANSITION MODELLING

The photographic time range is 45 years, representing a forest maturation sequence with large aspen in the area attaining ages of 60 to 90 years. The time frame is probably not long enough to effectively see transitions due to natural succession, which requires multiple regeneration cycles. However, the sequence should adequately show features typical of maturation such as increased crown closure as well as accelerated degradation as a product of contamination in later years.

This section starts with a description of objectives followed by Subsection 6.3.2 describing a preliminary tree to tree polygon comparison. Subsection 6.3.3 develops a follow-up technique, utilizing window sampling in combination with a neighbour model to alleviate limitations found in the tree to tree comparisons. Subsection 6.3.4 describes the model application to double aspect stem counts. Subsection 6.3.5 illustrates the similar application for high pass counts but is enhanced by including a measure of trend significance. Lastly, Subsection 6.3.6 discusses the methods used and the results.

6.3.1) Goal and Objectives

The goal of this study was to determine if tree density mapping as derived from aerial photography and neighbourhood

modelling in combination could be used to model past canopy changes and predict future changes in an area believed to be affected by acid mine drainage and wind exposure. Within this process, neighbour configuration statistics were compiled as a methodology for inferring spatial process. A difficulty with image modelling is the determination of whether behaviour is a portrayal of natural changes or a consequence of the image capturing methodology. Clearly, using an uncalibrated sensor heightens this concern. Generally studies derive transitions from a portion of the temporal dataset and then apply them to derive landscape distributions for the remaining imaged time periods. For assessment, a comparison is made between the bulk totals of cell classes between the predicted and the actual. In this case, where predictive ability may be poor due to the limited available time sequence and the variation in image quality, it was deemed to be more important to address the significance of the transitions and how their character may reveal natural behaviour.

Given these limitations, the objectives of the final stage of the research were;

- determine a methodology for comparing temporal tree counts;
- derive the significance of temporal trends evident at the Kam-Kotia Mine site;
- examine the spatial nature of transitions with reference to neighbour interaction and distance from

the tailings with the intent of understanding natural process.

At a relatively early successional stage in boreal mixed-wood forests, aspens usually dominate, while spruce and balsam fir are common in the understorey. In later successional stages conifers may become dominant (Lieffers, 1996). At Kam-Kotia, trees at the beginning of the photographic sequence (1946) were approximately 30 years old. Canopy expansion and closure is expected until ages are about 55 years (1972) after which relative stability would be expected until trees commence deteriorating from old age (> 80-90 years) (King, 1997).

During closed canopy conditions intense competition exists for limited resources, with light being competed for over small neighbour distances and soil nutrients at greater distances. Experiments show that beyond a certain density of neighbours, plants show significant reduction in growth whether by inter-specific competition or not (Goldberg and Werner, 1981). Peterson (1995b), studying a 10 year interval within a 60 year old second growth aspen-white pine forest in Northern Michigan, observed that the distribution of white pine and aspen tended toward greater clumping than modelling predicted from earlier measured mortality rates. He surmised that this might be due to the clonal nature of aspen such that community dynamics in nutrient deficient sandy soils may be governed by clone dynamics.

Figure 6-17: Double Aspect Stem Transitions
Using Apex-Point In "60%Cost"
Polygon Method

6.3.2) Preliminary Comparison Temporal Imagery

i) Temporal Matching Method

Tree stem comparison was undertaken using a point in polygon matching technique in which the points were the tree apexes and the polygons were defined at the sixty percent cost threshold. The lower box in Figure 6-17 shows the four tree comparison permutations along the left side corresponding to tree survival, growth, death, and no activity. Tree to tree transitions may either consist of the same tree or a new tree. Venn diagrams illustrating the relationship permutations between apex and polygon perimeter are given. Surviving trees were defined as those polygons in which the intersection between dates and both apical centres intersect. Clearly, as is shown in the lower right corner of the box, the larger cost threshold defining the polygon the more continuity will be maintained. Comparison between temporal images was implemented in both forward and backward sequences.

ii) Preliminary Results

Individual tree stem transitions in this technique showed poor continuity between image dates as evident from the low numbers of blue (stable) polygons, in Figure 6-17. New growth (green) in 1979-1991 transition was sparse and is consistent with a maturing canopy. The poor result is attributable to spatially variable radiometric image qualities. This effect can be seen in the lower third of the transition images (Figure 6-17) in which low fertility areas

(white) appear to interchange from west to east, with transitions following a growth-death sequence in the west and a death-barren sequence in the east. The table below shows the regression parameters of average grey levels for tree apexes using the 1979 photo as a base since it displayed the best contrast.

Table 6-3. Correlation of average apex brightness between differing image dates show poor regression coefficients indicating that more than a gain and offset correction would be required.

Image	Slope	Intercept	r
1949 vs. 1979	-0.0771	160.50	-0.17
1961 vs. 1979	0.2390	122.27	0.23
1991 vs. 1979	0.3535	110.98	0.34

iii) Discussion of Preliminary Tree to Tree Comparison

Understandably, if a large tree disappears the understorey will show through the canopy, or alternatively, the hole can be filled with fast growing understorey trees or branches from surrounding trees. The extent of any replacement is dependent upon the time period between dates. Due to the difficulty of matching tonal tree characteristics between image dates, one cannot ensure that earlier trees have not been completely replaced. This problem, combined with the difficulty of precise registration between long time intervals, made tree to tree changes unfeasible. It was therefore necessary to consider the use of forest classes as

a viable alternative. This required a technique for aggregating point counts and comparing them between image dates. A density apex counting methodology was adopted as a practical means to represent forest classes.

6-3-3) Transition Modelling Methods and Controlled Demonstrations

Individual tree apexes and crowns are characterized by grey tone, distribution and morphology, all of which can characterize a cover class. Previously, tree counts were related to distance from the tailings. The automata transition model attempts to qualify changes in both the x and y spatial dimensions in order to infer spatial process, which, in the study area, may have represented maturation and degradation of aspen forest.

i) Reconstructing Forest Classes from Stem Counts

A roving window technique and a raster aggregation technique were compared. Both utilized apex window counts for reconstruction of forest classes. The reconstructive capability of each was established through reconstruction of a synthetic point distribution. Figure 6-18 (top-left) shows the original controlling image used for creation of the synthetic images (Subsection 6.2.4). Yellow corresponds to the high point density class and blue to the low density class. Tests were undertaken using the double aspect synthetic count results from the smooth synthetic image (Figure 6-18 top centre) and the rough synthetic image (top-

right) as originally displayed in Figure 6-8. Demonstration showed graphically that a roving window (top row) was preferential over a straight raster aggregate sum (bottom row) for the creation of tree density maps. A Cramers V of 0.35, which is substantially greater than zero showed that the roving window could partially reconstruct the two density classes. The process smoothed the surface, the degree of smoothing varying with the window size. The advantage of this technique was that the sampling grid interval and window sample region were independent. The roving window, for all samples, was set at ~8m radius at ~4 metre interval. The roving window was then employed to convert the point data into gridded sample points indicative of apex counts, average brightness, and modal class. These results were then compared between dates of imagery.

[illegible]

 

[illegible]

Raster aggregation technique

Figure 6-18: Density Mapping Reconstruction from Synthetic Point Image

ii) Transition Model Simulation

A model of a maturing forest subject to a degradation gradient was constructed to visually demonstrate how neighbour transitions might be portrayed. The demonstration adopted the previously described annealing transition rule to simulate a maturing canopy in which openings were being progressively filled by aspen. Figure 6-19 shows the original 60% binary random image (left) and a progressive increase of homogeneity and higher order neighbour configurations (proceeding right), as a result of applying this rule.

The simulation area was subjected to degradation along a contamination gradient which was applied as a stepwise degradation function away from the edge (ie. the tailings) starting at 40% dieback, then decreasing to 20%, 10%, and 5% with increasing distance from the tailings. Each area comprised approximately a fifth of the total area with the lowest degradation percentage attributed to the farthest two sections from the tailings. This larger area permitted an increased sample size for more marginal transitions.

Two iterations of degradation were randomly applied to each anneal image and neighbour transitions calculated. Curves understandably show variability (~10%) in transition probabilities since individually a single anneal image would not portray an even sample over the neighbourhood configuration spectrum. The summation of transitions from

all image iterations of the anneal model sought to equalize the sample, approximating a neutral model.

Figure 6-19 (graph) shows the summation results of all neighbour transitions modelled using the stepwise degradation. Curves are shown to occupy a horizontal position approximately along the dieback probability applied. Reproducibility of the two iterations was found to be fairly high, with variability at the margins most likely due to smaller samples (sample sizes are annotated above each point). Understandably, as the percentage of forest decreased, fewer large areas existed, increasing perimeter/area ratios and decreasing homogeneity. Inherently, areas with large die back percentages will suffer from poor sample size, which must be accepted as a limitation of the model. More subtly, one must appreciate that density changes are accompanied by transition changes, with greater homogeneity accompanying higher density. An integrated deterministic model could therefore easily be some combination of an anneal rule with a residual dieback factor integrated as a function of the geochemical gradient. Ultimately, this study aimed at deriving this composite transition.

Figure 6-19: Images show the effect of applying the annealing which consists of taking a marginal majority within a roving 3x3 square neighbourhood creating a consolidation of space with each iteration.

Neighbour transitions for differing degradation rates. Counts and transitions are for all images combined, which insured a good neighbour sample spectrum.

iii) Method of Applying Tree Density and Transition

Techniques to the Study Area

The previously demonstrated tree density window sampling technique was applied to both the double-aspect and high-pass apex point data. The technique utilized the ~8m radius sample window and the ~4m grid interval used previously, which allowed a spatial comparative reference between image dates. The technique was undertaken consecutively upon the double-aspect apexes removing a portion of darker apexes in order to enhance land cover patterns by a brightness threshold. A second sampling upon the double aspect apexes was undertaken, using a window which determined the locally more numerous class. Point inputs for this consisted of binary classified grey-level apexes, indicative of a lighter class of overstorey aspen and a darker mixed class of conifers and understorey.

Similarly, the window sampling method was applied to the high-pass filter image, but instead of counting threshold apexes, the window function summed all high-pass cell values "indicative" of a tree cover class. "Indicative" pixel classes varied between images. For example, the 1946 image aspen class was characterized by high frequency, while the opposite was true for the 1961 and 1979 images. The window summation results were then compared and, rather than having only two classes, a third intermediate class was added during classification in order to alleviate uneven exposure problems.

Neighbourhood transitions using initially a Queen's case neighbourhood and later a Rook's case neighbourhood were calculated from the sampled images. The Queen's case double-aspect transition probabilities were subsequently incorporated into a preliminary predictive automata model and used to model canopy openings. The high-pass Rook's case neighbourhood-class transitions were used to assess tree cover type changes. Rather than incorporating them into an automata, the significance of the trends was assessed using the Mann-Krendall statistic, from plots with distance from the tailings.

6.3.4) Double-Aspect: Results of Integrating Tree Density Mapping with Neighbour Transition Modelling.

i) Forest Class Reconstruction using Double-Aspect Points

Window counts of double-aspect apexes were calculated at varying brightness thresholds. Figure 6-20 shows the four image dates (rows), increasing brightness thresholds along the columns, and roving window counts increasing with later imagery. Comparison of the derived counts with their original photographic imagery shows the varying representations of like cover types. For example, the spruce bog area, clearly defined on the western (left) edges of the photographs shows up quite differently with each sequence of the imagery.

In the 1946 data the bog is portrayed by low counts at a high brightness threshold (DN class > 3). In contrast, the

1961 data (DN class > 1), although partially outlining the bog, is accompanied by dark crowns along its north-eastern edge. The 1979 data shows much less delineation of the bog but shows higher densities of conifer apexes but similar in tone to surrounding aspens. The 1991 image shows the bog in shadow.

Despite such anomalies overall correlation was surprisingly very high unlike previous poor correlation of average grey level tone. Table 6-4 describes the correlation for window counts within three later image dates.

Table 6-4. Linear regression slopes between differing image sample dates.

	1991	1979	1961
1991	1		
1979	0.8273	1	
1961	0.7669	0.8048	1

Unfortunately window count results failed to outline tree cover classes. The results showed some similar features but no definite artifacts that adequately described temporal continuity. The emergence of dark areas on the lower portions of the imagery is largely a product of uneven tone mixed with a small component of physical change.

To test the double aspect point images further, the three later images (1961, 1979 and 1991) were utilized and apex points were divided along a visual brightness threshold

Figure 6-20: Double Aspect Apex Counts by Grey Tone

Apex grey tone ranges have been divided into 10 levels
(1 dark, 10 bright) of which the first 3 are shown for each image.

which approximated the threshold at which illuminated over-storey transformed to shadowy under-storey (Figure 6-21 2nd column). These binary points were then interpreted using the window sample technique enhanced by additionally calculating the majority apex class. Initial results showed the threshold division did not maintain image character for its lower portion, consequently, only the upper half of the image was thought to be validly modelled (Figure 6-21 3rd column). This represented the input to the automata model consisting of a 2550 point sample.

Table 6-5 shows the threshold tone and threshold percentage used to divide the images' peaks into the two cover classes, Class 1 being the bright aspen canopy above the given threshold, and Class 0 corresponding to shadowy peaks in the under-storey or conifers below the threshold. Also shown are the estimated areas of the two classes.

Table 6-5. Thresholds used for the division of image peaks into two classes, aspen and under-storey/conifer, and percentage area of each after gridding.

Image	Threshold Tone (DN)	Threshold Percentile	%Area Shadow/ Clearing (0)	%Area Canopy (1)
1961	107	45 (1080/2372)	42	58
1979	152	40 (892/2954)	35	65
1991	97	43 (1689/3935)	35	65

The gridding process divided the area into a 2 : 1 light canopy to dark under-storey proportion displaying an

aggregated cell texture similar to the pattern of peaks. The process showed a decrease in representation between the point threshold percentage and the area percentage, the assumption being that the darker centres showed a higher degree of auto-correlation. The high auto-correlation is indicative that a neighbourhood model is likely to be appropriate for the understanding of changing features.

Figure 6-21: Data path for transition neighbourhood modelling using tonally thresholded double aspect peaks and a modal class roving window .

ii) Aspen Canopy Neighbour Transitions

Double-aspect neighbourhood transition probabilities were plotted in relation to the number of Class 1, mature aspen canopy Queen's case neighbour cells. Curve $p(1,0)$ (Figure 6-21a, graph) represents a canopy degradation curve measuring probability of change from mature aspen towards immature canopy classes or a canopy opening (ie. death), while curve $p(0,1)$ (Figure 6-21b, graph) represents maturing canopy growth into the over-storey where previously there was an opening or under-storey only. The four neighbour glyphs associated with the graphs are intended to graphically show the extremes of this behaviour (red=aspen, blue = under-storey / conifer). Neighbourhood population counts used to derive the transitional probabilities are portrayed in the underlying bar graph. Orange/red bar numbers are greater than blue bar numbers indicating a trend away from upper canopy cover. The large samples at the margins of the neighbour configurations are also indicative of large input areas showing homogeneity.

Overall, the neighbourhood temporal transitions favoured the stability of homogeneous canopy, with homogeneous areas undergoing less change than heterogeneous areas. The degradation curves (Graph 6-21a) show relatively smooth transitions with upward inflections occurring when less than 3/8th's of the neighbours are canopy. In contrast, increased transition rates occur for the maturation curve (Graph 6-

21b) when seven or more neighbours are canopy. These curve inflections show increased rates of change with neighbourhood heterogeneity. This behaviour may have a natural ecological basis but is difficult to assess due to the reduced sample sizes accompanying the trend. Insufficient sample sizes (counts > 25) have been highlighted on Figure 6-21 by the "?" symbol.

Comparison of curves between the 1961-1979 and the 1979-1991 time frames shows that the degradation results have a high correspondence except for the configuration with two neighbours which is due to poor sampling. In contrast, the maturing canopy curves show lower probabilities of change towards mature canopy at later dates. Explanation for the decrease in canopy development may in fact be because of influx of metal contamination but also may be due to instability resulting from aspen approaching their maximum ages.

Transitions are confirmed by patterns within the images with holes progressively becoming filled. The alternating class changes, however, are most likely the result of image differences that are not associated with the landscape. An example of this are the underlying angular trends within the imagery, probably the result of sun angles, which rotate and affect transition calculations - (Photo times : 1961 - 10:40, 1979 - 2:30 and 1991 12:25).

iii) Prediction Estimates

True comparison between the transitions was difficult since differing time spans were being considered. The stochastic predictions were thought to better show their transition behaviours. Table 6-6 shows the prediction estimates calculated from the 1961-1979 (left) and the 1979-1991 (right) transitions. Predictions are expressed in percentage image area.

Table 6-6. Over-storey/mature aspen cover predictions over three transition iterations.

Prediction Year	1961-79 Trans		1979-91 Trans	
	Iter	% Aspen Area	Iter	%Aspen Area
1961	0	58 (orig.)		
1979	1	51	0	65 (orig.)
1991			1	59
1997	2	46		
2003			2	55
2015	3	45	3	48

*actual 1991 Area = 65%

Automata prediction to the year 2015 estimate a decrease of between 13% to 17% in area of the mature canopy class (Table 6-6). Raw observations showed an increase in upper canopy of 7% and 0% for the 1961-1979 and the 1979-1991 intervals in contradiction to these results. Table 6-6 similarly shows this fact through discrepancies between predicted and original area percentages for the same year.

iv) Discussion of Double-Aspect Transitional Modelling

The primary limitation of any model is its input parameters. The predicted degradation had a component attributable to differing tonal and illumination differences portrayed within the original imagery. Poor sample numbers of certain neighbour transitions within the spectrum are another limitation, such that the utilization of these transition probabilities for prediction purposes may cause incorrect exaggeration in behaviour. The random nature of transitions makes assessment of such factors difficult to assess. Ultimately, the predictive sequence can only be assessed through use of reference imagery not involved in transition matrix calculations, such that the predicted percentage could be directly compared to an image for that date and errors identified. Unfortunately, to undertake such an alternative the smaller scale photography would be required, compounding image derived limitations.

These concerns are addressed in the following high-pass density implementation. Three significant changes have been implemented.

- Incorporation of an intermediate class to compensate for contrast differences in the photography.
- A reduction in the number of differing neighbour configurations, in an attempt to increase sample sizes across the neighbourhood spectrum.
- A shift from a predictive stochastic approach to a trend evaluation technique using the Mann-Krendall Statistic.

6.3.5) High-Pass: Results of Integrating Tree Density Mapping with Neighbour Transition Modelling.

i) High-Pass Class Delineation

Unlike the double-aspect method which is highly dependent upon tone, the high-pass method produced a measure of convexity, which when individually considered separated the two major tree class types. The conifers were particularly evident in the 1961 and 1979 images, forming a broad ring of higher frequency. For the 1946 imagery the reverse appeared to be the case. The 1991 image characterized the conifers as high frequency because they were concealed in the shadows (Figure 6-16). These observations were used for classification of apex points into their two classes (aspen and coniferous/under-storey) and then each was run through the roving window count gridding process (Figure 6-22). Since the roving window counts were not directly comparable, the images were divided into three classes corresponding to under-storey including conifers/open areas, deciduous, and mixed forest. The mixed class appeared as a fuzzy grouping and was used to compensate for variations in exposure and contrast throughout the image. This feature was particularly evident in the 1949 image. An alternative could have been to run the roving window through each class of the raw high-pass filter results, followed by clustering and classification. The roving window size could also have been varied. Neither were attempted as they appeared not to offer any distinct advantages over a simple threshold.

Figure 6-22: High-Pass Filter Crown Classes

1991

1979

1961

1946

c:\freedell\oggreg\highclas\highclas.cdr

Legend
Coniferous & Open
Deciduous

ii) High-Pass Tree Class Trends

The Mann-Krendall significance measure consists of calculating the class differences between all the possible forward combinations between image dates. Individual transitions may be either; positive, if change is up-class (conifer/open to neutral or aspen), negative, if change is down- class (aspen or neutral to conifer/open) or neutral, if no change in class has occurred. Areas of significant change are established via a cumulative consistent direction within the transitions. Since there are four image dates and only three forest classes, a consecutive trend without a neutral or negative transition is not possible. As implemented, the Mann-Krendall test gives a maximum of five positive or five negative possible combinations. In application, the significance threshold was placed at $\alpha = 0.167$ corresponding to a sum exceeding or equal to 4 in either direction (Gilbert, 1987). By subtraction, this allowed a maximum of 1 backward transition, between 1 or 2 neutral transitions, and a minimum of 4 forward transitions within the combinations. This high level of significance was adopted so that long term trends would be less likely to be the result of aberrant photographic conditions and more the result of actual environmental change.

iii) High-Pass Transition Results as a Function of Distance from the Tailings

The pair-wise image transitions shown in Figure 6-23 showed similarities between one another although coincident

boundaries were poorly developed. Similarly, Mann-Krendall trends did not show cohesive areas of change, but did show increased openings developing nearer the tailings (blue) and a trend toward deciduous canopy closure farther away from the tailings (orange) (Figure 6-23). Figure 6-24a demonstrates this through averaging the Mann-Krendall results over 18m interval distances away from the tailings. These plots are displayed for both the deciduous (red line) and coniferous/open (blue line) trends, with the normalized difference between the two curves indicated by the green area. The strong negative to positive trend in the normalized difference confirms the visual interpretation of degradation nearer the tailings. Therefore, within 150m of the tailings, coniferous/open replacing deciduous is greater than deciduous replacing coniferous, while the reverse is true farther away from the tailings.

- Aspen over-storey is shrinking near the tailings while it is increasing at distances greater than 100m.

iv) High-Pass Transition Results as a Function Neighbourhood

Neighbour transitions occur between three classes forming nine possible transition class pairs. Neighbour transition results have been expressed as a class percentage stability (number of class transitions exhibiting no change/total initial number in the class). These neighbour results are calculated for pixels showing a significant trend ($\alpha = 0.167$) and as a function of similar (Figure 6-24b) and dissimilar (Figure 6-24c) numbers of Rook's case neighbours.

Differing probabilities at either end of the neighbourhood spectrum show that the frequency of change increased with lower similarity within the neighbourhood.

■ Neighbourhood transitions show that homogeneous landscape cover is more stable.

The two sets of curves are not completely complementary to one another since the neutral class rounds out the totals. Aspen appear to have a greater ability to maintain homogeneity within neighbour configurations exhibiting high similarities (6-24b) while this is not portrayed within "dissimilarity" curves which show coincident paths (6-24c). Curves in Figures 6-24b,c probably suffered from poor neighbour samples. A further consideration is the edge generalization, inherent within the window sampling technique, which could develop similar neighbour transition profiles.

The vertical average position of the plots is fairly synthetic being dependent upon the significance value. The observation that the derived neutral transitions total (~40%) approximates the theoretical projection and confirms that few backward transitions were included within the $\alpha = 0.167$ dataset.

Figure 6-23: Temporal transitions for the high-pass density classes and the Mann-Krendal Trend

Figure 6-24: Transition changes as a function of proximity to the tailings and neighbourhood configuration.

A

B

C

6.3.6) DISCUSSION

This chapter attempted to illustrate a possible implementation of a cellular modelling scenario utilizing stem point counts. Two differing transitional estimates were predicted using two modelling techniques, automata prediction and trend visualization. Estimates of change, however, cannot be confirmed as degradation caused by the nearby mine, as they might also be the result of natural succession dependent upon the age structure of the trees under study. Pixel to pixel comparison indicates degradation of the aspen dominated canopy near the tailings and maturation farther away. Neighbour modelling displays transitions favouring spatial homogeneity and also predicts a degradation trend. However, it suffers from poor neighbour sampling and shows little reproducibility between image sets.

Quality limitations associated with the use of aerial photographs made comparison of derived stems difficult. This constitutes the major limitation of the research. Raw tree counts were adversely affected as a consequence of lighting conditions within the imagery. Consequently, an aggregate method using tone and density was used to delineate canopy classes, showing some success when preceded by a high-pass filter. Ultimately, for tree delineation, sampling must be corroborated with ground data, which this site did not offer but a controlled site such as a tree plantation would. Transitional behaviours which resulted from modelling

appeared to be indicative of a competitive growth situation, and showed similarities to an annealing rule pattern discussed at 2.5.2(iii). The adoption of an annealing methodology, although not calibrated, to the natural areal changes in this study may more accurately model contagion and thematic edge measures. Development of a rule using a larger neighbourhood could perhaps lend more flexibility in adjusting this deterministic relationship to mimic the observed transitions. Conversely, a large neighbourhood implemented into a backward methodology is limited by its ability to derive a reasonable sample size of the differing constituent neighbourhood configurations. The insufficient neighbour counts in this study are considered to have contributed to the automata model's poor predictive agreement with ground area data. A larger universe or larger sample density could potentially mitigate this effect whilst lowering the influence of model boundary transitions, however it is difficult to envisage a sampling methodology that maintains neighbour kernel stationarity whilst providing a flat frequency spectrum. If an assumption of dimensional independence is upheld, perhaps neighbourhood frequencies could be developed using an hierarchical data structure. Alternatively, if points are used to replace the raster structure, equal frequency neighbour distributions could be formed through varying cutoff classes within continuous data.

Cellular automata appear to be a suitable tool for image

prediction but as with all such methods they require comparison between differing image sets and differing image characteristics. Differences in these image characteristics must be minimized in order to render true prediction of environmental change, but this may not always be possible because of practical data constraints. The advantage of automata is that they assume only that some spatial cross-correlation is inherent within change, and thereby do not unreasonably structure change. The methodology, although highly adaptable, is not necessarily a predictive mechanism for all behaviours. The characterization of the periodicity of natural events and the timing of data collection is the prime control upon effectively capturing natural dynamics. Despite these concerns automata have more than established themselves within the environmental modelling fields, representing an excellent qualitative visualization technique for studies of change.

CHAPTER 7: SUMMARY AND CONCLUSION

This research has attempted to use archival black and white photography to model environmental change adjacent to the Kam-Kotia mine tailings. Registered archival photography showed that the tailings denudation expanded quickly in the 1960's after which in the 1970's propagation of catastrophic effects had ceased, presumably replaced by subtle forest structure changes at its edge. Site surveys indicated that the present tailings boundary is coincident with local elevational controls. Beyond the tailings denudation boundary, vegetation damage was progressively more subtle but wind effects were still evident from development of large area openings. Areas nearer the tailings showed larger numbers of dead trees, a pattern which was evident to about 200m in the forest. Close to the present tailings margin a detailed study area was delineated which straddled a land cover transition between spruce bog and aspen dominated mixed forest. Previous researchers had confirmed a significant metal contamination gradient within the area. Topographic contours confirm the possibility of contaminated water flow from the tailings.

The research approach was to use archival photography to model individual trees as an indication of environmental changes. Tree modelling was preferred over mine tailings modelling, firstly, because the photography was taken for forestry purposes so that the tailings areas were often poorly imaged, and secondly, vegetation had long been known

to be a good indicator of metal contamination and would allow inference of subsurface contamination.

A stochastic approach to modelling change was favoured over a deterministic approach, since it was more generic and utilized image information rather than being dependent upon translocated assumptions of process. The principal challenge became marginalizing extraneous image differences in order to infer "true" change.

A tree sampling methodology was proposed as a means of segmenting the landscape into a discrete indicator of change. The two tree finding methods implemented utilized the conical shape within imaged grey tones to identify tree apexes. A prime concern was that the tree delineation technique was highly dependent upon image definition and film sensitivity. Tree branch lobes and shadowed understorey were commonly identified in later photography, causing tree counts to be much higher than found in earlier photography. Proposed corrective segment merging techniques proved ineffective and time consuming to employ. Additionally, image exposure, illumination and view angle differences largely negated individual tree matching between images, despite the selection of an area least affected by these differences. To compensate for these discrepancies, a window tree sampling methodology was employed which utilized the tree stem counts derived from the two methods to delineate canopy types. This window sampling technique

appears to have captured canopy characteristics, with forest class images derived, using the highpass filter apex delineation technique, being visually comparable to FRI interpretations. The tree apex and window sampling combination occupies a procedural position intermediate between aggregate texture techniques found within Grey-Level Co-occurrence Matrices (Haralick 1973) and a natural pre-attentive approach utilizing first order statistics via a Triangular Primitive Network technique proposed by Hay et al. (1994).

Temporal modelling measured transitions both related to distance from the tailings and a product of neighbourhood actions. A high-pass filter combined with a roving window sample showed the best visually interpretable image inputs to the model. Results indicated that there could be a degradation trend portrayed within the imagery between 1946 and 1991. Image evidence supporting this is:

- a decrease in numbers of bright (double-aspect derived) trees closer to the tailings, which may be a product of thinning crowns; and also,
- the Mann-Krendall trend showed greater openness within mature aspen canopy nearer the tailings.

Neighbour transition modelling showed that tree cover transitions favoured homogenization, consistent with maturing canopy and visually evident in the photography from larger openings and larger clumps. Implementing transitions

into a predictive model showed a degradation trend opposing visual trends within the imagery. It is surmised that poor sampling within the spectrum of neighbourhood configurations could be an explanation for these differences.

7.1 Limitations of the Study

The canopy degradation results displayed a spatial association with the tailings implying a source but not a process. A paradox became evident during the research that exists for most remote sensing applications, this is the requirement for ground data in order to qualify "remote" techniques, in this case, specifically temporal tree counts. The alternative, to obviate this shortcoming, is to analyze comparatively, however, the difficulty involved with minimizing photographic parameters does not provide any solace that transition observations are unfettered by them.

Raster automata modelling of tree inter-relationships was adopted in an attempt to derive spatial temporal structure. Difficulties in application naturally exist in that trees do not necessarily grow in a tessellated configuration. The solution was to create classes based upon stem density which could subsequently be modelled in the automata. The difficulty was justifying the chosen grid density and sampling window size, as the generalization effect of the roving window made it impractical when applied to finely patterned or high contrast edges. To address this concern, a synthetic demonstration of the reconstructive ability of the

methodology was thought to be sufficient. The combined effect of implementing this window sampling solution was a shift in modelling aims from individual trees, to modelling of canopy clumps. The transition results similarly shifted from being indicative of individual resource competition to aggregate stem clump/canopy dynamics. The chosen solutions may circumvent the original intentions of directly modelling the objects of change, but, demonstrate promising results and may provide some initial parameters for additional research.

7.2 Future Work

One of the requirements of this study was to overcome the photographic constraints of archival imagery. The difficulty encountered was determining if the results were correct and actually overcame the known photographic constraints.

Broadening of the data by the inclusion of other photographic dates and observation of stability within the results would help to confirm the results. Mann-Krendall statistics exponentially improve in their fidelity with each image addition, however, addition of more diverse imagery is unlikely to improve the significance of any trends. This leads to two possibilities, firstly, the utilization of calibrated digital imagery, or secondly, undertaking methods on a site of known change. The second appears more useful, with a plantation site or tailings re-mediation site being a possible location. Advantages would be that trees would be regularly arranged and health records would be available.

Preferably, it would be a plant species with a rapid turnover so that many neighbour transitions could be established. Optimally, individual transition changes would be synchronously captured. In such a model both ground estimates and image estimates could be compared. Colour photography would be a further innovation that would enhance segmentation, clarify tree types, or possibly even identify stress. Segmentation using stereo pairs could both enhance tree description and negate many lighting difficulties. Shadows could be information sources through comparison to synthetically calculated illuminations. This would require a massive upgrade in computing capability. The existing merging routines would have been less cumbersome with a faster computer. Prediction models would have benefited from more model runs to develop errors as a product of their random nature. Neighbourhood size, grid and window parameters could all be varied to establish model sensitivity. Ultimately, continuous class transition modelling could have been undertaken but for simplicity of interpretation cover classes were defined.

As the model exists, both a local transition and a regional transition gradient are defined. Further modelling could combine the two and apply them to a "neutral" landscape. Continued application and modification of these transitions could be a revealing process but beyond the confines of this exploratory study.

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APPENDIX 1

Table A-1 Kam-Kotia Images

(Note: Scan resolution, Tape File #, Size apply to OMNR scans at 5m)

Source	Date	Scale	Scan (dpi)	Photo #	Tape File #	Mb each
FRI	Summer 1946 (Fall?) 2:20 Area >20 ° SSE	1:15840	200	46-62A 302-24 46-62 215-27 46-63 215-21 46-63 215-22	46-62A 302- 24 a/b.tiff etc.	3.16
EMR	May 1954	1:70000	~600 dpi	A-14000-30 L3-W	A-14000- 30a/b.tiff	27.9
FRI	Summer 1961 10:40 Area<10°NE	1:15840	200	61-4825 54-58 61-4825 54-59 61-4825 54-60	61-58.pbx 61-59.pbx 61-60.pbx	2.2
	time gap					
EMR	May-June 1972	~1:50000		A22754 133 A22754 134	not scanned	
EMR	May-June 1976	~1:50000		A24344 93 A24344 94	not scanned	
FRI	1979 2:30 Area<10°NW	1:15840	200	79-4825-16 22 79-4825-16 23	79-4825-16 22a/b.tiff 79-4825-16 23a/b.tiff	3.2mb
EMR	July 1983	~1:50000		A26333 103 A26333 104	not scanned	
OBM	Summer 1984	1:50000		B84-50 265-13 117 B84-50 254-12 209 B84-50 254-12 210	B84-50 265-13 117a/b.tif B84-50 254-12 209a/b.tif not scanned	5.2
OBM	Summer 1990	1:5000		not obtained		
OBM	Summer 1991 12:25 Area >20°N	1:20000		91-4820-70-95 91-4820-70-96 91-4821-62-107	not scanned but have ITEK	
PRSO (colour)	Summer 1993	1:30000	150	UAGII 3002- 153- 16-4676 16-4677 16-4678 16-4679	76a/b.tiff 77a/b.tiff 78b.tiff 79a/b.tiff	1.8 x 3
PRSO (colour)	Aug 1993	1:15840		see above

1946

1954

1961

1972

1976

1979

1983

1984

1991

Appendix 2 Diffusion Weighting of the Tailings Edge

Definition of a fuzzy edge

Seed
Living Tree Dead Tree

PROCESS: Diffusion of Drainage flowing through a friction/elevation surface via cell neighbour

Figure below shows dilated areas developed by successive cell diffusion. Edge contrast statistics indicative of zones of influence may be developed using relative proportions of dead poles inside vs outside the buf

STATISTICAL DEFINITION

Assumption of Uniform Density

$$W_+ = \ln\left(\frac{C}{C_{\text{seed}}}\right) / \left(\frac{A_{\text{seed}}}{A_{\text{total}}}\right)$$

$$W_- = \ln\left(\frac{C}{C_{\text{seed}}}\right) / \left(\frac{A_{\text{seed}}}{A_{\text{total}}}\right)$$

Density Variation

$$W_+ = \ln\left(\frac{C}{C_{\text{seed}}}\right) / \left(\frac{A_{\text{seed}}}{A_{\text{total}}}\right)$$

$$W_- = \ln\left(\frac{C}{C_{\text{seed}}}\right) / \left(\frac{A_{\text{seed}}}{A_{\text{total}}}\right)$$

$$C = W_+ - W_-$$

$$\text{old } W_+ = (T_1 - T_2) / (T_1 - T_2) \cdot 0.5$$

$$\text{Err} = (\text{old } W_+)^2 + (\text{old } W_-)^2 \cdot 0.5$$

1950 Image Statistics

buffer	Seed	*	•	W+	W-	C	Err
1	247	6	21	0.212	-0.099	0.311	0.51
2	383	12	87	0.466	-0.639	1.105	0.54
3	528	13	137	0.225	-0.504	0.729	0.37
4	670	14	198	0.061	-0.245	0.306	0.64
5	865	17	280				
Pop.				extrapol. of area use total population			
1	27	6	21	1.36	-0.34	1.70	0.54
2	99	12	87	0.75	-0.81	1.56	0.54
3	150	13	137	0.414	-0.74	1.15	0.58
4	212	14	198	0.143	-0.48	0.62	0.65
5	297	17	280				

Contrast Plot 1950

Time Extrapolation

Assuming all buffers are representative of process, extrapolation can be used to predict the buffer sequence flow through the buffers

APPENDIX 3. C-PROGRAMS AND IDRISI BATCH FILES

RUN.BAT, March 2, 1997

```
cd \treedel\batch
call go 6 5 2 4
cd \treedel\batch
call go 6 5 7 1
cd \treedel\batch
rem call compexe 6 34 4 7
rem -----
cd \treedel\batch
call go 6 6 2 4
cd \treedel\batch
call go 6 6 7 1
cd \treedel\batch
rem call compexe 6 34 4 7
rem -----
cd \treedel\batch
rem windexe 9
cd \treedel\batch
call go 6 34 2 4
cd \treedel\batch
call go 6 34 7 1
cd \treedel\batch
rem call compexe 9 33 4 7
rem -----
cd \treedel\batch
rem call go 9 34 2 4
cd \treedel\batch
rem call go 9 34 7 1
cd \treedel\batch
rem call compexe 9 34 4 7
rem -----
rem -----
cd \treedel\batch
rem call aggreg 6 1
cd \treedel\batch
rem call aggreg 6 2
cd \treedel\batch
rem call aggreg 6 4
cd \treedel\batch
rem call aggreg 6 -
```

```
rem GO
rem *1 - imagesector [1-9]
rem *2 - first 100x 200 subwindow 1-35
rem *3 - time 1
rem *4 - time 2

rem call windexe *1
cd \tresdel\batch
call findexe *1 *2 *3 *4
cd \tresdel\batch
rem call compexe *1 *2 *3 *4
```

```

rem window [ 1 imagesector]

if "1"==" " goto end

md \treedel\window\1

md \treedel\window\1\w1
md \treedel\window\1\w2
md \treedel\window\1\w3
md \treedel\window\1\w4
md \treedel\window\1\w5
md \treedel\window\1\w6
md \treedel\window\1\w7
md \treedel\window\1\w8
md \treedel\window\1\w9
md \treedel\window\1\w10
md \treedel\window\1\w11
md \treedel\window\1\w12
md \treedel\window\1\w13
md \treedel\window\1\w14
md \treedel\window\1\w15
md \treedel\window\1\w16
md \treedel\window\1\w17
md \treedel\window\1\w18
md \treedel\window\1\w19
md \treedel\window\1\w20
md \treedel\window\1\w21
md \treedel\window\1\w22
md \treedel\window\1\w23
md \treedel\window\1\w24
md \treedel\window\1\w25
md \treedel\window\1\w26
md \treedel\window\1\w27
md \treedel\window\1\w28
md \treedel\window\1\w29
md \treedel\window\1\w30
md \treedel\window\1\w31
md \treedel\window\1\w32
md \treedel\window\1\w33
md \treedel\window\1\w34
md \treedel\window\1\w35

copy c:\treedel\images\11.tif c:\treedel\work\11.tif
copy c:\treedel\images\12.tif c:\treedel\work\12.tif
copy c:\treedel\images\13.tif c:\treedel\work\13.tif
copy c:\treedel\images\14.tif c:\treedel\work\14.tif
copy c:\treedel\images\15.tif c:\treedel\work\15.tif
copy c:\treedel\images\16.tif c:\treedel\work\16.tif
copy c:\treedel\images\17.tif c:\treedel\work\17.tif
copy c:\treedel\images\18.tif c:\treedel\work\18.tif
copy c:\treedel\images\19.tif c:\treedel\work\19.tif

cd \idrisi
environ x 2 \treedel\work\
tifidris x 1 11 11
tifidris x 1 12 12
tifidris x 1 13 13
tifidris x 1 14 14
tifidris x 1 15 15
tifidris x 1 16 16
tifidris x 1 17 17
tifidris x 1 18 18
tifidris x 1 19 19

del c:\treedel\work\*.tif
copy c:\treedel\work\11.* c:\treedel\window\1\11.*
copy c:\treedel\work\12.* c:\treedel\window\1\12.*
copy c:\treedel\work\13.* c:\treedel\window\1\13.*
copy c:\treedel\work\14.* c:\treedel\window\1\14.*
copy c:\treedel\work\15.* c:\treedel\window\1\15.*
copy c:\treedel\work\16.* c:\treedel\window\1\16.*
copy c:\treedel\work\17.* c:\treedel\window\1\17.*
copy c:\treedel\work\18.* c:\treedel\window\1\18.*
copy c:\treedel\work\19.* c:\treedel\window\1\19.*

rem call c:\treedel\batch\wind %1 0 0 200 200 1
call c:\treedel\batch\wind %1 0 0 200 200 1
call c:\treedel\batch\wind %1 200 0 400 200 2

```

```

call c:\treedel\batch\wind -1 400 0 600 200 3
call c:\treedel\batch\wind -1 600 0 800 200 4
call c:\treedel\batch\wind -1 800 0 1000 200 5
call c:\treedel\batch\wind -1 1000 0 1200 200 6
call c:\treedel\batch\wind -1 1200 0 1299 200 6

call c:\treedel\batch\wind -1 0 200 200 400 8
call c:\treedel\batch\wind -1 200 200 400 400 9
call c:\treedel\batch\wind -1 400 200 600 400 10
call c:\treedel\batch\wind -1 600 200 800 400 11
call c:\treedel\batch\wind -1 800 200 1000 400 12
call c:\treedel\batch\wind -1 1000 200 1200 400 13
call c:\treedel\batch\wind -1 1200 200 1299 400 14

call c:\treedel\batch\wind -1 0 400 200 600 15
call c:\treedel\batch\wind -1 200 400 400 600 16
call c:\treedel\batch\wind -1 400 400 600 600 17
call c:\treedel\batch\wind -1 600 400 800 600 18
call c:\treedel\batch\wind -1 800 400 1000 600 19
call c:\treedel\batch\wind -1 1000 400 1200 600 20
call c:\treedel\batch\wind -1 1200 400 1299 600 21

call c:\treedel\batch\wind -1 0 600 200 800 22
call c:\treedel\batch\wind -1 200 600 400 800 23
call c:\treedel\batch\wind -1 400 600 600 800 24
call c:\treedel\batch\wind -1 600 600 800 800 25
call c:\treedel\batch\wind -1 800 600 1000 800 26
call c:\treedel\batch\wind -1 1000 600 1200 800 27
call c:\treedel\batch\wind -1 1200 600 1299 800 28

call c:\treedel\batch\wind -1 0 800 200 1000 29
call c:\treedel\batch\wind -1 200 800 400 1000 30
call c:\treedel\batch\wind -1 400 800 600 1000 31
call c:\treedel\batch\wind -1 600 800 800 1000 32
call c:\treedel\batch\wind -1 800 800 1000 1000 33
call c:\treedel\batch\wind -1 1000 800 1200 1000 34
call c:\treedel\batch\wind -1 1200 800 1299 1000 35

```

```

:end
rem windexe [imagesector]

```

```

rem wind [imagsect] [x] [y] [x] [y] [windir]
if "%1"==" " goto end
if "%2"==" " goto end
if "%3"==" " goto end
if "%4"==" " goto end
if "%5"==" " goto end
if "%6"==" " goto end
window x +11 temp 1 -2 -3 -4 -5
copy c:\treedel\work\temp.* c:\treedel\window\1\w-5\11.*
window x +12 temp 1 -2 -3 -4 -5
copy c:\treedel\work\temp.* c:\treedel\window\1\w-5\12.*
window x +13 temp 1 -2 -3 -4 -5
copy c:\treedel\work\temp.* c:\treedel\window\1\w-5\13.*
window x +14 temp 1 -2 -3 -4 -5
copy c:\treedel\work\temp.* c:\treedel\window\1\w-5\14.*
window x +15 temp 1 -2 -3 -4 -5
copy c:\treedel\work\temp.* c:\treedel\window\1\w-5\15.*
window x +16 temp 1 -2 -3 -4 -5
copy c:\treedel\work\temp.* c:\treedel\window\1\w-5\16.*
window x +17 temp 1 -2 -3 -4 -5
copy c:\treedel\work\temp.* c:\treedel\window\1\w-5\17.*
window x +18 temp 1 -2 -3 -4 -5
copy c:\treedel\work\temp.* c:\treedel\window\1\w-5\18.*
window x +19 temp 1 -2 -3 -4 -5
copy c:\treedel\work\temp.* c:\treedel\window\1\w-5\19.*
: end
rem USAGE : wind [imagsect] [x] [y] [x] [y] [windir]

```

```

rem findexe [! image sector] [! window] [! 3 times] [! 4 times]
:find
if "%1"==" " goto end
if "%1"==" " goto end
if "%1"==" " goto end
if "%1"==" " goto end
del c:\treedel\work\*.img
del c:\treedel\work\*.doc
del c:\treedel\work\*.val
del c:\treedel\work\*.vec
del c:\treedel\work\*.dvc

copy c:\treedel\*.rc1 c:\treedel\work\*.
copy c:\treedel\window\1\w-2\1-3.img c:\treedel\work\*.
copy c:\treedel\window\1\w-2\1-3.doc c:\treedel\work\*.
copy c:\treedel\window\1\w-2\1-4.img c:\treedel\work\*.
copy c:\treedel\window\1\w-2\1-4.doc c:\treedel\work\*.

call find 1-3 1-4
rem find -11 -17
rem copy c:\treedel\work\*. c:\treedel\window\1\w-2\*.
copy c:\treedel\work\1?alp.* c:\treedel\window\1\w-2\*.
copy c:\treedel\work\1?cst.* c:\treedel\window\1\w-2\*.
copy c:\treedel\work\1?pk.* c:\treedel\window\1\w-2\*.
rem copy c:\treedel\work\1?low.* c:\treedel\window\1\w-2\*.
copy c:\treedel\work\1?w.* c:\treedel\window\1\w-2\*.
rem copy c:\treedel\work\1?gui.* c:\treedel\window\1\w-2\*.
rem copy c:\treedel\work\1?gulcst.* c:\treedel\window\1\w-2\*.
copy c:\treedel\work\1?spk.* c:\treedel\window\1\w-2\*.
copy c:\treedel\work\1?saic.* c:\treedel\window\1\w-2\*.
copy c:\treedel\work\1?scst.* c:\treedel\window\1\w-2\*.
copy c:\treedel\work\1?filt.* c:\treedel\window\1\w-2\*.

copy c:\treedel\work\1-3highf0.* c:\treedel\window\1\w-2\*.
copy c:\treedel\work\1-3highf1.* c:\treedel\window\1\w-2\*.
copy c:\treedel\work\1-3highf2.* c:\treedel\window\1\w-2\*.
copy c:\treedel\work\1-3highf3.* c:\treedel\window\1\w-2\*.

copy c:\treedel\work\1-3lowf0.* c:\treedel\window\1\w-2\*.
copy c:\treedel\work\1-3lowf1.* c:\treedel\window\1\w-2\*.
copy c:\treedel\work\1-3lowf2.* c:\treedel\window\1\w-2\*.
copy c:\treedel\work\1-3lowf3.* c:\treedel\window\1\w-2\*.

copy c:\treedel\work\1-4highf0.* c:\treedel\window\1\w-2\*.
copy c:\treedel\work\1-4highf1.* c:\treedel\window\1\w-2\*.
copy c:\treedel\work\1-4highf2.* c:\treedel\window\1\w-2\*.
copy c:\treedel\work\1-4highf3.* c:\treedel\window\1\w-2\*.

copy c:\treedel\work\1-4lowf0.* c:\treedel\window\1\w-2\*.
copy c:\treedel\work\1-4lowf1.* c:\treedel\window\1\w-2\*.
copy c:\treedel\work\1-4lowf2.* c:\treedel\window\1\w-2\*.
copy c:\treedel\work\1-4lowf3.* c:\treedel\window\1\w-2\*.

:end
rem findexe [!imagesector] [!subwindow]

```



```

echo 1
rem
rem usage: find [image1] [image2] ....
rem recommend 200 x 200 subimage
rem -----
cd \dris1
environ x 1 \treedel\work
copy c:\treedel\batch\*.rc1 c:\treedel\work\*.rc1
:getfile
shift
if "%0"==" " goto end
rem copy c:\treedel\images\%0\%0.* c:\treedel\work\imgw.*
copy c:\treedel\work\%0.* c:\treedel\work\img.*
rem tifdris x 1 %0 img
rem window x img imgw 1 -3 -4 -5 -6
REM RECLASS ZERO IN IMAGE FRICTION
reclass x 1 img imgw 2 1 0 1 -9999
REM RUN MODEL AT 4 DIFFERING FILTER RESOLUTIONS
filter x imgw 15 1
filter x 15 25 1
filter x 25 35 1
REM TAKE ASPECT OF IMAGES
surface x 2 imgw imgwa # d 1
surface x 3 15 15a # d 1
surface x 3 25 25a # d 1
surface x 3 35 35a # d 1
REM FLAT ASPECTS OF -1 ARE STORED
reclass x 1 imgwa 0flat 2 15 -10 0 0 0 361 -9999
reclass x 1 15a 1flat 2 15 -10 0 0 0 361 -9999
reclass x 1 25a 2flat 2 15 -10 0 0 0 361 -9999
reclass x 1 35a 3flat 2 15 -10 0 0 0 361 -9999
REM FIND FLAT AREA HIGHS AND LOWS
group x 0flat y 0flatgr
extract x 0flatgr imgw 1 4 avgflat0
assign x 0flatgr avgflat0 avgflat0 2
extract x 0flatgr 35 1 4 avgflat1
assign x 0flatgr avgflat1 avgflat1 2
overlay x 2 avgflat0 avgflat1 temp

reclass x 1 0flat 0flatx 2 1 1 31000 -9999
overlay x 3 0flatx temp temp1

reclass x 1 temp1 flatv 2 255 -600 -0.1 0 -0.1 600 -9999
reclass x 1 temp1 flatr 2 255 0.1 600 0 -600 0.1 -9999

REM RECLASS INTO BINARY HALFS * 4 = 45 DEGREES
reclass x 1 imgwa 0ns 3 ns
reclass x 1 15a 1ns 3 ns
reclass x 1 25a 2ns 3 ns
reclass x 1 35a 3ns 3 ns
reclass x 1 imgwa 0ew 3 ew
reclass x 1 15a 1ew 3 ew
reclass x 1 25a 2ew 3 ew
reclass x 1 35a 3ew 3 ew
reclass x 1 imgwa 0nesw 3 nesw
reclass x 1 15a 1nesw 3 nesw
reclass x 1 25a 2nesw 3 nesw
reclass x 1 35a 3nesw 3 nesw
reclass x 1 imgwa 0nwse 3 nwse
reclass x 1 15a 1nwse 3 nwse
reclass x 1 25a 2nwse 3 nwse
reclass x 1 35a 3nwse 3 nwse
REM TAKE 2 SURFACE OF DIRECTION FILES TO FIND EDGE
REM AND DETERMINE IF IT IS A PEAK OR VALLEY
surface x 2 0ns 0nssl # d 1
surface x 2 1ns 1nssl # d 1
surface x 2 2ns 2nssl # d 1
surface x 2 3ns 3nssl # d 1
surface x 2 0ew 0ewsl # d 1
surface x 2 1ew 1ewsl # d 1
surface x 2 2ew 2ewsl # d 1
surface x 2 3ew 3ewsl # d 1
surface x 2 0nesw 0neswsl # d 1
surface x 2 1nesw 1neswsl # d 1
surface x 2 2nesw 2neswsl # d 1
surface x 2 3nesw 3neswsl # d 1
surface x 2 0nwse 0nwsesl # d 1
surface x 2 1nwse 1nwsesl # d 1

```

```

surface x 1 3nwswsl 3nwswslr # d 1
surface x 1 3nwswsl 3nwswslr # d 1
REM RECLASS DIRECTIONS SO SUITABLE FOR BINARY OVERLAY 1,2,4,8
reclass x 1 0nssl 0nsslir 3 ns
reclass x 1 1nssl 1nsslir 3 ns
reclass x 1 0nssl 0nsslir 3 ns
reclass x 1 3nssl 3nsslir 3 ns
reclass x 1 0ewsl 0ewslir 3 ew
reclass x 1 1ewsl 1ewslir 3 ew
reclass x 1 0ewsl 0ewslir 3 ew
reclass x 1 3ewsl 3ewslir 3 ew
reclass x 1 0neswsl 0neswslir 3 nesw
reclass x 1 1neswsl 1neswslir 3 nesw
reclass x 1 2neswsl 2neswslir 3 nesw
reclass x 1 3neswsl 3neswslir 3 nesw
reclass x 1 0nwswsl 0nwswslir 3 nwse
reclass x 1 1nwswsl 1nwswslir 3 nwse
reclass x 1 2nwswsl 2nwswslir 3 nwse
reclass x 1 3nwswsl 3nwswslir 3 nwse

REM RIDGE = CLASS 1:1, 1:2 IE 5,8
REM VALLEY = CLASS 2:1, 2:2 IE 6,9
crosstab x 0nsslir 0ns 1 0nsx
crosstab x 0ewslir 0ew 1 0ewx
crosstab x 0neswslir 0nesw 1 0neswx
crosstab x 0nwswslir 0nwse 1 0nwsex

crosstab x 1nsslir 1ns 1 1nsx
crosstab x 1ewslir 1ew 1 1ewx
crosstab x 1neswslir 1nesw 1 1neswx
crosstab x 1nwswslir 1nwse 1 1nwsex

crosstab x 2nsslir 2ns 1 2nsx
crosstab x 2ewslir 2ew 1 2ewx
crosstab x 2neswslir 2nesw 1 2neswx
crosstab x 2nwswslir 2nwse 1 2nwsex

crosstab x 3nsslir 3ns 1 3nsx
crosstab x 3ewslir 3ew 1 3ewx
crosstab x 3neswslir 3nesw 1 3neswx
crosstab x 3nwswslir 3nwse 1 3nwsex

REM HIGHLIGHT CROSSTAB 5,8 RIDGES
reclass x 1 0nsx 0nsxr 2 0 0 5 1 5 6 0 6 8 1 8 9 0 9 999 -9999
reclass x 1 0ewx 0ewxr 2 0 0 5 2 5 6 0 6 8 2 8 9 0 9 999 -9999

reclass x 1 0nwsex 0nwsexr 2 0 0 5 4 5 6 0 6 8 4 8 9 0 9 999 -9999
reclass x 1 0neswx 0neswxr 2 0 0 5 8 5 6 0 6 8 8 8 9 0 9 999 -9999

reclass x 1 1nsx 1nsxr 2 0 0 5 1 5 6 0 6 8 1 8 9 0 9 999 -9999
reclass x 1 1ewx 1ewxr 2 0 0 5 2 5 6 0 6 8 2 8 9 0 9 999 -9999

reclass x 1 1nwsex 1nwsexr 2 0 0 5 4 5 6 0 6 8 4 8 9 0 9 999 -9999
reclass x 1 1neswx 1neswxr 2 0 0 5 8 5 6 0 6 8 8 8 9 0 9 999 -9999

reclass x 1 2nsx 2nsxr 2 0 0 5 1 5 6 0 6 8 1 8 9 0 9 999 -9999
reclass x 1 2ewx 2ewxr 2 0 0 5 2 5 6 0 6 8 2 8 9 0 9 999 -9999

reclass x 1 2nwsex 2nwsexr 2 0 0 5 4 5 6 0 6 8 4 8 9 0 9 999 -9999
reclass x 1 2neswx 2neswxr 2 0 0 5 8 5 6 0 6 8 8 8 9 0 9 999 -9999

reclass x 1 3nsx 3nsxr 2 0 0 5 1 5 6 0 6 8 1 8 9 0 9 999 -9999
reclass x 1 3ewx 3ewxr 2 0 0 5 2 5 6 0 6 8 2 8 9 0 9 999 -9999

reclass x 1 3nwsex 3nwsexr 2 0 0 5 4 5 6 0 6 8 4 8 9 0 9 999 -9999
reclass x 1 3neswx 3neswxr 2 0 0 5 8 5 6 0 6 8 8 8 9 0 9 999 -9999

REM FIND EDGES FOR ORIGINALLY FLAT AREAS
surface x 2 0flat 0flata # d 1
reclass x 1 0flata 0flatar 2 1 -999 0 0 0 361 -9999
surface x 2 1flat 1flata # d 1
reclass x 1 1flata 1flatar 2 1 -999 0 0 0 361 -9999
surface x 2 2flat 2flata # d 1
reclass x 1 2flata 2flatar 2 1 -999 0 0 0 361 -9999

```

```

surface x 2 3flat 3flata = d 1
reclass x 1 3flata 3flatar 2 1 -999 0 0 0 361 -9999

REM SUM LAYERS 15 = PEAK AND REMOVE FLAT AREA EDGES
overlay x 1 0nsxr 0ewxr temp1
overlay x 1 temp1 0nwsexr temp2
overlay x 1 temp2 0neswxr temp1
overlay x 3 temp1 0flatar 0nhighs

overlay x 1 1nsxr 1ewxr temp1
overlay x 1 temp1 1nwsexr temp2
overlay x 1 temp2 1neswxr temp1
overlay x 3 temp1 1flatar 1nhighs

overlay x 1 2nsxr 2ewxr temp1
overlay x 1 temp1 2nwsexr temp2
overlay x 1 temp2 2neswxr temp1
overlay x 3 temp1 2flatar 2nhighs

overlay x 1 3nsxr 3ewxr temp1
overlay x 1 temp1 3nwsexr temp2
overlay x 1 temp2 3neswxr temp1
overlay x 3 temp1 3flatar 3nhighs

REM DISPLAY RESULTS OVER IMAGE
color x n 0nhighs idr1: y 30 0
reclass x 1 0nhighs 0highsr 2 0 0 15 255 15 16 -9999
overlay x 7 0highsr imgw 0finalh
color x n 0finalh grey256 y 30 0

color x n 1nhighs idr1: y 30 0
reclass x 1 1nhighs 1highsr 2 0 0 15 255 15 16 -9999
overlay x 7 1highsr imgw 1finalh
color x n 1finalh grey256 y 30 0

color x n 2nhighs idr1: y 30 0
reclass x 1 2nhighs 2highsr 2 0 0 15 255 15 16 -9999
overlay x 7 2highsr imgw 2finalh
color x n 2finalh grey256 y 30 0

color x n 3nhighs idr1: y 30 0
reclass x 1 3nhighs 3highsr 2 0 0 15 255 15 16 -9999
overlay x 7 3highsr imgw 3finalh
color x n 3finalh grey256 y 30 0

rem WILL ONLY TAKE FIRST FILTER, ORIGINAL, AND FLAT
overlay x 7 0highsr 1highsr temp
rem overlay x 7 temp 2highsr temp2
rem overlay x 7 temp2 3highsr temp
overlay x 7 temp flatr highall

overlay x 7 highall imgw temp
color x n temp grey256 y 30 0

REM SIMILARLY FIND LOW AREAS CROSSTAB 6,9
reclass x 1 0nsx 0nsxrs 2 0 0 6 1 6 7 0 7 9 1 9 999 -9999
reclass x 1 0ewx 0ewxrs 2 0 0 6 2 6 7 0 7 9 2 9 999 -9999
reclass x 1 0neswx 0neswxrs 2 0 0 6 4 6 7 0 7 9 4 9 999 -9999
reclass x 1 0nwsew 0nwsewrs 2 0 0 6 8 6 7 0 7 9 8 9 999 -9999

reclass x 1 1nsx 1nsxrs 2 0 0 6 1 6 7 0 7 9 1 9 999 -9999
reclass x 1 1ewx 1ewxrs 2 0 0 6 2 6 7 0 7 9 2 9 999 -9999
reclass x 1 1neswx 1neswxrs 2 0 0 6 4 6 7 0 7 9 4 9 999 -9999
reclass x 1 1nwsew 1nwsewrs 2 0 0 6 8 6 7 0 7 9 8 9 999 -9999

reclass x 1 2nsx 2nsxrs 2 0 0 6 1 6 7 0 7 9 1 9 999 -9999
reclass x 1 2ewx 2ewxrs 2 0 0 6 2 6 7 0 7 9 2 9 999 -9999
reclass x 1 2neswx 2neswxrs 2 0 0 6 4 6 7 0 7 9 4 9 999 -9999
reclass x 1 2nwsew 2nwsewrs 2 0 0 6 8 6 7 0 7 9 8 9 999 -9999

reclass x 1 3nsx 3nsxrs 2 0 0 6 1 6 7 0 7 9 1 9 999 -9999
reclass x 1 3ewx 3ewxrs 2 0 0 6 2 6 7 0 7 9 2 9 999 -9999
reclass x 1 3neswx 3neswxrs 2 0 0 6 4 6 7 0 7 9 4 9 999 -9999
reclass x 1 3nwsew 3nwsewrs 2 0 0 6 8 6 7 0 7 9 8 9 999 -9999

REM DERIVE LOW CENTRES
overlay x 1 0nsxrs 0ewxrs temp1

```

```

overlay x 1 temp1 1nwsexrs temp2
overlay x 1 temp1 1neswxrs temp1
overlay x 3 temp1 1flatat 1lows

```

```

overlay x 1 1nsxrs 1ewxrs temp1
overlay x 1 temp1 1nwsexrs temp2
overlay x 1 temp2 1neswxrs temp1
overlay x 3 temp1 1flatat 1lows

```

```

overlay x 1 2nsxrs 2ewxrs temp1
overlay x 1 temp1 1nwsexrs temp2
overlay x 1 temp2 2neswxrs temp1
overlay x 3 temp1 2flatat 2lows

```

```

overlay x 1 3nsxrs 3ewxrs temp1
overlay x 1 temp1 3nwsexrs temp2
overlay x 1 temp2 3neswxrs temp1
overlay x 3 temp1 3flatat 3lows

```

REM FIND GULLEYS

```

reclass x 1 3lows 3gulley 1 255 1 999 -9999
filter x 3gulley 3gulleyf 3
cost x 3gulley 1mgw gulcost

```

```

color x n 0lows 1drisi y 30 0
reclass x 1 0lows 0lowsr 2 0 0 15 255 15 16 -9999
overlay x 7 0lowsr 1mgw 0finall
color x n 0finall grey256 y 30 0

```

```

color x n 1lows 1drisi y 30 0
reclass x 1 1lows 1lowsr 2 0 0 15 255 15 16 -9999
overlay x 7 1lowsr 1mgw 1finall
color x n 1finall grey256 y 30 0

```

```

color x n 2lows 1drisi y 30 0
reclass x 1 2lows 2lowsr 2 0 0 15 255 15 16 -9999
overlay x 7 2lowsr 1mgw 2finall
color x n 2finall grey256 y 30 0

```

```

color x n 3lows 1drisi y 30 0
reclass x 1 3lows 3lowsr 2 0 0 15 255 15 16 -9999
overlay x 7 3lowsr 1mgw 3finall
color x n 3finall grey256 y 30 0

```

```

overlay x 7 0lowsr 1lowsr temp
overlay x 7 temp 2lowsr temp2
overlay x 7 temp2 3lowsr temp
overlay x 7 temp flatv lowall

```

```

overlay x 7 lowall 1mgw temp
color x n temp grey256 y 30 0

```

REM ++++++

REM TREE TOP EXPANSION

REM INVERT IMAGE TO FORM FRICTION SURFACE

```

scalar x 1mgw inv 2 255
scalar x inv invw 3 -1
reclass x 1 1mgw border 2 255 0 1 -9999
overlay x 7 border lowall temp
copy c:\treedel\work\temp.* c:\treedel\work\lowall.*
scalar x lowall lowz 3 4
overlay x 1 lowz invw friction

```

REM GROUP THE HIGHS SINGLE TREE AND DO a COST SURFACE

```

group x highall y peakgr
cost x peakgr friction cost1
allocate x cost1 peakgr alloca
REM LOWS VALUE REDUCED SO NOT A POLYGON MAX VALUE
scalar x lowall low0 3 0
overlay x 7 low0 cost1 cost10
extract x alloca cost10 1 2 maxcst
REM FIND MAX COST/POLYGON RECLASS THEN OVERLAY ORIGINAL SURFACE
assign x alloca maxcst maxcst 2
overlay x 4 cost1 maxcst cost10
scalar x cost10 costper 3 100
REM REMOVE SMALL ADJOINING POLYGONS AT 10 percent
reclass x 1 costper 10costrt 2 0 10 999 1 0 10 -9999

```

```

overlay x 3 10costst alloca 10alloc
group x 10alloc y peakgr
cost x peakgr friction cost1
allocate x cost1 peakgr alloca
REM LOWS VALUE REDUCED SO NOT A POLYGON MAX VALUE
overlay x 7 low0 cost1 cost10
extract x alloca cost10 1 2 maxcost
REM FIND MAX COST/POLYGON RECLASS THEN OVERLAY ORIGINAL SURFACE
assign x alloca maxcost maxcost 2
overlay x 4 cost1 maxcost costst
scalar x costst costper 3 100

REM -----
copy c:\treedel\programs\pol-pt.exe c:\treedel\work\*.

REM FILTER PT FILE for 1st file
polyvec x peakgr peakgr y 0 n
cd \treedel\work
pol-pt peakgr.vec peakg.pt
pol-pt peakgr.vec peakg.vec 1
copy peakgr.dvc peakg.dvc
cd \idrisi
initial x pk 1 1 0 1 costper dn
pointtras x peakg pk 1

copy c:\treedel\work\peakg.vec c:\treedel\work\%0pk.vec

REM -----

rem Find Shadow Centres
reclass x 1 costper shad 2 0 0 95 1 90 999 -9999
group x shad y shadgr
rem copy c:\treedel\work\shadgr.* c:\treedel\work\%0shadgr.*

REM FILTER PT FILE for 2nd file
polyvec x shadgr shadgr y 0 n
cd \treedel\work
pol-pt shadgr.vec shadg.pt
pol-pt shadgr.vec shadg.vec 1
copy shadgr.dvc shadg.dvc
cd \idrisi
initial x spk 1 1 0 1 costper dn
pointtras x shadg spk 1

REM allocate for shadows
cost x spk imgw scst
allocate x scst spk salc

rem -----
copy c:\treedel\work\alloca.* c:\treedel\work\%0alc.*
copy c:\treedel\work\costper.* c:\treedel\work\%0cst.*
copy c:\treedel\work\pk.* c:\treedel\work\%0pk.*
copy c:\treedel\work\3f.* c:\treedel\work\%0filt.*

copy c:\treedel\work\peakg.vec c:\treedel\work\%0pk.vec
copy c:\treedel\work\shadg.vec c:\treedel\work\%0spk.vec
copy c:\treedel\work\peakg.pt c:\treedel\work\%0pk.pt
copy c:\treedel\work\shadg.pt c:\treedel\work\%0spk.pt

copy c:\treedel\work\0highsr.* c:\treedel\work\%0highf0.*
copy c:\treedel\work\1highsr.* c:\treedel\work\%0highf1.*
copy c:\treedel\work\2highsr.* c:\treedel\work\%0highf2.*
copy c:\treedel\work\3highsr.* c:\treedel\work\%0highf3.*

copy c:\treedel\work\0lowsr.* c:\treedel\work\%0lowf0.*
copy c:\treedel\work\1lowsr.* c:\treedel\work\%0lowf1.*
copy c:\treedel\work\2lowsr.* c:\treedel\work\%0lowf2.*
copy c:\treedel\work\3lowsr.* c:\treedel\work\%0lowf3.*

rem copy c:\treedel\work\lowall.* c:\treedel\work\%0low.*
rem copy c:\treedel\work\imgw.* c:\treedel\work\%0w.*
rem copy c:\treedel\work\3gully.* c:\treedel\work\%0gul.*
rem copy c:\treedel\work\gulcost.* c:\treedel\work\%0gulcst.*

copy c:\treedel\work\spk.* c:\treedel\work\%0spk.*
copy c:\treedel\work\salc.* c:\treedel\work\%0salc.*
copy c:\treedel\work\scst.* c:\treedel\work\%0scst.*

```

```
goto getfile
```

```
rem
```

```
:end
```

```
environ x 2 \treedel\work
```

```
rem usage:find [image1] [image2]...
```

```
rem image = over
```

```
rem =====
```

```

rem AGGREG [imagesector][time]
REM at present we only aggregate col five and six

cd \adrist
env:ron x 2 \treedel\work

del c:\treedel\work\*.img
del c:\treedel\work\*.doc
del c:\treedel\work\*.val
del c:\treedel\work\*.vec
del c:\treedel\work\*.dvc

copy c:\treedel\window\1\1-2.img c:\treedel\work\A.img
copy c:\treedel\window\1\1-2.doc c:\treedel\work\A.doc

initial x int 1 1 0 1 A dn

rem copy c:\treedel\work\int.* c:\treedel\work\outs.*
rem copy c:\treedel\work\int.* c:\treedel\work\outs.*
copy c:\treedel\work\int.* c:\treedel\work\ins.*

initial x inst 2 1 0 1 A dn
rem copy c:\treedel\work\inst.* c:\treedel\work\outcst.*
cd \treedel\batch
call insert -1 5 -2 800 0
cd \treedel\batch
call insert -1 12 -2 800 200
cd \treedel\batch
call insert -1 19 -2 900 400
cd \treedel\batch
call insert -1 26 -2 800 600
cd \treedel\batch
call insert -1 33 -2 600 800
cd \treedel\batch
call insert -1 6 -2 1000 0
cd \treedel\batch
call insert -1 13 -2 1000 200
cd \treedel\batch
call insert -1 20 -2 1000 400
cd \treedel\batch
call insert -1 27 -2 1000 600
cd \treedel\batch
call insert -1 34 -2 1000 800

copy c:\treedel\work\outs.* c:\treedel\aggreg\iZpkt-2.*
copy c:\treedel\work\outs.* c:\treedel\aggreg\iZpkt-2.*
copy c:\treedel\work\outcst.* c:\treedel\aggreg\iZcst-2.*

REM remember to save image into another directory !

```

```
REM INSERT [imagesector][subwindow][time][xcoord ul][ycoord ul]
REM places subwindow image into image
cd \idris1

copy c:\treedel\window\1\w_2\1-1-3pk.img c:\treedel\work\Apk.img
copy c:\treedel\window\1\w_2\1-1-3pk.doc c:\treedel\work\Apk.doc
copy c:\treedel\window\1\w_2\1-1-3spk.img c:\treedel\work\Aspk.img
copy c:\treedel\window\1\w_2\1-1-3spk.doc c:\treedel\work\Aspk.doc
copy c:\treedel\window\1\w_2\1-1-3cst.img c:\treedel\work\Acst.img
copy c:\treedel\window\1\w_2\1-1-3cst.doc c:\treedel\work\Acst.doc

concat x int 1 outt 2 Apk 1 :4 :5
concat x ins 1 outs 2 Aspk 1 :4 :5
concat x incst 1 outcst 1 Acst 1 :4 :5

copy c:\treedel\work\outt.* c:\treedel\work\int.*
copy c:\treedel\work\outs.* c:\treedel\work\ins.*
copy c:\treedel\work\outcst.* c:\treedel\work\incst.*
cd \treedel\batch
```



```

rem AGGREGATES ALLOCATION POLYGONS ACCORDING TO AGGREGATE IN 10 CLASSES
rem alcaggr {imagesector}{time}
cd \ldris1
enviro n x 2 \treedel\aggreg
window x 1 2dnrs 1 2dnrs 1 800 0 1200 1035
pause
copy c:\treedel\aggreg\1-2dnrs.* c:\treedel\work\apt.*
cd \ldris1
enviro n x 2 \treedel\work
initial x inalc 1 1 0 1 apt dn
initial x outalc 1 1 0 1 apt dn
call c:\treedel\batch\alcaggrw -1 0 0 200 200 5 -1
call c:\treedel\batch\alcaggrw -1 0 200 200 400 6 -2
call c:\treedel\batch\alcaggrw -1 200 0 400 200 12 -1
call c:\treedel\batch\alcaggrw -1 200 200 400 400 13 -2
call c:\treedel\batch\alcaggrw -1 400 0 600 200 19 -2
call c:\treedel\batch\alcaggrw -1 400 200 600 400 20 -2
call c:\treedel\batch\alcaggrw -1 600 0 800 200 26 -2
call c:\treedel\batch\alcaggrw -1 600 200 800 400 27 -2
call c:\treedel\batch\alcaggrw -1 800 0 1000 200 33 -2
call c:\treedel\batch\alcaggrw -1 800 200 1000 400 34 -2
copy c:\treedel\aggreg\1-2cst.* c:\treedel\work\acst.*
window x Acst Acstw 1 800 0 1200 1035
reclass x 1 acstw acstw60 2 1 0 60 0 60 999 -9999
overlay x 3 acstw60 inalc -1-2trcl
copy c:\treedel\work\1-2trcl.* c:\treedel\aggreg\1-2trcl.*

```

```
REM A subroutine run from ALCAGGR.BAT
REM ALCAGGRW (IMAGESECTOR) (ULROW) (ULCOL) (LLROW) (LLCOL) (WINDOW) (TIME)
copy c:\treedel\window\-1\w-6\i1.7alc.* c:\treedel\work\alc.*
window x apt aptw 1 -3 -2 -5 -4

extract x alc aptw 1 2 apkcl

assign x alc apkcl apkcl 1

concat x inalc 1 outalc 2 apkcl 1 -3 -2

copy c:\treedel\work\outalc.* c:\treedel\work\inalc.*
```

```
REM COMPEXE.BAT
```

```
REM COMP 1 2 3 4
REM 1 imagesector [1-9]
REM 2 200 x 200 subwindow 1-35
REM 3 time 1
REM 4 time 2
```

```
if "%1" == "" goto end
if "%2" == "" goto end
if "%3" == "" goto end
if "%4" == "" goto end
```

```
cd \dris1
enviro n x 2 \treedel\work
```

```
del c:\treedel\work\*.doc
del c:\treedel\work\*.img
```

```
copy c:\treedel\window\1\w-2\1-3filc.* c:\treedel\work\Aimg.*
copy c:\treedel\window\1\w-2\1-3cst.* c:\treedel\work\Acst.*
copy c:\treedel\window\1\w-2\1-3alc.* c:\treedel\work\Aalc.*
copy c:\treedel\window\1\w-2\1-3pk.* c:\treedel\work\Apk.*
copy c:\treedel\window\1\w-2\1-3scst.* c:\treedel\work\Ascst.*
copy c:\treedel\window\1\w-2\1-3salc.* c:\treedel\work\Asalc.*
copy c:\treedel\window\1\w-2\1-3spk.* c:\treedel\work\Aspk.*
```

```
copy c:\treedel\window\1\w-2\1-4cst.* c:\treedel\work\Bcst.*
copy c:\treedel\window\1\w-2\1-4alc.* c:\treedel\work\Balc.*
copy c:\treedel\window\1\w-2\1-4pk.* c:\treedel\work\Bpk.*
copy c:\treedel\window\1\w-2\1-4scst.* c:\treedel\work\Bscst.*
copy c:\treedel\window\1\w-2\1-4salc.* c:\treedel\work\Bsalc.*
copy c:\treedel\window\1\w-2\1-4spk.* c:\treedel\work\Bspk.*
```

```
REM CHANGE PT SET TO 1 FOR COUNTING
reclass x 1 Apk Apkx 2 1 1 31000 -9999
reclass x 1 Bpk Bpkx 2 1 1 31000 -9999
reclass x 1 Aspk Aspkx 2 1 1 31000 -9999
reclass x 1 Bspk Bspkx 2 1 1 31000 -9999
```

```
REM COUNT FOR MULTIPLES
cd c:\treedel\batch
call comp %1 %2 90 %3 %4
cd c:\treedel\batch
call comp %1 %2 75 %3 %4
cd c:\treedel\batch
call comp %1 %2 60 %3 %4
cd c:\treedel\batch
call comp %1 %2 45 %3 %4
cd c:\treedel\batch
call comp %1 %2 30 %3 %4
cd c:\treedel\batch
call comp %1 %2 15 %3 %4
```

```
REM FIND CST AT WHICH THE FIRST ONE:ONE RELATIONSHIP OCCURS
extract x Apk Bcst 1 1 A-BTcst
extract x Apk Bscst 1 1 A-BSbst
extract x Aspk Bcst 1 1 AS-Bcst
extract x Aspk Bscst 1 1 ASBSbst
```

```
REM CLASSES
REM TREE : TREE or MANY CLASSED BY #
REM TREE : SHADOW or MANY
REM SHADOW : SHADOW or MANY
REM SHADOW : TREE or MANY
```

```
copy c:\treedel\work\A-BTcst.val c:\treedel\window\1\w-2\1-3%1-4MTT.val
copy c:\treedel\work\A-BTcst.val c:\treedel\window\1\w-2\1-3%1-4MTS.val
copy c:\treedel\work\A-BTcst.val c:\treedel\window\1\w-2\1-3%1-4MST.val
copy c:\treedel\work\A-BTcst.val c:\treedel\window\1\w-2\1-3%1-4MSS.val
```

```
:end
```

```
REM COMPEXE.BAT
```

```
REM COMP %1 %2 %3 %4
REM 1 imagesector [1-9]
REM 2 200 x 200 subwindow 1-35
```

```
REM      3      time 1
REM      4      time 2

REM FILES PRODUCED
REM MIN EXTRACTION
REM c:\treedel\window\1\w-2\1-3-1-4MTT.val
REM c:\treedel\window\1\w-2\1-3-1-4MTS.val
REM c:\treedel\window\1\w-2\1-3-1-4MST.val
REM c:\treedel\window\1\w-2\1-3-1-4MSS.val
REM
REM THRESHOLD 90 75 60 45 30 10
REM c:\treedel\window\1\w-2\1-4-1x-3ST.val
REM c:\treedel\window\1\w-2\1-4-1x-3TS.val
REM c:\treedel\window\1\w-2\1-4-1x-3SS.val
REM c:\treedel\window\1\w-2\1-4-1x-3TT.val
```

```

REM COMP 1 2 3 4 5
REM 1 imagesector [1-9]
REM 2 100 x 200 subwindow 1-35
REM 3 threshold
REM 4 time 1
REM 5 time 2

if "%1" == "" goto end
if "%2" == "" goto end
if "%3" == "" goto end
if "%4" == "" goto end
if "%5" == "" goto end

cd \adriat
environ x 2 \treedel\work

REM FIND TREES AND SHADOW CORRESPONDING TO THRESHOLD
reclass x 1 Acst Acstx 2 1 0 13 0 -3 999 -9999
reclass x 1 Bcst Bcstx 2 1 0 13 0 -3 999 -9999

reclass x 1 Acstv Acstv 2 0 1 999 1 0 1 -9999
reclass x 1 Bcstv Bcstv 2 0 1 999 1 0 1 -9999

REM REMOVE SHADOWS OR TREES FROM TREE & SHAD ALLOCATION
overlay x 3 Acstx Aalc Aalcx
overlay x 3 Acstv Asalc Asalcx
overlay x 3 Bcstx Balc Balcx
overlay x 3 Bcstv Bsalc Bsalcx

REM COUNT T to MANY TREES
extract x Aalcx Bpkx 1 3 +3TT

REM COUNT T to MANY SHADOWS
extract x Aalcx Bspkx 1 3 +3TS

REM COUNT S to MANY TREES
extract x Asalcx Bpk 1 3 +3ST

REM COUNT S to MANY SHADOWS
extract x Asalcx Bspk 1 3 +3SS

REM EXTRACT THRESHOLD AREA, AVG DN, STD DN, MIN DN, MAX DN FOR EACH
area x Aalcx 2 1 +1+4ar+3

rem extract x Aalcx +1+4ar+3 1 4 +1+4ar+3
extract x Aalcx Aimg 1 4 +1+4avg+3

extract x Aalcx Aimg 1 7 +1+4std+3

extract x Aalcx Aimg 1 2 +1+4max+3

extract x Aalcx Aimg 1 1 +1+4min+3

area x Asalcx 2 1 +1+4Sar+3

rem extract x Asalcx +1+4Sar+3 1 1 +1+4Sar+3
extract x Asalcx Aimg 1 4 +1+4Savg+3
extract x Asalcx Aimg 1 7 +1+4Sstd+3
extract x Asalcx Aimg 1 2 +1+4Smax+3
extract x Asalcx Aimg 1 1 +1+4Smin+3

REM EXTRACT AREA OF UNDERLYING TREES AND SHADOW COMPARE TO EXTRACTED ASSOCIATED
REM POINTS

extract x Aalcx Bcstx 1 3 Btree
extract x Aalcx Bcstv 1 3 Bshad
extract x Asalcx Bcstx 1 3 BStree
extract x Asalcx Bcstv 1 3 BSshad
copy c:\treedel\work\Btree.val c:\treedel\window\%1\w+2\+1+4+5BSt+3.val
copy c:\treedel\work\Bshad.val c:\treedel\window\%1\w+2\+1+4+5BSt+3.val
copy c:\treedel\work\BStree.val c:\treedel\window\%1\w+2\+1+4+5BSt+3.val
copy c:\treedel\work\BSshad.val c:\treedel\window\%1\w+2\+1+4+5BSt+3.val

REM ASSIGN BAREA TO BPTS AND EXTRACT SUMB USING ALLOCATED A
area x Balcx 2 1 BTarea
area x Bsalcx 2 1 BSarea
overlay x 3 Bpkx BTarea Bpkarea

```

```

overlay x 3 Bpkx BSpkarea Bspkarea
extract x Aalcx Bpkarea 1 3 Bxttar
extract x Aalcx Bspkarea 1 3 Bxtsar

```

```

extract x Asalcx Bspkarea 1 3 Bxssarea
extract x Asalcx Bpkarea 1 3 Bxstarea

```

```

copy c:\treedel\work\BxtTar.val c:\treedel\window\1\w2\1-4-BXTT-3.val
copy c:\treedel\work\BxtSar.val c:\treedel\window\1\w2\1-4-BXTS-3.val
copy c:\treedel\work\BxSSar.val c:\treedel\window\1\w2\1-4-BXSS-3.val
copy c:\treedel\work\BxSTar.val c:\treedel\window\1\w2\1-4-BXST-3.val

```

```

copy c:\treedel\work\1-4ar-3.val c:\treedel\window\1\w2\1-4-5ar-3.val
copy c:\treedel\work\1-4avg-3.val c:\treedel\window\1\w2\1-4-5av-3.val
copy c:\treedel\work\1-4std-3.val c:\treedel\window\1\w2\1-4-5sd-3.val
copy c:\treedel\work\1-4max-3.val c:\treedel\window\1\w2\1-4-5mx-3.val
copy c:\treedel\work\1-4min-3.val c:\treedel\window\1\w2\1-4-5mn-3.val

```

```

copy c:\treedel\work\1-4sar-3.val c:\treedel\window\1\w2\1-4-5sar-3.val
copy c:\treedel\work\1-4savg-3.val c:\treedel\window\1\w2\1-4-5sav-3.val
copy c:\treedel\work\1-4sstd-3.val c:\treedel\window\1\w2\1-4-5ssd-3.val
copy c:\treedel\work\1-4smax-3.val c:\treedel\window\1\w2\1-4-5smx-3.val
copy c:\treedel\work\1-4smin-3.val c:\treedel\window\1\w2\1-4-5smn-3.val

```

```

copy c:\treedel\work\1-5ST.val c:\treedel\window\1\w2\1-4-1-5-3ST.val
copy c:\treedel\work\1-5TS.val c:\treedel\window\1\w2\1-4-1-5-3TS.val
copy c:\treedel\work\1-5SS.val c:\treedel\window\1\w2\1-4-1-5-3SS.val
copy c:\treedel\work\1-5TT.val c:\treedel\window\1\w2\1-4-1-5-3TT.val

```

```

REM MAKE A DISPLAY IMAGE

```

```

polyvec x Aalcx Aalcx y 0 n
polyvec x Asalcx Asalcx y 0 n

```

```

initial x coverA 1 1 0 1 Aalcx dn
initial x coverAs 1 1 0 1 Asalcx dn

```

```

lineras x Aalcx coverA
lineras x Asalcx coverAs

```

```

overlay x 7 coverA Apkx coverA2
overlay x 7 coverAs AspKx coverA2s

```

```

reclass x 1 coverA2 coverT 2 155 1 31000 -9999
reclass x 1 coverA2s coverS 2 0 1 31000 -9999

```

```

overlay x 7 coverT coverS out1
overlay x 7 out1 Aimg Adispl

```

```

copy c:\treedel\work\Adispl.* c:\treedel\window\1\w2\1-4-1-5po-3.*

```

```

:end

```

```

REM COMP %1 %2 %3 %4 %5
REM %1 imagesector 1-91
REM %2 200 x 200 subwindow 1-35
REM %3 threshold
REM %4 time 1
REM %5 time 2

```

```

cd \adris1
environ x 2 \treedel\temp

REM DERIVE SHADOW
reclass x 1 -1gulcst -1gul 2 1 0 1 0 1 99999 -9999
reclass x 1 -2gulcst -2gul 2 1 0 1 0 1 99999 -9999

overlay x 7 -2gul -2alc -2alcs

extract x -1pk -2alcs 1 2 -2maxid
extract x -1pk -2cst 1 2 -2maxcst
assign x -1alc -1out -2maxid 1
assign x -1alc -1cstal -2maxcst 1
color x a -2cstal adris1 y 30 0

rem overlay x 7 -1gul -1out -1outs

rem color x a -1outs adris1 y 30 0
rem color x a -2alcs adris1 y 30 0
REM SUBTRACT ALLOCATED AND NON
overlay x 2 -1out -2alc temp
REM 1= assigned 0 = unassigned FOR DISPLAY
reclass x 1 temp result 2 0 -999 0 1 0 1 0 1 9999 -9999
color x n result adris1 y 30 0
goto end

REM correlation between two polygon images
cd \adris1
reclass x 1 temp result 2 1 -999 0 0 0 1 1 1 999 -9999
overlay x 3 result -1cst -1nonal
overlay x 3 result -2cst -2nonal
reclass x 1 -1nonal -1nonalx 2 999 0 1 -9999
reclass x 1 -2nonal -1nonalx 2 999 0 1 -9999
extract x -1out -1nonalx 1 1 -1thresh
extract x -2alc -2nonalx 1 1 -2thresh
type c:\treedel\temp\1thresh.val !more
type c:\treedel\temp\2thresh.val !more
: end

```



```

density 12pkt 2c6.vec 1n 2c6d05.vec 5
density 12pkt 2c6.vec 1n 2c6d10.vec 10
density 12pkt 2c6.vec 1n 2c6d15.vec 15
density 12pkt 2c6.vec 1n 2c6d20.vec 20
density 12pkt 2c6.vec 1n 2c6d25.vec 25
density 12pkt 2c6.vec 1n 2c6d30.vec 30

```

```

density 12pkt 2c7.vec 1n 2c7d05.vec 5
density 12pkt 2c7.vec 1n 2c7d10.vec 10
density 12pkt 2c7.vec 1n 2c7d15.vec 15
density 12pkt 2c7.vec 1n 2c7d20.vec 20
density 12pkt 2c7.vec 1n 2c7d25.vec 25
density 12pkt 2c7.vec 1n 2c7d30.vec 30

```

```

density 12pkt 2c8.vec 1n 2c8d05.vec 5
density 12pkt 2c8.vec 1n 2c8d10.vec 10
density 12pkt 2c8.vec 1n 2c8d15.vec 15
density 12pkt 2c8.vec 1n 2c8d20.vec 20
density 12pkt 2c8.vec 1n 2c8d25.vec 25
density 12pkt 2c8.vec 1n 2c8d30.vec 30

```

```

density 12pkt 2c9.vec 1n 2c9d05.vec 5
density 12pkt 2c9.vec 1n 2c9d10.vec 10
density 12pkt 2c9.vec 1n 2c9d15.vec 15
density 12pkt 2c9.vec 1n 2c9d20.vec 20
density 12pkt 2c9.vec 1n 2c9d25.vec 25
density 12pkt 2c9.vec 1n 2c9d30.vec 30

```

```
copy e:\.* c:\treedel\agggreg\.*
```

```

c:
cd \adrist
for %f in ( 05 10 15 20 25 30 ) do copy c:\treedel\agggreg\12pkt-2c9.dvc
c:\treedel\agggreg\1n-2c1d-*.f.dvc
for %f in ( 05 10 15 20 25 30 ) do copy c:\treedel\agggreg\12pkt-2c9.dvc
c:\treedel\agggreg\1n-2c2d-*.f.dvc
for %f in ( 05 10 15 20 25 30 ) do copy c:\treedel\agggreg\12pkt-2c9.dvc
c:\treedel\agggreg\1n-2c3d-*.f.dvc
for %f in ( 05 10 15 20 25 30 ) do copy c:\treedel\agggreg\12pkt-2c9.dvc
c:\treedel\agggreg\1n-2c4d-*.f.dvc
for %f in ( 05 10 15 20 25 30 ) do copy c:\treedel\agggreg\12pkt-2c9.dvc
c:\treedel\agggreg\1n-2c5d-*.f.dvc
for %f in ( 05 10 15 20 25 30 ) do copy c:\treedel\agggreg\12pkt-2c9.dvc
c:\treedel\agggreg\1n-2c6d-*.f.dvc
for %f in ( 05 10 15 20 25 30 ) do copy c:\treedel\agggreg\12pkt-2c9.dvc
c:\treedel\agggreg\1n-2c7d-*.f.dvc
for %f in ( 05 10 15 20 25 30 ) do copy c:\treedel\agggreg\12pkt-2c9.dvc
c:\treedel\agggreg\1n-2c8d-*.f.dvc
for %f in ( 05 10 15 20 25 30 ) do copy c:\treedel\agggreg\12pkt-2c9.dvc
c:\treedel\agggreg\1n-2c9d-*.f.dvc

```

```
rem
```

```

initial x out 1 1 -1 1 -1 2 dn
for %f in ( 05 10 15 20 25 30 ) do copy c:\treedel\agggreg\out.* c:\treedel\agggreg\1n-2c1d-*.f.*
for %f in ( 05 10 15 20 25 30 ) do copy c:\treedel\agggreg\out.* c:\treedel\agggreg\1n-2c2d-*.f.*
for %f in ( 05 10 15 20 25 30 ) do copy c:\treedel\agggreg\out.* c:\treedel\agggreg\1n-2c3d-*.f.*
for %f in ( 05 10 15 20 25 30 ) do copy c:\treedel\agggreg\out.* c:\treedel\agggreg\1n-2c4d-*.f.*
for %f in ( 05 10 15 20 25 30 ) do copy c:\treedel\agggreg\out.* c:\treedel\agggreg\1n-2c5d-*.f.*
for %f in ( 05 10 15 20 25 30 ) do copy c:\treedel\agggreg\out.* c:\treedel\agggreg\1n-2c6d-*.f.*
for %f in ( 05 10 15 20 25 30 ) do copy c:\treedel\agggreg\out.* c:\treedel\agggreg\1n-2c7d-*.f.*
for %f in ( 05 10 15 20 25 30 ) do copy c:\treedel\agggreg\out.* c:\treedel\agggreg\1n-2c8d-*.f.*
for %f in ( 05 10 15 20 25 30 ) do copy c:\treedel\agggreg\out.* c:\treedel\agggreg\1n-2c9d-*.f.*

for %f in ( 05 10 15 20 25 30 ) do pointtras x 1n-2c1d-*.f 1n-2c1d-*.f 1
for %f in ( 05 10 15 20 25 30 ) do pointtras x 1n-2c2d-*.f 1n-2c2d-*.f 1
for %f in ( 05 10 15 20 25 30 ) do pointtras x 1n-2c3d-*.f 1n-2c3d-*.f 1
for %f in ( 05 10 15 20 25 30 ) do pointtras x 1n-2c4d-*.f 1n-2c4d-*.f 1
for %f in ( 05 10 15 20 25 30 ) do pointtras x 1n-2c5d-*.f 1n-2c5d-*.f 1
for %f in ( 05 10 15 20 25 30 ) do pointtras x 1n-2c6d-*.f 1n-2c6d-*.f 1
for %f in ( 05 10 15 20 25 30 ) do pointtras x 1n-2c7d-*.f 1n-2c7d-*.f 1
for %f in ( 05 10 15 20 25 30 ) do pointtras x 1n-2c8d-*.f 1n-2c8d-*.f 1
for %f in ( 05 10 15 20 25 30 ) do pointtras x 1n-2c9d-*.f 1n-2c9d-*.f 1

```

```
goto end
```

```
initial x 1n-2c1d05
```

```
initial x 1n-2c1d10
```

```
initial x 1n-2c1d15
```

```
initial x ln-2c1d05
initial x ln-2c1d10
initial x ln-2c1d15
```

```
initial x ln-2c2d05
initial x ln-2c2d10
initial x ln-2c2d15
initial x ln-2c2d20
initial x ln-2c2d25
initial x ln-2c2d30
```

```
initial x ln-2c3d05
initial x ln-2c3d10
initial x ln-2c3d15
initial x ln-2c3d20
initial x ln-2c3d25
initial x ln-2c3d30
```

```
initial x ln-2c4d05
initial x ln-2c4d10
ln-2c4d15
ln-2c4d20
ln-2c4d25
ln-2c4d30
```

```
ln-2c5d05
ln-2c5d10
ln-2c5d15
ln-2c5d20
ln-2c5d25
ln-2c5d30
```

```
ln-2c6d05
ln-2c6d10
ln-2c6d15
ln-2c6d20
ln-2c6d25
ln-2c6d30
```

```
ln-2c7d05
ln-2c7d10
ln-2c7d15
ln-2c7d20
ln-2c7d25
ln-2c7d30
```

```
ln-2c8d05
ln-2c8d10
ln-2c8d15
ln-2c8d20
ln-2c8d25
ln-2c8d30
```

```
ln-2c9d05
ln-2c9d05
ln-2c9d10
ln-2c9d15
ln-2c9d20
ln-2c9d25
ln-2c9d30
cd \treedel\batch
```

```
:end
```

```

rem [3] time2
rem [4] DN 1 threshold 1949,61 = 1; 1979,91 = 2
rem [5] DN 2 threshold

Calculates polygons = survivors, deaths, newgrowth
pt within opposites 60 cst = survivability
rem Input
rem 6#trcl @ 60%cst exists dn class
rem maskx area of interest
rem 6#dnrzw 10classes pt file
rem 6zalc# allocated image

cd \idrisi
rem goto start

environ x 2 \treedel\aggreg
overlay x 3 maskx %1zalc%3 %1%3alcm
overlay x 3 maskx %1zalc%2 %1%2alcm
window x %1%3alcm %1%3alcmw 1 800 0 1200 1035
window x %1%2alcm %1%2alcmw 1 800 0 1200 1035

rem reclass dn pt file eliminating lower noise
rem binary for later mult to corr class
reclass x i %1%2dnrzw %1%2ptA 2 1 %4 999 0 0 %4 -9999
reclass x i %1%3dnrzw %1%3ptA 2 1 %5 999 0 0 %5 -9999

rem reclass dn polygon file removing lower noise class
reclass x i %1%2trcl %1%2trclr 2 0 0 %4 1 %4 999 -9999
reclass x i %1%3trcl %1%3trclr 2 0 0 %5 1 %5 999 -9999

rem tree area allocated polygons minus low dns and at 60%
overlay x 3 %1%2trclr %1%2alcmw %1%2alcgra
overlay x 3 %1%3trclr %1%3alcmw %1%3alcgra

rem relevant tree pts set to 1 while low dn = 0
overlay x 3 %1%2trclr %1%2ptA %1%2ptr
overlay x 3 %1%3trclr %1%3ptA %1%3ptr

rem Give centroid pts allocation group # of polygon
overlay x 3 %1%2ptr %1%2alcgra %1%2ptalc
overlay x 3 %1%3ptr %1%3alcgra %1%3ptalc

rem create binary area image of trees or not
rem for time periods
reclass x i %1%2alcgra %1%2Tarbin 2 1 1 31000 -9999
reclass x i %1%3alcgra %1%3Tarbin 2 1 1 31000 -9999

rem assign centroid to class of other time image
extract x %1%3ptalc %1%2Tarbin 1 2 %1%3delt
rem pause
extract x %1%2ptalc %1%3Tarbin 1 2 %1%2delt
rem pause

rem area changes
rem reclass values file so 0 ->1 dead tree, 1->3 survival
rem so 0 can remain shadow S:S
reclass x a %1%2delt %1%2deltar 2 1 -1 1 3 1 999 -9999

rem and for new growth 0 -> 2 newtree, 1->3 survival
reclass x a %1%3delt %1%3deltar 2 2 -1 1 3 1 999 -9999
rem MUST SET 0-poly to zero
rem pause
cd \treedel\aggreg

```

```

rem :start
cd \idrissi
rem give polygons centres one of the four trans classes
assign x %1%3alcgra %1%3-%2t %1%3deltar 1
assign x %1%2alcgra %1%2-%3t %1%2deltar 1
pause
overlay x 7 %1%2-%3t %1%3-%2t %1%2%1%3tran

```

```

/* fgets example */

#include <string.h>
#include <stdio.h>
#include <stdlib.h>
#define length 80

int main(int argc, char* argv[])
{
    FILE *fpin;
    FILE *fpout;
    char string[80];
    float xcoord, ycoord, sumx, sumy;
    int x, group, number, lastnumber, newnumber, lastgroup, avgx, avgy;
    int idrisi = 0;
    // char string2[80];

    if (argc < 3)
    {
        fprintf(stderr, "Usage: pol-pt [inputfile] [outputfile] [format s or p] \n");
        exit(1);
    }
    if (argc > 3)
    {
        printf("Run as polygon centroid filter, output in idrisi format");
        idrisi = 1;
    }
    else {printf("Run in table comma delimited format"); }

    /* open a file for update */
    fpin = fopen(argv[1], "r");
    fpout = fopen(argv[2], "w");

    fscanf(fpin, "%d %d", &group, &number);
    newnumber = number;
    sumx = 0;
    sumy = 0;
    while (group != 0)
    {
        fgets(string, length, fpin); //move over end of line

        for(x=1; x < number-1; x++)
        {
            fscanf(fpin, "%f %f", &xcoord, &ycoord);
            fgets(string, length, fpin);
            sumx = xcoord + sumx;
            sumy = ycoord + sumy;
        }
        avgx = (int)sumx/newnumber;
        avgy = (int)sumy/newnumber;

        lastnumber = number;
        lastgroup = group;
        fscanf(fpin, "%d %d", &group, &number);
        if (lastgroup != group)
        {
            if (idrisi == 0) {fprintf(fpout, "%5d, %5d, %5d \n", lastgroup, avgx, avgy);}
            else {fprintf(fpout, "%d 1 %td %d \n", lastgroup, avgx, avgy);}
            avgx = 0;
            avgy = 0;
            sumx = 0;
            sumy = 0;
            newnumber = number;
            lastnumber = 0;
        } //endif
        else {newnumber = number + lastnumber;}
    }

    fprintf(fpout, "0 0");
    fclose(fpout);
    fclose(fpin);
    return 0;
}

```

```

// random

#include <string.h>
#include <stdio.h>
#include <stdlib.h>
#include <math.h>
#include <conio.h>
#include <time.h>
#define length 90

int main(int argc, char* argv[])
{
    FILE *fp;
    int numA=1;
    float xcoord1, ycoord1;
    int x,col,y,row, percent, out;

    if (argc < 4)
    {
        printf("random [outfile][col][row][int percent 2class];\n");
        exit(1);
    }
    col = atoi(argv[2]);
    row = atoi(argv[3]);
    percent = atoi(argv[4]);
    fp = fopen(argv[1], "w");
    randomize();

    for(y=row-1; y >= 0; y--)
    {
        for(x=0; x < col; x++)
        {
            if (random(100) > percent)
            {
                out = 2; printf("x");
            }
            else { out = 1; printf("."); }

            xcoord1 = (float)x;
            ycoord1 = (float)y;
            fprintf(fp, "%i %i \n", out, numA);
            fprintf(fp, "%f %f \n", xcoord1, ycoord1);
            // printf("%i %i \n", out, numA);
            // printf("%f %f \n", xcoord1, ycoord1);
        }
        printf("\n");
    }
    //fprintf(fp, "0 0");
    fclose(fp);
    return(0);
}

```

```

// randomtr.c

#include <string.h>
#include <stdio.h>
#include <stdlib.h>
#include <math.h>
#include <conio.h>
#include <time.h>
#define length 80

int main(int argc, char* argv[])
{
    FILE *fpin;
    FILE *fpout;
    float xcoord1, ycoord1, xout, yout;
    char string[80];
    int groupA, numA;

    if (argc < 3)
    {
        printf("randomtr [infile] [outfile]");
        exit(1);
    }

    fpin = fopen(argv[1], "r");
    fpout = fopen(argv[2], "w");
    randomize();

    do{
        if(fscanf(fpin, "%i %i", &groupA, &numA) != EOF){
            if ((groupA != 0) && (numA != 0))
            {
                fgets(string, length, fpin); //move over end of line
                fscanf(fpin, "%f %f", &xcoord1, &ycoord1);
                fgets(string, length, fpin);

                if(groupA == 2){
                    printf(".");

                    xout = (float)random(5) - (xcoord1 * 5.0);
                    yout = (float)random(5) - (ycoord1 * 5.0);
                    // printf(" %i %i \n", groupA, numA);
                    // printf(" %f %f \n", xout, yout);
                    fprintf(fpout, "%i %i \n", groupA, numA);
                    fprintf(fpout, "%f %f \n", xout, yout);
                }
                else if(groupA == 1){
                    printf(".*");
                    if(random(6) == 1){
                        xout = (float)random(5) + (xcoord1 * 5.0);
                        yout = (float)random(5) + (ycoord1 * 5.0);
                        // printf(" %i %i \n", groupA, numA);
                        // printf(" %f %f \n", xout, yout);
                        fprintf(fpout, "%i %i \n", groupA, numA);
                        fprintf(fpout, "%f %f \n", xout, yout);
                    }
                }
                // else { printf("?"); }

                // printf(" %f %f \n", groupA, numA);
                // printf(" %f %f \n", xout, yout);
            }
            else { groupA = 0; numA = 0; }
        }
    }while ((groupA != 0) && (numA != 0));
    //fprintf(fp, "0 0");
    //fprintf(fpout, "0 0");
    fclose(fpin);
    fclose(fpout);
    return(0);
}

```

```

REM TREEBALL [infile.vec][outfile.vec][noise]
REM Creates synthetic image
REM %1 - infile area class map 1 low density
REM %2 - outfile area class map 2 high density
REM %3 - noise density image
REM %4 - noise intensity image
cd \treedel\model
rem copy c:\treedel\programs\randtr.exe
REM density setting 1:(root)7
rem randtr %1.vec %2pt.vec
rem call show %2pt
cd \idrisi
environ :: 1 c:
environ :: 2 \treedel\model\
goto start
window :: %2pt %2ptw 1 0 0 200 200

REM SMOOTH MODEL
initial x out 1 1 10 1 %2ptw M
rem distance x %2ptw dist

cost x %2ptw out dist

stretch x dist temp2 1 min max: n 255 M
scalar x temp2 temp1 2 255
scalar x temp1 temp2 3 -1
filter x temp2 smooth 1
color x a smooth grey256 y 0 0
surface x 4 smooth temp2 -45 10 1
color x a temp2 grey256 y 0 0

rem :start
REM MAKE ROUGH EDGES
rem initial x %3 1 1 1 1 %2ptw M
rem polyras x %3 %3

rem color x a %3 idrisi y 0 0 0 -1 0 -1 fricclass 255 y
random x temp1 1 1 %2ptw 1 99
scalar x temp1 rd 1 1
rem color x a rd grey256 y 0 0

REM SET NOISE DENSITY %3 take min
overlay x 8 rd %3 temp
color x a temp grey256 y 0 0
overlay x 2 %3 temp noise
overlay x 1 out noise temp1
surface x 4 temp1 temp2 -45 10 1
color x a temp2 grey256 y 0 0 0 -1 0 -1 fricclass 255 y

color x a noise grey256 y 0 0
reclass x i noise noised 2 1 1 999 -9999
color x a noised grey256 y 0 0
overlay x 3 noised smooth temp1

rem :start
REM SET NOISE INTENSITY = %4
random x ri 1 1 %2ptw 1 18
scalar x ri noisei 2 8
color x a noisei grey256 y 0 0 0 -1 0 -1 fricclass 255 y

REM combine density and amplitude
overlay x 3 noisei noised noisei

```



```
color :: a noisef grey256 y 0 0 0 -1 0 -1 fricclass 255 y
```

```
REM TAKE MAX
```

```
overlay :: 1 noisef out noisy
```

```
color :: a noisy idrisi y 0 0
```

```
cost :: %2ptw noisy cost
```

```
stretch :: cost temp2 1 min max n 255 M
```

```
scalar :: temp2 temp1 2 255
```

```
scalar :: temp1 temp2 3 -1
```

```
filter :: temp2 rough 1
```

```
color :: a rough grey256 y 0 0 0 -1 0 -1 fricclass 255 y
```

```
REM COMPARE TWO DEMS
```

```
overlay :: 2 rough smooth diff
```

```
color :: a diff idrisi y 0 0 0 -1 0 -1 fricclass 3 y
```

```
REM SURFACE MODEL ROUGH
```

```
surface :: 4 rough temp2 -45 10 1
```

```
color :: a temp2 grey256 y 0 0 0 -1 0 -1 fricclass 255 y
```

```
stretch :: temp2 temp1 1 min max n 255 M
```

```
tifidris :: 2 temp1 grey 90 test
```

```
goto end
```

```
REM TEMP2 = DEM
```

```
REM CALCULATE FOR DIFFERING AZIMUTHS
```

```
surface :: 4 temp2 temp1 -67.5 10 1
```

```
stretch :: temp1 %2aza 1 min max n 255 M
```

```
tifidris :: 2 %2aza grey 90 %2aza
```

```
surface :: 4 temp2 temp1 -45 10 1
```

```
stretch :: temp1 %2azb 1 min max n 255 M
```

```
tifidris :: 2 %2azb grey 90 %2azb
```

```
surface :: 4 temp2 temp1 -22.5 10 1
```

```
stretch :: temp1 %2azc 1 min max n 255 M
```

```
tifidris :: 2 %2azc grey 90 %2azc
```

```
REM CALCULATE FOR DIFFERING SUN ANGLES
```

```
surface :: 4 temp2 temp1 -45 25 1
```

```
stretch :: temp1 %2an25 1 min max n 255 M
```

```
tifidris :: 2 %2an25 grey 90 %2an25
```

```
surface :: 4 temp2 temp1 -45 50 1
```

```
stretch :: temp1 %2an50 1 min max n 255 M
```

```
tifidris :: 2 %2an50 grey 90 %2an50
```

```
surface :: 4 temp2 temp1 -45 70 1
```

```
stretch :: temp1 %2an70 1 min max n 255 M
```

```
tifidris :: 2 %2an70 grey 90 %2an70
```

```
REM MEAN FILTER OVER DEM
```

```
cd \idrisi
```

```
filter x temp2 temp1 1
```

```
surface x 4 temp1 temp2 -45 10 1
```

```
rem pause
```

```
stretch x temp2 %2f1 1 min max n 255 M
```

```
rem pause
```

```
tifidris x 2 %2f1 grey 90 %2f1
```

```
rem pause
```

```
filter x temp1 temp2 1
```

```
rem pause
```

```
surface x 4 temp2 temp1 -45 10 1
```

```
rem pause
```

```
stretch :: temp1 %2f2 1 min max: n 255 M
rem pause
tifidris :: 2 %2f2 grey 90 %2f2
rem pause
filter :: temp2 temp1 1
surface :: 4 temp1 temp2 -45 10 1
stretch :: temp2 %2f3 1 min max: n 255 M
tifidris :: 2 %2f3 grey 90 %2f3
filter :: temp1 temp2 1
surface :: 4 temp2 temp1 -45 10 1
stretch :: temp1 %2f4 1 min max: n 255 M
tifidris :: 2 %2f4 grey 90 %2f4
```

```
REM CREATED %2 TIF FILE
REM IN COREL PAINT - MOTION BLUR (1) @ 120 degrees, Diffuse 2;
:end
```

```
goto start
loop:
    randm random image 60 then aggregates to form areas
    random rand60.vec 80 160 60
    amodel rand60.vec fuzan.2 cut6x1.vec 1.5
    amodel cut6x1.vec fuzan.2 cut6x2.vec 1.5
    amodel cut6x2.vec fuzan.2 cut6x3.vec 1.5
    amodel cut6x3.vec fuzan.2 cut6x4.vec 1.5
    amodel cut6x4.vec fuzan.2 cut6x5.vec 1.5
    :start
```

```
REM Comparison of neighbor transitions on random images of differing append.
REM no appendation in model
rem :start
REM Generate diffussn image using model
diff rand60.vec dpath.mod junk1.vec
diff junk1.vec dpath.mod junk2.vec
copy test.txt Riddpath.prn
```

```
REM 1A
REM 1 series = no appendation
REM A Area closest to tailings
neighb rand60.vec R1A0-1.z junk1.vec 1.5 128.0
neighb rand60.vec R1A0-2.z junk2.vec 1.5 128.0
neighb junk1.vec R1A1-2.z junk2.vec 1.5 128.0
append R1A0-1.z R1diff.prn
append R1A0-2.z R1diff.prn
append R1A1-2.z R1diff.prn
```

```
REM B
REM 1 series = no appendation
REM B Area near to tailings
neighb rand50.vec R1B0-1.z junk1.vec 1.5 96.0
neighb rand50.vec R1B0-2.z junk2.vec 1.5 96.0
neighb junk1.vec R1B1-2.z junk2.vec 1.5 96.0
append R1B0-1.z R1diff.prn
append R1B0-2.z R1diff.prn
append R1B1-2.z R1diff.prn
```

```
REM IC
REM l series = no appendation
REM C Area near to tailings
neighb rand60.vec R1C0-1.z junk1.vec 1.5 64.0
neighb rand60.vec R1C0-2.z junk2.vec 1.5 64.0
neighb junk1.vec R1C1-2.z junk2.vec 1.5 64.0
append R1C0-1.z R1diff.prn
append R1C0-2.z R1diff.prn
append R1C1-2.z R1diff.prn
```

```
REM ID
REM 1 series = no appendation
REM D Whole area
neighb rand60.vec R1D0-1.z junk1.vec 1.5 0.0
neighb rand60.vec R1D0-2.z junk2.vec 1.5 0.0
neighb junk1.vec R1D1-2.z junk2.vec 1.5 0.0
append R1D0-1.z R1diff.prn
append R1D0-2.z R1diff.prn
append R1D1-2.z R1diff.prn
```

```
rem copy Rldiff.prn c:\treedel\model\*.*
rem del *.prn
rem copy *.z c:\treedel\model\*.*
rem del *.z
```

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```

REM 2A
REM 2 series = aggreg1
REM A Area closest to tailings
neighb out6r1.vec R2A0-1.z junk1.vec 1.5 128.0
neighb out6r1.vec R2A0-2.z junk2.vec 1.5 128.0
neighb junk1.vec R2A1-2.z junk2.vec 1.5 128.0
append R2A0-1.z R2diff.prn
append R2A0-2.z R2diff.prn
append R2A1-2.z R2diff.prn

REM 2B
REM 2 series = agg1
REM B Area near to tailings
neighb out6r1.vec R2B0-1.z junk1.vec 1.5 96.0
neighb out6r1.vec R2B0-2.z junk2.vec 1.5 96.0
neighb junk1.vec R2B1-2.z junk2.vec 1.5 96.0
append R2B0-1.z R2diff.prn
append R2B0-2.z R2diff.prn
append R2B1-2.z R2diff.prn

REM 2C
REM 2 series = agg1
REM C Area near to tailings
neighb out6r1.vec R2C0-1.z junk1.vec 1.5 64.0
neighb out6r1.vec R2C0-2.z junk2.vec 1.5 64.0
neighb junk1.vec R2C1-2.z junk2.vec 1.5 64.0
append R2C0-1.z R2diff.prn
append R2C0-2.z R2diff.prn
append R2C1-2.z R2diff.prn

REM 2D
REM 2 series = agg1
REM D Whole area
neighb out6r1.vec R2D0-1.z junk1.vec 1.5 0.0
neighb out6r1.vec R2D0-2.z junk2.vec 1.5 0.0
neighb junk1.vec R2D1-2.z junk2.vec 1.5 0.0
append R2D0-1.z R2diff.prn
append R2D0-2.z R2diff.prn
append R2D1-2.z R2diff.prn

rem copy R2diff.prn c:\treedel\model\*.
rem del *.prn
rem copy *.z c:\treedel\model\*.
rem del *.z

```

```

rem -----
REM 3
REM AGGREG 2

```

```

diff out6r2.vec diff.mod junk1.vec
diff junk1.vec diff.mod junk2.vec
copy test.txt R3diff.prn

```

```

REM 3A
REM 3 series = aggreg2
REM A Area closest to tailings
neighb out6r2.vec R3A0-1.z junk1.vec 1.5 128.0
neighb out6r2.vec R3A0-2.z junk2.vec 1.5 128.0
neighb junk1.vec R3A1-2.z junk2.vec 1.5 128.0
append R3A0-1.z R3diff.prn
append R3A0-2.z R3diff.prn
append R3A1-2.z R3diff.prn

```

```

REM 3B
REM 3 series = agg2
REM B Area near to tailings
neighb out6r2.vec R3B0-1.z junk1.vec 1.5 96.0
neighb out6r2.vec R3B0-2.z junk2.vec 1.5 96.0
neighb junk1.vec R3B1-2.z junk2.vec 1.5 96.0
append R3B0-1.z R3diff.prn
append R3B0-2.z R3diff.prn
append R3B1-2.z R3diff.prn

```

```

REM 3C
REM 3 series = agg2
REM C Area near to tailings
neighb out6r2.vec R3C0-1.z junk1.vec 1.5 64.0
neighb out6r2.vec R3C0-2.z junk2.vec 1.5 64.0
neighb junk1.vec R3C1-2.z junk2.vec 1.5 64.0
append R3C0-1.z R3diff.prn

```

```

append R3C0-2.z R3diff.prn
append R3C1-2.z R3diff.prn

REM 3D
REM 2 series = aggr2
REM D Whole area
neighb out6r2.vec R3D0-1.z junk1.vec 1.5 0.0
neighb out6r2.vec R3D0-2.z junk2.vec 1.5 0.0
neighb junk1.vec R3D1-2.z junk2.vec 1.5 0.0
append R3D0-1.z R3diff.prn
append R3D0-2.z R3diff.prn
append R3D1-2.z R3diff.prn

rem copy R3diff.prn c:\treedel\model\*.z
rem del *.prn
rem copy *.z c:\treedel\model\*.z
rem del *.z

REM -----
REM 4
REM AGGREG 3

diff out6r3.vec diff.mod junk1.vec
diff junk1.vec diff.mod junk2.vec
copy test.txt R4diff.prn

REM 4A
REM 4 series = aggreg3
REM A Area closest to tailings
neighb out6r3.vec R4A0-1.z junk1.vec 1.5 128.0
neighb out6r3.vec R4A0-2.z junk2.vec 1.5 128.0
neighb junk1.vec R4A1-2.z junk2.vec 1.5 128.0
append R4A0-1.z R4diff.prn
append R4A0-2.z R4diff.prn
append R4A1-2.z R4diff.prn

REM 4B
REM 4 series = agg3
REM B Area near to tailings
neighb out6r3.vec R4B0-1.z junk1.vec 1.5 96.0
neighb out6r3.vec R4B0-2.z junk2.vec 1.5 96.0
neighb junk1.vec R4B1-2.z junk2.vec 1.5 96.0
append R4B0-1.z R4diff.prn
append R4B0-2.z R4diff.prn
append R4B1-2.z R4diff.prn

REM 4C
REM 4 series = aggr3
REM C Area near to tailings
neighb out6r3.vec R4C0-1.z junk1.vec 1.5 64.0
neighb out6r3.vec R4C0-2.z junk2.vec 1.5 64.0
neighb junk1.vec R4C1-2.z junk2.vec 1.5 64.0
append R4C0-1.z R4diff.prn
append R4C0-2.z R4diff.prn
append R4C1-2.z R4diff.prn

REM 4D
REM 4 series = aggr3
REM D Whole area
neighb out6r3.vec R4D0-1.z junk1.vec 1.5 0.0
neighb out6r3.vec R4D0-2.z junk2.vec 1.5 0.0
neighb junk1.vec R4D1-2.z junk2.vec 1.5 0.0
append R4D0-1.z R4diff.prn
append R4D0-2.z R4diff.prn
append R4D1-2.z R4diff.prn

rem copy R4diff.prn c:\treedel\model\*.z
rem del *.prn
rem copy *.z c:\treedel\model\*.z
rem del *.z

```

```

REM 5 -----
REM AGGREG 4

diff out6r4.vec diff.mod junk1.vec
diff junk1.vec diff.mod junk2.vec
copy test.txt R5diff.prn

```

```

REM 5A
REM 5 series = aggreg4
REM A Area closest to tailings
neighb out6r4.vec R5A0-1.z junk1.vec 1.5 128.0
neighb out6r4.vec R5A0-2.z junk2.vec 1.5 128.0
neighb junk1.vec R5A1-2.z junk2.vec 1.5 128.0
append R5A0-1.z R5diff.prn
append R5A0-2.z R5diff.prn
append R5A1-2.z R5diff.prn

REM 5B
REM 5 series = agg4
REM B Area near to tailings
neighb out6r4.vec R5B0-1.z junk1.vec 1.5 96.0
neighb out6r4.vec R5B0-2.z junk2.vec 1.5 96.0
neighb junk1.vec R5B1-2.z junk2.vec 1.5 96.0
append R5B0-1.z R5diff.prn
append R5B0-2.z R5diff.prn
append R5B1-2.z R5diff.prn

REM 5C
REM 5 series = aggr4
REM C Area near to tailings
neighb out6r4.vec R5C0-1.z junk1.vec 1.5 64.0
neighb out6r4.vec R5C0-2.z junk2.vec 1.5 64.0
neighb junk1.vec R5C1-2.z junk2.vec 1.5 64.0
append R5C0-1.z R5diff.prn
append R5C0-2.z R5diff.prn
append R5C1-2.z R5diff.prn

REM 5D
REM 5 series = aggr4
REM D Whole area
neighb out6r4.vec R5D0-1.z junk1.vec 1.5 0.0
neighb out6r4.vec R5D0-2.z junk2.vec 1.5 0.0
neighb junk1.vec R5D1-2.z junk2.vec 1.5 0.0
append R5D0-1.z R5diff.prn
append R5D0-2.z R5diff.prn
append R5D1-2.z R5diff.prn

rem copy *.z c:\treedel\model\*.z
rem del *.z
rem copy R5diff.prn c:\treedel\model\*.z
rem del *.prn

REM =====
Assess Gridding Density

```

[illegible]

```

// READ Trans FILE and Calculate Probabilities
fgets(string,length,fptrans);
fgets(string,length,fptrans);

for(x=0;x < 40 ;x++)
{
    if(!fscanf(fptrans,"%i %f %f",&classid,&nclasscnt[x],&percent)){exit(1);}
    //printf(" %i %i %f \n",classid,nclasscnt[x],percent);
    fgets(string,length,fptrans);
}
fclose(fptrans);

for(x=0;x < 40 ;x++)
{ printf(" %i %f \n",x,nclasscnt[x]);
  if((x%19) == 0 ){//getch();
  }
}

// getch();
// Calculate probability of cell becoming a 1 (1,2) after transition
for(x=1;x < 19;x++)
{
    if(x < 10){printf(" %i 1:1 %10.7f 1:2 %10.7f", x,nclasscnt[x],nclasscnt[x-19]);}
    if(x > 9){printf(" %i 2:2 %10.7f 2:1 %10.7f", x,nclasscnt[x+19],nclasscnt[x]);}

    if((denomin = nclasscnt[x] + nclasscnt[x-19]) > 0.0)
    {
        prob[x] = 100.0*(nclasscnt[x]/(float)denomin);
        printf(" %f\n",prob[x]);
    }
    else { printf(" %i undefined = define as 50%\n",x);
           //getch();
           prob[x] = 50.0;
        }

} //endfor
// edge probabilities
if((denomin = nclasscnt[39]+ nclasscnt[39]) > 0.0 )
{
    prob[19] = ((float)nclasscnt[39]/(float)denomin)*100.0;
    printf(" %i %10.7f %f\n",x,nclasscnt[39], prob[19]);
}
else { printf(" %i undefined probability transition = define as 50%\n";
           // getch();
           prob[19] = 50.0;
        }

//getch();
printf("\t Amodel %s %s\n",argv[1], argv[3]);
printf("=====\n");
printf(" > ");
do{
    if(fscanf(fpgrid,"%f %f",&groupA ,&numA)!=EOF){
        if ((groupA != 0.0000000) && (numA != 0.0000000))
        {
            fgets(string,length, fpgrid); //move over end of line
            fscanf(fpgrid,"%f %f",&xcoord1,&ycoord1);
            fgets(string,length,fpgrid);
            //-----
            ncellcnt = 0;
            nconfig=0;
            //-----
            // calculate window search
            minx = xcoord1 - threshold;
            maxx = xcoord1 + threshold;
            miny = ycoord1 - threshold;
            maxy = ycoord1 + threshold;

            // set return switches
            first = 1;
            pastit = 0;

            // loop for comparing with other points
            do{
                temp = ftell(fpample);
                if(fscanf(fpample,"%f %f",&groupB,&numB)!=EOF){
                    if(pastit == 1) {numB=0.0000000; groupB = 0.0000000;}
                    if ((numB != 0.0000000) && (pastit != 1))

```



```

fgetc(string,length, fpsample);
fscanf(fpsample, "%f %f", &xcoord2, &ycoord2);
fgetc(string,length, fpsample);
pastit = 0;
if(ycoord2 < miny - 1.0) {
    pastit = 1; // set switch skip rest of file
}

// filter out points outside window
if( (ycoord2 >= miny) && (ycoord2 <= maxy) )
{ // mark point of first ywindow contact to return to
    if(!first)
        contact = temp;

    first = 0;

    if( (xcoord2 >= minx) && (xcoord2 <= maxx) )
    {
        distance = sqrt( (ycoord2-ycoord1)*(ycoord2-ycoord1) +
            (xcoord2-xcoord1)*(xcoord2-xcoord1) );
        //printf(" distance %f", distance);
        if ((distance < (double)threshold) && ( distance >
0.01)) {
            //-----
            nconfig++;
            if(groupB > 1.0) {ncellcnt++;}
            //-----

            //} //endif dist < thresh

        } //endif window x
    } //endif window y

} //endif groupB !=0 and pastit
} //endif EOF2
else {groupB = 0.0000000; numB = 0.0000000; }
}while((groupB != 0.0000000) && (numB != 0.0000000));

//-----
if(nconfig == 8) {
    if(groupA < 2) {
        probclass = ncellcnt+1;
    }
    else if(groupA > 1) {
        probclass = ncellcnt+10;
    }
} // endif config
else { //on edge
    probclass = 19;
}
if((rand()%100) < prob[probclass]) {out=1;}
else {out=2;}
//-----

// set 2nd pointer to top of file
fseek(fpsample, contact, SEEK_SET);
//printf("\n\ncount cntz class      prob      out\n");
//printf("%3i %4.2f %3i %4.2f %4i\n", ncellcnt, groupA, probclass,
prob[probclass], out);

fprintf(fpout1, "%i %f \n", out, numA);
fprintf(fpout1, "%f %f \n", xcoord1, ycoord1);
// fprintf(fpout2, "%i %f \n", utree, numA);
// fprintf(fpout2, "%f %f \n", xcoord1, ycoord1);
// fprintf(fpout3, "%i %f \n", dead, numA);
// fprintf(fpout3, "%f %f \n", xcoord1, ycoord1);

//if(ptcounter % 20 < 1) {
clrscr();
printf(" Amodel %s %s %s %s\n", argv[1], argv[2], argv[3], argv[4]);
printf(" %i Points processed", ptcounter++);
//}

} //end if group1 !=0
} //end if EOF1

```

```
else { groupA = 0.0000000; numA = 0.0000000; }
}while ((groupA != 0.0000000)&&(numA !=0.0000000));

    fprintf(fpout1,"0 0");
    // fprintf(fpout2,"0 0");
    // fprintf(fpout3,"0 0");

    fclose(fpout1);
    // fclose(fpout2);
    // fclose(fpout3);
    fclose(fpgrid);
    fclose(fpsample);

    return 0;

}
```

```

#include <string.h>
#include <stdio.h>
#include <stdlib.h>
#include <math.h>
#include <conio.h>
#include <time.h>
#define length 80

int main(int argc, char* argv[])
{
    FILE *fpin;
    FILE *fpout;
    FILE *fp;
    char string[length];
    float xcoord, ycoord, ydiffmax, ydiffmin, lasty;
    float diffract;
    int x, groupA, numA, out, randn;
    int death[10]; // distribution
    div_t z;
    int first = 1;

    if (argc < 3)
    {
        fprintf(stderr, "Usage: diff [inpointfile] [model] [outfile] \n");
        printf("in - point vector file\n");
        printf("model 10 lines = int prob of death(0-100), \n 11th line max x diff dist, \n 12th
x(0)\n");
        exit(1);
    }

    randomize();

    // read model file
    fpin = fopen(argv[2], "r");
    for(x=0; x<10; x++)
    {
        fscanf(fpin, "%i", &death[x]);
        fgets(string, length, fpin);
    }

    fscanf(fpin, "%f", &ydiffmax);
    fgets(string, length, fpin);

    fscanf(fpin, "%f", &ydiffmin);

    fclose(fpin);
    printf(" ydiffmax = %f, ydiffmin = %f", ydiffmax, ydiffmin);
    //
    // -----
    fpin = fopen(argv[1], "r");
    fpout = fopen(argv[3], "w");
    fp = fopen("junk.txt", "w");

    do{
        if(fscanf(fpin, "%i %i", &groupA, &numA) != EOF){
            if ((groupA != 0) && (numA != 0))
            {
                fgets(string, length, fpin); //move over end of line
                fscanf(fpin, "%f %f", &xcoord, &ycoord);
                fgets(string, length, fpin);

                if(first){lasty = ycoord; first = 0;}

                if (groupA > 1){
                    if ((ydiffmax-ydiffmin) <= 0.0){ printf(" max - min <= 0"); exit(0);}
                    if(ydiffmin > ycoord){ diffract = 1.0;}
                    else(diffract = ((ycoord - ydiffmin)/(ydiffmax-ydiffmin))* 100;}

                    if (diffract > 100.0) {diffract = 100.0;}

                    // z corresponds to array defined by the *.mod file
                    z = div((int)diffract, 10);
                    randn = random(100);
                    fprintf(fp, "\n ycoord=%f fract=%f class=%i prob=%i randn=%i ", ycoord,
diffract, z.quot, death[z.quot], randn);

```

```
        if(randn < death[i].quot.){
            out = 1; fprintf(fp," = ");
        }
        else{out = 0;}

    } // if group > 1
    else {out = 1;}

    if(out == 1)
    {
        if ((int)ycoord == int.lasty){
            printf("-");
        }
        else {printf("\n -"; lasty = ycoord;}

        fprintf(fpout,"%10i\n",out, numA ;
        fprintf(fpout,"%10i\n", xcoord, ycoord);
    }

    else { groupA = 0; numA = 0; }

    while ((groupA != 0)&&(numA !=0));

    fprintf(fpout,"0 0");
fclose(fpout);
fclose(fp);
fclose(fpin);
return(0);
}
```

```

/* fgets example */

#include <string.h>
#include <stdio.h>
#include <stdlib.h>
#include <math.h>
#include <conio.h>
#define length 50

int main(int argc, char* argv[])
{
    FILE *fpin1;
    FILE *fpin2;
    FILE *fpout;
    char string[80];
    float xcoord1, ycoord1, minx, miny, maxx, maxy;
    float xcoord2, ycoord2;
    float distance;
    float threshold;
    float group1, class1;
    float group2, class2;
    int count;
    unsigned pcounter=1;

    if (argc < 3)
    {
        fprintf(stderr, "Usage: density [inputfile] [outputfile] [threshold distance] \n");
        exit(1);
    }

    /* open a file for update */
    fpin1 = fopen(argv[1], "r");
    fpin2 = fopen(argv[1], "r");
    fpout = fopen(argv[2], "w");

    threshold = atof(argv[3]);

    printf("\t DENSITY  s\n", argv[1]);
    printf("=====\n");
    printf(" > ");
    do {
        if (fscanf(fpin1, "%f %f", &class1, &group1) != EOF) {
            if ((group1 != 0.0000000) && (class1 != 0.0000000))
            {
                fgets(string, length, fpin1); //move over end of line
                fscanf(fpin1, "%f %f", &xcoord1, &ycoord1);
                count=0;

                // calculate window search
                minx = xcoord1 - threshold;
                maxx = xcoord1 + threshold;
                miny = ycoord1 - threshold;
                maxy = ycoord1 + threshold;

                // loop for comparing with other points
                do {
                    if (fscanf(fpin2, "%f %f", &class2, &group2) != EOF) {
                        if ((group2 != 0.0000000) && (class2 != 0.0000000))
                        {
                            fgets(string, length, fpin2);
                            fscanf(fpin2, "%f %f", &xcoord2, &ycoord2);

                            // filter out points outside window
                            if ( (xcoord2 >= minx) && (xcoord2 <= maxx) && (ycoord2 >= miny) &&
                                (ycoord2 <= maxy) )
                            {
                                distance = sqrt( (ycoord1-ycoord1)*(ycoord1-ycoord1) +
                                    ((xcoord2-xcoord2)*(xcoord2-xcoord2)) );
                                if (distance < threshold)
                                { count++; }
                            }
                        } //endif group2 !=0
                    } //endif EOF2
                } else {group2 = 0.0000000; class2 = 0.0000000; }
            }
        }
    } while (1);
}

```

```

        }while((group2 != 0.0000000)&&(class2 !=0.0000000) );
        // remove counting of itself
        count = count - 1;
        // set 2nd pointer to top of file
        fseek(fpin2,0L,SEEK_SET);
        fprintf(fpout,"i1 %f \n",count, group1);
        fprintf(fpout,"x1 %f \n", xcoord1, ycoord1);

getline();
printf("\t %d Points processed",ptcounter++);

! //end if group1 !=0
! //end if EOF1
else { group1 = 0.0000000; class1 = 0.0000000; }

}while ((group1 != 0.0000000)&&(class1 !=0.0000000) );

        fprintf(fpout,"0 0");
        fclose(fpout);
        fclose(fpin1);
        fclose(fpin2);

        return 0;

}

```

IMAGE EVALUATION TEST TARGET (QA-3)

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