STATISTICS AND GIS: TOOLS FOR LANDSLIDE PREDCTION IN THE LOWER FRASER VALLEY, SOUTHWESTERN BRITISH COLUMBIA

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ABSTRACT

A geographic information system (GIS) database was constructed and Bayesian statistics used to predict the probability of landslides in the lower Fraser Valley. This paper details computer hardware and software, and outlines database construction and statistical analysis. Statistics calculate predictive weights for fault, lineament, pluton, plutonic contacts, and hydrology GIS layers. Weighted layers are combined within the GIS to produce an *a posteriori* probability map of landslide occurrence. GIS analysis indicates that faults and lineaments are important factors in determining location and likelihood of future slides. The presence of plutonic rocks decreases the probability of slide occurrence. Attractiveness of this technique lies in ease of use, versatility and modest price of software packages.

RÉSUMÉ

Un système d'information géographique (SIG) de données et un modèle statistique Bayésian ont été utilisés pour prédire les glissements de terrain dans la partie inférieure de la vallée Fraser. Cette publication décrit les programmes et composantes d'ordinateur utilisés et explique sommairement la construction de la banque de données et l'analyse statistique. La statistique calcule les facteurs de pondération associés aux failles, linéaments, plutons, contacts plutoniques et couches hydrologiques du SIG. Les couches pondérées sont combinées à l'intérieur du SIG pour produire une carte de probabilités *a posteriori* de glissements de terrain. L'analyse du SIG indique que les failles et linéaments sont des facteurs importants et aident à localiser les glissements de terrain probables. Les roches plutoniques diminuent la probabilité de glissements de terrain. L'attrait de cette technique réside dans sa facilité d'utilisation et dans la versatilité et coût peu elevé des programmes d'ordinateur.

INTRODUCTION

Using GIS as a tool for geological applications is becoming more common, especially in recent years with the development of cheaper and more powerful PCs. GIS is employed in mineral exploration (Bonham-Carter et al. 1988) especially when integrated with raster based images such as Landsat TM, SAR, and aeromagnetics (Harris 1991). GIS has also received some attention for its potential geotechnical engineering applications (Wentworth 1987; MacDonald, Goodbrand and Johnstone 1991). For example, a GIS can be used deterministically (Shasko and Keller 1991; Ellen et al. 1993) or empirically to assess natural hazards (Wadge et al. 1991). Empirical techniques can produce hazard zonation maps by overlaying the location of past hazard events with surrounding data relevant to the hazard process. The hazard probability assigned to each polygon in the zonation map may be derived from rule-based or index models (Jayawardhana and Hill 1990; Gupta and Joshi 1990) or established multivariate or regression statistical models (Carrara et al. 1991; Yin and Yan 1988).

In this paper we outline a methodology for creation and application of a GIS geological database for producing landslide probability maps. We demonstrate use of the database through a working example. By combining binary map patterns (faults, lineaments, hydrology, and plutonic contacts) using Bayesian statistics, a map is produced showing areas favorable for large landslides in the lower Fraser Valley in British Columbia. The results are illustrative however, more rigorous analyses incorporating more database attributes are needed before the results can be used for planning purposes. This work is in progress.

HARDWARE AND SOFTWARE

Table 1 lists the hardware and software used in this study. This configuration can be purchased for about $8,000 Cdn. The software combination shown here is extremely versatile because text, drawing, and image data can be transferred quickly and efficiently from one package to another. Effective communication between software can help solve the problems inherent to dealing with diverse digital data sets. Attribute data can be transferred as ASCII text files and drawing files as Drawing Interchange Files (*.DXF). Digital images can be transferred as Tagged Image File Format files (*.TIF).

LANDSLIDES AND GEOLOGY

The lower Fraser Valley of southwestern British Columbia (inset Fig. 1) is one of the most strategically important transportation corridors in Canada. Large landslides in the valley have occurred repeatedly since the last glaciation (Savigny in press 1994). At the 28th International Geological Congress in Washington it was reported that the incidence of landsliding in Canada had not been assessed (Cruden et al. 1989). In response a large landslide inventory and lineament search was conducted between Chilliwack and Boston Bar (Fig. 1) using 1:50,000 scale black and white airphotos (Savigny in press 1994). This inventory covers approximately 8000 km^2. The region is situated along the boundary of the North Cascade and Coast Mountains.

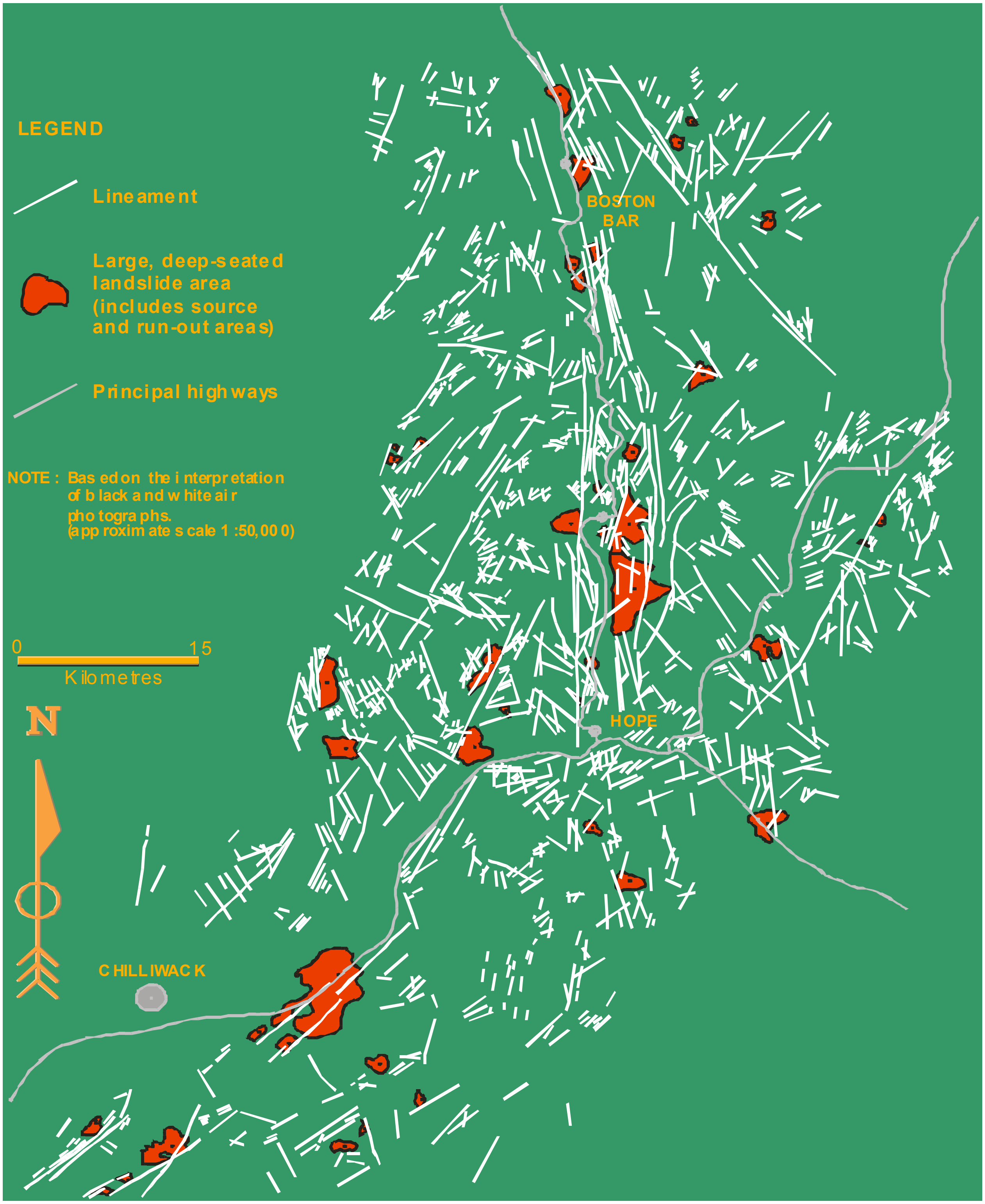


Figure 1 Study area showing the lineaments and landlsides in the lower Fraser Valley.

TABLE 1. Computer hardware and software used in this study.

Hardware:	
PC:	Intel 486DX 66 MHz CPU
Color Monitor:	17" NEC Multisync 5FGe (1024 x 768)
Graphics Card:	Diamond Viper SVGA with 2 Mb VRAM
Memory:	16 Mb Ram
Hard Disk:	Quantum 525 Mb IDE, 10 ms, 512k cache
Output:	HP LaserJet III laser printer
Digitizing Tablet:	SummaSketch II Professional (18x12)
Software:	
GIS (raster based):	IDRISI v. 4.0 for DOS
Database:	dBase IV v. 2.0 for DOS
Graphics:	Corel DRAW v. 4.0
Digitizing:	AutoCAD v. 10
Spreadsheet:	Quattro Pro for Windows v. 1.0
Word Processing:	Word for Windows v. 2.0
Operating System:	DOS v. 6.0, Windows v. 3.1

The valley floor is bounded by steep, irregular topography rising to 1500m. Steep slopes have been created by tectonic uplift and erosion. Glacial and later fluvial erosion has caused oversteepening of lower valley slopes and potential failure surfaces are commonly unsupported (Savigny in press 1994). Many of the peaks in the area comprise igneous plutons which are surrounded by metasedimentary and metavolcanic pendant rocks (Monger 1989). Surficial materials mantle the topography but contain only one of the 42 slides inventoried suggesting slides in these materials are of limited significance.

Savigny (in press 1994) proposed a possible correlation between the landslides, faults, plutonic contacts, and major lineaments in the area. The motivation for this study is to better assess these possible correlations using a GIS in the hope of developing a more rigorous landslide hazard zonation system for the lower Fraser corridor.

DATA INPUTS

Table 2 lists the types of data sources collected in the study area. Hardcopy maps showing plutons, faults, lineaments, landslides, streams, rivers, lakes, roads, and towns were available at the same scale. The digitizing required seven person days to complete. Large digitizing tables are recommended because photo reduction or enlargement of hardcopy maps will cause distortions in the digitized layers. Polygonal data such as bedrock geology, surficial geology, vegetation type or land use may be scanned from maps into a raster format but vectors should be digitized to retain their spatial accuracy. If remotely sensed imagery (Landsat TM or MSS,

TABLE 2. Sources and type of input data.

Data Layers	Type	Data Capture	Attributes
landslides	polygons	digitized[1]	name
plutons	polygons	digitized[1]	pluton name, age
pluton contacts	vectors	digitized	pluton name, age
faults	vectors	digitized	fault name, age
lineaments	vectors	digitized	id number, azimuth
streams	vectors	digitized	name
roads[2]	vectors	digitized	name, route number
towns[2]	points, polygons	digitized	name, population
seismicity	points, polygons	text file[3]	magnitude
airborne SAR[2]	raster, grey scale	exabyte tape[4]	digital numbers 0-255
Landsat TM[2]	raster, grey scale	exabyte tape[4]	7 spectral bands
digital topography[2]	points, vectors, polygons	3.5" disks[5]	x,y,z + planimetric data

[1]may be faster to scan instead of digitizing
[2]not used for this landslide prediction study
[3]purchased from the Pacific Geoscience Centre, Sydney, B.C.
[4]on loan from the Canada Centre for Remote Sensing, Ottawa, Ont.
[5]on loan from the B.C. Ministry of Environment, Victoria, B.C.

SPOT, airborne or satellite radar, airborne geophysics, or airphotos) is used these images must be geometrically corrected to a UTM map or digital elevation model (DEM) for use as accurate map layers within a GIS.

An attribute database was created using dBase for each GIS layer. Identifier numbers for each point, line, or polygon in the layer correspond to a record in the database file. This facility links the spatial information to the attribute information and constitutes a GIS. Attributes include names, pluton rock type, pluton age, type of slide, trend of lineament, magnitude of seismic record and so-on. The completed GIS database may now be employed for spatial correlations such as the landslide analysis presented below.

DATA ANALYSIS

The purpose of this analysis was to combine binary map patterns using Bayesian statistics and produce a map of rock landslide potential in the Lower Fraser Valley. The methodology for this statistical analysis was used by Bonham-Carter (1988) to produce a gold potential map in S.E. Nova Scotia. Agterberg (1989, et al. 1990) discusses the details of the technique and its advantages and disadvantages over other statistical methods.

Possible locations of new slides are predicted by *a posteriori* probability, based on factors associated with the slides and locations of existing slides (an *a prior* probability). In this study the factors, called binary maps (either present (on) or absent (off)), are lineaments, faults, plutons, plutonic contacts, and hydrology. Using conditional probability theory and areas calculated within IDRISI, weights (W^+ and W^-) are calculated for each binary map. W^+ is a number indicating the amount of positive influence that map has on the probability of a slide being present. W^- is the amount of negative influence the map has on the probability of a slide being present. The difference ($W^+ - W^-$) indicates the predictive power of that binary map. The higher this difference the more likely a slide will be present. Weights are calculated in a spreadsheet and are listed in Table 3.

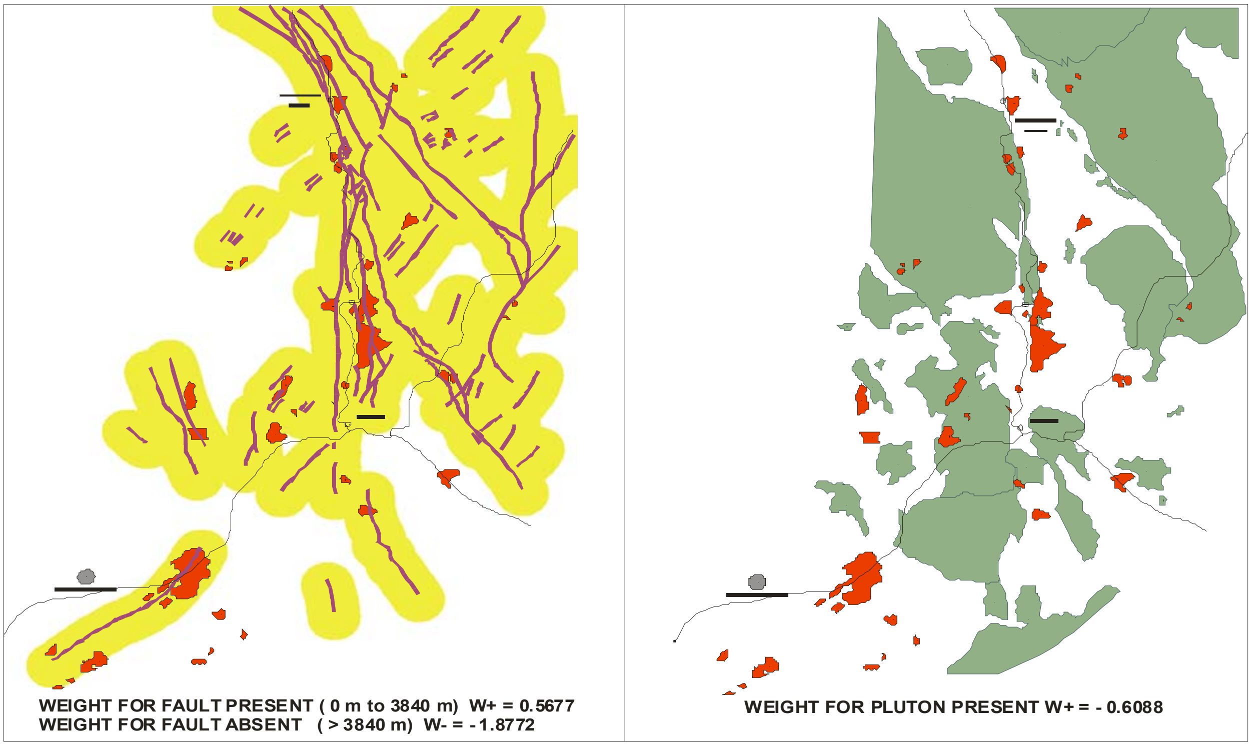
Vector features were assumed to have a zone of influence around them. Buffers 250 metres wide were created around each vector feature and weights calculated at intervals of 250 m. The zone of influence of each vector stops where ($W^+ - W^-$) is a maximum. For example, Figures 2a and 2b illustrate two binary maps and their weights. In Figure 2a the zone of influence extends 3840 m from each fault. Beyond this zone the difference ($W^+ - W^-$) begins to decrease. The weight assigned to this zone is W^+=0.5667 and outside of the zone the weight W^-=-1.8772 is assigned. Zones of influence are determined and weighted for lineaments, plutonic contacts, and streams. In Figure 2b plutons have no W^- weight since they are either present or another rock type exists. The binary maps with their zones of influence and corresponding weights are added together in IDRISI, statistically manipulated and a map of *a posteriori* probability of landslides is created.

TABLE 3. Predictive weights for each binary layer.

Binary Map	W^+	W^-	($W^+ - W^-$)
faults	0.5677	-1.8772	2.4449
lineaments	0.6310	-1.0778	1.7088
pluton contacts	0.4043	-0.0369	0.4412
streams	0.3225	-0.0596	0.3821
plutons	-0.6088	-	-

RESULTS

The weights in Table 3 indicate that the presence of faults and lineaments increase the probability of a slide being present while plutons will decrease this probability. The W^- weight for faults is strongly negative suggesting that slides are less likely beyond 3840 m from a fault. Figure 3 is a map of *a posteriori* probability of landslides. On this map, a pixel located within 3840 m of a fault, 960 m of a lineament, and 250 m of a plutonic contact and a stream has a 12% probability of containing a landslide. Presence or absence of the four binary layers generate probabilities between 12% and 0%. By superimposing the existing slides on this probability map 2% of the total slide area lies within the 10% to 12% probability zone. 58% of the total slide area lies within the 4% to 6% probability zone. Future studies will determine which of the four layers is present or absent in each probability zone.



(a) (b)

FIGURE 2. Two of the binary maps used to predict landslide occurance. Existing landslide polygons are shown in red. (a) Faults with buffer. (b) Plutons.

CONCLUSIONS

A GIS is a tool for organizing and quantitatively analyzing information to support a decision-making process. A GIS database allows rapid quantitative analysis of spatial and attribute information. Queries can be as simple as determining the area of a landslide polygon or generating a histogram of lineament trends intersecting a pluton. More complex queries include modelling of "what-if" scenarios for route planning or statistical analyses for hazard potential maps. Foremost among the disadvantages of a GIS approach are personnel issues. The technology is new and the learning curve is steep. Experienced geotechnics professionals frequently lack knowledge of database development and analysis. This may result in misunderstanding of concepts and misinterpretation of results. Other disadvantages include the time and cost of acquiring the necessary hardware and software. In the authors' opinion, successful integration of a GIS into geotechnics practice starts with a knowledgeable analyst (both technically and digitally) using easy-to-learn, inexpensive and versatile software.

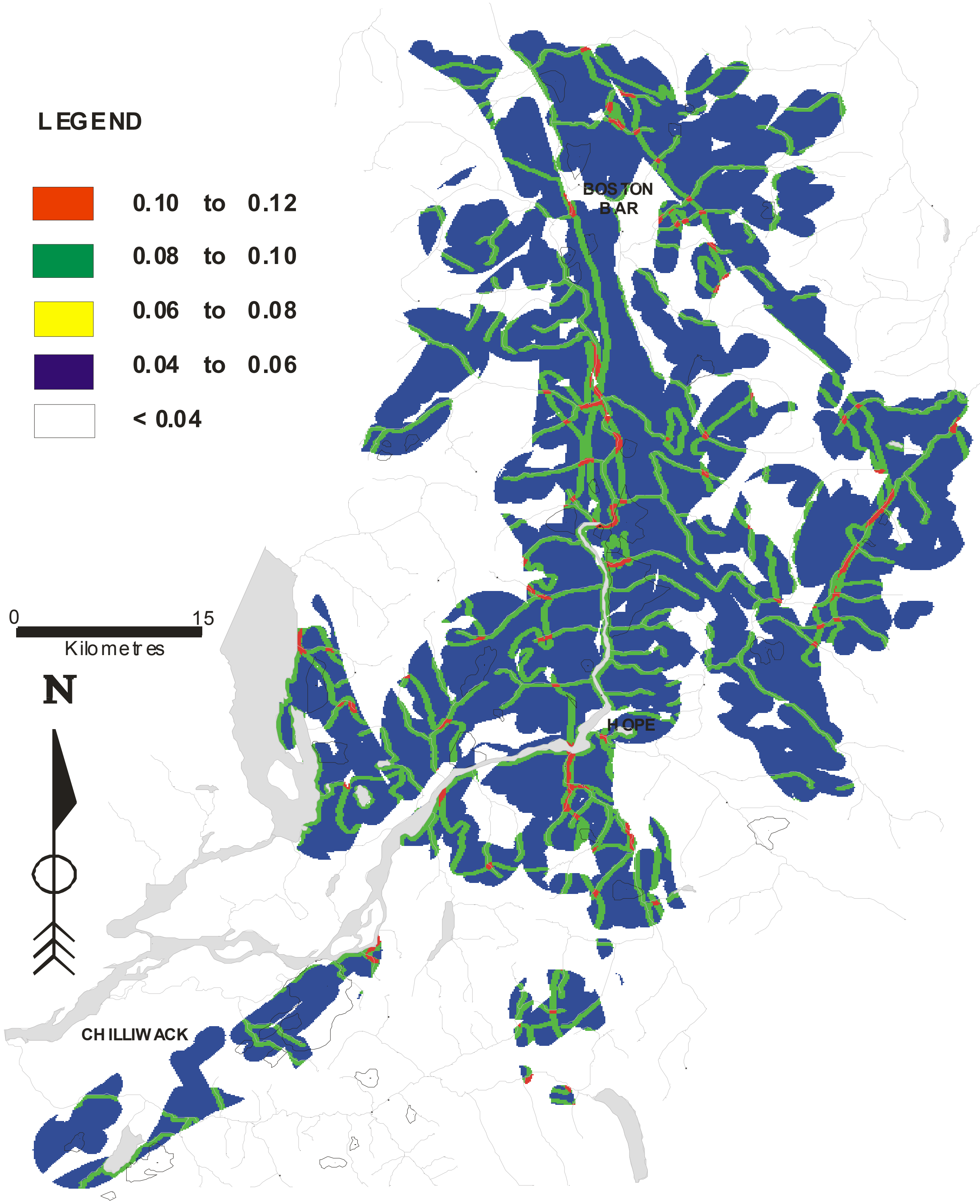


Figure 3 Map of a posteriori probability of landlsides in the lower Fraser Valley.

This study utilized readily available and commonly used software integrated with the GIS IDRISI. It took one person five weeks to create the GIS database and generate the probability map.

However, once a GIS database is created it has potential for numerous future studies. For example, a correlation between landslide type and lineament trend can be quickly investigated.

The method of combining the binary maps and Bayesian statistics in a GIS for landslide prediction has been outlined. The probability map produced provides potential insights for planners, engineers, and geoscientists involved with landslide hazard assessment and mitigation. Its utility must be further evaluated and developed with more rigorous study and analysis. In addition to the probability map, results of this study indicate that the presence of faults and lineaments are major factors in landslide occurrence. Plutonic bodies appear to have lower incidence of landslide activity. The authors feel the potential for GIS use in landslide research is clearly demonstrated by this study.

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