Strategies for an Environmental Zonal Evaluation of the City of Winnipeg

Urban Resources No. 3

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by S. Hathout & J. Romanowski
1992

The Institute of Urban Studies

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STRATEGIES FOR AN ENVIRONMENTAL ZONAL EVALUATION OF THE CITY OF WINNIPEG
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PREFACE

"Environment" is to be understood in holistic terms, consisting of both natural and cultural components, linked by processes effecting and affected by change, some of which we choose to perceive as "development." As powerful agents of development, we must view our efforts in this respect as necessarily impacting not only our well-being but also our environment.

The complexity of assessing, monitoring and managing the environment within urban areas has been a growing concern for us, particularly since we perceive that not all is as it should be with our management of those areas. Environmental zoning is one rational first step in the management of our urban environment. The main purpose of this study is the assessment of the usefulness of diverse environmental factors in carrying out environmental zoning of urban areas. We have found landscape (ground, space, and pollution index) and urban ecosystem (tree density, built-up area and biomass index) compound factors to be complementary in representing the urban environment. We have also found that the biomass index, derived from satellite imagery, can be used to carry out urban environmental zoning.

KEYWORDS: environmental zoning, landscape factors, ecological factors, biomass index.

ENVIRONMENTAL ZONAL EVALUATION OF THE CITY OF WINNIPEG

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1. INTRODUCTION

Most earth environments contain elements which are suitable for humans and those which are not. What is suitable depends not only on nature but also on the culture of humans. In context, urban environments also contain useful, useless and even undesirable elements, all of them forming a mosaic of spatial extent. Occupants of such environments learn to identify the usefulness of such elements and their extent within their living space. Urban planners and officials have developed indices of such urban environmental living quality. Among these are:

a. Density of vegetation cover or the biomass index;
b. Density and age of the built-up area; and
c. Types and intensities of pollution.

Such indices of urban environmental quality serve then as information for:

a. The assessment of real estate taxes;
b. Measures of environmental protection;
c. Adjudication of land-use conflicts, etc.

Planning of land use "remains a mainly local affair in which land-use change is regulated mostly through municipal zoning controls" (Bunce, 1989, p. 1). This local focus provides the best opportunities for weighing local factors. Optimal consideration of such local factors can still, however, yield an inappropriate habitat design at a more extensive level. Environmental zoning is seen as a tool for providing both accurate data at the local level and a comprehensive image at a regional (e.g., Winnipeg as a whole) level.

Our study has four objectives:

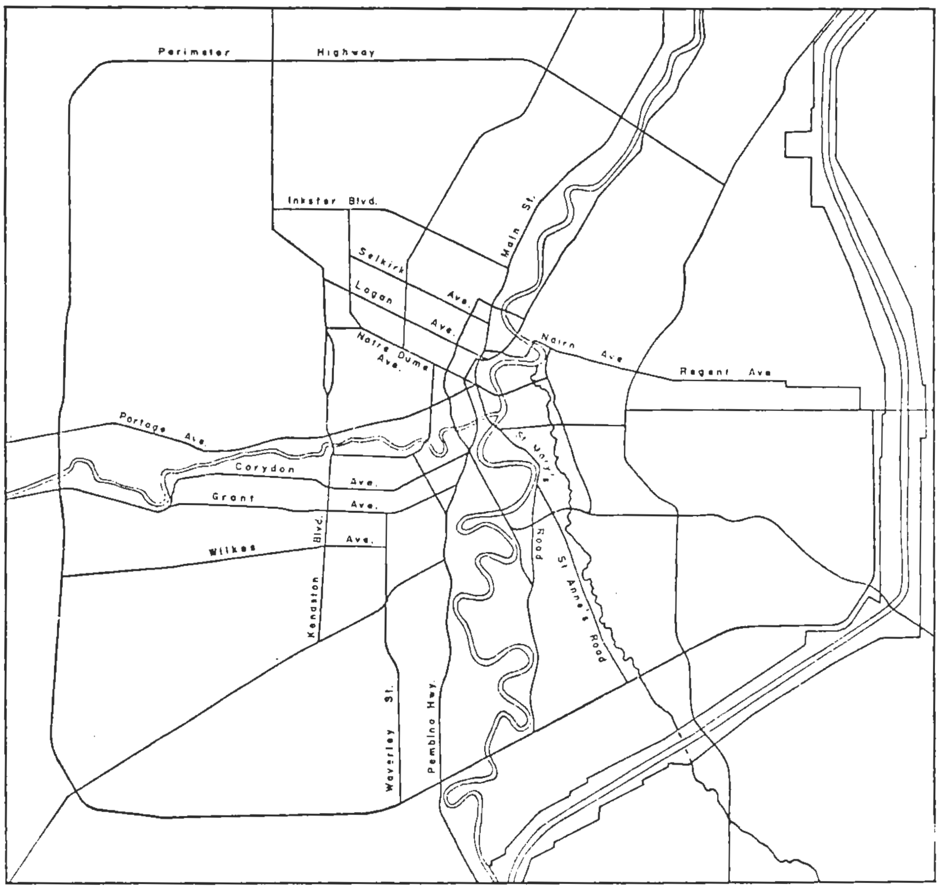
1. To compile a detailed environmental zonal map using the biomass index; density and age of the built-up area; types and intensity of pollution; the urban ecological index; the type and density of vegetation, and the urban landscape index; the morphology of the urban land use; and the types and intensities of pollution.

2. To compile a landscape environmental zonal map based on the ground, space and pollution indices of urban land use.
3. To compile an ecological environmental zonal map based on biomass, boulevard tree density, and the age and density of built-up area indices.
4. To compare a simple environmental map derived from the space biomass environmental index with a detailed environmental map derived from a combination of landscape and urban environmental indices.

2. STUDY AREA

Situated in the middle of the longitudinal extent of Canada, at the eastern apex of the Prairie oecumene and along the least-effort path (through Canada) to the Ontario-Quebec oecumene, Winnipeg has been a gateway and funnel city for humans and freight. Established as a town in the 1860s, the city soon experienced boom times with Manitoba's gaining of provincial status. Perhaps the most outstanding characteristic of Winnipeg today is its industrial diversification. Seventy-five percent of Canada's types of industries are represented in Winnipeg. While no longer booming in population, the city has continued to sprawl out in area. Environmental zoning is urgently needed to effectively manage that area. Figure 1 shows the extent of Winnipeg.

FIGURE 1
WINNIPEG CITY OVERLAY



3. METHODS

Satisfactory environmental evaluation depends on an appropriate sampling of the myriad information available from the environment. Many sampling methods are available, and the choice among them depends on the desired information product of the exercise. Among such sampling methods are:

i. random sampling of visual observers;

ii. systematic sampling of areal units, such as:

   a. the area is divided into circles, each circle covering an equal area for stereoscopic interpretation, 3.5 cm in diameter, of a photograph 1:15,000 in scale, i.e., 150 m on the ground for each cm on the photograph;

   b. the area is divided according to some grid design whose smallest cell represents the smallest significant environmental unit;

   c. the area is analyzed according to the existing census tracts;

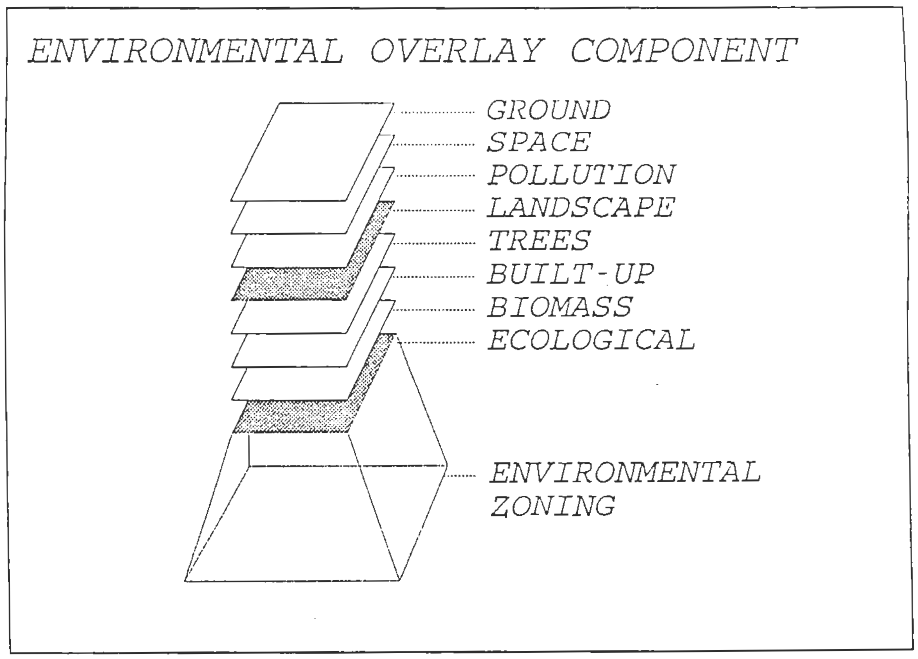
   d. the area is analyzed according to the standard size of ground cover of a pixel, be it 80 x 80 m, 30 x 30 m, 20 x 20 m, etc.;

iii. land-use unit sampling based on the aerial extent of land-use types; or

iv. sampling of land-use change based on equal samples of data sets from two different points in time (e.g., two different years).

Due to the diverse nature of data used, this study involved three different sampling methods: the viewing circle (iia); the census tract (iic); and pixel size (iid). The information thus obtained was later standardized according to geographic co-ordinates for the purposes of overlay mapping and analysis (Figure 2).

FIGURE 2
ENVIRONMENTAL OVERLAY COMPONENT



For each of the surveyed units, we have recorded the landscape index and the urban ecosystem index.

3.1 The landscape index consists of (Hathout, 1977): (i) the ground index; (ii) the space index; and (iii) the pollution index.

i. The ground index (Figure 3) contains the characteristics of the landscape which can be seen or interpreted either from the ground or from aerial photographs. The ground index consists of three different components: (a) the screen; (b) the skyline; and (c) the foreground and background.

a. The screen is the density of land coverage (whether buildings or trees). Five different classes were identified, with densest coverage forming the lowest class:

Class 1, very dense. Side-by-side buildings aligned on both sides of the street.

Class 2, dense. Buildings on both sides of the street separated from each other by distances equal or less than the width of the street.

Class 3, medium. Buildings separated with distances wider than the width of the street.

Class 4, low density . Buildings or trees scattered.

Class 5, very low density. Buildings or trees not present, open space.

According to Tunnard and Pushkarev (1967, p. 99), the five classes should be given a landscape value in the ascending order of 0 through 4.

b. The skyline is the irregularity in height of buildings or trees. This yields five classes ranging from 1 to 5:

Class 1, level skyline; dull, monotonous, nothing to rest the eye on.

Class 2, Interrupted; sudden changes in roof height are present.

Class 3, Irregular height between individual buildings.

Class 4, Undulating or gradual height changes.

Class 5, Mixed height block patterns.

Again, according to Tunnard and Pushkarev (1967, p. 296) these five classes should be given a landscape value in the ascending order of 0 through 4.

FIGURE 3
GROUND FEATURES OVERLAY

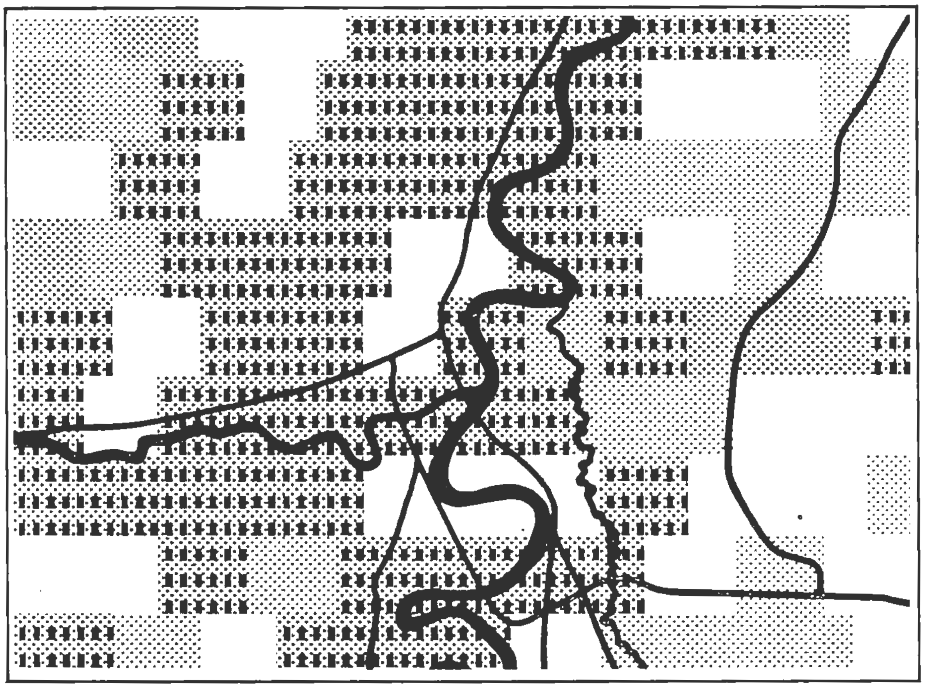


Fig. 3: Ground Features Overlay

Very Suitable
Suitable
Unsuitable
Moderately suitable

Class L, Spots uniform in size but positioned at different heights.

Class M, Spots of various sizes with spaces between them relative to their sizes.

According to Tunnard and Pushkarev (1967, p. 100), these classes should be given landscape values in ascending order from 0 to 4.

c. Linear characteristics. Linear structure patterns characteristic of the landscape ranging from straight lines representing low value to curved or circular lineaments representing high value.

Class O, Straight lines or the traditional rectilinear grid; monotonous.

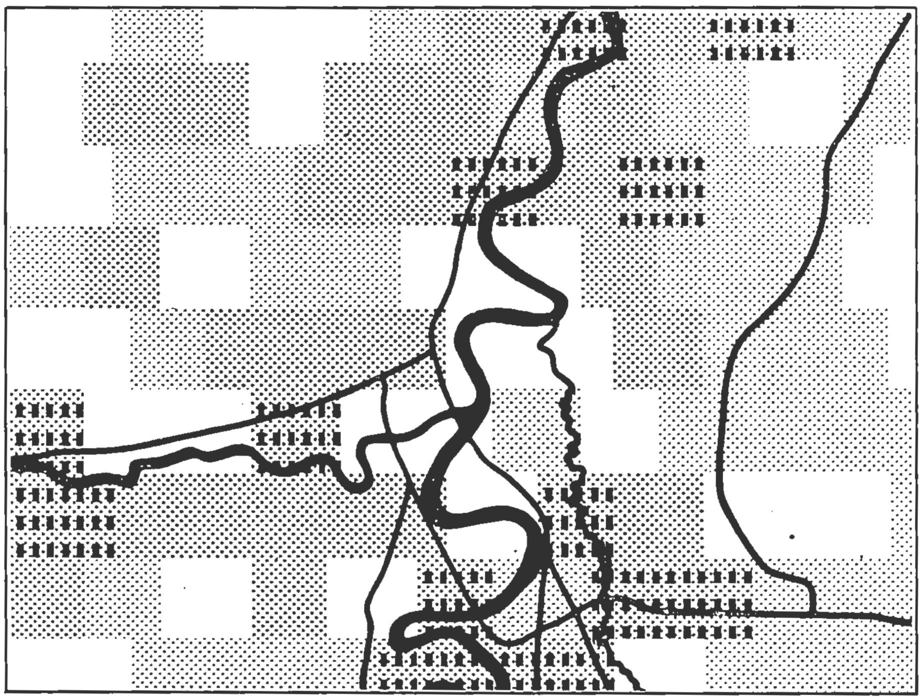
Class Y, Wavy or curved line. The new curvilinear grid; less monotonous.

Class W, Regular line or a repetitive rectilinear line arrangement as in rectilinear semi-loop streets.

Class Z, Circular lines or inconsistent pattern; rectangular houses arranged in a circle.

According to Tunnard and Pushkarev (1967, p. 100), these classes should be given values in ascending order from 0 to 4.

FIGURE 5
SPACE FEATURES OVERLAY



Space Features Overlay

Very Suitable
Suitable
Unsuitable
Moderately suitable

iii. The pollution index (Figure 6). Proximity and type of pollution such as water pollution, noise pollution, air pollution, and ground pollution. This index is evaluated in terms of the distance from the source of the pollution, ranging from <500 m (1 value), through 500-1000 m (2 index values) to >1000 m (3 index values). The pollution source was checked from ground truth, while the areas affected by that pollution were delineated from air photographs. The causes of the four different types of pollution were investigated and described as follows:

a. Water pollution (Ww), caused by thermals of steel mills or hydro plants, meat processing plants, food processing plants, sewage or stagnant water (Inhaber, 1974).
b. Noise pollution (Nn), caused by downtown crowding, traffic, trucks, industry, airport, railways or stadiums (Moore, 1974).
c. Air pollution (Aa). According to Lysyk and Kurrz (1971), Winnipeg is considered a clean city. There are, however, some air pollution problems caused by particulates, specially in the downtown area and around industrial zones, and on a seasonal basis.
d. Land pollution (Ll), caused by gravel pits, sanitary landfills, incinerators and erosion along rivers (Inhaber, 1974, pp. 798-805).

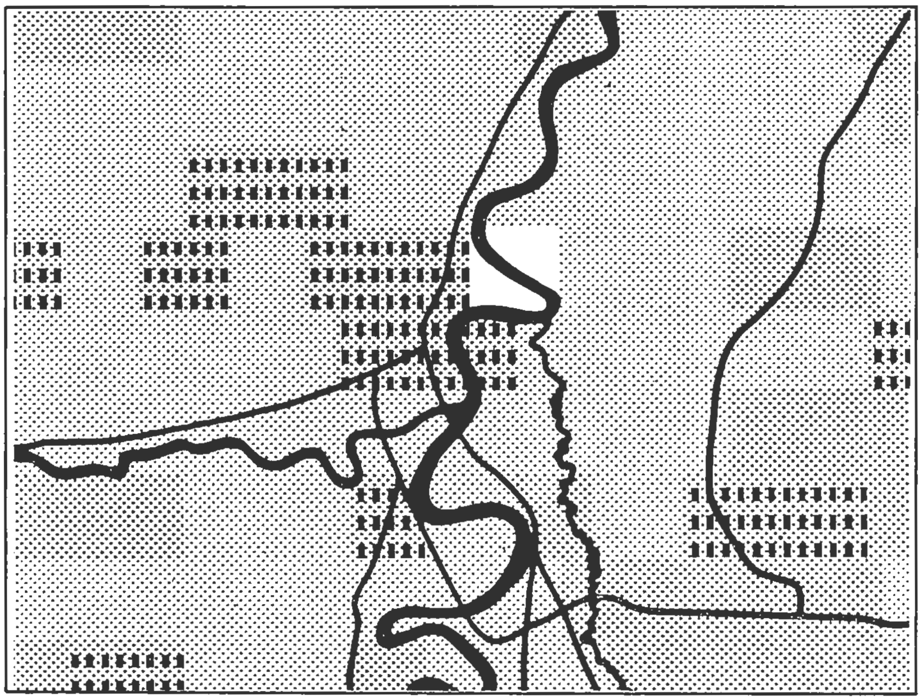
Each of the 125 circles or landscape units covering Winnipeg City was analyzed according to the above criteria. Landscape evaluations for 1974 were compared with those for 1950 as follows:

$$\text{The total landscape value (index)} = [\text{the ground value (index)} + \text{the space value (index)}] - \text{the pollution value (index)}$$

Figure 7 shows the elements of the total land-use value index for all 125 viewing circles of Winnipeg.

FIGURE 6

POLLUTION FEATURES OVERLAY



Pollution Features Overlay

Very Suitable

Suitable

Unsuitable

Moderately suitable

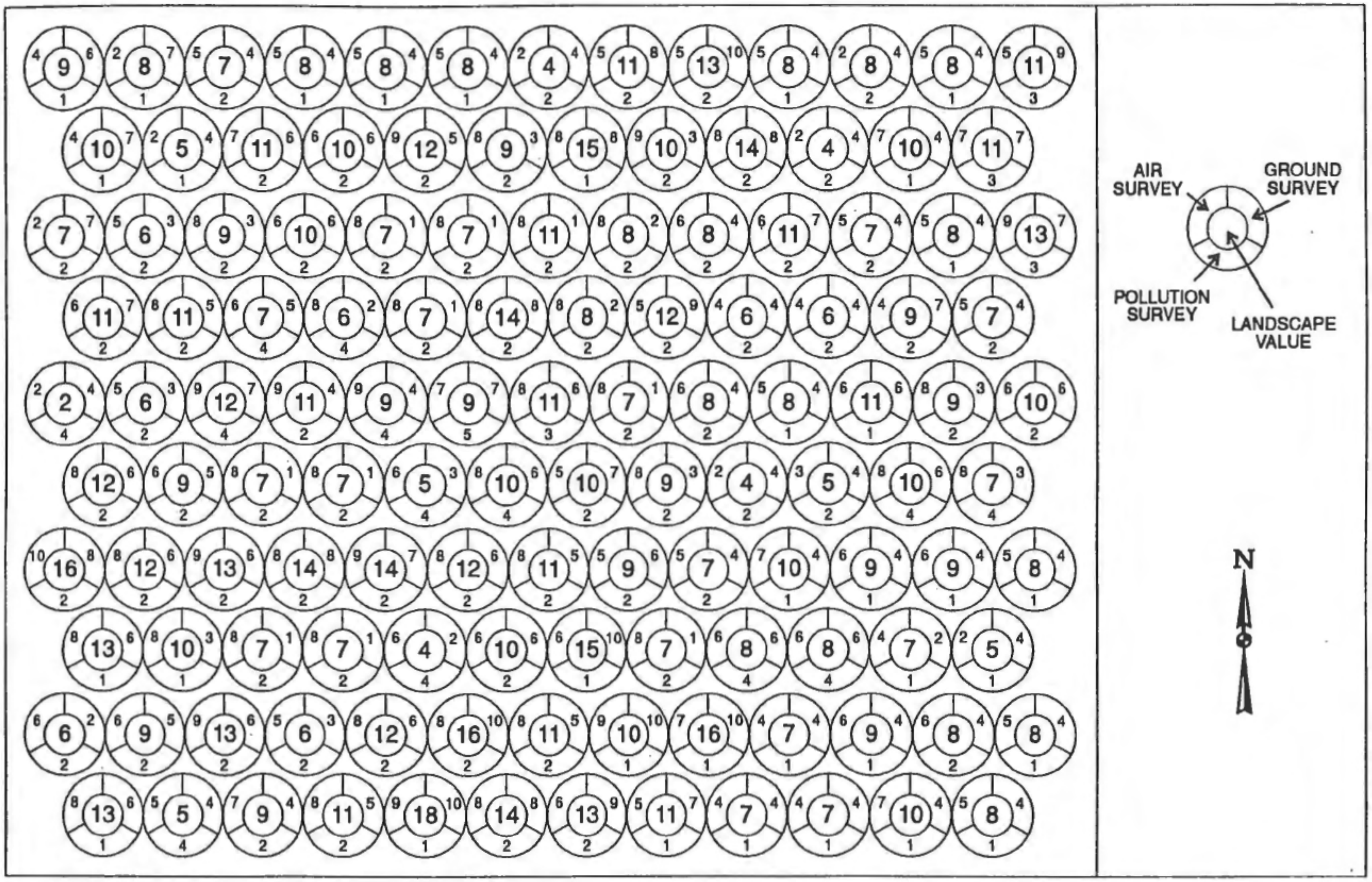


FIGURE 7 LANDSCAPE EVALUATION OF WINNIPEG AREA 1974

3.2 The urban Ecosystem index consists of (Hathout and Simpson, 1986): (i) the tree density index; (ii) the built-up area index; and (iii) the biomass index.

i. The tree density index (Figures 8 and 9). The average ground distance between boulevard trees, identified and measured in meters from aerial photographs using direct and indirect elements of recognition. "Boulevards," in context, are any public streets or roads lined with trees. The tree density was classified into six categories: <10 m; 10-20 m; 20-30 m; 30-40 m; 40-50 m; and >50 m.

Boulevard trees play an important role in the urban environment. They offer, particularly in the downtown area, by far the dominant opportunity for contact with the natural vegetative system. They have significant sanitary, aesthetic and recreational roles. They serve to modify the otherwise barren vistas of human-made structures, and they modify the microclimates. For such reasons, boulevard trees are considered desirable in urban areas. Research in urban studies, using remote sensing techniques, has indicated the "number, condition and type of trees present within various types of residential areas, to be an important indicator of the quality of the environment and housing conditions within these areas" (Joyce, 1973).

Jorgensen (1977) recommended a specialized branch of forestry, with the objectives of cultivation and management of trees for their present and potential contribution to the physiological and economic well-being of urban society.

Robinette (1972) explains the various functions of urban trees, e.g., to control natural and human-made glare and reflection, to direct and guide traffic, to reduce noise pollution, to absorb noxious gases, to clean the air of impurities, to produce oxygen, to deter soil erosion, to alter microclimate making the environment more pleasant in which to live, but also primarily to enhance the urban surroundings. A study by Nakajima in 1968 revealed that the degradation of boulevard trees caused by urban intensification in Tokyo caused a rapid increase in surface radiation heat, which in turn caused air to rise and brought the flows of polluted air to densely populated areas.

Aerial surveying, using black and white aerial photography, has proven to be the quickest, most accurate and cheapest technique for surveying tree density in the urban environment (Anderson, 1977). Conventional methods of data collection, involving ground surveys, questionnaires and interviews, are often slow, imprecise, and expensive. Moore and Wellar (1968) discuss four criteria pertinent to aerial photography that meet requirements of a solid data base for planning and research; these criteria are timeliness, reliability, compatibility and flexibility.

Forty-five black-and-white aerial photographs, covering the City of Winnipeg in 1976, were used for counting and calculating the density of boulevard trees. This imagery was cloud-free and allowed for good resolution at an average scale of 1:20,000. Identification of boulevard trees from the photographs was achieved using image shape, texture, tone, shadow, size, and, in particular, tree patterns. The practice of planting trees in a rigid linear pattern between the sidewalk and the road aided the delineation of trees along the boulevards.

In city areas where there are no sidewalks, trees that were planted in linear fashion along the roadway were counted as city trees. The counts were made per block and marked on a large base map (scale of 1:12,000) of the City of Winnipeg. Next, the linear distance of the boulevard was measured for each census tract, using a clinometer. This, and the tree total, provided a measure of tree density per census tract. This tree density was expressed in terms of the average ground distance between trees, in meters.

FIGURE 8

MEAN INTER-TREE DISTANCE

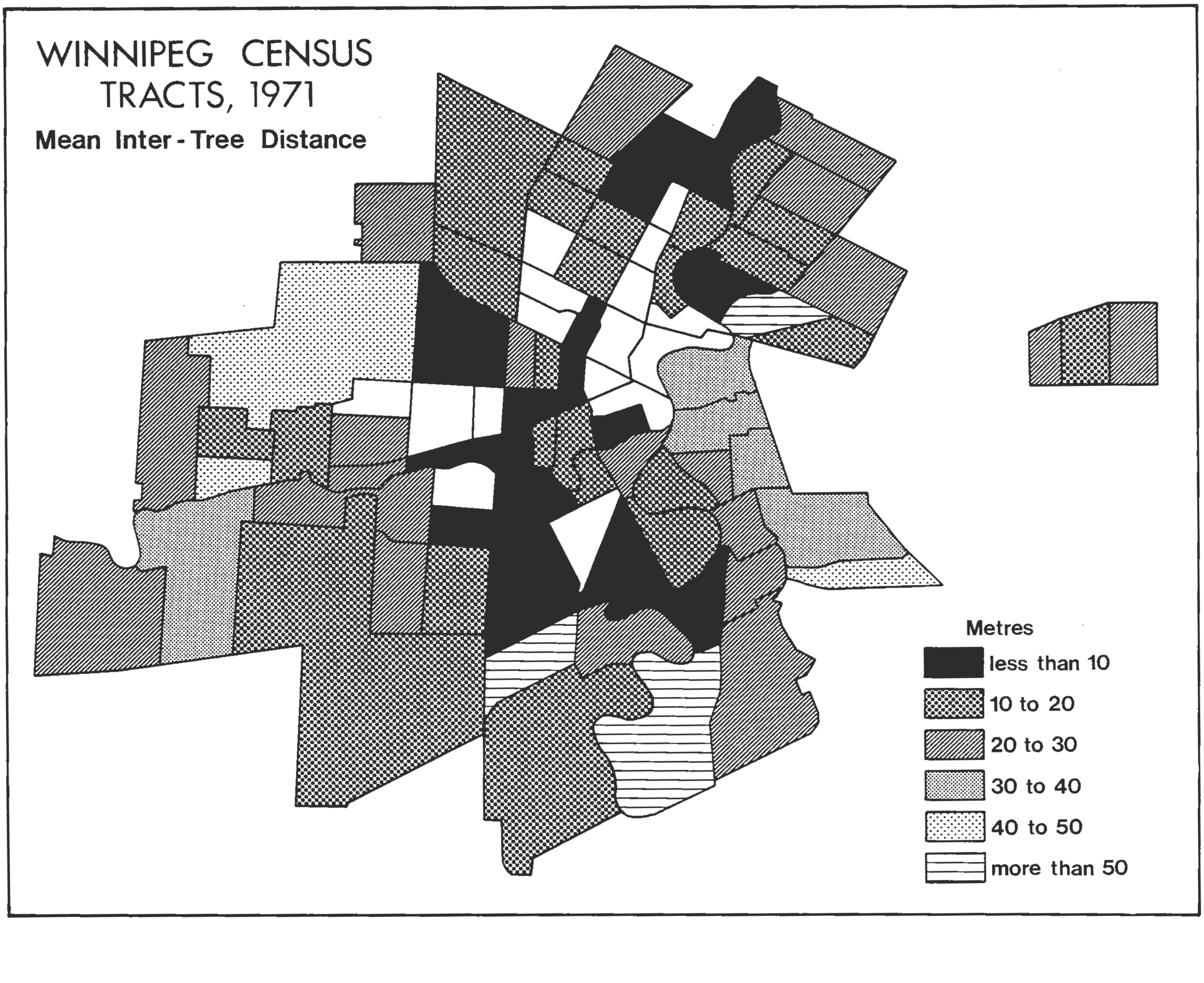
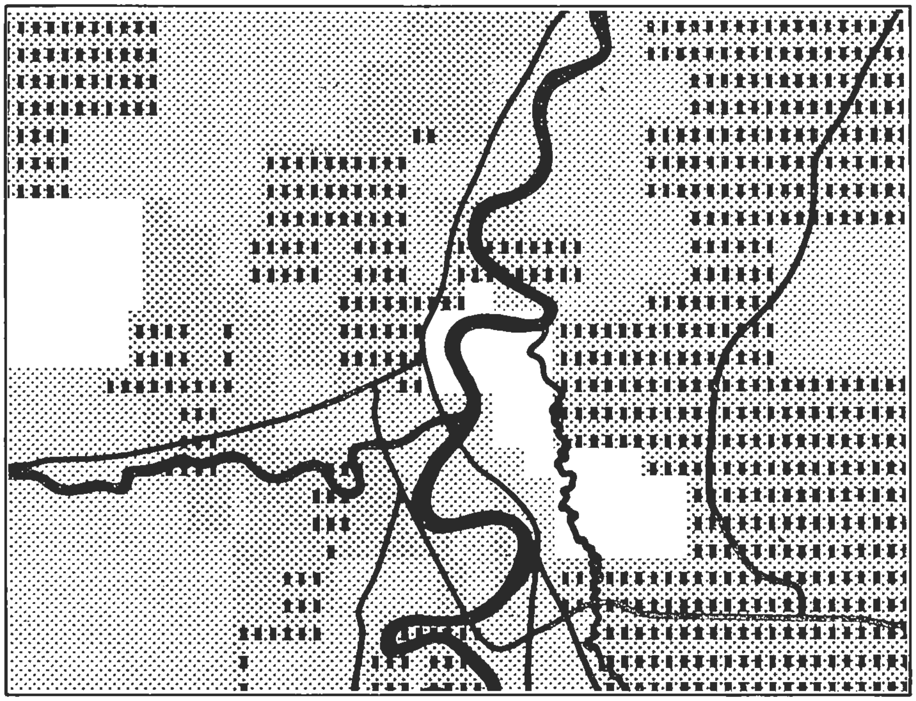


FIGURE 9
TREE COVERAGE OVERLAY



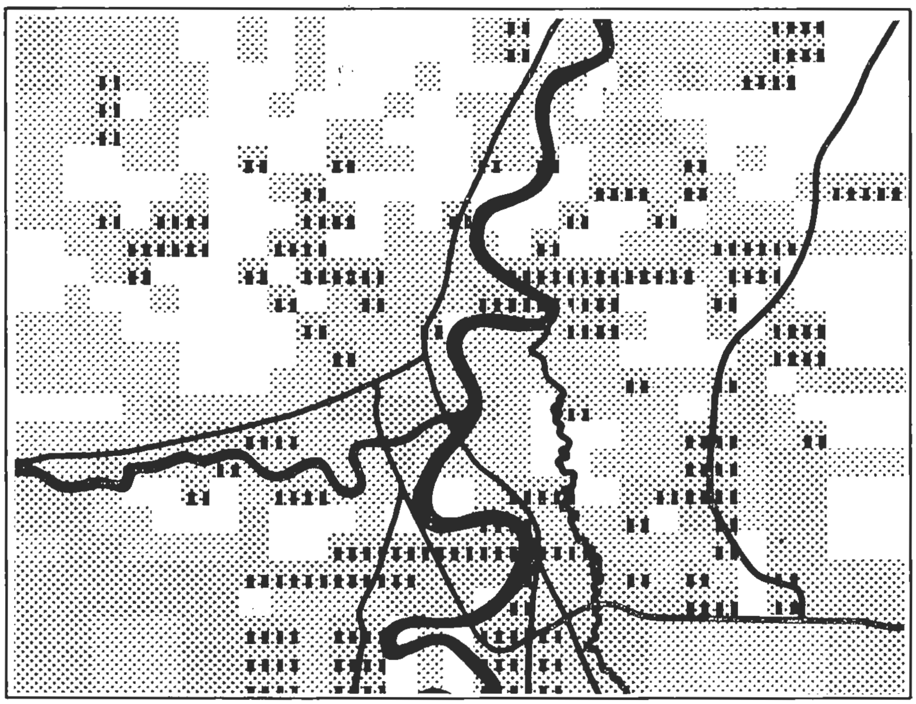
Tree Coverage Overlay

Very Suitable | Suitable
Unsuitable | Moderately suitable

Winnipeg Core - Spot Band 1

FIGURE 10 BUILT-UP AREA OF WINNIPEG.

FIGURE 11
BUILT-UP AREA COVERAGE OVERLAY



Built-Up Area Coverage Overlay

Very Suitable

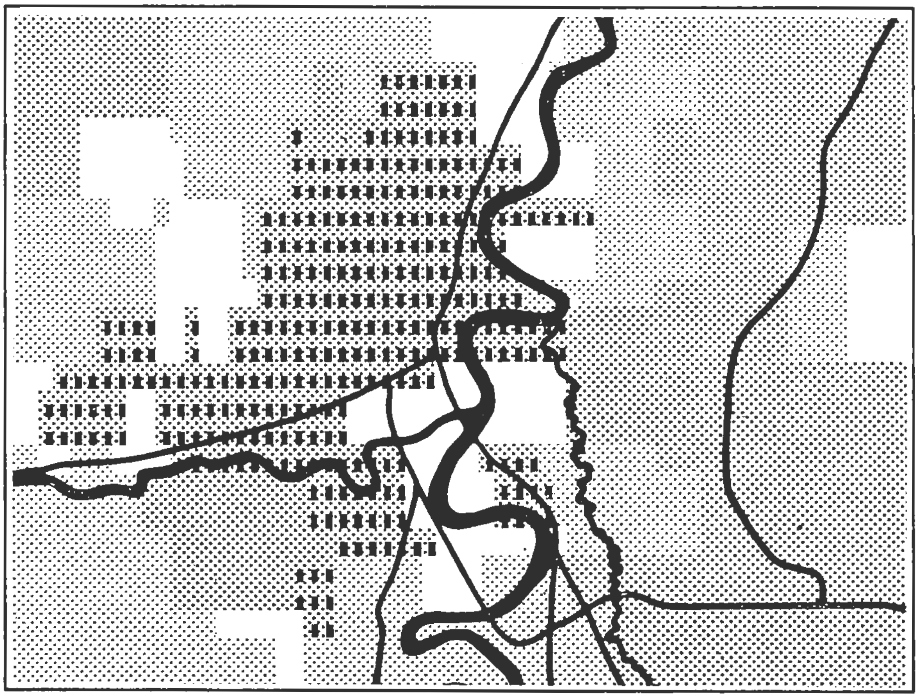
Suitable

Unsuitable

Moderately suitable

FIGURE 12
BIOMASS SPACE IMAGERY OF WINNIPEG

FIGURE 13
BIOMASS OVERLAY



Biomass Overlay

Very Suitable — Suitable

Unsuitable — Moderately suitable

ii. The built-up area index (Figures 10 and 11) measures the change in occupied dwellings, calculated as a ratio of the number of occupied dwellings in 1946 and 1971. Age of the occupied dwellings was obtained from census tract data for 1971 for the City of Winnipeg. The ratio of the number of occupied dwellings in 1946 and 1971 ranges from a low value of 0.01 to a high value of 0.89. Generally, the older the dwelling, the higher the vegetation volume tends to be, particularly in the Prairie region, including the City of Winnipeg.

iii. The biomass index (Figures 12 and 13) measures the organic matter produced by living organisms. This is also known as the greenness or the vegetation index. This index can be used as indicator of growing conditions or vegetation cover. It is measured by subtracting the radiance measured in the visible region from that measured in the reflected infra-red region, dividing then the result by the sum of the radiances in the visible and reflected infra-red regions.

Miller and Moore, (1983) introduced the greenness, or vegetation, index for monitoring growth and the accumulation of herbaceous vegetation in northwestern Arizona. They found that normalized AVHVV NOAA band 1 - band 2 / band 1 + band 2 images provide similar results to normalized MSS Landsat bans 7 - band 5 / band 7 + band 5 images.

Rouse and others (1974) have defined a procedure of monitoring herbaceous green vegetation by computing a transformed vegetation index based on the effect on Landsat MSS of changes in vegetation and land cover.

Deering and Haas (1980) have used a normalized difference index computed by subtracting radiance measured in the visible region from that measured in the reflected infra-red region and then dividing the result by the sum of the radiance in the visible and reflected infra-red regions. The large ND (normalized difference) values represent areas containing higher amounts of standing green biomass.

Gray and McCrary (1981) found a significant correlation (r2 = 0.74) between ND computed using AVHRR data and ND computed using MSSS data.

The biomass index was calculated from digital image analysis of Landsat digital data covering Winnipeg area as follows (Gallo and Daughtry, 1987):

$$\text{Biomass index} = \frac{\text{Channel 5} - \text{Channel 7}}{\text{Channel 5} + \text{Channel 7}}$$

The product of this investigation was arranged into six classes ranging from 1.5 (the most suitable index value), to 6.5 (the least suitable index value).

4. COMPUTER DATA PROCESSING

This chapter shows the sequence of steps taken on the computer in the environmental Zonal evaluation of the City of Winnipeg (Figure 14).

```
C:>MD\WINNIPEG
C:>CD\WINNIPEG
C:WINNIPEG>XCOPY A:*.* C:
C:WINNIPEG>CD\
C:>CD\AMAP
C:AMAP>AMAP
NEW FILE:  NO
FILE NAME:  WINNIPEG
PATH:  C:\WINNIPEG
LIST F10
TREES, GROUND, AIR, BIOMASS, BUILTUP, POLLUTION
DESCRIBE GROUND     F10
1 LOWEST VALUE INDEX
2 VERY DENSE

9 VERY OPEN
10 HIGHEST VALUE INDEX
RENUMBER GROUND FOR E1/
ASSIGN 1 TO 1 THRU 3
ASSIGN 2 TO 4 THRU 6
ASSIGN 3 TO 7 THRU 9
ASSIGN 4 TO 0       F10
LABEL E1  F10
1 UNSUITABLE
2 MOD. SUITABLE
3 SUITABLE
4 VERY SUITABLE          R/R
DESCRIBE AIR   F10
2 LOWEST VALUE INDEX
3 VERY DENSE

8 VERY OPEN
10 HIGHEST VALUE INDEX
RENUMBER AIR FOR E2/
ASSIGN 1 TO 2 THRU 3
ASSIGN 2 TO 4 THRU 6
ASSIGN 3 TO 7 THRU 9
ASSIGN 4 TO 0       F10
LABEL E2
1 UNSUITABLE
2 MOD. SUITABLE
3 SUITABLE
4 VERY SUITABLE     R/R
```

```
1 LOWEST VALUE INDEX
2 LOW POLLUTION
3 HIGH POLLUTION
4 HIGHEST VALUE INDEX
RENUMBER POLLUTION FOR E3
ASSIGN 1 TO 4
ASSIGN 2 TO 3
ASSIGN 3 TO 2
ASSIGN 4 TO 1       F10
LABEL E3  F10
1 UNSUITABLE
2 MOD SUITABLE
3 SUITABLE
4 VERY SUITABLE R/R
COMPUTE E1 PLUS E2 PLUS E3 FOR LSCAPE   F10
DESCRIBE LSCAPE     F10
RENUMBER LSCAPE FOR SCAPE/
ASSIGN 1 TO 3 THRU 5/
ASSIGN 2 TO 6 THRU 8/
ASSIGN 3 TO 9 THRU 11/
ASSIGN 4 TO 12 F10
LABEL SCAPE    F10
1 UNSUITABLE ZONE
2 MOD SUITABLE ZONE
3 SUITABLE ZONE
4 VERY SUITABLE ZONE
DESCRIBE TREES F10
1 < 10 M HIGHEST VALUE INDEX
2 10-20
3 20-30
4 30-40
5 40-50
6 >50 M LOWEST VALUE INDEX
7 NO TRRES
RENUMBER TREES FOR E4/
ASSIGN 1 TO 7
ASSIGN 2 TO 5 THRU 6
ASSIGN 3 TO 3 THRU 4
   ASSIGN 4 TO 1 THRU 2       F10
LABEL E4  F10
1 UNSUITABLE
2 MOD SUITABLE
3 SUITABLE
4 VERY SUITABLE     R/R
DESCRIBE BIOMASS    F10
1 VERY HIGH VALUE INDEX

7 VERY LOW VALUE INDEX
RENUMBER BIOMASS FOR E5
```

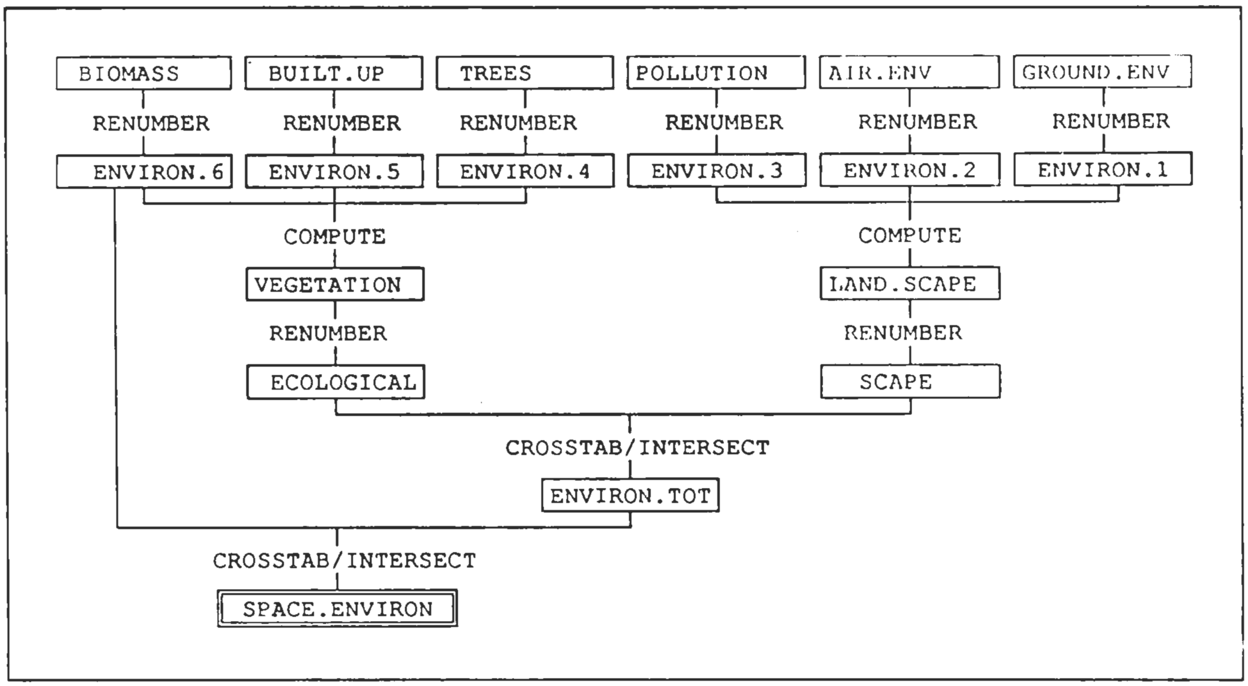
```
ASSIGN 1 TO 7
ASSIGN 2 TO 5 THRU 6
ASSIGN 3 TO 3 THRU 4
ASSIGN 4 TO 1 THRU 2          R/R
LABEL E5       F10
1 UNSUITABLE
2 MOD. SUITABLE
3 SUITABLE
4 VERY SUITABLE          R/R
DESCRIBE BUILTUP    F10
1 NONE         <0.2 OLD/NEW RATIO
2 VERY LOW
3 LOW
4 MOD. LOW     0.2-0.6 OLD/NEW RATIO
5 MODERATE
6 MOD. HIGH
7 HIGH         >0.6 OLD/NEW RATIO
8 VERY HIGH
9 ALL BUILT UP AREAS
10 OPEN LAND    0.0 OLD/NEW RATIO
RENUMBER BUILTUP FOR E6  F10
ASSIGN 1 TO 10 /
ASSIGN 2 TO 1 THRU 3/
ASSIGN 3 TO 4 THRU 6/
ASSIGN 4 TO 7 THRU 9     F10
LABEL E6  F10
1 UNSUITABLE
2 MOD.SUITABLE
3 SUITABLE
4 VERY SUITABLE
COMPUTE E4 PLUS E5 PLUS E6 FOR VEG      F10
DESCRIBE VEG        F10
3 LOW INDEX

12 HIGH INDEX
RENUMBER VEG FOR ECO
ASSIGN 1 TO 3 THRU 5
ASSIGN 2 TO 6 THRU 8
ASSIGN 3 TO 9 THRU 11
ASSIGN 4 TO 12      F10
LABEL ECO           F10
1 UNSUITABLE
2 MOD.SUITABLE
3 SUITABLE
4 VERY SUITABLE          R/R
```

```
CROSSTAB SCAPE WITH ECO       F10
1  1      2    1        3    1         4    1
1  2      2    2        3    2         4    2
1  3      2    3        3    3         4    3
1  4      2    4        3    4         4    4
INTERSECT SCAPE WITH ECO FOR ENVIRON
ASSIGN 1 TO 1 AND 1
ASSIGN 1 TO 2 AND 1
ASSIGN 1 TO 1 AND 2
ASSIGN 2 TO 2 AND 2
ASSIGN 2 TO 3 AND 1
ASSIGN 2 TO 1 AND 3
ASSIGN 3 TO 3 AND 3
ASSIGN 3 TO 3 AND 1
ASSIGN 3 TO 1 AND 3      F10
RENUMBER ENVIRON FOR ENVIRON-1
ASSIGN 4 TO 0       F10
LABEL ENVIRON-1          F10
1 UNSUITABLE
2 MOD SUITABLE
3 SUITABLE
4 VERY SUITABLE          R/R
CROSSTAB E5 (BIOMASS) WITH ENVIRON-1
1  1      2    1        3    1         4    1
1  2      2    2        3    2         4    2
1  3      2    3        3    3         4    3
1  4      2    4        3    4         4    4
INTERSECT E5 WITH ENVIRON-1 FOR SPACE.ENVIRON
ASSIGN 1 TO 1 AND 1
ASSIGN 2 TO 2 AND 2
ASSIGN 3 TO 3 AND 3
ASSIGN 4 TO 4 AND 4      F10
LABEL SPACE.ENVIRON
1 UNSUITABLE ZONE
2 MOD SUITABLE ZONE
3 SUITABLE ZONE
4 VERY SUITABLE ZONE
0 NO CORRELATION
```

REPEAT THE PROCEDURE UNTIL YOU MINIMIZE THE NUMBER OF CELL IDENTIFIED BY 0 BY CHANGING THE RECLASSIFICATION OF THE BIOMASS INDEX FROM THE FORMULA OR THE LEGEND. UPON THE COMPLETION OF CLOSELY CORRELATED MAP THE BIOMASS BECOME RELIABLE MEASUREMENT OF THE ENVIRONMENTAL ZONAL ANALYSIS. THIS PROCEDURE SHOULD BE REPEATED FOR DIFFERENT ENVIRONMENT AND SHOULD NOT BE COPIED.

FIGURE 14

FLOW CHART OF ENVIRONMENTAL ZONAL EVALUATION MODEL OF WINNIPEG CITY



5. RESULTS AND DISCUSSION

The raw data of six selected overlays, representing ground, space, pollution features, tree density, built-up area and biomass, were reclassified into very suitable, suitable, moderately suitable and unsuitable from the environmental point of view, as indicated in the flow chart (Figure 14).

By using the computer-assisted map analysis software package by Berry and Reed (1987), Hathout was able to compile two composite maps: a landscape environmental zoning map (Figure 15); and an ecological environmental zoning map (Figure 16). These two maps were then used to compile a detailed environmental zoning map (Figure 17). This final map consists of all the chosen variables associated with the environment, and should represent a reasonable coverage of the various environmental zones of Winnipeg.

This detailed environmental zoning map is the product of many data manipulations. The authors thus sought some less complex process to achieve the task of evaluating the environment. The biomass index from space appears to be such an alternative method of evaluation for urban environments. This was done by comparing the biomass map with the detailed environmental zoning map. After some digital manipulation and classification of the satellite multispectral imagery, we could relate the various classes from the detailed environmental zoning map with the biomass map. Intersecting the detailed environmental zoning map with the biomass map provided us with the following results:

a. There was very close correlation in the very suitable class between the two maps.
b. There was close correlation in the suitable class between the two maps.
c. There was relatively close correlation in the moderately suitable class between the two maps; but
d. there was little correlation in the unsuitable class between the two maps.

Correlation in the unsuitable class between the detailed and the biomass environmental maps can be achieved by changing the biomass index. This biomass index also needs to be adjusted for each environment, and to each method used to evaluate the environmental zoning system.

FIGURE 15

LANDSCAPE ZONING OF WINNIPEG

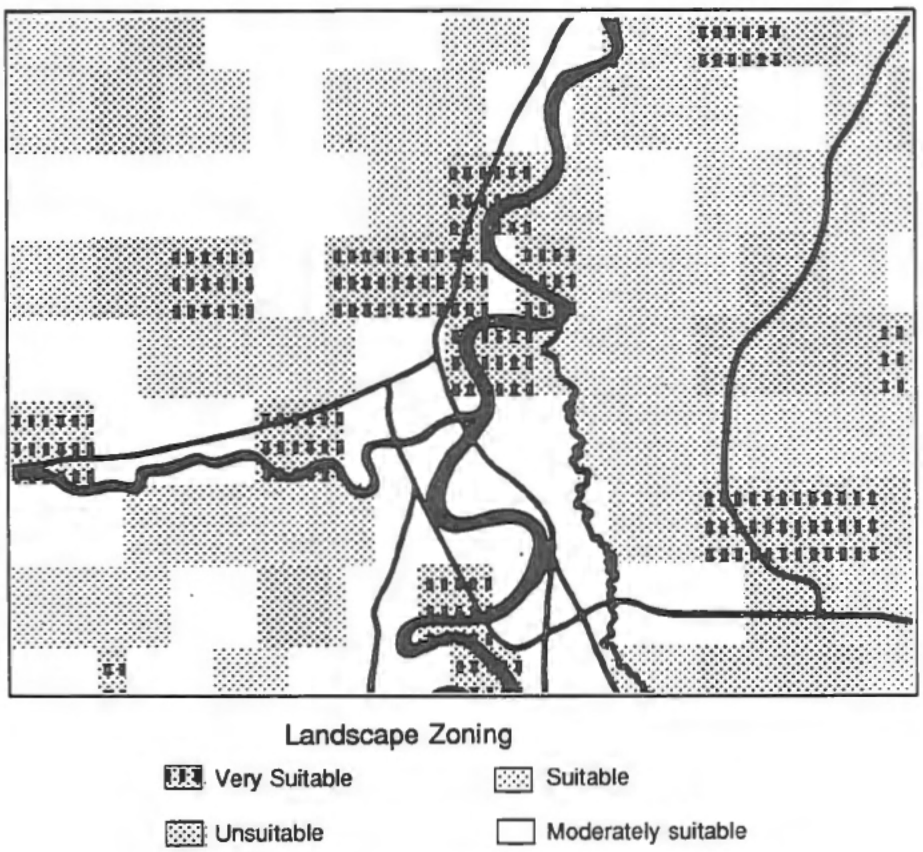


FIGURE 16

ECOLOGICAL ZONING OF WINNIPEG

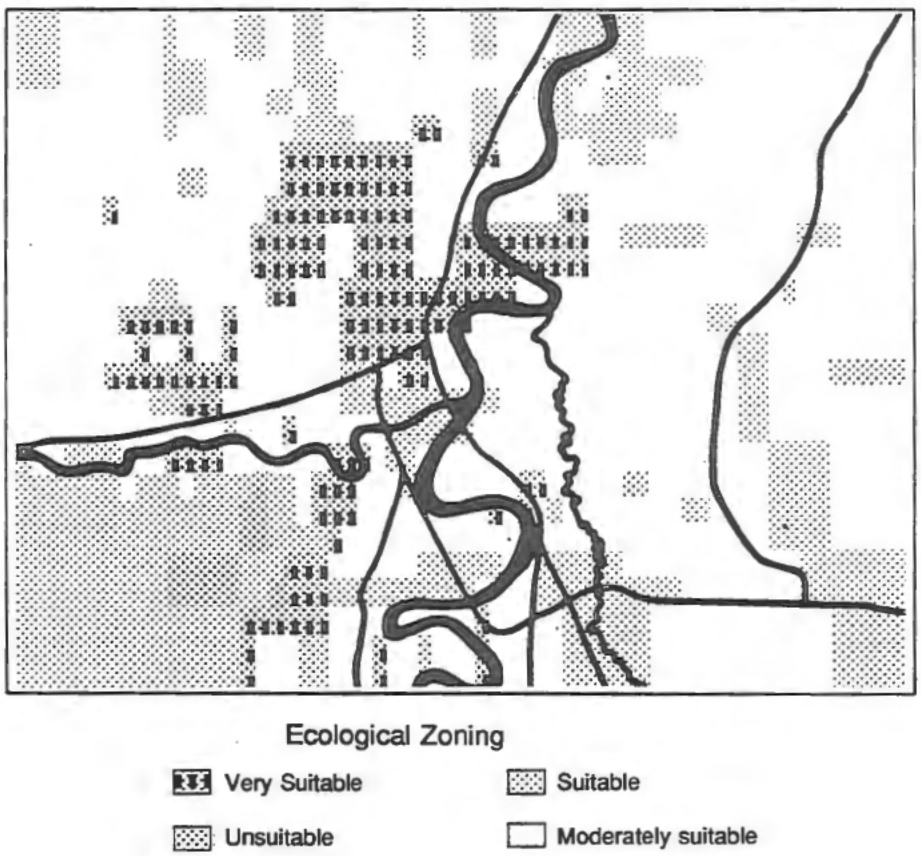
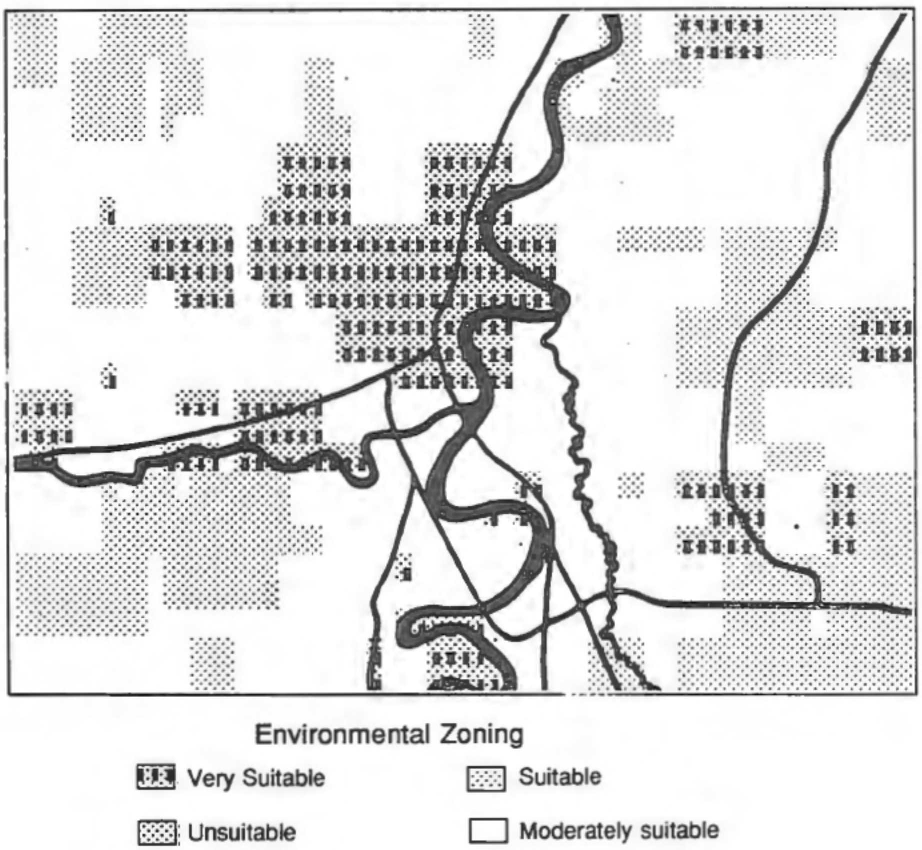


FIGURE 17

ENVIRONMENTAL ZONING OF WINNIPEG



6. CONCLUSIONS

Using cross tab between the very suitable, suitable, moderately suitable and unsuitable classes of the landscape zoning map (Figure 15) and of the ecological zoning map (Figure 16), the Cramers correlation value was found to be 0.12 within a range of 0 to 1. The contiguity coefficient correlation value was 0.203 within a range of 0 to 0.87. Both correlation values indicate weak relationships between the two maps. These results indicate that the variables that are selected for both maps seem to be complementary rather than duplicative, and that they can be used to good effect in compiling the detailed environmental zoning map (Figure 17).

The distributions of the four suitability classes were spread on the ecological environmental map, while they were rather concentrated on the landscape environmental map. However, the two higher suitability classes were found on both maps to be outside the downtown core of the City of Winnipeg.

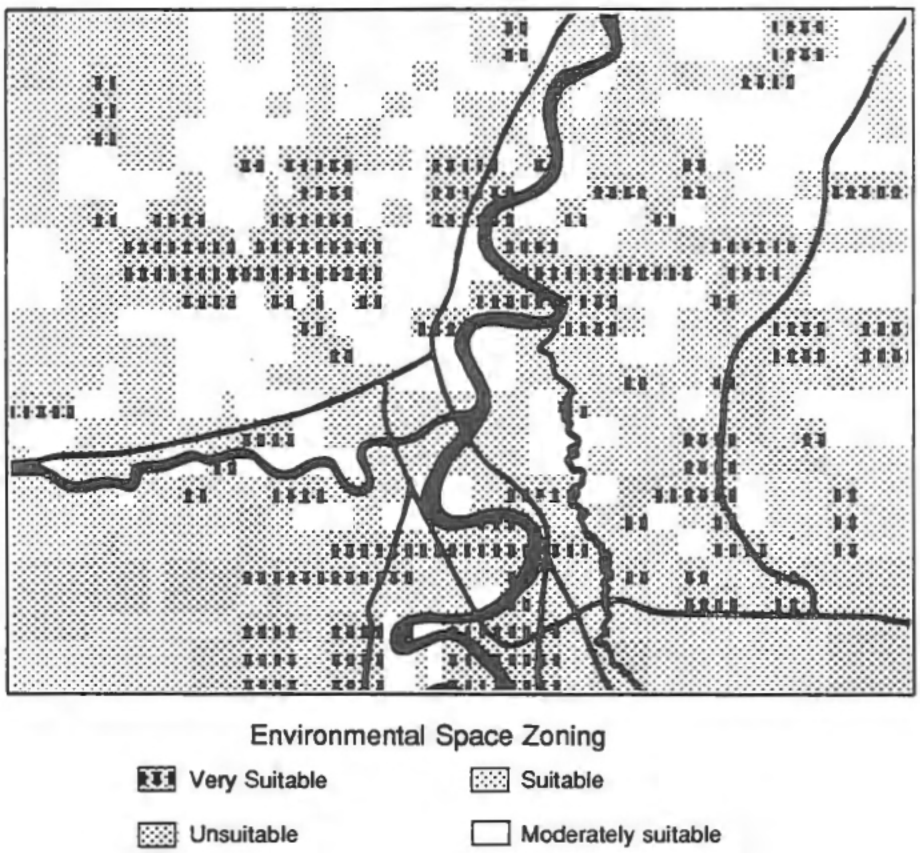
When the detailed environmental zoning map was compared with population age, dwelling occupance age, and population income (maps published by Bell *et al.* and Weir), the result indicated that the unsuitable class was associated with age 65 to 69 population and over 10 year occupancy of dwelling map. People with high income were found to occupy the very suitable environmental zoning class areas while those of low income were not.

Using cross-tab between the four suitability classes of the detailed environmental zoning map (Figure 17) and of the biomass environmental zoning map (Figure 18), the phi coefficient correlation value was 0.41 within a range from -1 to +1. This result indicates a strong correlation between the detailed and the biomass environmental zoning maps. This is not surprising, since both maps are partly derived from the same data sources.

By improving the resolution of the space imagery from 80 by 80 m to 30 by 30 m in the Landsat thematic mapper, or from 80 by 80 m to 20 by 20 m or 10 by 10 m as in SPOT-1 MLA and PLA, one can expect better results than the 80 by 80 m resolution used in this study.

In conclusion, both landscape zoning and ecological environmental zoning maps proved to be complementary in evaluating the environment as reflected in the weak correlation between the suitability classes. Both maps have shown that the majority of the City of

FIGURE 18
BIOMASS ENVIRONMENTAL SPACE ZONING OF WINNIPEG



Winnipeg lies in the moderately suitable to suitable environmental zones which are located mainly along the two main rivers, the Red and Assiniboine.

In contrast, comparison between the detailed environmental zoning map and the biomass environmental zoning map has shown a strong correlation between the suitability classes. Both the moderately suitable and suitable classes dominated the City. It was noticed that the unsuitable class was aggregated in the junction of the Red and Assiniboine rivers on the detailed environmental zoning map, while it was much more spread out on the biomass environmental zoning map, no doubt due to the brightness value of the space imagery. Nevertheless the spread of the unsuitable class in the biomass environmental map can be reduced by using better normalization of spectrum bands as well as by improving the resolution of imagery.

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