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THE DYNAMICS OF URBAN EXPANSION

A MODEL FOR PLANNING

by

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ABSTRACT

The implications of urban expansion as a dynamic, evolutionary process are far from self evident. Such problems as the ecologically sound allocation of land resources and the orderly provision of essential services in urban fringe areas, are not being solved. The importance of the rural-urban land conversion process, in long range planning for metropolitan regions, requires that a method be found for describing the likelihood of the rate, extent and location of urban expansion.

Within this context the study is concerned with firstly, the shortcomings of present methods for examining and forecasting urban expansion. It is pointed out that the regional planner needs to understand the dynamics of land assignment, in the urban expansion process, if he is to know in advance the probable consequences of his actions and be able to fulfil planning objectives. That this elementary point is frequently ignored or misunderstood can be seen in the attempts to prescribe how a process should behave, instead of first trying to discover how it does behave. This is most noticeable where techniques are used which entail optimization or conditional prediction, based on generalized and unrealistic assumptions of human values and behaviour. As a result, the dynamics of change, including the influence of chance events, are usually left unaccounted for in actions subsequently taken. Restrictive zoning is an example, which more often than not seeks to force rather than fit or guide urban development.

Secondly, a simulation model of rural-urban land conversion is developed for the Vancouver Regional Simulation Project, to demonstrate the advantages of experimental strategies and synthetic models in regional planning. The viewpoint is taken that urban expansion can be represented as a spatial diffusion process. When formulated stochastically, spatial diffusion processes account for uncertainty in land assignment practices. The model is organized in a regional systems framework, with structural properties (i.e., thresholds, boundaries, and lags), and feedback interactions represented, to reflect the complex and dynamic nature of urban expansion.

It is emphasized that the future cannot be forecast, on the basis of past and present conditions, with sufficient reliability for long range planning purposes. While it is implicit in the model formulated that emerging patterns of rural and urban land use bear some functional relationships to historical patterns, they are not constrained from evolving into new and different forms. Special attention is paid to change and chance mechanisms to avoid indiscriminate extrapolation of present trends.

The experimental nature of the model is considered its greatest strength. Because it facilitates experimental monitoring and regulation of process behaviour, we are made more aware of critical thresholds and capacity limits within metropolitan regional systems. Consequently, planning policies, compatible with the dynamic urban expansion process, can be devised with greater assurance of their success, and regional planning goals can be achieved more readily. Thus the approach is submitted as a progressive step beyond the traditional reliance on specific predictions as a primary basis for regional planning.

TABLE OF CONTENTS

PART I SELECTING A MODELLING APPROACH

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ACKNOWLEDGMENTS

This thesis is the cumulative product of two years spent at the University of British Columbia. In particular, it reflects courses taken and other assistance received from Dr. Craig Davis, Dr. Michael Goldberg (thesis supervisors), Dr. Walter Hardwick, Dr. Crawford Holling, Dr. Richard Ratcliff, and Dr. William Rees.

Most of the concepts and issues described will be familiar to those who followed developments in geography and regional science during the 1960's, in both Europe and North America. For my training in these disciplines, I acknowledge a special debt to Professor Andrew Learmonth, formerly of the Australian National University and now at the Open University, England.

Finally, the study is often concerned with philosophical and methodological aspects of regional planning. Largely, this concern reflects my reaction to the specialist-technique emphasis in regional planning education. I feel more planners should acknowledge Marshall McLuhan's warning that "the specialist is the one who never makes small mistakes while moving towards the grand fallacy."

Chapter 1

THE PLANNING PERSPECTIVE AND STUDY OUTLINE

Background: And Cities, Just Like Topsy Grew

The fact that most large North American cities have grown continuously over the last fifty years tends to obscure the cyclical nature of urban spatial growth. Recently, however, Malisz (1963, 1969) drew attention to the vacillating conditions of congestion and urban expansion in metropolitan regions and described urban expansion as a process which involved the crossing of numerous successive thresholds. Malisz observed in his studies of cities in Poland that at various stages in the development of urban regions congestion mounted until the pressure created reached a level at which the impediments to urban spatial growth were overcome, allowing a new phase of expansion to take place. The idea of cycles of urban spatial growth is not new; both Geddes (1915) and Mumford (1961) have considered it. According to this view, urban spatial growth is a function of two interrelated processes. On the one hand, increased demands for space are accommodated by concentrating activities and increasing population density through a process of drawing upon unused capacity in the urban system. However, the resilience of an urban system is finite, and after available capacity has been utilized, peripheral growth must take place to accommodate still more people and new activities. Thus the second process, urban expansion, can be recognized as the conversion of rural land to urban uses.

The dual interdependent processes of changing intensity and extent, which constitute urban spatial growth, can only be distinguished with considerable difficulty in actual situations. While in unusual circumstances one process may account for all of the growth in a limited time period, it is more likely that both processes will operate simultaneously; though with varying degrees of prominence. An important and unexplained issue is whether each of these growth processes is a function of different factors.

The pattern of urban spatial growth in the modern metropolis has so far eluded meaningful generalization. Each urban region has its own unique landscape characteristics and these have provided the only distinguishing features at the macro-scale. Apart from landscape influences, urban regions have been described as "a continuous shapeless mass" of urban fabric, undifferentiated except for the occasional green patch or major communication corridor (Mumford 1961 p.618). Both Patrick Geddes (1915 p.26) and Lewis Mumford (1961 p.619) depict the patterns of urban spatial growth in a manner which suggests that urban regions grow randomly. In the words of Mumford (1961),

> . . .as one moves away from the centre, the urban growth becomes ever more aimless and discontinuous, more diffuse and unfocused, except where some surviving town has left the original imprint of a more orderly life (Ibid. p.619) and

> . . .the chief factor that keeps this dispersal from being of an entirely random nature are the expressways and connecting roads that have made it possible (Ibid. p.627).

In addition to the processes of urban spatial growth and the patterns which are produced, there is the matter of the spatial limits of urban regions. Surprisingly, this aspect of urbanization has received little attention from scholars and in most instances the topic is ignored, or for convenience, the assumption is made of an infinite spatial environment (Korcelli 1970 p.134). There is really no satisfactory explanation of the spatial limits of urban regions and the indefinite nature of the urban boundary in the modern metropolis (i.e., the urban shadow or fringe), only adds to the difficulties. While it may be possible to describe the ultimate limits of an urban region, as Mumford has (1961 p.624), by resolving the competing demands of adjacent cities for sustaining resources (e.g. water and land) and finding an equilibrium point for the costs of transportation between these cities, this is not particularly helpful for establishing sequential boundaries through time.

Approaching this same issue from a different viewpoint, Blumenfeld

(1967 p.67) notes that attempts to halt urban spatial growth by prescribing definite boundaries for cities have, since the times of Elizabethan England, been as futile as they were regular. But the growth of cities has been only one of many problems. It seems that the variety of problems connected with urban spatial growth has multiplied as the size and population of urban regions have increased.

Urban Spatial Growth and Planning Problems

Planners are very familiar with a multitude of problems connected with urban spatial growth; in fact, a large proportion of the literature on the subject is directed at the disadvantages of urban sprawl. Given the complexity of urban systems, and a strong tendency for specialized and deterministic forms of thought, it is to be expected that the most easily recognized features of urbanization processes, that is the changes produced, should attract attention. Unfortunately, too few scholars have sought to analyze the nature of the underlying processes, particularly those operating at the urban fringe. Instead, most have merely deplored the emerging patterns from any number of different viewpoints (Leven 1968). Considering that community and regional planning is normally concerned with the monitoring and regulation of ongoing processes (Wilson 1969 p.3) this amounts to misplaced emphasis.

If public media are any indication, there is considerable confusion about the nature and value of urban growth. Metropolitan newspapers, radio, and television present numerous examples of conflicting viewpoints on the growth of cities. For each pronouncement by an "expert" of another problem caused by continuing urban growth, there is an inducement to consumers in the city area to escape to the serenity of nearby "open space communities"; and for every outcry for new controls on growth there is a corresponding demand to encourage new development for the sake of additional employment opportunities.

But it is not only the layman who is confused. Researchers in the social sciences have widely different evaluations and conflicting ideas on what should happen as a result of the spatial growth of the metropolitan area, depending on their values and the particular discipline from which they emerge. Geographers, sociologists, economists, architects, planners, regional scientists and ecologists have all made their contributions. The divergence of research findings and opinions is largely the result of different evaluative approaches to the issue (Haworth 1970). Urban spatial growth and associated settlement patterns are only rarely examined with reasoning free of social values. Consider, for example, the respective viewpoints of Webber (1963) and Lean and Goodall (1966).

Lean and Goodall (1966 pp.187-189) emphasize economic criteria and criticize the inefficient use of resources where discontinuous and sporadic settlement occurs. Harvey and Clark (1965), who voice similar views, imply that misguided public interference with the land market mechanism is largely responsible for "sprawl." To confuse the issue, the Hellyer (1969) report on housing and urban development in Canada, which also criticized urban sprawl as uneconomic and inefficient, called for more public intervention in the land market.

Webber, on the other hand, accepts urban spatial growth processes as the means to a new diversity and stability in communities, arguing that commonly held precepts of city form are outdated. These precepts are based, he claims, on rigid adherence to the separation of land uses, creating monotonous and sterile environments and tend to reflect social values which are no longer relevant.

In yet another respect, the difficulties have arisen partly from consideration of urban spatial growth itself as a problem. Clearly, it is not, for that is to mistake the processes for the changes produced. However, as recent detailed studies, summarized by Lithwick (1970 p.61), tend to show,

> . . .there can be no doubt that the central hypothesis is valid: the major urban problems relate directly to the process of urban growth.

So far these problems have not been spelled out. Sufficient attention has been given to the different problems associated with urban spatial growth in the literature and it would be repetitious to discuss them in depth here. Nevertheless, the main problems that have been documented in connection with the urban expansion process are set down in point form below:

(1) The costs of development, particularly for capital facilities, are higher than seems warranted for the standards of

housing produced (Harvey and Clark 1965, Pearson 1967, Clawson 1971).

(2) Land resources are often allocated to inappropriate uses and organized wastefully (Mumford 1961, Lower Mainland Regional Planning Board 1963, Harvey and Clark 1965, Clawson 1971).

(3) With respect to accepted planning ideals, the kinds of development which occur lack social and aesthetic appeal (Mumford 1961, Lower Mainland Regional Planning Board 1963, Clawson 1971).

(4) The land conversion process has failed to provide land for housing at a rate and cost considered desirable to meet the demands for housing (Mathieson 1970, Clawson 1971).

(5) In many cases, prime agricultural land is removed permanently from the rural sector, displacing skilled farmers and undermining the agricultural economy of the region (Lower Mainland Regional Planning Board 1963, Parker 1966).

(6) The land conversion process operates in a fashion characterized by high levels of uncertainty thus inhibiting effective planning (Milgram 1967, Mathieson 1971).

While all the points are significant, it is probably the last which has the greatest implications for community and regional planning and this study. Planning presupposes an understanding of the subject matter being planned for, and in the past the uncertainty inherent in urban spatial growth was sought to be reduced by collecting copious amounts of data. As will clearly emerge from later discussion, the availability of the data is a far less important problem than the lack of an understanding of the dynamics of urban spatial growth processes.

Urban Growth Dynamics

Considering the large amount of research into urban issues, one could be forgiven for presuming that at least the basic processes of urban spatial growth have been specified. This is not the case; in fact, the whole realm of research into urban spatial growth and structure has been characterized by the haphazard formulation of theory (Haggett 1968 p.65). Moreover, Leven (1968) shows there is still considerable disagreement about the appropriate conceptual approach to studies of urban spatial growth. He strongly criticizes conventional approaches for "their inability to come to grips with the urban process itself" as they proceed misguidedly,

> . . .from various particular points of view not necessarily related to the urban process, but rather hoping to derive an understanding of that process by focussing on a process _within_ or a _particular_ characteristic of the city (Leven 1968 p.12).

Obviously, without first specifying, systematically, the relationships of essential factors in urban growth, there can be little progress towards an appreciation of the mechanics of change. An understanding of the structural dynamics of complex systems is a prerequisite for tracing specific processes to their logical conclusion (Piaget 1970).

The implications of urban growth as a function of dynamic processes are far from self-evident. For example, nowhere in the planning or related literature, to the writer's knowledge, is there a plausible explanation for the different patterns of urban growth which occur under similar social and cultural conditions, while comparable patterns have been found to occur in entirely different social-cultural environments, widely separated in time and space. To illustrate this point. Branch (1962) has described the respective growth and land use patterns for Rome (Italy) and Richmond (Virginia), as a case study in topographic determinism.

Although separated by 2,500 years and more than 4,000 miles, both Rome and Richmond developed in a remarkably similar fashion. Given the initial settlement location of both cities on a navigable river at a point where crossing was not difficult, both spread fan-like, away from the river, while land suitable for urban uses, on the other side, remained relatively underdeveloped. Although the reasons for this similarity of urban spatial growth are not clear, at their respective stages of mature development, both Rome and Richmond had equivalent land use patterns for institutional, commercial and residential activities. Branch attributes these startling similarities to comparable landscape topographies and resources. But one would need to be a zealous environmental determinist to consider the similarities predictable, particularly in view of the divergent technologies, economies and social conditions. It is more likely that a person confronted with this knowledge would ascribe the similarities to chance.

In geographical research, the "chance" element in settlement patterns and processes has received specific attention by Curry (1964, 1966). By assuming that uncertainty is an inherent feature of social systems and a basic fact of life for individuals and communities, he was able to derive an interpretation of the particular settlement pattern which is summed up in the statement:

> . . .where nature shows only a single result, it is interpreted as the historical realization of a process which could just as easily have produced other results according to their attached probabilities (Curry 1966 p.40).

Within the urban realm, this can be interpreted more specifically, as the uncertainty evident in land assignment practices. Land assignment, the process by which land resources are allocated and organized for use by individuals and society, is a function of institutional, social, technological and economic factors (Vance 1971). Viewed circumspectly, it involves the resolution of all the decisions made with respect to land resources by individuals, communities and governments. In the North American context, the complexity of this process has defied all but the most simplistic of explanations. Furthermore, Vance (1971) has observed that currently, land assignment practices are in a state of transition. His study provides evidence that economic forces are weakening and social and institutional factors are becoming more important. Beyond this observation he was only able to conclude that the process operates in an unclear fashion and that its results are generally unpredictable. Curry (1964 p.138) arrives implicitly at the same conclusion, although he is refering to a more general situation when he states that,

> . . .in any general location problem, particularly in a dynamic framework, one cannot begin to comprehend the infinite number of decisions, rarely coincident in time and separately motivated under differing circumstances and degrees of information.

In an earlier study the author had occasion to examine the land assignment practices in British Columbia (Mathieson 1971). The general conclusion reached was that the results of land assignment practices are not only unpredictable, but that the practices themselves are completely disorganized, even where, (as within and between government departments), it was reasonable to expect them to be coordinated. The implications of this situation are more disturbing when it is realized that government decisions with respect to land resources in many areas have a dominant influence, not only on the overall land assignment patterns, but also on economic welfare (Seastone 1970, 1971). There is something ironic in the discovery that the uncertainty confronting planners, many of whom work for the government, is in part due to shortsighted government practices.

On the basis of the foregoing observations, it seems reasonable to draw the tentative conclusion that urban spatial growth, particularly that resulting from the conversion of rural land to urban uses, is characterized by uncoordinated growth and unforeseen change. In addition to emphasizing the dynamic nature of urban growth processes, both features strongly indicate that planners lack an appreciation of the mechanics of change and are still largely ignorant of general urban dynamics.

Furthermore, planners' current views of dynamic urban systems do not paradoxically admit of the further evolution of cities into new and radically different forms. There is a marked predilection among planners to accept as the final state, the basic patterns of human settlement which have existed for more than fifty years and were recognized and described by Patrick Geddes in his classic volume <u>Cities in Evolution</u>. This ignores, in the words of Bertram Gross (1966 p.137)

> . . .a central fact of this century; that the United States [and Canada!] is itself a transitional society in the throes of <u>a great transformation from the last stages of industrialism to the first stages of postindustrialism</u>.

While much larger urban regions may appear to be inevitable, history has shown few aspects of urban evolution to be that certain. Rather than persisting with the extrapolation of past trends, which appears to have no <u>a priori</u> justification, an approach to the study of urban spatial growth processes emphasizing the conditions for structural changes in urban systems is desirable.

The Study Context

The most advanced scientific methodologies have been found wanting, time after time, in promoting an understanding of the modern metropolis. This perplexing state of affairs has attracted the attention of many institutions, such as the Ford Foundation, and they have been funding innovative (and usually expensive) projects designed to improve our research technologies and eventually, our understanding of complex social systems. One such project, currently in progress at the University of British Columbia under the direction of Dr. Crawford Holling and Dr. Michael Goldberg, provided the impetus for this study. The project, called the Inter-Institutional Policy Simulator (IIPS) because of the cooperative nature of the venture, is still in its formulative stages, and is expected to take five years to complete (Goldberg 1970).

Briefly, the Resource Science Centre at the University of British Columbia, in conjunction with the Planning Director of the Greater Vancouver Regional District and Vancouver City Council, is developing a systems simulation model of man-environment interactions in the Vancouver Region, as a tool to assist in planning and policy formulation. Following the development of an elaborate mechanistic representation of the important community and environmental processes, it is intended to experiment with various policies and observe the consequences. It is hoped that our understanding of community and environmental processes and their interdependencies will be enhanced, and as a result, more effective policies can be conceived. The success of this venture will also greatly assist in determining the adequacy of the systems approach as an organizational framework for the investigation of complex systems.

The simulation model combines eight component sub-models covering the following areas: demography, land use, transportation, economics, human ecology, health services, capital service facilities and pollution. The model developed in this study represents the initial contribution to the development of a rural-urban land conversion component model of the larger land use sub-model. The object is not to formulate a general theory of urban expansion, although theoretical aspects are considered at some length, but to design a subject specific model for the particular purposes of examining the process of urban expansion and forecasting rural-urban land conversion in the Vancouver Region.

Study Purpose and Structure

The purpose of the study is twofold: (1) to demonstrate the inadequacies of present methods for examining urban spatial growth processes; and (2) to construct a model of rural-urban land conversion for long range planning, which increases our understanding of the dynamic nature of urban expansion. It is hoped that this contribution will help resolve a number of dilemmas concerning the role of research in the planning process, in addition to throwing light on the evolution of urban regions.

More specifically, in relation to the first objective, the following proposition is examined:

> the dominant urban spatial growth processes are stochastic and are properly represented by probabilistic models.

The argument is advanced that because of inherent uncertainty in the evolution and organization of the modern metropolis, the particular pattern existing at any time can be regarded as the historical realization of processes, which could have produced different patterns, in accordance with the probabilities attached to the process components (Curry 1966). The advantage of this approach, which derives from the basic characteristic of probability theory, lies in the explicit recognition of considerable ignorance about causal relationships in the processes.

In relation to the second objective, and on the basis of the experimental investigations reported in this thesis, it is submitted

> that urban expansion can be described as a spatial diffusion process in which the conversion of rural land to urban uses is directionally random, other things being equal. The probability of rural-urban land conversion is a function of the demand for additional space consequent upon population growth, the level of resilience in urban infrastructural systems, accessibility to urban nodes, proximity to existing development and barrier impediments inherent in the nature of land resources and settlement structure.

Throughout the study, the approach emphasized for understanding complex systems is that of the experimental sciences. Preconceived notions of behavioural motivations are strictly excluded and instead, it is sought to develop concepts and describe structural relationships by seeking order in empirical observations. As a result, the derived functions have a more objective basis than would otherwise be the case if particular behavioural values were assumed. The experimental approach is discussed more fully in the following chapters. For the most part, systems analysis is used to provide the organizational framework.

It has already been noted that most of the planning literature on urban expansion is evaluative of particular settlement patterns, and fails to come to grips with the processes by which they come about. Consequently, this thesis is concerned, more than usual, with the methodology of applied research as it relates to planning, (Chapter 2). Because of the generally haphazard development of urban growth theory and the poor specification of the various processes, the different conceptual approaches to urban growth are examined and compared (Chapter 3). However, it should be clear that only one of the processes of urban growth, that is urban expansion, is of direct concern. The ultimate objective is to develop a model of rural-urban land conversion for the Vancouver metropolitan region, which can be used to increase our understanding of the dynamic nature of the urban expansion process (Chapters 4 and 5).

Although the model is not presented in an operational form, because of time constraints and the lack of computer programming assistance, the approach can be supported generally, by empirical evidence on the nature of the spatial growth of cities. A summary evaluation of the research methodology and comments on the model are presented in Chapter 6.

A Note On Terminology

It became apparent from comments on early drafts that some of the terms used have acquired various meanings and sometimes in different disciplines, conceptual connotations are at odds with the needs of the present study. In particular, "accessibility" caused a lot of confusion. Unfortunately, this term, along with some others used, often appears in the literature and is used imprecisely or ambiguously. For example, Gould (1969 p.64) has observed that "accessibility. . .is a slippery notion. . . one of those common terms that everyone uses until faced with the problem of defining and measuring it!"

To avoid misunderstandings, the practice has been adopted of defining terms likely to be misconstrued, where the concept to which they relate is discussed. With proper deference to the English language, the appropriate Shorter Oxford English Dictionary definition has been preferred over others whenever inconsistencies have arisen.

PART I
SELECTING A MODELLING APPROACH

The Law of the Instrument. . .

Give a small boy a hammer,
and he will find that everything
he encounters needs pounding.
It comes as no particular surprise
to discover that a [planner]
formulates problems in a way
which requires for their solution
just those techniques in which
he himself is especially skilled.

Abraham Kaplan
<u>The Conduct of Inquiry</u>

Chapter 2

MODELS AS STRATEGIES

Although planners have used modelling approaches to problem solving as a matter of course for over a decade, it is still necessary to look beyond the planning literature to discover the full implications of the use of models. The occasional critique of planning methodology from authoritative sources outside planning (Wartofsky 1968, Haworth 1970) as well as the extensive literature on the theory of modelling in other disciplines (e.g. Ackoff 1962, Kaplan 1964, Chorley and Haggett 1967, Bartos 1967), reinforce the opinion that planners still lack a sound philosophical appreciation of the role of models in applied research. Without this appreciation, planners are likely to choose inappropriate research and problem solving strategies for their purposes, for example, a deterministic rather than a probabilistic interpretation of social processes inherently uncertain, or a macro rather than a micro approach to investigating residential location where clearly the diversity of individual decisions is very important. Consequently, in the following, a modest attempt is made to point out theoretical aspects of modelling commonly ignored or misunderstood by planners, through a discussion of the task of defining a modelling approach. In this way it will be possible to arrive at a context in which a particular model is appropriate for the present study.

The Nature and Role of Models in Applied Research

Planning has been described as "essentially anticipatory decision making," in that it is action oriented (Harris 1970, pp. 197-98). This statement is misleading, not for what is said, but for what is omitted. Like most definitions of complex constructs it is imprecise and offers only a partial specification of meaning by trying to identify the thing by one or more of its prominent features. Contrary to the more obvious practices, planning is not just concerned with techniques, tools and tactics for achieving prescribed goals. When referring to communities of people, planning entails a philosophy of social order and strategies for regulating it, in much the same way that planning in business management presupposes as definite form of business organization and process of operation. Thus community and regional planning, insofar as it is concerned with concepts of social order and cultural evolution, is also a behavioural science, and because it is action oriented, problem investigation involves applied research (Ackoff 1962, p.8).

Before proceeding with a discussion of the role of models in applied research, it is necessary to digress and consider briefly, philosophical aspects of community and regional planning methods. This is necessary because of the confusion surrounding the nature of "planning theory," (including the justification of planning methods), which is only too apparent from recent studies (Hightower 1969, Faludi 1970).

Firstly, unlike the natural and physical sciences, planning, to the extent that it is a behavioural science, involves two interpretive functions which need to be distinguished clearly: (i) initially, the components and structure of a process need to be specified for the purpose of understanding its behaviour, and (ii) then, the process is to be evaluated to arrive at a meaning of the behaviour (Kaplan 1964, p.32). Obviously, the order of the two interpretive functions is crucial, for it is not possible to evaluate behaviour which is not understood. This is because the value system inherent in evaluative methods interacts with and becomes indistinguishable from actual process behaviour. That this elementary point has been misunderstood or ignored in studies of urban expansion has already been noted.

Secondly, the methods for understanding behavioural processes are governed by the same methodological norms which regulate the methods for understanding natural or physical processes (Kaplan 1964, p.33). In other words, there are not two kinds of understanding, but different things to understand.* Thus, when it is stated that the methodology in a planning study is defined largely by the problem being investigated and the purpose of the study (Hamilton 1969, p.88), it is implicit that the approach is also

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* For what is meant by "understanding" in this study, see Chapter 6.

subject to the general constraints of logical scientific methods. However, this is not to imply that rigid adherence to accepted methodologies is a necessary or sufficient condition for scientific progress. Rather, as with the conditions for satisfactory (i.e. scientifically acceptable) measurement, methodological justification is desirable for objectivity and ease of comparative evaluation.

It has been suggested that in model building, one of the main objectives is to demonstrate characteristic properties of the particular system being studied (Haggett 1965, p.19). This helps to distinguish models from theories which are more general, conceptually. Barton (1970 p.25) reflects this view when he notes that

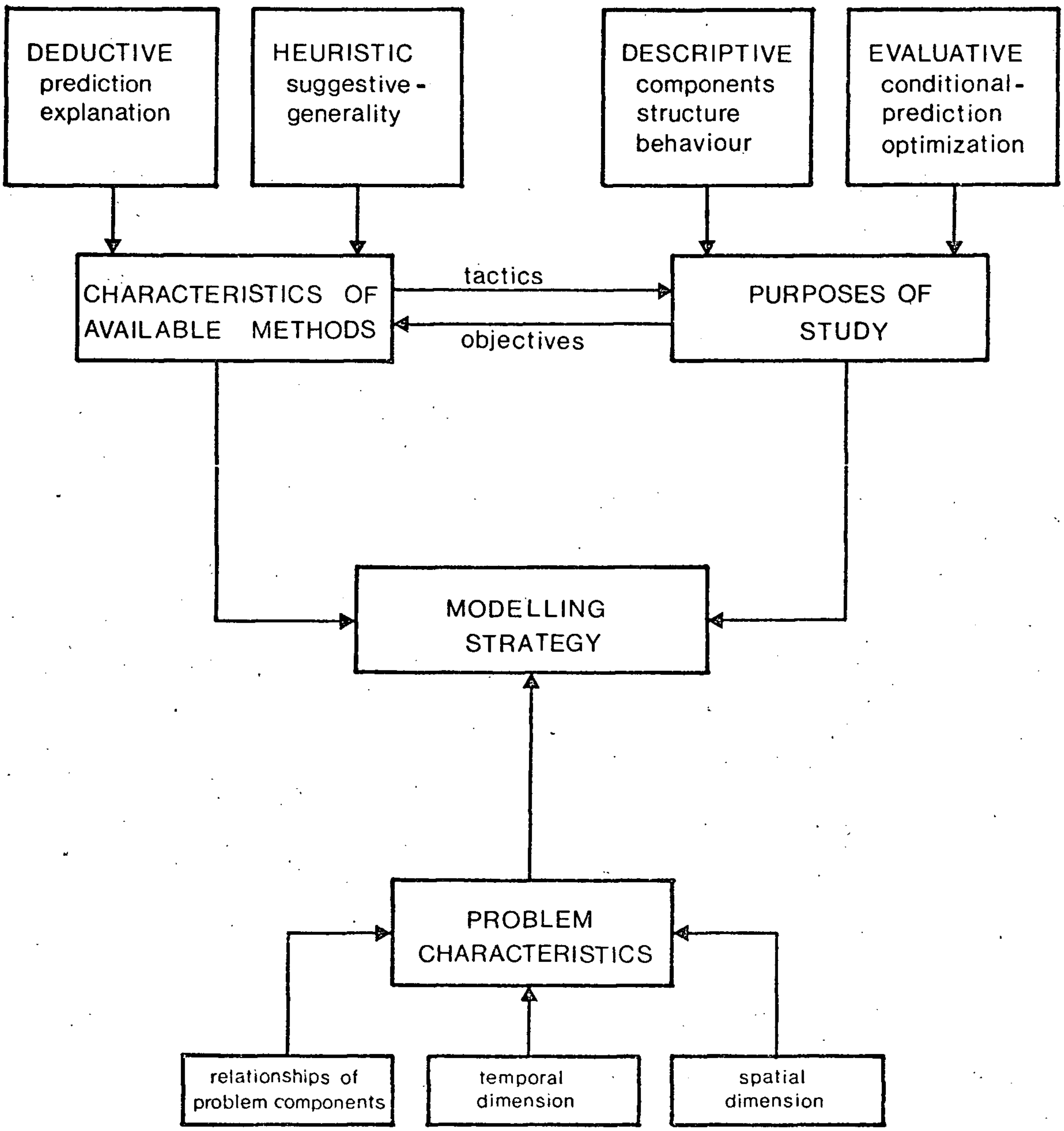
> theories are purposely broad; they try to generalize over many specific cases. This is really an economy of communication so that man does not need to pass hundreds and hundreds of detailed instances from one generation to the next. An object system is one of these detailed instances. To use theory, one must make the generalizations of the theory specific enough to guide the making of observations and the taking of actions. Models serve this purpose.

Because models are really an attempt to conceptualize and extend our perception of specific, complex systems, they are neither true nor false in a literal sense. Thus, the value of a model depends on both the contribution the model makes to our understanding of the system it represents and its usefulness for planning purposes (McMillan and Gonzalez 1965, p.7). From another perspective, models are strategies not only for analyzing processes or systems, but for investigating specific problem situations.

When faced with a particular problem to be resolved systematically, there are several issues one should consider. First of all, it is necessary to be clear as to the reasons for adopting a specific methodological approach. If it is proposed to investigate the problem using a model this means it is necessary to be aware of the characteristics of models to be taken advantage of. Secondly, for reasons associated with efficiency and relevancy of model strategy, the purposes of the investigation need to be explicitly defined. Finally, by combining the reasons for modelling and the study purposes with the problem characteristics, a general statement of model strategy can be derived. In return, the strategy largely defines the type of model needed. It helps in understanding how this is achieved if the reasons and purposes which are set out in Figure 1 are described.

Bartos (1967 pp.319-27) has described two main advantages to be gained from modelling which he refers to as "deductive" and "heuristic fertility." Deductive fertility is a function of three characteristics: (i) the model's ability to reflect the nature of real world phenomena, (ii) the manner in which it promotes understanding of process behaviour, and (iii) its ability to allow predictions about future states of the process. Heuristic fertility arises from the suggestive nature of models in that a successful model stimulates new observations, experiments and conceptualizations. Synthesizing the reasons for modelling, deductive fertility in a model is its successful abstraction of a specific process or system, while heuristic fertility refers to the extensions that can be made to more general situations.

FIGURE 1 DEFINING A MODELLING STRATEGY



The kinds of objectives the model builder is likely to have in mind can be classified according to whether they entail evaluation or description of process behaviour. Generally, evaluation involves the prescription of how a model process should behave on the basis of an assumed or inherent value system, while the description of a model process is a representation of how it does behave. Because evaluative models are normally concerned with alternative solutions, quantitative measurements of variables involved in the process are usually necessary. However, even if valid, comparable measurements could be taken, unless the process components and their relationships have previously been specified satisfactorily, there is no guarantee the variables measured are relevant indicators of process behaviour. Moreover, there are great difficulties in ascertaining relevant social indicators (Etzioni and Lehman 1967).

While Britton Harris (1968) seems to imply otherwise, not all models need to be evaluative to be useful in applied research and thus in the planning process. In fact, there is a growing tendency for descriptive models to be used, especially

> . . .as educational instruments which serve to bring to the consciousness of those who make decisions the complex interrelations among the variables, including those which can be manipulated for normative purposes. (Alonso 1968 p.253).

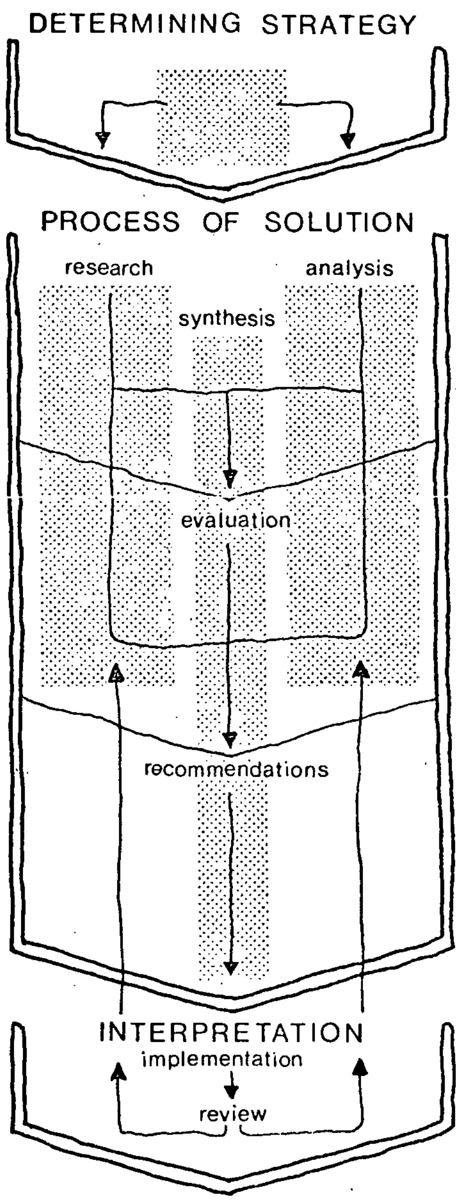
With the recognition that too little is known about social processes and system behaviour, more attention is being given to the merits of purely descriptive models which stimulate greater specification of structural relationships within systems. Hence, instead of spending large sums of money and considerable effort collecting detailed statistics of possibly inappropriate entities and suspect variables, the main issue becomes one of describing component interaction within the system. Afterwards, the model can be tested to determine the sensitivity of components and a subsequent decision made on the need for more detailed data.

Objectives requiring evaluative models give rise to another related issue concerning values and their role, not only in the planning process, but in model building. Because the planning process, especially as it concerns decision making, involves altering ongoing social and economic processes in order to satisfy certain goals (Wilson 1969 p.3) it is heavily value laden (Davidoff and Reiner 1962, Wartofsky 1968, Haworth 1970). It has been demonstrated, on the other hand, that models can be devoid of these same values and still be of considerable help to the planner. Thus it is imperative the model builder state at the outset, the purpose and role of his model in the planning process, possibly by reference to the criteria shown in Figure 1. Inadequate attention to this issue can lead to ambiguity and frustration for all concerned with interpretation of the results, as the history of land resource evaluation models shows only too clearly (Mathieson et al 1972).

To return to our objective of selecting a modelling approach, it can now be demonstrated, by linking the reasons for modelling, study purposes and problem characteristics, that the general type of model needed is prescribed by the model strategy. Once again models of urban expansion can be used for illustration. Traditionally, this process has been approached from one of two viewpoints. Either a micro-analytical market model has been used with urban expansion represented as a function of the aggregate pattern of individual decisions or a macro-analytical gravity analogue has been used in which new urban development is shown to occur to minimize the frictional effects of distance. Neither approach has proven successful for the long term prediction of urban shape and size for reasons outlined by Lowry (1965) and Brindle (1970). Consequently, a model builder faced with the problem of forecasting the rate, extent and location of future urban growth and determining an optimal growth strategy does not have an adequate theoretical base on which to build a model. Because he cannot be certain of the nature of the component processes, neither can he be sure that an intuitively developed evaluation model will produce results reflecting his objectives. Thus it is necessary to begin with a descriptive model and omit, (for the time being at least), value laden assumptions such as rational behaviour of individuals, until a reasonable specification of system behaviour has been made. While this descriptive model could provide the rate, extent and location of urban expansion as a result of ongoing processes, it is necessary, in order to find optimal growth strategies, for the model builder to introduce evaluative functions consistent with his goals, (e.g. least cost, greatest net benefit, or similar criteria). Here the information provided by the descriptive model becomes input for the evaluative model as shown in Figure 2.

In Figure 2, the regional planning process is represented, using a

FIGURE 2 THE REGIONAL PLANNING PROCESS



Nature of Problem
Objectives
Methodology

Representation
of Processes
and Systems

Delineation of
Alternatives

Resolution of
Alternatives

Decision
Implementation

Monitoring Results
Re-assessment
of Problem

Source Scottish Development Department (1968) flow diagram, as a relatively complex system with three main parts: (i) determining study strategy, (ii) process of solution, and (iii) interpretation. In the first part, the nature of the problem, objectives and methodology are outlined, hopefully with reasons for selecting a particular approach. The second part consists of three stages; initially, the subject process or system is specified, then, alternatives are delineated by evaluative procedures and finally, the alternatives are resolved according to whatever value system is chosen. Thus there is a logical solution process through synthesis of the various component processes specified, to evaluation and then recommendations. In the third part, the decision is implemented and results monitored and relayed back into the system. Hence it can be seen that the regional planning process is a synthesis of a large number of interacting and very different sub-models. The particular model suited to any part of the planning process depends on its role and purpose in the process.

Types of Models

The number of possible modelling strategies, in practice, is virtually unlimited, a fact more apparent when different possible combinations of the dimensions of models are considered. Listed below are some of the different dimensions used to categorize models which can be found in the literature, (see particularly Ackoff 1962, Lowry 1965, Chorley and Haggett 1967, Bartos 1967, Harris 1968, and Walters 1971). The form of presentation used, a sequence of dimensional dichotomies and antimonies, is adapted from Britton Harris' (1968) review of quantitative models and their role in metropolitan decision making. Unfortunately, his review purposely omits discussion of descriptive models (Ibid p. 363) without acknowledging their role in the planning process. Consequently, the review represents only a part of the picture and as a result, often leads to misunderstandings about the nature and merits of some modelling approaches. In an attempt to correct this situation, I have included several new dimensions and where necessary, made changes in existing dimensions and their terminology.

1. symbolic - iconic
2. descriptive - evaluative
3. synthetic - analytic
4. macro - micro
5. dynamic - static
6. probabilistic - deterministic
7. holistic - partial
8. process - compartmental

1. Symbolic-Iconic Models

All models are representations of phenomena but not all are abstractions. Here lies the distinction between iconic and symbolic models. Iconic models represent the same properties at a different scale, they look like what they represent (Ackoff 1962 p. 109). The physical representation of the relevant properties in the architect's design of a building and the planner's relief model of a landscape are iconic models. Symbolic models are representations by abstraction, by the use of symbols. When conventional mathematical symbols are used the model can be most easily manipulated (Ackoff 1962 p.10). This classification has been included for the sake of completeness and the remainder of this review is concerned only with symbolic models.

2. Descriptive-Evaluative Models

The difference between descriptive and evaluative models relates not to their form but to their function as perceived by the model builder (Bartos 1967 p.299). Descriptive models are representations of what has or will happen as a consequence of the operation of specific processes, in that they attempt to mimic real world phenomena. Evaluative models attempt to stipulate how change should occur on the basis of an assumed or inherent value system (i.e. they involve conditional prediction). Accordingly, they prescribe how a model process should behave, other things being equal, not necessarily how it does behave. To illustrate this point, in the initial formulation of the IIPS project, there was a conflict of opinion whether the model should seek to optimize certain social goals and values (evaluative approach) or seek only to mirror ongoing processes in the Vancouver Region (descriptive approach). It was decided that the descriptive approach would be adopted (IIPS Serial No. 18, 1970). Sometimes the term "normative" is used instead of "evaluative," to refer to the class of models described. However, as Wartofsky (1968) points out, all models are normative (dependent on values) in that they are chosen for some purpose in mind, even if that purpose is only to aid the understanding of a process or system. Thus it is desirable to avoid the use of "normative" in this respect.

3. Synthetic-Analytic Models

Whether a model is synthetic or analytic depends upon the methodological process required to arrive at a solution (Lowry 1965 p.162). For most modelling purposes the two terms are synonomous with inductive-deductive systems of problem resolution, respectively. Analytic models proceed by way of a process of logical deduction to arrive at a discrete solution, while synthetic models follow a step-by-step procedure to "construct" as it were, the general solution (Forrester 1968 pp.3-5). It is for this reason that simulation models, which are one form of synthetic models, have been referred to as "experiments" (Barton 1970 p.29).

When a process can be represented mathematically and solved analytically, it is usual to do so. However, often a mathematical statement of a situation cannot be resolved because it is intractable, in which case synthetic models sometimes referred to as iterative models, are employed (Lowry 1965 p. 162, Hamilton 1969 p.95). It was the intractability of certain mathematical problems concerning the atomic bomb that led to the development of Monte Carlo simulation during the 1940's (Barton 1970 p.138). By representing the mathematically unsolvable parts of the problems with stochastic processes, and by using probability theory, solutions were obtained indirectly through repeated experimentation.

4. Macro-Micro Models

The level of aggregation of entities in a population determines whether a model is macro or micro (Lowry 1965 p.160). In macro models the properties of collectives or total populations are used to reflect process behaviour, for example, the growth force models* of urban growth based on gravity analogues, are macro scale models. On the other hand, micro models focus on the behaviour of individual entities in a population. Economic models based on the assumed rational behaviour of individuals within a market mechanism, which seek to optimize the allocation of resources, are examples.

There is still considerable disagreement of the relative advantages of each approach and Goldberg (1970 p.3) has claimed that bridging the macro-micro gap remains one of the most important unresolved problems in modelling metropolitan development. Lowry (1965 pp.160-61) who prefers the macro approach, and Harris (1968 pp.373-75) who takes the opposite view, provide details of the respective positions.

5. Dynamic-Static Models

The feature element of this division is the treatment of process operation through time. Dynamic models concentrate on the changes brought about through the operation of processes, or variance in process components and functions, through time, while static models focus on equilibrium conditions of structural features in the past, present or future (Echenique 1968 p.13). Regional land use plans, based on a series of social, demographic and economic projections, and showing the proposed "optimal" allocation of resources at some future date, are essentially static models. Regional land development models, describing changes in land use over time, as a result of

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* In Growth Force Models "the dynamics of human behaviour and urban growth are based on assumptions about social forces rather than individual decisions" (Kilbridge et al 1970 p.15).

population growth, increased economic activity and the like, are dynamic models.

6. Probabilistic-Deterministic Models

The outcome of a process can be viewed as (i) a function of chance events, which could have produced a quite different result, or (ii) as a function of specific cause and effect relationships between events which could produce only one result (Curry 1966 p.40). Models reflecting the former view, and representing processes as stochastic, are probabilistic models, and successive runs of the model can produce varying results (Springer et al 1967 p.37). By comparison, deterministic models assume an understanding of causal relationships within a process, to arrive at predictions of single unique outcomes or changes as a result of process operation.

The variable results generated by probabilistic models do not mean the methods for handling stochastic processes are conceptually imprecise; on the contrary, they allow forecasts of process behaviour with very specific probabilities attached (Bartos 1967 p.8). Whether the use of either type of model is suitable or necessary in a particular case is indicated by the nature of the process being modelled and the purpose for which it is needed (Harris 1968 p.378).

7. Holistic-Partial Models

Each process or system can be represented by a number of components or subsystems and the manner in which this is done in a model determines whether it is holistic or partial (McMillan and Gonzalez 1965 p.9). A holistic model represents all components and subsystems and their interactions, to provide a general picture of the system's total behaviour. A partial model seeks to provide a detailed picture of specific parts of the system (Harris 1968 p.371). Thus the focus of the model builder, the number of variables determined outside the model and the purpose for which the model is needed, all indicate whether a model is partial or holistic. For example, if the Vancouver metropolitan region were the subject system and a model was required to generate the rate, extent and location of urban expansion, then one approach would be to focus on the rural-urban land conversion process and enter variables such as population growth and economic development, exogenously. This would be a partial model because essential structural components of the process were being determined independently of the model. However, if a model of the metropolitan area were produced with all the pertinent processes generated endogenously, as is being attempted in IIPS, then it would be a holistic model.

8. Process-Compartmental Models

This dichotomy reflects an emerging consciousness on the part of model builders between structural and aggregative methods of model building, and the different ways they reflect wholeness, transformations and regulation within systems (Piaget 1970). Compartmental models, adopting the aggregative approach, seek to represent systems as a composite of elements that are viewed, initially at least, independently of the total system and described in terms of history, morphology and function. Process models, adopting the structural method, seek to represent systems by the interactions or relationships (i.e. processes) linking component elements (Walters 1971 pp.285-92; Holling 1972 pp.5-9).

To illustrate the different methods, consider again the problem of modelling urban expansion. One common compartmental approach, economic market models, requires urban land uses to be segregated into functional categories; residential, commercial, industrial, institutional and open space. Future land requirements for each activity can be generated according to individual "rent ceilings" and historical locational preferences. Aggregation of each sector's land requirements represents the pattern of urban expansion. Alternatively, a process model would focus on the interactions of key component elements in the rural-urban land conversion process. A model relating the dispersal of urban development to the interplay of centrifugal and centripetal forces governing location would be a process model.

There is another dichotomy used frequently by planners in connection with models which relates to their predictive or explanatory nature (Lowry 1965 p.159; Alonso 1968 p.253; Kilbridge et al 1970 p.11). If I understand the import of this division correctly, then it appears that there is either considerable misunderstanding among planners concerning the nature and purpose of models, or that this particular use of terminology is ambiguous and to be avoided. "Explanatory" is generally used in these discussions in the sense of describing process behaviour in a similar way to that of descriptive models above (i.e. to represent operation and interaction of process components) while "predictive" is used to describe the ability of the model to arrive at conclusions of what will happen in the future. In fact, descriptive models are often used to provide forecasts of future states of the process or system and thus they are also predictive, in the sense that they are unconditional predictors (i.e. not constrained by value inputs and goals). What is generally implied when predictive models are referred to is that the prediction is conditional upon (i) a particular event occurring, for example, the implementation of regulating policies, public development and the like, or (ii) a prescribed value system, for example, by optimizing resource allocation on the basis of assumptions of rational behaviour. Thus conditional predictive models are evaluative models.

A final note on terminology is appropriate. There are frequent misunderstandings concerning the meaning and proper use of the terms "predict" and "forecast." Work (1968) in an excellent summary paper of the steps in decision making, chose to distinguish the terms in the following way:

> . . .forecasting is the process of stating an estimate of what one expects to occur in the future. Hopefully, this statement also contains information pertaining to the uncertainty of the estimate. Prediction, on the other hand, connotes stating what will occur in the future. Prediction is the province of the omniscient; forecasting is the province of (among others) the decision maker. (Ibid pp.16-17)

While Work's distinction is supported generally by dictionary definitions of the two terms, common usage tends to equate them. It seems that both are satisfactory, so long as it is clear that neither term is without qualification as to the degree of error when used in connection with modelling.

Causality and Chance: Accounting for Uncertainty

When little is known about the behaviour of a particular process, or when component elements of a process fluctuate inexplicably, the model builder is faced with the dilemma of how to account for uncertainty. At first, it may not be known whether the uncertainty is a function of elements essentially random by nature or due to incomplete information about the process. The situation is further confused by the knowledge that the aggregate pattern of a multitude of chance events may be ordered behaviour with an apparent causal explanation, and alternatively, that the interaction of independent and individually determinate events may result in random patterns (Bunge 1963 p.194).

There are some situations where observations of a particular process can be repeated under similar conditions but where, however rigorously uniform conditions are maintained, irregularities occur in the operation of the process and the change produced is still variable. In this case it is highly likely a component element is inherently random. Usually, however, it is not possible to observe the same phase of process operation repeatedly under controlled conditions, in which case experiments with models may provide clues to the nature of the process.

In applied research where the problems are more urgent, the issue is far more critical because action cannot be delayed indefinitely. But to ignore the uncertainty may be to ignore the proper nature of fundamental causal relationships. Sometimes it is felt that process behaviour has been adequately explained and structural relationships properly specified. In this situation, the treatment of uncertainty is relatively simple. A deterministic model can be used with the components provided with different values in each run of the model, (representing their probability range), to arrive at high and low outcomes, or optimistic and pessimistic future states of the process (Barton 1970 p.121). This is the technique of incorporating uncertainty in a deterministic framework. It entails the assumption of knowledge of causal relationships within the system being modelled.

More often than not, planning involvement with urbanization processes and regional development requires the modelling of systems which are imperfectly understood. In these circumstances it would be better to approach the problem acknowledging ignorance. This is the primary merit of probabilistic models, they do not require or assume the specification of causality within the model process (Curry 1966; C. Harris 1968; Barton 1970). The outcome is viewed as the realization of a stochastic process which could have just as easily produced a different result according to the probabilities attached to the component elements. This viewpoint is not difficult to grasp when it is appreciated that the basic entity in social processes, at least to the planner, is the human individual, (although normally treated in the aggregate). It is all the decisions made by individuals and institutionalized groups of individuals that result in changes in social systems. Because the absolute number of decisions involved in all but the most microscopic systems is enormous, and because of the incredibly diverse factors influencing these decisions, we are only just beginning to describe some basic decision forms (Isard 1969). We are still a long way from an understanding of causal connections in social systems that account for elementary decision processes, possibly for the reasons given by Bunge (1963 pp.194-197) which were noted earlier. Therefore, it seems eminently reasonable to suggest probabilistic modelling approaches to many of the problems confronting regional planners.

However, what appeared to be a logical trend in this direction has been criticized as fadish and counter-productive (Harris 1968 p.318). As the critic, Britton Harris, is one of the more prominent and respected advocates of modelling in urban planning, it is fitting that his criticisms be answered.

Harris argues that while there will always be chance elements in the patterns and processes of urban phenomena, the construction of models involving stochastic elements does not necessarily preclude the use of deterministic models. He allows of very few exceptions to his doctrine. For example, he claims that uncertainties arising out of human behaviour, particularly technological change and important decisions concerning the urban structure, (e.g. important communication links), should remain outside the model to be entered as inputs at the discretion of the investigator. Other uncertainties resulting from inconsistent behaviour, even those inherently random, should be included in the model as probabilistic statements of the error of measurements but within a deterministic framework. It is significant to note that this attitude corresponds to early views on the nature of indeterminism in science which are notlonger generally supported (Neyman 1960).

In his criticism of probabilistic models he seems to be saying that their outcomes are of little or no practical interest as such because they represent chance distributions which are difficult if not impossible to replicate. Consequently, they are difficult to relate to the planning-decision process. Further, they involve treating many phenomena as randomly motivated when in fact they may not be. On the other hand, the overriding advantage of deterministic models, (note that Harris is only considering evaluative models), is that they provide optimal solutions, on the basis of the information used, which can be demonstrated repeatedly.

Harris has raised two issues; firstly, he considers that the objective of modelling is predominantly to generate results (conditional predictions) which are both reliable and repeatable as an experiment, and secondly, he has questioned the treating of man's behaviour and activities as random.

In relation to the first issue raised by Harris, it is a short-sighted perspective of urban and regional problems which considers the reliability of a model's predictions in a unique case as the primary measure of its value, although at a particular stage of the planning process this aspect may appear to overwhelm all others in the eyes of planners. The ability to predict does not, by itself, provide solutions to urban problems. For example, even when it is known that urban expansion will occur, or is very likely to, the responsible decision making body is often unable to avert what may be perceived as the undesirable consequences, for a number of reasons. A satisfactory solution may not be known; constraints imposed by the cultural-institutional framework may effectively preclude implementation of a policy at the appropriate spatial-temporal dimension believed to be a solution; or it may be considered pointless to implement a policy known to be effective because it has indirect consequences considered just as undesirable as the original problem. It is implicit in the search for solutions to planning problems that the process is understood and can be regulated. The control and regulation of dynamic processes and systems is dependent, as McLoughlin (1969) has pointed out, upon knowledge of how they operate and the way they react to different intervening policies. Moreover, this argument does not take into account the fact that planners are continually being frustrated in their efforts to avert problems, such as those resulting from urban growth processes, because of the unexpected, chance elements in the evolution of communities and their environments that no one could have foreseen on purely scientific or rational grounds.

Notwithstanding, Harris' viewpoint ignores an elementary but nonetheless crucial aspect of scientific and planning philosophy which is inherent in the continuing drive for greater verification of general theories. Models in this respect are merely mental props necessitated by the number and complexity of variables being handled. Apart from the model's predictive ability, the model building approach provides an excellent opportunity to gain insight into the processes at work, in the system being studied, through experimentation. This quality has already been discussed and was referred to as the model's heuristic fertility. As a result, decision makers and model builders develop greater insight and become capable of asking better questions with their new found appreciation.

More importantly, Harris is to be criticized for supporting deterministic modelling approaches in situations where it is clear the process or system is imperfectly understood. Acknowledging limited understanding of relationships within a system on the one hand, and then assuming they have been correctly specified in the model, (inherent in the deterministic approach), on the other, is contradictory and amounts to a logical inconsistency in the methodological approach. Herbert Simon alludes to this point when he notes that:

> . . .the use of modelling in planning requires that the important features of system structure be already known--that is, that the basic research job has already been done. For this reason, the most serious limits on the use of modelling in planning today are limits on our understanding of system structure, not on limits on our data about the state of the system (Simon 1968 p.367).

The second issue can be clarified by reference to Gordon (1969 p.85) who points out that there are three cases where activity or behaviour can be legitimately treated as random for modelling purposes: (i) when the activity is random by nature, (ii) when the activity, although not random by nature, is poorly understood due to a lack of information about its behaviour and (iii) when the activity, again not intrinsically random, is causally so complex that the aggregate activity pattern is considered random, within certain constraints, as a matter of necessity.

An example of a study operating on the assumption of the second class is to be found in Curry's (1964) work where he argues cogently that men, motivated by various ideas, acting upon different degrees of information and operating in differing circumstances, act so that

> . . .from the point of view of the locational structure as a whole, their actions appear as random (Ibid p.146).

Examples of the third class are applications of sophisticated Monte Carlo simulation to find solutions to problems otherwise intractable (Hammersley and Handscomb 1964).

Finally, there is a practical problem arising from the use of deterministic models frequently ignored by both the model builder and the model user, which is explicitly accounted for in probabilistic models. Generally, the researcher-model builder cannot (or where he can is reluctant to do so), ascribe confidence limits to the predictive capacity of the model, deduced from the reliability of the data used. Subsequently, there is a dangerous tendency for predictions from deterministic models to be regarded with a respect not due to them. That each run of a deterministic model with the same inputs results in exact replication seems to reinforce this tendency, at least in the minds of some users.

In conclusion, it is proposed to advance, somewhat tentatively, guidelines for probabilistic modelling although it is realized the evidence presented does not support them soundly. However, I am encouraged by a number of observations, not the least of which is the decline in recent years in the traditional bent for deterministic modes of logic (Neyman 1960) and the theoretical undermining of optimality concepts (Simon 1957). While these trends in the methodology of science cannot be logically equated with progress, fashion itself, as Kaplan has noted (1964 pp.292-93), does not necessarily preclude scientific achievement. In this age of "dynamic indeterminancy" (Neyman 1960), it may be that social science can only aspire to probabilistic explanation in view of the nature of the phenomena dealt with (Nagel 1961).

If, in the recent past, there were believed to be no <u>a priori</u> reasons for selecting a deterministic or probabilistic modelling approach, there appears to be emerging a convincing argument favouring the latter, where future states of social systems (i.e. involving significant temporal dimensions) are being studied. In previous centuries when changes occurred at a slower pace, the causality principle made a lot more sense than it does today. Because of the rapid assimilation of technology and its profound effect on the dynamic nature of social systems, statements of causality in social processes appear to ignore the temporal aspect of reality as we are beginning to appreciate it. This means we must acknowledge the inadequacy of present specifications of cause-and-effect relationships in social processes, for the future. Thus the first guideline for probabilistic modelling can be stated thus:

> <u>Condition I</u>: Probabilistic models should be used whenever the problem concerning the investigator, involves time

> dimensions in which significant and unpredictable changes can be expected to occur in the nature of component elements. The corollary is that deterministic models are best suited to static conditions.

Obviously, the relevant time dimension changes with different social processes for the reason that some process components are more susceptible to change. In the telecommunication field where revolutionary changes seem to be the order, almost annually, forecasts of the situation five years ahead may be excessive for deterministic models, while forecasts of population growth in most regions might be made with reasonable reliability by deterministic models ten years ahead.

In cases where the use of deterministic models is not precluded by the time dimension limitation, it may be still more appropriate to use a probabilistic model. When there is incomplete explanation of the process or system behaviour it is necessary to use a probabilistic model if a logical inconsistency in the methodological approach is to be avoided. This point has already been discussed. Thus, the second conditions can be stated:

> Condition II: Probabilistic models should be used whenever cause-and-effect relationships between process components cannot be specified with reasonable assurance of their reliability.

What is "reasonable assurance" in any situation depends on the purpose of the model and is largely defined by the level of confidence required of model predictions.

Finally, if the process or system being modelled involves component elements which are inherently random, then a probabilistic model is appropriate, though not absolutely necessary. It may be that the uncertain behaviour of one or more components can be adequately accounted for in a deterministic model by changing their values for different runs. However, if these random components are central to the whole process and tend, therefore, to dominate process behaviour then a probabilistic model is definitely required.

> Condition III: Probabilistic models should be used whenever the process being investigated contains component elements inherently random, however, this rule may be relaxed if the components only play a subsidiary part in process behaviour, so long as they are represented in different runs of the model with opposing limit values.

It should be recognized that the guideline statements are not independent but contingent conditions for selecting a modelling approach. For example, before a deterministic model is decided upon in accordance with the third condition, the previous two need to be satisfied.

In conclusion, the representation of stochastic processes and the application of probabilistic models to practical issues concerning the regional planner is a field of research with recent origins and many unsolved problems. Because stochastic processes have proven particularly useful for the representation of phenomena exhibiting uncertain and rapid change over time, probabilistic models are being used to an increasing extent by those who wish to understand the nature of evolution and transformations within processes and systems (Haggett 1965 pp.23-7, Bailey 1967 pp.1-4).

Statisticians have sought to represent stochastic processes in rigorous theoretical formulations which now form the bulk of probability theory. These formulations are mathematically complex and the ability to derive original formulations suited to the more complex planning problems has proven beyond the skills of even the mathematically gifted. However, there is a considerable body of applied mathematics, adopting a more heuristic approach, which can be utilized to investigate the problems encountered in the regional planning process, with explicit recognition of uncertainty. Generally, these are the methods of probabilistic modelling.

Chapter 3

MODELLING THE URBAN EXPANSION PROCESS

In Chapter 2, the nature and role of models in the examination of planning problems were considered in the context of selecting a modelling approach. It is proposed in this chapter to describe particular characteristics of the urban expansion process which have a bearing on the selection of a model.

Every model of the urban expansion process contains a theory of the spatial growth of cities tying the model to the real world. There cannot be a 'theory-less' model, for it is either based on theory or abstracts and structures urban growth phenomena to a simpler form, thus creating theory (Kilbridge et al 1970 p.13). For example, models based on the gravity concept, whereby human behaviour and urbanization processes are considered in a growth force context, are theory based models. Lowry's (1964) model for the allocation of residential, industrial and commercial activities in Pittsburg is of this type. Market models, such as the model of the land conversion process by Drewett (1969), are also theory based, relying on concepts of rational choice within the market and general equilibrium conditions. An example of a model starting from observed phenomena and structuring the criteria inductively, thus creating theory, is the simulation model of urban expansion by Malm and Warneryd (1967).

As a result of research into diffusion processes and the influence of barriers on urban growth by Hagerstrand (1965, 1967), Morrill (1965, 1968), Brown (1968), and Korcelli (1970), diffusion models of urban expansion could be developed which were theory based. However, most of the operational diffusion models are descriptive with inductive methodologies, and are thus more theory creative than theory based. It is interesting to note, however, that descriptive analogues of diffusion processes have been used to explain patterns of urban development for many years. The works of Burgess (1925) and McKenzie (1925), Blumenfeld (1954), Vance (1964) and Griffin (1965) are some examples.

Spatial and Temporal Dimensions

Each problem of land resource planning has its appropriate time and space dimension of study. Consequently, it is important to regard, in proper perspective, the level of inquiry and the issues sought to be resolved here. Firstly, the appropriate spatial dimension for examining urban expansion processes does not correspond well with that involved in existing settlement theories. Settlement patterns and growth processes have been traditionally examined from one of two viewpoints. From one viewpoint, the objective has been to describe patterns of cities within a state or continental framework, as exemplified by central place studies. From the other, the internal structure of urban areas has been the focus for analysis, shown by concentric ring and sector theory approaches. These approaches, referred to as the macro and micro-scale approaches respectively, were designed for purposes different from that in mind in this study. Here we are concerned with forecasting where and when urban expansion will occur as a result of growth processes far enough in advance to permit regulatory action to be taken, if necessary. In this case the metropolitan region is the subject system; an intermediate order or scale which for the sake of consistent terminology, can be called the meso-scale approach. While neither the macro or micro scale approaches is particularly suited for forecasting where and when urban expansion will occur, at least in a way that reflects the mechanics of the expansion process, a meso-scale approach can be designed to specifically reflect these aspects.

Secondly, we are dealing with a process which falls within the ambit of long range planning, with a time dimension of approximately 5-10 to 20-30 years ahead. Within this time scale, we are concerned with only those characteristics of the urban expansion process, which can be reasonably expected to persist. The greater the dependence of the variables included, on current levels of technology and patterns of social and economic behaviour, the greater the possibility of results diverging from what will happen. Thus only the basic structural elements of the process, at the metropolitan regional scale, with long term implications, should be incorporated into the model. However, at the same time the results need to be sufficiently precise to be of use in the long range planning process. It is unlikely that this dilemma can be resolved completely in any one model. The best that can be done is to justify as far as possible on the basis of existing knowledge, the structure of component processes in the model, and demonstrate that the likelihood of changes in their composition is slight for the time horizon under consideration. However, it is possible to avoid gross assumptions about the dynamic nature of behaviour and technology, and thereby blunt the edge of arguments against forecasting. One purpose of having a series of interrelated land use models in IIPS is to systematically increase the degree of resolution of land use and decrease the level of uncertainty with progressively shortening time horizons. Different assumptions about behavioural patterns and technological change in the separate models can be formulated to accomplish this.

Thirdly, the model which accurately replicates past performance of urban expansion in the Vancouver Region is unlikely to be the appropriate model for simulating future growth. There is little basis for expecting that the unique forces which molded city shape and size until now will persist in the same form in the future, for with the assimilation of new technology and the evolution of new social and economic, behavioural patterns, different factors will undoubtedly play an important role (Wartofsky 1968). The uncertainty resulting from new innovations and social evolution which cannot be forecast and which inevitably alter the course of development (Drucker 1959), decreases the specificity of forecasts that can be made as the time horizon increases. Thus land will not be allocated to particular urban activities by the model of urban expansion, as this will be handled by sub-models designed specifically for this purpose (Goldberg 1971) This point underlines the importance of connecting the patterns of behaviour of individual decision makers, represented by the micro-scale models, with the total behaviour of the system (Lowry 1965, Goldberg 1970). Ideally, it should be possible to make judgements about the actions of individuals from the concepts inherent in the macro-scale models (Wilson 1970) but because this has generally proven impossible, the intermediary models should reconcile the inconsistency.

Traditional Models of Urban Expansion

The issues discussed above provide a suitable basis for evaluating traditional models of urban expansion. Two types of models in particular, market and gravity models, have been used frequently in the past and might normally be considered.

Market models are the main kind of a group of behavioural models which are based on a concept of man as a rational decision maker attempting to optimize his welfare according to prescribed criteria, such as locational advantages. The pattern resulting from the aggregated individual decisions represents the product of land market planning.

Conceptually and practically, land market planning stands as the pole opposite to state planning through legislation. Where legislation for the allocation and organization of land resources, including the regulation and prohibition of activities, is extensive, the likelihood is low that market planning forces are creating the settlement form and structure of the area. Because the conversion of rural land to urban uses has been characterized by a plethora of conflicting interests (with equally sincere groups of farmers, developers, speculators, and conservationalists at odds as to what should be done in the best interest of the community) the tendency for ad hoc responses by government bodies to the demands of various pressure groups has not been uncommon. As a result, the conversion process has become a confused medley of resolutions by uncoordinated government planning and market mechanisms (Clawson 1971). Therefore, it would be extremely difficult at present, if not impossible, to determine causal relationships between urban form and growth processes. Even within the scope of a large scale project such as IIPS, it would be a costly and probably impossible task to evaluate the influence of specific governmental and private decisions resulting in the present urban form, and even then extrapolation into the future could hardly be justified. We cannot be even reasonably sure that the severely constrained land market operates at all as theory or intuition dictates (Drewett 1969).

While the foregoing reason is no doubt sufficient, there are a number of other grounds for rejecting market models of the land conversion process. Firstly, they show a strong dependence on criteria such as land prices (a surrogate for a host of landscape and socio-economic features), which fluctuate widely over time (Hoyt 1960), and depend to a large extent on volatile social and economic conditions. Secondly, the basic assumption of rational individuals and groups optimizing their welfare, when they have only imperfect information, and different constraints, is questionable (Simon 1957). Thirdly, the integrity of the approach suffers when diverse interest groups, for example, residential commercial industrial, public authority and the like, are aggregated. The micro-analytic market approach is better suited to situations where high degrees of resolution are required for short periods ahead and when diverse interest groups or activities need to be separated. It was for these reasons that a different theoretical approach than a market-behavioural approach was sought.

Gravity models are the simplest and most popular of a group of macro-analytic models based on a growth force concept derived from Newtonian physics. In their simplest form they assume rationality and regularity in describing mass behaviour (Kilbridge et al 1971 p.15) according to the principle that the attractive force of a centre (e.g. the CBD), varies directly with the mass of the centre (e.g. commercial floor space) and inversely with the distance from the centre. When several centres are involved each exerting an attractional force, the concept of intervening opportunities is used to allocate proportional attraction. This results in practical difficulties, however, for the actual effect of the intervening opportunity is difficult to guage, as it depends heavily on unique social and cultural patterns of behaviour (Brindle 1970).

The gravity models have not been followed for reasons less pragmatic and more theoretical in nature. As Isard (1960) and Harris (1966) have capably demonstrated, the gravity analogue dependency on smoothed and aggregative data (i.e. distance and population), conceals important differences in the effect of accessibility for disparate activities and components of population. The practice of weighting various population groups and transposing straight line or cross country distance into surrogate indices such as trip-time, while necessary to better mirror reality, seems to be falling into the trap of patching up inadequate theory (Harris 1966 p.264).

More importantly, however, is the deficiency of gravity models in reconciling the macro and micro-analytical theories of urban development and metropolitan expansion. Gravity models have very poor specification of the actual processes of expansion and it is not possible to deduce explicit information about the behaviour of the individual decision makers.

To summarize:

> . . .the basic criticism of models of this type is not that they do not work--so far they have been used with greater success than microscopic models--but that there are theoretical and practical objections to the lack of explanation of causes. Critics point out that if projections are to be based on the assumption that present aggregated characteristics will apply in the future, then we should know the reasons for these characteristics if we want to modify them to fit possible changes in behaviour (Brindle 1970 p.2.25).

There are a number of other types of growth force models which have been used for modelling urban expansion. One in particular, the probabilistic model of residential land development by Donnelly, Chapin and Weiss (1964), has been influential in recent research. In this model, a growth index, based largely upon the "attractiveness" of different sites, allocates land to residential use. The criteria for determining site attractiveness were derived from a previous study of the factors influencing development, in which regression analysis was used extensively (Chapin and Weiss 1962). Some of the features incorporated in the growth index were land values, availability of sewerage, and accessibility to employment nodes, major communication corridors and elementary schools. The reliance of this model on factors, such as land values, which fluctuate considerably over time for reasons not necessarily associated with the urban condition, is a major deficiency for long term forecasts. Further, while the approach is essentially behaviouralistic in that residential preferences play a central role, the model falls short of promoting a reasonable explanation of the urban expansion process at the scale desired. For example, the overall directions of growth are taken as given and entered as inputs in the model. This limitation is recognized by the authors who emphasize that testing the particular methodology for application was their primary purpose in this particular model.

Diffusion Models

The spatial patterns associated with the growth of settlements have been frequently characterized by diffusion processes. Generally, diffusion can be considered the outward movement of a process or activity as a result of centrifugal forces. At the macro-scale, Turner's frontier hypothesis of the westward spread of settlement in the United States (Turner, 1920), Perry's analysis of the spread of settlement in New South Wales (Perry 1963) and the 'Berkeley School' of settlement geography, led by Carl Sauer, have their common bases in diffusion analogues. Nearer to the micro-scale, spatial diffusion, to describe the outward spread of city-type settlement, has been used in several recent studies to develop models for predicting the timing and location of urban expansion.

Morrill (1965) for example, hypothesized that the expansion of the urban fringe is a spatial diffusion process in which new development, essentially random in direction (land being equal), follows a direct probability distribution with respect to variations in land and neighbourhood quality and follows an inverse probability distribution with respect to distance from existing development. Morrill, being dissatisfied with the deterministic models of urban spatial structure and growth, adopted a stochastic approach whereby a probabilistic function is used to describe the relationships between the variables. His choice of variables and conceptualization of the development process reflects considerable dependence on the work of Chapin and Weiss (1962). He details for each of ten elements (constituting propinquity to existing development, accessibility and site quality characteristics), probability statements based on empirical data obtained from a study of actual land use changes in the north Seattle area. This information when incorporated into the model, permitted Morrill to simulate expansion in the study area. The patterns established by the simulation runs were at odds with the real world in some places, but considering the project was still in its preliminary stages and the somewhat intuitive formulation of the model, not sufficiently far off to wholly discredit the effect. Differences found seemed to reflect underestimation of institutional effects, such as land ownership patterns, degree of land fragmentation, and variation in land quality.

Malm and Wärneryd (1967), in a more simplistic approach, attempted to simulate urban growth as a diffusion process incorporating barrier effects. Again, the influence of Chapin and Weiss' (1962) work is noticeable, but more importantly, the authors have sought to build their model on a stronger theoretical base. To this end they relied on Yuill's interpretation of the influence of barriers in spatial diffusion processes (Yuill, 1965). The simulation model was based on the hypothesis that the degree of sprawl evidenced by a metropolitan community depends upon variations in total construction costs resulting from terrain characteristics, communication and utility networks. Costs are related to hypothetical housing units. The range of the set of random numbers reflected the magnitude of development costs.

A grid was placed on a map of the study area, part of the district of Hisingen, in Göthenburg, Sweden, and a set of random numbers assigned to each square. According to the rules of their 'game', squares where the terrain provided good foundation conditions were classified by number 1 and if 'hit' were accepted for development immediately. Number 2, hard bedrock areas, had to be hit twice and number 3, clay areas, had to be hit three times before acceptance. After each acceptance, costs for services and utilities were readjusted according to the new conditions, construction costs recalculated and transformed once again to random numbers and the game repeated. This sequence was repeated at regular intervals for the period 1920-40. The simulated pattern did not compare accurately with the actual built up areas. This is attributed, by the authors, to insufficient differentiation of the study area, due to the large square sizes used, and also as a result of underestimation of the importance of proximity to previously built up areas. Considering this simulation study was conducted without computer facilities, which were not available, (therefore it was only feasible to use a small number of cells and fewer variables), the approximate comparison obtained by the theoretical model of the real situation is a creditable performance.

Yuill (1970) synthesizes many of the elements, providing a focus for the two studies discussed above, into a general simulation model of urban spatial growth. The success he achieves demonstrates that the diffusion approach, reconstructed in its entirety since the early descriptive analogues, has considerable potential. His model for operational convenience is deterministic, and limited to a description of relationships between a large number of factors resulting in the shape, size and intensity of urban development. Thus it represents the product of both urban spatial growth processes. He uses the growth and distribution of population, in terms of varying density surfaces, as a universal metric in the model.

Following a diagnosis of the principal factors influencing urban spatial growth, in which he relies heavily on the works of Borchert (1961,1962) and his own earlier study (Yuill 1965) for the influence of the physical landscape, and of Chapin and Weiss (1962) for factors related to the cultural landscape, he formulates three input parameters: (i) the capacity of the urban site is a synthesis of factors determining the maximum capacity of residential population for any site and includes land suitability, competing uses of land, the nature of housing and social and political restrictions; (ii) site permeability and rate of growth is a function of characteristics, classified as having an accelerating or retardating effect on growth rates, such as varying topography, waterside locations, and proximity to polluting industries; (iii) connectivity and differential growth is a synthesis of accessibility factors and they can either impede or facilitate urban development. Allowance is made for their influence in terms of effective rather than direct distance measurements.

The values of input parameters remain constant throughout the simulation and no allowance is made for technological changes and the possible influence they may have. Nevertheless the simulated growth patterns for eleven cities selected in the U.S.A. are good, (better generally for the smaller cities than the larger ones) particularly as no account is made of important unique events (e.g. major bridge), in the simulation of the individual city. The model is primarily concerned with the general factors of spatial growth and not the particular factors.

While Yuill substantially fulfilled his objectives, the study has a number of weaknesses in relation to the purposes of the present study. Firstly, no attempt is made to distinguish, (or explain the codification of) the spatial expansion process from the spatial intensification process, which is more serious than may be immediately apparent. Brown (1968 pp.34-35) records that recent research on spatial diffusion processes tends to indicate that different phases of diffusion (e.g. expansion-intensification) are controlled by different processes. Secondly, there is no supporting explanation of actual process operation or social behaviour (cf. Korcelli 1970). The model seems too purposeless in its descriptive structure. Finally, the factors influencing spatial growth incorporated in the model, relate specifically to residential activities. It is a pity Yuill could not overcome this specialization and in fact produce a general model for urban growth.

Korcelli's (1970) work emphasizes the mechanics of diffusion processes more strongly than do the studies of Morrill, and Malm, and Wärneryd. As a point for departure, Korcelli has taken the concept of interaction between centrifugal and centripetal processes of population dispersal (Blumenfeld 1964) which, when combined with the fact of spatial growth on the urban periphery, implies a wave-like pattern of metropolitan expansion. By such a description, he means to imply both frontal and axial growth.

The initial, theoretical basis for Korcelli's model lies in the accessibility approach; that is locational decisions are considered to be taken so as to minimize the frictional effects of distance. In successive refinements, however, he departs from the gravity concept and includes geographic, social, and economic characteristics and relationships. The following is a summary of his procedures.

1. The initial model, because it assumes a Von Thunen type isolated and homogenous landscape, is constructed solely on accessibility criteria. The resulting pattern is symmetrical.

2. In the second step, the sociological concept of human succession (penetration, invasion, consolidation, and saturation), is incorporated, distorting the symmetrical shape.

3. At the regional scale, fluctuations in growth rates are caused by external forces such as economic, political and technological change. These factors are included by oscillating rates of increase of metropolitan territorial expansion.

4. In the fourth step, the differential attraction of regional sub-areas is accounted for. The factors affecting urban expansion are tabulated into an Index of Local Resistance which includes positive factors (site quality, transport, service, and settlement networks), and negative factors (physiological barriers and institutional restrictions).

5. He then hypothesizes the presence or emergence of a secondary growth point within the urban region whose growth is synchronized within the pattern of waves emanating from the region's main centre. Higher displacements result from the combined influence of the waves generated.

6. Finally, he superimposes part of another growth cycle, (possibly brought about by a major revision of the transportation system or reflecting the influence of another nearby metropolitan centre) and makes allowances for changes in wave amplitude consequent upon the passing of important thresholds in the system, such as city size thresholds.

At the time of publication, Korcelli's model was not operational and the model's ability to simulate the real world is supported only by limited diagramatic evidence.

The Scottish Development Department (1968), in conjunction with the Planning Research Unit at Edinburgh University, under the direction of Professor Percy Johnson-Marshall, has produced a detailed planning report for urban expansion in the Grangemouth-Falkirk Region based on population dispersal and barrier effects. The technique employed, referred to as threshold analysis, after a theory formulated by Malisz in Poland (Malisz 1963, 1969), is derived from empirical research showing that while the growth of population in most regions is represented by a smooth curve in arithmetic graphical representations, the spatial expansion of urban development is irregular and non-continuous. Minor increases or decreases (fluctuations) in population densities, resulting from changing standards of accommodation and proportions of excess capacity in infrastructural systems, are caused by barrier impediments to urban development (Malisz, 1969). While the economic significance of barrier effects may be less significant where operation of the market is not constrained, in communities where growth is controlled and directed, and frequently contained within specific areas for long periods, barrier effects assume increased economic importance as a resulting of bunching effects (Lean 1970; Famelis 1970).

The application of threshold analysis by the Planning Research Unit attempts to acknowledge these effects and was carried out in two parts. Firstly, urban growth potential was determined by ascertaining areas suitable for urban expansion throughout the Grangemouth-Falkirk region on physiographic and ecological criteria, e.g. land suitability. The areas were ranked according to priority criteria to provide a basis for sequential development and overall growth potential was calculated by applying average urban density standards. Three basic barrier effects were then investigated; topography, utility networks, and existing urban structure. For each, overlay maps were prepared showing per capita costs involved in developing particular areas: for example, slope and soil conditions, drainage, sewerage, roads, existing development, and degree of land required for conversion to urban use.

Secondly, cost indices of per capita costs required for each new immigrant within the potentially developable areas were determined from estimates of total expenditure needed to plan and develop the land for urban purposes within each expansion sector.

Decisions for sequential expansions of the urban area were based on a graphic solution to directions of least resistance (cost minimization). The Planning Research Unit claimed that the application of threshold analysis in the study resulted in less subjective decisions for succeeding stages of the planning process by providing a quantitative basis for selecting areas for development and by permitting the programming of public investment to be related comprehensively to the existing regional structure.

The diffusion approach to the spread of urban settlement based on population or activity dispersal as modified by the physical-cultural environment, is still being formulated. The above five studies are the only ones known to the writer presenting actual models based on diffusion processes which are in sufficient detail to warrant serious consideration. In the following, the study methodology is described and in Part III a model is developed, incorporating many of the ideas contained in these studies.

Urban Expansion as a Stochastic Process

Traditional approaches to the search for order in the urban region have mainly been concerned with describing urban structure and spatial growth patterns. This method, which can be compared with that used in compartmental modelling, relies on the identification of morphological features, sometimes by reference to the history of urban development and specialized activity functions. While this approach has enjoyed considerable popularity, especially among urban geographers, the degree of order found has been far less than the degree of order left unexplained. One of the main reasons appears to be that these attempts at discerning patterns have been based, implicitly, on a static concept of the urban region, which Blumenfield (1967) correctly considers anachronistic. The modern city, he says,

> . . .is constantly changing and growing, and, as it grows, it burst its girdle and overflows into the countryside. The result is universally viewed with alarm as "urban sprawl" as being "neither city nor country."
>
> In this fluctuating mass, the old static patterns dissolve. If any pattern can be discerned, it can only be the pattern of flux. This apparent chaos can no longer be grasped as formation but only as transformation,

as historical process. (Blumenfield 1967 p.50)

Moreover, as a result of this search for patterns in the urban region, the situation now exists, claims Simmons (1965 p.170), where geographers are in a state of cognitive dissonance; accepting simultaneously three concepts of urban structure, (concentric zone theory, sector theory, and multiple nuclei theory), which are in apparent conflict.

The point of this criticism is not to deny the usefulness of the search for order by describing patterns. Rather, the criticism is that the traditional geographic attempts to describe patterns, and hence to arrive at "morphological laws" (Bunge 1969, Gale 1970), appear to be biased by preconceived notions of the type of order to be found. In particular, there has been a marked emphasis on determining spatially discrete patterns in the organization of urban activities, classified according to different functions. The three conflicting theories referred to above, fall into this category. They seem to be seeking the type of order which existed in pre-industrial cities, where a definite pattern of spatial organization was engendered by a relatively stable social structure (Mumford 1961, Vance 1971). However, there is general agreement amongthe outstanding scholars of the modern metropolis that such order no longer exists. Contemporary patterns of urban spatial growth and structure are characterized by "a vast irregular growth" (Geddes 1968 p.26); "sprawling giantism. . . ever more aimless and discontinuous, more diffuse and unfocused" (Mumford 1961 p.619); and "constantly changing and growing" (Blumenfeld 1967 p.50). The obvious implication from these statements is that urban spatial growth and structure, and therefore urban expansion, should be viewed in terms of dynamic processes with explicit recognition of uncertainty.

While recent explorations into the nature of urban spatial growth and structure have resulted in a number of theories emphasizing dynamic aspects (Chapin 1964), there have been relatively few attempts to specifically account for uncertainty in the evolution of cities or particular development processes operating at the urban level. Notable exceptions have been the studies by Malm and Wärneryd (1965), Morrill (1965), Olsson (1966), Curtis Harris (1968) and Drewett (1969). However, these studies contain incomplete justifications for adopting the stochastic approach.

Only Curry (1964, 1966) and Rogers (1967) have pursued the issue of behavioural indeterminism to a significant depth. In substance, they have presented similar arguments in favour of probabilistic interpretations of human behaviour as they relate to urban spatial growth. They consider that the overwhelming complexity of human behaviour and social organization renders futile attempts to deterministically equate behaviour and urban spatial patterns. There is, they claim, a random element in people's behaviour that should be acknowledged in theories and models of urban spatial growth. Accordingly, both Curry and Rogers recommend the use of stochastic approaches.

The advantage of regarding urban expansion in this way becomes apparent when the nature of stochastic processes is examined. Processes refer to phenomena which exhibit or produce change in the course of time.

Their essence is the change produced. Stochastic processes generate variable results in an ordered sequence from probability functions, meaning each event in a sequence of events, depends on some chance element. Stochastic processes as represented in probabilistic models, are especially appropriate when we are concerned not only with the outcome but also with actual process behaviour (Springer et al 1968 p.39). They are to be contrasted with deterministic processes which generate a single unique result for each run where the input remains unchanged.

Two basic criticisms which have been levelled against modelling urban phenomena can be resolved by probabilistic models when used in the appropriate organizational framework. It has been argued that attempts to find order in the modern metropolis, (i.e. the level of abstraction necessary to satisfy the needs of modelling), are a fundamental denial of the disorderly and complex nature of urban phenomena (Kilbridge 1970 p.1). In response to this criticism it is acknowledged that many processes are inherently so complex they cannot be abstracted realistically by conventional mechanistic models. But the stochastic approach has the particular advantage of allowing a process to be investigated with recognition of considerable ignorance of its nature (Curry 1966). A stochastic process model requires the specification of process components and their interactions at a monotonic level, which allows their transformation and regulation to be observed, at a much higher level of complexity, when employed within the framework of systems analysis (Holling 1972). The degree of complexity which can be handled, therefore, is considerably greater than that which might otherwise be achieved through intuitive or conventional analytical approaches (Forrester 1969 pp.107-114) and as a result, our understanding of process behaviour is greatly enhanced. This is not to claim that the approach is entirely adequate for the investigation of complex phenomena. On the contrary, there are shortcomings but as yet their precise nature is not clear, for this type of study, due to the early stage of their development. However, the approach shows promise of being a considerable improvement over alternative methods available (Harvey 1967 pp.570-588).

The second criticism has been that the form of abstraction usual in model building is a regression to "nineteenth century scientism," particularly in view of contemporary realizations of the dynamic and indeterminate nature of many phenomena. It is argued that social evolution, changing technology, and their effects on patterns of human behaviour make nonsense of predictions (Kilbridge 1970 p.1). The grounds for response to this criticism have been considered at length in a previous section (Supra pp.38-48) and only the main points will be repeated here.

Where a process has been shown to be dynamic and characterized by uncertainty, the stochastic approach is eminently suitable because it does not require the specification of causation among component elements. It focuses on changes produced and explicitly allows for uncertainty arising out of chance events and inadequate representation of process behaviour, thereby compensating for the dynamic nature of processes and our limited ability to conceptualize (Curtis Harris 1968 p.29). When this approach is chosen it is usual to begin with:

> . . .unconstrained independent random variables and, by introducing dependencies and constraints, achieve results of various likelihoods. Where nature shows only a single result, it is interpreted as the historical realization of a process which could just as easily have produced other results according to their attached probabilities (Curry 1966 p.40).

If the complexity and uncertainty arising directly and indirectly from the development and assimilation of technology are manifested in the nature of urban structure and spatial growth processes, the advantage of approaching urban expansion in this manner is considerable.

One question remains to be answered. Can the pattern of urban land development on the urban periphery be considered random, legitimately, for the purposes of modelling? Theoretical justification is not denied by the fact that individual decisions concerning land development may be considered the outcome of a planned course of action. Even if the assumption is made that individual decisions are determinate, it does not necessarily follow that their sequence of collective pattern is not random. In fact, Bunge (1963 p.194) maintains that:

> . . .the interplay of numerous nearly independent and individually determinate entities results always in chaotic situations...orderly individual behaviour may fit a random collective pattern.

Recent studies by Vance (1971) and Clawson (1971) provide considerable evidence that actual patterns of urban expansion in North American cities can be interpreted in accordance with this principle. For example, Vance in his study of the dynamics of urban spatial growth and structure, through an examination of land assignment practices, in precapitalist, capitalist and postcapitalist cities, finds it necessary to conclude with respect to the modern metropolis that

> . . .the traditional practices have everywhere been questioned and in some places abandoned, but as yet land assignment within the postcapitalist city operates in an unclear fashion (Vance 1971 p.120).

Further, Clawson in his extensive study of the conversion of rural land to urban uses in the United States of America makes the following observations:

> . . .the decision-making process in urban expansion is highly complex and diverse. It is incredibly fragmented and diffused among a wide variety and large number of private individuals and organizations and among many public agencies at each of the major levels of government (Clawson 1971 p.58).

> It would be miraculous if such a diffused process came out with the same results as one where a single person or group was charged with the whole responsibility and given the means to exercise it. Under the diffused system, actions are often nullified, in part or in whole, by other actions (Clawson 1971 p.75).

It will be remembered that in a previous section (Supra pp.11-12) the allocation and organization of land in the Vancouver Region was described as a complex function of both market and state planning mechanisms, with the latter uncoordinated with respect to the former as well as internally. Consequently, it is submitted that there is adequate theoretical and empirical justification for the basic assumption required for a probabilistic model of urban expansion, that land development on the urban fringe can be treated as a stochastic process.

PART II

TOWARDS A MODEL OF URBAN EXPANSION THE VANCOUVER REGION

The Regional Planner can never reckon with "types" of landscape; he has no other recourse but to make an empirical study of the landscape in which he wishes to operate.

Arturo Glikson

Regional Planning and Development

Chapter 4

CHARACTERISTICS OF THE SPATIAL GROWTH OF VANCOUVER

Introduction

In this chapter, the aim is to identify the factors influencing the rate and direction of urban spatial growth in the Vancouver metropolitan region. The observations made are selective and are guided by (i) the spatial-temporal dimensions of the urban expansion process and (ii) the need to <u>interpret</u> the process of urban settlement, to arrive at concepts and structural relationships of phenomena with a bearing on urban expansion. Thus, the following account does not purport to <u>explain</u> the evolution of the Vancouver urban region to its present form or territorial extent. However, depending on the success of the model described in Chapter 6, it might be possible to advance a theory to this effect.

In a literal sense, the investigation is an exploratory experiment into the dynamics of urban expansion in which it is sought to identify the following specific characteristics:

1. associations between population growth, the spread of settlement, and the physical-cultural landscape which can lead to the formulation of concepts describing time lags and discontinuities in the process of urban expansion;
2. changes in the nature of urban expansion, in time and space, through an examination of the historical development of the urban region, which reflect the kinds of boundary conditions operating to contain urban spatial growth; and
3. relationships between factors observed to influence the spread of urban settlement which throw light on the nature of structural thresholds and resilience in the process of urban expansion.

Subsequently, an attempt is made to find order in these characteristics through classification and descriptive inter-relation. This is a necessary prerequisite to developing general concepts and specifying structural relationships of component elements in the urban expansion process. It is emphasized that the approach avoids, as far as possible with the limited data available, the specification of process behaviour directly from observed spatial patterns. Because the relationships between spatial form and process may be assymetrical (Olsson 1968) there are inherent dangers in specifying a process on the basis of trends in the aggregate patterns of urban growth. Moreover, when the process is required for predicting future conditions, the technique may become a circuitous device for perpetuating the past, indiscriminately. For these reasons, Borchert's (1962) time series analysis of the evolution of land use patterns in the Minneapolis - St. Paul region is not satisfactory for the present study. Ideally, quadrat analysis, a refined cell counting technique directed more towards characteristics of processes as they are manifested in spatial patterns (Rogers 1969) might have been used. Unfortunately, a lack of suitable and reliable data, precluded this possibility.

The conclusions reached in this chapter rely on a large and diverse collection of graphic materials, including a collection of photographic plates with a commentary on each. Some of these graphics have been included in the Appendixes for convenience. The virtue of these graphic materials lies in their ability to illustrate many facets of the spatial growth of Vancouver without the need for a lengthy text. They are also particularly helpful in providing the reader with an indication of the interpretative process used in formulating some of the concepts which otherwise might be obscure.

The Evolution of Urban Settlement

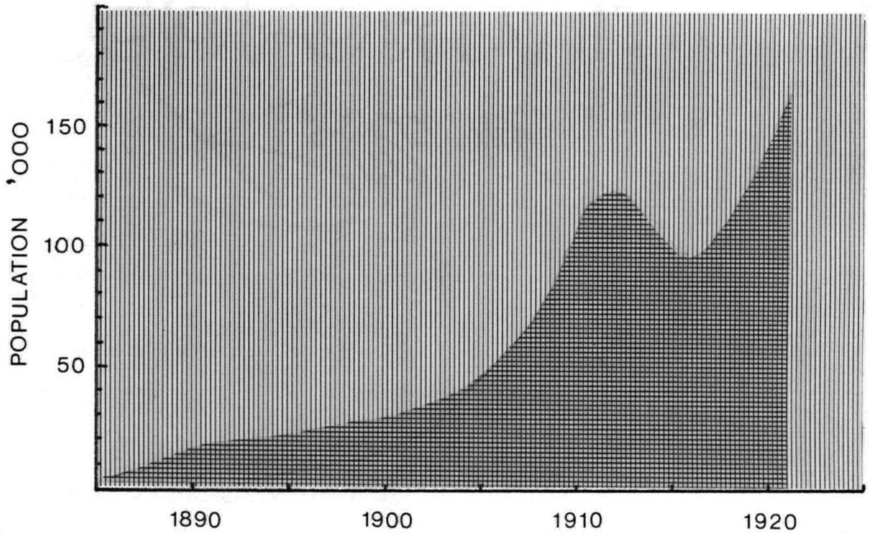
Settlement in the lower Fraser River - Burrard Inlet region was entering its third decade when a recognizable embryo of the present urban system formed. With the trans-continental Canadian Pacific Railway commencing operations in 1887, and three bridges crossing False Creek, to complete a basic network for communication, by 1889, a permanent superstructure was provided for the urban development to follow (Gunn 1968). By 1890, a commercial core had established in Gastown, industrial activities surrounded False Creek, and the East End and the Fairview area had consolidated into the first residential districts (Robinson 1971).

Of the other early settlement nuclei, at New Westminster, Moodyville (North Vancouver), Hastings townsite (now Hastings Park), and Marpole-Eburne at the entrance to the North Arm of the Fraser River (Figure 3), only Moodyville, connected by ferry to the foot of Granville Street, continued to grow in the first phase of urban expansion which took place from 1890-1910. New Westminster, the original administrative, commercial and military centre, had been eclipsed by Vancouver in the late 1880's and ceased to expand significantly, until after World War I. In Vancouver, development of the railway and related port and industrial activities, provided the catalyst for rapid urban growth and accession to regional dominance which has persisted to the present (Robinson and Hardwick 1968).

Urban development in the Fraser River - Burrard Inlet region occurred in alternating stages of expansion and stagnation which can be identified largely by the oscillating rates of population growth (Figure 4). In the first phase of urban expansion from 1890-1910, development was rapid and continuous with the peripheral spread of settlement notable for its relative compactness (Figure 5). At the same time, there was progressive consolidation of existing urban areas (Plate 2). On the north shore of Burrard Inlet, urban expansion, consisting mostly of single detached housing, spread fan-like from the ferry terminal and a growing number of commercial and industrial activities located at the foot of Lonsdale Street (Plate 5).

FIGURE 3 URBAN SETTLEMENT IN THE VANCOUVER REGION, 1898.

FIGURE 4. POPULATION: CITY OF VANCOUVER, 1886-1921.



In Vancouver, westward expansion was restricted by Stanley Park, then a military reserve where development was prohibited. However, residences quickly covered the limited land available (Robinson 1971). To the east, development extended by the end of the period to the old Hastings townsite. Hastings Street became a ribbon of commercial development and on either side residential development filled the available land, eventually joining in the south with the growing Fairview residential district. Elsewhere to the south, industrial development took place around False Creek, and with the impetus provided by street car lines extending into south Vancouver, residential development reached Twelfth Avenue and as far west as Jericho Beach.

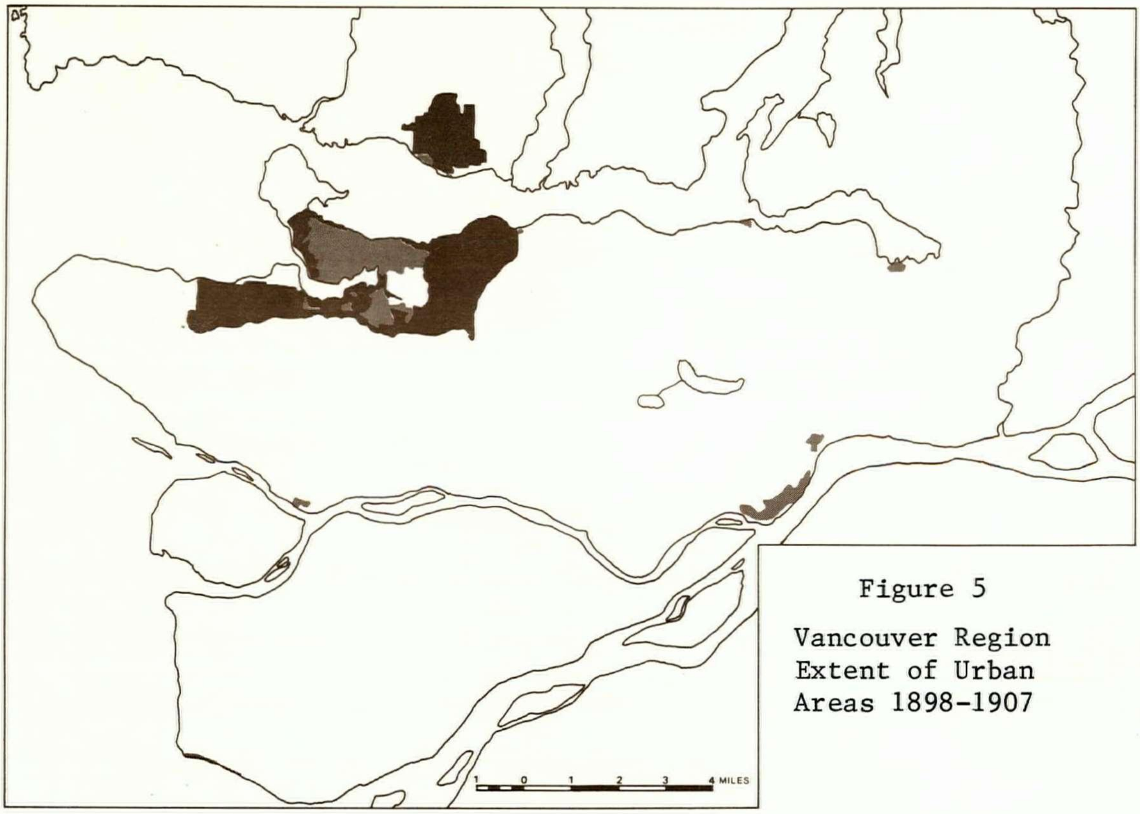


Figure 5

Vancouver Region
Extent of Urban
Areas 1898-1907

Explanatory Note: The light brown shading represents the urban areas at the start of the period; dark brown represents urban expansion during the period.

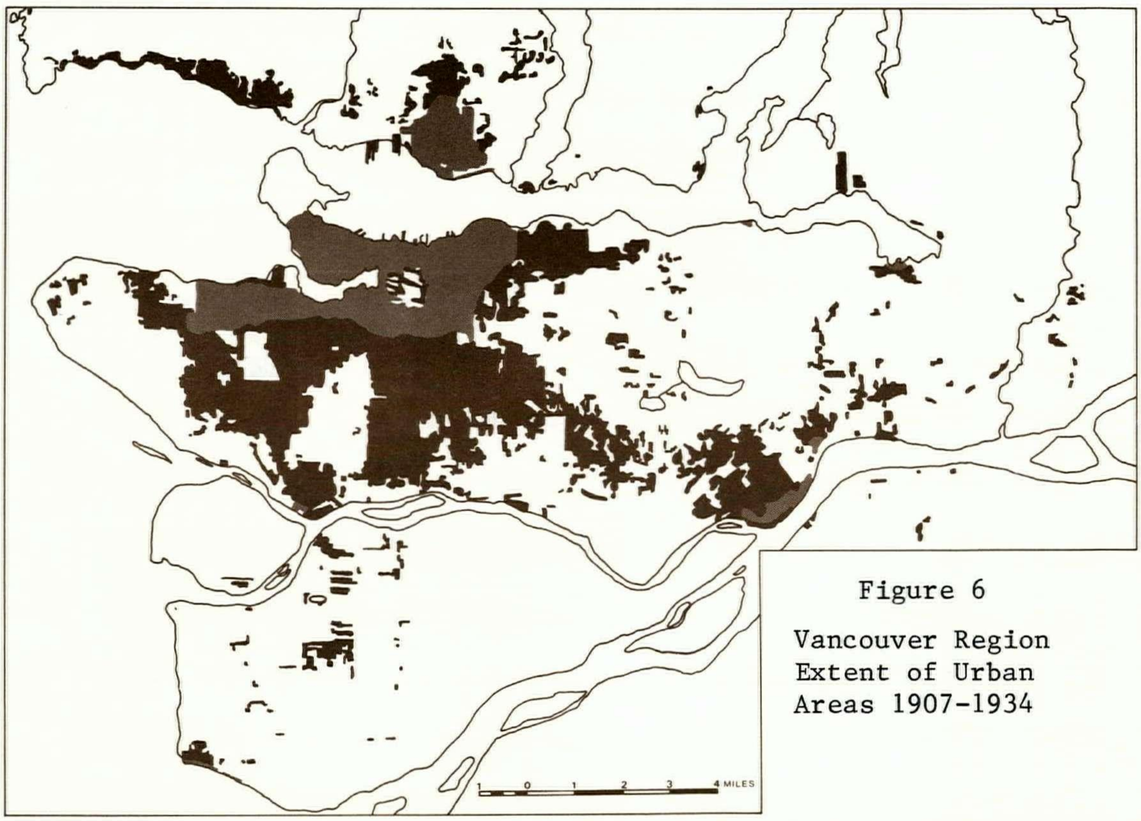


Figure 6

Vancouver Region
Extent of Urban
Areas 1907-1934

Data Source: Department of Mines and Technical Surveys, Atlas of Canada, 1957.

By the end of the first phase of expansion in 1910, a basic communications network had been established for the future Vancouver metropolitan region. All-weather roads joined the smaller centres south of Burrard Inlet directly to Vancouver or New Westminster. Bridges had been completed across the Fraser River, at New Westminster in 1904 and Mitchell Island in 1905 (Meyer 1966). Elsewhere, key crossing points were served by ferries. Railway construction had been particularly prolific. By 1910, Vancouver was linked directly to Port Moody and the upper Fraser Valley in the east; in the south to Marpole-Steveston; and through New Westminster to Delta-White Rock, Cloverdale-Langley-Aldergrove and Fort Langley-Mt. Lehman (Roy 1966).

Following the first wave of urban expansion, a period of economic stagnation and declining population lasted from 1911 to about 1916. Jones (1966 p.146) attributes this collapse in the development impetus to the economic recession preceding World War I. However, there is probably some truth in the observation by Robinson and Hardwick (1968 p.447) that in the first phase of expansion, Vancouver had also over-extended its economic potential for there was a substantial exodus of people from Vancouver during the five years that followed (Figure 4).

The second phase of urban spatial growth, from 1917-1930, came with improvement in the economic situation and in addition, was stimulated by two fundamental changes which had been occurring gradually but which were hastened along by World War I. The automation of industry and transportation was given a boost, with the result that intra-urban mobility was greatly increased, and economic activity became increasingly concentrated in the main urban centres (Jones 1966 p.152). The declining urban population was quickly reversed and in the period 1916-1921 the population of Vancouver rose 70 per cent from 96,000 to 163,000 (Figure 4). By 1930, the population was fast approaching the quarter million mark. While some other areas also recorded proportionately large increases, notably Burnaby and Richmond, the City of Vancouver absorbed three-quarters of the population increment in the region during 1921-1931 (Table 1).

The network of roads and railway lines built in the first phase of expansion became the major channels for growth in the second phase (Meyer 1966). Because the network was still incomplete in that it did not service all areas uniformly, expansion tended to occur only in those locations with close proximity to communications corridors. Several large pockets of land were left undeveloped and this broke the regular pattern of expansion which characterized the earlier expansion phase. For the first time, urban expansion ceased to be a continuous peripheral spread from the original settlement nuclei and became a series of movements often producing new nuclei separated from established urban areas (Figure 6, Plate 3).

In Vancouver, development extended south in parallel tongues along Dunbar, Granville and Fraser Streets to the North Arm of the Fraser River (Plate 4), and south east along Kingsway towards New Westminster. Hastings Street continued to provide a focus for development to the east which pushed well into Burnaby. The pattern of development in Burnaby, particularly along Kingsway, was sporadic and a number of villages located at the major stops

Table 1. VANCOUVER REGION POPULATION

1921--1971

MUNICIPALITY OR AREA	CENSUS OF CANADA 1921	1931	1941	1951	1956	1961	1966	1971
BURRARD PENINSULA								
Endowment Lands	-	575	636	2,120	2,999	3,272	2,979	3,510
Vancouver	163,220	246,593	275,353	344,833	365,844	384,522	410,375	422,278
Burnaby	12,883	25,564	30,328	58,376	83,745	100,157	112,036	124,036
New Westminster	14,495	17,524	22,959	30,108	33,093	35,104	38,013	42,083
Fraser Mills	600	616	552	369	216	165	164	157
Coquitlam	2,374	4,871	7,949	15,697	20,800	29,053	40,916	52,123
Port Coquitlam	1,178	1,312	1,539	3,232	4,632	8,111	11,121	19,570
Port Moody	1,030	1,260	1,512	2,246	2,713	4,789	7,021	10,780
Buntzen	-	540	468	482	528	570	669	-
Indian Reserves	-	-	148	199	239	284	325	-
TOTAL BUR. PENINSULA	195,780	298,855	341,444	457,662	514,809	566,027	623,619	674,537
NORTH SHORE								
West Vancouver	2,434	4,786	8,362	13,990	19,197	25,454	31,987	36,273
North Vancouver City	7,652	8,510	8,914	15,687	19,951	23,656	26,851	31,863
North Vancouver Dist.	2,950	4,788	5,931	14,469	26,252	38,971	48,124	57,123
Indian Reserves	-	-	384	519	621	738	845	-
Lions Bay	-	-	-	-	-	51	153	396
TOTAL NORTH SHORE	13,036	18,084	23,591	44,665	66,021	88,819	107,807	125,655
SOUTH SHORE								
Richmond	4,825	8,182	10,370	19,186	25,978	43,323	50,460	61,376
Delta	2,839	3,709	4,287	6,701	8,752	14,597	20,664	45,175
Surrey	5,614	7,888	13,240	29,729	43,927	70,838	81,826	96,651
White Rock	200	500	1,600	3,941	5,439	6,453	7,787	10,244
Barnston Island	-	-	-	88	93	94	98	-
Indian Reserves	-	-	56	76	91	108	123	-
TOTAL SOUTH SHORE	13,478	20,279	29,553	59,721	84,280	135,413	160,958	213,446
TOTAL	222,294	337,218	394,588	562,048	665,110	790,259	892,384	1013,638

INTER-CENSUS INCREMENTS - 1921-71

MUNICIPALITY OR AREA	1921-31	1931-41	1941-51	1951-56	1956-61	1961-66	1966-71 (2)
"METRO" AREA							
BURRARD PENINSULA							
Endowment Lands	575	61	1,484	879	273	-293	531
Vancouver	83,373	28,760	69,480	21,011	18,678	25,853	11,903
Burnaby	12,681	4,764	28,048	25,369	16,412	11,879	12,000
New Westminster	3,029	5,435	7,149	2,985	2,011	2,909	4,070
Fraser Mills (1)	16	-64	-183	-153	-51	-1	-7
Coquitlam	2,497	3,078	7,748	5,103	8,253	11,863	11,207
Port Coquitlam	134	227	1,693	1,400	3,479	3,010	8,449
Port Moody	230	252	734	467	2,076	2,232	3,759
Buntzen	540	-72	14	46	42	99	-
Indian Reserves	-	148	51	40	45	41	-
TOTAL BUR. PENINSULA	103,075	42,589	116,218	57,147	51,218	57,592	51,912
NORTH SHORE							
West Vancouver	2,352	3,576	5,628	5,207	6,257	6,533	4,286
North Vancouver City	858	404	6,773	4,264	3,705	3,195	5,012
North Vancouver Dist.	1,838	1,143	8,538	11,783	12,719	9,153	8,999
Indian Reserves	-	384	135	102	117	107	-
Bowen Island	-	-	-	-	-	-	-
Lions Bay	-	-	-	-	-	-	243
TOTAL NORTH SHORE	5,048	5,507	21,074	21,356	22,798	18,988	18,540
SOUTH SHORE							
Richmond	3,357	2,188	8,816	6,792	17,345	7,137	10,916
Delta	870	578	2,414	2,051	5,845	6,067	24,511
Surrey	2,274	5,352	16,489	14,198	26,911	10,988	14,825
White Rock	300	1,100	2,341	1,498	1,014	1,334	2,457
Barnston Island	-	-	88	5	1	4	-
Indian Reserves	-	56	20	15	17	15	-
TOTAL SOUTH SHORE	6,801	9,274	30,168	24,559	51,133	25,545	52,709
TOTAL "METRO" AREA	114,924	57,370	167,460	103,062	125,149	102,125	123,161

Notes: (1) Fraser Mills was incorporated into the Municipality of Coquitlam on Nov. 1, 1971.
(2) Figures for 1971 preliminary estimates only; D.B.S.

on the road and railway lines to New Westminster coalesced into a large island of urban settlement midway between Vancouver and New Westminster (Robinson 1971). The bridges built across the Fraser River allowed access to Richmond and Surrey and several small urban centres established (Plate 10). Coquitlam and Port Moody exhibited a similar pattern of sporadic development. Only on the North Shore in North Vancouver, and later in West Vancouver, was urban development relatively compact (Plate 6).

The 1930 economic depression precipitated the second period of stagnation. Population growth was halted in the Vancouver region but unlike the previous recession, there was not a large exodus of people to rural areas. However, with the exception of West Vancouver which benefited from the opening of the Lions Gate Bridge in 1938, urban expansion was negligible for the following decade and land in many premature subdivisions reverted to the municipalities in lieu of payment of taxes (Parker 1966 p.167). As before, the onset of war proved a stimulus and by 1940-41, moderate growth was being experienced.

The following decade from 1941-1950 was more a period of gradual recovery than a new wave of expansion. Although the population of the Vancouver region increased by 160,000 in the ten years, development was piecemeal and for the most part represented infilling and consolidation of vacant areas remaining from the second phase of expansion (Figure 7).

In the City of Vancouver this was the last period of significant urban spatial growth. The undeveloped enclaves of land considered unsuitable for development previously or not warranting the capital investment

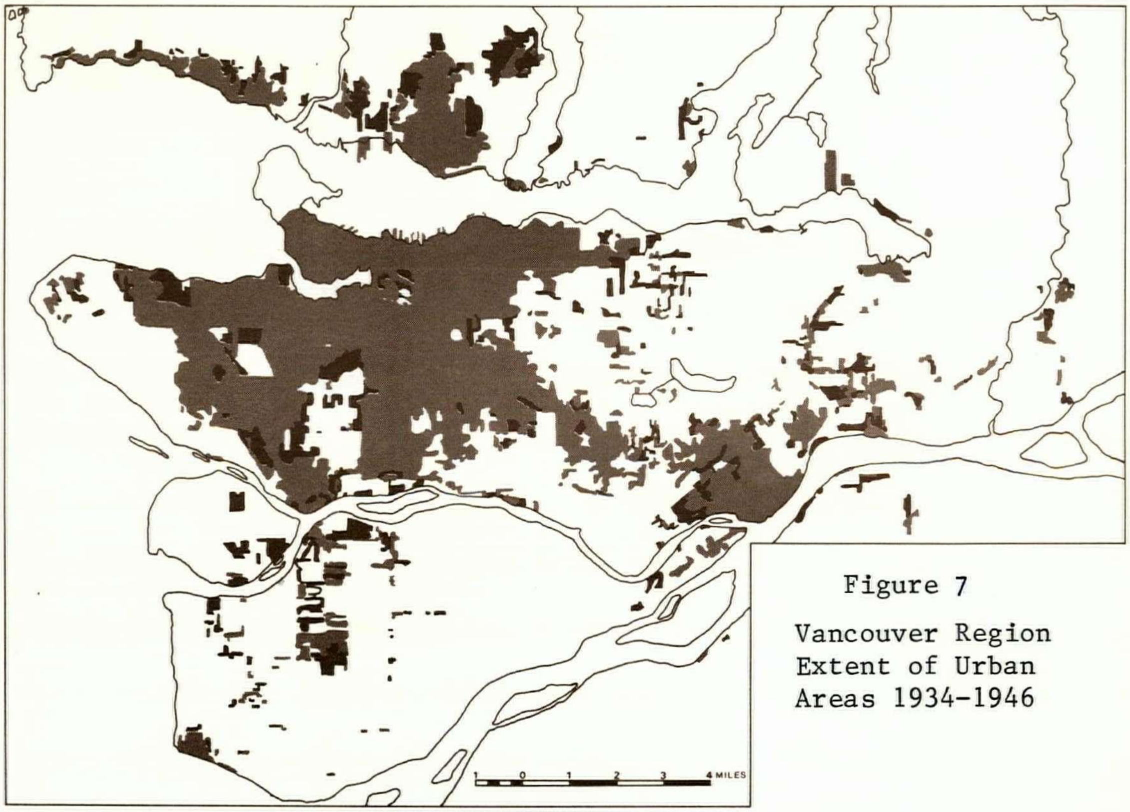


Figure 7

Vancouver Region
Extent of Urban
Areas 1934-1946

Explanatory Note: The light brown shading represents the urban areas at the start of the period; dark brown represents urban expansion during the period.

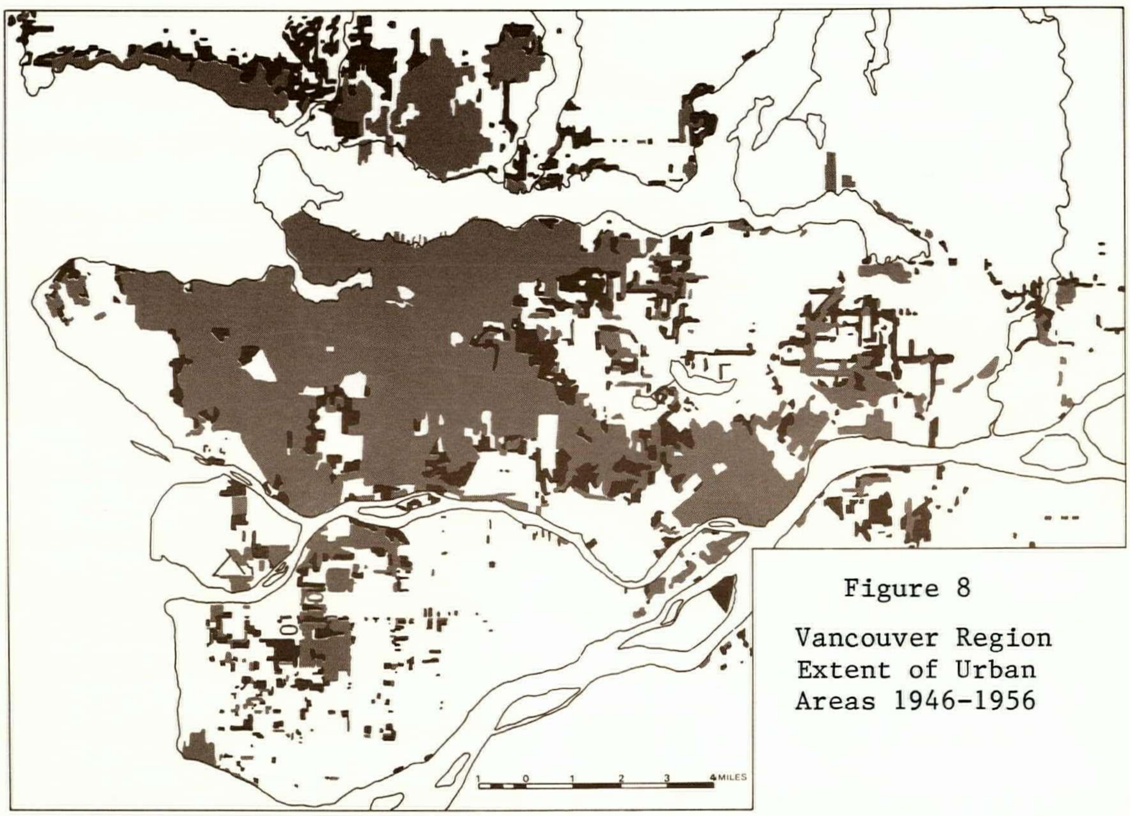


Figure 8

Vancouver Region
Extent of Urban
Areas 1946-1956

Data Source: Department of Mines and Technical Surveys, Atlas of Canada, 1957.

required for their development were taken up for urban uses. Subsequently, Burnaby became the most important urban expansion area and there was even a small overflow of development into Coquitlam. In Richmond some of the smaller scattered centres were consolidated by new development. Surrey was the only municipality to double its population in the decade but there was still not a sizable urban area, with numerous dispersed settlements remaining the rule. On the North Shore, urban expansion occurred uniformly in North and West Vancouver, once again as small rings of peripheral growth.

The <u>third phase</u> of urban expansion from 1951-1970, began slowly in the early 1950's following a large increase in population growth and quickly gathered momentum when the rate of population increase was maintained. In two decades, the Vancouver regional population almost doubled (Table 1). Four areas registered a three-fold population increase: Port Coquitlam, Port Moody, North Vancouver District and Delta. Another four areas more than doubled their population: Coquitlam, West Vancouver, Richmond and Surrey. By the early 1960's, the rate of urban expansion was being viewed with alarm, especially as less than one half of the land being converted from rural to urban uses was actually being developed (Lower Mainland Regional Planning Board 1963; See Appendices I and II).

It can be observed from Figure 8 that consolidation and infilling were still general traits of urban spatial growth until 1956. Richmond and Burnaby are notable in this respect (Plates 11 and 12). On the North Shore, West Vancouver and North Vancouver District were expanding peripherally in an orderly fashion. However, in the Coquitlam area to the east, and

Surrey and Richmond areas to the south, there were signs of the extensive urban development to follow. During the 1960's, large areas of scattered urban settlement in Richmond, north-east Surrey and Coquitlam, consolidated to become fully urbanized. At the same time, Port Coquitlam, south and east Surrey, Delta and White Rock, began large scale, piecemeal transformation from rural to urban areas (Figure 9).

Freeway construction was instrumental in the development of new urban areas during the most recent phase of expansion (Meyer 1966). The Deas Island Throughway and Massey Tunnel under the Fraser River increased substantially the ease of communication to established urban areas from Delta, White Rock and south Surrey (Plate 10). The Port Mann Bridge and the Trans-Canada Highway greatly stimulated urban development in East Surrey and Port Coquitlam. This is reflected in the traffic volumes and traffic times from outlying areas in 1967-1968 (See Appendix III).

The foregoing description of the spread of settlement in the Fraser River - Burrard Inlet region shows that urban expansion was neither symmetrical nor continuous. Rather, the urbanization of the region proceeded from a number of isolated centres in three distinct phases. From 1890 to 1910 growth occurred mainly around Burrard Peninsula, particularly along the foreshores of English Bay and Burrard Inlet. In the second phase of urban expansion from 1917 to 1930, development extended south to the North Arm of the Fraser River, along the major transportation route to New Westminster and east into Burnaby. A period of moderate growth followed from 1941 to 1950, characterized mainly by consolidation and infilling but with some small areas of peripheral expansion on the North Shore, and sporadic expansion in Richmond, Coquitlam and Surrey municipalities. The third phase of urban expansion from 1951 to 1970 resulted in the large scale conversion of rural land in Richmond, Delta, Surrey and Port Coquitlam.

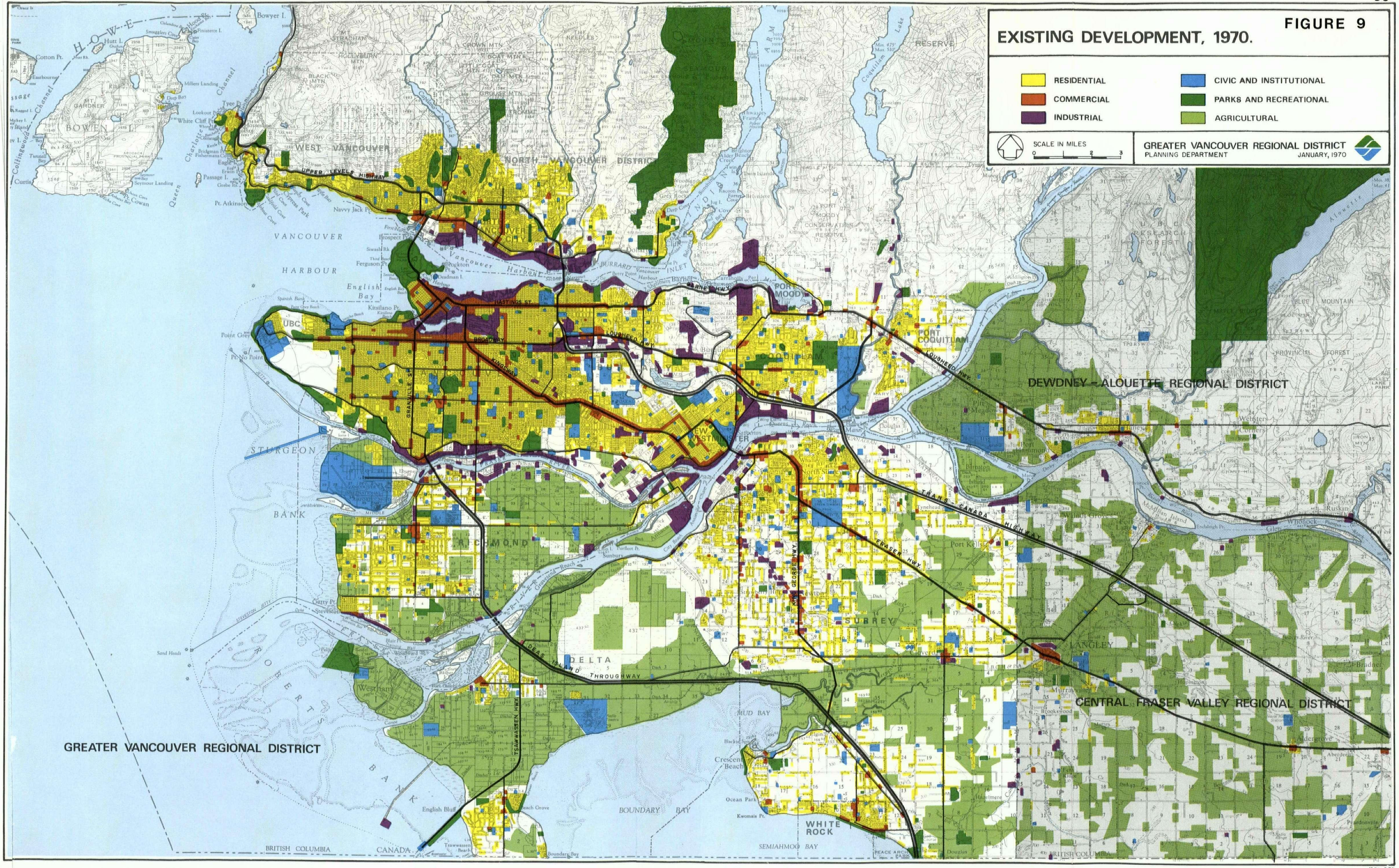


FIGURE 9

EXISTING DEVELOPMENT, 1970.

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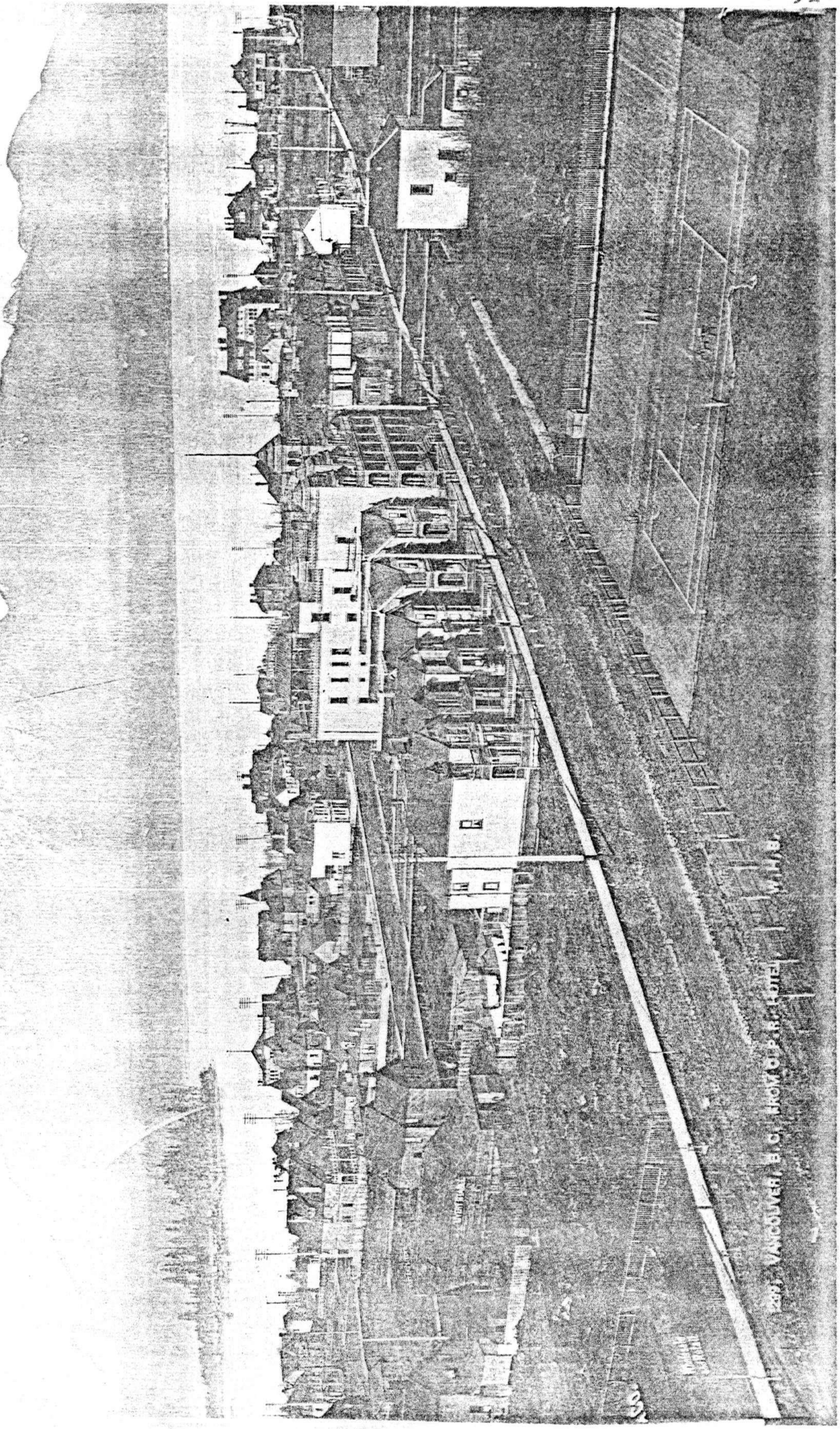
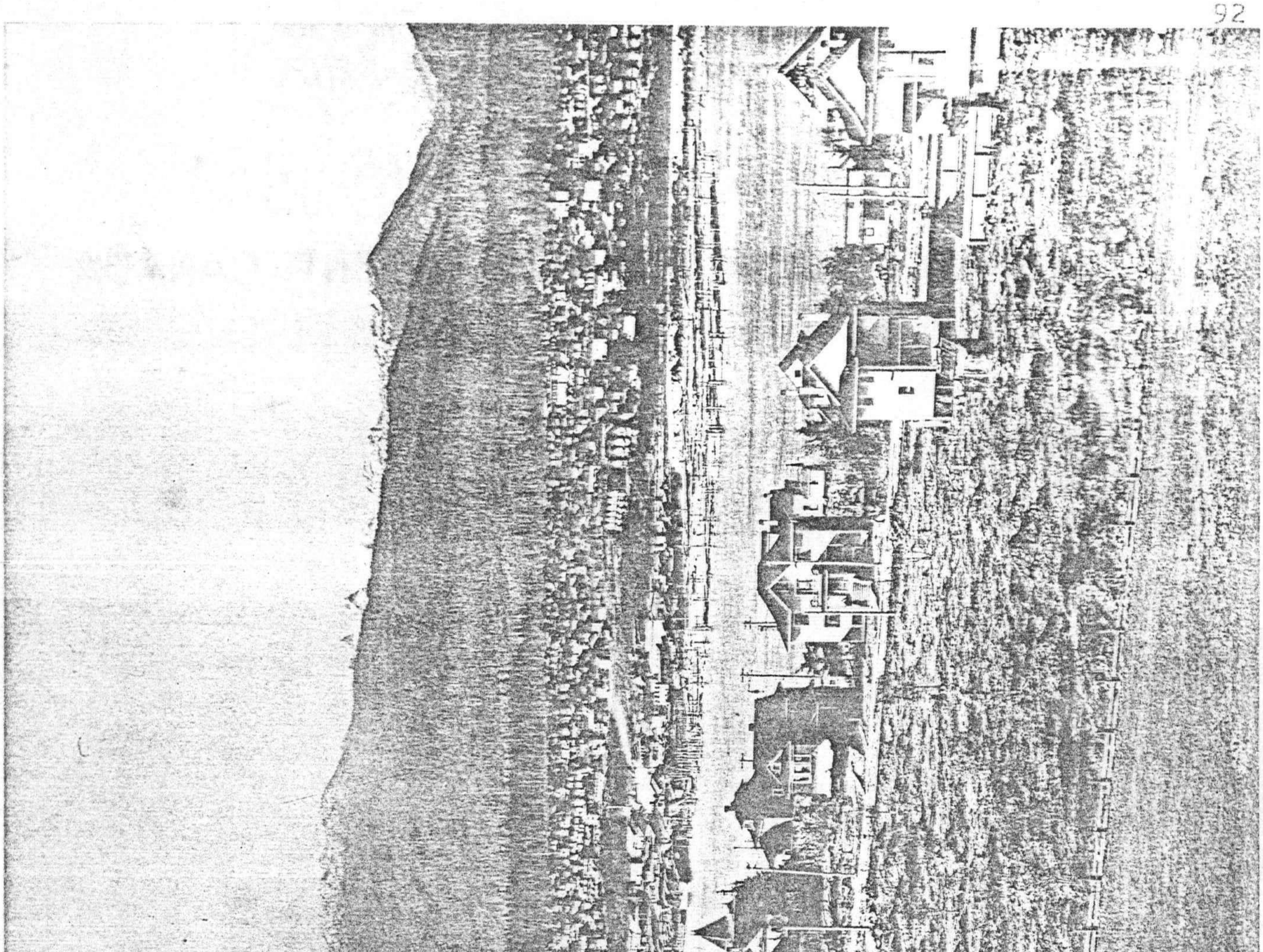
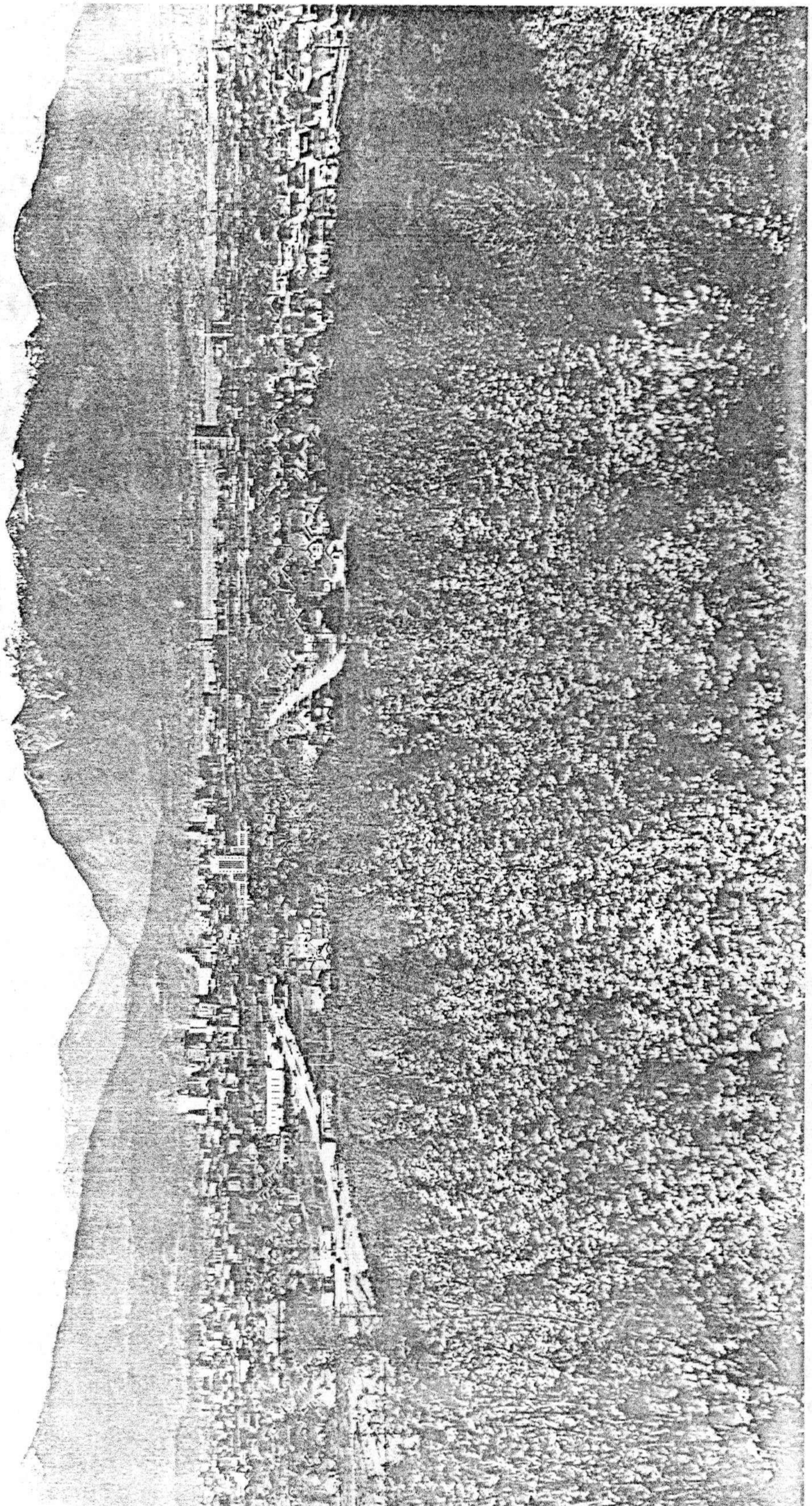


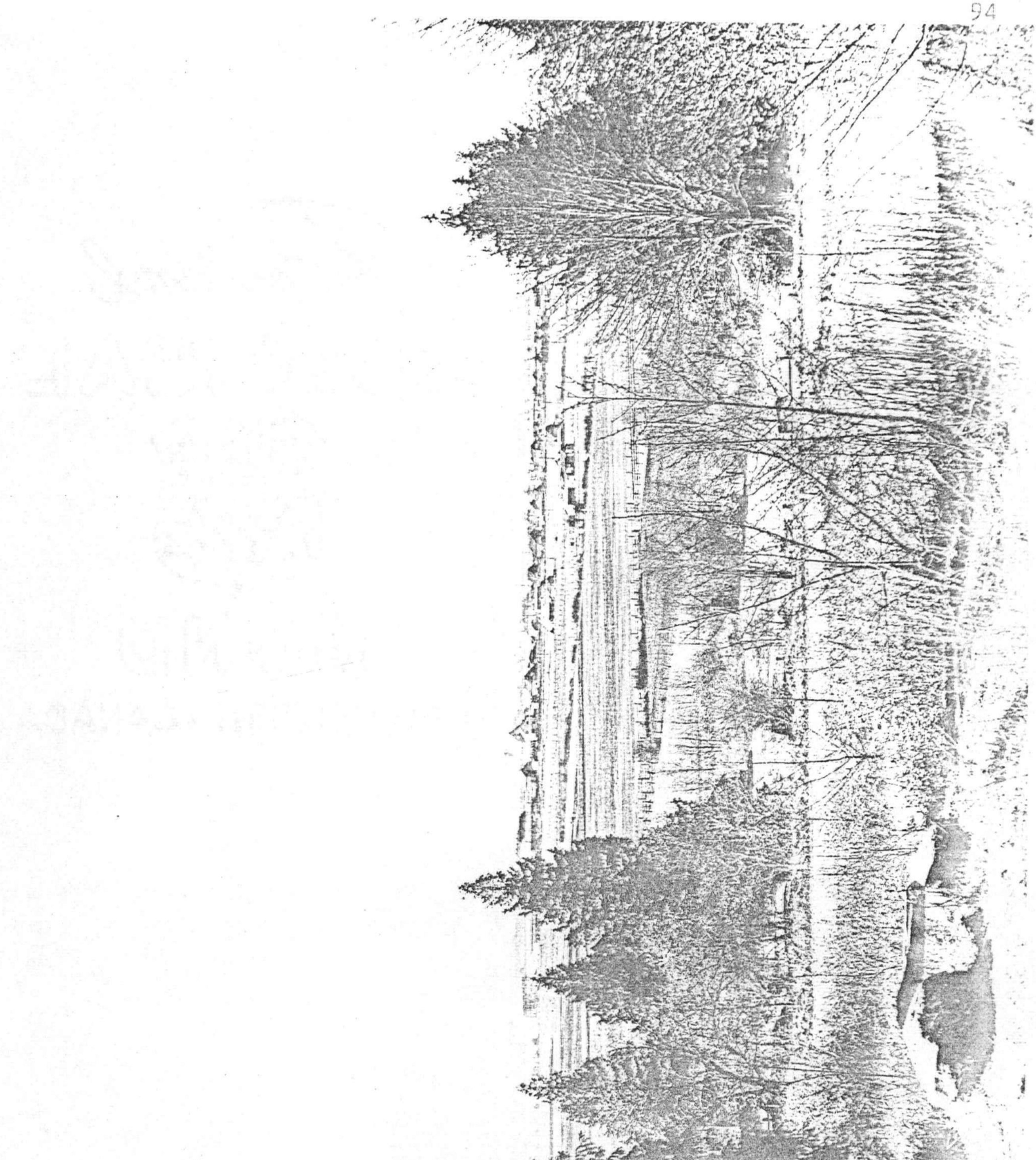
Vancouver: A Country Town (1890 circa)



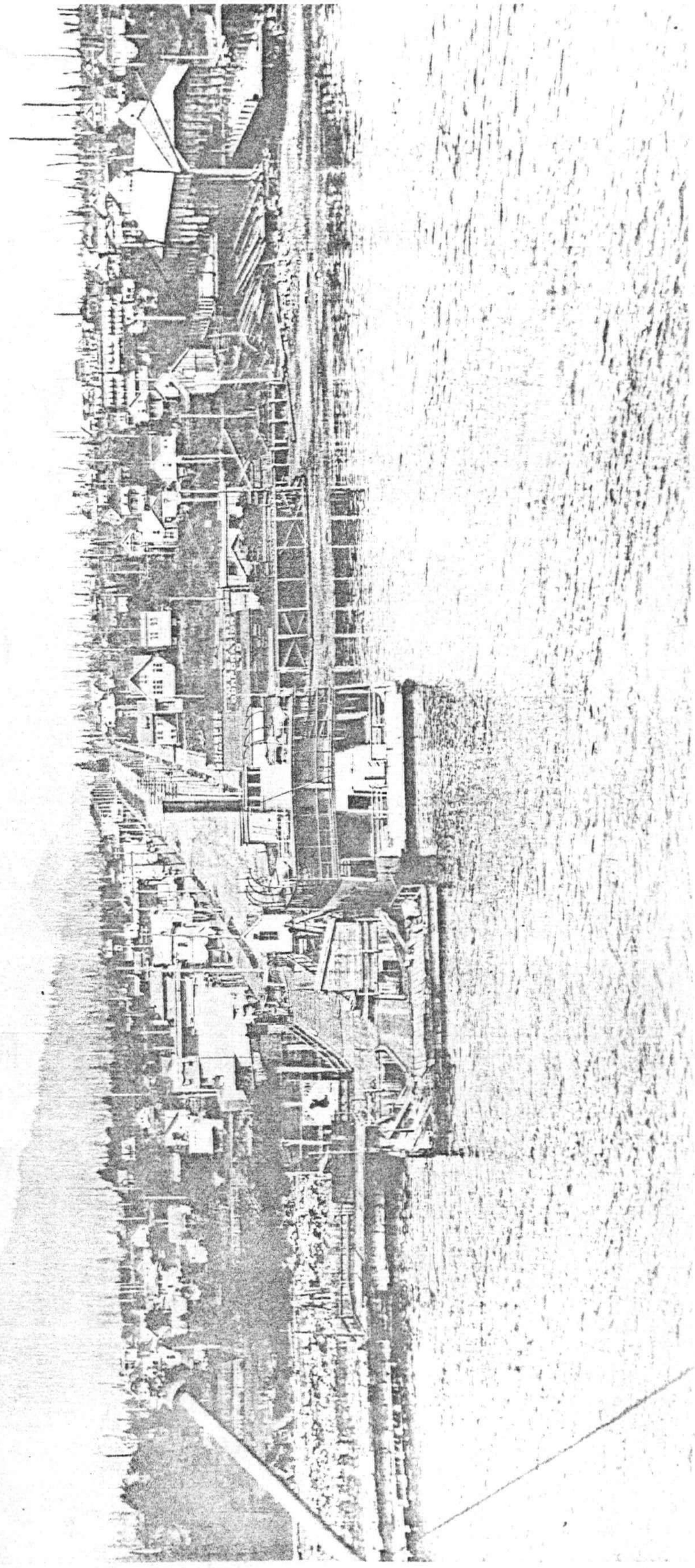
Vancouver: The Compact City (1910)



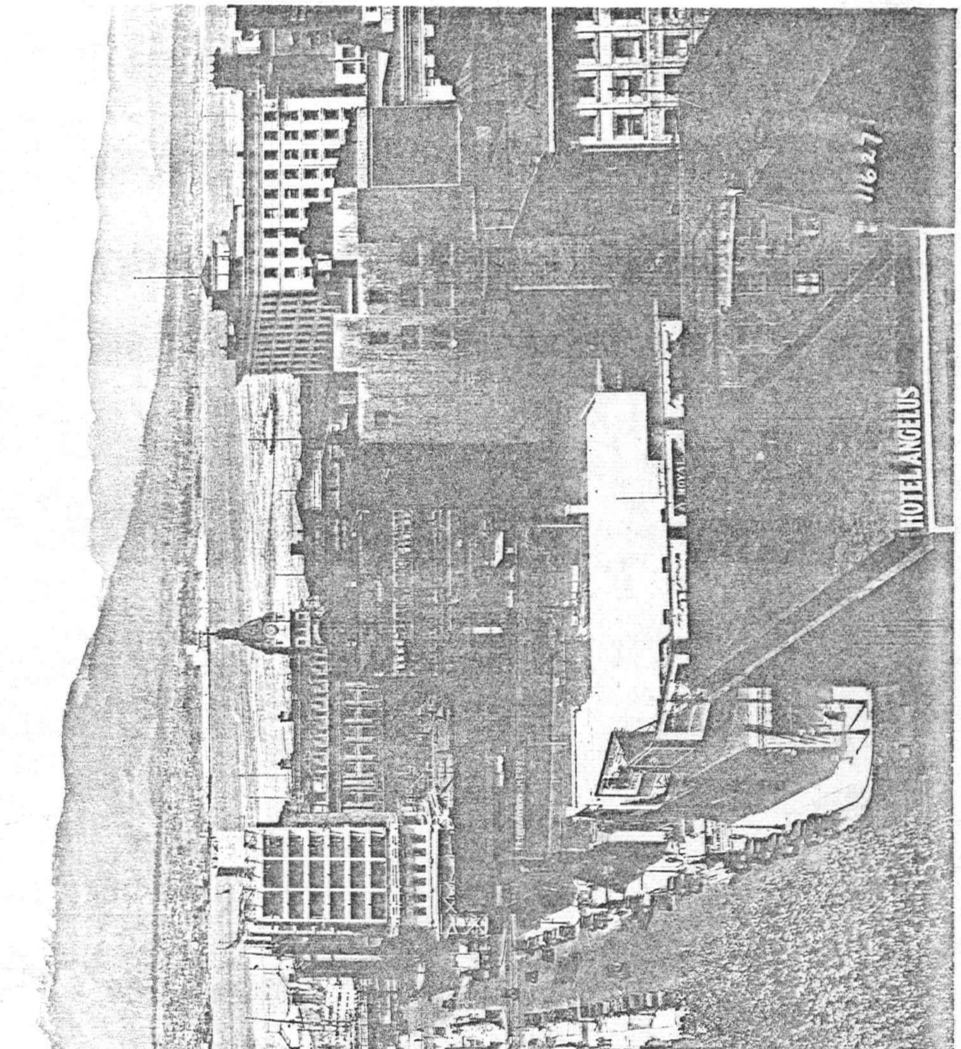
Vancouver: The Dispersed City (1939)



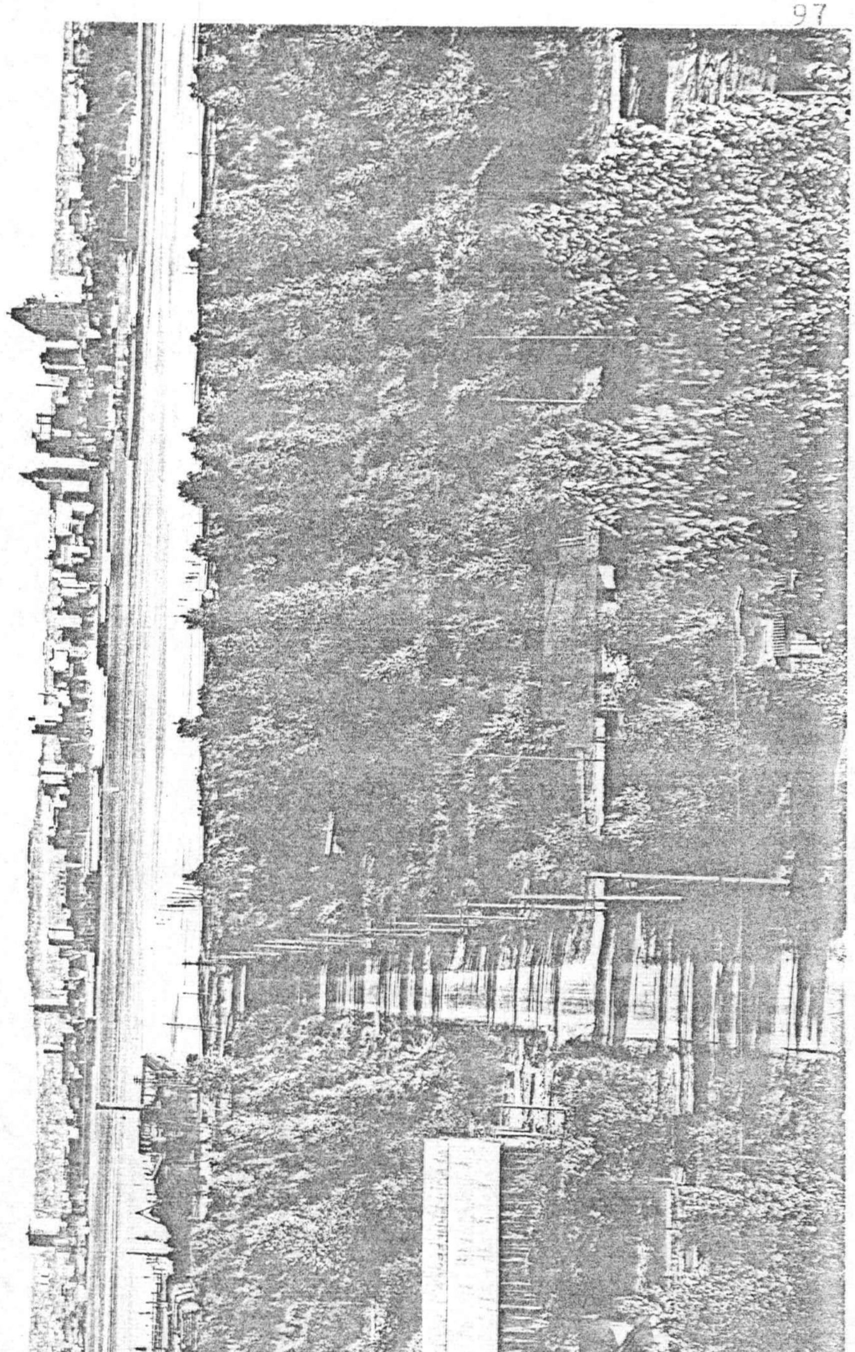
Rural-Urban Subdivision (1941)



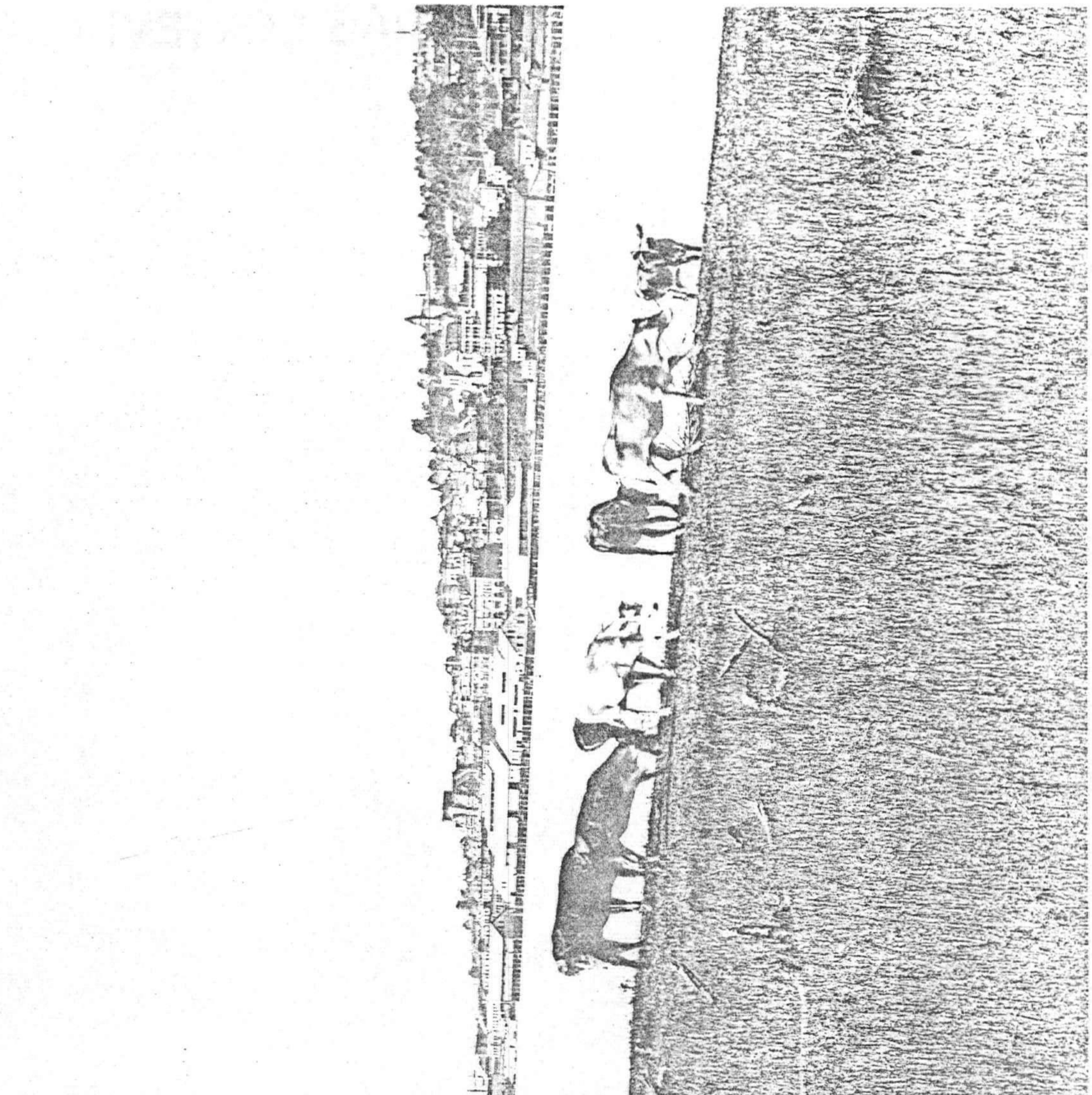
Moodyville: A Resource Town (1906)



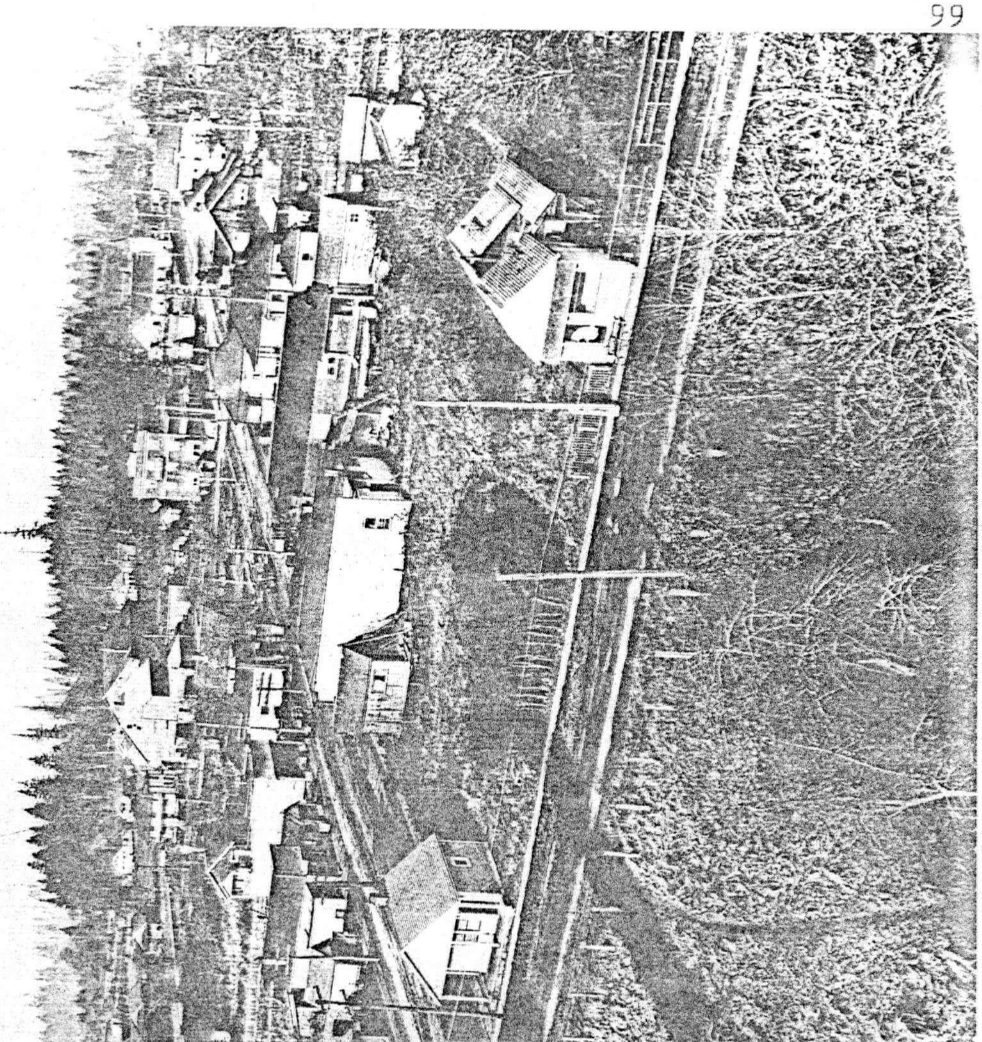
The Emergence of North Vancouver (1929)



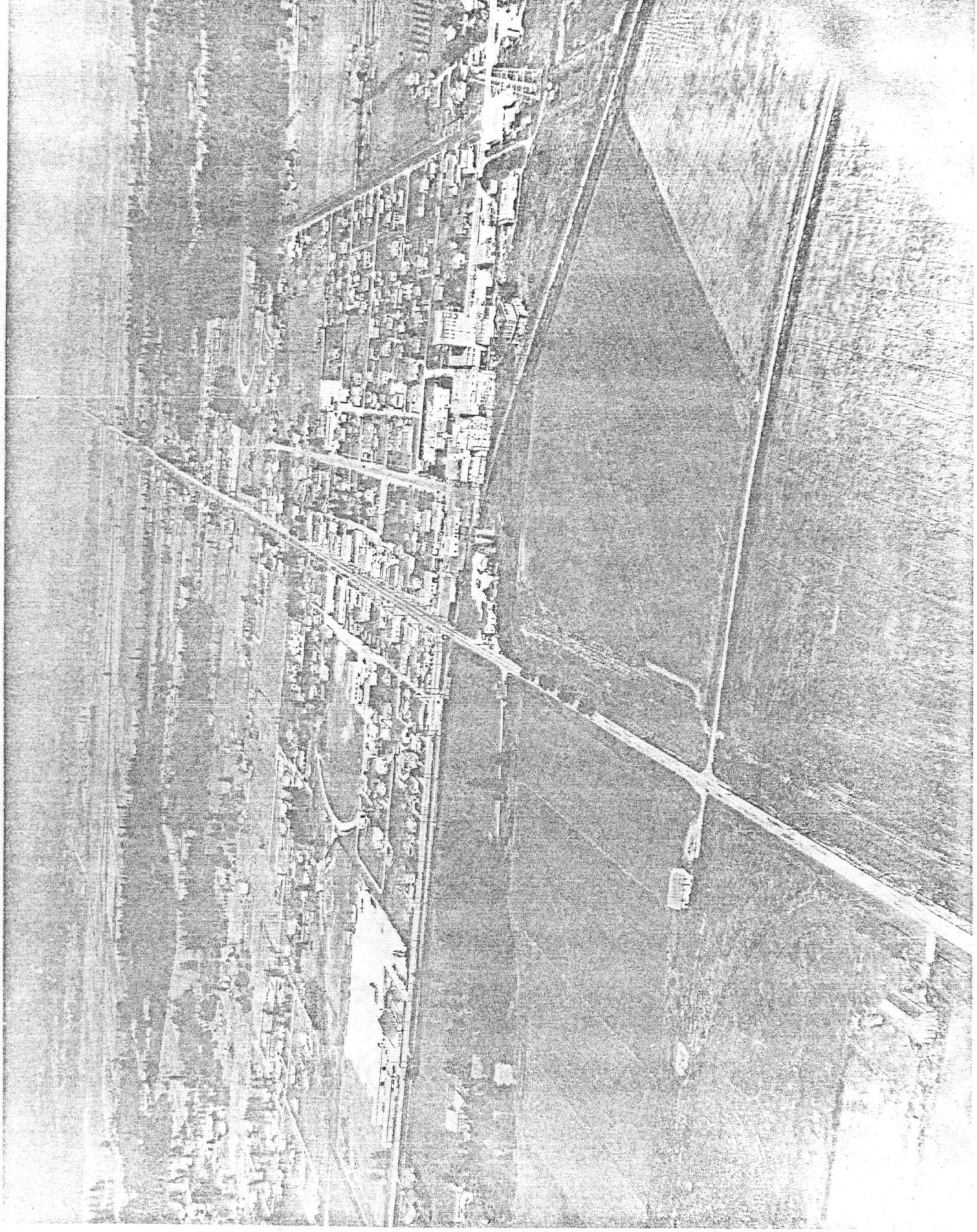
Burrard Inlet: Two Shorelines (1938)



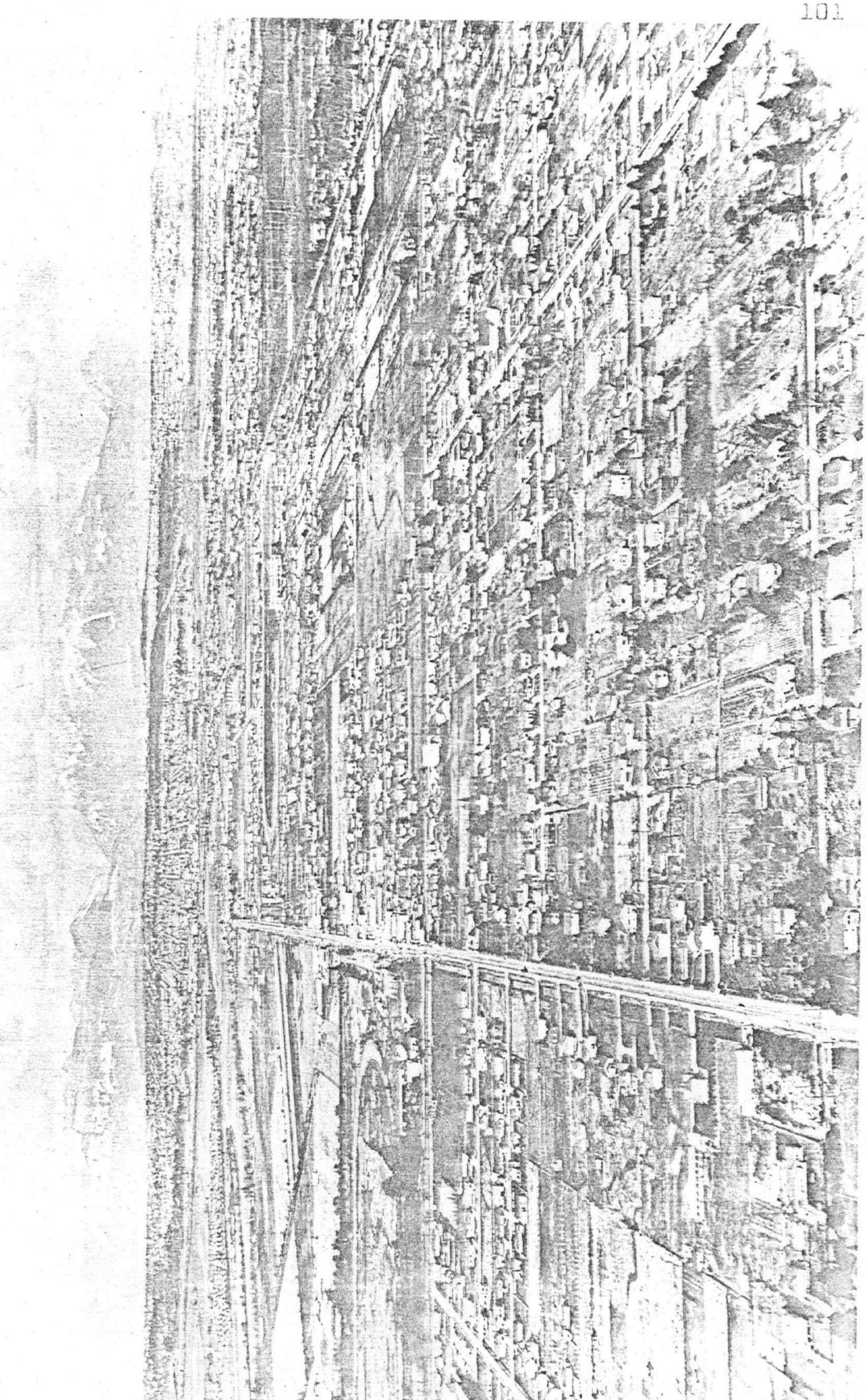
New Westminster: The Dormant City (1906)



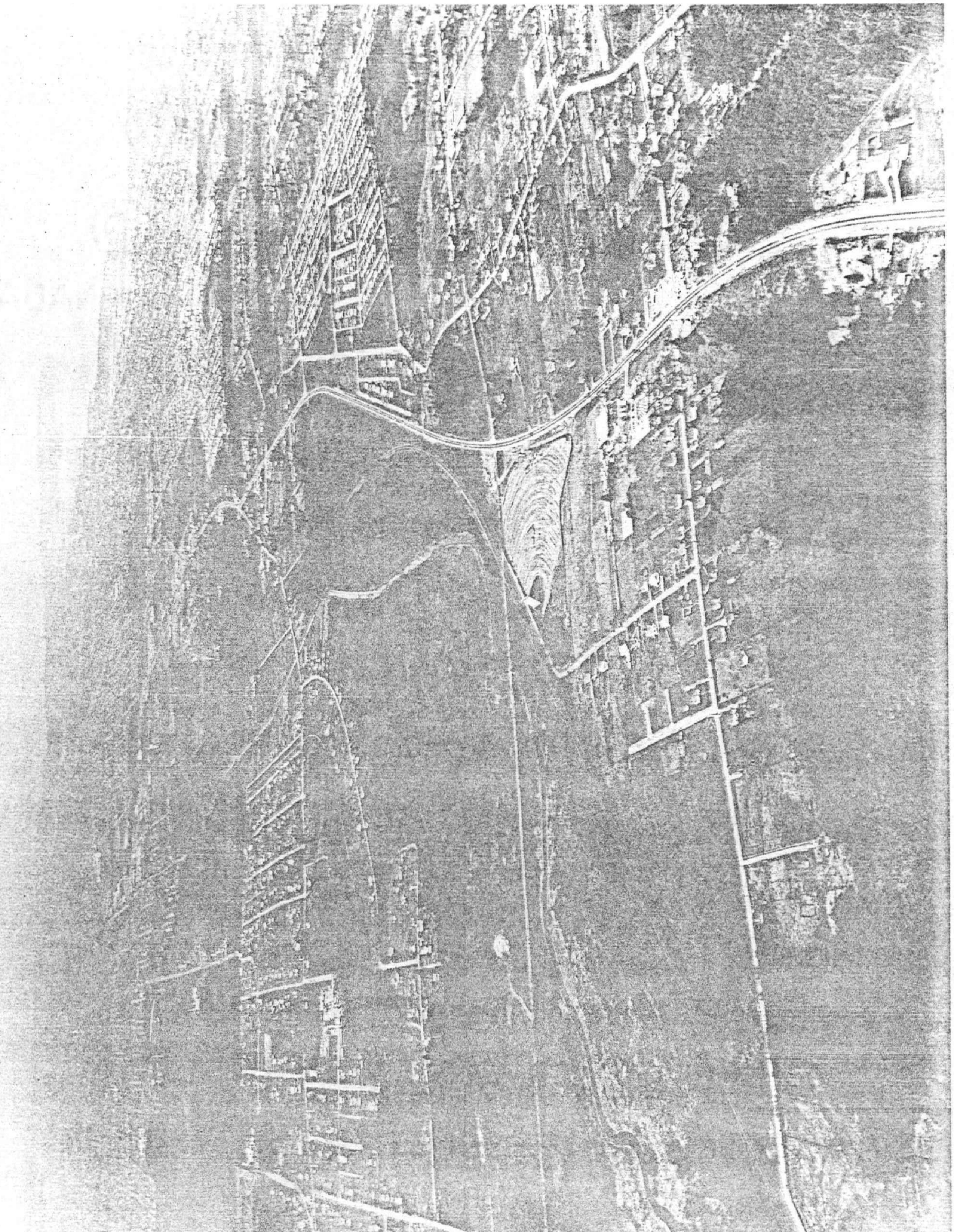
Hammond: A Rural Centre (1928)



Cloverdale: A Fringe Community (1953)



Richmond: Filling in the Gaps (1955)



Burnaby: The Dilemma of Ex-Urbia (1957)

PLATE 1. VANCOUVER: A COUNTRY TOWN (1890 circa.)

Two of the earliest settlement nuclei in the Fraser River-Burrard Inlet region were Moodyville, a timber resource town on the north shore of Burrard Inlet, and Vancouver, a quickly growing commercial centre. Both are shown in this photograph taken from the Canadian Pacific Railway Hotel about 1890. Vancouver had by this time become a significant deep sea port, and the terminal for a trans-Canada railway line. The population was over 10,000. The scattered settlement shown here is similar in many respects to the pattern of development in Hammond in 1928 (Plate 9) and Cloverdale in 1953 (Plate 10).

PLATE 2. VANCOUVER: THE COMPACT CITY (1910)

The largest settlement in British Columbia by 1910 was Vancouver with a population of 100,000. The original townsite had been completely developed and the first wave of urban expansion had reached its peak. Two of the three bridges crossing False Creek at this time providing access to Kitsilano, Point Grey and as far south as the Fraser River, are shown in this photograph taken from West 12th Avenue and Oak Street. In the foreground, the Fairview residential district is shown as the southern limits of urban development, while in centre-right, the filling of False Creek is already under way to provide level land for industry.

PLATE 3. VANCOUVER: THE DISPERSED CITY (1939)

Until the First World War, Vancouver was a compact city and spatial growth was outwards in a fan-like motion from the centre. However, during the 1920's, radial expansion along the major transportation lines became the rule, resulting in a more dispersed settlement pattern. Large islands of undeveloped land could be found near to the central city area even after the Second World War. In this panoramic view of downtown Vancouver and the North Shore, taken from Queen Elizabeth Park, (the focus of one island of vacant land), the edge of urban development is clearly evident. At the foot of the mountains on the north shore of Burrard Inlet, the well established settlement in North Vancouver (centre-right) and the comparatively recent settlement in West Vancouver (centre-left) are visible.

PLATE 4. RURAL-URBAN SUBDIVISION (1941)

During the second wave of urban expansion in the 1920's, development extended south from Vancouver in several parallel tongues to the North Arm of the Fraser River. After the depression years, and with the advent of the Second World War, there was a gradual economic revival and urban expansion proceeded. In Kerrisdale, at the foot of Elm Street, the landscape was still predominantly rural, however, this photograph records the beginnings of a transformation in 1941 to a suburban residential landscape. This scene is typical of development in Richmond, Delta and Surrey during the 1960's.

PLATE 5. MOODYVILLE: A RESOURCE TOWN (1906)

Moodyville developed from a sawmill-company town prior to 1890, to an important resource town and nucleus for settlement on the north shore of Burrard Inlet. By 1900, Moodyville had its own commercial and industrial base although it still relied heavily on Vancouver for many services. This 1906 photograph shows Lonsdale Street which was the axis for urban development in North Vancouver and the ferry which provided regular services to Vancouver.

PLATE 6. THE EMERGENCE OF NORTH VANCOUVER (1929)

The opening of the Second Narrows Bridge for road and railway traffic in 1925 proved a considerable stimulus for settlement in the North Shore municipalities. Both the City and Municipality of North Vancouver were assured of relatively easy access to Vancouver across Burrard Inlet. However, the location of the bridge was far less convenient for West Vancouver which grew slowly until the First Narrows Bridge (Lions Gate) was completed in 1938. In this 1929 photograph, taken from the Georgia Hotel in downtown Vancouver, residential development is shown extending well up the slopes and industry is beginning to locate along the foreshores of Burrard Inlet.

PLATE 7. BURRARD INLET: TWO SHORELINES (1938)

In comparison to the Vancouver waterfront across Burrard Inlet, the shoreline of North Vancouver was relatively undeveloped as late as 1938 when this photograph was taken. In that year, the Lions Gate Bridge was opened and during the 1940's and 1950's all the waterfront land in North Vancouver, except for the Indian Reserves, was taken up by industry. In West Vancouver, on the other hand, shoreline development was predominantly residential.

PLATE 8. NEW WESTMINSTER: THE DORMANT CITY (1906)

Good access from an area suitable for development to a major centre such as New Westminster is not necessarily a sufficient condition to encourage settlement. New Westminster had been the traditional centre for an extensive, productive rural region, including Delta, Surrey, Langley and Matsqui municipalities, since the earliest settlement in the region and when the first combined road-rail bridge across the Fraser River was built at New Westminster it was thought that urban development would spread across into Surrey. In fact, Vancouver attracted nearly all the new development, and North Surrey did not become urbanized until World War II. Meanwhile, New Westminster looked across the Fraser River at the rural landscape shown here.

PLATE 9. HAMMOND: A RURAL CENTRE (1928)

Throughout the Fraser Valley, small towns sprung up in the early decades of this century to serve the surrounding rural communities. Some of these have already become part of the urban region (e.g. Brighouse, Richmond); others have become focii for urban development in the most recent wave of urban expansion (e.g. Cloverdale, Surrey; Plate 10); and still others are showing signs of taking on this function in the immediate future. Hammond, between the Fraser River and Lougheed Highway and near to Haney, falls into the latter category. This particular photograph, although somewhat dated, shows the characteristic pattern of development in these centres prior to the influence of widespread urbanization forces.

PLATE 10. CLOVERDALE: A FRINGE COMMUNITY (1953)

Cloverdale is representative of old rural centres on the threshold of rapid urban growth. At one time it was one of two dominant centres (the other was Abbotsford), in the extensive rural region between the Lower Fraser River and the United States border. It stagnated until the 1950's, although served by two major arterial roads and a railway. Since then freeway development, immediately to the east and west, has brought it within commuting distance of commercial, industrial and cultural nodes in the urban region. Consequently, during the 1960's there was a revival and by 1970 it was obvious to the residents of Cloverdale that it was only a matter of time before their town became part of the Vancouver urban region.

PLATE 11. RICHMOND: FILLING IN THE GAPS (1955)

The sporadic growth of urban settlement, characteristic of Richmond since World War II, has resulted in a substantial crop of planning problems. Apart from large discrepancies in land development costs between dispersed and consolidated development (Rawson and Norville 1963), there are great difficulties in rationalizing subsequent development, i.e. filling in the under-utilized land. This aerial photograph taken in 1955 indicates the magnitude of the problem. The scene shown is an excellent example of settlement patterns resulting from the urban expansion process on the flat terrain in the south of the Vancouver Region. It is also possible to discern the abrupt change in the patterns of settlement on either side of the Fraser River which flows right to left, slightly above the centre of the photograph.

PLATE 12. BURNABY: THE DILEMMA OF EX-URBIA (1957)

Some urban residents like to live in a rural environment and typically, when they move to their new home they like to think that they will be the last newcomers. Apparently, so do the people who move in later. These semi-rural communities seldom last for very long and even if, through exclusionary zoning or the like, they are passed over for the time being, they soon become vulnerable to mounting development pressures. Often the very facility that allowed the early residents access to these rural areas (i.e. arterials and freeways), stimulates the forces which cause their *complete urbanization. Here the Lougheed Highway provides easy access to Vancouver (top-centre). The area shown in the photograph was almost completely developed by industry, commerce and housing at 1970.*

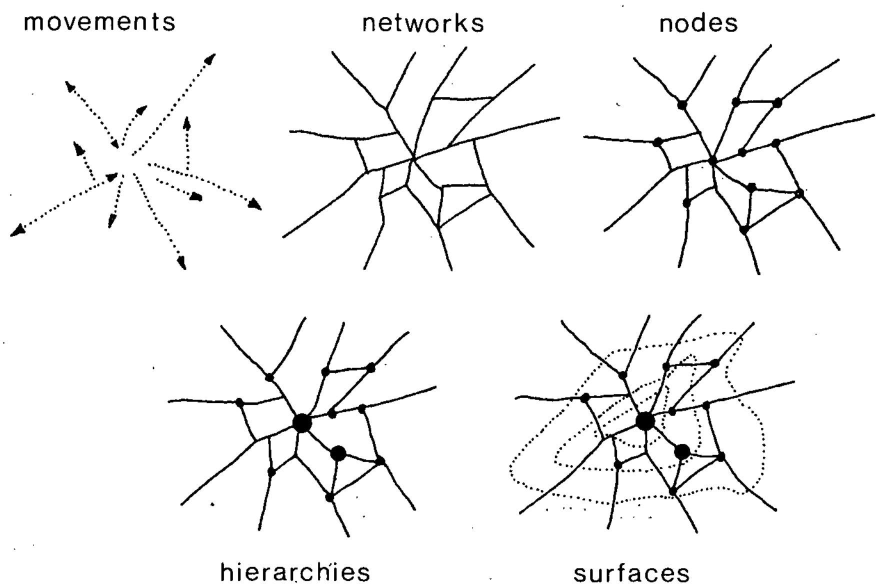
Characteristics of Urban Expansion

One of the difficulties faced when interpreting a dynamic process, such as urban expansion, is the need to break the process down into components. The more dynamic a process, the less justification to be found for dismembering it, for there is an increasing danger of obscuring fundamental interdependencies. Thus in examining the urban expansion process, through the identification of characteristics, we need to be constantly aware of the inter-relationships of components in the total process. This is facilitated in the following by taking the view that urban regions are open systems, defined by movements, networks, nodes, hierarchies and surfaces (Haggett 1965); i.e. a progression from energy flows to easily recognized landforms and settlement patterns (Figure 10). The interpretations of characteristics of urban expansion in the Vancouver region discussed in this section are derived in part from this abstraction of urban systems.

Five characteristics of urban spatial growth with a bearing on the dynamic nature of urban expansion have been identified from the description of urban settlement in the Vancouver region:

1. the bio-physical landscape,
2. the sequential development of the communications network,
3. the evolution of dominant nodes in the Vancouver region,
4. the diversity of urban settlement patterns in areas experiencing rural-urban land conversion,
5. time lags and discontinuities in the urban spatial growth processes

FIGURE 10. STAGES OF REGIONAL SYSTEMS



Source: P. Haggett (1965 p.18)

Each of these characteristics will be considered in detail.

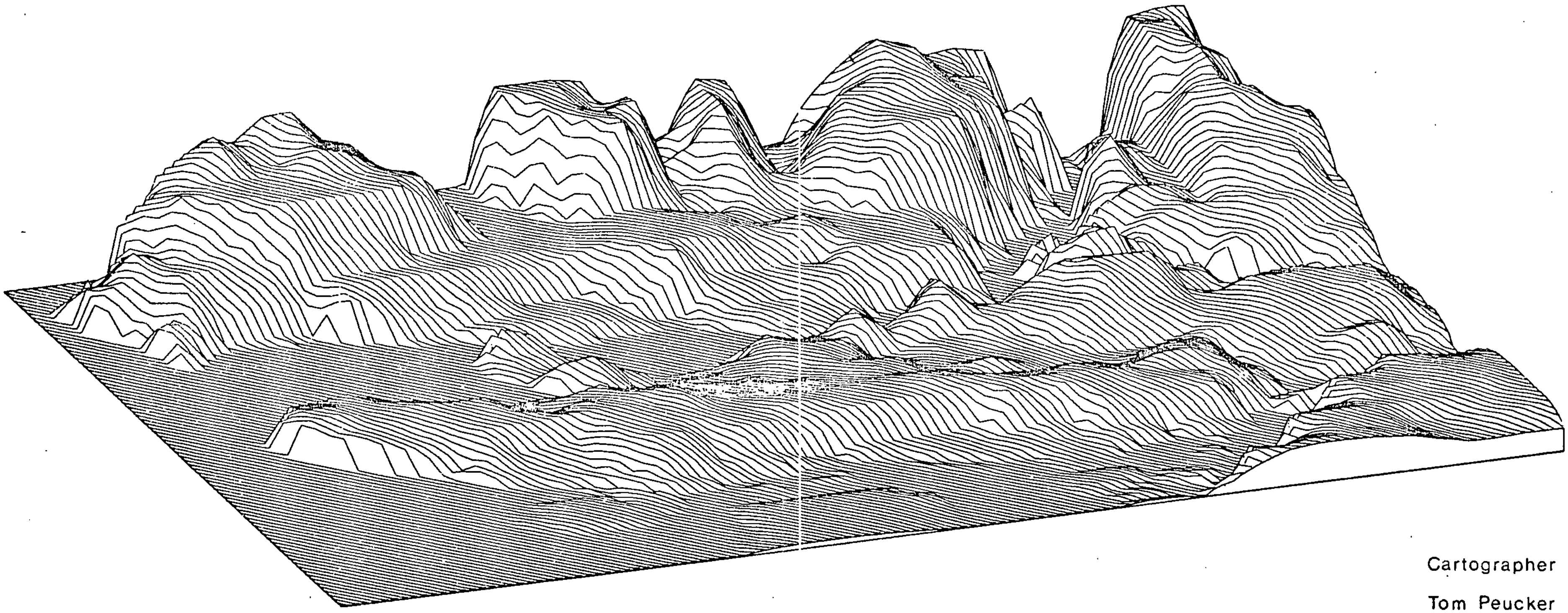
The bio-physical landscape is composed of the natural landforms, the vegetation and wildlife, and water bodies. In the Vancouver region, the spread of settlement reflects in many ways, the substantial molding influence of topography, and to a lesser degree, the distribution of particular flora and fauna.

It is difficult to portray the Vancouver regional landscape on a two dimensional surface in a way that adequately represents the dominant characteristics. However, a creditable attempt by cartographer-geographer Tom Peucker, in the form of a computer produced, block diagram, is shown in Figure 11. The mountainous north shore appears in strong contrast to the floodplains of Richmond to the south, while the Burrard Peninsula is shown as a moderately undulating core extending from east to west. In addition, each landform type is separated by a water body; Burrard Inlet separates Vancouver proper from the North Shore, and the Fraser River separates Richmond from Vancouver. This unique arrangement of diverse landforms and water bodies is reflected in both the aereal extent and density of urban development (Figure 9, Appendix II).

Changing slopes and terrain ruggedness, the suitability of different landforms for various types of urban activities (e.g. soil foundation conditions), and the likelihood of periodic innundation as a result of the Fraser River flooding are just some of the factors which determine the feasibility of urban expansion into different areas, as well as influence the location of development through variances in construction and land preparation (Hurd 1924, Yuill 1970).

A problem being faced in Port Moody-Coquitlam illustrates yet another aspect of the influence of topography. Even with good access, suitable land and considerable pressure for development, settlement has been curtailed east of Ioco because of an inability to reticulate water above the 300 foot contour without a major upgrading of the water supply system (Mann-Urban Program Planners--personnel communication).

FIGURE II. TOPOGRAPHY OF THE VANCOUVER REGION



Cartographer

Tom Peucker

The influence of the bio-physical landscape on the spread of urban settlement can be interpreted in terms of barrier impediments to the flow of movements (Malisz 1963, 1969; Yuill 1964). According to this view, different landscape characteristics operate to varying degrees to impede or facilitate urban expansion.

The <u>sequential development of the communications network</u> in the Vancouver Region was of paramount importance to the direction and spread of urban settlement for numerous inter-related reasons. These reasons have been detailed by Roy (1966) in a paper examining the development of railways in the Lower Fraser Valley, by Meyer (1966) in a comparable study of road development, and by Jones (1966) and Siemens (1966 pp.30,46) in more general studies of the evolution of settlement in the Fraser River - Burrard Inlet region. For present purposes it is sufficient to consider only the ones that relate directly to the main characteristics of urban expansion.

Firstly, the Vancouver urban region evolved almost completely within the period of automated road and rail transportation. As a result, the historic need for compact urban development, to facilitate intra-urban communication, ceased to be important early in the history of settlement. The potential urban region covered increasingly larger geographical areas as the distances which could be travelled, without involving prohibitive effort or time, multiplied. Secondly, Vancouver's importance as a port, from early in its history, for the export of natural resources and some manufactured goods, promoted the development of major communication links to all parts of its hinterland which were potentially productive. Consequently, the number of transportation links and the capacity of the communications network were generally far greater than the urban population would normally warrant. Finally, the limitations imposed in several directions by the topography were often overcome, not through pressure exerted by the urban population, but because of the progressive development of the communication network built to serve the hinterland. Transportation links often preceded urban settlement, particularly where major bridges were constructed, and as a result, had the effect of channelling future growth along these communication lines. In many cases, where these new communication lines met a road established earlier, to serve local rural needs, the development of a new village or town was encouraged, creating a new settlement nuclei in the urban region.

These characteristics have a number of significant implications. By providing a measure of the ease of communication among disparate localities, the communications network can be interpreted as either promoting or impeding urban spatial growth, directionally. Thus to a large extent, the communication network, existing at any point in time, helps to define the potential urban field. As a result, it is possible to derive, in conjunction with other factors, mathematical statements pinpointing the urban boundary with varying probabilities.

The <u>evolution of dominant nodes in the urban region</u> might be considered a <u>fait accompli</u> at this stage in the development of the Vancouver urban region. It was observed that urban expansion has combined to spread into peripheral rural areas from Vancouver and New Westminster from before the turn of the century. However, the fact that Vancouver and New Westminster have prevailed as the dominant nodes for eighty years does not preclude the possibility of the emergence of new focii for future urban development. Centres presently remote, such as Langley or Haney, (or even a completely new nuclei), could conceivably emerge as dominant nodes.

Dominant nodes can be identified as the locations of greatest commercial activity, or alternatively, as the areas with the highest population densities (Appendix II). This characteristic is inherent in all theories of urban spatial growth, although the nature of peripheral settlement often varies. The particular interpretation of this characteristic in the present study, requires little explanation, being a straightforward descriptive relationship based on empirical observation. Urban expansion is considered a process involving the diffusion of urban activities from the dominant nodes into the surrounding rural areas. Darwent (1969) and Korcelli (1970) discuss various theoretical interpretations of this characteristic.

The <u>diversity of urban fringe settlement patterns</u> in the Vancouver region challenges most traditional concepts of urban development which emphasize separation of urban activities on the basis of economic criteria and the formation of relatively static land use patterns indicating inherent locational advantages. However, while it was observed that in some areas, notably on the north shore of Burrard Inlet, relatively compact urban settlement occurred fitting traditional descriptions, in the Richmond-Delta-Surrey area to the south fragmented urban settlement was the rule, (often associated with numerous small commercial nuclei). The evolution of settlement in Burnaby and the Coquitlam area indicated that both types of urban settlement can be found in the same area.

An explanation of these differences would require, inter alia, intensive studies of the decision process of fringe area residents. However, a number of studies, including one by the Lower Mainland Regional Planning Board (1963) suggest interpretations consistent with these characteristics.

Firstly, there seem to be a large group of people, mostly with young families, who choose to live considerable distances from the city proper, so long as they can commute to the city within an hour (Hardwick 1970 p.116). They have many reasons for their decision and the reduced cost of land and housing is obviously very important (Harvey and Clark 1965, Lower Mainland Regional Planning Board 1963). Other reasons suggested include family and social ties in the area, a lust for the outdoors, space for the children, or just an affection for life in small communities (Lower Mainland Regional Planning Board 1963, Hodge 1970). The advancing boundary of the urban region is due in part to these people who are willing to travel further and further back to the city area to their jobs as accessibility is increased into the hinterland (Plate 12).

But, if it does not seem to matter to them how far away from the city area they live, they still show a strong tendency to seek out established or newly establishing communities. The lack of services and the general inconvenience of the most isolated localities is undoubtedly very important in this respect (Chapin and Weiss 1962). However, this characteristic could also be a manifestation of general social tendencies and if a study of planned residential communities in California is any indication, an important factor influencing their decision is the life style image of the community in the preferred location (Werthman, Mandel and Dienstfrey 1965).

Secondly, the dispersed settlement pattern can also be attributed in part to the operation of the land market. Sinclair (1967) has argued that contrary to the graded land use patterns described in the Von Thunen model, vacant and under-utilized land is a common feature on the periphery of contemporary urban regions as a result of the premature conversion of rural land. In successive periods some land is subdivided and sold while comparable adjacent land is held over by a diligent farmer or a more optimistic speculator. As a result, while there is a general trend for land holdings to become increasingly fragmented, only small parcels of land become available for actual development at the same time and therefore dispersed urban settlement patterns occur.

Time lags and discontinuities in urban spatial growth processes are characteristics frequently obscured by the spatial and temporal dimensions considered in most studies of urban areas. However, these characteristics emerge clearly from the foregoing description of urban evolution in the Vancouver region.

While large scale changes in the rates of population growth are reflected, more or less, in the main phases of urban expansion, the continuous smaller oscillations are not mirrored directly in spatial growth patterns. Robinson and Hardwick (1968 p.447) have noted in referring to the period immediately preceding 1910, that the development of the Vancouver region's economic base lagged behind commercial and residential expansion and Vancouver grew too fast. According to the Lower Mainland Regional Planning Board (1963) a similar situation prevailed in the late 1950's, and early 1960's. At other times, urban spatial growth seems to have lagged behind rapid increases in the economic base and large population increments, notably during the early years of both the First and Second World Wars.

Periods of consolidation and infilling were observed to precede a new wave of expansion suggesting that as the available capacity was taken up, conditions became ripe for a new wave of urban settlement. As the Lower Mainland Regional Planning Board (1963) has clearly shown, rapid urban expansion removes large areas of agricultural land from the rural sector, much of which remains undeveloped for considerable periods of time. By this process the development potential in the urban area is replenished. A similar situation has been observed in the Sydney region by Rutherford, Burdekin and MacGregor (1971).

The concept of development potential or unused capacity is well known to the investor-developer groups operating in urban areas. They may not refer to it by these names but the different terms employed have similar connotations. For example, the investor-developer group concentrating on the apartment market, pay keen attention to trends in apartment vacancies and the number of apartments under construction (Wendt and Cerf 1969). Both are used as indicators of future market potential. Investors and developers involved in the provision of office space, multiple purpose industrial premises, and retail space employ similar indicators for their purposes (Ratcliff 1961 pp.255-271). Planners, engineers, and real estate speculators are also concerned with monitoring the unused capacity in existing facilities and resources and the continuing provision of new capacity. All of these measures are, in effect, assessments of resilience in various parts of the urban system.

Both the time lags between significant changes in population growth and the resulting pattern of urban development, and the discontinuous nature of urban expansion, are important characteristics when the urban region is approached from a systems viewpoint. In particular, they reflect a domain of stability in the operation of urban systems in which minor oscillations in the number of urban activities and population can be absorbed without any dramatic change to the urban area. This stability is a consequence of resilience in urban infrastructural systems.

A Synthesis

It has been shown how, on the flat and gently undulating lands of Richmond, Delta, and Surrey, urban expansion was hindered for a long time by poor access to the primary centres in the Vancouver urban region. With the construction of bridges across the Fraser River, development of freeways, and the increased use of the automobile, early access was facilitated to the nodes of commercial, industrial and cultural activities. There being negligible other barriers to urban growth, settlement proceeded rapidly along the roadways. The resulting pattern has been characterized as sprawl and as Figure 9 and Plate 11 show, development in these areas was extremely dispersed, grid-like in appearance, and with the centres of the superblocks empty (see also Appendix I).

In contrast, settlement on the North Shore developed in a distinctly different pattern. Initially, access across Burrard Inlet was a limiting factor but with construction of the Lions Gate Bridge, this problem was overcome, temporarily. However, the ensuing development remained compact because of strong containing forces imposed by the physical terrain and the difficulties involved in extending utility networks into more remote areas.

On the basis of what has been discussed, it is proposed to advance a preliminary synthesis of the characteristics of urban expansion in the Vancouver Region and adopt it as the basis for formulation of the model in the next chapter.

Generally, urban expansion in the Vancouver metropolitan area can be considered the result of the spread of urban activities consequent upon population growth. The extent and location of urban settlement can be viewed as molded by two sets of interacting forces. Firstly, with the development of communication links facilitating accessibility into peripheral areas, the centrifugal forces stimulated by population growth are released, with subsequent dispersal of urban activities. Opposing this outward thrust is a containing force generally favouring propinquity of urban settlement.

This tendency for settlement to cluster around existing development, even in a period of rapid expansion, helps explain islands of urban development around existing rural centres before being brought completely within the compact urban field.

Secondly, barriers to urban expansion, inherent in the physical nature of the landscape and in urban structures (e.g. limits to the expansion of utility network systems and political boundaries), operate to contain urban settlement. Acting in opposition is a force which increases in strength as the resilience in urban infrastructural systems (e.g. vacant land, residential, commercial and industrial space) is exhausted.

When the forces exerted by demands for new space and facilities and stimulated by increased accessibility, exceed the counteracting forces, or rather containing influences, of barrier effects and the tendency for settlement propinquity, the threshold for urban spatial growth is crossed and urban expansion continues. Each of these forces operates with varying intensity, depending upon the particular attributes of the locality, the rates of population growth, the level of technology and most importantly, as a result of reinforcement by the institutional system in programs for public utility development, land use controls, regulation of urban activities and generally the permissable practices for allocation and organization of land resources.

Chapter 5

A DIFFUSION MODEL OF URBAN EXPANSION FOR VANCOUVER

In considering the spatial growth of Vancouver, the viewpoint has been taken that urban expansion can be represented as a spatial diffusion process whereby changes are produced in the distributional pattern of rural and urban land use over time. It is implicit in this viewpoint that emerging patterns bear a functional relationship to historical patterns, but they are not constrained from evolving into new and different forms (Brown 1968 p.87). When organized and investigated in an urban systems framework, diffusion processes are also characterized by structural properties (e.g. thresholds, boundaries and lags) and the typical systems quality of feedback interactions between process components (Holling and Orians 1971). The purpose of the proposed model is to describe these spatial, historical, structural and feedback properties.

The Nature of Spatial Diffusion Processes

Spatial diffusion has been defined by Brown (1968 p.2) as the spreading or dispersal of phenomenon over time, either through relocation or expansion within a given area. Because we are concerned only with a division between urban and rural land use functions, (i.e. dispersing urban land development in the aggregate), the problem of relocation of urban activities does not arise for all activities coopting land from the rural sector are considered members of the existing population of urban activities.

Brown (1968) in seeking to provide a framework for systematically examining spatial diffusion processes describes six different elements common to diffusion problems. They are:

(1) the subject area or environment where the diffusion occurs, defined by its spatial, physiological and cultural attributes;

(2) the time element, including the time intervals between diffusion generations and time lags before adoption by receptors;

(3) the item being diffused, which is expected to be functionally connected to the qualities incorporated in the diffusion process;

(4) the origin node, characterized by the frequency of emissions of diffused items and the time during which the node continues to operate as an emitter;

(5) the receptor or destination node which is character-

ized by locational criteria and the ability to receive the item diffused; and

(6) the relationship between the origin and destination nodes in time and space; including the paths of movement, distance, the history of movement between the nodes, intervening opportunities and the like.

Diffusion processes are sometimes thought of in terms of waves, but more often the process is represented by items (e.g. members of a population) being diffused through hierarchies of receptors with diffusion occuring in step-like penetration. Whatever the analogy used, the emphasis in diffusion processes is strongly oriented to structural relationships of phenomena in time and space as they appear in the particular process being studied. Fused in the idea of dynamic processes is the concept of interacting forces which indicates that diffusion models are in one respect another type of growth force models. However, the approach is essentially behavioural in that it focusses on the likelihood of people making decisions with respect to land development and personal migration (Yuill 1970 p.17). Therefore, it is an important conceptual step towards bridging the traditional discrepancies between macro and micro scale approaches.

Formulation of the Model

On the basis of the investigations reported in the foregoing chapters, it is submitted that urban expansion can be described as a spatial diffusion process in which the conversion of rural land to urban uses is directionally random, other things being equal. Furthermore, it is hypothesized that:

> the <u>probability of rural-urban land conversion</u> is a function of the demand for additional space consequent upon population growth and the level of resilience in urban infrastructural systems; and
>
> the probability of rural-urban land conversion <u>in a particular location</u> is dependent, in addition, on two sets of interacting forces:
> (i) the centrifugal force resulting from continually increasing <u>accessibility</u> into the urban hinterland which expands the potential boundary limits of the urban region, and the centripetal force requiring <u>propinquity</u> of new urban activities to existing urban development thereby promoting compact forms of urban settlement;
> (ii) the centrifugal force generated by diminishing levels of unused capacity, i.e. decreasing <u>resilience</u> in urban infrastructural systems, and the <u>barriers</u> to urban expansion inherent in the nature of land resources and settlement structure.

Basically, this means urban expansion occurs to accommodate new activities generated by increased population. However, for any area the relationship is not constant but depends on the particular set of attributes characterizing the locality. The relationship is modified by the boundary conditions imposed by limits of accessibility to the dominant urban nodes (the CBD and maybe New Westminster in the Vancouver urban region) and proximity to existing development in the locality. The closer the area to existing urban development, and to the major nodes of the urban region, the greater is the likelihood that conversion of rural land will occur. The relationship is also modified by fluctuations in the unused capacity of urban infrastructural systems reflecting the resilience of the urban system; as resilience increases, the probability of urban expansion declines because new activities can be absorbed without exceeding the domain of stability (Holling and Orians 1971). However, physiographic features, utility networks and existing rural development operate to various degrees, as barriers to outward expansion. As the aggregate barrier effect increases, the likelihood of urban expansion decreases.

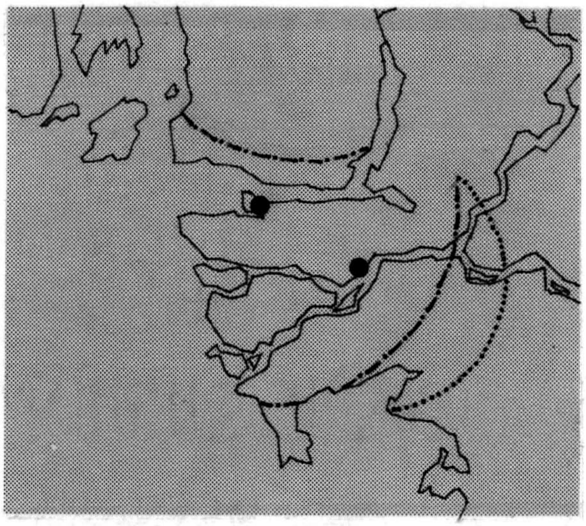
The nomenclature adopted to describe variables and the concepts which they involve need to be explained in more detail and given an operational form.

Urban land is defined, for the purposes of this study, as the area developed to urban uses and the area withdrawn from rural uses which is available for urban development. Thus it incorporates all land used for residential, commercial, industrial, recreational, civic and institutional functions which serve the urban population, and land used for transportation and communication utilities required for the preceding urban functions

(Gad 1970 p.3). In addition, vacant land earmarked for urban development, and on which rural pursuits have ceased, such as undeveloped subdivisions, is also considered urban land (Ibid., p.4).

Dominant Urban Nodes are the communications focii of the urban region. Their relative importance, (where there is more than one), can be measured by reference to the flow of people, goods, and services to and from them, or by the more usual surrogate, total commercial floor space. A particular node is considered dominant when its influence over nearby rural land is greater than any other node in the urban region. Thus on the basis of a study by Hardwick (1970), Vancouver could be considered a bi-nodal region as there is some evidence that New Westminster has a greater influence than the CBD over rural areas in the municipality of Surrey. However, as a result of construction and associated freeways which focus on the CBD, New Westminster may be eclipsed by Vancouver once again. A diagramatic representation of the hypothesized spheres of influence of dominant nodes in the Vancouver urban region is shown in Figure 12. It needs to be emphasized that the relationship between the dominant node and its rural hinterland is based on observation and is a purely descriptive relationship. However, recent studies on the concept of growth centres initiating and transmitting social and economic development into their hinterlands may provide a theoretical foundation for the relationship. Darwent (1969) provides an excellent review of the literature on growth centre theory.

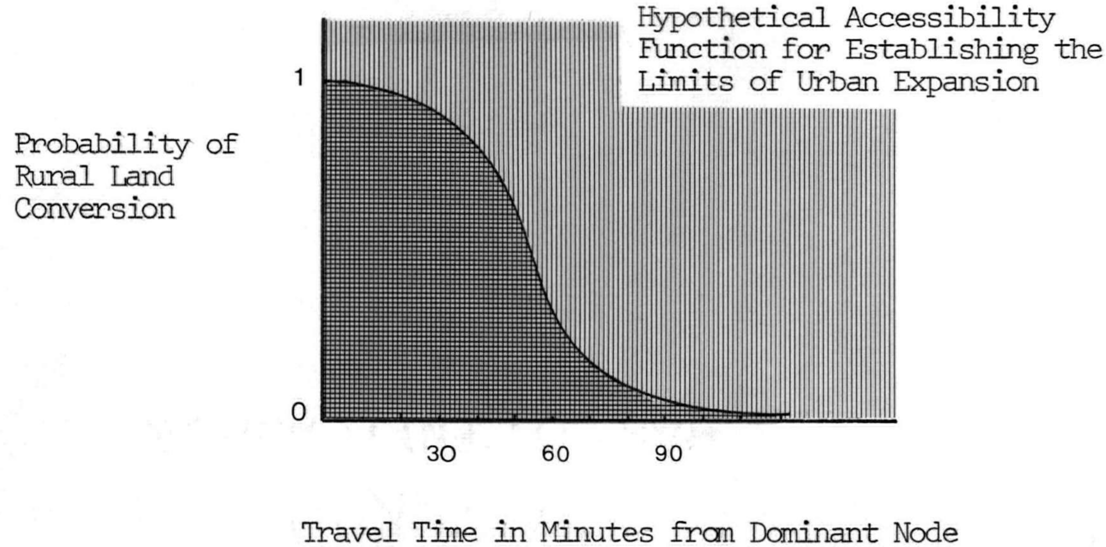
Figure 12. Dominant Nodes and Their Urban Fields
1965 Circa



Vancouver -·-·-·-·-   New Westminster ....

Accessibility has been treated in many different ways in the literature, sometimes as a measure of proximity between two points and other times as a measure of the inherent advantage of a locality with respect to overcoming the frictional effects of distance (Ingram 1971). In this study accessibility is used to connote the ease of communication between a particular locality and the dominant nodes in the urban region. More specifically, it is proposed to define an accessibility function which establishes probability limits for potential urban growth, (i.e. boundary conditions), in the form of a probability statement of land conversion, as shown in Figure 13.

Figure 13.



Sources: Wolforth 1965, Appendix III.

Often, models of urban expansion make no provision for boundary conditions and assume an unlimited environment (Korcelli 1970 p.134). The approach adopted here is an attempt to overcome this problem by defining boundary limits stochastically, in a way which reflects the comparative advantages of sites near to communication corridors focussed on the urban node rather than those further away from them (Yuill 1970 pp.122-127).

Accessibility is not constant over time, for with the assimilation of advances in communication and transportation technology, the potential boundary of the urban region is extended further into the hinterland. It will be necessary to either make assumptions with respect to adjustments in the time-distance relationships for the future to account for this or make provision for input from the IIPS transportation model.

While increases in accessibility extend the potential boundary of the urban region considerably and increase the probability of rural land conversion further afield, there is a counteractive force promoting spatial proximity of urban functions. This agglomeration force is referred to here as the tendency for propinquity of urban activities, indicating nearness in space. The concept behind this force is derived from Tornqvist (1968 p.101), who states that:

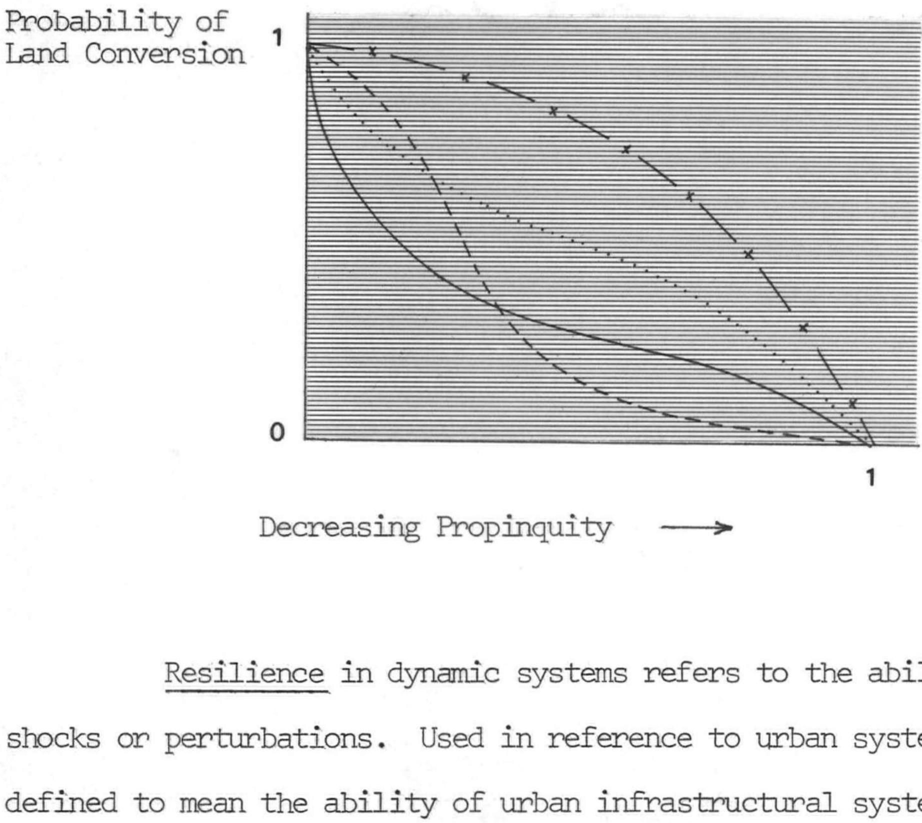
> The need for contacts and exchange of information between increasingly specialized functions in the community. . . .is an essential motive force in the process of urbanization.

The concept has also been applied successfully by Morrill (1965b) in his study of the diffusion by expansion of a ghetto in Seattle. In his study, he suggests there are psychological forces encouraging residential settlement propinquity. Webber (1963), on the other hand, claims that this type of social-physchological force is weakening for residential location and being superseded by ones reflecting specialization of occupations and interests. Notwithstanding, Tornqvist's view is not weakened for the reason that

> . . .the individual in today's society finds that the more advanced his education is and the greater the degree to which specialization has been carried, the narrower is his choice of possible places of residence (Tornqvist 1968 p.104).

Figure 14 suggests a series of possible relationships between decreasing propinquity (real or perceived?) to the probability of land conversion. Obviously, there is a need for basic data to determine the nature of this relationship in the Vancouver region.

Figure 14. Hypothetical Relationships Between Propinquity and the Probability of Land Conversion



Resilience in dynamic systems refers to the ability to absorb shocks or perturbations. Used in reference to urban systems it can be defined to mean the ability of urban infrastructural systems to absorb increases in population and urban activities.

Inherent in the concept of resilience is the identification of bounded entities (i.e. domain of stability) beyond which changes take place in the system, either to restore stability through evolution of a new system structure or resulting in a collapse of the system (Holling 1971).

Bounded entities can be recognized in urban systems, particularly as they relate to the urban expansion process. For one, land is finite and new demands for space have to be met by urban expansion if they cannot be satisfied by vertical development. Moreover, there are limits to the services and utilities that can be provided in limited areas, if community expectations are to be satisfied and excessive congestion avoided.

The primary need here is to identify suitable indicators of resilience in urban systems as they relate functionally, to the urban expansion process. Because residential development is the major user, at least initially, of land converted from the rural sector, this seems one promising area in which to search. For example, a suitable indicator might be dwelling vacancy rates as a function of total occupancy rates (i.e. vacancies per thousand dwellings occupied). However, there is a problem involved in the use of housing occupancy rates, as the basis of an indicator, because dwelling occupancy fluctuates over time and space for reasons not directly related to housing shortages. Changing social preferences for types of dwellings (e.g. the large increase in non-family dwellings in the last two decades in central city areas) and cyclical economic conditions, (particularly unemployment), cause significant deviations in numbers of people per dwelling.

Another potentially suitable indicator might be derived by comparing the rates of land conversion per capita increase, with the total amount of urban land consumed per capita in the urban region. The fact that data are available for a number of North American cities makes this indicator particularly attractive (Gad 1970). However, there are problems concerning changing space requirements per capita over time, as well as with increasing city size. Tables 2 and 3 give an indication of the nature of these problems and an idea of the differences between consumption and absorption rates. Notwithstanding, analysis of the situation in the Vancouver urban region might show that the problems are not as severe as they first appear.

It would seem desirable to avoid using a combination of factors for the likelihood of even larger errors occuring is increased (Alonso 1968). It is proposed that initially, a land absorption-consumption indicator should be tested for it has the desirable characteristic of adding a heuristic quality with respect to nature of land requirements.

Barriers to the growth of urban areas refer to the restraining influence of (i) physical barriers such as rivers, marshes, steep slopes, and rugged and dissected terrain, (ii) structural limitations which result from the need to displace existing activites and overcome severe fragmentation of property rights in land, for new development to take place, (iii) technological limitations imposed by the difficulties and great costs involved in extending public utility networks such as electricity and water reticulation, sewerage and stormwater drainage and communication facilities, into some new areas, and (iv) institutional impediments in the form of zoning restrictions and building controls (Malisz 1969, Yuill 1970 pp.105-114).

To simplify the quantification of barrier effects in the model, it is proposed to classify land for each of these four groups according to

Table 2. Summary of Land Consumption Rates (acres per 1,000 population)

City Size (pop.)	Source and Date of Survey					
	Bartholomew 1940's	Niedercorn 1960	Hind-Smith 1951	Hind-Smith 1961	DMA 1950-1960's	Metro Planning Board 1960's
10,000			191	175	115	
20,000	100		106	120	105	
50,000			92	106	93	
100,000	80		102(77)	97(94)	85	
200,000	80	85			78	
500,000	50	67			69	
1,000,000					63	62

Table 3. Summary of Land Absorption Rates (acres per 1,000 population increase)

City Size (pop.)	Source and Date of Survey				
	Niedercorn 1940-1960	Krueger, Sinclair 1934-1954	Krueger, Sinclair 1954-1958	Hind-Smith 1951-1961	Metro Planning Board 1960's
10,000				102	
20,000				206	
50,000		143	76	164	
100,000		95	75	72(136)	
500,000					
1,000,000					45
Average:	91				

Source: Gad (1970)

the following categories (Scottish Development Department 1968).

a. land unsuitable for urban development

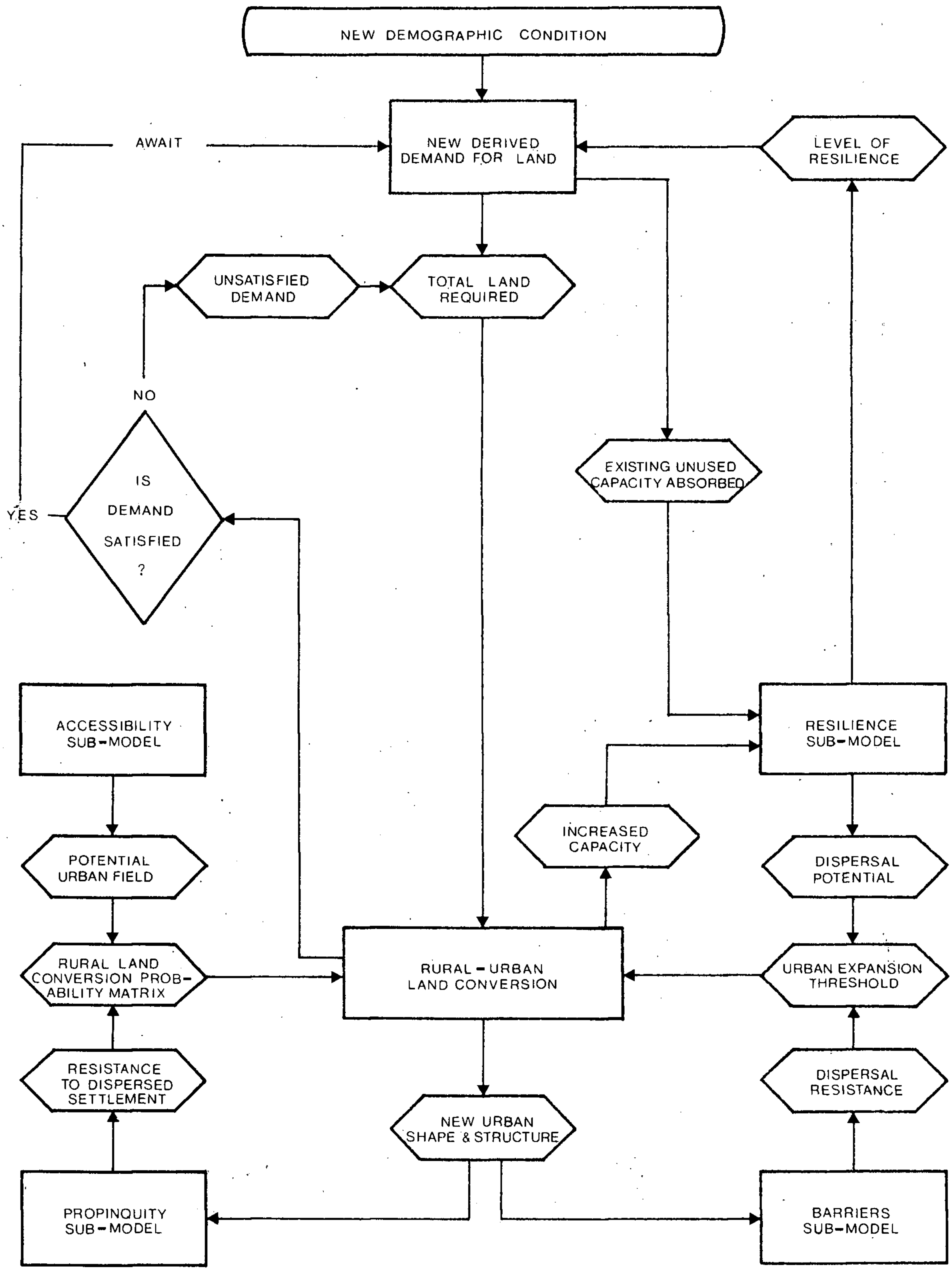
b. land needing improvements, or institutional changes before becoming suitable for urban development; i.e., requiring moderate expenditure for land preparation or hindered by fragmentation of land holdings

c. land immediately suitable for urban development; i.e., where new urban activities can locate without requiring significant changes in the institutional system or expenditures on land preparation and property consolidation.

Model Structure

The hypothesized interaction between the various parts of the model is demonstrated in Figure 15. With a change in the demographic condition, evidenced for example by population growth, demands are created for new activities, (housing, industry, etc.), and networks, (roads, communications, services, etc.). Some of this demand will be absorbed in unused infrastructural capacity, but eventually, if the population increase is large enough, new activities and networks will be needed and will emerge to meet the demand. Additional space requirements may result in conversion of rural land to urban uses as well as consolidation and infilling in some existing urban areas. The result will be a new urban content, shape, and size which may or may not satisfy the demographic condition. In the event that the new urban condition does satisfy the demands created by the additional population, the probability of further land conversion will tend towards zero, at least if there is no residual demand

FIGURE 15 FLOW DIAGRAM OF GENERAL RURAL–URBAN LAND CONVERSION

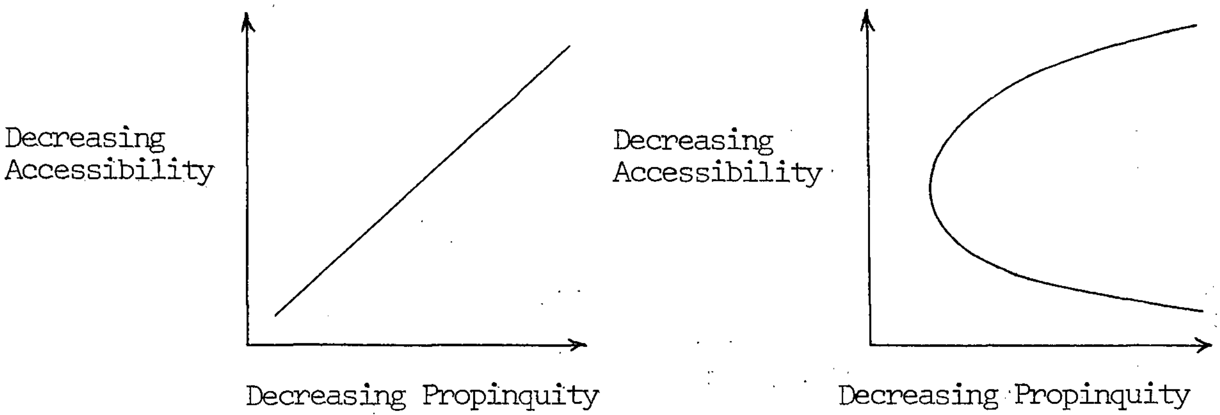


for land from the previous time period. On the other hand, a continuing deficiency will promote further activity and increase the probability of further land conversion. When resilience in the urban system is high, for example, where there is considerable opportunity for absorbing and increased housing needs, it can be anticipated that the time lag before activity and network response would be greater than if resilience were low.

The likelihood of rural-urban land conversion in any particular locality is modified by additional interactive forces. On the left hand side of the flow chart, the interaction of accessibility and propinquity forces results in the probability of land conversion resulting from the operation of these forces. To demonstrate the variable nature of the interaction of these two forces, Figure 16 shows two hypothesized functions relating accessibility to proximity for different localities in the Vancouver urban region. In the first case, representing a hypothetical locality immediately contiguous to the main urban area, (e.g. in south Richmond), the relationship is linear with decreasing accessibility matched by decreasing proximity. In the second example, representing a hypothetical locality near an 'island' of development in the outer metropolitan region, (e.g. White Rock or Cloverdale), it is possible to have a relatively high level of accessibility corresponding to a low level of proximity, in the rural area between the 'island' and the main urban area, followed by an increase in proximity closer to the 'island' before both accessibility and proximity decline on the metropolitan boundary side of the 'island'.

There is a feedback to the propinquity sub-model after each sequence of rural-urban land conversion, requiring readjustment of propinquity ratings. Variations in accessibility ratings are determined exogenously, possibly in the transportation model.

Figure 16. Hypothetical Relationships Between Accessibility and Propinquity Characteristics



On the right hand side of the flow chart, the interaction of barrier effects and resilience forces results in a series of threshold levels denoted by a step-like decrease in the probability of land conversion with increasing resistance to urban expansion. Because of the number of components constituting the barrier sub-model, the forms of relationships between the two counteractive forces can be expected to be diverse and numerous. The feedback effects resulting from land conversion require that new barrier and resilience ratings be calculated within the model after each diffusion sequence.

Generally, it would be difficult if not impossible to guess the likely outcome of each diffusion sequence, (even when a favourable situation was seen to exist in any area) because of the highly interactive nature of the model. This characteristic reflects the dynamic nature and the uncertainty inherent in the real world land conversion process.

The above flow chart and description represents the static condition and does not fully account for the likelihood of a particular site being converted from rural to urban uses in a discrete time period. This requires the inclusion of three additional elements; (i) a fixed time subscript, which could be one, two or more years, (ii) time lags in the response of some process components, for example, the resilience function, and (iii) the translation of population increases, in each time period, to demand for land by varying the number of diffusion emissions, in proportion to the population increase. So far, insufficient information is available on these elements to warrant specific recommendations at this stage. However, this is not considered of great importance for they can only be resolved during the testing of the model.

Assumptions

Two important assumptions have been made which conceivably limit the model's suitability for use in other urban regions but which detract little from the model's general validity with respect to the Vancouver Region.

Firstly, settlement is assumed to spread out from existing nodes. This is fundamental to diffusion processes and probably is not unrealistic in the Vancouver metropolitan region, where the pioneering centres of New Westminster and later Downtown Vancouver have acted as spring-boards for settlement of the hinterland (Rose 1966).

Secondly, while assuming a completely unlimited spatial environment, as Korcelli (1970) was obliged to, has been avoided, the model does not provide for modifying and limiting influences resulting from the growth of other urban centres such as Bellingham or Seattle. To the south it is possible to view the international border as an absolute boundary for the purposes of the model, although pragmatically, this is unreal, for Canada and the United States have a meagre but significant history of coordination in the provision of urban services and facilities. The implications of assuming the absence of negative feedback forces from other urban regions is not a major weakness at this point in time, but negative feedback could become very important within one or two decades. For example, undesirable consequences as a result of industrial development on the southern shores of Boundary Bay, and in the Puget Sound area in general, may make it necessary to incorporate an additional element in the barriers sub-model accounting for the localized effects of pollution. This could be handled without any difficulty.

Method for Application: Monte Carlo Simulation

Expansion of the urban area has been likened to a spatial diffusion process, with sequential urban development radiating out from the nodes of the metropolitan region. If the Vancouver Region is to be considered a bi-nodal region, which will be necessary in the final version of the model, the rate of diffusion emission can be taken to be proportional to the size of the nodes, measured for example by total commercial floor space. In the initial formulation, however, it is proposed that the Vancouver region be considered as having only one origin node for emissions, represented by the CBD.

The rural-urban land conversion process described can be simulated, appropriately, as a diffusion process using a probabilistic model. While Markov chain techniques have been adapted to probabilistic representations of urban expansion (Bourne 1969, Curtis Harris 1968, Drewett 1969) they are considered unsuitable here. In Markov chain techniques the probabilities of land conversion, represented by transition probability matrices for land use in each sub-area, remain constant over time. While this is not a serious weakness in short term forecasts, it is an unsatisfactory assumption, for obvious reasons, where medium and long range forecasting is involved. Although transition probabilities can be made to vary with time in Markov process techniques, this involves greatly increased mathematical complexity and a decrease in ease of operation (Harvey 1967). It is suspected that the stochastic processes contained in the present model are sufficiently complex, as a result of the number of variables and their interactive nature, that they could not be handled analytically by Markov analysis without an undesirable number of simplifying assumptions being made to avoid mathematical intractibility (Bailey 1964).

On the other hand, the Monte Carlo approach which involves proceeding from probability distributions describing the relevant variables, to the desired event or outcome, using a sampling procedure which reflects the structure of the process under examination (Bharucha-Reid 1960) seems suitable. Application of the Monte Carlo method to probabilistic problems sometimes referred to as direct simulation (Hammersley and Handscomb 1964), involves four basic operations:

(a) identifying the probability values or random variables in the stochastic process;

(b) obtaining a set of random numbers;

(c) using the random numbers to sample from the probability distributions to convert them to random variates according to some specified method; and

(d) repeating the operation many times to reduce variance and obtain an approximate solution to the model process (Harvey 1967 p.582).

Because diffusion processes are concerned with random flow in a generally deterministic medium they are appropriately studied by direct simulation, and it is recommended that Monte Carlo methods be used for application of the model.

Specifically, direct simulation of the land conversion process could take the form described below. The general approach is adapted from the technique described in the simulation study of barrier effects on urban growth by Malm and Wärneryd (1967). The methodology recommended for use in this model can be described in three parts, representing the three direct inputs to the land conversion process, shown in the flow diagram in Figure 15.

1. Directionally, the emission of the diffused particles (i.e. urban activities) in the diffusion process is assumed to be random. The aggregate number of 'particles' emitted, varies as a function of total population increase, translated into a demand for land, in each time period. Land conversion is assumed to take place when the required number of 'hits' have been registered in cells of a grid placed over the metropolitan region. On the basis of Malm and Wärneryd's (1967) study, 500 metre squares (i.e. approximately 63 acres) would seem to be a satisfactory size for models of metropolitan regions. When land already developed for urban uses has been excluded, the simulation model will be required to handle a maximum of 2,000 - 3,000 cells in any one iteration, involving a potentially developable area of approximately 200-300 square miles.

2. The combined effects of accessibility and propinquity factors in any locality, are registered, initially, as probabilities in the cells of a regional grid. This spatial probability matrix specifies for each cell area the probability of being hit in any time period. A hypothetical example of a field presented in this way, taken from Malm, Olsson and Wärneryd (1966), is shown in Table 4.

The probabilities in this figure can be interpreted, for present purposes, as the probability of land in any cell being converted to urban uses vis a vis land in any other cell. The differences in probabilities can be assumed, for purposes of illustration, to represent the effect of local area attributes on accessibility and propinquity.

Table 4

Hypothetical probability matrix

	a	b	c	d	e
A	.022	.028	.032	.028	.022
B	.028	.045	.063	.045	.028
C	.032	.063	.127	.063	.032
D	.028	.045	.063	.045	.029
E	.022	.028	.032	.028	.022

Source: Malm, Olsson and Wärneryd, 1966.

These probabilities are then transformed into a matrix of random numbers to facilitate the use of Monte Carlo methods as shown in Table 5. In the random number matrix from 000 - 999, each random number represents a probability of .001. Hence, the probability for Bc (.063) is represented by the numbers 205-267, Ce (.032) by 627-658, Da (.028) by 659-686 and so on. The diffusion of particles is simulated by the consecutive selection of random numbers in the 000 - 999 range, thus, the drawing of numbers 352 and 425 would be recorded as hits in cells Ca and Cb, respectively.

Whether in fact land conversion would be assumed in the cells hit depends on the restrictions imposed by the input from the resilience-barrier threshold shown in the flow diagram (Figure 15).

Table 5

Matrix of Random Numbers

	a	b	c	d	e
A	000-021	022-049	050-081	082-109	110-131
B	132-159	160-204	205-267	268-312	313-340
C	341-372	373-435	436-563	564-626	627-658
D	659-686	687-731	732-794	795-839	840-867
E	868-889	890-917	918-949	950-977	978-999

Source: Malm, Olsson and Wärneryd (1966)

3. The input from the resilience-barrier threshold level takes the form of step-like levels of resistance to land conversion, from 1 to 5, (i.e. the number of separate hits required by each cell in each time period before acceptance of land conversion).

To illustrate the technique consider the following example. Resilience and barrier effects can each be placed into three classes and resistance values assigned to each class, as shown in Table 6.

Table 6

Aggregate Barrier Effects	Number of Hits Required	Aggregate Resilience	Number of Hits Required
No significant barrier effects	1	Low Resilience	1
Moderate Barrier Effects	3	Moderate Resilience	3
Strong Barrier Effects	5	High Resilience	5

Obviously, the resistance values should bear a resemblance to the resistance of these factors in the real world. Initially, for operational convenience, this can be done by the reverse approach of classifying barriers and resilience factors according to the predetermined probability classes. By aggregating the resistance values assigned to resilience and barrier effects in each cell area, a single resistance factor can be entered into the land conversion process, from each cell area. To avoid difficulties with 'half-hits' the resistance values 1, 3 and 5 were chosen and the aggregate values divided by two. Consequently, there are five different levels of resistance depending on the particular combination of classification categories, as shown in Table 7.

To summarize, the probabilities of land conversion, when accessibility and propinquity factors are considered, are contained in the random number matrix in Table 5. In each period of diffusion emissions, a number of cell areas will be 'hit' and considered for conversion. Whether they are accepted depends on the level of resistance ascribed to each cell, as a result of resilience and barrier effects, to the form of the number of 'hits' required, Table 7. Because of feedback effects on some factors, caused by changes in the shape and structure of the urban region after land conversion, the probabilities for each cell will need to be revised after each diffusion generation. For operational convenience, this will need to be handled within the model.

The original intention in this study was to present the model in an operational form at this stage. Unfortunately, due to a shortage of computer programming assistance, this was not possible. Nevertheless, the notation and procedures for the model were tentatively resolved in discussions with a computer programming advisor at the University of British Columbia Computer Science Centre. They are presented in a generalized form, in Appendix IV.

Table 7

Total Number of Hits Required Before Acceptance	Corresponding Conditions
1	Insignificant barrier effects- low resilience
2	Insignificant barrier effects - moderate resilience
	Moderate barrier effects - low resilience
3	Insignificant barrier effects - high resilience
	Moderate barrier effects - moderate resilience
	Strong barrier effects - low resilience
4	Moderate barrier effects - high resilience
	Strong barrier effects - moderate resilience
5	Strong barrier effects - high resilience

PART III

THE DYNAMICS OF URBAN EXPANSION: SPATIAL ANALYSIS OR SYNTHESIS

The paradox of mechanization is
that although it is itself the
cause of maximal growth and change,
the principle of mechanization
excludes the possibility of growth
or the understanding of change.
For mechanization is achieved by
fragmentation of any process and
by putting the fragmented parts
in a series. Yet, as David Hume
showed in the eighteenth century,
there is no principle of causality
in a mere sequence.

Marshall McLuhan
The Medium is the Message

Chapter 6

INTERPRETATIONS

On Understanding Complex Systems

Throughout this dissertation, it has been maintained that the central purpose of modelling in applied science is to provide an understanding of behavioural processes. Unfortunately, what is mean by "understanding" behaviour is far from clear in this context. The point was made previously that planning, to the extent that it is a behavioural science, involves dual interpretative functions. The first involves the description of process structure and the second involves evaluation of process behaviour to arrive at an explanation for it. The confusion surrounding the concept of "understanding" can be traced, it is submitted, to the failure of behavioural scientists to appreciate the differences between these two functions.

Commonly, understanding is equated to explanation, denoting that reasons have been provided for the behaviour of a process. However, in complex systems evolving through time, the nature of cause-and-effect relationships is a function of the state of the system at a fixed point in time (Hardin 1963). As a result, causal relationships in complex and evolutionary systems can vary over time. Consequently, "explanatory" understanding is concerned with an instantaneous state of knowledge, it requires the system or process to be "frozen" in time to facilitate analysis. This is basically the analytical method. It is a "static" concept of understanding and the analytical approach to understanding evolutionary systems might be thought of as the historical method, in that the system structure at the moment of "freezing" is already in the past.

Instantaneous or static understanding is a poor conceptual basis for the investigation of dynamic conditions for as McLuhan (1965 p.16) has remarked, understanding stops action. However, the weakness of static understanding can be largely overcome by accepting a different concept of understanding, one less demanding and focussing on the rate and scale of change in human affairs over time.

Scheffler (1957) proposes that the type of understanding which acknowledges dynamic and evolutionary phenomena, is necessarily a function of <u>the specification of comprehensive relationships among events</u>. In a nutshell, this is the doctrine of a movement in the behavioural sciences called structuralism (Piaget 1970). In separate disciplines, structuralism is complemented by the more specific methodologies of systems theory, communication theory and cybernetics.

Structuralist's concepts underline much of the work used as a starting point for this study, particularly Forrester's (1968, 1969) work on the nature of systems and urban dynamics, and Holling's (1969, 1972) work on stability in spatial systems and process oriented modelling strategies. These studies are basically descriptive and involve specifying: (i) system components and their relationships to reflect feedback properties, (ii) functional relationships between components in time and space, and (iii) time lags, thresholds and boundaries (Forrester 1969 pp.112-114, Holling 1969).

The model or rural-urban land conversion described in earlier sections of this dissertation, represents a process which is an integral part of the much more complex system, the Vancouver region. The process is dependent on other component processes in the system and at the same time constrains in a number of ways the operation of these other processes. Through this interrelation of processes, the complexity and evolutionary nature of the Vancouver regional system can be approximated. Subsequently, our understanding of system behaviour can be enhanced by attending to several characteristics common to complex systems.

Firstly, complex systems are non-linear, and as a result, the behaviour of the total system is influenced to varying degrees by changes in component processes. The nature and degree of system response depends on the state of the system at the time when the change is registered (Hardin 1963).

Secondly, and arising out of the first property, cause and effect relationships are often widely divergent in time and space. Frequently, apparent causal connections are only the close correlation of coincident symptoms (Forrester 1969 p.110).

Finally, with most complex systems there are usually a few points in its structure which are focii of influence and small changes registered at these points can cause reverberations through the whole system. However, as a result of the two properties described above, these points are usually not self-evident and must be discovered through investigation of the structural dynamics of the system.

Modelling Spatial Systems

The emergence of regional spatial systems as a separate area of research, emphasizing evolutionary processes subject to change, has focussed attention on the indeterministic nature of spatial dynamics (Curry 1966). The argument that there is a strong random element in aggregate patterns of human behaviour is beginning to find support among social scientists as the number of probabilistic models of urban spatial growth clearly shows (supra Chapter 3). Moreover, the investigation and representation of complex social and economic systems, subject to change and chance mechanisms, (a major practical and theoretical difficulty in the use of deterministic models), is facilitated using stochastic methods.

The traditional probabilistic methods which are the basis of statistical theory, have been found ill-suited to the investigation of chance phenomena developing in time and space. Since World War II alternative procedures have been devised which concentrate on the frequency of various possible outcomes generated from processes defined stochastically. This is the approach characterized by Neyman (1960) as dynamic indeterminism, in comparison to statistical indeterminism which is essentially static. The basis of the new approach is the design of experiments using hypothetical chance mechanisms which simulate the process being investigated.

Spatial diffusion models have been among the most promising applications of the theory of stochastic processes to understanding complex human behaviour. Because spatial diffusion models are designed to handle social, economic or environmental processes in both time and space concurrently, they are especially suited to the investigation of spatial dynamics (Gould 1969).

The essence of spatial diffusion models is that emerging patterns of behaviour relate functionally to historical patterns. Thus they display two major characteristics of complex systems, spatial and historical properties. Further, by adapting easily to a systems framework, they can readily reflect feedback interactions and structural properties which characterize complex processes and systems. However, it is emphasized that future patterns of rural and urban land use are not constrained from evolving into new and different forms. Rather, it is acknowledged that the future cannot be forecast, on the basis of past and present conditions, with sufficient reliability for long range planning purposes. In fact, Drucker (1959 p.8) argues forcefully that "long range planning is necessary precisely because we cannot forecast." For these reasons, special attention has been paid in this study to change and chance mechanisms to avoid indiscriminate extrapolation of present trends.

While the concept of interacting forces is fused in spatial diffusion models, it does not necessarily mean that these models are simple growth force models like gravity analogues. Indeed the approach is fundamentally behavioural in that it focusses on the likelihood of people making decisions with respect to their personal migration, or of the distribution of phenomena (Yuill 1970).

One of the more contentious features of the new trend is the theoretical justification for stochastic representations of human behaviour and their incorporation in probabilistic models of spatial growth. The effect has been to generate discussion on scientific methods of applied research. While theoretical justification for probabilistic modelling has been found in contemporary theories of dynamic indeterminism in science, an interesting side effect of the general debate has been the disclosure of theoretical deficiencies in some fields using applied research methods. Planning in particular has come under heavy criticism (Gross, 1967, Rogers 1967, Wartofsky 1968, Forrester 1969, Haworth 1970) and much of the discussion in Part II is aimed at resolving some of these criticisms.

The Relationship of the Model Strategy to IIPS

In formulating the model of rural-urban land conversion in the Vancouver region, a definite strategy was used. This strategy was described in general terms in Chapter 2, but it remains to interpret the manner in which it relates to the development of the model for use in the IIPS project.

Seven interrelated requirements of the model were identified and they have been resolved in the following way.

1. The model needs to be generated within the present IIPS framework and meet the demands of the IIPS project.

The process of urban expansion represents only a small part of the complex system being modelled in the IIPS project. However, the fact that urban expansion has been considered separately in this study should not be interpreted as implying that urban expansion is independent of other regional processes or the other models in IIPS. On the contrary, various components in the rural-urban land conversion model are constrained by conditions generated in other sub-models. For example, transportation developments to serve the Port of Vancouver may not be a response to the needs of the metropolitan population, yet they would be significant to urban evolution. That transportation corridors influence the spread of settlement has already been established, and thus it is easy to see that the transportation sub-model will provide important parameters to the land conversion model. Similarly, changes in the shape and size of the urban region arising out of urban expansion will establish input parameters for the operation of other sub-models, notably the land use allocation models.

The model capitalizes on the advantages of the systems approach, adopted as the framework for the IIPS project, by utilizing direct simulation for its application. As a result, there was greater freedom in the specification of the urban expansion process, non-linear functions were able to be used, and structural properties could be represented which emphasize the dynamics of urban expansion.

2. The model should mimic the urban expansion process and generate the problems which characterize settlement on the urban fringe.

Throughout formulation of the model, the point was repeatedly made that the model is designed to reflect what is likely to happen, not what is thought desirable. In this respect the model is value free and inherently descriptive.

Most "problems" associated with urban fringe settlement take on this character because of the particular values of the individual perceiving them. Consequently, instead of trying to recreate "problems," the model was designed to mirror structural dynamics of the actual process. Thus the user is required to interpret or evaluate the process to determine the reasons for the problems he perceives.

3. The model should provide forecasts of rural-urban land conversion and at the same time promote an understanding of the urban expansion process.

The model is designed to provide forecasts of the rate, extent and location of rural-urban land conversion in each time generation.

A dominant emphasis in the model's construction was on the structural relationships of components in the urban expansion process, on the basis that only by seeking to identify the interactions of the primary forces which provide the impetus for urban spatial growth can we increase understanding of the process.

> 4. The model should account for uncertainty in the urban expansion process.

This is reflected strongly in the model by treating rural-urban land conversion as a stochastic process and by the explicit assumption, in the diffusion analogue used, that directionally, urban expansion is random. The implication of these two characteristics is that the particular pattern existing at any time can be interpreted as the historical realization of a process which might just as easily produce a different settlement pattern, according to the probabilities attached to the forces simulated.

> 5. The model should only incorporate those elements and relationships which can reasonably be expected to persist in the future and should omit factors overly susceptible to change.

In structuring elements and developing concepts for the model, a concerted attempt was made to work with those least dependent on existing social, economic and technological standards. Of course the dependence cannot be completely removed, but the resilience-barrier approach to urban expansion helps minimize the dependency. Further, calibration of the model will need to be guided by emerging conditions and not those recognized in the past.

How effectively this is done will have a great bearing on the model's success.

6. The model should reconcile the overall behaviour of the system (macro-scale characteristics) with the processes of the individual decision makers (micro-scale characteristics).

This aspect has not been resolved in the present model, to the degree originally hoped. It was discovered that really tackling this issue required introducing factors very susceptible to change over short time periods, thereby falling foul of point 5 above. In the final outcome, however, there are a number of innovations helping to bridge the macro-micro gap, normally not found in models of urban spatial growth. The propinquity element can be interpreted as recognizing the social tendency of people for close proximity to others in their place of residence as well as the need for the easy exchange of information between specialized community functions. The resilience element can be interpreted, depending on the level of resilience, as one of the motivating forces encouraging individuals and urban activities to move into suburbia and beyond in their search for space. Further, it could generally be observed that the types of barrier impediments considered in the model influence the individual decision maker in much the same way as they influence aggregate patterns of spatial growth. Finally, and most importantly, the diffusion approach links the dynamic growth forces at the macro level to individual behaviour in that it focusses on the likelihood of people making decisions with respect to land use.

7. The model should have a basic heuristic fertility in that it should not only enhance our understanding of the processes at work, but suggest new observations, experiments and conceptualizations.

The effects of barriers on urban spatial growth and the concept of stability in urban systems has attracted the attention of scholars in recent years, particularly since Malisz's conceptualization of threshold theory for long range planning (Malisz 1963, 1969, Scottish Development Department 1968). The pervasive influence of Malisz's theory on planning practices throughout Europe indicates that the approach has considerable heuristic fertility. Whether the present model has inherited the necessary "gene" depends on the response to the model of urban expansion described in this dissertation.

Implications for Regional Planning

In order to fulfil planning objectives, the regional planner must first understand behavioural processes if he is to know in advance the probable impact of intervening measures. From this apparently simple proposition, it is implicit that the regional planner exercises three functions. Firstly, to articulate objectives consistant with the planning environment, he is required to be a social philosopher. Secondly, in order to understand behavioural processes he needs to be a behavioural scientist. Thirdly, to evaluate in advance the consequences of his recommendations he needs to be proficient in applied research. This dissertation is primarily concerned with the two latter functions. However, the function of planners as social philosophers places a caveat on the other two roles which requires a brief discussion.

When referring to communities of people and their relationships to the environment, planning entails a philosophy of social order and strategies for regulating the operation of behavioural process (Glikson 1955). Thus it is necessary to make explicit the limitations of logic and scientific methods.

There are a number of issues which cannot be treated satisfactorily by existing scientific methodologies. Paramount among these, and of extreme importance to planning, is the matter of ethics. While logical methods of problem investigation may increase the likelihood of arriving at a better understanding of behavioural processes or suggest one or more possible solutions, there is no guarantee or justification to be derived from this logic that the solutions are morally or ethically "right." This issue is beyond science and remains a matter for independent formulation (Haworth 1970).

It is anticipated that as a result of the continuing debate on the nature of planning methodology, (including the use of modelling techniques), the philosophy of planning strategies could become a new focus of study in planning education. At a time when strategic procedures and philosophical issues are receiving considerably less attention than specialized tactics and the development of analytical techniques, the prospect is to be welcomed.

As behavioural scientists, it appears from earlier discussions, that regional planners have lagged behind in the assimilation of methodologies designed to promote an understanding of complex behavioural processes. In particular, this study has shown that there has been a tendency to adhere to fragmented conceptualizations of the nature of urban spatial growth. The proliferation of many deterministic and static theories of urban spatial growth processes, considering widely divergent spatial-temporal dimensions and sometimes at odds with each other, is symptomatic of this situation. To the detriment of planning, however, the aggregation of diverse and specialized techniques does not engender holistic appreciation. Moreover, the tendency to confuse the two interpretative levels of behavioural science is further evidence that regional planners as behavioural scientists, are not benefiting from available methodologies to the full extent possible.

The use of probabilistic and synthetic models, emphasizing the structural dynamics of complex processes, similar to the one developed in this study, is submitted to be a marked improvement. Not only do they account specifically for uncertainty in process behaviour, they are inherently dynamic and permit the evolution of different component elements to be monitored. Thus they provide a fuller understanding of the nature of change and chance elements in behavioural processes, in time and space.

It is in the field of applied research that regional planning is especially deficient. While by definition, planning is concerned with the futurity of present decisions (Drucker 1959 pp.8-9), there has been little real progress in the development of methods whereby various policies can be tested before they are implemented. The present study helps pinpoint this deficiency.

Theoretically and practically, the most critical implication of urban expansion as a dynamic and evolutionary process is that the future will bring changes in the rate, scale, or patterns of urban expansion. Consequently, it is highly desirable that the regional planner, through experimental methods, be able to represent ongoing processes in a way that permits tests to be carried out. For example, it is clear that automated transportation, particularly the extensive use of the private automobile, produced a substantial shock to the urban system in the early decades of this century and had the effect of thrusting the system into a new condition with a considerable increase in development potential. This crossing of a critical threshold or "break boundary" resulted in the city evolving into continuous urban highways, where for the first time, the countryside became the domain of leisure and the city the centre of work (McLuhan 1965 p.38). The implications of this evolutionary characteristic are obviously of crucial importance to the planner. Changes in the nature of component elements in a process, their relationships within the process, or a change in the relation of the process to other processes operating within the complex regional system <u>may</u> generate new potential in the system or result in its collapse.

Whether or not a change in process behaviour, whether by chance or design, will be critical in the sense of precipitating a rapid evolution (or devolution) to a new condition depends on three qualities: the nature of the change generated, where its impact is felt in the system and the state of the system at the time the change is felt (Hardin 1963). Consequently, the purpose of applied research in regional planning is not primarily a matter of predicting specific quantities at some future date but the experimental monitoring and regulation of behavioural processes so that we are more aware of critical thresholds and system boundaries. It is in this respect that the implications of the present study for regional planning are strongest. By design the rural-urban land conversion model was formulated as an interactive field-laboratory experiment, eminently suited to the examination of the urban expansion process and the testing of various planning policies.

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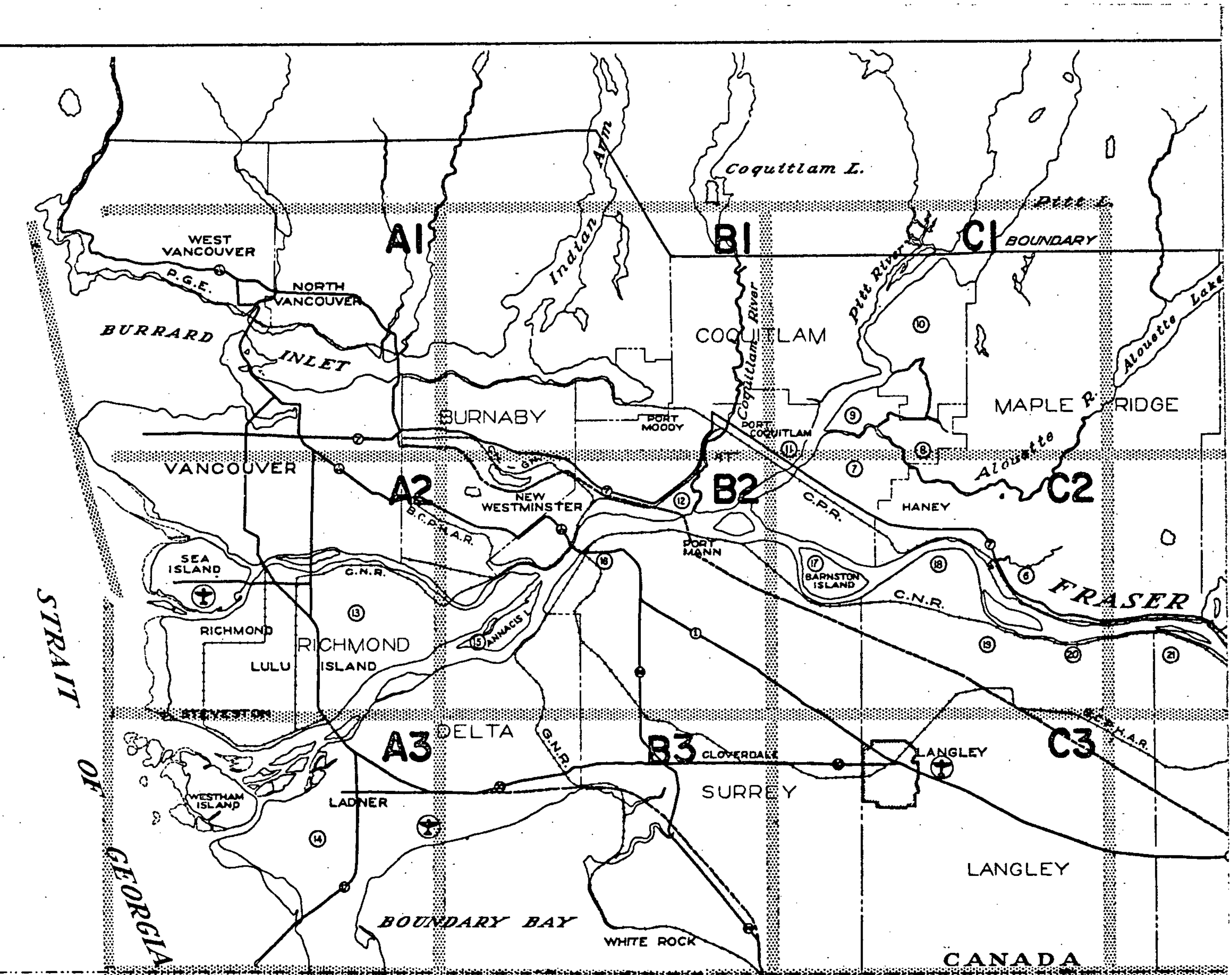
APPENDIX I

The Vancouver Region: A Series of Topographic Maps

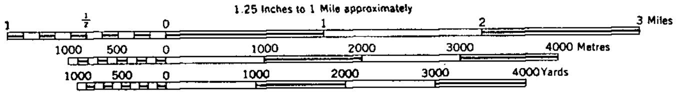


EXCERPTS FROM THE NATIONAL SYSTEM OF TOPOGRAPHIC MAPS

LEGEND

SCALE 1:50,000

1.25 Inches to 1 Mile approximately



Various contour intervals

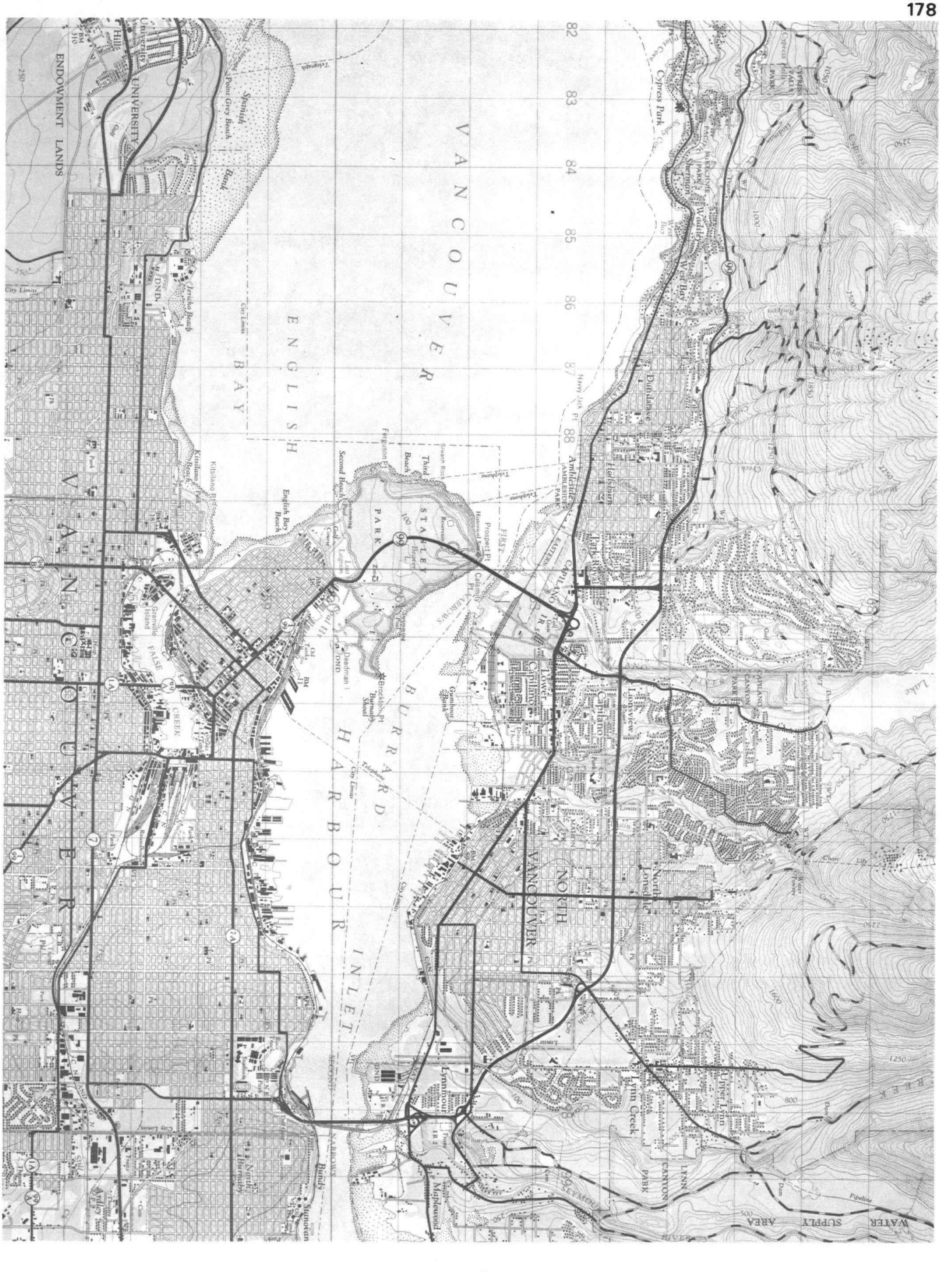
House; Building
School
Church; Church with spire
Post Office
Radio Station
Tower; Chimney .... 120′
Well; Tank .... oil
Cutting
Embankment
Cliff
Contours:
elevation 500 400
depression 500 400
approximate 500 400

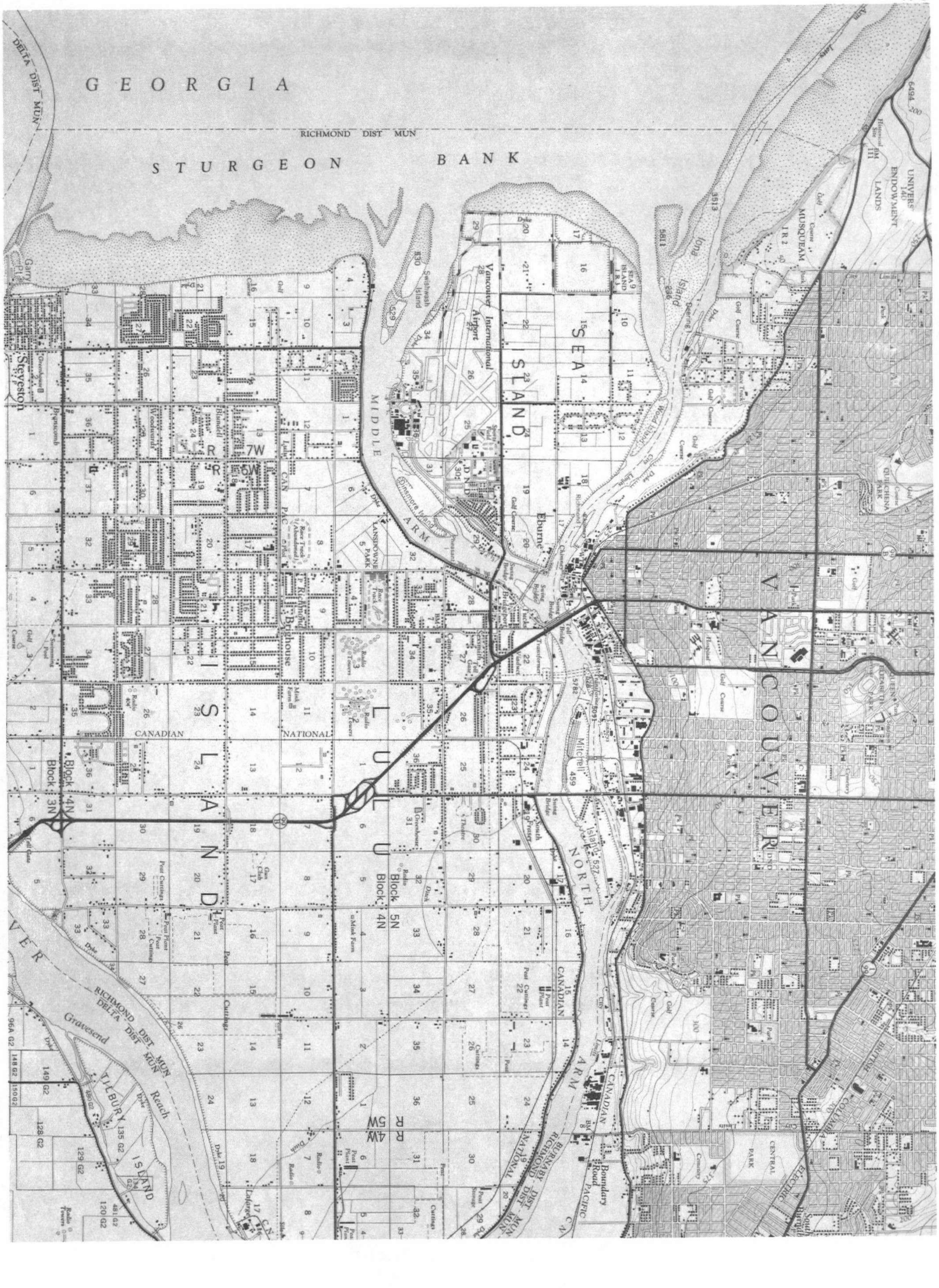
Roads:
hard surface, all weather .... more than 2 lanes Dual
hard surface, all weather .... 2 lanes 18 Route No
loose surface, all weather .... 2 lanes or more
loose surface, all weather .... less than 2 lanes
dry weather
cart track; trail, or cut line
Railways:
normal gauge, multiple track .... Station
normal gauge, single track .... Stop Siding
abandoned or under construction
underpass, overpass
Tunnel; Drawbridge
Power line; Telephone line

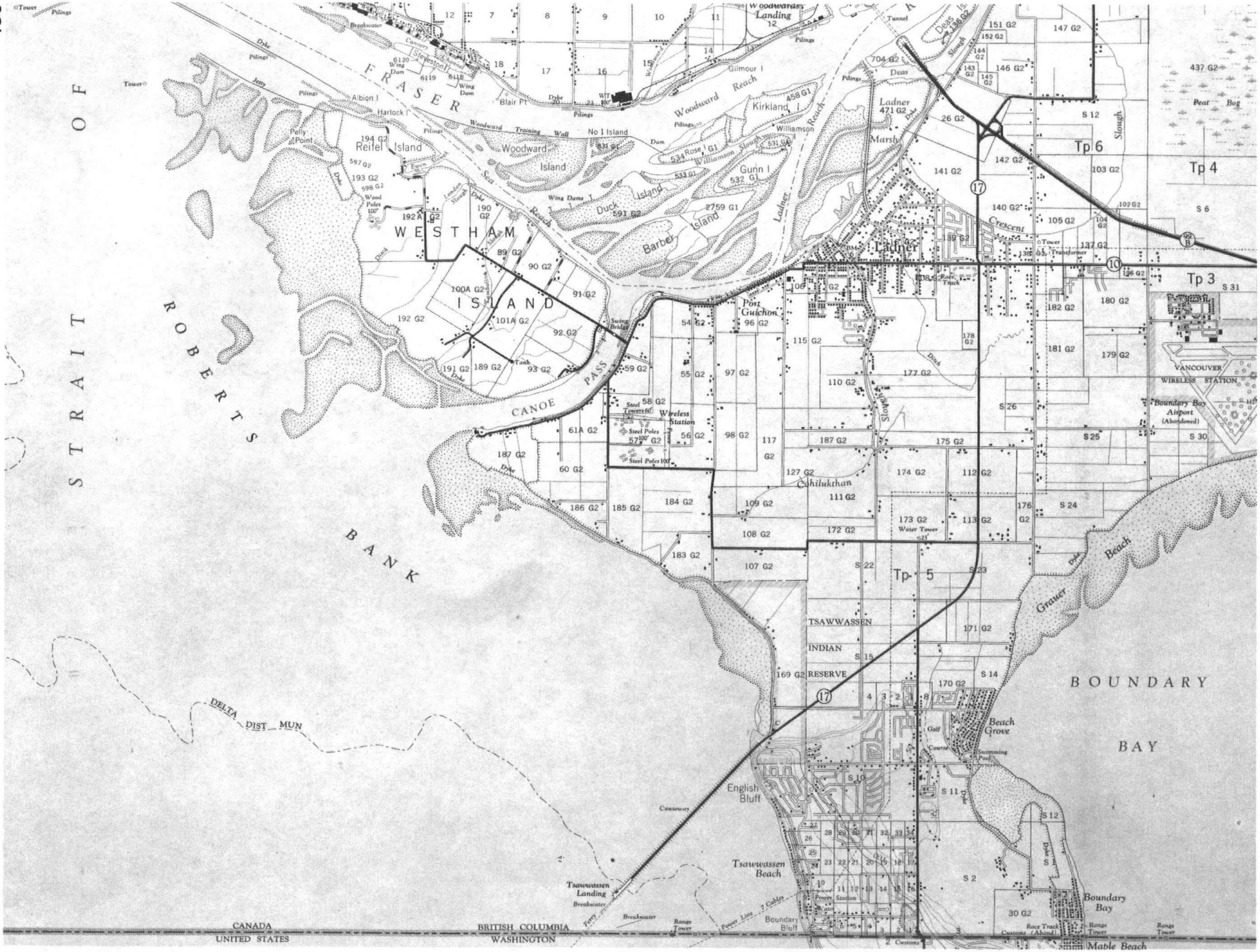
Foreshore flats
Lighthouse
Wharf or pier; Breakwater
Levee or dyke
Rocky reef
Swamp or marsh
Inundated land, seasonal
Intermittent lake, stream
Indefinite shoreline, stream
Rapids, large, small; Bridge
Ditch or flume
Snowfield; Glacier
Wooded area; unclassified, scrub
Vineyard; Orchard

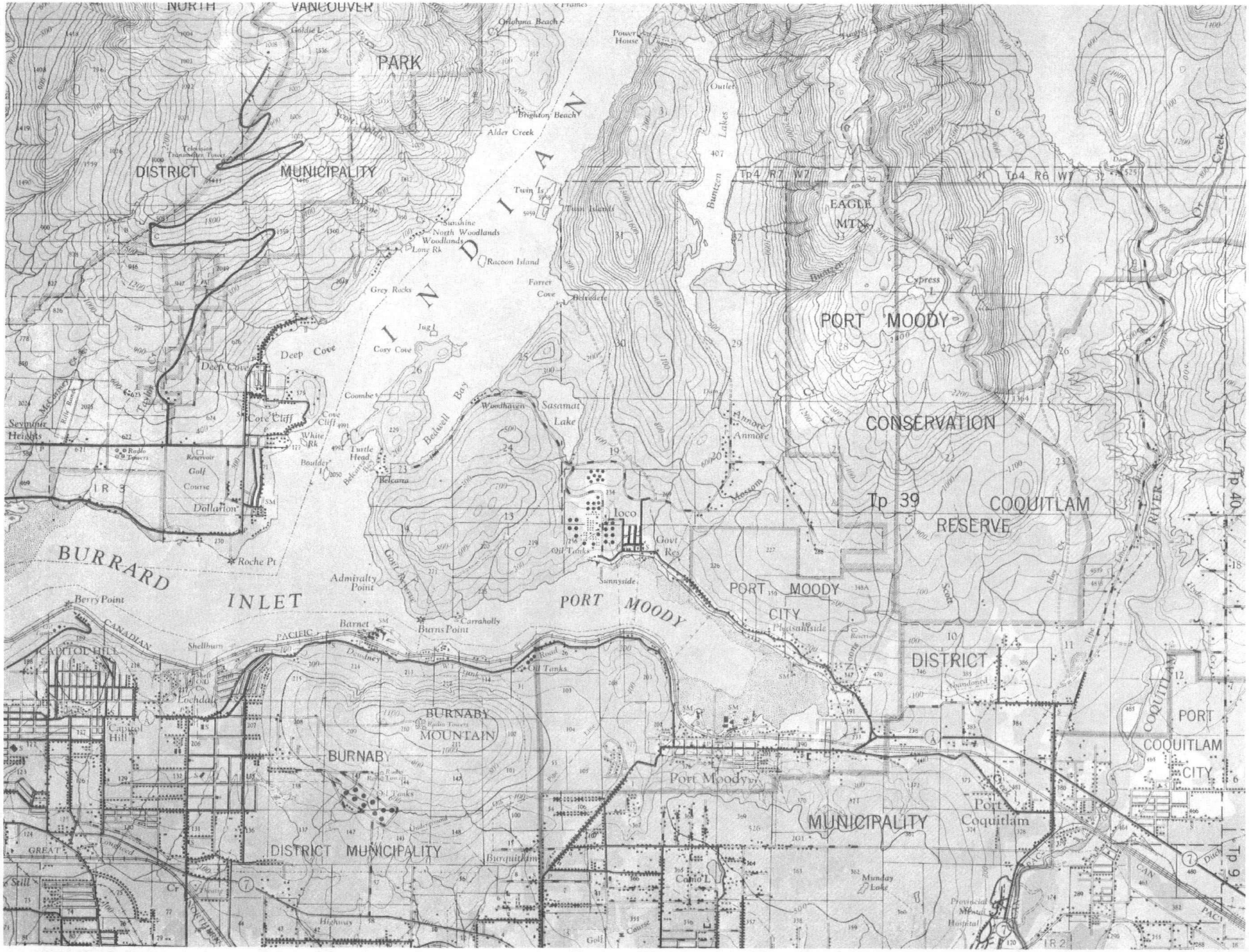
Boundaries:
international, with monument
provincial
county or district
township or parish
township or parish, unsurveyed
city or town
park, reserve, etc.
Horizontal control point, with elevation .... △582
Bench mark, with elevation .... ↑ BM 3025
Spot elevation; precise, approximate .... .4582 .757±
Historical site; Cemetery C
Mine or open cut; Quarry
Sand or gravel pit

Surveyed Line
Section Number 16
Lot Number 221
Surveyed Timber Licence Number .... T.L. 2071
Surveyed Pulp Licence Number .... P.L. 626

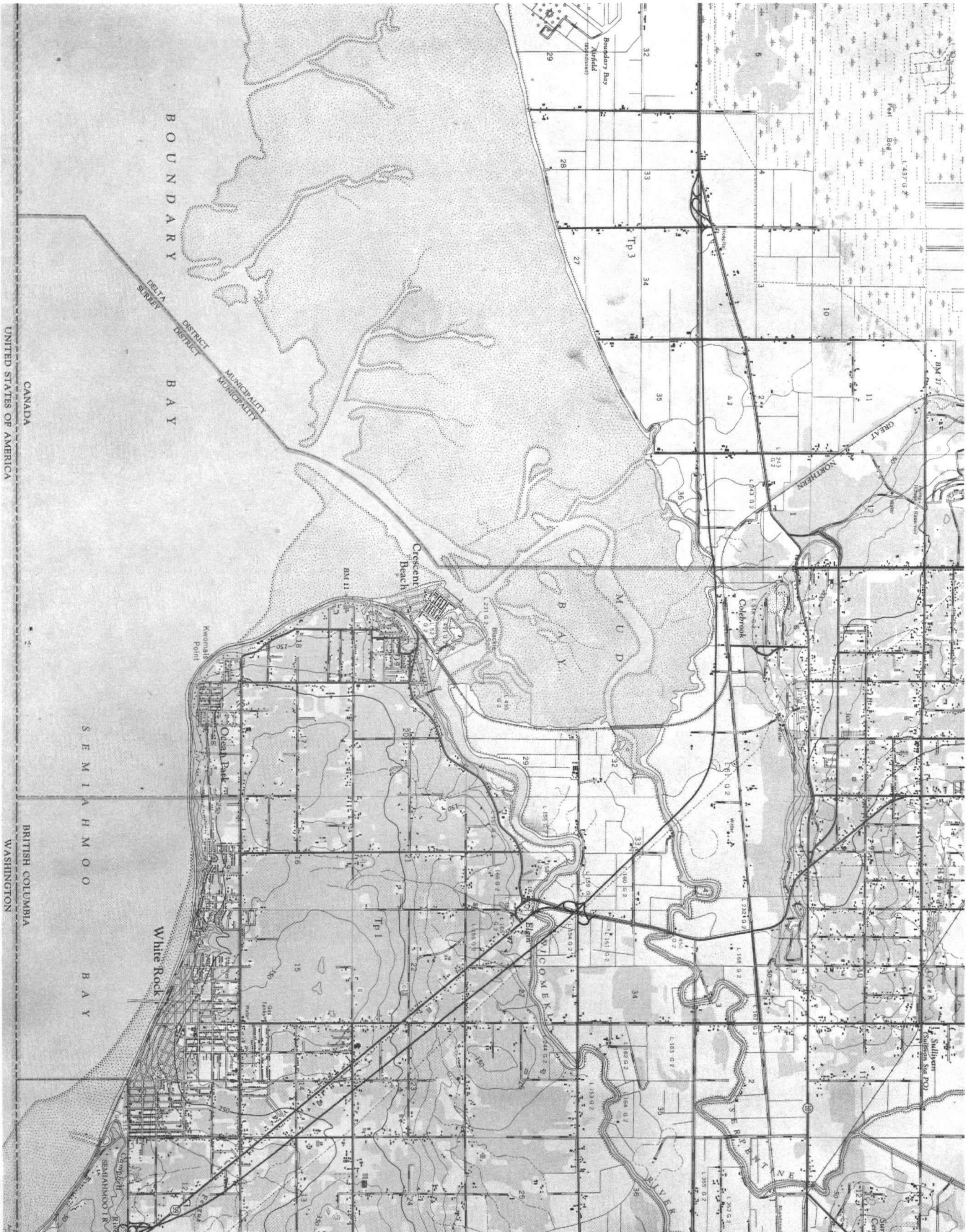

VANCOUVER
ENGLISH BAY
BURRARD INLET
HARBOUR
NORTH VANCOUVER
STANLEY PARK
FALSE CREEK
UNIVERSITY
ENDOWMENT LANDS
Spanish Bank
Point Grey Beach
Jericho Beach
Kitsilano Beach
English Bay Beach
Second Beach
Third Beach
Prospect Pt
Brockton Pt
Deadman I
Granville Island
Ambleside
Dundarave
West Bay
Cypress Park
Capilano
Lonsdale
Lynnmour
Maplewood
Lynn Creek
Upper Lynn
LYNN CANYON PARK
FIRST NARROWS
SECOND NARROWS
WATER SUPPLY AREA

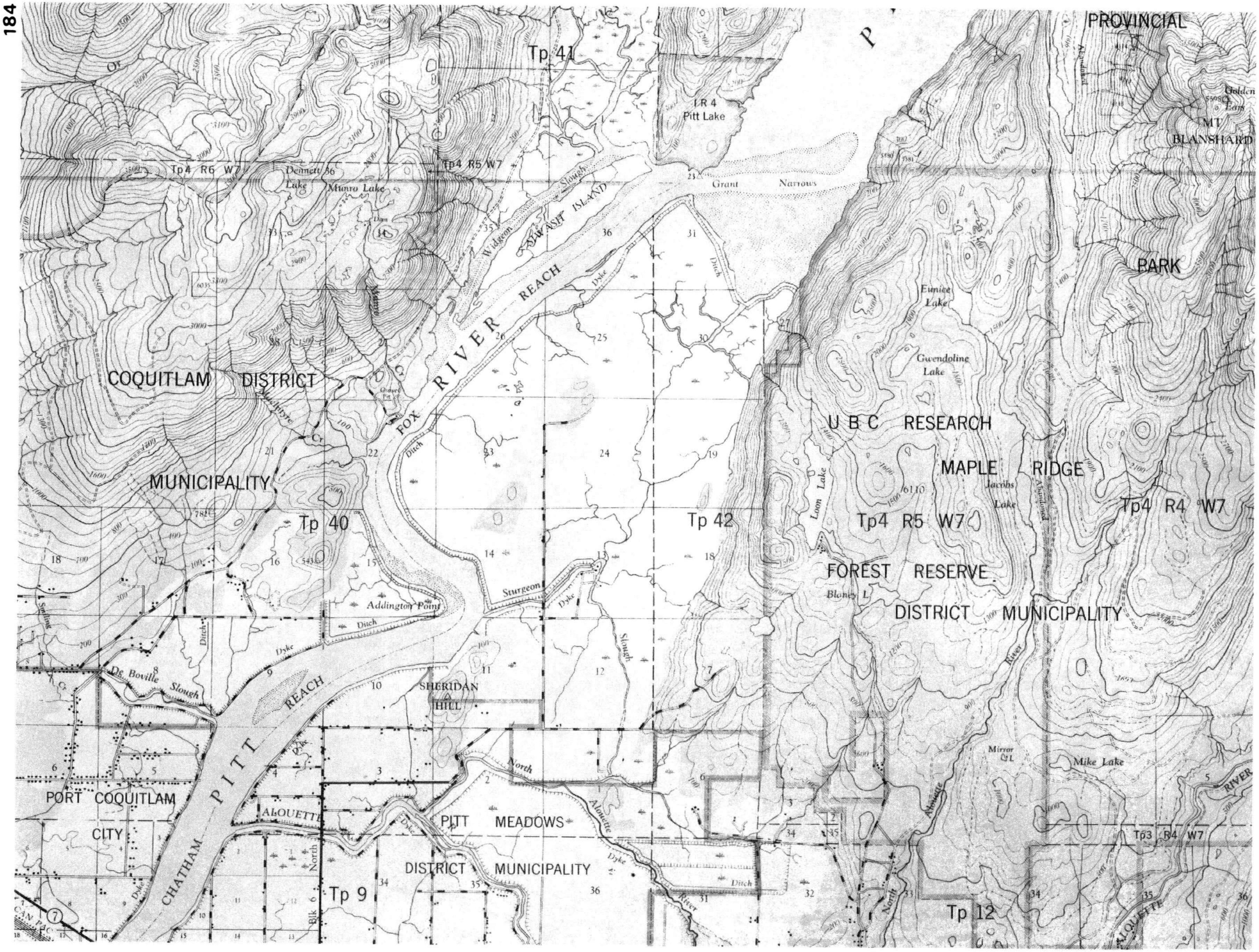

GEORGIA
DELTA DIST MUN
RICHMOND DIST MUN
STURGEON BANK
Vancouver International Airport
SEA ISLAND
MIDDLE ARM
Steveston
Eburne
Brighouse
LULU ISLAND
CANADIAN NATIONAL
NORTH ARM
Mitchell Island
VANCOUVER
MUSQUEAM I R 2
UNIVERSITY ENDOWMENT LANDS
Iona Island
Swishwash Island
Gravesend Reach
TILBURY ISLAND
RICHMOND DELTA DIST MUN
BURNABY DIST MUN
Boundary Road
CENTRAL PARK
BRITISH COLUMBIA ELECTRIC
CANADIAN PACIFIC
Block 4N
Block 3N
Block 4N
Block 5N
R 7W
R 6W
R 5W
R 4W


STRAIT OF
ROBERTS
BANK
FRASER
Woodward Reach
Woodwards Landing
Steveston
Albion I
Harlock I
Pelly Point
Reifel Island
Woodward Island
No 1 Island
Kirkland
Gilmour I
Rose I
Williamson Slough
Gunn I
Duck Island
Barber Island
Sea Reach
Ladner Reach
Ladner Marsh
Deas
Deas Slough
Ladner
Crescent
WESTHAM
ISLAND
CANOE PASS
Swing Bridge
Port Guichon
Wireless Station
Steel Towers
Steel Poles
Chilukthan Slough
Tp 6
Tp 4
Tp 3
Tp 5
Peat Bog
VANCOUVER WIRELESS STATION
Boundary Bay Airport (Abandoned)
Water Tower
Grauer Beach
TSAWWASSEN INDIAN RESERVE
Beach Grove
Golf Course
Swimming Pool
English Bluff
Causeway
Tsawwassen Beach
Tsawwassen Landing
Breakwater
Power Line 7 Cables
Boundary Bluff
Power Station
BOUNDARY BAY
Boundary Bay
Maple Beach
Race Track
Customs (Aband)
Range Tower
DELTA DIST MUN
CANADA
UNITED STATES
BRITISH COLUMBIA
WASHINGTON


NORTH VANCOUVER
PARK
DISTRICT MUNICIPALITY
INDIAN
Brighton Beach
Alder Creek
Twin Is
Twin Islands
Sunshine
North Woodlands
Woodlands
Lone Rk
Racoon Island
Grey Rocks
Farrer Cove
Belvedere
Jug I
Cosy Cove
Deep Cove
Coombe
Bedwell Bay
Woodhaven
Sasamat Lake
Cove Cliff
White Rk
Turtle Head
Boulder I
Belcarra
Seymour Heights
Radio Towers
Reservoir
Golf Course
IR 3
Dollarton
Roche Pt
BURRARD INLET
Berry Point
Admiralty Point
Barnet
Burns Point
Carraholly
Shellburn
CANADIAN PACIFIC
Ioco
Oil Tanks
Govt Res
Sunnyside
PORT MOODY
PORT MOODY CITY
Pleasantside
Power House
Outlet
Buntzen Lakes
Tp4 R7 W7
Tp4 R6 W7
EAGLE MTN
Cypress L
PORT MOODY
CONSERVATION
COQUITLAM
RESERVE
Tp 39
Tp 40
Anmore
COQUITLAM RIVER
DISTRICT
Abandoned
CAPITOL HILL
Lochdale
Capitol Hill
BURNABY MOUNTAIN
Radio Towers
BURNABY
Oil Tanks
DISTRICT MUNICIPALITY
Port Moody
MUNICIPALITY
Port Coquitlam
PORT COQUITLAM CITY
Burquitlam
Como L
Munday Lake
Provincial Mental Hospital
GREAT
Highway
Golf Course
Tp 9
IR 2

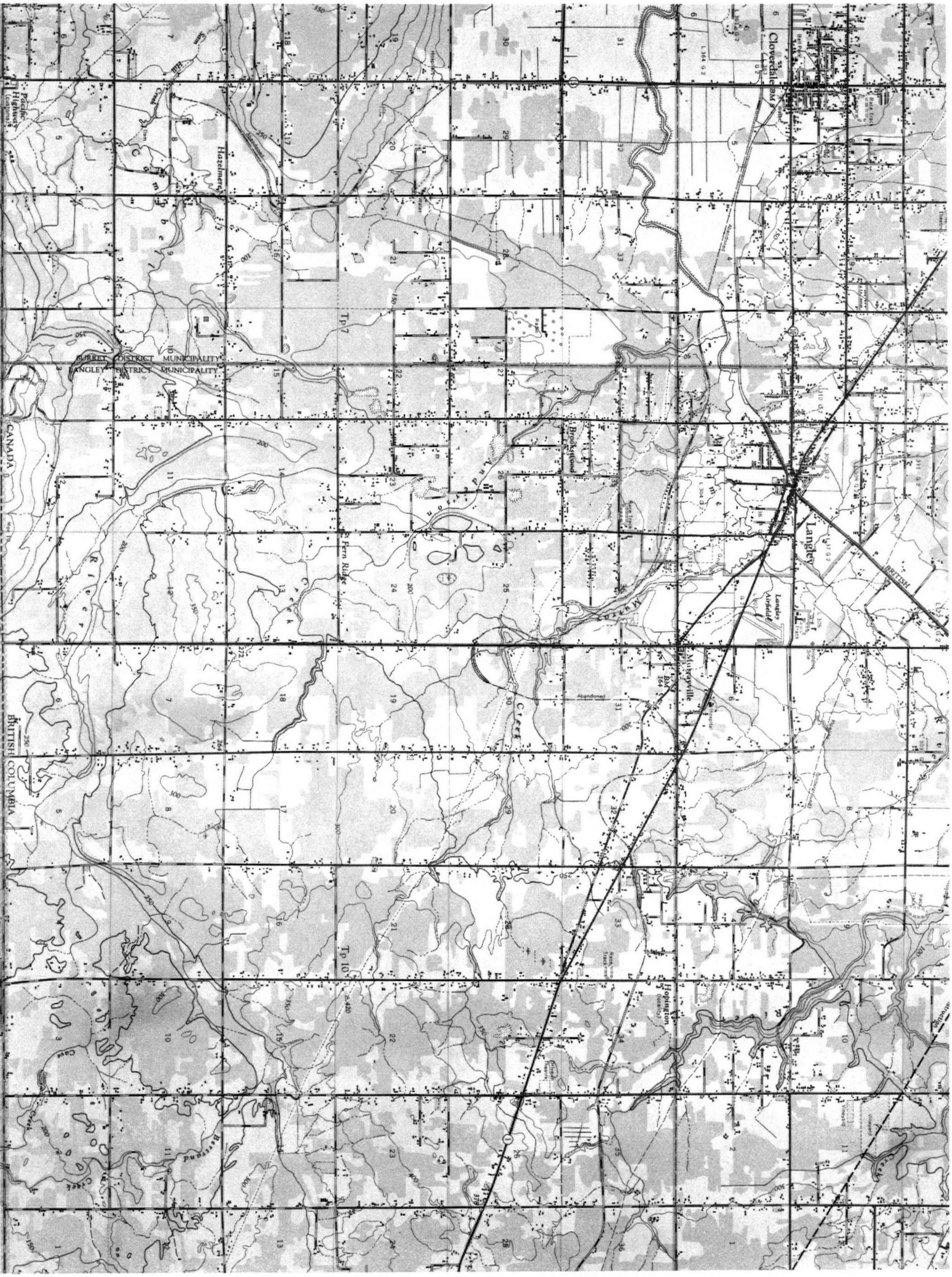

NEW WESTMINSTER
FRASER
RIVER
ANNACIS ISLAND
Annacis Channel
City Reach
Annieville Channel
Annieville
Poplar Island
LULU ISLAND
Sunbury
South Burnaby
Byrne Road
Ewen Junction
Sapperton Channel
Fraser Mills
Maillardville
Queens Reach
Port Mann
South Westminster
Fraser River Jct
Douglas Island
COQUITLAM
PORT COQUITLAM
CANADIAN
PROVINCIAL
COAST
MERIDIAN
GREAT NORTHERN

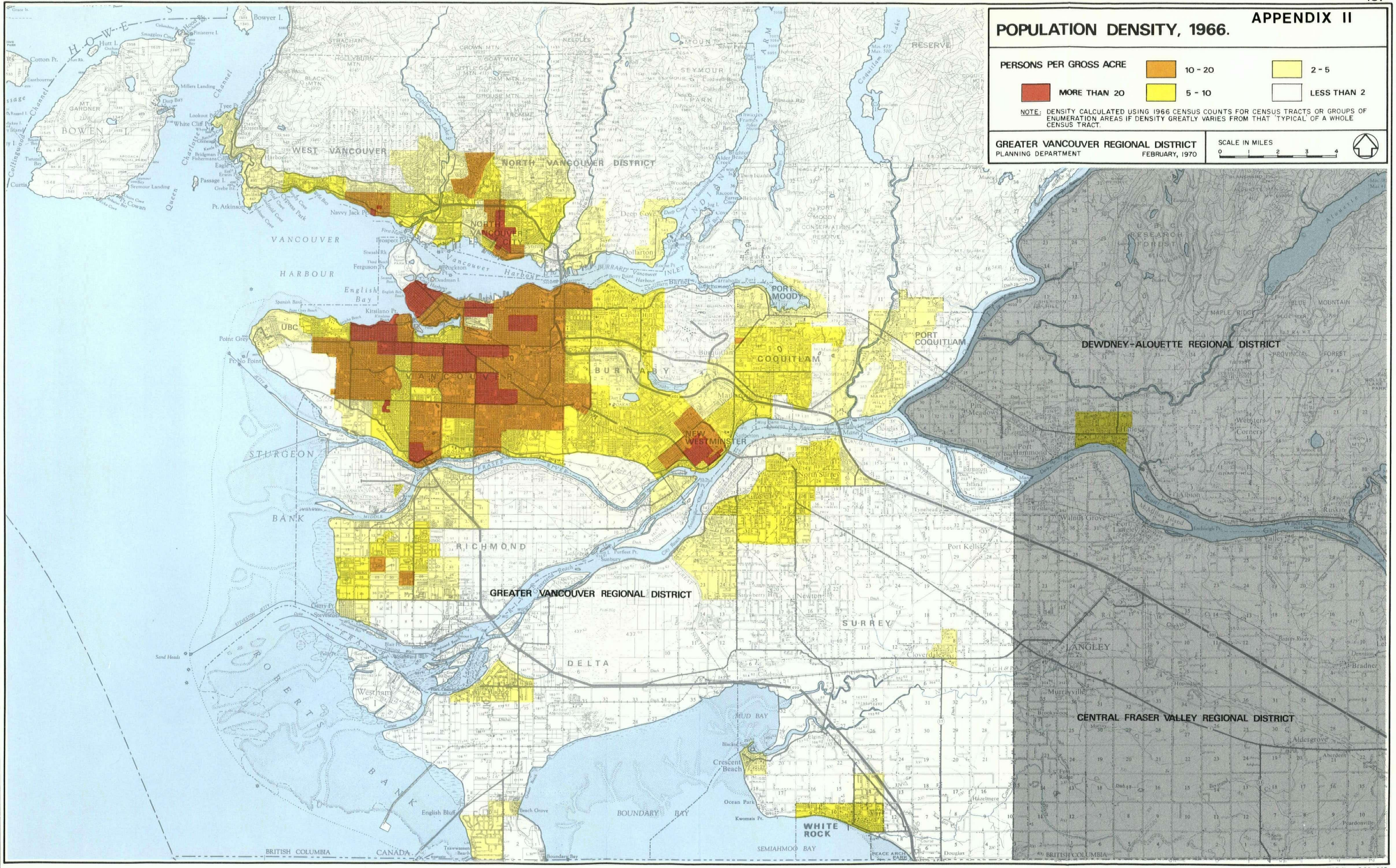

BOUNDARY BAY
MUD BAY
SEMIAHMOO BAY
CANADA
UNITED STATES OF AMERICA
BRITISH COLUMBIA
WASHINGTON
DELTA DISTRICT MUNICIPALITY
SURREY DISTRICT MUNICIPALITY
Boundary Bay Airfield
Peat Bog
Tp 3
Tp 1
GREAT NORTHERN
Crescent Beach
Kwomais Point
Colebrook
Ocean Park
White Rock
Sullivan
SERPENTINE
RIVER



Tp 41
I.R 4
Pitt Lake
PROVINCIAL
PARK
MT
BLANSHARD
Golden Ears
Tp4 R6 W7
Dennett Lake
Munro Lake
Tp4 R5 W7
Widgeon Slough
SIWASH ISLAND
Grant Narrows
FOX RIVER REACH
Dyke
Ditch
Eunice Lake
Gwendoline Lake
COQUITLAM DISTRICT
MUNICIPALITY
U B C RESEARCH
MAPLE RIDGE
Jacobs Lake
Loon Lake
Tp4 R5 W7
Tp4 R4 W7
Tp 40
Tp 42
FOREST RESERVE
Blaney L
DISTRICT MUNICIPALITY
Addington Point
Sturgeon
Slough
De Boville Slough
PITT REACH
SHERIDAN HILL
Mirror L
Mike Lake
North Alouette
PORT COQUITLAM
CITY
ALOUETTE
PITT MEADOWS
DISTRICT MUNICIPALITY
CHATHAM
Tp3 R4 W7
Tp 9
Tp 12
RIVER
ALOUETTE


FRASER
RIVER
Port Hammond
Haney
Fort Langley
Albion
Walnut Grove
Port Kells
BARNSTON ISLAND
Bishop Reach
Derby Reach
Parsons Channel
Tynehead
Westlang
Yorkson Creek
McMillan Island
INDIAN RESERVE 6 ISLAND
Kennedy
Whonnock
PITT MEADOWS DISTRICT MUNICIPALITY
SURREY DISTRICT MUNICIPALITY
MAPLE RIDGE DISTRICT MUNICIPALITY
LANGLEY DISTRICT MUNICIPALITY
CANADIAN PACIFIC
CANADIAN NATIONAL
Tp 8
Tp 9
Tp 11
Tp 12
Block 5 N Range 1 E
Block 6 N Range 1 E


Cloverdale
Langley
Murrayville
Hopington
Brookswood
Hazelmere
Fern Ridge
Langley Airfield
SURREY DISTRICT MUNICIPALITY
LANGLEY DISTRICT MUNICIPALITY
UNITED STATES OF AMERICA
CANADA
BRITISH COLUMBIA
WASHINGTON
Abandoned
Tp 7
Tp 10



MAP No: S20-005

APPENDIX IV

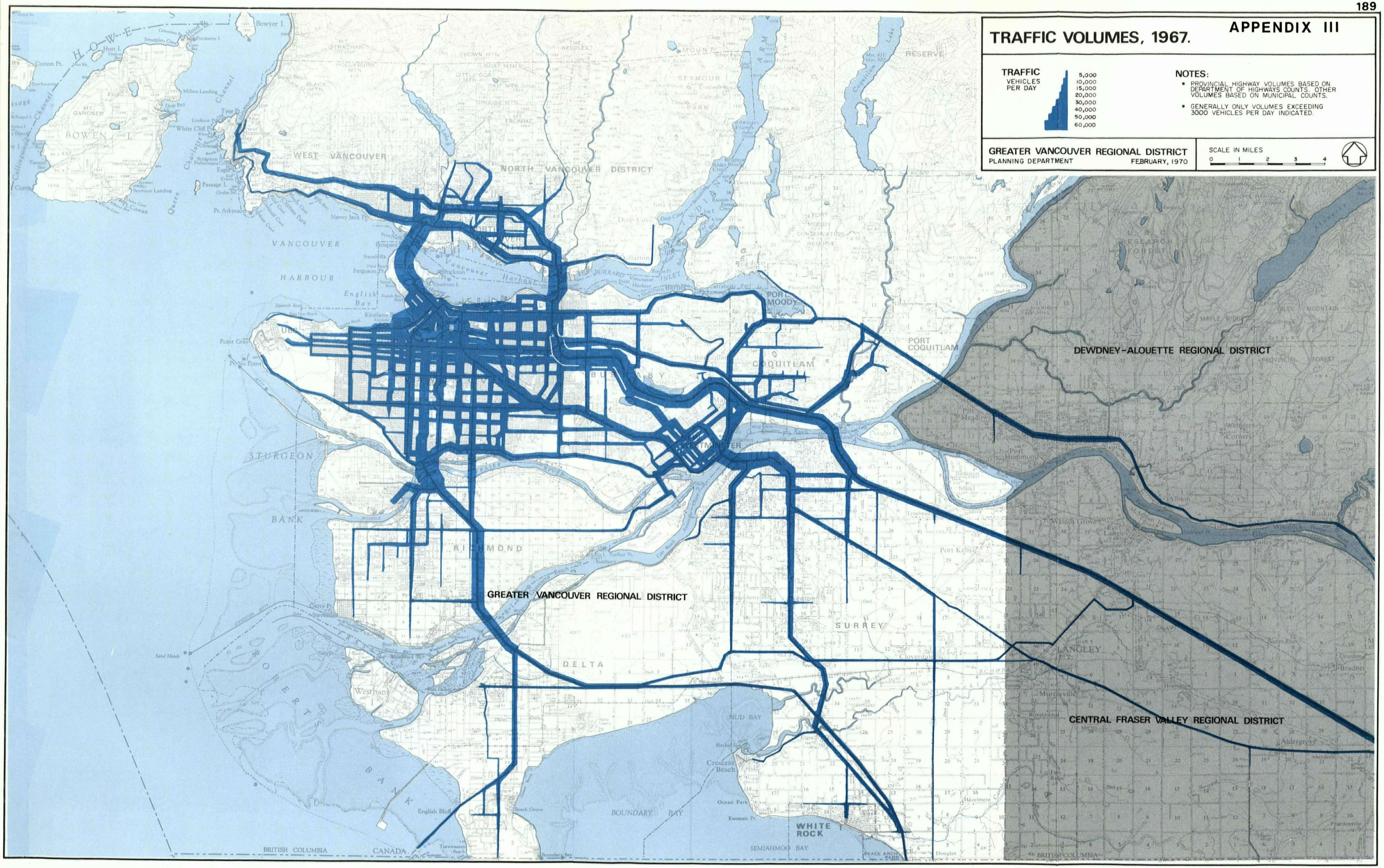
OUTLINE FOR OPERATION OF THE MODEL

In separate discussions with two computer programmers, (James Kestner, Daniel Purvis) with the University of British Columbia Computer Science Centre, the feasibility of the method of application was established, and the general form of model notation and operational procedures was developed. The method of application, Monte Carlo simulation of urban expansion as a spatial diffusion process, is described in Chapter 5. In the following, a brief outline of operational procedures is given.

Estimates of the time required for the model to be programmed and made fully operational ranged from four to six weeks.

Model Notation

A	=	Accessibility (Travel time at peak hour in minutes).
BAR	=	Barrier Limitations (Slight, moderate, severe).
D	=	Distance (Kilometres).
DDL	=	Derived Demand for Land (Hectares).



Map No. K62-066

INTRODUCTION

TRAFFIC FLOW is an expression of life in the city; the myriad ventures of people between their diverse places of work, study, shopping and leisure and their homes. Because travel is vital to urban life, the process of planning facilities to facilitate efficient movement of people and goods requires that the pattern and nature of this movement be understood. An overall traffic flow map is one element designed to develop that understanding and is prepared as part of a data inventory for a comprehensive plan study for Greater Vancouver. Such a study, tentatively titled the TRANSPORTATION AND URBAN PATTERN STUDY is to be carried forward by the G.V.R.D. and is designed to identify the best pattern for future physical development of metropolitan Vancouver.

The traffic flow map is simply a graphic image of the daily sum of vehicular travel counts on our principal traffic routes. It shows the general pattern and orientation of traffic. It thus approximates and measures the activity pattern of the metro community — the journeys of people and the automotive vehicles carrying goods to serve them. It depicts the currently preferred routes and the general destination of traffic movements and thus is a general indicator of the corridors of travel demand. Coupled with more precise data on origins and destinations of travel, the counts can help explain the amount and nature of travel to form a basis for assessing the adequacy of present transport facilities and operations and rectifying inadequacies in the system. By themselves, flow volumes are an inadequate basis for transportation planning. Additional data including knowledge of the future urban pattern, the number of trips per person; the purposes, origins, destinations and timing of these trips; travel mode, time and speed, and congestion levels now and in the future are also necessary.

TRAFFIC TEMPO. The flow of traffic is dynamic-varying with each year, month, week, day, hour and minute reflecting the changing rhythm and tempo of individual and community life in Greater Vancouver. Maximum annual travel occurs in July and August when tourist and recreational travel is highest. Weekly travel reaches a peak on Friday reflecting the effect of evening shopping and increased recreation added to normal work-to-home commuting. As is typical of urban transport systems, three peaking periods occur each day — the morning rush (home-to-work); the evening rush which is highest because it overlaps work-to-home, shopping and business trips; and the early evening surge due to shopping and leisure activity trips. A map of peak-hour traffic flows for metropolitan Vancouver, while potentially valuable, could not be prepared due to lack of ready data.

GREATER VANCOUVER FLOW PATTERN

The pattern of traffic flow in metropolitan Vancouver is essentially radial, fanning outward from the small downtown Vancouver peninsula where traffic movement is strongly focussed.

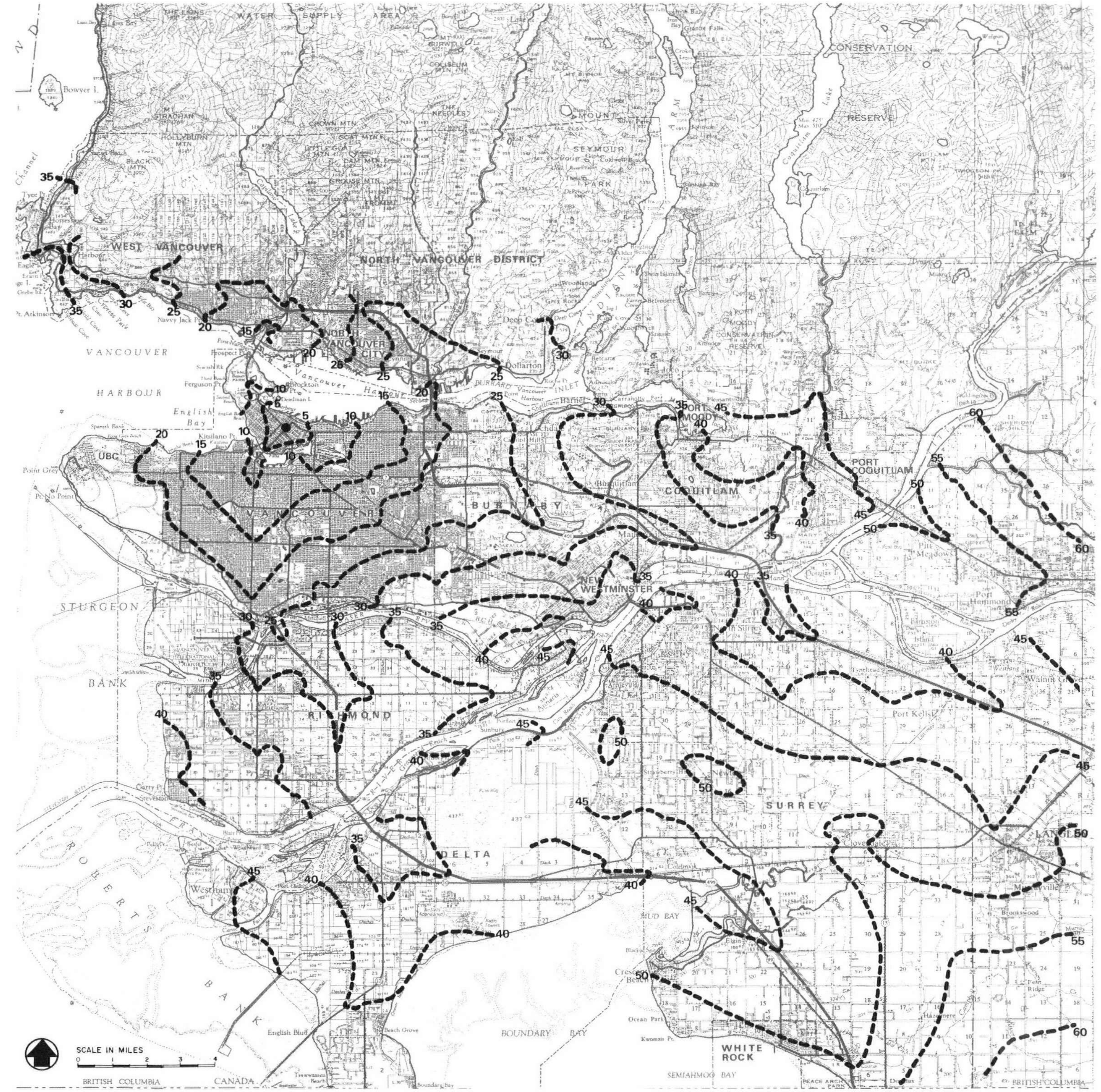
Physiography, particularly major water bodies, plays a key part in shaping the flow pattern because it has determined the location of many links in the major regional road network. The bridge crossings of Burrard Inlet linking the "Burrard Peninsula" and the "North Shore", and those across the Fraser River linking the peninsula and the "South Shore" serve to channel traffic into defined corridors. In addition, the sea restrains westward growth, and directs the main thrust of metropolitan growth to the south-east along the Burrard Peninsula. The trans-continental highway system enters Vancouver along this peninsula. For these reasons major flows occur along corridors to the south-east of downtown Vancouver.

The heaviest traffic volumes are concentrated on highways and arterials, which because of their ability to handle relatively large volumes with greater speed and safety, attract and collect vehicles from tributary streets and roads. In addition to autos, the truck and bus transit movements follow arterial streets and highways, adding to their vehicle volumes. However, these heavy volumes on particular routes are not necessarily true lines of travel desire because drivers select the most practical paths offered them by current facilities. Indeed where bridge crossings channel the movements, the driver has little or no choice. New facilities added to the network offer new choices and typically result in different flow patterns.

Heavy traffic volumes also mirror the pattern of urban development — particularly the major retail, office, industrial and other employment concentrations. The convergence on "downtown" Vancouver reflects the strong role of that area as a specialized regional retail and service centre. The volume map illustrates heavy movement between the metropolitan core and both the inner and outer suburbs and the urban-rural fringe. This is enhanced by movement generated within the higher density living areas fringing the metro core. There is a fairly uniform spread of volumes on the routes focussing on the core area from the east and south, reflecting a fairly uniform pattern of suburban development in the region.

The movement pattern is not a function solely of concentrated employment. It reflects the heavy emphasis of single-family housing and the suburban life-style which requires heavy reliance on the auto — particularly for commuting, because the overall development densities are currently too low to sustain a strong network of economical public transit services.

Considerable movement is in evidence on the more peripheral arterials which accommodate work trips to suburban service, institutional and industrial employment areas as well as a large number of shopping, social and recreational trips.



TRAVEL TIME — SUMMER 1968

- 5 MINUTE ISOCHRONES FROM INTERSECTION OF GRANVILLE AND GEORGIA IN DOWNTOWN VANCOUVER AT 4:30 PM BY FASTEST ROUTE.

DEM	=	Diffusion Emissions (Number of Emissions).
INST	=	Institutional Limitations (Slight, moderate, severe).
LAM	=	Land Absorption Multiplier (Dimensionless).
LAR	=	Land Absorption Rate (Hectares/1,000 persons).
LCR	=	Land Consumption Rate (Hectares/1,000 persons).
NET	=	Network Limitations (Slight, moderate, severe).
NODE	=	Dominant Urban Node.
P	=	Population (persons).
PIN	=	Population Increase (persons).
PLC(XY)	=	Probability of Land Conversion at Site XY (0 1).
PQ	=	Propinquity (Distance from urban area in kilometres).
R	=	Resilience (Low, Moderate, High).
RL	=	Rural Land (Hectares).
RM	=	Resilience Multiplier (Dimensionless).
RULC	=	Rural-Urban Land Conversion (Hectares).
THL	=	Threshold Level (number of "Hits" required).
TLR	=	Total Land Required (Hectares).
TOP	=	Topographical Limitations (Slight, Moderate, Severe).
TT	=	Travel Time (Minutes).
UL	=	Urban Land (Hectares).
USL	=	Unsatisfied Demand for Land (Hectares).
XY	=	Cell in Regional Matrix (Site).

Generalized Procedures

Formulation of the model begins with a given rural-urban land use pattern at time T. Land to be considered for urban expansion is represented in a regional grid in which each cell is identified by the appropriate row (X) and column (Y). Each cell or site (XY) is described in terms of the following characteristics: propinquity to nearest urban area, accessibility to nearest dominant urban node, and barrier restrictions.

(1) PQ(XY) = f [D(XY · UL)]

(2) A(XY) = f [TT(XY · NODE)]

(3) BAR(XY) = f [TOP(XY), NET(XY), INST(XY)]

In addition, the total urban system has a level of resilience which varies according to the land consumption rate;

(4) R = f [LCR]

Both the propinquity and accessibility characteristics of each site are combined to form a rural land conversion probability matrix for the region;

(5) PLC(XY) = f [PQ(XY),A(XY)]

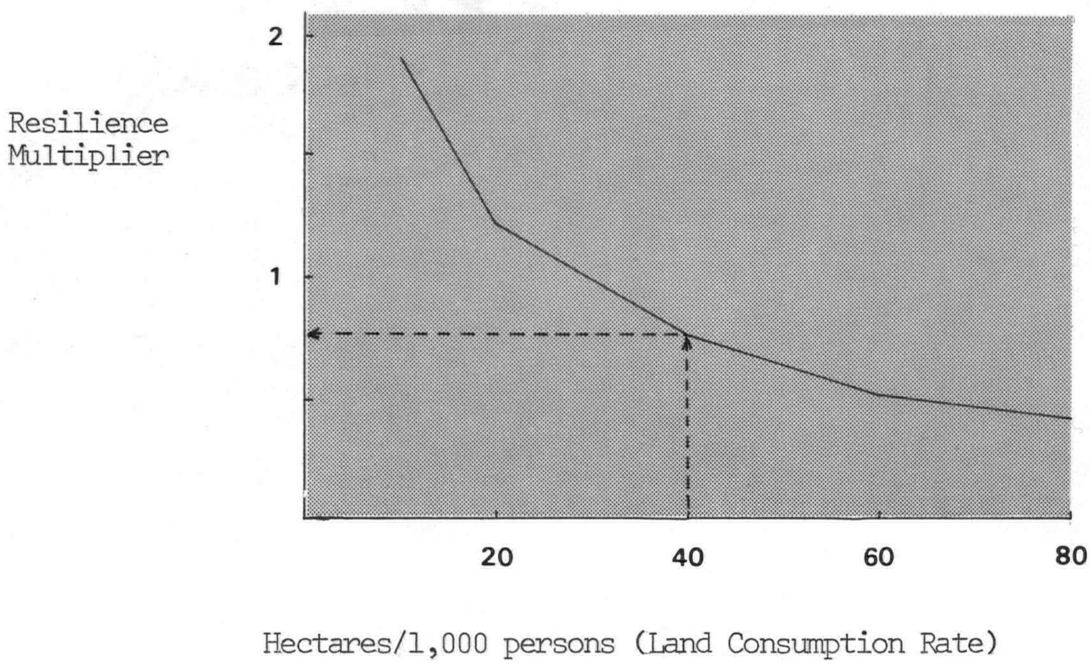
Similarly, to determine the number of "hits" required by a site before it is accepted as an urban area, resilience and barrier effects are combined to establish a site's conversion threshold;

(6) THL(XY) = f [R, BAR(XY)]

In order to obtain the number of diffusion emissions required in any diffusion period, it is necessary to first translate the population increase in the preceding time period, into a derived demand for land;

(7) DDL = f [PIN, RM, LAM]

Both the Resilience Multiplier (RM) and Land Absorption Multiplier (LAM) in Equation 7, are derived by converting the land consumption and land absorption rates, respectively, to constants as shown in the following illustration. For example, a land consumption rate of 40 hectares/ 1,000 persons in this hypothetical, non-linear table function results in a resilience multiplier of 0.75.



(8) RM = f [LCR]

(9) LAM = f [LAR]

To continue, it is assumed that in the initial time period T, there is no residual demand for land and thus;

(10) UDL(T) = 0

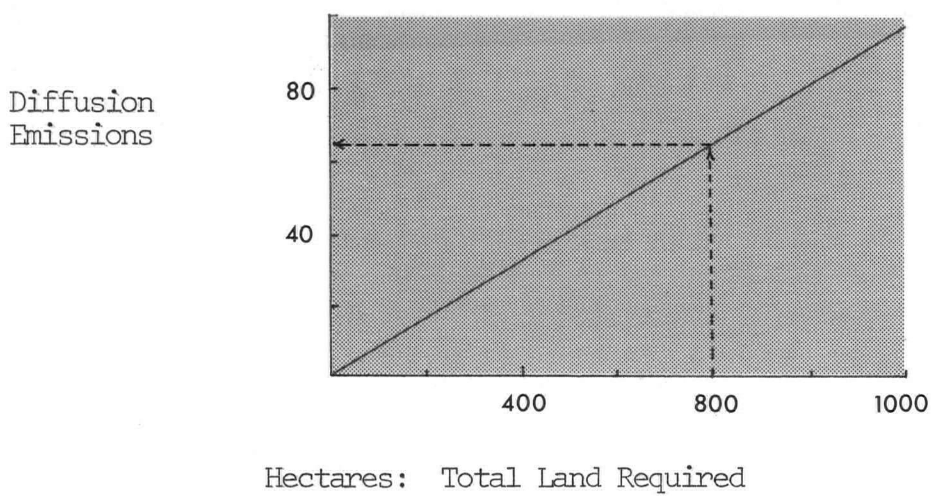
However, in the subsequent period the unsatisfied demand for land is found by subtracting the total rural land conversion in time T from the total land required in time T;

(11) UDL(T+1) = f [TLR(T) - RLC(T)]

Thus it is now possible to derive the total land required in any diffusion period;

(12) TLR = f [DDL, UDL]

The next step involves translating the Total Land Required from Equation 12, into the number of diffusion emissions for a time period. This is achieved by employing a table function, such as the one illustrated below. In this hypothetical example, a total land requirement of 800 hectares, in a diffusion period, involves the generation of 65 single emissions.



(13) DEM = f[TLR]

Finally, the rate, extent and location of rural-urban land conversion in any diffusion period is a function of three inputs: the number of diffusion emissions, the probability of land conversion and the threshold level for sites.

(14) RULC = f [DEM, PLC(XY), THL(XY)]