AIRPHOTO INTERPRETATION AS AN AID IN FLOOD SUSCEPTIBILITY DETERMINATION

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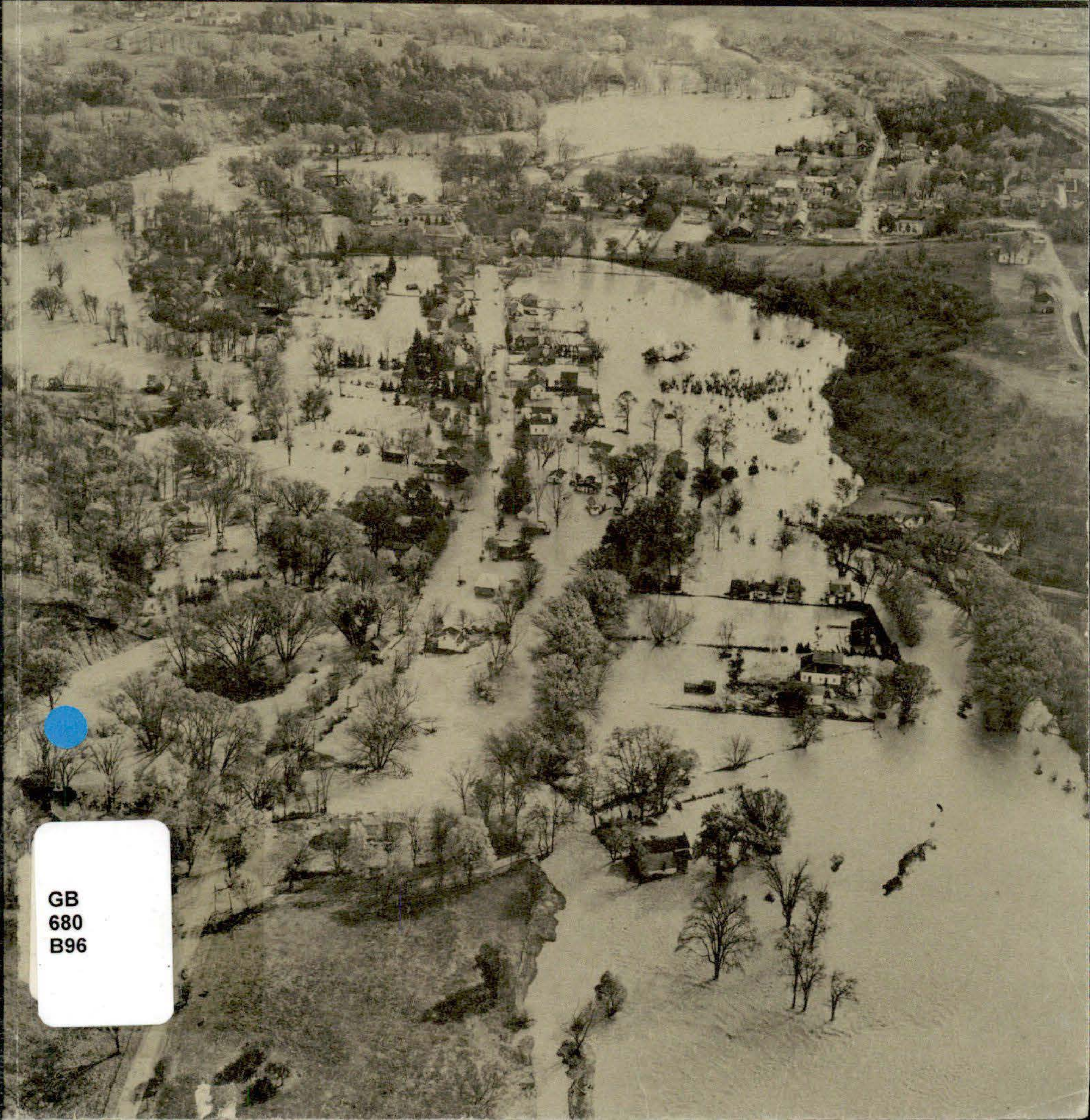

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ABSTRACT

Airphoto interpretation is an effective method of obtaining unique flood susceptibility information. Through perceptive interpretation of the available aerial photographs of an area, the extent, nature, and relative frequency of floods can be determined. It is not necessary to acquire special photography during flooding or subsequent to a major flood to obtain these results. The method described and future refinements should provide a useful tool in complementing the techniques currently employed in the advanced countries in flood-plain studies.

In the advanced countries, greater use of airphotos could be made in providing a sound basis for the regulation of flood-plain use. In the developing countries which cannot afford sophisticated flood-plain studies, airphoto interpretation can provide a valuable substitute.

While the effects of major floods are obvious, even the occurrence of consecutive minor floods leave distinct indicators on the flood plain. The cumulative effect of all overbank flow may be detected directly from observable natural and cultural features, and indirectly by inferences drawn from the adjustment of man and vegetation to flood-plain conditions.

This direct and indirect evidence of past flooding must be carefully analyzed in order to assign a specific area to a susceptibility class. All factors must be considered since few indicators will be sufficient in themselves. Since regions differ in climatic and cultural patterns, it may be expected that each will yield a different mix of clues.

Clues which indicate flood susceptibility may also be used singly or regrouped to determine the potential of an area for erosion, sedimentation, extremes in flood velocities, duration and extent of inundation.

The spatial relationships of areas differing in flood impact can be readily assessed through airphoto interpretation. Areas subject to destructive water current velocities, heavy sedimentation and slack-water inundation, for example, can be delineated to plan for most efficient flood-plain land use. Much of the value of airphoto interpretation lies in its unequalled ability to provide this type of comprehensive information.

Finally, the resolution of resource use conflicts, such as between flood control measures and recreation values, or between irrigation and other water use, can be facilitated through the ability of airphotos to provide a broad perspective of watershed conditions.

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".....along most rivers there seems to be a general relationship between frequency of flooding and certain alluvial features of the valley bottoms..... .....The relation of terrain to floods as an aspect of human geography has hardly been studied, at least not nearly so extensively as river hydraulics and hydrology." (6)

INTRODUCTION AND BACKGROUND

The recent flooding in northern Italy has perhaps received wider publicity than any flood in recent history, because of the damaged art treasures at Florence, and the great strain that has been placed upon the Italian economy by the magnitude of the general flood losses. However, few floods receive anything like this amount of publicity. Generally, the news media seem to report damaging floods more in terms of the number of persons drowned and families driven from their homes than in terms of the dollar value of damages incurred. It is also true that many floods do not merit worldwide or even national news coverage, even though today's sophisticated news media are fully capable of providing it. Even in the personal experience of residents of our many flood plains, flooding may be a relatively rare occurrence, for these disasters are unevenly distributed over time and directly affect only a small fraction of the total population. Furthermore, man has a propensity for forgetting the unpleasant. These factors would seem to be the main reasons for the insufficient awareness on the part of the public of the enormous damage caused by floods.

The gravity and chronic nature of flood problems may in large measure be appreciated, when one considers that in the United States, the country for which most complete figures are available, $4,000,000,000 was spent on flood control measures from 1936 to 1957. However, in spite of this expenditure, average annual flood damages continued on an upward trend which began about the turn of the century (12). This increasing average annual damage is accounted for in large part by continued encroachment of development upon the flood plains (6). Flood-plain development will, however, continue to take place regardless of whether absolute flood damages increase or decrease because this land form still has many obvious advantages for agriculture, transportation and urban development. There are several noteworthy examples of continuing flood-plain encroachment in Canada, one of which is the Lower Fraser River Valley. Here in 1948, one of the most extensive and certainly the most costly flood in the river's recent history occurred. Despite this disastrous flood, during the subsequent 1951 - 1961 census period, the population growth rate on the flood plain was double that of the valley as a whole, while the rate for the metropolitan Vancouver portion of the flood plain was almost four times as fast as for the rural area (11).

Proponents of flood-plain zoning acknowledge the inevitability of further encroachment on flood plains and the impossibility of providing complete flood protection by structural measures. Indiscriminate flood-plain development is wasteful because unnecessary flood damage occurs sooner or later. Complete prevention of flood-plain use is equally wasteful since the flood plain's distinct advantages for development are needlessly forfeited. The need for compromise between these extreme positions has been recognized by advocates of flood-plain zoning. Even zoning is but one of many alternative adjustments to floods, among which must be found the optimum compromise. Ideally, zoning should occupy the pivotal position in this group of flood adjustments in order to minimize costs and maximize benefits.

There are three main reasons why flood-plain zoning has not been accepted more widely and rapidly in the three decades since it was first introduced: 1) unwarranted faith in the ability of engineering structures to control floods, 2) aversion to restrictive laws, and 3) lack of a composite picture of the flood-plain environment upon which to base zoning regulations, particularly lack of flood susceptibility information. The purpose of this paper is to discuss a new method, namely airphoto analysis and interpretation, which can aid in eliminating this third obstacle.

But before going on to discuss the role of airphoto analysis and interpretation, it is desirable at this stage to digress briefly in order to show why comprehensive pictures of flood-plain conditions are not available. When zoning was first introduced, flood-plain information was only available as rather isolated facts such as stream gauge data that were difficult to interpret for planning purposes. It was not until the 1950's that in Canada and the United States a more composite picture of flood-plain conditions during flooding, was incorporated in reports that could be used by planners, thereby partially fulfilling a long standing need. These reports dating from the 1950's fall into three general categories: 1) comprehensive watershed planning reports, 2) flood control planning reports, and 3) flood hazard mapping reports. Although three different purposes lie behind the preparation of these reports as indicated by the titles, from the point of view of their usefulness to the prospective flood-plain zoner, they are remarkably similar in content.

Hydrologic data, historical records and field interviews provide the main basis for the flood-plain investigations which constitute all or a portion of these reports. Supplemental information on the major floods cited in these reports is sometimes obtained from specially flown flood or post-flood photography. However, unfavourable weather conditions or delay in arranging contracts, often prevents acquisition of this photography. Flood photography is unexcelled in depicting the outline of flood water at a particular point in time and is valuable in helping interpret pre-flood photography. Such flood photography, when obtainable, is also of great value to the hydrologist for the purpose of checking stage-discharge and stage-inundation relationships, but is less valuable to the regional or city planner because much of the flood plain is obscured by water during and after these relatively rare events.

Although such conventional flood-plain studies provide information on extent, frequency and depth of flooding, they neglect to include important aspects of the flooding phenomenon, aspects which are necessary for more rational flood-plain use or regulation. The reports commonly include maps showing the area inundated by one or two major historical floods, as well as the area expected to be covered by the "design" or maximum probable flood. Stream profiles indicate the water depth at various stations for both historical and probable floods. Dramatic newspaper photos, either ground level or aerial obliques, serve to emphasize the hazards of flood-plain occupancy even more than eyewitness accounts of specific floods. In sum, whereas hydrologists and flood control planners have, in presenting these flood-plain studies, considerably improved our knowledge and understanding of the frequency distribution of flooding of various depths and extent, little has been done to place these vital studies in an all-embracing framework. These more conventional studies have tended to emphasize flooding per se, but have neglected to specify the characteristic features of floods and flood plains which are crucially important for would be users of flood plains. This apparent lack of emphasis on interpretation of data for the use of planners, stems, I should imagine, partly from public pressure for flood damage prevention and also public apathy, heretofore, toward rational land use planning.

The foregoing pin-points the need for a more integrative approach to the study of flooding. A young but extremely promising discipline which can be and is being used to integrate the work of both hydrologist and planner is Air Photo Analysis and Interpretation which attempts among other things to comprehend the problem in its entirety.

In the industrialized countries, for instance, interpretation of aerial photographs taken under non-flood conditions can supplement flood-plain studies and watershed planning with information that is useful to the hydrologist and invaluable to the planner. The hydrologist concerned with minimizing damage from watershed runoff must pay heed to more than stage-discharge and stage-inundation relationships. For example, constrictions in the stream channel and the location of natural floodways each warrant his attention, and are given his consideration, but are not usually discussed in reports in such a manner that their full implications become apparent to those engaged in flood-plain regulation, use or development. On the other hand, there is apparently little awareness on the part of hydrologists, of the presence or importance of such terrain features as slack-water areas, in which flood water will be ponded for extended periods of time, nor of scoured areas, in which the highest overflow current velocities may be expected. Such information may be of limited use to the hydrologist, but it is essential for evaluation of the potentials and hazards of flood-plain occupancy - a vital element in rational flood-plain planning and development.

In the developing countries airphoto interpretation can be effectively used as a substitute for the more sophisticated and costly flood-plain studies alluded to above. Meaningful and detailed hydrologic studies require engineering expertise and a backlog of long-term hydrologic data. As will be described below, airphotos capture the effects of long-term stream flow and flooding. Furthermore, the information gained from the photos, will have potential for broader application than the more specialized but unobtainable hydrologic information.

WHAT IS AIRPHOTO INTERPRETATION?

Airphoto interpretation consists of three increasingly sophisticated levels of procuring information from aerial photographs. Photo reading, the simplest level, is the identification of physical and cultural features and the determination of their spatial relationships. Stereo viewing is helpful but not essential for this data-gathering procedure. Photo analysis, the intermediate level, includes the procedures of photo reading but goes further to allow analysis of the arrangements and physical characteristics of photo features. This analysis provides a basis for the classification of residential areas, soils, land use, and so forth. Stereo viewing is usually essential for this approach. The most advanced level, photo interpretation, goes on from a background of photo reading and analysis to "explain the meaning of information obtained from airphoto study in terms of some particular objective." (9) It may also be thought of as the technique of obtaining information of an inferential nature not directly visible on the photograph. Stereo viewing is essential to this approach, which depends for success upon the relevance of the interpreter's experience and training to his particular objective.

Airphoto interpretation is an effective method of obtaining unique flood susceptibility information. We will address ourselves to the perceptive interpretation of aerial photography, which has already been acquired at considerable expense for other purposes in nearly all countries. Though up-to-date information is lacking, one-half the land area of the world had been photographed at least once by 1959 (4). Most of the more developed countries have been covered by photography completely one or more times. So much new photography is obtained each year that it is now probably safe to say that even in the least advanced countries, practically any area of interest to a water resource administrator or specialist has photographic coverage. Since much of the world's aerial photography has been obtained by military agencies and aerial survey firms located in Canada, the United States, Great Britain and France, much of the information on overseas coverage is available through sources located in these countries, and not always in the country photographed. A national, seeking information in his own country on photo coverage, should direct his inquiries to those government departments which are concerned with Defence, Resources, and Development. Finally, in regard to the acquisition of aerial photography, it is worthwhile making a comment on the costs likely to be involved. The cost of 1:20,000 scale contact prints can range from a few cents to a few dollars per square mile of stereo-coverage. On the other hand, new photography will cost from a few dollars to a few tens of dollars per square mile. The economic advantage of utilizing available photography need scarcely be emphasized.

AIRPHOTO EVIDENCE OF MAJOR FLOODS

The large volumes of water involved in major floods and the resultant high velocity currents, ensure that these rarer floods leave conspicuous evidence of their impact. Property damage of one sort or another is usually the first to catch the eye of the ground observer, and because of the clarity of this evidence it is usually the first to be eliminated, primarily through repair and cleaning-up operations (1). But even if vertical photos are taken immediately after a flood they are unlikely to record the full extent of the damage unless they are supported by aerial obliques (4). Major floods may also leave new or accentuated flood evidence in the form of modifications of the natural landscape. These modifications may be as dramatic and significant as a newly cut channel section, though, even in the case of a major flood, are more likely to be confined to more subtle alterations of existing features such as sand splays or scour marks. Although on the ground this "natural" evidence of severe flooding is usually less obvious than property damage, from the air it stands out distinctly. Light greyish or brownish sand splays which may be nearly concealed from view in a weedy vacant lot appear as dazzling white on post-flood photography. Deepened scour marks will stand apart from portions of abandoned channels, a distinction less easily made on the ground. The existing features which may be high-lighted following severe flooding, are in most cases features that result from the effect of more frequent but less extensive overflows.

AIRPHOTO EVIDENCE OF MINOR FLOODS

Minor and more frequent floods differ from major floods more in degree than kind, at least as far as direct evidence upon the flood plain is concerned. These more frequently occurring floods cover a smaller portion of the flood plain, and the frequency-inundation relationship, which is so familiar to hydrologists, provides the basis for separating frequently and infrequently flooded areas. Minor floods do not erode, deposit or damage as extensively or severely as major floods. However, the relatively short time interval between minor floods means that this direct evidence may remain almost unmodified through natural processes or man's activities during the interflood periods. The frequent intensification of this flood evidence in susceptible areas helps to distinguish them, because the evidence on less frequently flooded areas may be more subdued through modification over a longer interflood time period.

Frequently flooded areas are also characterized by the closer adjustments of man's activities to flood-plain conditions. Indirect evidence of this type, subtle though some of it may be, is just as useful as that direct evidence which is left behind after a particular flood. Compensating for the sublety of the indicators is the degree of sensitivity expressed by adjustment of life to flood susceptibility. Flood-plain farmers, probably because they live "close to the land" often demonstrate a keen awareness of flood-plain conditions and a discrete response to them that their urban counterparts almost completely lack. By way of contrast, in urban centers where physical structures tend to obstruct a comprehensive view of the physical geography of the area, and where residents are forever on the move, it is small wonder that some residents can live within a stone's throw of a channel and be unaware of its significance. There seem to be more maladjustments to the flood plain in the urban than in the rural environment. Whereas in the rural situation maladjustment to flood-plain conditions often reflects misguided gambling with nature, in the urban situation maladjustment more often reflects decisions made in ignorance. It is important to recognize flood-plain maladjustments during airphoto interpretation which otherwise could result in erroneous flood susceptibility evaluation. Ways of avoiding this error are discussed subsequently.

The type and distribution of vegetation is a sensitive indicator of soil and moisture conditions which in turn reflect flood susceptibility. The relationship of vegetation distribution and crop condition to flood-plain conditions seems closest in the generally more flood-prone areas, because here soil conditions change most rapidly. Just as existing flood-induced physical features on the most susceptible portions of flood plains are accentuated by the more extensive major floods, so the adjustment of vegetation in these areas is likewise sharpened.

It is necessary to emphasize here that since major floods occur infrequently, and since any aerial photo records the cumulative impact of all preceding floods, most photographs whether taken before or after a major flood, will no doubt reflect approximately the same evidence with perhaps varying degrees of clarity. Thus, it would appear uneconomical to acquire "post-major flood" photography unless all existing photography fails to provide certain requisite information, because the disproportionate high cost of these photos is unlikely to be offset by the additional information.

FLOOD SUSCEPTIBILITY DETERMINATION

Direct and indirect evidence of flooding takes many forms, only a few of which have been mentioned in the preceding section. In providing an unbiased cumulative record incorporating all this evidence, the airphoto facilitates its compilation and analysis for the determination of relative susceptibility of an area to flooding. The value of this flood susceptibility information is superior in some respects to that which is or could be accumulated by ground methods alone, because it derives from a critical four dimensional examination of the total flood-plain environment. The photo background from which the information is gleaned, is at one and the same time a three dimensional panoramic and detailed view of the flood-plain, while time, the important fourth dimension is captured in the stream's geomorphic history and man's adaptations, as already noted.

In Canada, which was one of the first countries to obtain substantial airphoto coverage for peaceful purposes, sequential photography covers a span of more than four decades. The repetitive aspect of this coverage adds a time dimension of a different nature. Old photography which has captured the scene at intervals over the past few decades, has added value such as, permitting study of natural flood-plain features long since obliterated by urbanization, or facilitating land use change studies.

A complicating factor encountered in attempting to determine relative frequency of flooding is the wide variation in absolute flood frequency on different streams. Although recognized authorities have stated that a 1.5 year frequency of "bank full" stage seems a good average, little affected by physiographic setting or stream size, our perusal of many watershed planning reports indicates that in a substantial number of watersheds being treated for flood control, the streams flood up to 10 or 15 times per year (8). This apparent contradiction is accounted for in large part by their definition of "bank full". Since it is defined as the difference in elevation between the stream channel profile and the flood-plain profile, both being average lines drawn through a number of points, it follows that many points along the bank will be topped by flood water before the "average bank full" stage is reached. Many factors account for this very wide variation in absolute flood frequency, but this frequency should be recognized and taken into account in the determination of the relative susceptibility to flooding of different portions of flood plains.

For this and other reasons that are covered subsequently, no attempt is made to present a formal key for flood susceptibility classification. Rather, those indicators, visible or inferable from airphotos, which bear a positive or negative relationship to flood susceptibility, or which are otherwise useful in estimating susceptibility are grouped in Table 1 under six indicator classes: 1) Meteorologic, 2) Physiographic, 3) Geomorphic, 4) Topographic, 5) Pedologic and, 6) Socio-Economic. Some indicators have undoubtedly been omitted from this table, but it is believed the most relevant are included. The value of the indicators is not only for determining relative susceptibility of an area to flooding, but for determining other flood characteristics such as potential hazard from erosion, sedimentation and extremes in flood-water velocity as well as relative duration, depth and areal extent of inundation. In fact in many instances it is easier to ascertain characteristics of flooding or the susceptibility to certain types of flood hazards, than it is to determine relative flood frequency.

The characteristics of flooding are determined in the main by meteorologic and physiographic factors, thus, the meteorologic and physiographic classes are composed mainly of causative flood factors. On the other hand the geomorphic, topographic, pedologic and socio-economic indicators in large part <u>result</u> from flood characteristics and hence are derivative in nature. These six classes of indicators should also serve to guide the utilization of any available meteorologic,

TABLE 1 FLOOD SUSCEPTIBILITY INDICATORS

CLASS I - METEOROLOGIC

Climate
- Seasonality
- Temperature
- Precipitation
  - Distribution
  - Intensity

Storm Type
Storm Direction
Orographic Effect

CLASS II - PHYSIOGRAPHIC

Bedrock Composition
Bedrock Structure
Upland Physiography
Watershed Shape
Valley Orientation
Flood-Plain Shape
Proportion of Watershed in Flood Plain
Stream Drainage Pattern and Density
Discharge to
- Next Order Stream
- Much Larger Stream
- Lake
- Tidewater

Underfit Streams

CLASS III - GEOMORPHIC

Flood-Plain Type
- Meander Plain
- Cover Plain
- Bar Plain

Alluvial Fans
Terraces
Levees
- Active
- Abandoned

Point Bars and Swales
River Bars
Deltas
Channel Configuration
Channels
- Abandoned
- Oxbows
- Filled

Backswamp Areas
Marshes
Former Lake Beds
Dunes
Landslides
Springs and Seeps
Depth to Water Table
Swamping
Valley Trenching

CLASS IV - TOPOGRAPHIC

Relative Elevation
Slope
Slope Changes
Slope Complexity
Micro-relief

CLASS V - PEDOLOGIC

Structure
Texture
Organic
Salinity
Depth
Vertical Uniformity
Permeability
Drainage
Erosion
- Type
- Extent
- Severity

Deposition
- Type
- Distribution
- Freshness

CLASS VI - SOCIO-ECONOMIC

Land Use (Rural and Urban)
- Character
- Intensity
- Changes over Time
- Boundaries
- Alternatives
- Limitations

Building
- Type
- Location
- Condition

Transportation
- Type
- Location
- Condition

Flood Alleviation Measures
Channel Constrictions
Repair Work
Farm Characteristics
- Size
- Type
- Location
- Management Practices
- Crop Condition

Vegetation Removal
- Logging
- Land Clearing

Revegetation

geologic, soil or economic reports for susceptibility determination. Information in such reports may serve to strengthen conclusions drawn from the airphotos.

In the following treatment, selected indicators will be discussed to illustrate their value for flood character determination and to show their interdependence. Some consideration is given to the relative significance and dependability of the different lines of evidence, both in terms of inherent reliability and in terms of variability that results from characteristics of the photography.

METEOROLOGIC INDICATORS

Much of the meteorologic information of the type listed in the table will come from reports or be common knowledge, but this information has unequalled relevance to flooding and must be considered for accurate photo interpretation, whether it is derived from the photo or a report. For obvious reasons these indicators lend themselves to evaluation through airphoto interpretation less than those of any other class. However, when one considers the scarcity of meteorologic information which exists in many areas, even in the industrialized countries, the value of airphotos in obtaining and utilizing meteorologic information can be better appreciated. Commonly rainfall data are only available for a municipality in the lower reaches of a watershed. The distribution of rainfall in the watershed due to storm direction and the orographic effect can be determined on airphotos, at least in relative terms, from consideration of the topography and vegetation distribution. These and other considerations can lead to the determination of the relative amounts of runoff from different tributaries. This alone allows prediction of higher flood stages on the mainstem reaches below these tributaries. Small scale photography which provides the more all-inclusive view might be helpful for such meteorologic studies.

Seasonality in rainfall distribution that indicates when floods may be expected, takes on added significance when airphoto interpretation reveals the seasonal development of sand bars or spits at river outlets, which may restrict flow with the return of the rainy season. Winter temperatures which are extreme enough to allow ice to form on rivers are common in many countries in the high latitudes. The very long northward flowing rivers common to Canada and the Soviet Union are particularly prone to this complicating flood factor. The extent of inundation which is forecast on the basis of standard hydrologic procedures becomes an unreliable guide, under those conditions where ice jams form. On streams where ice jamming is a common event, careful airphoto study may reveal diagnostic clues. Alternatively, it may be possible to draw inferences about ice jam frequency and probable location from apparently unrelated evidence. A classical example of such airphoto interpretation "detective" work was in the case where "the grooves in lake bed sediments made by (wind blown) pan ice were related to shallow water of the (post-Ice Age) lakes, and thus to more salty soils." (2) The frozen condition of flood plains during spring runoff floods accounts for the anomalous indistinctness of scour marks on flood plains characterized by this seasonality of flooding. Deposition from such spring floods is not so greatly diminished because the channel acts as a source of sediment.

PHYSIOGRAPHIC INDICATORS

The gross physiographic characteristics of a watershed are indicative of the nature and frequency of flooding. The bedrock structure of an area has a profound influence upon the shape of watersheds, while the bedrock composition closely controls the drainage density and pattern. Nearly circular watersheds for example may develop in structural basins. Other factors being equal, frequent flooding is indicated for watersheds which tend to be circular and characterized by mountainous uplands and a dense drainage network. Some watersheds of this nature which are known to flood frequently over very broad flood plains shows surprisingly little in the way of flood-plain scour and sediment damage. In these cases however, it is in accord with flood-water ponding which results from constriction of the flood-plain down stream or results from backwater effects where streams empty to tide-water. This observation also illustrates the point that there is a close relationship between the larger features of the watershed and the smaller features of the flood plain. Flooding of this nature also may occur in limestone terrain, because limestone solution which has resulted in the development of a discontinuous surface drainage system, has not yet advanced far enough to carry storm runoff into the underground without prolonged surface ponding.

In any area where a stream empties into another, there may be the problem of the common flood plain, however it may be quite evident from the pattern of flood deposition on photographs which stream dominates the flood problem. Also the diminution of certain kinds of flood evidence in the lowest reach of a stream may indicate frequent flooding and backwater from the one into which it empties. For the purpose of assigning damage costs and benefits it is important that the problem of common flooding be accurately resolved.

In this brief discussion, the physiography of a watershed has been shown to be relevant to flood susceptibility, erosion and sediment damage, flood-water velocity, and duration and extent of flooding. As in the case of meteorologic indicators, the photo characteristic of most significance is probably scale, since small scale photography facilitates appraisal of gross watershed characteristics.

GEOMORPHIC INDICATORS

The numerous land forms and landscape features cited as geomorphic indicators are more easily grouped to designate expected flood characteristics than relative flood frequency. The reason lies in the fact that flood-plain features are quite well understood in terms of processes involved, texture, depositing water velocities and duration of inundation (8). But little has been written on the relation of these flood-plain features to frequency of flooding. Geologists recognize that meander plains built primarily through lateral channel migration and resultant point bar deposits, flood less frequently than cover plains which are blanketed by vertical accretion deposits. However, they have not gone much beyond this gross generalization.

The comparative elevation of different flood-plain or terrace levels clearly shows relative potential for flooding, but it is their subtle surface features which tell whether or not they are still subject to flooding. Terraces exhibit the same surface features as lower portions of the flood plains. Some of these features of course may be relicts from the time when a terrace was a more active flood-plain bottom, but others are present day features whose distinctness reflects the frequency of flooding. Especially on higher terraces, these clues may be so subtle as to be indistinguishable except from the air. Tonal and vegetational changes may be the most obvious expression of levee and slack-water deposits on a terrace.

Alluvial fans present flood problems that are peculiar to them alone, because of their relatively steep gradient and the transitory and branching nature of their multiple channels. Flood-water velocities, sediment load and texture are reflected in the channel configuration, cross-section shape and character of scour marks, which are most easily assessed on airphotos. Sequential photography records channel location changes which help predict new channel courses and areas of increasing flood hazard.

Along the larger streams, natural levees may provide almost the only land suitable for intensive development. Abandoned levees are less susceptible to overtopping than active ones, as indicated by the less distinct scour marks running down their back slopes. The soils on abandoned levees will be more mature and of higher productivity than texturally comparable soils on active levees, making them more attractive for agriculture. Much soil information of this nature can be obtained by airphoto interpretation. On abandoned levees, flood proofing specifications for buildings could be adjusted to take account of the diminished hazard from high velocity currents and intense scour and sedimentation which characterize flooding on active levees. The activity of a channel and consequently the degree of abandonment of a levee, can perhaps be better determined from examination of these features in the context of the whole flood plain on airphotos than any other way. Slack-water areas behind active levees may be more susceptible to flooding than the levees themselves, because water may move down the flood plain behind the levee before it is topped. Areas where the bank full stage is first reached are readily located by the large scour marks which identify them. If the soil at the time of photography is either too dry or too wet, or the flood plain is heavily vegetated, then less use can be made of soil tone changes in the recognition of scour marks, and more reliance must be placed upon vegetative and topographic clues to overbank flow. The configuration of the main channel will also indicate where overflow can be expected when other clues are weak.

A particularly easy guide to flood susceptibility is the presence of stabilized or vegetated sand dunes on river terraces. The persistence of these land forms in a stabilized condition is precluded by flooding, therefore their presence indicates non-susceptible areas. But certain other factors relevant to land development are then apparent. Special treatment of dune sand is required for road subgrades and severe wind erosion may follow soil disturbance resulting from other development. In the case of dune plains traversed by relatively small streams, the dunes may modify channel configuration and contribute substantially to flood hazard by decreasing its capacity.

Heavy rainfall on saturated ground which forebodes maximum flood hazard, also sets the stage for landslides in areas where soils are susceptible to this phenomenon. Particularly in areas of residual soils this hazard not only coincides in time and space with the flood hazard, but increases it, especially by contributing vast amounts of sediment and vegetative debris to flood waters. This was the case in the December, 1964 floods in the U.S. Pacific Northwest (1). The value of airphotos for locating these hazard areas is well established (7).

To optimize results from the interpretation of geomorphic indicators, photography should be large scale, and taken when the soil is quite moist and either before or after the growing season. In tropical areas photography that follows the harvesting of such rank growing crops as sugar cane may be most timely.

TOPOGRAPHIC INDICATORS

The relevance of topographic considerations to flooding is so obvious that at first one may wonder why it merits mention here. But even if large scale topographic maps were available for all regions, which is far from the actual case, the use of airphotos would still be justified. Micro-relief, (changes in elevation of less than the contour interval) is one of the most important of the topographic considerations, because it is a definitive indicator of certain erosional and depositional conditions and soil types (2). In some areas mounded soils which have a relief measured only in decimeters are found adjacent to, but not on, flood plains of small streams. The boundary of these soil types, so conspicuous on photos, accurately defines the extent of all but the most infrequent floods. No topographic map is made which does not lose some detail of relief between the contour lines that is relevant to flood susceptibility determination. When the scale of the photography is too small and/or the relief is too subtle for this relief perception, it may be accurately inferred from study of soil drainage patterns, photo tone changes and vegetation characteristics. Such detail is significant where soil drainage measures are to be carried out or where a river develops a flood plain on particularly flat terrain such as a coastal plain. On a somewhat larger scale, complex slopes along stream channels testify to local but intense scour and deposition.

Although all physiographic indicators except bedrock structure and composition may be derived from a topographic map, many of the geomorphic indicators, even larger ones, are lost between the contours. Study of all pertinent flood indicators can never be done from a topographic map, whereas the airphoto comes close to being the ideal base. The largest scale photography possible facilitates study of micro-relief and when available, coverage avoiding the growing season should be used.

PEDOLOGIC INDICATORS

The indicators in this class have a high degree of dependence upon the indicators already discussed because the influence of climate, topography, and parent material upon soil formation is so great. As a result it becomes more difficult to discuss indicators as isolated entities. Indeed they are not! Like other clues to flood characteristics, they are closely interrelated. Especially when considered in conjunction with geomorphic indicators they can be very definitive.

The fine grained organic rich sediments characteristic of oxbow lakes, filled channels and backswamp areas, testify to quiet water deposition. Long inundation periods can be expected here. Scour marks too may exhibit a veneer of sediment with this texture, since they also are topographic depressions in which a small volume of water will be ponded. However, the foundation conditions underlying these features which exhibit rather similar surface textures, are almost certain to be significantly different. Urban development and levee construction are both critically dependent upon subsurface conditions which may be inferred from airphotos as engineers have been doing, preparatory to intensive investigations, for about 20 years.

In arid areas, the white distinguishing badge of alkali on airphotos helps define subtle depressions and the movement of groundwater.

Soil permeability and drainage possibilities are closely related. It may be entirely feasible to lower the water table on a sandy flood plain but impractical or at least less successful in many clay soils. These soils can be distinguished on photography even of forested areas in undeveloped regions.

Erosion in the usual sense of the word is absent from flood plains. The low gradients of most flood plains and the changes wrought upon them by flooding prevent development of anything but scour marks from water leaving, or returning to, the channel. It is important on photos to distinguish between scour marks caused by flood water returning over a terrace edge and normal terrace face erosion.

The type, distribution and freshness of flood sediment is one of the best indicators of flood susceptibility. Sequential photography may reveal marked differences in the appearance, of areas subject to deposition which reflects timing of the photography relative to flooding. A deposit of fresh sand only a centimeter thick will appear just as white on post-flood photography as do thick sand drifts. Care must be taken not to over-estimate sediment damage because of the conspicuous appearance of fresh sediment. Photography which does not coincide with an immediate post-flood period is more reliable in this respect than that which does coincide. Distinction is more easily made between major and minor sand accumulations on the basis of tonal differences and other modifications when at least one growing season has elapsed between the time of deposition and photography.

SOCIO-ECONOMIC INDICATORS

If the pedologic indicators exhibited a degree of dependence upon other indicators, the socio-economic do even more so. In this class are presented man's adaptations to and his conflicts with the flood-plain environment. The background of other observations which we have built up allows very accurate and meaningful interpretation of these indicators in terms of flood characteristics. Generations of flood-plain residents have in some measure succeeded in synthesizing the information we have been discussing, albeit most of this has been done by rural residents. When they have struggled with the flood plain instead of adapting to it, their reasons can often be determined by airphoto interpretation

Burton has dealt at length with the adaptations of farmers to flood plains, including the paradox involving flood hazard awareness and non-adaption (3). A knowledge of local agriculture and economic conditions is certainly essential to get the most from socio-economic indicators in rural areas. Indeed for this work an airphoto interpreter must have an insight into the sociological conditions in the area. The farmer's decision-making process is influenced to a large extent by his motivation, which cannot be seen and not always inferred from airphotos. In fact we cannot always infer that he is motivated to maximize his monetary income as witnessed by the sub-marginal farmers in every country in the word, some of whom consciously forego financially advantageous urban employment alternatives. Nonetheless a high proportion of the (flood-plain) environment factor-land use relationships that were studied can readily be examined on air photographs, and their significance weighed in the light of other indicators. As Burton noted, the land use intensity-flood frequency relationship is rather weak, but in his study he explained the exceptions encountered, as for example the lack of non-flood-plain land to farm intensively, may force a farmer to crop even highly flood susceptible areas. One need not interview a farmer to ascertain such limitations to his land, a photograph will do as well. There is therefore, little danger of interpreting intensive use as indicative of a low frequency of flooding, especially in the light of other airphoto evidence to the contrary. On many flood plains there is a clear decrease in land use intensity with increasing flood frequency despite the exception just noted. Flood alleviation measures taken by local residents are accurate indicators of a high frequency of flooding, though these activities must be considered in the light of local economic and other conditions. Stream channel straightening, ditching and building of artificial levees by farmers indicate the location and extent of flood problems.

Land use boundaries on some flood plains coincide closely with lines separating areas of rather marked differences in flood hazard as determined from other evidence, thereby indicating a keen flood hazard awareness on the part of the farmer. This awareness of flood hazard by farmers is particularly evident in the case of farm house location and slightly less so for other buildings, though exceptions occur. In urban areas, the type, location and condition of buildings may or may not have a close relationship to flood frequency. Run down dwellings are often noted on very susceptible areas, but extreme exceptions occur in the case of some recent housing developments where expensive homes are located on "choice" streamside lots. In the latter situation it may be necessary to examine photos pre-dating the development to determine flood susceptibility. In some situations the flood hazard is then so obvious as to suggest that ignorance of the hazard which can honestly be attributed to the purchasers, cannot be attributed to the developer. It must be admitted in defence of some developers however, that what is glaringly evident on photographs may be relatively inconspicuous on the ground.

Intensely increased runoff and sediment damage can be anticipated from areas subject to injurious logging practices or land development. New housing developments in rolling countryside contribute vast amounts of sediment during the construction stage and greatly increased runoff thereafter, as many a suburban dweller has learned to his sorrow. Study of socio-economic indicators is perhaps best facilitated by examination of photos spanning as long a time period as possible.

SUMMARY

In the foregoing analysis I have endeavoured to show, among other things, the importance of certain specific flood susceptibility indicators, and indicator classes, but did not attempt to place priorities on them. This is not as easy as one would no doubt tend to imagine, because priorities tend to differ considerably with respect to desired objectives. If for instance one is concerned with a macro view, then one would probably be inclined in the initial stages of the inquiry to focus primarily on the meteorologic and physiographic indicators. On the other hand, if one's purpose is to examine in detail a relatively small area, then one, while not ignoring the previously named indicator classes, would be prone to place the greatest emphasis on the topographic and socio-economic indicators. However, this priority rating does not pretend to have universal applicability especially when it is recalled that flood susceptibility indicators have varying significance and import in various cultural, climatic and geographic regions of the world. For this reason it must be emphasize that meaningful analysis and interpretation must be based on the most appropriate combination of indicators that are dictated by the problem.

In sum, this paper has attempted to illustrate various ways in which airphoto analysis and interpretation can be profitably applied to flood-plain studies and by implication to watershed studies. I have shown at some length that airphoto interpretation is all-embracing in the sense that in its presentation of a comprehensive view of say a flood plain, it must perforce draw heavily on factors which fall within the purview of most disciplines in the natural and social sciences. One of the implications of this fact is that adequate studies of flood plains and watersheds are interdisciplinary activities, and airphoto analysis provides an integrative role based on a fairly comprehensive view of the region as a whole.

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Cover photograph courtesy of Lockwood Survey Corporation, Limited, Toronto, Canada; aerial view of receding flood waters on the Humber River, Toronto, Canada, October 16, 1954, following passage of Hurricane Hazel.

BIBLIOGRAPHY

1. Anonymous. "Deluge and Havoc in the Northwest". Life. Vol. 58, No. 1. 1965. pp. 20-28.

2. Belcher, Donald J. "Microforms and Features". Photogrammetric Engineering. Vol. 30, No. 6, 1959. pp. 773-778.

3. Burton, Ian. Types of Agricultural Occupance of Flood Plains in the United States. Chicago, Illinois, Dept. of Geography, University of Chicago, 1962. 167 pp.

4. Colwell, Robt. N. (Ed.). Manual of Photographic Interpretation Washington, D. C., American Society of Photogrammetry. 1960. 868 pp.

5. Howe, Robt. L. "The Application of Aerial Photographic Interpretation to the Investigation of Hydrologic Problems". Photogrammetric Engineering. Vol. 26, No. 1. 1960. pp. 85-95

6. Hoyt, Wm. G. and W.B. Langbein. Floods. Princeton, New Jersey, Princeton University Press. 1955. 469 pp.

7. Liang, Ta and Donald J. Belcher. "Airphoto Interpretation". Landslides and Engineering Practice, Highway Research Board Special Report 29. 1958. pp. 69-92.

8. Leopold, L.B., M.G. Wolman, and J.P. Miller. Fluvial Processes in Geomorphology. San Francisco, Cal., Freeman and Co. 1964. 522 pp.

9. Mollard, J.D. "Photo Analysis and Interpretation in Engineering - Geology Investigations: A Review". Reviews in Engineering Geology. Vol. 2. 1962. pp. 105-127.

10. Nakano, T., M. Ohya and T. Kanukubo. "Landform Classification for Flood Prevention Using Aerial Photographs". Transactions of the Symposium on Photo Interpretation, International Archives of Photogrammetry. Vol. 14. 1962. pp. 447-452.

11. Sewell, W.R. Derrick. Water Management and Floods in the Fraser River Basin. Chicago, Illinois, Dept. of Geography, University of Chicago. 1965. 163 pp.

12. White, Gilbert F. et al. Changes in Urban Occupance of Flood Plains in the United States. Chicago, Illinois, Dept. of Geography, University of Chicago. 1958. 256 pp.

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