PROCEDURES AND REQUIREMENTS

FOR

FLOOD HAZARD EVALUATION

Minnesota Department of Natural Resources

Division of Waters

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INTRODUCTION

Minnesota's flood-plain management standards and the provisions of ~~the~~ flood-plain zoning ordinamces being ~~beigh~~ adopted by counties, cities and villages require definition of the flood-plain boundary and determination of the effects of flood-plain encroachment. Regulations pertaining to the management and use of flood-prone areas are contained in "Statewide Standards and Criteria for Management of Flood-Plain Areas of Minnesota". 1/

Areas subject to regulatory controls are those that would be inundated upon occurrence of the regional (100-year) flood. These areas are defined by the water surface profile resulting from the regional flood discharge. The allowable extent of flood-plain development depends upon the degree of encroachment introduced and its ~~the~~ effect ~~of the encroachment~~ upon the regional flood profile.

Planning and implementation of a flood-plain management program requires reliable technical data to (1) define flood-plain limits, (2) determine flood protection elevations, and (3) evaluate the increases in the regional flood profile that will result from proposed development of flood-plain areas.

1/ Available from Documents Section, Department of Administration, 140 Centennial Building, St. Paul, Minnesota 55101.

The best method to determine regional flood elevations and to evaluate the effects of encroachment on the flood plain is to conduct an engineering study wherein a mathematical computer model is developed to calculate water-surface profiles for the riverine area under study. Using such a model the digital computer can calculate flood elevations for natural valley conditions. The model can then be adjusted to reflect various degrees of encroachment and will compute the increase in the 100-year flood elevations that may result from such proposed constrictions of the flood plain. A detailed engineering study requires a hydrologic analysis to provide the 100-year flood discharges for the river reach under study and detailed surveys that define valley flow areas and obstructions affecting flow conditions.

Where detailed engineering studies have not been completed, technical approximations may be employed to assure that flood plain uses are reasonably compatible with flood plain management standards. It is not always practical or possible to perform detailed water surface profile calculations for evaluation of flood plain development proposals. In many cases the cost of such a detailed engineering study could exceed the cost of the propsed development.

A normal depth or uniform flow analysis provides an approximate determination of flood stages and the effects of a proposed encroachmant utilizing a minimal amount of data. Such analysis are normally acceptable only for isolated case by case studies.

Purpose and Scope

This report is designed to present general guidelines for hydrologic analysis, to provide information relating to input data requirements and its acquisition for various types of flood plain studies, and to establish standardized criteria for floodway analysis. These guidelines are based upon the necessity of precisely defining flood hazard areas and accurately evaluating the effects of future flood plain development in urbanized or developing areas. No attempt is made to discuss all the technical aspects of a detailed engineering study as it is presumed that such studies will be performed by adequately trained technical personnel; however, there are certain judgmental factors involved and it is the intent to establish guidelines to ensure study results in accord with the standards established by the Minnesota Department of Natural Resources.

Previous Reports

Although previous documents released by the Department of Natural Resources have dealt with much of the information contained in this report, experience has indicated a need for additions, revisions, expansion of some items, and consolidation of the material into one report.

Previous informational releases are as follows:

(1) Technical Report 1-Field Surveys for Flood Hazard Evaluation, 1971.

(2) Technical Report 2-Normal Depth Analysis, 1971.

(3) Informal release-Proceedures for Flood Plain Delineation, 1972.

(4) Informal release-Technical Proceedures for Floodway Analysis, 1976.

Documents listed above are superseded by this report.

HYDROLOGY

The hydrologic analysis (determination of flow estimates for the required flood frequencies) is one of the more significant steps of any flood-plain study. Exertion of considerable effort in an engineering study by performing detailed field surveys for stream cross sections, making careful evaluation of retardance factors, and conducting sophistocated step-backwater calculations will not produce acceptable results if the hydrology is subject to significant change. Since hydrology is of paramount importance, proper emphasis should be placed on this aspect of any flood hazard evaluation.

The determination of flow estimates for the regional (100-year) flood have probably been subject to greater variation, owing to different methods of analysis, than discharge estimates for the more frequent floods as the 10-year or 25-year floods. Unfortunately the 100-year flood, being the regulatory flood, is the most critical. In the statistical analysis of existing streamflow records, the greatest variation between analysts was generally associated with frequency interpretations of short term systematic records, particularly those affected by unusual climactic conditions. Analyses requiring extension of frequency estimates to recurrence intervals several times beyond the documented period of record, could result in widely divergent flow estimates of the 100-year flood owing to different statistical methods of analysis and the handling of unusual annual flood events, such as those caused by severe drought or extreme floods. In more recent years, through efforts of the U.S. Water Resources

Council, guidelines have been developed to provide a greater degree of standardization for statistical analysis of existing streamflow records for natural flow streams. 2/ This should result in more uniformity between frequency analyses made by various governmental agencies and private consultants. Increasing length of available streamflow records should also contribute to a better determination of streamflow characteristics.

Unfortunately, no uniform methods have yet been developed for flow-frequency analysis where streamflow records are unavailable at or reasonably near the site undergoing study. As a result, the hydrologist still must make judgmental decisions in deriving regional flood-discharge estimates for many flood hazard studies.

Consistency of regional flood discharges between adjoining reaches of a stream is of prime importance. Many flood-plain studies have already been completed in Minnesota, particularly along the major streams. Consequently, 100-year flood discharges are already available for those areas. In commencing a new flood-plain study, the Department of Natural Resources should be consulted as to the availability of such data to ensure the flood-flow estimates for the new study will be compatible with those used in existing studies for adjoining areas.

2/ Guidelines for Determining Flood Flow Frequency, Bulletin 17A, U.S. Water Resources Council, 1977.

Flood-frequency estimates for new studies should be submitted to the Department of Natural Resources for approval, including documentation of methodology and significant parameters used in the analysis. Under an inter-agency agreement, the hydrologic analysis will be reviewed by the U.S. Army Corps of Engineers, U.S. Geological Survey, Soil Conservation Service and the Department of Natural Resources. The contractor performing the flood-plain study will then be notified of approval or of recommended revisions if the discharge estimates are found unacceptable.

Gaged Areas

Water Resources Council Bulletin 17A documents the recommended procedures for flow-frequency analysis based on systematic streamflow records. The method involves fitting a log-Pearson Type III frequency distribution to observed annual peak discharges. Log-Pearson Type III frequency analysis have been in use for some time; however, as noted previously, statistical interpretations have in the past often varied considerably, particularly in the case of short term records. This was primarily due to the fact that the skew coefficient (one of the three parameters involved in a log-Pearson analysis) is sensitive to extreme events. The shorter the record, the more pronounced is the effect and the arbitrary deletion of extreme values or the application of non-uniform adjustments could lead to considerable variation in flow estimates depending on the hydrologists judgment. Research conducted by the U.S. Water Resources Council resulted in the conclusion that generalized values of the skew coefficient, derived from studies of long-term records, would be more reliable for the analysis of short term records than the computed station skew. Bulletin 17A guidelines therefore recommend that regionalized values for the skew coefficient should be used in the log-Pearson analysis where less than 25 years of record are available, a weighted skew should be used when the length of record is between 25 and 100 years, and the computed station skew used when the station record is 100 years or longer. The guidelines also provide for the elimination of low outliers based on a standard test and a recommended the treatment of historic floods (documented floods of large magnitude) which occured during or outside the period of systematic record collection.

The generalized skew coefficients of logarithms furnished with Bulletin 17A were derived from a nationwide study and may not reflect the best interpretation of localized regional conditions. Local studies to develope generalized skew coefficients on a regional or statewide basis are encouraged by the Water Resource Council Guidelines. This would be desirable for Minnesota in that greater refinement of generalized skew values may be possible by more detailed analysis of local factors influencing the computed skew coefficients. A preliminary study of data generated by the U.S. Geological Survey for a statewide flood-frequency report indicates several basin parameters that should be evaluated in the derivation of generalized skew coefficients. Considering only those systematic records having 25 or more years of available data, it would appear that natural storage in upstream lakes, ponds and swamps tends to generate larger negative values of the skewness coefficient. Downstream storage areas located immediately above the data collection site, evidenced by abnormally wide flood plains in relation to the stream channel, generally tend to have the same effect. Such conditions are most prevalent in southeastern Minnesota where streams in the upland areas are deeply incised and have steep slopes tending to flatten in the low lands where the valleys become very broad. In such instances, generalized values of the skew coefficient based on statistical analysis of gaging station records collected in the lowland areas may not be representative of the skew parameters applicable to upland regions in the same basin.

Flow Frequency analyses based on the guidelines recommended in Bulletin 17A, or any subsequent revision thereof, should provide a greater degree of uniformity and more acceptance as to reliability for the situations where systematic records of streamflow are available. Log-Pearson Type III frequency analysis, conducted according to Bulletin 17A guidelines, are available for most streamflow data collection sites in Minnesota from the U.S. Geological Survey, St. Paul, Minnesota. Analyses at many selected sites are also available from the U.S. Army Corps of Engineers, St. Paul, Minnesota.

It should be emphasized that the procedures outlined in Bulletin 17A apply only to natural flow conditions (streams unaffected by artificial regulation). If a streamflow record reflects partly natural flow conditions and partly regulated conditions, special treatment would be required for the hydrologic study. Either the observed record would have to be adjusted to a common flow condition or an entirely different methodology would have to be employed for the hydrologic analysis. There may be situations where all the available streamflow records were collected under natural flow conditions, but recently constructed or planned reservoirs could have significant impact on the flow regimen. In such instances, reservoir routing and operating plans should normally be available for use in the flow-frequency study. Some reserviors, even those constructed for flood control, may have relatively small storage capacities that will diminish the more frequent flood flows but may have no significant effect on major events as the regional flood. Under these circumstances, a log-Pearson analysis might be valid for determination of the 100-year flood with adjustments based on reservoir operations being made for the more frequent floods.

Progressive urbanization is another factor that should be carefully considered in the statistical analysis of existing streamflow records, particularly ~~ofr~~ for basins having drainage areas of less than 100 Square miles. There may be instances where streamflow records have been collected in the past under rural or natural conditions, However, urbanization during more recent years could have caused substantial changes in the flood characteristics of the basin. Under these conditions a change in methodology from that outlined in Bulletin 17A Would be required.

Flood-plain studies for which streamflow records are available at the site under consideration are the exception rather than the rule. However, it is possible to transfer flood characteristics defined by hydrologic analysis ~~at~~ for a gaged site (where streamflow records are available) for some distance in either an upstream or downstream direction. Such transfers are made on the basis of drainage area ratios raised to an exponential power. The method os outlined in the U.S. Geological Survey Report, "Techniques for Estimating Magnitude and Frequency of Floods in Minnesota". 3/ It is suggested that use of the transfer relation be limited to sites differing in drainage area size by no more than 40 percent from the gaged site. There are exceptions, to the normally approved range for application of the transfer relation. These are situations exemplified by the Rum River Basin where large flood-plain storage areas (large in comparison to the rest of the basin) exist upstream from the streamflow data collection site.

3/ Techniques for Estimating Magnitude and Frequency of Floods in Minnesota, Water Resources Investigations 77-31, U.S. Geological Survey, St. Paul, Minnesota. May 1977.

In this instance flood flows upstream from the storage areas are greater than those recorded downstream at the gaged site. Under such conditions the 100-year flood estimates would decrease according to the transfer relation in an upstream direction only to the lower limit of the stroage area. Upstream of the storage area, the 100-year flow estimate would show an increase and then gradually decrease again upstream in relation to drainage area size. In the example ~~cited~~ above, 100-year flood estimates in ~~the~~ central Isanti County (above the storage areas cited) would be greater than those computed downstream at the gaging station site in central Anoka County. Under these conditions, a correction for storage would be required in applying the transfer relation or a different methodology would have to be employed for the hydrologic analysis. If the situation is reversed so that the unusually large flood-plain storage areas exist downstream of the gaged site and upstream from area under study, a statistical analysis of the streamflow records ~~can be~~ made according to the Bulletin 17A guidelines ~~which~~ and can then be adjusted by routing procedures so as to apply to the site under consideration.

Ungaged Areas

Flood-plain studies conducted in ungaged water sheds pose a special problem in hydrologic analysis. Flow-frequency estimates for these areas may be subject to wide variation depending on the analyical methods employed and the interpretation of judgmental factors involved in the application of some theoretical methods.

In Minnesota, major floods in the larger river basins usually result from snowmelt or from a combination of rainfall and snowmelt. Severe rainstorms capable of producing high rates of runoff are not likely to have sufficient areal coverage to produce floods of great magnitude in the bigger basins; however, a winter's accumulation of snow having a high amount of water content over a large area, which if triggered by rapid melting and/or rainfall, can produce disasterous floods in these basins.

In the smaller watersheds, particularly in the range below about 50 square miles, the situation is reversed. Intense rainstorms are more likely to produce the more severe floods in these small basins where the storm may cover all or most of the drainage area. Snowmelt, on the other hand, may produce significant volumes of runoff but the runoff rate is slower and local obstructions may cause temporary ponding tending to extend the runoff period and diminish peak flows.

Rainfall runoff models, sometimes coupled with snowmelt variations, are frequently used for the hydrologic analysis of ungaged areas. In addition to the complications pertaining to snowmelt and/or rainfall noted previously, there are other factors such as soil types, antecedent conditions, rainfall interception, storage, overland flow rates, storm intensity, and possibly other factors requiring evaluation and judgmental decisions. For example, a 100-year rainstorm, occuring over a given period of time, (itself subject to interpretation) could produce peak flood flows having a wide range in recurrence interval depending on antecedent conditions or the pattern of storm intensity. Rainfall on frozen or saturated ground will produce substantially higher peak flows than the same precipitation occuring on unfrozen dry soil. Also storms having a high degree of intensity in the earlier stages of the storm will produce different peak flows than those having the greater intensity during the later part of the storm. Therefore, a 100-year rainstorm does not necessarily equate with a 100-year flood. Obviously the use of runoff models requires careful evaluation of basin and storm parameters by experienced hydrologists.

Runoff models are most useful for flow-frequency analysis in small watersheds having drainage areas of less than 20 square miles where homogeneity of basin parameters is more likely. They can be adapted to reflect either urban or rural basin conditions. With increasing size of drainage area, the complexity of variables increases and the reliability of flow estimates tend to decrease. It is recommended that flow-frequency estimates derived from synthetic model studies be compared with those obtained by the use of other methods whenever possible.

Several computerized runoff models developed by governmental agencies or private consulting firms have been used for flood-plain studies conducted in Minnesota. Government agencies having such computer programs are:

St. Paul District, U.S. Army Corps of Engineers,
St. Paul, Minnesota

Soil Conservation Service, U.S. Department of Agriculture.
St. Paul, Minnesota.

Another method for defining the flood characteristics in an ungaged watershed is by use of regionalized flood-frequency equations developed by the U.S. Geological Survey and presented in the report, "Techniques for Estimating Magnitude and Frequency of Floods in Minnesota" (See footnote 3/). Flow-frequency equations are given for eight distinct hydrologic regions which define frequency relations up to the 100-year recurrence interval. These equations were derived by multiple regression analysis of calculated frequency relations at 201 gaging stations having drainage areas ranging in size from less than 0.1 to 5,280 square miles. Variables required for solution of the equations are combinations of drainage area, stream slope and/or basin storage, all of which can be measured from topographic maps. The method applies to all natural flow streams which are not significantly affected by man-made regulations, diversion or urbanization. For main-stem streams crossing regional divides, and which may be affected by regulation, graphs are provided showing floods of selected frequency plotted against drainage area. Flow-frequency estimates for intervening sites along the Minnesota River, Mississippi River, and the Red River of the North can be obtained from these graphs.

Although the regional flow-frequency equations apply to any size river basin, with the exception of main stem streams noted above, they are particularly useful in the hydrologic analysis of smaller watersheds having drainage areas of less than a few hundred square miles. Many of the larger river basins have systematic records of streamflow available for which frequency relations can be defined and then transferred to the study site according to the transfer relation given in the report. This is the recommended procedure to be followed whenever possible within the imposed limitations.

As in any method of deriving flood characteristics, the procedures recommended in the above report are subject to error, however, they do have the advantage of providing uniformity along with relative ease in application. It should ~~be also~~ also be recognized that the relations expressed therein were derived from observed flood data which are usually considered a viable basis for predicting future events.

Flood-frequency estimates for ungaged sites can also be obtained from "General Relations" curves based on frequency studies made at two or more gaged sites in the basin. Curves relating floods of selected recurrence intervals to drainage areas for the gaged sites, can be drawn from which flow estimates for intervening ungaged sites can be obtained. Curves should be drawn on logarithmic paper. Figure 1 illustrates the method.

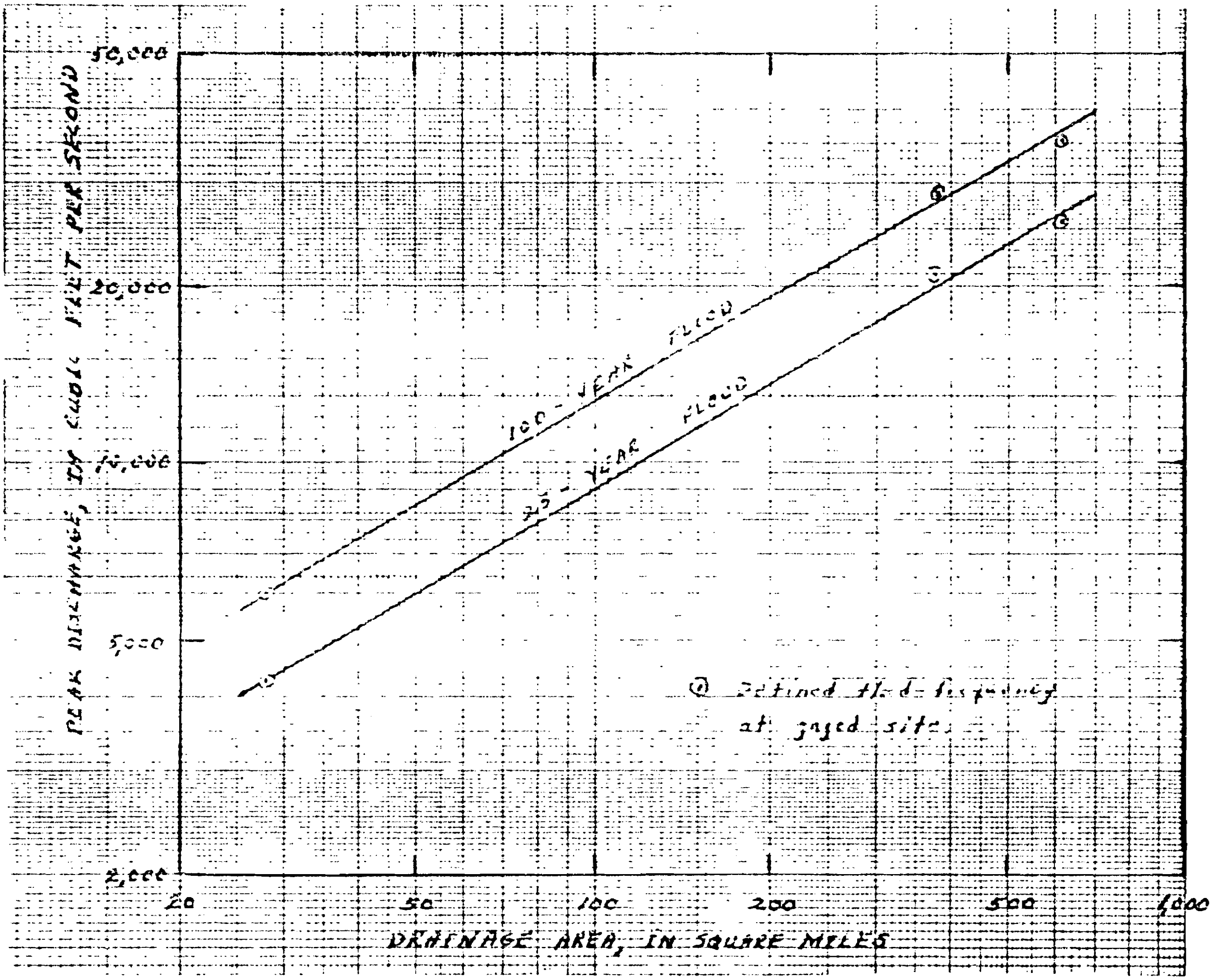

Figure 1. Graph of generalized flood-frequency relations

Extrapolation of the curves should be limited to a 40 percent change in drainage area size from the extreme values. This conforms to the limitation imposed to the transfer of flood frequency characteristics in the U. S. Geological Survey frequency report. The method should be limited to those watersheds which have relatively uniform basin parameters. Significant parameters would be stream slope, storage, and soil type.

FLOOD-PLAIN DELINEATION

In accordance with Minnesota Regulations NR 86(c), the Commissioner of Natural Resources hereby sets forth guidelines to provide uniformity in the technical analysis of flood hazards and the effects of various artificial and natural obstructions on flood flows within flood plain areas of Minnesota. These guidelines are to remain in effect until such time as other standards of nationwide scope and acceptance are developed. Flood hazard evaluation studies currently being performed by various state and federal agencies generally conform to these guidelines.

Engineering Studies

The most reliable method for the definition of flood hazard areas and evaluating the effects of flood-plain encroachment is by development of a digital computer model that expresses in mathematical terms the geometry of the river valley and the roughness coefficients (retardance factors) that control the slope of the water-surface profile. The term "Engineering Study" implies such a procedure.

A. Water-Surface Profile Calculations

Through the use of a digital cumputer, water-surface profiles can be calculated for any desired flood flow magnitude using Bernoulli's equation. 4/

4/ For a technical discussion of this equation refer to a text book on the hydraulics of open-channel flow.

Water-surface profiles for the regional flood are calculated by standard step-backwater methods utilizing accepted engineering principles of open channel hydraulics. The Department of Natural Resources has adopted a digital computer program HEC-2 (number 22-J2-L232) developed by the U. S. Army Corps of Engineers, Hydrologic Engineer Center, for this purpose. This program is available for use by agencies or consultants performing flood plain delination studies in Minnesota.

The calculations start at a given location along a stream and proceed upstream in segments determined by the location of cross-sectional data. Each segment or reach of a stream is represented by a cross section. The assumption is made that the cross section is typical of field conditions half way between the previous section and the next section upstream. The water-surface elevation at each cross-section location is then calculated. A profile of the water surface may be developed by plotting and connecting the computed points. Figure 2 illustrates some of the above concepts.

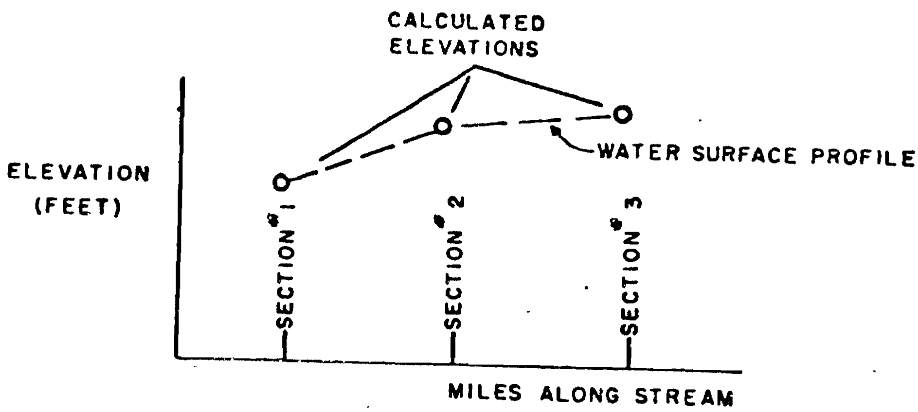

Figure 2. Sample profile.

B. Surveys and Data Requirements

1. Selection of Cross Sections

There are many engineering judgments and field considerations that enter into the selection of ~~the~~ locations where survey data should be acquired. The location of the cross-section should be at those points where: (1) there are changes in the cross-sectional area of the flood plain, (2) the retardance to flood flows change (i.e.. changes in vegetation cover, natural and man-made obstructions, etc.) (3) changes in the slope of the stream bed or water surface occur, (4) at man-made restrictions such as bridges, roadgrades, filling, or other flood plain encroachments, and (5) at regular intervals along the stream ~~reaches of streams~~ where none of the above factors occur.

Since the surveyed cross-section indicates the area through which flood waters will flow, the cross sections should be located at approximately right angles to the direction of flow. Again, for the same reasoning, cross sections should not be taken at areas which are not effective in conveying flows such as bays or inlets where the water is not flowing but is in storage during the flood peak. See figure 3 for an illustration of some considerations in selection of cross section locations.

Note: we use straight sections in illustration so as not to emphasize broken section alignments.

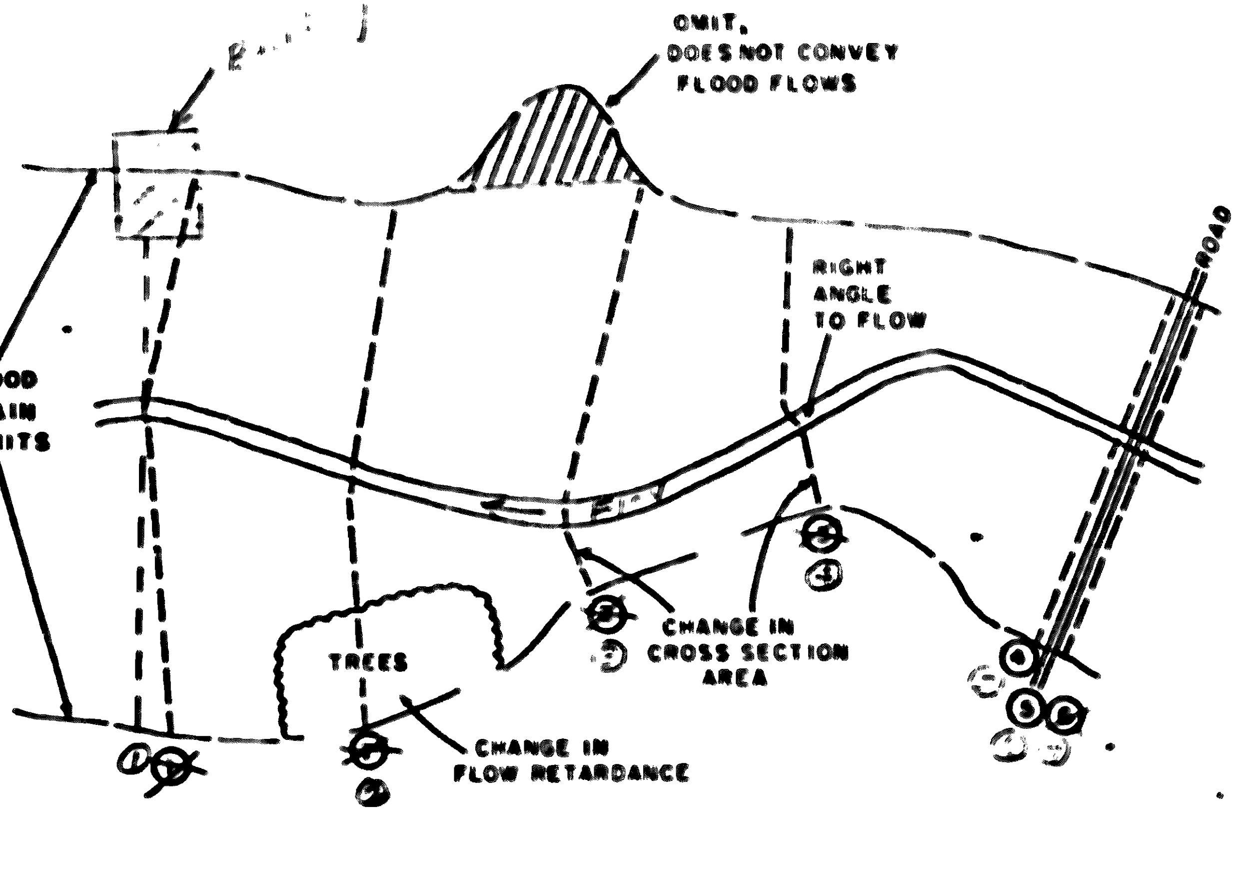

Figure 3. Location of cross sections.

2. Spacing of cross Setions

The spacing between cross sections, which determines reach lengths in computer calculations, will vary in accorance with the above criteria and whether the study is for a rural or urban area.

In urban areas or in any area where flood-plain development is occurring, it is desiracle to achieve greater accuracy in the calculated profile to allow for a more precise flood-plain delineation, and to provide a more accurate means for evaluating the effects of future flood-plain encroachments. Distances between consecutive cross sections for uniform valley conditions generally should not exceed 1½ times the average width of the cross sections, but should fall within the following limits:

a. Stream slope less than 3 feet per mile - maximum spacing 1,800 feet

b. Stream slope greater than 3 feet per mile - maximum spacing 1,200 feet.

Where the cross sectional width exceeds one mile with a stream slope of less than 2 feet per mile, the maximum spacing for uniform conditions should not exceed one-half mile.

NOTE: All measurements are vally miles.

If there are unusual conditions that are not covered by these guidelines or which require deviations therefrom, the contractor performing the study should consult with the Department of Natural Resources.

In rural areas not under-going development, equivalent accuracy is not needed and greater spacing of cross sections is reasonable. Distance between cross-section locations for uniform valley conditions generally should not exceed twice the average width of the cross sections but should fall within the following limits:

a. Stream slopes less than 3 feet per mile - maximum spacing 3,000 feet.

b. Stream slopes greater than 3 feet per mile - maximum spacing 1,800 feet.

Where the cross-sectional width exceeds one mile with a stream slope of less than 2 feet per mile the maximum spacing for uniform conditions should not exceed 4,000 feet.

NOTE: All measurements are valley miles.

Unusual situations requiring deviation from these guidelines should be called to the attention of the Department of Natural Resources.

3. Bridges and Other Controls

Structures such as road grades, bridges, culverts, levees and dams which restrict flood flow and control upstream water-surface elevations ~~upstream~~ have to be surveyed in the field to determine certain geometric factors which are then entered onto the digital computer model. The following information is needed for each bridge or culvert and roadway:

a. Cross sections about 50 feet downstream and 50 feet upstream of the roadway and parallel to it. Care should be taken during the actual field survey that the cross section reflects natural ground conditions and not the fill material for the roadway.

b. A cross section of the waterway opening under the bridge or culvert showing the low portion of the superstructure, bridge abutments, piers and other factors which affect the area and the manner in which flow occurs through the opening.

c. A profile of the top of the roadway together with elevations and descriptions of the bridge railings (e.g. can water pass through the railing)

d. An indication of the type of roadway (two lane, divided, single or dual railroad tracks, etc.)

Figure 4 illustrates some of the above concepts.

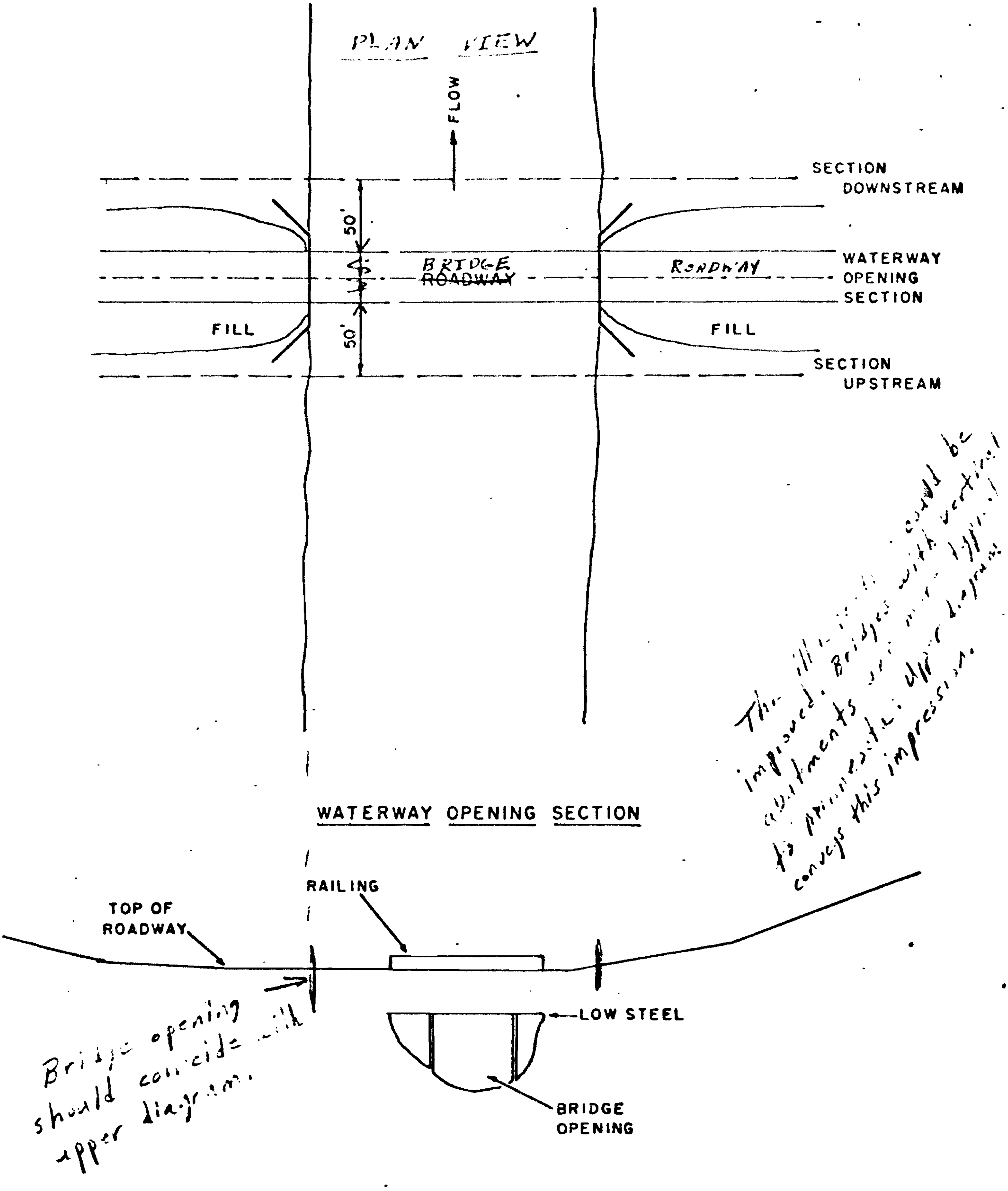

Figure 4. Bridge survey details.

Similar information is required for any dams located in the study area which should include the following:

a. Cross sections located upstream and downstream of dam.

b. Longitudinal profile of fixed crest dams or spillway section of regulatory dams.

c. Cross section of spillway or fixed dam crest.

d. Size and elevation of gate openings and description of gates.

4. Field Survey of Cross Sections

The location of the cross sections should first be designated on accurate topographic maps and/or aerial photographs to define the longitudinal direction of the field surveys. It should be emphasized that the distance between cross sections, which is a critical input value to the digital computer model, will normally be determined from the section layout on the topographic map or aerial photographs. Therefore, it is essential that accurate scaling is possible on whichever medium is used.

An excellent method is to make a preliminary layout of the cross sections on a topographic map and then transfer the locations to large scale ~~areal~~ aerial photographs if they are available. The topographic map provides a good perspective of the general valley alignment which materially aids in properly orienting the sections at right angles to the flow. In many cases, the configuration of the valley flood plain is much less meandering than the stream channel, necessitating broken cross section alignment to maintain the right angle orientation to flow, ~~direction across the entire flow area.~~ Such conditions are less obvious from ground inspection at the field survey site. The cross section locations should then be transferred to large scale aerial photographs, whenever available, for use in the field to identify sections locations. Aerial photographs permit refinement of cross section lines based on vegetative cover or other obstructions not apparent on the topographic maps and provide more positive identification of the section alignment in the field.

Outer extremities of the cross sections can be designated by establishment of a minimum elevation for the terminating point of each section or by geographic location on the map or aerial photograph. Minimum elevations can be designated in terms of mean sea level, distance above stream bed, or distance above existing water surface. Particularly in the case of cross sectional layout on aerial photographs, a prescribed minimum elevation to define the lateral extent of the cross sections is the most reliable. Extreme care should br taken to assure that the lateral survey limits cover all the area that could be inundated by flood waters.

Field inspection may on occasion require re-orientation of cross-section alignment, however, such cases are rare in that the ground perspective is severly limited when considering the broad expanse of the total flood plain.

In the field, the location where the cross-section is to be surveyed can be determined by visual observation through reference to identifiable points on the map or areial photograph. Where accurate maps are not available the location of ~~survey~~ cross sections may have to be determined by surveys.

The elevation of ground points should be determined along the survey line at all major breaks in gound slope and at reasonable intervals based on the length of the survey line. It is important to remember that a cross section should represent or be typical of the flow area halfway between two consecutive sections. Therefore, local irregularities in the ground surface, such as depressions or rises that are not representative of the reach should be eliminated in the field survey. This is also true of embayments or inlets to the flood plain which may be inundated by the 100-year flood but are not effective in carrying flood flows.

The survey chief should exercise judgment in acquiring the survey data. Where site distances would be considerably improved by slightly shifting the survey line, such practice is encouraged to reduce survey costs. Then too, the survey line may need to be changed under unusual situations to more accurately reflect field conditions. Whenever the location or alignment of the survey line is changed it should be indicated on the map or photo and submitted with the survey data.

An Alternative to field surveys for obtaining cross section data is the use of photogrammetric compilation. The method is discussed in a later section of this report.

Stadia accuracy is adequate for all cross section surveys with horizontal distances being read to the nearest foot and vertical elevations being read to the nearest one-tenth foot. Longitudinal distances of the cross sections defined by field survey should be compared to those scaled from topographic maps or aerial photographs to eliminate gross errors.

Field surveys should be made in mean sea level datum whenever possible, ~~and~~ which should be carefully documentd as to origin. In Minnesota, two different sea level datums have been in general use: (1) general adjustment of 1912, and (2) datum of 1929. Of the two, the datum of 1929 is now the most generally accepted and is used in the preparation of topographic maps published by the U. S. Geological Survey. Variations betweed the two datums can exceed one foot, depending upon the area of consideration, therefore, explicit documentation of the datum used is required.

If mean sea level datum cannot be established, which is a rare occurrence in Minnesota, a common datum must be utilized which can later be translated into sea level datum by a uniform conversion factor.

Bench marks of a semi-permanent nature should be established at intervals throughout the flood-plain area in connection with the field surveys. Bench marks should have accuracy standards associated with ordinary differential leveling requirements. (Elevations furnished to accuracies of 0.01 foot). A description of the location and the elevation of all bench marks should be made part of the final flood-plain study.

5. <u>Use of Available Detailed Topographic Maps</u>

Where detailed topographic maps are available (usually 2 foot contour intervals and map scale of up to 1 inch = 200 feet for urban areas; 5 foot contour intervals and up to 1 inch = 500 feet for rural areas) the the overbank portion of the cross section can be obtained by scaling the distances to the contour lines. Use of 5 - foot contour interval maps should be limited to those situations where no more than 30 percent of the total regional flood flow occurs in the overbank areas.

Since topographic maps usually do not provide sufficient detail on the channel portion of the section and do not show stream bed elevations, the channel portion of the cross section normally requires field surveys. If the percentage of flow carried by the channel is very small compared to the percentage of flow carried by the overbanks, a hand level may be used to obtain the channel portion of the cross section. This is illustrated in Figure 5.

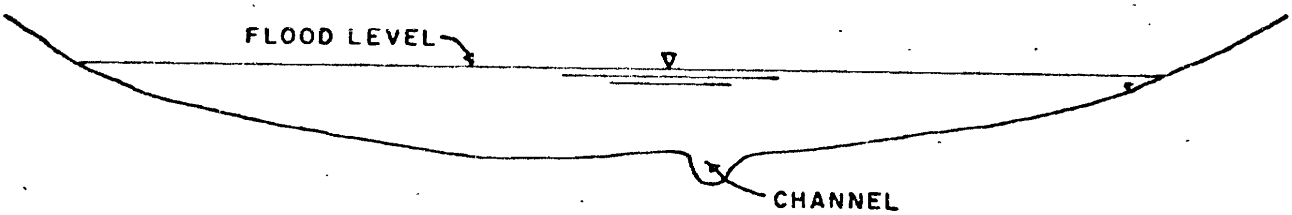

Figure 5. View of Cross Section

It is important to properly tie the cross-section data acquired from detailed topographic maps, or photogrammetric compilations, to the surveyed channel data. Therefore, the channel information obtained in the field should include a point at least 50 feet on each side of the channel as shown in Figure 6. The overlap areas on each bank will provide the means for accurately fitting the channel and overbank portions of the section together.

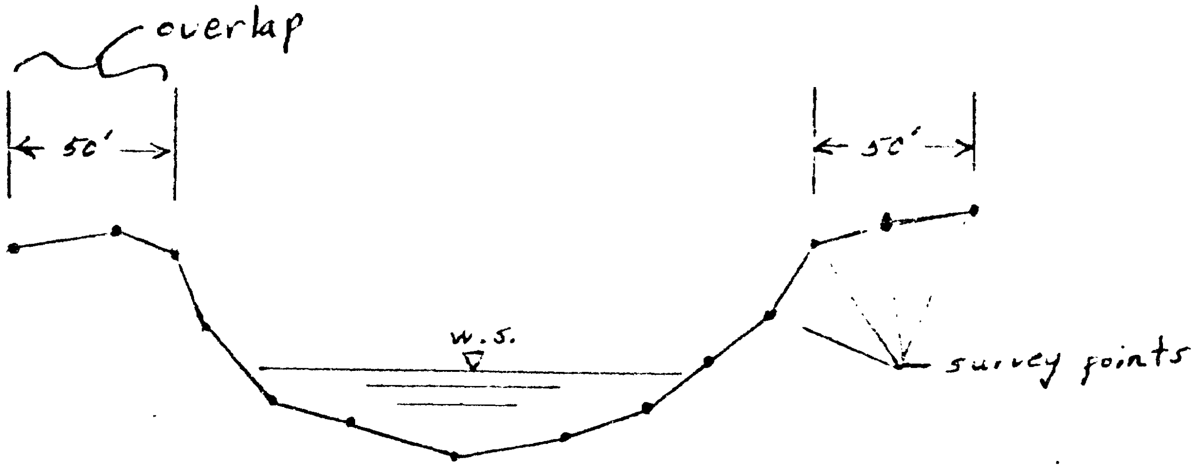

Figure 6. Channel section survey tie to overbank section.

6. Plotting of Survey Data

The survey information should be plotted so that it may be interpolated to the nearest 0.1 foot vertically and to the nearest foot horizontally. On 10 x10 division to the inch graph paper the smallest scale that should be used to meet the above criteria is: vertically 1 inch = 5 feet; horizontally 1 inch = 50 feet. However, for very long survey lines, such as 1,000 feet or more, a smaller horizontal scale may be practical.

7. Selection of Retardance Factors

Retardance factors ("n" values in the Manning formula) are very critical to the computation of cross section conveyance (flow-carrying capability). For this reason, "n" values should be carefully selected in the field, preferably by on-site inspection conducted by two experienced hydrologists. Notations made during the field survey of cross sections as to the stationing where vegetative cover changes occur, or other obstructions exist, are extremely helpful in determining the lateral limits for assigned "n" values. It is extremely difficult to define the areal extent of different "n" values in broad flood plains where ground observation is limited to a small percentage of the total area. Aerial photographs showing the cross section locations are probably the best method to locate where "n" values should change under these conditions.

C. Delineation of Flood-Plain Outlines

Flood-plain outlines in urban or developing areas should be delineated upon either detailed topographic maps having a 2-foot or lesser contour interval and a horizontal scale of no more than 500 feet per inch; or on aerial mosaics, orthophotos, or suitable street maps not exceeding this horizontal scale.

In rural areas, delineation of the flood plain may be based upon either detailed topographic maps having a 5 - foot or lesser contour interval and a horizontal scale not exceeding 1,000 feet per inch, or by aerial mosaics or orthophotos not exceeding this horizontal scale.

Flood-plain delineation on aerial mosaics or existing street maps will require field surveys to substantiate the outline.

Accurate flood-plain outlines can be obtained by photogrammetric compilation. This is most practical when the cross section data are obtained by photogrammetric methods. A section devoted to photogrammetric compilation contained in a later section of this report will provide more details.

Approximate Methods for Flood-Plain Definition

In rural areas not presently undergoing development, less precise methods may be used to define flood-hazard areas. These involve the use of historic flood data, soil maps, or aerial photographs of experienced floods, which may be utilized either singly or in combination, depending on the availability and applicability of the data. When using historic flood data or aerial photos of experienced floods, a hydrologic analysis to determine the regional flood elevation at some point in or near the study area would be required to provide a basis for adjusting the available data to regional flood conditions. (See "Hydrology" section of this report),

A. Historical Flood Data

High-water marks, defining a profile of an experienced flood, can be used to establish regional flood elevations by an adjustment based on the difference between the estimated 100-year flood elevation (determined by hydrologic analysis) and the observed high-water mark at a site in or near the study area.

Where flat (2-3 feet per mile) uniform slopes occur, flood marks should be available at approximately 2-3 mile intervals along the stream. For other stream slopes the spacing of available flood marks will be evaluated consistent with the slope. Where man-made or natural constrictions occur, high water mark spacing should not exceed one-half mile. When historic flood data are used to develop a regional flood profile, the elevation of the historic flood at any location should generally not be more than 2 or 3 feet from the estimated elevation of the regional flood at that location. Delineation of the flood-plain areas using historic flood data should conform to the requirements for rural areas outlined above in Section C under "Engineering Studies" whenever possible. In the event that the more detailed topographic maps referred to above are not available, flood-plain outlines should be made on U. S. Geological Survey topographic maps having no greater contour interval than 10 feet and a horizontal scale of no more than 2,000 feet per inch.

B. Soil Maps

Detailed soil maps may be used to define flood hazard areas for mature landscapes with streams well incised in deep valleys. Such conditions generally occur in the southeastern area of Minnesota. Use of soil maps in other areas of the state will be accepted only after investigations are made to determine the correlation between soil mapping and engineering studies. All flood-plain delineations using soil maps must be reviewed and approved by the State Soil Scientist, Soil Conservation Service, U. S. Department of Agriculture, before acceptance by the Department of Natural Resources.

C. Aerial Photographs

Aerial photographs suitable for defining the horizontal extent of experienced floods are very rare. Seldom is the aerial photography obtained at the time of the flood peak so that the maximum degree of inundation is not pictured. It is also necessary for the peak stage of the experienced flood to be close to the elevation associated with the regional flood if the aerial photography is to be used for delineation of the flood plain. This required combination of circumstances seldom occurs. Aerial photography obtained under less than the idealized conditions noted above may still be very useful in conjuction with other methods of flood-plain delineation.

ENCROACHMENT EVALUATION

As outlined in Minnesota Regulations NR 87 (d), "Statewide Standards and Criteria for Management of Flood Plain Areas of Minnesota", floodway limit (for maximum encroachment) shall be determined by using an equal (uniform) degree of encroachment method (also called "equal degree of conveyance reduction" or "engineered floodway" in this report). The regulations also state the following:

> "The limits of the floodway shall be designated so that permissible encroachments on the flood plain will not cause an increase in stage of the regional flood (100-year) of more than 0.5 feet in any one reach or for the cumulative effect of several reaches of a watercourse."

The principle of equal encroachment ensures that lost flow carrying capacity on one side of the flood plain, owing to maximum permitted development, cannot exceed possible lost capacity on the other bank where such capacity is available. This applies whether the option to allow development is exercised or not, by one community, when different communities are situated on opposite sides of the stream. Governmental units having zoning jurisdiction (cities or counties) may be more restrictive in the development of flood-plain areas by designating wider floodways than the minimum prescribed by State Regulations, in which case the degree of encroachment need not be equal on both sides of the stream.

The regulations NR 87 (e) also provide for establishing flood protection elevations which shall correspond to a point not less than one foot above the water-surface profile associated with the regional flood plus any increases in flood stages attributable to permitted encroachments on the flood plain. The one foot increase should be measured from the final floodway profile as determined by the guidlines which follow.

Technical Procedures for Floodway Analyses

Development of floodways based on equal degree of encroachment, or analysis of designated floodways for compliance with State Standards, may sound simple enough; however, many complex situations may arise. Some examples are starting elevations for the floodway analysis, split jurisdiction of the floodway between two different communities on opposite sides of the river, protection of a communities rights for future revision of designated floodways, and the cumulative effects of flood-plain encroachment which must be considered in subsequent studies of upstream areas. The following guidlines give detailed analytical procedures for the more complex situations, and provide for the application of uniform standards in the evaluation of floodways as required by the Minnesota regulations for flood-plain management.

Regulations permit a 0.5 foot increase in the regional flood elevation (0.2 foot if the community occupies only one side of the flood plain) owing to encroachment, but frequently communities opt to designate more restrictive floodways which develop less than the prescribed maximum increase. The regulations also empower the Commissioner to limit the increase in the regional flood elevation to less than 0.5 foot where substantial amounts of damage could occur. ~~This does not prevent the community~~ A community is not prevented from revising it's floodways at some future date providing that the standards for maximum increases in the regional flood elevation are not exceeded. The increase in the regional flood elevations is always measured from the existing conditions found in the initial engineering study, not from the adjusted elevations defined from previously designated floodways. Adherence to the guidlines will protect a communities future rights for these situations.

The following basic rules will provide assistance in understanding and using the floodway analytical procedures which follow.

1. Check for adopted floodways upstream, downstream, and across the stream from the area to be studied. Available data from existing floodway analyses for adjacent areas is essential to implementation of these guidlines. Transitions between floodway alignment for adjacent communities upstream and downstream should be as smooth as is practical under exising conditions.

2. The natural floodway elevation is the same as the 100-year (regional) flood elevation for existing conditions. The natural floodway is determined by eliminating any ineffective flow areas at the ends of each cross section. It is this elevation from which increases in the regional flood caused by encroachments on the flood plain are measured. Surcharge as used herein means the increase in elevation above the regional flood level associated with the effect of floodways.

3. Deviations slightly above a 0.5 foot (or 0.2 foot if appli-

cable) increase may be allowable on a case by case basis if approved by the Commissioner. However, the 0.5 foot increase must not be exceeded at the upstream corporate limit of each community.

4. In the case of two cities across the river from each other, the total allowable increase, as in all cases, is 0.5 foot. However, due to various methods of calculation, the allowable increase attributable to either city's individual encroachment must not exceed 0.20 foot. This will assure that the combined effect of both cities encroachments will not cause increases greater than 0.5 foot.

5. The procedures have been developed in such a manner that a city can exercise the following options:

   a. Less than maximum encroachment may be designated at present, but in the future the city can request its maximum allowable encroachment (with one exception as stated in (b) below).

   b. Excessive encroachment (beyond the limits of an engineered floodway) that would otherwise exceed state standards may be found to be acceptable (i.e. all total increases will still remain less than or equal to 0.5') if a sufficient "compensating effect" is realized upstream and/or downstream. This can be done by designating floodway limits upstream and/or downstream that are sufficiently less restrictive to flood flows than the limits determined by the equal degree of conveyance reduction (engineered) method. However, once this option is exercised, the city cannot at a later date request that option (a) be applied to these upstream and/or downstream areas, if the cumulative effect would violate State standards.

A. Main-Stem Studies

This section deals with floodway analyses for a single river reach which may involve adjacent upstream and/or downstream communities, and situations where different communitites occupy opposite sides of the river flood plain as illustrated in Figure 7. Tributary streams entering the main stem in a study reach require special treatment which will be dealt with in a subsequent section.

In the following examples, starting elevations are prescribed at the downstream corporate limits of the community under study for designing engineered floodways or evaluating the validity of designated floodways according to State standards; however, a different starting elevation may be required for computing the final floodway profile, depending on the conditions cited.

Note: Whenever a starting elevation based on the natural floodway profile plus 0.5 foot is prescribed, the following exceptions apply: If complete encroachment (to the river bank) in the area downstream from the community under study results

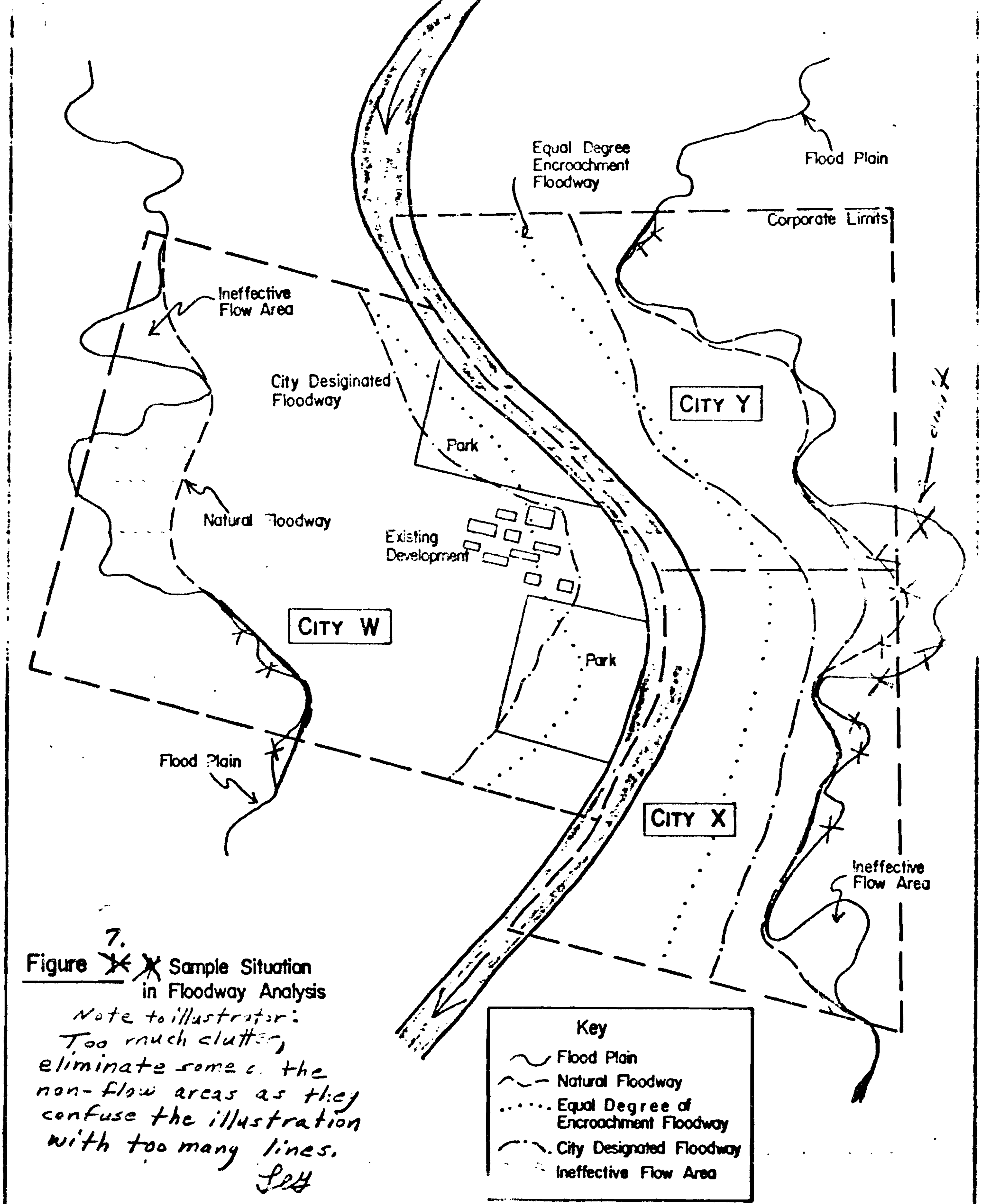

Figure 7. Sample Situation in Floodway Analysis

Note to illustrator: Too much clutter, eliminate some of the non-flow areas as they confuse the illustration with too many lines.
Sey

in an increase less than 0.5 foot, then this actual computed increase is to be used to determine the starting elevation (in lieu of the specified 0.5 foot surcharge). The surcharge used to determine the starting elevation should be based on realistic probabilities and should not exceed the maximum profile increase attainable for existing conditions. If the data necessary for this type of evaluation are not available, then the 0.5 foot surcharge is used, with the following exception. Where it is obvious from field inspection and study of topographic maps that there would be no significant increase resulting from complete encroachment, it would be permissible to use a starting elevation equal to the 100-year natural elevation with no surcharge added. High vertical banks on both sides of the river would be an example of this condition. These situations are relatively rare and should be carefully documented in order to qualify for the exemption.

Procedures for floodway analysis are defined by four sample cases listed below. The examples should provide guidance for virtually all situations to be encountered; however, if some unique condition should occur to which the examples are not applicable, the Department of Natural Resources should be consulted.

Case A

City V occupies area on both banks of river (refer to Figure 8).

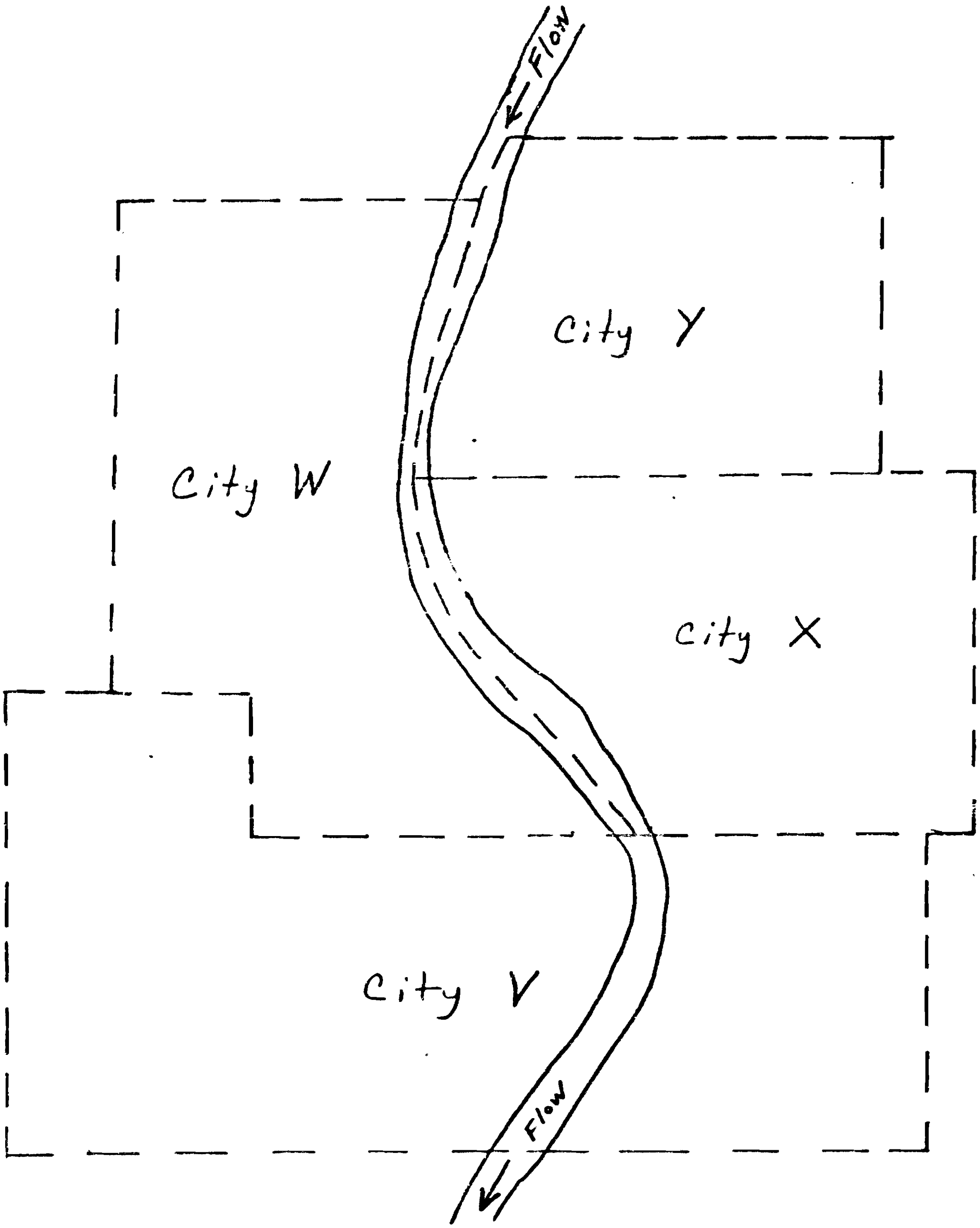

Figure 8. Illustrated community layout for following examples.

Case B

City W selecting floodway, neither cities X or Y have a floodway (refer to Figure 8).

Case C

City X selecting floodway, W has adopted acceptable floodway (refer to Figure 8).

Case D

Cities W and X selecting floodway. City Y may or may not have a floodway (refer to Figure 8).

Whenever 0.5 foot surcharge is to be added to natural 100-year profile for starting elevations in the following examples, refer to preceding "Note" for possible exceptions.

Case A - Community V only (refer to Figure 8)

Step 1. Evaluate engineered floodway or designated floodway using a starting elevation derived by adding 0.5 foot surchage to natural (100-year) floodway elevation at downstream corporate limits. If permissible 0.5 foot surcharge is not exceeded through V, floodway is acceptable. If excessive increases in elevation are found, the floodway will have to be adjusted.

In this situation, where a single community has jurisdiction on both sides of the river, small surcharge increases in excess of 0.5 foot may be acceptable, upon approval of the Commissioner, provided the 0.5 foot is not exceeded at the upstream corporate limits.

Step 2. Final floodway profile to be plotted should be derived by using a starting elevation for the appropriate conditions described below:

a. If floodways have not been designated downstream from community V, use 100-year natural elevaion plus 0.5 foot (see exceptions under "Note").

b. When floodways have been designated for the downstream area, use 100-year natural elevation plus actual computed surcharge applicable at downstream corporate limits of V.

Case B - City W selecting floodway, X and Y have no floodway. (refer to Figure 8)

Step 1. If desired floodway is an engineered floodway go to Step 3 below.

Step 2. If inspection indicates ~~the this~~ that the community designated floodway probably provides for less than allowable encroachment (i.e. surcharge increase of less than 0.20 foot can be expected, then analysis should be made as follows. Otherwise go to Step 3.

a. Set cross-section limits for W along designated floodway line. Cross-section limits for the other side of the stream remain at the natural floodway limit.

b. Using a starting elevation for W equal to 100-year natural elevation plus 0.25 foot, compute profile.

c. If increases (other than at the first two cross-sections) resulting from W's designated floodway are less than 0.20 foot, then the designated floodway is acceptable.

d. If surcharge exceeds 0.20 foot, go to Step 3.

Step 3. If the desired floodway is to be an engineered floodway, or if Step 2. is not satisfied, then the analysis should be made as follows.

a. Using a starting elevation equal to the 100-year natural flood level plus 0.5 foot, compute an engineered (equal degree of conveyance reduction) floodway for W and the opposite bank areas in X and Y. The resulting floodway should be tested for exceedance of the 0.5 foot maximum surcharge. If the engineered floodway is to be used, it can be accepted if it meets the above test standards.

The procedures itemized in (b), (c) and (d) below can then be eliminated.

b. If a designated floodway is to be evaluated, set the cross-section limits for W at the selected floodway line while the cross-section limits for the other side of the stream (cities X and Y) remain at the equal conveyance reduction limits as determined in (3. a.) above.

c. Compute the floodway profile using a starting elevation equal to the 100-year natural level plus 0.5 foot.

d. If the surcharge at any point in the reach is greater than 0.5 foot, then adjustments must be made in W's designated floodway and a new profile computed.

Step 4. Starting elevations for computation of the final floodway profile should be determined as follows:

a. If community V has no designated floodways, starting elevation should be 100-year natural elevation plus 0.5 foot.

b. When adopted floodways are available for community V, use computed surcharge at upstream limits of V plus 100-year natural flood level for starting elevation.

Step 5. Final floodway profile should be computed, using starting elevations as determined in Step 4., following the procedures outlined below:

a. Set the cross-section limits for W at the designated (or engineered as applicable) floodway line and the cross-section limits in X and Y at the natural floodway line. Compute profile.

b. Final floodway profile should be determined by adding 0.25 foot (or less if required) to computed elevations from Step 5. a. above, but limiting total increase above 100-year natural flood elevation to 0.5 foot. Table 1 illustrates the procedure.

Table 1. Profile Elevations in Feet

Cross Section No.	100-year Natural Elevation	Designated Floodway Elevations *	Added for Cities X ‡ Y †	Final Floodway Profile
1 ‡	980.40	980.90	0	980.90
2	980.80	981.15	0.15	981.30
3	981.35	981.62	0.23	981.85
4	981.75	981.94	0.25	982.19
5	982.20	982.35	0.25	982.60
6	982.75	982.92	0.25	983.17
7	983.18	983.41	0.25	983.66

* From profile computed according to Step 5. a.

† Maximum value is 0.25 foot.

‡ At downstream corporate limits of City W.

The procedure outlined above will allow for future designation of floodways in Cities X and Y without any substantive change in the floodway profile.

Case C - City X selecting floodway, W has adopted floodway (refer to Figure 8).

Step 1. An engineered floodway for cities W and X should be computed (if one is not available from the previous analysis of W's designated floodway), using a starting elevation equal to the 100-year natural floodway level plus 0.5 foot applicable at downstream limits of X (Corporate boundaries may or may not coincide at river).

Step 2. Set X's cross-section limits along the designated floodway. W's limits remain at equal degree of conveyance reduction limits as determined in Step 1. Using these limits and the same starting elevation as in Step 1, determine floodway profile.

Step 3. If profile increases exceed 0.5 foot, then adjustment is necessary in X's designated floodway.

Step 4. Starting elevation for computation of the final floodway profile should be determined as follows:

a. If community V has no designated floodways, starting elevation should be 100-year natural flood level plus 0.5 foot.

b. If floodways have been adopted in City V, determine starting elevation by using computed surcharge at upstream limits of City V plus 100-year flood elevation.

Step 5. Compute final floodway profile, using starting elevation from Step 4., by setting cross-section limits at the designated floodway line in City X and the adopted floodway line in City W. Any increases above 0.5 foot resulting from this combination should be amall and will be acceptable. *

* The reasons for going through Steps 1 through 4 may not be readily obvious; however, if each step is carefully studied, it will be seen that this procedure is the only way to protect the rights of both communities.

Case D.- Cities W and X selecting floodways simultaneously, City Y may or may not have adopted floodway. (refer to Figure 8)

Step 1. Starting elevation should be equal to 100-year natural elevation plus 0.5 foot.

Step 2. Compute equal degree conveyance reduction (engineered) floodway through study reach. Make computer run with model adjusted for engineered floodway to ensure that increases in 100-year flood elevation do not exceed 0.5 foot. If designated floodway limits do not exceed engineered floodway alignment, Steps 3 and 4 below can be eliminated.

Step 3. Using the same starting elevation, compute floodway profile with cross-section limits defined by W's designated floodway line on one side and X and Y's engineered floodway line on the other side. All profile elevation increases must be within the prescribed 0.5 foot limit, if not, modify W's designated floodway.

Step 4. Again using the same starting elevation, compute floodway profile using cross-section limits defined by X's designated floodway line on one side and W's equal degree of conveyance reduction line on the other side. Increases in the 100-year flood profile cannot exceed 0.5 foot, otherwise, designated floodway for City X must be modified.

Step 5. Starting elevation for computation of the final floodway profile should be determined as follows:

a. If community V has no designated floodways, starting elevation should be equal to 100-year natural level plus 0.5 foot.

b. If City V has adopted floodways, starting elevation should be determined by using computed surcharge at upstream limits of City V plus 100-year elevation.

Step 6. Final floodway profile should be derived by using the appropriate starting elevation from Step 5 above, and then proceeding as follows:

a. Compute floodway profile using designated floodway lines for terminating cross sections in Cities W and X. If City Y has designated a floodway, it should be used to define cross-section limits;

otherwise, use natural floodway limits for terminating cross sections in Y.

b. If City Y has designated floodways, final floodway profile shall be the computed values from Step 6 a. above.

c. If City Y has no designated floodways, the final floodway profile should be determined by using the computed values from Step 6. a. for the reach coincident to Cities W. and X. Upstream from the corporate limits of City X, the computed profile from Step 6 a. must be adjusted by adding 0.25 foot (or less if required), but limiting total increase above the 100-year natural elevation to 0.5 foot. See sample calculations for Case B in Table 1.

B. Tributary Streams

Floodway evaluation for small tributary streams poses special problems with respect to starting elevations. The probability of major flood peaks (such as the regional flood) occurring simultaneously at the confluence of a minor tributary and a large main-stem stream is considerably less than one percent. If too high a starting elevation is used, the floodway evaluation would permit excessive encroachment through the backwater reach of the tributary owing to the artificially increased cross-sectional area for the higher water-surface level. For this reason, the following procedures have

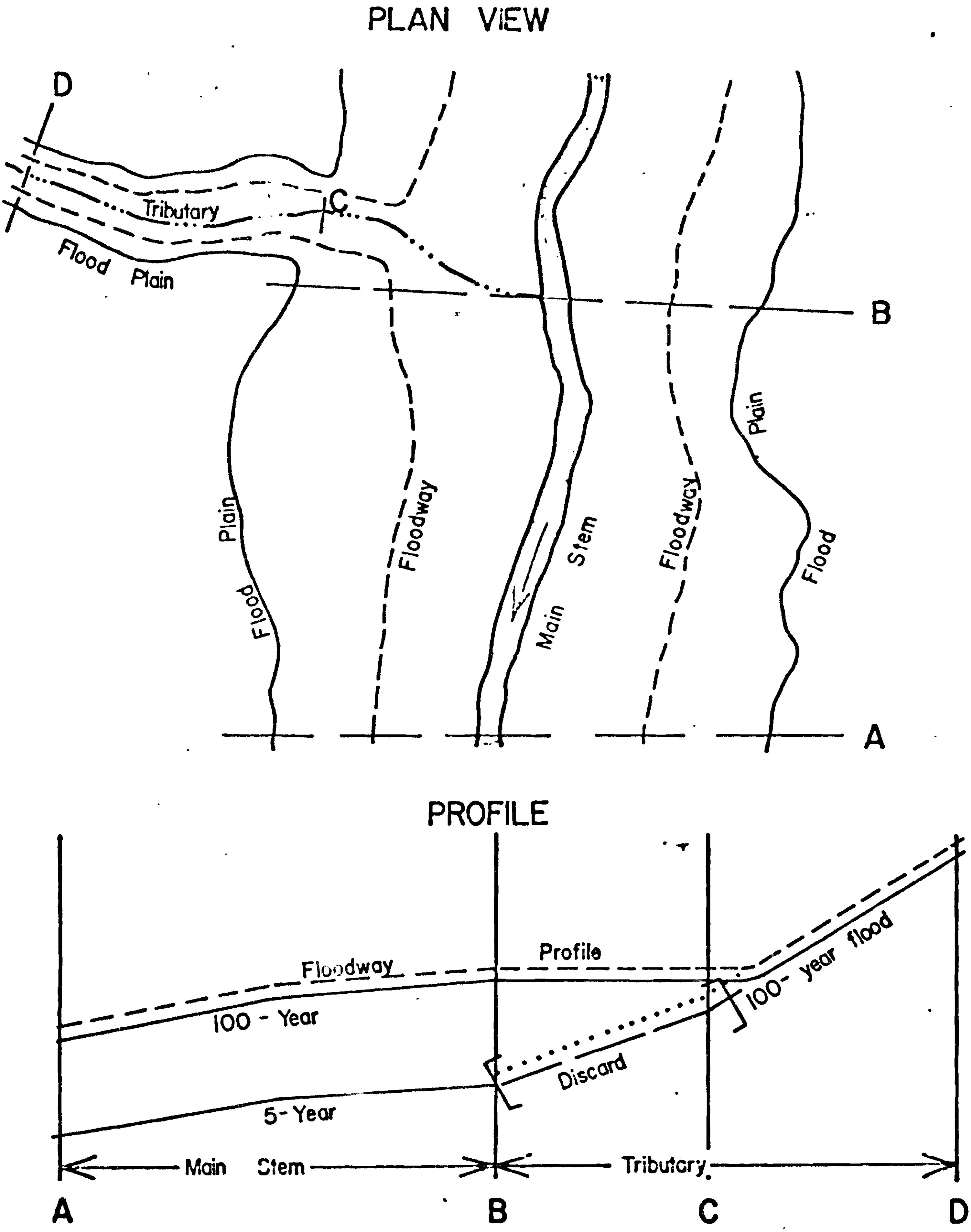

Figure 9.
Analysis of a Floodway Involving a Tributary and Main Stem

been developed. Refer to Figure 9 for an illustration of the process outlined in the guidlines.

Step 1. Determine the floodway on the main stem using the applicable situation as outlined in "Section A. Main-Stem Studies".

Step 2. The tributary starting elevation for the 100-year natural profile at Point B is determined as follows:

a. Drainage area ratio of tributary to main stem is 1:50 or greater, starting elevation equals 5-year flood elevation of main stem at confluence.

b. Drainage area ratio is between 1:50 and 1:15, starting elevation equals 10-year flood elevation of main stem at confluence.

c. Drainage area ratio is 1:15 or smaller, starting elevation equals 100-year flood elevation of main stem at confluence.

Note: The 5-year flood elevation on the main stem at point B can be determined from a stage-frequency curve based on available frequency elevations.

Step 3. Compute 100-year natural floodway profile for tributary using appropriate starting elevation from above.

Step 4. From point B, horizontally extend the main stem

100-year natural elevation through the backwater reach on the tributary to intersect the tributary profile computed in Step 3 above (from point B to somewhere near point C). With a smooth transition this new profile is the 100-year natural floodway profile for the tributary stream.

Step 5. Following the guidlines outlined in "Section A. Main-Stem Studies" evaluate designated floodway, or compute engineered floodway as required, for tributary stream using starting elevation at determined point B by adding 0.5 foot to elevation determined in Step 2. If complete encroachment on the main stem causes less than a 0.5 foot increase in the 100-year flood level at point B, for the condition set forth in Step 2. c. only, use the computed surcharge from complete encroachment in lieu of the 0.5 foot.

Step 6. Compute initial floodway profile for tributary stream, using same starting elevation at point B as prescribed in Step 5, by following procedures for final floodway profile calculations outlined in "Section A".

Step 7. Final floodway profile for tributary stream should be determined by horizontally extending main-stem floodway elevation from point B until it intersects profile computed in Step 6. in vicinity of point C. Make a smooth transition at point of intersection.

Normal Depth Analysis

The normal depth, or uniform flow analysis, provides an approximate determination of flood stages utilizing a minimal amount of data. It is generally used on a case by case basis for an approximate evaluation of the effect of encroachment on flood flows. The method is usually limited to estimating flood levels in undeveloped rural areas where the stream characteristics are reasonably uniform over a considerable reach and no downstream obstruction, such as a bridge or dam, affects the flow pattern.

In the absence of engineering studies, local flood-plain management ordinances can be based upon experienced flood data or soil maps, where appropriate, by providing a conditional use permit procedure for engineering review of proposed developments. With this approach, a minimum amount of data is necessary for both adoption of local ordinances and evaluation of proposed developments.

Under these conditions, normal depth analysis can be used to assure that proposed flood plain uses are compatible with the ultimate requirements when flood plain regulations are adopted consistent with "Statewide Standards and Criteria for Management of Flood Plain Areas in Minnesota" (See footnote 1/).

Normal depth analysis is the application of Manning's equation $Q = \frac{1.49}{n} AR^{2/3} S^{1/2}$ to determine the flood characteristics for flows of a given magnitude in natural or manmade channels. Strictly speaking, Manning's equation is applicable only to the uniform flow condition wherein the discharge, waterway cross section, mean velocity, and depth remain constant throughout the study reach. For flow in natural streams and rivers, these conditions exist rarely, if ever. However, normal depth analysis is still a useful technical tool in that it will give a good approximation of elevations associated with a specified magnitude of flow and will, in most practical applications, define the minimum cross-sectional area required to pass a given discharge without exceeding the maximum prescribed surcharge.

Normal depth analyses for proposed flood-plain encroachments should be submitted to the Department of Natural Resources for review.

A. Data Requirements

The data required for a normal depth analysis consists of an estimate of the regional flood magnitude, selected retardance factors (Manning's roughness coefficient "n") map of area under consideration, cross section of stream channel and overbank areas, stream slope, photographs of study area, details of any stream obstructions, description of proposed development, and land use of the property across the stream from the development site. The following guidlines provide additional details pertaining to the acquisition of the required data.

1. Regional (100- year) flow estimates should be determined according to the guidlines contained in the "HYDROLOGY" section of this report. Assistance can be obtained from the Department of Natural Resources if local expertise is not available for the hydrologic analysis, or if questions arise as to the

analytical process in estimating the regional flood discharge.

2. Selection of roughness coefficients (Manning's "n") requires considerable hydrologic experience. These coefficients will usually have to be determined by Department of Natural Resources personnel based on photographs (supplied by the applicant) or by on-site investigations. Roughness coefficients can be calculated from experienced flood events where the slope of the water surface is recorded, or defined by high-water marks, and the peak discharge for the experienced flood is known. With these data available, the area and hydraulic radius can be determined by acquisition of a cross section, and the Manning equation can then be used to solve for the value of "n". The problem with this approach is that the calculated "n" value is a composite figure reflecting the combined roughness coefficients for the main channel and the overbank areas, which normally vary to a great degree. For this reason, the calculation of usable "n" values by this approach is severely limited.

> Note: Items listed above are quite technical in nature and may require complete input from the Department of Natural Resources, or assistance in the analysis as the case may be. Items listed below, however, represent minimal data requirements which must be furnished by the local governmental unit with the application for approval.

3. A planimetric or topographic map having a designated scale

should be provided showing the proposed development and the entire flood plain for a distance of at least 500 feet, and preferably 1,000 feet, upstream and downstream. It is important that the direction of streamflow is indicated on the map. An illustration of a typical map layout is shown in Figure 10.

4.A representative cross section, defining the main channel and overbank areas up to an elevation not to be exceeded by the 100-year flood, is required. The cross section should be determined by differential leveling, using an established datum, and should be oriented so as to be at right angles to the direction of flow. The surveyed section should define existing ground elevations typical of the area, pot holes and embayments which do not carry flow should be eliminated.

A graphical plot of the cross section, with designated scales, should be furnished showing the lateral extent and elevation of the proposed encroachment (flow area to be eliminated by proposed development). It is desirable to keep the distortion of the graphical plot within a range of 1:10 (i.e. vertical scale versus horizontal scale). Larger scale distortions make it more difficult to analyze roughness coefficient distribution and to determine equal conveyance reduction. The cross section plot should also show changes, and extent of vegetative cover to aid in the selection and distribution of roughness coefficients. It is extremely important that left and right bank of the cross section are

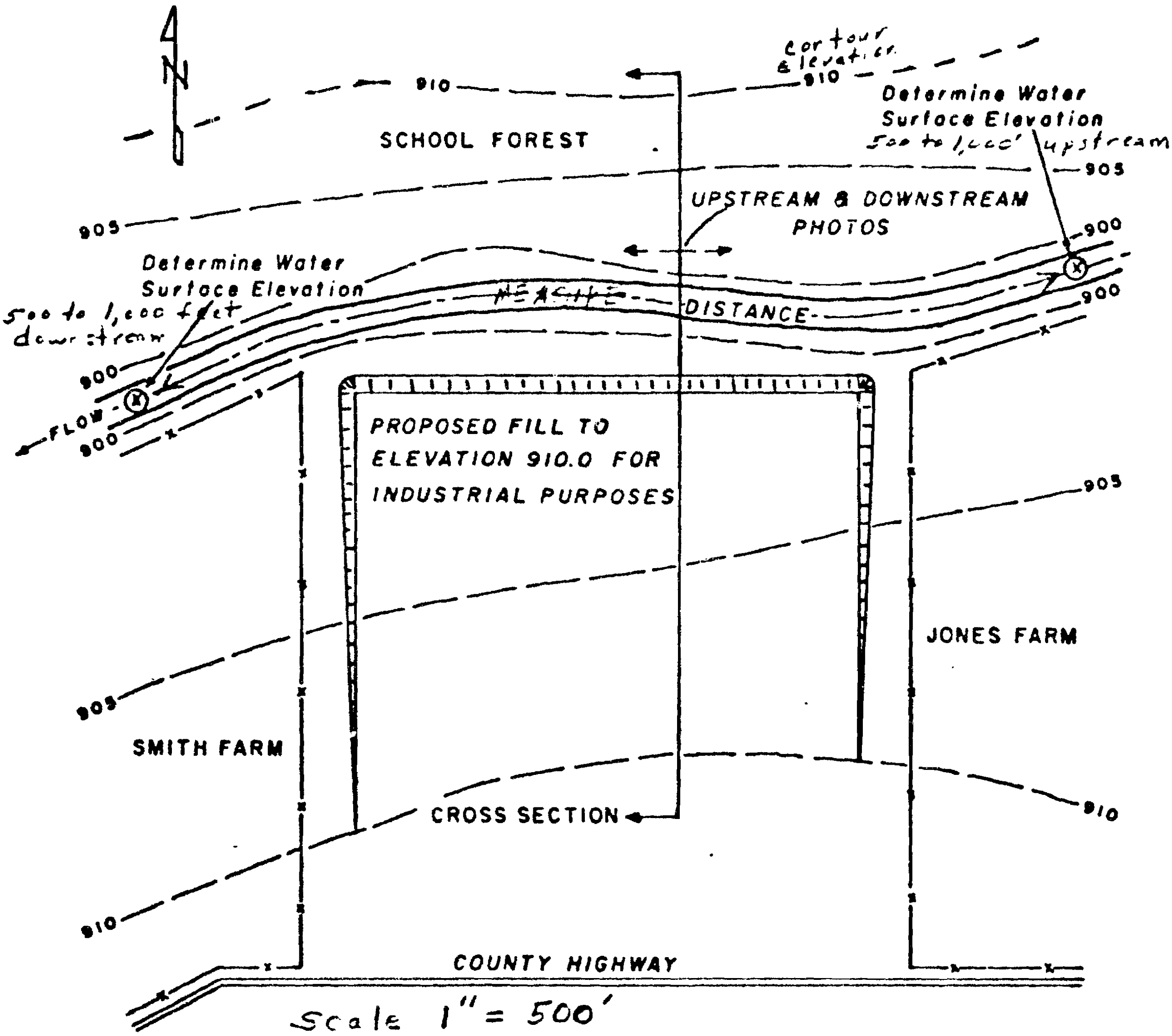

Figure 10. Map layout for normal depth analysis.

identified on the plot. Left and right banks are determined by facing downstream. See Figure 11 for an example of a typical cross-section plot.

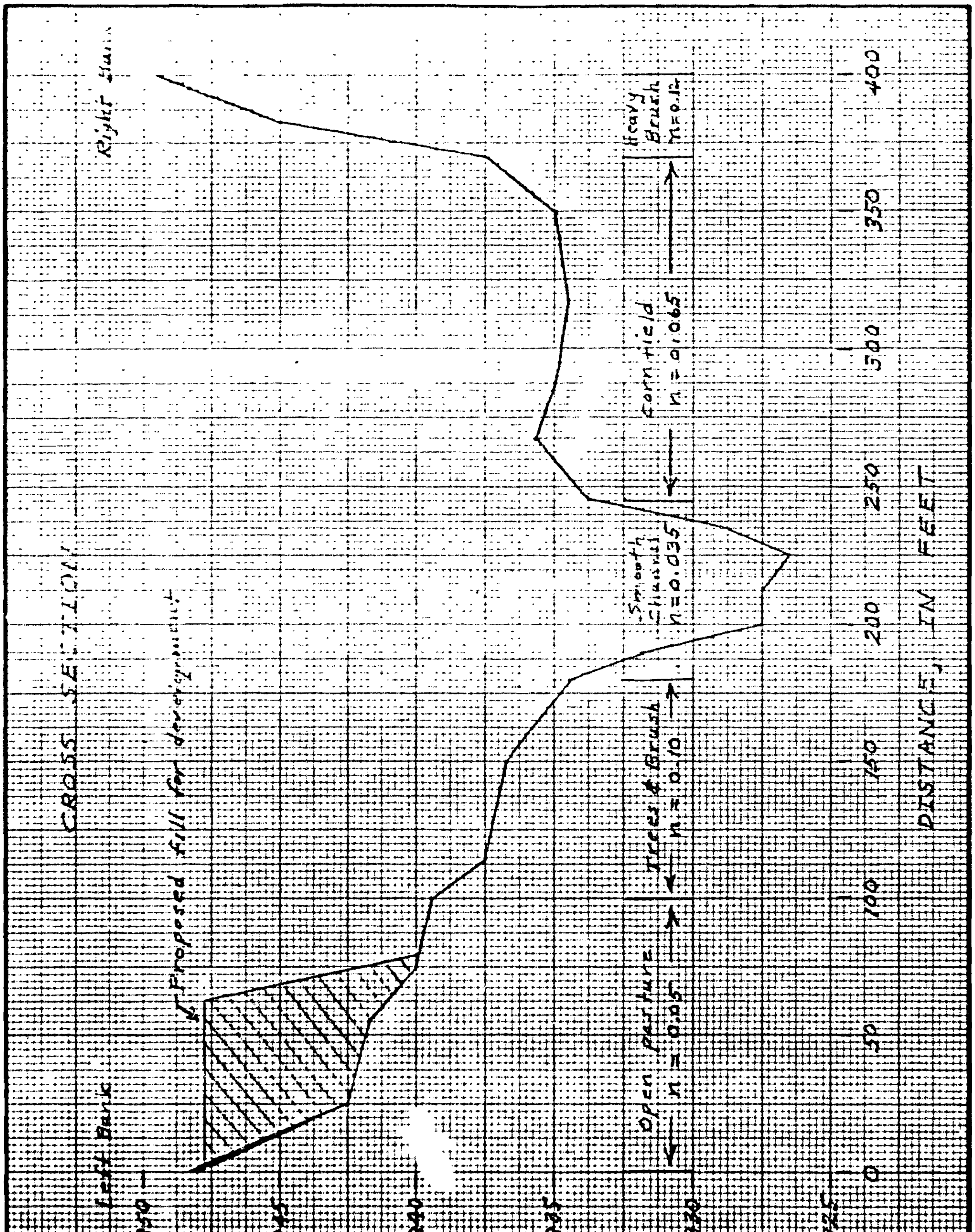

Figure 11. Cross-section plot.

5. The stream slope should preferably be obtained from a profile of an experienced flood at the project site. Such a profile can be developed from existing high-water marks (providing such marks are reliable) by running a line of differential levels and measuring the distance between marks. Distances should be measured along the valley alignment so as to parallel the flow lines. Lacking historic profile data, the slope should be computed from elevations of the existing water surface determined at the development site and 500 to 1,000 feet upstream and downstream. Distances between water-surface elevation points should be measured along the stream channel. The difference in elevation divided by the distance will equal the slope. If the upstream and downstream slopes differ, use an average of the two values. Extreme care should be exercised in determining the slope from the existing water surface, particularly during periods of low flow. During low-flow periods, small riffles representing breaks in the smooth water-surface profile may appear. The slope determined from elevations having a riffle in the intervening reach will probably not be indicative of the slope prevailing during a flood. Under these conditions it would be necessary to wait for an increase in flow, sufficient to eliminate the riffle effect; or to extend the reach for slope determination by a considerable distance thereby minimizing the potential error of a localized break in water surface.

6. Photographs of the topography looking both upstream and downstream from the development site should be provided to permit estimation of "n" values. Sufficient pictures, properly labeled as to view ~~locatation~~ orientation, should be obtained so as to clearly depict the main channel and ground cover conditions on both sides of the flood plain.

7. Any waterway obstruction existing in the vicinity of the project area should be described and photographed. The location of any such obstruction should also be shown on the map specified in item 3 above.

8. A description of the land use in the flood plain on both sides of the river at the proposed development site is required. Ownership of the property across the river from the area to be developed should be specified.

B. Methodology

As previously mentioned, the Manning equation is:

$$Q = \frac{1.49}{n} A R^{2/3} S^{1/2} \qquad (1)$$

where Q = Discharge, in cubic feet per second

n = Manning's roughness coefficient

A = Cross sectional area through which flow occurs, in square feet

R = Hydraulic radius, in feet

S = Slope of the water surface profile in feet/foot

WP = Wetted perimeter, linear distance measured along bottom configuration of inundated cross-sectional area of river valley, in feet

$$R = \frac{A}{WP}$$

The Manning equation is often written in the following alternative forms:

$$Q = K S^{1/2} \qquad (2)$$

where $$K = \frac{1.49}{n} A R^{2/3} \qquad (3)$$

and $$Q = \frac{1.49}{n} Z S^{1/2} \qquad (4)$$

where $$Z = A R^{2/3} \qquad (5)$$

$\therefore$ $$K = \frac{1.49}{n} Z \qquad (6)$$

"K" in the above equations is called the conveyance and "Z" is called the section factor. With any given waterway cross section, the conveyance or section factor, whichever is the most convenient under the particular circumstances, can be calculated for any depth of flow using equation (3) or (5), because both the area and hydraulic radius are dependent on the depth. Also, the required conveyance or section factor for the given discharge and slope can be calculated with equation (2) or (4).

A trial and error solution is necessary for the normal irregular waterway cross sections. The problem is solved when the conveyance or section factor, whichever is being used, for an estimated depth of flow is equal to the required conveyance or section factor for a given slope and discharge.

The concept of the section factor is utilized to simplify the calculations in the following example problem.

Example Problem

Given: The 100-year flood flow (Q) = 7,000 cubic feet per second (cfs).

Slope (S) = 0.0036 (from a field survey during a low flow period. $S^{1/2} = 0.06$.

Roughness coefficients (n) = 0.07, left overbank; 0.035, channel; and 0.09, right overbank (from field estimates).

The waterway cross section (from field survey data) and location of the proposed encroachment are shown in Figure 12.

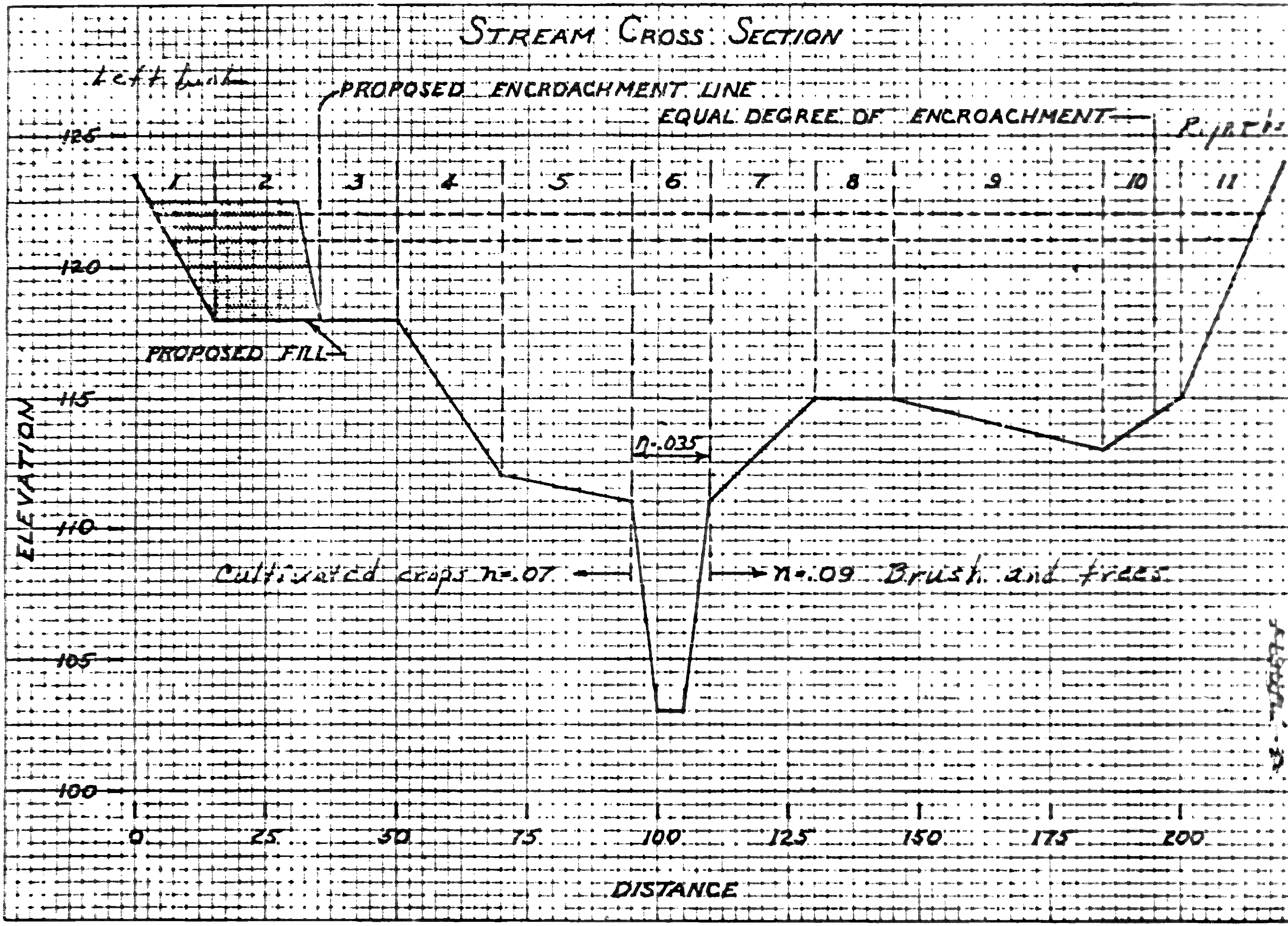

Figure 12. Cross-section for normal depth analysis in example problem.

Problem: Determine the increase in the 100-year flood stage resulting from the proposed encroachment, considering an equal degree of encroachment on the opposite bank.

Method of Solution: The waterway cross section is divided into a number of increments or segments, making certain that one division is located at the proposed encroachment line. Where convenient, the divisions can be made at 10 or 100 - foot intervals. Several water surface elevations are assumed. The total discharge under existing conditions for each elevation of flow is then calculated as the sum of the flows through the various sectors, which are composed of segments having like "n" values. The actual water surface elevation for the regional flood discharge is determined by interpolation between the computed flows at the two assumed elevations. If the computed discharges for the two assumed water-surface elevations do not bracket the 100-year flood discharge, an additional discharge computation for another assumed elevation will be required.

To determine the effects of encroachment, the conveyance of each overbank must be reduced by an equal amount because under the "equal protection of the law" clause, those located in a like manner have a right to equal use of their respective lands. This does not apply, however, in instances where there is reasonable assurance that the opposite bank will remain in open-space use, such as city-owned park land, etc. The elevation of the water surface after encroachment is then calculated in a manner similar to that outlined above.

In these and similar calculations, it is well to remember the following:

1. The area within each segment of a cross section can be determined by counting squares, calculation using scaled dimensions or planimetry.
2. The wetted perimeter of an overbank area whose width is large relative to its depth can be assumed to be the top width of the increment.
3. The wetted perimeter of a stream channel whose width is great in relation to its depth can be assumed to be the top width plus twice the channel depth.
4. The hydraulic radius is the waterway area divided by the wetted perimeter.

Summary of Calculations: Table 2 summarizes the determination of the section factors for two selected elevations of flow through the given cross section. Substituting these "Z" values into equation (4) and recognizing that the total discharge is the sum

TABLE ~~X~~ 2. Normal Depth calculations

~~Normal Depth Calculations.~~

Existing Conditions

Water Surface Elevation	Segment No.	A Area Sq. Ft.	WP Wetted Perimeter, ft.	R Hydraulic Radius, ft.	$R^{2/3}$	$Z = AR^{2/3}$
121.0	1	13	9			
	2	60	20			
	3	45	15			
	4	120	20			
	5	237	25			
	Σ1-5	475	89	5.34	3.06	1450
	6	230	24	9.58	4.51	1040
	7	160	20			
	8	90	15			
	9	280	40			
	10	105	15			
	11	39	14			
121.0	Σ7-11	674	104	6.48	3.48	2340
122.0	1	23	12			
	2	80	20			
	3	60	15			
	4	140	20			
	5	262	25			
	Σ1-5	565	92	6.14	3.36	1900
	6	245	24	10.20	4.70	1150
	7	180	20			
	8	105	15			
	9	320	40			
	10	120	15			
	11	54	17			
122.0	Σ7-11	779	107	7.27	3.75	2920

of the individual discharges through the main channel and both overbanks, it is found that:

$$Q = \frac{1.49}{n_L} Z_L S^{\frac{1}{2}} + \frac{1.49}{n_c} Z_c S^{\frac{1}{2}} + \frac{1.49}{n_R} Z_R S^{\frac{1}{2}}$$

and $$Q = 1.49\, S^{\frac{1}{2}} \left[\frac{Z_L}{n_L} + \frac{Z_C}{n_C} + \frac{Z_R}{n_R} \right]$$

The subscripts L, C and R refer to the left overbank, channel and right overbank, respectively.

$$Q_{121} = (1.49)(0.06) \left[\frac{1450}{0.07} + \frac{1040}{0.035} + \frac{2340}{0.09} \right] = 6{,}830 \text{ cfs}$$

$$Q_{122} = (1.49)(0.06) \left[\frac{1900}{0.07} + \frac{1150}{0.035} + \frac{2920}{0.09} \right] = 8{,}250 \text{ cfs}$$

The subscripts 121 and 122 refer to the assumed water surface elevations.

The water surface elevation corresponding to Q = 7,000 cfs is determined by interpolation:

$$E = 121.0 + \left[\frac{7000 - 6830}{8250 - 6830} \right] = 121.1$$

The proposed encroachment will reduce the section factor of the left overbank for each of the two assumed depths of flow because of the reduction in cross-sectional ~~total~~ area, and the ~~increase~~ change in ~~the~~ wetted perimeter ~~of~~ for the remaining area. The new section factors are calculated as follows (see Table 2):

Elevation 121:

$$A = 45 + 120 + 237 = 402$$

$$WP = 18 + 20 + 25 = 63$$

$$R = 402 \div 63 = 6.38$$

$$R^{2/3} = 3.44$$

$$Z_L = AR^{2/3} = (402)(3.44) = 1380$$

$$\Delta Z_L = 1450 - 1380 = 70$$

Elevation 122:

$$A = 60 + 140 + 262 = 462$$

$$WP = 19 + 20 + 25 = 64$$

$$R = 462 \div 64 = 7.22$$

$$R^{2/3} = 3.73$$

$$Z_L = (462)(3.73) = 1730$$

$$\Delta Z_L = 1900 - 1730 = 170$$

An equal degree of encroachment on the right overbank will likewise reduce section factors, but by an amount greater than those calculated above. This is proven by equating the reductions in conveyance of the two overbanks using equation (6):

$$\Delta K = \frac{1.49}{n_L} \cdot \Delta Z_L = \frac{1.49}{n_R} \cdot \Delta Z_R$$

$$\Delta Z_R = \frac{n_R}{n_L} \cdot \Delta Z_L \qquad (7)$$

Therefore, $\Delta Z_R = \left(\frac{0.09}{0.07}\right)(70) = 90$ (Elev. 121.0)

$$\Delta Z_R = \left(\frac{0.09}{0.07}\right)(170) = 220 \qquad \text{(Elev. 122.0)}$$

With equal encroachment on both overbanks, the ~~waterway capacities~~ computed discharges at elevations 121.0 and 122.0 are:

$$Q_{121} = (1.49)(0.06)\left[\frac{1380}{0.07} + \frac{1040}{0.035} + \frac{(2340-90)}{0.09}\right] = 6,650 \text{ cfs}$$

$$Q_{122} = (1.49)(0.06)\left[\frac{1730}{0.07} + \frac{1150}{0.035} + \frac{(2920-220)}{0.09}\right] = 7,820 \text{ cfs}$$

Again, the water surface elevation necessary to convey 7,000 cfs is determined by interpolation:

$$E = 121.0 + \left(\frac{7000 - 6650}{7820 - 6650}\right) = 121.3$$

Accordingly, the increase in the 100-year flood stage amounts to only about 0.2 feet, which is acceptable. The statewide flood-plain management standards generally provide that increases in the regional (100-year) flood stage due to flood plain development shall not exceed 0.5 feet in any one reach or for the cumulative effect of several reaches.

Establishing the location of the equal encroachment line on the right bank requires a trial and error solution. At elevation 121.0, the conveyance to be removed from the left overbank by equation (?) (see Table 2) is:

$$K = \left(\frac{1.49}{0.07}\right)(60 + 13)\left(\frac{60 + 13}{20 + 9}\right)^{2/3} = 2,880$$

Estimating that the line of equal encroachment on the right bank is located as shown in Figure 12 and calculating the conveyance thus removed:

$$A = 72$$

$$WP = 19$$

$$R = {}^{72}/_{19} = 3.78$$

$$R^{2/3} = 2.43$$

$$K = \left(\frac{1.49}{0.09}\right)(72)(2.43) = 2,900 \approx 2,880$$

Therefore, the right bank encroachment line is correctly located as shown.

C. Limitations

~~V. LIMITATIONS OF NORMAL DEPTH ANALYSIS~~

A normal depth analysis produces only an approximation of flood heights. Experience has shown that the depth of flow or the stage of a given discharge will normally be understated by this method, sometimes by a foot or more in severe cases. Also, this method usually overstates the backwater effect of a given encroachment on the order of a fraction of a foot. Due to the difference in magnitude, these errors may not be compensatory. Thus, flood protection elevations computed by this method sometimes fail to provide the intended degree of protection for flood plain developments without the addition of sufficient freeboard.

Where the stage of the regional flood and the effects of development on flood flows can be evaluated from documented flood events or calculated from controls such as dams, such should be done in lieu of a normal depth analysis. In areas where it is apparent that flood stages are influenced by conditions such as road grades, bridges or other waterway restrictions, additional cross sections should be obtained and water surface profile calculations should normally be made as outlined under "Engineering Studies".

Especially in areas subject to intense development pressures, efforts should be made to initiate a ~~flood plain information~~ detailed engineering study rather than relying on the normal depth approximation.

PHOTOGRAMMETRIC COMPILATION OF SURVEY DATA

Photogrammetry is defined as the science of making accurate and reliable measurements of topography from aerial photographs. It provides an alternative to field surveying for acquisition of cross sections for overbank areas and, in addition, can be used to produce maps for delineation of flood-plain areas required for detailed engineering studies. Lacking adequate topographic maps of the study area, photogrammetric compilation, utilizing the combination of cross-section data acquisition and delineation of flood hazard areas on compiled maps, is usually more economical than extensive field surveys to meet the accuracy requirements for engineering studies. Through specification of flight altitude for the aerial photography and stereoplotter accuracy limits, the photogrammetric compilation of data can be controlled so as to meet all normal standards for a flood-plain study.

It should be emphasized that use of photogrammetric procedures can supply only the cross-sectional data for overbank areas of the flood plain, underwater portions of the cross section must still be obtained by ground survey.

There are three basic types of output that can be obtained from photogrammetric compilation as follows:

(1) Complete cross-sectional data for the overbank areas. This can be obtained in a punch card format suitable for direct use in the digital computer.

(2) Accurate planimetric maps to a designated scale. After the regional flood profile has been calculated,

the outlines of the flooded area can be super-imposed on these maps by the photogrammetric process.

(3) Topographic maps to a specified scale and contour interval for delineation of ~~If the maps are to be used only to define the~~ flood hazard areas. ~~the contouring can be limited to bands encompassing the level of the regional flood on both sides of the flood plain.~~

Aerial Photography

For mapping purposes, aerial photos are obtained by an aircraft carrying a precision camera at a predetermined altitude to yield a photo scale suitable for the accuracy requirements of the project. By exposing the photographs at successive intervals with approximately 60% overlap between one another, it is possible to later reconstruct the earth's surface by stereoscopic (three-dimensional) viewing of these overlaping photos. Figure 13 illustrates four exposures or photographs and the three stereo-models they will form.

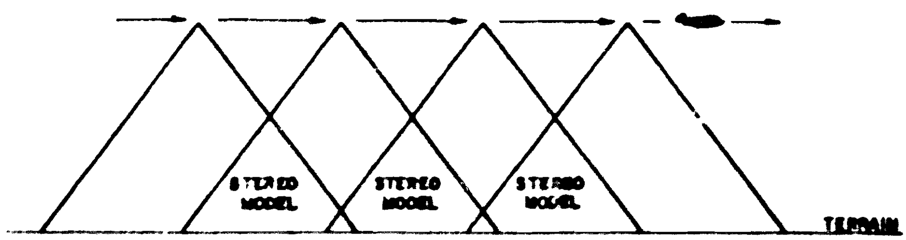

Figure 13. Stereo-model illustration.

Acquisition of aerial photography suitable for flood-plain mapping purposes in Minnesota is limited to two short periods during the year. These periods are: (1) in spring after the snow has melted, before the trees leaf out and while there is no overbank flooding along the streams, and (2) in fall after leaf drop has occurred and before the ground is obscured by snow. The most desirable photography is obtained in spring, ~~before high water conditions occur, at a time~~ when the solar angle is at the highest point during an acceptable flying season.

If photogrammetric compilation is to be utilized, it is most desirable to have the photography and compilation done by the same contractor; however, with uncertain time schedules, and the limited flying season, it is some times expedient to obtain the aerial photography under a separate contract and then negotiate a subsequent contract for the compilation.

Experience has shown that optimum conditions for aerial photography are at a prescribed flight altitude of 4,800 feet using 6-inch focal length precision camera (photography scale will be 1" = 800'). Negatives for such photography will measure 9 inches square. Each stereo-model (comprising two photos having 60 percent overlap) will provide coverage suitable for mapping an area equivalent to about 2,880 feet in length as measured along the flight line, and 5,600 feet wide as measured perpendicular to the line of flight. If dual flight lines are necessary to cover the study area, allowance should be made for a 30 percent overlap between photos from adjacent flights. For multiple flight lines, the coverage length measured along the flight line will remain the same, but the usable width (measured perpendicular to the flight line) of the stereo-models for each flight will be reduced by approximately 10 percent from the single flight coverage noted above.

The 1" = 800' scale photography will permit compilation of 4' contour intervals under National Map Accuracy Standards, which implies an accuracy of ± 2'. Contouring is more of an averaging process and the accuracy level is less than can be obtained from spot reading of elevations. Spot reading of elevations, which is the process required for obtaining cross sections and, to a certain degree, the delineation of flood outlines, can achieve an accuracy of ± 1' from the same photography. Use of a high-order stereo-plotter can increase the accuracy level to ± 0.5' for ideal conditions.

Aerial photography is a relatively small part of the cost involved in the use of photogrammetric compilation for a flood-plain study. The major expense is for setting the stereo-models, illustrated in Figure 13, and obtaining the ground control needed to establish accurate horizontal and vertical scales in the model. Considering the relative cost aspect, it is desirable to obtain ample photographic material from the photogrammetric contractor for use in the study. Photographic items to be supplied should include a photo index, complete set of contact prints, and a set of 2-time enlargements of alternate photos. Alternate photos will provide complete coverage of the area owing to the required 60 percent overlap. The ~~2-time~~ enlargements are particularly useful for the layout of cross-sections, field identification of section alignment, and evaluation of roughness coefficients.

If the initial contract is for acquisition of aerial photography only (compilation of cross-section data and maps not included) the contractor must be required to furnish the film negatives and a calibration certificate for the camera and lens.

Ground Control

Reference points are selected on the aerial photos and a ground survey party is sent to the field to obtain elevations and horizontal measurements for the selected points. The survey is usually tied to mean sea level and state plane coordinate datums.

Each stero-model must have a basic number of survey points needed to orient the model in a plotting instrument.

Horizontal control should be obtained by the photogrammetric contractor as they normally have access to existing data available from the National Geodetic Service or the U. S. Geological Survey. Bridging techniques between established horizontal control points are usually permissible to establish uniform map scale throughout the study area.

Each stereo-model should have at least 4 to 6 vertical control points. There are analog bridging and aerotriangulation techniques available to determine vertical control for the model from widely spaced points of known ground elevation. However, analog bridging can introduce vertical errors totally unacceptable under the standards established for an engineering study; and areotriangulation methods, although having a higher level of vertical accuracy than analog bridging, still may introduce errors greater than allowed by the standards. Therefore, it is recommended that full vertical control (4 to 6 identifiable control points for each stereo-model with elevations determined by ground survey) be required for all photogrammetric compilation.

Surveys for vertical control should be closely coordinated with the photogrammetric contracotr to avoid duplication of effort. If the contractor is to perform the field surveys for vertical control, it should be stipulated that semi-permanent benchmarks be established throughout the flood-plain area as required for a detailed engineering study, and supplementary points of known elevation should be defined along the stream channel ~~which can be used~~ to establish sea level datum for the survey of the underwater portions of the cross sections.

In many instances, the consultant performing the flood-plain study may find it expedient to acquire the underwater portion of the cross sections before the photogrammetric compilation is started. This requires establishment of sea level datum along the stream channel on which the underwater section surveys are based. Under such conditions, the consultant can reduce photogrammetric compilation costs by supplying the vertical control network already established, to serve as a base for acquisition of the vertical control required for the stereo-models. It may even be adventageous for the consultant to furnish elevations for the stereo-model control points identified by the contractor. The main consideration is to plan the project so that duplication of effort in performing required ground surveys is eliminated, or at leaset kept to a bare minimum.

Cross-Section Reading

? aerial photo images are reproduced on glass plates for dimensional stability and set up as models consisting of successive overlapping pairs, in a precision instrument called a stereo-plotter. A photographic three-dimensional model of the earth's surface formed in the plotter is used to interpret and plot the topographic data. The plotter orientation is made to correct for tip and tilt of the aerial camera, variation in altitude at time of the individual exposures, and to level and scale the model to the ground survey control. The pre-selected location of the cross sections are plotted on map manuscripts and placed on the plotter table. The plotter operator reads cross section elevations and distances for that portion of the section which lies above the existing water surface. Beginning at a point above the estimated level of the 100-year flood, elevations are read at regular intervals and at changes in slope down to water level, then up the opposite bank to a point above the 100-year flood elevation thereby completing the cross section. As the elevation points are read by the operator, vertical and horizontal position data are automatically transferred to punched cards for direct use in a digital computer. The consultant must orient the underwater sector (which he has procured in the field) with the photogrammetrically compiled overbank portions of the section, and then splice the punched data cards for the underwater area into the card deck furnished for the overbank area. Orientation is easily accomplished by matching overlapping portions of the section at the edges of the stream channel. Thus, a punched card data set representing a complete continuous cross section is created.

Base maps showing planimetric detail can be compiled at the same time cross sections are being read. The base maps may also be made by a photographic process known as orthophotography wherein detail ia shown on the final map by the actual photographic image, however this method is more costly. Compilation of topographic maps can also be accomplished in conjunction with the cross-section readout. Usually, contouring of the entire study area is economically unfeasible, however, if the maps are primarily for delineation of the flood plain, contouring can be limited to a band encompassing the regional flood level along each side of the flood plain. It should be emphasized that establishment of the stereo-models is the major cost item, additional data can be obtained at relatively low cost once the models have been set up.

Flood-Plain Delineation

After calculation of the 100-year flood profiles, the photogrammetric models can be reset in the stereo-plotter and the flood-plain limits plotted on the original planimetric base map (previously compiled in conjunction with the cross-section readout). Although this process requires another set-up of the stereo-models, orientation data for the model are already available and the cost of resetting is relatively low. Normally a two-phase operation comprised of (1) readout of the overbank cross sections and compilation of planimetric maps, and (2) delineation of flood-plain limits in a second set-up of stereo-models, is more economical than a single phase operation involving compilation of topographic maps for outlining the flood plain.

Accuracy Check

Photogrammetrically compiled data for a flood-plain study should be authenticated by random checks on the vertical datum. This can best be done by comparing a compiled cross section along a roadway or railroad fill with a section obtained by ground survey. Spot elevation checks can also be made where the overbank section crosses a street, railroad, or other identifiable location. Accuracy checks must be confined to areas which can be clearly identified on the aerial photgraphy so as to avoid dispute regarding location if the vertical accuracy is questionable. Cross sections of the natural valley can undergo substantial change through minor undefined horizontal displacement; and therefore, are not reliable indicators. ~~indications~~ for a check on vertical accuracy.

The most serious inaccuracies occur when the stereo-model is not properly oriented, thereby introducing consistant vertical errors throughout the model area. This can have a substantial effect on calculated profiles and, subsequently, on the flood-plain delineation. Errors introduced from erroneous readings made by the plotter operator are usually not serious as they are localized, are random in nature, and may even be compensating. The random vertical control checks recommended above are primarily aimed at eliminating the more serious potential for error in the improper orientation of the stereo-models.

ADMIN 1000 (Rev. 1/78)

DEPARTMENT OF NATURAL RESOURCES

STATE OF MINNESOTA

Office Memorandum

TO : Zona DeWitt
Assistant for State Documents
Legislative Reference Library

DATE: April 24, 1979

FROM : Larry Seymour, Director
Division of Waters

PHONE: 296-4810

SUBJECT: SUBMISSION OF COPY OF CONSULTANTS REPORT - LOWELL C. GUETZKOW

Enclosed is a photo copy of a consultant's report prepared for the Division of Waters by Lowell C. Guetzkow. The contract was originally due June 30, 1978, but was subsequently amended to require submission by April 15, 1979.

LS/mfr:ls

Enclosure

C-1

April 2, 1979

Mike Robinson
Division of Waters, D.N.R..
444 Lafayette Road
St. Paul, Mn. 55101

Dear Mike:

Enclosed are the final draft copy of the report, "Procedures and Requirements for Flood Hazard Evaluation" and 3 copies of my bill. The items for which you requested comment or modification of the draft are discussed below.

Item 1. Page 6. The last paragrapn on page 6 referring to the consideration of 10 years future development in the hydrologic analysis is unreasonable in my belief. The only reasor for it's inclusion was that it was cited as D.N.R. policy in the mimeographed handout titled "Procedures for Flood Plain Delineation" under section I. 2. This policy is contradictory to the guidlines issued by F.I.A. who provide the major input for floodplain studies. I presume from your inquiry that this may not be actual D.N.R. policy, and if so, the paragraph should be deleted. I have deleted the paragraph from the final draft copy; however, the decision must be yours if it reflects established D.N.R. policy.

Item 2. Page 13. The comparative reliability of TR-20, HEC-1 and multiple regression techniques for hydrologic analyses is a judmental decision which has never been resolved among sponsoring agencies. Future guidlines from the Water Recources Council will probably deal with the problem of inconsistency between various methods of analysis for ungaged watersheds. There seems to be some inconsistency even in your inquiry. You intimate that HEC-1 and TR-20 produce more reliable results (this premise is questionable) and should be used for detailed engineering studies, while multiple regression is suitable for normal depth analysis or hydraulic analysis of bridges. Many bridges are constructed in developed or developing areas and the backwater resulting from such structures is just as critical as the backwater effect from other flood-plain development. Therefore, it would seem that hydraulic analyses of bridges should have the same accuracy requirements as a detailed engineering study.

It should be pointed out, that sophisticated engineering practices do not necessarily equate with quality. One of the reasons for development of a multiple regression analysis method for Minnesota was to improve on existing techniques for hydrologic analysis of ungaged watersheds. Your agency participated in financing this project. As noted in the report, these data reflect actual observed conditions (whether the flood was caused by snow melt or excess precipitation) and are more encompassing than hydrology derived solely from a 100-year rainstorm.

The conception noted in your letter is probably predicated on opinions formed by Jim Wright during his tenure with the Wisconsin D.N.R. This sort of hand-me-down attitude has no basis in fact to my knowledge, and therefore was not considered in the preparation of this report.

My personal belief is that the multiple regression analysis method is suitable for any detailed engineering studies within the prescribed limitations. It is extremely difficult to be objective in making a definite recommendation of one method versus another; therefore, I attempted to point out the pluses and minuses of all methods discussed in the report. If you have personal preferences of one method over another, such preferance would have to be dictated by D.N.R. policy as I don't think such a decision can be substantiated by technical analysis at this time. I propose no change in the report unless you have over-riding reasons for a revision. The fact remains that competent hydrologists who can substantiate their analyses are still required for a good flood-plain study.

Item 3. Page 18. I have no knowledge of other computer models which would improve on the accuracy of HEC-2. There are models developed by other agencies which probably would be competitive with HEC-2 in terms of accuracy. However, these are not readily available to consultants, so I think the reference to the computer model furnished by your office should remain unchanged. ✓ I took the number of the D.N.R. digital computer program from one of your earlier publications - check to see if the reference is still valid.

Item 4. Page 29. The use of 5' contour maps for deriving cross-section data was taken from "Technical Report 1", page 8, which I presumed was a reflection of D.N.R. policy. The availability of such maps for rural areas would be a rare occurence.

In my opinion, use of such maps should be limited to situations where the overflow areas would generally carry no more than 30 percent of the total flow for the regional flood. Five-foot contour intervals by National Map Accuracy Standards are subject to a plus or minus 2½ foot accuracy limitation (½ the contour interval). Therefore, a detailed engineering study predicated on such accuracy standards, with substantial flow in the overbank areas, could be subject to considerable error.

I am proposing to limit the use of such 5' contour interval maps according to the general flow distribution criteria outlined above. Final draft copy has so been amended.

Item 5. Page 36. Insertion of the Commissioners option to require less than a 0.5 foot surcharge has been made on final draft copy.

Item 6. Page 41. You refer to physical, political or economic restraints which might preclude the use of a 0.5 foot increase in starting elevation for floodway analysis. In my opinion, physical constraints are amply provided for in the report guidlines. The report specifies that where complete encroachment would generate less than 0.5 foot surcharge, the lesser amount should be used.

Political or economic restraints seem to be a very uncertain factor. One political entity can exercise very stringent controls for flood-plain development while a subsequent political group can change the policy completely. Economic restraints would seem to reflect a current situation. When that situation changes, past economic restraints may no longer be valid.

Use of the 0.5 foot increase has generated some opposition owing mostly to the lack of understanding of the upstream effects. Introduction of the 0.5 foot surcharge for starting elevation is normally reduced to a minimal factor within a short distance upstream for most situations and tends to have a somewhat compensating effect, resulting from the artificially increased flow area at the higher water-surface elevation.

There may be other situations of which I am unaware that may justify waiving the 0.5 foot starting surcharge, and if such action reflects D.N.R. policy, reference to these situations should certainly be made in the report. If this is to be done, the report should list those conditions that would allow waiving the 0.5 foot surcharge requirements. A simple statement noting that the surcharge requirement can be waived would not be very helpful and would invite illegitimate requests.

In my opinion, we should discuss this item further when I return to Minnesota and any amendments to the report can easily be made at that time.

You may have my permission to list my name as author of the report if you so desire.

We plan to be back in Minnesota by April 16. I will call you then and we can arrange a meeting to discuss any unresolved issues.

Sincerely,

Lowell C. Guetzkow

Lowell C. Guetzkow