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ENGINEER INTELLIGENCE / GUIDE

EIG 32

STREAM HYDROLOGY AND HYDRAULIC STRUCTURES

A TECHNICAL SERVICE INTELLIGENCE DOCUMENT

PREPARED UNDER THE DIRECTION OF THE
CHIEF OF ENGINEERS
DEPARTMENT OF THE ARMY
WASHINGTON 25, D. C.

STREAM HYDROLOGY AND HYDRAULIC STRUCTURES

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CHAPTER 1
INTRODUCTION

1. Purpose

This EIG is intended to:

a. Give the requesting officer, normally the officer responsible for furnishing hydrologic and hydraulic data in an assigned area, an understanding of the usefulness and limitations of photography in furnishing the type of information needed, and thereby make it possible for him to plan for the photo coverage and interpretation required.

b. Give the photo-interpreter sufficient knowledge of hydrology and hydraulics to be able to satisfy requests for information that can be secured from photographs and become aware of the need for communicating changes in states or conditions, such as, breaks in levees, sudden drawdown or filling of reservoirs, rising water in rivers, and formation and breakup of ice jams. The photo-interpreter will generally be required to supply only that information necessary to fill gaps in data and not the interpretation of every facet of every item presented in the key.

2. Scope

a. This guide considers hydrology and hydraulic items that can be interpreted, partially or wholly, from photographs by using the equipment normally found in a photo-interpretation kit, namely, a pocket stereoscope, scales, dividers, various magnifying devices, and some simple apparatus for measuring parallax.

b. Insofar as possible, the text covers the following factors for each item:

(1) Background information.

(2) Recommended types and scales of photography.

(3) Recognition features.

(4) Interpretation problems.

(5) Required information.

c. The hydrologic and hydraulic items presented in the key are considered to be those most likely to be involved in the majority of military requests for hydrologic information and do not represent an exhaustive list of all items that are of interest to the hydraulic engineer. Each item is illustrated by the best photographs available at the time of the preparation of the key, and the photo-interpreter is urged to add to or replace them to improve and maintain the key as an up-to-date reference tool.

d. The study of hydrology and hydraulics includes some items in common with other fields of study; hence, some of the items in this key are also the subject of other keys. For these items, only the features of interest to the hydrologist are presented here, and these items are referenced to other keys.

3. Military significance of hydrology

a. Hydrology, the science that treats of water, its properties, phenomena, and distribution over the earth's surface, is of military importance in that it provides a method whereby the characteristics and effects of flowing water can be predicted. Recent military history provides a number of instances in which hydraulic warfare was used to create devastating floods, isolate troops, cut off supply lines, hinder river corssings, and disrupt military timetables. Reference 8 discusses in detail a number of these events such as the following:

(1) The British bombing of the Moehne and Eder Dams, Germany, May 1943.

(2) The German flooding of the Ill River, France, 1944-45.

(3) The German flooding of the Pontine Marshes, Italy, 1944.

b. The solutions of many military problems require the application of hydrologic principles. The most important of these problems are as follows:

(1) Artificial floods as weapons of warfare.

(2) Selection of sites for static military operations.

(3) Selection of sites for river crossings.

(4) Establishment and operation of flood prediction services.

(5) Utilization of hydraulic installations for logistical purposes.

CHAPTER 2

PHOTOGRAPHS AS SOURCES OF HYDROLOGIC AND HYDRAULIC DATA

4. General

The required accuracy of the data depends upon their intended use. If the data are to be used in a detailed analysis of the physical and hydrologic characteristics of an area, they must be secured in precise mathematical form, and photographs are of no particular value. If, on the other hand, the data are to be used in a general description of an area, they can be presented in much less precise terms. Most data for military use fall into this category, and photographs are extremely useful.

5. Scale of photography

Certain scales and/or ranges of scale of photography are recommended in Figure 1 and in the discussion of individual items contained in Chapters 3, 4, and 5. A single scale given represents the minimum usable scale. A range of scale represents the maximum and minimum usable scale of photographs for the interpretation of the particular item. Photographs at scales outside these established limits are of less value but should not be ignored. The basis for the selection of scale in this study was the size of the object and the intended use of the data.

6. Evaluation of usefulness

Figure 1 is a tabulation of the items giving an evaluation of the usefulness of photographs to furnish the data required for each item, and recommended scale and type of photograph. The evaluation terms are defined as follows:

Evaluation term	Explanation
Poor	Can provide only a general description of an item.
Fair	Can provide general description and some broad ranges of dimensions of an item.
Good	Can provide more detailed description and some dimensions of an item.

FIGURE 1: EVALUATION OF PHOTOGRAPHS AS SOURCES OF HYDROLOGIC AND HYDRAULIC DATA

Item	Elements of Data From Photographs	Recommended Photographs Type AP - Airphoto GP - Ground ST - Stereopairs	Scale	Evaluation	Remarks	Paragraph Number (Text)
Conduits	1. Description a. Type b. Purpose c. Alinement 2. Dimensions a. Length b. Cross-sectional area	AP–Verticals(1)* Obliques(1) Vertical ST(2)	1:20,000(1) 1:1,000(2)	Fair(3) Poor(4)	(1)For data elements 1a-c and 2a. (2)For data element 2b. (3)If conduit visible. (4)If conduit not visible.	25
Dams	1. Description a. Type b. Construction material c. Purpose 2. Dimensions a. Crest length b. Crest width c. Height	AP–Vertical(1) Vertical ST(2) Oblique ST(2)	1:20,000(1) 1:30,000(1) 1:40,000(1) 1:10,000(2)	Fair(3)	(1)For data elements 1a and b. (2)For data elements 1c and 2a–c. (3)Data element 1c will on occasion be difficult to interpret.	23
Direction of Flow	Determination of the direction of flow	Any type AP's and GP's	Any scale	Good		19
Drainage Basins	1. Description a. Land slope b. Basin shape 2. Dimensions a. Length of longest water course b. Average width c. Surface area	AP–Verticals Vertical ST	1:20,000 to 1:40,000	Fair(1) Good(2)	(1)Using uncontrolled mosaic. (2)Using controlled mosaic.	8
Flood Plains	1. Description a. Orientation to stream b. Vegetative cover 2. Dimensions a. Average length b. Average width c. Surface area	AP–Verticals(1) Vertical ST(2)	1:10,000 to 1:30,000(1) 1:20,000(2)	Fair	(1)For data elements 1a and b. (2)For data elements 2a–c.	17
Floodways	1. Description a. Layout including location of entrance, exit, and diversion works. b. Operation 2. Dimensions (diversion work) a. Crest length b. Height of crest above the river water surface c. Size of gates or gate openings	AP–Verticals Vertical ST	1:5,000 to 1:10,000(1) 1:1,000(2)	Fair	(1)For data elements 1a and b. (2)For data elements 2a–c.	32
Glaciers	Dimensions a. Surface area b. Cross-sectional area of main outlet stream	AP–Vertical(1) Vertical ST(2)	1:30,000 to 1:50,000(1) 1:5,000(2)	Fair	(1)For data element a. (2)For data element b.	12, 16
Groins	1. Description a. Type b. Construction material 2. Length of river affected	AP–Verticals Obliques	1:10,000	Fair		33

*Note: Numbers in parentheses refer to Remarks column.

FIGURE 1 CONTINUED

Item	Elements of Data From Photographs	Recommended Photographs			Remarks	Paragraph Number (Text)
		Type AP - Airphoto GP - Ground ST - Stereopairs	Scale	Evaluation		
Hydroelectric Plants	1. Description of layout including number of penstocks, draft tubes, and operating turbines. 2. Dimensions a. Length of penstocks b. Diameter of penstocks c. Height of forebay water surface above tailrace water surface	AP-Verticals, obliques and GP's(1) Vertical ST(2)	1:10,000	Fair	(1)For data elements 1 and 2a. (2)For data elements 2b and c.	28
Ice Conditions (Lakes and streams)	Description of the ice conditions	AP-Vertical ST	1:30,000	Good		10
Intake Structures	Description a. Location b. Type	AP-Vertical ST Obliques	1:10,000	Poor(1) Fair(2)	(1)If structure submerged. (2)If structure visible.	24
Irrigation Systems	1. Description a. Orientation of main supply conduits to field supply conduits b. Diversion works c. Water source 2. Dimensions a. Cross-sectional area of main conduits b. Surface area of irrigated field	AP-Verticals Vertical ST	1:20,000(1) 1:1,000(2)	Fair	(1)For data elements 1a and c and 2b. (2)For data elements 1b and 2a.	30
Lakes	1. Description a. Number of inlets b. Number of outlets c. Ice conditions 2. Dimensions a. Water surface area b. Former water surface areas	AP-Verticals Vertical ST	1:30,000	Fair		10
Levees and Floodwalls	1. Description a. Type (open or closed) b. Alinement including minimum maximum, and average distance from river c. Area protected (open structures) 2. Dimensions a. Length b. Top width, base width, and height c. Height of levee over river water surface d. Surface area of protected region (closed structure)	AP-Verticals Vertical ST	1:5,000 to 1:10,000	Fair		32
Marshes and Swamps	1. Classification as swamp or marsh 2. Surface area	AP-Verticals(1) Vertical ST(2)	1:20,000	Fair	(1)For data element 1. (2)For data element 2.	13
Natural Channel Formations	Description a. Type and relative number b. Location	AP-Vertical ST	1:20,000	Fair		15

FIGURE 1 CONTINUED

Item	Elements of Data From Photographs	Recommended Photographs			Remarks	Paragraph Number (Text)
		Type AP - Airphoto GP - Ground ST - Stereopairs	Scale	Evaluation		
Navigation Locks	1. Description a. Location b. Number of chambers 2. Dimensions a. Length and width of chambers b. Height of upstream water surface above downstream water surface	AP-Verticals Vertical ST	1:10,000(1) 1:5,000(2)	Fair	(1)For data elements 1a and b. (2)For data elements 2a and b.	29
Ponding Areas	1. Description a. Location b. Outlet works 2. Surface area	AP-Verticals Vertical ST	1:5,000 to 1:10,000(1) 1:1,000(2)	Fair	(1)For data elements 1a and 2. (2)For data element 1b.	32
Revetted Banks	See Groins, above.					33
Sluices	Description a. Location b. Number of openings	AP-Obliques Oblique ST GP's	1:10,000	Poor		27
Snow Cover	Dimensions of surface area	AP-Verticals	1:20,000 to 1:40,000	Fair		11
Special Techniques	Estimations a. Discharge b. Average depth c. Velocity (average and surface) d. Reservoir volume	AP-Vertical ST(1) Verticals (2)	1:30,000	Fair	(1)For data elements a-d. (2)Data element d requires surface area measurements in addition to parallax measurements.	16, 21, 34
Spillways	1. Description a. Type and location b. For gated spillways, type and number, and position (open, closed, etc.) of gates 2. Dimensions a. Spillway crest length b. Depth of spillway crest below dam crest c. Width and spacing of piers d. For gated spillways, width and height of gates	AP-Verticals Vertical ST Obliques GP's	1:10,000(1) 1:5,000(2)	Fair	(1)For data elements 1a and 2a-c. (2)For data elements 1b and 2d.	26
Streambeds and banks	1. Description a. Streambed and bank material b. Condition of banks c. Bank slope, if not measured d. Vegetation cover of valley floor 2. Dimensions a. Water surface width b. Depth of water c. Height of bank	AP-Verticals and low obliques (1) Vertical ST(2)	1:2,000 to 1:20,000(1) 1:5,000(2)	Fair(1) Poor(2)	(1)For data elements 1a-d, 2a and c. (2)For data element 2b.	16
Stream Patterns	Description a. Type stream pattern b. Drainage texture	AP-Verticals	1:20,000 to 1:40,000	Fair		9
Stream Slope	Description of water surface slope	AP-Verticals Vertical ST	1:20,000	Poor		15
Training Walls	See Groins, above.					33
Velocity	Estimation of surface velocity	AP-Verticals(1) Obliques(1) Vertical ST(2) GP's(1)	1:20,000(1) 1:10,000(2)	Poor(1) Fair(2)	(1)Estimations based on flow characteristics. (2)Estimations based on the drift of objects.	20

CHAPTER 3

HYDROLOGIC CHARACTERISTICS OF WATERSHEDS

7. Background

a. A watershed may be defined as the region that contributes to the supply of water of a river or a lake. In technical hydrologic literature the term, watershed, has been replaced with the more precise term drainage basin or drainage area. Every watercourse, ranging from the tiniest rill to the largest river, has its own watershed. The volume, time of concentration, and rate of runoff from precipitation over a watershed are influenced by the size, shape, slope, type of soil, vegetal covering, and other characteristics of the watershed.

b. The data needed for deriving hydrologic characteristics of watersheds are divided into the following categories:

(1) Stream patterns and the size, shape, and slope of the individual watersheds of major streams.

(2) Location, size, and the orientation, one to another, of standing bodies of water (lakes, reservoirs, snowfields, etc.).

(3) Porosity of the soils and vegetal covering in the area.

(4) Hydrometeorological data including intensity and duration of precipitation, ambient temperatures, and stream discharges and stages.

c. Photographs may be used to supply most of the information requirements listed in categories (1), (2), and (3); however, they cannot supply category (4) information. For a summary of required information and an evaluation of photographs as sources of data listed in categories (1), (2), and (3) above, reference should be made to Figure 1. Category (4) data may be secured by field measurement and past observations might be found in published records.

8. Size, shape, and slope of drainage basins

a. Background. A vital factor in the study of a stream system is its drainage basin. Drainage basins are predominantly ovoid (egg-shaped), although some are rectangular, circular, triangular, belled, leafed or linear. Once a drainage basin has been delineated, its area can be determined, and its surface and shape, as well as the character and position of its drainage system, can be studied. The shape of a drainage basin has a marked effect on the time of concentration of runoff; e.g., a much longer time is required for a flood crest to reach the outlet of a lanceolate (long and narrow) drainage basin than to reach the outlet of an ovoid basin of the same area. Area slope also has an important effect on time of concentration, and basins that have steep slopes are sometimes referred as being "flashy", i.e., floods crest at the outlets shortly after the major rainfall. Heavy rainfall over steep headwater areas of a large drainage basin, especially in deserts or semi-arid areas, often produces sudden and dangerous flood waves along the dry or almost dry stream channel. These flood waves can, and often do, reach far downstream, surprising and trapping people camping within or very close to the channel.

b. Recommended types and scales of photography. Vertical or vertical stereopairs of airphotos, 1:20,000 to 1:40,000 scale, are recommended for the interpretation of this item. These small scales reduce screening effects and cover a fairly large area.

c. Recognition features. A drainage basin is bounded by a divide line that separates it from adjacent drainage basins. The divide line around the basin follows the highest points (ridge line) between adjacent streams and crosses the main stream only at the outlet. Pronounced ridge lines indicate steep land slopes.

d. Interpretation problems.

(1) In areas of strong relief, divides are true lines (fig 2). However, on nearly level plains and in areas of undulating relief, the divide line is not so apparent. Under these conditions, the stream pattern of the drainage area under study and the patterns of adjacent drainage areas are traced, and then the alinement of the divide is derived indirectly (fig 3).

(2) Difficulties in delineating drainage basins may arise, especially in areas of weak relief, because of heavy forest (fig 4) or heavy snow cover (fig.5).

e. Required information.

(1) Delineate the divide line.

(2) Describe the land slope.

(3) Describe the basin shape.

(4) Measure the length of longest watercourse.

(5) Estimate the average width of the basin.

(6) Measure the area of the basin.

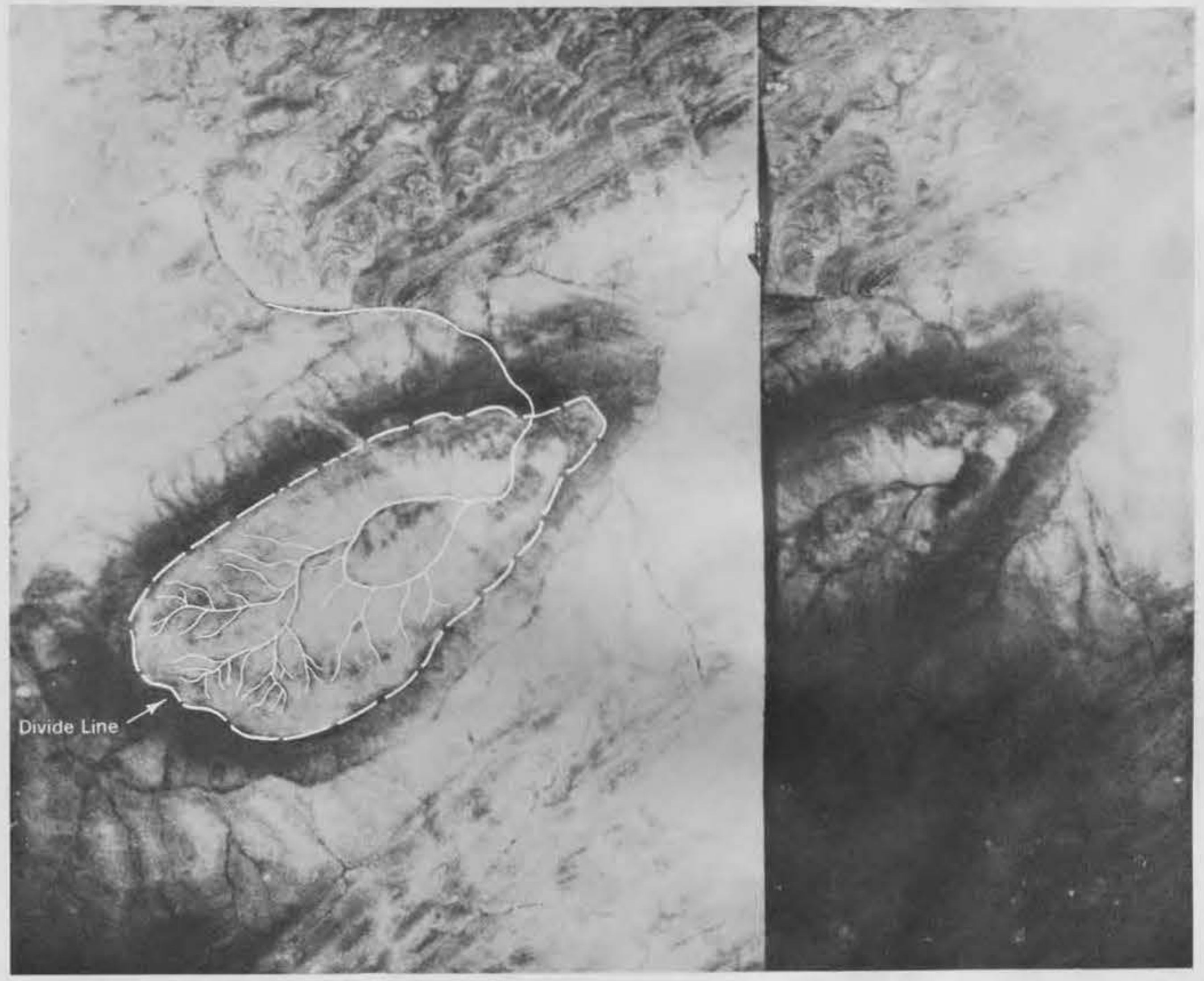

Figure 2: Drainage Area - Strong Relief
Scale 1:42,000 (approx.)

1. Recognition features - Sharp well-defined divide line between the drainage basin under consideration and neighboring basins.
2. Interpretation
   a. Land slope - The slope is very steep in the headwater reaches, steep to moderate in the middle reaches, and moderate in the lower reaches.
   b. Basin shape - Ovoid
   c. Length of longest watercourse through the basin=approximately 3.0 kilometers or 1.8 miles
   d. Average width=approximately 1.3 kilometers or 0.8 mile
   e. Area of basin=approximately 3.3 square kilometers or 1.2 square miles.

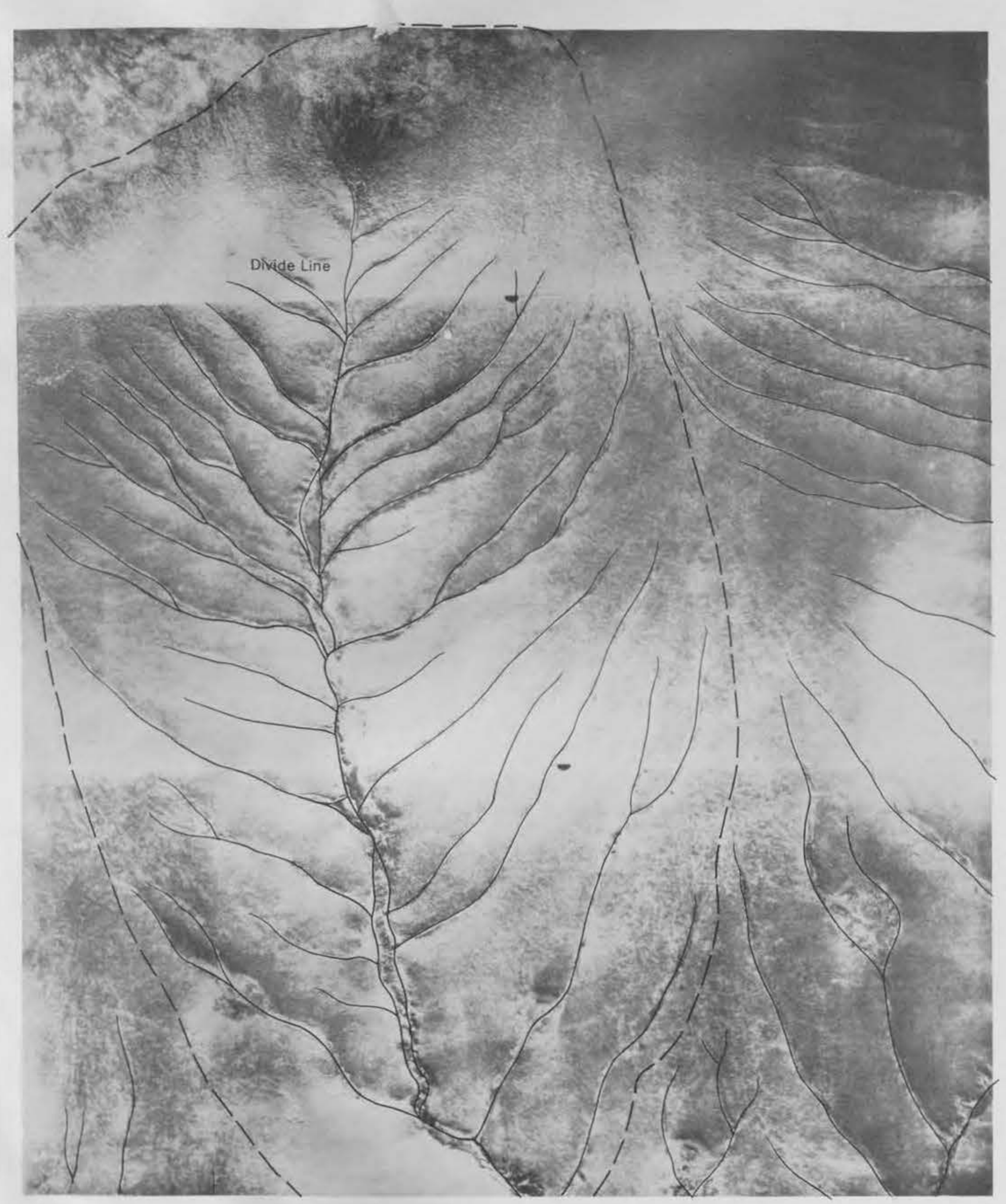

Figure 3: Drainage Area - Undulating Relief
Scale 1:18,500 (approx.)

1. Recognition features - Divide line must lie between the source of the tributary streams in the drainage area under consideration and the source of the tributary streams of the neighboring drainage areas.
2. Interpretation
   - a. Land slope - Although the slope of the stream channels appears to be moderate, the land slope appears to be steep and generally perpendicular to the axis of the streams.
   - b. Basin shape - Ovoid.

Figure 4: Screening Effect of Trees
Scale 1:21,000 (approx.)

To establish the divide line between these two streams would require a field survey.

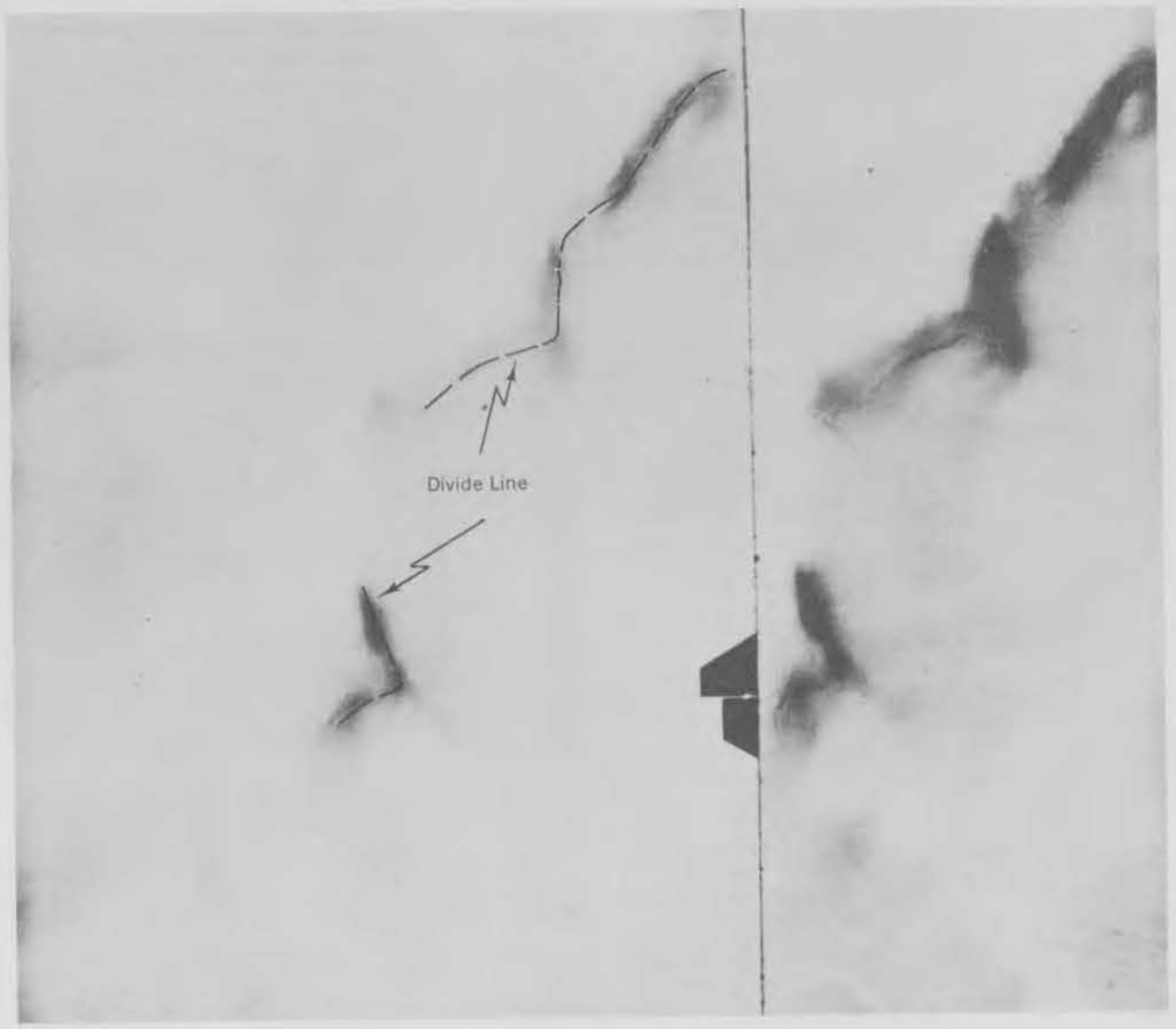

Figure 5: Screening Effect of Heavy Snow
Scale Unknown

Although some intermittent stretches of the divide line can be delineated, any attempt to delineate the total divide line would be very difficult.

9. Stream patterns

a. Background. It has been accepted by most scientists and engineers that soils and bedrocks influence the evolution and character of the patterns of a region's many rivers and tributary streams. This leads to the theory that the stream patterns developed in a region may indicate the types of soil and bedrock in that area. Hence geologists have classified stream patterns into many types. Most authorities agree, however, that all the types are modifications of the six basic patterns illustrated in Figure 6. Two other major aspects of interest to the hydrologist, besides the particular stream pattern itself, are the following:

(1) The texture of the pattern, that is, the spacing or density of the tributaries in the stream system. If the tributaries are closely spaced, the texture is "fine," and if widely spaced, it is "coarse." A fine textured pattern indicates short distances of overland flow, consequently, a rapid concentration of runoff at the outlet of the drainage basin.

(2) The alinement of the pattern. In areas where military installations are to be established, the drainage pattern of the drainage basin involved must be studied in order to provide the installations with adequate drainage facilities and flood protection structures.

b. Recommended types and scales of photography. It is recommended that vertical aerial photos 1:20,000 up to 1:40,000 scale be selected for interpretation. These small scales reduce screening effects and cover a fairly large area.

c. Recognition features. Natural streams appear on airphotos as irregular lines, the major bends are rarely symmetrical, and a natural stream network will never appear as a perfect geometric pattern (fig 7). Man-made ditches and canals, on the other hand, appear as regular lines, the major bends are either symmetrical curves or regular angles, and a whole system will have a fairly regular geometric pattern (fig 8).

d. Interpretation problems

(1) Stream pattern is one of the most outstanding features on a photograph. In heavily forested areas, however, especially during the foliage season, interpretation difficulties may arise because trees are often arched over a small stream channel partially or wholly screening it (fig 9). On winter photography of rather flat areas the smaller streams in a pattern may be screened by a heavy blanket of snow (fig 10).

(2) Estimation of stream texture (fig 7) may be accomplished in the following manner:

(a) Grid a piece of transparency at intervals corresponding to one square mile of the photographed area.

(b) Place the gridded transparency over the photograph of the area and trace the stream pattern.

(c) Estimate the miles of stream channel within an individual grid.

(d) Repeat step (c) using a number of grids scattered well over the drainage pattern.

(e) Total the stream channel lengths and divide the total by the number of grids used. The result is the average channel length in miles per square mile.

(f) The texture is classified as follows:

Miles per square mile	Texture
<1	Coarse
>1 <3	Medium
>3	Fine

Note:

<	Less than
>	Greater than

e. Required information

(1) Classify the stream pattern.

(2) Estimate drainage texture.

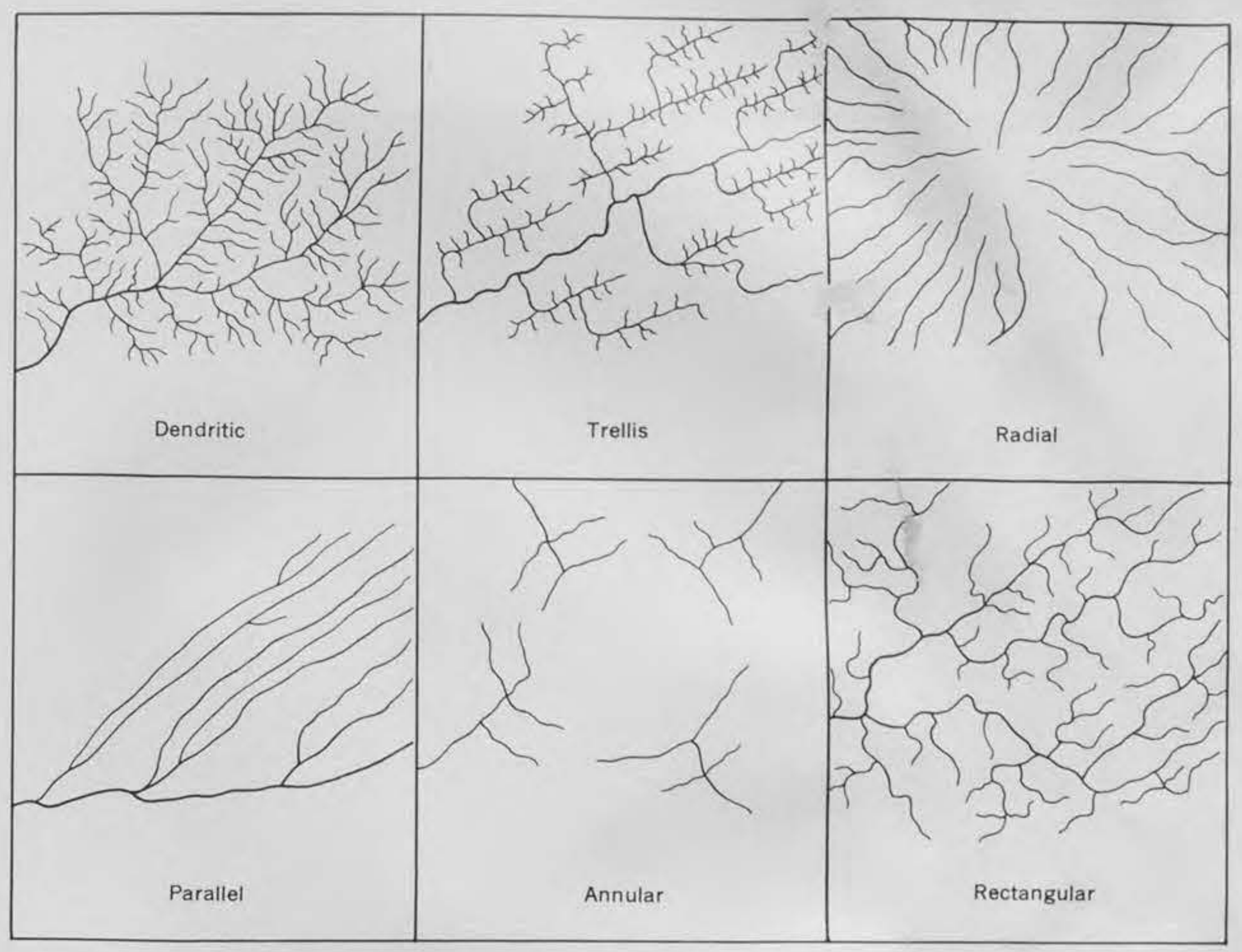

Figure 6: The Six Basic Stream Patterns

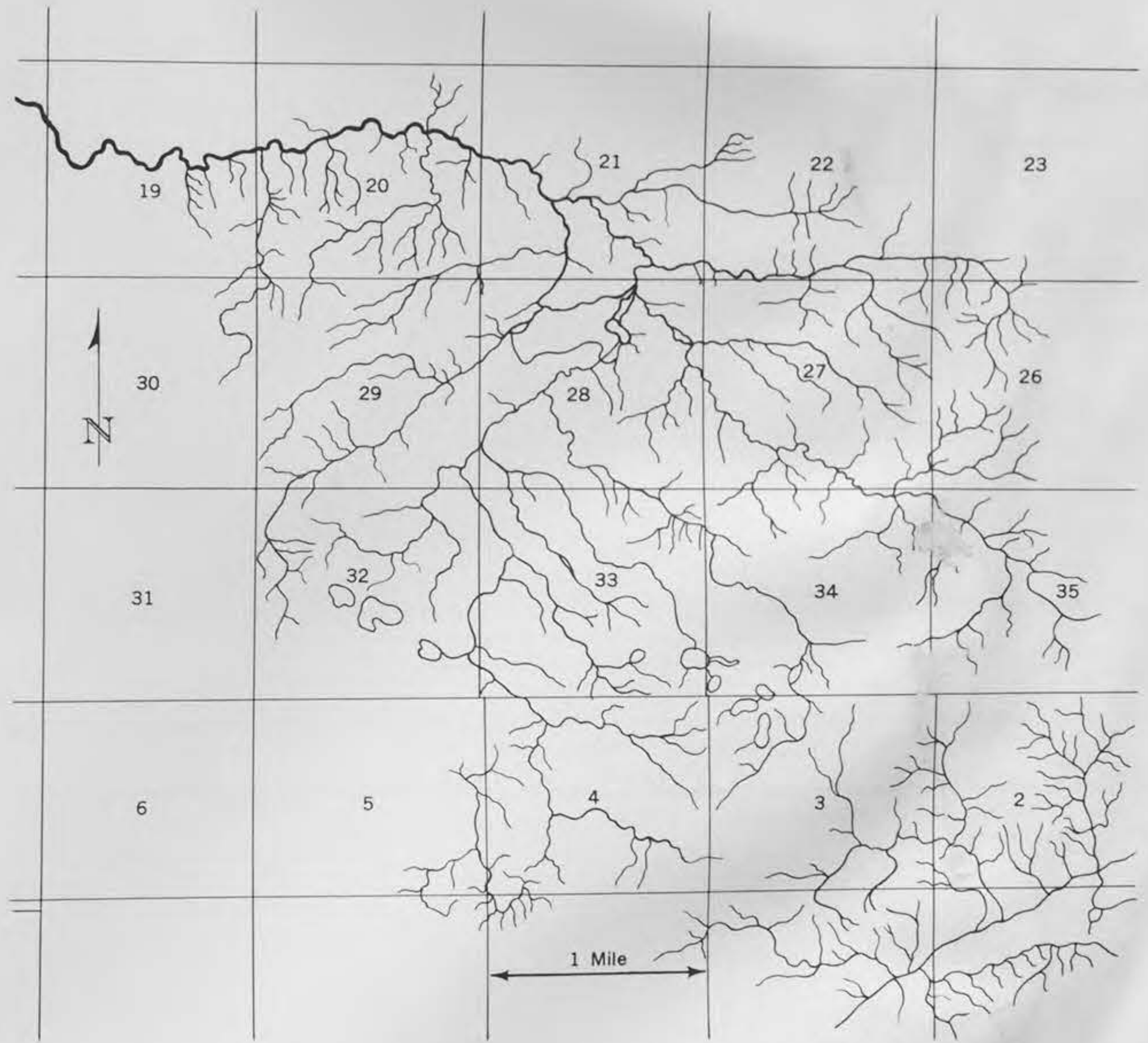

Figure 7: Dendritic Stream Pattern - Fine Texture
Scale 1:68,000 (approx.)

1. Recognition features - Tree-like branching of tributary streams.
2. Fine texture - More than 3 miles of channel per square mile of area.

Figure 8: Drainage Ditches
Scale 1:21,000 (approx.)

1. Recognition features
   a. Regular alinement of channels.
   b. Major bends are regul[illegible]ngles.
2. Interpretation - Presen[illegible] muck pockets and channels, as well as floodwater fluves, indicates that these are drainage ditches and not irrigation canals.

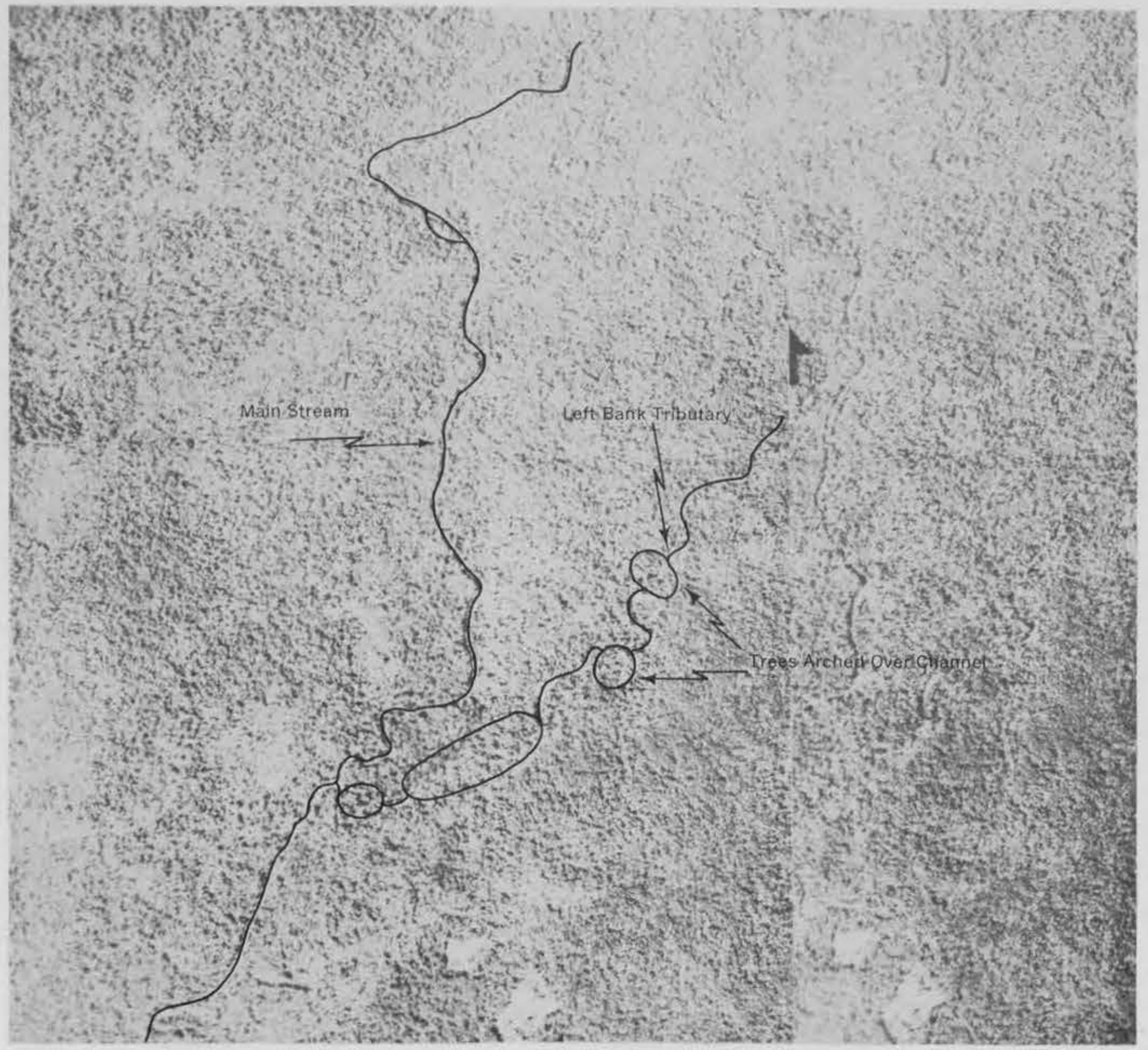

Figure 9: Screening Effect of Trees
Scale 1:21,000 (approx.)

Trees are arched over the channel at the points indicated. In this heavily forested area the channel of the large left-bank tributary appears only at widely separated intervals.

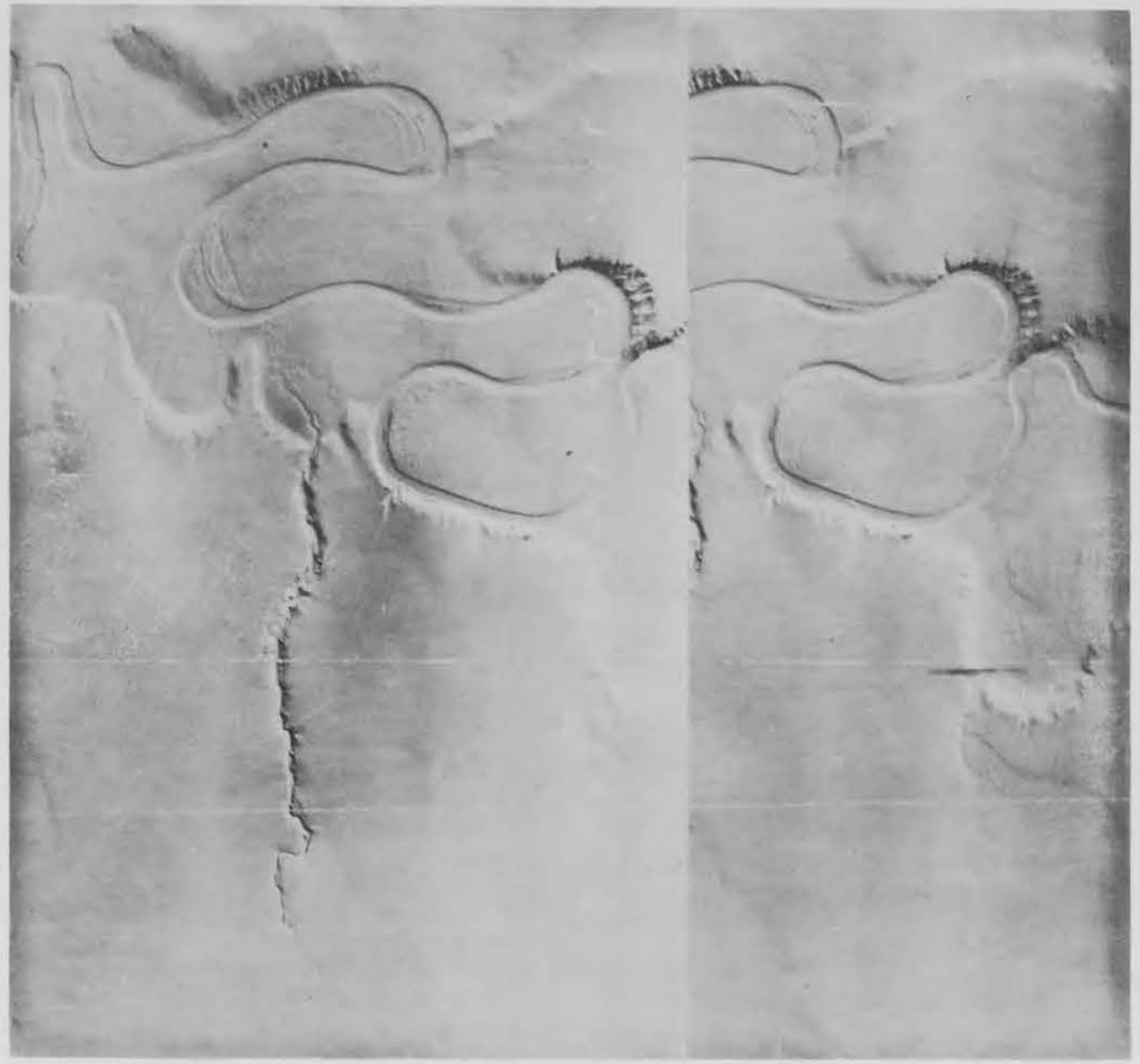

Figure 10: Screening Effect of Heavy Snow
Scale Unknown

The heavy snow-cover has screened the tributaries of this stream so that the pattern cannot be traced.

10. Lakes

a. Background. Lakes are formed whenever and wherever natural drainage is blocked or obstructed. Consequently, they exist everywhere in the world--on plains, plateaus, islands, in mountains, volcanic craters, and even deserts. Lakes may be classified as either fresh or salt-water lakes. They vary in size from very small ponds with a surface area of a few square yards to large seas, such as the Caspian with an area of many square miles. Lakes influence streams in that they tend to regulate streamflow, act as settling basins, and absorb floods.

b. Recommended types and scales of photography. Vertical or vertical stereopairs are recommended for interpretation. The scale selected depends on the size of the lake, but it should not be smaller than 1:30,000. A lake must be photographed in its entirety, since no distinction can be made on a large-scale photograph between part of a large lake, an unusually wide river, or part of a reservoir. In the case of a very large lake, a mosaic will be needed to determine the water surface area, delineate the bank line, and locate the inlet and outlet streams.

c. Recognition features

(1) Lakes are identified as well-defined water areas of smooth textural appearance.

(2) Clear, deep water in a lake may photograph in gray tones varying from white to black depending on the angle of incidence of the reflected rays of the sun (fig 11).

(3) Lakes heavily laden with sediment (muddy) will have a uniform light gray tone (fig 12).

(4) Fresh-water lakes are recognized by their inlet and outlet streams (fig 13). Salt lakes (fig 14) have inlet but seldom, if ever, outlet streams.

(5) Clear lake ice is dark gray in tone (fig 15). If covered with snow, the ice appears nearly white. The ice on a freezing lake appears smooth, thin, and dark gray in tone (fig 16). Melting lake ice has a light gray tone and the surface has the appearance of a honeycomb (fig 17).

d. Interpretation problems

(1) Differentiation between salt and fresh-water lakes will be very difficult, if not impossible, in regions of granular soil materials (karst areas), because the outlets (and sometimes the inlets) of fresh-water lakes are often subterranean and cannot be seen in airphotos.

(2) Clouds blot out lakes or parts of them depending upon the degree of cloud cover. Clouds appear on airphotos as very irregular (ragged) white splotches, and their shadows are similar splotches but black in tone. If the cloud itself does not appear in the print, its shadow may be mistaken for a clear deep lake or a muck pocket (fig 18).

(3) Ice accumulates in a ridge along the shore of a lake during cold weather and registers a gray tone on aerial photos. This tone often blends so well with the tones of the shore that the shoreline is difficult to detect (fig 19).

(4) The difference between a muddy lake (fig 12) and a dry lake (fig 20) is sometimes difficult to detect because both the muddy water and the bottom of the dry lake are recorded on airphotos in light gray tones; however, the tone of the dry lake bottom is usually dull.

e. Required information

(1) Measure the water surface area of the lake.
(2) Delineate the inlets and outlets (if visible).
(3) Measure the surface area bounded by vestiges of former water levels (see par 34).
(4) Describe the ice conditions.

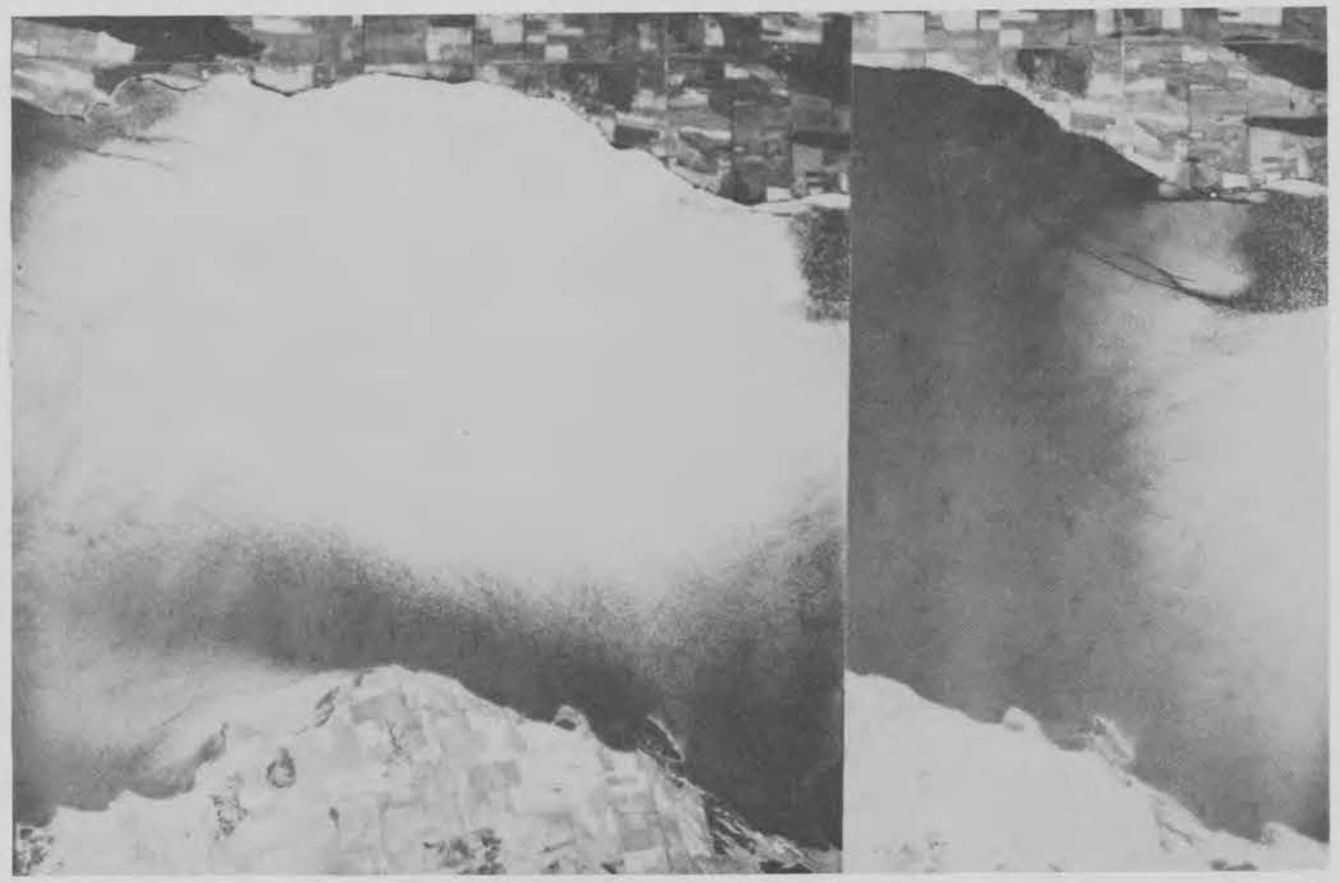

Figure 11: Effect of Reflected Sunrays on Water Tone
Scale 1:50,000 (approx.)

Lake has registered on the photograph in gray tones ranging from white to black because of the angle of incidence of the reflected rays of the sun.

Figure 13: Inlets and Outlet of a Fresh-water Lake
Scale 1:21,000 (approx.)

A fresh-water lake always has an outlet. The outlet here appears to have sufficient discharge capacity to allow a fairly regular replenishment of the water in the lake.

Figure 12: Muddy Lake
Scale Unknown

The uniform light gray tone of this lake indicates that is it heavily laden with silt.

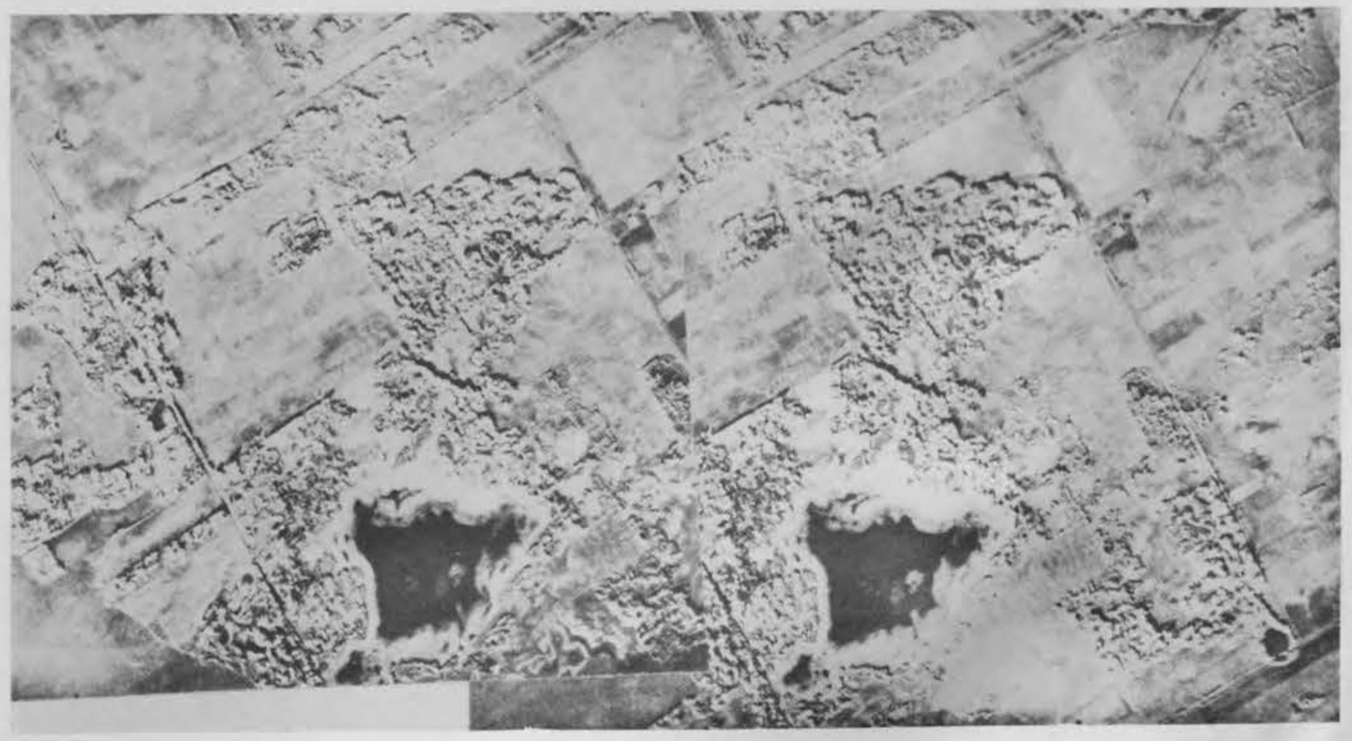

Figure 14: Salt Lake
Scale Unknown

This small lake has no outlet. The water slowly evaporates causing a high concentration of salts.

Figure 15: Frozen Lake
Scale Unknown

Note that the lake ice is dark gray in tone when not covered with snow. The white specks are snow accumulated around irregularities on the ice, and the white lines are snow-filled cracks.

Figure 16: Freezing Lake
Scale Unknown

The ice appears smooth and thin; much open water remains, indicating that the freezing action has just begun.

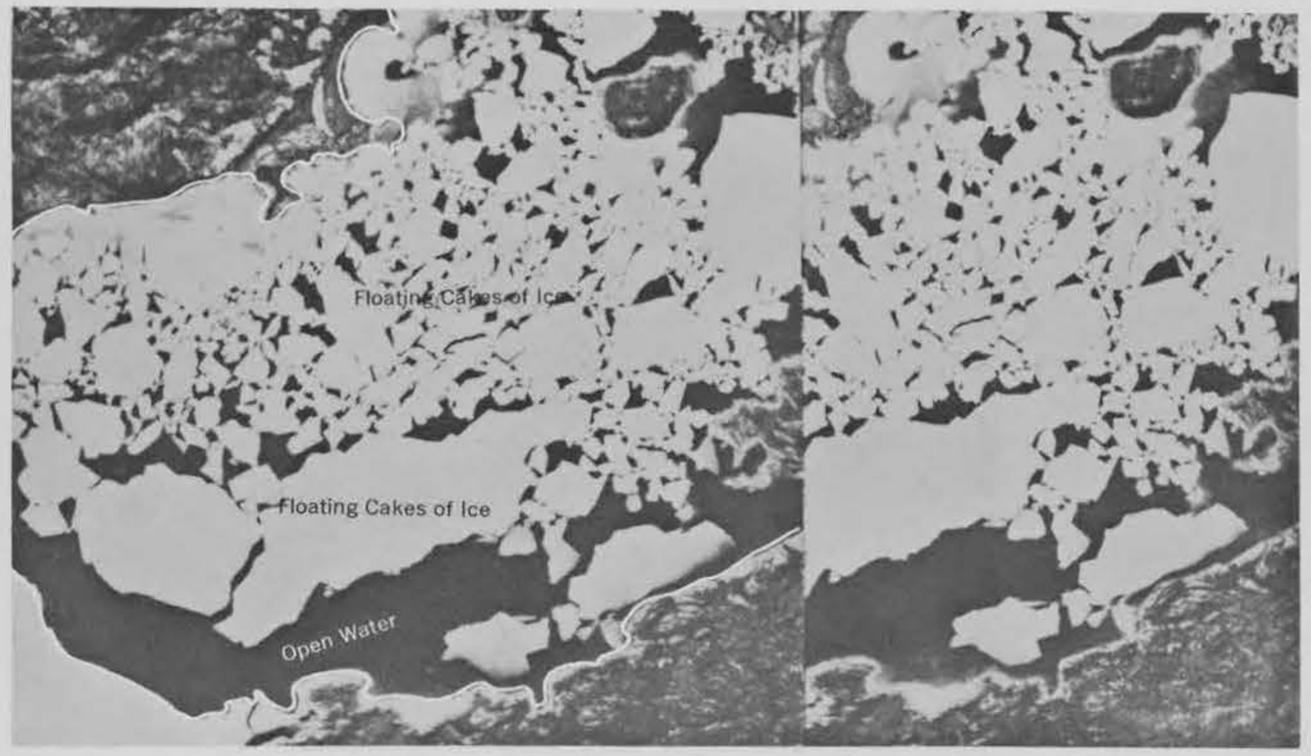

Figure 17: Thawing Ice
Scale Unknown

Note the typical honeycomb appearance of the surface of the melting ice.

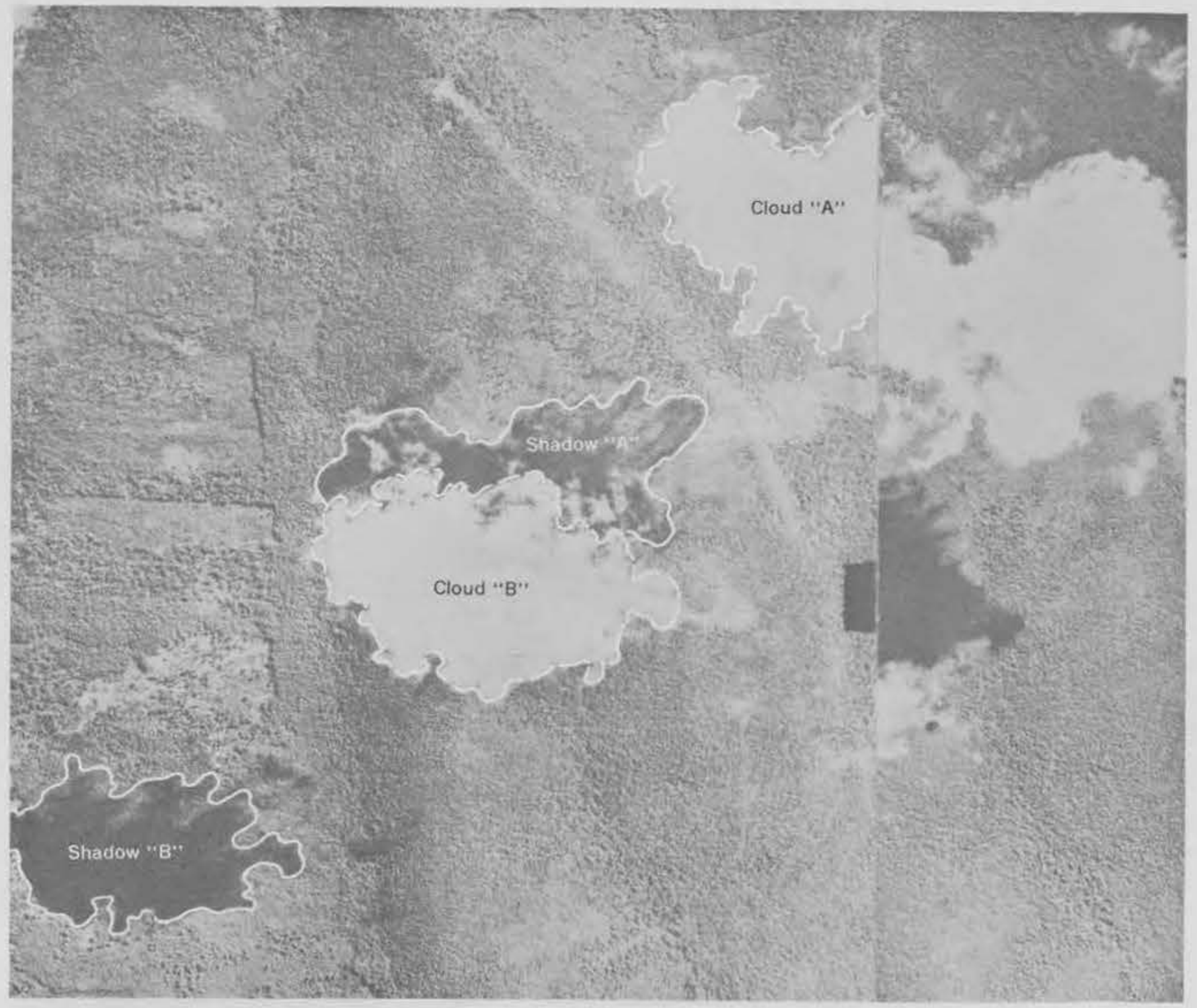

Figure 18: Cloud Image and Shadow
Scale Unknown

Cloud shadow B looks a little like a clear deep lake.

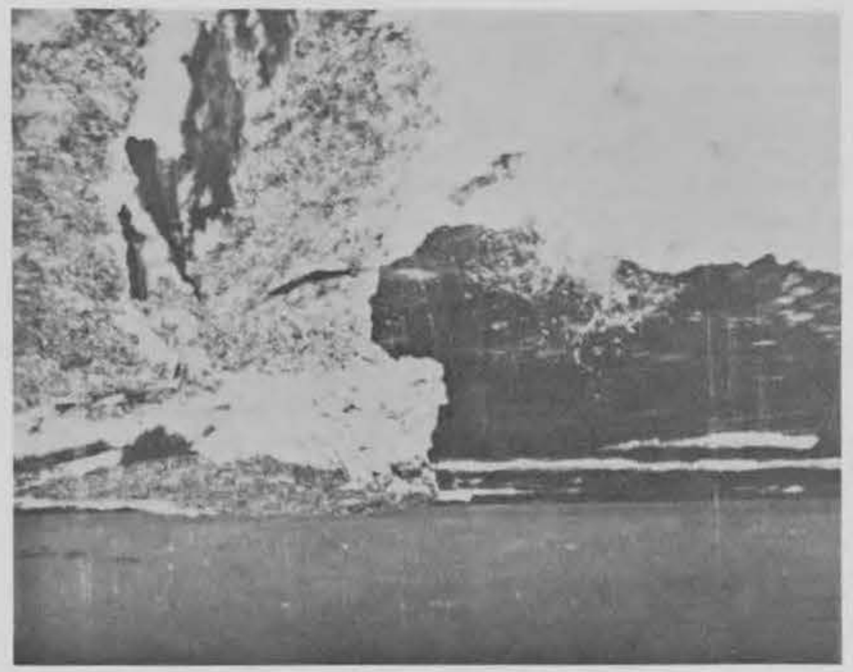

Figure 19: Ice Accumulated on Lake Shore
Scale Unknown

If this were an airphoto, the gray tones of the ice would blend so well with the tones of the shore that it would be difficult to delineate the shoreline.

Figure 20: Drying Lake
Scale Unknown

The exposed bottom of the drying lake has a slightly duller tone of gray than the muddy lake visible in the upper portion of the photograph.

11. Snow cover

a. Background. The term snow cover refers to the extent of the ground area covered by snow, regardless of the depth of snow or its water equivalent, while the term snowpack refers to the total volume of snow on a basin. Airphotos can be used to determine snow cover provided that the project is carefully planned by the hydrologist and closely coordinated with the pilot and the photo-interpreter. Airphotos are of very limited value, however, in estimating depth of snowpack and water-equivalent. The snow cover areas considered in this paragraph are located in mountainous terrain, and the data are used primarily to make short-range forecasts of runoff during the snowmelt season.

b. Recommended types and scales of photography. Vertical airphotos from 1:20,000 to 1:40,000 scale are recommended for outlining and measuring the snow cover. Large-scale obliques, verticals, and stereopairs are often useful in determining short lengths of the edge of the snow cover (snowline) in areas that are difficult to outline.

c. Recognition features. Snow registers on airphotos in light gray to white tones.

d. Interpretation problems

(1) The identification of snow, in most cases, is a deductive process that takes into consideration the time of year the photograph was taken and the geographic location of the area photographed, because the light gray to white tones registered by snow do not differ appreciably from those registered by hayfields, grainfields, and bare sandy or clay areas (figs. 21 and 22).

(2) The snowline during the winter accumulation period is fairly regular and varies primarily with elevation; however, during the spring snowmelt period, it becomes highly irregular and its delineation is very difficult (figs. 23-26).

(3) Some reaches of the snowline may be obscured by trees and shadows. In determining the snowline in heavily forested reaches, large scale oblique airphotos may be useful; however, in thinly forested areas large scale vertical airphotos will probably be the best.

e. Required information. Delineate and measure the snow-covered area.

Figure 21: Grainfield
Scale Unknown

The light gray to white tone registered by the grainfield is very similar to that registered by the same field (fig. 22) when covered with snow.

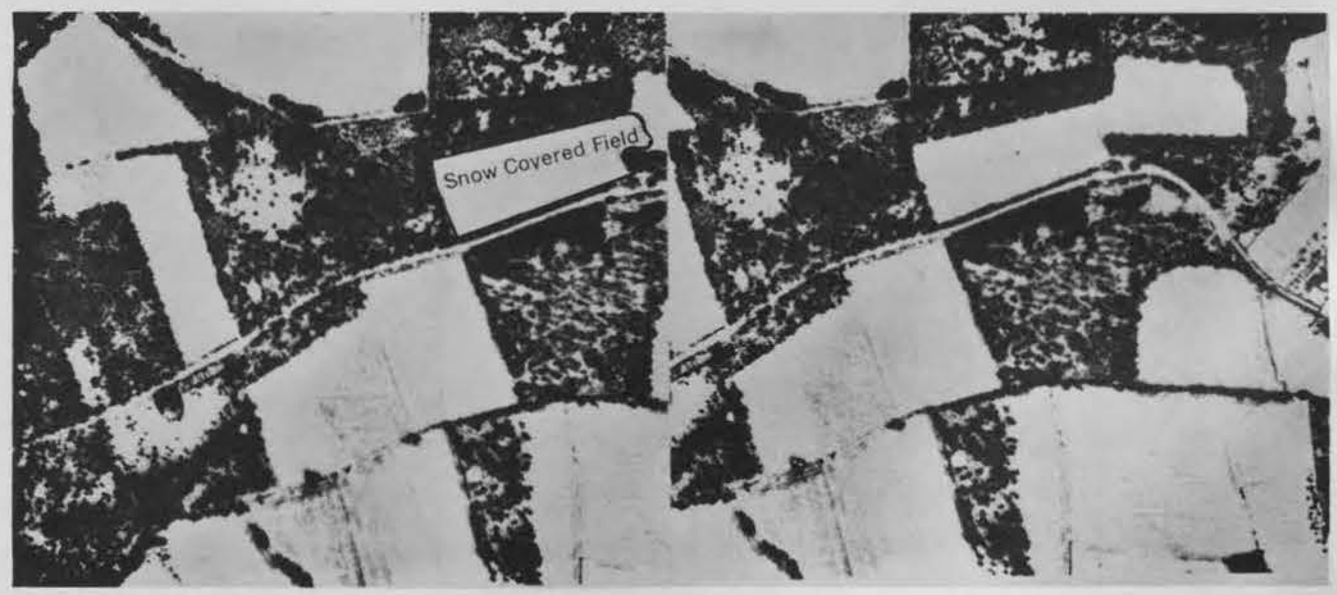

Figure 22: Snow-covered Field
Scale Unknown

Same field as one illustrated in Figure 21.

Figure 23: Mountainous Region, Partly Snow-Covered
Scale 1:45,000 (approx.)

This photo shows the condition of snow cover on 2 May, near the midpoint of the snowmelt season; note the wide diversity of areas bare of snow because of topographic variations in this fairly heavily forested mountainous region (elevation range from 4,500 to 8,600 feet msl). Seasonal progression of snow cover depletion within the dash-lined square is shown in Figures 24–26).

Figure 24: Snow Cover on 7 April
Scale 1:26,000 (approx.)

Dash-lined area of Figure 23 as it appeared on 7 April. Area practically entirely snow covered.

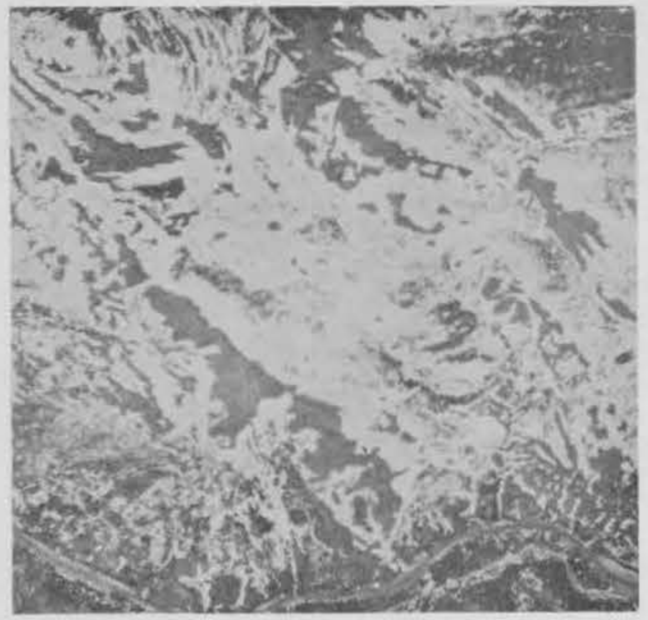

Figure 25: Snow Cover on 24 April
Scale 1:26,000 (approx.)

Same area, 24 April. Bare spots appearing on some wind-swept ridges and exposed slopes.

Figure 26: Snow Cover on 2 May
Scale 1:26,000 (approx.)

Same area, 2 May. Growth of bare spots since 24 April (Figure 25) is apparent.

12. Glaciers

a. Background

(1) Glaciers are classified as: ice streams, which form in mountain valleys and move downslope under the pull of gravity; and icecaps, now found only in the polar regions, which cover large land masses and spread out radially because of the great pressures built up by their weight. Ice streams have their sources at high elevations where low temperatures retard melting, and normally precipitation more than compensates for any losses from melting. The glacial cirques (steep-walled recesses) formed at the head of narrow mountain valleys by ice-flow erosion are so-called because they are shaped like large amphitheaters. This shape favors the accumulation of snow, because the wind blows snow from the adjacent slopes into the hollow. As a result, the annual increase of snow and ice on a glacier may be several times the actual amount of precipitation on the surface of the glacier itself.

(2) Runoff from glaciers occurs mostly in the summer and consequently does not normally contribute to flooding, because during this season rivers are usually at their lowest water level. Accurate estimation of runoff from a glacier requires the installation of various types of instruments in and around the glacier, and a fairly rigid schedule of observations. In the absence of this type of data airphotos can be used by the hydrologist to make a very crude estimate of the runoff potential. From airphotos he can secure the overall size of the glacier, trace the pattern of the streams that develop on its face, and estimate the dimensions of the stream or streams that develop below it.

b. Recommended types and scales of photography. For delineation and measurement of the surface area, vertical airphotos taken at scales from 1:30,000 to 1:50,000 are recommended, because these small scales cover a large area. For measuring the dimensions of the main outlet stream, vertical stereopairs at 1:5,000 are recommended (see par 16).

c. Recognition features

(1) Glaciers register on airphotos in much the same tone as snow -- light gray to white.

(2) An ice stream usually develops a pattern very similar to that of a fairly large stream and its major tributaries (fig 27).

(3) Flow lines or pressure ridges are plainly visible on the surface of a glacier. These lines diverge and converge around obstructions, curve around bends, and then straighten out. Tributary flow lines curve smoothly downslope and merge with the flow lines of the main glacier (fig 28). Crevasses, moulins (nearly vertical shafts in a glacier into which a stream of water pours), and sometimes streams of water (fig 29) are also apparent on the surface of glaciers.

(4) A glacial tongue, the ice front or terminus of a glacier, is usually fairly easy to identify because of its shape and the rough, pitted appearance of its surface (fig 30). A terminal lake may be impounded between the tongue and the terminal moraine (fig 31).

(5) The boundaries of a glacier are usually very well defined, because the white or light gray tone of the glacier stands out against the dark gray tones of the bare windswept terrain.

d. Interpretation problems. There are no significant interpretation problems.

e. Required information

(1) Outline the boundary of the glacier and measure its area (see fig 32).

(2) Estimate the cross-sectional dimensions of the main outlet stream below the glacier (not the streams present on the face of the glacier). For details of this phase of the interpretation, see Paragraph 16.

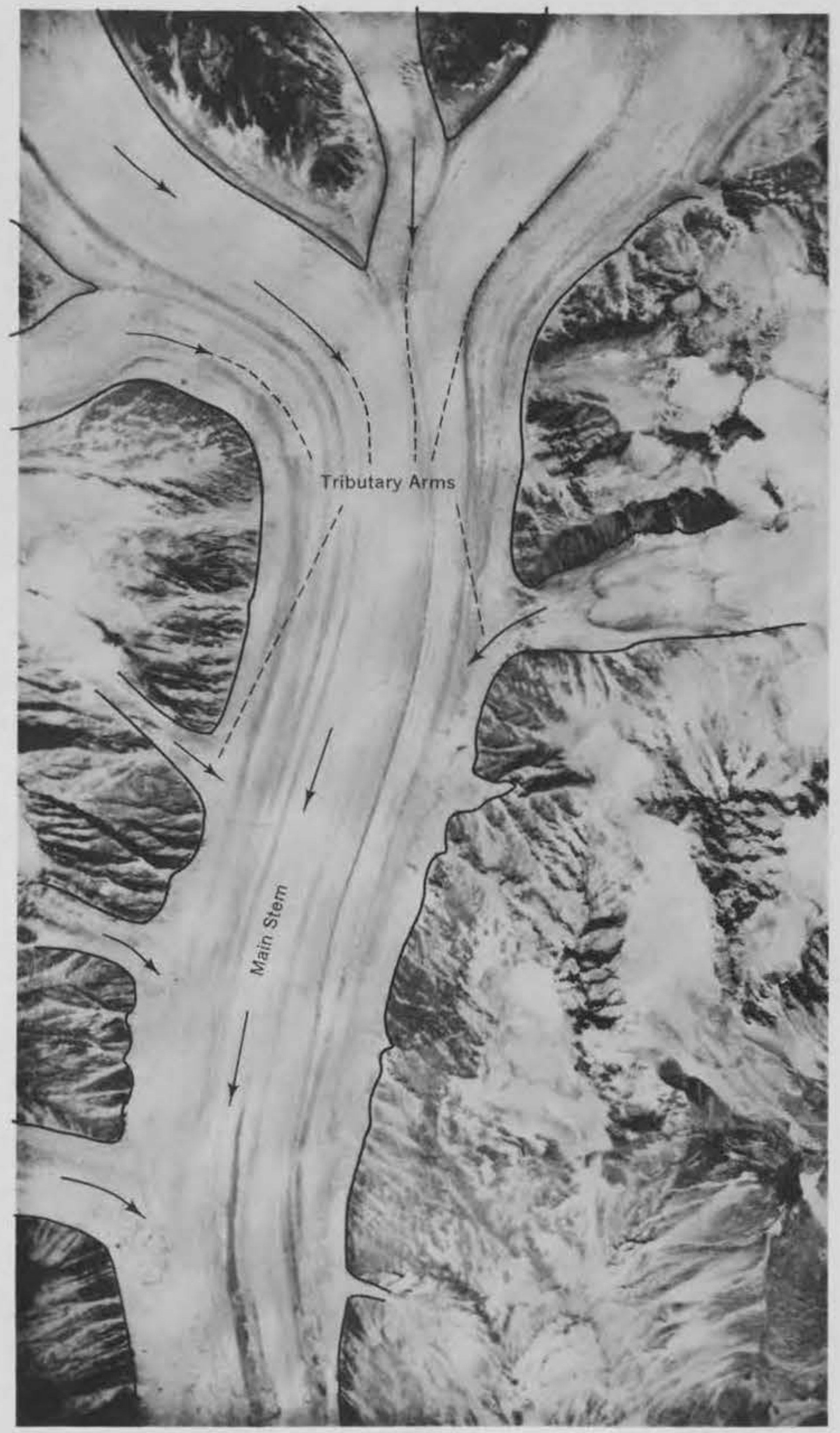

Figure 27: Ice Stream
Scale Unknown

Note the striking resemblance to a stream.

Figure 28: Glacial Flow Lines
Scale Unknown

Ice under sufficient pressure will become a viscous mass and will flow. The dark bands are flow lines (pressure ridges) indicating the direction of movement.

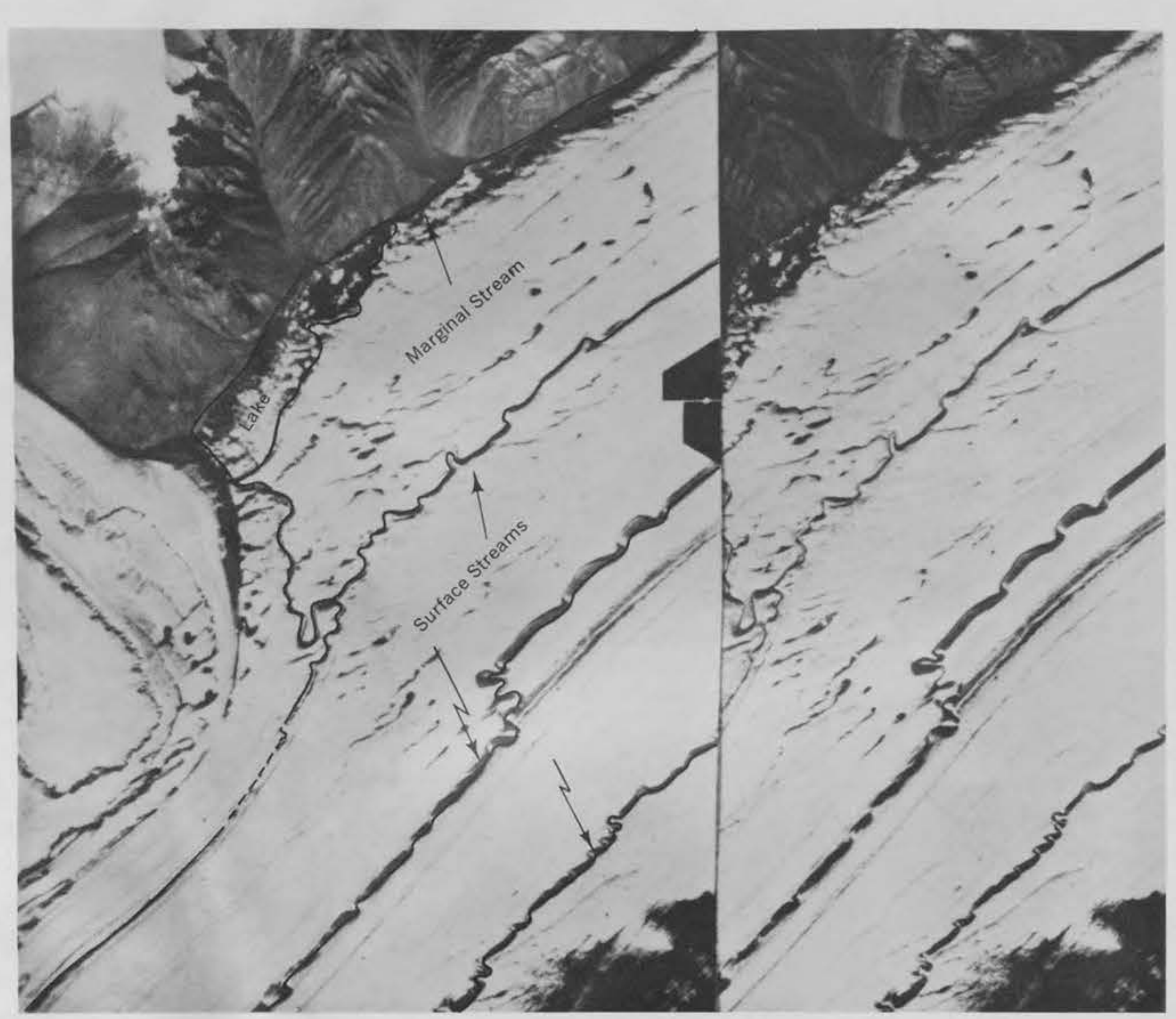

Figure 29: Streams on the Surface of a Glacier
Scale 1:42,000 (approx.)

Surface streams on glaciers are recorded on airphotos as dark gray lines. Their channels are often recognized by the shadows of their valley walls of ice. The marginal stream runs in a channel created at the contact line between the glacier and the mountain.

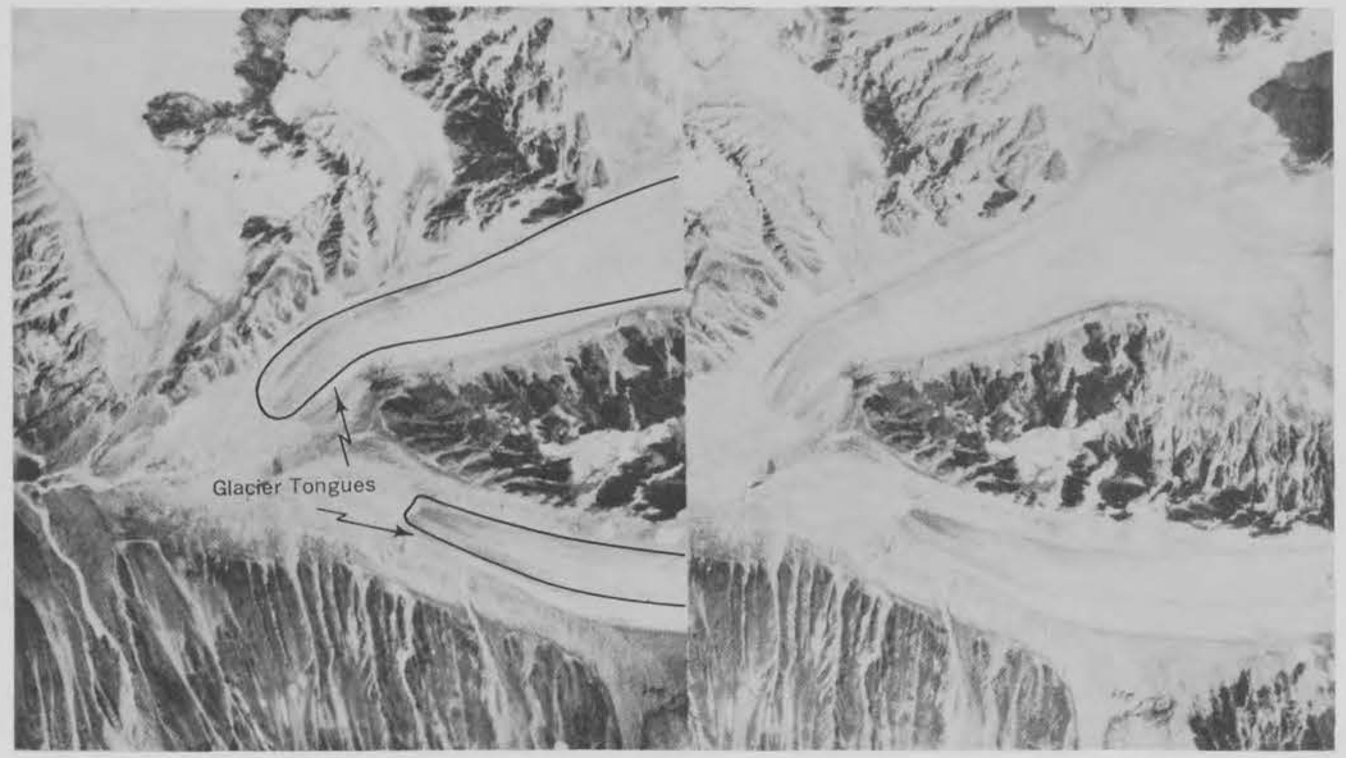

Figure 30: Glacial Tongues
Scale Unknown

The farthest downstream progression of a glacier is often marked by a tongue.

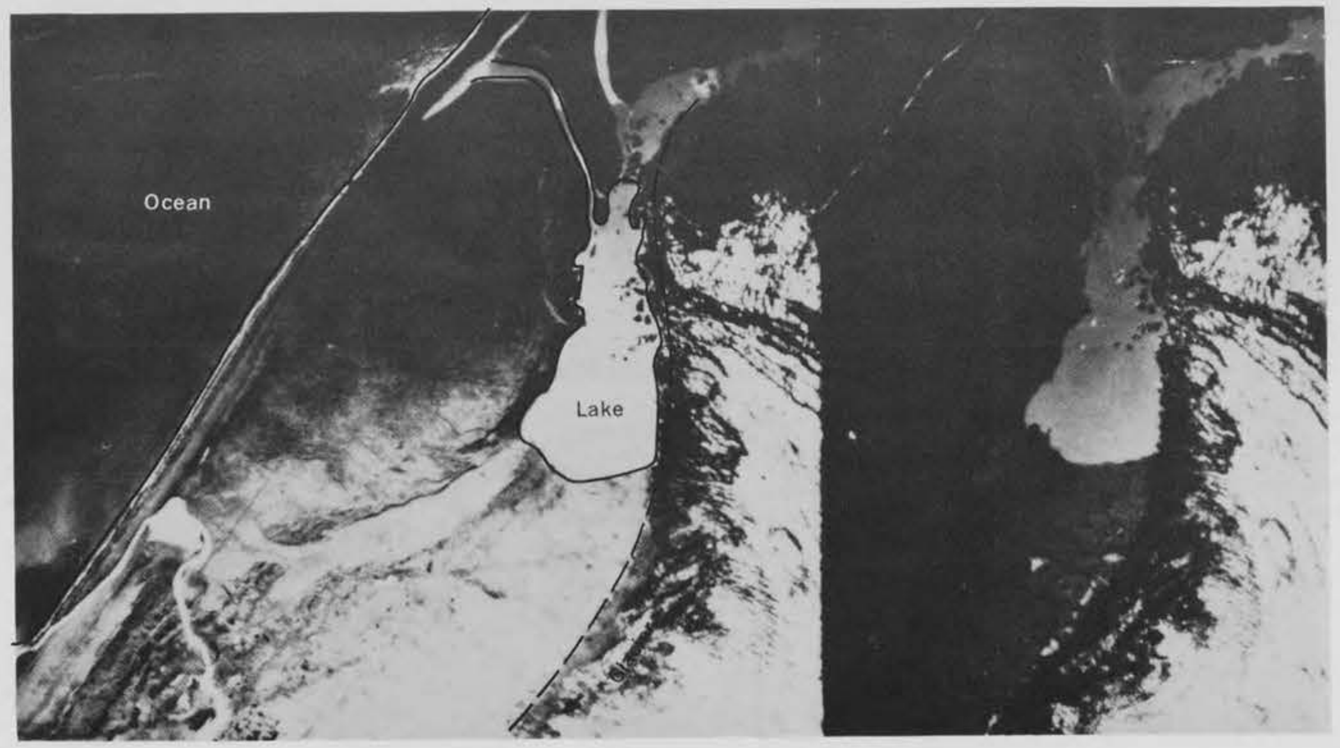

Figure 31: Lake at the Foot of a Glacier
Scale 1:48,000 (approx.)

The uniform light gray tone shows that the lake is heavily laden with sediment from the glacier indicating that the glacier is melting fairly rapidly.

Figure 32: Small Valley Glacier
Scale Unknown

The delineation of the boundary of a glacier is not difficult. If the scale were known here, the area of the glacier could be measured

13. Marshes and swamps

a. Background. Marshes and swamps are tracts of soft, wet ground supporting vegetation, and they may be covered with water to a slight depth. They are classified according to the type of vegetation present. If the only vegetation present is reed or moss, the area is classified as a marsh; if trees and bushes grow on its surface, it is classified as a swamp. The main stream channels in the marsh or swamp often remain open and act as both tributaries and distributaries. The water level fluctuates according to the stage of the master stream in the valley. Marshes and swamps, like lakes, occur all over the world wherever drainage is restricted, and are not confined to any one type of soil terrain. They are of interest to the hydrologist because they act as settling basins to absorb floods and provide temporary storage for runoff.

b. Recommended types and scales of photography. For identification, delineation, and measurement of surface area, vertical airphotos and vertical stereopairs at 1:20,000 scale are recommended.

c. Recognition features

(1) Marshes and swamps appear on airphotos as dark gray areas (fig 33). The dark gray tone is due to the ever present high water table. Boundary lines in a photo are indefinite, because the marsh or swamp appears to blend with the dry land.

(2) Large marshes or swamps may show a definite flow structure or drainage pattern (fig 33). The master stream in the area is generally meandering.

(3) Swamps have a gravelly or scabby appearance in an airphoto because of the presence of trees and bushes (fig 33); however, marshes usually appear velvety or mossy in an airphoto (fig 34).

(4) A type of marsh or swamp known as a muck channel develops when abandoned stream channels become filled with vegetation and sediment from floodwaters. The muck channel may be scarcely discernible to a ground observer but appears as a dark gray band in an airphoto (fig 35).

d. Interpretation problems

(1) It is very difficult to distinguish between muddy water covering a marsh or swamp and highly saturated soil (mud) (fig 36).

(2) The boundary line of a marsh or swamp is rather indefinite.

(3) The best method by which seasonal variations in the extent of marshes and swamps can be determined is to secure "before-and-after" airphotos. Such photography cannot be planned in advance and no rigid schedule can be followed; however, periodic interpretation over an extended period should reveal considerable information.

e. Required information

(1) Classify as marsh or swamp.

(2) Delineate and measure the surface area.

Figure 33: Swamp
Scale Unknown

This swamp exhibits a weak flow structure. The swamp is identified by its gravelly or scabby texture, different from the velvety or mossy appearance of the marsh in Figure 34. Note that the master stream is very meandering.

Figure 34: Marsh
Scale Unknown

This reed-filled marsh immediately around the lake is identified by its velvety or mossy texture. Note how this texture differs from the gravelly or scabby appearance of the swamp in Figure 33.

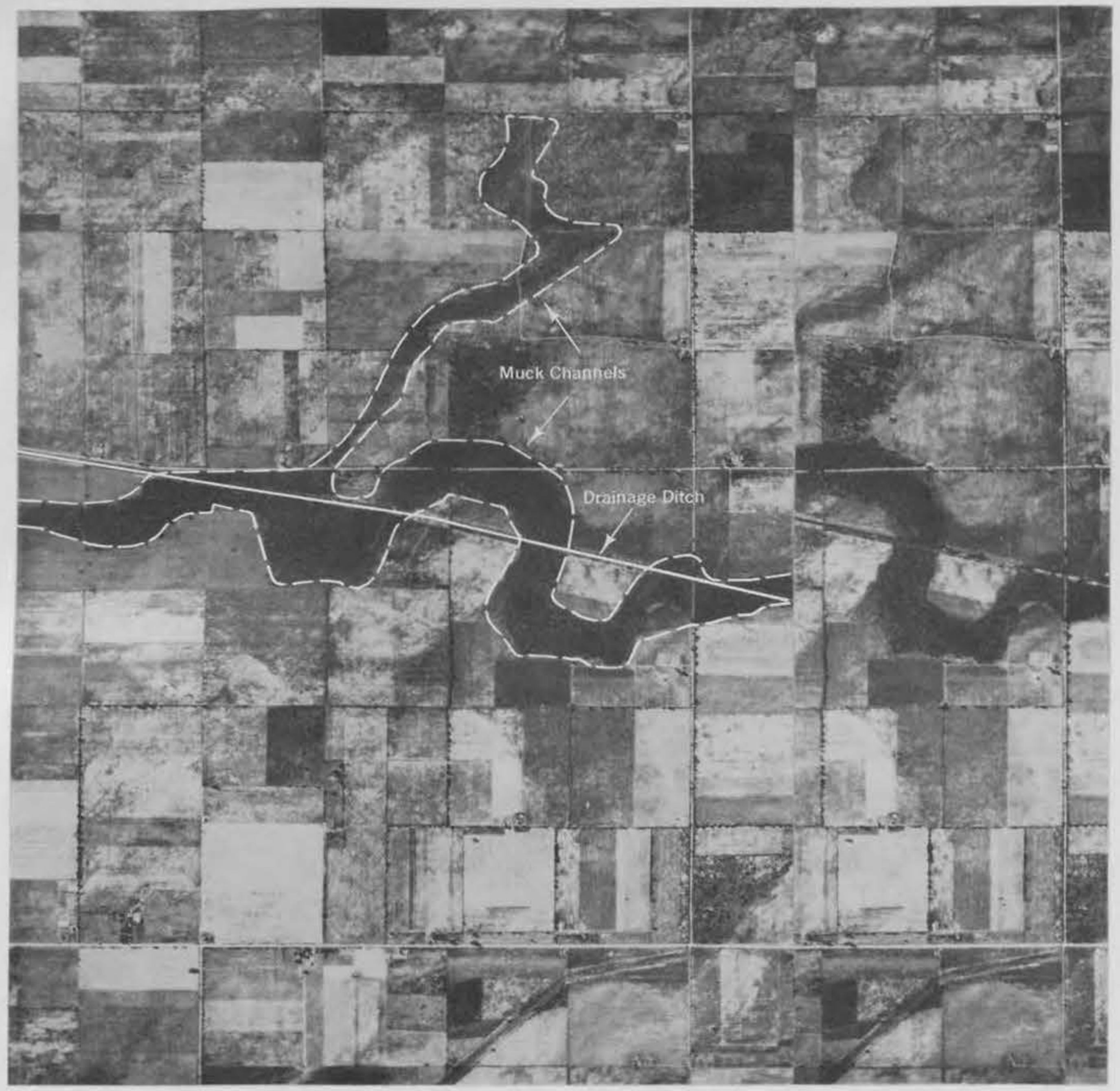

Figure 35: Muck Channel

The dark gray band is the muck channel that has developed from an abandoned stream channel. It contains no stream even though a slight depression exists. A ditch has been dredged to improve drainage conditions. The spoil banks of the ditch across the channel are dark gray in tone, indicating rather deep muck. The spoil banks across the high ground are light gray in tone, indicating granular material that drains freely.

Figure 36: Color Tones of Mud and Muddy Water
Scale 1:10,000 (approx.)

With the exception of the river channel itself, it is impossible to differentiate between the areas that are underwater and those that are not, because mud and muddy water register in the same light gray tone.

CHAPTER 4

HYDROLOGIC CHARACTERISTICS OF STREAMS

14. Background

a. The study of the hydrologic characteristics of streams involves hydraulics, the branch of science or engineering that treats of water or other fluid in motion. The hydrologic characteristics of a stream are affected by its physical characteristics, such as, width, depth, and slope. Hydrologic characteristics, such as, the volume and velocity of flow in a river at a particular time, may be roughly estimated from simple observation: e.g., at the time of observation, the river was apparently deep and slow moving. More precise determinations of physical and hydrologic characteristics require more, exact data and are difficult to derive from simple observation.

b. The data needed by the hydrologist for deriving the hydrologic characteristics of streams are divided into the following categories:

(1) Longitudinal stream profiles that show the slope of the water surface at various stages of flow, as well as the bottom slope.

(2) Cross-sectional dimensions of streams including both the channel and valley.

(3) Plan views of streams and their valleys that show the location of channel formations (such as, sandbars, rapids, waterfalls, boulders), flood plains, and land cover (forests, meadows, barren, cultivated, and urban areas).

c. If the accuracy requirements permit broad error limits, photographs may be used as a source of most of the required data listed in the three categories. If the accuracy requirements permit only narrow error limits, then with few exceptions, photographs may be used as a source of only category (3) information. Thus, the value of photographs as a source of information depends on the particular situation. For a summary of required information and an evaluation of photographs as sources of the data, reference should be made to Figure 1.

15. Stream slope and natural channel formations

a. Background

(1) The water surface slope of a stream is of great importance to the hydrologist, because the velocity of a stream varies approximately as the square root of its slope. The slope of a stream may be generally described (as low, moderate, or steep) from airphotos and, within broad error limits, from topographic maps. The water surface slope of a stream is not a constant figure for the whole length of a stream, but varies in different reaches.

(2) A general description of the slope of a stream may be made according to its alinement and certain formations occurring in its channel: sandbars, rapids, waterfalls, shoals, and alluvial fans.

(3) Precise determinations of slope for each length of stream at various water surface elevations require precise leveling and triangulation. Airphotos may be used in connection with established geodetic control points and benchmarks to determine water surface slope. Rivers in flood are photographed, and various distinctive points along the water's edge are noted on the photograph. After the water has receded, these points are located on the ground and their locations and elevation established by a survey party. The difference in elevation between upstream and downstream points is, of course, the fall of the river, and the water surface slope between the points can thus be computed.

b. Recommended types and scales of photography. To describe the slope of a stream without established survey control, vertical and vertical stereopairs of airphotos at 1:20,000 are recommended. For a stream with established survey control, vertical stereopairs of airphotos at 1:10,000 are recommended.

c. Recognition features. The physical features that are included here indicate the general nature of the stream slope. Making precise determinations of slope on streams with established control involves the recognition of the edge of the water, discussed in Paragraph 16.

(1) Slope-indicating features

(a) Low slope is generally indicated in the following instances:

1 Meandering stream lying in weak relief (fig 37)

2 Braided stream (fig 38)

3 Presence of numerous sandbars (figs 39 and 40)

4 River reach immediately upstream from a shoal (fig 42)

(b) Moderate slope is generally indicated in the following instances:

1 Long straight reaches in a predominantly meandering or braided stream without rapids or waterfalls (fig 41)

2 Meandering stream in strong relief without rapids, waterfalls, or numerous sandbars (fig 42)

3 Reaches immediately upstream and downstream from waterfalls or rapids (fig 44)

4 Reaches immediately downstream from a shoal (fig 42)

(c) Steep slope is generally indicated in the following instances:

1 The section of a river reach containing rapids, a waterfall, or shoal (figs 42-44)

2 Headwater streams (fig 45)

(2) Change in slope. This is indicated by the presence of an alluvial fan. The fan is composed of river sediment (fig 39) and occurs most commonly at river junctions (fig 40) -- wherever an abrupt change of slope occurs. See (1) above to describe slopes above and below an alluvial fan.

d. Interpretation problems

(1) Islands occur in any condition of slope, and there may be some difficulty in differentiating between them and relatively old sandbars. The surface material and vegetation cover on an island are usually similar to those on the surrounding terrain (fig 46). (Islands are usually composed of particularly resistant material, and the stream has cut its way through less resistant materials lying on each side of the island,) Sandbars, on the other hand, are composed of water-deposited material -- sand, gravel, or both, and the vegetation cover on old sandbars is composed of semi-aquatic fast-growing plants, such as salt cedar or willows (fig 47). Occasional sandbars may be found in any stream, but numerous sandbars are found only under low slope conditions.

(2) Streams in flood may inundate many slope-indicating formations; however, enough generally remain visible to make it possible to describe the slope. A river reach in flood has a slightly steeper slope than it has ordinarily (fig 48).

e. Required information

(1) Describe natural channel formations.

(2) Describe the water surface slope for various reaches of a stream.

(3) On photos of streams with established survey control points, locate the water's edge at various points. Orient the photographs to existing base maps or describe the location of the points in enough detail so that a survey crew can locate them in the field.

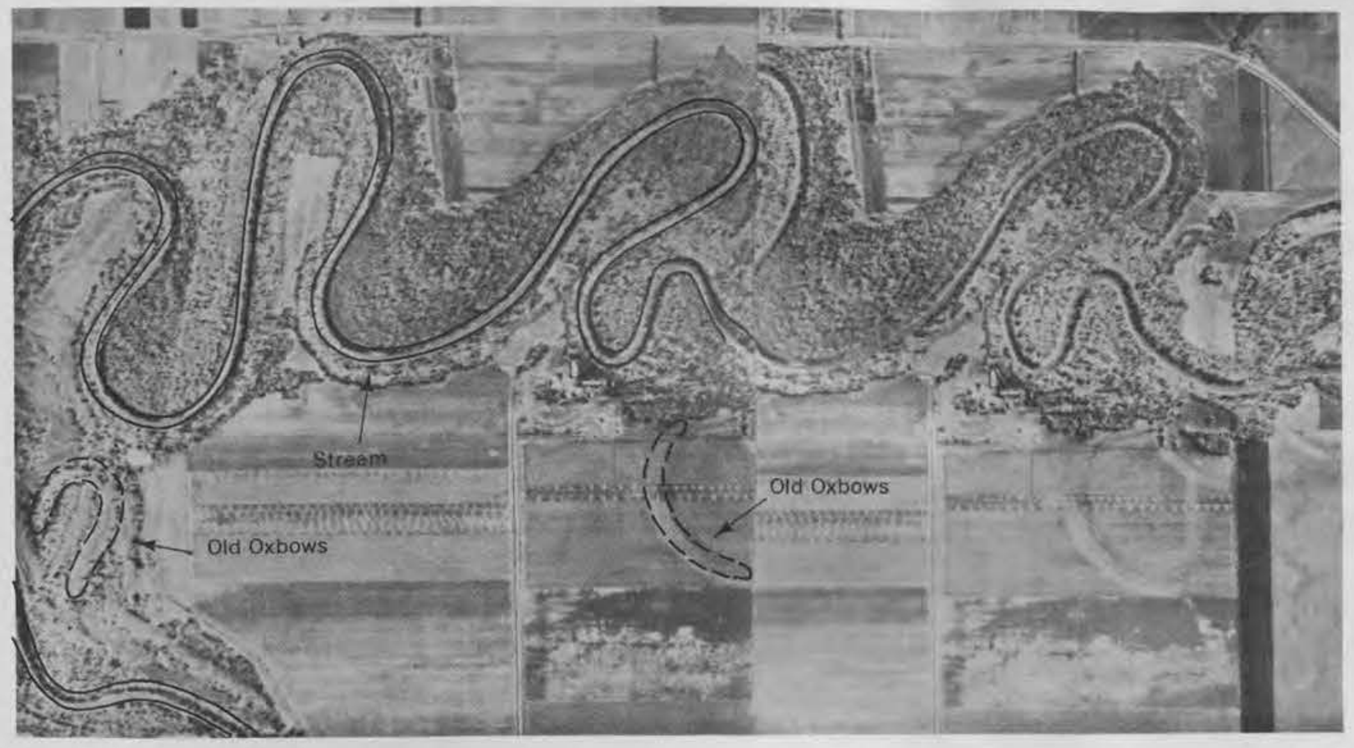

Figure 37: Meandering Stream in Weak Relief
Scale Unknown

The meandering course of the stream and the presence of old oxbows (abandoned meander loops) indicate that this reach of the stream has a low slope.

Figure 38: Braided Stream
Scale Unknown

The tangled interwoven pattern of a braided stream indicates a low slope.

Figure 39: Sandbars
Scale Unknown

The presence of numerous sandbars indicates low slope in the reach below the alluvial fan. The presence of the fan indicates a change in slope; hence, the reach above the fan is probably moderately sloped.

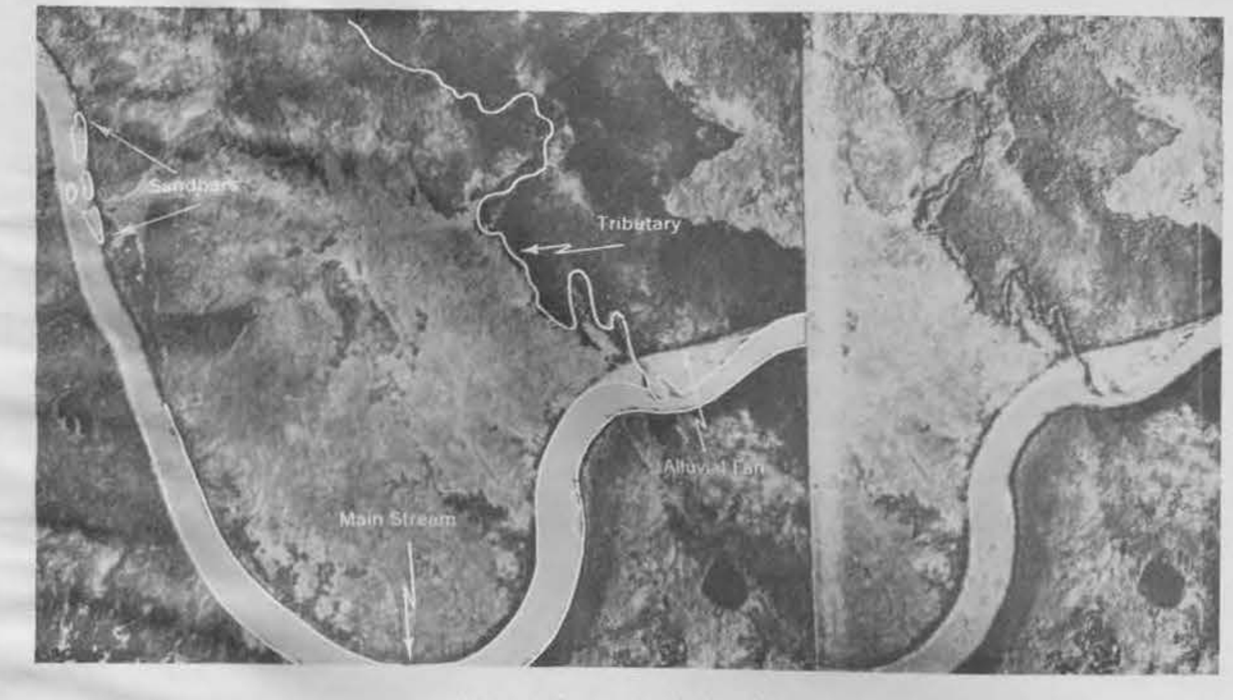

Figure 40: Sandbars and Alluvial Fan
Scale Unknown

The sandbars in the main stream indicate that it has a low slope. The alluvial fan at the mouth of the tributary indicates that the tributary slope is steeper.

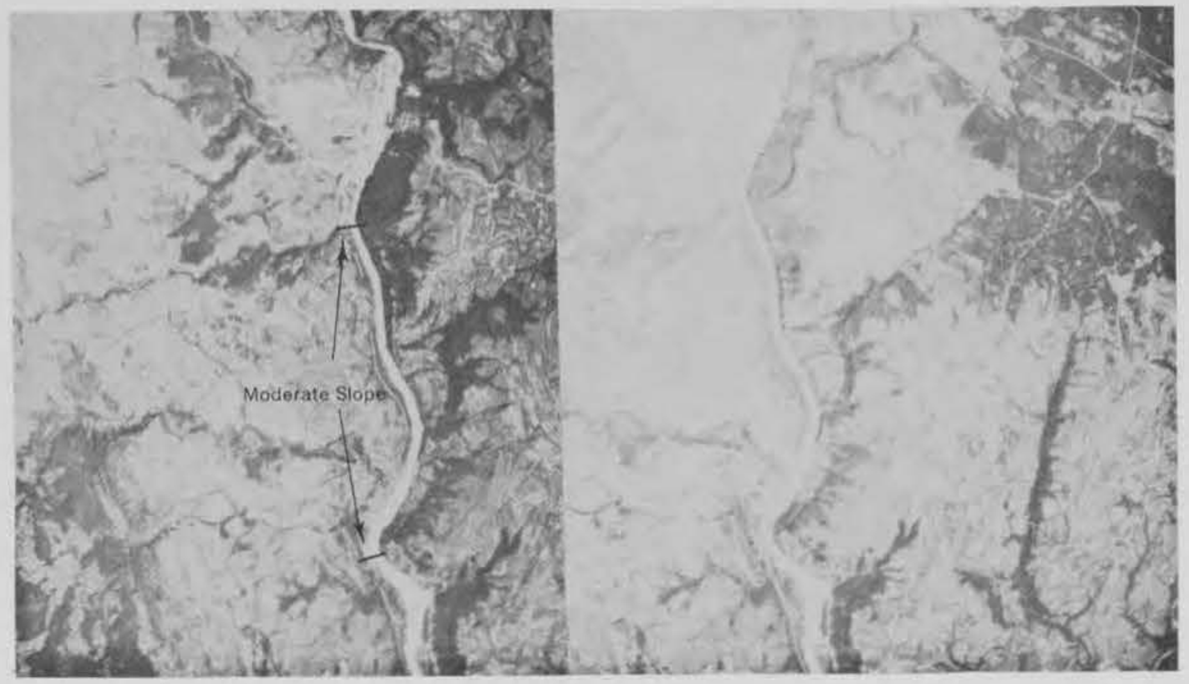

Figure 41: Straight Stream
Scale Unknown

This stream reach is moderately sloped, because the channel is straight, the relief of the area is fairly strong, there is only an occasional sandbar, and there are no rapids or waterfalls.

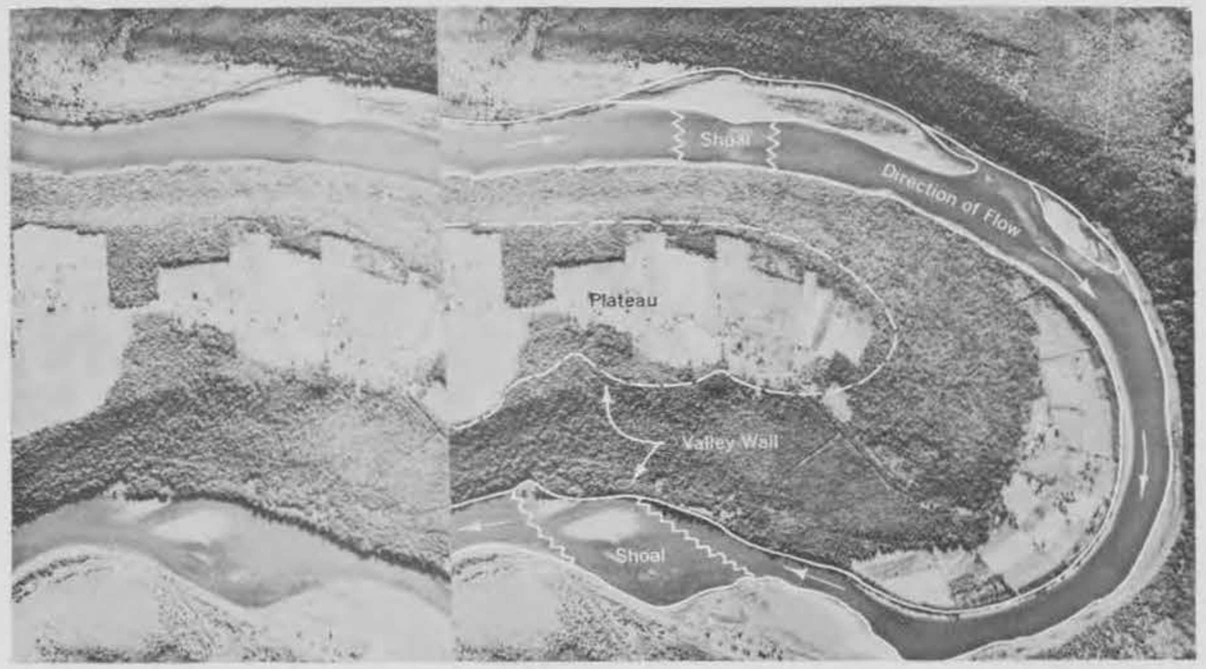

Figure 42: Meandering Stream in Strong Relief
Scale Unknown

The slope of this meandering stream ranges from moderate to low in the reach between the upstream and downstream shoals.

Figure 43: Rapids
Scale 1:2,600 (approx.)

Rapids indicate steep slopes and show on airphotos as scaly textured areas in the smooth textured ribbon representing the stream. When viewed in stereo, the area has a choppy, rough appearance.

Figure 44: Waterfall
Scale Unknown

The river has cut its way through a resistant layer of stone. Water is ponded behind the falls, and in this ponded reach the slope is moderate to low; however, at the falls and downstream of the falls the slope is steep.

Figure 45: Mountain Stream

The slope of a stream is always steep in its headwater reaches. These mountain streams have a very steep slope.

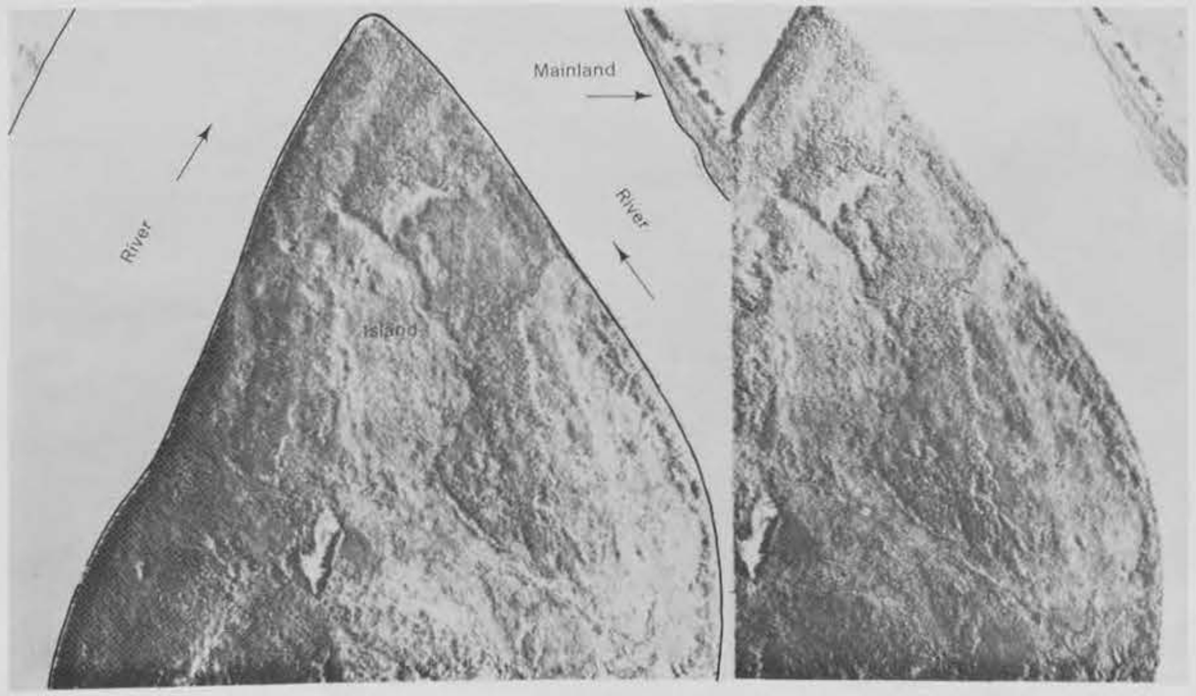

Figure 46: Island

An island is formed when a river forks and cuts off a piece of the mainland. The vegetation of an island is usually similar to that on the mainland. Islands may be found under any conditions of slope, and hence cannot be used as a definite indicator of slope.

Figure 47: Old Sandbar

The presence of the sandbar indicates that the slope is low. The sandbar has been exposed for a number of growing seasons as indicated by the vegetation.

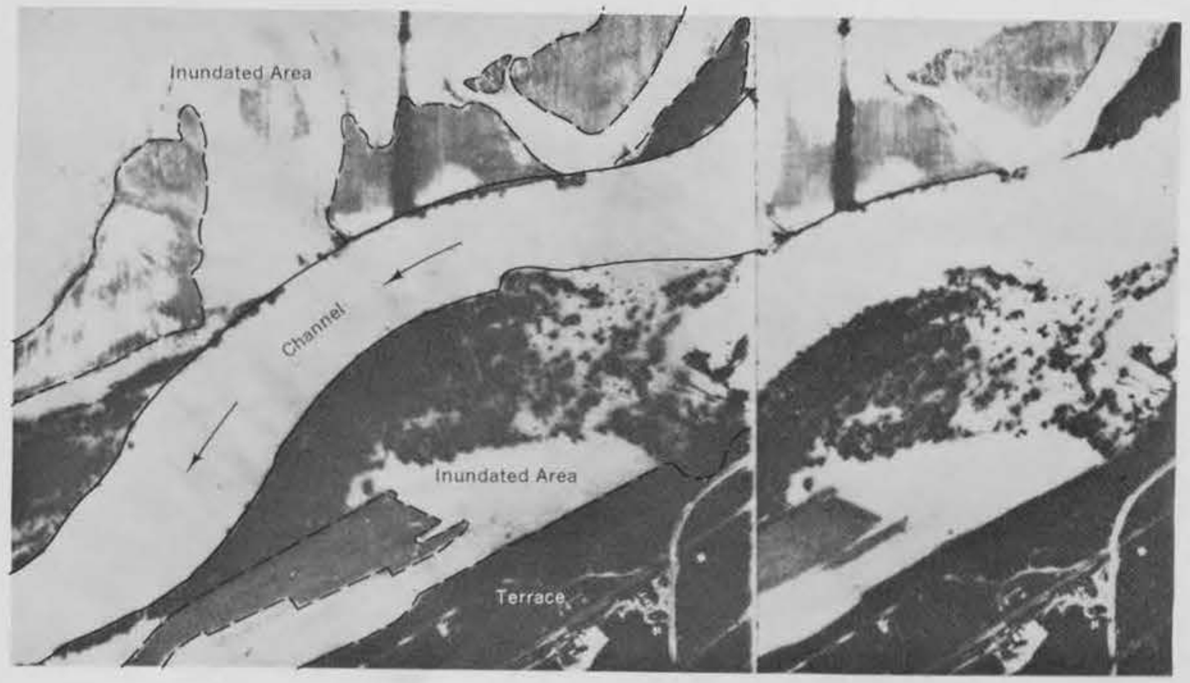

Figure 48: Stream in Flood
Scale 1:7,500 (approx.)

This stream in flood has a steeper slope than it would have under normal flow conditions.

16. Streambeds and banks

a. Background. The size and configuration of the cross-sectional opening of a stream are needed to determine the depth, rate, and volume of flow. Precise determinations of the size and configuration of a stream cross section require precise leveling and triangulation. Photographs, however, are sources of data for making rough estimates of the required dimensions, as well as good descriptions of the valley floor, streambed, and streambanks. Photographs can therefore furnish most of the information needed by military field units, for example, for planning a stream-crossing operation.

b. Recommended types and scales of photography. The following are recommended:

For measuring stream depths: vertical stereopairs at 1:5,000.

For measuring widths and bank heights: vertical stereopairs at 1:20,000.

For descriptions of bed and bank material: verticals and low obliques from 1:2,000 to 1:5,000.

For descriptions of vegetation cover of valley floor: verticals and low obliques at 1:20,000.

c. Recognition features. Successful establishment of measurement points requires the recognition of the water edge under the following conditions:

(1) Clear, deep water in contact with sandbanks or open turfed banks has a dark tone, and the water edge is easily distinguished (fig 49).

(2) Clear, deep water in contact with an eroded bank also has a dark tone. The water edge in this case is jagged, and care must be exercised in establishing the mean width (fig 49).

(3) Clear, shallow water over a sandy beach has a bright tone. The line may be difficult to determine, because there is usually a strip of saturated sand along the water edge that has almost the same bright tone. The water edge is easy to determine, however, if the water surface has been at or near the same level for some time. Careful examination of the area on a good-quality, large-scale vertical stereopair will often reveal a small shelf that is formed along the water edge by the action of the water. The shelf appears as a dark band between the shore and water surface (fig 50, lefthand photograph).

(4) Aquatic vegetation has a speckled surface appearance. The water edge is the boundary between the aquatic vegetation and the bank.

d. Interpretation problems. In many cases, the water edge is concealed by shadows of trees, bushes, etc., and the clarity with which it is defined depends upon the density and continuity of the shadows.

(1) When the shadows are not very dense, a thin white line formed by reflections on the water surface outlines the banks and without great error may be assumed to delimit the water edge (fig 50, righthand photograph).

(2) If the shadows are dense but broken, the water edge can be determined at unshadowed points and estimated in the shadowed portions on the basis of these points (fig 51).

(3) When a dense unbroken shadow occurs, the water edge cannot be determined.

e. Required information

(1) Make an overlay of the photograph with:

(a) Annotated outlines of the areas of the valley floor that are forested, barren, cultivated, meadow, etc., and

(b) A line representing the alinement of the valley cross section under study.

(2) Describe the following:

(a) Streambed and bank material (References 4 and 15 contain useful details for identification of soils).

(b) Bank (eroded, turfed, etc.).

(c) Bank slope (overhanging, steep, moderate, etc.), if not measured.

(3) Measure the water surface width on a line perpendicular to the long axis of the stream channel and from water edge to water edge (fig 52).

(4) Measure the height of the bank from a point on the water edge to the top of the bank (fig 53) and the horizontal distance from the top of the bank to the water edge. Compute the bank slope by dividing the height by the horizontal distance.

(5) Estimate the depth of water. This may be estimated if: 1) a high-quality vertical stereopair at a scale no smaller than 1:5,000 is available, 2) the water at the time of photographing was clear, and 3) some feature of bottom relief is visible enough to use as a fixed bottom point. The depth from a selected point (either on the water surface or at the water edge) to the fixed bottom point may be obtained by using some device for measuring parallax. The depth derived must be multiplied by a factor that accounts for the difference in refraction between water and air. This factor varies according to the angle of the camera lens as shown below:

Lens	Refraction factor
Narrow angle	1.38
Normal angle	1.40
Wide angle	1.44

Figure 49: Water Edge, Smooth and Eroded Bank
Scale Unknown

The location of the water edge in the lefthand photograph is not difficult. Establishing the average width of the stream will require several careful measurements, however, because of the jaggedness of the eroded bank.

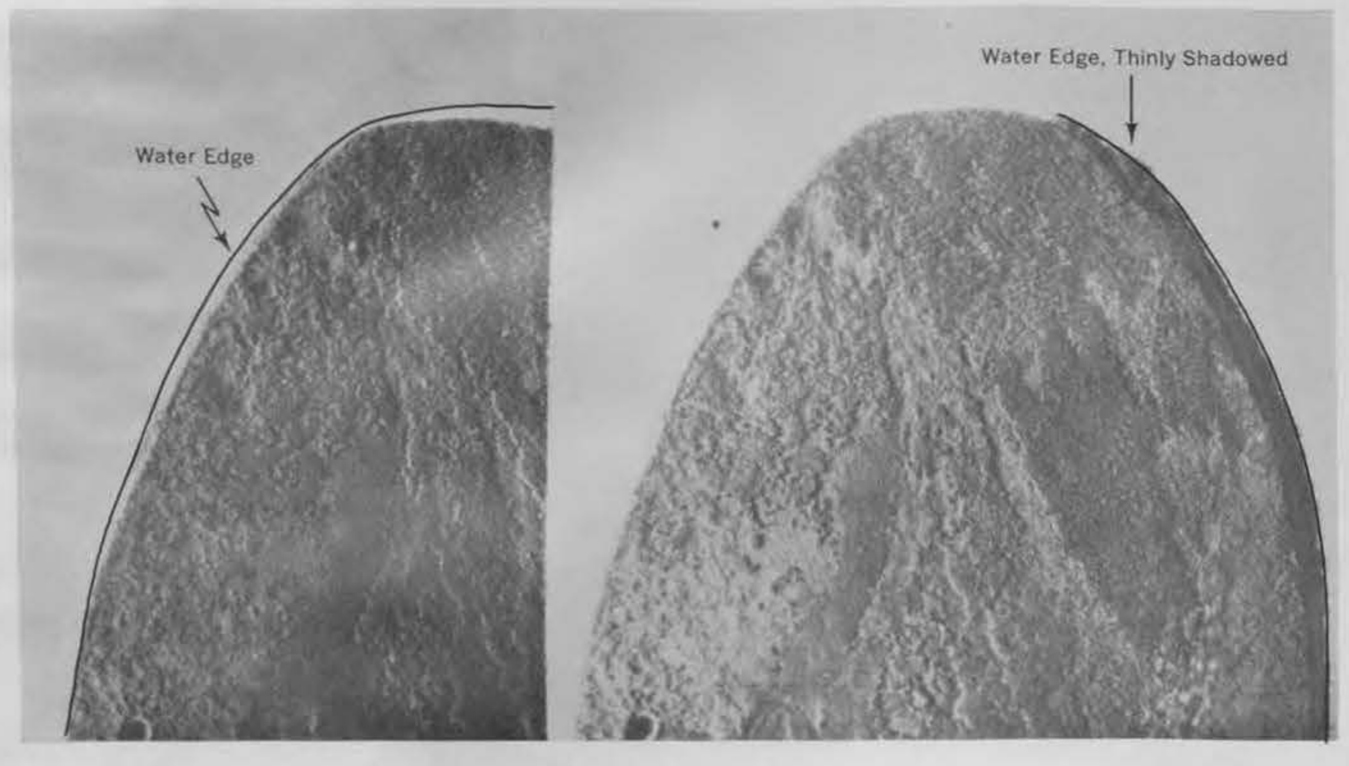

Figure 50: Shoal Banks
Scale 1:21,000 (approx.)

The small shelf, the dark band along the left side of the island, marks the water edge. It is visible between the very light gray tone of the sandy beach and the somewhat darker gray of the water (indicating that the river has maintained this condition or stage of flow for some time). The right side of the island is thinly shadowed. Here the outer edge of the light toned bank marks the water edge.

Figure 51: Screening Effect of Trees
Scale Unknown

The water edge is entirely screened by the shadows of the trees; it is assumed, however, that a line; parallel to and following the curving tree belt connecting point A to point B; would be a reasonable estimate of the water edge.

Figure 52: Stream Width Measurement
Scale 1:20,000

The width of the river at point A is found to be 0.25 inches on the photograph. At the scale of 1:20,000, 1 inch equals about 1,665 feet; therefore, the actual width of the river is about 416 feet (1,665 x 0.25=416).

Figure 53: Bank Height Measurement
Scale 1:21,000

The bank height is determined by the following formula:

$\triangle h = (H/b) \triangle p$

where: $\triangle h$ = height of the bank

b = (2.66 inches) average distance between the principal points of the overlapping photographs

$\triangle p$ = (0.002 inches) differential parallax between point A and the water surface

and $H = Sh(F)$

where: Sh = (1 inch = 1,750 feet) approximate average scale of the photo

F = (8.25 inches) focal length of the camera

and H = (1,750 x 8.25 = 14,400 feet) height of plane above the ground

therefore: $\triangle = \frac{14{,}400 \times 0.002}{2.66} = 11$ feet (approx.)

17. Flood plains

a. Background. For the purposes of this key, stream flood plains are considered to be areas that exhibit evidence that they have been underwater some time in the past five to ten years.

b. Recommended types and scales of photography. For the location and description of flood plains, vertical airphotos at a scale of 1:10,000 up to 1:30,000 are recommended. For the identification, delineation, and measurement of a flood plain, vertical stereopairs of airphotos at 1:20,000 are recommended.

c. Recognition features

(1) A stream having a flood plain generally has a meandering course; the flood plain is usually a band of fairly level alluvium. Flood water fluves (channels or ponds in which floodwaters flow or stand) are often present in the flood plain (fig 54).

(2) Streams often form natural levees that may be easily distinguished from manmade levees. They are not regularly alined and do not have regular geometric cross sections. They have numerous irregularly spaced low sections that are frequently overtopped by high water. Other sections are high and overtopped so infrequently that vegetation often grows on them (fig 55). The levee serves as a divide separating the flood plain from the river channel.

(3) In well defined valleys the boundary of the flood plain may be described as the line dividing the uniform gray flood plain area and the variegated mosaic of the valley (fig 56).

(4) The valley of a meandering river often has "displacement fans" (old abandoned meander loops or oxbows). The line encompassing such fans may be considered as the boundary of the flood plain of such a river (fig 57).

(5) Vestiges of former high water levels may be used to delimit the flood plain. During floods a shoulder is often formed as a result of undercutting; the slope of this shoulder can often be recognized as a bright band (fig 58). The debris (fig 59) deposited as a flood recedes can be traced on a photograph; brush or twigs appear as a bright irregular line; larger debris, logs, trees, etc., can be clearly distinguished.

(6) In many cases the edge of the flood plain may be considered to be the lower edge of any plowed ground, since usually only land beyond the reach of frequent flooding is cultivated. Near populated places, however, portions of frequently flooded areas may be devoted to truck farming. Truck farming areas are normally small plots of land and appear as a variegated mosaic on airphotos (fig 60).

d. Interpretation problems. Flood plains are bare, forested, or turfed. If densely forested, a flood plain is difficult to recognize and cannot be delineated. If enough ground may be seen to estimate the relative elevation of the terrain in respect to the river bank, it might be determined that a relatively small rise of the river's water surface would overflow the area. No exact outline of the flood plain could be determined.

e. Required information

(1) Describe the area: its orientation to the stream and its vegetative cover.

(2) Measure the surface area.

(3) Determine the average width and length.

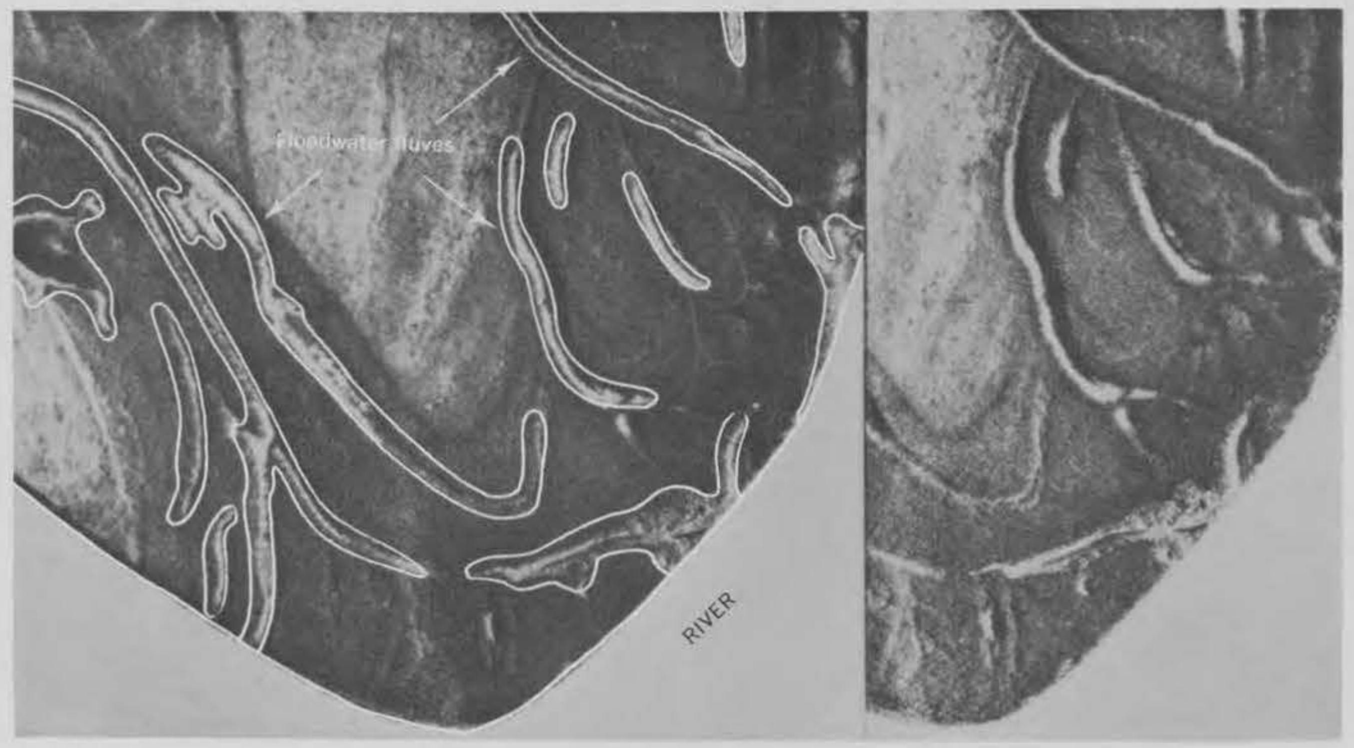

Figure 54: Floodwater Fluves
Scale Unknown

The floodwater fluves (channels or ponds in which floodwaters flow or stand) indicate that the area is frequently flooded; hence; a line marking the outer limits of the fluves would encompass the flood plain.

Figure 55: Natural Levees
Scale Unknown

This river is in flood, and some of the lower portions of the natural levee system are underwater. Other portions are high enough to support vegetation on the crest and landward slope.

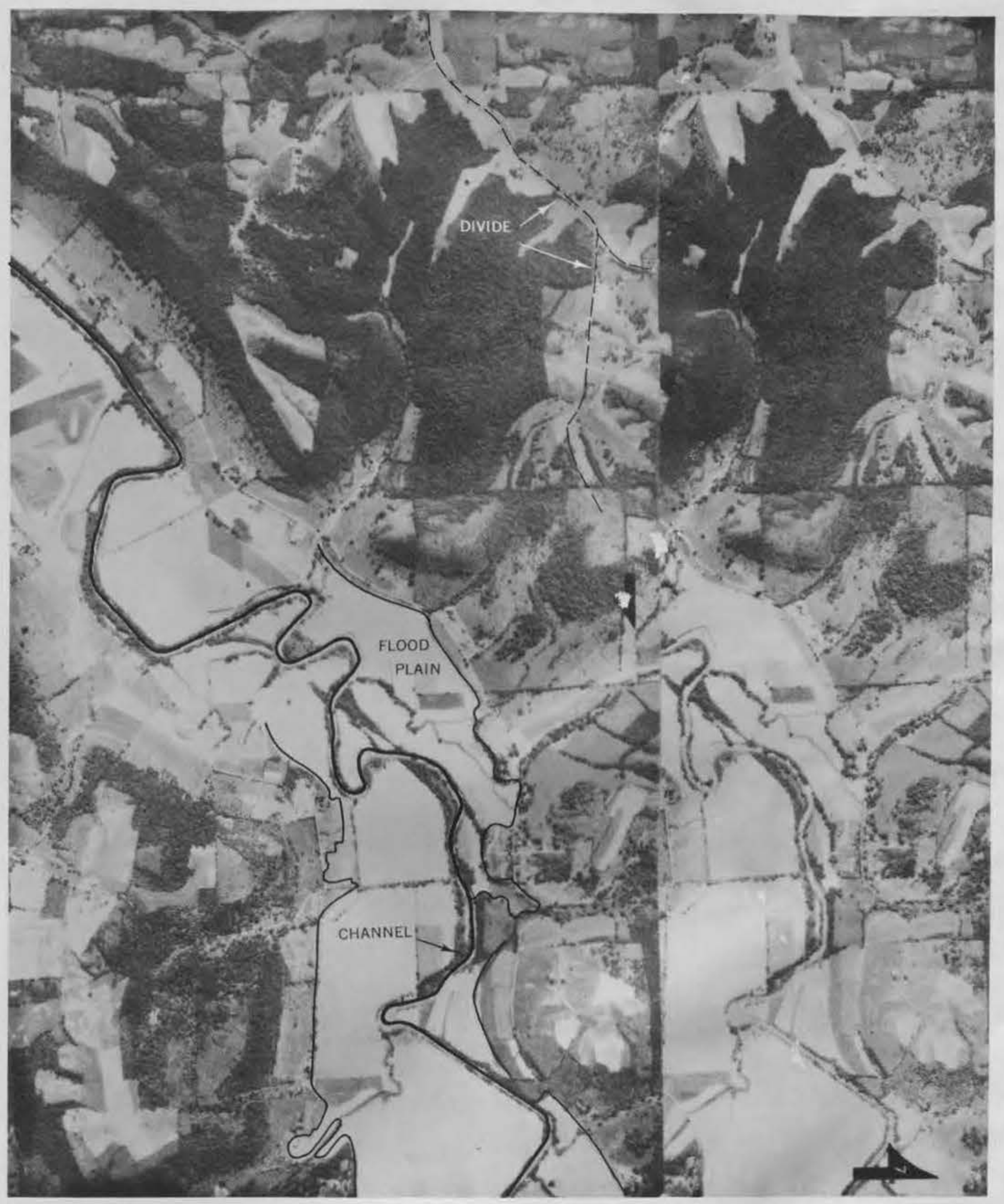

Figure 56: Flood Plain in Well-defined Valley
Scale 1:21,000 (approx.)

The entire flood plain is probably inundated at least once every ten years and large portions of it annually. This is evidenced by noting that: 1) all dwellings are located on the toe of the valley slope; 2) although fields can faintly be distinguished, the flood plain has a washed appearance; and 3) the gray tone of the flood plain indicates a heavy deposit of sand from a fairly recent flood.

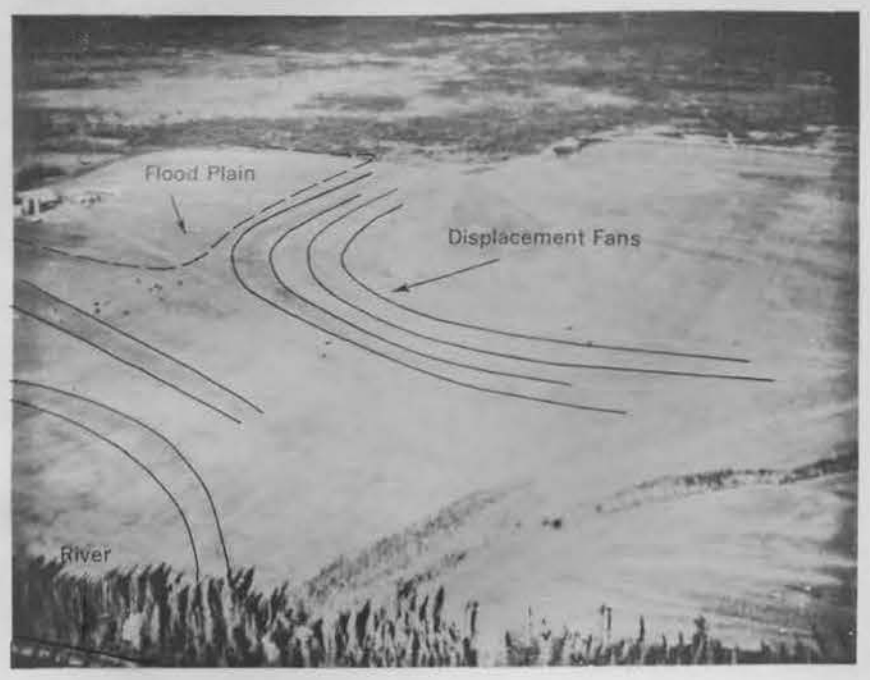

Figure 57: Displacement Fans

The flood plains of meandering rivers are marked with the remnants of old meander loops that have been nearly filled with sediment left by receding floods.

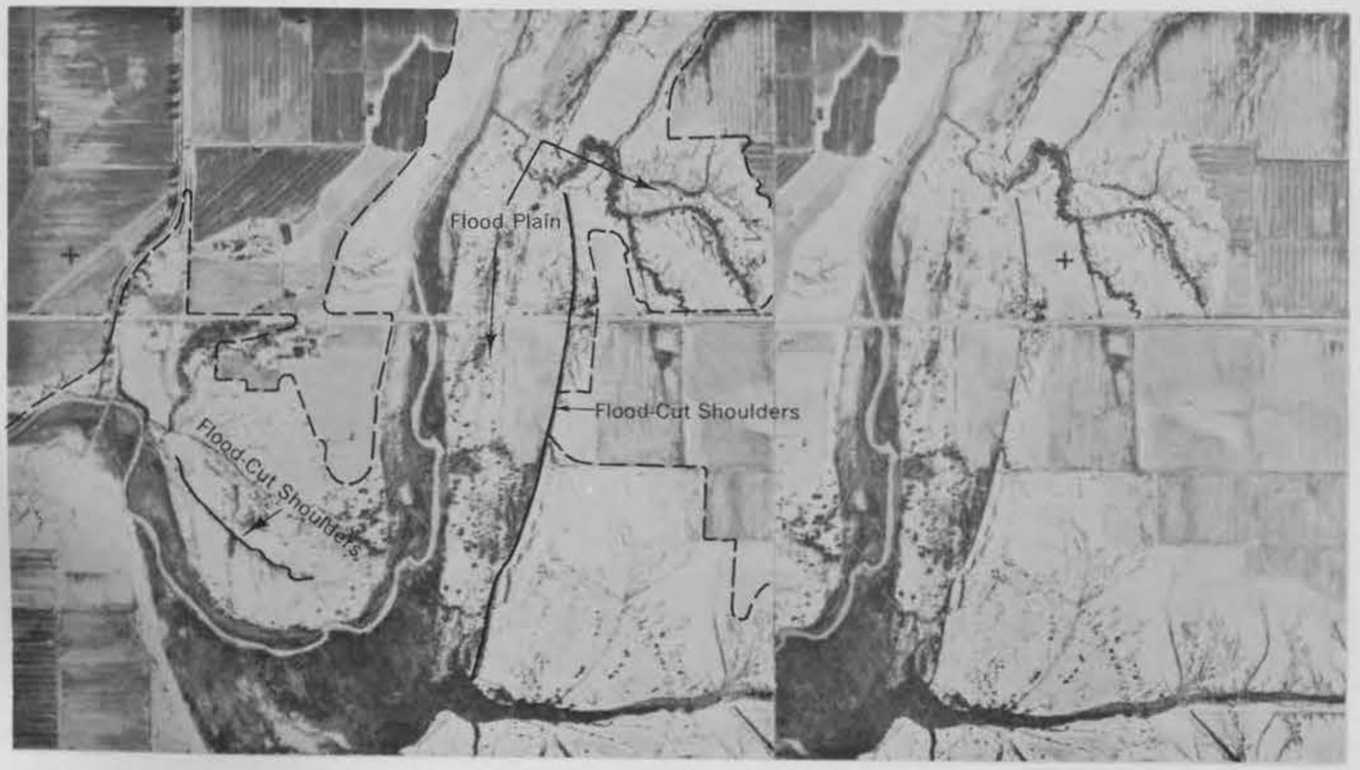

Figure 58: Flood-cut Shoulders
Scale Unknown

This stream is evidently very violent during most stages of flooding. In addition to the high steep shoulder cut by a large flood, there are many others between it and the river cut by smaller floods.

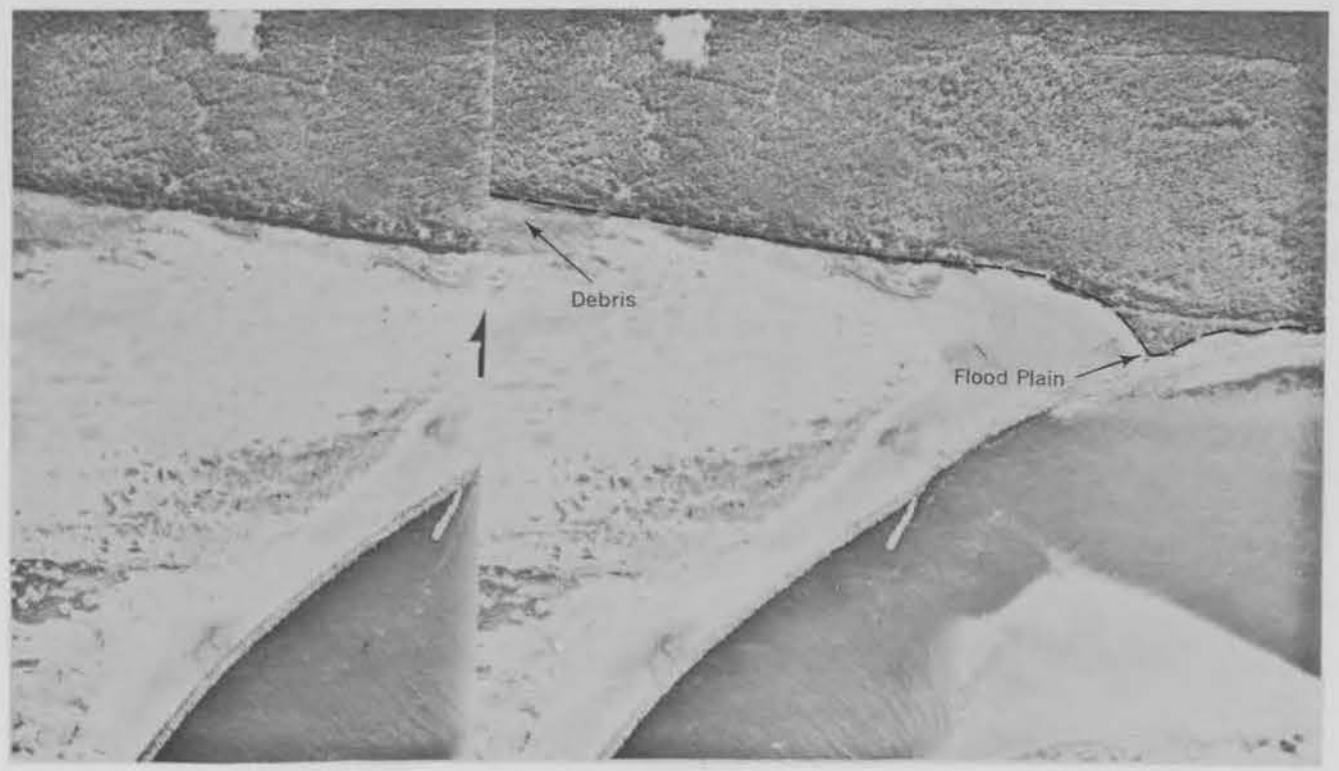

Figure 59: Flood-deposited Debris
Scale Unknown

The log-drifts along the flood plain boundary line shown on the photo indicate the overflow limit of a past flood.

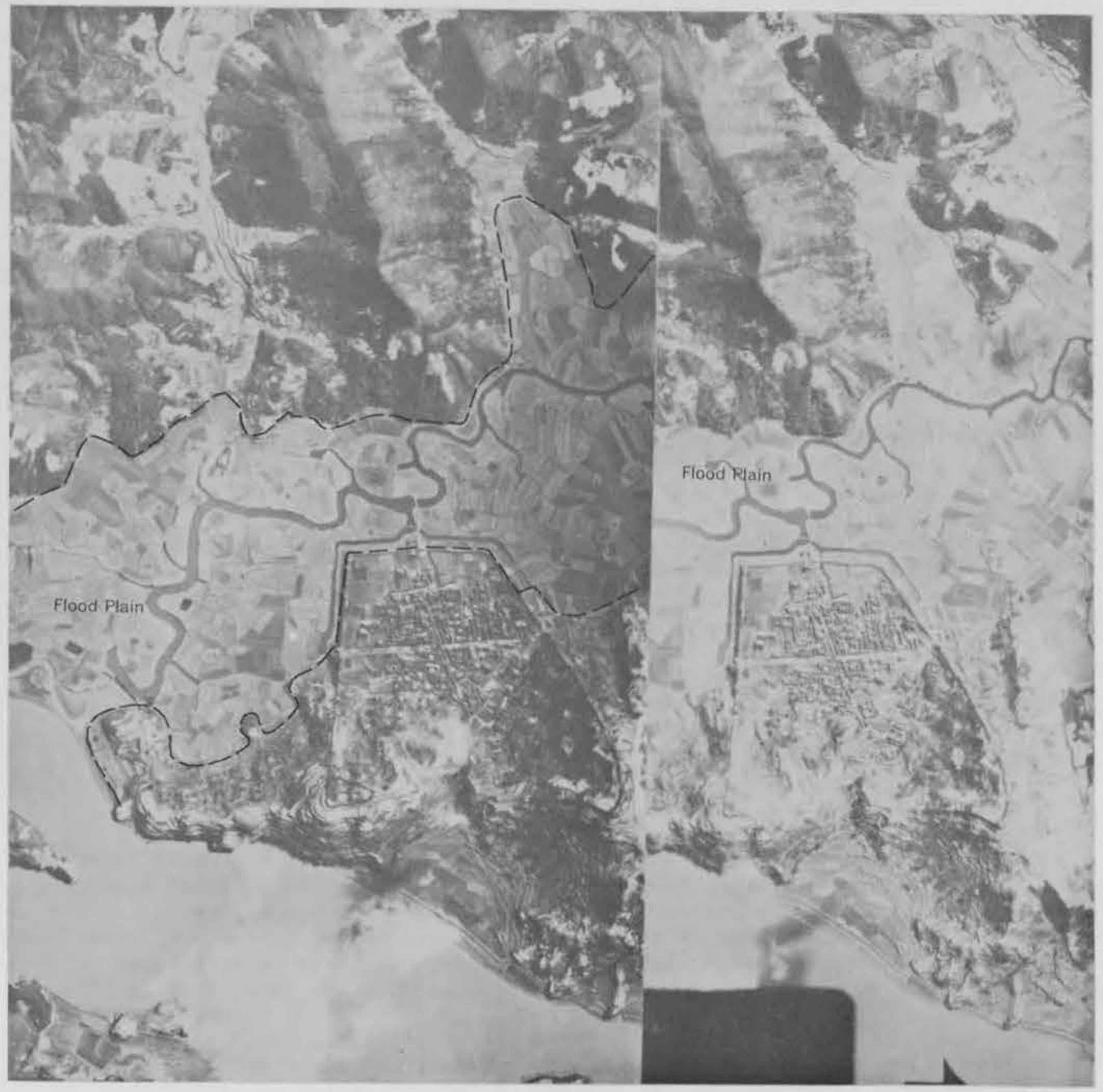

Figure 60: Truck Farms in Flood Plain
Scale Unknown

Note the fine mosaic presented by the small truck farms in the flood plain.

18. Ice conditions

Ice conditions are similar in streams and lakes. For coverage of this topic, see Paragraph 10.

19. Direction of flow

a. Background. When stream systems are viewed in their entirety, it is not difficult to establish the direction of flow. When only small segments are viewed, however, as on large-scale photographs, it is often very difficult to determine the direction of flow. This is especially true for the lower reaches where the slope of the stream is low, and the channel has a uniform width or is braided.

b. Recommended types and scales of photography. Any type and scale of photographs may be useful.

c. Recognition features.

(1) Tributary streams converge with the main stream at acute angles and hence show the direction of flow. In rugged terrain they converge generally at angles of less than 45 degrees (fig 61). In nearly level terrain, they converge at larger angles, from approximately 45 to 85 degrees (fig 62). In a region where the bedrock is controlling their course, tributary streams join the main stream apparently at right or even obtuse angles; however, close examination of the exact point of junction shows that the tributary enters at an acute angle (fig 63).

(2) Sandbars and/or islands indicate the direction of flow, since the blunt ends are always upstream (figs 64, 65, 66).

(3) Asymmetrical meander loops indicate direction of flow. Meanders tend to migrate downstream and an arcuate (bow-like) pattern appears on the downstream side (fig 67).

(4) Joining of muddy and clear streams indicates direction of flow. Muddy water registers in photographs as a light gray tone; clear water is almost black. If a muddy stream enters a clear stream, the muddy water mingles with the clear water at a point downstream from the junction (fig 68). Likewise, if a clear stream enters a muddy stream, the clear water mingles with the muddy water of the main stream downstream from the junction (fig 69).

(5) If the streamflow is being deflected against a bend or around an object in the channel, such as a boulder or a drift, the disturbed water appears as white bands fanning out downstream from the point of deflection (fig 70).

(6) If there are drifting objects on a stream, it is often possible to find the same one on both photographs of a vertical stereopair. By knowing which photo was taken first, the direction of flow can be established (fig 71).

(7) An optical illusion can sometimes be taken advantage of to ascertain the direction of flow. If it is known which photograph of a vertical stereopair was taken first, this photograph is mounted as the righthand member of the pair; then if the water surface from bank to bank appears concave (fig 72), it is known that the plane was flying downstream at the time of photography. If it appears convex (fig 73), the plane was flying upstream.

d. Interpretation problems. There are no special interpretation problems.

e. Required information. Determine the direction of flow.

Figure 61: Stream Flowing in Rugged Terrain
Scale Unknown

The main stream is flowing from right to left as indicated by the acute angle convergence of the streams. The angle of convergence is, in general, less than 45°.

Figure 62: Stream Flowing in Nearly Level Terrain
Scale 1:20,000 (approx.)

The main stream is flowing from right to left as indicated by the acute angle convergence of the tributaries and the main stream. The angle of convergence is generally between 45 and 85 degrees.

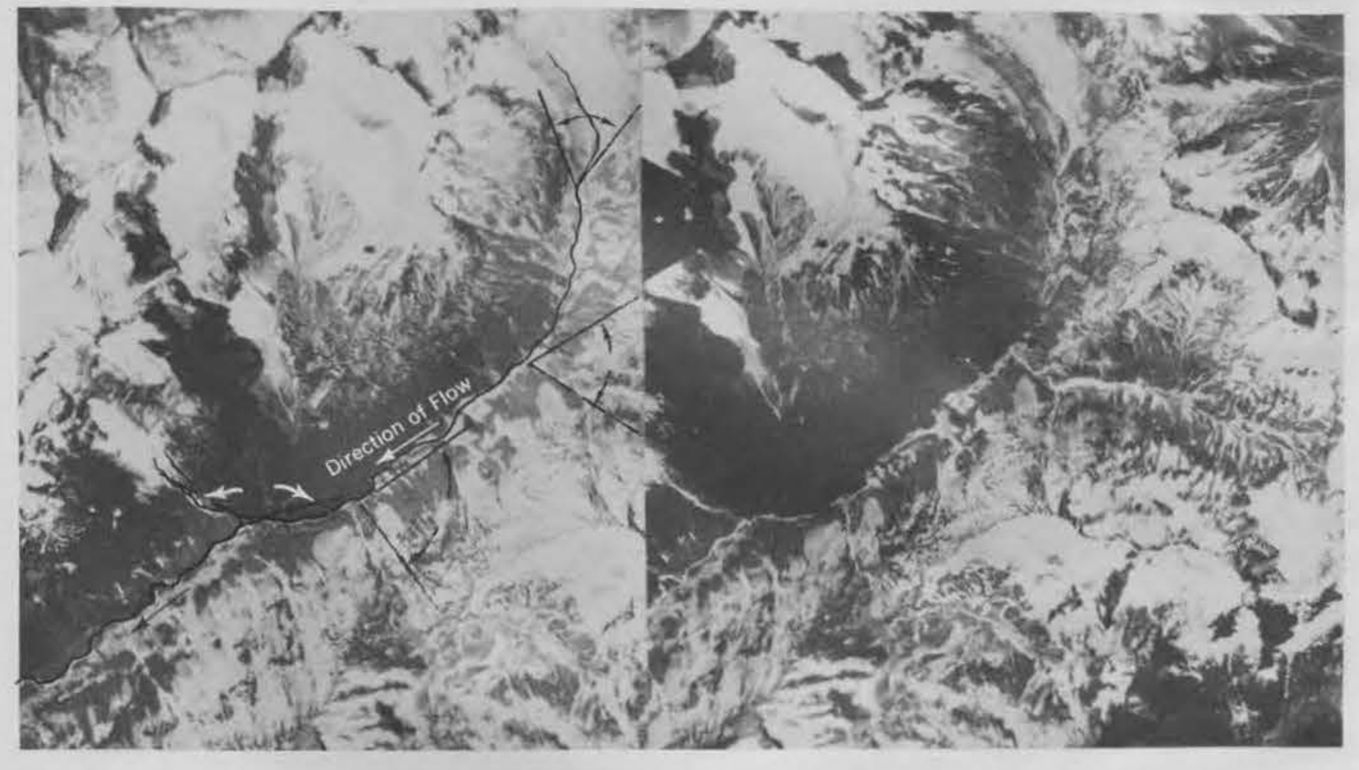

Figure 63: Bedrock Control of Stream Pattern
Scale Unknown

The main stream is flowing from right to left as evidenced by the source of the stream. Note that the angle of junction of some of the tributaries appears to be obtuse on the photo. Ground observation, however, would show that the angle of junction in every case is acute.

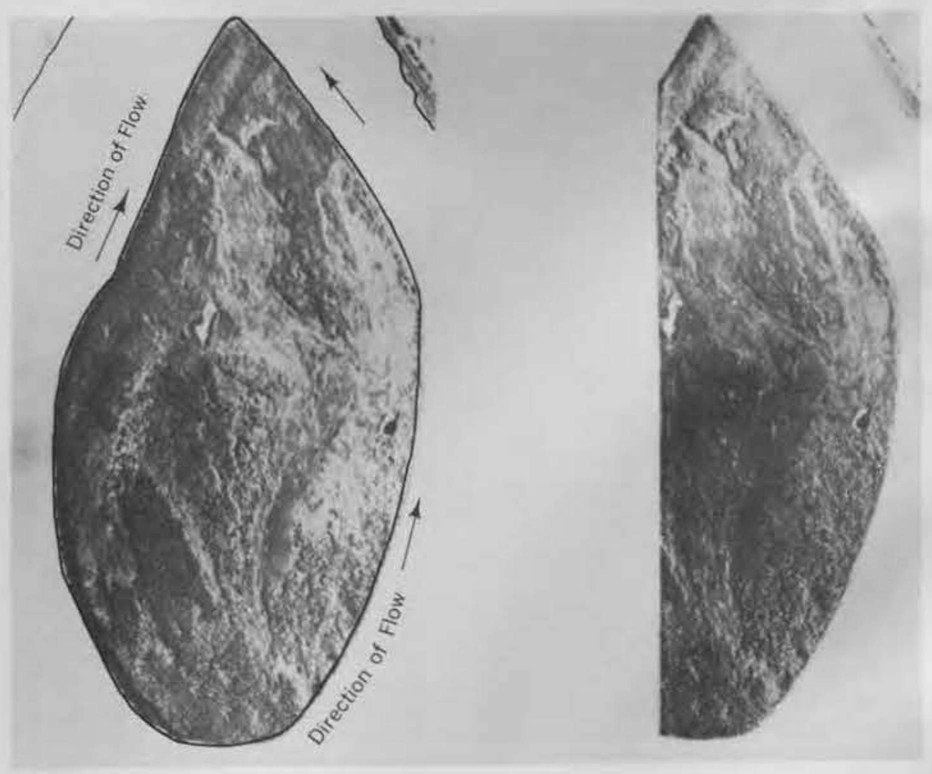

Figure 64: Typical Island
Scale Unknown

The island has a typical tear-drop shape with the blunt end upstream.

Figure 65: Island
The blunt end of the island is upstream.

Figure 66: Sandbar
The blunt end of the sandbar is upstream.

Figure 67: Meandering River
The arcuate (bow-like) pattern of the downstream slopes of the meanders indicates the direction of flow.

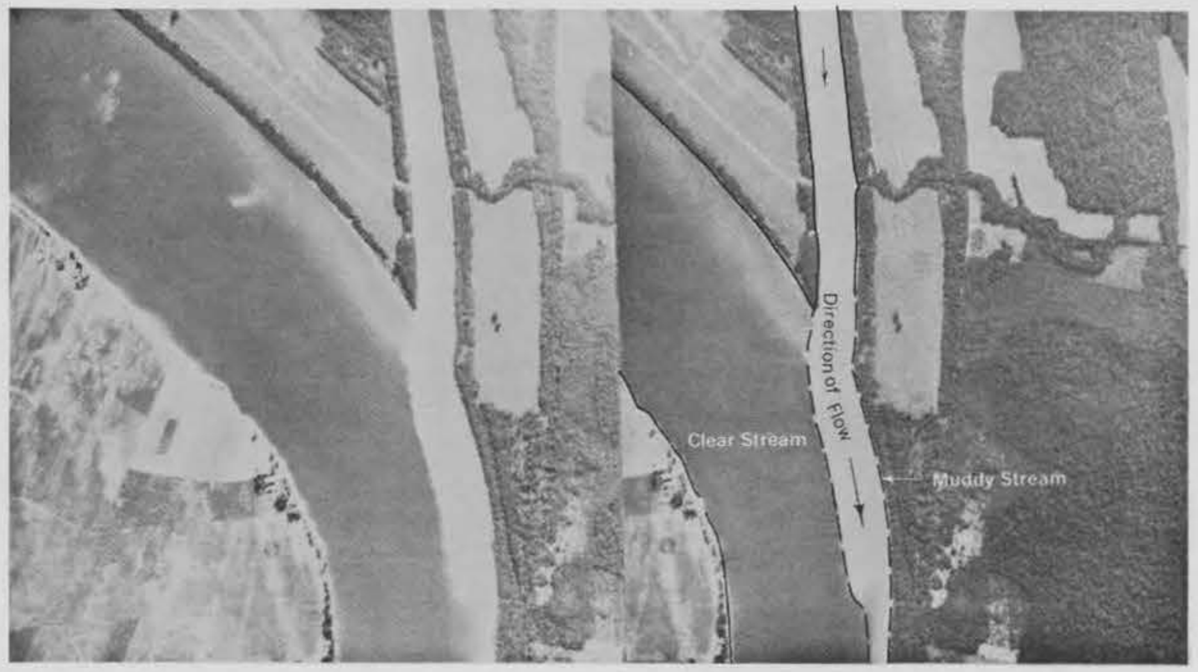

Figure 68: Muddy Stream Entering Clear Stream
Scale Unknown
The muddy water of the tributary is mingling with the clear water of the main stream downstream from the junction.

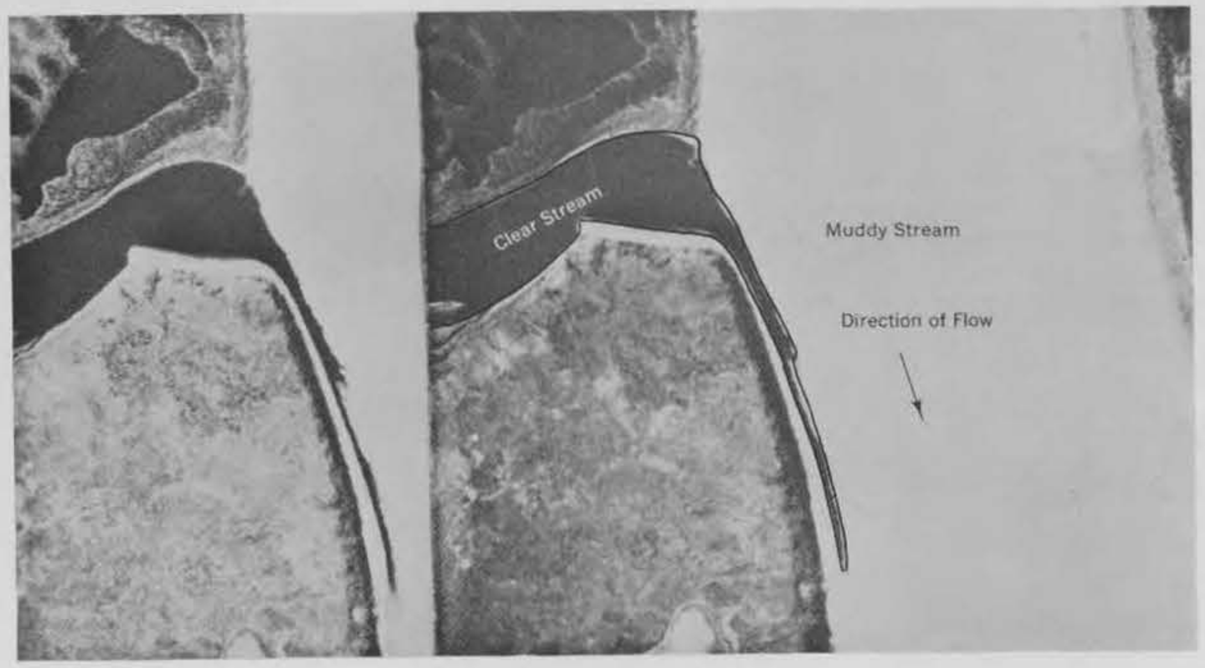

Figure 69: Clear Stream Entering Muddy Stream
Scale 1:21,000 (approx.)
The clear water of the tributary stream is mingling with the muddy water of the main stream downstream from the junction.

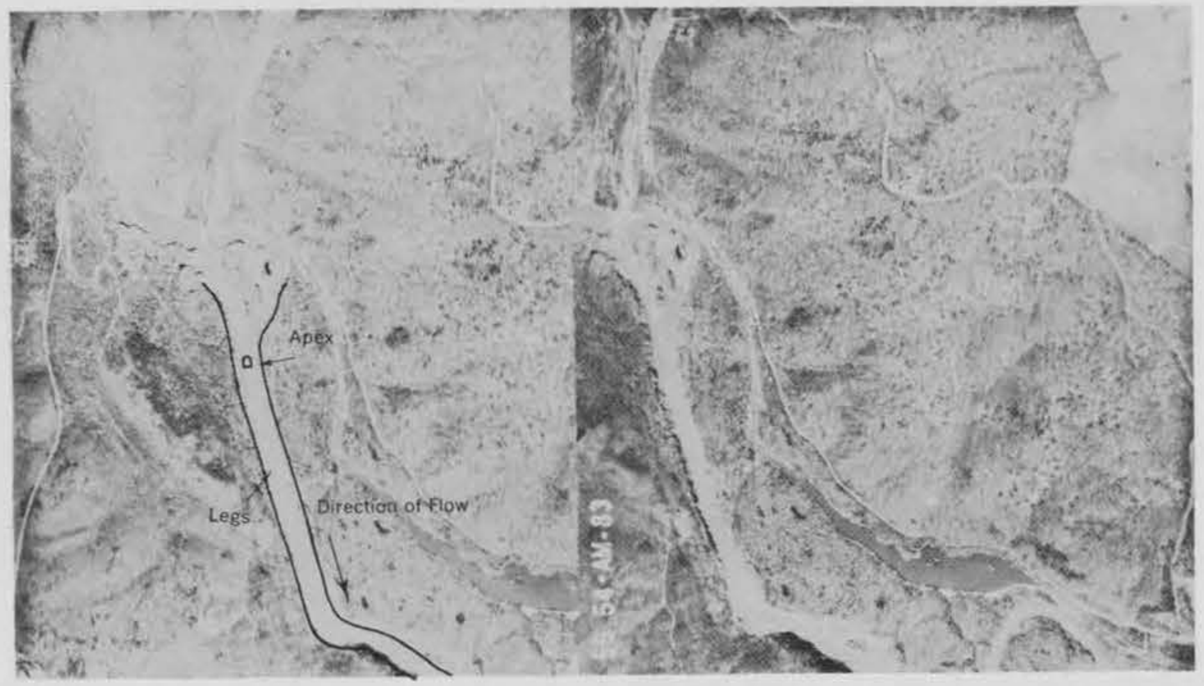

Figure 70: Water Deflected around Objects in the Channel
Scale Unknown
Water deflecting around objects forms parabolic waves with the apex on the upstream side and the legs fanning out downstream.

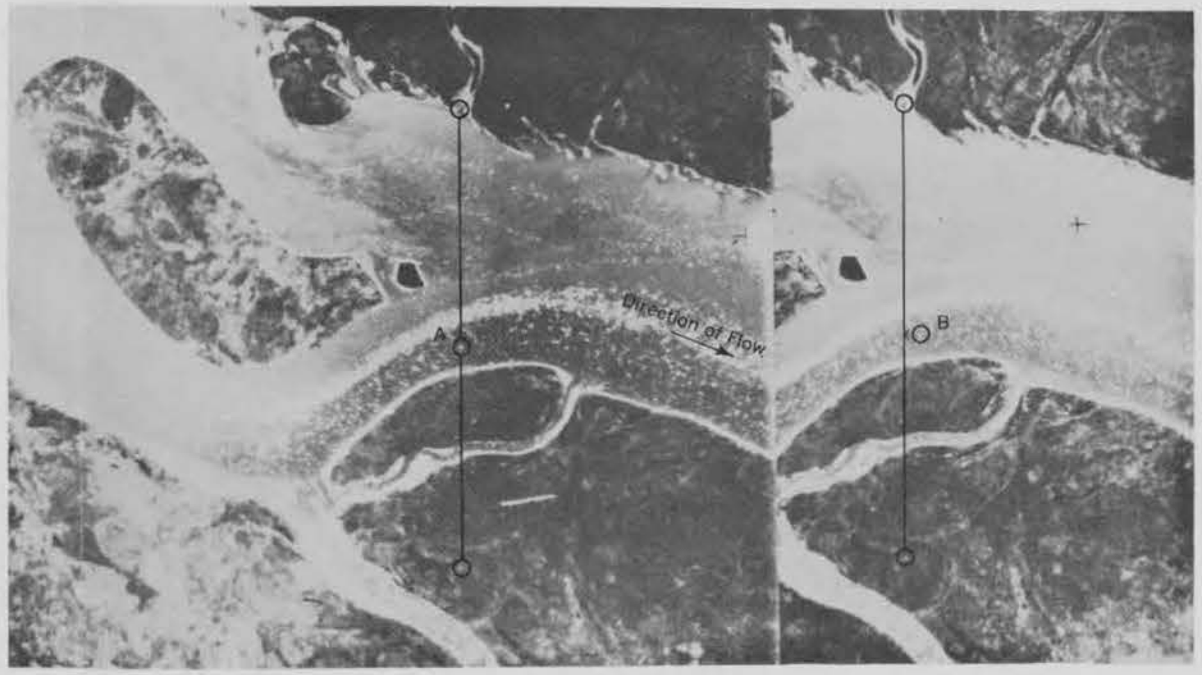

Figure 71: Drifting Objects

The ice cake at point A on the left print is located at point B on the right print. The direction of flow is from left to right, because the right photo was taken later than the left photo. (If the scale and time interval between camera exposure were known, the surface velocity could be calculated.)

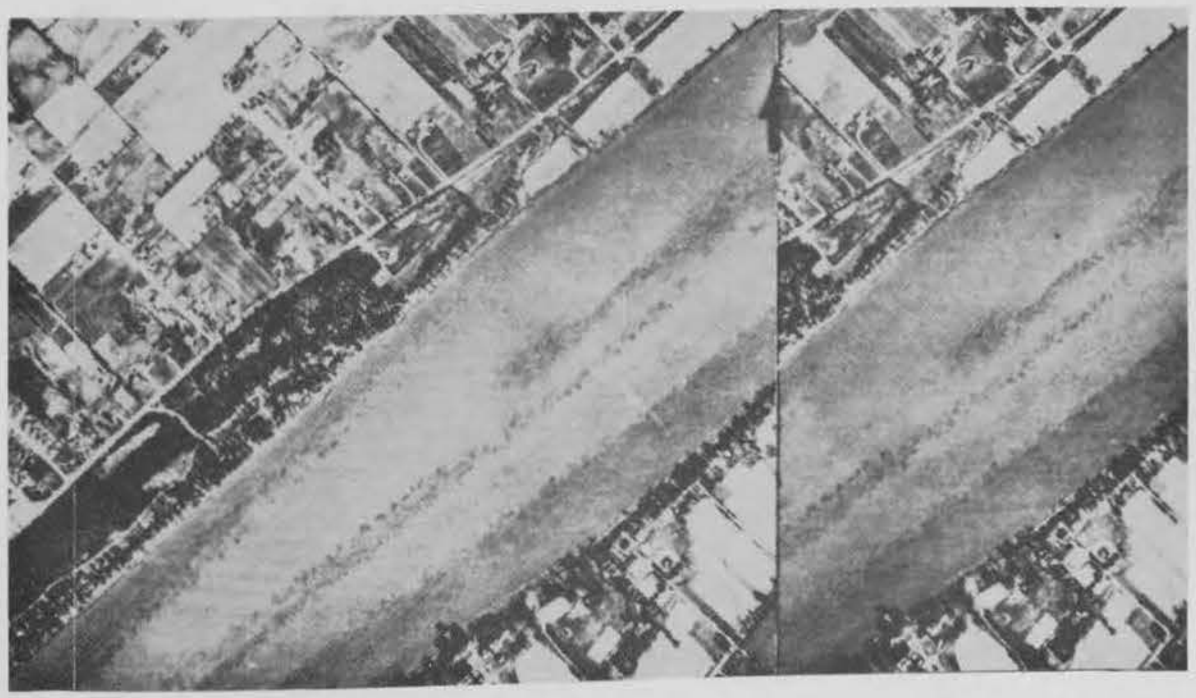

Figure 72: Optical Illusion, Concave Stream
Scale 1:25,000 (approx.)

The photo mounted on the right was taken first, and the stream surface appears to be concave, which indicates that the plane was flying downstream at the time of photography; therefore, the stream is flowing toward the lower left corner of the illustration.

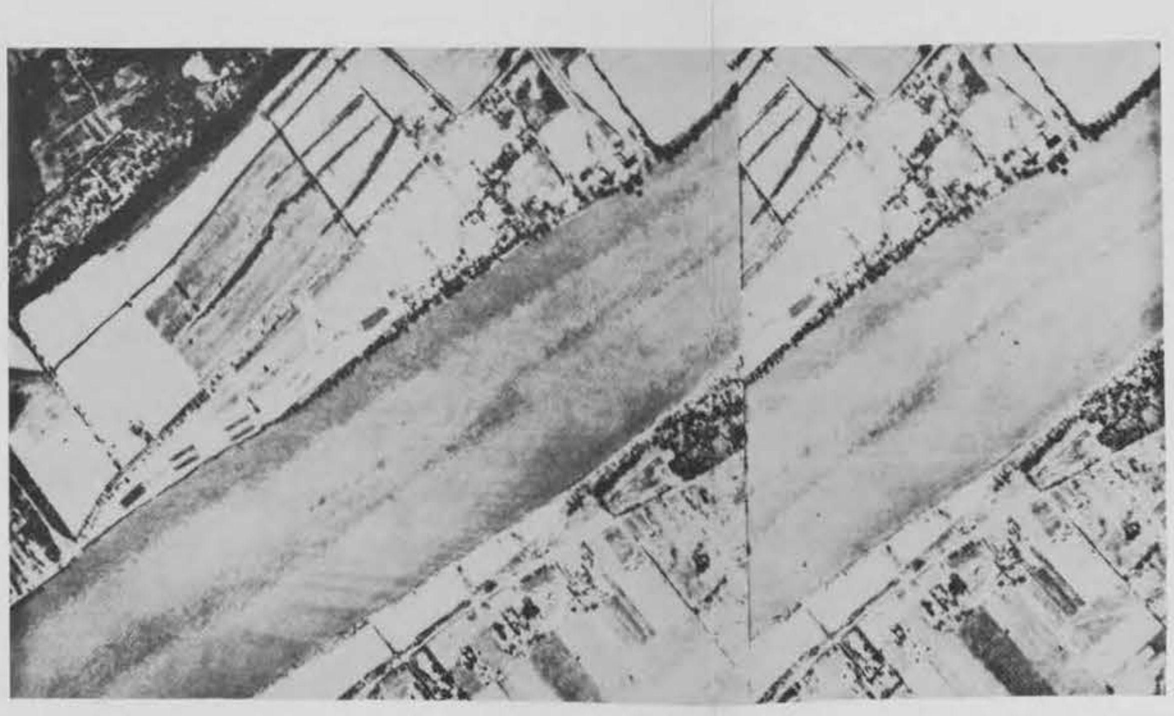

Figure 73: Optical Illusion, Convex Stream
Scale 1:21,000 (approx.)

The stream appears convex, which indicates that the plane was flying upstream at the the time of photography. It is known that the right photo was taken before the left photo; hence, the direction of flow is toward the upper right corner of the illustration.

20. Velocity

a. Background. The velocity of streamflow varies according to the configuration of river cross sections, depth of flow, channel obstructions and restrictions, and local variations of slope. In addition, velocity measurements made in a particular cross section at a particular time will vary from point to point along the horizontal plane and from depth to depth in the vertical plane. In hydrologic studies, the stream velocity used is the average of all the velocity measurements made at a particular time in a given cross section and cannot, of course, be obtained from photographs. (See Paragraph 21b(3) for a special technique for estimating mean velocity.) Certain flow characteristics that indicate surface velocity within a broad degree of accuracy acceptable for many military requirements can be obtained from photographs, however.

b. Recommended types and scales of photography. Vertical, oblique and ground photographs at 1:20,000 scale are recommended for the estimation of surface velocity on the basis of flow characteristics. Vertical stereopairs at 1:10,000 scale are recommended for estimating surface velocity from the drift of floating objects.

c. Recognition features. The principal features of a stream by which surface velocity may be determined from photographs are as follows:

(1) In a plan view the river bed outline is seen to be a meandering river in weak relief. This indicates a slow velocity at low river stages -- not more than one foot per second (fig 74).

(2) The presence of vegetation in the stream channel also indicates slow velocities -- not more than one foot per second (fig 75).

(3) Rapids and waterfalls may indicate high velocities. If the water is shallow, however, this may be only an optical illusion and the overall velocity probably on the order of one to five feet per second (fig 76). As the water level rises, the velocity increases rapidly (fig 77) and may reach a rate of 25.0 to 30.0 feet per second.

(4) The water surface image is interrupted. A pattern of white bands running along the direction of flow (eddies around obstacles in the channel: abutments, bridges, ice guards, rocks, etc.) is usually observed with velocity of above five feet per second. If the white bands formed by the agitated water in flowing around the object have a parabolic form (the object forms the apex of the parabolas and the legs spread downstream), the distances between the ends of the parabolas (the point of their greatest divergence on the photograph) are proportional to the increase in level of the backed up water at the obstacle. Experiment on actual streams has shown that water flowing around an object backs up from 0.6 to 3.3 feet, which corresponds to a range of velocity of from 6.5 to 13.0 feet per second. Since the precise relationship between the distance between the legs of the parabolas to the water backup has not been determined, the velocity must be estimated visually. For a wide diverging band, assume a flow of approximately 13.0 feet per second; for a small divergence, approximately 6.0 feet per second (fig 78).

(5) A drifting object may be seen in successive camera exposures. The surface velocity may be approximated closely by measuring the distance a floating object has moved downstream between consecutive exposures. The method is illustrated in Figure 79.

d. Interpretation problems. There are no particular problems.

e. Required information. Estimate the surface velocity.

Figure 74: Meandering River in Weak Relief
Scale Unknown

The water is flowing at a low stage and the surface slope is low; thus, the velocity probably does not exceed 1.0 feet per second.

Figure 75: Vegetation in a Stream

The presence of vegetation in the stream channel indicates a low velocity of not more than 1 foot per second.

Figure 76: Rapids at Low-water Stage

The stream appears to have a very high velocity because of its turbulence over the extremely rough bed. The average velocity, however, is probably less than 5 feet per second.

Figure 77: Rapids, above Normal Stage
Scale Unknown

The white water seems to be formed into bands. This leads to the assumption that the steps and/or rocks forming the rapids are almost submerged, indicating that here the velocity is in excess of 5 feet per second.

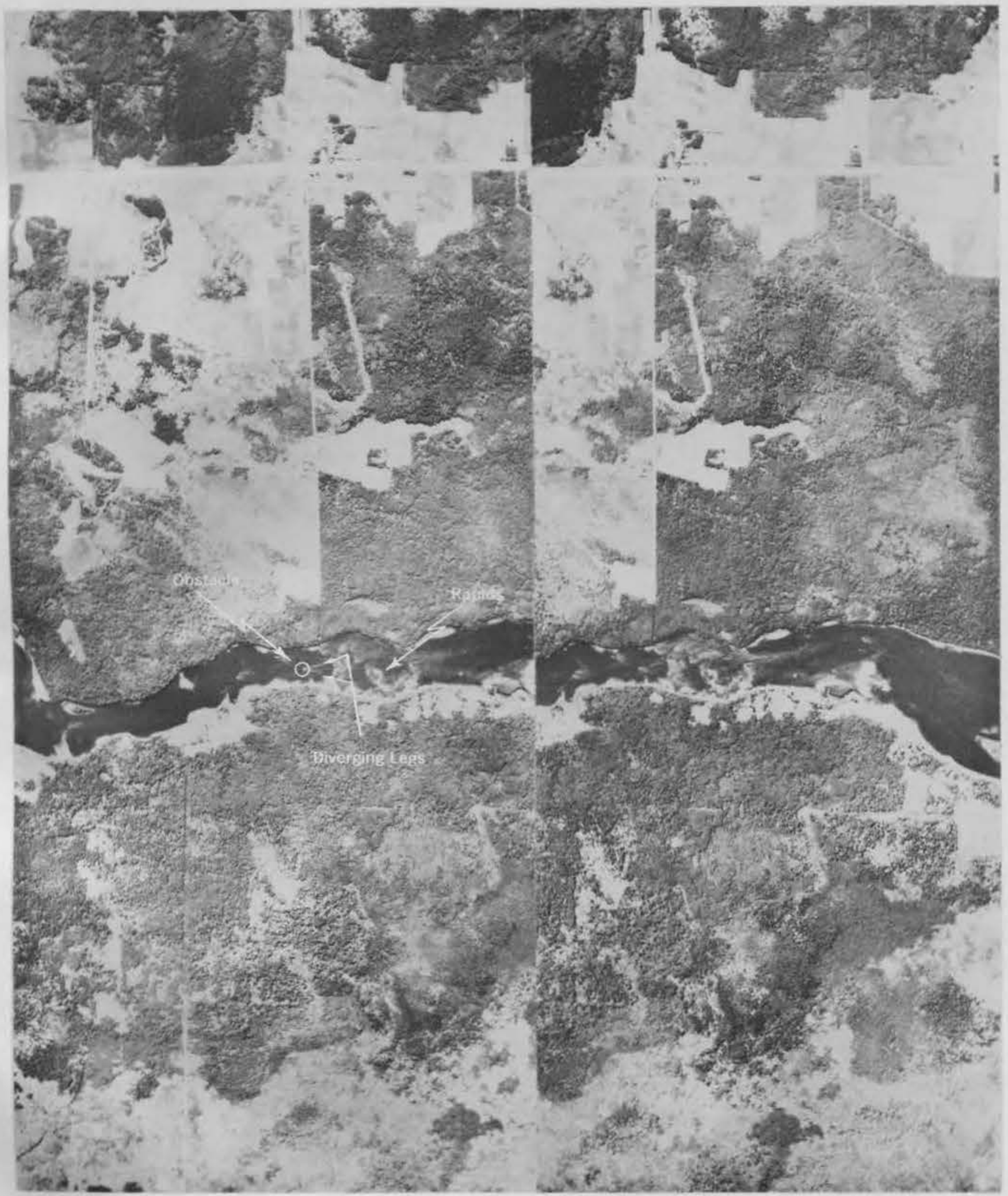

Figure 78: Water Flowing around Obstacles
Scale Unknown

The white water in and below the rapids and the eddying above indicate that the velocity is in excess of 5 feet per second. Since the diverging bands form a definite spread, yet are not wide, the estimated velocity is probably around 7 or 8 feet per second.

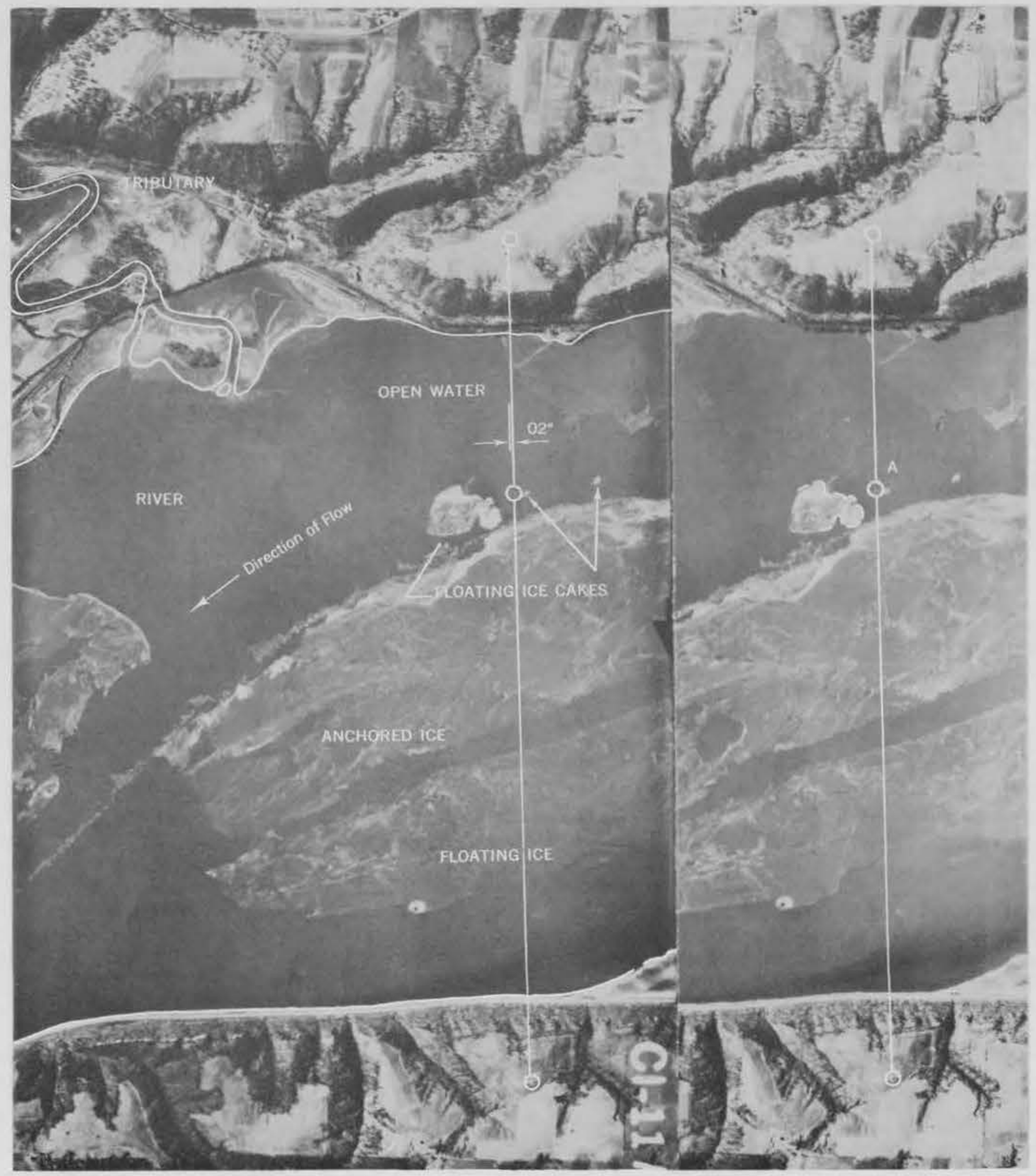

Figure 79: Measuring Surface Velocity
Scale 1:20,000

One inch on the photo is equal to about 1,650 feet. The distance the small ice cake A has moved between exposures is 33 feet (1,650 x 0.02). Assuming the time interval between exposures to be 30 seconds, the velocity is about 1.1 feet per second.

21. Special techniques for estimating discharge, depth, and velocity

a. Background. The discharge (volume of flow per unit of time), depth, and velocity of streams may be required in an area where no streamflow or other hydraulic data are available. These values are interrelated, and the U. S. Geological Survey (USGS), Department of Interior, has developed a tentative procedure for estimating them by using photographs and enough prior knowledge of an area to classify it as either semi-arid (annual rainfall, 8-20 inches) or subhumid (annual rainfall, 20-50 inches). For detailed information on the procedure, see Reference 11. The basic assumptions used by the USGS in developing the procedure were that:

(1) The discharge of a river flowing at bankfull stage (the stage that is equaled or exceeded once or twice a year) is primarily a function of the drainage area upstream from the cross section rather than a function of stage.

(2) The width, on a photograph, of the water surface of a river flowing at less than bankfull stage is very near the actual width of the water surface at the bankfull stage.

b. Techniques

(1) Bankfull discharge. Figure 80 illustrates the relationship between stream width and bankfull discharge and can be used to estimate the bankfull discharge based on the width of a stream. Since a natural river channel varies greatly in width, the average of several individual measurements should be obtained. The width of a braided stream should be measured in a reach where all the water flows in a single channel. Given a width value alone, the bankfull discharge is read from the dashed line on Figure 80. For example, a stream with an average width of 100 feet has a bankfull discharge of 500 cubic feet per second.

(a) Error limits. The solid lines in Figure 80 mark the error limits.* For example, for a bankfull discharge of approximately 300 cubic feet per second shown on the graph, the limits of actual discharge may be between 100 and 870 cubic feet per second.

(b) Error limits, type of stream or area. If the stream can be classified as either braided or meandering, the error limits may be reduced by about one-half.** For a braided stream at a specified width, the discharge should be read on Figure 30 midway between the dashed and upper solid lines. For example, a braided stream 100 feet wide will have a bankfull discharge of approximately 300 cubic feet per second. The limits of actual discharge, however, may be between 170 and 500 cubic feet per second. For a meandering stream at a specified width, the discharge should be read midway between the dashed and lower solid lines. For example, a meandering stream 100 feet wide will be found to have a bankfull discharge of approximately 900 cubic feet per second, with a possible range of error from 500 to 1,500 cubic feet per second. If the stream is neither braided nor meandering, the error limits may still be reduced by one-half provided the area can be classified as either semiarid or subhumid. If the area is semi-arid, the lines on Figure 80 applicable to braided streams are used; if subhumid, the lines applicable to meandering streams are used.

(2) Depth. The mean depth (average cross-sectional depth) is related to bankfull discharge as shown in Figure 81. Given a discharge value alone, the estimated minimum mean depth is read from the lower dashed line, and the estimated maximum mean depth is read from the upper dashed line. For example, given a discharge value of 1,000 cubic feet per second, the estimated minimum mean depth will be 1.5 feet and the estimated maximum mean depth, 4.9 feet. The difference between the readings may be reduced by about one-half provided the area can be classified as either semi-arid or subhumid. For a semi-arid area, the minimum and maximum mean depths are read from the lower dashed line and the middle solid line respectively. For example, in a semi-arid area given a discharge value of 1,000 cubic feet per second, the minimum mean depth will be 1.5 feet and the maximum mean depth, 2.7 feet. For a subhumid area, the minimum and maximum mean depths are read from the middle solid line and the upper dashed line respectively. For example, in a subhumid area given a discharge value of 1,000 cubic feet per second, the minimum mean depth will be 2.7 feet and the maximum mean depth, 4.9 feet.

(3) Velocity. Mean velocity (average cross-sectional velocity), bankfull discharge, width, and mean depth are related. For military purposes, the most useful velocity value is the average surface velocity, which has been found to be about 20% greater than the mean velocity. The mean velocity can be estimated using the equations for discharge and area as follows:

(a) $Q = AV$ (discharge equation)

where Q = bankfull discharge (derived from Figure 80)

A = area of the cross section

V = mean velocity

(b) $A = WD$ (area equation)

where W = average width (derived from photograph)

D = mean depth (derived from Figure 81)

(c) By substituting the area equation (b) into the discharge equation (a), the velocity equations are derived as follows:

$Q = WDV$; and by transposing

$V = Q/WD$ and

$V_s = Q/WD \times 1.20$

where V_s = average surface velocity

(4) Values at less than bankfull stage. Figure 82 may be used in conjunction with Figures 80 and 81 to estimate discharge, mean depth, and mean velocity at a cross section of a stream flowing at less than bankfull stage. After the bankfull discharge, mean depth, and mean velocity have been established at a cross section, it is possible to estimate values at some lower stage of flow, for example, at median stage (the stage that is equaled or exceeded 50% of the time). From Figure 82, therefore, it can be seen that the median discharge corresponding to the 50% point on the ordinate (Point A) is .06 or 6% of the bankfull discharge. The range of mean depths for the median discharge is determined from Figure 81, and the average surface and mean velocities are computed by using the velocity equations given above.

c. Example problem. The example is presented to illustrate the procedure and clarify the use of Figures 80-82.

(1) Situation. An operation is being planned for crossing a meandering river in a subhumid area where no streamflow or other hydraulic data are available. From vertical airphotos, using methods discussed in Paragraph 16, it has been determined that the average width in the stream reach under study is 300 feet.

(2) Required information: the discharge, mean depth, and average surface velocity at bankfull stage and at the mean annual stage (the stage that is equaled or exceeded approximately 30% of the time).

(3) Procedure

(a) The bankfull discharge read from Figure 80 is found to lie midway between the error limit lines for meandering streams. The value of discharge is 8,000 cubic feet per second, but the actual discharge may be between 4,800 and 14,000 cubic feet per second. From Figure 81 and using the average surface velocity equation, the following values at bankfull stage are obtained:

Discharge, cfs	Mean depth, ft		Area, sq ft		Average surface velocity, fps	
	Min	Max	Min	Max	Min	Max
4,800 (lower limit)	4.7	8.6	1,410	2,580	4.1	2.2
8,000 (midpoint)	5.6	10.2	1,680	3,060	5.7	3.1
14,000 (upper limit)	6.8	12.5	2 040	3,750	8.2	4.5

(b) The mean annual discharge corresponding to the 30% point on the ordinate (Point B, fig 82) is .08 or 8% of the bankfull discharge. The value of the mean annual discharge is 8,000 x .08 = 640 cubic feet per second, but the actual mean annual discharge may be between 380 and 1,120 cubic feet per second. From Figure 81 and using the average surface velocity equation, the following values at mean annual stage are obtained:

Discharge, cfs	Mean depth, ft		Area, sq ft*		Average surface velocity, fps	
	Min	Max	Min	Max	Min	Max
380 (lower limit)	1.9	3.5	570	1,050	0.8	0.4
640 (midpoint)	2.3	4.2	690	1,260	1.1	0.6
1,120 (upper limit)	2.8	5.0	870	1,500	1.5	0.9

*It was assumed that the average width of water flowing at less than bankfull stage measured on a photo would be about equal to the actual width at bankfull stage.

(c) The tabulations should be presented with an explanation that the actual values of discharge, mean depth, and velocity will be between the upper and lower limit values, and probably fairly close to the midpoint values.

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* Under the condition of very high discharge, these error limits may become as great as ±5 times; that is, the discharge read off the graph corresponding to a specified width may actually be either 5 times or only one-fifth the actual discharge.

** That is, ±2.5 times.

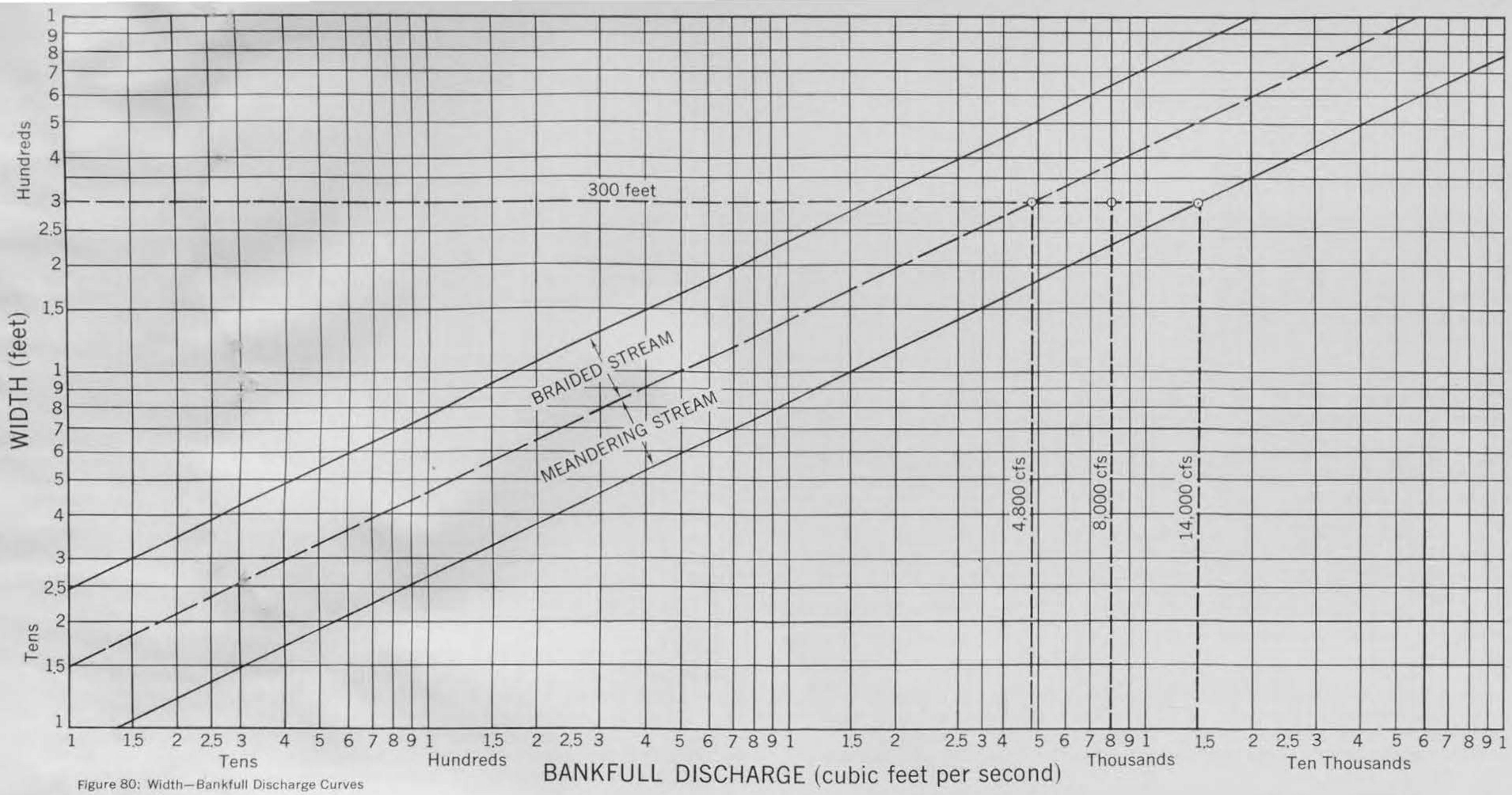

Figure 80: Width—Bankfull Discharge Curves

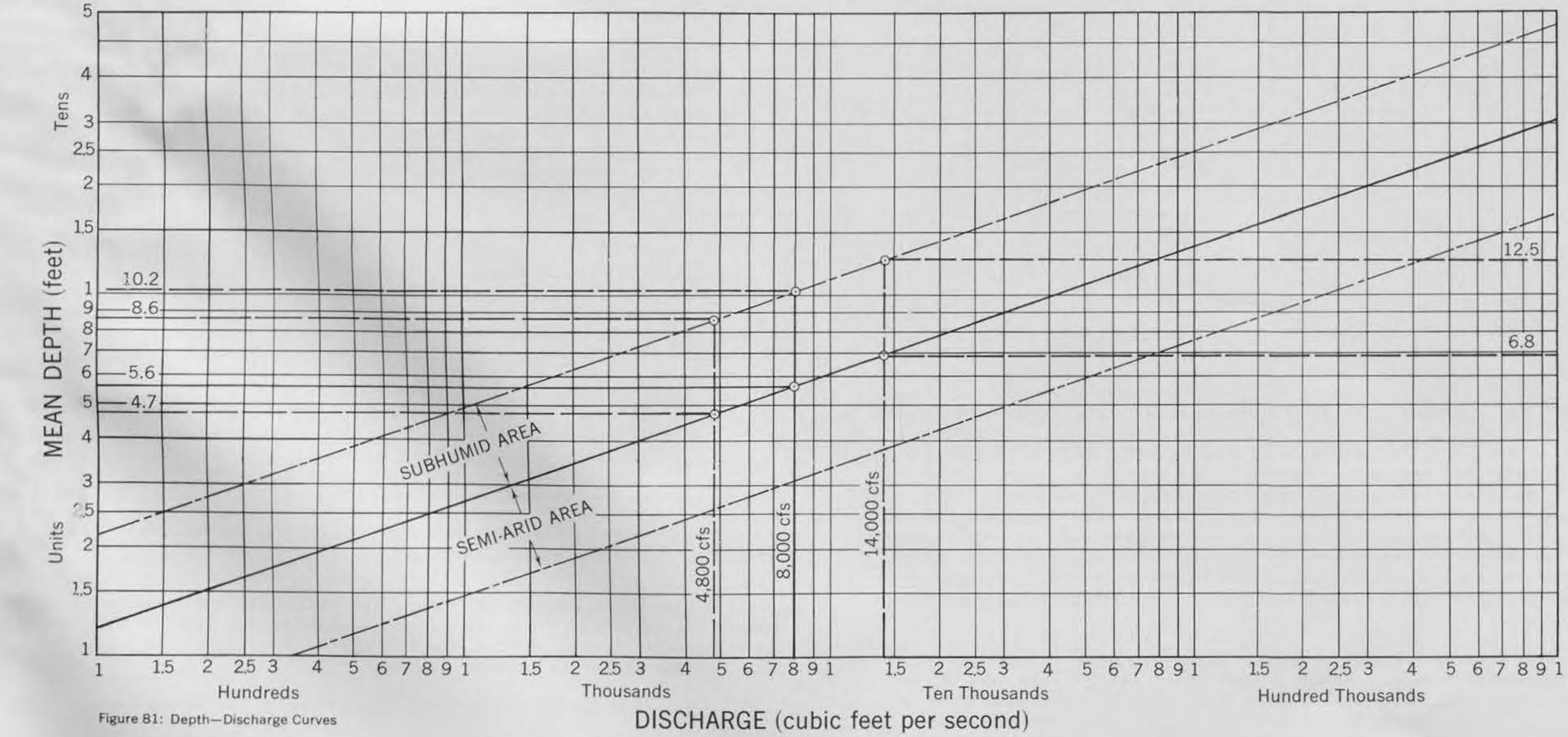

Figure 81: Depth—Discharge Curves

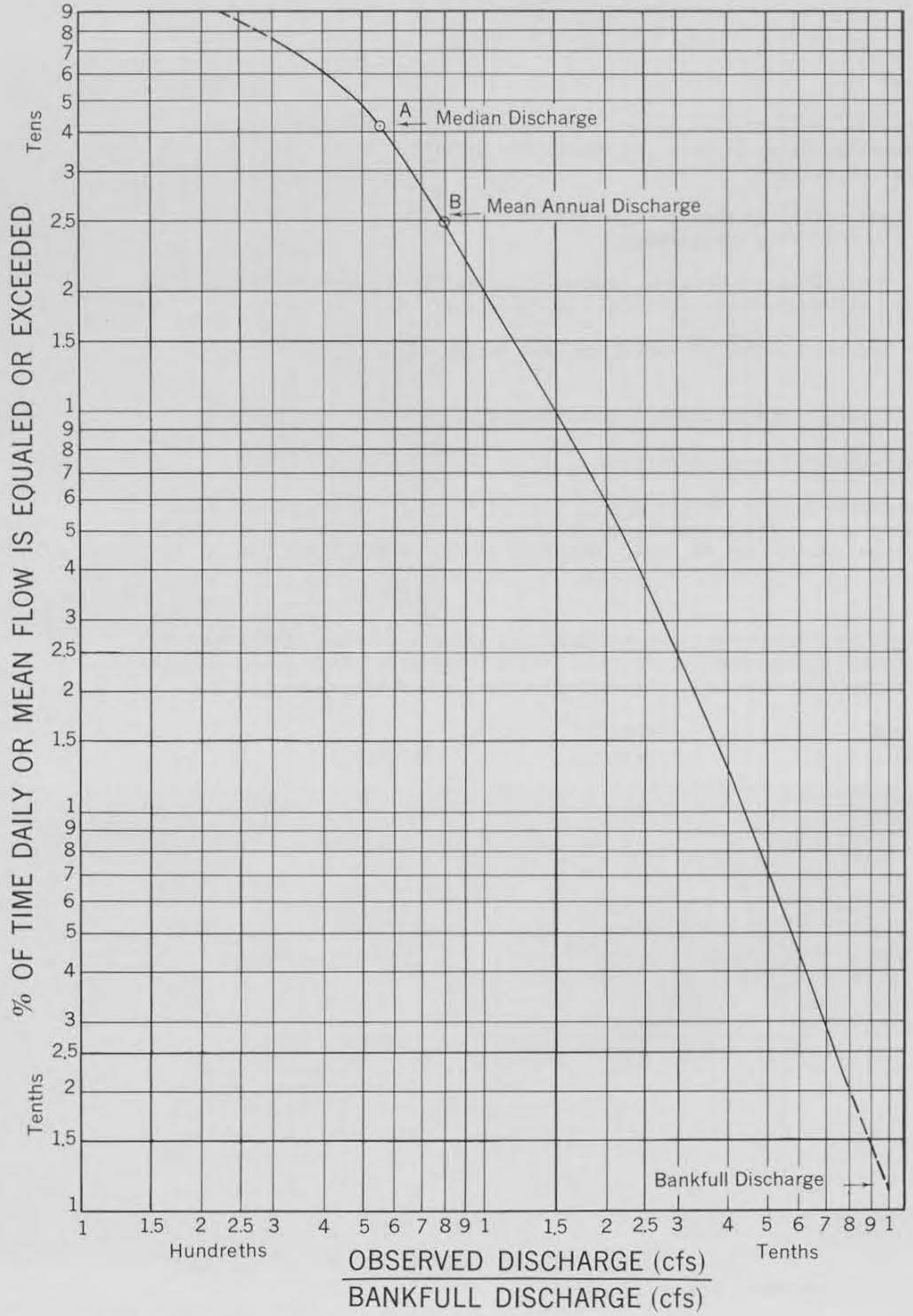

Figure 82: Duration—Frequency Curves

CHAPTER 5

HYDRAULIC STRUCTURES

22. Background

a. The normal operation of hydraulic structures, such as canals, locks, navigation channels, dams, levees, and reservoirs, affects the hydrologic characteristics of streams.

b. The basic military requirements for data on hydraulic structures are divided into the following categories:

(1) Physical and hydrologic characteristics of the construction site and of the area affected by the operation of the structure.

(2) Purpose, method of operation, and design of the hydraulic structure and appurtenances.

(3) Physical dimensions and construction materials of the structure.

(4) Records of past operation.

c. Photographs may be used to supply some of the information in the first three categories only. For a summary of required information and an evaluation of photographs as sources of the data, reference should be made to Figure 1.

23. Dams

a. Background. Dams are constructed across streams to impound and control water. The stored or impounded water is called a reservoir. Dams are classified according to structural material, structural design, and purpose, as follows:

Structural material	Structural design	Purpose
Embankment* Earthfill Rockfill Both	Gravity	Power Water supply Irrigation Navigation Flood control or any combination (multipurpose)
Masonry Concrete Reinforced concrete Masonry stone	Gravity Arch Buttress or any combination	

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*Embankment dams may have masonry sections.

The great weight of gravity dams resists overturning pressures and holds them in position. The arch dam is not nearly so massive as the gravity dam, and its stability depends on the continuous curving upstream face to concentrate overturning pressures into the foundation and abutments. A buttress dam depends for stability on the evenly spaced buttresses located on the downstream side of the dam to concentrate the overturning pressures into the foundation.

b. Recommended types and scales of photographs

(1) For identification, vertical airphotos at 1:20,000 (for low dams) and 1:40,000 (for high dams) are recommended.

(2) For structural material and design classification, vertical and oblique stereopairs of airphotos at 1:10,000 are recommended. Ground photos will also be useful.

(3) For purpose classification, vertical airphotos at 1:30,000 for orienting the dam to the region, and vertical and low oblique stereopairs at 1:10,000 for detailed study are recommended. Ground photos will also be useful.

c. Recognition features

(1) Features used to distinguish dams from bridges (fig 83), especially on small-scale photography, are as follows:

(a) Alinement. On an airphoto man-made structures crossing a stream appear either as a symmetrical curve or as a straight line. The former indicates that the structure is probably a dam because bridges are seldom curved. The latter may indicate either a dam or bridge.

(b) Water surface widths. A greater width of water surface above than below a structure indicates that the structure is a dam. Usually there are only minor differences in water surface widths above and below a bridge.

(c) Elevation of water surface. A definite difference in elevation of the water surface above and below a structure is usually conclusive evidence that the structure is a dam.

(d) Passage of water through structure. Water being released through a dam shows as a churning frothy-white area immediately below the dam but not above it. Water passing under a bridge may show as some very minor white areas above and below the piers.

(2) Features used to distinguish reservoirs from lakes (figs 84 and 85) are as follows:

(a) A reservoir occupies an area that had developed a distinct drainage pattern. The impounded reservoir water gives the effect of flooded landscape and appears to be an abnormal terrain feature (fig 84). A natural lake, however, seldom gives this effect and appears to be a normal terrain feature.

(b) A reservoir's shoreline is normally very jagged because of the numerous small tributaries (fig 84). A natural lake usually has very few tributaries; consequently its shoreline is relatively smooth (fig 85).

(c) The water surface line of a reservoir has an even more jagged appearance than its shoreline (fig 84). The water surface line of a natural lake, however, is generally as smooth as its shoreline.

(d) The vertical height between a reservoir's water surface and the shoreline may range from as little as three feet up to as much as 20 feet in one season, depending on the replenishment from inflow and the demands on the reservoir. The water level in a natural lake seldom fluctuates to such an extent.

(3) Features used to classify dams as to structural material and design are as follows:

(a) Gravity earthfill embankment dams (fig 86). In vertical airphotos this dam looks like a V-type feeding trough turned upside down, and the upstream and downstream slopes are gradual. The upstream slope ranges from about 2:1 (two horizontal to one vertical) to 3:1, and the downstream slope is seldom less than 3:1. The alinement of these structures is usually straight, but is sometimes a slight curve to fit the topography. The texture and configuration of the surface of these dams vary because of the different methods of stabilizing the slopes. Usually the downstream slope is either turfed or covered with a gravel blanket, and there is a drainage ditch at the toe of the slope. The downstream slope is often broken with one or more berms (flat ledges about 6 to 20 feet wide); if there are several berms, the downstream slope has a corrugated appearance. The upstream slope is usually faced with either riprap (hand placed or dumped stone) or a thin concrete slab. This protection normally extends from the toe of the slope to about 8 to 10 feet above the highest expected reservoir level.

(b) Gravity rockfill embankment dams (fig 87). On vertical airphotos these structures resemble earthfill dams except that: 1) the face slopes are somewhat steeper (upstream normally about 0.5:1 to 1:1; downstream never less than 1.3:1); 2) they seldom have berms; and 3) the slopes are generally stabilized with either dry masonry (rough stone, hand laid) topped with a watertight cover of asphalt or concrete, or a very heavy gravel blanket.

(c) Gravity masonry dams (fig 88). On vertical airphotos the upstream face of these dams appears almost vertical, ranging in slope from about 0.2:1 to 0.1:1. The downstream slope is milder but usually steeper than that of a rockfill dam, about 0.5:1 to 1:1. The alinement of the axis may be either straight or curved. (When the alinement is curved, the structure is often called an "arch gravity" dam. The differentiating feature between it and the true arch dam is that the gravity masonry dam has a more massive, outward sloping downstream face.)

(d) Arch masonry dams (fig 89). On vertical airphotos these structures resemble an upended saucer with a sector of the top cut off. The convex and concave sides represent the upstream and downstream faces, respectively. The alinement of the axis is always curved.

(e) Buttress masonry dams (figs 90 and 91). These structures are easily recognized by the evenly spaced buttresses on the downstream face that show clearly on ground photos or oblique airphotos. On vertical and oblique airphotos or ground photos, the upstream face resembles either a series of barrels laid side by side (multiple arches) or the flat face of a gravity masonry dam. The alinement of the axis of a buttress dam is usually straight but may be slightly curved to fit the topography.

(4) Features used to classify dams as to purpose are as follows:

(a) Auxiliary works (those facilities required to pass the water through or around the dam, such as intakes, conduits, spillways, and sluices). These works are discussed in subsequent paragraphs.

(b) Appurtenant works (those facilities required to use the water impounded by the reservoir, such as powerhouses, ship locks, irrigation systems, and water treatment plants). These works are discussed in subsequent paragraphs.

d. Interpretation problems

(1) It is usually sufficient to classify an embankment dam as such. If it is clearly a rockfill or earthfill structure, that fact should be stated. It is difficult to determine from airphotos, however, whether an embankment dam is a combination earthfill and rockfill structure; other sources of information or expert opinion will be needed if the classification is essential.

(2) An especially heavy cross-sectioned arch masonry dam may be mistaken for a relatively thin-sectioned gravity masonry structure. Identification is necessary, however; therefore, in those cases where classifying is difficult, other sources of information or expert opinion are needed.

(3) In ascertaining the purpose of a dam, the main problem is to identify the appurtenant work. The difficulty is that it is often located miles from the dam and connected by an underground conduit (fig 92). In many cases, therefore, this information cannot be gained from photographs alone, and other sources will have to be consulted.

e. Required information

(1) Classify the dam according to material, design, and purpose.

(2) Measure the crest length or total length of dam. Measure along the axis of the dam from abutment to abutment.

(3) Measure the sectional crest lengths if the structure is an embankment dam with a masonry section.

(4) Measure the height using some device for measuring parallax. Measure the difference in height between a point on the crest of the dam and the lowest visible point at the foot of the downstream face (usually the water surface of the downstream channel).

(5) Measure the crest width (perpendicular to the axis of the dam).

Figure 83: Dam and Bridge Compared
Scale Unknown

The features that distinguish the dam (1) from the bridge (6) are the following: There is a distinct difference in the water surface elevation above and below the dam and none at the bridge; and there is a large stream of white water immediately downstream of the dam and none above the dam. The following features of the dam will be discussed later in the text: forebay curtain wall (2); powerhouse (3); forebay and lock approach (4); and navigation lock (5).

Figure 84: Reservoir
Scale Unknown

The features used to identify this body of water as a reservoir, exclusive of the dam, are the following: 1) The terrain appears flooded and abnormal; 2) the shoreline is jagged because of the numerous flooded tributaries; and 3) the relatively large vertical height between the water surface and the shoreline indicates a rapid fluctuation of the depth of water.

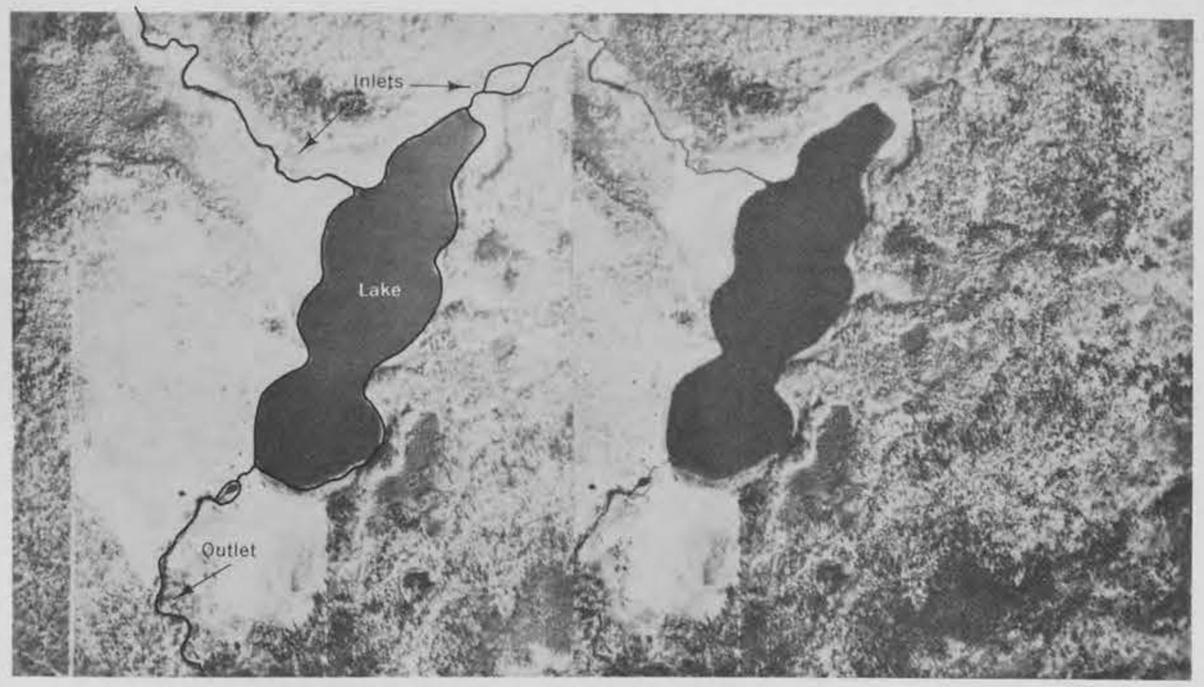


Figure 85: Lake
Scale Unknown

The features used to distinguish this lake from a reservoir are the following: 1) The lake appears as a normal terrain feature; 2) the shoreline is smooth because there are only two tributaries (inlets), and their mouths are not flooded; and 3) there is no evidence of rapid fluctuation of depth.

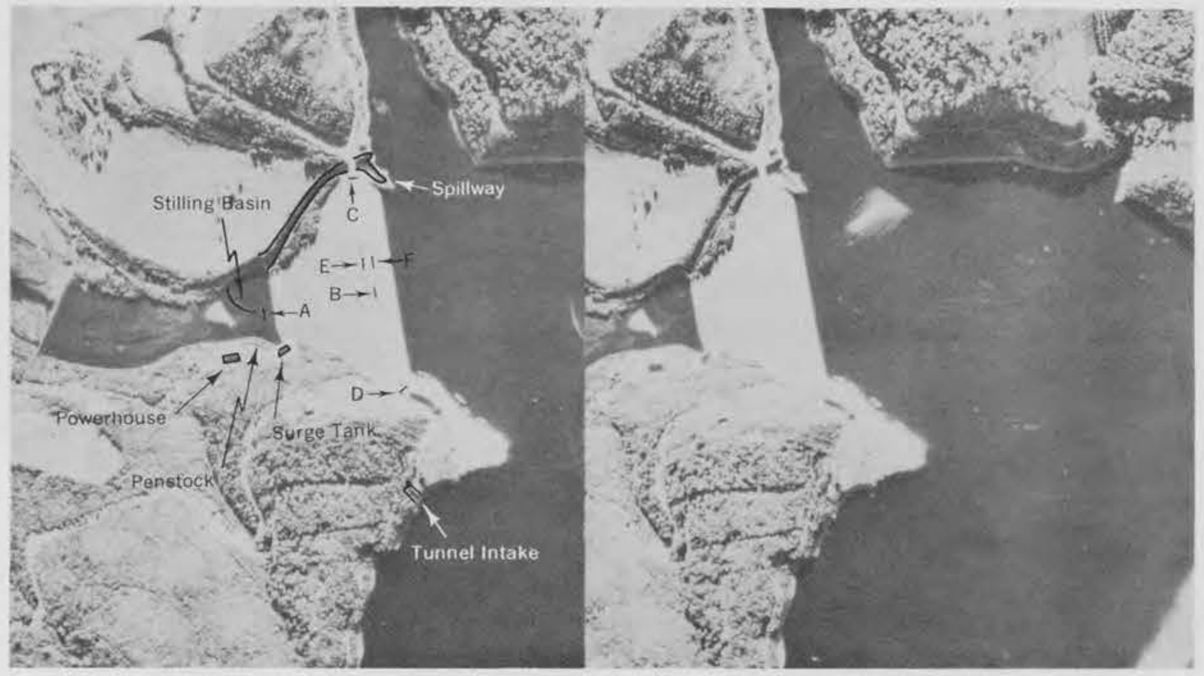


Figure 86: Gravity Earthfill Embankment Dam
Scale 1:10,000 (approx.)

The features used to classify this dam are the following: 1) The inverted V-shape; 2) the upstream and downstream slopes are gradual; 3) the alinement of the axis is straight; and 4) the downstream slope is turfed and broken by berms. The results of measurement are given as follows: 1) height (A to B), 60 meters; 2) crest length (C to D), 310 meters; 3) crest width (E to F), 10 meters. Other features of this dam are noted because they will be of interest later in the text.

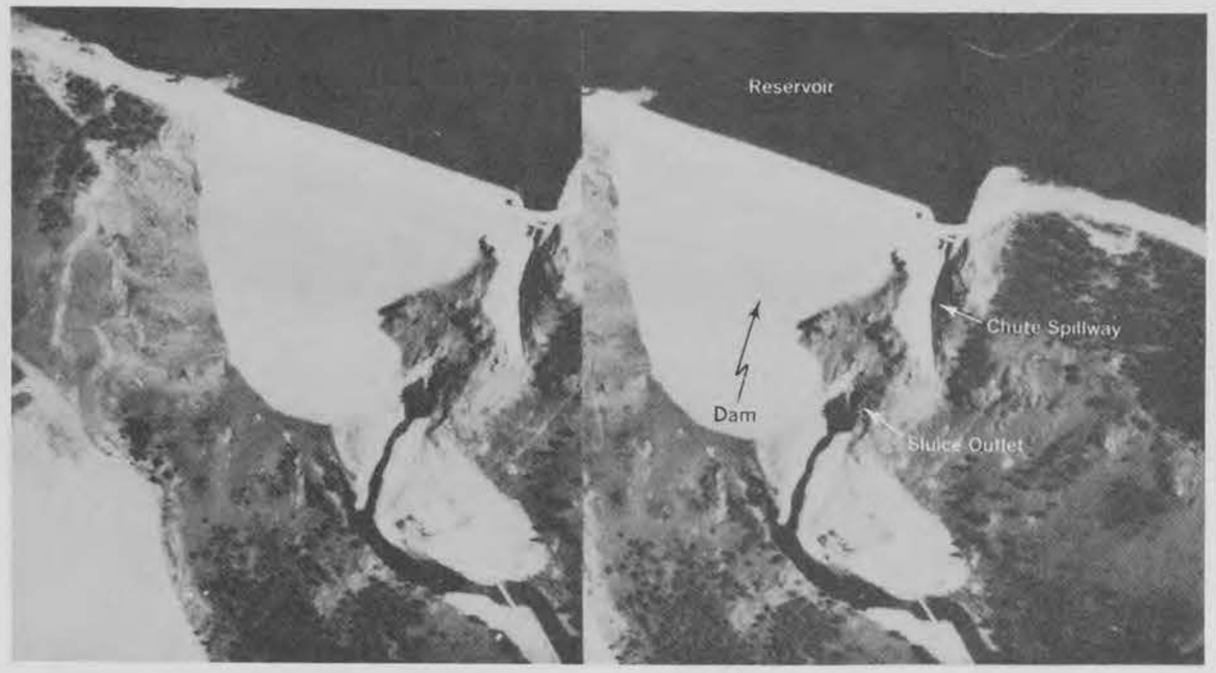


Figure 87: Gravity Rockfill Embankment Dam
Scale Unknown

The feature used to classify this dam are the following: 1) The relatively steep slope of the upstream and downstream faces; 2) absence of berms on the downstream face; and 3) the dense gravel blanket on the downstream face. Note the spillway and sluice outlet (to be discussed later in text).

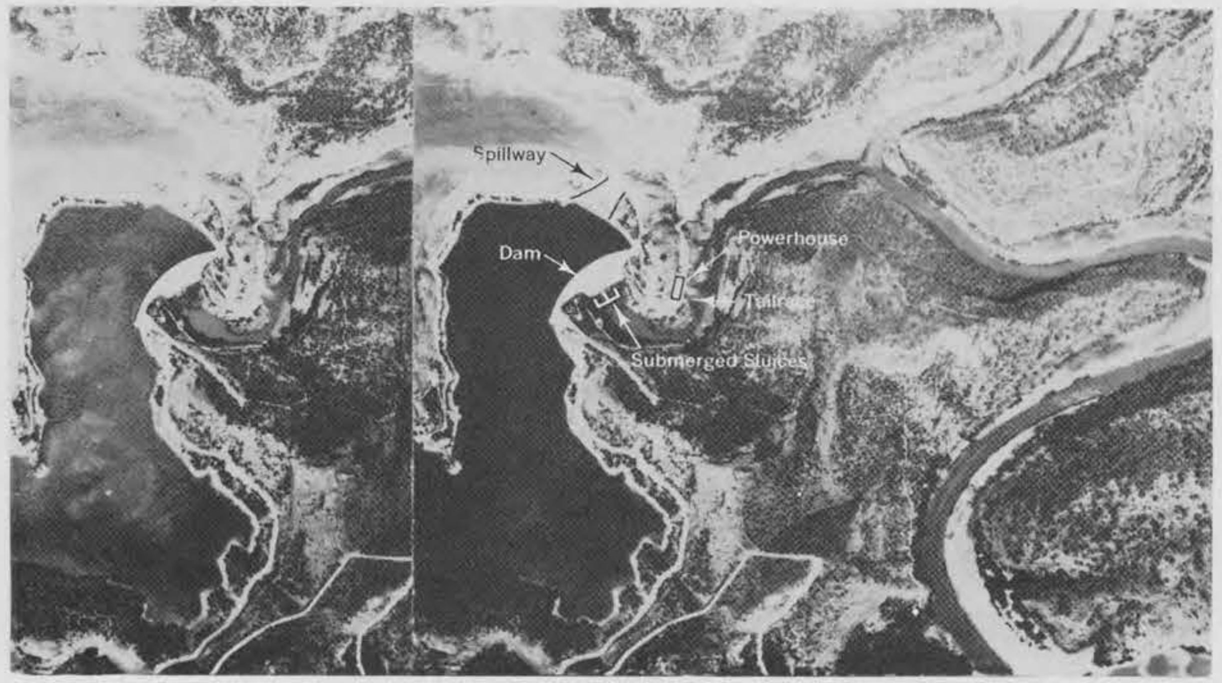


Figure 88: Gravity Masonry Dam
Scale 1:10,000 (approx.)

The features used to classify this dam are the following: 1) Upstream slope is very steep; 2) downstream slope is milder; 3) the alinement is curved; and 4) the downstream face is massive. (Note the single stream of turbulent water in the tailrace, indicating that one turbine is operating. In addition, note the two streams of turbulent water at the foot of the dam, indicating submerged sluices. These features will be discussed later in the text.)

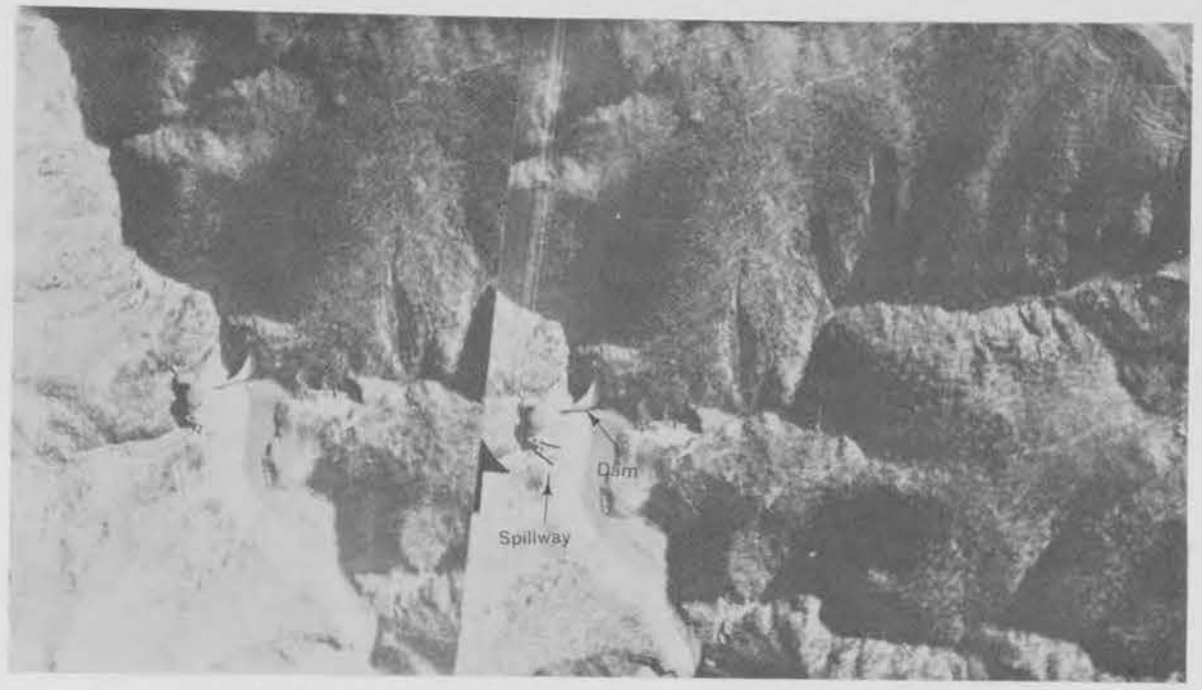


Figure 89: Arch Masonry Dam
Scale 1:11,000 (approx.)

The features used to classify this dam are the following: 1) The upstream face is convex; 2) the downstream face is concave; and 3) the alinement of the axis is curved.

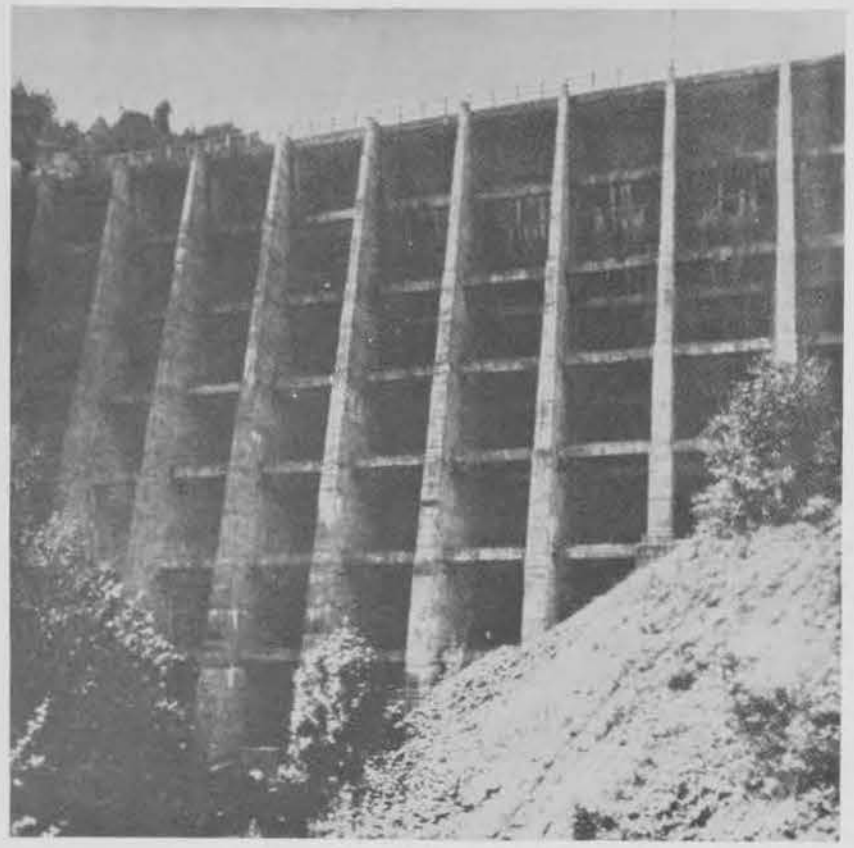


Figure 91: Buttress Dam, Downstream Face

The photograph shows the typical structural appearance of the downstream side of a buttress dam.

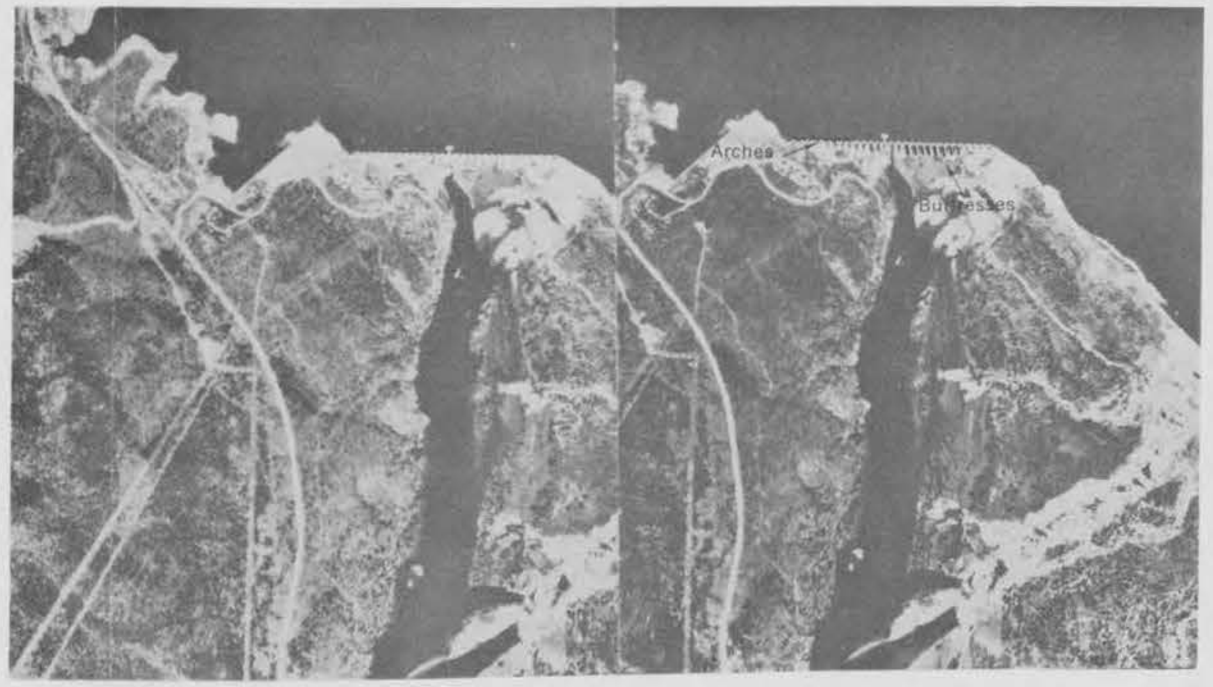


Figure 90: Buttress Dam
Scale Unknown

The features used to classify this dam are 1) the buttresses forming the downstream face and 2) the multiple arches forming the the upstream face.

Figure 92: Powerhouse Located Away from Dam
Scale Unknown

The intake tower at point A is connected to the powerhouse (point C) by a long tunnel, but it is not possible to trace the line of the tunnel from the photo. At point B (the tunnel exit), two penstocks emerge and lead to the two surge tanks located on the powerhouse. A transformer yard is located across the river at point D.

24. Intake structures

a. Background. An intake structure is required at the entrance to a conduit through which water is withdrawn from a reservoir or river. It may be either a separate structure or an integral part of a dam. Intake structures vary from simple concrete blocks supporting the end of a pipe to elaborate concrete intake towers. They may be located anywhere within a reservoir but are usually in the vicinity of the dam. They may be completely or partially submerged. Completely submerged intakes are widely used on small dam projects and in rivers, because they are low in cost and do not obstruct navigation. Partially submerged intakes, such as intake towers, are often used where there is a wide fluctuation of water level or where it is desirable to withdraw water from various levels of a reservoir.

b. Recommended types and scales of photography. For identification, vertical stereopairs and low oblique airphotos at 1:10,000, depending on the size of the structure, are recommended. For locating possible intake structures, even smaller scale vertical photography is useful.

c. Recognition features

(1) Trash racks (fig 93). These are provided at the entrances to intakes to keep out debris. They are usually steel bars spaced 2 to 6 inches center-to-center, depending on the maximum size of the debris that can be permitted in the conduit.

(2) Cylindrical or square structures protruding above the reservoir water surface (figs 94, 95, and 96). These are usually intake structures.

(3) A submerged or partially submerged intake. Such an intake is often associated with either a small building or a skeletal structure located very near the edge of the reservoir. In this case, a pipe or several pipes extend from the structure into the water or a trash rack will be observed. The pipe or pipes usually connect to a submerged intake structure and indicate that the reservoir has a water supply purpose. The trash rack usually serves a partially submerged intake and does not indicate any particular purpose (fig 97).

(4) Surface intakes for all types of canals (irrigation, water supply, power, etc.) (fig 98). These are usually located very near the dam and have the same general arrangement. At the upstream end there is a curtain wall with trash racks, a basin called the approach channel, a panel wall, and a gated weir. Between the approach channel and the river there is another outlet, known as a waste gate or sluice, which is used to flush sediment out of the approach channel.

d. Interpretation problems. Submerged intake structures cannot be located exactly, and sometimes their presence can only be deduced from indirect evidence. Their internal construction and capacity cannot be determined from photographs alone.

e. Required information. Describe locations and types of intake structures.

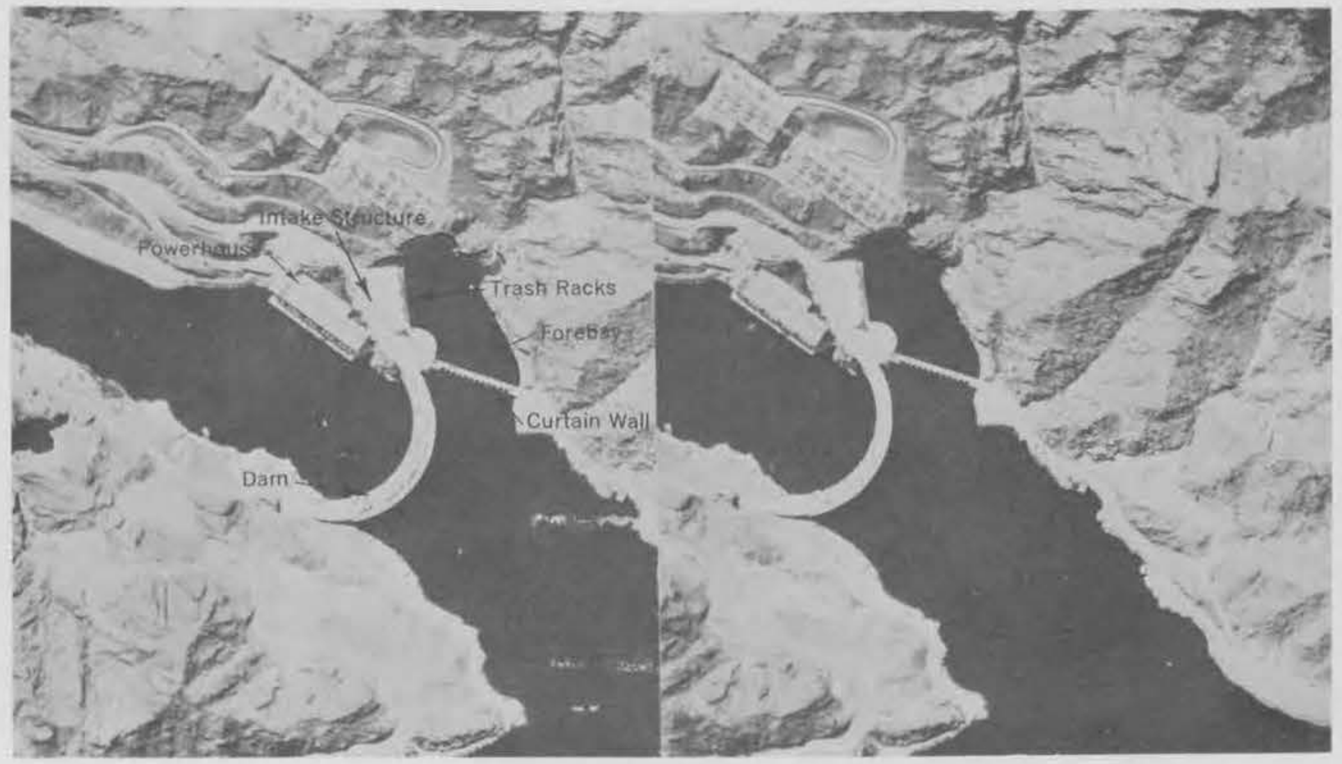


Figure 93: Trash Racks
Scale Unknown

The curtain wall accommodates coarse trash racks. Fine trash racks are mounted in front of the intake to the penstocks.

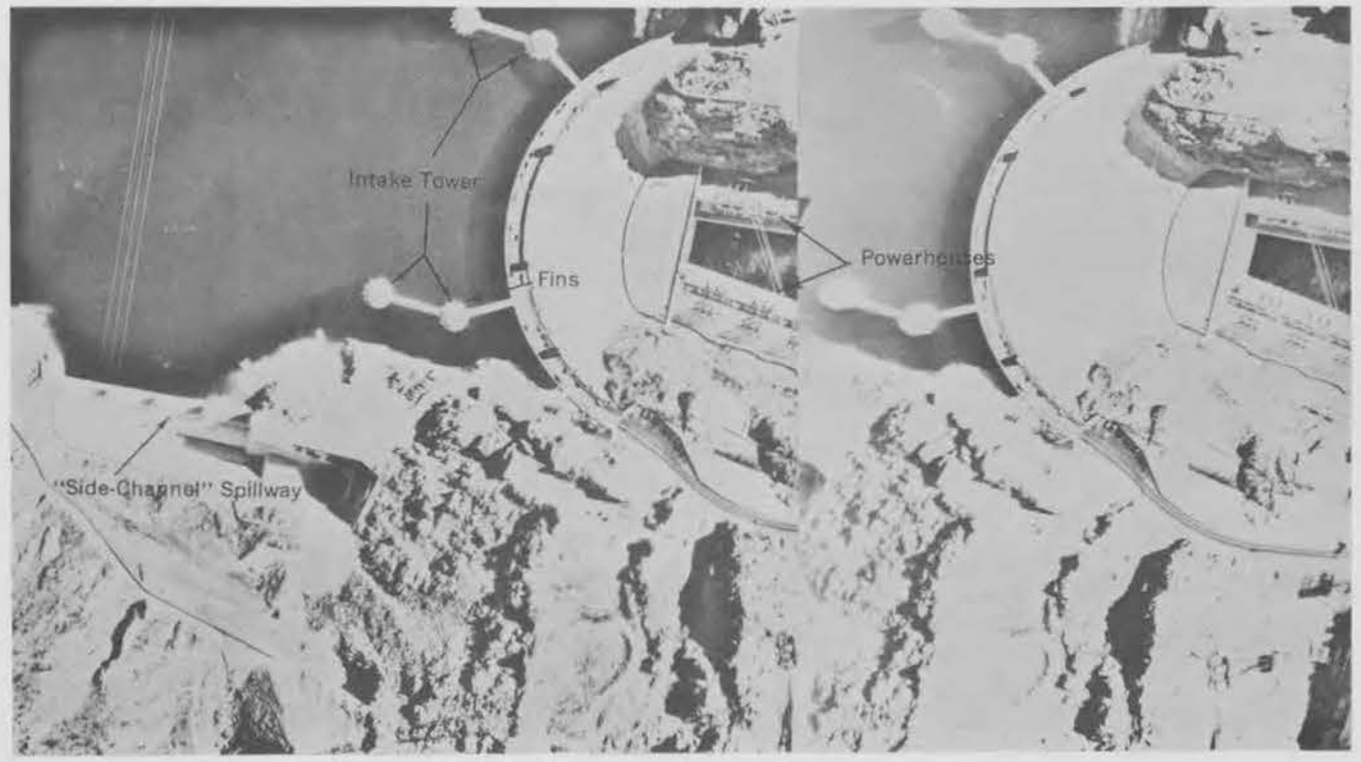


Figure 94: Intake Towers near Dam
Scale Unknown

These four towers are connected to the powerhouse by tunnels. The fins around each tower support trash racks.

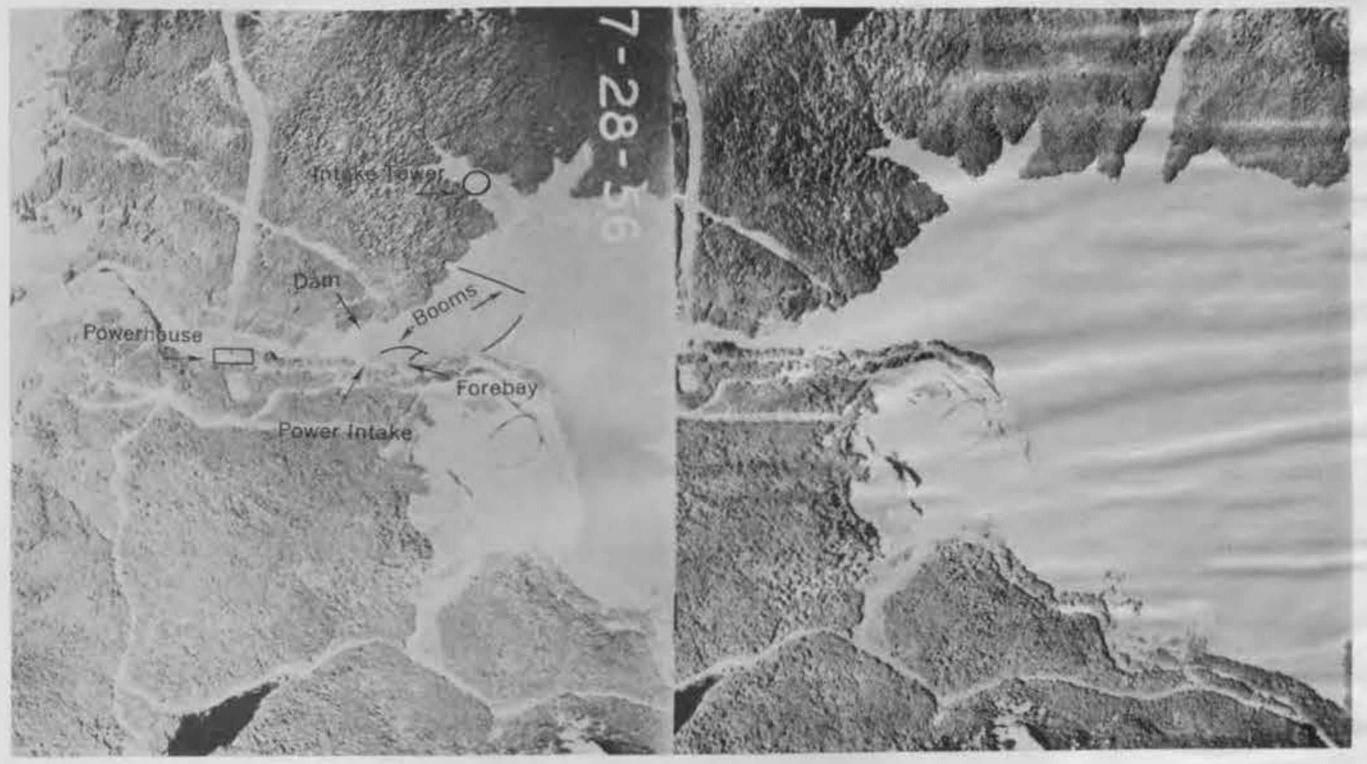


Figure 95: Intake Tower at a Distance from Dam
Scale Unknown

Cursory examination of this photo would be misleading because one might overlook the intake tower. In that event, one might classify this structure as a single-purpose dam when in reality it is a multipurpose dam. Note the booms: these support coarse trash racks in front of the power intake.

Figure 96: Water Supply Intake
Scale Unknown

The intake tower serves the water treatment plant and its clearing basins.

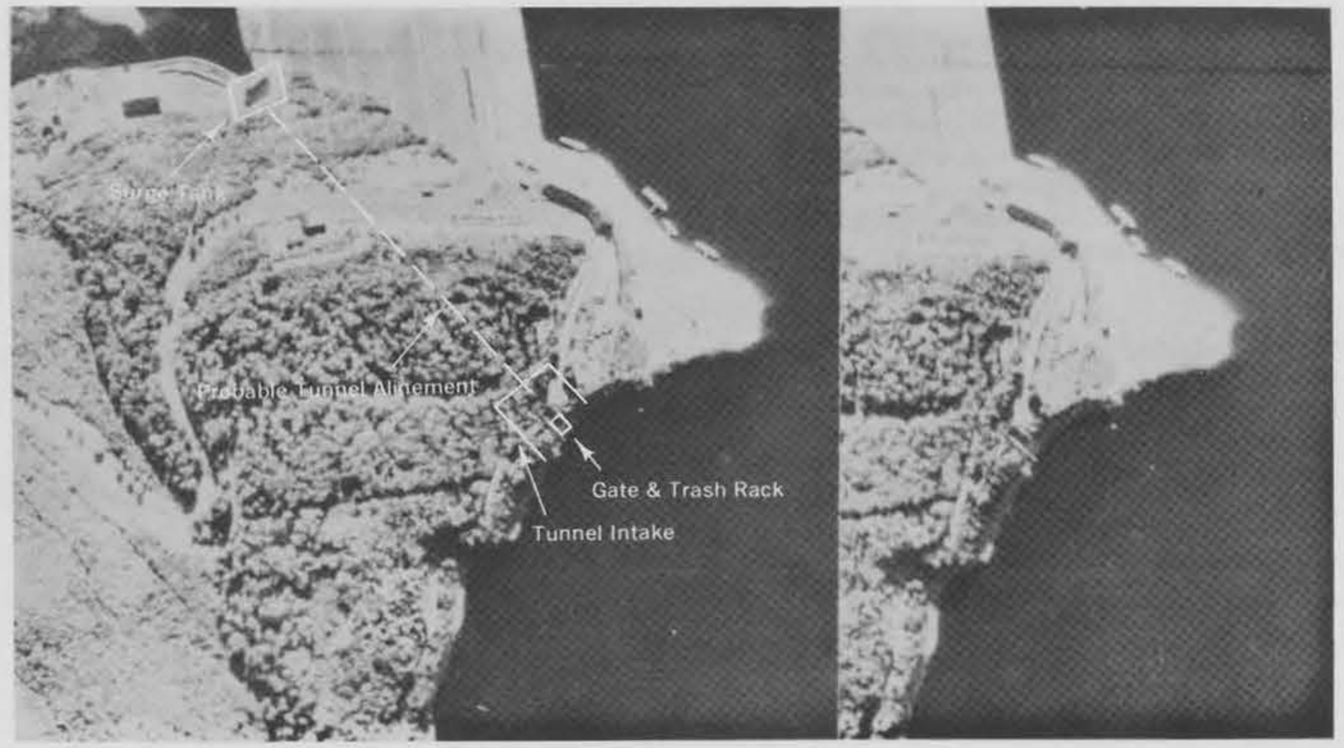


Figure 97: Partially Submerged Intake
Scale Unknown

The procedure in locating the intake is as follows: First, the powerhouse, penstocks, and surge tank are located on the left abutment (see fig. 86). Since this is an earthfill dam, it is not likely that a conduit leads from the surge tank through the dam. A careful examination of the reservoir shoreline then reveals the intake.

Figure 98: Canal Intake Structure

Intake approach of typical diversion works: (a) Gated weir, (b) waste outlet, (c) scouring sluice, (d) curtain wall, and (e) panel wall.

25. Conduits

a. Background. Conduits convey water from the reservoir to an appurtenant work. They may be roughly divided into four classes: canals, tunnels, pipes, and those contained within a dam. A single conduit may be a combination of any or all of the four. Canals, tunnels, and pipes usually have intake structures at the upstream end, but those that are contained within the dam usually do not. Conduits vary in length from a few feet to many miles and in diameter or width from a few inches to many feet.

b. Recommended types and scales of photography. Vertical, vertical stereopairs, and low oblique airphotos are recommended. If only alinement is required, scales at 1:20,000 are recommended. If cross-sectional dimensions are required, vertical stereopairs at 1:1,000 should be used.

c. Recognition features

(1) Upstream from dam. Look for intake structures or trash racks located on the face of the dam or somewhere near the shoreline of the reservoir. These indicate conduit entrances.

(2) At the dam

(a) Look for large steel pipes resting on the face of the dam or on concrete blocks. These pipes are called penstocks and convey water to power turbines. If penstocks emerge directly from the face of the dam, there is normally no separate intake structure provided, and the water enters the penstocks directly through gated openings built into the upstream face of the dam (fig 99). If the penstocks emerge from the abutment, they probably lead from a tunnel that connects to an intake structure located in the reservoir (figs 100 and 97).

(b) Look for regularly alined open water channels (canals) leading from a canal intake to a ship lock, powerhouse, water treatment plant, or other appurtenant work (fig 101).

d. Interpretation problems

(1) Although not all conduits are visible (for example, underground pipes and tunnels), their alinement may sometimes be estimated on the basis of the relative location of the visible intake structures and appurtenant works (fig 102). Many times the association of a particular intake with a specific appurtenant work will be a guess based on a knowledge of engineering principles applied to the particular situation. If the information is needed in these doubtful cases, technical assistance and reference to other sources will be necessary.

(2) Openings or holes often observed on the downstream face of a masonry dam are called sluices. They differ from conduits in that they do not convey water to an appurtenant work. They are discussed in Paragraph 27.

e. Required information

(1) Describe type, purpose, and alinement of conduit.

(2) Measure length and cross-sectional area if possible.

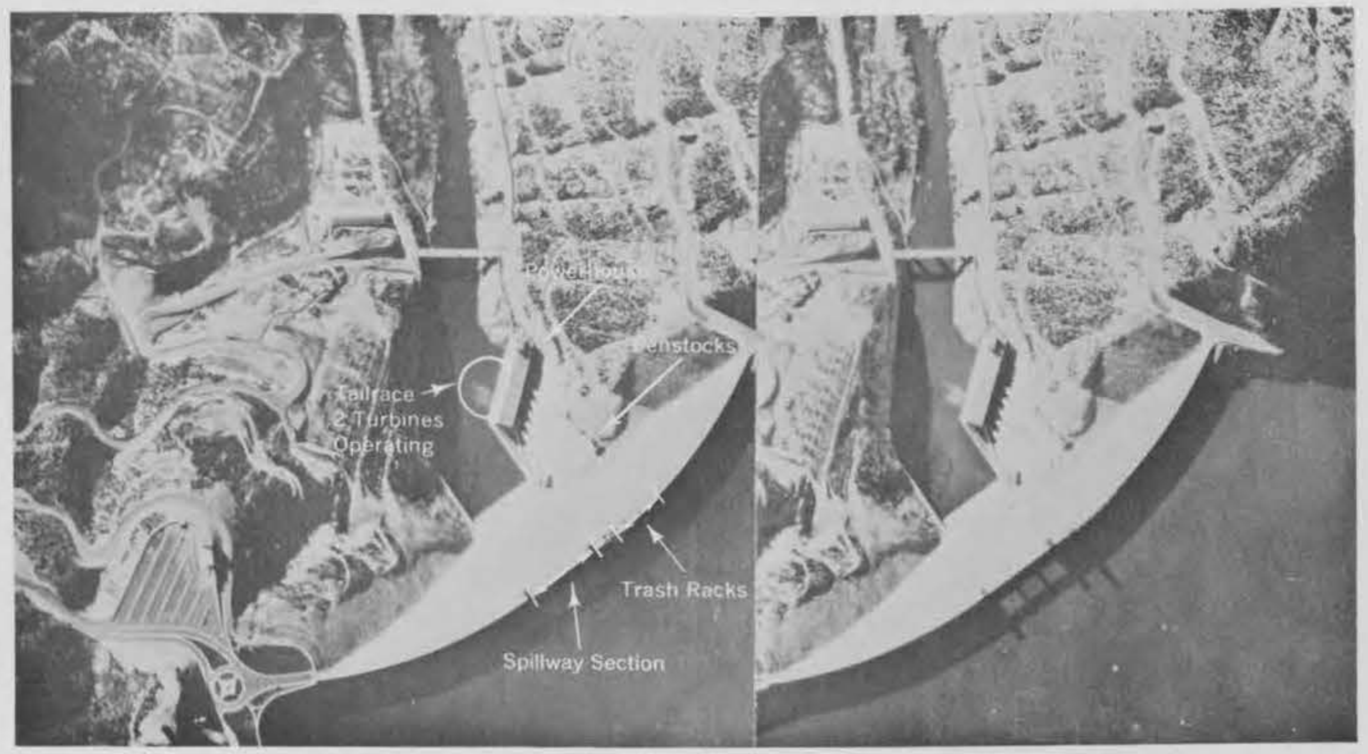


Figure 99: Penstocks Emerging Directly from Downstream Face of Dam
Scale Unknown

The intakes form an integral part of the dam. Note the trash racks mounted on the upstream face of the dam. In the tailrace section, note the two gray bands of turbulent water indicating that two turbines are operating.

Figure 101: Diversion Canal (Hydropower)

Photograph depicts a typical layout of a diversion structure: (a) dam, (b) canal intake, (c) canal, (d) powerhouse, (e) withdrawal section of river, and (g) dam tender's house.

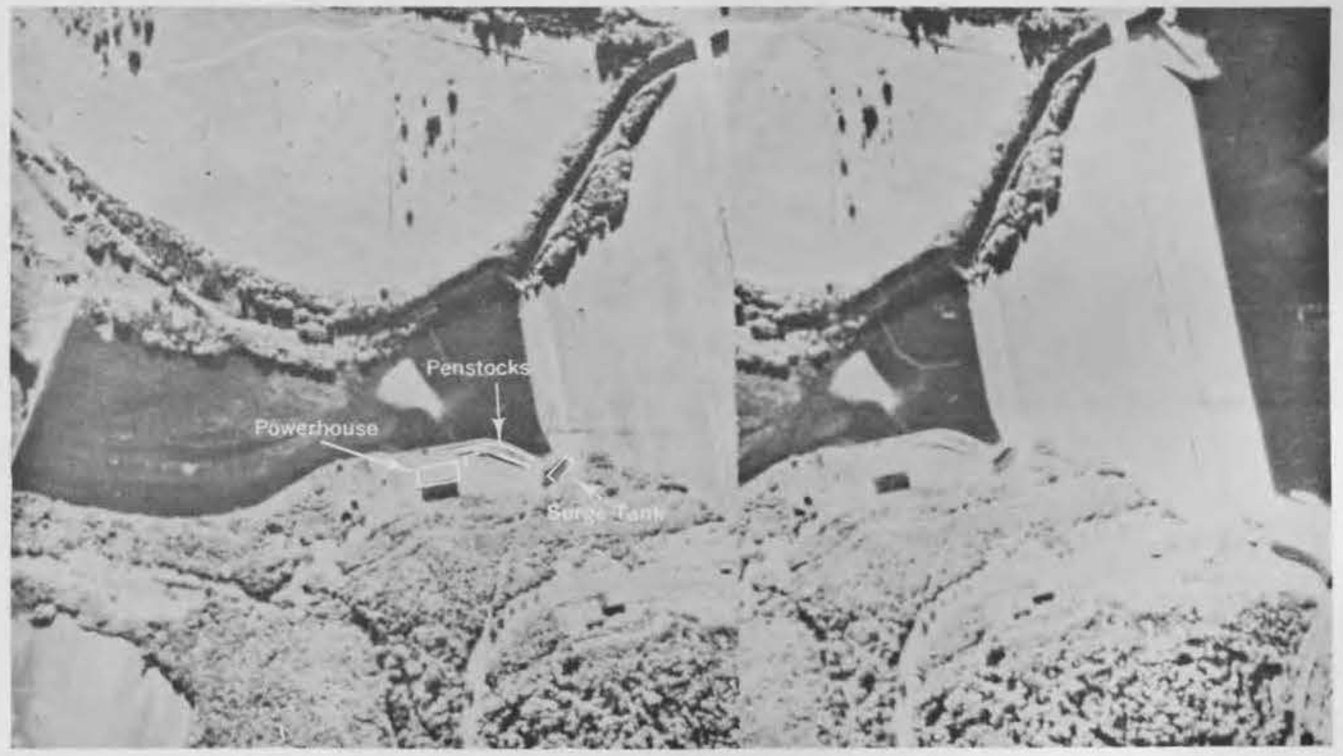


Figure 100: Penstocks Emerging from Dam Abutment
Scale Unknown

The penstock leads from the surge tank to the powerhouse and is fed via a tunnel. For probable tunnel alinement and location of intake, refer to Figure 97.

25. Conduits

a. Background. Conduits convey water from the reservoir to an appurtenant work. They may be roughly divided into four classes: canals, tunnels, pipes, and those contained within a dam. A single conduit may be a combination of any or all of the four. Canals, tunnels, and pipes usually have intake structures at the upstream end, but those that are contained within the dam usually do not. Conduits vary in length from a few feet to many miles and in diameter or width from a few inches to many feet.

b. Recommended types and scales of photography. Vertical, vertical stereopairs, and low oblique airphotos are recommended. If only alinement is required, scales at 1:20,000 are recommended. If cross-sectional dimensions are required, vertical stereopairs at 1:1,000 should be used.

c. Recognition features

(1) Upstream from dam. Look for intake structures or trash racks located on the face of the dam or somewhere near the shoreline of the reservoir. These indicate conduit entrances.

(2) At the dam

(a) Look for large steel pipes resting on the face of the dam or on concrete blocks. These pipes are called penstocks and convey water to power turbines. If penstocks emerge directly from the face of the dam, there is normally no separate intake structure provided, and the water enters the penstocks directly through gated openings built into the upstream face of the dam (fig 99). If the penstocks emerge from the abutment, they probably lead from a tunnel that connects to an intake structure located in the reservoir (figs 100 and 97).

(b) Look for regularly alined open water channels (canals) leading from a canal intake to a ship lock, powerhouse, water treatment plant, or other appurtenant work (fig 101).

d. Interpretation problems

(1) Although not all conduits are visible (for example, underground pipes and tunnels), their alinement may sometimes be estimated on the basis of the relative location of the visible intake structures and appurtenant works (fig 102). Many times the association of a particular intake with a specific appurtenant work will be a guess based on a knowledge of engineering principles applied to the particular situation. If the information is needed in these doubtful cases, technical assistance and reference to other sources will be necessary.

(2) Openings or holes often observed on the downstream face of a masonry dam are called sluices. They differ from conduits in that they do not convey water to an appurtenant work. They are discussed in Paragraph 27.

e. Required information

(1) Describe type, purpose, and alinement of conduit.

(2) Measure length and cross-sectional area if possible.

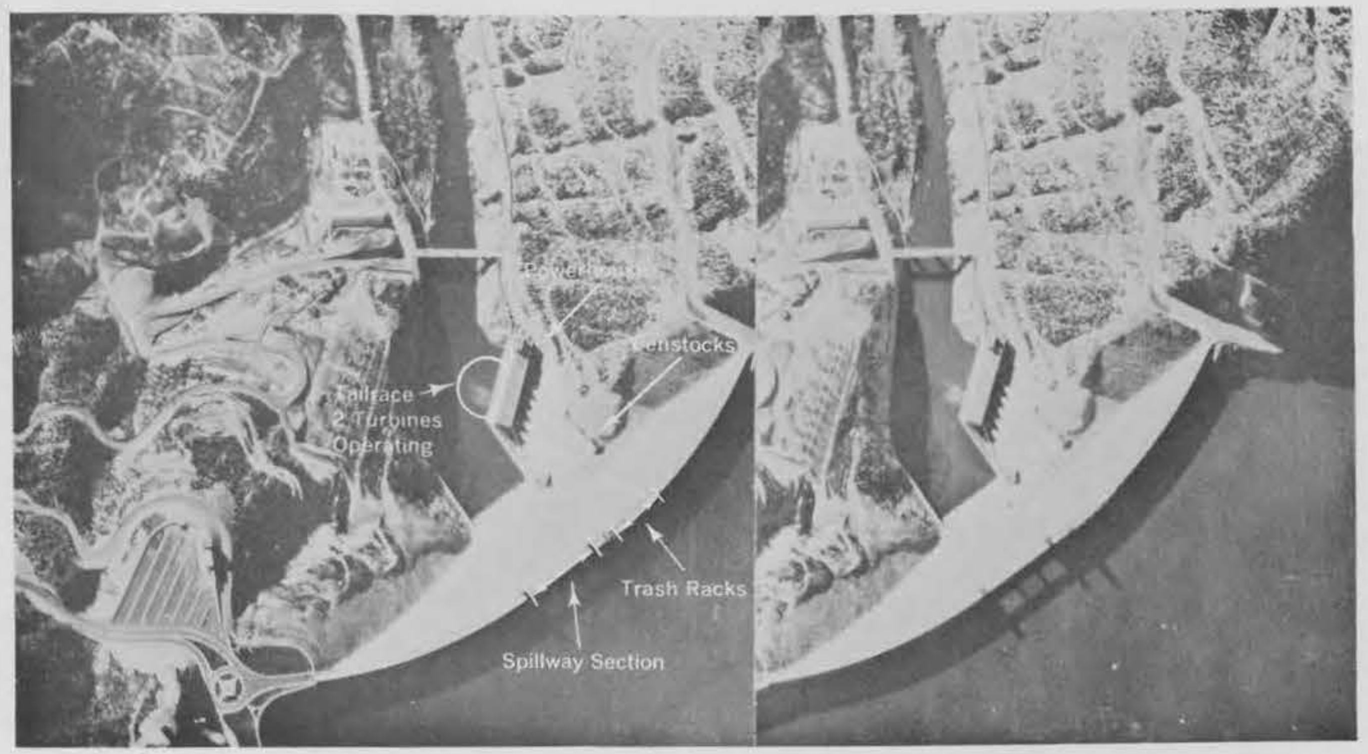


Figure 99: Penstocks Emerging Directly from Downstream Face of Dam
Scale Unknown

The intakes form an integral part of the dam. Note the trash racks mounted on the upstream face of the dam. In the tailrace section, note the two gray bands of turbulent water indicating that two turbines are operating.

Figure 101: Diversion Canal (Hydropower)

Photograph depicts a typical layout of a diversion structure: (a) dam, (b) canal intake, (c) canal, (d) powerhouse, (e) withdrawal sectio of river, and (g) dam tender's house.

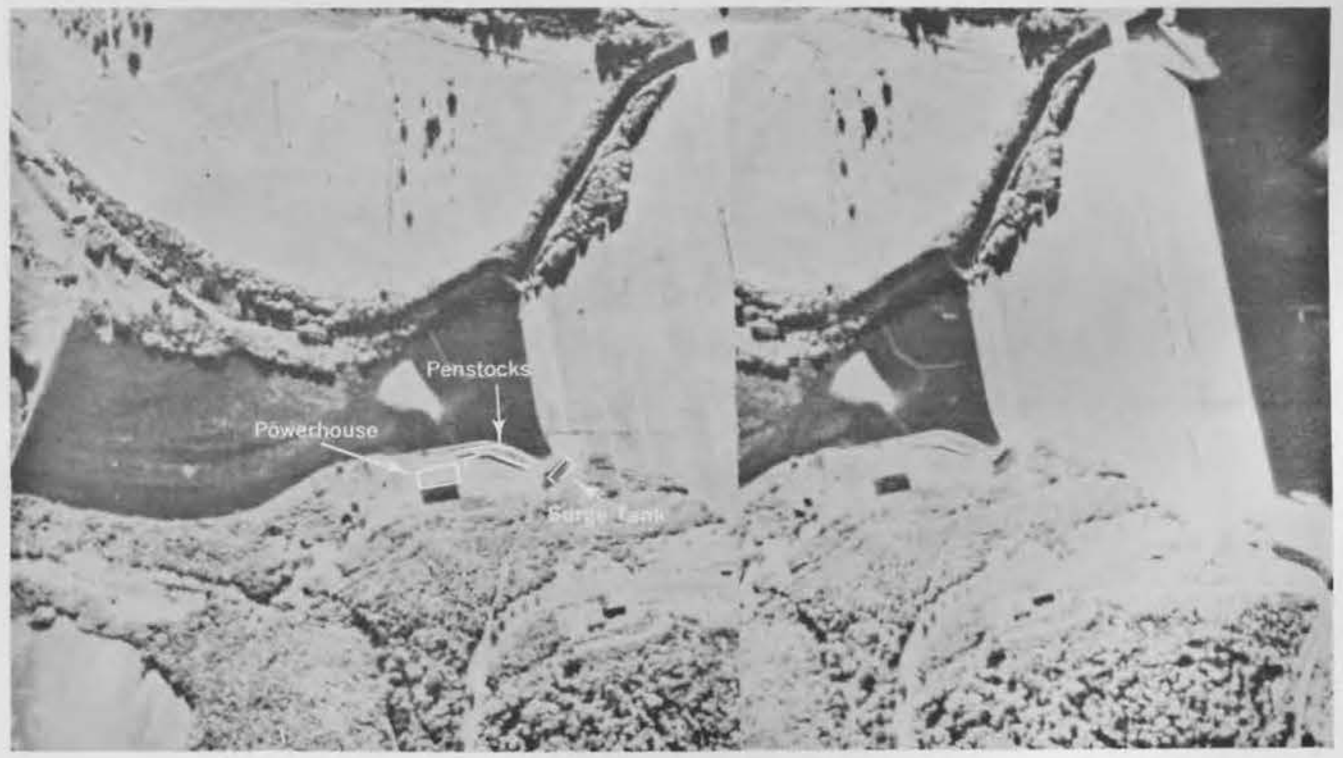


Figure 100: Penstocks Emerging from Dam Abutment
Scale Unknown

The penstock leads from the surge tank to the powerhouse and is fed via a tunnel. For probable tunnel alinement and location of intake, refer to Figure 97.

Figure 102: Tunnel
Scale Unknown

Examination of the area immediately downstream from the dam fails to reveal any kind of appurtenant work. A powerhouse is found directly across the divide from the intake tower in the reservoir. Penstocks emerge from the mountainside directly behind the powerhouse and are alined with the intake tower. Hence, it is assumed that the reservoir is connected to the powerhouse by a tunnel.

26. Spillways

a. Background. A spillway is a passage provided to release surplus water from a reservoir in order to prevent overtopping of the dam. There are five basic types: overflow, chute, side-channel, shaft, and siphon spillways. They may have gated or ungated crests. There are many varieties of spillway gates, but nearly all may be classified as either vertical or radial lift gates. Some gates are raised and lowered by mechanical means, such as, gantry cranes, hydraulic-jack devices, or windlasses; others are hydraulically operated by employing the buoyant effect of water. The structural features required for the latter type of gate operation are shown on Figure 112. Although this figure illustrates a beartrap gate installation, the water entrance and exit tubes and the watering chamber shown on the lower diagram are typical of all gates that use the buoyant effect of water for operation. Release water usually flows under mechanically lifted gates, and over hydraulically operated gates.

b. Recommended types and scales of photographs. Vertical or vertical stereopairs at 1:10,000 scale are recommended for locating and classifying spillways. Vertical stereopairs, low obliques, and ground photos at 1:5,000 scale are recommended for detailed analysis and typing of gates.

c. Recognition features

(1) Overflow spillways (fig 103). An overflow spillway is a section of dam designed to permit water to pass over the dam crest. This type is used on masonry gravity, arch, and buttress dams. Some embankment dams have a masonry gravity section designed to serve as an overflow spillway. The following features identify an overflow spillway:

(a) The spillway is always located on the dam crest, and the spillway crest is always at a lower elevation than other sections of the dam.

(b) Watermarks may be seen on the downstream face of the dam indicating past flow.

(c) Water may be seen flowing over a section of a masonry dam crest or the masonry gravity section of an embankment dam and spilling directly on the downstream toe.

(d) Large gates may be mounted on the spillway crest.

(2) Chute spillway (fig 104). A chute spillway is designed so that water flows over the spillway crest into a steep-sloped open canal which is called a chute. The chute is usually constructed of reinforced concrete slabs 10 to 20 inches thick. These spillways are adaptable to any type of dam. Depending on topographic conditions a chute spillway may be located in many places, commonly on one or both abutments or in a saddle formation somewhere along the lower periphery of the reservoir. In addition, since this type is light, it is sometimes used on embankment dams where topography of the damsite makes it necessary to place the spillway on the embankment. The following features identify a chute spillway:

(a) A relatively long, steep, concrete-lined open canal beginning at the reservoir and ending somewhere in the river downstream of the dam.

(b) Water may be flowing over the spillway crest and down the chute into an open stream leading to the river or into the river itself.

(c) There may be large gates on the spillway crest near the entrance to the chute.

(3) Side-channel spillways (fig 105). A side-channel spillway is one in which the flow, after passing over the spillway crest, is carried away in a channel running parallel to the spillway crest. The spillway crest is usually a concrete gravity section, but it may consist of pavement laid on an earth embankment or natural ground surface. This type of spillway is used in narrow canyons where sufficient spillway crest length is not available for overflow or chute spillways. The following features identify a side-channel spillway:

(a) Spillway crest is alined nearly perpendicular to the dam crest.

(b) There may be gates on the spillway crest.

(c) Side channel is parallel to spillway crest.

(d) The side channel may empty into a tunnel; therefore, a low oblique downstream view of the dam might show the exit of the tunnel.

(e) The side channel may empty into a clearly visible chute.

(4) Shaft spillways (fig 106). A shaft spillway is a vertical shaft through which the water drops into a horizontal conduit (usually a tunnel) conveying it past the dam. A shaft spillway is used when it is not possible to use one of the three spillways described above. Shafts are usually made of reinforced concrete; however, small shafts may be constructed of metal or concrete pipe or clay tile. All shafts have distinctive circular flared inlets that are called "glory holes." The following features identify a shaft spillway:

(a) On a large shaft spillway, the inlet usually resembles the petal arrangement of a morning-glory. On a small shaft, the inlet resembles the top of a funnel.

(b) When the spillway is discharging (inlet not visible), the water surface over the inlet looks like a whirlpool.

(c) Shaft spillways usually empty into a tunnel; therefore, a low oblique airphoto showing the downstream area should reveal the tunnel exit.

(5) Siphon spillways (fig 107). A siphon spillway is a siphon device formed within the dam. They are used in masonry dams if a large spillway discharge capacity is not required and it is desirable to regulate the reservoir water level within close limits. A siphon spillway cannot readily be identified on a photograph because it is contained within the dam structure.

(6) Spillway gates. Features used to distinguish various spillway crest gates are as follows:

(a) Vertical lift gates (fig 108 and 114).

1. Usually the width of the gate between gate piers is not over 40 feet, and the height of the gate is the same as or approximately three-fourths of the width.

2. There is usually a superstructure supporting a movable gantry crane or a gate control house atop each pier.

3. The gates are usually straight and flat, operating in vertical grooves or tracks on the sides of the piers.

(b) Radial lift gates, mechanically lifted -- These are of two general types: Tainter and roller gates.

1. Tainter gates (fig 109)

(a) These are similar to vertical lift gates in height, width, and superstructure apparatus.

(b) The face of the gate resembles a segment of a cylinder laid on its side with convex side upstream and concave side downstream.

(c) A steel A-frame support is attached to the face plate. The apex of the A-frame is usually pivoted on trunnions set in the downstream portion of the piers; however, on occasions the gate is pivoted nearer to the middle section of the A-frame, and the apex is weighted as a counterbalance.

2. Roller gates (fig 110)

(a) The width of the gates may be as much as 150 feet, but is seldom less than 60 feet. The height is much shorter than the width.

(b) The gate control houses are mounted atop the piers and are usually connected by a light service superstructure.

(c) The gate is a cylindrical drum that rolls up or down an inclined slot in the side of the pier.

(c) Radial lift gates, hydraulically lifted

1. Drum gates (fig 111)

(a) These are normally used on high dams.

(b) These are similar to roller gates in height

(c) Usually there is no superstructure.

(d) The gate is a sector of a hollow cylinder laid on its side with the curved face upstream. In the lowered position, it fits into a large recess in the top of the spillway. When water is admitted to the recess, the hollow gate is forced upward to the closed position.

(e) When the reservoir is low, water entrances into the water chamber may be seen on the upstream face of the spillway.

2. Beartrap gates (fig 112)

(a) These are normally used on low navigation dams.

(b) These are similar to roller gates in height and width.

(c) There is no superstructure.

(d) The gate consists of two leaves of timber or steel with the lower edges hinged to the dam. In the lowered position the gate fits into a relatively small recess in the top of the spillway and the upstream leaf overlaps the downstream leaf. When water is admitted to the recess, the leaves are forced upward into the gate-closed position.

(e) When the reservoir is low, water entrances into the water chamber may be seen on the upstream face of the spillway.

d. Interpretation problems

(1) Chute, side-channel, and shaft spillways may be located at considerable distances from the dam. In addition, dams may have two spillways: one at or near the dam and one somewhere on the lower periphery of the reservoir. It may be difficult to locate these spillways, especially the shaft spillway.

(2) A single spillway may exhibit features of two or three types of spillways. For example, a side-channel spillway may, on occasion, empty into a shaft or into a chute.

(3) In using watermarks to identify an overflow spillway, care must be exercised to distinguish them from stains and shadows on other sections of the dam. Watermarks are sharply delineated and perpendicular to the spillway crest. Shadows and stains appear blurred and are not usually perpendicular to the spillway crest.

(4) In order to estimate the height of a gate on vertical airphotos, the shadow of the gate must be visible, The gate itself can be seen on oblique airphotos, but the photograph must be rectified before usable measurements can be secured.

(5) Differentiation between drum gates and beartrap gates directly from an airphoto is impossible when the gates are in the open (recessed) position, and very difficult in the closed (raised) position. A reasonable assumption as to which type is present may be made, however, since drum gates are usually installed on high dams (fig 105) and beartraps are usually used on low navigation dams.

e. Required Information

(1) Ungated spillways (fig 113)

(a) Describe the type and location of spillway.

(b) Measure the depth of spillway crest below that of the dam.

(c) Measure the spillway crest length.

(d) If piers are present, measure the width of the piers and their spacing along the spillway crest.

(2) Gated spillways (fig 114).

(a) Follow (a) thru (d) above.

(b) Describe the type of gates and give the number of gates.

(c) Describe the position of gates (open, partially open, or closed).

(d) Measure the width of gates (spacing of piers on smallscale photographs is sufficient).

(e) Measure the height of gate (closed position) or measure the height of opening (open position).

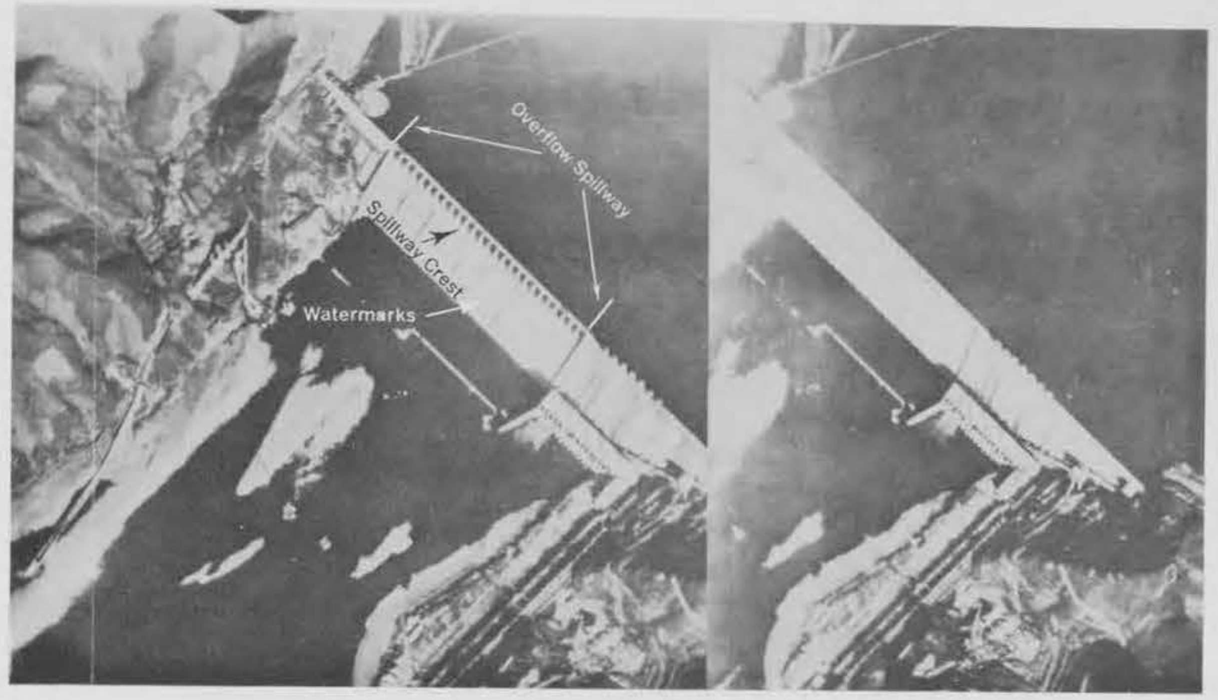


Figure 103: Overflow Spillway
Scale Unknown

Features used to type this spillway are the following: 1) The spillway section forms a section of the dam; 2) the spillway crest is lower than other sections of the dam; and 3) watermarks appear on the downstream face of the spillway section. (The marks appearing to the right of the spillway are shadows and stains.)

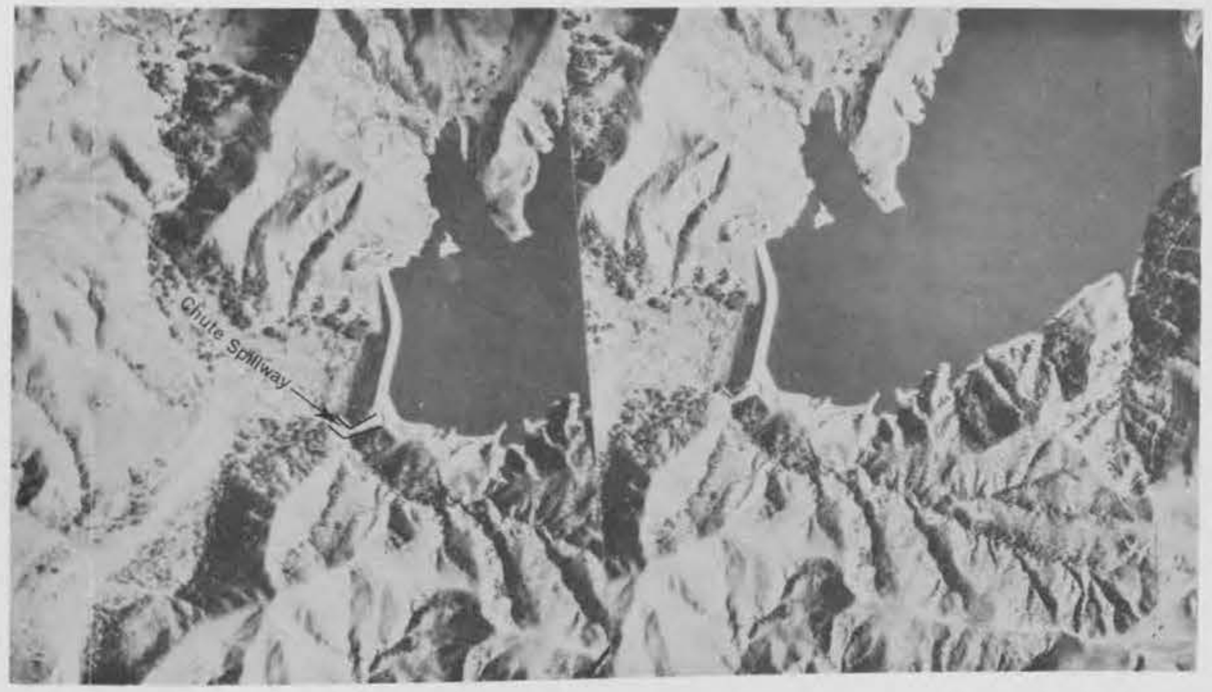


Figure 104: Chute Spillway
Scale 1:12,000 (approx.)

The long, steep, concrete-lined canal on the left abutment beginning at the spillway crest and ending at the river downstream of the dam, identifies this structure as a chute spillway.

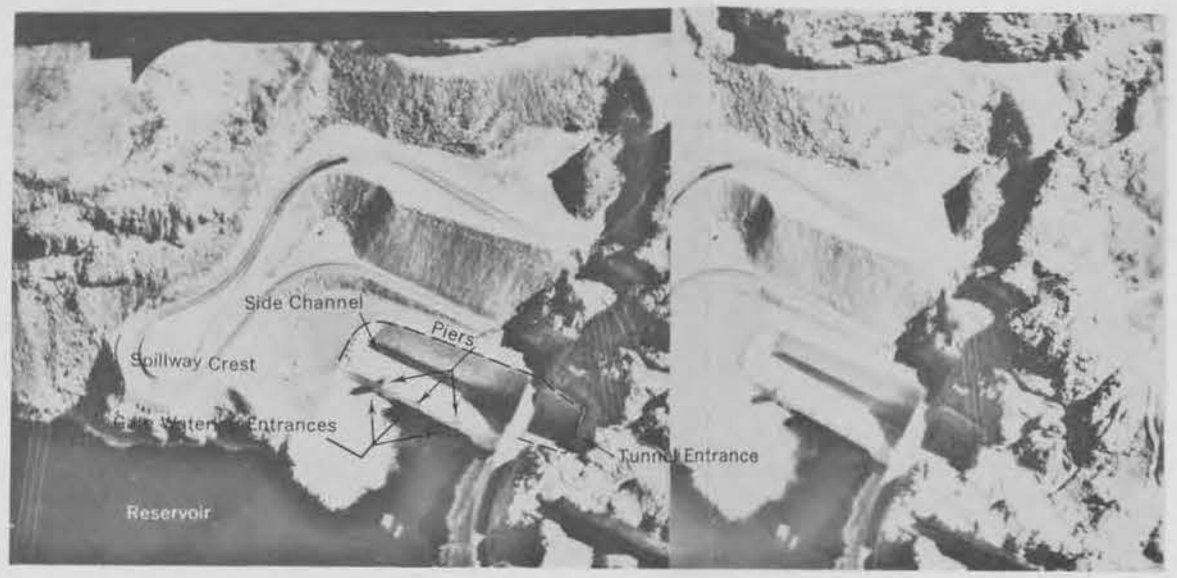
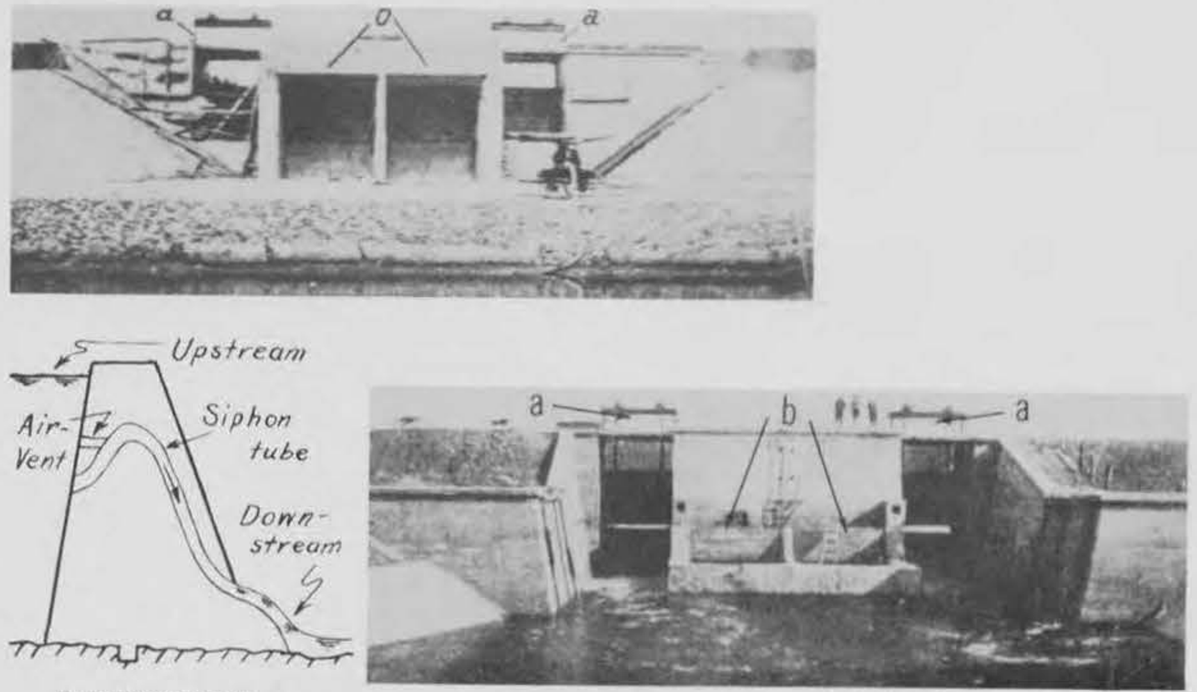


Figure 105: Side-channel Spillway
Scale Unknown

The side channel running parallel to the spillway crest and emptying into the tunnel identifies this structure as a side-channel spillway. The three piers on the spillway crest and the gate-watering entrances at the pier bases are proof that either drum gates or beartrap gates are present. This is a high dam; therefore, it is assumed that these gates are drums.

Figure 106: Shaft Spillway
Scale 1:11,000 (approx.)

The glory hole identifies this structure as a shaft spillway. The horizontal conduit, in this case, is a tunnel whose exit is visible at the point noted as the spillway outlet. Note sluice outlet.



Typical Cross-Section

Downstream View

Figure 107: Siphon Spillway
Scale Unknown

The openings at "b" on the upstream view are the spillway entrances, and on the downstream view are the exits. (The presence of the sluices "a" (see paragraph 27) does not indicate that this is a siphon spillway.) The cross section illustrates a typical design for a siphon spillway.

Figure 108: Vertical Lift Gates
Scale Unknown

The gantry cranes indicate that these are lift gates. The relatively close spacing of the piers indicates that the gates could be either vertical lift or tainter. They are vertical lift gates, however, because the surfaces are straight and flat, and the height and width are almost equal.

Figure 109: Tainter Gates
Scale Unknown

The gantry crane indicates that these are lift gates. The relatively close spacing of the gate piers indicates that the gates could be either vertical lift or tainter. They are tainter gates, however, because the downstream surface of the gates is concave, and each gate has two A-frame supports attached to the piers at the apex of the frame.

Figure 110: Roller Gates
Scale Unknown

The gate control houses atop each pier, and the water flowing under the three righthand gates indicate that these are lift gates. They are roller gates because the shape of the gate is cylindrical, each end of a gate fits into an inclined slot in the side of a pier, and the pier spacing is relatively wide.

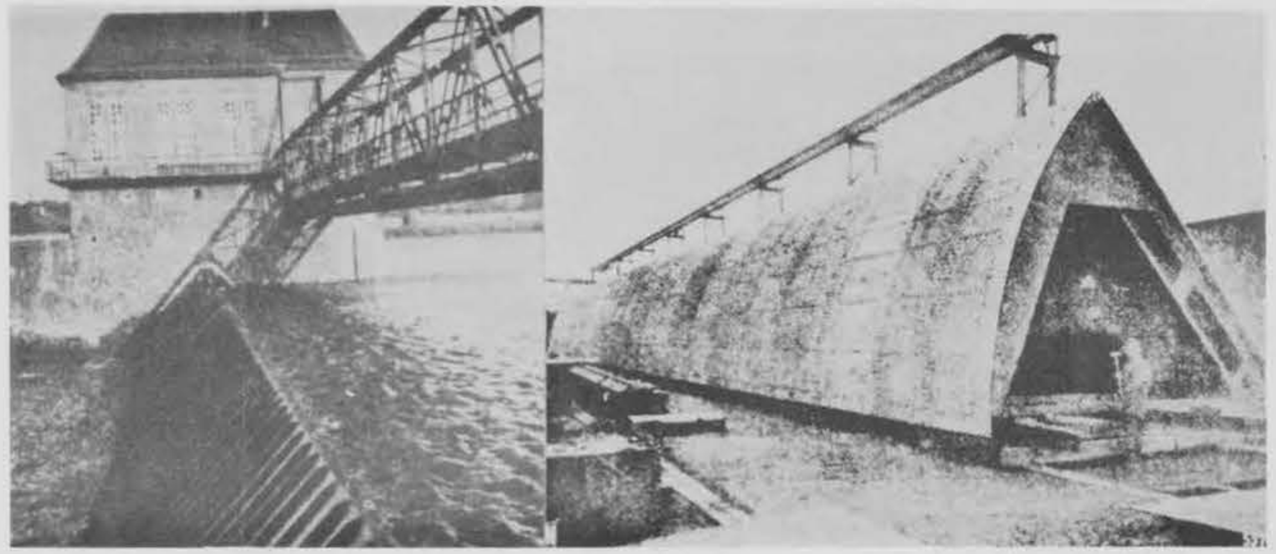


Figure 111: Drum Gate
Scale Unknown

The lefthand photograph is a downstream view of a drum gate in the closed (raised) position. This is not a beartrap gate because the upstream face of the gate does not overlap the downstream face (Figure 112). The righthand photograph shows a drum gate before installation. The curved face will point upstream when the gate is installed. The large size of these gates is demonstrated by comparing the gate height to that of the man.

Figure 112: Cross-sectional Diagram of a Beartrap Gate

The upper diagram illustrates a typical beartrap gate in the closed (raised) position and in the open (lowered) position. The lower diagram illustrates the watering chamber. The small gates in the chamber are usually screw-type valve gates that are operated manually. The upstream valve is opened to allow water into the chamber, thus raising the beartrap gate. When the upstream valve is closed and the downstream valve is opened, the water escapes from the chamber allowing the beartrap gate to lower into the recess (upper diagram).

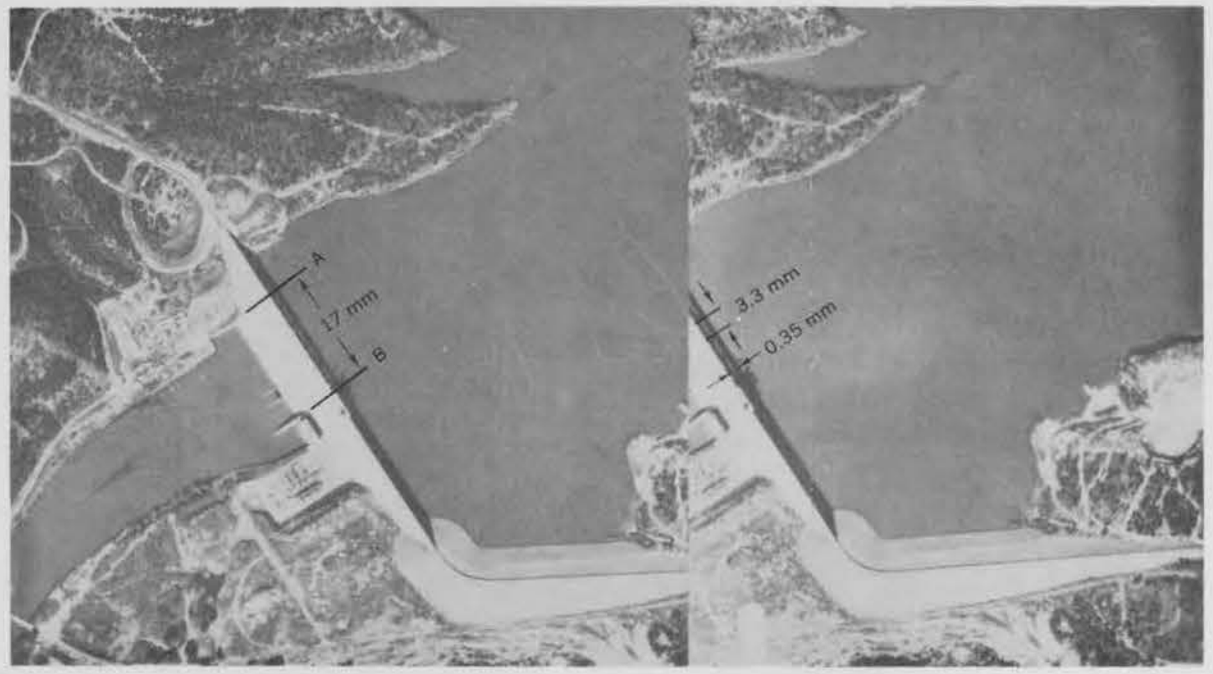


Figure 113: Ungated Spillway
Scale 1:13,500

This is an overflow spillway, and the piers support a roadway across the spillway section. 1 mm (photo)=44.3 ft (ground). The photo was taken on 15 April at 1300 hours, and the geographic coordinates are 98°W., 30°N. Crest length (A to B)=17 mm=753 ft; spacing between piers=3.3 mm=146 ft; the pier width=753—(146 x 5) divided by 4=6 feet. Height of the spillway opening=0.35 mm x 44.3 ft x height-to-shadow ratio of 2.3=36 feet. (The method used to determine the height of the spillway opening is described in Reference 14 Paragraphs 30240-3.)

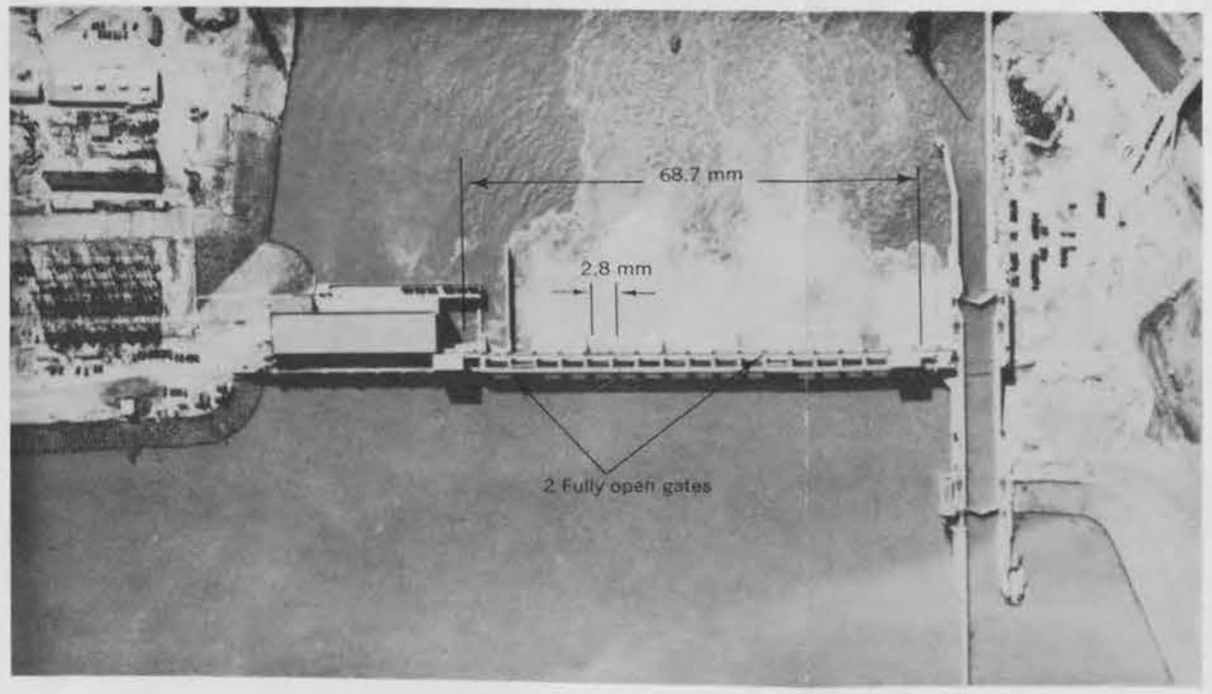


Figure 114: Gated Spillway
Scale 1:4,300 (approx.)

This is an overflow spillway with 18 vertical lift gates. Two gates are fully open, and the rest (16) are partially open. 1 mm (photo) =14.2 ft (ground). Average width between piers=2.8 mm=39.5 ft (acceptable as gate width). Spillway crest length=68.7 mm= 970 ft. Average pier width=970—39.5 x 18 divided by 19=13.7 ft. The gate height cannot be measured on this photo; however, it is estimated to be between 30 and 40 ft (about the same as or three-fourths of the width).

27. Sluices

a. Background. Most of the time a reservoir's water level is below the spillway crest; therefore, outlet works at lower elevations must be provided so that water can be drawn from the reservoir as needed. These outlets are called sluices, and they discharge water into the channel somewhere downstream from the dam. They are always gated and are used to regulate the reservoir water level, release small floods, maintain minimum flow in the downstream channel, or flush accumulated sediment from the reservoir.

b. Recommended types and scale of photography. Ground or low oblique stereopairs and singles of the downstream face of the dam, at 1:10,000 scale, are recommended.

c. Recognition features. A sluice appears either as a rounded or rectangular opening on the downstream face of the dam or as a tunnel exit from one or both abutments.

(1) In embankment dams (fig 115) sluices are usually located in the abutments. They are always located in the masonry section, if present, of an embankment dam.

(2) In masonry dams sluices usually appear on the downstream face of the dam. Sometimes the sluice openings are placed very low on the downstream face and are either partially or completely submerged. Occasionally, where topography permits, they may be placed in the abutments. In high masonry dams, the sluices are arranged in several rows of equally spaced, rounded or rectangular openings. Low masonry dams (fig 116) generally have only one row of sluices.

d. Interpretation problems.

(1) The detection of sluice outlets will on occasion be very difficult, because they may be far downstream from the dam and screened by trees or shadows.

(2) It will be difficult to detect submerged or partially submerged sluice outlets unless they are discharging. If a sluice is discharging, turbulent water may be visible at the outlet (fig 88).

(3) The discharge capacity of sluices cannot be determined from photographs. If the information is required, other sources of information must be used.

e. Required information. Describe location and number of openings.

Figure 115: Sluice Outlets, Embankment Dam

Downstream view of an embankment dam showing two sluices discharging. Note that the sluices are located in the abutment not in the embankment. (See Figure 87 for another embankment dam sluice).

Figure 116: Sluice Outlets, Masonry Dam

Downstream view of low masonry dam showing five of the ten sluices discharging. Note the water marks under the closed sluices. (See Figure 106 for different sluice arangement).

28. Hydroelectric plants

a. Background. A hydroelectric powerplant uses water for the production of electric power. It may be an integral part of the dam, attached to it, or anywhere from a few yards to several miles downstream from it (fig 102). The military hydrologist's primary objective in studying a hydroelectric plant is to deduce the rate of discharge through the turbines; i.e., he needs to know how the operation of the powerplant affects the river's flow and stage. The basic data he requires include; the effective or net head on the turbines, the horsepower or kilowatts produced for some definite time period, and the size and alinement of the penstocks. Much of this information cannot be derived from photographs, but certain information from photographs can be used in making a rough estimate of the net head and the length and diameter of the penstocks. In addition, a good general description of the plant layout can be made. Reference 1 gives procedures for detailed photo interpretation of hydroelectric plants including how to distinguish them from thermal powerplant.

b. Recommended types and scales of photography. Vertical stereopairs at 1:10,000 are recommended. If available, 1:10,000 scale low oblique air and ground photos will also be useful.

c. Recognition features

(1) Hydroelectric plant layouts have many variations. The entire layout may be in the vicinity of the dam (fig 117), associated with but not in the vicinity of the dam (fig 118), or not associated with a dam (fig 119).

(2) The powerhouse building is usually a heavy masonry, steel frame structure.

(3) Penstocks (see para 25c(2)) are large steel pipes usually visible leading from the dam to the powerhouse.

(4) Surge tanks are tall upright cylindrical structures placed in long penstocks to maintain steady water pressure in the penstocks. They supply or store water when the flow of water in the penstock is being accelerated or retarded.

(5) Draft tubes are the outlets for the water discharged from the turbines located in the powerhouse. They are fairly large openings through which the water is either led directly into the river or into a concrete-lined canal called a tailrace. Each turbine has a draft tube. In many cases a stream or streams of turbulent water will be visible in the tailrace; each stream indicates that a turbine is operating (fig 88).

(6) The forebay is the area of the reservoir between the penstock intakes and either a curtain wall (fig 117) or a boom supporting a coarse trash rack (fig 95). The coarse trashrack deflects large floating debris, such as ice and trees, away from the power intakes (see par 24c(1)).

(7) Transformer substation may be visible as a skeletal pattern of steel girders on the roof of the powerhouse or nearby on the stream bank.

(8) Regularly spaced, tall steel towers supporting the transmission lines are often seen leading away from the powerhouse.

d. Interpretation problems

(1) A hydroelectric plant located on a bank immediately downstream from the dam or at a considerable distance from the dam may be difficult to detect or identify.

(2) It will be difficult to find the number of draft tubes if power is not being produced or if the openings are shadowed. Also, sometimes a passageway around the powerhouse or the powerhourse itself extending beyond the draft tube openings may hide them from view.

(3) There are no special forebay areas in reservoirs that are always free of heavy debris, such as ice and trees, and in plants whose source of water is a retention basin.

e. Required information

(1) Describe the layout of the plant, including the number of penstocks, draft tubes, and operating turbines.

(2) Measure the length and diameter of the penstocks.

(3) Measure the difference in water surface elevation between the tailrace and forebay.

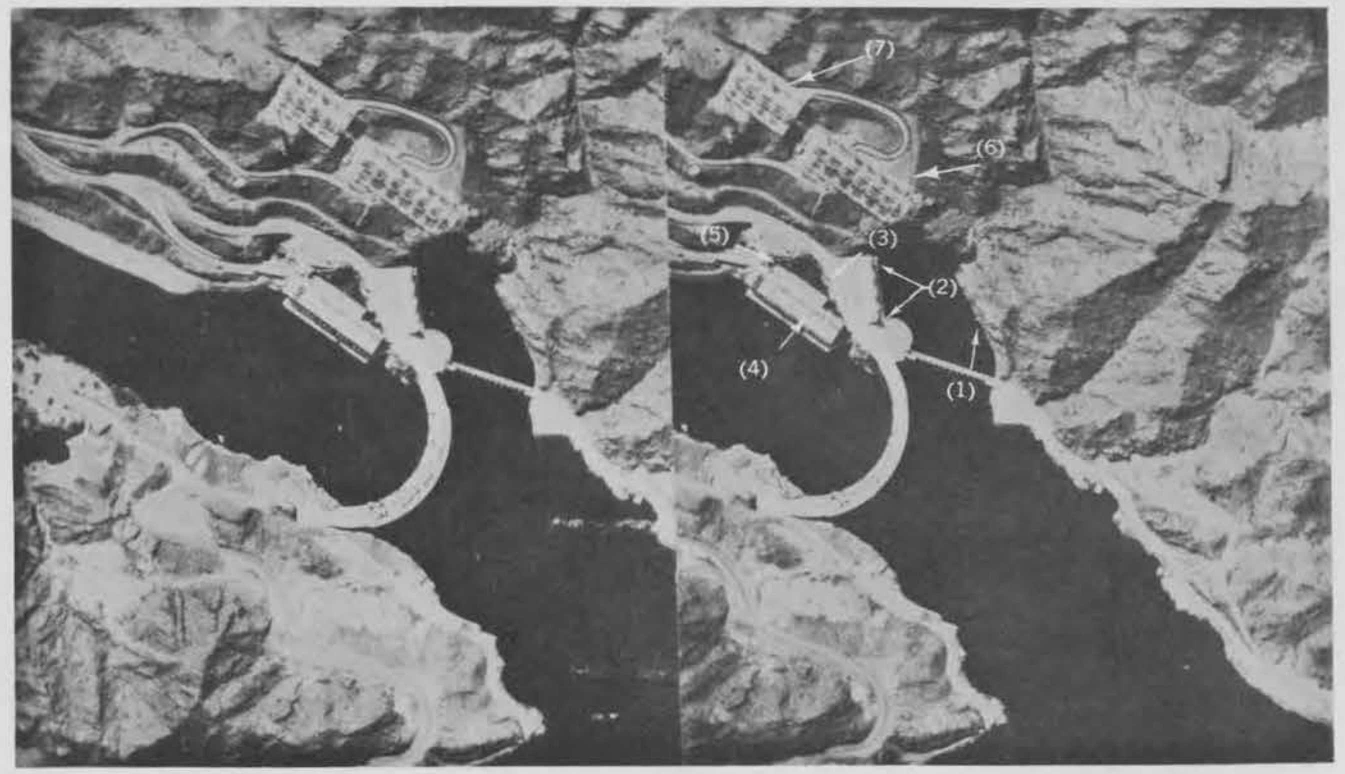


Figure 117: Hydropower Plant at a Dam
Scale Unknown

This is a typical hydropower layout at a dam. When the plant produces power, water in the forebay (1) is let into the penstocks (not visible) through the fine trash racks (2), passes through the turbines in the powerhouse (3), and then out through the draft tubes (hidden by the platform (4) into the river. The transformer yards are located at (5), (6), and (7).

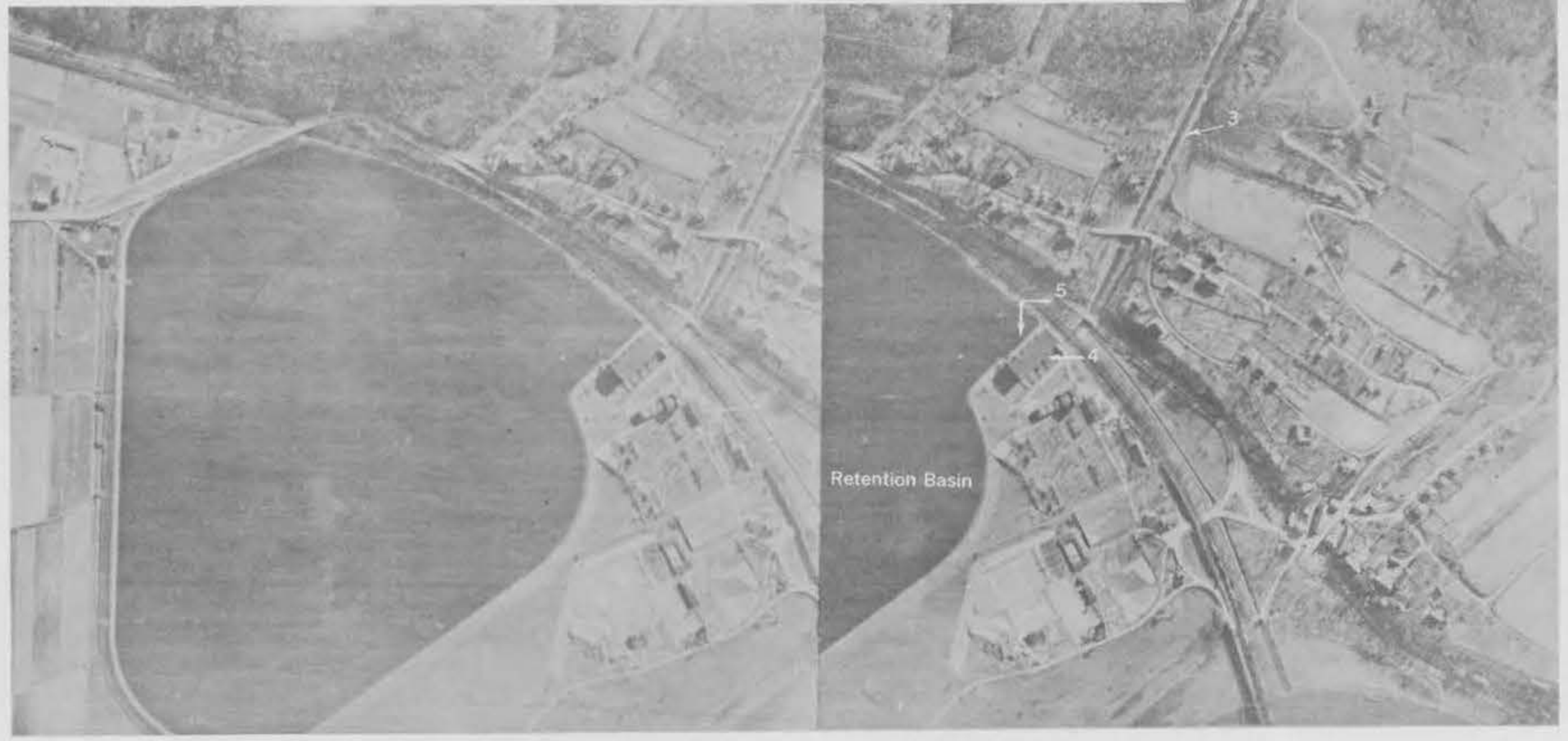


Figure 118: Hydropower Plant at a Distance from a Dam
Scale Unknown

The photo illustrates a fairly common type of hydropower layout. When the plant is producing power, water is let into the penstocks (3) via a tunnel through the dam (1), passes through the surge tanks (2), into the turbines in the powerhouse (4), and then out through the tailrace (5) into the retention basin.

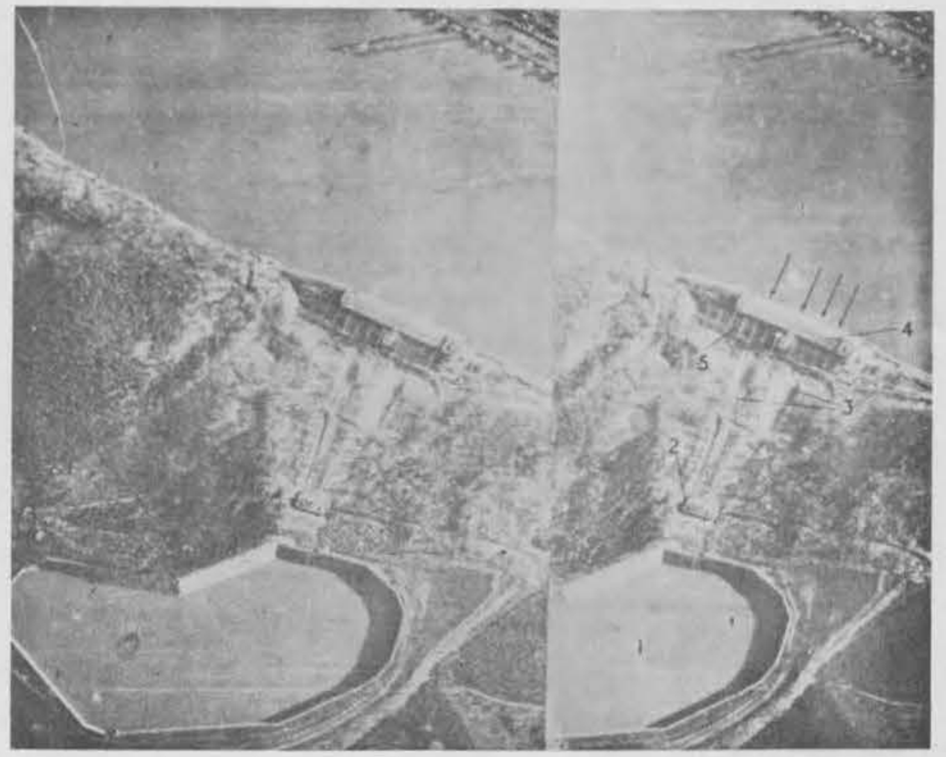


Figure 119: Hydropower Plant without a Dam
Scale Unknown

This plant is somewhat similar in operation to the one illustrated in Figure 118, except that the source of water is the river. The water is pumped through a pipeline (not visible on the on the photograph) into the retention basin (1) (in this case also the forebay), then it is taken through the gatehouse (2) into the penstocks (3), and thence through the turbines in the powerhouse (4). The transformer substation is located at (5).

29. Navigation locks

a. Background. A navigation lock is an enclosure in a canal, river, etc., with gates at each end, used in raising or lowering boats as they pass from level to level. Although various types of gates are used in locks, probably the most common and distinctive is the miter gate. It consists of a pair of symmetrical leaves abutting against each other along the centerline of the lock forming an obtuse angle whose vertex points upstream (fig 120). The width and length of a lock depend on the size of the boats expected to pass through it. The depth, however, depends on the draft of the boats and the difference in water level above and below the lock. A lock may have one to several chambers (boat passages). The operation of a lock requires an ample water supply; hence, somewhere upstream of the lock, provision must be made to store water. Usually a dam is constructed on the river or on one or more of its tributaries.

b. Recommended types and scales of photographs. For identification of locks, verticals and vertical stereopairs of airphotos at 1:10,000 scale are recommended. For dimensioning, vertical stereopairs of airphotos at 1:5,000 scale are recommended.

c. Recognition features (fig 120)

(1) Large rectangular chambers located in waterways or dams with the long axis parallel to the direction of flow.

(2) Miter gates at one or both ends of the rectangular chamber. Although miter gates are not always used in locks, they are seldom used in any other type of hydraulic structure.

(3) Boats in the lock or moored in a straight line above or below it.

(4) Water in and downstream of the lock rarely appears turbulent.

d. Interpretation problems

(1) Fish and/or raft locks (figs 121 and 122) are sometimes built in dams and may be differentiated from navigation locks by the following: they are smaller than navigation locks, have gates only at one end, the approaches to the lock are never very elaborate, and the water in and downstream of the chamber is generally quite turbulent.

(2) Special purpose locks (fig 123) are often found in the vicinity of ports and harbors. These locks are similar to navigation locks. They are used in wet docks (artificial basins in which water is kept at a constant level so that ships always remain afloat, irrespective of the water level outside the dock) to maintain a constant water level in the dock and to provide access to it. Occasionally they are used as graving docks (a form of drydock) to facilitate cleaning and painting a ship's bottom. Their alinement in respect to the alinement of the river will generally differentiate them from navigation locks.

e. Required information

(1) Describe lock including location (left bank, right bank, etc.) and number of chambers.

(2) Measure the length and width of the lock chambers.

(3) Measure the difference in height between the water level upstream and downstream of the lock.

Figure 120: Navigation Lock
Scale 1:11,000

Illustrates a double-chamber navigation lock (3) located on the left abutment. Both the upper and lower ends of the chambers are closed with miter gates. On the photograph, each chamber measures 2.2 mm wide and 24.5 mm long. At the scale of 1:11,000, 1 mm equals 36 feet; therefore, the actual width of each chamber is 79 feet and the actual length is 880 feet. The depth of the chamber cannot be determined. The numbered features are: 1) spillway, 2) powerhouse, 3) navigation locks, 4) forebay curtain wall, 5) trash rack, and 6) loading facilities.

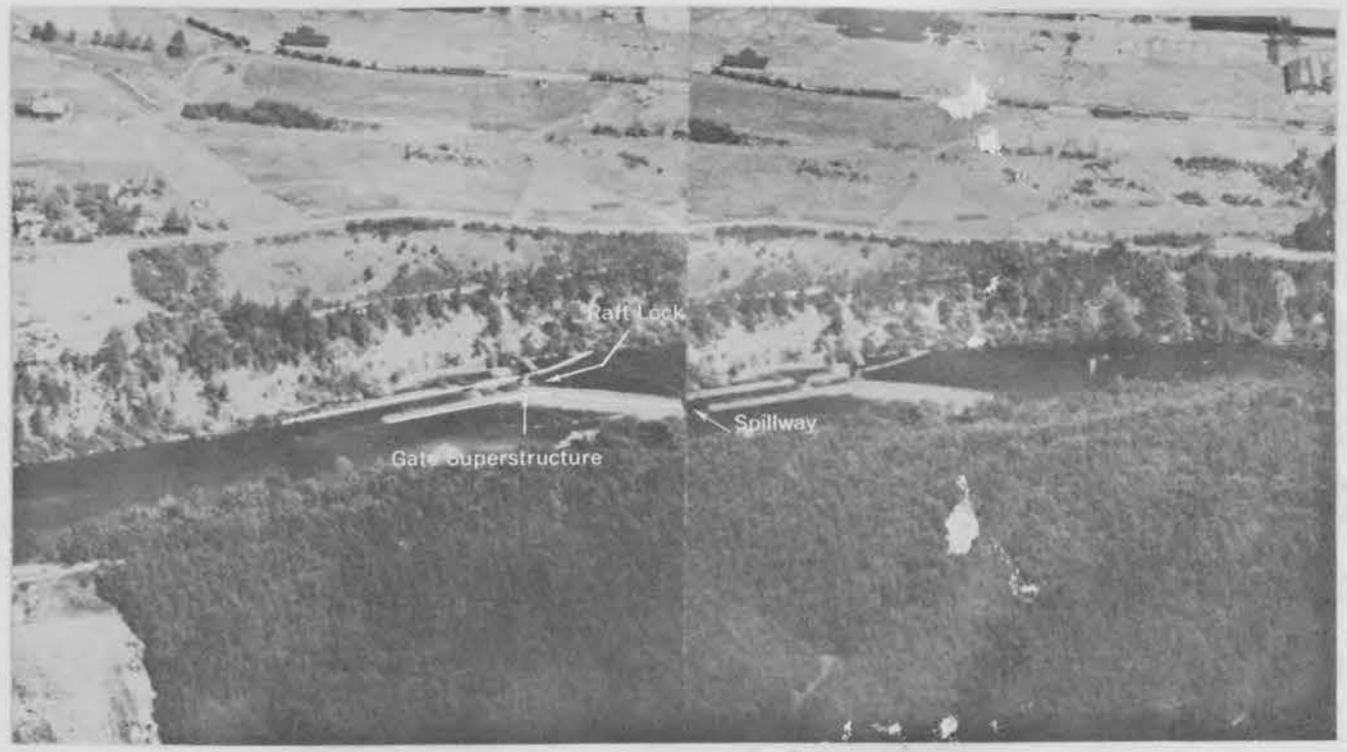


Figure 122: Raft Lock (Oblique View)
Scale Unknown

This view shows the gate superstructure of the raft lock illustrated in Figure 121.

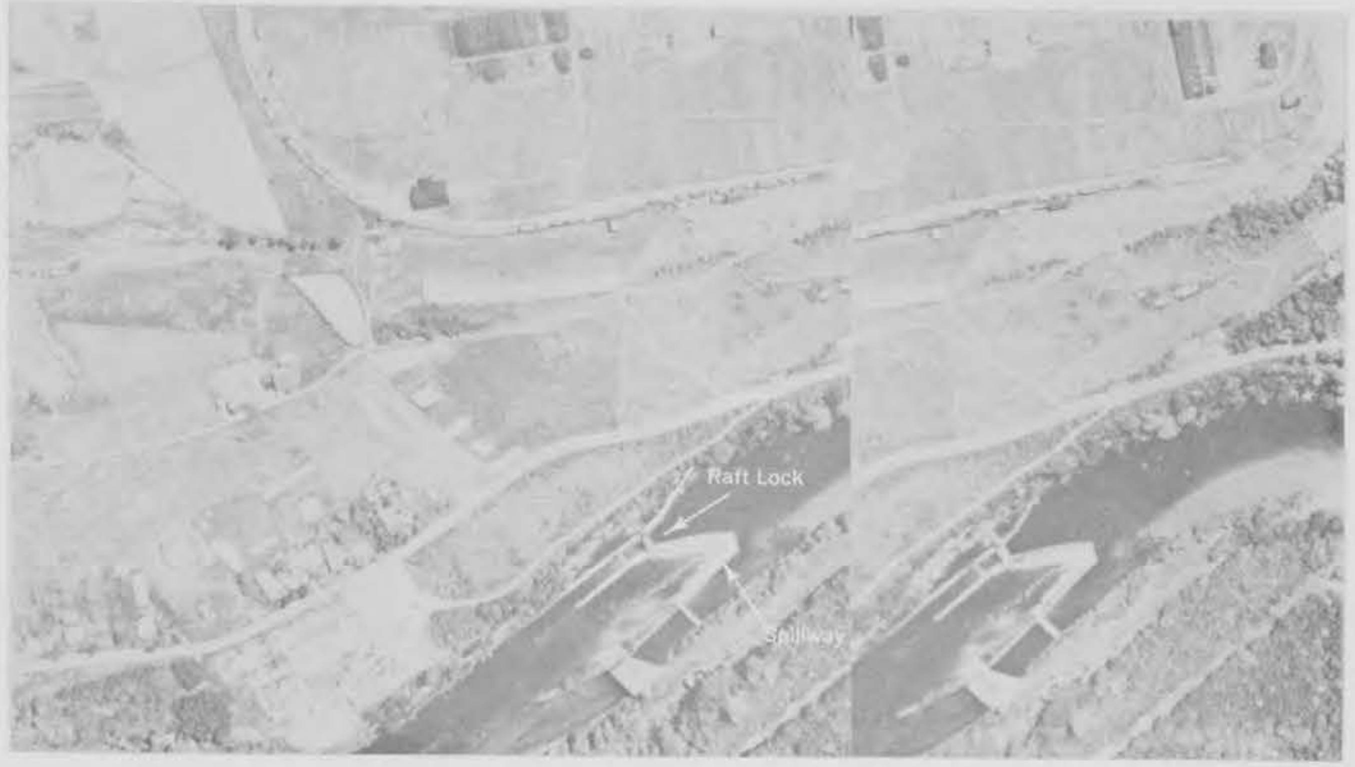


Figure 121: Raft Lock (Vertical View)
Scale 1:5,000 (approx.)

This structure is identified as a raft lock, because there is only one gate in the chamber and the water in the chamber is turbulent.

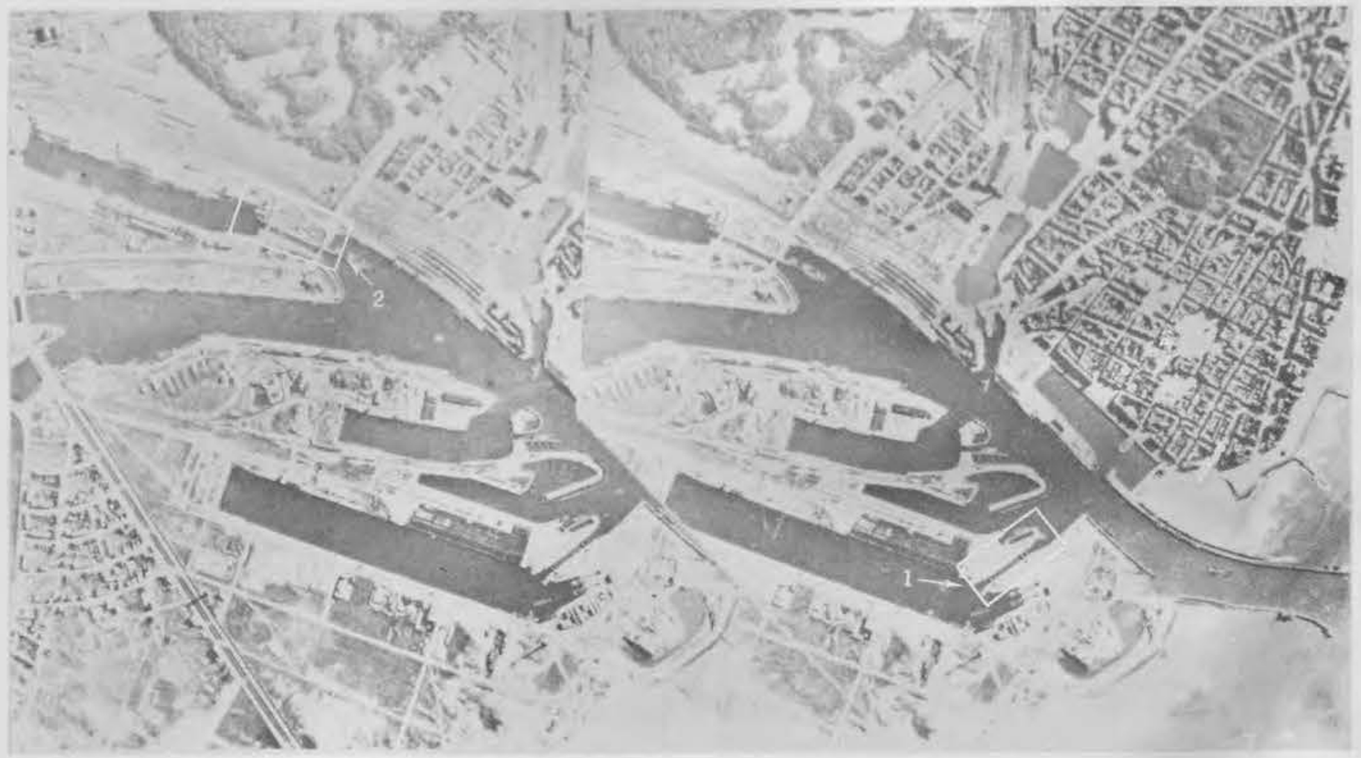


Figure 123: Special Purpose Locks
Scale Unknown

These locks are similar to navigation locks; however, their purpose is to provide access to the wet docks. The use of double miter gates in the two large locks (1) and (2) indicates that the water in the wet docks may be at an either higher or lower level than the water outside the locks. When the water level in the wet docks is high, the two miter gates with the apexes pointing into the wet dock are operated; when the water level outside the locks is high, the other two gates are operated.

30. Irrigation systems

a. Background. Irrigation is the artificial watering of farmland by canals, ditches, flooding, etc., to supply growing crops with moisture. The source of water for an irrigation system may be a reservoir, lake, stream, well, or spring. The water is taken into the system from the source by either a gravity flow system or pumps. The methods used to deliver water to the individual field supply conduits from the main conduit depend on the orientation of the latter. If the main conduit is at a lower elevation than the field supply conduits, a system of pumps and pump stands is used. The pump stands are water tanks connected on one side to the outlet pipe of the pump and on the other side to a distribution pipe. The pump maintains a head of water in the stand sufficient to force the water upgrade through the distribution pipe to a field supply conduit. If the main conduit is at a higher elevation than the field supply conduits, advantage is taken of gravity flow. Gravity flow systems use a series of diversion works, either permanent or temporary, that can be operated to direct the water into the field supply conduits. These diversion works are of many types, such as weirs, pump stations, check dams, siphons, sluices, and valves. The methods used to deliver the water to the field from the supply conduits vary greatly. Reference 21 discusses the interpretation of irrigation structures in more detail.

b. Recommended types and scales of photography. Vertical and vertical stereopairs of airphotos at 1:20,000 scale are recommended for identification and location of the irrigated fields and water sources. Vertical stereopairs at 1:1,000 scale are recommended for detailed interpretation of individual structures.

c. Recognition features. Irrigation systems are identified by:

(1) Channels, uniform in width and alinement, that form a definite geometric pattern; bends and junctions are symmetrical (figs 124 thru 126).

(2) In gravity flow systems, some type of diversion structure is slways present. They are usually located at the water source and at the intersections of main and secondary conduits.

d. Interpretation problems.

(1) It is often difficult to distinguish between an irrigation and a drainage system. It is not unusual for an irrigation system to be used for drainage during wet seasons. Since the features distinguishable on airphotos are similar for both types, other sources of information must be used to establish the purpose of a system.

(2) It may be difficult to locate the water source, especially if it is a reservoir or lake at some distance from the fields. A pump and pump stand on the bank of a stream might seem to indicate that the stream is the source of water. The stream, however, may well be only a link in a long system of canals and tunnels leading from a reservoir or lake located in an adjacent watershed. The best solution of this problem, of course, is the use of other sources of information, such as technical publications and intelligence documents.

e. Required information

(1) Describe the orientation of the main conduit to the field supply conduits.

(2) Describe diversion works.

(3) Determine dimensions of the main conduits.

(4) Measure the area of the irrigated fields.

(5) Locate the water source.

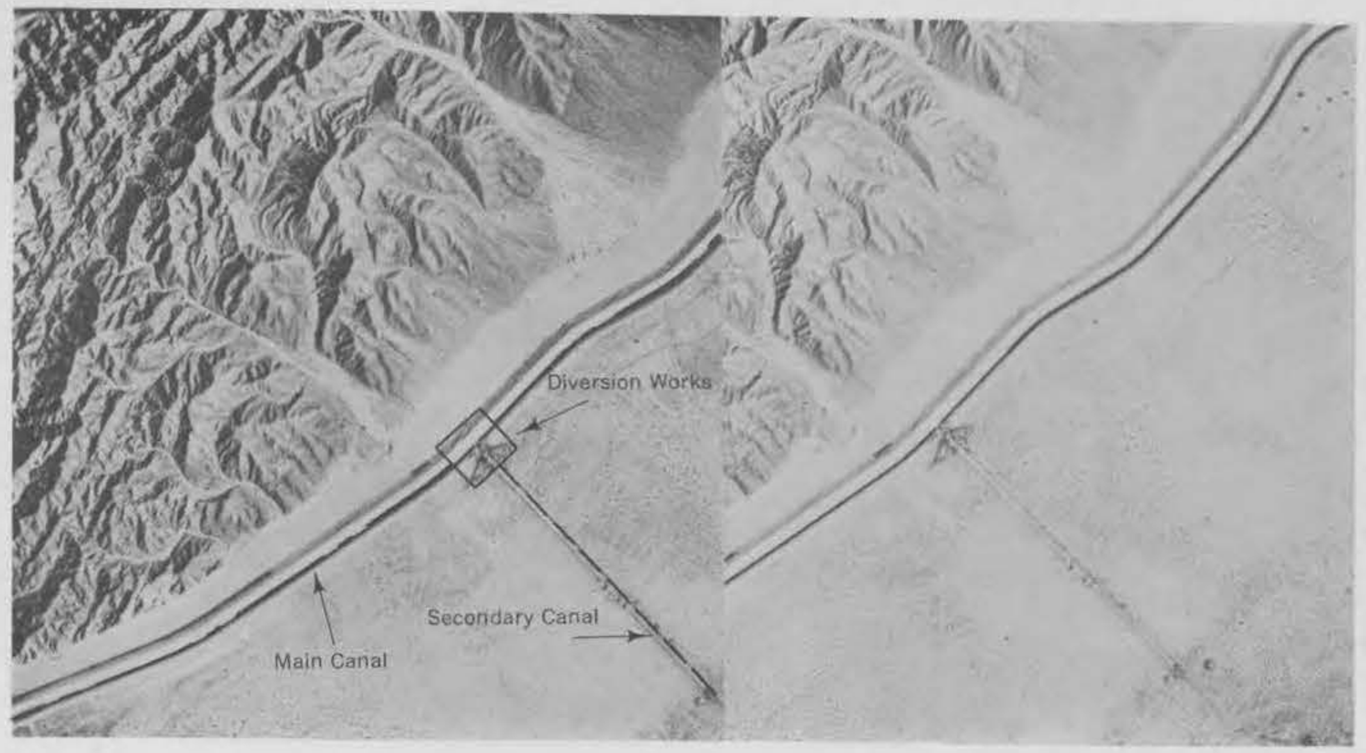


Figure 124: Irrigation Canals
Scale Unknown

These irrigation canals are identified by the following features:
(1) Channels are uniform in width.
(2) The bends and junction are symmetrical.
(3) There are diversion works to direct water from the main canal into the secondary canal.

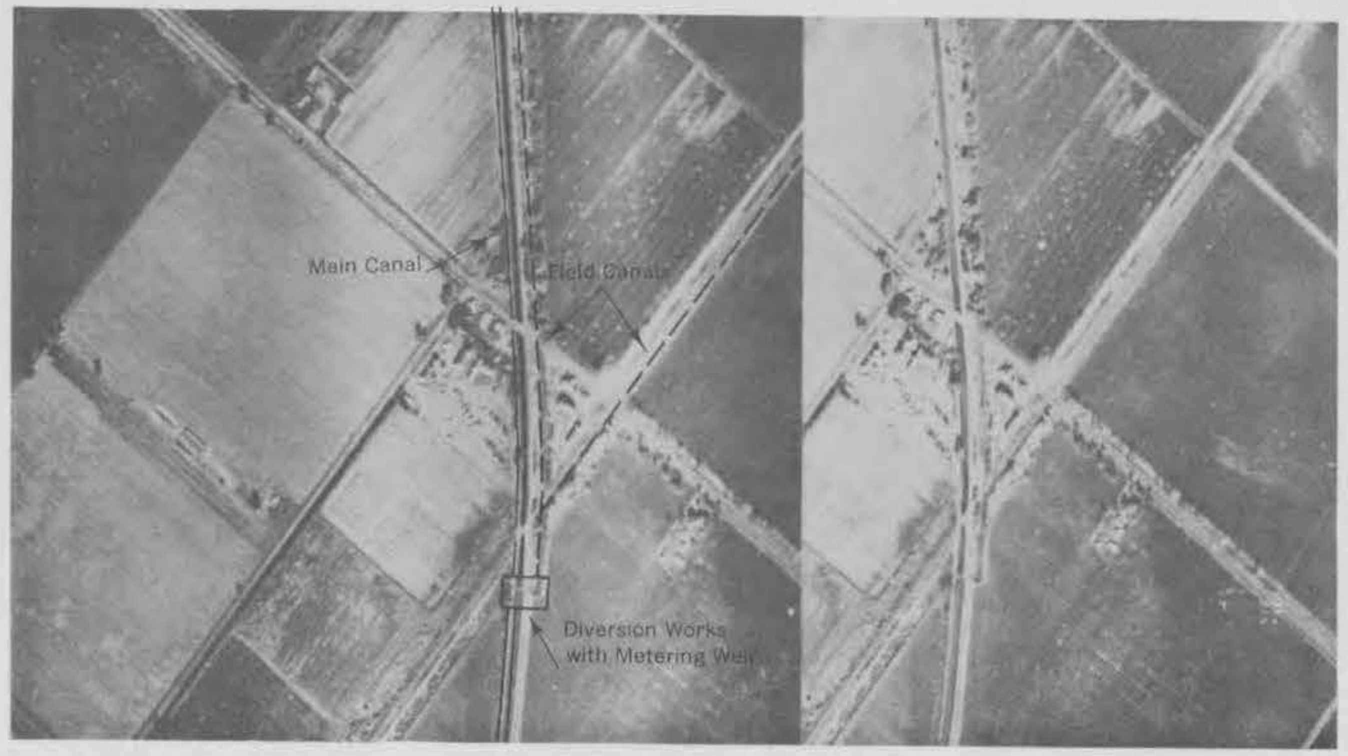


Figure 126: Gravity Flow Irrigation System
Scale Unknown

The water is taken out of the main canal through small diversion work. Since the water surface in the main canal is higher than the surrounding irrigated area, gravity flow is used to feed the field canals.

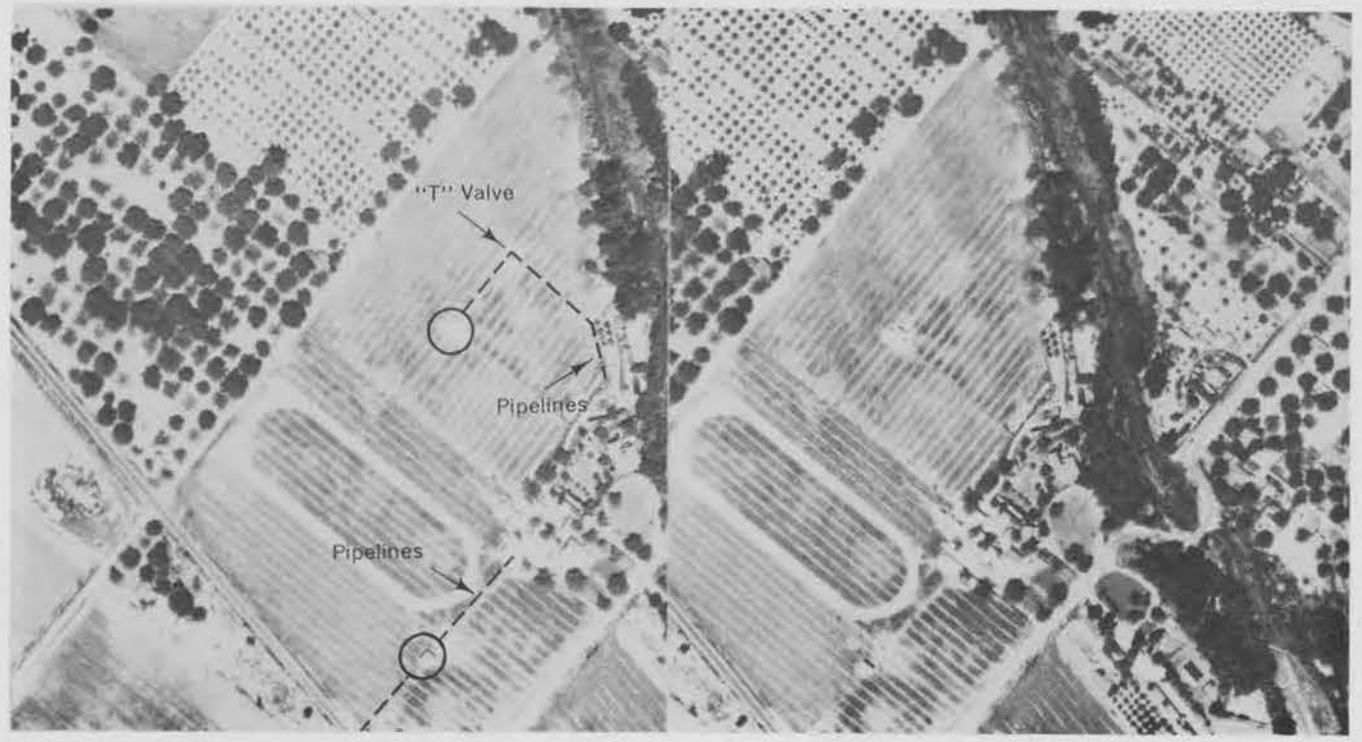


Figure 125: Pumped Irrigation System
Scale Unknown

The source of water is deep wells. The large buildings circled on the photograph house the wells and pumps.

31. Water treatment plants

a. Background. The feature of a water treatment plant of interest to the hydraulic engineer is the source of water.

b. Interpretation. The procedures for interpreting this item are covered in detail in Reference 1.

32. Flood protection structures

a. Background. Flood protection structures are defensive works that do nothing to mitigate floods. They consist of levees, floodwalls, ponding areas, and floodways, discussed as follows:

(1) Levees are the oldest and most common type of flood protection structure. They are earth embankments on one or both sides of a river, and their crests are above the maximum flood stage.

(a) A levee designed for complete protection against flood is a "closed" (continuous) levee (fig 127). It is tied to natural terrain of higher elevation than the levee crest, both upstream and downstream of the area to be protected. Small, particularly important areas where the elevation of the natural terrain is below the flood stage may be protected by a closed levee that completely encircles the area. Precipitation over the protected area must be released into the river through outlet structures (such as culverts equipped with flap gates) placed through the levee at strategic points.

(b) Levees designed to deflect water away from endangered places are "open" levees (fig 128). These are tied upstream of the protected area to natural terrain at the same or higher elevation than the levee crest. The downstream end of the levee is left open; i.e., it is not tied to terrain of higher elevation.

(2) Floodwalls (figs 129 and 130) are masonry structures that have the same purpose as a levee. They are used when construction space between the protected area and the river is so limited that a levee cannot be built. Floodwalls are normally open, but they may be closed.

(3) Ponding areas (fig 131) are provided behind closed levees to store internal drainage (runoff from the protected area). Ponding areas are provided because: 1) when the river is in flood, it may be impossible or undesirable to evacuate the internal drainage; or 2) it may not be desirable to provide outlets of sufficient discharge capacity to evacuate the internal drainage without ponding. The water in a ponding area may be pumped out (fig 132) or drained out through a gated structure, such as a culvert equipped with a slide gate (fig 133).

(4) Floodways (fig 134) are channels designed to divert river floodwater away from an area, such as a heavily populated community. A diversion structure is provided at the entrance of a floodway to divert all or part of a river's flow above a certain stage. The diverted water is led back into the river downstream from the protected area (through a tributary of the river or through a canal), or it is led into a lake or natural depression.

b. Recommended types and scales of photography. For location, identification, and alinement, vertical airphotos from 1:5,000 to 1:10,000 scale are recommended. For interpretation of technical details, vertical stereopairs at 1:1,000 are recommended.

c. Recognition features

(1) Levees (figs 127 and 128). Look for long, regularly alined earth embankments running generally parallel to the stream. The river side may be turfed or revetted with riprap or concrete. Trees are never allowed to grow on levees.

(2) Floodwalls (figs 129 and 130). Look for long, regularly alined masonry walls running generally parallel to the stream.

(3) Ponding areas (figs 131 thru 133). Look for water or a low-lying waste area (possibly a dry ponding area) directly on the landward side of the levee. Then examine the levee for culverts or pumps, and examine the ponded area for streams or channels leading from the interior to the levee.

(4) Floodways (fig 134). Look for channels branching off from the river. The entrance to the channel has large diversion works visible.

d. Interpretation problems. Because most of the auxiliary structures, such as culverts and headwalls, are small and often partially or wholly covered, it will generally be difficult to determine how the project operates. In most cases, the only interpretation possible will be a general description of the flood protection structure.

e. Required information

(1) Levees and floodwalls.

(a) Describe alinement and give minimum, maximum, and average distance from the river.

(b) Measure length of structure.

(c) Measure top width, base width, and height.

(d) Measure difference in elevation between levee crest and river water surface.

(e) For closed levees or floodwalls, measure the area protected.

(f) For open levees or floodwalls, describe the area protected.

(2) Ponding areas

(a) Give location (river or levee mile).

(b) Measure surface area.

(c) Describe outlet works.

(3) Floodways

(a) Describe layout, including location of entrance and exit.

(b) Describe operation.

(c) For diversion structures, measure crestline length; for gated structures, also measure gate openings.

(d) Measure the difference in elevation between the crest of the diversion structure and the water surface elevation of the river.

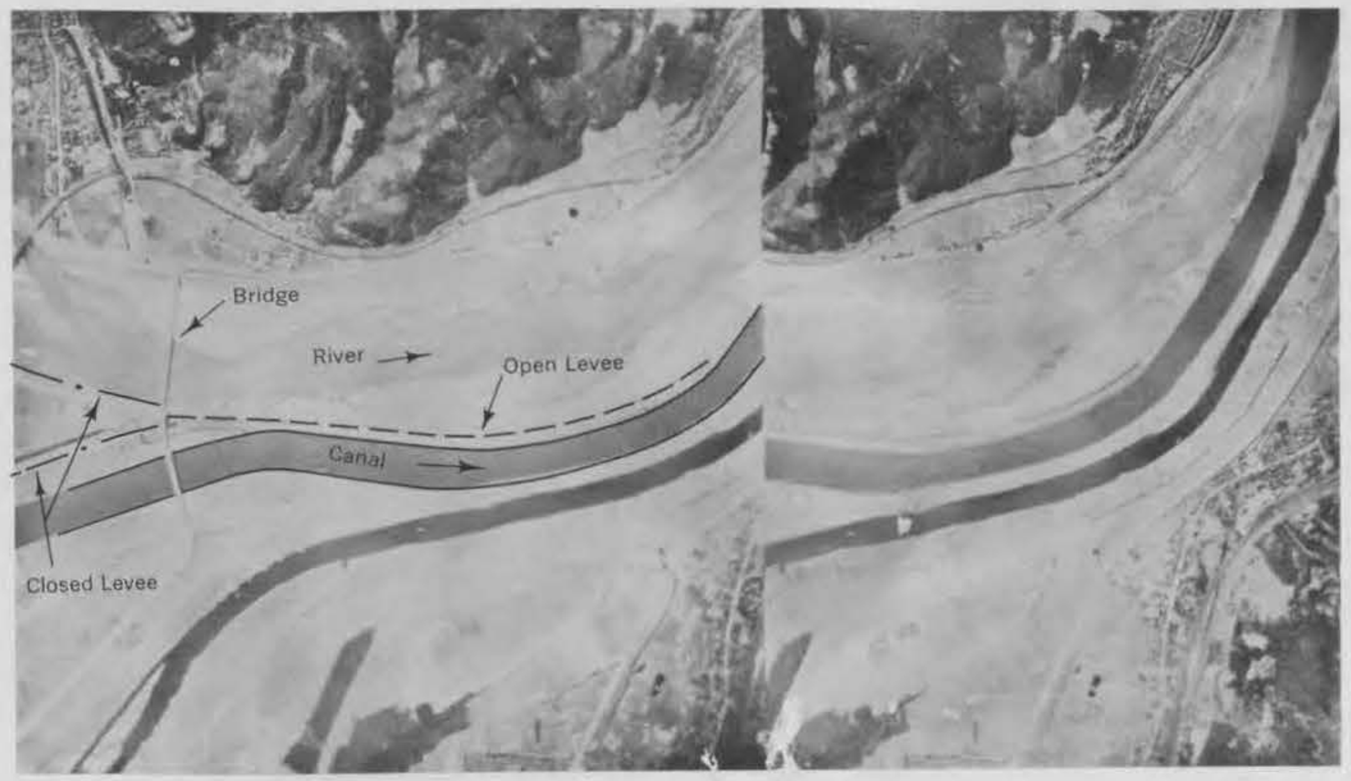


Figure 127: Closed Levee
Scale Unknown

This levee has been closed (tied into higher terrain) to protect the area behind the levee against flooding.

Figure 128: Open Levee
Scale Unknown

The open levee is not tied into higher terrain downstream and merely diverts the river floodwater. It thus protects the canal, the closed levee, and the bridge abutment against the eroding effects of large floods.

Figure 129: Floodwalls
Scale Unknown

These floodwalls were constructed to divert the current away from the low-lying buildings, as well as to canalize the normal river flow.

Figure 130: Floodwall

A floodwall, instead of a flood protection levee, was erected here because of the limited space.

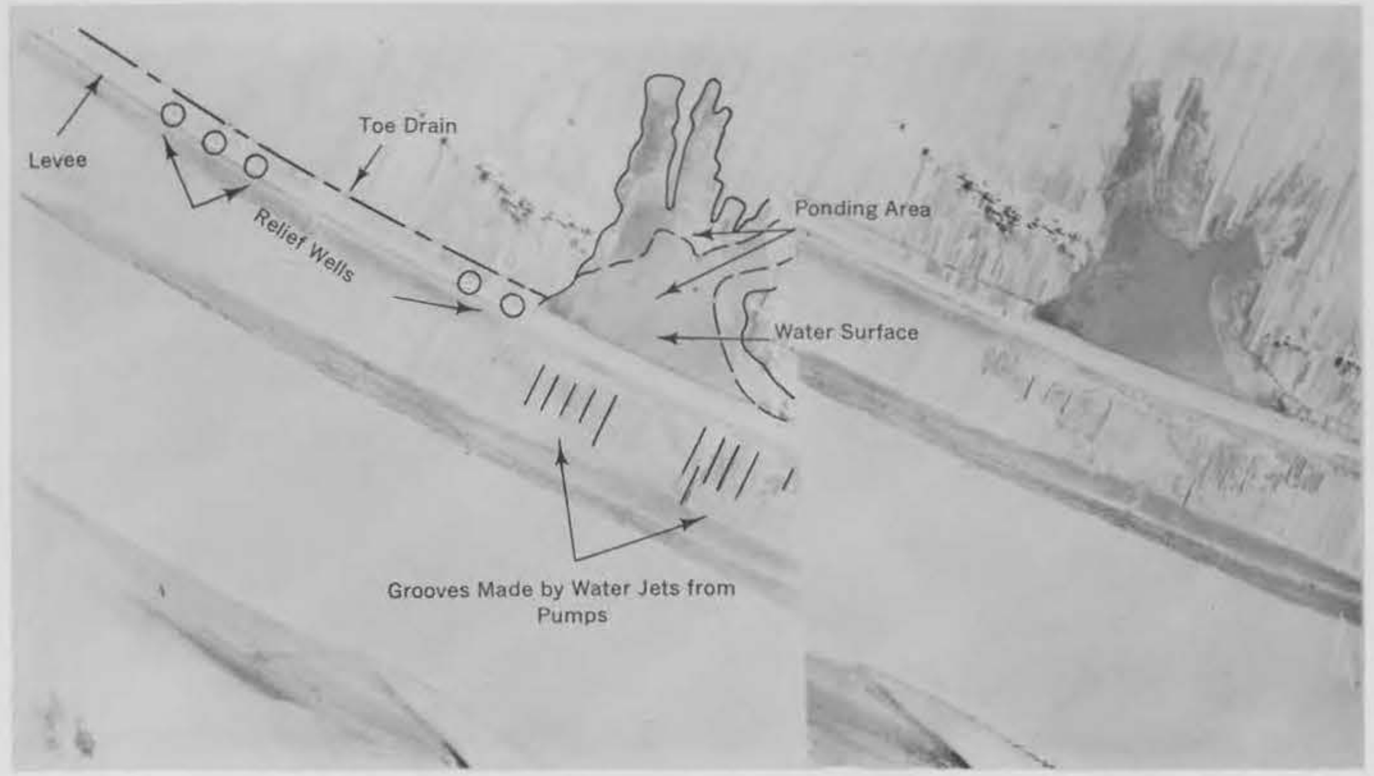


Figure 131: Ponding Area
Scale Unknown

This ponding area has no visible outlet works; however, the deeply cut grooves on the river side of the levee indicate that mobile pumps are used to empty the pond. (The small circled structures on the landward slope of the levee are relief wells for dissipating uplift pressures produced by ground water under the levee.)

Figure 132: Levee Pumps

During a flood, water is backed up against the river side of the levee (right foreground). These pumps are provided to keep the internal drainage water from flooding behind the levee during such periods.

Figure 133: Gated Culverts

These gated culverts are provided 1) to release internal drainage water into the river, and 2) in flood times to prevent the river from flooding into the area behind the levee.

Figure 134: Floodway Diversion Works
Scale Unknown

The floodway has been constructed to divert the riverflow during floods. At critical times when the water tops the low levee, the sluices are opened and the floodwater flows through the floodway. Flow markings can be seen in the bottom of the floodway, Landward of the sluices.

33. River contraction and bank protection works

a. Background. These works are employed on large meandering and braided rivers either to narrow, straighten, and deepen the river channel or to protect banks against erosion. There are innumerable types of structures; the most common and probably the most important are training walls, groins, riprapping, and revetments. Training walls and groins are primarily river contraction works; after the new bank has been formed, they ultimately become bank protection works. (An example of how these works are constructed in stages is as follows: A proposed new bank line may be selected, and a low training wall constructed along the line (low to allow it to be overflowed at all stages higher than mean stage) and tied to the old bank at the upstream end. The river deposits silt behind the wall, and as the silt builds up, the wall is raised until the desired height is reached.) The materials used in these structures range from brush pinned down in the river to concrete walls and dikes. These structures affect streamflow, because they change the cross-sectional dimensions of a stream. The hydraulic engineer needs to know the location, length, and alinement of such works so that, if necessary, he can secure new cross sections of the river reach.

b. Recommended types and scales of photography. Airphotos at 1:10,000 scale are recommended.

c. Recognition features.

(1) Training walls are long walls running parallel to the river and placed in the edge of the river. They may have short traverses (sidewalls) perpendicular to the bank on the landward side. The traverse may be connected to the wall and/or the bank (figs 135-137).

(2) Groins are short walls perpendicular to the bank. They may be either transverse (straight) (figs 138 and 139) or hooked (fig 140).

(3) Riprapped and revetted banks are easily recognized. See Figures 141-145 for some examples.

d. Interpretation problems. The main interpretation problem will be that if the river is at a high stage when photographed, these works may be underwater and not visible.

e. Required information.

(1) Describe the type of structure and construction material.

(2) Give the length of the river reach concerned.

Figure 135: Training Wall without Traverses

This is a first-stage training wall; i.e., average flows will overtop it. Main features are as follows: a) gravel-core fascines, b) gravel-core roll, c) wattle, and d) random riprap.

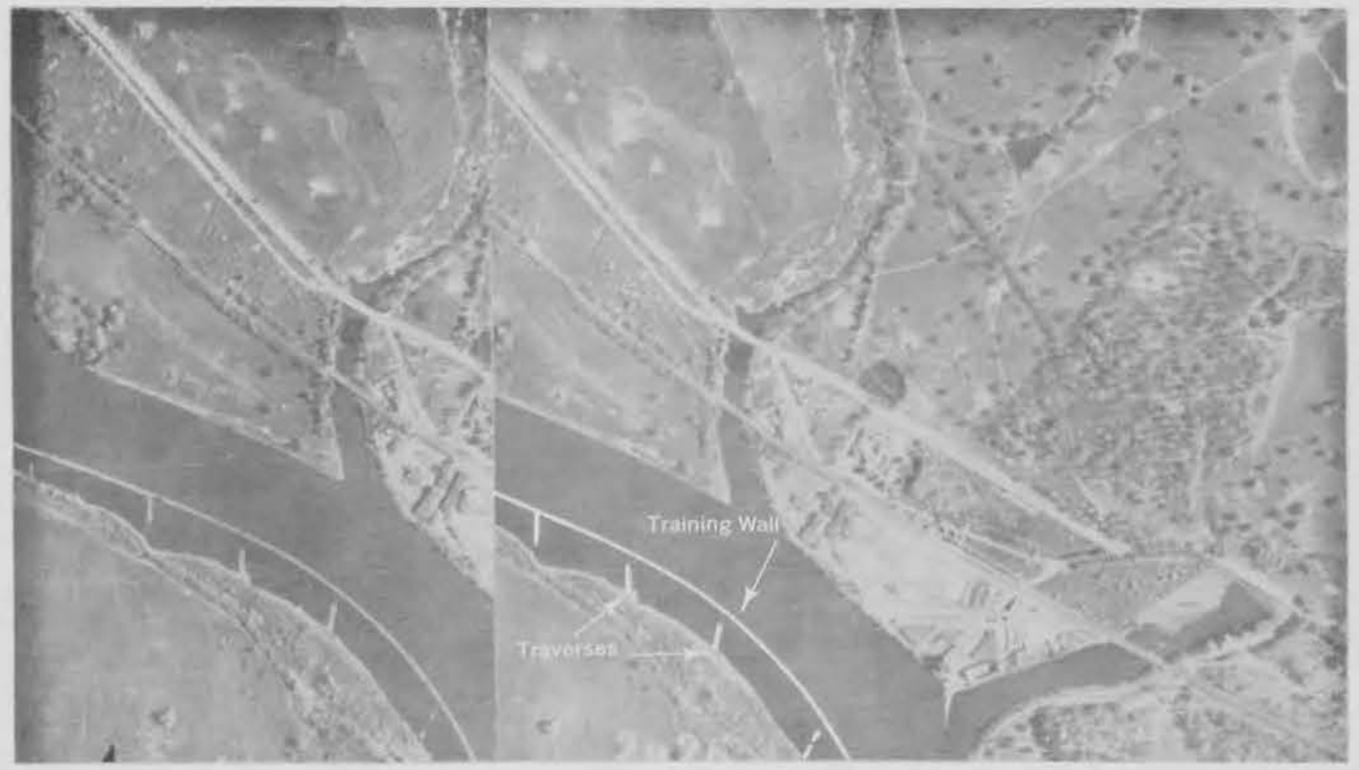


Figure 136: Training Wall with Traverses
Scale Unknown

In time the area between the wall and the bank will fill in with silt.

Figure 137: Training Wall with Traverse

This wall with traverse is in the second stage; i.e., it has been raised so that only average high-water flows will overtop it.

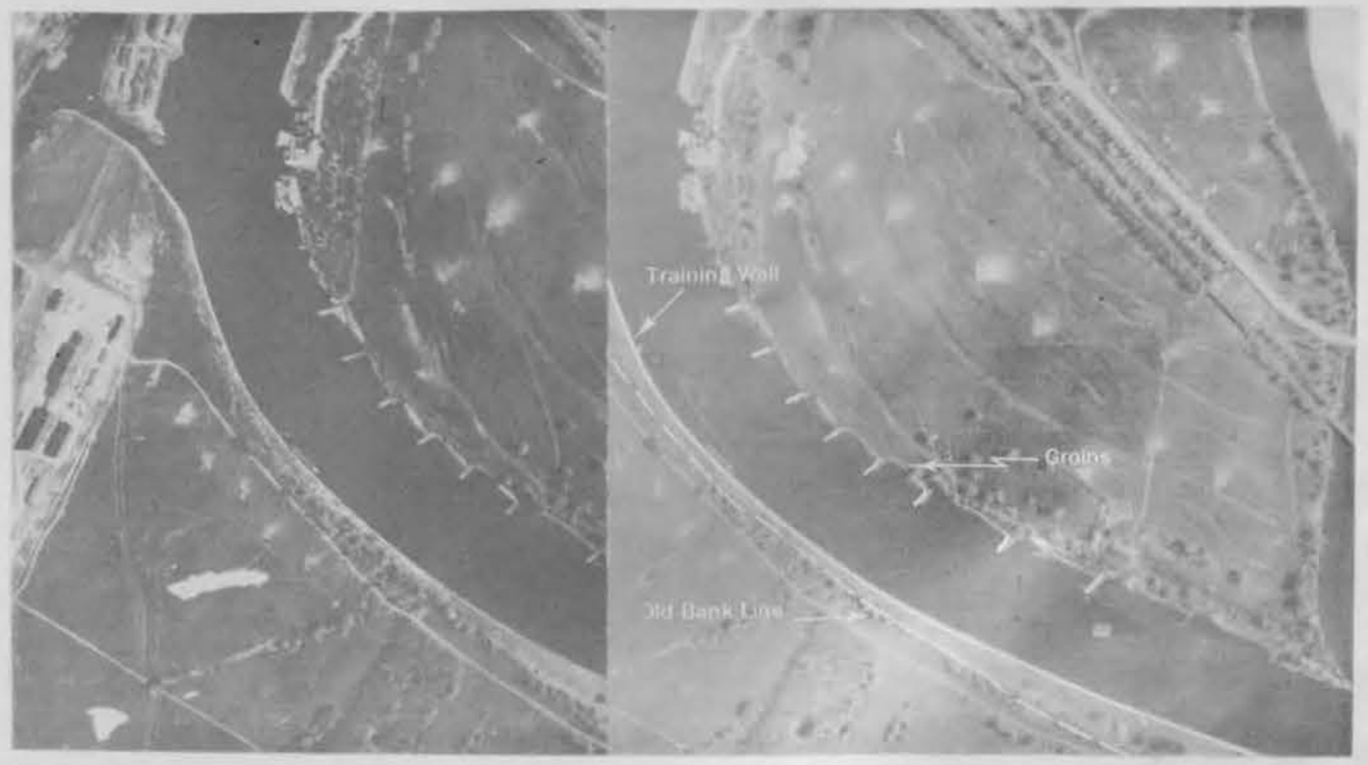


Figure 138: Transverse Groins
Scale Unknown

Note that these groins are relatively short and project into the river. Also note that the training wall on the other side of the river is in its final stage; the area between it and the old bank is almost completely silted up.

Figure 139: Transverse Groin

This is an especially heavy rubble-masonry groin. The groin is keyed into the bank (note the excavated material). The river is at high stage and most of the extended groin is under water.

Figure 140: Hooked Groins

These hooked groins contract the river by collecting silt and debris. They also retard bank erosion.

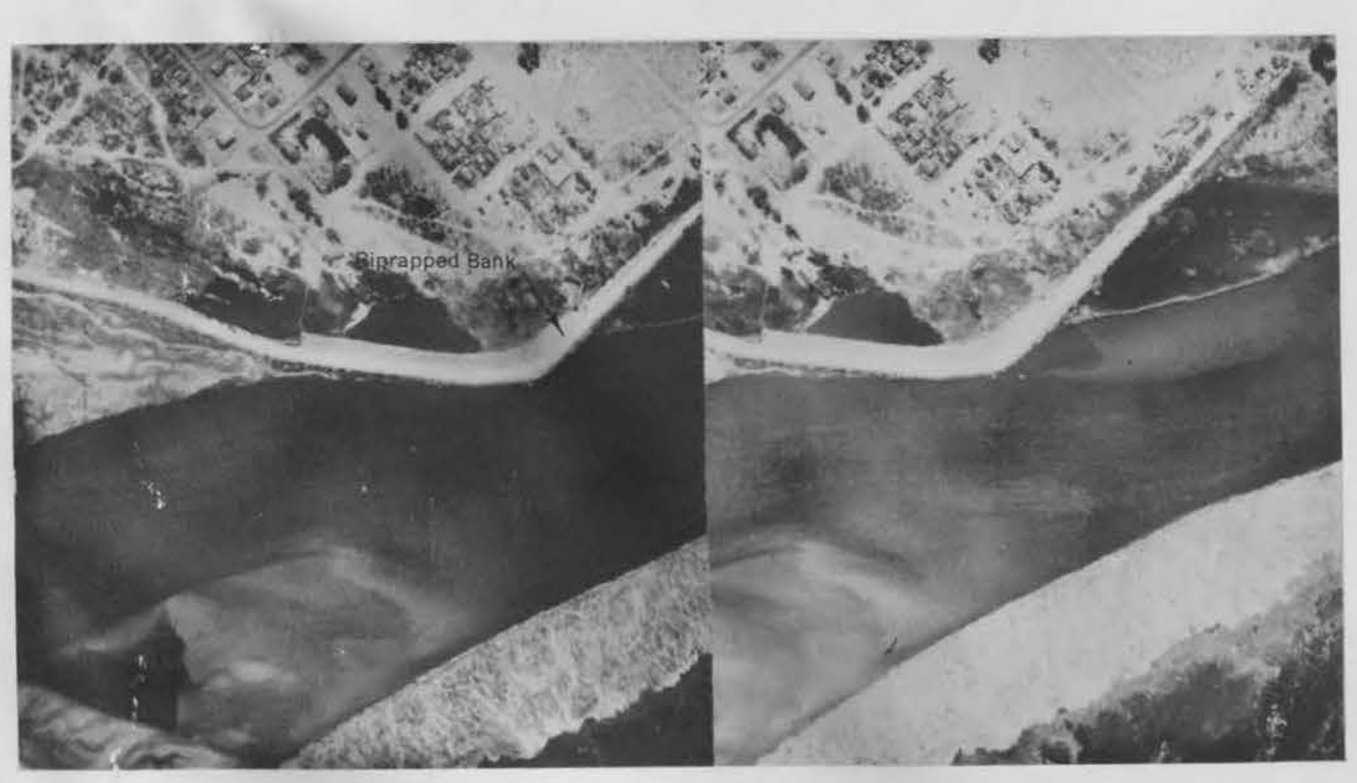


Figure 141: Riprapped Bank

The waterside slope of causeways and levees is often riprapped to prevent erosion.

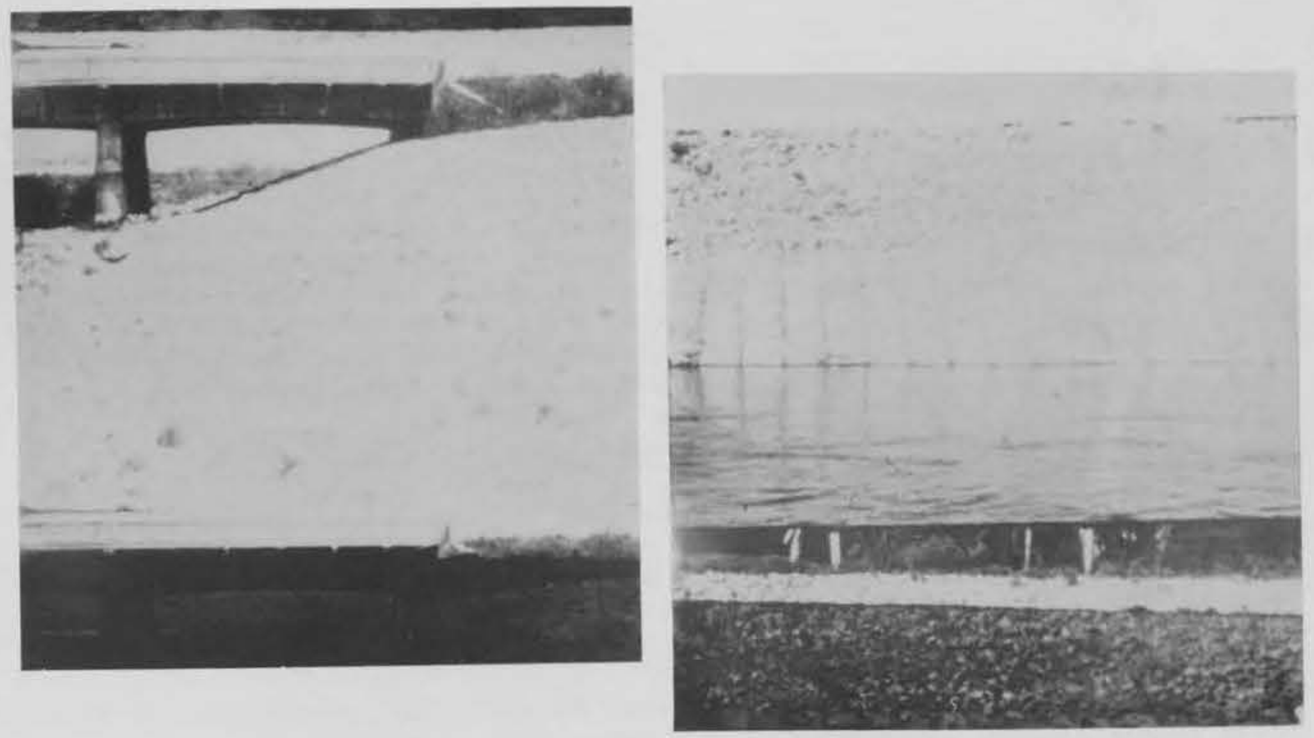


Figure 142: Dumped Riprap

Both photos illustrate banks protected by random dumped riprap. The right photo illustrates random dumped riprap on top of an articulated concrete mat (fig 145).

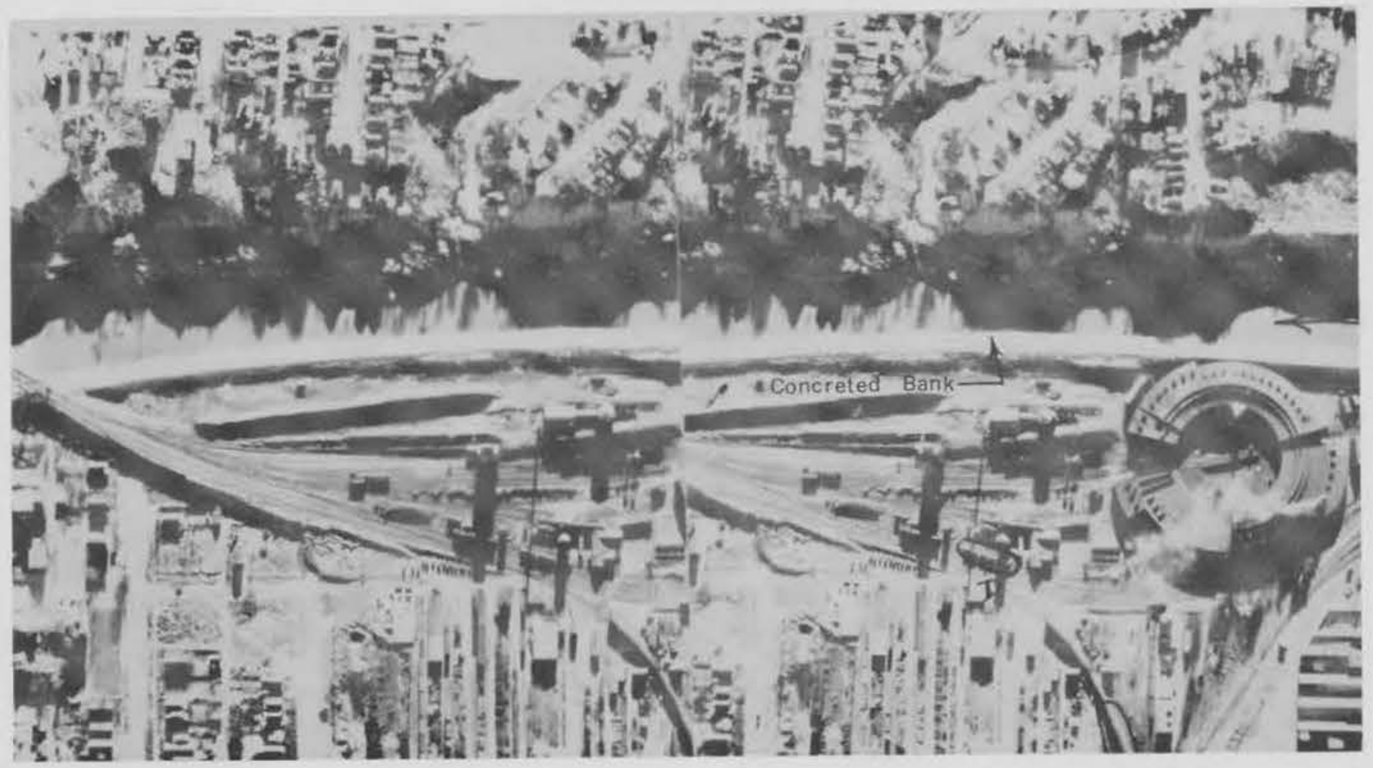


Figure 143: Concreted Bank
Scale Unknown

The waterside slope of this levee has been protected by a concrete slab. Bank erosion could not be curbed by turfing or riprapping, because the current velocity in this reach is very high during floods.

Figure 144: Concrete Revetment

Revetments are used to stabilize banks. The primary features illustrated here are: a) concrete riprap; b) paving; c) poured concrete crest; d) reserve supply of concrete blocks for riprap; and e) berm.

Figure 145: Articulated Concrete Mats

Articulated mats are made of concrete blocks fastened together with heavy "hook and eye" pins. They are lowered into place from a barge.

34. Special techniques for estimating reservoir volume.

a. Background. In order to estimate the probable downstream effects of the operation or breaching of a dam, the volume of water in storage in a reservoir at various water levels must be determined. These volumes and the discharge capacity of the various outlets determine the rate and duration of outflow from the reservoir. The relationship between reservoir volume and water level is usually presented as a curve referred to as the storage-elevation curve. The accuracy requirements in civilian practice in designing and operating a dam are generally more stringent than they are in military practice. The basic data necessary in civilian practice to produce a curve accurate enough for use are obtained by measuring the surface area bounded by the contours of the reservoir site on a large-scale topographic map, multiplying the average area within adjacent contours by their difference in elevation, and accumulating these products. The accumulated storage is then plotted against the elevation of the contour. In military practice, an estimated storage-elevation curve will generally be sufficient; therefore, in those areas where topographic maps are not available, vertical airphotos may be substituted.

b. Techniques.

(1) The following steps are necessary to secure the basic data (areas and elevations) from airphotos: 1) delineate and measure the area of the water surface and the areas at former water levels, and 2) measure the height of each delineated area above a selected datum point (point of zero reference). Either the water surface immediately downstream from the dam or the lowest discernible point on the downstream toe of the dam is selected as the datum point. The former water surfaces (fig 146) are recognized as follows:

(a) Normally, a light gray strip of bare terrain appears between the water surface and the darker tone of the reservoir slopes usually covered by vegetation. The outer edge of this light gray strip, in most instances, can be assumed to be at the maximum water level, and the area bounded by the outer edge of the strip is selected for delineation and measurement.

(b) Occasionally a reservoir may have been rapidly drawn down to a very low level. On an airphoto taken after the drawdown, a dark gray strip will appear between the water surface and the inner edge of the light gray strip. The outer edge of this dark gray strip marks the former water level, and the area it bounds should be selected for delineation and measurement.

(2) The basic data thus derived are used to determine the constants in an area formula and a storage formula developed by the Engineer School, Fort Belvoir, Virginia (Reference 5). These formulas are presented as follows:

$A = pmh^{m-1}$ (area formula) and $S = ph^{m}$ (storage formula)

where A = area in square units, corresponding to any depth of water

p = a constant related to the slope of the reservoir bottom

m = a constant related to the side slopes of the reservoir

h = height or depth of water in linear units, over the datum plane

S = storage in cubic units, corresponding to any depth of water.

(a) If two or more area values with their corresponding height values can be derived from airphotos, an area-elevation curve can be plotted on logarithmic paper. The area values are plotted as the ordinate and the heights, as the abscissa. The slope of the straight line drawn through these points is equal to m-1 (fig 147). The value p can then be derived by substituting the m value with any corresponding area and height values read from the area curve (fig 147) into the area formula. Once the values p and m are determined, the storage-elevation curve (fig 148) can be computed by substituting them and selected values of h into the storage formula. In the cases where three or more area points are derived, all the points may not fall on a single straight line (fig 147). Therefore, values for m and p must be calculated for each segment. The lowest point on each segment is taken as the datum (h in the formulas is then the height over the new datum) to be used in computing p and m for each segment. For example, in Figure 147, the datum point for line XY is the downstream water surface and for line YZ is point Y.

(b) In cases where only one area value can be derived because the reservoir has been photographed at its maximum level, m cannot be determined because the area curve cannot be developed. The best procedure is to wait for later photographs of the reservoir at a different level and then follow the steps in (a) above.

(c) A means of crudely estimating a storage-elevation curve has been devised for these cases where there is only one surface area value and it is not possible to wait for later photographs. Since the m value becomes larger as the reservoir side slopes become steeper and the steepness of the side slopes is usually indicated by the topography of the reservoir site, the following table developed experimentally may be used as a guide in selecting an m value:

Type of terrain	Side slopes	Value of m
Flood plain and foothill	Low to moderate	1.5 to 2.5
Hill	Moderate to steep	2.5 to 3.5
Gorge	Steep to vertical	3.5 to 4.5

Once the m value is selected, the procedure for deriving the storage-elevation curve is the same as described in (a) above.

NOTE: This is an emergency procedure. The m value is very critical and there are some reservoirs whose side slopes are very different from the slope of the visible terrain. The m value selected could therefore be seriously in error. For example, if the water level of the reservoir shown in Figure 146 had been up to the outer edge of the light gray strip (maximum water level), it would not have been possible to see that the steepness of the side slopes is really between low and moderate. An m value between 2.5 and 3.5 (hill) would have been selected from the table, and the reservoir volume would have been dangerously underestimated.

c. Example problem

(1) Situation. It is assumed that 1) the reservoir in Figure 146 is in enemy-held territory, 2) the stereopair is the only available source of information on it, and 3) a stream-crossing operation is being planned downstream. Since the reservoir water level at the time of crossing cannot be known in advance, the planners have requested a storage-elevation curve to estimate the effects on the crossing, of a sudden release of the impounded water at various reservoir levels.

(2) Procedure

(a) On Figure 146, delineate and measure the areas bounded by the water surface, the outer edge of the dark gray strip, and the outer edge of the light gray strip.

(b) Measure the height between the downstream water surface (datum) and each delineated area.

(c) Tabulate the data secured in (a) and (b) above, as follows:

Water level	Surface area, sq ft	Height above datum, ft
Present	200,000	15
Recent	860,000	97
Maximum*	1,930,000	187

* The outer edge of the light gray strip apparently coincides with the crest of the spillway.

(d) Plot the data tabulated in (c) above, on logarithmic paper and connect the points (X and Y, Y and Z) with straight lines as shown in Figure 147.

(e) Construct triangles ABC and EFG as shown in Figure 147 and measure the length of lines AC, CB, EG, and GF.

(f) Derive the values of m-1 and m for lines XY and YZ as follows:

Line XY, triangle ABC

$$m-1 = \frac{CB}{AC} = \frac{0.78}{1}$$

$m-1 = 0.78$

$m = 0.78 + 1$

$m = 1.78$

Line YZ, triangle EFG

$$m-1 = \frac{GF}{EG} = \frac{1.21}{1}$$

$m-1 = 1.21$

$m = 1.21 + 1$

$m = 2.21$

(g) Derive the value of p for line XY and YZ as follows:

Line XY

$A = pmh^{m-1}$

and $p = \dfrac{A}{mh^{m-1}}$

From Figure 147 at point B

read: A = 496,000 sq ft

and h = 48 ft*

$$\text{Then } p = \frac{496{,}000}{1.78 \times 48^{0.78}} = 13{,}600$$

Line YZ

$A = pm\,(h_Z - h_Y)^{m-1}$

and $p = \dfrac{A}{m(h_Z - h_Y)^{m-1}}$

From Figure 147 at point Y (datum point)

read: h_Y = 97 ft

and at point Z

read: A = 1,930,000 sq ft

and h_Z = 187 ft

$(h_Z - h_Y) = (187-97) = 90$ ft

$$\text{Then } p = \frac{1{,}930{,}000}{2.21 \times 90^{1.21}} = 4{,}000$$

---

* Datum is downstream water surface.

(h) Compute the storage and elevation data between X and Y and between Y and Z as follows:

Line XY*

$S = ph^m$

$m = 1.78$ (par (f) above)

$p = 13{,}600$ (par (g) above)

$h = 15$ ft (point X)

$S = 13{,}600 \times (15)^{1.78}$

$S = 1{,}670{,}000$ cu ft (at point X)

$h = 97$ ft (point Y)

$S = 13{,}600 \times (97)^{1.78}$

$\underline{S = 46{,}100{,}000 \text{ cu ft (at point Y)}}$

Line YZ*

$S = p(h_Z - h_Y)^m + S_Y$**

$m = 2.21$ (par (f) above)

$p = 4{,}000$ (par (g) above)

$h_Y = 97$ ft (point Y)

$h_Z = 187$ ft (point Z)

$(h_Z - h_Y) = (187-97) = 90$ ft

$S = 4{,}000 \times (90)^{2.21} + 46{,}100{,}000$

$S = 83{,}500{,}000 + 46{,}100{,}000$

$\underline{S = 129{,}600{,}000 \text{ cu ft (at point Z)}}$

* Basic data taken from Figure 147 unless otherwise noted in tabulation.

** Point Y is the datum point; therefore, for total storage the storage computed at point Y must be added to the storage between Y and Z.

(i) Prepare the storage and elevation data derived in (h) above for plotting on Figure 148. For convenience in plotting, cubic feet are usually converted to acre-feet (43,560 cubic feet in an acre-foot). A tabulation such as the following is usually prepared to facilitate the final plotting of the storage-elevation curve (fig 148):

Location	Height, ft	Storage, cu ft	Storage, acre-feet
Point X	15	1,670,000	38
Point Y	97	46,100,000	1,060
Point Z	187	129,600,000	2,980

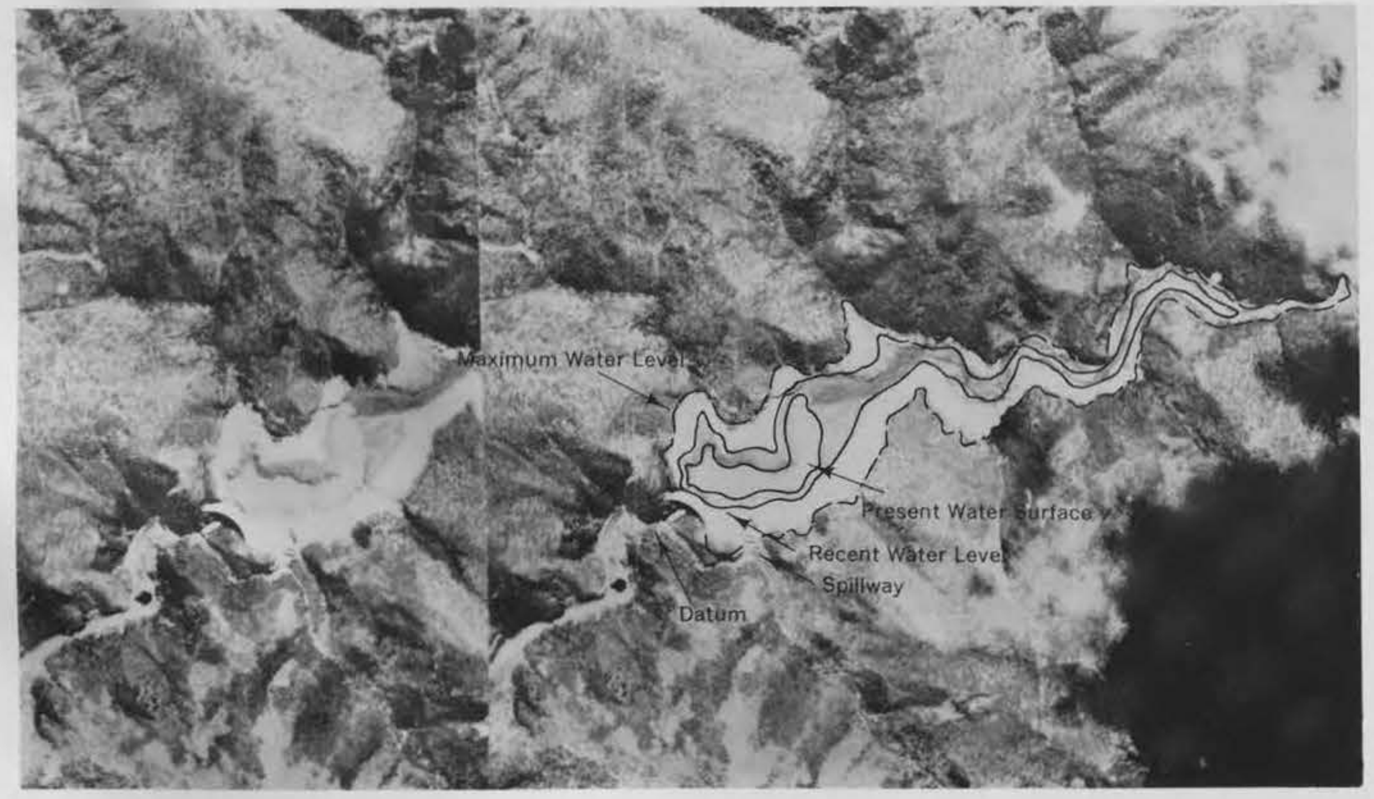


Figure 146: Reservoir at Low-Water Level
Scale 1:14,500

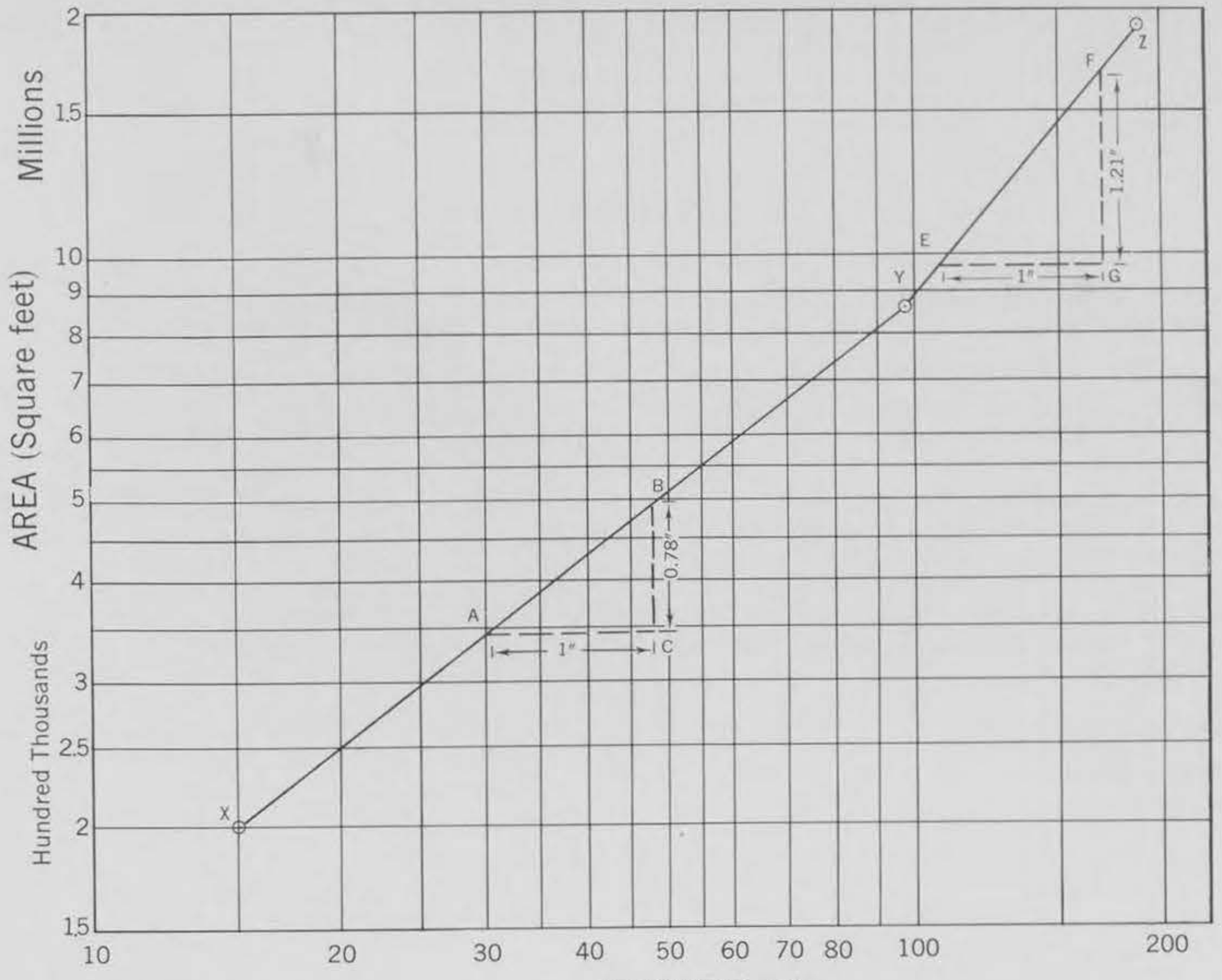


Figure 147: Area—Elevation Curve

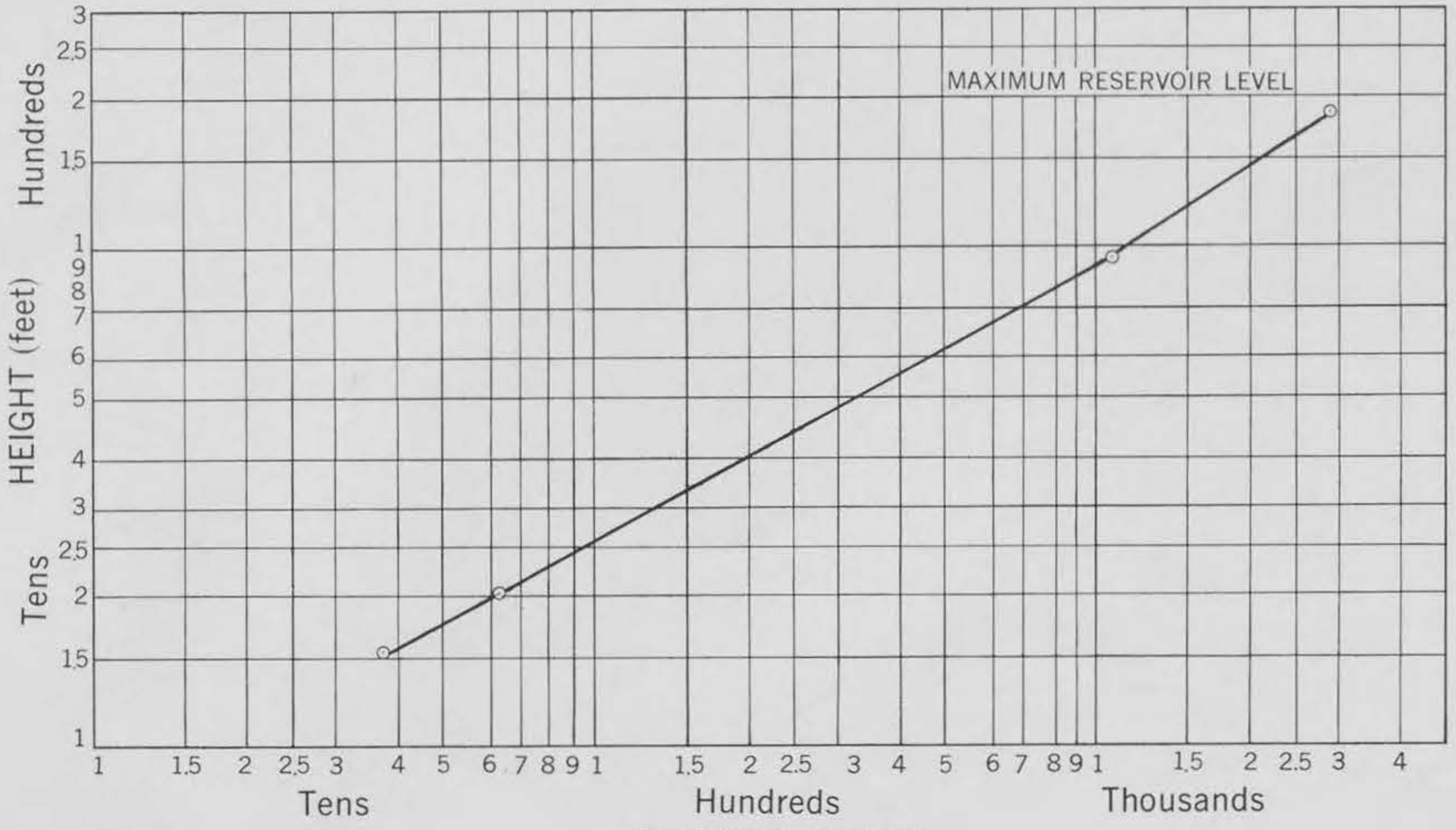


Figure 148: Storage—Elevation Curve

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