Design of Open Channels

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Soil Conservation Service
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TECHNICAL RELEASE NOTICE 25-5

This technical release notice transmits a new edition of Technical Release No. 25 titled "Design of Open Channels." It supersedes the version of Technical Release No. 25 dated December 15, 1964, and all subsequent revisions. Technical Release Notices 25-1 through 25-4 are canceled.

New material on the use of landscape architecture has been added to Chapters 2 and 7. Chapter 6 has been revised to include current state of the art concepts for channel stability analysis.

Geology Note 2 is being prepared and should be ready for issuance in the near future. The Note is referred to in Chapter 6. A new Chapter 8 on "Landscape Architecture Design" is also being developed and will be added to Technical Release No. 25 when available.

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Director
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Enclosure

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DESIGN OF OPEN CHANNELS

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PREFACE

This technical release was prepared by Soil Conservation Service specialists for the use of field personnel. It supersedes Technical Release No. 25 dated December 15, 1964, and all revisions to this document. Previous editions should be discarded. This version incorporates visual resource and environmental considerations and updates stability analysis information.

The technical release covers procedures for design of open channels and related measures such as floodways. Cirteria and standards applicable for each situation should be used in conjunction with these procedures.

Designers of open channels should find the technical release useful in considering the numerous technical aspects that are important to sound channel modifications. Close coordination of many technical fields is important if channels with minimum environmental impacts are to be developed.

DESIGN OF OPEN CHANNELS

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TECHNICAL RELEASE

NUMBER 25

DESIGN OF OPEN CHANNELS

CHAPTER 1. GENERAL CONSIDERATIONS

This guide defines the technical aspects of open channel planning and design. Channel design involves the fields of hydrology, geology, hydraulics, drainage, irrigation, erosion control, soil mechanics, landscape architecture* and structural design. Adequate planning and design require close coordination of these technical fields.

Open channels are used to serve a variety of functions. These include flood protection, drainage, irrigation, diversion of water to control erosion and sedimentation, and for recreational and other purposes, either singly or in multiple purpose combinations.

The contents of this technical release are primarily directed at the design and planning of floodways and open channels where channel erosion is of primary concern. The planning and design of low gradient channels such as irrigation canals, drainage ditches, grassed waterways and so on are covered in other service handbooks.

Channel Planning

The objectives of the project first must be clearly defined. The level of development or adequacy of improvements for each purpose and the general location and layout also needs to be resolved in early stages of planning. Economic and other factors which are outside the scope of this guide should be considered with the engineering alternatives, based on the procedures presented herein.

After the functional requirements of the channel have been determined in planning channel work, the following steps in preparing open channel plans and design are necessary:

1. Field surveys to provide topographic information and other physical data pertinent to location and hydraulic and structural design.

2. Geologic and soil investigation and testing of soil materials for planning and design requirements.

3. Analysis of hydrologic or other conditions to determine channel capacity needed to meet project objectives.

* A Glossary of technical terms for Landscape Architecture may be found in Chapter 2, Appendix A.

4. Analysis of geomorphology viewsheds, visual resource values and landscape use values to determine visual resource planning and design requirements.

5. Use of the above data in developing the engineering aspects of project formulation.

In the formulation stage, physical conditions should be determined and an appraisal should be made of other limitations imposed on channel work that might limit functional performance in meeting objectives. These include:

1. Adequacy of outlets to handle required flow without excessive scour or deposition, and without damaging downstream flooding.

2. Protection of water rights.

3. Availability of rights-of-way.

4. Satisfying minimum flow requirements.

5. Environmental considerations including landscape resources that must be conserved.

Adequacy of Outlets

Basic requirements. - - In determining adequacy of outlets, the following basic requirements should be met:

1. The capacity of the outlet should be such that the design flow from its watershed can be discharged into it at an elevation equal to or less than that of the hydraulic gradeline that is used for design of the project. The storm used for this analysis should have the same chance of occurrence as the storm used for design of the improvements.

2. Where subsurface drainage is needed, the depth of the outlets should be such that subsurface drains may be discharged into it above normal low water flow.

3. The capacity of the outlet should be such that the discharge from the project watershed, after proposed improvements, will not result in stage increases that will cause significant damages below the termination of the project channel.

4. Flow conditions in the outlet should be capable of maintaining equilibrium with the sediment transport of the project channel. There should not be excessive scour or deposition of sediment in the outlet.

Evaluation of project effects. - - Many items must be considered in evaluating project benefits, among these are:

1. The stage-discharge relationship of the project channel, including overbank-flow, should be determined for "before" and "after" project conditions.

2. Stage-discharge curves for the outlet should be developed by computing the water surface profile through two or more cross sections below the outlet using the existing roughness coefficient.

3. The effect of project improvements on stages in the outlet should be analyzed for storms of at least two recurrence frequencies. Storm frequencies selected for the analysis should be that used for project design and one other significantly different from the design discharge.

   Procedures outlined in National Engineering Handbook, Section 4, Hydrology, Part 1, Watershed Planning, shall be used for the analysis.

4. Where downstream effects of channel improvement are significant (stage increases will cause damages below the termination of the project channel) an analysis to determine effects should be carried downstream to the point where effects have been dissipated.

5. Geologic and soil investigations to determine the effect of project improvements on the stability of the outlet should be made as outlined in Chapter 3, "Site Investigations."

Special outlet conditions. - -

1. Tidal Influence. Where channel improvements discharge into rivers, estuaries, bays, and sounds, which are subject to tidal influence, the effect of the tides on discharge from the channel should be determined. This is true if the outlet is a tidegate, which opens and closes according to the relative elevations of the tide and the hydraulic grade of the channel; or if the channel discharges directly into tidewater, without a tidegate.

   The characteristics and types of tides are discussed fully in "Tidal Datum Planes."1/ Annual editions of "Tide Tables, High and Low Water Predictions" are available from the Coast and Geodetic Survey, U.S. Department of Commerce.

2. Pumping. Where the project is provided with pumps to discharge the runoff from the watershed, the area may be protected by levees.

1/ Numbers refer to numbered references at end of this technical release.

In this case the levees should meet the National Engineering Standards for Dikes and Levees, the pumping capacity should be adequate for the design runoff, and the outlet into which the pumps discharge should meet the basic requirements for outlets.

Legal Requirements

Applicable provisions of state water laws must be met in all channel work. Existing water rights may require protection or rebuilding of diversion works, control structures for regulating flows, etc.

Preliminary investigations should determine the existence of any water rights on channels to be improved and the limitations that they may impose on the improvements.

Rights-of-Way

Acquisition of rights-of-way is an essential element of channel improvement. Careful consideration of this element from the preliminary investigation or reconnaissance stage through the construction stage will greatly expedite the job and reduce its cost. Certain modifications of location and alignment, within the limits of good design, may be made to ease rights-of-way problems.

Environmental Considerations

Landscape resources shall be given full consideration from the preliminary investigation through final inspection. These resources include visual, fish, wildlife and recreational and may include areas outside of the right-of-way that are affected environmentally as a result of the project. A guide for planning and design considerations related to wildlife, fish and recreation resources may be found in Chapter 7.

A guide to visual resource data needed in planning and design may be found in Chapter 2, Appendix A. Visual changes in the landscape that result from channel work should be examined. The before and after appearance of the site should be documented and discussed with the local community and other interested individuals or groups. Procedures discussed in Chapter 8 shall be used for designing the visual resource.

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CHAPTER 2. FIELD SURVEYS & PLAN LAYOUT

General

Objectives of the Engineering Survey

The surveys for channel improvement work should be in sufficient detail to:

1. Determine the location, hydraulic properties, visual characteristics and condition of existing channels and associated structures.

2. Determine the needed improvements on existing channels and the required additional channels and appurtenant structures.

3. Determine the cost of the needed improvements.

4. Prepare suitable landrights work maps for easements and working permit requirements.

These objectives apply to both planning surveys and final design surveys and differ only in the amount of detail and precision needed for the respective stages of project development.

Preliminary Surveys

Information Needed

To accomplish the objectives stated above, the following information is needed for planning channel work:

1. Drainage area at junctions of tributaries and all flow control points. Drainage areas also should be delineated for valley sections used for hydrologic and economic evaluations where these are needed at locations other than at junctions of tributaries and structural control points.

   The drainage area determinations, including those needed for drainage purposes, should be made carefully for use in both the planning and the final design stages of the project.

   Where topographic quadrangle maps are available they are usually sufficiently accurate for delineating and planimetering the required drainage areas, except on extremely flat land. Field surveys may be required to determine watershed divides on flat land. Where feasible, the delineation of drainage areas should be checked by means of a stereoscopic study of 4-inch or 8-inch = 1 mile aerial photos.

All maps, especially in flat topography, should be field checked. This step should be done preferably in the preplanning stages to avoid the need for revisions as the planning work progresses.

2. Approximate profiles of the existing channel showing the elevation of the existing channel bottom, low bank, points of natural low ground away from, but subject to, drainage into the channel, and elevation and dimensions of all structures in or over the channel. In flat areas, occasional topography or perimeter and spot elevations may be needed to determine the drainage pattern. Existing tributaries should be located and sufficient bottom and ground elevations obtained to permit correlation of hydraulic gradelines and design of any grade control structures that may be needed.

3. Representative channel and valley cross sections for each hydraulic or economic reach. Additional channel cross sections should be taken as needed for reliable estimates of quantities of excavation and clearing, to determine easement requirements.

4. Mannings coefficient "n" for each channel and valley cross section. The "n" value should be representative of the hydraulic reach to which the section applies, except that where segments of a cross section differ significantly in flow retardance factors either within the channel, between the channel and the flood plain, or between segments of the flood plain, separate "n" values should be recorded for each segment.

5. The location and elevation of all soil investigation sites along the proposed channel.

6. The location of viewpoints and viewsheds along the proposed alignment.

7. The landscape character and use patterns along the alignment.

8. Stationing and delineation of apparent ownership boundary lines in the vicinity of probable channel improvement work.

9. Data including-dimensions, elevations, kinds of material, and condition of existing structures such as bridges, culverts, drops, and dams.

10. Data including acreage and density of brush, trees and debris on clearing required.

11. Other significant features affected such as roads, pipelines, power and telephone lines, buildings, wells, cemeteries, and fences. Such features should be located on aerial photographs or base maps and the elevations of strategic points recorded.

Survey Procedures

The survey procedure for "Preliminary Surveys" outlined in the National Engineering Handbook Section 16,2/Chapter 2, is applicable. This procedure should be augmented by "Landscape Architecture Survey and Analysis" as outlined in Chapter 2, Appendix A. Technical Release-62, (TR-62), contains guidance for notekeeping and stationing.

Horizontal Control

Where suitable 8-inch aerial photographs or photo mosaics are available which show sufficient detail to locate and identify an existing channel that can be used as a base line, it will not be necessary to run a transit traverse in the planning stage to establish a base line. Other existing maps or plans of equivalent accuracy sometimes are acceptable for this purpose.

Horizontal control for the planning and design of stream channel work varies with the survey method selected. In most cases, sufficiently accurate horizontal control can be obtained from semicontrolled photo mosaics for both planning and preliminary design of channel work. The photo mosaic also may be used to show drainage areas, flood plain area, control elevations, channel locations, land ownership, etc.

The following steps are involved in obtaining semicontrolled photo mosaics:

1. Using the latest available aerial photos of the flood plain (preferably the 4" = 1 mi. scale), select two points near the center of each aerial photo, which can be identified on both the aerial photo and on the ground. These points should be at least 500 feet apart and, preferably parallel with the flood plain. Some additional accuracy may be obtained by selecting a second line, approximately perpendicular to the first, on each photo. To facilitate identification and measurement, these lines should be selected along established lines, such as roads or fences. Also, delineate the approximate area of the flood plain on the aerial photos.

2. Measure the distance to the nearest foot between the selected points in the field. Stadia distances may be used for lines up to about 1000 feet long. Identify the points on the photos by a small pin prick at each point. Circle the pin points on both the front and back of the photo. Also, number or letter each point for identification and mark the distance between the points on the back of each photo. For a permanent reference, record each measurement in a field notebook as follows:

Photo No.	Date	Point	Line	Approx. Brg.	Length	Description
DGB-2E 110	27 Apr. 1949	A				¢ rd. at bridge Roanoke Chan.
			A-B	NE	548'	
		B				N.W.cor.fld.N. of rd. and E. of Chan.
DGB-2E 112	27 Apr. 1949	C				S.W.cor.fld.with N-S lines, N. of Roanoke Chan.
			C-D	ENE	942'	
		D				S.E.cor.fld.with N-S lines, N. of Roanoke Chan.
DGB-2E-4S	27 Apr. 1949	E				¢ rd.in line with N-S fence W. of barn about 300' W. of rd. junc.
			E-F	SSW	736'	
		F				¢ rd.in line with N-S fence on W. side of L-shaped fld. S. of rd.

3. Have prepared from these photographs a semicontrolled photo mosaic of the flood plain to a scale not smaller than 1" = 400'. A film positive should be prepared of the aerial mosaic on 22" x 30" planprofile sheets with the aerial mosaic as the plan portion of the sheet. At least two copies of each film positive are suggested-one for use in preparing a problem location map and profile of the channel and flood plain, and the other for use in preparing the location plan and profile of channel improvement. Also, ozalid prints of each sheet are suggested for use, as working copies by all planning specialists in planning and evaluating project works of improvement.

4. In areas for which USGS topographic maps (scale 1" = 2000') have been completed recently by photogrammetric methods, the aerial mosaic may be semicontrolled to these USGS quadrangle sheets. In this case, the steps outlined in items 1 and 2 above would not be needed.

Where semicontrolled photo mosaics are used for horizontal control, the location of stream channel improvement may be shown on these mosaics. Other existing maps or plans of equivalent accuracy sometimes are acceptable for this purpose.

The following steps are needed:

1. Draw a preliminary centerline in pencil on the mosaic, showing curves, intersecting angles, etc. Plot and measure intersection angles by the tangent method for accuracy. To locate the center of curvature accurately, erect perpendiculars - do not use triangles.

2. Walk the full length of the flood plain, noting on an ozalid print of the aerial mosaic:

   Probable channel realignment,
   Points of significant breaks in grade,
   Location of all channel cross sections obtained with a hand level,
   Location of all rock outcrops or critical soil conditions,
   Approximate locations where valley cross sections may or should be obtained,
   Location of significant tributary junctions and places where side inlets may be needed,
   Location of all homes, institutions, roads, parks and recreation areas that maybe effected by the channel work. These include but are not limited to facilities that are within 500 feet of the alignment,
   Location of tree areas and large individual trees adjacent to the alignment,
   Location of utility crossings, such as: powerlines, telephone lines (aerial or buried) and pipelines. Obtain hand-level cross section of the channel at all visible pipeline crossings to show general relation of the pipeline elevation with the present channel bottom and bank elevations, and
   Location of fence lines and/or apparent property lines, foot bridges, etc., if not already visible on aerial photo.

3. Make a photo record of the landscape surrounding the project and record the viewsheds of the project from view points.

4. Following the field check, accurately establish the revised centerline on the photo mosaic. The final selection of alignment should be based on full use of all cross section, geologic and environmental data.

5. Show the actual location of all surveyed cross sections on the photo mosaic.

If suitable aerial photographs are not available it will be necessary to establish a base line in the field by means of an instrument survey. Where feasible, the base line should be located close to the improvement area but outside of brushy or wooded areas and any probable construction

areas. This will facilitate survey work and avoid the necessity of establishing a new baseline at the time of construction. This is usually done by staking a series of tangent lines offset a convenient distance from the centerline of the existing channel. It is recommended that all points of intersection (PI's) of the tangent lines be staked with metal pins, when practicable, for later use in final design and construction layout surveys. A closed traverse survey should be made on this baseline. For closed traverse surveys, the error of angular closure should not be greater than $1.5\sqrt{N}$ minutes, N being the number of angles in the traverse. Horizontal closure of chained distances should not exceed 1.0 foot per 1000 feet of traverse length. All traverse angles should be doubled and checked by comparing computed bearings with observed magnetic bearings.

The use of a coordinate system will often facilitate the drafting and layout of complex horizontal controls. The coordinates should be related to existing systems in the area, where established, or to an assumed origin located so that all traverse points will plot in the same quadrant.

Vertical control

Vertical datum. - - Mean sea level datum is recommended for all channel improvement work.

Bench marks. - - Reasonably permanent bench marks should be established in the work plan stage at tributary junctions, at or near bridges or culverts where channels intersect roads, and at the beginning and end of channels. In addition, bench marks are suggested at approximately one-half mile intervals along the valley to facilitate the survey of valley cross sections and the preparation of an adequate profile.

All bench marks should be set by making turns through each bench mark; they should never be set by side shots from the level circuit. Level circuit surveys should be closed within the required degree of accuracy. The bench mark may be a plate or cap set in concrete, a plate on a concrete post similar to those used by USGS, or other similar means that will give the same degree of permanency. Manufactured survey markers, consisting of metal stakes with bronze caps are sometimes used because they are relatively inexpensive and can be set quickly and easily. Where manufactured markers are not used, it is advantageous to tag each bench mark with an aluminum tag showing the bench mark number and elevation.

Permissible error of closure. - - For most channel work, vertical control is of paramount importance. Channel designs are dependent upon the amount of fall between hydraulic control points. Therefore, "third order" leveling (i.e., .05 times the square root of the length of level circuit in miles) should be maintained for all bench level circuits, including subcircuits within larger circuits. These bench marks should be established to the specified degree of accuracy in the planning stage for use in both the planning and final design surveys.

Stationing

Main channel. - - The base line should be stationed in conformance to Engineering Memorandum SCS-39.

Where semicontrolled aerial mosaics are used to show the location of channels, mark the stationing on the centerline with a short dash at each 200-foot point.

Determine the stations at all cross sections and the pertinent features noted during the field reconnaissance by scaling the distances between points on the aerial mosaic. Although the points and the cross sections may be numbered both on the mosaic and in the notebook, these points also should be stationed in the field notebook as a permanent record. Thus, complete profile notes are obtained without actually measuring the distances in the field.

Where preliminary location surveys are obtained by means of an instrument survey, stationing is accomplished by measuring with a chain or stadia in the field.

Tributary channels. - - Base lines on tributary channels should be tied into the main channel base line.

Reaches

The length of design reaches normally is governed by the distance between points where a change of elements of the channel occurs, such as the entry of a side tributary or a change in gradient, depth, width, etc. Where the elements of a channel are constant for relatively long distances, the reach should be subdivided so that no design reach will exceed about 1/2 mile in length.

Cross Sections

Valley flood plain. - - The survey of valley cross sections used to develop water surface profiles for damage evaluation should be extended on each side of the valley to be above the maximum high water mark to permit computation of flood plain storage and to establish the vertical relationship between viewers and the channel work. Normally, this work is done in sufficient detail in the planning stage to serve for both the planning and final design requirements.

Sufficient points should be surveyed to represent adequately the hydraulic and visual characteristics of the cross section. Elevations should be established at all significant changes in slope. The distance between points on the cross section should not exceed 300 feet where the slopes are relatively uniform.

Channels. - - Channel sections are required to make reliable estimates of quantities and to determine easement requirements. They should extend far enough to permit improved channel alignment without additional surveys or at least 50 feet beyond the expected right-of-way, whichever is greater. The allowable distance between cross sections will vary with channel and valley conditions. Normally, 300 to 1000 feet are sufficient for work plan estimates. These sections should be tied into the same basic datum as the other sections in the watershed.

Structures

The condition and serviceability of all structures should be recorded. Adequate survey data are needed for all bridges and culverts in order to compute the carrying capacity for each. A minimum of three cross sections is needed at each structure; i.e., an inlet or approach section, a section perpendicular to the direction of flow through the structure, and an exit section. The entrance and exit sections usually are taken approximately 50 feet from the respective ends of the structure. The section through the structure should include the size of the opening, size of bridge piers, abutment footing elevations, and elevations of the bottom of bridge girders and the road surface. This section should be extended along the centerline of the road on either side of the structure beyond any probable overflow elevations. The grade and length and invert elevations of all bridges and culverts also should be obtained. See National Technical Release 14.

The three sections described for bridges and culverts also should be taken for all grade control structures along the channel. Similarly, cross sections are needed for all rock ledges which act as grade or hydraulic control sections.

Visual Resources

The data necessary to identify, plan, and design the visual resources will vary considerably among projects and may vary among parts of the same project. For example, given a flat terrain covered solely by a crop pattern with only stream way trees, the needed data may include only recording the possible road viewsheds and noting how the treetop edges contribute visual variety or a visual sense of space. However, in an urban landscape it may be necessary to pinpoint the locations of landscape elements such as large trees, accoustical and visual screen shrub masses, and landforms. Landscape architecture survey outline including a visual resource survey appears in Chapter 2, Appendix A. A more detailed discussion of visual resources and landscape architectural design appears in Chapter 8.

Plotting Data

General. - - Plan, profile, and cross section data obtained during the planning stage should be neatly plotted for use in preparing preliminary drawings. The scales used for plotting the data should be selected so that the information can be clearly shown on as few sheets as practical

Plan data. - - The plan should show the location of the existing channel; base line; cross sections; apparent property lines; general land use of adjacent areas; bench marks; existing vegetation, noting general size and specie, especially individual trees with greater than 6—inch diameter and trees with less than 6-inch diameter that are unique or not common for the watershed; roads, bridges and culverts; houses and institutional buildings that are within or adjacent to right-of-ways; and any utilities that may fall within the planned right-of-way. The base line should show either azimuths, bearings, or deflection angles. They may be shown as traced from aerial photographs. The direction and stationing of the cross sections should be shown on the plan. The plan may be made from an overlay of corrected 8-inch aerial photographs, plane table sheets, or a plot made from transit survey field notes. If coordinates are used, they should be shown on the plan.

Profile. - - Data obtained from the survey of valley cross sections and cross sections surveyed at hydraulic structures, supplemented if necessary with information from available USGS quadrangle sheets, should be used to plot a profile of the existing channel and valley. Standard sized sheets of profile paper or plan-profile paper should be used for this purpose, to facilitate preparation of preliminary drawings. (See Figure 2-1.)

The profile should show the water surface of the design flood for present conditions; the present ground line; the existing bottom grade; cross section locations; soil investigation sites; the elevation and location of any exposed or underground utilities, roads and existing or proposed bridges and culverts, junctions of tributaries; etc.

It may be desirable to plot separate profiles for use in considering existing and planned conditions if it is expected that existing alignment will be changed significantly.

Cross sections. - - Cross sections should show any existing channels; the intersection with the base line; the elevation of the design flood for existing conditions; the elevation of any exposed or underground utilities; and any existing or proposed bridges.

Preparation of Preliminary Drawings

Preliminary drawings may include plan, profile and cross sections of all channel work proposed for the project. In the case of large complex channel systems, it may be expedient to show only representative channels in this degree of detail in order to reduce the bulk of the preliminary document.

In either case the following preliminary design data should be shown in addition to the survey data collected as shown above:

1. Proposed channel alignment with bearings or azimuth should be shown for each tangent. Curve data is usually not needed at this stage or development.

2. Proposed grade and water surface profile should be shown on the profile including pertinent elevations and invert gradient.

3. Typical cross sections showing existing and proposed sections one for each type or size of proposed section should be included on each sheet of plan-profile.

4. If structures are proposed for the project, a drawing of a typical structure showing general dimensions should be included.

5. Drawings, sketches, cross sections or photo montages should be included to illustrate how the proposed project will appear in the surrounding landscape.

Profile and cross sections may be omitted in reaches to be cleared and snagged only.

A horizontal scale of 1 inch = 200 ft. to 1 inch = 1000 ft. for plan-profile is usually adequate for preliminary drawings. If the original plot of survey data can be made to the same scale as that needed for drawings, considerable time and effort will be saved.

Documentation

All data developed during the planning phase should be properly documented and filed. This will insure that such data will be of maximum use for future reference. All notes, computations, and drawings should be properly identified and be complete so that they can be used in preparing detailed plans for design and construction. The data should be dated, since Service criteria are modified from time to time. All papers should show the initials of the person preparing the data sheets or making the computations. A reference should be made to indicate the methods or source of data used.

Survey for Final Design

General Requirements

The section covering "Design Surveys - Surface Drainage" in the National Engineering Handbook Section 16, 2/ Chapter 2, will serve as a useful reference for final design surveys, where applicable. As indicated in the NEH, a staked base line is required. An exception to this requirement may be made where clearing and snagging is the only work needed to provide the desired level of protection. For this condition, no additional surveys over those recommended for planning may be needed for design purposes. However, sufficient data must be obtained to permit the determination that this treatment will result in a stable channel which

will meet the desired project objectives.

Field Check of Design Layout

For most projects it is highly desirable to check the final design on the ground. Verify the following:

1. Alignment and stationing.

2. Rights-of-way boundaries.

3. Construction easement limits.

4. Structure locations.

5. Stationing and description of bench marks.

6. Utility locations.

7. Apparent ownership boundaries.

8. Woody vegetation locations, including individual large and/or unique trees.

9. Home and institutional locations when potentially visible from the project site.

Land Rights Work Maps

The land rights work map may be prepared by making a full scale or photographically reduced overlay of the appropriate portions of the strip map. Judgment must be exercised to insure that adequate land rights are provided for the channel, spoil bank area, visual design areas and the maintenance and construction operations.

Except where specified otherwise in existing state laws, the land rights work map should show the existing channel, utilities, apparent ownership boundaries, roads, base lines showing key stations, and proposed works of improvement. If requested by the sponsors or required by state law the apparent acreage of right-of-way for each landowner should be indicated on the land rights work map.

A typical cross section should be shown on the land rights work map to illustrate the various elements of the proposed works of improvement within the right-of-way area. When utilities are involved, the actual cross section including the elevation of the design flow should be shown at the intersection with the utility.

Supplementing Planning Surveys

Field survey data obtained in the planning phase must be supplemented to provide basic design data. In fact, budgetary considerations will often preclude much of the detail described above for the planning phase so that the survey data used in preparing preliminary drawings may be of little value as design data.

Supplemental data needed to establish the visual resource design may be determined by the outlines shown in Chapter 2, Appendix A.

Bench levels must be checked and supplemented. Damaged BM's should be reestablished and additional bench marks should be set and tied in as needed.

Coordinate control should be established by traverse and closed within third order accuracy. Triangulation may be used to establish control on large, complex projects, if desired.

Topographic strip maps of the area will be needed for layout and design. Data for these maps may be secured either by plane-table or transit topography tied to the traverse. Strip map data must be secured to provide accurate location of contours, fences, buildings, bridges, culverts, roads, utilities, the edges of woody vegetation areas, large trees, orchards, existing drainage or irrigation ditches and structures, and all other physical or man-made features within the probable limits of work.

Test pits and borings should be accurately located and the elevation should be established on a reference hub adjacent to the site.

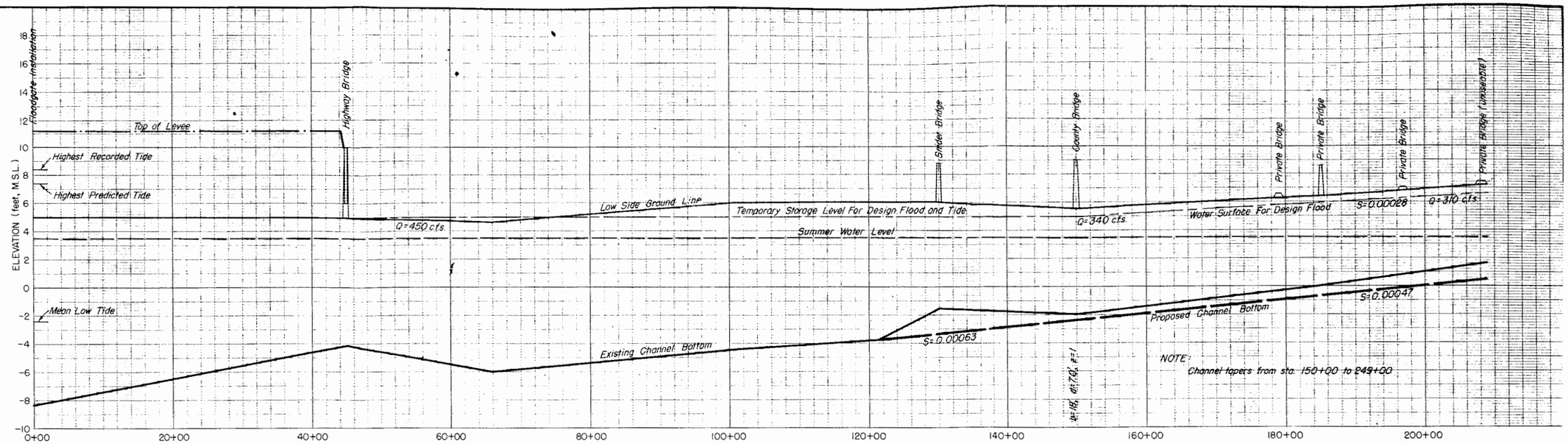
Preparation of Strip Maps and Profile

Strip maps should be plotted to the same scale as that intended for final drawings - usually 1 inch = 40 ft. to 1 inch = 200 ft., depending on the detail needed. For convenience, strip maps should be plotted on transparent paper or cloth sheets not exceeding 42 inches in width and 20 ft. in length. This provides sufficient length for proper selection of long tangents and curves for the "paper location."

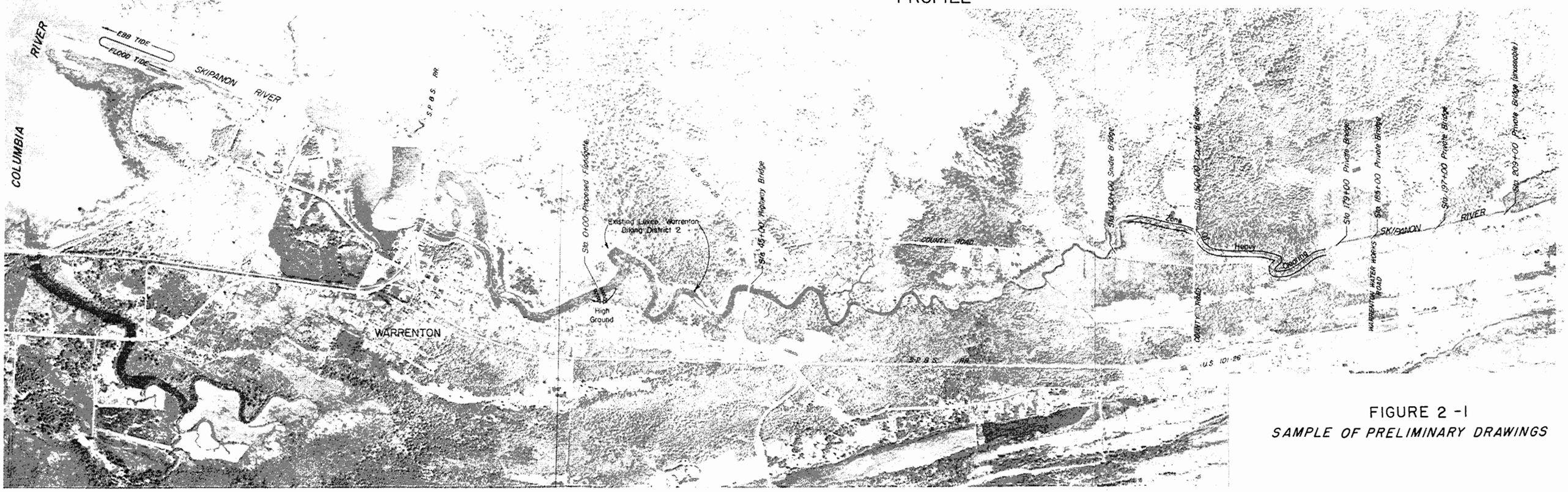
Trial locations complete with stationing and curve data are then superimposed on prints of the strip maps and profiles are plotted on equally long profile sheets to permit selection of long tangent grades.

As the hydraulic design progresses and design cross sections are selected one of the alternate locations will usually emerge as apparently superior. The best apparent alternate including right-of-way requirements should then be drawn on the strip maps. Design grades and cross sections should

be drawn on the strip profile. Prints should then be made of both the maps and profiles for field checking, prior to tracing final drawings on standard sheets.



PROFILE



PLAN

800 0 800 1600 2400
SCALE IN FEET

FIGURE 2 -1
SAMPLE OF PRELIMINARY DRAWINGS

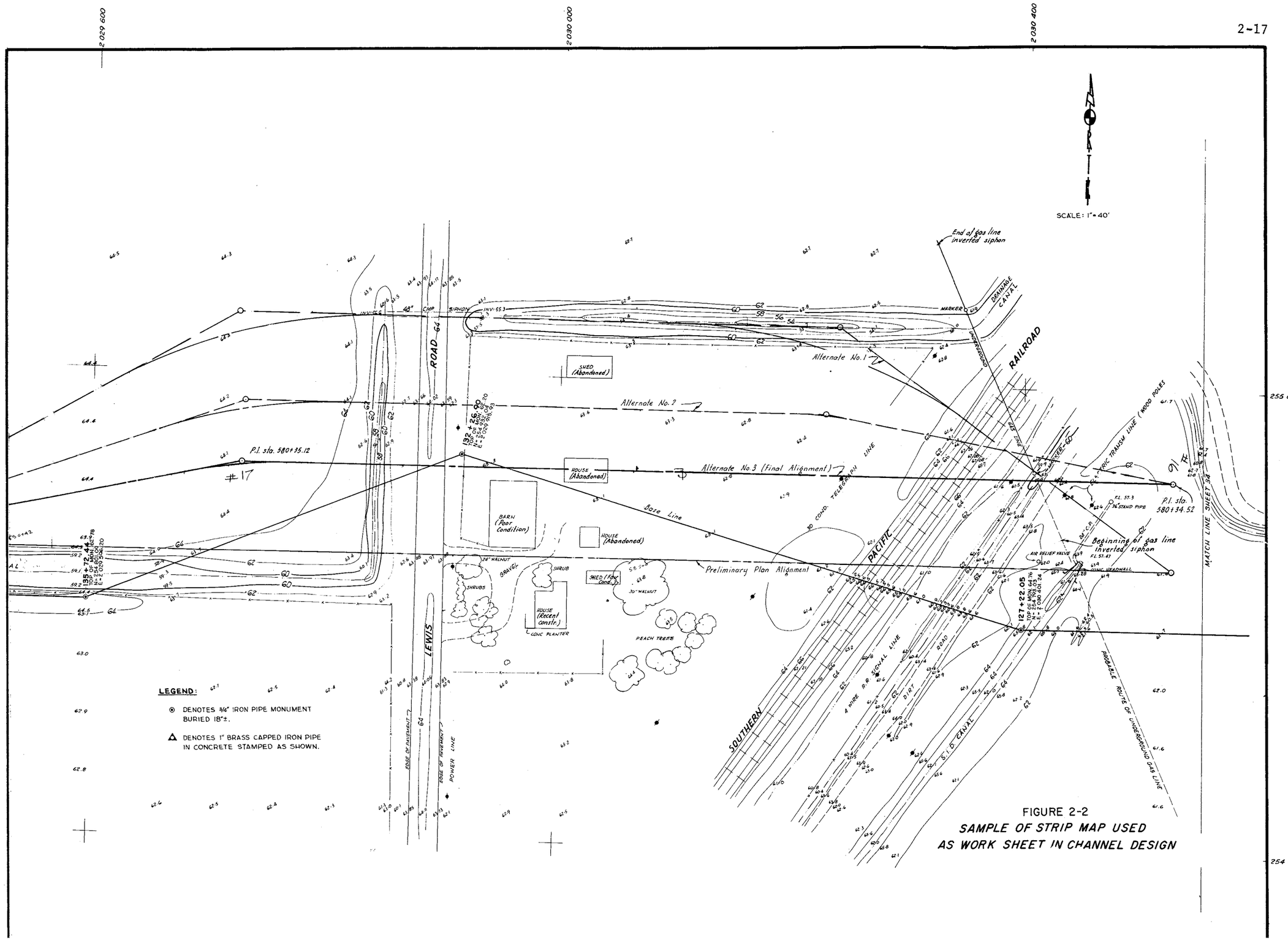


FIGURE 2-2
SAMPLE OF STRIP MAP USED AS WORK SHEET IN CHANNEL DESIGN

17-927 O - 78 (Face blank p. 30) No. 2

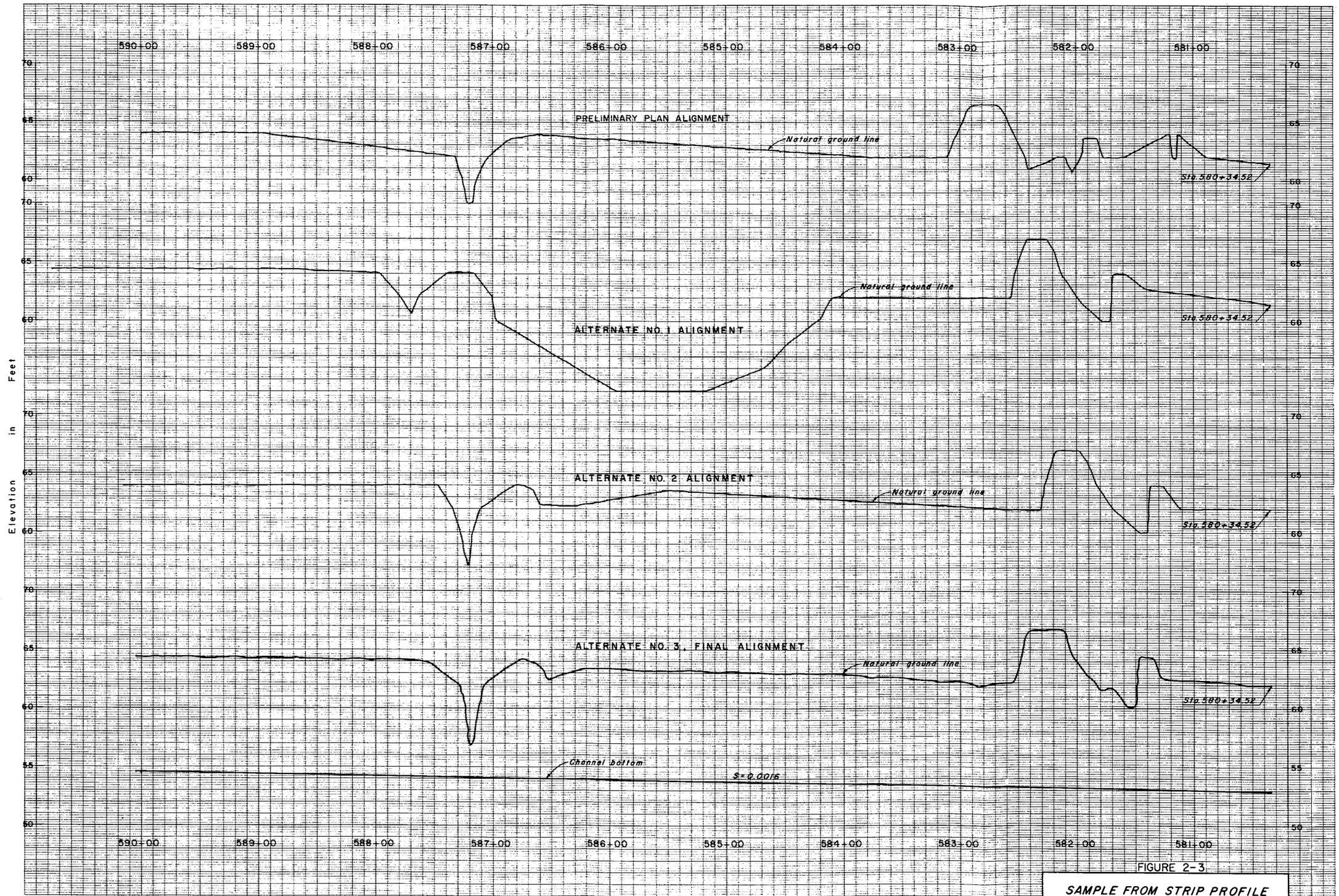
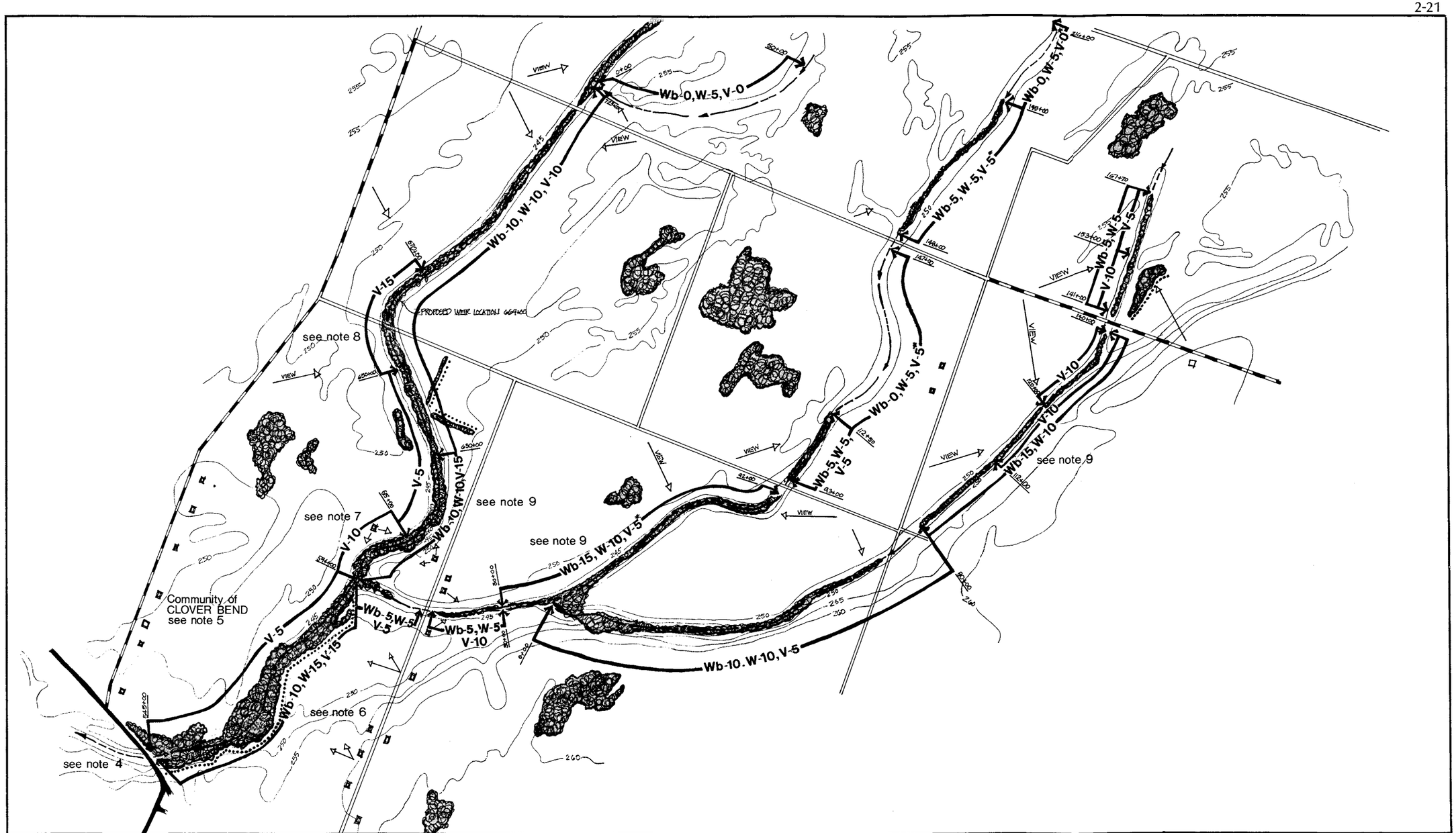


FIGURE 2-3

SAMPLE FROM STRIP PROFILE
(DESIGN WORK SHEET)

247-327 O - 78 (Face blank p. 30) No. 3



NOTES

1 THE PURPOSE OF THIS SHEET IS TO IDENTIFY GRAPHICALLY THE RESOURCE VALUE OF LANDSCAPE ELEMENTS OCCURRING WITHIN OR ADJACENT TO THE R/W'S OF CHANNELS PROPOSED FOR MODIFICATION UNDER THIS CONTRACT.

2 THREE MAJOR RESOURCES WERE STUDIED. (1) WINDBRAKE RESOURCE, (2) WILDLIFE HABITAT RESOURCES, AND (3) VISUAL RESOURCES.

3 THE RELATIVE VALUE OF EACH RESOURCE CAN BE IDENTIFIED AT ANY POINT ON THE CHANNEL TO BE MODIFIED. (SEE LEGEND FOR IDENTIFICATION OF SYMBOLS.)

4 STATE HIGHWAY #228 IS ELEVATED ABOVE THE CHANNELWAY APPROX. 20 FT SO THAT OBSERVERS WILL BE LOOKING DOWN ON CHANNEL. (TIME OF VIEWING @ 50 MPH IS 5 SEC.) CHANNEL ALIGNMENT IS SUCH THAT LENGTHY DOWN CHANNEL VIEWS WILL BE CREATED. *SELECTIVE TREES COULD BE LEFT WITHIN THE CLEARING LIMIT TO BREAK UP SIGHT LINE DOWN CHANNELWAY. * SPOIL PLACEMENT AND SHAPING SHOULD BE PERFORMED TO SIMULATE MORE NATURAL LAND FORM CHARACTERISTICS.

5 THE CHANNELWAY, INCLUDING WOODLAND EDGES IS NOT SIGNIFICANTLY VIEWABLE FROM PAVED COUNTY ROADWAY OR RESIDENCES WEST OF PROPOSED CHANNEL MODIFICATION. THUS THE LOW VISUAL VALUE RATING FROM STATION 545+00 TO 599+00.

6 THE CHANNELWAY (PARTICULARLY THE WOODLAND EDGE) IS IN CLOSE PROXIMITY TO A GRAVELLED COUNTY ROADWAY AND A NUMBER OF RESIDENCES. SIGHT LINES ARE PRIMARILY PERPENDICULAR INTO WOODLAND EDGE. VISUAL QUALITY IS HIGH BECAUSE OF THE WIDE SECTION OF WOODLAND AREA (200-800 FT.). CHANNEL MODIFICATION WILL BE SCREENED FROM VIEW AND VISUAL QUALITY WOULD NOT BE ALTERED. * CLEARING SHOULD BE LIMITED TO THE MINIMUM NEEDED FOR EXCAVATION AND SPOIL SPREADING ON BOTH SIDES.

7 VISUAL VALUE OF WOODLAND EDGE RATED PROXIMITY MODERATE BECAUSE OF RESIDENCE. * NEED TO RETAIN TREE LINE TO SCREEN CHANNEL WORK.

8 WOODLAND EDGE HIGHLY VIEWABLE FROM STATION 650-00 TO 670-00, THUS VISUAL RATING OF 15. * SHOULD ATTEMPT TO MAINTAIN TREE LINE EDGE ON ONE SIDE.

9 ON REACHES OF THE CHANNEL WHERE ANY RESOURCE VALUE IS RATED @ 15 I.E., WB-15, W-10, V-5, CONSTRUCTION SHOULD BE LIMITED TO ONE SIDE FOR RETENTION OF WOODS ON OPPOSITE SIDE. * RETENTION OF WOODLAND EDGE FOR ONE PURPOSE OR ANOTHER WOULD NORMALLY BENEFIT OTHER RESOURCES.

KEY

- STATE HWY, MODERATE TO HEAVY DUTY
- PAVED COUNTY RD, MODERATE TO LOW DUTY
- GRAVELLED COUNTY RD, LOW DUTY
- CONTOUR LINE (5 FT. INTERVAL)
- RESIDENCE
- WOODLINE
- SCREENING EFFECT OF WOODS OUTSIDE CHANNEL R/W
- VIEW — SIGHT LINES OF SIGNIFICANCE
- LIMITS OF VALUE RATINGS

Wb WINDBRAKE
W WILDLIFE HABITAT
V VISUAL RESOURCE
V* ASTERIC DENOTES VISUAL VALUE RATING AS VIEWED FROM EITHER SIDE OF CHANNEL

RATING:
15 HIGH VALUE
10 MODERATE VALUE
5 INSIGNIFICANT
0 LOW VALUE

FIGURE 2-4

SAMPLE LANDSCAPE VALUE SURVEY

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

Designed	Date	Approved by	
Drawn		Title	
Traced		Title	
Checked		Sheet No of	Drawing No.

147-927 O - 78 (Face blank p. 30) No. 4

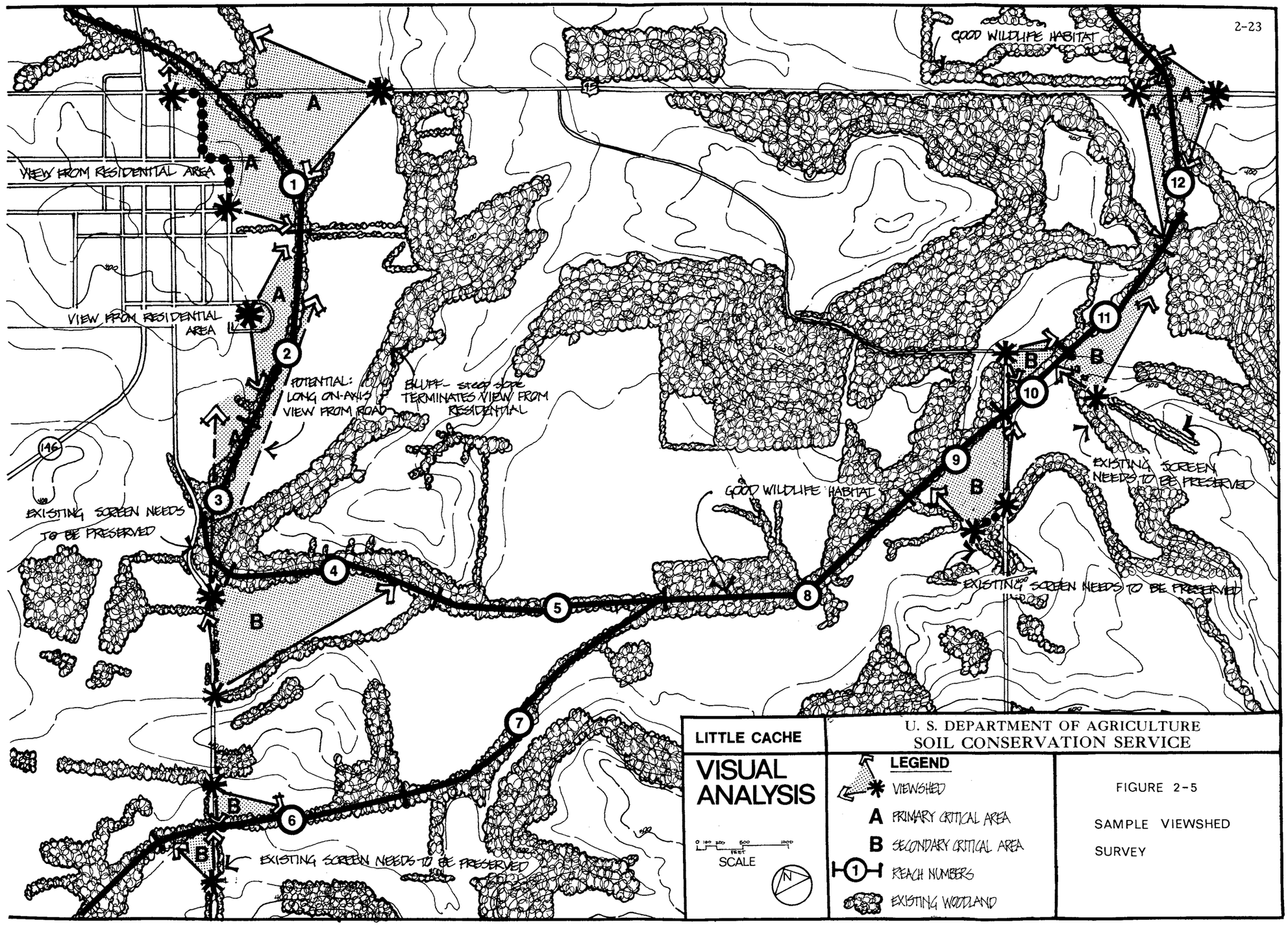
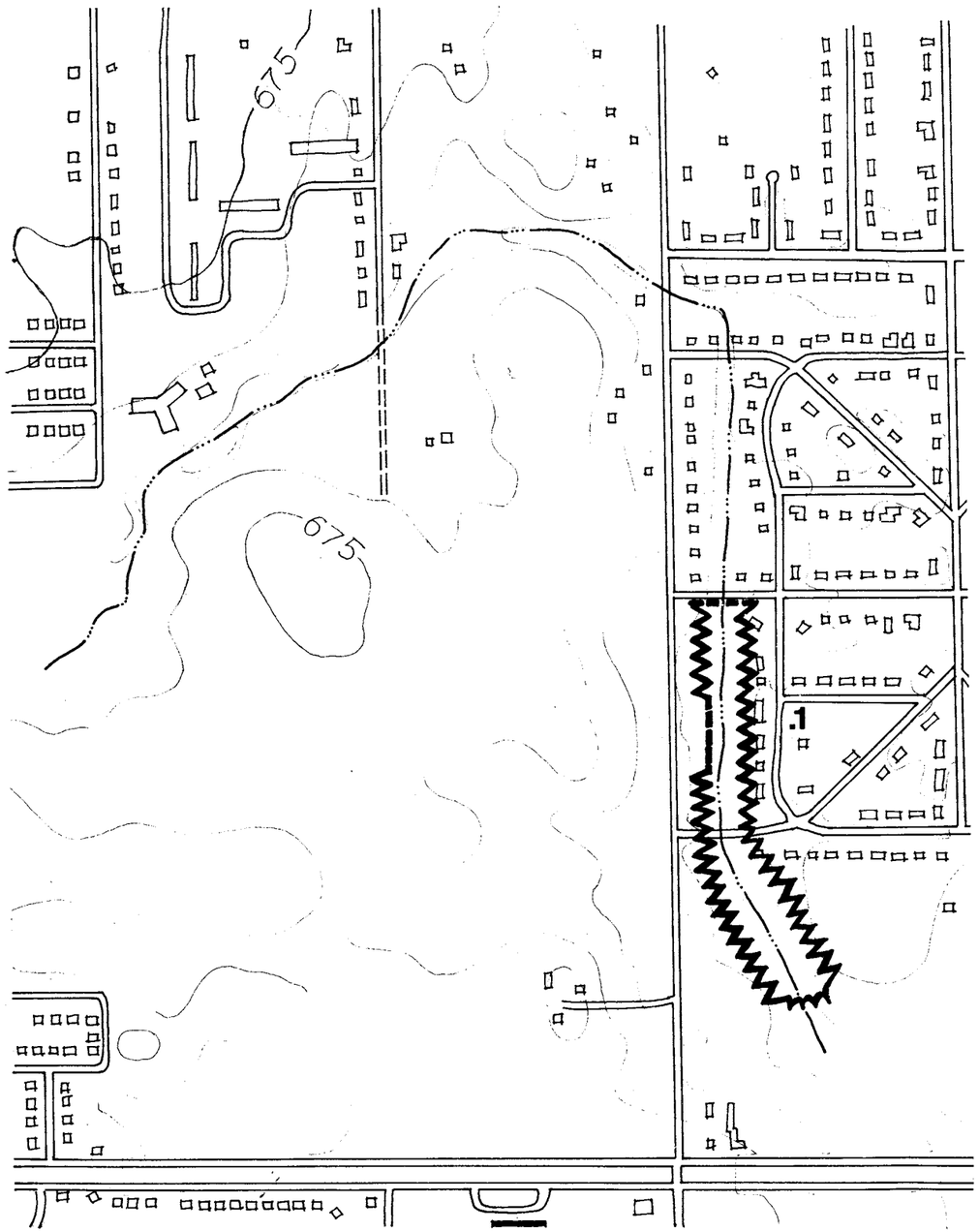


FIGURE 2-5

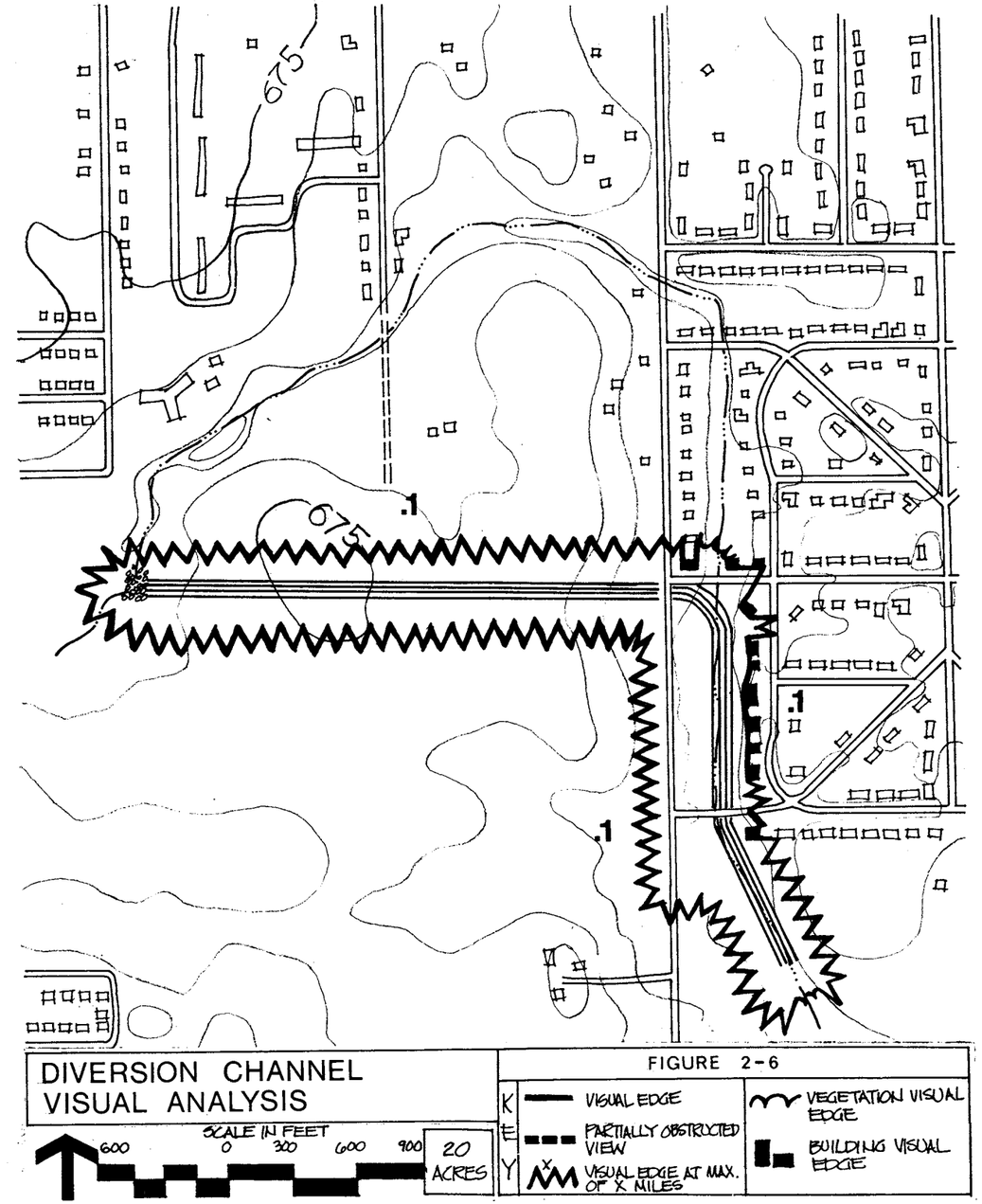
SAMPLE VIEWSHED SURVEY

O - 78 (Face blank p. 30) No. 5

Visual Conditions Before Construction: Winter



Visual Conditions After Construction: Winter



DIVERSION CHANNEL
VISUAL ANALYSIS

SCALE IN FEET
600 0 300 600 900

20 ACRES

FIGURE 2-6

KEY

- VISUAL EDGE
- PARTIALLY OBSTRUCTED VIEW
- X VISUAL EDGE AT MAX. OF X MILES
- VEGETATION VISUAL EDGE
- BUILDING VISUAL EDGE

CHAPTER 2. APPENDIX A.

LANDSCAPE ARCHITECTURE SITE SURVEY AND ANALYSIS

INTRODUCTION

The goals of landscape architecture are to identify, analyze, plan and design so as to retain, replace, or improve as many landscape resource values as possible. Material in this Appendix will cover the identification and analysis procedures. Planning and design will be discussed in Chapter 8. Material presented in this technical release assumes prior landscape architectural inputs have occurred in the development of project alternatives. Some of the material discussed herein could be used in the initial project assessment phase.

Meeting the goals of landscape architecture in channel work does not always mean a channel should be built to appear as it did before the project or necessarily to appear as a "natural landscape." The project site appearance can change drastically, as long as the landscape resource values have been retained, replaced, or improved. To achieve these goals the following four step procedure should be followed:

1. Landscape Architecture Site Survey to identify and map the landscape use and visual resource values* and to modify these values as indicated by project visibility.

2. Landscape Architecture Site Analysis to identify opportunities and problems and to define objectives so as to utilize opportunities and overcome problems.

3. Planning to identify alternates that achieve the objectives. In this phase the landscape architectural objectives merge with other engineering objectives to find the best possible alternatives.

4. Design to detail the chosen alternative so as to achieve the best structural and environmental solution.

LANDSCAPE ARCHITECTURE SITE SURVEY

Any landscape architecture (LA) site survey includes two basic factors the landscape (its physical characteristics) and people (how they see and use the landscape.) Judgment should be used to determine what data are needed. Obviously the scope and detail of the data will vary depending upon the size and location of the channel. Both the explict value of the landscape and some sense of the landscape's implicit value as perceived by its users and viewers must be considered in channel

* definition may be found in Glossary at the end of Appendix A.

work. For example, a channel may have a straight alignment and may be a previously dug ditch; but it may be perceived as valuable because it is used by the public as an open space. A LA site survey for channel work should cover the following factors:

1. Landscape Use Value
2. Visual Resource
3. Project Visibility

1. Landscape Use Value

The LA site survey should note how the existing project area is used by the public. In most cases, channel work can be designed so the landscape will retain its utility for human use, while improving its hydrologic characteristics. Data to be noted and/or mapped for various reaches include but are not limited to:

A. Identifying places where existing streamway vegetation function as a:

(1) Shelterbelt to help control wind erosion.

(2) Privacy screen between homes.

(3) Buffer between incompatible land uses such as industrial and residential areas.

(4) Noise barrier such as between homes and a busy highway.

(5) Safety barrier controlling pedestrian traffic such as between schools and roads.

(6) Climate shelterbelt such as a wind/sun screen providing energy conservation to homes and institutions.

B. Identifying areas along the streamway that function as or contain:

(1) Pedestrian paths between homes, schools and commercial areas.

(2) Recreation areas contiguous to existing playgrounds, schools and parks.

(3) An open space or environmental corridor within a developed area.

2. Visual Resource (VR) Value

Investigating the visual resource values should not involve a personal judgment as to beauty. For example, a previously dug ditch might be judged as "ugly" and yet have high VR value because it provides variety in an otherwise monotonous landscape. A concrete drop structure may be judged "ugly" and yet have high VR value because it relates architecturally to the surrounding landscape. Visual resource value involves an assessment

of several measurable factors. The factors cited in Rating Charts A-C below were developed from research and preference studies cited at the end of this Appendix. These charts must be used within a local frame of reference and must be verified by citizen participation. For example, water carrying sediment may appear relatively muddy or clear depending on the appearance of other streams within the area.

The Rating Charts A-C below rank VR values into only two groups, high or low. One or more middle groups do exist between high and low. These charts should be expanded into at least three groups and the criteria shifted to fit the locale. For example, crystal clear water (Chart B, item 1) may not exist in a locale. In that case, the clearest water for the locale should be rated as a high value visual resource and all other water clarity rated in comparison to it. Investigation of VR values include, but is not limited, to identifying and/or mapping the existing landscape as to the following.

RATING CHART A: Visual Resources of Streamway and Surrounding Landscape

Rural Areas

High Value Visual Resource	Low Value Visual Resource
(1) Adjacent landscape has no linear patterns, no agricultural activity, few or no manmade structures.	(1) Adjacent landscape contains many linear forms and patterns, (other channels, transmission lines, field patterns).
(2) Streamway has the major trees in the landscape providing the only variety and spatial definition to surrounding landscape.	(2) Streamway provides no spatial definition or variety to surrounding landscape.
(3) Surrounding landscape has no visual detractors (strip mining, derelect lands, erosion, etc.) and/or is highly maintained with obvious care for its appearance.	(3) Surrounding landscape has obvious visual detractors.

Urban Areas

(1) Streamway area is highly maintained (lawn, shrubs and trees) and/or is a visual part of residential lots, school grounds and parks.	(1) Streamway area is not a visual part of any maintained area.
(2) Adjacent landscape is highly maintained with obvious care for its appearance (lawns, residential gardens, industrial parks).	(2) Adjacent landscape is derelict, poorly maintained with no obvious concern of its appearance.
(3) Large, mature and/or flowering trees along streamway.	(3) No significant woody plants along streamways.

RATING CHART B: Visual Characteristics of the Water

High Value Visual Resource	Low Value Visual Resource
(1) Clear, generally transparent water.	(1) Visible color or turbidity, and/or pollution and/or algae.
(2) Desirable drift material such as leaves.	(2) Floating debris and trash.
(3) Variety of bottom material (bedrock boulders, gravel or unique bottom material for area).	(3) Homogenous bottom material commonly found in all area streamways.
(4) Conspicuous water movement, rapids, riffles or slow movement with high reflecting ability.	(4) No open water, weed choked or imperceptible water movement with no reflecting ability.
(5) Variety of movement from fast reaches to still pools.	(5) Homogenous movement with no visible variety.

RATING CHART C: Visual Resources within the Streamway

High Value Visual Resource	Low Value Visual Resource
(1) Streamway is obvious, meandering visual edge in landscape.	(1) Previously dug straight ditch.
(2) Variety of streambank slopes.	(2) Uniform streambank slopes.
(3) Variety in size and shape of cross section.	(3) Uniform cross section.
(4) Unique streamway vegetation compared to surrounding landscape (cypress, beech, birch).	(4) Vegetation in streamway is weedy or commonly seen in surrounding lands scape.

3. Project Visibility

Investigate the types of viewers and their significant viewsheds* to determine how visible the project will be within a locale. Determining the public's opportunities to see the project will modify the use and visual resource values determined previously. The charts below are guides to identifying project visibility and evaluating its significance. The guides should be modified to fit a local context. For example, viewers who may see the project one time only may or may not need to be considered depending on the local frame of reference. Visibility factors to be noted and/or mapped include but are not limited to:

CHART D: Viewers

		Critical	Important	Normal
1.	Purpose of seeing or being on project site	•Homeowner, including farmer •Recreationist •Tourist •Local resident	•Resident of region •Adjacent businessman •Students at school	•Farmer at work
2.	Frequency of view	•Daily >1 min	•Daily <1 min •Infrequent but for longer time periods >1 hour	•Infrequently for short time periods
	Speed of viewer	Slow such as •Pedestrian •Bicyclist •Canoe or slow moving boat	•Moderate 15-30 MPH	•Fast 30 MPH

CHART E: Viewshed and Viewpoints

		Critical	Important	Normal
1.	Viewpoint location relative to project	•Elevated as from bridge, road, or two story bldg. (> 20')	•Elevated <20'	• Ground level
		•Scenic hwy or overlook	•Interstate, state or busy country roads	• County or farm road
		•From residential, institutional or recreational areas	•From isolated home or farmstead	• From commercial areas
2.	Location of project within viewshed	•Foreground* only •Foreground to background* or a long vista on channel	•Middleground* only •Middleground and background	• Background only

See Figures 2-5 and 2-6 for examples of viewshed maps.

LANDSCAPE ARCHITECTURE SITE ANALYSIS

The intensity of a site analysis will vary between projects but the following steps remain the same:

1. Locate opportunity and problem sites in the project area.

2. List in priority the landscape architecture objectives for both problem and opportunity areas.

3. Document the analysis in a supporting data file.

1. Opportunity and Problem Sites

Opportunity sites are defined as areas where the channel design may retain or rehabilitate existing landscape values. Problem sites are defined as areas where the channel design may reduce or eliminate existing landscape values. Opportunities and problems are located by superimposing landscape value areas (use and visual) and project visibility data. For example, an area of low visual resource value, moderate project visibility and high use may be an opportunity site; whereas an area of high visual resource value, high use, and moderate project visibility may be a problem area. The relative importance of the visual resource value, use value and visibility within the decision process can shift depending on the project. For example, retaining the use value of the landscape may

be most important in some locations; while in other areas retaining the visual resource values may come first.

2. Landscape Architecture, (LA), Objectives

The LA objectives should be the logical outcome of the LA analysis, and a LA design, (Chapter 8) should be the logical product of the objectives. The success of the final design will depend on how well the site analysis has been done and how clearly the landscape architectural objectives have been stated. These objectives should be prioritized and stated as objectives, not design solutions. For example, an objective might be "to retain the climate shelterbelt value of urban trees." The various options for achieving this might include; moving the channel alignment, changing the side slopes to retain trees, selective clearing to retain the most functional trees or replanting with mature trees. The decision to choose among these design options should be correlated with other engineering factors in final design.

3. Documentation

Documentation of the site survey, analysis and objectives can be done on several formats: reports, maps with notes, photo record with notes, computer graphics or a combination of any of these. Often the analysis and documentation can be done in a single process by mapping with notes (See Figure 2-4). A photographic record of use and visual resource value areas and critical viewsheds should be done for all channels in urban areas or areas of projected future urban development.

GLOSSARY

1. BACKGROUND is the viewshed zone most distant from the viewer. Details are not seen in this zone. The horizon line is prominent in this zone as are general form, colors, and textures.

2. FOREGROUND is the viewshed zone nearest the viewer. It is the zone in which details, such as construction joints, movement of water and the finish of earth grading, are visible.

3. MIDDLEGROUND is the viewshed zone between the back and foreground. Some details can be seen in this zone but only those which are in sharp contrast visually.

4. VIEWSHED is the zone of view or volume in a given direction as seen from a specific viewpoint.

5. VISUAL RESOURCE is the appearance of the landscape as described by the measurable visual elements; topography, vegetation, water, and human structures and patterns, and by the measurable patterns of interaction among these elements.

6. VISUAL RESOURCE VALUE is the relative desirability of a visual resource unit as evaluated by rational criteria.

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CHAPTER 3 - APPENDIX

OUTLINE TO PLAN SITE INVESTIGATIONS AND PREPARE REPORTS FOR CHANNEL IMPROVEMENT

CHAPTER 3. SITE INVESTIGATIONS

Introduction

Methods of investigation and testing of soil conditions along a channel system are discussed in this chapter. The purposes of these investigations and testing are to evaluate the resistance of the soils in the bed and banks of the channel to erosion forces, to evaluate the sediment transport relationships, to determine slope stability against sloughing and sliding, to estimate earth loads that may act on structural members, and to determine the rate of water movement through the soils.

The procedures include identification, sampling, and testing or evaluation of stratigraphic units encountered in the channel system to be modified and an evaluation of the sediment transport characteristics of the system.

Investigation Requirements

There are conditions specific to investigations for channel improvements that cause them to differ from investigations at other types of construction sites. One usually significant difference is that channels may extend for many miles through a variety of materials. This fact demands that data obtained from any one test hole must be correlated on as knowledgeable a basis as possible with data obtained at the next test hole, both upstream and downstream. A distinguishing feature of investigations for channel improvements is that almost always they are located in alluvial material. The stability of channels is affected by watershed conditions upstream that control the availability of bed material, and by ground-water conditions at the site. A similarity with foundation investigations for other structure sites exists in that the in-place characteristics of the soil materials are very important if these characteristics that pertain to erodibility differ from those that exist when the material is disturbed.

The following sequence of work is needed to appropriately recognize the conditions specific to investigations for channel improvements while ensuring that an adequate amount and type of data are obtained.

1. Determine the geomorphology of the deposits in which the channel is to be located to the limit necessary for this purpose.

2. Identify stratigraphic units along the proposed channel route and to a depth of at least three feet below the invert or channel bottom elevation as proposed. A stratigraphic unit is defined in this instance as an identifiable stratum of alluvium or other soil material whose susceptibility to erosion is a reflection of the original materials, mode of accumulation and the changes that have occurred since deposition or soil formation.

3. Log soils within stratigraphic units and classify and sample for evaluation or determination of erodibility characteristics.

Geomorphology of Deposits

Significance of the Stratigraphic Unit

There are a number of factors which influence the erodibility or stability of soil materials. Erodibility and stability are explained in this context as responses of the soils to the environment of channel boundaries. Erosion results from the flow of water against the boundary as expressed by mean velocity, tractive force, or a combination of these parameters such as tractive power, the product of mean velocity and tractive force. Instability of stream banks often results from internal seepage forces. The soil's ability to resist erosion is affected by the kinds, amount, and character (dispersive or aggregated) of clay, the amount and size distribution of coarse particles, and the nature and amount of cementing agents. The term coherent is used to describe soils that resist erosion as a mass because of bonding action of clay, cementing agents or other causes. The climate and age of the deposit since its accumulation have a strong bearing on these erodibility characteristics. There is an almost infinite variation that can occur in each of these factors and in their influence on the others. Deposits change with geologic time. Each change produces an expression of the dominant factor and interfactor relationships persisting at that time. Thus, a combination of forces acting on a deposit produce a layer of material identifiable as a stratigraphic unit. Relative uniformity of location in an alluvial profile, uniformity of appearance, and erodibility are a result of a similarity in source of materials, the history of deposition, and the weathering characteristics associated with the areas. In time, with certain exceptions, weathering, consolidation, cementation, accumulation of humus or other influences increases the significance of structure on erodibility. By the same token the significance of local variations in texture is diminished.

The delineation of stratigraphic units simplifies the field investigations in that the units may extend for distances that can include the entire route of channels to be improved. Their thickness and depth below the surface may be relatively uniform and consistent, providing a means for correlation and representative sampling. At the other extreme, alluvial fan deposition can result in a heterogeneous mixture of sand, silt and gravel where correlation of individual beds may be not only impossible but not particularly useful.

Identification of Stratigraphic Units

The origin of the defined stratigraphic units as alluvium dictates that certain relationships existed between the deposits and the carrying capacity of the stream at the time. Further, the relationships that exist today are not necessarily the same as at the time the sediment was deposited. For example, during portions of the Pleistocene, runoff and sediment transport were on an appreciably larger scale than at present.

The primary identifying characteristics of a stratigraphic unit are: color, thickness, grain size distribution, texture, structure, plasticity, consistency, density, dispersive characteristics and cementation. Slight variations that may occur do not necessarily signify the presence of a new stratigraphic unit, particularly if the deposits are conformable with units above and below the one being described.

The location of stratigraphic units areally within the alluvial valley is as important as their position and identification within the vertical profile. Because most alluvial channels meander about within a relatively short geologic time period, it is probable that stratigraphic units in a valley confined by side slopes will be at about the same elevation across the valley. This requires field checking before assuming a uniform valley-wide distribution of stratigraphic units exists.

Geomorphic History as a Determinant of Erosion Resistance

The history of the stratigraphic unit from the moment of deposition determines its erosion resistance. The grain size distribution and texture of the deposit is initially the most important characteristic and it may remain so if the environment following deposition is not conducive to modifications tending to change the arrangement or bonding of particles. These modifications can be produced by one or a number of post depositional changes such as the movement downward of particles from the overlying deposits, by weathering, by consolidation or chemical action that increases or decreases the bond between particles.

The result of this geomorphic history is that the stratigraphic unit responds in characteristic manner to the hydraulic forces that may be exerted against its exposed profile. The unit may remain as individual particles free of any bond with adjacent ones, or it may resist as a mass due to coherence between particles. The bond between particles that may be reflective of a long history in a particular environment may be destroyed when the profile is disturbed.

The following is an example of the depositional and environmental influences that can affect the erosion resistance of a stratigraphic unit. A sequence of stratigraphic units may indicate that in this instance they are alluvial deposits consisting of (1) light colored, finely stratified noncoherent silt and fine sand about two feet thick. Below this unit there is (2) a compact dark gray clayey silt horizon several feet in thickness. Then there is (3) a layer of gravel in a matrix of compact brown silty clay that starts a foot above the stream bed in the exposed banks and extends below the streambed and the proposed invert grade to unknown depths.

The reasons for a uniqueness in character of stratigraphic units within a profile are several fold. Taking the profile cited above as an example, the number 1 stratigraphic unit of this hypothetical profile is an accumulation of recent sediment. Soil forming processes have not had time to modify the sediment's characteristics over that contributed by the texture and grain size distribution of the transported sediment and its mode of deposition. The bulk of unit 2 accumulated either as a mixture of, or dominantly of, lateral accumulation as the stream meandered or vertical accumulation during overbank flooding. The developed soil in this unit indicates a following period relatively free of deposition or erosion. Time was available for limited weathering of the sediment, and for humus to accumulate. The gravel layer identified as unit 3 was deposited at a time of relatively high velocity flow. The high discharges that brought down the gravel could have formed a braided wash that extended from one side of the valley to the other. During flows of lower velocities fine sediment was deposited and migrated into the gravels. With age and weathering of clay forming materials this stratigraphic unit, with its characteristic erosion resistance properties, evolved.

The sediment source, texture, and mode of deposition of units 1 and 2 could be very similar, yet their appearance including color, degree of consolidation, and erosion characteristics can be quite different. These differences created by changes occurring since deposition can vary widely depending upon the interaction of the average annual climatic environment: humid or arid, cold or hot. The climate following deposition can create a wide change in erosion characteristics for different reasons. In a humid hot climate, textural changes can occur by weathering of clay forming minerals, leaching of soluble salts, carbonates, etc. or by movement of fine clay-size particles from the upper to the lower profiles. Structural changes can be caused by alternate wetting and drying, and consequent swelling and shrinking, as well as by growth and decay of vegetation.

In an area affected by a permanently high water table, little or no post-depositional changes in the deposits may occur. This is especially the case when there is little oxygen in water in which the stratigraphic unit is submerged. The reason for this is that oxidation essential to

the weathering process has been prevented or retarded. Reduction of iron, resulting in grayish, greenish, or bluish coloration, however, can occur. Thus sediment which may give the appearance of being recent in origin could have been deposited at about the same time as a nearby unit with a profile containing morphological evidence suggestive that it has been in place for a long period of time.

Accumulations of or cementation by silica or carbonates, or both, can change the structure and erosion resistance of the sediments without changing the engineering classification materially because the cementing material may not noticeably add to the finer soil constituents.

The junction with tributaries can change the uniformity of main stream stratigraphic units, depending upon whether the tributary has been or is a significant contributor of sediment. The type of sediment deposition may be so similar to the main valley deposits that interfingering or mixing results in an accumulation that is not separately distingishable. Tributary deposits could also be quite different either in age, color, texture or all three.

Figure 3-1 illustrates a geomorphic setting and related stratigraphic units that would be pertinent to proposed channel improvements on a stream and some of its tributaries. Unit 1 consists of recent main stream deposits and unit 2 of recent deposits from the identified tributaries. These deposits constitute a replacement of older alluvium that was eroded during a lowering of base level in times past. Unit 3 consists of old alluvium which has undergone aging and the development of a profile. Unit 4 is a still older buried profile and unit 5 is an old stream terrace remnant.

Discontinuities in Alluvial Stratigraphic Units

Discontinuities are here defined as breaks in stratigraphic units that were originally continuous. Such breaks, narrow or wide, can have a bearing on the stability of an improved channel since the deposit may be replaced by more or less erodible material. Discontinuities can occur in a number of ways. One example is illustrated by Figure 3-1 where fine grained coherent soils developed at a higher base level than exists today. A lowering of this base level, created by a lowering of the nearby sea level elevation, caused downcutting of the main stream and then its tributaries. A subsequent raise in base level induced replacement by more recent sediments that are erodible.

Discontinuities similar to the above described type can occur without changes in base level. For example, a tributary producing a different type of sediment than the main stream can determine the characteristics of the deposit on the main floodplain in the vicinity of that tributary.

Occasionally the character of certain stratigraphic units differs widely from the type normally expected for a particular environment. For example, the occurrence of a very dark, highly coherent unit in a semi-arid environment near the sea coast. In known instances where these disparities occurred, this coherent unit was interpreted to have accumulated during a rise in sea level. Fine sediment deposition in an embayment followed by the growth of marsh vegetation was probably the origin of this stratigraphic unit.

Another example of seeming disparity is the presence of an old fan of gravelly deposits encroaching on a valley but lacking a watershed of a size and geology capable of furnishing these materials. Inspection of geologic maps indicates that the gravelly fan deposits accumulated prior to stream piracy which transferred most of the watershed and also the source of coarse sediment to another drainage system.

Stratigraphic Units Without Internal Continuity

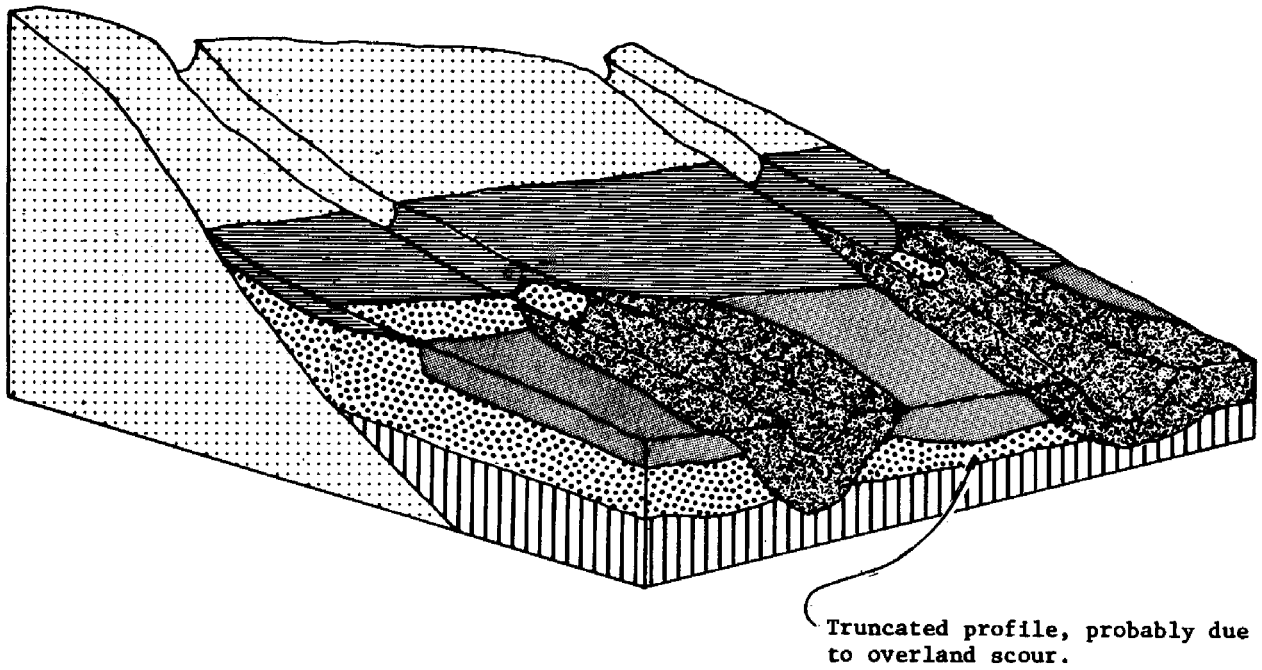
In certain geomorphic environments, the sediment deposited varies widely in texture within a short distance. If there is any unit identification, it is to the effect that there is a range in particle sizes from silt to gravel, all noncoherent, except for possibly some lens cementation. Such deposits are extensive in arid, semiarid and glaciated regions where in a network of ill-defined channels, the deposits were reworked during flood flows. Variability on a smaller scale may occur in humid climates where deposits accumulated during braided flows, but weathering and other factors contributing to development of coherent soil may be inhibited by such environmental factors as a high water table. In arid or semiarid climates, caliche by cementation can provide a resistant stratigraphic unit in an otherwise noncoherent alluvial deposit.

In the instances cited above, the absence of continuity, as well as the lack of coherence, should be established in the investigations stage preliminary to sampling. Then procedures to establish continuity can be modified.

Conducting the Site Investigation

Data Requirements and Observations Preliminary to Site Investigations

A longitudinal profile of the channel reaches to be improved, with survey stationing and profiles of the existing and proposed channel invert and top of bank is needed. A profile of the top of one bank is usually sufficient in alluvial valleys where the flood-plain surface is about the same on both sides of the channel. In addition, a flood-plain map is needed that shows the existing channel, the proposed channel, and the survey base line. The location of test sites and other pertinent geologic features are to be shown on the map.



Unit 1 - Recent deposits, principal stream

Unit 2 - Recent deposits, tributary

Unit 3 - Buried soil profile

Unit 4 - Buried, developed soil profile

Unit 5 - Terrace deposits

Unit 6 - Bedrock or residual soil

Figure 3-1 - STRATIGRAPHIC UNITS RELATED TO CHANNEL IMPROVEMENTS ALONG A STREAM AND ITS TRIBUTARIES (SIMPLIFIED)

Guidance on the erodibility of soils in a proposed channel improvement may be obtained by observation of existing channel performance. However, there should be a good general understanding of how flows will differ after project installation from what is characteristic under present conditions, that is, the change in grade, if any, the relative change in peak flows for frequent as well as infrequent events, and the relative change in duration of flows as well as frequency of bankfull flows. Observations on present stability are relevant if minor changes in flow characteristics are to be made. Such observations are substantially less relevant if major alterations in channelized flow are to result. These alterations could consist of on-site changes such as straightening and enlargement, or off-site changes such as upstream reservoirs that reduce the peak but substantially increase the duration of flows. For one example, an existing meandering channel is so small that overbank flooding may occur annually or more frequently. A proposed realigned and enlarged channel to be built to carry the ten percent event will cause a substantial increase in hydraulic stresses. The fact that existing stream banks are stable is not in itself supporting evidence that bank stability can be expected following construction. Then too, a major change in the rate of bed material load transport, if such load is present, can occur as a result of increased channel flow. While a general knowledge of changes in flow characteristics with project installed will suffice early in the field investigations, specific information will be needed in evaluating the erosion resistance of soils following sampling and laboratory analysis.

Bank sloughing or sliding may be a problem independent of changing discharge characteristics and needs to be identified. Fine sands, silts and some clays are susceptible to sloughing or slips under a range of moisture conditions. Sliding or sloughing may result from a rapid decline in water stage leaving a steep seepage gradient within the bank. The bank may slide or slough because of being undermined by erosion at the toe or by excavation below the water table. Underground flow from tributaries or springs, excessive rainfall, or over-irrigation can provide a source of ground-water flow which may result in bank sliding or sloughing. The location of any seeps or springs with reference to such problems should be identified.

Reconnaissance of Site for Channel Improvements

The initial field studies phase of site investigations should include inspection of the soils to and below the proposed channel invert level to interpret the geomorphology and to identify stratigraphic units. It is of primary importance to determine what stratigraphic units exist and their relationship one to another. This knowledge should be used to determine whether the same units occur at other randomly picked locations

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based on their appearance and lithology. Decisions on sampling sites, units to be sampled, and types of samples to be obtained must await their approximate delineation through the reach to be improved. Soil surveys along a proposed channel alignment can be useful in organizing the investigation and identifying stratigraphic units. It should be borne in mind that soil survey information is limited to a depth of about 5 feet and is frequently not reflective of stratigrahpic units at greater depth.

The inspection of the alluvial soil profile may be achieved by one or a combination of several means. Exposures along the banks of streams offer a frequently available means of study. This has the advantage of enabling observation of in-place characteristics as well as relating these characteristics to erosion from stream flow or bank stability from seepage forces. Bank stability may be due to protection by vegetation, or an irregular alignment which increases the roughness and thereby reduces the velocity or other reasons.

From the standpoint of bank stability from seepage forces, the existing channel could have sufficient vegetation, a protecting coating of fine sediment, or a ground-water level which has adapted to the channel depth over time. New excavation could cause problems which do not presently exist. Information gained from inspection of stream banks and bottom must be supplemented by borings or test pits when exposures along the banks do not provide sufficient information on the in-place characteristics of the deposits.

Exposed banks are often disturbed, desiccated or cracked and exhibit a different set of properties than the protected materials along the proposed cut and gradelines.

The place of observation along the channel is identified on the profile. Observation points in addition to those along the channel alignment will usually be required in order to interpret the stratigraphy and continuity of the valley deposits. The tentative upper and lower surfaces of stratigraphic units are determined and recorded on the profile. Each unit is to be numbered and geomorphically classified. For example, unit 1 is a recent sediment deposit overlying unit 2, a buried soil profile. Field notes and logs should describe the appearance and condition, including color, grain size, texture, structure, moisture, etc. of each unit in accordance with ASTM D-2488. Geomorphic terms are to be used in correlating between observation points. Identification as a stratigraphic unit is required in addition to the specific characteristics that can be described.

The tentative position of stratigraphic units within the profile and their extent along the channel alignment should form the basis for selecting soils investigation sites. The unit delineation must be informative enough to indicate the location of sites required to provide adequate data in the detailed investigation.

Determining the Intensity of Investigations

Four factors control the intensity of needed site investigations: (1) design requirements that may be independent or partially independent of the soil materials in the study reach; (2) hazard to life or property in the event of failure or partial failure; (3) complexity of the geomorphology in the site area; and (4) possible effects on quality of environment.

Concerning design requirements, for example, restrictions in availability of rights-of-way and capacity for each earth channel may dictate that the channel be a lined one, irrespective of the kind of materials in the reach involved. In this instance the investigations need only obtain the information that may affect construction such as classification of materials to invert grade, location of the water table and of seeps or springs. The presence of rock outcrops, layers of hard caliche, etc. should be carefully identified by location and description.

Where the water table is above proposed invert grade, its elevation should be identified in the logs of test holes or pits. If the water table fluctuates from season to season so that in one part of the year its elevation is below invert grade, the average time period this occurs and the dates of occurrence should be estimated. A high water table may interfere substantially with construction or affect the stability of an earth channel after excavation. If drop structures or other installations requiring data on bearing strength are being considered, investigations should be made in accord with recommendations in NEH, Section 8, Engineering Geology.

Channels located in urban or intensively developed agricultural areas differ widely in damage potential if a failure occurs than do channels in rural areas. In an urban area, the channel is usually designed to retain the one percent event with even minor erosion generally not tolerable. In both instances, the erosion characteristics of the bed and bank materials must be identified by procedures which include stratigraphic unit delineation and representative sampling and testing. Stratigraphic units must be more thoroughly delineated and variations within the units more closely identified by sampling and testing in intensively developed areas than in agricultural areas.

Complexity in the geomorphology of the site has a strong bearing on all phases of the investigation. Contrasting levels of complexity may include on the one hand a geomorphology as simple as one having a single stratigraphic unit uninterrupted by discontinuities, or maybe thin beds of sand or gravel that lack continuity and can be treated as one highly variable unit, to another that consists of a number of overlapping units frequently broken by discontinuities or disappearances from one reach to the next. In all instances, including those with the most complex array of stratigraphic units, an understanding is needed of the sedimentation processes and geologic history facilitates correlation and delineation of units, locations of discontinuities, etc.

The presence of dispersive clay soils along proposed channel alignment will have an effect on the intensity of investigation.

Dispersive clay soils often occur in lenses, spots and discontinuous strata. In order to tentatively identify dispersion problems, it will be necessary to check each stratigraphic unit at each test hole site for dispersive clays by means of the field "crumb" test performed on material at natural moisture. If field tests indicate possible dispersion problems, sufficient holes and samples should be established to delineate the problem areas or depths.

Location of Sites for Sampling and Logging

The location of pit or drill hole sites is based on the tentative delineation of stratigraphic units. There is a two-fold purpose in selection of these sites. One purpose is to obtain representative samples, the other is to "prove out" the tentatively identified stratigraphic units shown on the profile. If the logs at one test site fail to correlate with those at the site next upstream or downstream, then another site should be chosen between them, at least for the purpose of correcting the profile if not for additional sampling.

For long reaches where continuity of stratigraphic units has been established, it is best to sample widely from any one stratigraphic unit rather than concentrate in a small part of the total reach. This will improve the possibilities for discerning variations within the unit.

The usual location for test hole sites is on top of the bank near to but not necessarily immediately adjacent to the stream. The preliminary geomorphic determinations should indicate whether sites on both sides of the channel must be investigated.

In the process of investigation, the geologist should bear in mind that one part of a stream bank may be more subject to erosion than another due to differences in the hydraulic stresses that are exerted by the flow. These stresses are greatest on the bed, on the outside of bends, and along the toe of the banks. Greater emphasis in logging, sampling and testing should be used in searching for and identifying by thickness and location any easily erodible stratigraphic units from midbank to the invert level of the proposed channel. A bank is only as resistant as its weakest segment, particularly if this segment is low in the bank.

Determining the Sample Types to be Obtained

Prior to the detailed investigations, the geologist and engineer have made a tentative decision as to whether data from undisturbed and disturbed samples are to be obtained and the best means for obtaining them. Each stratigraphic unit observed in an undisturbed condition is evaluated before the decision is made as to the type of sampling to be done. It is a good rule to obtain undisturbed samples when in doubt as to whether the unit is characteristically composed of discrete particles or of aggregates that would resist erosion as a mass. The effects of the environment on sediment, once it has accumulated, is discussed in the section on the geomorphology of alluvial deposits. The in-place behavior of materials that resist erosion as a coherent mass cannot be determined by testing disturbed samples. Hence, undisturbed sample analysis is critically important if the in-place deposits differ in erodibility from that of the individual particles. The Unified Soil Classification System and similar systems do not identify erosion characteristics of an undisturbed coherent soil mass except that soils with a high plasticity index (P.I.) are usually more resistant to erosion than noncoherent soils. Some undisturbed soils with a low P.I. are about as resistant to erosion as those with high P.I., and under certain conditions, material with a high P.I. can be as erodible as one with a low P.I. such as soils that are highly dispersive. Another such condition exists when the soil mass is weakened by a fine network of fractures such as that which may be caused by expansive clays. The fractures may or may not be filled with dissimilar material. The above would have to be determined by appropriate tests and observations.

Careful selection of investigation tools and procedures for investigations are necessary to obtain samples and logs of the natural, undisturbed in-place materials. Augers, excavation equipment and many laboratory procedures disturb the soils and provide data which result in erroneous interpretations of in-place properties.

Selection of Equipment for Logging and Sampling

The frequently limited depth required in field investigations for channel improvements and the advantages afforded by in-place examination of the alluvial profile indicates that at least a framework of pit excavations is desirable. Safety precautions must be rigidly maintained. The backhoe is the preferred equipment for such excavations. Once in-place profiles can be examined and sampled above water tables, the pits can be supplemented by drill holes below water tables. Limitations of pits include the possibilities that the depth of sampling required exceeds the capabilities of available equipment, that a high water table would restrict or prevent investigations below that level, and that access is sometimes limited for physical reasons or property owner objections. The advantages of drilling equipment are no depth or ground-water limitations, in-place testing with less site disturbance, and greater safety. For guidance in maintaining safe working conditions, refer to the safety manual for geologic investigations. Light weight drilling equipment mounted on track vehicles may provide a means of collecting disturbed and undisturbed samples from areas that are not accessible to heavy drill rigs.

Sampling equipment is described in NEH, Section 8, Chapter 2. In instances where drilling equipment is used, push tube sampling of relatively soft fine-grained soils or Denison core barrel sampling of hard fine-grained soils are recommended. Special equipment has been devised for undisturbed sampling of soils in investigations for channel improvements where pits or stream banks are the sampling sites. Figure 3-2 is a drawing of the sampling tool which is designed for placement on a shelf dug in the side or bottom of a pit or bank. It is built to obtain more than one sample from the same setup. The thin-walled brass tubes used should be at least two inches and preferably larger in diameter by five or six inches in length. This size is usually sufficient for shear strength tests. Duplicates from the same stratum must be obtained in the event one is damaged in shipping or handling. Following tests in an undisturbed condition, the same material is used for classification, or an additional sample of the disturbed soil can be obtained. The sample or samples are judged to be undisturbed if the soil column on the inside of the tube and on the outside are both level with the upper edge. A tendency for compaction to occur in a tough, dry soil because of the frictional resistance can be reduced by pre-wetting the inside of the tube with water or a small amount of a light lubricant. On completion of sampling, the tubes are sealed. It is essential that the undisturbed samples do not become desiccated.

The cutting of cubes or other block shapes for laboratory testing is another means of obtaining undisturbed samples. It may, in fact, be necessary to obtain such samples if other equipment compacts or otherwise

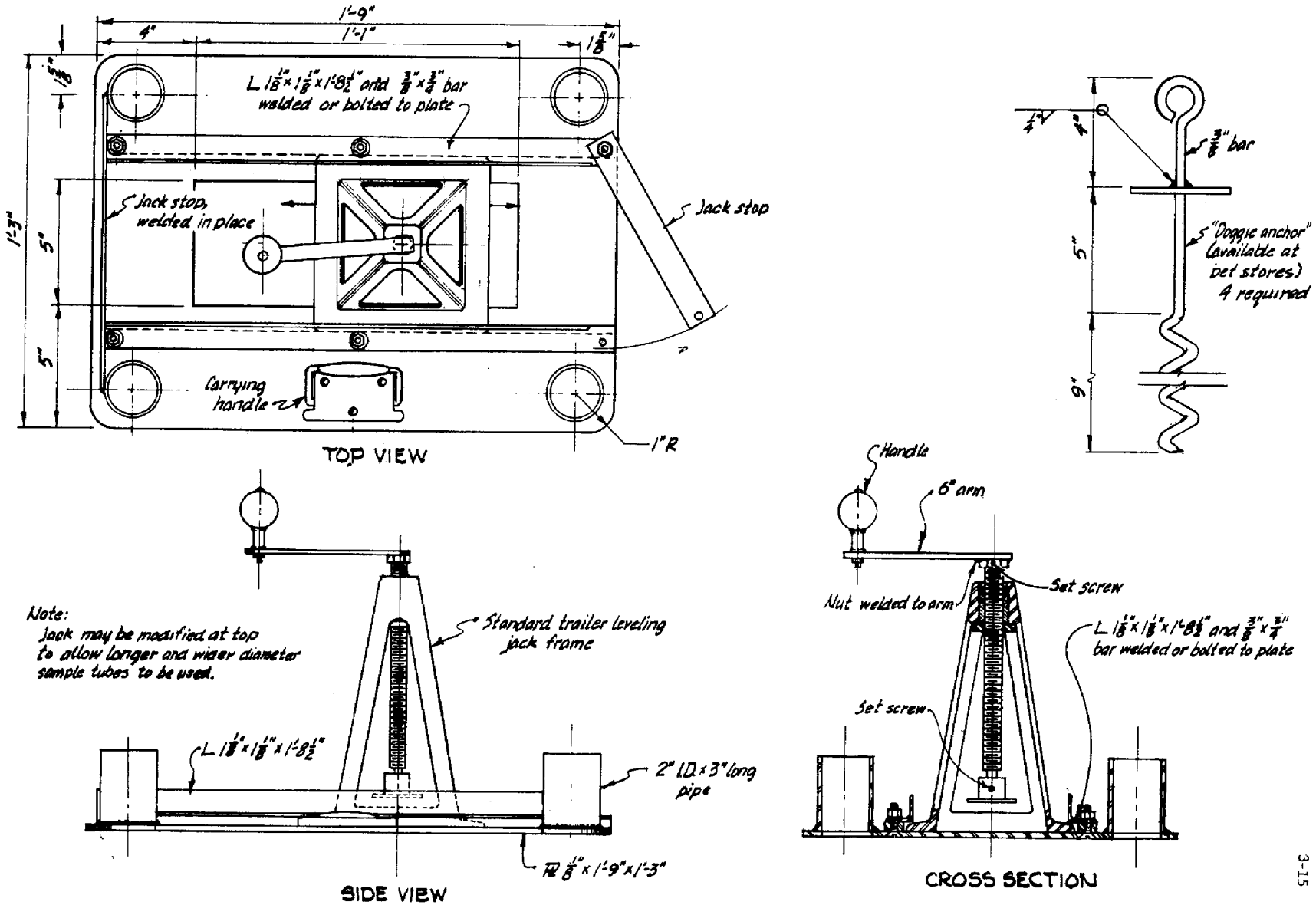

Fig 3-2 - UNDISTURBED-SAMPLE CYLINDER PRESS

disturbs the soil. While this sampling procedure is usually much more time consuming than push tube methods, it generally results in a much better sample. The presence of coarse sand or gravel in the soil can render the push tube or drill hole sampling equipment unsuitable for use in obtaining undisturbed samples. Exposures in stream banks or pits sometimes exhibit pockets of fine-grained matrix free of the coarse particles. These pockets frequently contain the same material and the same erosion resistance properties as the matrix in an intimate mixture of coarse and fine particles. Sampling and testing of this fine-grained matrix can provide information on the erosion resistance of the mass. Careful evaluation is necessary to insure the applicability of such data.

Channel improvements may include the construction of dikes or embankments to protect adjacent lands from overflow or to increase the resistance of natural materials by compaction. The sample needs for these construction purposes as well as for foundations for all structures should be discussed with the engineer prior to the detailed site investigations. The amounts of disturbed samples needed for various tests and sizes of material are described in Tables 3-3 and 3-4. Packaging and shipping instructions are given in NEH, Section 8, Chapter 3, pages 10 and 11.

Test Hole Logs

Logs of test holes should contain necessary information to ensure that the stratigraphic units are identified and their characteristics, depth of occurrence in the hole and thickness are recorded. If a stratigraphic unit identified in the adjacent test hole fails to appear in this one, this information should be noted. Figure 3-3 is a suggested field worksheet for logging and sampling at test hole sites.

Generally bedrock will not be drilled during investigations. Descriptions of bedrock characteristics are to be provided for the engineer's use. These descriptions must be thorough, complete and accurate.

Determination of the Availability of Movable Bed Material

The availability of movable bed material, specifically sand and gravel, must be determined in order to evaluate its impact on the stability of the improved channel. The most apparent source of supply is deposits that may have accumulated in the bed of the stream within and above the reach to be improved. Whether or not the bed-material supply is a threat to the operation or reasonable maintenance of the improved

channel depends on several factors. These include the amount and ease of transport of the material and the difference in hydraulic characteristics between the reach to be improved and the reach upstream that contains the bed material. The relationship between bed material availability and channel stability is discussed in NEH, Section 3, Chapter 4, Transportation of Sediment by Water, pages 4-36 and 4-37.

The channel investigation should include an estimate of the volume of bed material available in the bed of the stream and where the deposit is located with reference to the proposed improvement. If the bottom of the deposit cannot be reached, this should be indicated in the notes. Representative samples of the bed material are to be obtained. The amount required for various gradations of material is given in Table 3-2, NEH, Section 8, Chapter 3. A sample of the surface armor should be obtained, if present, as well as a sample of the underlying finer accumulation.

For analysis of stability, the geologist is expected to define whether discharges critical for stability should be defined as "clear water" or sediment laden flows. In most instances, the wash load will not be of sufficient concentration to classify the flows as other than "clear water". An examination of suspended load records on a regional basis will provide good clues as to the likelihood of significant concentrations. A knowledge of the watershed will also serve to indicate the extent of critical erosion. Reservoirs will reduce concentrations to relatively low levels.

The influence of bed material on the stability of channels is discussed in NEH, Section 3, Chapter 4, pages 4-25 to 4-28.

Where bedrock is to be removed from the channel, the potential effects on stream banks and bed both upstream and downstream must be considered. Where rock is to be removed from a channel section, its disposal must be planned. Alternative disposal methods may include wasting in a preselected area, use in channel construction (riprap, filters), salvage, etc. Local highway agencies are often valuable sources of information concerning rock quality and ease of removal.

Site Investigation Reports

Completion of the Stratigraphic-Unit Profiles

The first step in preparation of site investigation reports is to complete the longitudinal profile and description of stratigraphic units in the channel reach to be improved. As stated on page 3-11, this is

Sheet ____ of ____
Date _____

WORK SHEET
FOR
LOGGING AND SAMPLING DATA-GEOLOGIC INVESTIGATIONS FOR CHANNEL IMPROVEMENT

Watershed *Cottonwood* Stream *Cottonwood Creek* County *Jones* State *Any*

Site location by survey stationing *65+60* Investigation site number *8* Method of investigation *backhoe*

Log of Unit

Depth (ft) From	To	
0	*3*	STRATIGRAPHIC UNIT NO. *1*
		Description: *A recent deposit of dry, firm, homogeneous, light brown silt (ML), low in organic*
		matter. The deposit breaks down easily into discrete particles and is identified in the field
		as noncoherent. This is the same stratigraphic unit as at investigation site 7, from 0-3.5 ft.
3.0	*6.5*	STRATIGRAPHIC UNIT NO. *3*
		Description: *A dark grey, moist, firm, homogeneous silty clay (CL) relatively free of jointing,*
		roots or other factors that may affect erosion. The unit is identified in the field as coherent.
6.5	*8.0*	*Contains yellow mottling indicative of poor drainage conditions. This stratigraphic unit*
		(3.0 to 8.0 ft.) was identified between 3.5 and 7.5 ft. at site 7. Water table at 7.0 ft.
		STRATIGRAPHIC UNIT NO. ____
		Description:

Figure 3-3

to be developed in tentative form during the preliminary investigation of the site. With the benefit of the additional information obtained during logging and sampling, the original profile is to be refined to include more precise information on the extent, thickness and position in the profile of stratigraphic units. The survey stationing, bank line, and proposed invert level are to be plotted, as are the locations and logs of pits or drill holes. The upper and lower elevations of stratigraphic units will be shown at the appropriate station site. When the correlation of units between pit or drill hole sites has been determined, correlation lines are drawn as shown on Figure 3-4. In this example, it is implied that correlation between test hole sites has been facilitated by exposures in stream banks. Additional test holes would be required where such exposures are not available.

The "U" on the right of the profile test hole location indicates that an undisturbed sample was obtained. A disturbed sample may or may not be obtained at the same site depending upon whether enough material is available in the undisturbed sample for classification. The investigators have identified this stratigraphic unit as consisting of soil which would resist erosion as a mass rather than as discrete particles. The "D" indicates that a disturbed sample has been obtained. The investigators have made a field determination that the unit is non-coherent and that erosion characteristics are dependent on the individual particle characteristics. The stratigraphic unit delineations on Figure 3-4 are not dependent on the indicated investigation sites alone but include determinations from observations along stream banks and from hand borings. When the test data have been obtained, results pertinent to the erosion or stability characteristics may be shown or listed on attached report sheets with the data clearly identified with the appropriate units. Ground water, if encountered, should be shown at each of the investigation test hole locations.

The longitudinal profile with stratigraphic unit interpretations is primarily for purposes of stability evaluation, and without it the designer does not know that interpretations of soil characteristics have been made between investigation sites.

The logs of test pits or drill holes and the plan map showing the location of these investigation sites should accompany the profiles as supporting and supplemental information and a copy will be placed in the design folio.

The geologic profile and plan map should show the locations and the extent of outcropping bedrock. They should also show its verified or estimated depth below the present streambed and its relation to the proposed channel invert. Existing erosion or deposition features associated with the outcrop (either up or down stream) should also be shown.

Analysis of Channel Stability

With the longitudinal profiles, logs and laboratory test data available, the geologist and engineer are in a position to make an analysis of the stability of the proposed channel improvement. In addition, information is needed on the design discharge if bed-material load is not involved as a problem, and the hydrographs for design as well as more frequent discharges if bed-material load has been determined as a problem. Chapter 6 of this Technical Release or designated supplements are to be used for determining the stability of channels that are not affected by bed material transport. NEH, Section 3, Chapter 4, is to be used for the analysis of bed-material transport that may affect channel stability.

Report Outline and Documentation

The longitudinal profile, the plan view, logs, field and laboratory test results, and stability analysis are to form the documentation for a brief report based upon the following outline. Geologists and engineers are both involved in an analysis of these problems. They should work closely together in the determinations and report preparation.

A. Conclusions and Recommendations

B. Description of the geomorphology of the channel improvement area

   Basis for stratigraphic unit delineation with reference to longitudinal profiles or reasons for lack of stratigraphic unit delineation.

C. Copies of logs and test data

D. Criteria used to establish stability

   1. Condition of flow to be used in stability analysis: clear or sediment-laden water. Basis for criteria used.

   2. Bed material evaluation procedure used among those recommended in NEH, Section 3, Chapter 4.

E. Stability analysis

   1. Stability under proposed as-built conditions

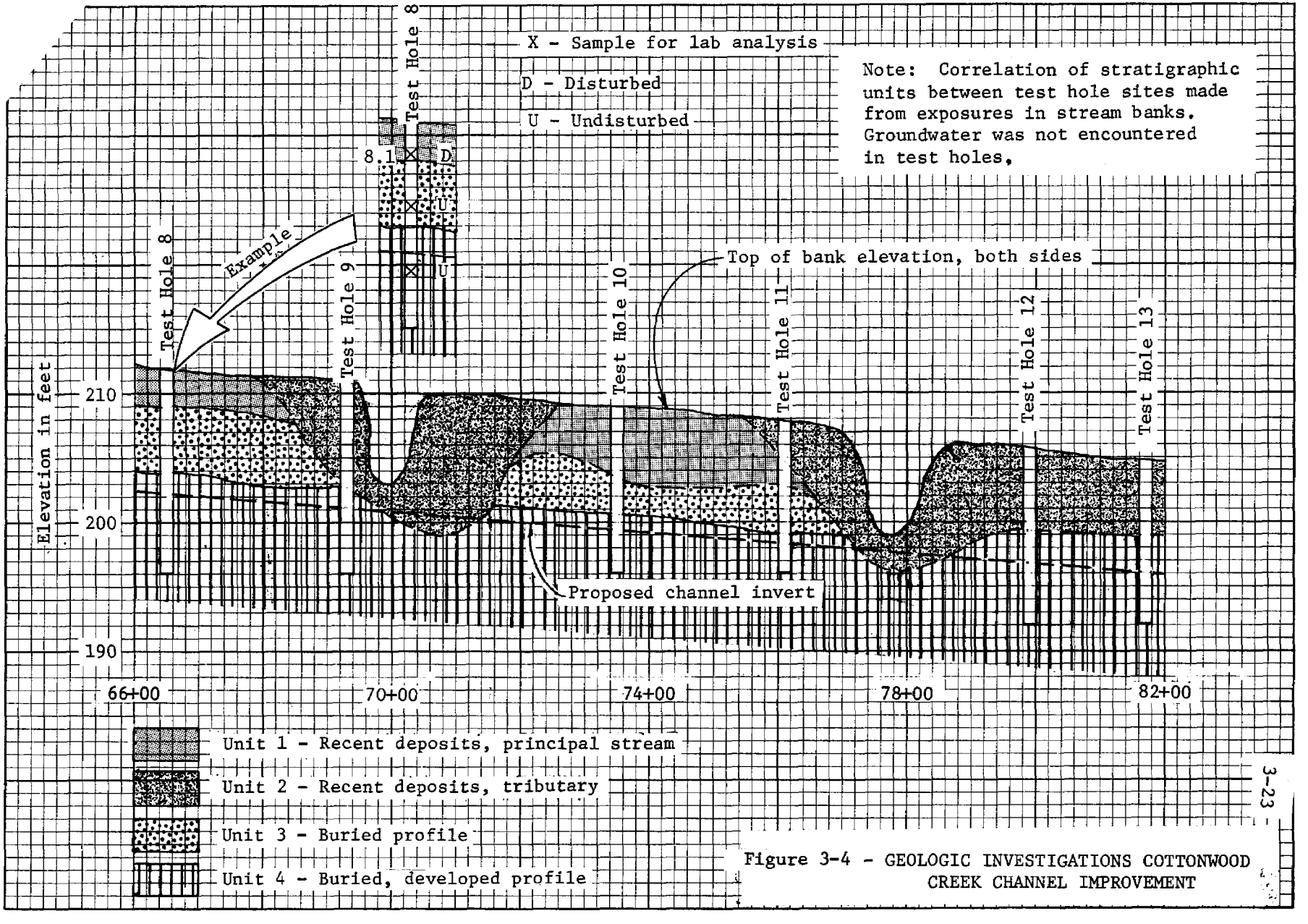

Figure 3-4 - GEOLOGIC INVESTIGATIONS COTTONWOOD CREEK CHANNEL IMPROVEMENT

a. Location of projected unstable reaches, if unprotected; bed and/or banks by stationing.

(1) Elevation of unit or units with reference to invert level.

(2) Cause of predicted conditions, such as tractive stress or velocity in excess of allowable or internal seepage forces.

b. Discuss unique conditions not fitting into the assumptions made in Technical Release 25.

2. Bed material sediment problems if these influence stability of proposed channel improvements.

3. Effect of program installations, such as floodwater, floodwater detention or multipurpose structures, debris basins and grade control structures on downstream reaches.

Evaluation in the Construction Stage

Unexpected discontinuities or unaccounted variations in soil characteristics affecting stability may be revealed during excavations for improvements. It should be standard procedure for the geologist, design engineer and soils engineer to examine the channel during or immediately after excavation. With the profiles at hand, the geologist should make any pertinent adjustments in unit delineation and interpretations over those prepared during the design investigations. Any significant alterations pertaining to stability should be immediately called to the attention of the project and construction engineers.

Testing

Purposes of Testing

The purposes of testing soils from channel projects are fourfold:

1. To develop design values and correlation between properties of fine-grained soils and field evaluation and classification of erosional activity in constructed or natural channels now in use.

2. To provide values for use in the design of stable channels in gravels and coarse sands from the standpoint of erosional activity.

3. To provide values for the design of channel banks from the standpoint of shear strength and sliding.

4. To evaluate earth loads on structural members.

Test Procedures

Tests may be conducted in the field and/or in the laboratory. Testing procedures should conform to standards of the American Society for Testing Materials (ASTM) or American Association of State Highway Officials (AASHO).

Types of Tests

Two categories of tests are presented---primary tests and supplementary tests. Primary tests are those that provide values that may be used directly (1) to evaluate erosion by either the tractive force, limiting velocity, or tractive power procedures discussed in Chapter 6, or (2) to analyze bank slope stability problems discussed in Chapter 6. Supplementary tests are those that will provide supporting or indicator information that may be of assistance in evaluating erosional resistance and bank stability. These latter tests may be made at local option; results from these tests are not needed to use the design criteria set forth in this Guide, but they may provide valuable clues to the designer.

Index and engineering properties tests are listed in Table 3-1 for erosional analyses and in Table 3-2 for bank stability analyses. Field tests that may be used where conditions warrant are discussed in NEH, Section 8, Chapter 1.

Classification. - - Soils should be fully described and classified according to the Unified Soil Classification System (ASTM D-2488).

Particle size distribution. - - A mechanical analysis should be made on selected samples representing soils that are or may be exposed to erosional forces in channel bottoms and banks to determine the distribution of particle sizes. The coarse fraction should be analyzed using the following U. S. Standard Sieves as the minimum number of size separations: No. 200, 140, 40, 20, 10, 4 and 3/8", 3/4", 1 1/2", and 3". Other size separations may be introduced if considered necessary. The fine fraction should be analyzed using the standard hydrometer tests. Results should be reported on the basis of total material.

Soil consistency tests. - - The liquid limit, plastic limit, and plasticity index should be determined for all soils, except clean sands and gravels, in order to differentiate between materials of appreciable plasticity and slightly plastic or non-plastic materials.

Table 3-1

Erosional Analyses

A. Index Tests

1. Classification 1/

   a. Mechanical analysis

   b. Liquid limit

   c. Plastic limit

   Plasticity index

2. Dispersion

   a. Field tests to identify possible problem areas

   b. Lab tests for soils with more than 15% >.005 mm and for a P.I. >8

3. Soluble salts

4. Natural dry unit weight

B. Engineering Properties Tests 2/

1. Permeability

2. Shear strength

   a. Unconfined compression 3/

   b. Vane shear

1/ For tractive force, limiting velocity or tractive power procedures.

2/ These tests may be made at local option. Results will provide supporting information which may assist in evaluating erosional stability.

3/ For tractive power procedure only.

Table 3-2

Bank Slope Stability Analyses

A. Index Tests

1. Classification

   a. Mechanical analysis

   b. Liquid limit

   c. Plastic limit

   Plasticity index

2. Specific gravity

   a. Particles smaller than No. 4 sieve

   b. Particles larger than No. 4 sieve

3. Natural dry unit weight and natural moisture content

4. Compaction

B. Engineering Properties Tests

1. Shear

   a. Unconfined Compression

   b. Direct

   c. Triaxial

   d. Vane

2. Permeability

C. Other Tests 1/

1. Dispersion

2. Soluble salts

3. Linear shrinkage

1/ These tests may be made at local option. Results will provide supporting information which may assist in evaluating bank stability.

Specific gravity. - - When soils are composed of particles having 95 percent or more (by dry weight) smaller than the No. 4 sieve (4.76 mm.) and when compaction or shear tests are required, specific gravity tests should be performed on the minus No. 4 fraction.

When soils contain five percent or more (by dry weight) of hard particles larger than the No. 4 sieve and when compaction or shear tests are required, absorption and bulk specific gravity (saturated, surface dry) tests should be performed on the coarse materials as well as on the fraction smaller than the No. 4 sieve.

Results of specific gravity tests are needed for computation of porosity, void ratio, and associated air-water-solid relationships; also results are needed for adjustment of moisture-density relationships for compacted materials having five percent or more larger than the No. 4 sieve (by dry weight).

Strength considerations. - - Some measure of inter-particle attraction may prove helpful in evaluating erosional stability of channels on the basis of the tractive force theory. Although shear strength obtained by various tests has been used by some investigators, it may not be a true indicator of inter-particle attraction.

Strength values for use in slope stability analyses of banks should be governed by site conditions and the method of analysis to be used. Therefore, some latitude is needed by the engineer in the selection of appropriate tests to be performed at a given site for determination of shear strength parameters.

1. Unconfined compression test. This test is commonly called a q_u test and may be performed on saturated, undisturbed specimens. The test may be made for two purposes: (1) to obtain unconfined compressive strength values for use in estimating erosional stability (by the tractive power method) of those soils in which individual particles cohere under natural field conditions, and (2) to obtain values of cohesion (no load strength) for use in analyzing the stability of banks from a strength standpoint. In the latter case, the test is generally applicable to highly plastic soils, but it may be used for other soils where the in-place strength will simulate ultimate field conditions.

   The q_u test should not be performed on those soils in which natural planes of weakness are an inherent characteristic of the soil, as exemplified by stiff, fissured clay or soils having blocky or columnar structural development.

The effects of weathering should be considered in using q_u test results from samples taken at a depth which will later be unloaded and exposed to the atmosphere -- both in an erosional evaluation and in a bank stability analysis. This consideration will be a matter of judgment and local experience.

2. Direct shear tests. Drained, direct shear tests are recommended for determining the strength parameters for use in the analysis of banks against sliding when the effect of pore water pressure is included as a separate item. Cohesive and non-cohesive soils may be tested in this manner.

3. Triaxial shear tests. Consolidated, undrained, triaxial shear tests may be used, but will generally not be required, for strength parameters unless fractured or structurally cleaved soils are involved.

   Consolidated, undrained, triaxial tests may be made without pore pressure measurements when pore pressures which are anticipated in the field can be simulated during testing.

   When triaxial shear tests are used instead of direct shear tests and when pore pressures are considered separately in the stability analysis, it will be necessary to perform consolidated, drained tests or to perform consolidated, undrained tests with pore pressure measurements.

4. Vane shear tests. The vane shear test is a field test which is well adapted to obtaining in-place shear strength of saturated, plastic soils that do not contain gravel. Shear strength values obtained by vane shear tests may be used for bank stability analyses. This type of test is especially applicable when soils are sensitive and when it is difficult to secure and transport undisturbed samples. Vane tests should include results on remolded strength as well as peak strength.

Natural dry unit weight and moisture content. - - The natural dry unit weight and natural moisture content should be recorded for all undisturbed samples. These determinations can be made in conjunction with shear test operations. Proper interpretations of shear test results are dependent upon data on variations in natural dry unit weight and moisture content.

The erosional resistance of many soils, particularly those which are weakly coherent, increases as dry unit weight (density) increases. The natural (in-place) dry unit weight of soils exposed in the channel will provide valuable guidance in the review and evaluation of the performance of existing channels functioning under similar conditions to a planned channel.

Compaction (moisture-density relationship). - - The moisture-density relationship of soils (for a given compactive effort) should be known before shear testing of disturbed (borrow) materials can be instigated or before field control of moisture and density can be maintained. Compaction and field control may be necessary either (1) to assure adequate density and shear strength in levee or dike fills or (2) to increase the erosional resistance of low density, weakly coherent soils which form the bottoms and sides of channels.

Compaction tests should be performed on disturbed samples of selected representative soils on which shear tests are required for design and/ or field control of moisture and density are required during construction operations. Compaction tests are also used to evaluate collapse potential of soils. Most highly collapsible soils are also generally highly erosive.

Permeability. - - In those cases where seepage from channel banks may be a problem, the permeability of natural materials may be required to construct flow nets and to analyze seepage forces. Permeability tests should be performed on undisturbed materials which are representative of soils in the problem area.

Field permeability tests will usually be the most effective means of determining permeability rates (a) in non-coherent soils which are difficult to sample representatively, handle and transport to the laboratory and (b) in lenticular and highly stratified soils.

Methods of making field permeability tests are described in NEH, Section 8[5/], Chapter 2; Section 16[2/], Chapter 2; Special Publication SP-SW-0262 of the American Society of Agricultural Engineers[7/]; and the Earth Manual, First Edition, U. S. Bureau of Reclamation[8/].

A permeability test may also be performed as a secondary and companion test to the unconfined compression test when the purpose of the latter is to provide values for use in an erosional analyses of coherent or cemented soils[9/] (see Chapter 6). The permeability test described hereafter is not necessary when the unconfined compression test is made for the purpose of providing values for a bank stability analysis.

A permeability test, as a companion test to the unconfined compression test, should be performed in a falling head permeameter on undisturbed specimens having a ratio of height to diameter equal to approximately two. As soon as consistent head readings are obtained, the test should be discontinued; the specimen should be removed from the permeameter immediately and subjected to an unconfined compression test to determine the coherence of the saturated specimen.

Dispersion. - - The terms dispersive clay or dispersion refer to the stability of soil aggregates when exposed to water. Dispersive soils are highly erosive. When dispersed soils are exposed to weathering, they are easily distinguished by field observation. They tend to melt down like sugar, develop land forms that resemble typical "badland" relief (macro or micro) and form "slick spots" that are generally bare of vegetation.

There are several tests that identify dispersive soils.

1. The field "crumb" test identifies dispersive soils by the formation of a colloidal cloud around a small clod of moist soil dropped into distilled water or very dilute sodium hydroxide.

2. The laboratory dispersion test identifies most dispersive soils by comparing the amount of 0.005 mm. material in a suspension without deflocculating chemicals to the total amount of 0.005 mm. material determined by mechanical analysis.

3. The field dispersion test is an abbreviated version of the laboratory dispersion test.

4. Chemical tests identify dispersive soils by comparing the amount of soluble sodium and the total salt content in the saturation extract or pore fluid of the soil.

None of these tests <u>always</u> correlates with the others or with field performance. It is sometimes necessary to run all tests in order to properly evaluate the adverse effects of dispersive soils.

Whenever dispersion is suspected in an area, laboratory tests should be run to verify and evaluate the problem.

Soluble salts. - - Soils that contain considerable soluble salts, particularly gypsum, are highly erodible and may slough badly. It appears that the recrystallization of gypsum and other salts during sedimentation results in an open, honeycombed soil structure that may be compared to loessial materials. These soils have sufficient stability to stand on vertical banks as long as they are dry, but they slough and erode rapidly when exposed to moisture. Sodium salts have a dispersive effect on soils and generally increase the erodibility of soils. Although high soluble salt content in soils tend to keep the soil in a flocculated or aggregated (erosion resistant) state, these salts would generally be removed or leached back into channel

banks during high flows, possibly leaving a deflocculated, dispersed, erodible surface layer. In arid and semi-arid regions, the soluble salt content may be determined for representative samples, even though results of this test cannot be used quantitatively at present.

Linear shrinkage. - - Coherent soils which have linear shrinkage factors in the range of ten percent or more are generally subject to considerable density and strength changes with variations in moisture content. Results from linear shrinkage tests on coherent soils serve as indicators of potential problems related to bank stability.

Field Sample and Test Specimen Requirements

The quantity of materials needed for testing depends primarily on such factors as (1) number, type and purpose of tests to be performed, (2) particle size characteristics of the material, and (3) homogeneity of the natural materials, particularly when undisturbed specimens are to be tested. The minimum number of test specimens for one test is given below:

Unconfined compression	1
Direct shear	3
Triaxial shear	3
Permeability	1

It is suggested that undisturbed samples be large enough so that an additional test specimen will be available as a spare. In the case of small diameter tube samples, duplicate sampling should be obtained.

Sample sizes and specimen requirements for testing of soils from channel projects are given in Table 3-3 (Disturbed Samples) and 3-4 (Undisturbed Samples). The specimen sizes given in Table 3-4 are those which are actually required for testing; these sizes do not include allowances for trimming.

Table 3-3

Minimum Size of Disturbed Samples

Required for Testing Purposes

Test	Maximum Size to be Included in Samples	Gradation Characteristics of Natural Material		
		90-100% Passing #4 Sieve	50-90% Passing #4 Sieve	0-50% Passing #4 Sieve
Mechanical analysis, liquid limit, plastic limit, specific gravity, dispersion, soluble salts, linear shrinkage	3 in.	4 lb.	10 lb. 1/	40 lb. 1/
Compaction and shear	3 in.	25 lb.	40 lb. natural material	2/

1/ Provide estimates of the percent of oversized material (plus 3 inch size) excluded from samples shipped to laboratory.

2/ Forty pounds of these materials will be adequate for all applicable tests.

Table 3-4

Minimum Specimen Requirements (After Trimming) for Testing Undisturbed Samples

Maximum Particle Size	Test 1/	Size of Specimen
No. 4 sieve (4.76 mm.) 2/	Unconfined compression	1.4" dia. x 3" long
	Direct shear	2.0" x 2.0" x 1" thick
	Triaxial shear	1.4" dia. x 3" long
	Permeability	2" dia.
1/2 inch 2/	Unconfined compression	2.8" dia. x 6.0" long
	Triaxial shear	2.8" dia. x 6.0" long
	Permeability	4.0" dia.
1 inch 2/	Triaxial shear	4.0" dia. x 8.0" long
	Permeability	6.0" dia.
1 1/2 inches	Triaxial shear	6.0" dia. x 12.0" long
	Permeability	6.0" dia.

1/ Table 3-3 gives the sizes of materials which are required for mechanical analysis, liquid limit, plastic limit, specific gravity, dispersion, soluble salts and linear shrinkage. If undisturbed samples are not large enough to meet these requirements, disturbed samples of the sizes indicated should be taken at the same elevation from an adjacent hole to represent the undisturbed materials.

2/ If materials have scattered particles larger than the sizes shown, it may still be possible to trim these test specimens without going to a larger specimen size.

Appendix to Chapter 3

OUTLINE TO PLAN SITE INVESTIGATIONS AND PREPARE REPORTS FOR CHANNEL IMPROVEMENTS

I. Introduction

A. Investigational considerations

1. Channel improvements may be many miles in length.
2. Depths to channel bottom are shallow, usually less than 20 feet.
3. Correlation is necessary to predict presence of boundary materials between holes to avoid inadequate design.
4. An understanding of the geomorphology of alluvial deposits and the identification of stratigraphic units at each site are necessary for correlation of deposits with similar erodibility.

B. Definition of a stratigraphic unit

A stratigraphic unit is defined in this instance as an identifiable stratum of alluvium or other soil material whose susceptibility to erosion is a reflection of the original materials, mode of accumulation and the changes that have occurred since deposition or soil formation.

II. Geomorphology of deposits

A. Significance of the stratigraphic unit and factors that affect the characteristics and erodibility or resistance of stratigraphic units.

1. The characteristics of the original deposits.
2. Age of the deposit.
3. The environment since deposition.

B. Identification of stratigraphic units

1. Primary identifying characteristics are color, particle size, particle size distribution, plasticity, cementation, density, dispersion, structure, and thickness.
2. A stratigraphic unit occupies the same position relative to other beds in a sequence.
3. A stratigraphic unit usually occupies the same position across the valley as it does near the present channel.

C. Geomorphic history determines the erosion resistance of stratigraphic units

1. The particle size distribution and texture of the deposit are the primary determinants of erosion resistance initially.
2. Changes in the character of the material occur with time such as:
   a. The movement downward of fine particles.
   b. Weathering.
   c. Consolidation by overburden, alternate wetting and drying, desiccation, etc.
   d. Cementation.
   e. The accumulation of humus.
3. The geomorphic history results in a characteristic erosion resistance for each stratigraphic unit.
4. The unit may consist of individual particles without connecting bonds.

a. A grain size (as D_{50}, D_{65}, D_{75}) is the quantitative identifier of erosion resistance.

b. Disturbance does not affect the erosion resistance.

5. The unit may consist of particles that cohere or that do have a connecting bond.

a. The degree of coherence is strongly affected by the geomorphic history.

b. Disturbance destroys some of the affects of geomorphic history on the unit's erosion resistance.

D. Discontinuities in stratigraphic units

1. The stratigraphic unit may completely disappear from one test hole site to another. This is identified as a discontinuity.

2. The stratigraphic unit may be interrupted by erosion and replaced by different materials. This is also identified as a discontinuity.

3. The stratigraphic unit may locally thin or thicken. This is a variation within a continuous unit, <u>not</u> a discontinuity.

E. Stratigraphic units without internal continuity

1. Some stratigraphic units vary widely in grain size and other characteristics within a short distance.

2. Such variations cannot be correlated between one test hole and another.

3. Such units are identified as lacking internal continuity.

III. Data requirements and observations preliminary to site investigation

A. Data requirements prior to investigations

1. Longitudinal profile of channel reaches to be improved and includes:

   Survey stationing and profiles of existing and proposed channel invert (bottom) and top of bank

2. Flood plain map to include:

   a. Existing channel.

   b. Proposed channel.

   c. Survey base line.

3. When to evaluate stability of existing channels prior to field investigations.

   a. Capacity, slope, frequency at bank full, and other hydraulic measurements are similar to proposed improvement.

   b. Channel boundary soils are exposed to hydraulic forces.

   c. Stability of channel under specified flood discharges and frequencies can be identified.

   d. Water table fluctuations affect bank stability.

B. Reconnaissance of site for channel modifications

1. Inspect soils to and below proposed channel invert level. Study exposures along stream banks and in stream bed. Supplement by test pits or borings where necessary.

2. Interpret geomorphology, tentatively identify stratigraphic units. Geologic, soil survey and topographic maps are very useful for study preliminary to the investigation.

3. Identify places of observation on longitudinal profile.

4. Prepare tentative stratigraphic unit delineation on profile from observations made above.

IV. Site investigations

A. Determine the nature and intensity of site investigations. Factors that affect the intensity of site investigations:

1. Site limitations may require channel lining independent of soil characteristics. Investigations limited to determination of site preparation and construction problems.

2. A potential high hazard to life and property can require a closer spacing of test holes, more intensive soil sampling and testing than a low hazard site.

3. A complex geomorphology will require a closer spacing of test holes, more sampling and testing than a site with few stratigraphic units that are continuous.

4. Environmental considerations.

B. Location of sites for logging and sampling

1. Evaluate information obtained under Item A above.

2. Determine the sample types to be obtained

a. For any specific reach, consider whether coherent soils will be exposed at the toe and/or lower bank.

b. If the answer under 2a is affirmative, plan undisturbed soil sampling of this and overlying coherent stratigraphic units.

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c. If the answer under 2a is negative, plan disturbed soil sampling of this and overlying stratigraphic units, whatever the characteristics of the latter.

C. Select equipment for logging and sampling

1. Choose backhoe or dragline for site investigations where possible and if water table is below invert.
2. Choose drilling equipment if depth is greater than practical for excavation equipment, because of high water table, or if in-place observations are unnecessary or impossible.
3. Select appropriate equipment and containers for undisturbed samples.

D. Data requirements at test holes

1. Log test holes (A suggested worksheet is included as Figure 3-3 of Chapter 3 (revised) TR-25) to depths of at least three feet below invert.
   a. Log test holes by stratigraphic units.
   b. Log appearance and condition in accord with ASTM D-2488 (Unified Soil Classification System).
2. Identify elevation of water table if encountered.
3. Record results of field tests.
4. Obtain representative samples of stratigraphic units. Sampling in undisturbed or disturbed state depends on determinations under IV B 2 above.

5. Supplement to site investigations plan.

   A break in continuity of stratigraphic units, changes in dispersion test results or other significant changes in soil characteristics between test holes requires an additional hole or holes to delineate changes.

F. Determine availability of bed material

1. Sand or gravel can aggrade an improved channel.
2. The hazard to the improved channel depends on whether expected flows will:
   a. Exceed the allowable tractive force for the characteristic grain sizes.
   b. The supply of bed material is sufficient to cause aggradation problems.
3. Measure or estimate depth of bed material in reach to be improved and in channel upstream. Note if bottom cannot be reached.
4. Obtain representative bed-material samples for determination of size distribution.

G. Define "clear water" or "sediment load" flow condition where required.

1. Evaluation of channel stability (allowable velocity or critical tractive force) may depend on how flow is classified.

2. For appropriate classification consider:

   a. Suspended sediment load records in the area.

   b. Severity of erosion in the watershed.

   c. Reservoirs or other structures affecting sediment load.

V. Site investigation report

A. Organization of field data

1. Adjust longitudinal profile of stratigraphic units prepared in tentative form as indicated in Item III B 4 to reflect more detailed observations under IV, Site Investigations.

2. Attach logs of test holes and results of field tests.

B. Report on findings

1. Prepare brief statement on site geomorphology to support delineations on longitudinal profile.

2. Prepare brief statement concerning findings under IV F. - availability of bed material.

3. Prepare brief statement on findings under IV.G. - "clear water" or "sediment load" flow conditions.

VI. Field and laboratory soil testing

A. Field testing

1. In-place density

2. In-place moisture content

3. Vane shear

4. Permeability

5. Dispersion of clay soils - Crumb test

B. Laboratory testing

1. Index tests

a. Classification

(1) Mechanical analysis

(2) Liquid limit

(3) Plastic limit

b. Specific gravity

c. Compaction

2. Engineering properties tests

a. Strength

(1) Unconfined compression

(2) Direct shear

(3) Triaxial shear

b. Permeability

3. Other tests

a. Shrink-swell

(1) Shrinkage limit

(2) COLE

(3) Linear shrinkage

(4) Free swell

b. Soluble salts

c. Base exchange

d. Dry unit weight - natural moisture

e. Dispersion

(1) Laboratory dispersion test

(2) Crumb test

(3) Chemical tests

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CHAPTER 4. DETERMINING DESIGN DISCHARGES

General

Procedures for determining peak rates and volumes of runoff are available in the NEH, Section 4.[17] Procedures for determining channel capacity for irrigation canals and laterals may be found in NEH, Section 15,[18] and for drainage channels in NEH, Section 16[2].

The adaptation of hydrology will be related to two principles in channel design. One principle is the design of a channel for a peak rate of discharge for a selected frequency of occurrence. The second principle is to determine the rate of discharge required to remove a volume of runoff within a specified time limit.

Flood routing requirements will be different for the two principles. The requirements will differ, too, for other needs as illustrated in Table 4-1.

Procedure for Determining Required Channel Capacity

The usual practice in determining the capacity requirement for channels is to make estimates in the planning stage that are sufficiently detailed for final design. A reconsideration of capacity requirement in the design stage will ordinarily be necessary only if there is a departure from the original plan.

Channels Designed for a Peak Rate and Selected Frequency

These channels are planned and constructed to contain the peak rate of runoff for a design flood of a given frequency. The hydrology for this type of channel involves estimates of local runoff for the design frequency and flood routing through the channel system.

The method of determining runoff and flood hydrographs from subwatersheds for the desired frequency can be selected from those described in NEH, Section 4,[17] Chapters 5, 10, 16 and 18. Chapter 5 describes the use of stream flow data for estimating the rate of discharge. Chapter 10 covers "Estimation of Direct Runoff from Rainfall," for cases where stream flow data are not available or adequate. Rainfall amounts for selected frequencies and durations, as found in the Weather Bureau's Technical Paper No. 40, Rainfall Frequency Atlas of the United States,[19] are generally adequate to provide a basis for an estimate of direct runoff from a specified area. Chapter 16 of NEH, Section 4,[17] covers development of hydrographs, and Chapter 18 describes statistical methods for determining the frequency of flood events.

TABLE 4-1

Investigational Procedure	Flood Routing Required by Project Purpose		
	Containment of a Peak Rate of Runoff of Specified Freq.	Removal of a Volume of Runoff Within a Time Limit	Open Ditch1/ Drainage
1. Determination of design discharge	Channel 2/	None	None
2. Economic evaluation of flood damage reduction			
a. Based on percent chance of occurrence	Channel and overbank 3/	Channel and overbank	None
b. Based on drainage criteria	None	None	None
3. Determination of effects of program on downstream flood peaks	Channel and overbank	Channel and overbank	Channel and overbank 4/

1/ Open ditch for either surface or subsurface drainage.

2/ Channel routing indicates that only storage characteristics of channel are considered in routing computations.

3/ Channel and overbank routing indicates that storage characteristics of both channel and overbank areas are considered in routing computations.

4/ Open ditch channels are frequently designed from drainage criteria which only deals with peak rates of runoff. If a routing is required, design hydrographs must be developed.

The "Convex" routing method described in NEH, Section 4, Chapter 17,17/ is appropriate for establishing the design flood discharge capacity. The permissible mean velocity, channel reach length and the hydrograph of inflow to the reach, are required for channel routing.

A check should be made in every case to determine if the channel will be carrying ground-water flow. If so, an estimate of the discharge

rate of ground-water flow should be added to the design capacities, computed above. NEH, Section 4,[17] Chapter 6, describes the separation of ground-water flow from surface flow of recorded flow data.

Channels Designed to Remove a Volume of Runoff Within a Specified Time Limit

The function of these channels is to remove the volume of runoff causing overbank flooding within a period of time that will prevent damage. The required discharge capacity may be calculated by the empirical procedure described in NEH, Section 16,[2] Chapter 6. These procedures are adapted primarily to locations where comparatively level land area is substantial with respect to the watershed area, where watershed boundaries are difficult to delineate, where it is not necessary to flood route and where channels designed on similar sites have provided adequate protection. It may also be based on a design flood of a given frequency.

Drainage Capacity Related to Frequency

General

It is sometimes necessary to estimate the frequency of protection provided by a channel designed by drainage criteria. The frequency may be related to either a peak discharge or a design flood volume for a specified time interval.

Drainage Capacity Related to Annual Flood Peak Frequency

The frequency, equivalent to drainage criteria, may vary between individual reaches and should be estimated for each reach. The flood frequency equivalent may be obtained by the following procedure from NEH, Section 4.

1. If stream flow data are available, the annual flood peaks, minus ground-water flow, may be related to frequency by the procedure described in Chapter 18. Since the bankfull capacity of the channel can be computed, this discharge can be related to the frequency curve developed from annual flood peaks. Average ground-water discharge that the channel will carry may be estimated by procedure described in NEH, Section 4[17], Chapter 6.

2. If stream flow data are not available, the annual flood may be estimated from rainfall. Obtain rainfall amounts for selected storm durations from Weather Bureau Technical Paper No. 40.[19] Select two or more storm frequencies that will encompass the design channel capacity in all reaches. For each selected

rainfall frequency, compute the volume of direct runoff, develop subwatershed hydrographs, and flood route through channel reaches. Plot the routed peak discharge versus volume of runoff in equivalent inches of depth over the watershed area for the selected frequencies, for each reach. See Figure 4-1. The plotted points are described by a straight line originating at zero. The selected frequencies are shown for their respective volume of runoff. The heavy dash lines with arrows indicate entering the graph with the given design discharge for each reach and reading the volume of runoff. The volume of runoff will in turn relate to a specific storm frequency. This is the storm frequency at which the peak discharge can be contained below a damaging stage.

Drainage Capacity Related to Flood Volume Frequencies

A procedure for determining the frequency of a flood volume that can be removed from the overbank areas by channels with a capacity based on drainage criteria, involves the following assumptions:

1. On-farm drainage and tributary laterals have been constructed with outlets into the designed channel.

2. The volume of storage in the channel network is negligible.

3. The overbank areas are broad and almost flat wherein the variation in the overbank stage with respect to time is relatively small.

Analysis with stream flow data. - - When stream flow data are available, a volume-duration-frequency analysis should be made. Volume-duration-frequency analyses have been provided to many states for streams with drainage areas under 1,000 square miles, by the Central Technical Unit, Hydrology Branch, Washington office, and should be used when available. This analysis can be made according to procedure contained in NEH, Section 4[17], Chapter 18. The analysis can be made for any duration; however, a duration of 24 hours will be used for comparison. Volume-duration-frequency curves are shown for 24, 48, and 72-hour durations in Figure 4-2.

Using the dimensions of the proposed channel, compute the discharge rate for the average overbank stage of flooding for each reach. This computation can best be made at road crossings or other control points where the outflow is confined to the new channel. The average overbank flood stage can usually be estimated within 10 percent at properly selected points such as this. Estimate the average rate of discharge out of the reach by the slope-area

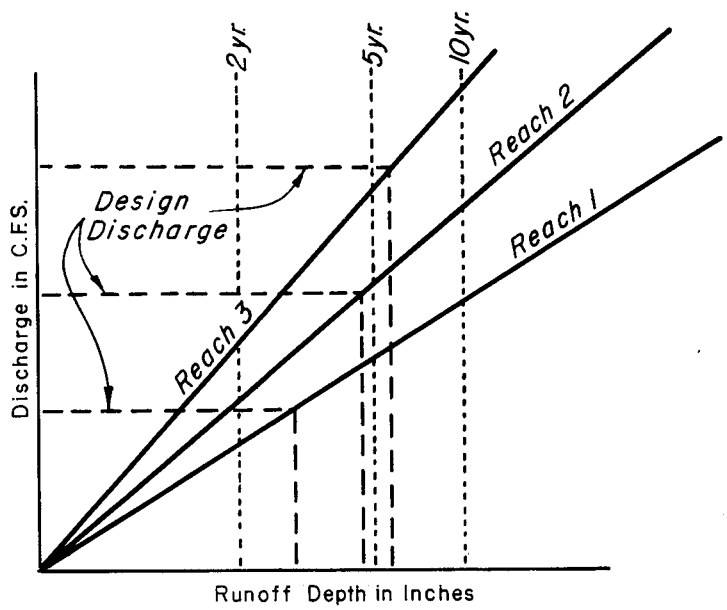

FIGURE 4-1
ROUTED PEAK DISCHARGE VERSUS
AVERAGE DEPTH OF RUNOFF, BY REACH

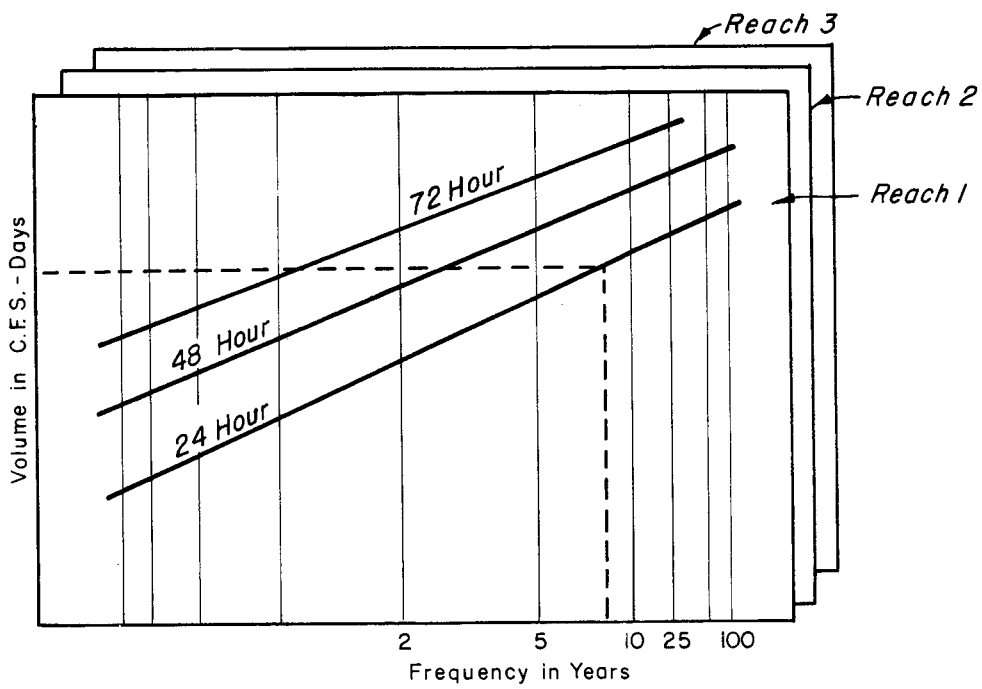

FIGURE 4-2
VOLUME DURATION FREQUENCY ANALYSES

method. This rate of discharge multiplied by 24 hours equals the flood volume removed in cfs-day units. This flood volume is compared with the 24-hour volume-duration-frequency curve from stream flow data to determine the frequency equivalent of the design drainage capacity. (See Figure 4-2.)

The frequency equivalent may be expressed for either of two situations. In many northern states it may refer to the winter and spring snow-melt season or to the summer rain-storm season.

Analysis without stream flow data. - - Where stream flow data are not available, the volume-duration-frequency curves for a 24-hour period may be derived from Weather Bureau rainfall data. The Weather Bureau's Technical Paper No. 40[19] contains maps showing the amount of rainfall expected to occur during a 24-hour period for various frequencies. This may be converted to runoff depth in inches by the procedures in NEH, Section 4[17], Chapter 10. The volume of runoff may be converted to cfs-days by the following conversion factor:

$$\text{Inches depth} \div 0.03719 = \text{cfs-days per square mile}$$

Volume in cfs-days plotted versus frequency provides a graph similar to Figure 4-2. Precipitation amounts for durations longer than 24 hours may be obtained from an analysis of individual precipitation records or by an extrapolation on log paper if this has proven to be valid in the area under consideration. The required frequency equivalent for a channel designed by drainage criteria can be obtained in a manner similar to that for gaged data. See U. S. Weather Bureau TP-49, Two-to-Ten-Day Precipitation for Return Periods of 2 to 100 years in the United States.

This method is limited to channels with drainage areas less than 400 square miles.