
Chapter 2

**Engineering Geologic
Investigations**

Issued January 2012

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Preface

This chapter and related chapters in the National Engineering Handbook (NEH) Part 631 replace NEH Section 8, Engineering Geology, which was last released in 1978.

Additional guidance materials are also included here and deleted from the National Engineering Manual (NEM) Part 531.

| | | |
|-----------------|-----------------|--|
| Contents | | |
| | 631.0200 | Introduction 2-1 |
| | 631.0201 | Intensity of engineering geology site investigations 2-1 |
| | 631.0202 | Minimum requirements for engineering geology investigations 2-2 |
| | | Structure classifications.....2-2 |
| | 631.0203 | Geologic reconnaissance 2-2 |
| | 631.0204 | Preliminary site investigation 2-3 |
| | | (a) Purpose.....2-3 |
| | | (b) Assembly of data2-4 |
| | | (c) Use of imagery2-4 |
| | | (d) Field study.....2-4 |
| | | (e) Mapping2-5 |
| | | (f) Report of preliminary investigation2-6 |
| | 631.0205 | Detailed site investigation 2-6 |
| | | (a) Group A structure sites2-7 |
| | | (b) Group B structure sites2-10 |
| | | (c) Preparation for subsurface exploration2-10 |
| | | (d) Subsurface exploration: correlation and interpretation of geologic2-10 conditions |
| | | (e) Report of detailed geologic investigation2-16 |
| | 631.0206 | Minimum requirements for sampling and testing of structure sites 2-18 |
| | | (a) Sampling group A structure sites2-18 |
| | | (b) Sampling group B structure sites2-19 |
| | 631.0207 | Investigation of potential seismic hazards 2-19 |
| | | (a) Fault rupture2-19 |
| | | (b) Earthquake loading2-19 |
| | | (c) Liquefaction2-21 |
| | 631.0208 | Geologic investigation during project implementation and construction (as-built) 2-22 |
| | 631.0209 | Investigations for repair, rehabilitation, and decommissioning of structures 2-22 |
| | 631.0210 | Groundwater investigations 2-23 |
| | | Investigation procedures2-23 |

| | | |
|-----------------|---|-------------|
| 631.0211 | Investigation of structural problems caused by erosion or sedimentation | 2-25 |
| 631.0212 | Watershed sediment yield studies for structures and conservation practices | 2-26 |
| | (a) Reservoir sedimentation surveys | 2-26 |
| | (b) Sediment storage design for reservoirs and ponds..... | 2-26 |
| 631.0213 | Stream channels and stream corridors | 2-27 |
| 631.0214 | References | 2-28 |

Tables

| | | |
|------------------|---|------|
| Table 2-1 | NRCS structure classifications | 2-2 |
| Table 2-2 | Test hole numbering system | 2-11 |
| Table 2-3 | Approximate vertical-stress values of earthfill structures weighing 100 pounds per cubic foot | 2-13 |
| Table 2-4 | Presumptive bearing values of soils (approximate maximum safe-load values) as related to the Unified Soil Classification System | 2-14 |
| Table 2-5 | Seismic risk and evaluation screening tool for dam sites | 2-20 |
| Table 2-6 | Exceedance probabilities by hazard classification | 2-20 |

631.0200 Introduction

Geologic investigations commonly conducted in the agency focus on siting and designing engineering practices, ranging from high-hazard classification earth fill dams to farm ponds and animal waste storage or treatment structures. Additionally, geologists investigate landslides and their potential to occur, structural failures or deficiencies in practices already built, and participate in stream restoration planning, design, and implementation. An emerging workload focuses on the rehabilitation of existing watershed protection structures and potentials to decommission or remove structures and practices, involving investigations of stored sediment quantity and quality (toxicity), which could possibly become mobilized.

U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) geologists conduct engineering geology investigations on request and for the planning, siting, design, and implementation of engineering structures and engineering conservation practices across a broad spectrum of programs carried out by the agency. Nongeologists do perform many reconnaissance-level geologic investigations for some conservation practices through the agency's system of authority that is delegated by the State conservation engineer (SCE) on the basis of individuals' training and experience (USDA NRCS 2010a (Part 501)).

631.0201 Intensity of engineering geology site investigations

Requirements for design and construction of structures, conservation practices, and conservation systems vary widely depending on size and purpose of the structure, kinds of construction materials, site conditions, and economic and safety considerations. Specific policies for geologic investigations are in the National Engineering Manual (NEM), Part 531.

Geologic site investigations and soil mechanics tests are done in sufficient detail and intensity for planning, design, and implementation of conservation engineering practices. The procedures and intensity of investigation and the kinds of samples taken therefore vary from site to site and for the particular purpose or structure.

Geologic investigations may also be accomplished through the use of remote sensing techniques or other noninvasive methods that characterize mass properties of in situ earth materials. Additionally, topographic, land use, and other earth science information are available in digital form, allowing advanced analysis of geologic site conditions.

631.0202 Minimum requirements for engineering geology investigations

The following criteria establish the minimum site investigations that are acceptable for design and construction. Additional investigations depend on the complexity of the site and the specific design requirements for the structure (e.g., hazard classification).

Structure classifications

To establish criteria for geologic investigation and sampling, structure sites are categorized into two groups according to the fill height of the structure, construction materials, purpose of structure, and hazard classification, as illustrated in table 2-1.

631.0203 Geologic reconnaissance

The results of the geologic reconnaissance are used to assess the need for more detailed investigation and whether additional technical expertise is needed.

Geologic reconnaissance includes the collection and review of existing data. Characteristics of the site should be assessed, including geomorphology, topography, drainage, and other conditions that might affect the suitability of the site for its intended use and for potential impacts on natural resources. Site visits may be conducted to assess the suitability of the area for the proposed project, verify the accuracy or adequacy of existing information, and identify significant gaps in information needed to continue with the design.

Table 2-1 NRCS structure classifications

| Group | Hazard classification | Height (ft) | Type or function |
|---------|--|-------------------|---|
| Group A | High-hazard (H) dams Significant-hazard (S) dams Low-hazard (L) dams | Any Any >35 | Any |
| | Any | >20 | Concrete or masonry arch or gravity dams Drop spillways Box-inlet drop spillways Chutes |
| | | ≥20 | Principle purpose is forming storage reservoirs for recreation, municipal water supply, or irrigation where the product of the storage (in acre-feet) times the height (in feet) of the dam is equal to or greater than 3,000 |
| Group B | Any | Any | Dams and embankments that do not classify as Group A, including Low-hazard (L) dams with a maximum fill height of 35 feet or less, and conservation practices* such as Pond (378), Waste Storage Facility (313), Dike (356), Diversion (362), and Grade Stabilization Structure (410) |

*Refer to NRCS National Conservation Practice Standards (CPS) for more information.
<http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/alphabetical/ncps>

The engineering properties of soil and rock materials need to be evaluated. Consideration of how the operation of the proposed project, structure, or practice might affect local natural resources must be addressed. Logistical concerns, such as access, that may affect future activities also need to be addressed. Existing data and information should be reviewed before field investigation. Data and information sources include geologic maps, topographic maps, well logs, aerial photographs and other imagery, soil surveys, water and mineral resource reports, and other reports and information sources that pertain to the area of the site and the nature of the project.

Limited on-site investigations may be conducted to assess the feasibility and suitability of the site, to recognize hazards, to verify the accuracy or adequacy of existing information, and to identify significant gaps in information needed to continue with design. Data gathered during the reconnaissance are primarily descriptive and should include the following:

- general geology of the site: surface and subsurface earth materials
- geologic conditions that may affect erosion and sedimentation
- geologic conditions that may influence groundwater movement and recharge
- general character of topography and stream system
- engineering properties of soil and rock materials
- presence and activity of faults
- general relationship between the geologic conditions at the site and known or typical design requirements for the proposed conservation practice or structure
- known or projected mining activities and oil or gas extraction

631.0204 Preliminary site investigation

A preliminary investigation consists of a field study and a review of available literature and maps relating to regional geology and physiography. The general physical feasibility of the site is assessed and specific questions to be answered during the design process posed. Field studies should include a thorough inspection of outcrops, cut banks, and other surface exposures and an examination of erosion conditions, landslides, seeps, springs, and other conditions on and adjacent to the project site.

The geologist and the designer should discuss geologic conditions that may influence the design, construction, cost, and functioning of the proposed structure. If these conditions appear adverse, a more intensive investigation may be required to assess site feasibility.

In areas where the soils and geologic conditions are well known, a detailed investigation may not be necessary for small, low-hazard structures. For such structures, the preliminary investigation needs to be sufficiently detailed to provide relevant information on site materials, conditions, and engineering characteristics for planning, design, and cost estimates.

(a) Purpose

The purpose of a preliminary site investigation is to establish the geologic feasibility of the site and to determine the extent and precision of detailed subsurface investigations required to obtain the information needed for design and construction.

For some sites, the preliminary investigation, together with experience in the area, may be adequate to determine the geologic conditions and engineering characteristics of materials. At other sites, enough information on subsurface materials may be readily obtained during preliminary examination from test pits, hand-auger borings, trenching, or other methods, so that a detailed subsurface investigation may not be required. However, a detailed subsurface investigation needs to be scheduled where information needed for design cannot be obtained with the tools available during the preliminary examination.

(b) Assembly of data

Before beginning a field study of a site, available geologic, physiographic, and engineering-experience data are reviewed. Sources of reference data include publications of the U.S. Geological Survey (USGS); State geological surveys; USDA soil survey reports; special reports and papers in scientific publications; and Federal, State, or local engineering experience information where available. A base map on a usable scale, topographic sheets, aerial photographs, and geologic and soil maps are also helpful. Preliminary information on the location of the proposed structure is essential. The following site information is needed:

- purpose of structure or practice
- estimates of height of structure and volume of compacted fill required
- estimated maximum and normal pool elevations
- hazard classification of structure
- approximate area in reservoir basin
- approximate location of auxiliary spillway(s)
- approximate location of outlet structure

The geologist should make use of the general design, experience, and performance of structures in the area. Interviews with engineers or other technicians familiar with the design and operation of these structures, and visits to structures under construction, are particularly helpful. Available reports on laboratory analyses of local materials should be reviewed to determine physical and engineering properties for possible application to the site.

Note that information may be in the form of maps and published reports, as well as digital information layers and databases.

(c) Use of imagery

(1) Aerial photographs

Photographs and digital images may be available from USDA cropland monitoring programs. Other images may be from satellites or high altitude flights. Aerial photos may also be available from local sources, vendors, and State and Federal agencies.

Color tone, vegetation, landforms, and drainage patterns often are indicators of geologic features, including kinds of rock, fractures, faults, lineaments, sinks, and landslides, and of moisture and soil conditions. Stereoscopic prints provide three-dimensional interpretations that help to establish the general geology during subsequent field studies, as well as changes over time between the dates the images were obtained.

(2) Other imagery

LiDAR—Light Detection and Ranging (LiDAR) uses the signature of light reflection to provide extremely detailed maps of the land surface and cover. The digital output can be analyzed and interpreted for creating detailed surface maps of topography, water bodies, and streams. LiDAR maps are available commercially or can be developed by specific contract, although tripod-based LiDAR systems are being developed that can produce detailed surface exposure maps of rock faces, abutments, stream channels, quarries, etc.

Radar—Radar imagery can provide stark contrast images between land and water, and further definition of the landscape.

Infrared—Heat signatures of soil, rock, and plants can provide important clues about the structure of a site, where lineaments and fractures occur, and where plant vigor indicates changes in chemical composition of the soils and higher soil moisture.

(d) Field study

A preliminary geologic investigation may include a shallow subsurface investigation, using a backhoe or hand auger, to generally characterize shallow stratigraphy, soil mechanics properties of underlying geologic materials, groundwater hydrologic conditions, and other geologic attributes required to complete a geologic site assessment and support preliminary engineering design.

A field study of the site and the surrounding area should include a traverse of the valley for about a mile above and a mile below the site. The traverse should include a study of slopes, tributary valleys, landslides (active and inactive), faults, springs and seeps, sinkholes, exposed rock sections, and the nature of unconsolidated overburden. An inspection of upland and valley slopes may provide clues to the thickness and

sequence of formations and rock structure. The field study should also include inspections of the shape and character of channels and the nature of residual, colluvial, alluvial, fan, slide, and other kinds of sedimentary deposits. Any groundwater observations, especially in alluvial deposits, should be recorded. Possible sources and approximate amounts of borrow material should be noted. A few hand-auger borings or test pits may be needed.

All geologic formations visible at the surface should be identified and described, noting their orientation and topographic positions. Local dip and strike of the formations, stratigraphic relationships, or structural features should be noted, especially those which could lead to problems of seepage, excessive water loss, and sliding or collapse of the embankment.

All faults should be identified and mapped by type and evidence of activity or inactivity. If faults are active or show large displacement, it may be necessary to relocate the dam or the principal spillway. In addition to other problems, faults and fault zones may cause serious leakage.

Depth to groundwater, depth to bedrock, thickness of recent alluvium and colluvium, and availability of suitable borrow material are conditions that may require further investigation and definition.

(e) Mapping

A geologic map of the site should be prepared, using the best available base maps or aerial photographs. USGS topographic contour maps provide an excellent mapping base and are available digitally and in hard copy. Sub-meter Global Positioning System (GPS) surveys may be needed. Features to be shown on the map include:

- areal geology of all surface formations, including delineation of unconsolidated deposits
- texture and classification of surface soils
- structure of bedrock, including dip and strike, faults or fractures, fissures, discontinuities, stratification, porosity and permeability, schistosity, and weathered and altered zones
- groundwater features, including seeps, springs, observable water tables, and drainage

- areas of modern deposits (result of accelerated erosion), or excavations (quarries, mines, etc.), unstable slopes, slips, and landslides
- active mining of sand, gravel, coal, or other minerals; and oil or gas extraction activities and extent

A geologic evaluation map is a plan view illustration, depicting the orientation and location of key geologic and related features that could significantly affect the performance of a proposed or existing structure or practice. Cross sections, profiles, fence diagrams, columnar sections, perspective drawings, and other illustrations may be used to represent geologic features. The map may include profiles, cross sections, or other supplemental figures to help illustrate the information. A geologic evaluation map is used to support planning documents such as an environmental assessment or an environmental impact statement. It may include profiles, cross sections, or other supplemental figures to help illustrate the information.

For small structures at low-hazard sites, a site sketch may be adequate. A site sketch is typically drawn freehand or on a geographic information system (GIS)-based platform from observation or uncontrolled surveys showing approximate space, scale, and orientation of the main features of the site or area. The accuracy and scale of a map must be commensurate with the scope of the project and complexity of the site. Digital images may also be used to show important formation contacts and other site features.

When mapping, an understanding of the area's geomorphology may be useful in understanding the geologic history of the area. In addition, the mapper may note changes in vegetation, which may differentiate underlying soils and rock due to different water holding capabilities, for example (such as vegetation on shale vs. sandstone). Vegetation may also indicate shallow groundwater.

Maps are prepared on the best available topographic base map or aerial photograph using standard signs and symbols, at a chosen scale and projection. The standard is the [Digital Cartographic Standard for Geologic Map Symbolization by the Federal Geographic Data Committee \(FGDC–STD–013–2006\)](#) (FGDC 2006).

Maps drawn to scale must include a graphic scale. Note the original scale at which the map was produced, published, or both. Maps with exaggerated vertical scales are explained with a statement, such as “1 inch equals 1 mile,” or a representative fraction, such as “1:2000.” The legend of profiles or cross sections with exaggerated vertical scales must include a statement such as “vertical scale = 10X horizontal scale.” All maps and sketches must include a title or subject, area covered, key to symbols used, scale, north arrow, date, and name and title of mapper.

The accuracy and scale of the map vary, depending on the scope, complexity, potential hazards associated with the project, and on the geologic complexity of the project site.

(f) Report of preliminary investigation

The report for the preliminary geologic investigation assesses the feasibility of the site and makes recommendations for further investigation needs. Form SCS-533, Log of Test Holes, or equivalent, can be used to record information obtained from test holes or pits. The preliminary site investigation and knowledge and experience of the geology in the area may provide enough information for design purposes without further detailed investigation.

If samples from other sites with similar conditions have been analyzed, and the data are used as criteria in preparing the recommendations, a reference to these samples and the availability of the data should be noted in the report. For those sites where previous information permits a preliminary investigation to be used for the design, it is necessary to locate and delineate borrow areas. This can be done only by subsurface exploration. A detailed investigation must be made of all borrow areas.

631.0205 Detailed site investigation

A detailed site investigation is made to verify and supplement reconnaissance level and preliminary level investigations to provide the designer with specific and quantifiable information for use in design and construction. Detailed subsurface investigations must be of sufficient intensity to determine all the conditions that may influence the design, construction, and functioning of the structure. The extent of geologic investigation required for a particular site depends on complexity of site conditions, size of the structure, potential damage upon failure, and purpose and function of the structure.

Test holes are used to explore and log materials in the foundation, borrow areas, and spillway(s); to perform mass properties of the earth materials; and to collect samples for further analyses. Pits or trenches may also be used.

Test holes must be deep enough to characterize the earth materials at the site. The number and spacing of test holes must be adequate for correlation in both longitudinal and transverse directions and to the distance needed for complete interpretation of any condition that may influence the design of the structure. Trenches are especially useful for logging the geologic materials in detail and their structure over the length of the trench.

Geologic structural features, such as faults, folds, and joints, must be identified and located. Sufficient information must be obtained on unconsolidated deposits to determine their location, thickness, and extent. Where drilling methods are used, the following tests can be used to characterize the in situ strength of foundation materials: standard penetration test (SPT), permeability tests, vane shear tests, and cone penetrometer tests.

Data gathered are analyzed onsite, and the logged behavioral characteristics and engineering significance of the materials and conditions are evaluated to identify potential engineering problems and to determine possible methods for solution. From this analysis and evaluation, the geologist and designer determine further sampling and testing needs and what labora-

tory analyses are needed for design and construction. This determines the kind, number, and size of samples needed. The necessary samples are obtained by using appropriate sampling procedures. Any additional test holes or special in-place field tests that are needed should be made. Such recommendations are a logical outcome of an investigation, depending on the complexity of the site and the hazard classification of the structure.

A detailed geologic investigation may include any combination of the following:

- conducting subsurface investigations, including exploration holes, trenching, pitting, geophysical and seismic evaluations
- obtaining soil and rock samples for laboratory analysis and performing in situ testing
- analyzing remotely sensed data and imagery
- evaluating the geomorphology, geologic units, and structures at and near the site
- developing sediment budgets and sediment storage requirements or sediment management, including sediment production, transport, and yield
- defining structural or cultural features in the area of interest (may include water wells, oil and gas wells, mine shafts and adits, quarries)

A detailed site investigation provides information on subsurface conditions that cannot be obtained by surface examination or by shallow subsurface investigation. Equipment such as backhoes, bulldozers, power augers, or drill rigs are typically used to perform detailed site investigations, sampling, and testing. The following information and assessments are required:

- Knowledge of the foundation materials and conditions is of sufficient scope and quality to serve as a basis for geologic interpretation and structural design.
- Fill materials are of suitable quality and are available in sufficient quantity.
- Storage reservoir basins are free from sinks, permeable strata, and fractures or fissures that might lead to moderate or rapid water loss.

- Subsurface water conditions are known that might materially affect the design of the structure or the construction operations.
- Stability characteristics are known for material in the auxiliary or other open spillways and channels under anticipated flow conditions during operation of the structure.
- Allocated sediment storage will not be exceeded during the design life of the structure.

The detailed site investigation secures the information and supplements the knowledge of the site gained through the reconnaissance and preliminary investigations.

(a) Group A structure sites

The geologist and design engineer jointly develop a detailed geologic investigation plan that describes what data to collect and how the data will be used to support sound engineering design. Preliminary findings are reviewed to determine the adequacy of the subsurface investigation, including in situ testing and sampling for soil mechanics testing. The data are reviewed for adequacy for use in all stages of design and construction.

(1) Intensity of investigations

Products and outcomes may include, but are not limited to:

- Delineation and determination of engineering properties, continuity, relative permeability, and other characteristics of all materials to the specified depth beneath the entire base and abutment area, or area of influence, of the dam and outlet structures. The structural area of influence may be far into the abutments or may be the entire reservoir basin under some geologic conditions or structure purposes. Stratigraphic and structural discontinuities, such as faults, joints, voids, and fractures with engineering significance must also be characterized.
- Determining the attitude, location, extent, and character of folds, faults, joints, lineaments, solution cavities, disconformities, and unconformities. Note also schistosity, slaty cleavage, and bedding characteristics. In some cases,

angle holes may be needed to define hazardous conditions.

- Delineating the incompressible rock surface, where it occurs within the depth of influence of the structure.
- Evaluating the need for hydraulic pressure testing in rock foundations and abutments of proposed dams for water storage reservoirs.
- Assessing the influence of rock mass properties on the slope stability of rock materials in spillway cut slopes.
- Determining the extent and character of materials to be excavated for open spillways and the character and slope stability of the material in the spillway cut slopes.
- Locating and determining the depth, thickness, continuity, distribution, and engineering properties of the earth materials proposed for use as fill.
- Determining the depth to groundwater, seasonal variation of water table, and extent and character of aquifers within the zone of influence of the structure.
- Evaluating the need for controlling groundwater during construction and determine the need for controlling moisture content in borrow material.
- Evaluating the seepage potential of the permanent pool area and dam site of water-holding reservoir sites.
- Evaluating whether economic mineral deposits, including sand and gravel, occur within the area of influence or would be preempted or otherwise impacted by the project. Also assessing the potential impact of current or future mining or oil or gas withdrawal from below or near the structure site.
- Assessing the effects of earthquake loading on the proposed structure.
- Determining reservoir sediment storage requirements based on results of a watershed sediment yield study.
- Evaluating reservoir slope stability where the slopes are steeper than 3H:1V.

An engineering geologic map must be drawn to identify and spatially represent zones of geologic material that meet similar engineering performance criteria. The map must include the locations of all measurements, samples, or observations, and the data collected.

Supplements may include structural contour maps showing elevations of geologic contacts, tops of key beds, or other surfaces of interest, and isopach maps showing contoured thicknesses of each mapped unit. Cross sections, profiles, fence diagrams, columnar sections, perspective drawings, and other illustrations may be used to represent geologic features. In some cases, a geomorphic map, showing landforms, slope stability, and topography is appropriate.

(2) Test hole locations and depths

All soil and rock units need to be characterized beneath the footprint of the structure and the abutments.

For all earthfill dams in group A, borings at all stations within the footprint of the structure must be extended to depths equal to or greater than the equivalent proposed height of fill associated with the points of boring or to hard, massive, unaltered rock or similar limiting layer.

For all concrete dams, borings must extend to depths equivalent to at least 1.5 times the proposed effective height of the dam as measured from the maximum proposed depth of excavation.

Sufficient borings must be made along the proposed centerline of dams to provide correlation of geologic materials and to define the rock surface profile. Borings must extend deep enough into rock to establish depth to unaltered bedrock.

Sufficient borings must be made along the proposed centerlines of risers, inlet structures, or other conduits to provide correlation of geologic materials from the riser to the outlet and to a depth equal to the zone of influence of the structure. At least one test hole must be placed at the riser, at the intersection of the centerlines of the dam and conduit and at the outlet with sufficient holes in between to allow reliable correlation.

Sufficient borings must be made along the centerline of drop inlets or other conduits to provide reliable correlation of all strata from the riser to the outlet and to

a depth equal to the zone of influence of the structure. Where rock occurs within the zone of influence, the investigation must accurately delineate the rock surface below the centerline of the conduit.

The depth of investigation under the footprint of the structure must be equivalent to the proposed height of the structure unless hard, massive, or otherwise unaltered impervious rock is encountered at a shallower depth. Borings must extend far enough into rock to determine its character and condition and whether it is in-place. For all concrete dams, the depth of borings will be no less than 1.5 times the height of the controlled head of the dam.

The minimum depth of borings in weak or compressible materials, where the influence of loading by the structure may be significant to depths greater than the height of the dam, will be determined in consultation with the design engineer. Depths of investigation ultimately depend on the significance of the material and mass characteristics of earth materials to the overall design.

Hydraulic-pressure tests must be made in rock foundations and abutments of proposed dams forming storage reservoirs. This test consists of a holding test of not more than one psi per foot of depth below ground surface, followed by a pumping test if the pressure drop in the holding test exceeds 10 psi.

All borings must be sufficiently deep and closely spaced to establish reliable correlation of strata under the entire base of the structure. The number, depth, and spacing of holes needed depend on the regularity, continuity, and attitude of strata and character of geologic structures.

Where an excavated auxiliary spillway is planned, investigations must be of sufficient intensity to determine quantity and character of the materials to be excavated, limits of common and rock excavation, suitability of the excavated material for use in construction, and erodibility of the resulting spillway channel. Each boring for investigations must extend to a depth of not less than 2 feet below the bottom of the proposed auxiliary spillway. A sufficient number of auxiliary spillway holes must extend a minimum of 30 feet below the bottom to determine the potential erodibility of the bulk of the material in the spillway.

Enough borings must be made in the borrow areas to identify and establish the distribution and thickness of all materials to be used for fill. All borrow area borings should extend at least 5 feet below the expected depth to which material is to be removed, unless consolidated material that is not suitable for fill is found. Determine the depth to groundwater at the time of boring for all borrow area borings.

(3) Structures with permanent storage

For structures with permanent storage, undisturbed samples of all compressible, fine-grained materials are obtained for consolidation tests. Undisturbed samples are obtained from the foundation to a depth equivalent to the maximum height of the dam, as measured from the lowest point on the downstream toe to the lowest point on the dam (crest). If compressible materials or materials that may undergo liquefaction are suspected to occur at greater depths, extend testing to depths within the zone of influence.

Samples for compaction and shear tests must be obtained from the borrow areas and auxiliary spillway areas. Investigations should also determine if dissolvable minerals exist in the dam foundation and abutments (e.g., salt and gypsum).

For all dam sites with permanent storage, the groundwater regime and hydraulic characteristics of the entire reservoir area, abutments, and embankment foundation must be evaluated to determine leakage potential and the need for reservoir sealing. Where significant leakage is suspected, samples must be obtained of materials underlying the permanent pool area to determine reservoir sealing requirements. Potential effects, including damages, of seepage from a reservoir on lands adjacent to or downstream from the structure must be evaluated.

(4) Structures subject to deep subsidence

A geologist must determine whether sinkholes, solution cavities, underground mine collapse, or the removal of fluids such as petroleum, water, and natural gas could impact the design, function, and safety of the dams, particularly by abrupt differential settlement. The geologist must provide recommendations to the design engineer on identified geologic concerns that need to be addressed in the operations and management plan for the structure. Subordination of mineral rights within a limited area at the site does not necessarily prevent subsidence of the structure. If

studies indicate that the predicted subsidence cannot be remedied, the site must be abandoned.

(5) Structures underlain by economic mineral deposits or oil and gas deposits

The geologist must identify and generally characterize any economic mineral deposits underlying the dam site that might be mined or extracted in the future.

The geological investigation must encompass an area that extends outward beyond the base of the dam, a horizontal distance equivalent to the depth of the deepest mineral deposit below ground surface. This requirement may be modified as a result of a detailed, site-specific study by, and at the consequent recommendation of, a qualified mining engineer.

Additionally, oil or gas leases that may involve multiple wells or horizontal wells and hydrofracturing of the pay formations may require further investigations.

Results of the investigation may be used to recommend measures or actions to:

- prevent the development or removal of such minerals from unmined areas in order to prevent subsidence of the structure
- prevent horizontal oil and gas wells from being developed near or underneath the structure or reservoir
- preserve or build and maintain adequate support to ensure against future subsidence of the structure foundation for mined areas or due to oil or gas extraction

(b) Group B structure sites

Intensity of investigations

The intensity of subsurface exploration and sampling needed for sites of larger structures in group B is similar to that for group A sites. General experience in the area, existing geologic information, and the preliminary geologic examination, however, may provide enough information so that a less intensive program of subsurface exploration and sampling may suffice for the sites of smaller structures in this group. Specific design elements must be supported by the geological site investigations, however.

(c) Preparation for subsurface exploration

(1) Assembling maps, reports, and basic data

Available geologic information may indicate the intensity of investigation needed. Data collected during the preliminary geologic examination and the report of investigation should be examined in detail. This study may determine the need for additional information.

Before the field work is started, the surface geology, geologic cross sections, engineering-survey information, and any available preliminary design data should be plotted on Forms NRCS-35A, -35B, and -35C or their equivalent, so that the geologist can locate and log the test holes and correlate between them. The preliminary plan of the proposed structure is prepared on Form SCS-35A or equivalent, including the proposed centerlines of the dam, principal outlet structure, auxiliary spillway(s), the present stream channel, and a map of the proposed borrow area(s) containing grids or traverse reference. Cross sections of the borrow area should be recorded as the investigation proceeds and volumes of suitable borrow material tabulated.

(2) Staking and clearing

Locations of the proposed centerline of the dam, centerline of the principal spillway, and cross sections of the auxiliary spillway should be staked. Alternate locations for the principal spillway should also be staked. All gridlines in the borrow area, auxiliary spillway cross sections, centerline of the principal spillway, and centerline of the dam should be cleared to a width sufficient to provide easy access for the exploration equipment. Stream crossings must be located to minimize riparian damage and to avoid poorly drained areas.

(d) Subsurface exploration: correlation and interpretation of geologic conditions

(1) Purpose and objectives

The purposes of the detailed subsurface investigation are to:

- identify, delineate, and correlate the geologic materials
- locate, identify, and interpret geologic features
- determine groundwater conditions

- interpret engineering properties of the materials
- determine testing and sampling locations
- perform sampling and in situ testing
- determine what materials need to be sampled for design and construction

Split-tube or thin-wall drive samplers are recommended for exploratory investigations and provide an accurate log of unconsolidated, thinly-bedded, and highly variable materials.

The number, distribution, and size of test holes and the number of samples needed to establish subsurface conditions vary widely from one investigation to another, depending on the variety and complexity of the conditions. Test holes must be of adequate number and depth for the geologist to delineate and correlate the underlying strata and for the designer and the geologist to determine the kinds and locations of samples and testing needed.

Where experience or previous examination indicates that only shallow test holes are needed, the excavation of open pits with hand tools or bulldozers and backhoes may be adequate. Where cobbles and boulders are numerous, backhoe or dozer pits or trenches may be the most practical method of exploration. Where pits and trenches in the foundation area cannot be left open, their location and extent should be accurately recorded and shown on the plan so that, if necessary, they can be reopened and properly sloped and back-filled during construction.

(2) Numbering test holes and logs

Table 2-2 shows the standard system of numbering test holes and logs used in NRCS investigations.

Principal-spillway, channel, and auxiliary spillway test holes on the centerline of the dam should be given principal-spillway, channel, and auxiliary-spillway numbers rather than centerline-of-dam numbers. Foundation holes should be numbered as “other” in the area of the base of the dam, not in the immediate vicinity of the centerline of the dam or appurtenances.

(3) Determining location and depth of proposed test holes

Exploratory borings are made along the centerline of the dam, along the centerline of the outlet structure, in the spillway area, and in the borrow areas. Additional exploratory borings are needed if relief wells or foundation drains may be required, or if special information is needed because of site conditions encountered during the investigation.

(4) Foundation test holes

Foundation investigations must determine:

- if the site will provide a stable vertical and horizontal support for the structure
- if the subsurface strata have enough strength to prevent crushing, excessive consolidation, and plastic flow
- if water movement through the foundation or abutments will cause piping, detrimental uplift pressure, or excessive water loss

Conditions that must be recognized and located include:

- the nature, extent, and sequence of strata
- highly dispersed soils
- soluble salts
- liquefiable soils
- aquifers (confined, unconfined, perched)
- any weak bedding planes, joints, faults, voids, or other structural weaknesses in the underlying formations

Table 2-2 Test hole numbering system

| Location | Test hole numbers |
|----------------------------------|-------------------|
| Centerline of dam and abutments | 1-99 |
| Borrow area | 101-199 |
| Auxiliary spillway | 201-299 |
| Centerline of principal spillway | 301-399 |
| Stream channel | 401-499 |
| Relief wells | 501-599 |
| Other | 601-699 |
| Other | 701-799, etc. |

The spacing and number of test holes needed along the centerline of the structure or beneath the proposed base depend principally on the complexity of the geology. Some of the more important factors are character and continuity of the beds, attitude of the strata, and presence or absence of joints or faults. Depth, thickness, sequence, extent, and continuity of the different earth materials must be determined.

A convenient system of boring to determine site conditions is to locate one test hole on the floodplain near each abutment and one on the centerline of the outlet structure. Additional holes may then be located between these holes, as needed, to establish good correlation of strata.

At least one test hole should be in each abandoned stream channel that crosses the centerline. At least one test hole is usually required in each abutment; however, several test holes may be needed to adequately define the geologic conditions. It is highly important that enough investigation be carried out to establish continuity of strata and potentially hazardous or defective zones throughout the area underlying the base of the proposed structure. Pervious, unstable, or compressible materials must be identified to a depth equal to the height of the structure, unless impervious and indurated, virtually incompressible material is encountered.

(5) Foundation loading strength, presumptive bearing values, and test hole depths

Depth of exploration depends on the character of material and on the combined pressure exerted by overburden and embankment.

Table 2-3 shows the approximate vertical-stress values of earthfill structures weighing 100 pounds per cubic foot.

Table 2-4 shows the approximate loading values of earthfill structures by height and depths and the presumptive bearing values of various unconfined materials for different consistencies and relative densities. These values are approximate loads for soil materials without excessive settlement. Note that a given amount of settlement per unit thickness may be of minor significance for a thin layer but may be excessive for a thick stratum. The estimate of consistency and relative density must be made from examination of representative samples, standard penetration test

blow count, drilling characteristics, or an estimate of the density and void ratio of the material.

An example of how to use tables 2-3 and 2-4 to determine appropriate depths of test holes follows.

Example: Test Hole Depth Determination for Foundation Investigation

A test hole has been drilled to the minimum depth of 50 feet in the foundation for a structure designed to be 50 feet high. The test hole is still in compressible materials. The approximate vertical stress at this depth from a 50-foot structure is 1.9 tons per square foot (table 2-3). The material at the bottom of the hole is stiff, inorganic plastic clay (CH). Table 2-4 shows that stiff CH has a presumptive bearing value of 1.5 tons per square foot. This indicates that the formation is subject to deformation under the proposed load and that exploration must continue to a greater depth until the vertical stress is equal to or less than the safe load value. For this example, the test hole needs to be extended to a depth of 85 feet.

(6) Principal-spillway test holes

Complete information on the strata underlying the outlet structure is needed for its design. Potential for differential settlement must be assessed, which may result in cracking. If the outlet conduit is to be located on or near rock with an irregular surface, the profile of the rock surface must be accurately defined. The number of test holes needed for this purpose depends on the configuration of the rock. If the rock surface is undulating, numerous test holes may be required so that the needed depth of cradle and the treatment of the foundation can be determined. Where feasible, use trenching to expose and characterize the nature of the soil/rock interface.

Test holes are also needed at the proposed riser location, at the downstream toe of the structure, and at the downstream end of the outlet conduit. For other types of outlets, exploration requirements vary widely from site to site, but test holes must be adequate to provide the information necessary for the design bearing strength and to assess the potential for sliding.

The minimum depth of test holes along the centerline of the outlet should be equal to the height of the proposed fill over the outlet conduit, or 12 feet, whichever is greater, unless unweathered rock is encountered.

Table 2-3 Approximate vertical-stress values of earthfill structures weighing 100 pounds per cubic foot

(Do not use for design purposes)

| Height of structure (ft) | Depth (ft) | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|-----------------------------|----------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|--|
| | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 110 | 120 | 130 | 140 | 150 | | | |
| | Tons per square foot | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | | | | | | | | | | | | | | | | | | | | | | | |
| 10 | 0.5 | 0.4 | 0.3 | 0.3 | 0.2 | 0.2 | | | | | | | | | | | | | | | | | | | | | | |
| 15 | 0.7 | 0.6 | 0.6 | 0.5 | 0.5 | 0.4 | 0.4 | 0.4 | 0.3 | | | | | | | | | | | | | | | | | | | |
| 20 | 1.0 | 0.9 | 0.8 | 0.8 | 0.7 | 0.7 | 0.6 | 0.6 | 0.5 | 0.5 | 0.4 | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 25 | 1.2 | 1.1 | 1.1 | 1.1 | 1.0 | 0.9 | 0.9 | 0.8 | 0.8 | 0.7 | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 | | | | | | | | | | | | | |
| 30 | | 1.4 | 1.3 | 1.2 | 1.2 | 1.1 | 1.1 | 1.0 | 1.0 | 0.9 | 0.9 | 0.8 | 0.8 | 0.8 | 0.7 | 0.7 | 0.7 | 0.6 | | | | | | | | | | |
| 35 | | | | 1.5 | 1.4 | 1.3 | 1.3 | 1.2 | 1.2 | 1.1 | 1.1 | 1.0 | 1.0 | 1.0 | 0.9 | 0.9 | 0.9 | 0.8 | 0.8 | 0.8 | 0.7 | | | | | | | |
| 40 | | | | 1.7 | 1.7 | 1.6 | 1.5 | 1.5 | 1.4 | 1.4 | 1.4 | 1.3 | 1.3 | 1.2 | 1.2 | 1.1 | 1.1 | 1.0 | 1.0 | 1.0 | 0.9 | 0.9 | 0.8 | 0.8 | | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 45 | | | | 2.0 | 1.9 | 1.9 | 1.8 | 1.8 | 1.7 | 1.7 | 1.6 | 1.5 | 1.5 | 1.4 | 1.4 | 1.3 | 1.3 | 1.3 | 1.2 | 1.2 | 1.1 | 1.1 | 1.0 | 0.9 | 0.9 | | | |
| 50 | | | | | 2.2 | 2.1 | 2.0 | 2.0 | 1.9 | 1.8 | 1.8 | 1.7 | 1.7 | 1.7 | 1.6 | 1.6 | 1.5 | 1.5 | 1.4 | 1.4 | 1.4 | 1.3 | 1.3 | 1.2 | 1.2 | 1.1 | 1.0 | |
| 55 | | | | | | 2.4 | 2.3 | 2.2 | 2.2 | 2.1 | 2.0 | 2.0 | 1.9 | 1.9 | 1.9 | 1.8 | 1.7 | 1.7 | 1.6 | 1.6 | 1.6 | 1.5 | 1.5 | 1.4 | 1.3 | 1.3 | 1.2 | |
| 60 | | | | | | | 2.6 | 2.5 | 2.4 | 2.4 | 2.3 | 2.2 | 2.2 | 2.1 | 2.1 | 2.0 | 2.0 | 2.0 | 1.9 | 1.9 | 1.9 | 1.8 | 1.7 | 1.6 | 1.5 | 1.5 | 1.4 | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 65 | | | | | | | | | 2.8 | 2.7 | 2.6 | 2.5 | 2.5 | 2.4 | 2.4 | 2.4 | 2.3 | 2.2 | 2.2 | 2.2 | 2.1 | 2.1 | 2.0 | 1.9 | 1.7 | 1.7 | 1.7 | |
| 70 | | | | | | | | | | 3.0 | 2.9 | 2.8 | 2.7 | 2.7 | 2.6 | 2.6 | 2.6 | 2.5 | 2.4 | 2.3 | 2.3 | 2.2 | 2.1 | 2.0 | 1.9 | 1.9 | 1.9 | |
| 75 | | | | | | | | | | | 3.2 | 3.1 | 3.1 | 3.0 | 2.9 | 2.9 | 2.8 | 2.7 | 2.7 | 2.6 | 2.6 | 2.5 | 2.4 | 2.2 | 2.1 | 2.1 | 2.1 | |
| 80 | | | | | | | | | | | | 3.4 | 3.3 | 3.2 | 3.2 | 3.1 | 3.1 | 3.1 | 3.0 | 2.9 | 2.9 | 2.8 | 2.7 | 2.6 | 2.4 | 2.3 | 2.3 | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 85 | | | | | | | | | | | | | 3.6 | 3.5 | 3.4 | 3.4 | 3.4 | 3.3 | 3.2 | 3.1 | 3.1 | 3.0 | 2.8 | 2.7 | 2.6 | 2.6 | 2.6 | |
| 90 | | | | | | | | | | | | | | 3.9 | 3.8 | 3.7 | 3.6 | 3.6 | 3.4 | 3.3 | 3.3 | 3.2 | 3.1 | 3.0 | 2.9 | 2.8 | 2.8 | |
| 95 | | | | | | | | | | | | | | | | 4.0 | 4.0 | 3.9 | 3.8 | 3.7 | 3.6 | 3.6 | 3.4 | 3.3 | 3.2 | 3.1 | 3.0 | |
| 100 | | | | | | | | | | | | | | | | | 4.3 | 4.2 | 4.2 | 4.1 | 3.9 | 3.8 | 3.8 | 3.7 | 3.6 | 3.5 | 3.4 | |

The minimum depth of holes below the riser should be equal to the difference in elevation between the top of the riser and the natural ground line or 12 feet, whichever is greater.

(7) Auxiliary spillway test holes

The investigation must determine the stability and erodibility of spillway material and provide adequate information on the extent and volume of the various types of material to be excavated and on the suitability of the excavated material for use in construction. The SITES computer program, “[Earthen/Vegetated Auxiliary Spillway Erosion Prediction for Dams](#)” (USDA NRCS and Agricultural Research Service (ARS), and Kansas State University 2010) is used for determining spillway design erodibility. Sampling and testing should be consistent with the requirements of this analytical tool (USDA NRCS, ARS, and Kansas State University 2010). A series of geologic cross sections at

right angles to the centerline of the spillway should be developed if conditions are highly variable or if long spillway sections are planned.

Initially, one cross section should be located approximately at the control section, one in the outlet section, and one in the inlet section of the spillway. Additional cross sections can then be located as needed for correlation, to locate contacts, or to obtain additional needed data. Test holes should be located on each cross section at the centerline and at the boundaries of the spillway. Where deep spillway cuts are planned, additional test holes may be needed to determine the character of the material and water table in the sides of the cut. Where consolidated rock is encountered in the spillway, the rock surface should be carefully delineated, which may require more test holes and cross sections.

Table 2-4 Presumptive bearing values of soils (approximate maximum safe-load values) as related to the Unified Soil Classification System

| Coarse-grained materials | | | | | | | | | |
|--------------------------------|-------------------------------|------|------|------|------|------|------|-------|------|
| Relative density ^{1/} | N ^{2/} (blows/ft) | GW | GP | SW | SP | GM | GC | SM | ML |
| Tons per square foot | | | | | | | | | |
| Very loose | <4 | — | — | 0.50 | 0.50 | 0.25 | 0.25 | <0.25 | — |
| Loose | 4–10 | 1.75 | 1.75 | 1.00 | 1.00 | 0.50 | 1.25 | 0.75 | 0.25 |
| Medium or firm | 10–30 | 3.50 | 3.25 | 2.25 | 2.00 | 1.40 | 2.40 | 1.75 | 1.00 |
| Dense or compact | 30–50 | 5.25 | 5.00 | 3.75 | 2.25 | 2.80 | 3.50 | 2.50 | 1.75 |
| Very dense or very compact | 50+ | 6.00 | 5.75 | 4.50 | 3.25 | 3.50 | 6.25 | 3.00 | 2.00 |
| Fine-grained materials | | | | | | | | | |
| Consistency ^{1/} | N ^{2/} (blows/ft) | SM | SC | ML | CL | OL | MH | CH | OH |
| Tons per square foot | | | | | | | | | |
| Very soft | <2 | 0.25 | 0.25 | — | 0.25 | — | — | — | — |
| Soft | 2–4 | 0.50 | 0.50 | 0.25 | 0.50 | — | 0.25 | 0.25 | — |
| Medium | 4–8 | 0.75 | 1.00 | 0.75 | 1.00 | 0.25 | 1.00 | 1.00 | 0.25 |
| Stiff | 8–15 | 1.50 | 2.25 | 1.75 | 2.25 | 1.00 | 2.25 | 1.50 | 1.00 |
| Very stiff | 15–30 | 2.00 | 2.75 | 2.00 | 2.75 | 1.50 | 2.75 | 1.75 | 1.25 |
| Hard | 30+ | 2.50 | 3.25 | 2.50 | 3.25 | 2.00 | 3.25 | 2.25 | 1.50 |

^{1/} Relative density and consistency as related to standard penetration test (table 2-1) of saturated soils.

^{2/} Standard penetration test

Note that these are approximate values, are used only to guide investigation needs, and not for design criteria.

Borings for auxiliary spillway investigations must extend to a depth of not less than 2 feet below the bottom of the proposed auxiliary spillway. Investigations for rock excavation must be of sufficient detail to estimate quantities of rock that can be commonly excavated, ripped, or require blasting. This usually requires drilling equipment, even where delineation of the rock surface has been accomplished by using a bulldozer or backhoe. Material to be excavated should be carefully logged, noting any structural features such as:

- rock material strength
- weathering
- density of fractures (crushed, intensely fractured, etc.) (recorded as Rock-Quality Designation (RQD) in core samples)
- thickness of beds
- attitude, character, and condition of bedding and joint planes (type, shape, roughness, and type of infill such as clay, calcite, etc.)
- schistosity
- cleavage
- flow banding
- cavities and solution channels, and strength, degree, and kind of cementation.

These factors influence the method and cost of excavation. Under some combinations of these conditions, rock can be ripped and removed. Other combinations may require special equipment or blasting.

(8) Borrow area test holes

Proposed borrow areas are investigated to identify and classify the materials for quantity, location, and suitability for use in constructing the dam. From these investigations, the location and quantities of desirable materials and the areas in which borrow areas pits may be most conveniently developed can be determined. The location and approximate extent of any undesirable materials must be determined. Depth to groundwater, if reached, must be recorded. All borings should extend at least 5 feet below the expected depth of removal of material, unless consolidated material is encountered that is not suitable for use. Usually about three test holes per acre are adequate to determine borrow area suitability.

(9) Reservoir-basin test holes

Subsurface exploration may also be required in the reservoir basin, if water-holding is to be a function, and in the general area of the structure site. The location, number, and depth of these test holes depend on the specific problems to be assessed or solved. If cavernous or permeable strata are encountered that may adversely influence the functioning or stability of the structure, further investigations are needed.

(10) Foundation-drain and relief-well test holes

If permeable materials are encountered along the centerline of the proposed structure, foundation drains, relief wells, or both may be needed and their locations investigated. Relief wells are usually located at or near the downstream toe of a structure. Foundation drains may be located between the centerline and the downstream toe, depending on the specific problems and conditions. Foundation drainage methods and/or relief wells may be necessary to control uplift pressure, to facilitate consolidation, or to prevent piping. Deep foundation drains, consisting of trenches backfilled with properly designed filter materials, can be used as an economical alternative for relief wells. This method is suited to stratified or lenticular materials and where aquifers can be tapped feasibly by excavation.

(11) Stream-channel test holes

If the stream channel contains boulders, roots, debris, and organic matter, it may be necessary to remove these materials from beneath the structure as “special stream-channel excavation.” Usually, excavation is required to prevent leakage through the foundation, from the upstream toe of the structure to a point two-thirds of the distance from the centerline to the downstream toe. Channel investigations provide information on the depth, nature, quantity, and location of the deposits to be removed.

The stream channel may be a local source of sand or gravel for use in foundation drains, filter blankets, and roadways. The geologist should carefully log, sample, and compute quantities of these materials and their potential suitability, including anticipated washing and screening requirements.

(12) Other investigations

Test holes may be needed at other locations to determine the continuity of materials upstream and downstream throughout the foundation and reservoir area.

Information may be needed on the depth, nature, quantity, location, and extent of undesirable deposits within the foundation area, such as organic soils, liquefiable soils, very soft silts and clays, and boulders. Structural features, such as faults and contacts, may need to be accurately located and their attitude mapped through the site area.

(e) Report of detailed geologic investigation

The detailed geologic investigation report must clearly document the methods of the investigation and the information obtained, including copies of all field logs, maps, cross sections, and conclusions. The following outline can be used in preparing the narrative report.

(1) Geologic investigation report outline

I. Introduction

A. General

1. Date of exploration
2. Personnel engaged in exploration
3. Watershed (name and location)
4. Site number
5. Site group and structure class
6. Location
7. Equipment used (type, size, makes, models, etc.)
8. Site data
 - a. Size of drainage area above site (square miles and acres)
 - b. Maximum pool depth
 - (1) Sediment pool
 - (2) Flood pool
 - (3) Other pools
 - c. Structure
 - (1) Maximum height
 - (2) Length
 - (3) Location of spillway
 - (4) Volume of fill

B. Surface geology and physiography

1. Physiographic area
2. Topography
 - a. Steepness of valley slopes
 - b. Width of floodplain

3. Geologic formations and surficial deposits
 - a. Names and ages (e.g., Jordan member, Trempealeau Formation, Cambrian Age; Illinoisan till; Recent alluvium)
 - b. Description
 - c. Topographic position
4. Structure
 - a. Regional and local dip and strike
 - b. Faults, joints, unconformities, etc.
5. Evidence of landslides, seepage, springs, etc.
6. Sediment and erosion
 - a. Gross erosion, present and future, by source
 - b. Delivery rates
 - c. Sediment yield
 - d. Storage requirements and distribution
7. Downstream-channel stability
 - a. Present channel conditions
 - b. Anticipated effect of the proposed structure

II. Subsurface geology

A. Embankment foundation

1. Location and types of test holes and number of samples of each type collected
2. Depth, thickness, and description of pervious or low-volume-weight strata. Give detailed data on aquifers or water-bearing zones
3. Depth and description of firm foundation materials
4. Location, depth, thickness, and description of any questionable materials
5. Description of abutment materials, including depth and thickness of pervious layers or aquifers
6. Location, attitude, pattern, and other pertinent data on any geologic structural features such as joints, bedding planes, faults, and schistosity
7. Location of water table and estimated rate of recharge (high, medium, low)
8. Permeability of abutments

-
- B. Centerline of outlet structure
 - 1. Location and type of test holes and number of samples of each type collected.
 - 2. Depth, thickness, and description of pervious or low-volume-weight strata
 - 3. Depth and description of firm foundation materials
 - 4. Location, depth, thickness, and description of any questionable materials
 - 5. Location, attitude, pattern, and other pertinent data on any geologic structural features such as joints, bedding planes, faults, and schistosity
 - 6. Location of water table and estimated rate of recharge (high, medium, low)
 - C. Emergency or other open spillway
 - 1. Location and types of test holes and number of samples of each type collected
 - 2. Location, depth, thickness, and description of materials encountered, including:
 - a. Hard rock or unconsolidated material to be removed and volume estimated of each
 - b. Material at base of excavation
 - c. Any questionable material
 - D. Borrow area(s)
 - 1. Location of test holes and number and type of samples collected
 - 2. Location, depth, thickness, description, and estimated quantities of various types of material
 - E. Relief-well and foundation-drain explorations
 - 1. Location of test holes and number and type of samples collected
 - 2. Description of materials, including location, depth, thickness, and description of pervious strata
 - F. Other explorations
 - 1. Purpose
 - 2. Location of test holes and number and types of samples collected
 - 3. Description of materials
 - G. Water supply
 - 1. Available sources (farm ponds, rivers, wells, municipal, etc.) and quantity
 - 2. Quality of available water. If questionable, what samples were taken for analysis?
 - H. Construction materials (other than earthfill)
 - 1. Sources of materials for concrete aggregate, riprap, impervious blanket, wells, and drains
 - 2. Description, location, and estimated quantities of materials available
 - III. Logs. Attach completed copies of Form SCS-533 or equivalent
 - IV. Interpretations and conclusions ("For in-Service use only")
 - A. Interpretations
 - 1. Interpretations of geologic conditions at the site
 - 2. Possible relation of conditions to design, construction, and operation of structure
 - B. Conclusions. Geologic conditions that require special consideration in design and construction.
 - C. Attach completed copies of Forms SCS-35A, -35B, and -35 or their equivalent.
- (2) Report supplement for in-service use only**
 Record only basic data and facts in the geologic report. On request, this report is made available for inspection by non-NRCS interests. The report contains a section on interpretations and conclusions and should be labeled "For In-Service Use Only." Copies of completed plan and profile sheets for geologic investigations must accompany the report supplement. Geologic conditions must be documented for the site and their possible relation to the engineering feasibility of the site and to the design, construction, and operation of the proposed structure. Problems related to the geologic conditions must be clearly articulated, such as foundation weakness, seepage problems, excess groundwater during construction, difficulties of excavation, spillway problems, or problems concerning available borrow materials.
- The geologist should make specific recommendations in the report for alternative methods to address problems posed by the geologic conditions of the site. Recommendations might include suggestions to the design engineer on such items as alternate locations for the principal spillway, auxiliary spillways, depth of core trench, and depth of keyways into abutments.

The need for an impervious blanket, grouting, or other control of excessive water loss may also be indicated. Special problems should be highlighted that may arise during construction of the structure, such as difficulties in excavation and suitability of the excavated rock for use as riprap, sources of concrete aggregate, and recommendations on sources of water for construction.

631.0206 Minimum requirements for sampling and testing of structure sites

The intensity of sampling needed, like the intensity of site investigations, varies with design requirements. The minimum sampling and testing needs are identified by the geologist and design engineer, based on the complexity of the geology of the site, existence of geologic hazards for which specific design elements will be needed, and hazard classification of the structure.

Some samplers used for logging test holes furnish small disturbed samples that are adequate for laboratory testing; others do not. Undisturbed samples and larger or additional small disturbed samples of unconsolidated materials may be required for soil mechanics testing and analyses. See NEH 631.05 for a description of the various sampling methods, equipment, and sample size requirements.

(a) Sampling group A structure sites

Disturbed and undisturbed samples are taken of representative unconsolidated materials at the site. Rock core samples may also be needed as well. Representative samples for classification purposes should be taken of all types of materials in the borrow areas, foundation, relief-well, and spillway sections. Samples for compaction and shear tests should be taken from the borrow areas and auxiliary spillway areas.

Undisturbed samples should be taken for shear tests from all strata of fine-grained soils of questionable stability in the foundation within a depth equivalent to one-half the height of the structure.

Undisturbed samples should be taken for consolidation tests of all fine-grained materials of questionable stability within a depth equivalent to the maximum height of the structure. Where compressible materials extend to depths greater than the height of the structure, sampling depths must be increased. Questionable materials of low shear strength, such as soft clays and soft silts, should be sampled in the foundations of structures more than 25 feet high. Water supplies to be used for construction of the embankment or of concrete appurtenances should be sampled if high con-

centrations of salts (particularly sulfates and alkalis) or acids are suspected. Samples should be secured of all materials proposed for stabilization by soil cement or chemical methods.

Reservoir bottom and abutment materials should be sampled to determine reservoir-sealing requirements, if storage (other than sediment-pool storage) is part of the design and if moderate or serious leakage is suspected.

(b) Sampling group B structure sites

Representative samples should be taken for classification purposes of all types of materials in the borrow areas, auxiliary spillway, foundation, and relief-well sections. Samples for compaction tests should be taken from the borrow areas and auxiliary spillway areas.

Undisturbed samples for shear tests are required if questionable materials of low shear strength are encountered, such as soft clays and silts. Undisturbed samples may not be required for shear tests of foundation materials of embankments less than 25 feet high.

Samples for consolidation tests are required under the same conditions as those outlined for shear tests. If compressible materials are encountered, samples may be needed from depths greater than the equivalent height of the structure. The sampling requirements for permeability tests, water analyses, soil cement tests, and reservoir-sealing tests for structure sites in group B are the same as for structure sites in group A.

631.0207 Investigation of potential seismic hazards

Evaluation of seismic hazards must comply with local, State, and Federal laws and regulations. For non-Federal dams, the State dam safety office must be consulted to determine seismic hazard evaluation requirements.

(a) Fault rupture

Geologic investigations must document the existence or absence of faults classified as “Holocene-active,” with evidence of fault rupture within the past 12,000 years, or “conditionally active,” with evidence of Quaternary fault rupture ($<1.6\text{my}$), but its displacement history within the past 35,000 years is unknown. Dams are usually not located on Holocene-active faults, and high-hazard dams with permanent storage may not be located on conditionally active faults without specific design features that address potential fault movement.

(b) Earthquake loading

The effects of earthquake loading must be considered for all dams. As part of the reconnaissance investigation, the geologist and the responsible engineer must jointly determine if additional seismic analysis is required. Where State or local laws do not specify the scope of the investigation, the screening tool in table 2-5 may be used.

Where no method is specified, a probabilistic determination of minimum earthquake loading using the exceedance probabilities listed in table 2-6 may be used, assuming a shear-wave velocity that reasonably characterizes the site. Additional ground motion information is available through the [Pacific Earthquake Engineering Research Center \(PEER\) Ground Motion Database](#) (PEER 2011).

Where additional seismic evaluation is required, the geologist and responsible engineer must jointly determine sampling, testing, and other data requirements for a detailed earthquake loading analysis, which varies depending on the method and approach used. The method and scope of the analysis that is undertaken

as part of the geologic and engineering investigation of the dam site is a function of local and State laws and regulations, regional seismic hazards, the potential consequences of dam failure, and other site-specific characteristics that influence the performance of the dam under earthquake loading.

Where State or local laws and regulations require a particular method of analysis, that method must be used. Where no method is specified, a probabilistic determination of minimum earthquake loading using

the exceedance probabilities listed in table 2–6 may be used, assuming a shear-wave velocity that reasonably characterizes the site.

For significant or high-hazard dams, a site-specific seismo-tectonic study, performed in accordance with the “[Federal Guidelines for Dam Safety: Earthquake Analysis and Design of Dams](#),” (Federal Emergency Management Agency (FEMA) 2005) may be performed in lieu of using the loadings shown above, if allowed by State or local law.

Table 2–5 Seismic risk and evaluation screening tool for dam sites

| Probable ground acceleration (PGA) with 2% probability of exceedance in 50 years (%g) | Seismic risk | Hazard class (NEM Part 520, Subpart C, Dams) | Effective dam height (ft) | Additional seismic evaluation required? |
|---|--------------|--|---------------------------|---|
| <10 | Low | All | Any | No |
| 10 to <20 | Medium | Low | <35 ≥35 | No Yes |
| | | Significant | <20 ≥20 | No Yes |
| | | High | <20 ≥20 | No Yes |
| | | All | Any | Yes |
| ≥40 | Very High | All | Any | Yes |

Table 2–6 Exceedance probabilities by hazard classification

| Hazard class | Return period (years) | Exceedance probability |
|--|-----------------------|------------------------|
| Low | –1,000 | 5% |
| Significant | –2,500 | 2% |
| High (with no potential for loss of life from failure at permanent pool) | –5,000 | 1% |
| High (with potential for loss of life from failure at permanent pool) | –10,000 | 0.5% |

(c) Liquefaction

For dam sites where additional seismic evaluation is required, the preliminary engineering geologic investigation must include an assessment of liquefaction potential, including the following:

- historic occurrences of liquefaction in the dam site area
- geomorphic map that delineates active depositional areas, including stream channels, active floodplains, marshes, and estuaries, and inactive depositional units, such as older terraces
- highest groundwater level anticipated to occur, assuming as-built conditions
- distribution of surficial geologic units and soils, with an emphasis on Quaternary-age, unconsolidated to moderately consolidated deposits

A geotechnical field investigation must be conducted to support an engineering analysis of liquefaction potential if results of the preliminary assessment document the presence of any of the following conditions:

- Evidence that liquefaction has occurred during historical earthquakes.
- Uncompacted or poorly compacted fills containing liquefaction-susceptible materials that are saturated, nearly saturated, or may become saturated.
- Unconsolidated sediments in active depositional environments where the highest anticipated groundwater is less than 40 feet from the ground surface and the anticipated earthquake peak horizontal ground acceleration (PHGA), having a 10 percent probability of being exceeded in 50 years, is greater than 0.1 g.
- Moderately consolidated Holocene-age sediments in inactive depositional environments, such as terraces, where the shallowest anticipated groundwater is less than 30 feet from the ground surface, and the 10-percent-per-50-year PHGA is greater than 0.2 g.
- Late Pleistocene-age deposits that are approximately 15,000 to 12,000 years old, where the highest anticipated groundwater is less than 20

feet from the ground surface and the 10-percent-per-50-year PHGA is greater than 0.3 g.

The standard penetration test (SPT) is the preferred method for field testing of liquefaction potential. If other tests are used, they must be calibrated with SPT measurements taken from the project site.

631.0208 Geologic investigation during project implementation and construction (as-built)

Geologic materials become exposed during excavation of pipeline trenches, structure foundations, core trenches, auxiliary spillway cuts, and borrow areas. If an unanticipated geologic condition that requires design modification is encountered during construction of any NRCS project, structure, practice, or component, the responsible field person must notify the State conservation engineer (SCE) as soon as possible. The SCE determines the need for and secures the services of a qualified geologist to conduct a site assessment of the geologic condition and to provide interpretations and technical support for design or installation changes. Additional sampling and testing may be needed.

Documentation may also include revised geologic maps, cross sections prepared in earlier investigations, photos or video recordings, or supplemental topographic or geospatial positioning system (GPS) surveys.

631.0209 Investigations for repair, rehabilitation, and decommissioning of structures

Engineering structures and practices requiring repair or rehabilitation may need additional geologic information. Additional investigations may be required, beyond the scope of the original investigations, due to design changes required for a higher hazard class, changes in criteria or standards, anticipated changes in function, or other watershed alterations.

Engineering structures and practices selected for decommissioning may involve the complete or partial removal of a structure or a change in its original design function. Investigations of impoundment structures and practices selected for decommissioning must address the quantity, location, type, quality, and fate of deposited sediment that will be affected by the decommissioning project, either by capping, exposure to erosion and downstream transport, or sluicing, dredging, or excavation. Assessment must also include the potential effects of changes in the sediment-water balance on streams upstream and downstream from the reservoir sediment pool area.

Rehabilitation plans may include changing the function of the structure or reservoir, such as redesigning as a “dry” structure with no permanent water impoundment. Effects of such changes in function or purpose should be evaluated.

631.0210 Groundwater investigations

Groundwater conditions may influence the design, construction, and operation of a structure. Where groundwater is at or near the ground surface, special design features may be needed to ensure stability. In addition, special construction procedures may be needed. Shallow groundwater during the time of excavation may eliminate some areas from consideration as a source of borrow material.

If the water table is deep, obtaining adequate supplies of water to use in construction may be a problem. Artesian water may also create special problems (groundwater under pressure that rises up in a well, or may actually flow at the ground surface). Impounding water in the reservoir, even temporarily, may modify groundwater conditions. New springs may be created, the flow of springs within the reservoir area may be reversed, and springs may emerge at new locations. Additionally, unsaturated rock or soil materials may become saturated, significantly changing their engineering characteristics and behavior. Other changes in the location and movement of groundwater may occur.

Groundwater geology and groundwater hydrology guidance is found in NEH 631.30 through NEH 631.33 (USDA NRCS 2010b).

Investigation procedures

Springs and seeps must be identified and characterized at the structural site and in the reservoir area. Samples should be taken for analysis, and locations and elevations of springs and seeps mapped, noting source of the water, volume of flow, its quality, whether flow is perennial or seasonal, and location of the recharge area.

For all test holes, elevation of the water table must be recorded and plotted on geologic cross sections and profiles. Logs should specify at what depth free water is reached, or if artesian groundwater conditions are encountered. A water table (potentiometric surface) contour map may need to be prepared. Seasonal fluctuation of the water table and the source of this information should be noted. Water levels in test holes are

measured after one day to allow time for stabilization of the water level. All aquifers are logged, including information on the hydrostatic-pressure levels or flow volumes, if water flows from the test hole.

If permeable materials are discovered in the foundation, abutment, and reservoir areas, their locations, thickness, elevation, and continuity are determined. Where permeability is a critical factor, values for the coefficient of permeability are obtained either by field tests or by laboratory tests on undisturbed samples.

The following techniques can also be used to characterize groundwater conditions:

- dye tracers—water-soluble organic dyes, such as sodium fluorescein, have been used successfully to determine groundwater flow paths
- monitoring wells—used for short- or long-term determination of groundwater levels; some test holes may be secured as temporary monitoring wells as needed
- piezometers—measure pressure conditions for specific subsurface zones; are also used to monitor changes in pressure over time
- pressure tests—locate permeable zones
- pumping-in tests—determine the value of the coefficient of permeability
- pumping-out tests—reveal changes in water levels, springs, etc.

The following investigations or studies may be needed to provide information for planning, designing, and implementing structure, systems, and conservation practices:

- agricultural drainage and irrigation water management activities
- engineering drainage for excavation, dewatering of foundations, borrow areas, quarries, buildings, and mines
- seepage evaluations for blankets, drains, filters, and grouting
- engineering subsurface drainage for slope stability

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- groundwater conditions as part of a geological investigation of dam sites
 - engineering performance of conservation practices or components by employing groundwater quality monitoring, sampling, and testing methods, practices, or geophysical techniques according to appropriate ASTM standards
 - subsidence associated with groundwater withdrawal
 - influence of karst terrain on construction and performance of conservation practices and structures, including locating groundwater divides and delimiting recharge areas
 - evaluating potential for underground disposal of surface waters
 - evaluating potential for conjunctive use of groundwater with surface water supplies
 - determining aquifer boundary conditions and potential for well interference
 - evaluating groundwater quantity, quality, and geologic factors that influence design and construction of production wells and wellhead protection measures

To provide sufficient information for planning or design, the NRCS geologist investigates and evaluates the following:

- groundwater pollution potential of agricultural point and nonpoint sources, including components of agricultural waste management systems
- aquifer restoration or enhancement
- location, construction, rehabilitation, decommissioning, and problem investigations of water wells
- delimiting recharge areas in karst terrain and other highly solutioned geologic materials, and the influence of karst topography on construction and performance of conservation practices and structures
- areas having groundwater recharge potential
- locating groundwater divides and determining aquifer characteristics
- locating saline seeps and areas where they may develop
- areas with potential for saltwater intrusion
- evaluating groundwater development potential of aquifers
- conducting groundwater budget analyses in watersheds and evaluating groundwater overdraft potential
- estimating groundwater consumption or demand in watersheds

631.0211 Investigation of structural problems caused by erosion or sedimentation

Watershed geomorphic investigations may be conducted to support the planning, design, and evaluation of conservation practices. Investigations may entail, but are not limited to:

- assessing the relative impacts of historic and current land-use practices and significant natural disturbances (including flood events, wildfire, earthquakes, mining, land use conversions, etc.) on present, near-term, and future geomorphic processes, including sedimentation
- assessing the relative contributions of different processes (including sheet and rill erosion of upland slopes; erosion and hydrologic modification associated with roads, landslides, and other slope failures; streambank degradation or scour; floodplain scour; gullyng; etc.) and subregions in a watershed to average annual and event-based estimates of sediment yield
- evaluating the impacts of proposed and existing practices and management systems on upland erosion conditions, downstream sedimentation, and surface water quality

The scope and intensity of geomorphic investigations must be consistent with the geomorphic complexity of the study area; pertinent social, economic, and safety considerations; and the purpose and complexity of the structure, practice, or project.

Methods for determining watershed sediment yield are provided in the NEH section 3, chapter 8 (USDA NRCS 1983), and may include an analysis of reservoir sediment survey results. Geomorphic processes, including sediment and debris production, transport, and deposition, are spatially and temporally variable and complex and are difficult to quantify in an absolute sense. Other methods not described in the NEH section 3 may be considered at the discretion of the investigating geologist.

A report of investigation must be written and submitted that summarizes observations, methods used, assumptions, conclusions, and recommendations.

If structural problems are caused by erosion or sedimentation, an engineering investigation may be conducted at the discretion of the State conservation engineer (SCE). For example, excessive sediment accumulations in a pond, reservoir, or other sediment-retaining structure may exceed the designed rate, and may result in functional limitations during the structure's design life. The investigation must address the extent of the problem, identify the causes of the increased sedimentation rate, and outline possible solutions.

A sedimentation study is also required during engineering investigations of structural problems caused by channel instability.

631.0212 Watershed sediment yield studies for structures and conservation practices

Watershed sediment yield studies, including the development of watershed sediment budgets, are conducted to evaluate the effectiveness of land treatment and structural measures in controlling erosion and reducing sediment yield and related damages in the treated area. These studies also provide basic data for the planning and design of soil and water conservation measures and programs.

Watershed sediment yield studies are also undertaken to support sound engineering design of all dams and of other sediment- or water-control structures where erosion, transport, and sedimentation processes potentially impact feasibility, design, or performance. Numerous empirical and theoretical methodologies and models have been developed to estimate average annual and event-based sedimentation rates, which in part reflects the large spatial and temporal variability and complexity of erosion, transport, and sedimentation processes. Sound technical judgment, therefore, is requisite in the consideration of process relationships, the selection of field techniques to be used in studies, and the formulation of hypotheses.

Methods for determining watershed sediment yield are provided in the NEH section 3; ASTM D6145 Standard Guide for Monitoring Sediment in Watersheds; and other appropriate ASTM standards related to sediment studies.

Results of reservoir sediment surveys, including published results of previous surveys, or surveys conducted as part of the geological investigation for a project site, provide valuable data that may be used to estimate watershed sediment yield in support of dam and embankment structure design.

(a) Reservoir sedimentation surveys

Reservoir sedimentation surveys may be conducted as part of the geological investigation of existing or proposed dam sites to help determine sediment storage criteria and predict sedimentation impacts on other components of design and performance. Reservoir

sedimentation surveys of NRCS National Conservation Practice Standard (CPS), Code 378, Ponds must be conducted by personnel trained in performing such surveys. Surveys of group A and B structures and CPS Code 402, Dams must be conducted or supervised by a qualified geologist. The [Reservoir Sedimentation Survey Database \(RESSED\)](http://ida.water.usgs.gov/ressed) (ACWI-SOS 2011) is available online at <http://ida.water.usgs.gov/ressed>.

Reservoir sedimentation surveys may also be conducted as part of geological investigations to support proper planning and design of ponds and other embankment structures or for other purposes as directed by the SCE.

Sedimentation surveys must conform to procedures in the NEH section 3, and to the appropriate ASTM standards. Sound technical judgment is required, and industry standards will be used at the discretion of the investigating geologist. The data collection format must conform to ASTM D4581, Standard Guide for Measurement of Morphologic Characteristics of Surface Water Bodies.

Reports for each reservoir sedimentation survey must be prepared according to requirements in the NEH section 3, and must include data on watershed conditions that affect sediment yield, including soils, surface geology, topography and land forms, land use and treatment, and all types of significant erosion. The report must include information about land-use management changes through time in the contributing watershed.

(b) Sediment storage design for reservoirs and ponds

Sediment storage allocations are provided by the geologist to the design engineer as part of the geologic investigation of dam sites as described in NEM 531.32D. The investigating geologist, in consultation with the design engineer, must use methods in NEH Section 3, Chapter 8, Sediment Storage Design and Criteria. Other methodologies that are more appropriate to the region may be applied if approved by the SCE.

Sediment storage criteria may also be developed for embankment and other low-hazard water- or sediment-control structures where sedimentation potentially impacts planning, design, or performance. The criteria

may be developed by the person holding the appropriate job approval authority for the practice or as directed by the SCE. A geologist must be consulted in areas where experience or information is limited, or geomorphic conditions are complex.

631.0213 Stream channels and stream corridors

Geomorphic investigations of stream corridors are conducted to support the planning, design, and implementation of streambank stabilization and fluvial geomorphic restoration practices and projects. The complexity of fluvial geomorphic processes necessitates an interdisciplinary approach to assess stream form and function and may include input from or consultation with geomorphologists, hydrologists, geologists, biologists, soil scientists, and engineers.

The science of fluvial geomorphology is still developing, and numerous methods are available for investigating and assessing stream systems. They vary considerably in the information they provide, the information they require, the spatial and temporal scales they consider, and the complexity, expertise, and resources required for their use. To be successful, any method's design recommendations must take into full consideration the fundamental principles and modern theories of fluvial geomorphology, particularly the dynamic equilibrium of a stream, and balanced with sound engineering applications and principles.

Fluvial geomorphic investigations may include analyzing sediment transport capacity of the channel, determining change in transport capacity caused by the planned modification, and determining bedload sediment sources. Stream channel investigations may consider the dimension, pattern, profile, and other pertinent geomorphic factors of the stream, as well as activities in the watershed that can affect sediment supply and subsequent stream channel behavior and stability.

A stream assessment generally includes data collection, a process-based identification of potentially destabilizing factors, and a determination of the equilibrium stage of the stream. The equilibrium stage of various stream reaches and the changes occurring in the stream system must be accurately assessed to allow for the prediction of a proposed project's impact on stream geomorphology, on the equilibrium of the system, and the impact the natural processes will have on the functionality of the project.

Stream channel classification, analyses, and interpretations for predicting the behavior of the channel and riparian area that have alternative designs take into full consideration fundamental principles and modern theories of fluvial geomorphology.

Recommendations for design must give full consideration to channel stability concepts for natural streams that allow a stream to develop a dimension, pattern, and profile that will be in dynamic equilibrium over the life of the project.

NEH 653, Stream Corridor Restoration—Principles, Processes, and Practices, contains background information on stream corridors, their processes, characteristics, and functions (Federal Interagency Stream Restoration Working Group (FISRWG) 1998). It contains guidance on the development of a stream corridor restoration plan, and on applying restoration principles.

Technical guidance and detailed procedures for stream assessments, principals of channel design, and treatment techniques for streambank stabilization are provided in NEH 654, Stream Restoration Design Handbook (USDA NRCS 2007).

631.0214 References

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