SUSITNA HYDROELECTRIC PROJECT

1982-84 GEOTECHNICAL PROGRAM

SUBTASK 5.07 REPORT

DRAFT

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SUSITNA HYDROELECTRIC PROJECT
DESIGN LEVEL GEOTECHNICAL INVESTIGATIONS PROGRAM

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1 - GEOTECHNICAL INVESTIGATIONS PROGRAM GOALS

1.1 - Design Level Program Goals

(a) Program Philosophy

The preparation of a geotechnical investigation program on the design level is set forth as subtask 5.07 under the Plan of Study for the Susitna Hydroelectric Project. The stated scope is to accomplish:

> "Design of the geotechnical exploratory investigations program for 1982-1984 to obtain basic design data for Watana damsite, dam construction materials and reservoir area, and for the selected access road and transmission line routes."

In order to accomplish this scoping task, an integrated look at total design data requirements was necessary. The work scoped as the 1982-84 activities represents the total design level geotechnical data collection program up to award of contracts for construction, but does not include such items as test fills, excavation stability monitoring, and pre-production placement condition testing; which properly falls under construction monitoring and design parameters verification costs. For this reason, the program outlined below has been designated the Design Level Geotechnical Investigations Program to distinguish it from the other various phases of investigations (Figure 1.1).

The schedule of geotechnical activities has been based on the preliminary engineering design and construction schedule presented in Plate 16 of the Feasibility Report Summary, March, 1982. Changes in this schedule may have a major impact on geotechnical activities. Similarly, the program presented in this report assumes that overland access will be restricted during 1982-84; thereby limiting the type of equipment to be used, as well as the field program planning.

The Design Level Geotechnical Investigations Program has been developed to expand the feasibility level information into a complete geologic, rock mechanics, and physical model of appropriate detail to support detailed engineering and design on the Susitna Hydroelectric Project. For simplicity and appropriate distinction between various aspects of the project, the program scope has been separated into four distinct and essentially independent areas of investigation:

- Watana damsite and reservoir;
- Devil Canyon damsite and reservoir;
- Access routes; and
- Transmission corridor.

This breakdown is appropriate because it reduces the scope into areas of activity that may be conducted independently. It also represents a logical separation in planning and supervision both in terms of geographic locale and of probable phasing of the work to correspond to varying start-of-construction dates in the overall project schedule.

(b) Data Uses

The overall program for design level investigations will provide information for a number of design and planning activities, a representative list of which is given below:

- General arrangement adjustment;
- Feature design and optimization;
- Construction quantity and cost optimization;
- Alternative technical factor selection;
- Facility design and construction method simplification and value engineering;
- Environmental impact assessment and mitigation design; and
- Responding to public inquiry and concern.

(c) Previous Explorations

Previous explorations at the Susitna sites are documented or referenced in the 1980-1981 Geotechnical Report. The future investigations will supplement and expand upon this previous work. Previous investigations included geologic mapping, subsurface exploration in overburden and rock, seismic surveys, down hole testing, and laboratory testing of rock and soil samples. The information gathered so far has been sufficient in proving the feasibility of the project, but further explorations are necessary for design and construction of the facilities.

(d) Constraints

(i) Schedule

The investigations will be split into two stages. Stage I, conducted in Fiscal Year 1983 (July, 1982 - June, 1983), will enhance understanding and data on general geology of the Watana site. Details of this program are summarized in this report and further defined in Fiscal Year 1983 Geotechnical Exploration Program. This will enable arrangements and layouts to be optimized and confirmed. Investigations for final design of the Watana features (Stage II) will provide specific design data for structures at specified locations, data for detailed estimates, and data for the construction schedule; as well as providing all the layout and design geotechnical data for those construction items which are not on the critical design schedule; such as camp facilities, emergency spillway, switchyard, and site contruction roads. Due to the scheduling constraints, the two stages will not be distinct but will tend to overlap, with the 1982-1983 program providing the basis for layout of the subsequent explorations in the critical areas as shown on Figure 1.2.

The preliminary schedule is based on a preliminary construction activities schedule as presented in the Feasibility Report Summary, and as shown in Figure 1.3.

(ii) Budget

An inherent constraint with the geotechnical program is budgetary limitation and the fiscal year basis of funding. Funding for the project is based on a 12 month fiscal year ranging from July 1 to June 30. The fiscal year ends in the middle of the summer field seasons. Therefore, detailed planning and scheduling must be allowed for to insure that site activities are not restricted due to budgetary limitations during the prime good weather months.

The total budget will have to include all design level geotechnical activities through preparation of bid documents, which might, depending on project schedule, run into FY85 for some activities at Watana. Clearly, a large portion of the site access and virtually all the Devil Canyon and transmission design will be conducted after 1984 because the schedule does not require this data at an early date.

(iii) Access and Weather

This investigation program is planned on the assumption that access roads to the damsite will not be constructed until after the FERC license is granted, and that overland movement of vehicles and equipment is limited to the winter period when the thickness of frozen ground and snow cover is acceptable to the U.S. Bureau of Land Management and any other responsible regulatory agency. Therefore, the program takes into account the restrictions this imposes on the investigation by limiting the type of equipment that can be used onsite, which will reduce efficiency of onsite geotechnical work. These restrictions will increase costs due to continual helicopter support requirements, increased unproductive time during drill rig moving, winter work loss of productivity, and limitation of the program flexibility in locating explorations.

1.2 - Investigative Procedures

(a) Investigative Methodology

The methodology for the investigation program has been developed with four primary considerations in mind:

- DATA INTEGRITY, to assure accuracy and standardization of information.

- MAXIMIZATION OF FEATURE DETECTION probability, both of anticipated and unexpected features with emphasis on collection of fully descriptive data at each significant feature.

- PROGRAM FLEXIBILITY, to increase or decrease committment to a particular feature based on the ongoing interpretation effort.

- FISCAL CREDIBILITY, both in terms of data received for dollars spent in investigations, and in terms of dollars spent in the investigations as compared to the sensitivity of the project schedule or construction cost to potential variability in the geotechnical condition explored.

These considerations are discussed in the following sections and are reflected in the explorations methodology shown in simplified form on the Explorations Program Development schematic (Figure 1.4).

(i) DATA INTEGRITY - The criteria of ensuring accuracy and standardization of information introduces several equipment and support requirements. The basic primary approach to this criteria is use of a detailed field procedures manual and specific forms to guide the data collection activities. Other standardization will be instituted in the following areas:

- Utilization of current nationally accepted standards of testing and measurements, both to facilitate understanding of the results and to ensure uniformity of sampling and testing procedures, and thereby, site-wide comparability of results.

- Use of adequate sampling and testing methods that will accurately define site geotechnical conditions, with particular attention to effect of sample size on data results.

- Training of field personnel to ensure conformity of field procedures and data collection.

- Standardization of reporting format and forms to serve as a guideline to data collection.

- Adequate amounts of testing to provide a valid data base for analysis of expected variability of in-situ conditions, and to provide a data base against which individual results can be tested to detect anomalous results, results which have been inadvertantly included in the wrong data set, or that are a result of errors in field sampling procedure.

(ii) The MAXIMUM OF FEATURE DETECTION methods involves use of a variety of data collection and reduction means ranging from visual observation through precise field and laboratory instrumentation. The various means of investigation which may be used are described in Section 1.2(b), broken down into four general classes by level of sophistication (Figure 1.5). Basically, the Reconnaissance and Primary means have been utilized in prior investigations at the sites, and will be used throughout the continuing program to evaluate areas not covered in the pre-design level work and to obtain additional data density in the existing work areas. The Advanced Explorations can provide more representative data, data from locations where Primary exploration is prohibitively expensive or does not provide adequate information, and to detect properties of materials which can only be measured through use of more sophisticated means and equipment. The Special Techniques include sophisticated and highly specialized means that can provide the desired information where other methods fail. The Special Techniques, in many instances, may not be required at all on the project. This systematic procedure of data collection, by combining progressively more advanced explorations with concurrent data reduction, will increase the efficiency of the exploration and interpretation activities.

(iii) The development of PROGRAM FLEXIBILITY requires procedures for program planning and field operations which minimize the chances of failing to observe or sample significant features, without committing resources in excess of those necessary to obtain the required information. The basis for this goal is sequential development of the interpretation model utilizing the results of the existing data at each phase. Continuing effort will be made to assess the potential of additional data collection efforts, detecting additional features or obtaining the more detailed and precise information needed in design.

The combination of phased explorations, utilizing increasingly sophisticated methods in each subsequent phase, allows checkpoint review of the exploration effort being expended versus the information being obtained. In most instances, preliminary contact with a specific feature or material has been achieved in Reconnaissance or Primary stage explorations, and based on the results of that work the proper level of investigation can be determined at this time for production of design level data.

For optimization of the overall exploration and geotechnical design program, a large degree of flexibility in field equipment and schedule is desirable, and with the magnitude of program required on this size project, the adaptability and flexibility of the primary exploration equipment may be increased by three primary procedures:

- Selection of versatile equipment;
- Augmentation with additional resources and specialized tools and equipment; and
- Onsite availability of a diverse selection of equipment.

By having diverse and versatile equipment onsite and supplementing this with significant backup and support tools and facilities, the large-scale program will inherently have the physical flexibility to adapt to unexpected conditions that may be encountered. The field supervision will then operate under the program procedure to adapt to various conditions through the following options:

- Modification of data collection method;
- Selection of alternative equipment;
- Repositioning of exploration sites; and
- Selection of a different level of sophistication.

(iv) The FISCAL CREDIBILITY of the explorations programs is being incorporated through four basic means, all of which are based on the utilization of composite data reduction with a methodology to maintain all field data compilations up to date with the exploration program progress, as outlined in Section 1.2(c). The four means of control in the planning are:

- Use of the progressive levels of exploration sophistication to utilize only as complex and expensive a method as is called for to obtain the desired information.

- Use of a staged exploration scheme which will utilize the simpler and, therefore, less expensive methods for initial target definition, thereby saving the detailed methods of investigation for areas that have been definitively located and determined to be critical. Ideally, each stage of exploration will progress concurrent with the design stages to provide the level of information that is consistent with requirements for design criteria.

- Combination of detailed and general investigations to provide very specific information at critical control points, with less specific confirmatory data to fill out intervals between the detailed data points and to provide basis for extrapolation while still maintaining confidence in the final model.

- Assessment of the sensitivity of project schedule or cost to the geotechnical data on any specific feature, with the intent of weighting the exploration expenditures in favor of those features or considerations which have the greatest potential impact. A detailed risk analysis or least cost sensitivity matrix analysis would not be justified, either on the basis of the man-hours it would take to develop and monitor, or considering the complexity and diversity of geotechnical conditions. However, a subjective and estimate level objective assessment of construction sensitivity to various parameters will be utilized to assess the merits of additional or more sophisticated studies.

(b) Methods of Exploration

The diversity of exploration methods that can be used to obtain geotechnical data is limited only by the cost effectiveness of the systems. Because of the wide range of conditions and factors being investigated on the project sites, this section will present a summary of the various methods, their uses, and the applicability of the methods, in general, to the project. The specific design feature scope statements will be presented in subsequent section as a set of summary sheets showing which methods of exploration are anticipated for use on each feature.

As discussed in Section 1.2(a), (i), and (ii), the geotechnical program has been planned on the basis of four general levels of sophistication in data collection, and use of standardized testing and sampling procedures. The levels of exploration studies are:

- Reconnaissance Level studies which serve to give an overview of work requirements and the best techniques to be used for obtaining the desired information. They also serve as the basis for locating most Primary Investigations.

- Primary Investigations, which includes most of the traditional means of drilling and geologic mapping, and includes routine "disturbed" sampling" and testing, and laboratory testing usually associated with routine geotechnical design.

- Advanced Explorations include the sophisticated down hole and laboratory testing techniques, "undisturbed" sampling, in-place testing methods, and the specialized drilling and sampling techniques for penetration of zones which cannot be routinely sampled, or in which normal "primary" sampling methods are not effective. These methods also include the more sophisticated, yet commonly available remote sensing and profiling methods for surface detection of subsurface conditions.

- The Special Techniques include those methods or equipment which are either prohibitively expensive or too time consuming for conventional use, but produce the detailed or sophisticated information needed for a detailed understanding of conditions, and are used on features or materials which are critical in development of design criteria or design solutions.

Each of the different generic types of exploration activity can be broken down into this expanded level of sophistication system (Table 1.1). The generic types of activity to be utilized are determined through use of the systematic exploration program development methodology (Figure 1.4) and can include any of the various detailed techniques and variations shown on Table 1.2. These specific and trade-name techniques can be combined into generic subsets, each of which includes a set of specific applications which introduce similar levels of sophistication or expense. By assessing the potential significance of the geotechnical feature being explored, one can use the risk reduction or potential savings from availability of the data to define the level of sophistication (and, consequently, the exploration cost) which is appropriate to that feature.

(c) Data Reduction and Compilation

Data reduction and compilation is the single most critical activity involving office and field staff coordination because unless the data is reduced, compiled, and summarized properly, the significance and validity of the field data can easily be lost or misrepresented. This common problem can be minimized through use of comprehensive data collection forms that eliminate the need for office "interpretation" of the data itself. Use of such forms and record keeping procedures places the total responsibility of accurate data taking with the field or laboratory personnel, so the office personnel can then concentrate on defining data relationships and correlations which will extend the understanding of the geologic model. Therefore, the data collection procedures will be conducted in accordance with the applicable procedure manual or standardized test procedure, and the flow of information and check procedures will be in accordance with the flow diagram on Figure 1.6.

The field sampling and laboratory testing procedures will be conducted, to the greatest extent possible, in accordance with the American Society for Testing and Materials (ASTM) annual books of standards.

Where ASTM standards or guidelines are not available or adequate, the following organizational standards or procedure manuals will be applied:

(i) American Association of State Highway and Transportation Officials (AASHTO).

(ii) U.S. Army Corps of Engineers, Office of Chief of Engineers (COE) Design Guides, Engineering Manuals, and Standard Specifications.

(iii) U.S. Bureau of Reclamation (USBR) Design Standards and Engineering Monograph Guidelines.

(iv) U.S. Bureau of Land Management (BLM) Technical Bulletin Guidelines and Procedures (alluvial and placer deposit sampling and reserve calculations).

(v) U.S. Bureau of Mines (USBM) testing procedures and reserve calculation methods.

The particular parameters which may be tested are presented in Table 1.3. Each feature or project aspect (Sections 2-5) also references summary tables of anticipated testing, broken out by purpose and applications.

(d) Interpretation and Reporting

The interpretation and reporting procedures from the crux of the design parameter definition process. Since the level of geotechnical effort to accurately define the geotechnical subsurface conditions at the site is unknown, the interpretive technique(s) that can best be applied cannot be clearly specified at this time. Therefore, only a guideline list of possible correlations can be developed, with the intent of investigating the validity of these potential correlations, as the detailed data is received. A partial matrix of possible relationships that may apply at a particular feature or area is presented on Table 1.4. Adherence of the data to any of these relationships will be tested statistically in the final interpretation, with initial apparent relationships being developed from the field and office working media shown on Table 1.5. In many instances, correlations may appear by coincidence due to the local conditions but would not be expected to prevail site-wide, while other correlations which might be expected may not appear in the analysis due to local site variability, erosional history, or other transient influences. In most cases, the correlation matrix method will be used to point out relationships of apparent significance which might merit further interpretation or investigation, rather than to form a primary basis of conclusions.

Report presentation will emphasize the pertinent relationships derived in the interpretive process, with the majority of the data being prepared in graphical or tabular format. Emphasis will then be placed on descriptive text utilizing extensive cross-referencing to the location figures, tables, and correlation graphs used to develop the interpretation.

TABLE 1.1: EXPLORATION METHODS

GENERIC ACTIVITY	LEVEL OF SOPHISTICATION: RECONNAISSANCE	PRIMARY	ADVANCED	SPECIAL	NOTES
SURFACE & SAMPLING:					
Geologic Mapping	Aerial overflights or spot field walk-over, air photo interpretation.	Air photo interpretation, and tape and brunton traverses.	Survey controlled detail feature mapping and photography.	Telephoto mosaic, full surveyed grid system, large-scale mapping.	Primary level normally adequate for general mapping.
Remote Sensing of Surface Features	Uncontrolled air photo mosaic evaluation.	Controlled air photo study, transfer to base map by air photo interpretation methods.	Satellite imagery, airborne radar, infrared photography.	Advanced satellite, low-level multi-special scanning; low-level towed airborne detectors.	Advanced stage usually reserved for hard to detect critical features. Special rarely used in geotechnical work.
Remote Sensing for Evidence of Subsurface Features	Standard 9 x 9" air photos - color or black and white, map lineament studies.	ERTS Satellite, SLAR, low-level photography, thermal thematic mapping.	Profiling radar, non-visible band imagery - airborne or ERTS.	Surface radar, magnetometer, gravimeter.	Advanced stage usually reserved for hard to detect critical features. Special rarely used in geotechnical work.
Feature Location Surveys	Field-pick on air photos or USGS 1 inch = 1 mile maps.	Air photo panel or tape and Brunton, compass resection.	Survey instrument, stadia/resection survey.	Grid control survey with large-scale mapping.	Level normally progressively increases from reconnaissance through construction.
Borehole/Explorations Location Surveys	Field-spot on air photos or topographic maps.	Stadia/intersection survey; tape and Brunton, air photo panel location.	Full transit or EDM survey.	Theodolite/high precision EDM survey; auto-surveyor.	New precision equipment frequently cheapest.
Hydrographic/River Cross Section Surveys	Scale from air photos and maps.	Field survey by soundings.	Seismic sonar profiling.	Sonar/radiometric grid or blanket surveys.	Soundings and sonar profiling usually adequate.
Quarry Material Location	Geologic mapping air photo interpretation.	Hand dug samples, face exposure channel samples.	Test blasts, laboratory tests.	Systematic geochemical, media separation method sampling.	Geotechnical level seldom exceeds the advanced phase.
Borrow Material Location	Geologic mapping air photo interpretation.	Hand dug test pits and channel samples.	Bulk sampling - test trenches.	Systematic geochemical, media separation method sampling.	Geotechnical level seldom exceeds the advanced phase.
SUBSURFACE:					
Stratigraphy, Bedrock Location	Outcrop mapping, probe holes.	Seismic, resistivity, drilling, test pits or trenches.	Shafts, adits, large-diameter borings.	Radar, down hole geophysics.	Primary usually limit of methods used.
Rock Quality Determination - Shallow	Surface outcrop sampling.	Core drilling, probe holes with bottom grab samples, seismic methods.	Shaft, test trench or large diameter boring, geophysics.	Down hole rock mechanics instrumentation, advanced borehole geophysics.	Level usually advances through reconnaissance to final design programs.
- At Depth	Inferred from surface geologic mapping.	Rock coring, drill hole logging.	Down hole camera, geophysical logging, downhole rock mechanics instrumentation.	Down hole logging* and instrumentation, adits and shafts, in-situ testing.	*See logging and instrumentation summary.
Damsite & Quarry Sampling - Shallow	Outcrop sample collection.	Surface geophysics, percussion probe holes.	Test trenches.	Trial blast.	Normally limited to primary methods.
- At Depth	Inferred from surface mapping.	Rotary core boring.	Pattern core boring.	Trial blast, large diameter bored shafts or calyx holes.	Level advances through reconnaissance to final design programs.
Overburden & Borrow Material Sampling - Shallow	Exposure sampling.	Auger sampling, test pitting.	Large test trenches.	Trial excavation face.	Level depends on exposure availability.
- At Depth	Inferred from surface mapping.	Auger or small diameter rotary borings.	Bucket auger, large reverse circulation borings, down hole geophysics.	Trial shaft/caisson.	Level depends on exposure availability.
Borrow Material Extent, Quality at Depth	Inferred from geologic mapping, interpretation.	Surface geophysics, probe borings.	Large diameter borings, large test pits.	Shafts, exploratory development.	

* See instrumentation and testing interpretation.

TABLE 1.1: EXPLORATION METHODS (Cont'd)

GENERIC ACTIVITY	RECONNAISSANCE	PRIMARY	ADVANCED	SPECIAL	NOTES
	LEVEL OF SOPHISTICATION				
INSTRUMENTATION & TESTING:					
Water Table Detection	Surface waters reconnaissance.	Resistivity probes, standpipes, air lift recovery.	Piezometers.	Dielectric, sonic probes.	
Water Table Monitoring	Surface reconnaissance photography.	Floats, standpipe measurements.	Piezometers.	Electric, nuclear recorders.	
Water Quality Testing	Surface sampling.	Bailing, pump samples.	Electric meters.	Continuous automatic sampler.	
Ground Water Flow Measurement	Surface mapping.	Dye tracing, piezometers.	Downhole flow tracer (flowmeter).	Radionuclide tracing, integrated analog coupled piezometers.	
Permafrost Detection	Thermometer on surface materials and water, inferred photography.	Visual/thermometer on recovered boring samples, down hole probes.	Multi-point thermistor strings, infared scanning.	Automatic continuous reading system of thermistors.	
Thermal Monitoring	Repetitive thermometer readings.	Thermal probes.	Thermistors.	Automatic continuous reading system of thermistors.	
Thermal Properties Determination	Based on material type, gradation.	Disturbed sample laboratory testing.	In-place thermistor evaluation, undisturbed sample laboratory testing.	Continuous profile recorder data regression analysis.	
Permeability	Based on material type, gradation.	Standard casing or packer testing.	Grouted packer or well screen testing.	Large-scale aquifer pump testing with multiple holes and observation system.	
Groutability	Estimate based on material gradation, fracture frequency.	Based on permeability, single-hole test grouting.	Multiple-hole test grout program.	Full-scale test with subsequent coring, excavation to check effectiveness, losses.	
Geologic Age Determination	Based on published geologic history of area.	Based on mapped stratigraphy.	Radio carbon, Potassium-Argon, Strontium dating.	Remnant magnetism, salt concentrations, radio-isotope concentration and ratio comparison.	
Stratigraphy - Horizons	Inferred from geology, surface samples, standard drive samples.	Inspection of recovered samples.	Resistivity, gamma logging.	Down hole photography.	
- Density	Inferred from geology, surface samples, standard drive samples.	Drilling, surface geophysics, standard drive penetration.	Neutron density (gamma).	In-situ sampling.	
- Moisture	Inferred from geology, surface samples, standard drive samples.	Recovered samples.	Spontaneous seismic, resistivity, gamma.		
- Continuity	Inferred from geology, surface samples, standard drive samples.	Multiple drill holes with testing of recovered samples.	Cross-hole seismic, resistivity, gamma.	E-M induced current, cross-hole radar, radio.	
- Chemistry		Recovered boring, ground water samples.			
Boring - Inclination	"Pajari", single-shot camera.	"Acid Bottle" or inclinometer.	Electric inclinometer.	Gyroscopic surveyor.	
- Direction	Single-shot compass camera.	Inclinometer.	Electric down hole compass.	Gyroscopic surveyor.	
- Condition	Caliper log, resistivity, gamma logs.	Borehole camera.	Acoustic profiler.	Down hole displacement probe, down hole radar.	
Rock Fractures/Joints	Recovered core, outcrops.	Borehole camera/video.	Caliper log, acoustic profiler.	Down hole radar, acoustic profiles (SCAT), X-ray diffraction.	
Rock Properties	Recovered core, outcrops.	Laboratory testing of recovered core, down hole seismic, gamma logging.	Goodman jack, CSM or plate jack, cross-hole seismic.	Hydrofracturing, overcoring.	

* See instrumentation and testing interpretation.

TABLE 1.2 - DETAILED EXPLORATION METHOD BREAKDOWN

1. SURFACE OBSERVATION

MAPPING
- Air photo base field mapping
- Detailed base map field mapping
- Plane Table
- Tape & Brunton/studies mapping
- Theodolite/precision survey mapping

REMOTE SENSING
- Vertical, high and low oblique, horizontal surface controlled and uncontrolled photography
- Tele-photo or photo-transit ground photography
- Satellite imagery/multi-spectral thematic scanner
- Aerial narrow-band scanner
- Towed magnetic, gravity, radioactivity, gas detectors
- Aerial strip, side looking, integrated scanning radar
- Airborne thermal infared imagery, thermal thematic mapping

2. DRILLING

PLUG/PROBE
- Rotary drag or tricone drilling
- Rotary-percussion (blast drill)
- Percussion (airtrack, jackhammer)
- Wash boring
- Jetting/chopping jet drilling

OVERBURDEN SAMPLING
- Spiral or single flight augers
- Hollow stem augers
- Bucket auger
- Reverse circulation rotary
- Reverse circulation rotary-percussion
- Churn
- Rotary coring
- Spoon and tube sampling
- Rotary drive barrel sampling
- Penetratometer/vane shear testing

CORE
- Rotary carbide or diamond
- Hollow stem drive cores
- Calyx
- Reverse circulation "air lift" coring

3. EXCAVATION

TEST TRENCH
- Test trench - hand
- Test trench - dozer, backhoe, dragline
- Test trench - chain or belt excavator
- Test block - in-situ hand excavated
- Test block - sawed or sliced

TABLE 1.2 (Cont'd)

TEST PIT/BLAST	- Hand dug sample pit - Machine sample test pit - Explosives sample test pit - Hand dug "channel" or "block" sample - Machine excavated rock face - Test blast
CAISSON/SHAFT	- Hand-dug - Backhoe/clamshell - Drilled/raise based - Mechanical drill/blast/muck - Caisson - Bucket auger - Calyx
ADIT	- Exploratory adit - Drilled access

4. SURFACE GEOPHYSICS

- Seismic refraction
- Seismic reflection
- Resistivity
- Sonar/sonic profiling
- Magnetometer
- Gravimeter
- Radar
- Radiation detection
- Gas sensors

5. PERMANENT DOWNHOLE INSTRUMENTATION

THERMAL	- Thermocouple/thermistor strings - Thermistor probe standpipes - Recording thermometer
PIEZOMETRIC	- Standpipe - Pneumatic - Electric, dielectric - Nuclear probe - Mechanical float - Continuous automatic sampler
DEFORMATION	- Inclinometers - Extensometers, borehole - Borehole deformometers - Adit/opening extensometers - Seismometer - Impression packers

TABLE 1.2 (Cont'd)

6. DOWNHOLE TESTING

WATER LEVEL	- Manual "plunking" - Air lift - "M" scope (resistivity, ion detection) - Piezometer - Sonic probes - Bailing - Imagery (see following) - Visual/mirror
PERMEABILITY	- Open hole tests - falling head; constant head; rising head; pump recharge - Packer pressure testing - Cross-hole dye/radionuclide testing - Downhole borehole flow meter - Coupled piezometer readings - Electro-magnetic induced current
SEISMIC VELOCITY	- Single point "P" wave - Single point Shear ("S") wave - Multi-point "S" wave - Cross-hole seismic
IMAGERY	- Borehole camera-single shot ("bullseye"); reel or circumferential (conventional); video; television - Acoustic profiling (SCAT) - Thermal profiling - Downhole profiling dielectric response radar - Fiber optic "periscope" - Digital imagery processor
DENSITY, MOISTURE	- Nuclear (gamma-gamma) - Induced resisvitity - Nuclear (neutron density) - Spontaneous potential - "Chirp" acoustics - Cross-hole radio - Probe (physical penetration)
MODULUS	- Plate Jacking - Radial Jacking ("Goodman" type) - Dilatometer - Dynamic shear wave - Direct laboratory stress-strain testing - Nuclear logging
HARDNESS	- Downhole penetrometers - Drillability index, petrographic tests

TABLE 1.2 (Cont'd)

IN-SITU STRESS	- Oriented jacking - Overcoring (CSM, CSIRO, USBM) - Closed tunnel pressure tests - Hydrofracturing - Screw-plate tests
INCLINATION DEFORMATION	- Inclinometer, electric - Impression packer - "Acid-bottle" inclinometer - "Pajari" type deviation meter - Gyroscopic surveyor - "Totco" type inclination single-shot inclinometer - Extensometers (rod) - Caliper

TABLE 1.3 - SPECIFIC FIELD AND LABORATORY TESTS

The following list is intended to be representative of the generic parameters or data collection methods that will be utilized, as approporiate. Within each parameter, a number of specific test procedures are implied for evaluation of various elements, factors, or variables within the general parameters.

1. WATER

GROUND WATER
- Piezometric levels
- Aquifer transmissivity, anistropy
- Aquifer permeability
- Aquifer source determinations flow tracing, gradients

QUALITY
- Drinking & camp use
- Closed circuit cooling, HVAC use
- Effect on permanent installation (precipitation, corrosion solutioning)
- Concrete mix use
- General environmental discharge acceptability, post-project (Relict Channel, drainage facilities)

2. SOIL AND OVERBURDEN - IN-SITU

- Composition, petrology, stratigraphy
- Gradation
- Weathering, age
- Permeability
- Dynamic behavior
- Density, porosity (disturbed and in-situ)
- Swelling/collapsing behavior

3. ROCK IN-SITU

- Petrology
- Mineralogical composition of critical material
- Rock quality (fractures, voids)
- Weathering, age
- Permeability
- Strength - mass and discontinuities
- Existing stress conditions (downhole jacking; overcoring; pressure testing; plate jacking, etc.)
- Mass seismic velocity

TABLE 1.3 (Cont'd)

4. CONSTRUCTION MATERIALS

AGGREGATE, FILL MATERIAL	- Moisture, absorption - Gradation - Density - Impurities, adverse constituents - Weathering resistance (shrinkage, soundness) - Processing resistance (L.A. abrasion) - Alakali reactivity - Freeze-thaw resistance, frost heave susceptibility - Adverse coatings, leachates - Petrology - Strength (static, dynamic-compressive, tension, shear) - Placement/compaction properties - Permeability & consolidation behavior (laboratory and test fill) - Dynamic behavior - Piping, erosion behavior
CONCRETE	- Mix design, specifications - Strength - Modulus, Poissons ratio - Weathering resistance (soundness) - Freeze-thaw resistances
PAVEMENT (non-concrete)	- Mix design, specifications - Penetration resistance, strength - Thermal performance - Particle surface bonding characteristics

5. THERMAL CONDITIONS (applies only to permafrost areas and critical earth fill materials)

- Incident energy, degree-day environment
- Permafrost detection
- Conductivity (lab and by retrofit of temperatures at depth to known incident energy)
- Soil creep, consolidation properties when frozen
- Static, dynamic modulus (compressive, shear)
- Heat capacity, diffusivity
- Frost susceptibility
- Freeze-thaw expansion/contraction
- Compactive effort on frozen soil at various degress of saturation

TABLE 1.4: CORRELATION MATRIX OF POTENTIAL RELATIONSHIPS

PHYSICAL OR SAMPLING FACTOR (INDEPENDENT FACTOR)	MATERIAL PROPERTY OR CONDITION DETECTION (DEPENDENT FACTOR): MATERIAL CLASSIFICATION	STRATIGRAPHY	CLEAVAGE/FOLIATION	BEDDING	GRADATION	MAX. PARTICLE SIZE	WEATHERING	DENSITY	POROSITY/VOIDS	PERMEABILITY	COEFFICIENT OF CONSOLIDATION	MOISTURE	WATER TABLE	STRENGTH	COHESION	MODULUS	HARDNESS	DYNAMIC SENSITIVITY	ATTERBERG LIMITS	IN-SITU STRESS	SPT RESISTANCE	JOINTS/FRACTURES	SHEARS	RESISTIVITY	SEISMIC VELOCITY	PERMAFROST
TOPOGRAPHIC:																										
Elevation	0	0	-	-	0	0	-	-	-	-	-	0	+	-	-	-	-	-	-	-	-	-	-	-	-	+
Depth from Surface	0	+	-	+	+	+	+	+	+	0	+	+	0	-	-	0	-	+	+	+	+	+	-	0	0	+
Depth Into Rock	0	+	-	+	-	-	+	-	0	+	-	0	0	-	-	0	-	-	-	+	/	+	0	+	+	+
Lateral Extent	+	+	+	0	+	0	0	0	0	0	0	+	0	-	-	-	-	0	0	-	0	+	0	0	-	0
Exposure Direction	-	-	-	-	0	-	+	-	0	-	-	0	0	-	-	-	-	0	0	-	-	-	-	0	-	+
Distance from Surface Water	-	-	-	-	0	-	0	0	0	0	-	+	+	-	-	-	-	0	-	-	+	-	-	+	+	+
Topographic Morphology	-	-	-	-	+	+	+	+	0	+	-	+	+	-	-	-	-	0	0	+	+	0	-	0	0	+
Depth above/below Water Table	0	-	-	-	-	-	+	0	0	+	+	+	/	0	0	-	-	+	-	0	+	-	-	+	+	+
GEOLOGIC:																										
Distance from Geologic Feature	+	0	+	-	-	-	0	-	0	0	-	0	0	0	-	+	-	0	-	+	-	+	+	0	0	0
Geomorphologic Location	+	+	-	-	+	+	+	-	+	+	-	+	0	-	-	-	-	-	-	+	+	0	0	-	-	+
Rock/Soil Type	/	+	+	+	+	+	+	+	+	+	+	0	+	+	+	+	+	+	+	0	+	+	0	+	+	0
Permeability	-	-	0	-	+	-	+	-	+	/	0	+	+	0	0	0	-	+	+	0	0	-	-	+	+	0
Density	-	-	-	-	-	-	-	/	-	0	+	-	-	+	0	+	+	+	-	0	+	0	-	+	+	0
Permafrost	-	-	-	-	0	-	0	0	0	+	+	+	+	+	+	+	-	+	-	0	+	-	-	+	+	/
Rock Quality/Fractures	-	+	0	-	-	+	+	+	+	+	+	+	+	+	+	+	-	+	-	+	+	/	+	+	+	0
Stratigraphy	+	/	+	+	+	+	+	+	+	0	-	0	-	+	+	+	+	0	0	0	0	+	+	+	+	-
SAMPLING: (or Test Zone)																										
Sampler Diameter	-	-	-	-	+	+	-	0	0	+	0	-	-	+	+	0	-	+	0	+	+	+	+	+	0	+
Sample Volume	-	-	-	-	+	-	-	-	+	+	-	-	-	-	-	+	-	+	0	+	+	+	0	+	+	0
Sampler Type	-	-	-	-	0	+	-	+	+	+	0	+	-	+	+	+	-	+	+	+	+	+	+	+	+	+
Sampling Pro[illegible]ure	-	0	-	-	+	0	0	+	+	+	+	+	+	+	+	0	-	+	-	+	+	0	0	0	0	+
Test Method	-	-	-	-	+	+	-	+	+	+	+	-	+	+	+	+	+	+	+	+	+	-	-	0	0	+
Test Procedure	-	-	-	-	+	+	-	+	+	+	+	+	0	+	+	+	+	+	+	+	+	-	-	+	+	0
Sample Handling	-	0	-	-	0	+	-	+	+	-	+	+	-	+	+	+	-	+	-	+	-	+	-	/	/	+

+ Likely to be a significant influence or correllation.

0 Possible influence or correllation.

\- Unlikely source of influence.

/ Not applicable, or identify case.

TABLE 1.5: GEOTECHNICAL INTERPRETATION WORKING MEDIA

PHYSICAL MEDIA	- Borehole "stick" models representing explorations in three dimensions. - Physical profile or "fence" diagrams with wood cross sections on a topographic base map creating an interlocking "fence" network of sections. - "Block" models of geologic conditions or borrow material areas. - Rock and soil sample comparison boards showing "type" samples.
CARTOGRAPHIC	- Isometric "fence" diagrams and sections. - "Isopach" or "iso-value" maps of particular properties or physical characteristic. - "Layer" maps of data grouped by type or magnitude of feature or characteristic. - Plotted weightings of vertical averages including "strip", "triangle", and weighted cumulative "depth" block analyses as applied to mining reserve calculations for determination of weighted or area average values.
GRAPHIC	- Two and three-variable plots on rectangular and triangular graphs. - Summary plots and range-of-value graphs of physical sizes orientations, properties, typically including the following typical properties: . Gradation and grain size coefficients; . Rock quality indices; . Permeability and temperature data; . Moisture and Atterberg limits; and . Rock and soil classifications. - Geologic sections and elevations including borehole logs and stratigraphic columns showing several factors on adjacent columns.
MATHEMATICAL	- Statistical analysis, such as: . Means and standard deviation comparisons; . Method of moving averages; and . Monte Carlo simulation. - Mathematical correlation determination by: . Linear and curvilinear regression; . Multi-variate correlation analysis; and . Distribution curve-fitting (Weibull or equivalent).

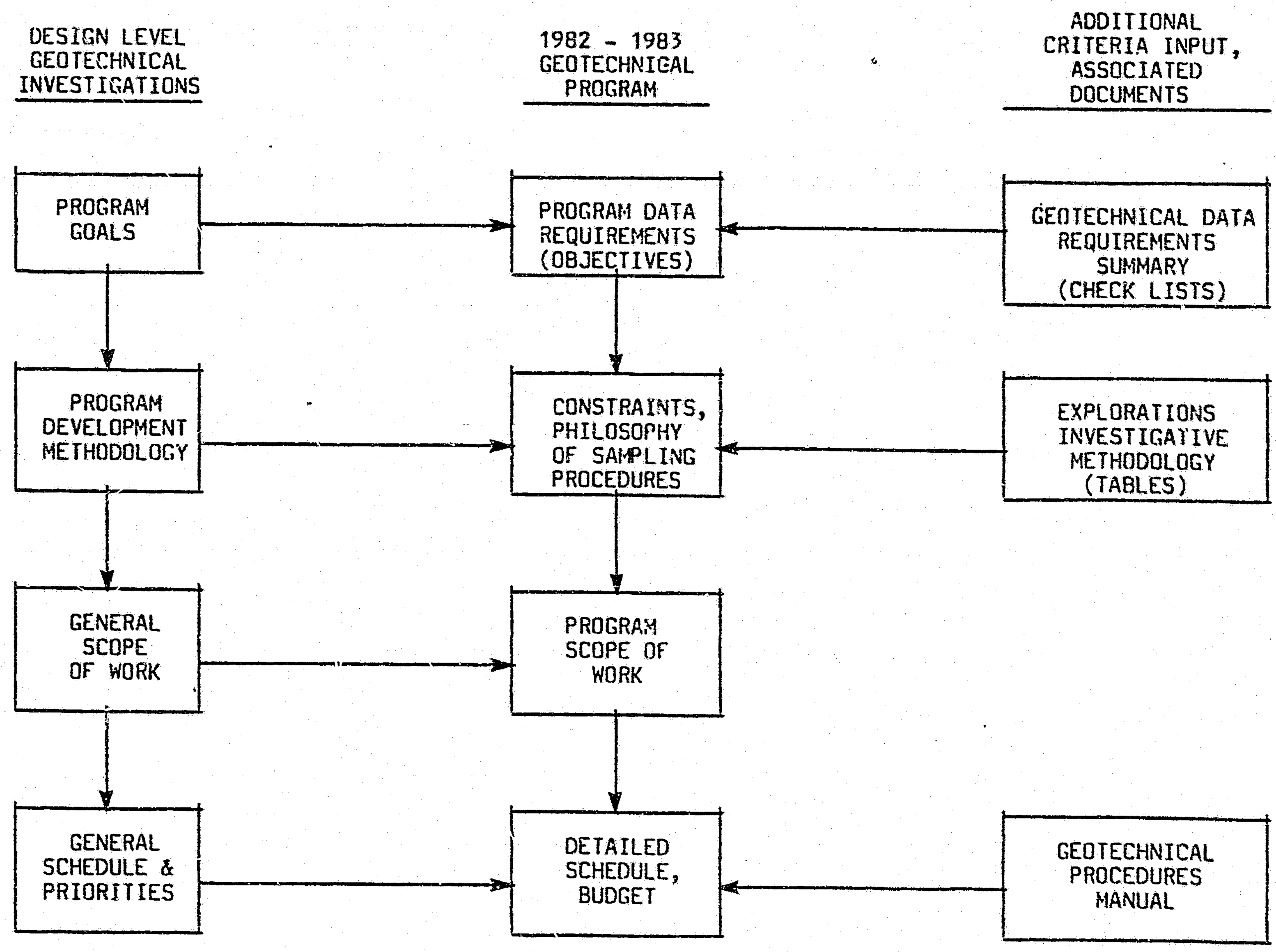
TABLE 1.6: INVESTIGATIVE PROCEDURE - SCOPE PRESENTATION FORMAT

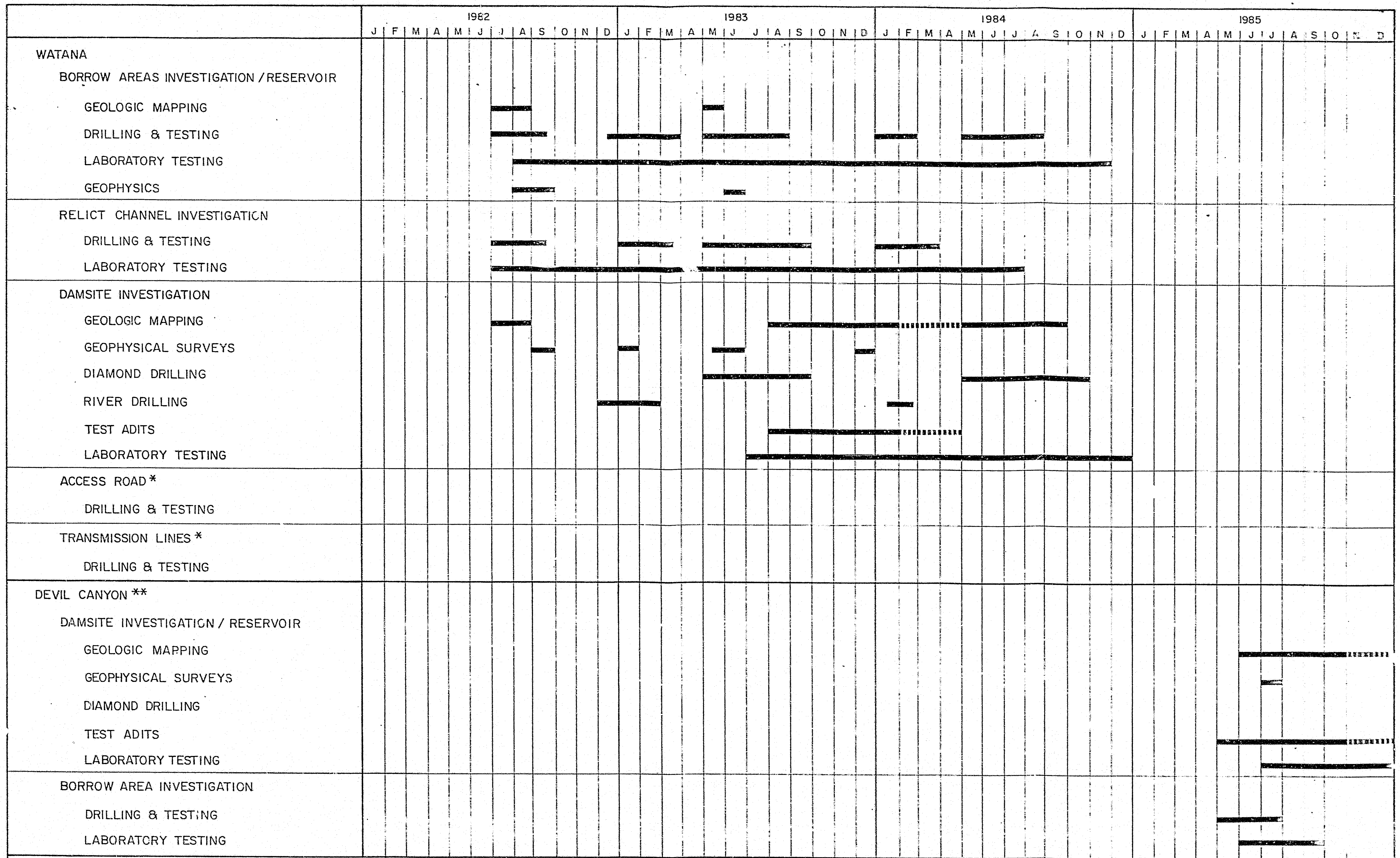
OBJECTIVES	- Design data requirements.
	- Requirements for in-situ natural condition data.
	- Known conditions needing clarification.
	- Potential conditions needing clarification.
	- Data/parameters to be acquired in this scope objective.
APPROACH	- Exploration methods planned for known and potential conditions.
	- Design parameters (initial) development.
	- Preliminary design.
	- Test for cost/design sensitivity to parameters.
	- Modify/optimize parameters/design.
DISCUSSION	- Interaction with design disciplines.
	- Optimization coordination-schedule and costs.
	- Simplification/standardization of design.
	- Other major significant factors.

FIGURE 1.1: SCHEMATIC OF PHASES OF GEOTECHNICAL INVESTIGATIONS

YEAR	PHASE	PERFORMED BY	
1918 1952	SITE IDENTIFICATION	USGS USBR	(Watana & Devil Canyon) (Watana & Devil Canyon)
1957 1975	SITE RECONNAISSANCE	USBR, USGS COE	(Devil Canyon, Transmission Access Routes) (Watana)
1957 - 58	PREFEASIBILITY STUDIES	USBR, USGS	(Devil Canyon, Transmission Access Routes)
1960 1978 - 79 1975	FEASIBILITY DETERMINATION	USBR (Report) COE Alaska Power Administration (Report)	(Devil Canyon) (Watana, Transmission)
1980 - 1982	FEASIBILITY CONFIRMATION/ REEVALUATION	Acres Commonwealth Assoc. Acres/R&M	(Devil Canyon, Watana) (Transmission Intertie) (Transmission, Access Routes)
Scheduled (1982 - 1984)	DESIGN LEVEL	TO BE DETERMINED	
(1985 - 1994)	CONSTRUCTION MONITORING/ VALIDATION		
(1993 - --)	OPERATIONAL MONITORING		

FIGURE 1.2: GEOTECHNICAL PROGRAM FORMAT - WATANA





* TO BE DETERMINED AT A LATER DATE

** SCHEDULE FOR INVESTIGATION IS DEPENDENT ON DESIGN & CONSTRUCTION SCHEDULE

1982 - 85 PROPOSED GEOTECHNICAL INVESTIGATION PROGRAM

FIGURE 13

FIGURE 1.4: EXPLORATIONS PROGRAM DEVELOPMENT

LEVEL OF EFFORT	ACTIVITY	OBJECTIVE
	ITEMIZE DATA REQUIREMENTS	"Wish List" of information needed for design activities.
Individual team members plan program in respective area of prime expertise	PRIORITIZE & SCHEDULE ACTIVITIES	Balance data requirements against design demand and priorities, design schedule.
	DEVELOP RECOMMENDED SCOPE	Scope out realistic program within budget, schedule constraints.
	EVALUATE RECOMMENDED SCOPE	Evaluate best methods of data collection.
Team review with direct first level management input	DEVELOP PRELIMINARY ITEMIZED SCOPE	Match data requirements to explorations methods to develop detailed methodology, assign levels of effort for each data collection activity.
	ASSESS CONFLICTS, OVERLAPS, PRIORITY CONSEQUENCES	Evaluate conflicts between various data demands and exploration/design schedules.
Team concurrence	DEVELOP RECOMMENDED PROGRAM	Produce recommended program combining all individual team member requirements.
	RESCOPE AS NECESSARY	Incorporate comments.
	PRODUCE FINAL SCOPE	Product detailed scope of work statements, plans.
	ESTIMATE COSTS, DELAY POTENTIAL	Detailed schedule and program cost development.
	DETAILED SCHEDULE	
Full managerial and in-house consultant review	PRODUCE CONTRACTS, ACQUIRE MATERIALS	Program preparation and mobilization activities.

FIGURE 1.5: SYSTEMATIC PROCEDURE FOR EXPLORATIONS AND DATA INTERPRETATION

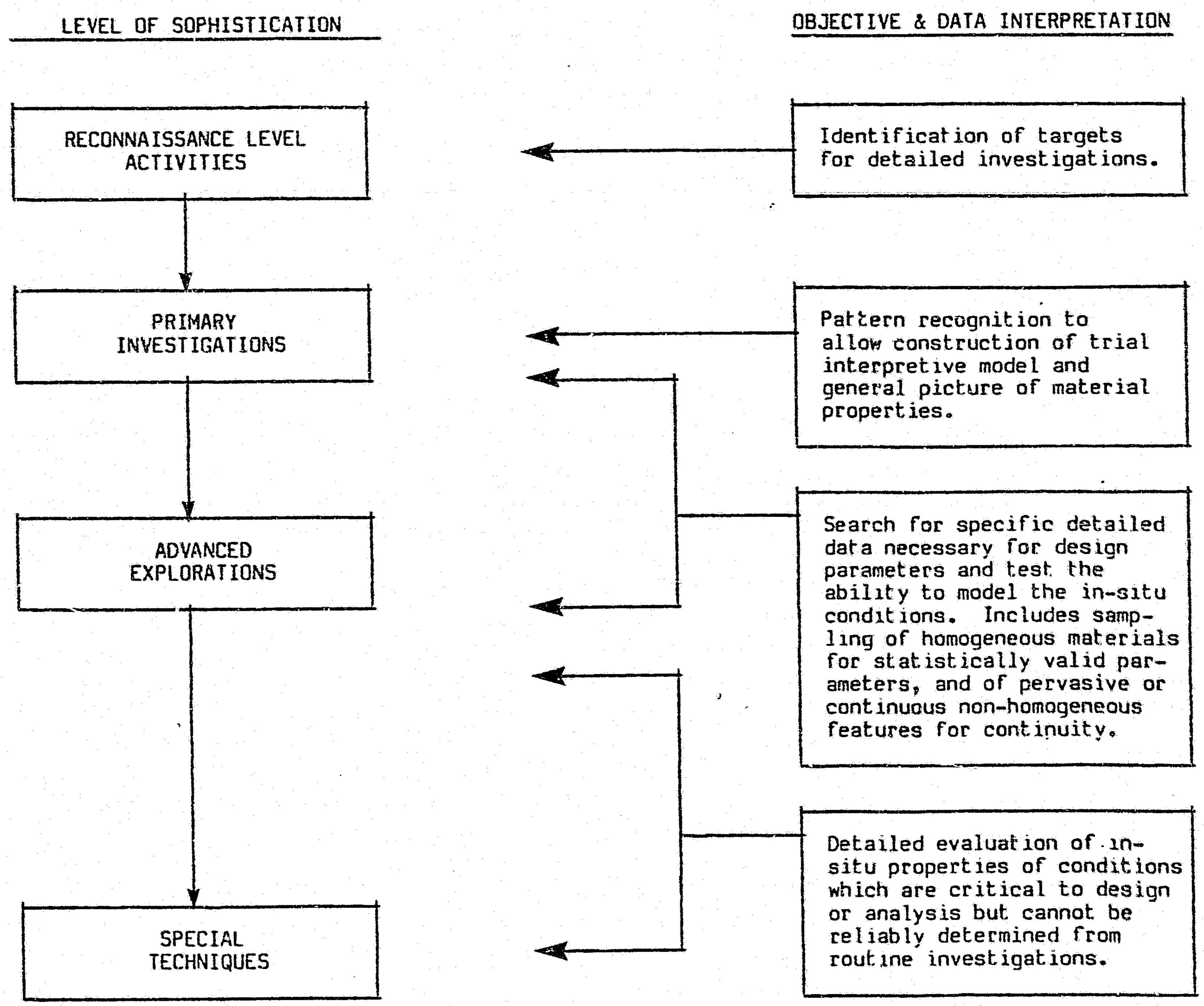
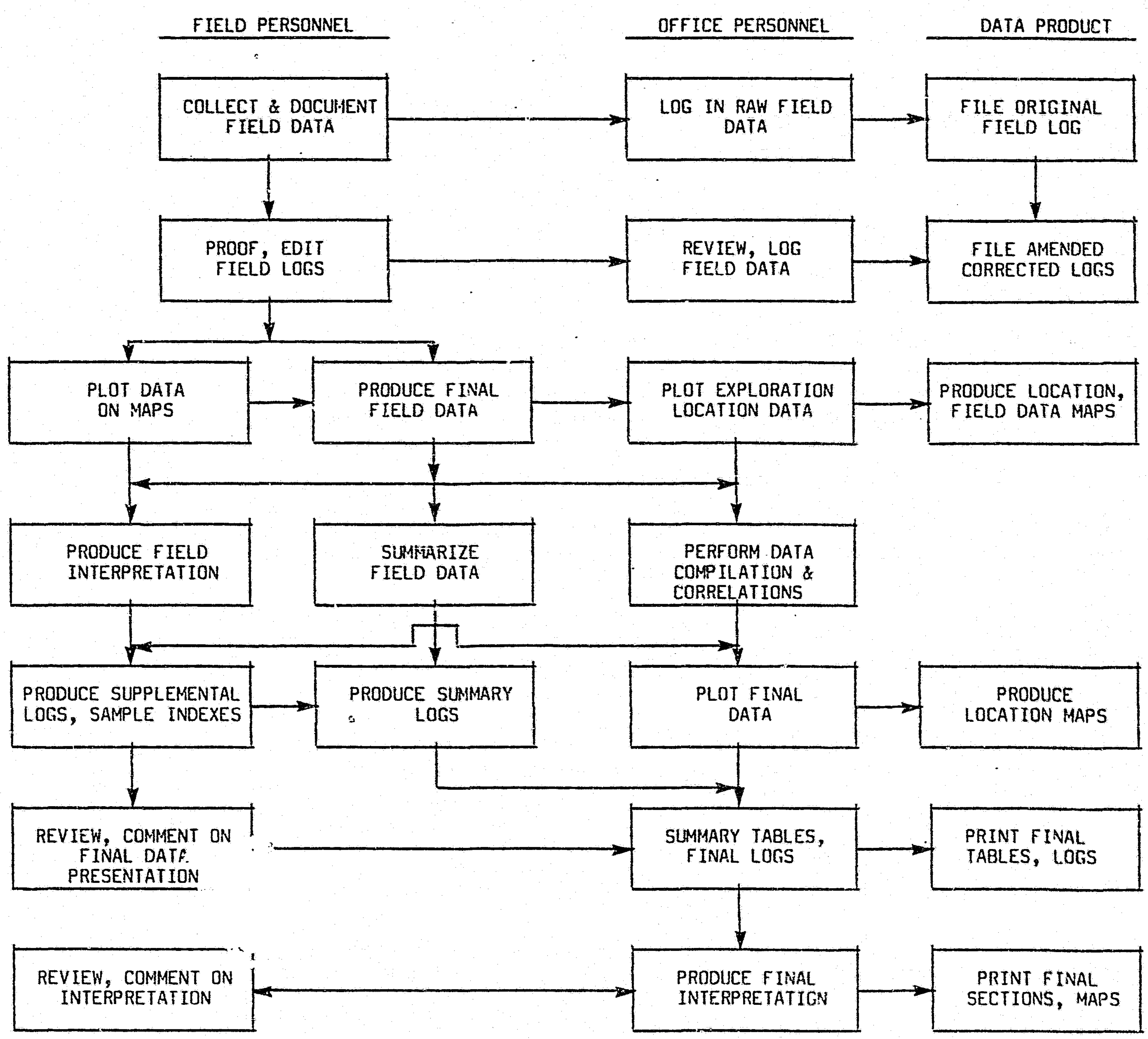


FIGURE 1.6: DATA REDUCTION AND COMPILATION PROCEDURE



2 - DESIGN LEVEL GEOTECHNICAL INVESTIGATIONS - WATANA

2.1 - Program Development

For purposes of program scoping, the watana geotechnical investigations have been broken out by physical areas in which the work would be performed, as follows; and each scope statement will be outlined in the presentation format shown on Table 1.6.

- Damsite - Abutments and Underground, including all power facilities, underground structures and tunnels, and spillway facilities.

- Damsite - River Area, including all foundation areas within the active flood plain, river grout and cutoff sites, cofferdam sites, and plunge pool area; including adequate upstream and downstream coverage of areas where riverbed material removal may be required for diversion training or outlet channel modifications.

- Relict Channels, including both the primary concern area between Deadman and Tsusena Creeks, and the southern Relict Channel between the Susitna River and Fog Creek, designated the Fog Lakes Relict Channel.

- Impervious Boirrow Sources concentrating on Borrow Area Site D, with Borrow Site H being discussed as a potential backup source.

- Granular Fill and Aggregate Sources including Borrow Sites E, F, I and J, with emphasis on Sites E and I since this combined area is currently expected to produce essentially all the concrete aggregate, filter material, and dam shell material for the project. Borrow Sites F and J will be covered by the geologic mapping and general limit delineation seismic investigations, but since they are not critical to project feasibility or onstruction costing, drilling and ampling operations can be delayed until the critical geotechnical investigations at the damsite, relict channels, and primary borrow sites have been completed.

- <u>Rock Quarry Sites</u> including Quarry Site L, which has been delineated for potential cofferdam construction, and Quarry Site A which comprises the backup quarry. Because Site L constitutes a potentially lower cost and more readily developed shell material source than Site E, it comprises a backup to Site E which is not critical to schedule or overall costs. The site will be investigated to determine its suitability for use, and the magnitude of its potential for shifting shell material development off the critical path in the cofferdam construction schedule. Quarry Site A should be investigated later in the program to the feasibility level only to assure that it constitutes a viable backup in case of need.

- <u>Reservoir</u> containment and operational factors and constraints including potential for water losses, slope instability or failures, and environmental consequences of operation from the geotechanical factors viewpoint.

- <u>Auxiliary Facilities</u> including construction camp and permanent village facilities, airfield, off-site maintenance, recreational, and associated non-operational facilties.

Each writeup will discuss the more critical or specific conditions and parameters which may affect design of construction, assuming the exploration alternatives presented and discussed in Section 1.2. The general rundown of geotechnical parameters and objectives which may be considered for each particular feature or structure is presented in tabular format, as for example in Table 2.1 for the damsite areas. The objectives will be discussed in the text only for the most critical and controversial cases. The subsequent approach and discussion statements will then cover the particular techniques or unique applications which might be used in the geotechnical investigations, with a tabular format of recommended exploration methods summarizing the entire range of structures, as for example in Table 2.2, for the damsite areas. The tabular format is applicable to each section, lising the particular problems anticipated and the probable explorations methods as applicable to each major structure or identified features.

2.2 - Design Level Geotechnical Investigations - Watana

(a) Damsite - Abutments and Underground

Objectives

The objective of this investigation will be to obtain the necessary design level geotechnical data to finalize the general arrangements, to establish construction costs and schedules for the surface and underground civil features (Figure 2.1). This data will consist of the geology and engineering properties of the materials on the dam abutments and underground. The investigations will examine geologic conditions and geotechnical problems within the damsite area that were identified in the 1980-81 Geotechnical Report and need further study. In addition, provisions within the program should be made to examine any as yet unknown conditions which may become evident during the design level investigation.

Table 2.1 is a matrix of the types of geotechnical factors which will be assessed for the surface and underground civil structures (Figure 2.1) within the damsite area. The matrix is a prioritized system which shows the criticality of the geotechnical factors to the design of the civil structures. The rating system ranks the geotechnical factors on a scale of 1 to 4, with 1 being critical to design and 4 having little engineering impact. This system is described in detail on Table 2.1. The geotechnical factors for which data will be acquired are divided into the following categories: geologic, physical environmental, geomorphologic, in-situ material properties and operational properties. The criticality of design level data in these categories is discussed below.

Geologic factors include lithology and discontinuities. Knowledge of lithologic variations is essential to the design of both surface and subsurface structures, but is not critical to the general arrangement.

The location of discontinuities will have major impact on the orientation and support requirements for underground structures and on the large rock cuts in the main spillway.

Physical factors include the surface water, ground water, and thermal characteristics of the damsite. The surface and ground water characteristics will impact on drainage requirements, concrete mixtures, linings and construction methods. Thermal conditions which will impact on the site are permafrost and the presence of free ice. These conditions could lead to differential settlement under surface foundations such as the freeboard dike. The effect of water and thermal characteristics will primarily influence costs and scheduling.

Geomorphology includes topography, weathering and stability in the damsite. The topography of the ground and bedrock surface will affect the location and depth of excavations and so will be a major influence on the arrangement of surface civil features such as the dam and spillways, as well as the diversion tunnel portals and power intake structure. Rock stability in the damsite is primarily related to the discontinuities which are discussed above. The underground structures are affected strongly by unstable rock conditions and will be located and oriented to minimize the effect of discontinuities. Potential stability problems following inundation could affect the materials beneath the freeboard dike, as well as cuts at the power intake and diversion tunnel portals. Both rock stability and post-inundation stability data are essential to the general site arrangement

In-situ material properties include those physical characteristics of soil and rock which are measured in the field or laboratory. Rock properties such as compressive, shear and tensile strengths are required to determine the behavior of the mass under various stresses which will occur in foundations and underground openings. The effect of rock strength is generally not as critical as the presence of discontinuities in the rock mass so these properties, although essential to design, are not normally critical to general arrangement.

Soil and overburden properties will only have a major impact in the area of the freeboard dike, because they are normally removed under the major structures. Radical changes in overburden thickness, which is also included in this section, can affect estimated dam quantities and necessitate changes in general arrangement. Underground structures are not effected by overburden thickness except at the portals, where unanticipated thicknesses will affect cost and schedule.

Permeability will primarily affect the design considerations of grout curtains and cutoff walls, but usually will not affect general arrangement. It will also influence the grouting procedures, mixtures and equipment which will be used both on the surface and underground.

The erodibility, pipeability and dispersion characteristics of the materials in the damsite are critical to the arrangement of the freeboard dike due to the dike location and the depth of overburden beneath it. Other areas where these characteristics are of concern can be remedially treated and so will not normally affect arrangement.

Seismic response and the effects of inundation are two operational properties which will have major impact on the design of both surface and subsurface structures. These properties are critical primarily to the arrangement of the freeboard dike and major cuts.

Approach and Discussion

To obtain the types of data discussed under "Objectives", a detailed design level investigation has been outlined. The investigation of the abutments and underground areas is considered in two parts: geologic features and civil features. Geologic features include the major lithologic and structural features in the damsite. Civil features include all foundations, caverns, tunnels and spillways in the damsite. These features are listed in Table 2.2. The geologic features are discussed separately from the civil structures because they will be investigated not only for their effect on the design of civil structures, but also for the development of a geologic model of the damsite. This model will be used to predict geologic conditions at depth and in other areas of scarce data.

The geotechnical factors discussed above will be determined, where appropriate, for the geologic and civil structures. These factors will be investigated by various methods: surface observations, drilling, excavation, surface geophysics, downhole instrumentation and downhole testing. Details of the methods are presented on Table 2.2, which is a matrix of recommended geotechnical exploration methods versus geologic and engineering features. The matrix shows the suitability of the various exploration methods for a particular geologic or civil feature.

(i) Geologic Features

Details of the geologic features in the damsite are presented in the 1980-81 Geotechnical Report. In summary, the geologic features in the damsite area include the major shear zones, "The Fins" and "Fingerbuster", smaller damsite shears (GF1-GF7), an alteration zone on the left abutment (GF8), and the contact between the diorite pluton and the surrounding country rock (Figure 2.2). These discontinuities were identified during feasibility investigations, but will require more detailed study. Large scale mapping will be required for all features except the pluton boundary, and will delineate surface extent and character. Full survey control will be utilized in critical areas.

Drilling will consist of probe holes, overburden sampling and rock coring. Core drilling will be used to investigate features to determine lithology and extent of discontinuities. Samples will be taken for in-situ material properties, and overburden will be sampled for those features which lie beneath the dam foundation. Plug and probe holes will be drilled if required.

No extensive excavations are planned in the investigation of geologic features. Test trenches may be dug across the damsite shears and in the area of the alteration zone to determine conditions of discontinuities, lithologic variations, weathering and stability. Samples will be taken as required. All excavations will be mapped in detail.

The components of a surface geophysical program are shown on the footnotes to Table 2.2, and in further detail on Table 1.3. The seismic refraction method has been used extensively on the abutments of the damsite with good success. The primary area for geophysical surveys will be on the left abutment alteration zone and right abutment excavation areas to define extent, overburden thickness, top of rock surface and bedrock quality. Other seismic techniques will be used where appropriate.

Permanent downhole instrumentation will be principally placed in those geologic features beneath the dam foundation. Thermistors and piezometers will be installed to monitor changes in the physical environment of the abutments, and to provide design data and construction monitoring of frost-thawing and aggradation.

Downhole testing will be conducted on all features except the pluton boundary. Testing methods, shown on Table 2.2, will be used to collect data on the physical environment, in-situ properties and stresses, and extent of discontinuities as appropriate to each feature.

(ii) Civil Features

The types of civil features to be investigated in the damsite area are listed in Table 2.2. The geotechnical investigation will examine surface conditions for the main dam, cofferdams, freeboard dike and spillway foundation, and subsurface conditions for underground features.

Surface observations, which include geologic mapping and photo interpretation, will be used primarily for the main dam abutments. Large scale detail mapping of geologic and geomorphologic features will be done using survey control. All surface mapping for underground features should be completed before the detailed feature design phase begins.

Drilling will be done for all civil features, and includes subsurface drilling in test adits. Plug/probe holes should be drilled for all features except in the powerhouse adit, to determine general overburden thickness and rock quality. Overburden samples will be taken for lithologic identification, stability analysis and material properties tests. Sampling for subsurface features is recommended for the portal areas. Core drilling can recover rock samples to identify surface and subsurface discontinuities and depth of weathering beneath the foundations. Samples will be taken where appropriate for laboratory testing. Both plug/probe holes and core holes will be used for testing and instrumentation equipment installation.

Excavations to examine surface and subsurface geologic conditions should be done for major surface foundations and underground features. Test trenching can be done beneath the spillway and freeboard dikes to examine overburden and bedrock lithology, permafrost conditions, weathering, stability, and erosion and piping potential. It is recommended that test adits be excavated into the major underground features to determine geotechnical conditions for design of the underground structures, and to develop efficient underground design.

Seismic refraction surveys or other geophysical metnods can be used to determine overburden thickness, rock surface and rock quality.

Permanent down hole unstrumentation should be installed beneath all major dam foundations and in the underground features. Thermistor strings and piezometers will be installed in drill holes as required to measure thermal and ground water conditions. Inclinometers will be installed where necessary to evaluate slope stability.

Down hole testing covers a wide range of geotechnical test methods. Various tests have already been done at the damsite; however, additional testing is recommended in the design phase drill holes. Testing should be done at the location of all civil features to define the water and thermal characteristics, rock and soil material properties, permeability and operational response properties.

(b) Damsite - River Area

Objectives

The objective of this part of the investigation will be to obtain the necessary design level geotechnical data to finalize the general arrangement and to establish construction costs and schedules for civil foundations located within the active river floodplain. This data will consist of the geology and engineering properties of the bedrock and alluvium to determine the suitability of the material for a dam foundation. The thickness and lithology of alluvium in selected areas was examined during feasibility studies, which determined that, due to lack of information at this stage, this material should be assumed unsuitable for feasibility estimates. Design level studies should expand these previous studies to examine the in-situ material properties and operational properties of the alluvium to determine its suitability as a foundation. Significant design, cost and scheduling benefits may be realized if the alluvium proves suitable for foundation use.

The types of data to be acquired for the river area are shown on Table 2.1. The format of this table is described in the previous section (2.2 (a)). The criticality of river area data is primarily listed under "Cofferdams" on Table 2.1. The heading "Dam Foundation" includes both the abutments and the river area foundations. The geotechnical factors for which data collection is recommended are divided into the following categories: geologic, physical, geomorphologic, in-situ properties and operational properties. The criticality of design level data in these categories is discussed below.

Geologic factors include the lithology and discontinuities within the bedrock and alluvium. These factors are necessary to the design of the dam, but are not critical to general arrangement since unsuitable material can be treated or removed. Discontinuities should have no effect on cofferdam design.

The physical environment factors are the surface water, ground water and thermal characteristics of the river area. These characteristics may be used to determine if leakage or settlement will occur under the main dam or cofferdam foundations. Problems related to these factors may be treated during construction and are primarily cost and schedule related.

Geomorphologic factors include topography, weathering and stability of the materials beneath the river. The topography of the rock surface may be critical to the arrangement if the surface is radically different than anticipated, thereby affecting the dam dimensions. Weathered bedrock material requiring removal from the foundation would have a significant cost and schedule influence only.

Topography and weathering are not critical to cofferdam arrangement. Data on stability related problems is critically necessary to the foundation design and arrangement. The suitability of material beneath the main and coffer dams is essential since it may not be removed, and so could affect overall dam excavation levels, and hence overall space requirements.

The in-situ material properties of the rock and alluvium should be supplemented by laboratory testing. These properties will generally affect design considerations of the main dam and cofferdams. However, the thickness of the alluvium could require a change in the arrangement of the main dam if this material is to be removed. Alluvial properties such as density, porosity, compressive strength, dynamic strength, erodibility and pipeability are generally critical to arrangement since this material may serve as the cofferdam foundation.

Operational properties such as seismic response, effects of inundation, wave funnelling and thermal degradation will influence design parameters with impact on general arrangement.

Approach and Discussion

The exploration methods for the river area should be designed to supply adequate data to satisfy the requirements of the geotechnical designs. The exploration methods are shown on Table 2.2, which is a matrix comparing geologic and civil features versus exploration method. In section 2.2 (a), the geologic factors were presented in terms of establishing a geologic model. Since this has been described previously, it will not be repeated here. The effects of the geologic factors will be presented here strictly in terms of their effects on civil features.

Surface observations of the river area civil features should be completed prior to the design phase. Drilling activities should be partially completed prior to design level activities. During the design phase, the drilling program should continue with alluvium sampling and rock coring. These samples may be used for determining geologic conditions and in-situ material properties. Drill holes will be used for downhole instrumentation and downhole testing where appropriate. Excavation in the river area should be done only where geologic conditions warrant it.

Surface geophysical exploration should be completed prior to the design phase investigations.

Permanent downhole instrumentation should be installed in selected drill holes beneath the main dam and cofferdams. Thermistor strings may be used to determine the thermal conditions within the alluvium and bedrock. Piezometers should be installed as required.

Additional design level down hole testing should consist of a variety of geotechnical methods to be performed in alluvium and bedrock. Recommended tests are shown on Table 2.2, and should be designed to measure the water depths, permeability, seismic velocities, density and moisture contents. Test results can be used for determining in-situ material properties and operational properties, particularly the seismic response and effects of inundation.

(c) Relict Channels

Objectives

The two identified relict channel areas at the Watana damsite (Figure 2.3) were discussed in depth in the 1980-81 Geotechnical Report, and the particular potential problems associated with these abandoned river channels were discussed in the Feasibility Report. Basically, the primary concerns regarding these areas are:

- Potential for excessive reservoir leakage of such magnitude as to affect project economics;

- Potential for excessive flow gradients under reservoir head, which might cause piping (internal erosion) of material and hence, induce progressive failure of the reservoir confinement;

- Overburden instability or seismic liquefaction potential, which could result in breaching of the reservoir rim; and

- Crest settlement due to saturation and permafrost thawing.

The definition of present conditions and the development of a conceptual engineering model of the relict channels is necessary to provide a determination of necessary remedial action or operational procedure rules.

Approach

The definition of the relict channel conditions can be accomplished by dividing the investigation into a series of parameters to be defined, such as:

- Stratigraphy;
- Material Properties;
- Boundary conditions;
- Geohydrology;
- Permafrost conditions; and
- In-situ physical properties.

The program of investigations has been divided into two stages and may include assessment of the various parameters as shown on Table 2.3

- Stage I-Fiscal Year 1983 (July 82-June 83)

  Stage I investigations will utilize limited seismic refraction surveys to refine the Watana Relict Channel configuration data, and to assess the overall width and local gradients of the Fog Lakes Relict Channel. Detailed stratigraphic and materials sampling is planned for the summer and winter phases in the Watana channel, with a limited local borehole permeability testing program. Following collection of the basic stratigraphy, hydrology and boundary conditions, the final design phase would incorporate a detailed investigation based on the results of the Stage I studies.

- Stage II - Design Level Investigation

The detailed investigation will be planned only after the analysis of Stage I data. Under ideal conditions, the Stage I studies could remove all concerns about the relict channel areas. However, in all likelihood, at least a limited design level and operation program will be required. The recommended Stage II program would include the following activities, as detailed on Figure 2.4, dependent on Stage I and progressive Stage II results:

- Stratigraphic borings, sampling and downhole geophysical logging;
- Large diameter material sampling borings, using both "disturbed" and "undisturbed" sampling;
- Laboratory testing to evaluate sensitivity, pipeability and consolidation properties;
- Field density and shear strength tests;
- Field permeability, piezometric testing;
- Field aquifer flow tracing;
- Computer aquifer modeling;
- Field thermal monitoring for permafrost, including recovery of permafrost samples;
- Age determination for evaluation of stratigraphic relationships;
- Pump testing in large diameter wells; and
- Construction and operation of a flow monitoring weir system at the channel outlet area.

Discussion

The specific potential problem areas are discussed below.

- Leakage requires knowledge of the hydraulic characteristics of the channels, including bedrock profile, width, reservoir exposure, gradient, transmissivity and stratigraphy. Hydraulic modelling would probably be required to develop an understanding of channel characteristics under operational conditions, utilizing piezometric and flow characteristics under natural conditions to provide initial calibration of the model.

- Piping evaluation requires the gradient and flow stratigraphy information described above, plus detailed information on the material quantities and cohesion in the potential flow zones.

- Instability could involve either reservoir rim slope stability problems, which requires geologic information and general soil strength parameter data; and seismic instability potential, which is dependent on in-situ hydrostatic conditions and in-situ material properties. Analysis would be conducted on hypothetical failure modes using data from "undisturbed" sampling operations.

- Settlement could involve natural material response to saturation, which can be determined from undisturbed borehole sampling; or thawing of permafrost. In either case, systematic borings and sample testing can be used to assess the potential magnitude of the problem and to design any necessary remedial measures.

In general, the investigations for the relict channels require first an assessment of potential parameters which could be beyond acceptable ranges, then progressively more sophisticated parametric testing and evaluation for those conditions which merit continued concern. The entire program, in order to avoid excessive expense, must be a continual program of feedback of field and laboratory information into engineering evaluation to assess the impact and potential resolution of problem areas encountered. An indication of the range of potentially significant parameters is shown on Table 2.3.

(d) Impervious Borrow

Objectives

The current project general arrangement (Feasibility Report, 1982) calls for a compacted impervious till core in the Watana dam. Because of the critical seismic conditions and permafrost environment at the site, a number of generic material properties could be significant in the design or construction of the project. The full range of potentially significant factors is indicated on Table 2.3, ranked by estimated importance to general design activities. The major geotechnical properties of significance are shown below:

- In-situ Borrow Site Properties
  - Stratigraphy and available reserves
  - Ground water
  - Permafrost
  - Continuity of material properties
  - Moisture content

- Placement and Processing Requirements
  - Workability (plasticity, cohesion)
  - Gradation (maximum particle size, piping protection)
  - Compaction properties (Proctor density)
  - Consolidation, internal strength

- Operational Properties
  - Seismic response (dynamic strength)
  - Permeability, piping resistance, cracking behavior
  - Surface frost penetration behavior
  - Long term consolidation

Approach

The potential dam impervious core material sources identified in previous studies have been designated as Borrow Sites D and H (Figure 2.3). Due to the site proximity and apparently better-drained character of Borrow Site D, it has been designated as the primary source. All explorations will be concentrated there unless conditions are found to be less desirable, in which case, the type of program planned for site D, would be extended to Site H.

The planned program incorporates the same two-stage investigations as the Watana Relict Channel (Section 2.2 (c)), with the FY83 investigations being a consequence of the need for Relict Channel information will serve to simultaneously address, with additional lab testing, the major in-situ Borrow Site D condition questions. The specific geotechnical conditions to be tested or evaluated are indicated with an approximate measure of significance, on Table 2.3.

Discussion

The detailed sampling and testing procedures outlined on Table 2.4 can be used to varying levels of sophistication (Table 1.2) as required to obtain the necessary design data and construction procedure/cost estimates. The special sampling and detection methods that are required for design level investigations, will be controlled by the probable critical parameters, which are listed below.

- In-situ Borrow Site Properties

    - Moisture content and uniformity
    - Permafrost ice content and temperature, which affects excavation difficulty
    - Ground water level and transmissivity, potentially affecting borrow pit operation
    - Excavation area trafficability, which is a function of soil strength and moisture
    - Available reserves and stripping ratio, which controls production cost

- Placement and Processing Requirements

  . On-fill transport, raising and compaction equipment requirements
  . Compaction density and strength
  . Gradation and internal coefficients
  . Consolidation and triaxial strength

- Operational Properties

  . Dynamic response behavior of the construction materials after dam completion, which is a critical factor in the dam design, and will involve dynamic testing and simulations

  . Core permeability and piping resistance, and the self-healing characteristics in event of seismic or settlement fracturing, which is critical to design considerations and will control placement specifications in construction

  . Post-construction behavior of the core face and crest area under the influence of freezing winter temperatures, critical for design considerations, but is not likely to result in significant design or cost variations

  . Long-term dam consolidation and creep performance, which may affect the detailed design of the dam section and is therefore significant even though the general arrangement or overall cost is not likely to be affected by these factors

In general, the specific boring information developed in pre-design stages (including the FY-83 program) will have to be expanded on larger scale samples through test pit operations and large-diameter laboratory testing, with a confirmation program in construction entailing a test-fill and construction performance monitoring.

(e) Granular Borrow

Objectives

The objectives of the granular borrow investigations will be to identify in sufficient detail and accuracy the availability, properties, and cost of fill and aggregate materials for the various project uses. The properties and quantities available must be sufficient for anticipated construction needs, and of adequate quality for the long-term life applications proposed below.

- Dam granular fill;
- Dam and auxiliary filters;
- Concrete aggregate;
- Asphaltic concrete aggregate;
- Gravel road surfacing;
- Road sub-base; and
- Camp structure base pads.

Approach

The investigations approach needs to assess a number of factors which affect cost or usability of the materials for a specific use. The parameters which might affect a particular borrow site are listed on Table 2.3.

Based on the investigations to date, three general source areas have been identified, as shown on Figure 2.3. These areas are Tsusena Creek, the Susitna River valley, and possibly the overburden in Borrow Site D. The explorations and data compilation programs will incorporate factors such as haul distance, elevation, material suitability and adverse natural conditions. The particular exploration methods which might be expected to be used are shown in Table 2.4.

Discussion

There appears to be adequate quantities of granular borrow material in the Watana area. However, a number of factors which will strongly influence suitability for various uses need to be assessed. Due to the varying constraints on cost, volume required, and engineering properties limits, it may result that different areas may be utilized for different purposes. The primary factors are listed below:

- Transportation distance (haul costs);
- Deposit configuration (controls size and hence economics of mining equipment);
- Water table in borrow site (determines mining method);
- Permafrost (controls equipment selection, wastage, rehandle);
- Gradation;
- Percentage of fines, cohesive material (processing requirements);
- Elevation (controls haul costs);
- Stream/river flood potential (affects risks of losing production, access to site);
- Environmental factors such as vegetation, stream/river diversion requirements, visual impact, siltation potential, and
- Material weathering characteristics.

In general, explorations to date have determined the material in Borrow Site E (Figure 2.3) as suitable. Therefore, utilization of Sites F, I, and J will depend on restraints on the use of E or limited benefits in haul distance to the usage point. Risk analysis and environmental factors may influence the final site selection, so the geotechnical investigations need to anticipate this fact and evaluate alternatives in sufficient detail to provide flexibility in selection and contractor operations.

the usage point. Risk analysis and environmental factors may influence the final site selection so the geotechnical investigations need to anticipate this fact and evaluate alternatives in sufficient detail to provide flexibility in selection and contractor operations.

(f) Rock Quarry

Objectives

The feasibility level design and estimate are based on all construction materials being from the granular borrow sources (E, F, I, J, Figure 2.3) with the only blasted rock use being for economic disposal of waste rock from excavations. Therefore, the investigations of potential rock sources (Figure 2.3, Quarry Sites A, B, L) will be limited to reconnaissance level work to ensure backup availability, if needed.

Approach

Should a need or economic advantage develop for quarry rock production, the full range of geotechnical explorations (Table 2.4) could be applied to the potential quarry site. Under the full development plan, a series of critical factors could influence production and usage plans:

- Type and breakage characteristics;
- Weathering characteristics;
- Placement and compaction effort requirements;
- Placement and compaction durability; and
- As-built strength and dynamic behavior.

The design criteria would be developed through examination of rock quality in place and by borings and laboratory testing.

Discussion

The three potential quarry sites which have been identified to date, in addition to waste rock from excavations, could be utilized early in construction as a readily available source of access road fill, or for cofferdam construction. The investigations to date, which have been limited to reconnaissance mapping and one set of weathering durability tests now in progress indicate that Quarry Site B would be uneconomical when compared to the other sites because of excessive overburden as the face retreats into the hillside. Site L, along the river, was designated to provide a readily accessible quarry for the critical cofferdam construction activities, if needed. Quarry Site A appears to have adequate capacity for providing far more than any anticipated demand for blasted rock. It is also in the most suitable location for site construction.

The determination of quarry requirements, optimal source location, and the economics of development will certainly control the anticipated use of these sites and hence, the requirements for explorations and geotechnical evaluation.

(g) Reservoir

Objectives

The reservoir area is significant to geotechnical design in two areas: slope stability and leakage potential. The objective of studies in the reservoir area, exclusive of "Relict Channels", (Section 2.2 (c)), would be as follows:

- Determine leakage potential to adjacent drainage;
- Determine possible one-time reservoir filling losses in saturating previously unsaturated areas;

- Assess current active or historic slides to evaluate potential for activation or progressive reactivation, and to assess the potential of adjacent similar areas failing;

- Assess the potential for new sliding or bank failures under the influence of reservoir wetting or from fluctuating reservoir levels;

- Assess the potential for significant turbidity deposit migration from reservoir banks or riverbed deposits to the damsite which might interfere with dam operation;

- Assess the potential for significant bank erosion and leaching under reservoir fluctuation, waves or ice action; and

- Assess the potential for adverse natural chemical contamination of reservoir waters from contact with overburden or rock along the reservoir.

Approach

The general approach to addressing these potential areas of concern would be to evaluate the significant potential geotechnical parameters controlling the physics of each condition, as outlined in Table 2.3. The physical factors would be evaluated first by field reconnaissance mapping to validate and expand on the initial reservoir mapping (1980-81 Geotechnical Report). For those areas of potential concern, soil sampling by hand and by air-transportable drill would be used to obtain samples of the material. Laboratory testing of such samples would provide the necessary design parameters. If areas of significant slope or rock instability were encountered, an expanded drilling program with piezometric and thermistor installation and monitoring would be considered to further evaluate the potential for failure, and other detailed investigations might be conducted as outlined in Table 2.4.

Discussion

Due to the great expanse of the reservoir area and the very significant cost of explorations in the remote reservoir areas, a parametric assessment of the benefit of exploration would be conducted. Reconnaissance level surficial geology mapping would suffice for most environmental, aesthetic and engineering assessments. Expansion to drilling and instrumentation should be weighed against several factors listed below, which might show expense to be excessive for the benefit gained.

- Cost of remedial "cosmetic" repairs to eroded areas versus cost of detailed, assessment of erosion potential.

- Cost of lost energy value potential in worst case versus cost of determining probable loss due to leakage, reservoir bank retention or bank creep into the reservoir area.

- Cost of physical slide hazard removal versus cost of measuring and monitoring potential slide area.

- Probability of damage to project features from a particular slide or slope failure, as a function of distance from the critical features.

The last two considerations are probably the most significant in terms of cost, because the expense of drilling and instrumentation would be significant for even minimal investigations. Most potential slide or instability features would not be hazardous to operation or physical facilities due to their distance from the damsite and could therefore be deleted from consideration. Likewise, slide areas of significance, if local or widely scattered in nature, could be intentionally removed prior to pool filling in a controlled manner, at less cost than analyzing and monitoring their condition. However, if recreational shore and boating use of the reservoir is considered, the slope stability question assumes a greater significance due to safety aspects. At this time, no major hazard to any users or the project has been detected, but investigations to an appropriate level of detail should be conducted prior to commencement of reservoir filling.

(h) Auxiliary Facilities

Objectives

The Auxiliary Facilities grouping has been introduced to include such support, maintenance, living and recreational facilities as may be constructed and include the following types of features:

- Site access roads;
- Runways/airfields/helipads;
- Construction camp;
- Permanent operating personnel village;
- Shop/maintenance structures;
- Control buildings;
- Switchyard;
- Water supply;
- Waste disposal facilities (liquid, solid);
- Fuel storage; and
- Visitor centers, campsites, recreational areas.

The investigations would be designed to provide the necessary geotechnical design parameters for siting and design of these structures.

Approach

The investigations programs for these features would be very similar to that for an equivalent structure in any location. The geotechnical factors which are considered potentially significant to these structures are listed on Table 2.3. Each type of structure, being of a different use and design life, would be designed using the exploration best suited to economically design the feature.

Discussion

While the specific exploration methods which might be selected from Table 2.4 might vary, the following general factors apply to all structures and would be considered in each case:

- Foundation conditions;
- Ground water;
- Permafrost;
- Water quality;
- Inherent stability;
- Natural hazards (flood, slide debris flows, avalanche, rock falls, icing, fire); and
- Project-induced hazards; (flood, waves, bank sliding, rise in water table, permafrost thawing, falls, machinery, roads, water releases) to visitors/guests/residents.

TABLE 2.1: WATANA DAMSITE - GEOTECHNICAL PARAMETERS

GEOTECHNICAL FACTOR	DAM FOUNDATION	FREEBOARD DIKE	MAIN SPILLWAY	EMERGENCY SPILLWAY	COFFERDAMS	DIVERSION TUNNELS	POWER INTAKE	POWER TUNNELS	POWER CAVERNS	ACCESS TUNNELS
GEOLOGIC:										
Lithology - Material Type	2	2	2	2	-	2	2	2	2	2
- Material Density	2	1	2	2	2	2	2	2	2	2
- Material Uniformity	2	1	2	2	2	2	2	2	2	2
Discontinuities - Shears	2	-	2	2	-	1	1	1	1	1
- Joints	2	-	1	2	-	1	2	2	1	2
- Contacts	2	2	2	2	-	2	2	2	2	2
- Inclusions	-	-	2	-	-	2	2	2	2	-
PHYSICAL:										
Water - Water Table	3	2	3	3	2	2	3	3	2	3
- Aquifers, Flow Direction	2	2	2	2	2	2	-	2	-	2
- Surface Drainage	3	3	3	3	-	3	-	-	-	-
- Chemistry	-	-	3	-	-	3	-	3	3	3
Thermal - Temperature	2	2	2	3	3	2	2	2	2	2
- Ice Filled Voids	3	2	3	3	3	3	3	3	3	3
- Conductivity, Thermal Properties	2	2	-	-	-	-	-	-	-	-
GEOMORPHOLOGY, WEATHERING:										
Topography - Ground Surface	1	2	1	1	1	3	3	3	-	3
- Rock Surface	1	2	1	1	2	1	1	2	2	2
Weathering - Weathering in Bedrock	3	-	3	1	-	1	1	3	-	3
Stability - Rock	2	-	1	2	2	1	1	1	1	1
- Overburden	3	3	3	1	3	3	3	-	-	-
- Organic Mat	3	-	-	-	-	-	-	-	-	-
- Existing or Ancient Slides	2	-	1	2	2	1	2	1	-	1
- Reworked Stability	-	2	-	-	2	-	-	-	-	-
- Inundated Stability	2	1	-	-	1	1	1	-	-	-
- Riverbed Materials	3	-	-	-	1	2	-	-	-	-

TABLE 2.1 (Cont'd)

GEOTECHNICAL FACTOR	DAM FOUNDATION	FREEBOARD DIKE	MAIN SPILLWAY	EMERGENCY SPILLWAY	COFFERDAMS	DIVERSION TUNNELS	POWER INTAKE	POWER TUNNELS	POWER CAVERNS	ACCESS TUNNELS
IN-SITU MATERIAL PROPERTIES:										
Rock - Density	2	-	2	2	-	2	2	2	2	2
- Compressive Strength	2	-	2	2	2	2	2	2	2	2
- Tensile Strength	-	-	2	-	-	2	2	2	2	2
- Shear Strength	2	-	2	-	-	2	2	2	2	2
- Modulus	2	-	2	-	-	2	2	2	2	2
- Effect of Wetting	2	-	2	2	-	2	2	2	-	-
Borrow Material, Overburden										
- Density	-	1	-	-	1	-	-	-	-	-
- Voids, Porosity	-	1	-	-	1	-	-	-	-	-
- Compressive Strength	-	1	-	-	1	-	-	-	-	-
- Shear Strength	-	2	-	-	2	-	-	-	-	-
- Modulus	-	2	-	-	2	-	-	-	-	-
- Compressibility	-	1	-	-	2	-	-	-	-	-
- Moisture	-	2	-	-	-	-	-	-	-	-
- Thickness	1	2	3	3	2	3	3	3	-	3
Permeability, Groutability										
- Shears, Fractures	3	-	3	3	-	2	3	2	2	2
- Stratified Overburden	-	2	-	-	2	-	-	-	-	-
Erodability, pipeability, dispersion characteristics	2	1	2	2	1	2	-	-	-	-
OPERATIONAL RESPONSES:										
- Seismic	2	1	2	2	2	2	2	2	2	2
- Repeated inundation	2	1	-	-	2	2	2	-	-	-
- Repeated wave action	2	2	-	2	2	-	-	-	-	-
- Thermal effect on permafrost	2	2	-	-	-	-	-	-	-	-

LEGEND: 1 = Critical to design. Adverse condition could affect feasibility of current general arrangement to extent of changing overall feature location or design. Uusually involves overall stability or support problem, or potential failure from applied project or seismic effects. Inherently implies cost significance.

2 = Further information needed to provide values or refined criteria assumptions for use in development of detailed design. Usually involves items of strength, erodability, topography that can be solved through design without major changes in general arrangement. Generally includes all structural factors. Inherently includes cost significance.

3 = Factors that could be expected to significantly affect only construction costs, schedule or quantity estimates, and therefore might dictate design changes or feature relocation for cost rather than functional or structural considerations.

TABLE 2.2: WATANA DAMSITE - GEOTECHNICAL EXPLORATION RECOMMENDATIONS

FEATURE - CIVIL	SURFACE OBSERVATION: MAPPING (1)	SURFACE OBSERVATION: PHOTOGRAPHY (2)	DRILLING: PLUG/PROBE (3)	DRILLING: OVERBURDEN SAMPLING (4)	DRILLING: CORE (5)	EXCAVATION: TEST TRENCH (6)	EXCAVATION: TEST/PIT BLAST (7)	EXCAVATION: CAISSON/SHAFT (8)	EXCAVATION: ADIT (9)	SURFACE GEOPHYSICS (10)	PERMANENT DOWN HOLE INSTRUMENTATION: THERMISTOR (11)	PERMANENT DOWN HOLE INSTRUMENTATION: PIEZOMETER (12)	PERMANENT DOWN HOLE INSTRUMENTATION: INCLINOMETER (13)	DOWN HOLE TESTING: WATER LEVEL (14)	DOWN HOLE TESTING: PERMEABILITY (15)	DOWN HOLE TESTING: SEISMIC VELOCITY (16)	DOWN HOLE TESTING: CAMERA (17)	DOWN HOLE TESTING: DENSITY MOISTURE (18)	DOWN HOLE TESTING: MODULUS (19)	DOWN HOLE TESTING: IN-SITU STRESS (20)
Main Dam - River	P,S	P,S	S	P,S	P,S	N	N	Q	N	P,S	D	Q	N	P,D	P,D	D	Q	S,D	Q	N
- Abutments	P,S,D	P,S,D	D	D	P,D	Q	N	Q	Q	P,S	P,D	P,D	Q	P,D	P,D	D	D	D	D	D
Cofferdams	S	S	P,S	P,S	P,S	N	N	Q	N	P,S	D	Q	N	P,D	P,D	Q	Q	S,D	Q	N
Diversion Tunnels	S	S	D	N	D	N	Q	N	D	S	D	D	Q	D	D	D	D	D	D	D
Intake Structure	S	S	D	D	D		N	N	N	S	Q	D	Q	D	D	D	D	D	D	D
Penstocks	S	S	D	N	D	N	N	N	Q	Q	D	D	N	D	D	D	D	D	D	D
Powerhouse	N	N	N	N	P,D	N	N	Q	D	N	P,D	D	N	P,D	P,D	D	D	D	D	D
Surge Chamber	N	N	D	N	D	N	N	Q	D	N	D	D	N	D	D	D	D	D	D	D
Tailraces	S	S	D	D	D	N	N	Q	D	N	D	D	Q	D	D	D	D	D	D	D
Access Tunnels	S	S	D	D	D	N	N	N	D	S	D	D	Q	D	D	D	D	D	D	Q
Outlet Control	S	S	D	D	D	Q	N	N	N	S	Q	D	Q	D	D	D	D	D	Q	Q
Main Spillway	S	S	D	D	D	D	Q	N	N	S	P,Q	D	Q	D	D	D	D	D	Q	Q
Plunge Pool	P,D	S	D	D	Q	N	N	N	N	S	N	N	N	N	N	Q	N	Q	N	N
Emergency Spillway	S	S	D	S,D	D	D	Q	N	N	D	Q	D	N	Q	Q	Q	Q	D	N	N
Freeboard Dike	S	S	P,S,D	P,S,D	Q	D	Q	Q	N	C	P,S	P,S	Q	P,S	P,D	Q	Q	P,S,D	Q	N
Site Roads	D	D	D	P,D	Q	P,D	Q	N	N	Q	Q	D	N	D	Q	N	N	P,D	N	N
Camp/Village	D	D	P,D	P,D	N	D	N	N	N	D	D	D	N	D	Q	N	N	D	N	N

LEGEND: C = Completed
N = Not likely to be appropriate
Q = Questionable - will be revised only if geologic conditions warrant use
D = Scheduled for design level investigations
P = Partially completed in previous explorations
S = Schedule for FY83 explorations

NOTES: Design Level Investigations Estimate - Watana
Categories include following methods/technology:

1. All levels of on-the-ground geologic mapping.
2. Controlled and uncontrolled vertical and oblique aerial photography, and low oblique to horizontal surface photography, with associated geologic/geomorphologic interpretation and map preparation.
3. Rotary, auger, percussion, wash boring and jetting type holes in which only the cuttings are sampled. Used to detect stratigraphic variations and rock surface.
4. All types of drilling in which deliberate sampling is conducted including hollow stem, sprial flight or bucket auger, reverse circulation, churn, coring, spoon, and tube sampling.
5. Diamond, carbide, and calyx core recovery methods. Also includes reverse circulation "air lift" type coring methods.
6. Trenches or blocks excavated to provide linear exposure by means of hand shovel, saw, backhoe, dozer, dragline, etc.
7. Pits and face exposures produced by bulk excavation with dozer, backhoe, or explosives on a larger scale than (6) to check bulk homogenity and in depth of material properties.
8. All forms of deep vertical excavation to allow in-place inspection of materials. Inclues hand-dug, clamshell, and large diameter bucket auger/calyx operations.
9. Rock excavation to gain access for in-place deep underground rock mechanics testing and in-situ geologic evaluation.
10. Surface geophysics includes all of the following methods listed in approximate order of probability of use on the project:
    - Seismic refraction
    - Seismic reflection
    - Resistivity
    - Sonar/sonic profiling
    - Magnetometer
    - Gravimeter
11. Thermistor strings, thermal probe standpipes; both permanent down hole instrument and intermittent reading manual systems.
12. Standpipe, pneumatic, and electric systems.
13. Any type of bore hole deformation or displacement device including "slope indicator" type instruments and extensometers, deformometers.
14. Any means of water level detection prior to hole completion; manual "plunking", air lift, "M-Cope" or piezometer.
15. Any combination of all permeability and aquifer tests including packer tests and open hole tests such as falling, constant, or rising head and pump tests, and cross-hole aquifer tracing by dye or radionuclide.
16. Both single-point seismic shear or "P" wave, and cross-hole seismic.
17. Bore hole camera, video, acoustic profiling.
18. Nuclear and video, acoustic profiling.
19. All types of plate or radial jacking, dilatometer, direct shear, bulb, and shear wave tests.
20. Oriented jacking, overcoring, closed tunnel pressure tests, and hydrofracturing.

TABLE 2.3: WATANA RELATED AREAS - GEOTECHNICAL PARAMETERS

GEOTECHNICAL FACTOR	RELICT CHANNELS WATANA	RELICT CHANNELS FOG LAKES	IMPERVIOUS BORROW	GRANULAR FILL BORROW	CONCRETE AGGREGATE	ROCK QUARRY	RESERVOIR	SITE ACCESS ROADS	RUNWAY	CAMP FACILITIES	MISC. AUX. FACILITIES
GEOLOGIC:											
Lithology - Material Type	2	2	3	3	2	2	4	2	-	-	-
- Material Density	1	1	-	-	-	3	-	-	2	2	2
- Material Uniformity	1	1	3	3	3	3	4	-	2	2	2
Discontinuities - Shears	2	2	-	-	-	3	-	-	-	-	-
- Joints	-	-	-	-	-	2	-	2	-	-	-
- Contacts	2	2	2	3	-	2	-	2	-	-	-
- Inclusions	-	-	-	-	2	3	-	-	-	-	-
PHYSICAL:											
Water - Water Table	2	2	3	3	3	3	4	2	2	2	3
- Aquifers, Flow Direction	2	2	3	3	3	3	4	-	-	4	4
- Surface Drainage	-	-	3	3	3	3	4	3	3	3	3
- Chemistry	4	4	4	4	4	4	4	-	-	4	4
Thermal - Temperature	2	2	2	3	3	3	4	2	-	2	2
- Ice Filled Voids	1	1	3	-	-	3	4	3	2	2	2
- Conductivity, Thermal Properties	-	-	2	-	-	-	-	-	2	2	2
GEOMORPHOLOGY, WEATHERING:											
Topography - Ground Surface	2	2	3	3	3	-	-	3	3	3	-
- Rock Surface	2	2	3	3	3	3	2	3	-	2	2
Weathering - Weathering in Bedrock	-	-	-	-	-	3	-	-	-	-	-
Stability - Rock	-	-	-	-	-	-	2	2	-	-	-
- Overburden	1	1	3	3	3	3	2,4	2,4	2	-	4
- Organic Mat	2,4	4	4	4	4	-	4	4	2,4	2,4	4
- Existing or Ancient Slides	2	2	3,4	3,4	3,4	3,4	2,4	2	-	-	-
- Reworked Stability	2,4	-	4	4	4	4	-	2	2	2	-
- Inundated Stability	1,4	1,4	4	4	4	-	1,4	2	-	-	2,4
- Riverbed Materials	-	-	-	-	-		4	-	-	-	-

TABLE 2.3 (Cont'd)

GEOTECHNICAL FACTOR		RELICT CHANNELS		IMPERVIOUS BORROW	GRANULAR FILL BORROW	CONCRETE AGGREGATE	ROCK QUARRY	RESERVOIR	SITE ACCESS ROADS	RUNWAY	CAMP FACILITIES	MISC. AUX. FACILITIES
		WATANA	FOG LAKES									
MATERIAL PROPERTIES:												
In-Situ	- Lithology	2	2	2	2	2	2	4	-	2	2	-
	- Uniformity	2	2	3	3	3	3	-	-	2	2	-
	- Laterial Extent	2	2	3	3	3	3	-	-	2	2	-
	- Vertical Extent	2	2	3	3	3	3	-	-	2	2	-
	- Density	1	1	2	-	-	2	-	-	2	2	2
	- Moisture	2	2	2	-	-	-	-	2	2	2	2
	- Compressibility	2	2	-	-	-	-	-	2	2	2	2
	- Voids	2	2	-	-	-	-	-	-	2	2	2
	- Permeability	2	2	2	-	-	-	2	-	2	2	2
	- Processability	-	-	1	1	1	2	-	-	2	-	-
	- Wastage, Reserves	-	-	2	2	2	2	-	-	2	-	-
CONSTRUCTION PLACEMENT PROPERTIES:												
	- Compaction	-	-	1	1	-	2	-	2	2	-	-
	- Moisture	-	-	1	2	-	-	-	2	2	2	-
	- Compressibility	-	-	2	2	-	2	-	2	2	-	-
	- Weathering Resistance	-	-	2	2	1	2	-	-	-	-	-
	- Uniformity	-	-	3	3	3	3	-	3	3	3	-
	- Gradation	-	-	2	2	2	2	-	2	2	2	2
	- Frost Susceptibility	-	-	2	2	1	2	-	2	2	2	2
	- Concrete Reactivity	-	-	-	-	1	-	-	-	-	2	-

LEGEND: 1 = Critical to design. Adverse condition could affect feasibility of current general arrangement to extent of changing overall feature location or design. Usually involves overall stability or support problem, or potential failure from applied project or seismic effects. Inherently implies cost significance.

2 = Further information needed to provide values or refined criteria assumptions for use in development of detailed design. Usually involves items of strength, erodability, topography that can be solved through design without major changes in general arrangement. Generally includes all structural factors. Inherently includes cost significance.

3 = Factors that could be expected to significantly affect only construction costs, schedule or quantity estimates, and therefore might dictate design changes or feature relocation for cost rather than functional or structural considerations.

4 = Features or items that demand attention for development of a model of site conditions for use in environmental, general project development or public affairs issues.

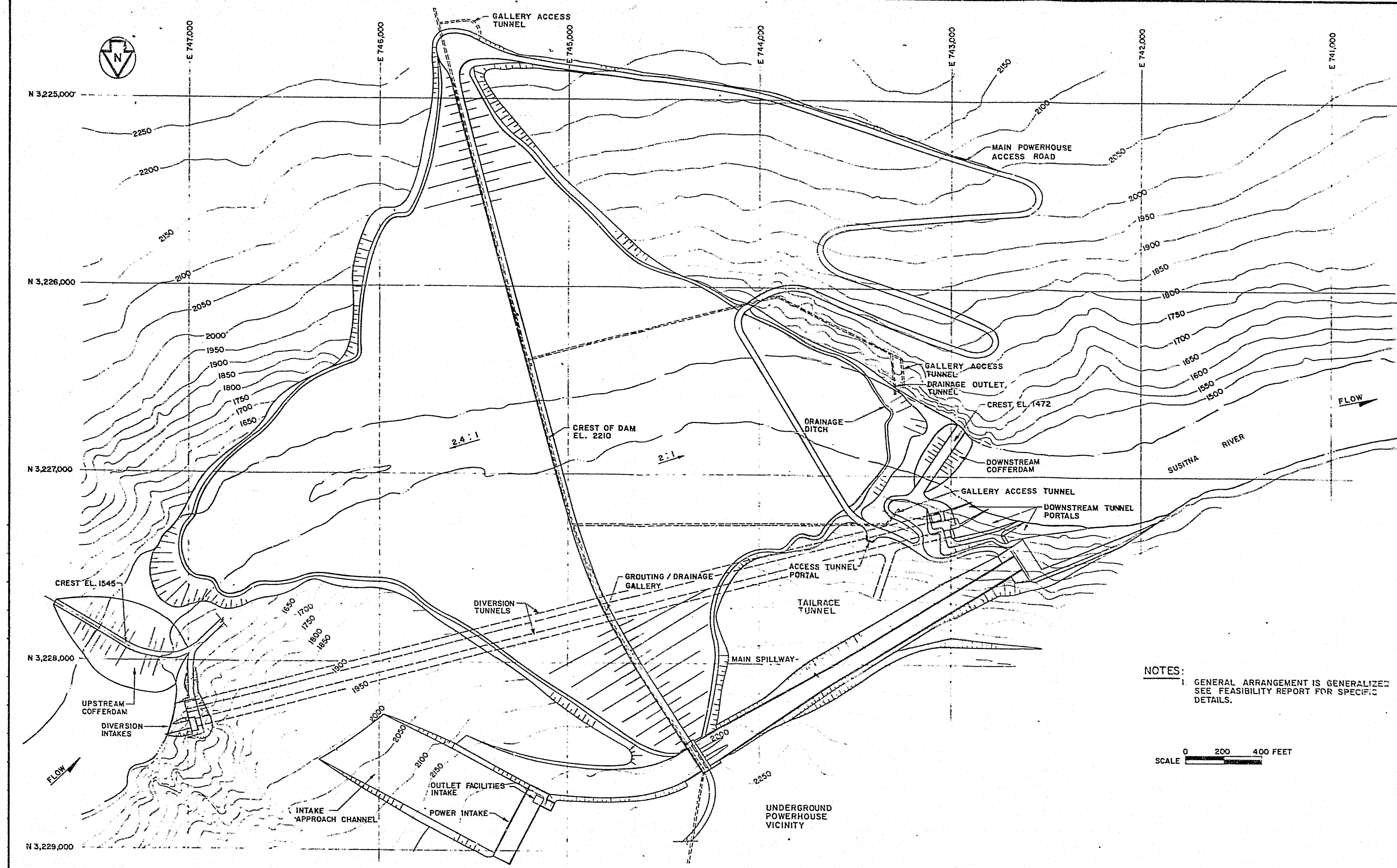
TABLE 2.4: WATANA RELATED AREAS - GEOTECHNICAL EXPLORATION RECOMMENDATIONS

FEATURE	SURFACE OBSERVATION: MAPPING (1)	SURFACE OBSERVATION: PHOTOGRAPHY (2)	DRILLING: PLUG/ PROBE (3)	DRILLING: OVERBURDEN SAMPLING (4)	DRILLING: CORE (5)	EXCAVATION: TEST TRENCH (6)	EXCAVATION: TEST/PIT BLAST (7)	EXCAVATION: CAISSON/ SHAFT (8)	EXCAVATION: ADIT (9)	SURFACE GEOPHYSICS (10)
GEOLOGIC:										
Watana Relict Channel	S	S	P,S	P,S,D	S	N	N	Q	N	P,S
Fog Lakes Relict Channel	S	S	Q	D	N	N	N	Q	N	P,S,D
"The Fins"	P,S,D	P,S	Q	Q	D	Q(D)	N	N	Q	P,S
"Fingerbuster"	P,S,D	P,S	Q	Q	P,D	Q(D)	N	N	Q	P,S
L.A. Alteration Zone	S,D	S	Q	D	P,D	D	N	N	N	P,D
Damsite Shears	P,S,D	P,S	D	D	P,D	D	N	N	Q	P,S
Pluton Boundary	P,S	P,S	Q	Q	D	Q	N	N	Q	P,S
Reservoir Stability	D	D	N	D	N	N	N	N	N	Q
MATERIAL SOURCES:										
Impervious	P,S	P,S	P,S	P,S,D	P,S	P,D	D	Q	N	P,[illegible]
Granular	P,S	P,S	P,D	P,S,D	N	P,D	D	Q	N	P,Q
Rock	P,S,D	P,D	D	D	D	N	D	N	N	D

FEATURE	PERMANENT DOWN HOLE INSTRUMENTATION: THERMISTOR (11)	PERMANENT DOWN HOLE INSTRUMENTATION: PIEZOMETER (12)	PERMANENT DOWN HOLE INSTRUMENTATION: INCLINOMETER (13)	DOWN HOLE TESTING: WATER LEVEL (14)	DOWN HOLE TESTING: PERMEABILITY (15)	DOWN HOLE TESTING: SEISMIC VELOCITY (16)	DOWN HOLE TESTING: CAMERA (17)	DOWN HOLE TESTING: DENSITY MOISTURE (18)	DOWN HOLE TESTING: MODULUS (19)	DOWN HOLE TESTING: IN-SITU STRESS (20)
GEOLOGIC:										
Watana Relict Channel	P,S	P,S	Q	P,S	S,D	D	N	P,S	N	N
Fog Lakes Relict Channel	Q	D	Q	D	D	Q	N	D	N	N
"The Fins"	N	Q	N	D	D	D	Q	N	Q	Q
"Fingerbuster"	N	D	N	P,D	P,D	D	D	N	D	Q
L.A. Alteration Zone	D	P,D	N	P,D	P,D	D	Q	N	Q	Q
Damsite Shears	P,D	P,D	N	P,D	P,D	D	P,D	N	P,D	Q
Pluton Boundary	N	N	N	N	Q	Q	Q	N	Q	N
Reservoir Stability	D	D	D	D	Q	N	N	D	N	N
MATERIAL SOURCES:										
Impervious	P,S	P,S	N	P,S	N	D	N	P,S	N	N
Granular	S	P,S	N	P,S	N	D	N	P,S	N	N
Rock	D	D	N	D	N	D	Q	N	N	N

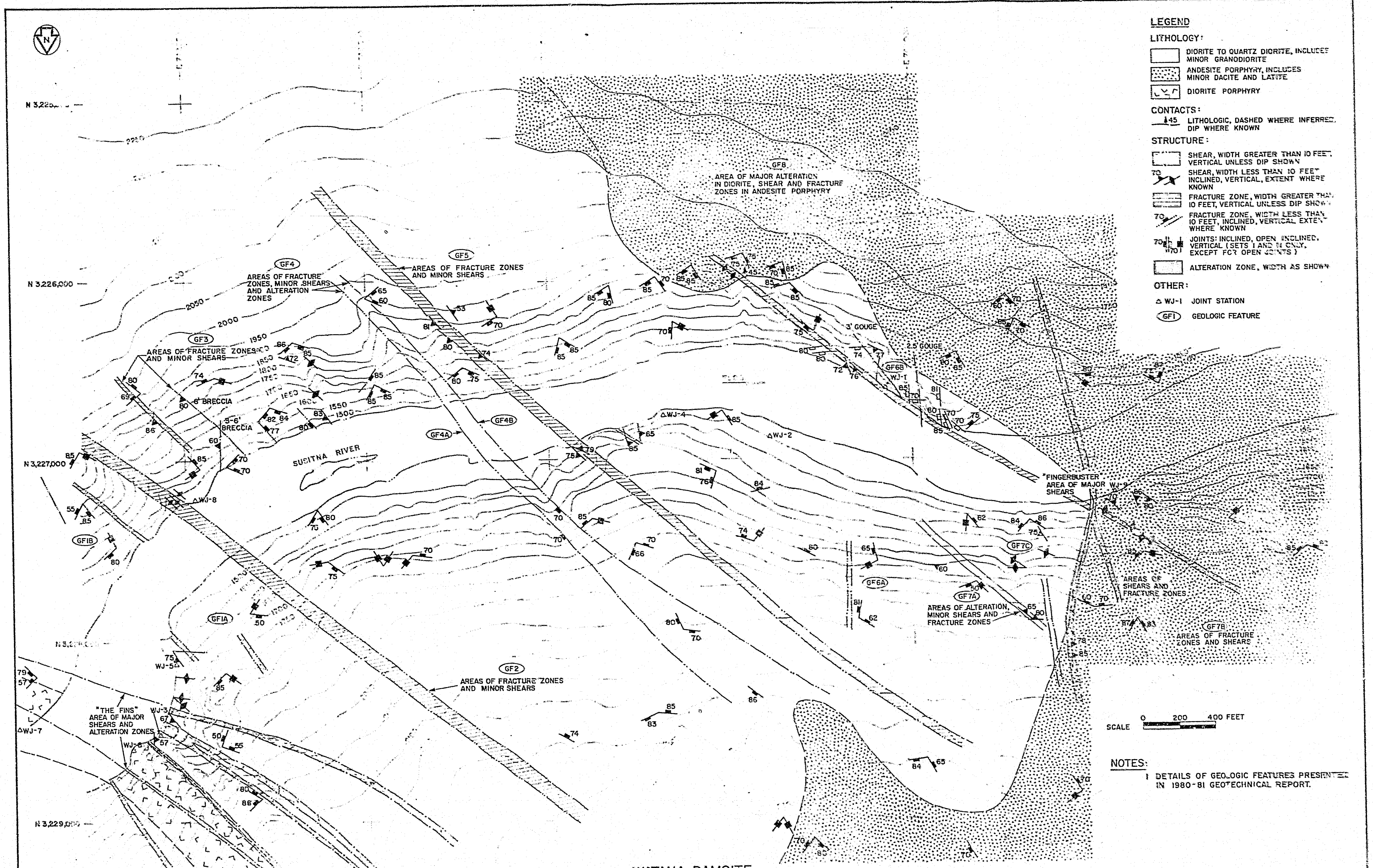
LEGEND: C = Completed
D = Scheduled for design level investigations
N = Not likely to be appropriate
P = Partially completed in previous explorations
Q = Questionable - will be required only if geologic conditions warrant use.
S = Scheduled for FY83 explorations

NOTE: For Footnotes 1 through 20 see Table 2.2



WATANA
GENERAL ARRANGEMENT

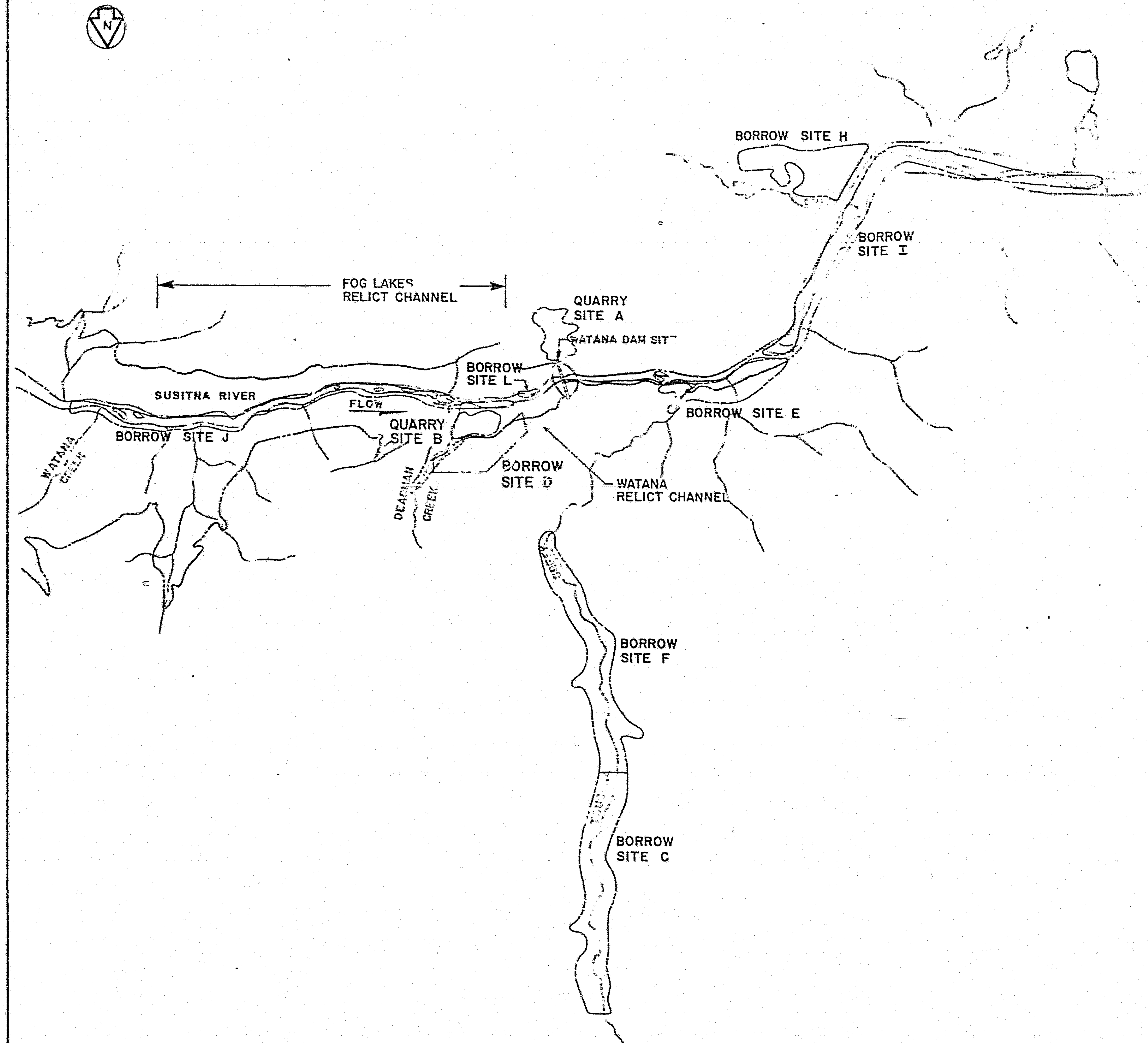
FIGURE 2.1

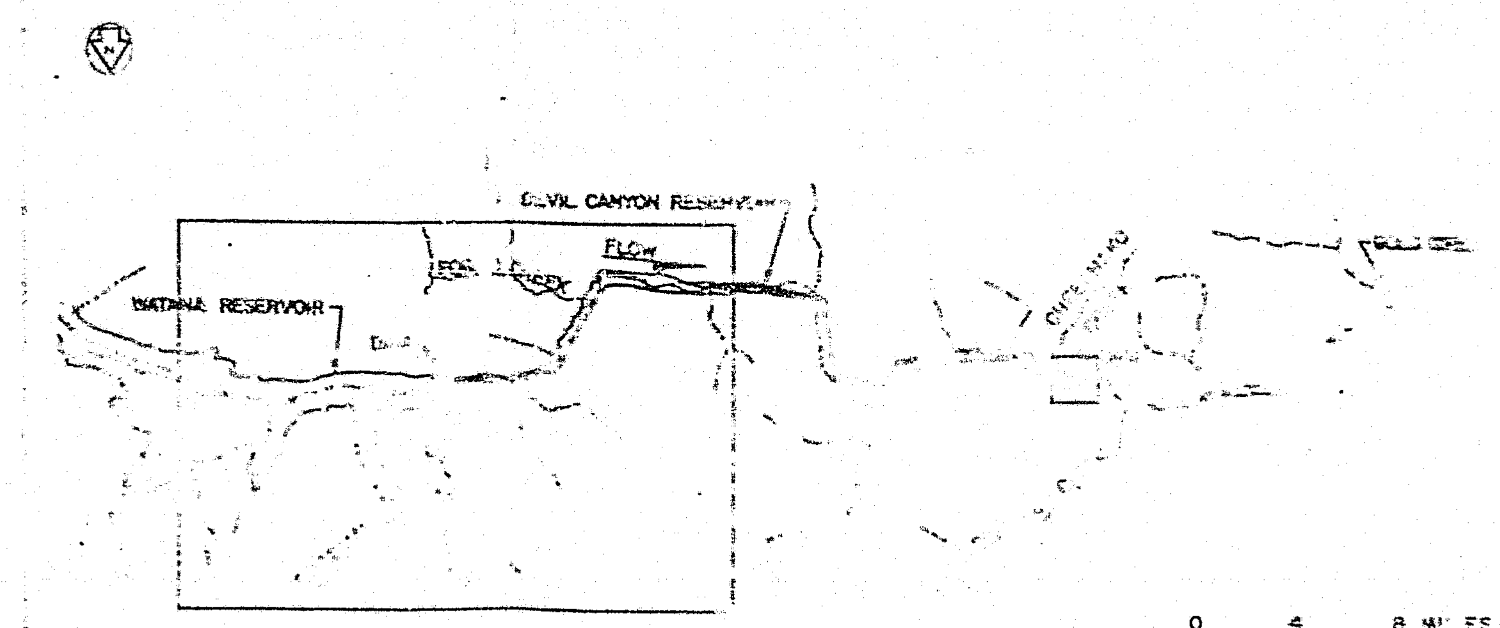


REFERENCE: BASE MAP FROM COE, 1978 - 1" = 200' WATANA TOPOGRAPHY, SHEET 8 & 13 OF 26, COORDINATES IN FEET, ALASKA STATE PLANE (ZONE 4)

WATANA DAMSITE
GEOLOGIC MAP

FIGURE 2.2





LOCATION MAP

LEGEND

BORROW / QUARRY LIMITS

NOTES:

1. DETAILS OF BORROW SITES PRESENTED IN 1980-81 GEOTECHNICAL REPORT.

SCALE 0 1 2 MILES

WATANA
BORROW SITE MAP

FIGURE 2.3

3 - DESIGN LEVEL GEOTECHNICAL INVESTIGATIONS - DEVIL CANYON

3.1 - Program Development

The Devil Canyon development is scheduled, under the current overall project schedule, to lag behind Watana by approximately 9 years. Since it is unlikely that further geotechnical investigations will be conducted at the Devil Canyon site during the 1982-84 period, a detailed Devil Canyon geotechnical program has not been developed in this report.

For simplicity and coherence in the geotechnical program development, the Devil Canyon activities have been broken out into the same eight areas as at Watana, and area listed below. Each of the areas has been defined in relation to the Feasibility Report General Arrangement, a simplified version of which is presented in Figure 3.1.

- Damsite - Abutments and Underground, which includes all power generation and flow regulation facilities, underground structures and tunnels, and spillway facilities. This classification also includes main dam thrust blocks and the left abutment saddle dam.

- Damsite - River Area, including all foundation and cofferdam areas within the active floodplain, grout curtain and cofferdam cutoff areas, and the spillway plunge pool areas. It also includes adequate upstream and downstream coverage of areas which might be excavated for diversion or tunnel outlet channel training.

- Relict Channel - which at the Devil Canyon site is limited to the depression which is planned as the saddle dam construction area. This feature also bounds the left abutment thrust block, and intercepts the discharge area of the emergency spillway.

- Impervious Borrow Sources, which has not been identified in proximity to the site. While the quantity of core material required for the saddle dam is not excessive, at the feasibility level no local source was located, so the estimate assumed a very long haul from the Watana borrow site.

- Granular Fill and Aggregate Sources, which to date include Borrow Site G, immediately upstream of the dam at river level; and possible use of excavated material from the saddle dam area.

- Rock Quarry Sites, which to date include possible use of excavated material from the spillway and thrust block areas and from required underground and dam foundation excavation; and a designated "Quarry K" approximately a mile south of the damsite.

- Reservoir containment and operational stability, including potential for water loss, slope failures, and environmental consequences of geotechnical behavior under reservoir operational conditions.

- Auxiliary Facilities, which include construction and permanent living, support, and maintenance facilities; switchyard structures; and recreational and associated non-operational facilities.

Because the scope of this report does not entail development of specific program recommendations, an outline format has been adopted to note the major factors or areas of concern, without expansion to the detail presented in the Watana section. While specific geotechnical parameters and exploration method tables have not been produced, the factors and procedures presented on Tables 2.1 through 2.4 would apply equally to the Devil Canyon site, although with variances in the criticality and priorities.

3.2 - Design Level Geotechnical Investigations - Devil Canyon

(a) Damsite - Abutments and Underground

Objective

The objective of the design phase geotechnical investigation of the abutments and underground areas should be to define the surface and subsurface conditions for the location of the main dam and saddle dam foundations, and the location and orientation of tunnels and caverns (Figure 3.1). The investigation objectives should be based on known geological features identified during previous studies (Figure 3.2) and other potential adverse conditions which may be found. A detailed discussion of the site geology is presented in the 1980-81 Geotechnical Report. In summary, known geologic features include discontinuities such as northeast trending dikes (M1-M4 and F1-F8), and shear zones (GF1-GF11), open joints on the left abutment and bedding plane foliation, which may effect the stability of the foundation and subsurface features, and an apparent bedrock low beneath Borrow Site G of unknown origin (Figure 3.3).

An east-west trending shear zone (GF1) lies beneath the saddle damsite, as well as thick overburden conditions which may allow leakage or settlement beneath this structure.

To meet the design requirements of this site, a detailed list of geotechnical factors to be studied must be assembled as was done for the Watana site (see Section 2.2 and Table 2.1). The geotechnical factors include geologic conditions, physical environment, geomorphologic conditions, in-situ material properties and operational properties. These factors should be considered where appropriate for dam and spillway foundations underground tunnels and caverns, and the numerous auxiliary construction features.

Approach and Discussion

The required geotechnical data discussed above and in Table 2.1 must be obtained through a comprehensive exploration program. This program, as at the Watana site (Section 2.2a), should be comprised of an investigation of geologic features both for a geologic model of the site, as well as for their effects on civil features Table 2.2 shows the exploration methods recommended for the Watana site.

Similar techniques will be used for the Devil Canyon explorations. These techniques and the geotechnical factors for which they should be used are discussed below.

Surface observations will be conducted for all civil features to map in larger scale the lithology and discontinuities, topography, weathering, and slope stability at the sites.

Drilling activities will consist of plug/probe holes, overburden sampling and rock coring. Plug or probe holes will be used for determining overburden thickness, top of bedrock surface and bedrock quality, as well as for installation of down hole instrumentation and for down hole testing. Overburden and rock samples will be taken for determining lithology and in-situ material properties. Overburden samples may be necessary primarily in the relict channel beneath the saddle dam area (Figure 3.2). Rock coring will be done across shears and dikes on both abutments of the main dam, as well as across feature GF-1 beneath to saddle dam.

Exploratory excavations will be planned across geologic features to determine lithologic extent of discontinuities, topography, weathering, and stability. Test trenches or pits will be most appropriate for surface structures such as the intake, spillways, left abutment thrust block, and saddle dam foundation. Shafts and/or adits will be used for the underground features where design parameters are critical to cost or support design.

Surface geophysics includes a variety of techniques listed on Tables 1.3 and 2.2 These methods will be used where appropriate to determine the extent of discontinuities, overburden thickness, bedrock topography, and weathering. Surveys will be done in the area of the bedrock low, across shear GF1, along the spillways and dam abutments, and for underground features, particularly in the portal areas.

Permanent down hole instrumentation will be installed to monitor the physical environment and slope stability. Thermistor strings and piezometers will be used where appropriate beneath surface features and in underground areas to determine thermal conditions and ground water, respectively. Inclinometers may be installed if necessary.

Down hole test methods are listed on Tables 1.3 and 2.2. These are recommended for determining water level, aquifers, permafrost, weathering in bedrock, stability, in-situ material properties, and operational properties for all features as appropriate.

(b) Damsite - River Area

Objective

The objectives of the design phase geotechnical investigation of the river area will be to define the subsurface conditions beneath the main dam and cofferdam foundations. This includes determining the properties and thickness of alluvium, and defining bedrock discontinuities and weathering. The investigation objectives will be based on known geological features identified during previous studies (Figure 1.1) and potential conditions which may be found. Known geologic features include northeast trending dikes (M1-M4 and F1-F8) and shear zones (GF1-GF11) mapped on the abutments (Figure 3.2), and bedding plane foliation which may affect stability and leakage beneath the foundation. Potential conditions to be anticipated may be the presence of an east-west trending shear, similar to GF1, beneath the river, and unfavorable alluvial material beneath the cofferdams which may affect groutability and foundation stability.

To meet the design requirements, detailed geotechnical data must be obtained. A list of the recommended geotechnical factors to be studied was assembled for the Watana site (Table 2.1), and is discussed in Section 2.2 and listed in Table 2.1. These factors include geologic conditions, physical environment, geomorphologic conditions, in-situ material properties and operational response properties.

Approach and Discussion

The required geotechnical data discussed above and in Table 2.1 may be obtained through a comprehensive exploration program. Table 2.2 shows the exploration methods recommended for the river area at the Watana site. Similar techniques will be used for the Devil Canyon explorations. These techniques and the geotechnical factors for which they should be used are discussed below.

Surface observations for river area features were essentially completed during prior explorations.

Drilling activities in the river area will be used to determine alluvial thickness, bedrock surface, lithology and discontinuities, and down hole testng and instrument installation. Samples will be taken for in-situ material properties tests. Drilling will be done at both cofferdam locations and beneath the river through bedrock between the abutments.

Detailed structural explorations in the river area may consist of caissons in alluvium of the cofferdam area, and an adit beneath the river to determine lithology, discontinuities, weathering, stability, and rock mechanics properties.

Surface geophysics may not be practicable in the river area due to high water velocities. Permanent down hole instrumentation and testing will be done to determine the thermal environment, in-situ material properties and operational properties of the alluvium and bedrock.

(c) Relict Channels

Objective

The objective of investigations of Relict Channels in the Devil Canyon Reservoir will be twofold. The first, which is explained in detail under Section 2.2(c) for the Watana site, relates to water tightness and potential reservoir rim instability. The second, which applies only to the Devil Canyon damsite, is the engineering stability of the relict channel which occupies the saddle damsite, which is significant to the actual damsite arrangements and saddle dam design.

Approach and Discussion

To date, no evidence of potential leakage or rim instability problems has been detected. While a more thorough field reconnaissance is required, the fact that a vast majority of the reservoir area is exposed igneous or metamorphic rock reduces the risk, and makes slope stability a less significant problem. The question of block rock-slide failure will require additional in-depth study, but the evaluaton of reservoir stability and water-tightness is expected to be straight forward and definitive.

The saddle dam relict channel was identified in the initial site reconnaissance investigations, and has therefore been considered throughout the preliminary arrangement studies. The issues at question which need resolution in the design studies are listed below, and relate to the dam arrangement and cross-section shown in Figures 3.1 and 3.3.

- Alluvial depth;
- Allivium bearing capacity with depth;
- Seismic response and stability of alluvium if used for saddle dam;
- Permeability of alluvium if used for foundation;

- Rock permeability under saddle dam area;

- Alluvium erodability and bedrock surface between the saddle damsite and the valley which the emergency spillway is designed to empty into, which is significant under any final design arrangement with the current emergency spillway location, but is particularly critical if the downstream shell of the saddle dam were to be designed to rest on the alluvium rather than on bedrock; and

- Depth of weathering in the rock under the saddle damsite, which will be a function of the geologic history of the channel.

In summary, the currently available information on the reservoir stability and saddle dam relict channel indicate that while more detailed studies are needed, the results of the studies are likely to influence only project costs, rather than arrangement; and then only in a beneficial manner since preliminary design was based on conservative assumptions.

(d) Impervious Borrow Sources

Objective

The objective of the impervious borrow studies will be to locate a more economic and suitable source of impervious or semipervious material for the Devil Canyon development. The current planning assumed trucking material from the Watana damsite, because of a lack of suitable material in the Devil Canyon vicinity.

Approach and Discussion

The only anticipated use of impervious material at this time is for saddle dam, cofferdam, and emergency spillway fuse plug core material. The continued search for suitable material will be based on the assessment of several different alternative designs, which could tolerate varying quality of materials in the structures. Alternatives of artificially crushed or bentonite-mixtures material manufactured into a suitable material, concrete or metal faced or core structures, and various pervious core alternatives may be looked at to determine tradeoff economics. Geotechnically, four alternatives would be investigated in detail to assess the potential for cost reductions:

- Selective fine enhancement of natural local material by crushing or screening;
- Production of suitable material by direct crushing of available rock;
- Selective mining and blending of locally available source materials; and
- Importation of materials by rail from a till or lacustrine deposit downstream of the damsite.

In all cases, the effect of the impervious borrow studies must be controlled by the potential economics of targeted schemes prior to investigation, to ensure that any possible scheme would result in a cost savings over the present alternative. While the availability of suitable material might affect the design of the various earthfill dams proper, it is not likely to result in general arrangement changes, and hence, is not a design critical function.

(e) Granular Fill and Aggregate Sources

Objective

The granular borrow investigations have the goal of identifying adequate reserves of material in suitable quality and at reasonable cost for the following uses:

- Concrete aggregate and sand,
- Grout and shotcrete aggregate and sand;

- Construction roads and pads - subgrade
  - wearing surface (gravel)
  - aggregate (concrete)
- Camp/village pads and footings;
- Filter material; and
- Dam shells, as required by design criteria.

Approach and Discussion

The investigations to date have identified two source areas for granular borrow; the saddle dam excavation and relict channel area, and Borrow Site G immediately upstream of the damsite (Figure 3.1). The suitability of the material for all uses must continue to be investigated to assure that it satisfies the same criteria as detailed in Section 2.2(e) for Watana. A critical cost factor is the suitability of the saddle dam area material without excessive processing cost, and the geotechnical factors listed in Table 2.3 apply equally to the Devil Canyon damsite.

A critical schedule and cost function is the overall project development schedule, because the use of Borrow Site G depends on a diversion scheme which does not significantly elevate the river. Therefore, the diversion tunnel size and the availability of Watana damsite regulation is critical to the project. In order to assess the impact of these factors, detailed reserve and suitability blocking will be required.

(f) Rock Quarry Sites

Objective

The investigation for rock quarry material will be directed at providing adequate construction rock and riprap for use in:

- Construction roads;
- Construction pads;
- Dam shells (cofferdam, saddle dam);
- Slope erosion protection; and
- Concrete aggregate.

Approach and Discussion

The level of investigations which may be performed will depend totally on the anticipated demand for blasted rock materials. The factors influencing cost and the exploration methods which might be utilized are comparable to those listed in Tables 2.3 and 2.4.

The preliminary reconnaissance and sampling indicates that reserves and general rock quality will not be a concern, so once reserves and performance suitability are confirmed, emphasis would be placed on the economics of production and particular suitability for each application.

(g) Reservoir

Objective

The reservoir safety and economics depend on a number of factors, as listed below, and can be assessed in terms of risk and anticipated damage, which then controls the level of remedial or preventive measures to be taken in design and construction.

- Water tightness;
- Overburden stability;
- Rock stability;
- Bedload/sediment behavior;
- Environmental restraints;
- Seismic response;
- Reservoir fluctuation and wave response; and
- Icing and wave erosion.

The objective of reservoir geotechnical assessment wo: be to adequately answer questions and address in design the following issues:

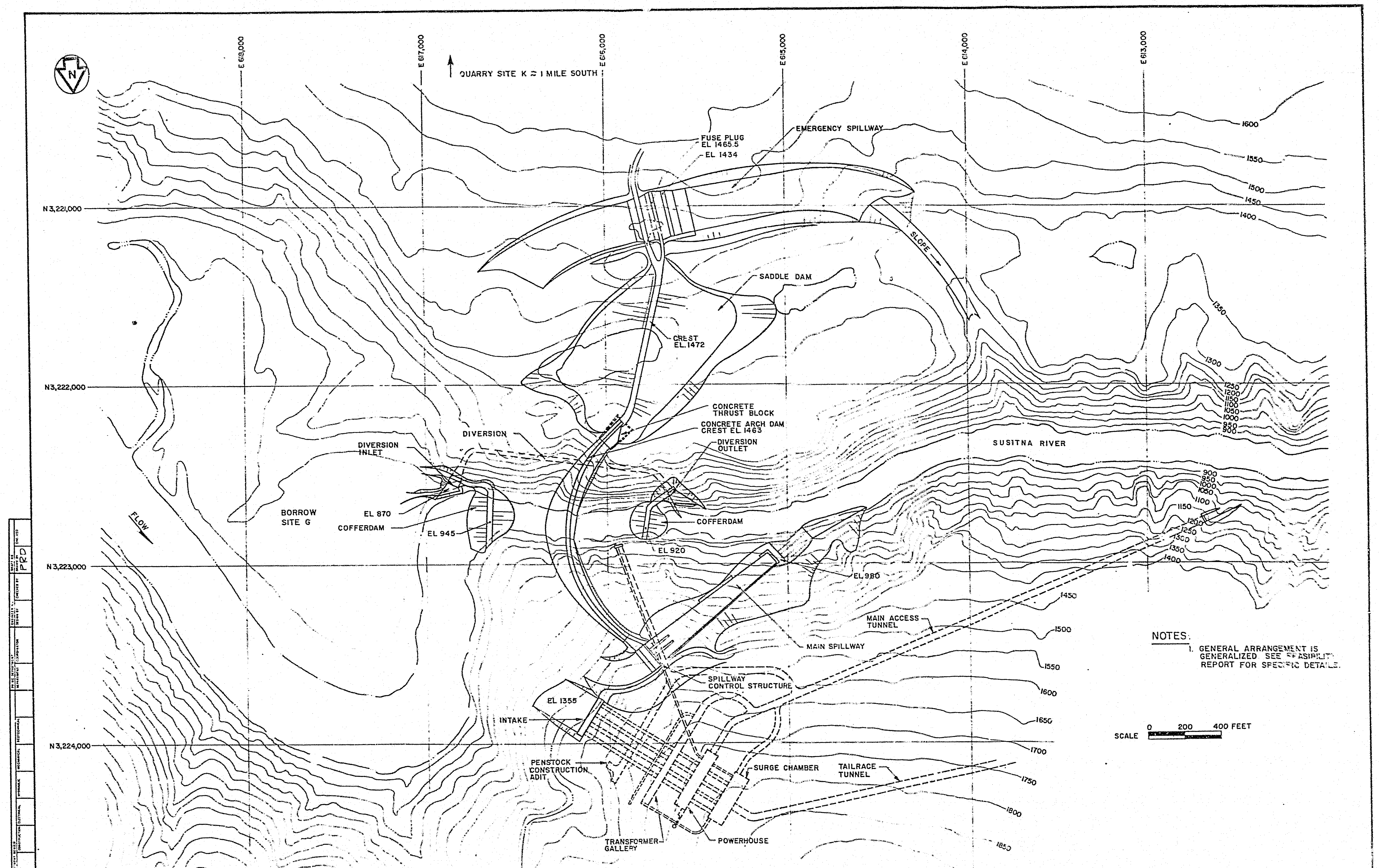
- Water retention;
- Damsite safety;
- Recreational safety;
- Environmental damage/impact;
- Operational restraints.

Approach and Discussion

The approach to the reservoir studies would consider the same factors as those listed in Table 2.3, and for the same reasons as stated for the Watana Reservoir (Section 2.2[g]), so no specific discussion will be presented here.

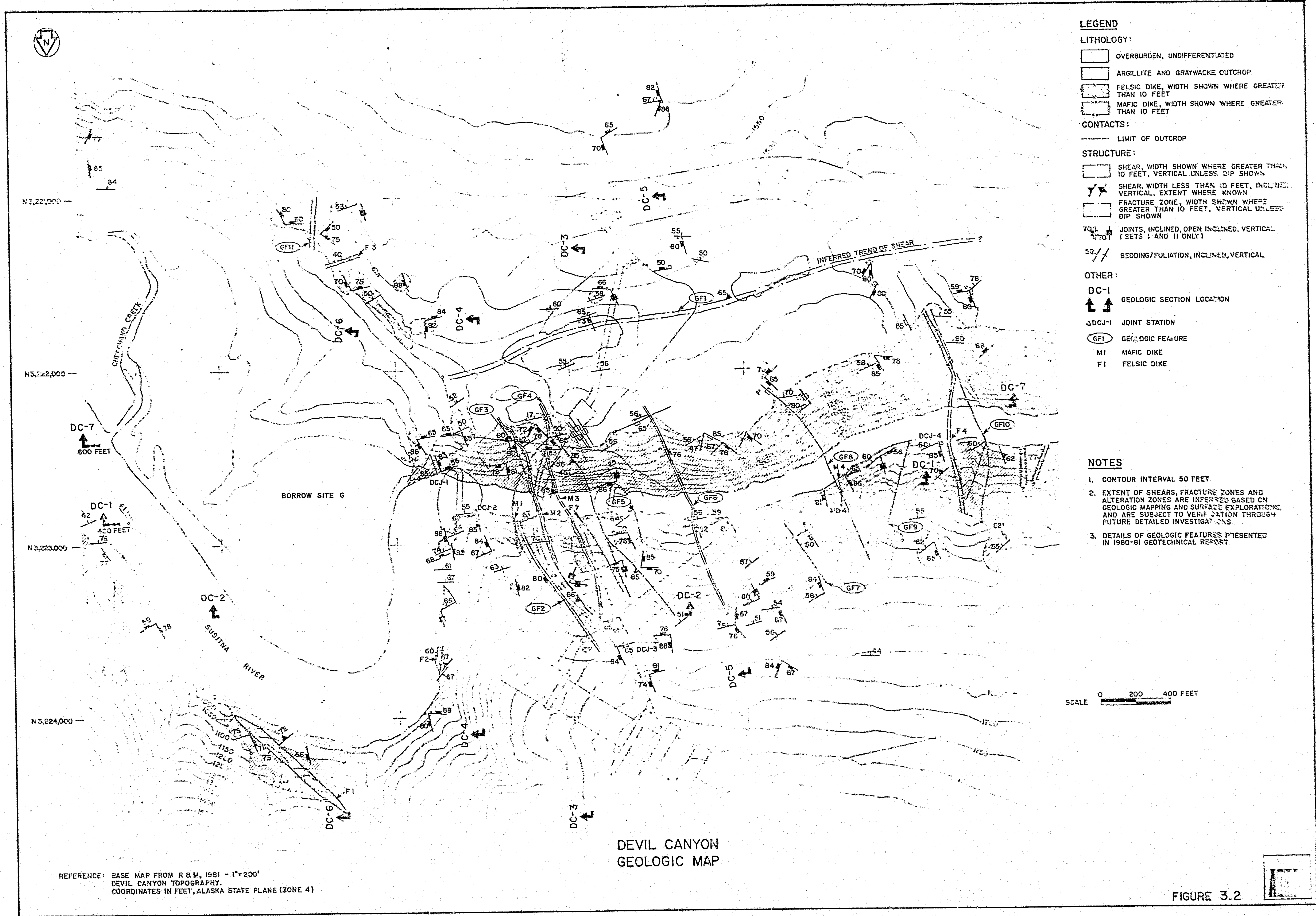
(h) Auxiliary Facilities

Because both the Watana and Devil Canyon projects incorporate the same auxiliary features, there is no need to duplicate the discussion in this section.



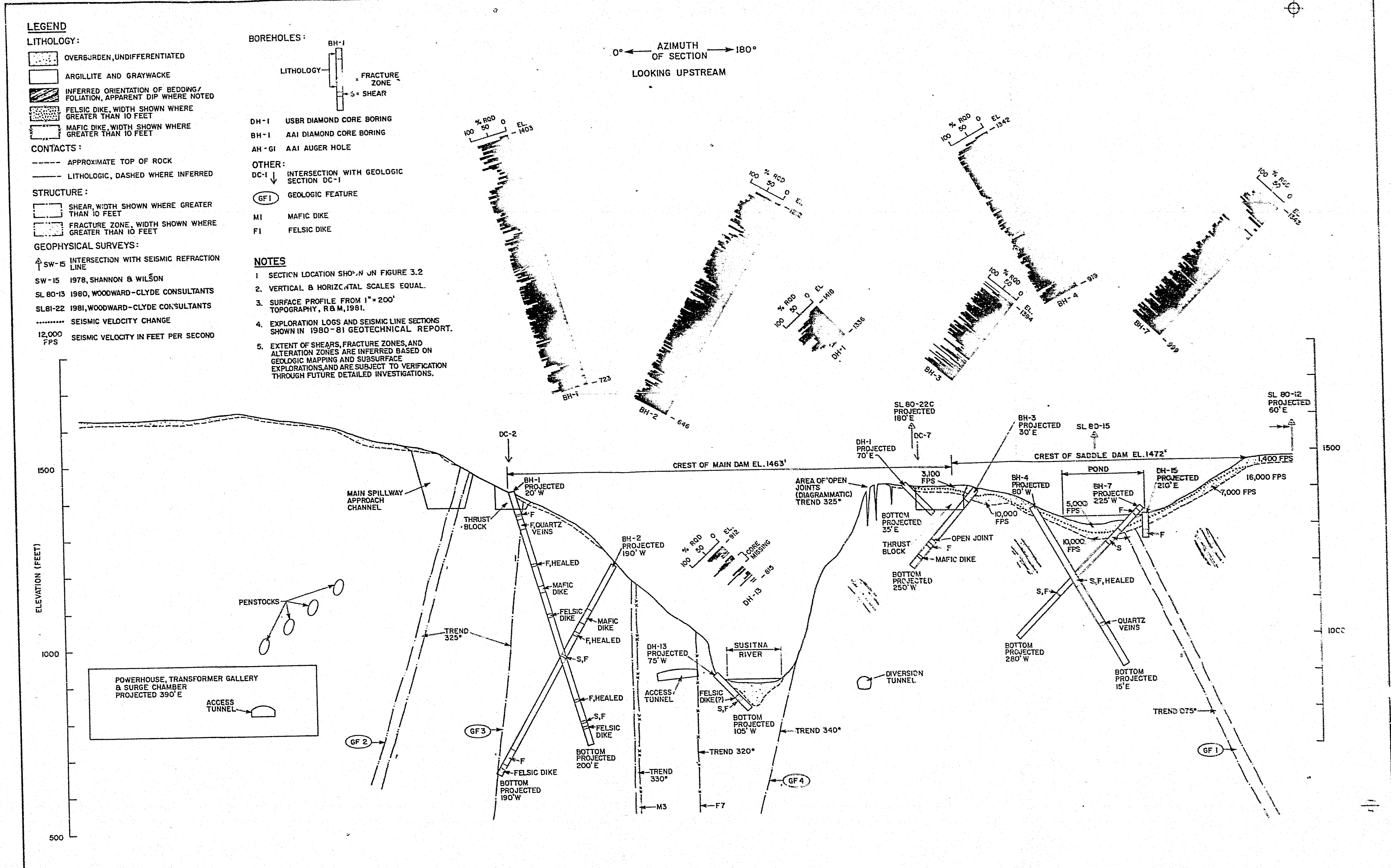
DEVIL CANYON
GENERAL ARRANGEMENT

FIGURE 3.1



DEVIL CANYON
GEOLOGIC MAP

FIGURE 3.2



DEVIL CANYON
GEOLOGIC SECTION DC-3

FIGURE 3.3

4 - ACCESS ROUTES

4.1 - Program Development

For program scoping, the following breakdown of geotechnical investigation categories has been used:

- Route alignment;
- Bridge locations;
- Slope/cut stability and hazard analysis;
- Subgrade conditions; and
- Borrow materials.

Because the current construction schedule calls for delaying access road construction until after receipt of the FERC license, the exploration activities may not fall in the time frame covered by this report. Therefore, only a brief checklist format presentation has been made which lists the major geotechnical considerations which would need consideration in the design phase.

4.2 - Program Scope

Objective

The random of geotechnical factors given in the "Approach" section below is intended as a general guideline of the major factors which are readily apparent as potential influences on access road design or costs, and is not intended to be an outline of all factors to be considered in the detailed design activities. The general geotechnical factors needing consideration are generally the same as for "Site Access", and are listed in detail in Table 2.3, and the exploration methods which could be utilized to conduct data collection are presented in Table 2.4.

Approach

(a) Route Alignment

- General suitability of geologic conditions over varying adjustments in alignment within the selected corridor;

- Potential mass geologic effect on route;

- Potential gross reservoir operating effect on route segments near reservoir rim; and

- General seismic loading environment.

(b) Bridge Locations

- Minimum safe clearance for future river of slide meanders, growth, bank collapse or erosion;

- Potential for mass wasting or deposition at bridge site or nearby, causing flow diversion or blockage;

- Foundation adequacy under design loads;

  - Hydraulic;
  - Geostatic;
  - Seismic;
  - Construction loads (both during bridge construction and loads being carried by bridge during construction of the project);

- Evaluation of alternate bridge types for bridge site,

- Specific site selection, and

- Site remedial measure requirements.

(c) <u>Slope/Cut Stability and Hazard Analysis</u>

- Rock/land slides, talus slides;
- Creep of rocks or soil, including solifluction and rock glacier movement;
- Avalanche;
- Flood,
- Seismic - (direct motion of structure, foundation/footing collapse, induced slide/avalanche hazard); and
- Reservoir bank erosion/wave hazard.

(d) <u>Subgrade Conditions</u>

- Bearing capacity;
- Long-term consolidation/creep;
- Overburden slope stability;
- Ground water seepage/blockage;
- Permafrost, especially free ice;
- Organics in soil, peat, moss, etc.
- Frost susceptibility; and
- Seismic stability, especially liquefaction.

(e) <u>Borrow Materials</u>

- Weathering resistance;
- Hau[illegible] [illegible]tance;
- Con[illegible]C. suitability; and
- Wear[illegible] [illegible]urface durability;

5 - TRANSMISSION

5.1 - Program Development

For the purposes of program scoping, the transmission facilities geotechnical investigations have been broken into the following major areas of concern:

- Route Alignment;
- Major Crossings;
- Hazard Analyses;
- Tower Foundation; and
- Substations/Switchyards.

Each writeup has been developed to address the major geotechnical areas of concern or design activity and does not present all exhaust the parameters which would be considered in final design. While the general parameters which might be considered are the same as on Table 2.3., the development of specific scope and recommendations is not within the scope of this report because the current construction schedule places commencement of transmission line beyond 1984.

5.2 - Program Scope

Objective

While the development of a specific program of proposed exploration is beyond the time frame encompassed in this report, a general rundown of the major parameters has been developed below, in checklist format. Each major factor, along with its various ramifications and associated criteria, would be evaluated to an adequate extent for design, with provision for construction phase confirmation where the factor is not critical to design and can more economically be handled in construction. The general conditions and geotechnical philosophy, as described in Section 4.2 preceeding, apply to transmission studies as well.

Approach

Major factors to consider in design studies:

(a) Route Alignment

- Geotechnical influence on span lengths;
- Seismic response on alternative adjustments; and
- Access road right-of-way stability.

(b) Major Crossings

- Minimum safe clearance from natural features being crossed;
- Long-span guying and additional support requirements;
- Long-span versus suspended conduit type structure foundation difficulties;
- Geotechnical stability of feature being crossed (probability of river meandering, slide area extending to adjacent areas, etc.); and
- Foundation adequacy to handle line pulling loads to cross obstacle.

(c) Hazard Analysis

- Rock/landslides;
- Creep;
- Avalanche;
- Flood and,
- Seismic - direct motion, foundations collapse, slides/avalanche hazard.

(d) Tower Foundation

- Soil depth, stratigraphy,
- Soil strength/bearing capacity, depth to bearing layer,

- Deformation characteristics;
- Anchor pullout resistance;
- Soil/rock weathering potential;
- Stability under loading;
- Chemically corrosive conditions;
- Electrical grounding resistivity;
- Permafrost;
- Water table;
- Frost heave potential;
- Concrete borrow material locations; and
- Alternative foundation designs, with test loadings.

(e) Substations/Switchyards

- Soil depth, stratigraphy;
- Bearing capacity, depth to bearing layer,
- Deformation/consolidation properties;
- Stability under load;
- Seismic response;
- Corrosive condition;
- Electrical grounding resistivity;
- Permafrost;
- Water table;
- Frost heave potential;
- Concrete/road borrow material locations;
- Footing/pad alternative designs and;
- Access facilities foundations stability.