Preliminary Geotechnical Feasibility Study
Newhalen River Canal Diversion Project

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1. INTRODUCTION

1.1 Purpose and Scope

Stone and Webster Engineering Corporation has been retained by the Alaska Power Authority to perform feasibility analyses and prepare a Federal Energy Regulatory Commission license application for the Bristol Bay Regional Power Plan. One of the alternative regional power plans considered in the Bristol Bay Region is the Newhalen River Canal Diversion project. Preliminary geologic and geotechnical investigations of the Newhalen project area were performed by Shannon and Wilson, Inc. to assist Stone and Webster Engineering Corporation with the feasibility analysis and conceptual design for the Newhalen River Canal Diversion.

The original scope of our geotechnical studies consisted of the drilling of three exploratory borings, as discussed in our proposal dated March 17, 1982, and authorized by Stone and Webster in a letter dated March 23, 1982. Consideration had previously been given to performing seismic refraction surveys to provide information on depth to bedrock at the site. However, it was felt that if bedrock was relatively shallow that the seasonally frozen ground would make interpretation of the seismic refraction data difficult. This led to the decision to mobilize a drill rig to the site.

Based on the conditions encountered in the original three borings, the scope of our exploratory work was expanded to include additional borings and several vertical electric soundings (resistivity profiles). A total of eight exploratory borings and seven vertical electric soundings were completed at the site. Limited geologic reconnaissance of the project area was performed by our geologist concurrent with the drilling
operations. A more detailed reconnaissance, planned following the completion of the drilling program, was curtailed by a heavy snowfall.

The scope of Shannon and Wilson's involvement in this feasibility assessment of the Newhalen River Canal Diversion project was limited to the gathering of geologic and geotechnical data in the field. Limited discussion of the engineering implications of this data is contained in this report, with recommendations for further studies if the project is pursued beyond the feasibility stage. The discussions and recommendations should not, however, be considered exhaustive.
2. BACKGROUND

2.1 Site Description

The proposed site of the Newhalen River Canal Diversion is well suited to hydroelectric development from a topographic standpoint. From river mile 7, where the river begins a series of rapids, it flows south and then turns east (see Figure 1). By river mile 2, the water surface has dropped about 110 feet.

The proposed canal alignment (see Plate 1) traverses a highland to the east and north of the river where the topography has been shaped by local glacial and fluvial influences. Stream erosion is evident throughout the study area in the form of terraces, and is boldly reflected in the sharp risers and broad treads of a series of prominent terraces found at the southern area of the alignment. Here the tundra-covered banks describe the meandering mouth of the Newhalen River as it drains into Lake Iliamna. A relatively abrupt drop in elevation coincides with this terraced area at the proposed outlet structure location, as the topographic profile drops about 120 feet to the river within about 1500 feet along the alignment. From this drop northwesterly to the intake structure area, the land surface is relatively gentle, with occasional southwest facing shallow terraces. This broad highland area above the river achieves its peak elevation of about 200 feet in the area to the east and south of the intake structure. Aerial oblique views of the project area are shown in Photo Plates 1 through 4.

Except for occasional grasslands found just above the river, the entire area is covered with a mat of tundra. This organic layer varies in
thickness from six inches to three feet throughout the area. Thick willow and alder stands grow at the banks of the river, and willow is found randomly throughout the area. Some spruce trees grow along the river and in thin forests at the perimeters of the project area.

2.2 Project Description

As currently envisioned, the Newhalen River Canal Diversion project consists of 14,000 feet of canal, with adjunct intake, spillway, penstock, and powerhouse structures. The intake structure would be located near river mile 7, and the spillway near river mile 2 (see Figure 1 and Plate 1).

The canal invert will drop 1 foot in every 1000 feet, and its elevation can be seen on the cross section drawn along the canal alignment (Plate 2). We understand that the invert elevation is controlled by the need to pass an adequate flow at low river levels and with a potential for a thick ice cover on the water in the canal. This results in a depth below existing ground surface to the bottom of the canal of about 45 to 55 feet along much of the canal alignment. Although the canal side slopes were originally planned to be quite steep, the depth of overburden now known to exist will require flatter slopes (at least down to the bedrock surface) and we understand that consideration is being given to using roller compacted concrete to line the portions of the canal which are not in rock.

We further understand that the intake structure and portions of the spillway system will consist of concrete gravity structures and that it is very desirable that these structures be founded on bedrock.
The hydroelectric development presently being considered is not related to previously proposed development on the Newhalen River which was described on the two sheet map "Plan and Profile, Newhalen River, Alaska, Damsite" published by the U.S.G.S. in 1967. That project involved consideration of a damsite at about river mile 11½, some 4½ miles upstream from the proposed intake structure of the diversion canal.

2.3 Site Regional Geology

Both the surficial and bedrock geology of the area of the proposed Newhalen River Canal Diversion have been mapped by Detterman in his studies of the Iliamna Quadrangle\textsuperscript{1,2}. The volcanic bedrock at the site is generally mantled by glacial and glaciofluvial deposits.

The project area was probably covered by glacier ice most recently during the two oldest stades of Brooks Lake Glaciation of late Wisconsin age. It may also have been glaciated during early Wisconsin time. Surficial deposits at higher elevations in the project area have been mapped by Detterman as "hanging delta and outwash fan deposits". These may be the result of later stades of Brooks Lake Glaciation, whereas the subsurface deposits of apparent till and outwash encountered in our borings may relate to the earlier stades. Deposits at lower elevations along the Newhalen River in the project area have been identified by Detterman as "stream terrace deposits". In addition, Detterman has mapped a high strandline of glacial Lake Iliamna, about 150 feet above present lake level, as crossing the upper end of the project area.

At this feasibility study stage of the project, no rigorous attempt has been made to reconstruct the glacial history of the area as related to conditions observed in our borings.
The volcanic rocks exposed along the banks of the Newhalen River through the project area are mapped by Detterman as Tertiary "basalt and andesite", with minor rocks of other composition. Tuffaceous volcanic rocks are mapped to the east of the project area. Regarding reconstruction of the volcanic stratigraphy of the area, Detterman comments that "lava flows, tuffs, and rubble flows are intimately mixed and change rapidly within a short distance."

3. FIELD EXPLORATIONS

3.1 General

A drill crew from our Arctic Alaska Testing Laboratories division was mobilized to the site on March 28, 1982 by a chartered Hercules C-130 aircraft. Field work was supervised at the site by Geologist Roger Troost. Project coordination in Fairbanks was provided by Rohn D. Abbott, Vice President and Manager of the Fairbanks office, and by John Cronin, Associate Geologist.

Borings were drilled at a total of eight locations during the period of March 29 through April 10, 1982. Only one of the originally planned three borings encountered bedrock within the 50 foot target depth, and additional drill tools were mobilized to the site to allow drilling to a greater depth. Four of the additional five borings encountered bedrock.

To supplement the information obtained from the exploratory borings, vertical electric soundings (resistivity profiles) were performed at seven locations at the site. Geophysicist Clyde Ringstad, president of Geo-Recon International, Ltd., of Seattle, performed the resistivity work between April 3 and April 5, 1982.

Surveyors from the Fairbanks office of Ellerbe-Alaska, Inc. were on site twice during the field work. The initial survey work consisted of locating the three original borings and two alternate boring locations. The later work involved locating the additional borings and resistivity profile locations.
A limited geologic reconnaissance was performed by our geologist concurrent with the drilling program. A more detailed reconnaissance, planned following the completion of the drilling, was curtailed by a heavy snowfall on April 10, 1982.

3.2 Exploratory Borings

The project area was explored with a total of eight exploratory borings. Seven of these were drilled on or near the proposed canal alignment; boring B-8 was offset about 1250 feet from the alignment. Boring locations are shown in plan view on Plate 1, and logs of the borings are contained on Figures 2 through 9.

The borings were drilled to depths ranging from 20.3 feet to 69.5 feet using a track-mounted CME-55 drilling rig equipped with continuous flight, hollow stem auger. Drilling operations were supervised and logged by Roger Troost, a geologist with our firm. As the borings progressed, soil samples were generally obtained at 2.5-foot intervals to a depth of 20 feet, and at 5-foot intervals below 20 feet. Sampling was accomplished by driving a 3-inch O.D. split-spoon sampler 18 inches into the soil at the base of the auger with a 340-pound drop hammer falling 30 inches onto the drill rods. For each sample, the number of blows required to advance the sampler the final twelve inches is the penetration resistance and measures the relative density of granular soils and the relative consistency of fine-grained soils. Soil samples obtained using this technique were visually classified in the field, sealed in airtight containers, and returned to our laboratory for testing of selected samples. Penetration resistance is presented graphically on the borings logs.
When rock was encountered, the boring was advanced by diamond coring with an NXD4 double-tube core barrel to determine if the rock was a boulder or bedrock. If the rock was a boulder, further attempts were made to advance the auger, and if unsuccessful the boring was abandoned and relocated. Because of the difficulty in advancing casing through the overburden materials, coring was often limited to a single 5-foot run. Photographs of the rock core obtained during our explorations are included as Photo Plates 5 through 14.

The drilling program consisted of a total of 363 feet of soil drilling and 45 feet of rock coring.

In borings B-5 through B-8, observation wells were installed to allow more accurate measurement of depth to the water table. These installations consisted of a short length of slotted PVC pipe connected to a solid PVC riser pipe. In the other borings, groundwater information was obtained during drilling by measuring water depth on the drill rods when they were extracted from the hole after a sampling attempt.

Pertinent information for each boring, such as location and elevation, and depth and elevation of bedrock and water table, are shown in Table 1.

3.3 Resistivity Survey

Vertical electric soundings (resistivity profiles) were performed at seven locations along the canal alignment to supplement the information obtained from the borings. The soundings were made with an ABEM SAS-300 earth resistivity meter, using a conventional Wenner electrode array. The resultant resistivity values were reduced with the aid of a computer program to simplify interpretation of the results of the soundings.
Resistivity profiles developed by the soundings were correlated to subsurface conditions observed in the exploratory borings to assist in the interpretation.

The interpreted depth to bedrock and water table in each of the soundings is listed in Table 2. Locations of the soundings are shown on Plate 1.

High ice content in the seasonally frozen surficial soils interfered with the resistivity soundings at three locations, VES-2, VES-3 and VES-9. The low conductivity of the icy soils at these locations limited maximum penetration of the soundings to 57, 49 and 30 feet, respectively. Problems with ice-rich surficial soils at other locations may also have affected the resistivity data, but this was not readily apparent.

Interpretation of the resistivity data was limited to the picking of apparent depth to bedrock and water table as depicted in Table 2. The complex stratigraphy of the site, with interbedded outwash sands and gravels, till, and silts precluded a more detailed analysis of the data at this time.

3.4 Topographic Survey

Topographic survey work for the project consisted primarily of establishing locations and elevations for the borings and vertical electric soundings. With the exception of boring B-7, which was relocated following the demobilization of the survey crew from the field, all borings and soundings were located by the surveyors. Boring B-7 was located by hand level, Brunton compass, and string chain from surveyed boring B-6.
In addition to location of borings and electrical soundings, various features such as river elevations, rock outcrops, springs, and ground elevations were located horizontally and vertically, and are shown on Plate 1.

Due to the lack of BLM section corner monumentation in the field, horizontal control for the surveying was established by using the scaled location of the FAA Flight Service Station from the original drawing of Plate 1 and the bearing of the centerline of the east-west runway at the Iliamna airport. This results in the horizontal locations being somewhat approximate, both as located in the field and as shown on Plate 1. The survey has been tied into airport monumentation, photo panels of unknown origin, and a BLM section line river crossing monument discovered at the completion of the surveying program. If the project proceeds beyond the feasibility stage, further research should allow refinement of the surveyed locations.

Vertical control for the survey was established by referencing all elevations to the ice surface of the small lake shown as elevation 177 to the southwest of Pike Lake on the U.S.G.S. 1:63,360 map.

It is our understanding that the topographic base for Plate 1 was prepared by Stone and Webster by enlarging portions of the Iliamna D-6 and C-6 1:63,360 U.S.G.S. maps. The locations of surveyed features from our field explorations depicted on Plate 1 were plotted referenced to the corner of sections 8, 9, 16 and 17 near the Iliamna airport. The inherent lack of detail in the original U.S.G.S. maps, complicated by the enlargement process, results in some features being shown as apparently mislocated with respect to physiographic features on Plate 1. For instance, resistivity sounding VES-10 was actually located below the bluff in section 17, rather than above the bluff as shown on the Plate.
Likewise, the rock outcrops in section 20 were actually adjacent to the Newhalen River; the river elevation at the intake structure was measured in the river, not on land as shown on the Plate; and the spring southwest of station 67+50 was actually at the base of the bluff, rather than at the top of the bluff as shown.

3.5 Geologic Reconnaissance

A limited geologic reconnaissance was performed by our field geologist, Roger Troost, during the course of our field explorations. The findings of this work are incorporated into the discussions of the subsurface conditions in Section 4 of this report.

3.6 Laboratory Testing

Laboratory testing was performed on a representative selection of samples from the eight borings drilled for this investigation. The tests were performed as a supplement to the field observations of the samples to verify classifications and to provide a general indication of the soil properties.

Water contents were determined on selected samples obtained from above water table, and grain size analyses, including hydrometer and specific gravity analysis, were performed on representative samples of the soil types encountered. Atterberg Limits were determined on samples from the silt beds found in borings B-3 and B-8.

Results of the water content and Atterberg Limits determinations are shown on the boring logs, Figures 2 through 9. Grain size gradations are plotted on Figures 10 through 15.
4. **SUBSURFACE CONDITIONS**

4.1 **General**

Two basic geologic influences are represented in the subsurface materials encountered in this investigation. Glacial drift deposits, which Detterman states can locally be more than 100 feet thick in the Newhalen area, overlie bedrock of volcanic origin. The variable depositional environments suggested in the profiles observed in the borings from this exploration program depict a complex sequence of glacial events, reflecting the recent geologic history of this area. However, limited available information about the underlying bedrock types encountered precludes anything but a very general regional view of volcanic history and bedrock configuration.

4.2 **Soils**

Except for the mat of tundra that blankets the landscape, all of the soils found above bedrock appear to be of glacial or proglacial origin. Considering the complex nature of events in a once glacially active region, with the advance, retreat, or stagnation of ice masses influencing many agents of transportation and deposition, it is not surprising to find different sequences or magnitudes of deposition represented at each of the locations explored.

Clean to slightly silty sands and gravels, products of glacial outwash, are the predominant representatives of a glacial environment, and were randomly encountered in various amounts at each location explored. These medium dense to very dense stratified deposits range from well-sorted to poorly-sorted in composition and the constituents are
generally subrounded to rounded. These deposits occasionally contain silty interbeds.

In a few instances, specific clues to the regional glacial history are presented in the properties of the outwash samples. In boring B-5, a clean sand sampled from about 19 feet was found to be very dense, relatively uncharacteristic for the outwash sands sampled elsewhere in this exploration program. This suggests a glacial readvance over the previously deposited outwash sands. In boring B-2, samples from about 10 feet to 20 feet were predominantly subangular and were generally greenish in color, implying a relatively short transport of these gravels from a common local source area.

Glacial till was found in various thicknesses in all of the borings except B-2 and B-4. This poorly sorted material is generally very dense and commonly contains cobbles and boulders. The coarse-grained constituents are subrounded to rounded and the fines segment is non-plastic.

Two distinct zones of till were encountered in all of the borings southeast of about station 95+00, and from about station 104+00 southeast to the outlet structure area, a surficial deposit of till was found at each of the four locations explored. While the complexity of subsurface conditions and the distances between the borings precludes any correlation of buried till beds, the surficial deposits could be related. Another correlation might be speculated from the fact that in four of the five borings in which bedrock was confirmed at depth, it is directly overlain by glacial till. In one of the borings, B-8, a sample of till taken from 54 feet, just above the soil/bedrock contact at 58.0 feet, contained fragments of weathered bedrock, suggesting plucking during glacial advance over bedrock.
Silt beds were encountered in two of the borings, B-3 and B-8, in thicknesses of 17 feet and 8½ feet, respectively. These non-plastic deposits contain traces of sand and fine gravel. While the silts found in B-8 were laminated (1/16" to 1/8" thick), those from B-3 showed only a trace of lamination structure. Although correlation of these beds is improbable, considering the 8500 foot distance between the two borings, in both cases the alluvium directly overlies glacial till that has been deposited on bedrock.

4.3 Bedrock

The bedrock units encountered in the exploratory program are of volcanic origin. Andesitic rocks of varying composition, apparently extrusive flows, were cored in borings B-3, B-4, and B-7, north of about station 98+00. In the southern area of the alignment, south of about station 130+00, pyroclastic rock, volcanic breccia, was found in borings B-5 and B-8. Bedrock was not encountered in borings within the 3200 foot distance between stations 98+00 and 130+00, therefore a contact between the bedrock units identified cannot be verified. The relationship of bedrock units can be seen in Plate 2, Subsurface Profile Along Canal Alignment. The rock classification system used by Shannon and Wilson is presented in Table 3.

Bedrock was found to be as shallow as 10 feet in boring B-4, at the intake structure area near the river, and as deep as 59 feet in boring B-7, at approximately station 98+00. Aside from the apparent thinning of the overburden layer near the north end of the alignment, and again, slightly, in the vicinity of the outlet structure area, depth to bedrock along the alignment is apparently fairly consistent, at about 50 to 60 feet.
The limited data available from this investigation suggests that the bedrock surface dips in a general southerly direction on the order of one-half degree. Although depth to bedrock at any given location along the alignment might be estimated from this trend, actual rock integrity cannot be assumed when factors such as weathering and jointing are considered. Both rock types encountered in our borings show evidence of lessened competence within the depths explored because of jointing and weathering characteristics.

In general, the bedrock was very closely to closely jointed within the depths explored. Joint spacing varied throughout each core run, and only in borings B-5 and B-7, in volcanic breccia and basaltic andesite, respectively, did joint spacing spread to moderately close in deeper runs, suggesting increased competence of bedrock within immediate depth. Joint inclination ranges from $15^\circ$ to $90^\circ$ in the basaltic rocks, and from $15^\circ$ to $45^\circ$ in the breccia. Numerous healed joint sets are apparent in the andesitic rocks and are commonly filled with quartz; healed joints were not apparent in the volcanic breccia.

Weathering of the bedrock examined, in most cases, becomes less significant with depth. The extrusive rocks from borings B-3, B-4, and B-7 tend to show a marked decrease in clay filling of joints and weathering stains on joint surfaces with depth.

A significant difference exists between the pyroclastic breccia samples taken from borings B-5 and B-8. In boring B-5 the rock becomes relatively competent after about three feet of depth. However, the core from B-8, which appears to be the same rock type as that from B-5, is generally very severely to completely weathered, and, in fact, appears substantially more weathered at depth within the depth explored. Yet the elevation of top of bedrock at boring B-8 is about 16 feet lower
than at boring B-5. This greater depth could be the result of overdeepening in the area around B-8 by glacial processes or an abandoned channel of the Newhalen River at this location.

Bedrock crops out at many locations along the Newhalen River between both ends of the proposed alignment. Undulations in the top of bedrock surface were observed along the river near the upper rapids which should be considered in a regional concept of bedrock configuration. A single estimation of this undulation noted a drop of 15 to 20 feet from the top of bedrock outcrop to river level over a distance of about 400 feet.

4.4 Groundwater

The complex arrangement of subsurface conditions encountered throughout this exploration program is reflected in variations of the depths at which water tables were encountered. Groundwater was observed in all of the borings except B-4, at the north end of the alignment where bedrock was found at 9.7 feet; however, the distances between the borings and the observed elevation differences of the water tables make correlation between them difficult. Water tables observed in borings and interpreted from electric soundings are shown in cross section on Plate 2.

Because all of the water tables were observed at elevations well above river level at their respective locations, it must be concluded that the origin of groundwater in this area is from other distant sources. The relatively clean nature of the predominant gravel and sand soil types encountered would not only provide a relatively large groundwater reservoir, but their high permeability could allow high rates of flow into an excavation. Indeed, heaving conditions were usually encountered
during drilling wherever clean gravels and sands were sampled below a water table, confirming the permeability of these materials.

The existence of relatively impervious strata in this region allows the possibility of more than one water table to exist at any given location. Perched water tables are not uncommon in glacial soils, where till layers and silt zones can provide a seal which will hold water. Because of groundwater conditions observed during the drilling of boring B-1, it was originally thought that two water tables might exist at this location. However, subsequent interpretation of the subsurface materials and drilling conditions de-emphasized this speculation, and we now believe that only one water table exists there at about 25 feet.

During drilling of boring B-5, the groundwater level was interpreted as being at about 14.3 feet, however later measurement showed water at about 20 feet. In boring B-6, sand samples from about 17 feet to 29 feet were saturated when extracted from the ground, yet subsequent monitoring of groundwater level in B-6 showed the water table to be at 29 feet. In both of these cases, the possibility of a perched water table exists.

Frozen spring flows were observed atop rock outcrops at the river at both ends of the alignment, suggesting the possibility of groundwater flowing directly on top of bedrock. Frozen conditions prevented any measurement of this flow, but it was observed as minimal. Another spring was observed in the field area at the base of a bluff southwest of the alignment at about station 67+50. The existence of this minor flow suggests groundwater flowing above some impermeable strata at this location.
4.5 Frozen Ground

The possibility of sporadic permafrost exists in this region, however, none was encountered in our exploration. The surficial mat of tundra was, in most cases, frozen, and the observed visible ice content was as high as 40%. In borings B-1, B-2, B-3, and B-8, surficial soil deposits were frozen, and the deepest penetration of frost was 4 feet in B-1; however, no visible ice was observed in these frozen strata. The shallow frost penetration observed in our exploration suggests that it is seasonal frost.
5. **DISCUSSION**

5.1 **General**

The geotechnical implications of conditions encountered at the site for the Newhalen River Canal Diversion project are discussed in this section. Sections are presented on depth to bedrock, groundwater conditions, excavations, and slope stability. These discussions should not be considered a complete analysis of geotechnical conditions in the project area, as the scope of Shannon and Wilson's studies was primarily exploration and not engineering.

5.2 **Bedrock Depth**

The elevation of the bedrock surface with respect to invert elevation along the canal alignment can be seen in the cross section on Plate 2. This bedrock surface has been interpreted from a combination of information obtained from borings and electric soundings.

As can be seen, only the first approximately 6000 feet of the canal invert as presently planned is interpreted as being on or in bedrock. Only about the first 3000 feet of the canal would require more than 10 feet of excavation into rock, as interpreted.

The cross section depicts a relatively uniform dip of the bedrock surface from station 0+00 to near station 100+00. Southeast of this point, two interpretations are possible, depending on whether or not Boring B-8 is projected into the section from 1250 feet to the northeast, and whether the depth to rock interpreted from electric sounding VES-10 is believed. Without this projection, the bedrock surface appears almost flat from station 100+00 to the river, although control
from either borings or electric soundings is absent for about 4600 feet along the section. Acceptance of the projection of B-8 and the interpretation of VES-10 implies an overdeepening of the bedrock surface of about 20 feet near station 140+00. In our opinion, such overdeepening is possible in this area, either as a result of glacial processes or as a result of burial of an old channel of the Newhalen River. We understand that depth to bedrock may be critical in this area because of the need to found gravity concrete structures for the spillway on bedrock.

In most of the borings where encountered, the upper few feet of rock were slightly to moderately weathered. In boring B-8, however, all 10 feet of rock cored was very severely weathered, with the rock almost completely weathered to soil. This boring was located in the creek about 1250 feet northeast of the alignment near station 130+00. It is not known whether the rock under the alignment is similarly weathered.

It is not likely that water flow in the creek caused this weathering, because the measured water table is about 21 feet below ground surface at this location. Most of the rest of the area has a water table at a similar depth, yet the rock does not show similar weathering. Though no faults have been mapped in the area, it is possible that a fault or shear zone at the location of boring B-8 could be responsible for the weathering observed in the rock. Alternately, if the location is part of an old buried channel there maybe increased groundwater flow which could be responsible for the increased weathering.

Anomalous resistivity values in electrical sounding VES-7 below a depth of 62 feet may represent another zone of severely weathered rock, or possibly a very old till deposit which was buried by a volcanic flow.
5.3 Groundwater Conditions

Groundwater table was measured in borings or interpreted from resistivity profiles significantly above canal invert elevation at almost all locations. As many of the overburden soils at the site consist of clean sands and gravels which are assumed to have a high permeability, the possibility exists of significant rates of flow of water into an excavation. No pumping or permeability tests were performed as part of our field explorations, and it would be difficult to quantify rates of flow at the present time.

Additionally, observed perched water tables present the possibility of encountering water in an excavation at elevations above the main water table.

Problems were experienced in many of the borings with heaving sands below the water table. If an excavation encountered deposits of sands below the water table which are confined by till or other impervious materials, these sands could be expected to "run" into the excavation.

5.4 Excavations

5.4.1 Soil Excavations

The overburden soils at the site are not expected to be difficult to excavate, although groundwater flow may present problems as outlined in the previous section. The volume of material which will require excavation to cut the side slopes at a stable configuration will be large.
The granular soils encountered in our borings were generally medium dense to dense. Where encountered, cobbles comprised about 10 to 20% of the material, and boulders up to about two feet in diameter were encountered. Given the glacial origin of the overburden, larger boulders or glacial erratics might be encountered in the overburden.

Only seasonally frozen surficial soils were encountered in our explorations. In our opinion, the chance of encountering permanently frozen soil (permafrost) in the excavation is fairly slight.

Although the till and till-like silty soils encountered in our explorations might be stable at a steeper cut slope than the granular soils, in our opinion the canal excavation should be planned for a uniform stable slope. Determination of what constitutes a stable slope will require detailed slope stability analyses, taking into account the groundwater table. Pore pressure will be particularly critical following installation of the canal lining but prior to filling of the canal.

Preliminary plans called for use of the material excavated from the canal to construct a road embankment adjacent to the canal. Any major embankment close to the edge of the canal can be expected to influence the stability of the adjacent slope.

Construction safety for personnel and equipment working on excavation of the canal should also be considered during planning of the canal side slopes.
5.4.2 Rock Excavation

Based on limited observations of the bedrock at the site, both in outcrops and in the cored portions of the borings, it is anticipated that stable excavations in the rock can be made with relatively steep side slopes. More detailed geologic mapping of the area, including comprehensive studies of the spacing and orientation of joints and other discontinuities, would be required as input to rock slope stability analyses.

The upper portion of the bedrock which was cored in our borings was generally very closely to closely jointed. It may be possible to excavate this jointed rock by heavy ripping, but in our opinion, drilling and blasting may be necessary to facilitate a significant amount of the rock excavation at the site. Seismic refraction studies, if performed to further define subsurface conditions at the site, would help in determining rippability of the rock.

Another possibility which should be anticipated is encountering unforeseen zones of severely weathered rock, such as that observed in boring B-8. Such zones might require overexcavation or other special treatment beyond the planned scope of excavating work.

5.5 Slope Stability

Stability problems associated with the excavation of the canal have been discussed in the previous section. This section deals with the stability of natural slopes at the site.

From discussions with Stone and Webster, we understand that two areas of concern exist. The first is the prominent bluff near station 140+00
which the spillway structure traverses. The second is the bluff south of the proposed alignment in the vicinity of station 80+00.

While these slopes may be stable in their present natural state, changes in the groundwater regime because of seepage from the canal could adversely affect their stability. Spring flow caused by increased groundwater could result in erosional failure, or an increase in pore pressure could cause more massive failures. In our opinion, the bluffs to the west of the canal alignment at the PI near station 30+00 may also be subject to the same types of potential instability as the two areas of concern described above.

Field reconnaissance in the area just above the Newhalen River at the proposed site of the spillway structure revealed what appeared to be rotated slump blocks of material. It is possible that this area has been subject to slope failures in the past, and it should be studied in more detail if the project proceeds beyond the feasibility level.
6. RECOMMENDATIONS FOR ADDITIONAL STUDIES

6.1 General

The geotechnical studies discussed in this report were performed to assist Stone and Webster in a preliminary analysis of the feasibility of hydroelectric development by a diversion of the Newhalen River. Additional studies will be required to assess the feasibility of the project in greater detail. The studies which in our opinion would be useful in further feasibility assessment or design engineering are outlined in this section of the report.

6.2 Geophysical Studies

6.2.1 Seismic Refraction Survey

In our opinion, a seismic refraction survey performed along the entire length of the canal alignment would provide a more detailed profile of depth to bedrock along the proposed alignment. In addition, it should be possible to interpret the varying stratigraphy of the overburden soils, and differentiate between some of the till and outwash deposits.

In addition to developing a seismic profile along the canal alignment, seismic surveys performed perpendicular to the alignment at selected locations would assist in developing three dimensional information on the bedrock surface.

There are several problems inherent with the use of seismic refraction methods at this site. The first involves the presence of seasonal frost; a refraction survey would preferably be performed after the surficial soils were entirely thawed. The other problems with the
method involve hidden layers and blind zones resulting from velocity inversions. A hidden layer results when a relatively thin intermediate layer is not detected because the wave front propagating through a deeper, higher velocity layer arrives at the surface first. Velocity inversions are masking effects resulting from a higher-velocity layer overlying a lower-velocity layer. An example of a velocity inversion would be a compact till overlying a gravel layer with no appreciable water.

The interpretation of the seismic records can be performed with less uncertainty when subsurface information from another source is available. Either direct information from exploratory borings, or substantiating information from another geophysical method such as resistivity, would be helpful.

Seismic refraction work at the site would also be useful in estimating the rippability of the bedrock.

6.2.2 Vertical Electric Soundings

Difficulties were encountered in performing and interpreting the results of vertical electric soundings (resistivity profiles) at the site during this field program due to the high ice content of the seasonally frozen soils. Resistivity work performed after the seasonally frozen surficial soils had thawed would be very helpful when correlated to seismic refraction work or additional exploratory borings.
6.3 **Exploratory Borings**

In our opinion, detailed design work for the proposed river diversion should be preceded by the drilling and sampling of additional exploratory borings. These borings should be used both for correlation with geophysical explorations and for site-specific foundation studies of soil and rock conditions at locations of major structures. In addition, pumping tests or in-hole permeability tests should be performed to assess the magnitude of groundwater flow which can be expected into excavations at the site.

Information gained during our preliminary studies regarding subsurface conditions at the site and depth of exploration required should allow mobilization of the necessary drilling equipment to obtain the information required during any future studies.

6.4 **Field Reconnaissance**

Geologic reconnaissance of the project area during this preliminary study was limited by time constraints associated with the drilling program, and later by a heavy snowfall.

Additional geologic mapping, primarily in the area along the banks of the Newhalen River where bedrock is exposed, would further our understanding of the nature and distribution of bedrock at the site. Detailed studies of the frequency and orientation of joints and other discontinuities would be essential to determining the angle at which rock slopes would be stable in the canal excavation.

Additionally, a general reconnaissance of the site after the ground was thawed might reveal the location of other springs in the area. This
information would be useful in developing an understanding of the groundwater regime.

6.5 Topographic Surveys

Detailed topographic survey information on the area proposed for the diversion canal is presently lacking. Such information will be vital for further geotechnical studies, including slope stability analyses, interpretation of seismic refraction data, and correlation of boring and resistivity data.

Although the information obtained from a series of profiles and cross sections could be utilized, in our opinion, a photogrammetric survey in conjunction with these traverses would be quite useful.
7. LIMITATIONS

The scope of Shannon and Wilson's involvement in this feasibility assessment of the Newhalen River Canal Diversion project was limited to the gathering of geologic and geotechnical data in the field. Limited discussion of the engineering implications of this data is contained in this report, with recommendations for further studies if the project is pursued beyond the feasibility stage. The discussions and recommendations should not, however, be considered exhaustive.

The analyses, discussions, and recommendations contained in this report are based on site conditions as they presently exist and further assume that the exploratory borings, and soil resistivity data are representative of the subsurface conditions throughout the site (i.e., the subsurface conditions everywhere are not significantly different from those disclosed by the exploration).

The geotechnical studies for this project are preliminary in nature and were designed to assist Stone and Webster Engineering Corporation and the Alaska Power Authority in assessing the feasibility of hydroelectric development by diverting the Newhalen River. In our opinion, additional site specific field investigations will be required before definitive geotechnical recommendations can be developed for the project.

SHANNON & WILSON, INC.

By Rohn D. Abbott, P.E.
Vice President & Manager
### TABLE 1

**SUMMARY OF SUBSURFACE EXPLORATIONS**

<table>
<thead>
<tr>
<th>VORING NO.</th>
<th>APPROXIMATE STATION AND OFFSET</th>
<th>GROUND SURFACE ELEVATION</th>
<th>TOTAL DEPTH</th>
<th>BEDROCK DEPTH</th>
<th>WATER TABLE ELEVATION</th>
<th>PROPOSED CANAL INVERT ELEVATION</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-1</td>
<td>129+35 40'L</td>
<td>175.0'</td>
<td>50.0'</td>
<td>---</td>
<td>25.0'</td>
<td>149.0'</td>
<td>43.0'   132.0'</td>
</tr>
<tr>
<td>B-2</td>
<td>90+20 20'L</td>
<td>182.0'</td>
<td>53.0'</td>
<td>---</td>
<td>25.0'</td>
<td>157.0'</td>
<td>46.0'   136.0'</td>
</tr>
<tr>
<td>B-3</td>
<td>46+00 50'L</td>
<td>194.0'</td>
<td>53.0'</td>
<td>48.0'</td>
<td>146.0'</td>
<td>178.0'</td>
<td>54.0'   140.0'</td>
</tr>
<tr>
<td>B-4</td>
<td>250' N of 0+00 200'L</td>
<td>188.0'</td>
<td>20.0'</td>
<td>10.0'</td>
<td>178.0'</td>
<td>---</td>
<td>43.0'   145.0'</td>
</tr>
<tr>
<td>B-5</td>
<td>144+50 290'R</td>
<td>143.0'</td>
<td>43.0'</td>
<td>33.0'</td>
<td>110.0' **14.0/20.0' 129.0/123.0'</td>
<td>12.0'   131.0'</td>
<td></td>
</tr>
<tr>
<td>B-6</td>
<td>102+30 155'L</td>
<td>184.0'</td>
<td>52.0'</td>
<td>---</td>
<td>29.0'</td>
<td>155.0'</td>
<td>49.0'   135.0'</td>
</tr>
<tr>
<td>B-7</td>
<td>97+90 45'L</td>
<td>174.0'</td>
<td>68.0'</td>
<td>59.0'</td>
<td>115.0'</td>
<td>168.0'</td>
<td>39.0'   135.0'</td>
</tr>
<tr>
<td>B-8</td>
<td>130+00 1290'L</td>
<td>152.0'</td>
<td>70.0'</td>
<td>58.0'</td>
<td>94.0'</td>
<td>131.0'</td>
<td>---     132.0'</td>
</tr>
</tbody>
</table>

**NOTE:** All depths and elevations have been rounded off to the nearest foot.

### TABLE 2

**SUMMARY OF VERTICAL ELECTRIC SOUNDINGS**

<table>
<thead>
<tr>
<th>VERTICAL ELECTRIC SOUNDING NO.</th>
<th>APPROXIMATE STATION AND OFFSET</th>
<th>GROUND SURFACE ELEVATION</th>
<th>INTERPRETED BEDROCK DEPTH</th>
<th>INTERPRETED WATER TABLE ELEVATION</th>
<th>PROPOSED CANAL INVERT ELEVATION</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>YES-1</td>
<td>46+00 50'L</td>
<td>194.0'</td>
<td>46.0'</td>
<td>148.0'</td>
<td>173.0'</td>
<td>54.0'   140.0'</td>
</tr>
<tr>
<td>YES-2</td>
<td>90+20 20'L</td>
<td>182.0'</td>
<td>&gt;75.0'</td>
<td>&lt;125.0'</td>
<td>161.0'</td>
<td>46.0'   136.0'</td>
</tr>
<tr>
<td>YES-3</td>
<td>129+35 40'L</td>
<td>175.0'</td>
<td>&gt;49.0'</td>
<td>&lt;126.0'</td>
<td>149.0'</td>
<td>43.0'   132.0'</td>
</tr>
<tr>
<td>YES-7</td>
<td>26+00 CL</td>
<td>199.0'</td>
<td>44.0'</td>
<td>155.0'</td>
<td>171.0'</td>
<td>57.0'   142.0'</td>
</tr>
<tr>
<td>YES-8</td>
<td>66+80 190'R</td>
<td>180.0'</td>
<td>44.0'</td>
<td>136.0'</td>
<td>141.0'</td>
<td>42.0'   138.0'</td>
</tr>
<tr>
<td>YES-9</td>
<td>109+80 20'L</td>
<td>185.0'</td>
<td>&gt;30.0'</td>
<td>&lt;125.0'</td>
<td>167.0'</td>
<td>51.0'   134.0'</td>
</tr>
<tr>
<td>YES-10</td>
<td>140+90 40'R</td>
<td>150.0'</td>
<td>61.0'</td>
<td>59.0'</td>
<td>137.0'</td>
<td>19.0'   131.0'</td>
</tr>
</tbody>
</table>

**NOTE:** All depths and elevations have been rounded off to the nearest foot.
### TABLE 3
DESCRIPTION OF ROCK PROPERTIES

#### WEATHERING

- **Fresh** - Rock fresh, crystals bright, few joints may show slight staining. Rock rings under hammer if crystalline.
- **Very Slight** - Rock generally fresh, joints stained, some joints may show clay if open, crystals in broken face show bright. Rock rings under hammer if crystalline.
- **Slight** - Rock generally fresh - joints stained and discoloration extends into rock up to 1 in. Open joints contain clay. In granitoid rocks some occasionally feldspar crystals are dull and discolored. Crystalline rocks ring under hammer.
- **Moderate** - Significant portions of rock show discoloration and weathering effects. In granitoid rocks most feldspars are dull, discolored; some show clayey. Rock has dull sound under hammer and shows significant loss of strength as compared with fresh rock.
- **Moderately Severe** - All rock except quartz discolored or stained. In granitoid rocks all feldspars dull and discolored and majority show kaolinite. Rock shows severe loss of strength and can be excavated with geologist's pick. Rock goes "clunk" when struck. (Saprolite)
- **Severe** - All rock except quartz discolored or stained. Rock "fabric" clear and evident but reduced in strength to strong soil. In granitoid rocks all feldspars kaolinitized to some extent. Some fragments of strong rock usually left. (Saprolite)
- **Very Severe** - All rock except quartz discolored or stained. Rock "fabric" discernible but mass effectively reduced to "soil" with only fragments of strong rock remaining.
- **Complete** - Rock reduced to "soil." Rock "fabric" not discernible or discernible only in small scattered locations. Quartz may be present as dikes or stringers.

#### HARDNESS

- **Very Hard** - Cannot be scratched with knife or sharp pick. Breaking of hand specimens requires several hard blows of geologist's pick.
- **Hard** - Can be scratched with knife or pick only with difficulty. Hard blow of hammer required to detach hand specimen.
- **Moderately Hard** - Can be scratched with knife or pick. Gouges or grooves to 1/4 in. deep can be excavated by hard blow of point of geologist's pick. Hand specimens can be detached by moderate blow.
- **Medium** - Can be grooved or gouged 1/16 in. deep by firm pressure on knife or pick point. Can be excavated in small chips to pieces about 1 in. maximum size by hard blows of the point of a geologist's pick.
- **Soft** - Can be gouged or grooved readily with knife or pick point. Can be excavated in chips to pieces several inches in size by moderate blows of a pick point. Small thin pieces can be broken by finger pressure.
- **Very Soft** - Can be carved with knife. Can be excavated readily with point of pick. Pieces an inch or more in thickness can be broken by finger pressure. Can be scratched readily by finger nail.

#### JOINT BEDDING AND FOLIATION SPACING IN ROCK

<table>
<thead>
<tr>
<th>Spacing</th>
<th>Joints</th>
<th>Bedding and Foliation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 2 in.</td>
<td>Very close</td>
<td>Very thin</td>
</tr>
<tr>
<td>2 in to 1 ft.</td>
<td>Close</td>
<td>Thin</td>
</tr>
<tr>
<td>1 ft. to 3 ft.</td>
<td>Moderately close</td>
<td>Medium</td>
</tr>
<tr>
<td>3 ft. to 10 ft.</td>
<td>Wide</td>
<td>Thick</td>
</tr>
<tr>
<td>More than 10 ft.</td>
<td>Very wide</td>
<td>Very thick</td>
</tr>
</tbody>
</table>

* After Deere, 1963^a

**NOTE**: Joint spacing refers to the distance normal to the plane of the joints of a single system or "set" of joints which are parallel to each other or nearly so.

#### ROCK QUALITY DESIGNATOR (RQD)

<table>
<thead>
<tr>
<th>RQD In % = 100</th>
<th>Length of Core in Pieces 4 in. and Longer</th>
<th>Length of Run</th>
</tr>
</thead>
<tbody>
<tr>
<td>90%</td>
<td>Excellent</td>
<td></td>
</tr>
<tr>
<td>75-90%</td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td>50-75%</td>
<td>Fair</td>
<td></td>
</tr>
<tr>
<td>Less than 50%</td>
<td>Poor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Very Poor</td>
<td></td>
</tr>
</tbody>
</table>

* After Deere 1967^b

**NOTE**: Diagnostic Description is intended primarily for evaluating problems with tunnels or excavations in rock.


* For Engineering Description of Rock - not to be confused with Moh's scale for minerals.
From Sheet 1, "Plan and Profile, Newha1en River, Alaska, Damsite" USGS, 1967

Scale: 1 Inch = 2000 Feet

Stone & Webster Engr. Corp.
MAP OF PORTION OF THE NEWHALEN RIVER
April 1982 K-0517-01
Soil Description

Station: Approx. 129+35, 40'L
Surface Elevation: 175'

Brown sandy silt to silty sand w/ organics (Tundra) Vr/Vx ~40%, w/ ice lenses to 1/4".

Very dense, gray-brown to gray, silty to silty, sandy, fine to coarse gravel. Nbn where frozen (Glacial Till?)

Very dense, gray, clean, sandy, fine to coarse gravel.

Medium dense, gray-brown, clean, fine to medium sand, trace of coarse sand and fine gravel.

Dense to very dense, gray-brown, clean, sandy, fine to coarse gravel.

Medium dense zone ~15' - 19'

Medium dense, gray to gray-brown, clean to slightly silty, fine to medium sand.

(Cont.)
SOIL DESCRIPTION

Station: Approx. 129+35, 40'L  
Surface Elevation: 175'

Very dense, brown, silty sandy GRAVEL  
(Glacial Till?)

Dense, gray, slightly silty fine SAND, trace of medium to coarse SAND

NOTE: Subsurface conditions from 41.5 to 50.0' interpreted from drilling action

Medium dense to dense, sandy GRAVEL

Bottom of Exploration  
Completed 3/30/82

LEGEND

Frozen Ground

Gravel
Sand
Silt
Clay
Peat
Organic Content

Impervious seal
Water level
Piezometer tip
Thermocouple
3" O.D. split spoon sample
3" O.D. thin-wall sample
Sample not recovered
Atterberg limits:
Liquid limit
Water content
Plastic limit

Note: The stratification lines represent the approximate boundaries between soil types and the transition may be gradual.

Stone & Webster
Newhalen River Canal Diversion
Newhalen, Alaska

LOG OF BORING NO. B-1 (CONT.)

April 1982

SHANNON & WILSON, INC.
GEOTECHNICAL CONSULTANTS

FIG. 2
SOIL DESCRIPTION

Station: Approx. 90+20, 20' L
Surface Elevation: 182'

Brown, sandy SILT, w/organics (Tundra)
Soft, red-brown, fine sandy SILT, tr. of roots, scattered fine gravel.
Becomes sandier with depth

Med. dense, red-brown to gray-brown, silty fine SAND, w/occasional thin lenses of slightly silty fine sand

Dense, gray-brown, clean, sandy, fine GRAVEL

Dense to very dense, gray-brown to gray-green, clean to slightly silty, sandy, fine-coarse GRAVEL, subangular

Medium dense to dense, gray-brown to brown, slightly silty sandy GRAVEL

Interbedded, medium dense to dense, clean to slightly silty gravelly SAND and sandy GRAVEL

(continues)
SOIL DESCRIPTION
Station: Approx. 90+20, 20'L
Surface Elevation: 182'

Interbedded SANDS and GRAVELS, as above

Loose, gray-brown, slightly silty fine SAND, trace of coarse sand and fine gravel

Bottom of Exploration Completed 3/31/82

NOTE: *Subsurface conditions from 51.5' to 53.0' interpreted from drill action.
SOIL DESCRIPTION

Station: Approx. 46+00, 50'L
Surface Elevation: 194'

Brown, fine sandy SILT, with organics (Tundra)

Very dense, gray-brown, clean to slightly silty, sandy, fine to coarse GRAVEL, with cobbles

S-4, medium dense

S-8, dense

Stiff to very stiff gray to gray-brown SILT, trace of fine to coarse sand

LEGEND

- Impervious seal
- Water level
- Piezometer tip
- Thermocouple
- 3" O.D. split spoon sample
- 3" O.D. thin-wall sample
- Sample not recovered
- Atterberg limits:
  - Water content
  - Plastic limit
  - Liquid limit

Note: The stratification lines represent the approximate boundaries between soil types and the transition may be gradual.

Stone & Webster
Newhalen River Canal Diversion
Newhalen, Alaska

LOG OF BORING NO. B-3

April 1982

SHANNON & WILSON, INC.
GEOENGINEERING CONSULTANTS
**SOIL DESCRIPTION**

Station: Approx. 46+00, 50'L  
Surface Elevation: 194'

*SILT, as above*

Medium dense to dense, gray-brown, silty, gravelly SAND and sandy GRAVEL (Glacial Till)

---

**LEGEND**

- Frozen Ground
- Water content
- Impervious seal
- Water level
- 3% O.D. split spoon sample
- 3% O.D. thin-wall sample
- Sample not recovered
- Atterberg limits: Liquid limit
- Water content  
- Plastic limit

**LOG OF BORING NO. B-3 (CONT.)**

April 1982  
SHANNON & WILSON, INC.  
GEOTECHNICAL CONSULTANTS  
K-0517-01
SOIL DESCRIPTION

Station: Approx. 250' N. of Sta. 0+00, 200' L

Surface Elevation: 188'

Brown, sandy SILT, with organics (Tundra)

Very dense, brown, slightly silty to silty, sandy, fine to coarse GRAVEL

Very dense, gray-brown, clean to slightly silty, sandy, fine to coarse GRAVEL

(cont.)

LEGEND

Gravel
Sand
Silt
Clay
Peat
Organic Content

Impervious seal
Water level
Piezometer tip
Thermocouple
3" O.D. split spoon sample
3" O.D. thin-wall sample
* Sample not recovered

Atterberg limits:
Liquid limit
Plastic limit

Note: The stratification lines represent the approximate boundaries between soil types and the transition may be gradual.

Stone & Webster
Newhalen River Canal Diversion
Newhalen, Alaska

LOG OF BORING NO. B-4

April 1982
SHANNON & WILSON, INC.
GEOTECHNICAL CONSULTANTS

FIG. 5
<table>
<thead>
<tr>
<th>DEPTH</th>
<th>GRAPHIC LOG</th>
<th>DESCRIPTION OF MATERIALS</th>
<th>SAMPLE RUN NO</th>
<th>GROUND TEMP. (°F)</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.9</td>
<td>+ +</td>
<td>GRAVEL, as above</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>+ +</td>
<td>Moderately hard, light brown to gray DACITE/RHYOLITE, very closely jointed @ 30°-45°</td>
<td>1</td>
<td>100</td>
<td>auger refusal @ 9.7'</td>
</tr>
<tr>
<td></td>
<td>+ +</td>
<td>9.9'-11.9' joints spaced 1&quot; to 2&quot;, joint faces irregular @ ~45° w/clay coating</td>
<td>1</td>
<td>31</td>
<td>Began NX diamond coring @ 9.9'</td>
</tr>
<tr>
<td>15.1</td>
<td>+ +</td>
<td>11.9'-15.1' joints spaced 2&quot; to 6&quot; (4&quot; to 6&quot; common)</td>
<td>2</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td></td>
<td>+ +</td>
<td>15.1'-16.7' joints spaced 1&quot; to 3&quot;, stained</td>
<td>2</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td></td>
<td>+ +</td>
<td>16.7'-20.3' joints spaced 2&quot; to 8&quot; (5&quot;-8&quot; common)</td>
<td>2</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>20.3</td>
<td>+ +</td>
<td>19.1' - 20.0' near vertical joint, stained Numerous healed joint sets throughout</td>
<td>2</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td></td>
<td>+ +</td>
<td>Bottom of Exploration Completed 4/3/82</td>
<td>2</td>
<td>31</td>
<td></td>
</tr>
</tbody>
</table>
SOIL DESCRIPTION

Station: Approx. 144+50, 290'R
Surface Elevation: 143'

Very dense, brown, silty, sandy fine to coarse GRAVEL, with cobbles (Glacial Till)
cobbly zone 3'-5'

NOTE: auger refusal @~3'. Tri-cone and coring through materials allowed further auger penetration (NX core run 1, 4.7'-9.9', L=5.2, Rec=3.0)

Medium dense to dense, gray-brown clean to slightly silty, fine gravelly, fine-coarse SAND

Medium dense, gray-brown, slightly silty fine SAND, laminated, tr. of clay

Very dense, clean to slightly silty, fine SAND, with local silty lenses and occasional thin laminae of sandy clayey silt

Very dense, brown, silty, sandy GRAVEL, with cobbles (Glacial Till)

(cont.)

LEGEND

Gravel
Sand
Silt
Clay
Peat
Organic Content

Frozen Ground

Impervious seal
Water level
Piezometer tip
Thermocouple
3" O.D. split spoon sample
3" D.D. thin-wall sample
Sample not recovered

Atterberg limits:
Liquid limit
Water content
Plastic limit

Note: The stratification lines represent the approximate boundaries between soil types and the transition may be gradual.

Stone & Webster
Newhalen River Canal Diversion
Newhalen, Alaska

LOG OF BORING NO. B-5

April 1982
SHANNON & WILSON, INC.
GEOTECHNICAL CONSULTANTS

FIG. 6
<table>
<thead>
<tr>
<th>Depth</th>
<th>Material Description</th>
<th>Sample &amp; Run No.</th>
<th>% REC</th>
<th>% RQD</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>Glacial Till, as above</td>
<td>2</td>
<td>25.4</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Brown, moderately severely weathered VOLCANIC BRECCIA, w/local very severely weathered zones. Joints @ 15°-60° spaced 1&quot; to 2&quot;, thick clay coatings in most joints</td>
<td>3</td>
<td>31.0</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>Gray, very slightly to slightly weathered VOLCANIC BRECCIA, closely to moderately closely jointed @ 15°-45° (15° common, .5' and 1'-2' spacing common) 38.7'-39.3', 40.3'-40.7' zones of very closely spaced joints</td>
<td>4</td>
<td>33.0</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>Bottom of Exploration Completed 4/5/82</td>
<td>5</td>
<td>41.7</td>
<td>100</td>
<td>Began NX diamond coring @ 24.5'</td>
</tr>
</tbody>
</table>
SOIL DESCRIPTION

Station: Approx. 103+30, 155'L
Surface Elevation: 184'

<table>
<thead>
<tr>
<th>Depth, ft.</th>
<th>Sample</th>
<th>Ground Water</th>
<th>PENETRATION RESISTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.4</td>
<td>S-1</td>
<td></td>
<td>50 ▲</td>
</tr>
<tr>
<td>5</td>
<td>S-2</td>
<td></td>
<td>50 ▲</td>
</tr>
<tr>
<td>10</td>
<td>S-4</td>
<td></td>
<td>50 ▲</td>
</tr>
<tr>
<td>14.0</td>
<td></td>
<td></td>
<td>50 ▲</td>
</tr>
<tr>
<td>15</td>
<td>S-6</td>
<td></td>
<td>50 ▲</td>
</tr>
<tr>
<td>20</td>
<td>S-7</td>
<td></td>
<td>50 ▲</td>
</tr>
<tr>
<td>23.5</td>
<td>S-9</td>
<td></td>
<td>50 ▲</td>
</tr>
<tr>
<td>30</td>
<td>S-10</td>
<td></td>
<td>50 ▲</td>
</tr>
</tbody>
</table>

Note: Auger refusal at 11.4' required
Nx coring to advance borehole.
Auger was able to penetrate
after coring run 1, 11.4' to
12.2' (L=.8, Rec=.5)

- Brown, sandy SILT, with organics
  (Tundra)
- Very dense, brown to gray-brown,
silty sandy GRAVEL, with cobbles
  (Glacial Till)

NOTE:

Medium dense to dense, gray to
gray-brown, clean to slightly silty
fine SAND, laminated

Medium dense, gray-brown, clean to
slightly silty, fine to coarse SAND,
with occasional lenses of silty fine
sand to fine sandy silt

---

LEGEND

- Gravel
- Sand
- Silt
- Clay
- Peat
- Organic Content

- Water level
- Piezometer tip
- Thermocouple
- 3" O.D. split spoon sample
- 3" O.D. thin-wall sample
- Sample not recovered
- Atterberg limits:
  - Liquid limit
  - Water content
  - Plastic limit

Note: The stratification lines represent the approximate boundaries between soil types and the transition may be gradual.

Stone & Webster
Newhalen River Canal Diversion
Newhalen, Alaska

LOG OF BORING NO. B-6
April 1982 K-0517-01

SHANNON & WILSON, INC.
GEOTECHNICAL CONSULTANTS
SOIL DESCRIPTION

Station: Approx. 103+30, 155'L
Surface Elevation: 184'

SAND, as above, scattered gravels below ~35'

Very dense, gray, silty, sandy GRAVEL (Glacial Till)

NOTE: Auger refusal at 45.5'. Borehole advanced by Nx coring through Glacial Till. (Run 2 45.5' to 51.5', L=6.0', Rec=2.0')

Bottom of Exploration
Completed 4/6/82

LEGEND

NOTE: The stratification lines represent the approximate boundaries between soil types and the transition may be gradual.

Stone & Webster
Newhalen River Canal Diversion
Newhalen, Alaska

LOG OF BORING NO. B-6 (cont.)
April 1982

SHANNON & WILSON, INC.
GEO TECHNICAL CONSULTANTS

FIG. 7
SOIL DESCRIPTION

Station: Approx. 97+90, 45'L

Surface Elevation: ~174'

Brown, sandy SILT with organics (Tundra) (Top 0.5' is ice)

Stiff, brown, sandy SILT, trace of fine gravel

Very loose to medium dense, gray-brown to orange-brown to gray, silty fine SAND, w/local traces of medium to coarse sand and fine gravel

Alternating zones of very dense, orange-brown to gray-brown, slightly silty, sandy, fine to coarse GRAVEL and gravelly, fine to coarse SAND

Medium dense to dense, gray-brown, clean to slightly silty, gravelly, fine to coarse SAND and sandy fine to coarse GRAVEL

Medium dense, gray, silty, sandy GRAVEL (Glacial Till)

Medium dense, gray, clean to sl. silty gravelly SAND and sandy

LEGEND

Gravel  
Sand  
Silt  
Clay  
Peat  
Organic Content  

Frozen Ground  

Impervious seal  
Water level  
Piezometer tip  
Thermocouple  
3" O.D. split spoon sample  
3" O.D. thin-well sample  
Sample not recovered

Note: The stratification lines represent the approximate boundaries between soil types and the transition may be gradual.

Stone & Webster
Newhalen River Canal Diversion
Newhalen, Alaska

LOG OF BORING NO. B-7

April 1982  K-0517-01

SHANNON & WILSON, INC.

GEOTECHNICAL CONSULTANTS

FIG. 8
## Soil Description

- **Station:** Approx. 97+90, 45'L
- **Surface Elevation:** ~174' N174'

**Gravelly SAND**, and sandy GRAVEL, as above

occasional zones of fine sand

Very dense, gray-brown, silty sandy GRAVEL (Glacial Till)

---

### PENETRATION RESISTANCE

(340 lb. weight, 30" drop)

<table>
<thead>
<tr>
<th>DEPTH, ft.</th>
<th>20</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>PENETRATION RESISTANCE</td>
<td>▲ Bows per foot</td>
<td></td>
</tr>
<tr>
<td>52.0</td>
<td></td>
<td>▲</td>
</tr>
<tr>
<td>55</td>
<td>▲</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td></td>
<td>▲</td>
</tr>
</tbody>
</table>

---

**LEGEND**

- **Gravel** |
- **Sand** |
- **Silt** |
- **Clay** |
- **Peat** |
- **Organic Content** |
- **Frozen Ground**

- **Impervious seal**
- **Water level**
- **Piezometer tip**
- **Thermocouple**
- **3" D.D. split spoon sample**
- **3" D.D. thin-wall sample**
- **Sample not recovered**
- **Atterberg limits:**
  - Liquid limit
  - Water content
  - Plastic limit

**Note:** The stratification lines represent the approximate boundaries between soil types and the transition may be gradual.

---

**LOG OF BORING NO. B-7 (CONT.)**

April 1982

SHANNON & WILSON, INC.
GEO TECHNICAL CONSULTANTS

FIG. 8
<table>
<thead>
<tr>
<th>DEPTH</th>
<th>DESCRIPTION OF MATERIALS</th>
<th>% REC</th>
<th>% RQD</th>
<th>GROUND TEMP. (°F)</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>Moderately hard, dark gray to black, very slightly weathered BASALTIC ANDESITE, closely jointed at all angles. Serpentine coating on irregular joint faces. Numerous healed joints throughout. Common joint spacings:</td>
<td>60.5</td>
<td>100</td>
<td>Thermistor casing not installed</td>
<td>Began NX diamond coring @ 60.5'</td>
</tr>
<tr>
<td>63</td>
<td>60.5'-63.0' 3&quot;-5&quot; 63.0'-64.5' 1&quot;-2&quot; 64.5'-66.5' 10&quot;-15&quot; 66.5'-67.5' 1&quot;-2&quot; 67.5'-68.1' ~7&quot;</td>
<td>68.1</td>
<td>39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>Bottom of Exploration Completed 3/9/82</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
SOIL DESCRIPTION

Station: Approx. 130+00, 1290'L
Surface Elevation: 152'

Very dense, gray-brown, silty, sandy GRAVEL, with cobbles
(Glacial Till)

Dense, gray-brown, clean, fine to coarse SAND and fine to medium SAND, trace of fine gravel

Loose to medium dense, gray, clean fine SAND

Medium dense, gray, clean, fine to medium SAND, with scattered layers of silty fine sand

Dense to very dense, gray-brown, slightly silty fine SAND

Hard, gray SILT, laminated, trace of fine to coarse sand and fine gravel

LEGEND

Gravel
Sand
Silt
Clay
Peat
Organic Content

Impervious seal
Water level
Piezometer tip
Thermocouple
2" O.D. split spoon sample
2" O.D. thin-wall sample
Sample not recovered
Atterberg limits:
Liquid limit
Water content
Plastic limit

Note: The stratification lines represent the approximate boundaries between soil types and the transition may be gradual.

Stone & Webster
Newhalen River Canal Diversion
Newhalen, Alaska

LOG OF BORING NO. B-8
April 1982 K-0517-01

SHANNON & WILSON, INC.
GEO TECHNICAL CONSULTANTS

FIG. 9
SOIL DESCRIPTION

Station: Approx. 130+00, 1290'L
Surface Elevation: 752'

SILT, as above

Very dense, gray, silty, sandy GRAVEL (Glacial Till)

from 54' Till color is locally mottled red and/or blue-gray with weathered bedrock fragments

Severely weathered Bedrock

(cont.)

LEGEND

Gravel
Sand
Silt
Clay
Peat
Organic Content

Impervious seal
Water level
Piezometer tip
Thermocouple
3" O.D. split spoon sample
3" O.D. thin-wall sample
Sample not recovered
Atterberg limits:
Peat
Liquid limit
Water content
Plastic limit

Note: The stratification lines represent the approximate boundaries between soil types and the transition may be gradual.

Stone & Webster
Newhalen River Canal Diversion
Newhalen, Alaska

LOG OF BORING NO. B-8 (cont.)

April 1982 K-0517-01

SHANNON & WILSON, INC.
GEOTECHNICAL CONSULTANTS

FIG. 9
**PROJECT:** Stone & Webster  
Newhalen River Canal Diversion

<table>
<thead>
<tr>
<th>DEPTH IN FEET</th>
<th>GRAPHIC LOG</th>
<th>DESCRIPTION OF MATERIALS</th>
<th>SAMPLE RUN NO.</th>
<th>% REC</th>
<th>GROUND TEMP (°F)</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td></td>
<td>Glacial Till, as above</td>
<td>59.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>65</td>
<td></td>
<td>Soft to very soft, blue-gray, moderately severely to very severely weathered VOLCANIC BRECCIA. Weak, easily fractured. Highly fractured zones spaced 0.3-0.6 ft. apart. Clayey texture, especially in fractured zones from 66.5'-68.5', very severely weathered, brown, local completely weathered zones</td>
<td>1 100 64.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>70</td>
<td></td>
<td>Bottom of Exploration</td>
<td></td>
<td>2 100 69.5</td>
<td></td>
<td>Began NX diamond coring @ 59.6'</td>
</tr>
<tr>
<td>75</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>85</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>90</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>95</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
### Sieve Analysis

<table>
<thead>
<tr>
<th>Size of Opening in Inches</th>
<th>Number of Mesh Per Inch, U.S. Standard</th>
<th>Grain Size in MM</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>2</td>
<td>0.06</td>
</tr>
<tr>
<td>20</td>
<td>4</td>
<td>0.04</td>
</tr>
<tr>
<td>40</td>
<td>8</td>
<td>0.02</td>
</tr>
<tr>
<td>60</td>
<td>12</td>
<td>0.01</td>
</tr>
</tbody>
</table>

### Hydrometer Analysis

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Depth (ft.)</th>
<th>U.S.C.</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-1</td>
<td>7.5-9.0</td>
<td>SP</td>
<td>Medium dense, gray-brown, gravelly, fine to medium SAND, trace of coarse sand and silt</td>
</tr>
<tr>
<td>S-3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B-1</td>
<td>15.0-16.5</td>
<td>GP</td>
<td>Medium dense, gray, slightly sandy, fine to coarse GRAVEL</td>
</tr>
<tr>
<td>S-6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **NAT. W.C. %**: 4
- **LL**: 5
Newhalen River Canal Diversion Project
BORING B-2
Stone & Webster Engr. Corp.
April 1982 K-0517-01
SHANNON & WILSON
GEOTECHNICAL CONSULTANTS
SAMPLE NO. | DEPTH-FT. | U.S.C. | CLASSIFICATION | NAT. W.C. % | LL | PL | PI
---|---|---|---|---|---|---|---
B-3 | 24.5-26.0 | ML | Stiff, gray-brown SILT, trace of sand | 20 | 25 | NP
S-9 | | | | |
B-3 | 44.5-46.0 | GM | Medium dense, gray-brown, silty, sandy, GRAVEL | | | |
S-13 | | | | |
### Sieve Analysis

<table>
<thead>
<tr>
<th>Size of Opening in Inches</th>
<th>Number of Mesh per Inch, U.S. Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/16</td>
<td>140</td>
</tr>
<tr>
<td>1/8</td>
<td>42</td>
</tr>
<tr>
<td>3/16</td>
<td>29</td>
</tr>
<tr>
<td>5/32</td>
<td>23</td>
</tr>
<tr>
<td>1/4</td>
<td>16</td>
</tr>
<tr>
<td>3/16</td>
<td>12</td>
</tr>
<tr>
<td>5/32</td>
<td>10</td>
</tr>
<tr>
<td>7/32</td>
<td>8</td>
</tr>
<tr>
<td>1/8</td>
<td>6</td>
</tr>
<tr>
<td>5/32</td>
<td>4</td>
</tr>
<tr>
<td>7/32</td>
<td>3</td>
</tr>
<tr>
<td>3/16</td>
<td>2</td>
</tr>
<tr>
<td>1/4</td>
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</tr>
<tr>
<td>3/8</td>
<td>0</td>
</tr>
<tr>
<td>1/2</td>
<td>0</td>
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</tbody>
</table>

### Hydrometer Analysis

<table>
<thead>
<tr>
<th>Grain Size in mm</th>
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</thead>
<tbody>
<tr>
<td>0.004</td>
</tr>
<tr>
<td>0.008</td>
</tr>
<tr>
<td>0.012</td>
</tr>
<tr>
<td>0.016</td>
</tr>
<tr>
<td>0.020</td>
</tr>
<tr>
<td>0.023</td>
</tr>
<tr>
<td>0.026</td>
</tr>
<tr>
<td>0.030</td>
</tr>
<tr>
<td>0.033</td>
</tr>
<tr>
<td>0.036</td>
</tr>
<tr>
<td>0.040</td>
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<td>0.043</td>
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<td>0.046</td>
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</tr>
<tr>
<td>0.053</td>
</tr>
<tr>
<td>0.056</td>
</tr>
<tr>
<td>0.060</td>
</tr>
<tr>
<td>0.063</td>
</tr>
<tr>
<td>0.066</td>
</tr>
<tr>
<td>0.070</td>
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<td>0.073</td>
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<td>0.076</td>
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<td>0.093</td>
</tr>
<tr>
<td>0.096</td>
</tr>
<tr>
<td>0.100</td>
</tr>
</tbody>
</table>

### Sample Classification

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>B-6</td>
<td>7.0-8.3</td>
<td>GP</td>
<td>Very dense, gray-brown, sandy GRAVEL, trace of silt</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B-6</td>
<td>17.3-19.8</td>
<td>SM</td>
<td>Medium dense, gray-brown, silty fine SAND, trace of medium to coarse sand</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-7</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

---

**Newhalen River**
Canal Diversion Project
G R A I N S I Z E C L A S S I F I C A T I O N
BORING B-6
Stone & Webster Engr. Corp.
April 1982
K-0517-01
SHANNON & WILSON
G E O T E C H N I C A L C O N S U L T A N T S
**Sieve Analysis**

<table>
<thead>
<tr>
<th>Size of Opening in Inches</th>
<th>Number of Mesh per Inch, U.S. Standard</th>
<th>Grain Size in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4</td>
<td>4</td>
<td>0.635</td>
</tr>
<tr>
<td>3/8</td>
<td>2</td>
<td>0.953</td>
</tr>
<tr>
<td>1/2</td>
<td>1</td>
<td>1.270</td>
</tr>
<tr>
<td>3/4</td>
<td>0.5</td>
<td>1.905</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>2.540</td>
</tr>
<tr>
<td>1 1/2</td>
<td>0.5</td>
<td>3.810</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>5.080</td>
</tr>
<tr>
<td>2 1/2</td>
<td>0.5</td>
<td>6.350</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>7.620</td>
</tr>
<tr>
<td>3 1/2</td>
<td>0.5</td>
<td>9.525</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>12.700</td>
</tr>
</tbody>
</table>

**Hydrometer Analysis**

<table>
<thead>
<tr>
<th>Per Cent Finer by Weight</th>
<th>Per Cent Coarser by Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>00</td>
</tr>
<tr>
<td>90</td>
<td>10</td>
</tr>
<tr>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td>70</td>
<td>30</td>
</tr>
<tr>
<td>60</td>
<td>40</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>40</td>
<td>60</td>
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<tr>
<td>10</td>
<td>90</td>
</tr>
<tr>
<td>00</td>
<td>100</td>
</tr>
</tbody>
</table>

**Sample No.**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>B-8</td>
<td>39.0-40.5</td>
<td>ML</td>
<td>Hard, gray, SILT, trace of sand and gravel</td>
<td>27</td>
<td>26</td>
<td>NP</td>
<td></td>
</tr>
<tr>
<td>S-12</td>
<td>39.0-40.5</td>
<td>ML</td>
<td></td>
<td>27</td>
<td>26</td>
<td>NP</td>
<td></td>
</tr>
</tbody>
</table>

**Newhalen River Canal Diversion Project**

**Grain Size Classification**

BORING B-8

Stone & Webster Engr. Corp.

April 1982  K-0517-01

SHANNON & WILSON

GEOENGINEERING CONSULTANTS
PHOTO PLATE 1
Intake Structure Area
View from east side of river, which is flowing towards the south, right to left. The upper rapids would be at the right edge of the photo.

PHOTO PLATE 2
Intake Structure Area
View from east side of river, looking northwest. River flows right to left. Boring B-4 was drilled just off the right margin of the photo.
PHOTO PLATE 3
Outlet Structure Area

View looking northeast. River flows left to right. River mouth opening begins at left edge of photo.

PHOTO PLATE 4
Outlet Structure Area

View looking northeast. River flows to the right. Boring B-5 was drilled in small clearing at left center of photo.
PHOTO PLATE 11
Boring 6

PHOTO PLATE 12
Boring 7