Alaska Power Authority
Susitna Hydroelectric Project

Subtask 4.09

DESIGN MANUAL FOR THE LONG-TERM EARTHQUAKE MONITORING SYSTEM FOR THE SUSITNA HYDROELECTRIC PROJECT

June 1982

Prepared by

Woodward-Clyde Consultants

for

Acres American Incorporated

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TABLE OF CONTENTS

		Page
1	INTRODUCTION	1
2	DATA REQUIREMENTS	4
	2.1 Hypocentral Locations	4
	2.2 Focal Mechanisms	5
	2.3 Magnitudes	6
	2.4 Source Parameters and Attenuation	6
	2.5 Strong-Motion Data	7
3	NETWORK CONFIGURATION AND SITE SELECTION	8
	3.1 High-Gain Station Configuration	8
	3.2 Strong-Motion Station Configuration	10
4	INSTRUMENTATION	10
	4.1 Instrumentation System Design	11
	4.2 Preliminary Instrumentation Specifications and Estimated Costs	15
	4.3 Strong-Motion Instrumentation	17
	4.4 Implementation and Schedule	17
5	OPERATIONAL RESPONSIBILITIES	18
	REFERENCES	20
	TABLES	21
	FIGURE	30

1 - INTRODUCTION

Woodward-Clyde Consultants (WCC) conducted detailed seismic hazard studies as part of the feasibility assessment of the Susitna Hydroelectric Project (WCC, 1982). For this project, possible earthquake sources and associated strong ground-motion potential that could affect the Project sites were evaluated. The results of these studies suggest that relatively strong ground motions could occur at the Project sites during the lifetime of the facilities. To further evaluate the effect that these motions will have on the seismic design and performance of the dam and auxiliary structures, it is important to collect data during earthquakes that may occur prior to, during, and subsequent to design and construction of the dams. Collection of these data requires the installation of suitable instrumentation prior to the occurrence of such motions.

The purpose of this report is to discuss the instrumentation design and operational features of a long-term earthquake monitoring system for the Susitna Project. This discussion incorporates general considerations on seismic instrumentation for dams (Bolt and Hudson, 1975; Sharma and Raphael, 1981) as applied to the specific seismic and operational environment of the Susitna Project (Woodward-Clyde Consultants, 1981 and 1982).

Seismic instrumentation for the Susitna Project has two major objectives: 1) to provide important data for the continous monitoring of the earthquake environment of the project, particularly with respect to the possible occurrence of reservoir-induced seismicity; and 2) to provide necessary data for evaluating the engineering severity of strong ground motions that may occur at the site. The instrumentation and the data it provides are thus important in evaluating the seismic design of the project and in monitoring the performance of the design under seismic loading. To satisfy these objectives, two subsystems of instrumentation should be operated.

- First, a network of sensitive (high-gain) seismograph stations should be operated to allow for the detection and location of earthquakes of magnitude approximately 1 and larger. The area of coverage of these stations should be within 30 km of the reservoir system axis, since this is the area considered potentially susceptible to reservoir-induced seismicity (Woodward-Clyde Consultants, 1982). This network should be installed several years prior to the construction of the reservoir in order to establish a stable baseline of earthquake data against which to compare possible post-reservoir-filling changes in the seismic environment. Operation of the network should continue for at least 10 years after filling, as this is the time interval during which induced seismicity is more likely to occur.

- Second, strong-motion (low-gain) instruments should be operated to record the effects at the dam sites of any strong ground shaking (accelerations exceeding 0.01 g). These instruments should be placed on the abutments and their near vicinity in locations that will not cause the recorded ground motions to be modified by local geologic conditions. The high-gain data accurately identify hypocentral locations of earthquakes generating strong ground motions.

Four key system characteristics should also be emphasized in developing the instrumentation system.

- The system should yield data of uniformly high quality and optimum utility.

- The instrumentation should be highly reliable. To ensure this reliability, the instrumentation should provide redundancy of functions, it should be environmentally hardened, and it should be proven in the field.

- Sophisticated instrumentation consistent with proven reliable operation should be used to reduce long-term operational costs and maintenance costs.

- Automated functioning should be used to rapidly provide the system operators with data upon which good engineering and public safety decisions can be made.

Recommendations for the design of the long-term earthquake monitoring system for the Susitna project are developed and presented in this report on the basis of the above system objectives and key characteristics. The data requirements and field station configuration, as they influence design, are discussed in Sections 2 and 3. Recommendations for the instrumentation design are presented in Section 4; Section 4 also identifies representative components and their costs as of January 1982. Operational responsibilities for the system are discussed in Section 5.

It is expected that this report will be used for planning purposes in proceeding with the design of the Susitna Hydroelectric Project. Appropriate review and finalization of the instrumentation design should be carried out in conjunction with the next stage of overall Project design. Procurement documents can be based on the design and cost elements of Section 4. The resulting operational system should well serve the Susitna Project and the Alaska Power Authority.

2 - DATA REQUIREMENTS

The design of the Susitna Project long-term earthquake monitoring system is derived from the kinds of data from recorded earthquakes that are required for engineering and operational purposes. These data include hypocentral locations, focal mechanisms, magnitudes and other source parameters, and strong ground motions. The following discussion explains the data requirements and specifies the measurements to be made for each recorded earthquake.

2.1 - Hypocentral Locations

Earthquake hypocentral locations form the basis for all detailed investigations of seismicity. The area of interest for the Susitna Hydroelectric Project is centered around the dams and lies within 30 km of the reservoirs; it is also expected that this area could be influenced by the earthquake-inducing effects of reservoir filling. Spatial and temporal patterns of naturally-occurring local seismicity will form a baseline against which the possible seismic effects of reservoir filling can be identified and evaluated. Considering the relatively low level at which these possible changes in seismicity patterns may be initially observable, hypocenters within the crust should be accurate to within a kilometer. Hypocenters in the Benioff zone below the crust should be accurate to within approximately 5 km.

Several factors control the accuracy with which hypocenters can be determined. These include: 1) station spacing and azimuthal coverage; 2) the accuracy with which arrival times can be determined; and 3) how well the velocity model used represents the velocity structure of the crust under the network. For locating crustal earthquakes, a station spacing of 10 to 15 km is usually adequate. Focal depths less than about 5 km may be inaccurately determined if the closest station to the event lies more than 5 km from the hypocenter. Such extremely shallow events are not expected to be common in the area; however, if they do occur, accurate depths may be calculated by using waveform modelling or other advanced techniques. For the second factor, proper identification of P and S waves is needed so that correct travel paths can be specified in the computer program used for determining hypocenter locations. The use of three-component seismometers at several stations should provide unequivocal phase identifications. For the third factor, a local velocity model should be developed and refined by crustal refraction and time-term studies. It is anticipated that sufficient data for these studies would be provided by network recordings of local blasts associated with construction of either or both of the dams (and perhaps by a limited number of blasts detonated specifically for crustal structure investigations).

Measurements needed to provide hypocentral locations are the arrival times of correctly identified P-wave and S-wave phases at the network stations. Absolute timing is needed to within 0.01 seconds.

2.2 - Focal Mechanisms

Well-constrained, accurate focal mechanisms are important to further evaluate the correlation of seismicity with geologic structures and to assess the orientation of tectonic stress in the area. Factors affecting the accuracy of focal mechanisms include: the accuracy of hypocentral locations, particularly of focal depth; the location of the earthquakes relative to the network; and the accuracy of the local velocity model.

Measurements needed to obtain focal mechanisms are the direction of motion of P-waves and S-waves and undistorted waveforms of the P- and S-waves.

2.3 - Magnitudes

Accurate magnitudes are important in characterizing the local seismicity patterns before, during, and after filling the reservoirs. In order to produce a homogeneous data set, the local magnitude scale should be consistent for all areas of the network. Local magnitude values must be calibrated against the standard Richter magnitude scale (M_L), thus producing equivalent M_L values for the study area.

Measurements needed to calculate magnitudes are the durations of seismic wave codas recorded at low-noise stations and the undistorted maximum amplitudes of ground motion at all amplitude levels.

2.4 - Source Parameters and Attenuation

Earthquake source parameters that can be estimated from waveform modelling and spectral analysis of local network data include stress drop, fault displacement, rupture dimensions, and seismic moment. These parameters are extremely useful in investigating the details of earthquake source processes and in assessing the magnitude and orientation of local tectonic stress. Compilation of these parameters over time will aid in identifying possible changes in the local seismic environment. Determination of the seismic attenuation characteristics of the local crust provides a basis for the calculation of ground motions at the site resulting from local earthquakes. These characteristics will be very useful in analyzing data from strong-motion accelerographs at the sites in order to evaluate site-specific ground motions. Knowledge of seismic attenuation characteristics is also necessary for the successful determination of earthquake source parameters. Seismic attenuation studies will involve similar waveform and spectral analysis of local network data as for source parameter studies.

The primary requirement for waveform and spectral analysis is digitally recorded data from an accurately calibrated network. At least one three-component station with a broad frequency response in the range 10 seconds to 50 Hz is desirable. An additional three-component station would enhance the scope and reliability of source parameter and attenuation studies. The network has been designed on the basis of state-of-the-art techniques in computational seismology; it is anticipated that advances in this field within the next five years will further increase the usefulness of such studies.

The measurements needed to calculate source parameters are undistorted whole seismograms recorded by well-calibrated stations.

2.5 - Strong-Motion Data

The recording of possible strong ground motions at the foundation (free-field) level of the Watana and Devil Canyon sites is of high value in evaluating the performance of the seismic design of the dam.

Ground motions from moderate (M_S 5) and larger earthquakes within about 100 km of the dam sites should trigger the strong-motion recorders as well as be recorded by the high-gain seismograph stations. The acceleration data will be recorded on self-contained, independent accelerographs with a trigger level of about 0.01 g and a peak dynamic range of at least 1.0 g.

Measurements needed to evaluate strong ground motions at the site are undistorted three-component records of the ground motions of an earthquake following the first time in the motion that 0.01 g (the trigger level) is exceeded. The data must be in the frequency range from 0 to 20 Hz and must be of good enough quality to put in digital form. Absolute time should be recorded for correlation with the high-gain data.

3 - NETWORK CONFIGURATION AND SITE SELECTON

The planned configuration of the stations of the long-term earthquake recording system is discussed in terms of the high-gain network and the strong-motion stations. The generalized configuration of the stations is shown in Figure 1.

3.1 - High-gain Station Configuration

As currently planned, the central recording facility for the high-gain network will be located at the Watana dam site, which is the geographical center of the system. If the camp is maintained during the construction phase, as we assume it will be, a reliable 110 VAC power supply, necessary to power the recording system, will be available at the Watana camp. The Watana camp is also a convenient location for the routine operation of the network, as described in Sections 4.1 and 5.

The high-gain network for the Devil Canyon-Watana reservoir system consists of 13 field stations; the data from these stations will be telemetered by VHF radio or hard wire to Watana. The preliminary locations of the stations, as shown in Figure 1, provide reasonably uniform coverage of the area within approximately 30 km of the reservoirs. The best azimuthal coverage (greater than 180° from the hypocenter to the stations) is provided for the region lying within about 15 km of the reservoirs. Final selection of field station sites will be based on the results of a seismic noise survey, using a portable instrument in the field to identify the quietest sites at the localities shown. The distance between closest station pairs is approximately 15 to 20 km, and the majority of earthquakes that occur within 20 km of the reservoirs will be at an epicentral distance of less than 10 km from one of the stations. The network, therefore, is designed to provide good constraint (± 1 to 2 km) on the hypocentral locations of earthquakes that occur within 30 km of the reservoirs and with focal depths greater than approximately 5 km. Fair control (± 3 km) on focal depths shallower than 5 km will be achieved, but this control will decrease for very shallow earthquakes unless they happen to occur very close to an individual station.

Eleven of the stations are planned to have vertical-component, one-second free period seismometers. The remaining two will be three-component stations. The first of these two, located near the Watana site, is planned as a three-component, broad-band system, which is located close to the rock-site strong-motion accelerograph (see Section 3.2). Data from this station will be transmitted by hard-wire to the recording facility. This station will provide high-quality, broad-band data for spectral analysis and for ground-motion evaluations. The location of the second three-component station is planned near the western end of the array. This station will incorporate one-second free period seismometers and will provide additional data for shear wave identification and for spectral analysis. Since data from this station will be multiplexed and telemetered by VHF radio link, the instrumentation could be relocated to any other station site to optimize the collection of three-component data. Two of the vertical-component stations and both of the three-component stations will be dual-gain. This will allow for a wider dynamic range (about 100 db above noise) and should allow for on-scale recordings over the range of microearthquake motions to strong motions recorded on the accelerographs.

The configuration of the high-gain stations, as shown in Figure 1, covers both reservoirs. If the Devil Canyon construction is to follow the Watana dam by more than a year or two, installation of the four westernmost stations could be delayed without compromising the data obtained for the Watana dam. In that case, the three-component station could be moved to the station site due east of Watana camp.

3.2 - Strong-Motion Station Configuration

During the pre-construction phase, strong-motion instruments should be installed at three locations for each dam site: one on each of the two abutments in a position that is out of the way of immediate construction activities, and one at a bedrock site within a few kilometers of the abutments. The final locations of the two abutment instruments must be determined on the basis of detailed construction plans. The bedrock site should be planned in conjunction with the three-component broad-band instrument. Access to the accelerometers is required for maintenance and calibration on a regular schedule and after the occurrence of an earthquake that generates strong ground motion.

Following construction of the dam, additional strong-motion recorders should be installed within the galleries and on the crest of the dam. Placement of these instruments will depend on the final configuration of the dam.

4 - INSTRUMENTATION

The design of the instrumentation system needed to carry out successful long-term seismic monitoring at Susitna is described here in generic terms. Section 4.1 presents the design factors used to select the instrumentation system that meets the data requirements of Section 2. Section 4.2 and Table 1 describe the components for the field stations and central recording facility, give examples of representative available equipment, and present a cost estimate for the instrumentation. Section 4.3 discusses the strong-motion instrumentation.

4.1 - Instrumentation System Design

The system design is based upon the use of a triggered, microcomputer-based recording system to record data at the central recording facility located at the Watana site. Data will be telemetered from the remote field stations to Watana as modulated VHF radio transmissions. Data from the three-component, broad-band station near Watana will be transmitted using a hard-wire link. At the central recording facility, the signals will be demodulated and digitized in real time and input to the microcomputer, where a sophisticated earthquake detection and discrimination algorithm will continuously scrutinize the incoming signals on all channels. The incoming data will initially be stored on disc. When a seismic event is detected, the digitized data will be copied from disc to tape for permanent storage. Recording will cease when the detection algorithm declares the event to be over.

Data from selected stations will also be recorded on six drum recorders that produce analog paper records. Earthquake data will be retained on disc for at least several hours after the event, together with summaries of the network status, number of events recorded, and other operational information. These data will be accessible via a dial-up telephone telemetry link for rapid transmittal from Watana to distant locations. Data from tape or disc will also be available for preliminary data analysis using the microcomputer. Such analysis can be carried out without interrupting the primary data acquisition function of the computer. Absolute timing will be provided by a self-correcting crystal-controlled clock, which will be continuously synchronized to satellite standard time broadcasts; back-up timing will be provided by a second crystal-controlled clock and a WWV time code receiver.

The microcomputer-based system will provide the flexibility, data quality, and low operational and maintenance manpower which are ideally required for the long-term monitoring program. Important factors in the design of the system are discussed below.

(a) Capability to Acquire Desired Data: The data needs discussed in Section 2 indicate that the following features are necessary:

- timing accuracy of 0.01 seconds, referred to Universal Coordinated Time, to achieve location accuracy.
- centralized recording to simplify the routine operation of the network and data analysis.
- triggered digital recording of earthquakes to minimize the volume of digital data saved.
- multiple-gain recording for selected stations to provide a wide dynamic range.
- well-calibrated digital data to allow for high-quality source and attenuation analyses.
- preliminary local data processing to allow dam operators to respond appropriately to potentially significant earthquakes.

All of these features can be provided by a computer-based system as described above. In particular, it will be possible to use a more effective triggering algorithm with a computer-based system than with alternative systems, such as existing digital event recorders. This is because the capacity of the computer allows the algorithm to be sophisticated, while at the same time the algorithm can be finely tuned to the prevailing field site conditions by reprogramming at the central recording facility in a high-level computer language (such as FORTRAN) by an operator with only moderate programming expertise. Analog recording systems, such as FM tape or Develocorders, will record continuously, and hence a large amount of background recording will either have to be edited or archived. The capability to carry out relatively sophisticated preliminary data analysis at the recording site will be provided by the microcomputer. This could be carried out automatically (on-line) or interactively without the need to produce and analyze analog paper records from cassettes or FM tape.

(b) <u>Reliability and Maintenance:</u> In order to maximize the amount, continuity, and quality of data recorded and to minimize costs for major maintenance, the instrumentation chosen for the system must be capable of operating reliably for long periods of time (up to two years) without significant maintenance or adjustment. This is particularly true for the field station instrumentation, which must be capable of withstanding the severe environmental conditions of the Susitna area. Many of the field stations will be inaccessible for several months each year, and failures at these stations will involve the loss of data for long periods of time. Instrument reliability can be maximized by first choosing instruments with proven performance. The reliability of the system as a whole can be further enhanced by careful installation and by environmentally hardening the field sites to withstand anticipated conditions. Experience in field operations in Alaska gained by Woodward-Clyde Consultants, the University of Alaska Geophysical Institute (UAGI), and the U.S. Geological Survey (USGS) has been incorporated into the recommended system design.

(c) <u>Redundancy:</u> The system must incorporate sufficient redundancy to accommodate component failures without significant impairment of operations or data quality. Redundancy in data acquisition is incorporated by operating a sufficiently large network so that temporary loss of several stations due to severe weather conditions or lack of maintenance access at remote sites is not likely to significantly degrade data quality. Sufficient replacement parts should also be maintained at the central site to allow some repairs to be made without substantial technical support from outside the network area.

Redundancy in recording will also be incorporated by providing multiple means of data recording. Primary recordings will be made by a computerized earthquake detection and recording system. Detected events will be preliminarily located, then dubbed onto a digital tape for further analysis later. Backup will be provided by three dual-channel pen recorders that will monitor six of the 13 stations on paper records. The earthquake data will also be available to off-site agencies via dial-up telephone data transfer.

(d) Rapid Data Access: The instrumentation design will allow for immediate (within a few minutes) availability of preliminary earthquake locations as well as access to arrival time data. Thus, should an earthquake generate significant ground motions, the location will be available for revision and possible action by APA or other agencies on the basis of accurate seismological information.

(e) Routine Operation and Maintenance: Routine operation and maintenance at the Watana site will consist of record changing at the central recording facility, monitoring the performance of the system on a regular basis, minor maintenance such as changing batteries and adjusting telemetry levels, documenting the network operation on a day-to-day basis, and performing preliminary data analysis. Record-changing activities will be minimized by using the triggered computer-based system. In addition, other activities, such as performing time corrections and calibrations, will be automated. The computer-based system will maintain a continuous diagnostic check on its own operation and on the condition of incoming signals, and will generate diagnostic messages. Data reduction and analysis will also be automated, as described in (a) above; this will greatly streamline these operations and reduce operational manpower costs.

4.2 - Preliminary Instrumentation Specifications and Estimated Costs

A list of the instrumentation planned for each type of field station and for the central recording facility is shown in Table 1. Basic specifications for the components are also given. The second column of Table 1 gives examples of commercially available components that would be suitable for the system. Table 1 is not a procurement document, and these specific models are included only to illustrate the types of components that are available and to enable the cost of the system to be estimated; alternative instrumentation that would be equally suitable is available from other manufacturers in many cases. Cost estimates are based on manufacturers' quoted prices as of January 1982. When the network is implemented, Table 1 will serve as the basis for preparing a procurement document.

Environmental hardening of the field stations will consist primarily of mounting the radio antennas and electronics packages on 20-foot-high towers. This will reduce the chance that the antennas may be buried under snow or that they may be harmed by animals. The towers are substantial, rigid structures set in concrete bases to enable them to withstand snow and ice loading and high winds. The battery enclosures are 50-gallon drums with foam insulation set in concrete. Together with modifications of the voltage controlled oscillators to ensure temperature stability and fabrication of automatic calibration modules, these features increase the cost of the entire system by about $50,000;

however, they are judged to be necessary to provide highly reliable continuous data recording from the stations and to minimize major maintenance. The relay stations included in the cost estimate may not be needed, depending on the final station configuration of the network.

The cost estimate for the central recording facility includes the cost ($150,000) of a complete computerized data acquisition system. This system includes the central processor unit, analog to digital convertor, disc drive and discs, dual tape drives, terminal, printer, and interfaces. Alternative modes of data recording were considered for the project. These alternatives and their estimated costs are: nine digital event recorders with an array trigger device and associated playback equipment, $84,000; two FM tape recorders plus associated playback equipment (not including digitization facilities), $93,000; and three Develocorders and associated equipment and a viewer/copier, $123,000. However, because none of these alternatives allow for automation of the data processing or for telephone access to the data, they were not considered further. Also, because the alternatives require additional personnel time for maintenance and data reduction, any immediate cost savings would be eliminated when prorated over the lifetime of the array.

The uninterruptible power supply provides regulated, frequency-stabilized 110V AC power regardless of fluctuations in line power, and back-up power for up to four hours in the event of line power failure.

With regular maintenance (see Section 4.4), the average operating life of individual electronic components of the system is expected to be in the range of five to eight years. However, it is estimated that approximately 8 to 10% of the field equipment will need to be replaced every year to maintain the system in a fully operational condition. Therefore, over the projected 10-

year or longer period of monitoring, it is expected that the equivalent of the entire system will be replaced at least once.

4.3 - Strong-Motion Instrumentation

The strong-motion system planned for the preconstruction phase consist of three independent, internally triggered, battery-operated strong-motion acceleration recorders for each dam site. For reliability of long-term operation in a rugged environment, 70 mm film recorders are recommended. Internal timing should be included to allow for earthquake identification and comparison with the high-gain data. Suitable instruments are listed in Table 1. Routine maintenance can be carried out in conjunction with the operation of the high-gain system.

In the post-construction phase, a more sophisticated strong-motion system, incorporating free-field and structural accelerographs with digital recording and rapid operator readout, should be installed. At that time, the film recorders will serve as backup recorders.

4.4 - Implementation and Schedule

The next steps in implementing the Susitna Project network would be to finalize the system design on the basis of the generalized design presented in Sections 3 and 4 and to prepare bid documentation for the hardware. Finalization of the design will take into consideration any experience or developments in instrumentation available following the date of this report. The instrumentation will then be procured and the system assembled. The entire system will be fully tested and calibrated prior to installation in the field. Meanwhile, the location of the field sites will be finalized by field reconnaissance, radio line-of-sight transmission tests, and a noise survey using a portable seismograph. If the potential schedule shown in Table 2 is followed, the network will begin operating nine months after authorization.

The estimated level of effort required for implementation of the network is shown in Table 3 in terms of person-days. The estimated salary costs shown in Table 2 are based on Woodward-Clyde Consultants' 1982 schedule of charges.

Table 4 presents estimated personnel time requirements and costs for the routine operation and maintenance of the network and for data analysis. Item 1 covers visits to the site by outside technicians for non-routine maintenance, such as equipment repairs and major recalibration. Most of the other estimated yearly cost for Items 1 and 2 is for helicopter support, which has been estimated at $500 per hour.

5 - OPERATIONAL RESPONSIBILITIES

The successful operation of the long-term earthquake monitoring system is based on support and direction provided by the Alaska Power Authority. While the specifics of the operational assignments may shift in order to respond to changes in agency capabilities or other factors, a focused program direction must be maintained by APA so that the data are of high quality and are appropriately available to APA to allow safe and proper operation of the Susitna Hydroelectric Project. This level of responsibility is consistent with the APA's primary financial responsibility for the long-term earthquake monitoring program.

Personnel located at the central recording site (Watana Camp) will be responsible for field operations, including record changing, maintenance, and preliminary data analyses. This will require training of several part-time staff who will be in residence at the central recording site. The results of the preliminary data analysis and the digital tapes and analog records will then be sent out for review, final analysis, and interpretation, as described below. The APA should verify that the seismic record archives are adequate and that the system operation is well documented.

Under the APA's overall direction, the primary technical and review responsibility for data quality and data interpretation will be held by seismologists with the expertise necessary to meet the objectives of the long-term monitoring program. All preliminary locations and data analysis carried out by the field personnel will be reviewed and finalized by these seismologists. The resulting summary reports of seismic activity will be issued by the APA. Data analysis procedures and instrument calibrations will be reviewed by appropriate seismological specialists. Depending on the capabilities of the field personnel, additional personnel may be needed to carry out non-routine field maintenance and major maintenance as needed. Also on an as-needed basis, seismological experts will provide review and assistance to the APA in responding to possible safety-related issues derived from the monitoring program.

During the ongoing operation of the monitoring network, the APA, other state agencies, and all parties interested in the safe and effective operation of the Susitna Hydroelectric Project will benefit by the compilation of a reliable, high-quality, and well-documented data set. Specific procedures and computer programs will change as newer and more effective techniques are made available. Data storage and retrieval methods will also vary, depending on further evaluations of the role and capabilities of the Alaska state agencies. The commitment on the part of the APA to conduct long-term monitoring should ensure a successful monitoring program.

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Table 1: REPRESENTATIVE INSTRUMENTATION AND ESTIMATED INSTRUMENTATION COSTS FOR THE SUSITNA LONG-TERM SEISMIC MONITORING SYSTEM (1)

(Page 1 of 6)

ITEM	REPRESENTATIVE SUPPLIER/MODEL NUMBER	UNIT COST (1)	QUANTITY	TOTAL COST (1)
Field Stations				
1) Vertical-component, short-period, high-gain single, channel field station		$8,150	9	$73,350
Comprised of:				
1-second free period seismometer	Mark Products L4-C-B			
Field telemetry system, temperature stabilized, with 2-channel relay capability (incorporates seismic amplifier, voltage controlled oscillator, auto-calibration module, and multiplexer/band-pass filters)	Sprengnether, PTS-8 (auto calibration module and multiplexer/band-pass filters to be fabricated)			
VHF transmitter, 250 milliWatt	Monitron TX-101			
Yagi antenna	Scala CA5-150H			
8 Carbonaire batteries	McGraw-Edison			
2 DC-DC convertors	Wall Industries			
Enviromentally sealed electronics enclosure	Hoffman Enclosures, Inc.			
Insulated battery enclosure	(to be fabricated)			

Table 1 (Page 2 of 6)

ITEM	REPRESENTATIVE SUPPLIER/MODEL NUMBER	UNIT COST (1)	QUANTITY	TOTAL COST (1)
20 ft, self-supporting antenna tower, to withstand 100 mph wind and 250-lb ice load				
2) Vertical-component, short-period, dual gain channel field station;		$9,575	2	$19,150
Comprised of:				
The same components as in (1) plus:				
1 additional amplifier	Sprengnether AS-110			
1 additional VCO	Sprengnether TC-10			
Additional field enclosure	(to be fabricated)			
3) 3-component, dual-gain short-period field station		$12,550	1	$12,550
Comprised of:				
The same components as in (1) plus:				
2 horizontal, 1-second free-period seismometers	Mark Products L4-C-H			
4 additional amplifiers	Sprengnether AS-110			
4 additional VCO's	Sprengenther TC-10			

Table 1 (Page 3 of 6)

ITEM	REPRESENTATIVE SUPPLIER/MODEL NUMBER	UNIT COST (1)	QUANTITY	TOTAL COST (1)
4) 3-component, broad-band field station, hard-wired to central recording site		$14,750	1	$14,750
Comprised of:				
Vertical seismometer, 5-second free period	Kinemetrics SV-1			
2 horizontal seismometers 5-second free period	Kinemetrics SH-1			
6 amplifier/VCO's	Kinemetrics AOM-1			
2 calibration modules	Kinemetrics CM-1			
2 multiplexers	Kinemetrics			
2 field housing units with voltage regulator in environmentally sealed enclosures	Kinemetrics TH-3 (environmentally hardened)			
2 miles "Spiral-4" cable				
5) Relay station (estimated maximum 2)		$5,550	2	$11,100
Comprised of:				
Multiplexer/band-pass filter unit	To be fabricated			
VHF transmitter	Monitron TX-101			

Table 1 (Page 4 of 6)

ITEM	REPRESENTATIVE SUPPLIER/MODEL NUMBER	UNIT COST (1)	QUANTITY	TOTAL COST (1)
Yagi antenna	Scala CA5-150H			
6 Carbonaire batteries	McGraw-Edison			
Environmentally-sealed electronics enclosure	Hoffman Enclosures Inc.			
Insulted battery enclosure	To be fabricated			
20' lattice tower				
ESTIMATED TOTAL FIELD STATIONS COST				$133,750
Central Recording Facility				
Microcomputer-based central recording system		$215,000	1	$215,000
Comprised of:				
Computerized data acquisition system	Woodward-Clyde Consultants			
12 Yagi antennas	Scala CA5-150H			
12 VHF receivers	Monitron RX-101			
18 discriminators	Sprengnether TC-20			
6 discriminators	Kinemetrics DM-1			
3 discriminator card cages	Sprengnether CG-1			
3 discriminator power supplies	Sprengnether PS-2			
1 discriminator card cage	Kinemetrics DP-1			
1 discriminator power supply	Kinemetrics PP-1			

Table 1 (Page 5 of 6)

ITEM	REPRESENTATIVE SUPPLIER/MODEL NUMBER	UNIT COST (1)	QUANTITY	TOTAL COST (1)
Uninterruptible power supply, 4 KWatt				
2 visual recorders, 2-channel, with amplifiers	Sprengnether VR-60			
Satellite-corrected clock	True Time 468-DC			
WWV receiver	True Time WVTR			
Crystal-controlled clock	Sprengnether TS250			
2 racks	Sprengnether RRC-6			
2, 20' lattice towers				
ESTIMATED TOTAL CENTRAL RECORDING FACILITY COST				$215,000
Strong-Motion Recorders				
Strong-motion accelerograph, with integral WWVB time-code receiver	Kinemetrics SMA-1	$3,250	6	$19,500
ESTIMATED TOTAL STRONG-MOTION RECORDER COST				$19,500
Test Equipment				
Comprised of:				$6,000
Dual-channel oscilloscope,	Tektronics RS110, with 5A18N and 5B10N plug-in			

Table 1 (Page 6 of 6)

ITEM	REPRESENTATIVE SUPPLIER/MODEL NUMBER	UNIT COST (1)	QUANTITY	TOTAL COST (1)
Field oscilloscope	Tektronics 212-02			
Frequency counter	Hewlett-Packard 5315A + 120 + 001 + 002			
Function generator	Exact Electronics NIDL. 119P (battery powered)			
Digital multimeter	Hewlett-Packard 3466A (battery powered)			
ESTIMATED TOTAL TEST EQUIPMENT COST				$6,000
ESTIMATED TOTAL EQUIPMENT COST(2)				$374,250

Notes: (1) The representative instrumentation and costs presented in this table are intended to specify the design features of the long-term earthquake monitoring system for the Susitna Hydroelectric Project and do not constitute a procurement document. These cost estimates are based on 1982 dollars.

(2) Spare parts are shown in Table 4.

TABLE 2: ANTICIPATED SCHEDULE FOR IMPLEMENTATION OF LONG-TERM NETWORK

ACTION	MONTH AFTER START (1)
Finalize design and prepare bid documents	1
Order equipment	2
Receive and test equipment installation materials	6
Select station sites	7
Install and test system	8
Initiate routine operation	9

Note: (1) Field conditions require that installation occur during the summer (months 7, 8, and 9).

TABLE 3: ESTIMATED PERSONNEL TIME COSTS AND EXPENSES THROUGH SYSTEM INSTALLATION

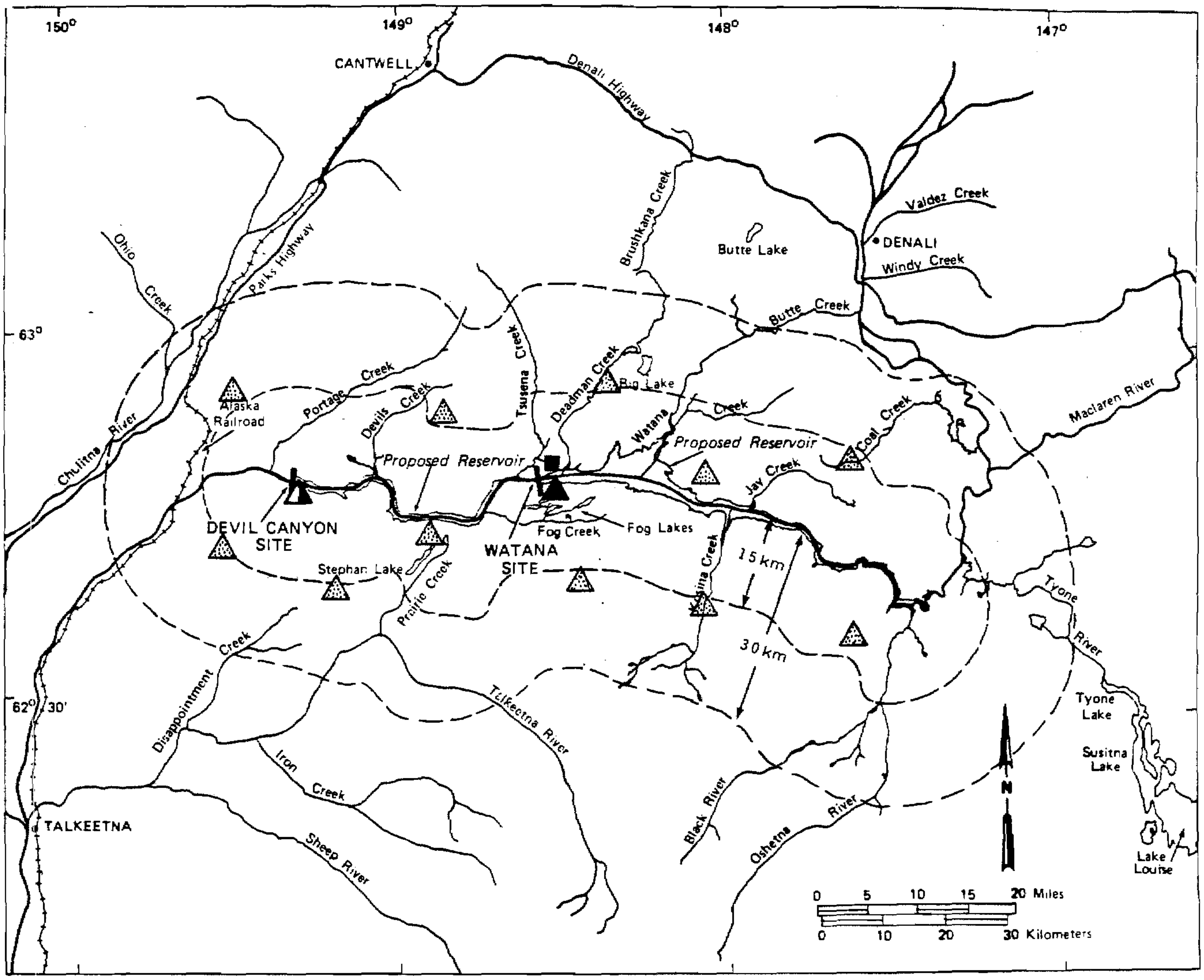
Task	Estimated Person-Days	Estimated Salary Costs(1)	Other Estimated Costs(1)	Estimated Total Cost
1. Finalize system design	15	10,000	-	10,000
2. Prepare procurement document and receive equipment	10	6,000	2,000(2)	8,000
3. Carry out system integration, bench-testing, and calibration(4)	15	14,000	-	14,000
4. Select sites, install system, and check operations.	125	63,000	50,000(3)	113,000
Total	165			$145,000

Notes:
(1) Based on estimated 1982 costs, including office expenses.
(2) Shipping costs.
(3) Shipping, per diem, travel, and helicopter costs.
(4) Estimated costs for instrument modifications and fabrication are included in Table 1.

TABLE 4: ESTIMATED YEARLY PERSONNEL TIME COSTS AND OPERATING EXPENSES FOR NETWORK OPERATION, MAINTENANCE, AND DATA ANALYSIS

	Item	Estimated Person-days Per Year	Estimated Yearly Salary Cost (1)	Other Estimated Yearly Costs (1)	Estimated Total Cost
1.	Maintenance visits by technician to field stations and central recording facility	25	12,500	13,000 (2)	25,500
2.	Network routine operation, preliminary data analysis (site personnel)	180	25,000	10,000 (3)	35,000
3.	Detailed data analysis and operations review	180	30,000	2,000 (4)	32,000
4.	Replacement Parts	--	--	$36,000 (5)	36,000
				ESTIMATED TOTAL YEARLY COST	$128,500

Notes:
(1) Based on estimated 1982 costs.
(2) Travel, per diem, and helicopter costs.
(3) Travel, per diem, helicopter, recording supplies, and data shipping costs.
(4) Travel and per diem costs.
(5) Based on 10% of the original equipment cost.



LEGEND

- Vertical-component, short-period, telemetered station
- Three-component, short-period, telemetered station
- Three-component, broad-band station
- Central recording facility
- 15 km and 30 km zones around reservoir system
- Strong motion instrumentation located at dam sites

Figure 1

GENERAL CONFIGURATION OF THE PROPOSED SUSITNA NETWORK