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UNIVERSITY OF UTAH RESEARCH INSTITUTE
UURI
EARTH SCIENCE LABORATORY
391 CHIPETA WAY, SUITE C
SALT LAKE CITY, UTAH 84108—1295
TELEPHONE 801-524-3422

July 18, 1985

Dr. Barry Voight
Department of Geosciences
Pennsylvania State University
University Park, PA 16802

Dear Barry:

Thank you for the opportunity to respond to the suggested outline for a report by the Task Group on Snow Avalanches. I feel very strongly that a study of snow avalanches should be included in the overall effort of the Committee of Ground Failure Hazards. The hazard from avalanches is high in many areas, their potential for damage is great, the need for research is largely unappreciated, and the possibility of having a positive effect on hazard reduction exists. These conditions justify inclusion of avalanches in a report.

A major accomplishment of a study could be to raise the national profile of avalanches as geologic hazards. Their destructive potential is not appreciated by the public or by decisionmakers. Population pressures are increasing in the mountains, as a result of expanding towns and ski areas, recreational home development, and other growth. Some land use planners are aware of the problems they face, but many are not. Planners in Utah have questions, but do not have reliable sources for answers in many areas. The highway department in Utah is not always able to manage avalanche problems. They are currently redesigning a road, which is typically shut several times a year by avalanches, but they are not sure if they will be able to fund a study to identify frequent and infrequent paths. The relatively early stage of expanding mountain development suggests that in many cases there is still time to have a positive impact on hazard avoidance.

Raising the national profile of avalanches could also have a positive impact on funding for research. The closing of centralized research at Ft. Collins, and the inability of another federal agency to take on a funding role, means that at a time when research is expanding in many earth science areas, avalanche studies are not increasing proportionally. It is my impression that the applications of sophisticated electronic instrumentation and computer data compilation and analysis are only recently making an impact in avalanche studies. Expansion of these efforts may lead to major advances in understanding both pure and applied aspects of avalanches. Funding problems, which could inhibit such efforts, should be discussed in the study by the committee.

One point that I feel is important, but is not reflected in your outline, is the nature of the existing data base. Unlike most hazards, which have an extensive literature of engineering and geologic studies by professionals, avalanche studies are a mixture of technical investigations and applied studies by ski area personnel. In Utah, good data on avalanche path location and history exist for only a few canyons, and for only a few decades in those canyons. Most information is limited to the lifetimes of current observers, and many years of these observations are not rigorously documented. This is too short a time to evaluate a geologic hazard, in which large magnitude, long recurrence interval events create the greatest hazards. It is my impression that many avalanche workers do not appreciate possible 100 year events. I therefore suggest that the nature of the data base be discussed in the report, and that possible mechanisms for bridging the gaps between "ivory tower types" and "ski bums", both of whom have valuable contributions to make, be suggested.

Mountain meteorology is not addressed in the outline. This topic, which is the subject of a national workshop this fall, is crucial in understanding avalanches. The workshop convenors should be able to provide you with much more information.

These are my first brief reactions to the outline. Overall I think that it is quite good, and it certainly represents an ambitious effort. I would be happy to provide you with further thoughts, if you would like.

Sincerely,

Duncan Foley

Duncan Foley
Geologist/Project Manager

DF/jp

3 PM 8 Mar '85

Mike-
I haven't looked @ this @ all, but
will be working it over before Wed.
D.F.

PROPOSAL: A CENTRAL PROGRAM FOR ALPINE RESEARCH

by

Sue A. Ferguson, Ph.D. (Geophysics)

Avalanche Forecaster
Utah Avalanche Forecast Center
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Salt Lake City, Utah 84116
(801) 524-5523 (FTS) 588-5523

Publisher
The Avalanche Review
P.O. Box 510904
Salt Lake City, Utah 84151-0904
(801) 521-5295

This preliminary proposal outlines the current functions of avalanche forecasting and research within the Wasatch Mountains of Utah. It also addresses the need for a centrallized program to manage the operational program of avalanche forecasting, to develop and implement improved mountain weather forecasts, to organize and analyze the volumes of snow, avalanche, mountain weather, and backcountry usage data collected by the current Utah Avalanche Forecast Center, and to develop and support snow, avalanche, and other related alpine research.

There has been an astronomical increase in winter backcountry use over the last few years. Also there has been a dramatic increase in residential and commercial mountain development. This puts greater pressure on any centrallized avalanche program to provide more accurate assessments of avalanche potential for each special interest group. Unfortunately the study of snow and avalanching is still in its infancy and the increasing demand for predictive accuracy is met with an increasing need for research.

The most famous and productive avalanche research project in this country was performed by the Alta Study Center which was disbanded in the early 1970's. The establishment of the Wasatch mountains as a study center has a long and reveared history and the absence of the study center has been felt by all who work in the mountains.

The Rocky Mountain Forest and Range Experiment Station in Ft. Collins, Colorado took over the snow and avalanche research project. This was the only snow and avalanche research center in this country until last fall when the program was terminated. The only other avalanche research in the U.S. is performed by a few members of the Engineering and Engineering Mechanics Department at Montana State University in Bozeman, Montana. In addition, some faculty at other universityies occassionally get involved in snow and avalanche research projects.

There are four regional avalanche forecast centers within the United States, the Colorado Avalanche Information Center, Utah Avalanche Forecast Center, Northwest Avalanche Center, and Alaska Avalanche Forecast Center. There are no avalanche research centers. There are only five full time mountain weather forecasters in all of the Americas. Three are avalanche forecasters at the Northwest Avalanche Center and two others work in conjunction with the Alaska Avalanche Forecast Center. All are self taught.

Understanding avalanche phenomena is an interdisciplinary problem. For example, the principles of chemistry are applied to crystallographic changes of deposited snow grains. Geology and geography techniques are used to evaluate snowpack stratigraphy and map hazardous terrain. Designing sensitive instrumentation to test delicate snow properties and extreme weather conditions, evaluating snowpack stresses and avalanche impact pressures all pose engineering problems. The meteorological aspects of a developing snowcover are strategic for avalanche control and forecasting. Understanding the stress, fracture, and flow properties of snow require techniques of physics and mathematics. Problems in forestry are addressed in reforestation projects within avalanche paths and the influence of avalanche terrain upon vegetation. The hydrology of a melting snowpack can also be applied to wet snow metamorphism, wet snow avalanching, and snow glide. Sociological aspects of backcountry attitudes on risk and hazard evaluation are important factors for determining forecasting and control services. Avalanche mapping and zoning is also a problem for land use planners.

The reestablishment of a snow and avalanche research program in the Wasatch Mountains would fill a much recognized void. ∧ This is an ideal place to study snow, avalanches, and mountain weather because of its proximity to

Housing the program
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ake advantage of
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departments

very active and hazardous avalanche terrain, a spring runoff whose flood potential is highly dependent upon spring snow conditions and winter avalanche cycles, close connection with the NWS regional office, an avalanche aware backcountry community, and a scientific community who are well tuned to the problems of geologic hazards.

To this end, we propose a program administered by the University of Utah which would combine the current avalanche forecasting activities with studies on mountain weather as well as other related research projects. Below is a summary of programs now in effect and proposed projects.

Avalanche Forecasting - There are several local avalanche forecasting and control programs within the Northern Wasatch Mountains of Utah. There is also one centrally located backcountry avalanche forecasting program. The Utah Department of Transportation (UDOT) employ two full time and two part-time avalanche forecast and controllers to cover avalanche terrain affecting the Big and Little Cottonwood Canyons. In addition, each ski area has a designated snow safety team to evaluate and control in-area avalanche potential. Backcountry conditions are monitored by the Utah Avalanche Forecast Center.

The Utah Avalanche Forecast Center is currently managed by the USDA Forest Service Wasatch/Cache District. The program is housed within the National Weather Service (NWS) Forecast Office. Twice daily assessments and forecasts of the avalanche and mountain weather conditions are distributed through 24-hour telephone recordings. Data on mountain weather and snowpack conditions are collected from remote weather observation stations, and mountain observers (snow safety personnel within each ski area and UDOT personnel in Big and Little Cottonwood Canyon). In addition, all of the available NWS analyses and prognoses are at the disposal of the avalanche forecasters.

These data are analysed by experienced snow and avalanche technicians and interpreted for a 90 second message explaining conditions to backcountry users. An observer report is also recorded on a separate telephone line which details the weather and avalanche conditions with a lengthy meteorological synopsis and a summary of observations, avalanche accidents, and snowpack structure. In addition, during high hazard conditions, special statements are distributed to all forest service districts, the media, and other NWS stations.

An educational program is also a part of the Avalanche Forecast Center's functions. Talks are given to special interest groups, outdoor clubs, other state and federal agencies, and school groups. Special effort is made to interact with backcountry users, mountain observers, and other avalanche forecasters and controllers.

Accidents are investigated and reports prepared for public information. Special activities also include advising city and county planners on avalanche zoning problems.

Three forecasters are currently employed full time from November through April. A fourth forecaster is employed part-time for the major part of the winter. Although the dollar amount ($55,000) of program funding is completely Forest Service, in kind payment is also received from the UDOT and local ski areas for daily weather, snow, and avalanche observations. The NWS also helps by providing office space and use of all their forecast facilities.

Avalanche forecasting is still an art. Each forecaster develops his/her own methodologies of forecasting based upon personal experience, unique climatic conditions of the mountain range, unique attitudes of backcountry travelers, as well as knowledge of snowpack mechanics, mountain terrain, and influences of weather. Much work needs to be done to analyze the volumes of data collected daily. Quantitative tools for analyzing and predicting need to be developed. We do not understand how avalanches initiate. We do not understand how snow responds to the variety of stresses that create avalanches. Basic research on these topics will help prediction. The social aspects of backcountry users who travel within hazardous terrain should also be studied so a more useful avalanche summary can be established.

Mountain Weather - Currently the weakest link in avalanche control and forecasting is the 6 to 12 hour weather forecasts. The avalanche forecasts and control programs rely on generalized zone forecasts that do not necessarily reflect mountain conditions. Without accurate predictions of wind speed and direction, temperature fluxuations, and precipitation amount, intensity, duration, and timing, an efficient control program is difficult and has often relied on the "sixth sense" of experienced field personnel and an incredible amount of luck.

The National Weather Service is aware of the problem but does not have enough personnel or time to provide the precise forecasts called for in mountain management operations. They have indicated a desire to employ a mountain weather forecasting program if financial support could be found. The management level of private ski areas are also aware of the need to support a good mountain weather program and have indicated the possibility of helping to fund such a program.

In the early 1970's the University of Washington recognized the need for improved mountain weather forecasts and a project was funded by the Washington State Department of Transportation to initiate weather forecasts by two meteorology students at the UW, housed withing the NWS forecasting offices. This program has since saved the WDOT so much money in avalanche control operations that they recently awarded the UW with a merit of excellence. Since then the Northwest Avalanche Center (now managed by the USDA-Forest Service) has provided precise mountain weather and avalanche forecasts twice daily by trained meteorologists who are also snow scientists.

In the early 1980's the USDA-Forest Service Alaska Avalanche Warning System employed two meteorologists to forecast mountain weather in the South Central mountains of Alaska. Since these meteorologists were not trained in snow science, they have since had to hire extra personnel to act as liason between the meteorologists and the avalanche forecasting program. The entire program is now administered by the University of Alaska Arctic and Environment Data Center in Anchorage.

Developing a wind flow model for the Wasatch will help devise a much needed quantitative precipitation forecast. Understanding the mesoscale phenomenon of over-land air masses could improve hourly forecasting. Increasing ridgetop weather stations will provide much needed data to develop and improve forecasting programs. These are just a few suggestions to improve our understanding of mountain weather. Because there are so few mountain weather forecasters throughout the world, and because there is no unified research on the problems of forecasting mountain weather, a research center established to study these problems would be a great asset.

Current Activities - Several mountain observers within the Northern Wasatch mountains have expressed a desire to be involved in avalanche research. These include geologists, engineers, avalanche forecasters, and snow safety directors. In addition, several structures have been offered as potential alpine observation stations.

Currently one project is already underway which is supervised by Ferguson. A specially designed camera has been set up near Alta Ski Area to photograph snow crystals as they are falling through a storm. This information will be corellated with upper air weather observations and avalanche occurrence to improve forecasting techniques for new-snow avalanches. The camera is being maintained by a ski patrol member, Mark Kawataski, who is using his own dark room equipment to process the pictures. Funding for this program is being sought and a proposal is planned for continued work next winter. The findings will be presented at a snow science conference in Davos, Switzerland in the fall of 1986.

Recently a proposal was submitted to the USGS in response to RFP 1586 by Ferguson and Duncan Foley (Geologist, Project Manager, Earth Science Laboratory, University of Utah Research Center) entitled, "Earthquake-induced Avalanches along the Wasatch Front, Utah." This is a 17 month $76,500 proposal to catalog the avalanche paths that affect lifelines along the Wasatch Front, estimate the avalanche trigger efficiency of a large earthquake, and map the zones of influence.

A proposal is being submitted to the UDOT to catalog all avalanche paths that affect highways that are not supervised by an avalanche control program. These include Provo, Daniels, Ogden, North Ogden, and Logan Canyons. All of those were blocked by snow slides this winter. It is felt that if the Utah Avalanche Forecast Center knew the starting zone elevations, aspects, and slope configurations of each of the avalanche paths that affect these roads, an early warning system could help to alleviate any potential loss of life or damage to equipment.

Ferguson will teach an upper level snow physics course next year through the U. of U. Physics Department. This will be an extension of the course offered by Peter Lev in the Geography Department and will require students to have a science and math background.

Ferguson owns "The Avalanche Review," a monthly publication for avalanche professionals. This publication is co-sponsoring an Avalanche Weather Seminar with the American Avalanche Institute to be held October 25, 26, and 27, 1985 in Salt Lake City. This seminar may be an opportune time for the University of Utah to become involved in avalanches as a the third sponsor.

<u>Funding</u>.- Funding operational programs come from the users themselves. If an Alpine Research Center were established

and were to manage a backcountry avalanche forecasting program it is felt that the Forest Service would continue to support a bulk of the program as a service to Forest land users. Outdoor clubs, state parks, and the Utah Ski Association will also be asked to support the operational programs. Personal communications with UDOT and private ski areas indicate they have a desire to help support an improved mountain weather forecast. They may also support development of computerized guidance programs and instrumentation for weather, snowpack, and avalanche occurrence. A project designed to imporve the prediction of avalanches affecting state highways that do not employ a regular avalanche control team may solicit support from the UDOT. Basic research projects would be supported by the federal DOT, NSF, USGS, NOAA, etc. An extension of the program to include other public lands within the state may attract support from other state and local agencies that service winter backcountry skiers, snow mobilers, snow shoers, road crews, and mining operations.

Project Plan

Activity	Cost	Funding Source	Staff
First Year:			
a. Establish a concrete definition of purpose.			S.A. Ferguson and D. Foley
b. Develop a marketing plan and carry it out.	$1,000?	?	S.A. Ferguson, D. Foley, and R. Mandahl (marketting consultant and ski patroller)
c. Develop a cooperative agreement between government agencies and private groups to fund the operational avalanche forecasting program.	$3,000 (2 months summer salary)	U. of U. ?	S.A. Ferguson
d. Continue operational back-country avalanche forecasting.	$70,000	USFS Utah Ski Association UDOT Outdoor clubs NWS Ski Areas	S.A. Ferguson, D. Bowles, A. Soucie, and P. Lambrose
e. Solicit grants for a few special projects to begin a credible foundation for research.	$140,000	USGS (UDOT,NSF)	S.A. Ferguson, D. Foley, P. Gibbs (professor of Physics, U of U), M. Kawataski (photographer and ski patroller), O. Weiringa (snow safety director for Alta, and avalanche forecaster for UDOT/LCC), S. Rosso (engineer and ski patroller), R. Wyatt (geologist and avalanche forecaster for UDOT/BCC)
Second Year:			
a. Continue Marketing			
b. Continue operational forecasting program			
c. Begin to quantify and analyze the volumes of data. Develop a filing system for detailed accounts of all avalanche accidents. Begin a historical survey of avalanche accidents to add to this file.			
d. Establish an improved mountain weather program. Develop more quantitative ways to display and transmit snow, weather, and avalanche information.			
e. Continue research efforts with special project funding.			
f. Solicit support from researchers in other departments.			

Third year:

a. Continue marketing plan.

b. Broaden scope of forecasting to include other areas within the state, and specific forecasts for special events.

c. Continue development of data collection, analysis, and transmission techniques.

d. Continue special grant projects.

e. Begin developing a high mountain research and observation station.

f. Implement a post-doctoral research program.

Fourth year:

a. Continue marketing plan.

b. Continue operational forecasting program.

c. Continue special grant projects.

d. Add technical support personnel to research and develop instrumentation and analysis techniques performed at the field station.

OMB Approval No. 0348-0006

FEDERAL ASSISTANCE

1. TYPE OF SUBMISSION *(Mark appropriate box)*
☐ NOTICE OF INTENT (OPTIONAL)
☐ PREAPPLICATION
☒ APPLICATION

2. APPLICANT'S APPLICATION IDENTIFIER
a. NUMBER
b. DATE *Year month day* 19 85 2 28

Leave Blank

3. STATE APPLICATION IDENTIFIER *NOTE: TO BE ASSIGNED BY STATE*
a. NUMBER UT850228-050
b. DATE ASSIGNED *Year month day* 19 85 02 28

SECTION I—APPLICANT/RECIPIENT DATA

4. LEGAL APPLICANT/RECIPIENT
a. Applicant Name University of Utah Research Institute
b. Organization Unit Earth Science Laboratory
c. Street/P.O. Box 391 Chipeta Way, Suite C
d. City Salt Lake City
e. County Salt Lake
f. State Utah
g. ZIP Code 84108
h. Contact Person *(Name & Telephone No.)* W. L. Forsberg (801) 524-3442

5. EMPLOYER IDENTIFICATION NUMBER (EIN) 51-0204678

6. PROGRAM *(From CFDA)*
a. NUMBER N/A
MULTIPLE ☐
b. TITLE N/A

7. TITLE OF APPLICANT'S PROJECT (Use section IV of this form to provide a summary description of the project.)
Earthquake-Induced Avalanches along the Wasatch Front, Utah

8. TYPE OF APPLICANT/RECIPIENT
A—State
B—Interstate
C—Substate Organization
D—County
E—City
F—School District
G—Special Purpose District
H—Community Action Agency
I—Higher Educational Institution
J—Indian Tribe
K—Other *(Specify)*: Non-profit
Enter appropriate letter K

9. AREA OF PROJECT IMPACT *(Names of cities, counties, states, etc.)*
Salt Lake, Davis, Morgan, Summit, Utah, Wasatch

10. ESTIMATED NUMBER OF PERSONS BENEFITING
Unknown

11. TYPE OF ASSISTANCE
A—Basic Grant
B—Supplemental Grant
C—Loan
D—Insurance
E—Other
Enter appropriate letter(s) A

12. PROPOSED FUNDING

a. FEDERAL	$ 76,500 .00
b. APPLICANT	.00
c. STATE	.00
d. LOCAL	.00
e. OTHER	.00
f. Total	$ 76,500 .00

13. CONGRESSIONAL DISTRICTS OF:
a. APPLICANT 2
b. PROJECT 1,2,3

14. TYPE OF APPLICATION
A—New
B—Renewal
C—Revision
D—Continuation
E—Augmentation
Enter appropriate letter A

15. PROJECT START DATE *Year month day* 19 85 08 01

16. PROJECT DURATION 17 *Months*

17. TYPE OF CHANGE *(For 14c or 14e)*
A—Increase Dollars
B—Decrease Dollars
C—Increase Duration
D—Decrease Duration
E—Cancellation
F—Other *(Specify)*:
N/A
Enter appropriate letter(s)

18. DATE DUE TO FEDERAL AGENCY ► *Year month day* 19

19. FEDERAL AGENCY TO RECEIVE REQUEST U. S. Geological Survey
a. ORGANIZATIONAL UNIT (IF APPROPRIATE) Branch of Procurement and Contracts
b. ADMINISTRATIVE CONTACT (IF KNOWN) Duleep I. Pandite
c. ADDRESS
Mail Stop 205C, Room 1D104
12201 Sunrise Valley Drive
Reston, Virginia 22092

20. EXISTING FEDERAL GRANT IDENTIFICATION NUMBER

21. REMARKS ADDED
☐ Yes ☐ No

SECTION II—CERTIFICATION

22. THE APPLICANT CERTIFIES THAT► To the best of my knowledge and belief, data in this preapplication/application are true and correct, the document has been duly authorized by the governing body of the applicant and the applicant will comply with the attached assurances if the assistance is approved.

a. YES, THIS NOTICE OF INTENT/PREAPPLICATION/APPLICATION WAS MADE AVAILABLE TO THE STATE EXECUTIVE ORDER 12372 PROCESS FOR REVIEW ON:
DATE 2-28-85

b. NO, PROGRAM IS NOT COVERED BY E.O. 12372 ☐
OR PROGRAM HAS NOT BEEN SELECTED BY STATE FOR REVIEW ☐

23. CERTIFYING REPRESENTATIVE
a. TYPED NAME AND TITLE James J. Brophy, President
b. SIGNATURE Stanley H. Ward for

SECTION III—FEDERAL AGENCY ACTION

24. APPLICATION RECEIVED *Year month day* 19

25. FEDERAL APPLICATION IDENTIFICATION NUMBER

26. FEDERAL GRANT IDENTIFICATION

27. ACTION TAKEN
☐ a. AWARDED
☐ b. REJECTED
☐ c. RETURNED FOR AMENDMENT
☐ d. RETURNED FOR E.O. 12372 SUBMISSION BY APPLICANT TO STATE
☐ e. DEFERRED
☐ f. WITHDRAWN

28. FUNDING

a. FEDERAL	$ .00
b. APPLICANT	.00
c. STATE	.00
d. LOCAL	.00
e. OTHER	.00
f. TOTAL	$ .00

29. ACTION DATE► *Year month day* 19

30. STARTING DATE *Year month date* 19

31. CONTACT FOR ADDITIONAL INFORMATION *(Name and telephone number)*

32. ENDING DATE *Year month date* 19

33. REMARKS ADDED
☐ Yes ☐ No

NSN 7540-01-008-8162
PREVIOUS EDITION IS NOT USABLE

424-103

STANDARD FORM 424 PAGE 1 (Rev. 4-84)
Prescribed by OMB Circular A-102

APPENDIX D

SUMMARY FOR THE SMITHSONIAN SCIENCE INFORMATION EXCHANGE

Congressional District: *Utah 2nd*

Project Title: Earthquake-induced Avalanches along the Wasatch Front, Utah

Date Project Started:

Program Objective: Element III. Regional Earthquake Hazards Assessments, Objective R-1: Mapping and synthesis of geologic hazards and establishment of information systems

Principal Investigator(s): Dr. Duncan Foley

Organization and Address: Earth Science Laboratory
University of Utah Research Institute
391 Chipeta Way, Suite C
Salt Lake City, Utah 84108

Estimated cost for current fiscal year: $76,500

States (or foreign countries) to which project pertains: Utah

Key Words (to indicate major emphasis of project): Avalanches, Earthquakes, Snow mechanics, Lifeline destruction, Avalanche path identification

In 200 words or less, give a succinct statement of the project objectives, work plans, and implications of anticipated results for the proposed duration of the project:

The potential for earthquake-induced avalanches along the Wasatch Front of Utah has never been evaluated, despite the high probability of a major earthquake and the often unstable nature of the Utah snowpack. This study has two parts: to assess the mechanical stability of the Wasatch snowpack, and to identify sites where lifelines or other critical facilities are threatened by avalanches. Data on mechanical stability of the snowpack will be useful in modeling trigger mechanisms for shaking-induced release of the snowpack. Sites identified with presently unknown hazards will be important data for emergency planners.

Signature of Principal Investigator: Duncan Foley Date: 28 Feb, 1985

APPENDIX E to U.S. Geological Survey RFP 1586

REPRESENTATIONS, CERTIFICATIONS AND OTHER STATEMENTS OF OFFEROR

(THIS PART MUST BE COMPLETED AND RETURNED ALONG WITH YOUR PROPOSAL.)

The following representations and certifications shall be filled in by the offeror (check or complete appropriate boxes or blanks) and must be executed by an official authorized to bind the offeror. Offerors must set forth full, accurate and complete information as required by this solicitation (including attachments). As used in this document, the term "offeror" shall be understood to mean "applicant or offeror." The penalty for making false statements in offers and quotations is prescribed in 18 U.S.C. 1001.

1. CONTINGENT FEE REPRESENTATION AND AGREEMENT (APR 1984) FAR 52.203-4

(a) Representation. The offeror represents that, except for full-time bona fide employees working solely for the offeror, the offeror--

[Note: The offeror must check the appropriate boxes. For interpretation of the representation, including the term "bona fide employee", see Subpart 3.4 of the Federal Acquisition Regulation.]

(1) [ ] has, [X] has not employed or retained any person or company to solicit or obtain this contract; and

(2) [ ] has, [X] has not paid or agreed to pay to any person or company employed or retained to solicit or obtain this contract any commission, percentage, brokerage, or other fee contingent upon or resulting from the award of this contract.

(b) Agreement. The offeror agrees to provide information relating to the above Representation as requested by the Contracting Officer and, when subparagraph (a)(1) or (a)(2) is answered affirmatively, to promptly submit to the Contracting Officer--

(1) A completed Standard Form 119, Statement of Contingent or Other Fees, (SF 119); or

(2) A signed statement indicating that the SF 119 was previously submitted to the same contracting office, including the date and applicable solicitation or contract number, and representing that the prior SF 119 applies to this offer or quotation.

2. TYPE OF BUSINESS ORGANIZATION (APR 1984) FAR 52.215-6

The offeror or quoter, by checking the applicable box, represents that it operates as [X] a corporation incorporated under the laws of the State of Utah, [ ] an individual, [ ] a partnership, [X] a nonprofit organization, or [ ] a joint venture.

3. PLACE OF PERFORMANCE (APR 1984) FAR 52.215-20

(a) The offeror or quoter, in the performance of any contract resulting from this solicitation, ☐ intends, ☒ does not intend (check applicable block) to use one or more plants or facilities located at a different address from the address of the offeror or quoter as indicated in this proposal or quotation.

(b) If the offeror or quoter checks "intends" in paragraph (a) above, it shall insert in the spaces provided below the required information:

Place of Performance (Street Address, City, County, State, Zip Code)	Name and Address of Owner and Operator of the Plant or Facility (if Other than Offeror or Quoter)

4. SMALL BUSINESS CONCERN REPRESENTATION (APR 1984) FAR 52.219-01

The offeror represents and certifies as part of its offer that it ☐ is, ☒ is not a small business concern and that ☐ all, ☒ not all supplies to be furnished will be manufactured or produced by a small business concern in the United States, its possessions, or Puerto Rico. "Small business concern," as used in this provision, means a concern, including its affiliates, that is independently owned and operated, not dominant in the field of operation in which it is bidding on Government contracts, and qualified as a small business under the size standards in this solicitation.

5. SMALL DISADVANTAGED BUSINESS CONCERN REPRESENTATION (APR 1984) FAR 52.219-02

(a) Representation. The offeror represents that it ☐ is, ☒ is not a small disadvantaged business concern.

(b) Definitions.

"Asian-Indian American," as used in this provision, means a United States citizen whose origins are in India, Pakistan, or Bangladesh.

"Asian-Pacific American," as used in this provision, means a United States citizen whose origins are in Japan, China, the Philippines, Vietnam, Korea, Samoa, Guam, the U.S. Trust Territory of the Pacific Islands, the Northern Mariana Islands, Laos, Cambodia, or Taiwan.

"Native Americans," as used in this provision, means American Indians, Eskimos, Aleuts, and native Hawaiians.

"Small business concern," as used in this provision, means a concern, including its affiliates, that is independently owned and operated, not dominant in the field of operation in which it is bidding on Government contracts, and qualified as a small business under the criteria and size standards in 13 CFR 121.

"Small disadvantaged business concern, as used in this provision, means a small business concern that (1) is at least 51 percent owned by one or more individuals who are both socially and economically disadvantaged, or a publicly owned business having at least 51 precent of its stock owned by one or more socially and economically disadvantaged individuals and (2) has its management and daily business controlled by one or more such individuals.

(c) Qualified groups. The offeror shall presume that socially and economically disadvantaged individuals include Black Americans, Hispanic Americans, Native Americans, Asian-Pacific Americans, Asian-Indian Americans, and other individuals found to be qualified by the SBA under 13 CFR 124.1.

6. WOMEN-OWNED SMALL BUSINESS REPRESENTATION (APR 1984) FAR 52.219-03

(a) Representation. The offeror represents that it [ ] is, [x] is not a women-owned small business concern.

(b) Definitions.

"Small business concern," as used in this provision, means a concern, including its affiliates, that is independently owned and operated, not dominate in the field of operation in which it is bidding on Government contracts, and qualified as a small business under the criteria and size standards in 13 CFR 121.

"Women-Owned," as used in this provision, means a small business that is at least 51 percent owned by a woman or women who are U.S. citizens and who also control and operate the business.

7. CERTIFICATION OF NONSEGREGATED FACILITIES (APR 1984)

FAR 52.222-21 is hereby incorporated by reference.

8. AUTHORIZED NEGOTIATORS (APR 1984) FAR 52.215-11

The offeror or quoter represents that the following persons are authorized to negotiate on its behalf with the Government in connection with this request for proposals or quotations:

Names	Titles	Telephone Numbers
Technical: Duncan Foley	Project Manager	(801) 524-3431
Financial: Wilford L. Forsberg	Associate Director	(801) 524-3442

9. PREVIOUS CONTRACTS AND COMPLIANCE REPORTS (APR 1984) FAR 52.222-22

The offeror represents that--

(a) It [x] has, [ ] has not participated in a previous contract or subcontract subject either to the Equal Opportunity clause of this solicitation, the clause originally contained in Section 310 of Executive Order No. 10925, or the clause contained in Section 201 of Executive Order No. 11114;

(b) It [x] has, [ ] has not filed all required compliance reports; and

(c) Representations indicating submission of required compliance reports, signed by proposed subcontractors, will be obtained before subcontract awards.

10. AFFIRMATIVE ACTION COMPLIANCE (APR 1984) FAR 52.222-25

The offeror represents that (a) it [x] has developed and has on file, [ ] has not developed and does not have on file, at each establishment, affirmative action programs required by the rules and regulations of the Secretary of Labor (41 CFR 60-1 and 60-2), or (b) it [ ] has not previously had contracts subject to the written affirmative action programs requirement of the rules and regulations of the Secretary of Labor.

11. CLEAN AIR AND WATER CERTIFICATION (APR 1984) FAR 52.223-1

The Offeror certifies that--

(a) Any facility to be used in the performance of this proposed contract [ ] is, [x] is not listed on the Environmental Protection Agency List of Violating Facilities;

12. CLEAN AIR AND WATER CERTIFICATION (Cont'd)

(b) The Offeror will immediately notify the Contracting Officer, before award, of the receipt of any communication from the Administrator, or a designee, of the Environmental Protection Agency, indicating that any facility that the offeror proposes to use for the performance of the contract is under consideration to be listed on the EPA List of Violating Facilities; and

(c) The Offeror will include a certification substantially the same as this certification, including this paragraph (c), in every nonexempt subcontract.

13. CONTRACTOR "DATA UNIVERSAL NUMBERING SYSTEM" (DUNS) IDENTIFICATION

The offeror's DUNS Contractor Establishment Number is 99-092-0589.
(If offeror does not have a DUNS number, please enter "NONE".)

14. COST ACCOUNTING STANDARDS NOTICES AND CERTIFICATION (NONDEFENSE) (APR 1984)

FAR 52.230-2

Note: This notice does not apply to small businesses or foreign governments.

(a) Any contract over $100,000 resulting from this solicitation shall be subject to Cost Accounting Standards (CAS) if it is awarded to a business unit that is currently performing a national defense CAS-covered contract or subcontract, except when--

(1) The award is based on adequate price competition;
(2) The price is set by law or regulation;
(3) The price is based on established catalog or market prices of commercial items sold in substantial quantities to the general public; or
(4) One of the exemptions in 4 CFR 331.30(b) applies (also see Federal Acquisition Regulation (FAR) 30.301(b)).

(b) Contracts not exempted from CAS shall be subject to full or modified coverage as follows:

(1) If the business unit receiving the award is currently performing a national defense contract or subcontract subject to full CAS coverage (4 CFR 331), this contract will have full CAS coverage and will contain the clauses from the FAR entitled Cost Accounting Standards (52.230-3) and Administration of Cost Accounting Standards (52.230-4).

(2) If the business unit receiving the award is currently performing a national defense contract or subcontract subject to modified CAS coverage (4 CFR 332), this contract will have modified coverage and will contain the clauses entitled Disclosure and Consistency of Cost Accounting Practices (52.230-5) and Administration of Cost Accounting Standards (52.230-4).

A. Certificate of CAS Applicability

The offeror hereby certifies that--

[x] The offeror is not performing any CAS-covered national defense contract or subcontract. The offeror further certifies that it will immediately notify the Contracting Officer in writing if it is awarded any national defense CAS-covered contract or subcontract subsequent to the date of this certificate but before the date of the award of a contract resulting from this solicitation. (If this statement applies, no further certification is required.)

[ ] The offeror is currently performing a negotiated national defense contract or subcontract that contains the Cost Accounting Standards clause at FAR 52.230-3.

[ ] The offeror is currently performing a negotiated national defense contract or subcontract that contains the Disclosure and Consistency of Cost Accounting Practices clause at FAR 52.230-5.

15. CAS NOTICES AND CERTIFICATION (NONDEFENSE) (Cont'd)

B. Additional Certification--CAS Applicable Offerors

[ ] The offeror subject to Cost Accounting Standards further certifies that practices used in estimating costs in pricing this proposal are consistent with the practices disclosed in the Disclosure Statement where it has been submitted pursuant to CAS Board regulations (4 CFR 351).

C. Data Required--CAS Covered Offerors

The offeror certifying that it is currently performing a national defense contract containing either CAS clause (see A above) is required to furnish the name, address (including agency or department component), and telephone number of the cognizant Contracting Officer administering the offeror's CAS-covered contracts.

Name of Contracting Officer: ____________________

Address: ____________________

____

Telephone Number: ____________________

16. PARENT COMPANY AND IDENTIFYING DATA (APR 1984)

(a) A "parent" company, for the purpose of this provision, is one that owns or controls the activities and basic business policies of the offeror. To own the proposing company means that the parent company must own more than 50 percent of the voting rights in that company. A company may control an offeror as a parent even though not meeting the requirement for such ownership if the parent company is able to formulate, determine, or veto basic policy decisions of the offeror through the use of dominant minority voting rights, use of proxy voting, or otherwise.

(b) The offeror [x] is, [ ] is not owned or controlled by a parent company.

(c) If the offeror checked "is" in paragraph (b) above, it shall provide the following information:

Name and Main Office Address of Parent Company (incl. Zip Code)	Parent Company's Employer's Identification Number
University of Utah Park Building Salt Lake City, Utah 84112	69-0870189

(d) If the offeror checked "is not" in paragraph (b) above, it shall insert its own Employer's Identification Number on the following line 51-0204678 .

17. IMMUNITY FROM TORT LIABILITY

The offeror [x] does, [ ] does not represent that as a state agency or charitable institution, the offeror is [x] partially immune, or [ ] totally immune from tort liability. Indicate below the applicable statute or code under which such immunity is provided:

Utah Code ANN. 63-30-1 Following

(1953 Code as ammended)

18. LSA PREFERENCE IN OFFER EVALUATION -- NON SET-ASIDE

As required by FAR 52.220-1 (incorporated by reference in Part II), to be entitled to LSA preference in offer evaluation, the offeror must identify, below, the Labor Surplus Area(s) in which costs will be incurred, amounting to 50% or more of the contract price.

19. DUPLICATION OF COST

The offeror represents and certifies that any charges contemplated and included in his estimate of cost for performance are not duplicative of any charges against any other Government contract, subcontract or other Government source.

20. OFFEROR'S DATA CERTIFICATION (NOV 1983) USGS P&P 83-19

The offeror shall certify below whether he has delivered or is obligated to deliver to the Government under any contract or subcontract the same or substantially the same technical data included in his offer; if so, he shall identify one such contract or subcontract under which such technical data was delivered or will be delivered, and the place of such delivery.

None delivered or obligated to be delivered.

21. CONFLICT OF INTEREST CERTIFICATION -- USGS EMPLOYEE

The offeror hereby certifies that:

(a) The offeror [ ] is, [x] is not, a present or former USGS regular or special employee whose USGS employment terminated within one year prior to submission of this proposal.

(b) The offeror [ ] does, [x] does not, employ a present or former USGS regular or special employee whose USGS employment terminated within one year prior to submission of this proposal and who will be involved directly or indirectly in the management, administration, or performance of any contract resulting from this proposal.

(c) The offeror [ ] will, [x] will not, employ as a consultant on any contract resulting from this proposal a current or former regular or special USGS employee whose USGS employment terminated within one year prior to submission of this proposal.

(d) A current or former USGS employee whose USGS employment terminated within one year prior to submission of this proposal or such employee's spouse or minor child [ ] does, [x] does not, hold a controlling interest in the offeror firm.

22. OFFEROR'S ACCOUNTING SYSTEM

Indicate whether or not offeror's accounting system has been approved by any U.S. Government agency and whether offeror has had an audit by any Government contracting agency within the last year; if so, state: yes

(a) Name and location of cognizant audit agency:

Health and Human Services
1745 West 1700 South
Salt Lake City, Utah

(b) Name and telephone number of cognizant auditor:

Eckhard Bauer (801) 524-4111

(c) Types of contracts and payments for which system is approved:

All types of contracts and payment methods.

23. BUSINESS MANAGEMENT INFORMATION

(Note: Completion of this #28 is not required of educational institutions or state and local government agencies.)

(a) Indicate the percentages of offeror's business performed for commercial customers and under Government contracts (including subcontracts under Government contracts).

Commercial 55% Government 45%

(b) Provide the names and locations of any other divisions or subsidiaries which will perform under proposed contract, if awarded.

Name	Location
None	

(c) Indicate date offeror was organized: December 1972

24. BUSINESS MANAGEMENT INFORMATION (Cont'd)

(d) Indicate, by number, your manpower resources as follows:

(1) Total employees	43
(2) Total technical employees qualified in an area similar or related to the proposed effort	2
(3) Total direct labor employees who will perform proposed contract	2

(e) Indicate the volume of work similar to that covered by this solicitation that the offeror could perform in a 12 month period: 1.5 times

(f) Experience

If offeror has received an award under this program within the past three years, the following information is not required. Other offerors are requested to identify two previous contracts awarded by a U.S. Government agency for similar research activities, including any performed within the past three years.

NOTE: SEE NOTE FOLLOWING PAGE

(1) Contract Number ______________________

Agency ______________________

Date of Award ____________ Completion Date ____________

Type of Contract ____________ Amount $____________

Name and Telephone Number of Contracting Officer:

____

(2) Contract Number ______________________

Agency ______________________

Date of Award ____________ Completion Date ____________

Type of Contract ____________ Amount $____________

Name and Telephone Number of Contracting Officer:

____

If your firm has not previously been awarded Government contracts for this work, provide the above information for commercial contracts on which similar work was performed.

25. OFFEROR NAME AND ADDRESS

Offeror should provide below the correct legal name under which his offer is submitted and to which any resultant award should be made.

Offeror Name University of Utah Research Institute

Address 391 Chipeta Way, Suite C
Number and Street
Salt Lake City Utah 84108
City State Zip Code
Salt Lake #2
County Congressional District

The Earth Science Laboratory/University of Utah Research Institute has not directly contracted with the government for identical work to that proposed herein. These unique applications proposed for proven snowpack evaluation techniques have not been made anywhere to date. However, both professionals assigned to this effort are highly qualified to do the tasks. Dr. Foley is familiar with geologic hazards and hazard mapping, from the standpoints of research, writing, and consulting. He teaches a course on geologic hazards at the University of Utah, and has co-edited a book on environmental geology. Dr. Ferguson has had government contracts to study avalanches (NSF 80-17750), has written a dissertation on the mechanical stability of snowpacks, and publishes the Avalanche Review, which is a newspaper-style monthly during the winter. Dr. Foley is a full-time employee of the Research Institute, Dr. Ferguson is an associate, who is also employed by the U.S. Forest Service as an avalanche forecaster (this work will not interfear with her efforts on this proposal).

26. ADDRESS OF PAYMENT

Offeror should state below the address to which payment should be mailed, if such address is different from that shown for the offeror.

____

____

____

____

27. OFFEROR'S CERTIFICATION

The foregoing representations, certifications and acknowledgments are submitted in response to RFP No. 1586.

Stanley H. Ward for	February 28, 1985
Signature	Date
James J. Brophy, President	(801) 581-(7236)
Name & Title	Telephone Number

END OF APPENDIX E

Proposal Submitted to the U.S. Geological Survey
in Response to RFP 1586

Earthquake-induced Avalanches along the Wasatch Front, Utah

Earth Science Laboratory
University of Utah Research Institute
391 Chipeta Way, Suite C
Salt Lake City, Utah 84108

Utah 2nd Congressional District

Program Objective: R-1

Cost for First Year: $76,500

Total Requested Amount: $76,500

Proposed Duration: 17 months

Desired Starting Date: August 1, 1985

Principal Investigator(s): Duncan Foley

Earth Science Laboratory
University of Utah Research Institute
391 Chipeta Way, Suite C
Salt Lake City, Utah 84108
(801) 524-3422

Authorized Institutional Representative: Dr. Phillip M. Wright
Technical Vice President
Earth Science Laboratory
University of Utah Research Institute
391 Chipeta Way, Suite C
Salt Lake City, Utah 84108
(801) 524-3422

Principal Investigator:
Duncan Foley

Duncan Foley
Project Manager / Geology
February 27, 1985

Authorized Representative:
Phillip M. Wright

Phillip M Wright
Technical Vice President
February 27, 1985

SUMMARY FOR THE SMITHSONIAN SCIENCE INFORMATION EXCHANGE

Congressional District: Utah 2nd

Project Title: Earthquake-induced Avalanches along the Wasatch Front, Utah

Date Project Started:

Program Objective: Element III. Regional Earthquake Hazards Assessments, Objective R-1: Mapping and synthesis of geologic hazards and establishment of information systems

Principal Investigator(s): Dr. Duncan Foley

Organization and Address: Earth Science Laboratory
University of Utah Research Institute
391 Chipeta Way, Suite C
Salt Lake City, Utah 84108

Estimated cost for current fiscal year: $76,500

States (or foreign countries) to which project pertains: Utah

Key Words (to indicate major emphasis of project): Avalanches, Earthquakes, Snow mechanics, Lifeline destruction, Avalanche path identification

In 200 words or less, give a succinct statement of the project objectives, work plans, and implications of anticipated results for the proposed duration of the project:

The potential for earthquake-induced avalanches along the Wasatch Front of Utah has never been evaluated, despite the high probability of a major earthquake and the often unstable nature of the Utah snowpack. This study has two parts: to assess the mechanical stability of the Wasatch snowpack, and to identify sites where lifelines or other critical facilities are threatened by avalanches. Data on mechanical stability of the snowpack will be useful in modeling trigger mechanisms for shaking-induced release of the snowpack. Sites identified with presently unknown hazards will be important data for emergency planners.

Signature of Principal Investigator: Duncan Foley Date: Feb. 27, 1985

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BUDGET

A. Salaries and Wages:			$25,610
1. Senior Personnel			
D. Foley	85 days		
S. Ferguson	84 days		
2. Support Personnel			
Drafting	10 days		
Secretary	15 days		
B. Employee Benefits: (Note 1)			
1. 40.0%* of Salaries and Wages			10,244
C. Equipment:			None
D. Supplies and Expendable Equipment:			
1. Office Supplies		$250	
2. Laboratory Supplies		250	
3. Computing Supplies		300	
4. Field Supplies (including maps and photos)		500	
Total Supplies and Expendable Equipment			1,300
E. Subcontracts of Consultants:			
1. Dr. Ed LaChapelle ($250/day)			2,500
F. Travel:			
1. Field Work Mileage-2,250 miles (Est. 45 trips @ 50 mi/trip avg.)		$ 675	
2. Technical Meetings (2)		1,380	
Total Travel			2,055
G. Publication Costs:			
1. Technical articles (3) @ $125/page		$2,000	
2. USGS final report		200	
Total Publication Costs			2,200
H. Other Direct Costs:			
1. Airplane flights			500

I. Total Direct Costs:	$44,409
J. Indirect Costs: (Note 1)	
1. 46.0% of "I"	20,428
K. General and Administrative Costs: (Note 1)	
1. 15.0% of "I"	6,661
L. Total Direct, Indirect and G & A Costs:	$71,498
M. Fee:	
1. 7.0% of "L"	5,002
N. Facilities Capital Cost of Money:	None
O. Cost Share:	None
P. Estimated Cost Plus Fixed Fee:	$76,500
Q. Government-Furnished Material or Services:	None

Note 1. See Appendix B for rate agreement.

* Proposal purposes only

TRAVEL SCHEDULE

Destination	Purpose	No. of Trips	No. of People	No. of Man Days	Airfare	Per diem	Auto Rental & Misc.	Total
Mountain Research Sites	Data Collection	45	2	90	--	--	675*	675
Technical Meetings	Present Paper	1	2	6	720	540	120	1,380

*2,250 miles @ $.30/mile

PROPOSED COST SCHEDULE

FY 85-86

$ = 1,000

EARTHQUAKE-INDUCED AVALANCHES ALONG THE WASATCH FRONT, UTAH

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$	$
Monthly	2	4	4	4	4	5	5	5	6	6	6	6	6	6	3	2	2
Cum.	2	6	10	14	18	23	28	33	39	45	51	57	63	69	72	74	76

IDENTIFICATION AND SIGNIFICANCE OF PROJECT

Discussion of Specific Problem

Avalanches have killed more people than any other geologic hazard in Utah (Mandahl, 1983). These deaths have occurred in many canyons of the Wasatch Mountains (Perla, 1972), but unfortunately very little is known about the location and areal extent of these avalanches. Therefore, few data exist that could be of use to emergency planners to evaluate the potential impact of a massive snow avalanche cycle that could be released by a major earthquake near the Wasatch Mountains. The Earth Science Laboratory/University of Utah Research Institute (ESL/UURI), in conjunction with personnel from the U. S. Forest Service, proposes a seventeen month program to evaluate the likely mechanical impact of a major earthquake on snowpacks in the Wasatch Mountains in the Salt Lake City area, and identify critical facilities that may be threatened during a massive avalanche cycle.

Earthquake-induced avalanches have plagued mountainous areas throughout the world. One of the most dramatic examples is the Huascaran avalanche in Peru in 1970, which killed approximately 18,000 people when an offshore earthquake triggered a massive ice and snow avalanche that ran through several villages (Pflaker and Ericksen, 1978). In Alaska in 1964 many large avalanches were triggered by the magnitude 8.6 earthquake. Fifteen-foot fractures within the snowcover were reported, releasing tons of snow onto the valley floors (B. Sandahl, personal communication, 1985). Airplane pilots reported avalanches falling on either sides of valleys, which seemed to coincide with the ground motion (Field, 1966). Earth tremors induced by the volcanic activity of Mt. St. Helens in Washington State have created major avalanche cycles since its initial modern eruption in 1980. Avalanche occurrences on this mountain as well as on other Cascade volcanoes are well documented with visual identification and infrared scans (e.g., Qamar and St. Lawrence, 1983; LaChapelle, 1982). An elaborate array of seismic sensors shows coincident earth tremors (Crossen, personal communication, 1980; 1985) with avalanche activity. In addition, major avalanches are constantly threatening mountain climbers during earthquakes (Lev, 1976).

Although there have been no major earthquakes along the Wasatch Front in Utah since the area was settled in 1847, the likelihood of a major event remains high (Schwartz and Coppersmith, 1984). It is predicted that a Richter magnitude 7.5 event may occur (Rogers and others, 1976). Massive release of snow in such an event is highly likely, but current syntheses of geologic hazards (Mabey, 1985) do not discuss this problem. Kelner (1980) reports historical documentation that small levels of earth shaking, induced by mine blasting at Alta, released avalanches.

The Wasatch Range has a high avalanche hazard, due to both the nature of the snowpack and the high level of day use, permanent housing, and transportation and utility corridors in these mountains. Destructive avalanches occur every winter in the northern Wasatch Mountains, often as early as October and as late as June. At present, personnel affiliated with the Utah Department of Transportation, the U. S. Forest Service, and the many ski areas, each have a role in forecasting and controlling the overall avalanche hazard. Each of these agencies has specific jurisdiction, which has been established through a memorandum of understanding among the individuals. No agency is responsible for compilation of a range-wide hazard synthesis.

Previous research effort in the Wasatch was conducted by the U. S. Forest Service, at the Alta Avalanche Studies Center. This center was active until the early 1970s, and compiled much useful data on the Wasatch snowpack. No central research effort has been conducted since the center was disbanded, and results of studies conducted there are no longer available in any central files.

At present, no modeling of the nature of the Wasatch snowpack (or other mountain snowpacks) has been done to evaluate the likelihood of the large releases that could occur during ground shaking. The mechanical response of snowpacks to shaking is not known. A model for avalanches would need to develop typical snowpack profiles, evaluate conditions for release, and identify conditions of weakness that would lead to release during an earthquake.

No comprehensive map of avalanche paths exists for much of the Wasatch Range. Some mapping has been done in the private sector, notably by ski areas (L. Fitzgerald, personal communication, 1985) and map publishers (Alpentech 1982; Kelner and Hanscom, 1976). An avalanche safety plan was developed by vonAllmen and others (1979) for Little and Big Cottonwood Canyons, which includes some mapped avalanche paths. These maps need updating because they have largely relied on personal accounts by present-day observers. No rigorous effort has ever been made to document avalanche paths within the Wasatch Range into a comprehensive avalanche atlas.

The long-term history of many mapped paths is unknown. Rare, catastrophic events, which punctuate the geologic record of other hazards, have not been documented for avalanches in the Wasatch. Some data may be available from mining camp records and newspaper accounts. Other data may be deduced from tree ring records. It is anticipated that much of the evaluation of catastrophic avalanche events will have to be extrapolated from smaller events in the Wasatch, modeling based on source area accumulation, path morphology, and run-out zone characteristics, and comparison of the Wasatch with catastrophic events during earthquakes in other parts of the world.

The tasks proposed herein will examine the mechanical stability of the snowpack, analyze the likely stability of the snow during an earthquake, and map avalanche paths that threaten lifelines or other critical facilities. The area proposed for study is the Wasatch Front in Salt Lake and Wasatch Counties, as this is the most densely populated and intensively used portion of the mountains.

Mechanical studies will concentrate on the efficiency of ground shaking to trigger release mechanisms for typical Wasatch snowpacks. These will be based on methods for recognizing unstable snowpack structures (Ferguson, 1984) and synthesized with theories of avalanche mechanics (Johnson, 1980; McClung, 1981) and earthquake motion (Hays and King, 1984). Documenting avalanche path characteristics will follow state-of-the-art avalanche atlasing techniques (e.g., LaChapelle and others, 1971; Fitzharris and Owens, 1980). Unpublished maps of avalanche paths in the Wasatch and theoretical models for calculating maximum run-out distances and likely impacts (Mears, 1976) will be used as foundations for identifying and mapping the paths.

Importance of the Problem

Existing studies of damage anticipated from an earthquake in Utah have typically focused on the valley areas (e.g., Rogers and others, 1976). Evaluation of mountain hazards has been confined largely to the important questions of dam stability and landslide potential. No maps are available that depict all of the fault traces in bedrock of the Wasatch range.

Explosive growth in winter use of the Wasatch Range and in permanent housing in the range has led to the development of a great hazard from avalanches. Ski area use in Little Cottonwood Canyon alone has been as great as 12,000 people in one day, with more in the backcountry. Other canyons in the Salt Lake City and Park City areas also receive much use from residents, skiers and other recreationists. Many of these people would be exposed to avalanche hazard, particularly from the major releases that would accompany an earthquake. Rescue after an earthquake would be very complex, due to snow blockage and destruction of roads, destruction of utilities, lack of communication, and unknown location of victims. The present lack of knowledge about the snowpack and likely paths to slide would complicate this problem.

Figure 1 is a map of the Wasatch Range near Salt Lake City. Table 1 lists facilities in each canyon along the Wasatch Front in Salt Lake and adjacent Counties, which could be impacted if a major avalanche cycle were to be triggered. As housing developments in the Salt Lake City and Park City areas have climbed higher on the benches, some of these areas have also become exposed to avalanche danger (B. Sandahl, personal communication, 1985; J. Barnes, S. L. County Planning Office, personal communication, 1985; J. Harrington, Park City Planning Office, personal communication, 1985). Other canyons outside the area covered in this proposal (but candidates for future study) have avalanche hazards as well. Provo Canyon, with major highway and water supply lines, and Weber Canyon, with highway, railroad, and water are just two of these.

Understanding the mechanical stability of the snowpack is important for ongoing prediction and control efforts. The data gathered in this study will provide a useful quantification of important parameters, such as stress states, that are now largely qualitative. The results of this study will be applicable to snowpack stability problems in other seismically active areas.

The techniques used to map the avalanches depicted on existing informal maps are usually limited to personal observation of slides. No comprehensive data base extends back more than 20 years. Unfortunately, major avalanches have been known to destory 50 year old bridges (Martinelli, 1984) and 100 year old trees (Mears, 1976). Only an in-depth review of historical accounts and the application of unbiased theoretical models can predict the occurrence of these catastrophic, low recurrence interval events. This has not been done

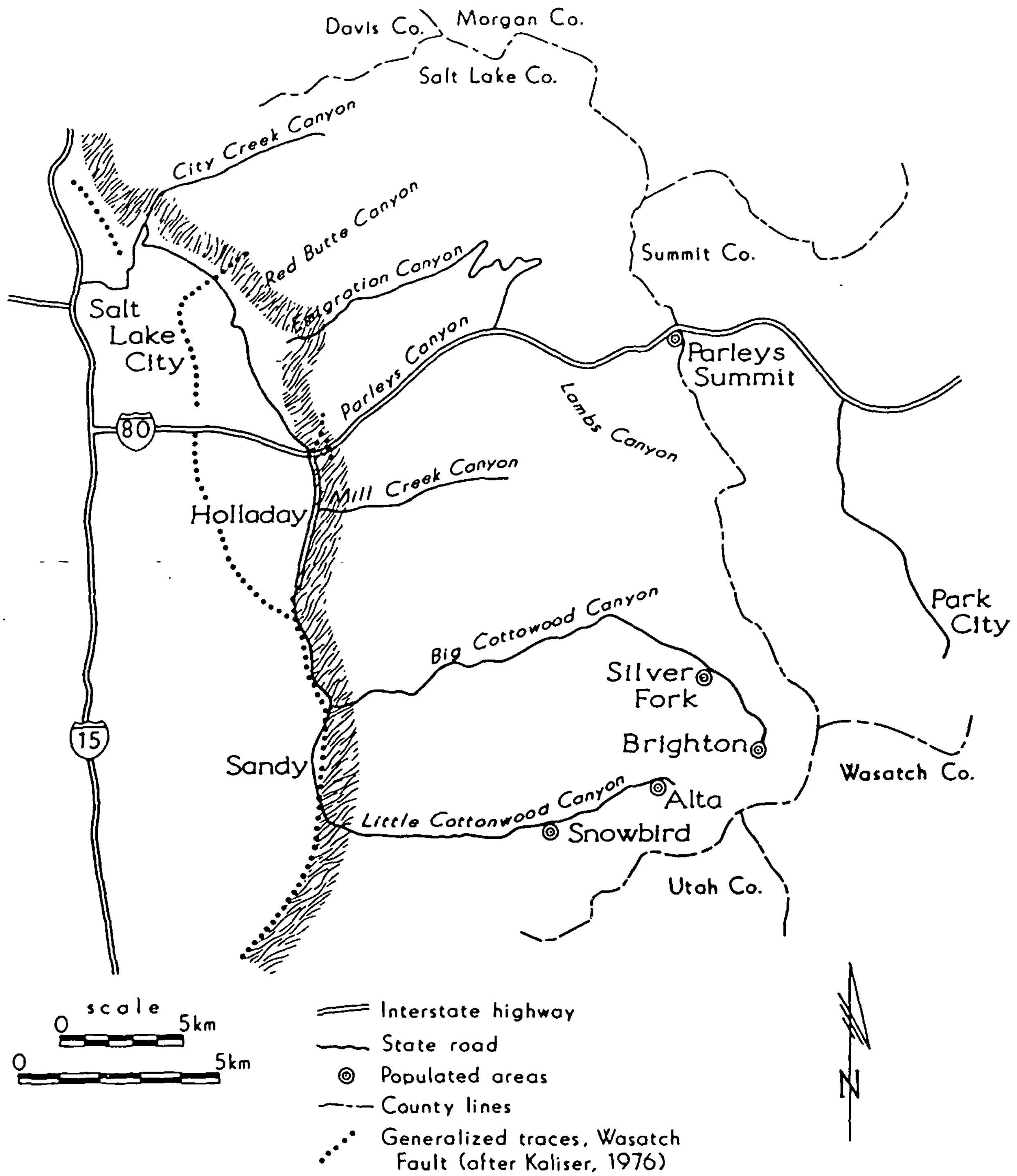

Figure 1. Earthquake-induced avalanches study area.

TABLE 1. THREATENED FACILITIES, EARTHQUAKE-INDUCED AVALANCHES, WASATCH MOUNTAINS, SALT LAKE AND SUMMIT COUNTIES, UTAH

Canyon	Facilities Related to Canyon	Facility Important to Valley Population
Little Cottonwood	Snowbird ski area and housing Alta ski area Alta town Albion Basin housing Highway	Water supply
Big Cottonwood	Housing in Brighton, Silver Fork Highway Brighton ski area Solitude ski area	Water supply
Millcreek	Housing in lower canyon	
Parleys	Housing	I-80 Water supply pipeline and reservoir
Lambs	Housing	
Emigration	Dense housing Highway	Water supply Gas pipeline
Red Butte		Reservoir
City Creek		Water treatment plant
Park City Area	Deer Valley ski area Park City ski area Park West ski area	Housing
Salt Lake Valley Range Front		Dense population - housing and lifelines

Note: all mountain areas have power and phone line service that is likely to be impacted during sliding.

for the Wasatch Mountains.

Table 2 lists the types of threats avalanches pose to each type of facility in the canyons. These threats will have an impact on both canyon residents and those in the valley who depend on canyon services, such as water, for survival.

Contribution to Earthquake Hazards Reduction Program

This proposal is responding to Element III, Objective R-1, which calls for synthesis of data for definition and mapping of ground failure hazards, and research to fill gaps in knowledge. This objective also calls for transmittal of the data to other researchers and policymakers.

No synthesis of the earthquake-induced avalanche hazard along the Wasatch Range has ever been prepared, no basic data exist to determine the likely response of the Utah snowpack to shaking, and emergency planners are not prepared to handle the emergencies that may rise due to extensive canyon blockage by snow during an earthquake (W. Dewsnup, personal communication, 1985). Our proposal addresses these points, as a first stage in developing the knowledge required to respond to an emergency.

This proposal also responds to the action item designated by the Governors Conference on Geologic Hazards (Mandahl, 1983) for more research in avalanches.

PROJECT PLAN

Research Concepts

The fundamental hypothesis we will be examining is that earthquake-induced ground shaking could cause the release of many avalanches, and that the locations and magnitudes of these releases could cause many deaths, destroy much property, and create impediments to rescue. The specific research questions we will examine are:

1. What will the likely impact of ground shaking on the stability of typical Utah snowpacks be?
2. Where are potential problems from the colocation of houses, lifelines, and other critical facilities, with avalanche paths?
3. What will be the magnitude of snow releases?

TABLE 2. NATURE OF AVALANCHE THREAT TO MOUNTAIN FACILITIES

Facility	Threat
Highways	Burial of vehicles and victims Blockage of emergency access Destruction of road
Housing	Destruction of homes Burial of victims Bury access to hotels for rescue
Ski areas	Burial of victims Blockage of access to trapped people (ski lift damage) Difficult rescue - dispersed population
Reservoirs	Slides displace water, causing floods Slides block creeks, create temporary artificial dams Block water intakes
Water lines	Block or break facilities
Gas line	Bury access to possible areas of breakage

4. What will be the run-out distance of avalanches?
5. Will there be an increased frequency of releases?
6. Will there be an increased likelihood for delayed releases?
7. How can these data best be presented to snow scientists, geologists, land-use planners, and emergency personnel?

The conceptual framework of this study will in part be similar to other hazard evaluations, but with recognition of the different nature of the avalanche data base. Similar to the evaluation of other hazards, locations of potential slides, locations of critical facilities, interpretations based on local data, and application and refinement of models developed elsewhere will be made.

A slightly different approach to hazard evaluation will be taken with this study of avalanches, however, since there are so few data available about the mechanical stability of snowpacks. What little data that are available for the Wasatch from the research effort in the 1960's must be combined with qualitative information collected by non-technical observers since then. Because so few current technical data exist and no research-trained personnel are actively studying Wasatch snowpacks at this time, we propose quantitative studies of the snowpack stability as a necessary part of this project.

We will adapt the techniques developed for analysis of avalanche paths in Little and Big Cottonwood Canyons and the backcountry areas. These will be combined with state-of-the-art mapping techniques in other mountainous areas and applied to sites in Wasatch front canyons.

Data Collection and Analysis

Existing Data. No central source of existing data on avalanches in the Wasatch Range exists. Extensive compilation efforts will be required to obtain all relevant data on mechanical stability of the snowpack, avalanche paths, and facility locations.

Mechanical data on snowpack stability in the Wasatch will be available from the files of the Alta Avalanche Studies Center, which existed until the early 1970s, the U. S. Forest Service Forecast Center, the Utah Department of Transportation, and various ski areas. These data may not be quantified in a similar manner, however, so interpretation will be required prior to their integration. Even data from the Alta Center may be widely dispersed. Already some has been located in Canada, Colorado, and New Mexico.

Very little information is available on the mechanical response of snowpack structure to shaking. However, there have been studies on the effect of other trigger mechanisms that may be applicable to the problem of earthquake induced avalanches. For instance, explosions over the snow and below the snow surface as avalanche triggers have been examined (Brown, 1980; Gubler, 1977; Johnson, 1978). The flexural strength of snow slabs has also been investigated in cases where avalanches are assumed to initiate by enhanced bending stresses encountered in a snowpack that has catastrophically lost its basal support (Lang and Brown, 1977). These trigger mechanisms will be compared to the energy provided by ground-shaking events to evaluate an order of magnitude estimate of the expected efficiency of earthquake triggers.

These estimates will be compared with actual seismic data of earth tremors acquired just prior to the Mt. St. Helens volcanic eruption in 1980, which triggered major avalanche cycles. Some of the largest tectonic events ever recorded for that area occurred just prior to the actual eruption (R. Crosson, personal communication, 1985). Avalanche occurrence records are available for that period through the USDA-FS Northwest Avalanche Center and seismic records and earthquake location data are available through the University of Washington Geophysics Program. (Ferguson was employed by both groups at that time and has maintained contact with each program). These data provide the most objective source of information on earthquake induced avalanching currently available.

Other, less quantitative data, on earthquake-induced avalanching and the response of snowpack structure to shaking and dynamic forces will also be compiled and analyzed for their applicability to the proposed problem.

Existing data on avalanche paths will be compiled from many sources. The most reliable data are informal, unpublished maps that exist for the lower highway, Snowbird, and Alta areas of Little Cottonwood Canyon (vonAllmen and others, 1979). These maps have been prepared by the Utah Department of Transportation, Snowbird ski area, Alta ski area, and the town of Alta, and are based on events observed in the past few years (primarily since the 1920s). Other maps, even less formal, exist for Big Cottonwood Canyon, part of Emigration Canyon, and a small portion of the front of the Wasatch Range. We will compile the avalanche information from these maps at a uniform scale and discuss the various techniques used in their generation.

Other existing data on avalanche paths will be compiled from the Alta Avalanche Study Center records, as well as records from other ski areas, the USDA-FS Utah Avalanche Forecasting Center, and from people involved in the production of private maps (Alpentech, 1982). Data from city and county planning agencies will also be compiled, and selected consultants who have performed the work for these government agencies will be contacted to evaluate the applicability of their methodology to our efforts. If appropriate, we will also contact sources such as snowplow drivers, to identify areas that naturally release that may not be widely known. Extrapolation to the 1800s will be accomplished by study of mining camp records and newspaper accounts, as several camps were wiped out by avalanches (Kelner, 1980).

Data on critical lifelines will be compiled from map depictions, conversations with emergency planners, and, where appropriate, conversations with utility companies. Lifelines we will identify will include highways, utilities (electrical, gas, water), potentially impacted reservoirs, and areas with present or proposed housing. The Utah Geological and Mineral Survey is considering internal funding for a compilation of lifelines. We would coordinate with this effort, as far as applicable. Data on population areas will be compiled from county and city planners, and will include land use and land ownership status.

New Data. Existing data on the mechanical stability of the snowpack, and existing path analyses, are not adequate to provide an evaluation of the hazard from earthquake-induced shaking. We will compile new data on both of these topics.

New mechanical data will be gathered from snowpits to develop composite profiles of typical Utah snowpacks. Snowpit data will include shear-frame tests to evaluate the shear strength of buried weak layers and bending-beam tests to estimate the tensile strength of the overlying slab (Perla and Martinelli, 1978; Perla, 1969). Both of these field techniques are familiar to mountain observers in the Wasatch and are proven to be meaningful and consistent (D. Bowles, personal communication, 1985; Rosso, 1982). Therefore, personnel in ski areas and with the Utah Avalanche Forecasting Center may add to the data set without loss of objectivity.

Additional snowpit data will be acquired at the fracture surfaces of actual avalanches. The trigger mechanisms for these avalanches will be documented and the areal extent of avalanching will be recorded. These data will be compared to other snowpit data to better define the unstable snowpack structure. In addition, the style and magnitudes of each trigger mechanism will be compared to the areal extent of subsequent releases to evaluate the efficiency of various triggering sequences. This will provide valuable comparative data with earthquake mechanisms.

To understand and evaluate the potential motion of a magnitude 7.5 earthquake, a brief overview of the geology of avalanche starting zones within the Wasatch Mountains will be necessary. Shear moduli of rock types will be compiled to evaluate the acceleration potential of surface waves. Some distinction between horizontal and vertical wave motions may be necessary, as one would enhance shear failure within the snowcover and the other would enhance failure by collapse of the basal layers. Each mechanism is addressed in current avalanche mechanical theories (McClung, 1981; Lang and Brown, 1977, respectively).

New data on avalanche paths will be based on direct observation during winter, and indirect observation during summer. Winter observations will include at least two plane flights after major avalanche cycles, to allow comprehensive mapping of paths that threaten facilities. The elevation, aspect, areal extent, and slope configuration will be documented for the starting zones, tracks, and run-out zones of each known avalanche path. Total amount of snow available for avalanching will be determined by monthly snow depth measurements within starting zones. A search of climate data will ensure that all possible wind loading patterns are documented. Information on the tracks will be acquired by analysis of terrain features and historical data. The extent of run-out zones will be determined by historical accounts, as well as evidence of vegetation damage and destruction, vegetation changes, lingering snow debris, and slope characteristics (Martinelli, 1974). Avalanche paths are often colocated with landslide areas (Ives and Plam, 1980). The recent increase in landslide activity in Utah (Anderson and others, 1984) may affect local avalanche activity.

Sites suitable for calculation of long-term recurrence intervals through tree-ring chronologic methods (Dexter and Armstrong, 1984) will be identified. Geologic mapping of avalanche paths and run-out zones, in areas where the terrain has not been highly disturbed, may be a possible technique to evaluate long-term recurrence interval events (Potter, 1974; Mears, 1976).

Data Analysis. Threat to facilities will be determined by the run-out distance of various slide paths. Where historical data exist, these can be extrapolated to give likely maximum distance estimates. Where these data do not exist, a simple empirical estimate of maximum run-out distance will be determined, based on path geometry (Lied and Bakkehoi, 1980).

Data on avalanche paths and lifelines will be compiled and presented on 1:24,000 scale maps. The extent of earthquake-induced avalanching will be estimated from the recognized instabilities occurring within starting zones. Unstable snowpack structure will be determined from historical records and newly acquired snowpit data. These will be represented as composite snow profiles for several winter climate patterns found in the Wasatch (e.g., Armstrong, 1982).

Trigger mechanisms will be analyzed from newly acquired snowpack information of actual avalanches. These will be compared to estimates of ground shaking that may occur with a magnitude 7.5 earthquake and actual observations of earthquake-induced avalanching in other mountains. The areal extent of avalanching will be estimated for each composite snow profile.

Threat to facilities will be evaluated, based on analysis of likely avalanche types, run-out distances, preliminary calculations of impact energies, and evaluation of recurrence intervals. The relatively coarse (1:24,000) nature of this preliminary analysis will require further refinement to achieve detailed results for individual paths.

Slab avalanches are the most hazardous type in the Wasatch. Relatively dry powder avalanches and heavier flowing avalanches are both likely. Powder avalanches cause damage from their high speed and long run-out distance; flow avalanches cause damage from their mass (Mears, 1976). Maximum run-out distances have been calculated from maritime climates using relatively straightforward geometrical analysis of the avalanche path (Lied and Bakkehoi, 1980) and from climates more similar to Utah using avalanche path characteristics and avalanche dynamics (Mears, 1976). Both of these models will be applied to the Utah snowpack, and their ease of use and applicability to the Wasatch will be evaluated. Impact energies are difficult to assess, particularly during a regional study. We will calculate, however, where appropriate data can be gathered, and critical facilities are identified, a preliminary estimate of such energies, by generally following the techniques of Mears (1976). Recurrence intervals for newly mapped paths will be estimated by vegetative analysis, evaluation of geologic debris (where preserved), and review of historical records. Sites appropriate for future detailed analysis of tree-ring records will be noted, but these analyses will not be carried out in this proposal.

Analytic techniques and models developed during this study will be applicable to ongoing snow safety efforts in the Wasatch Mountains. The models we develop will be in a format compatible with data handling methods at the Forest Service Forecast Center and the various ski areas.

Continuing Efforts

The largely unstudied nature of the Wasatch snowpack, particularly since the early 1970s, implies that the work proposed herein will form a valuable data set on which further studies may be based.

Two major directions of continued work are suggested. The first is to continue to develop mechanical models of snowpacks under shaking, and the second is to continue to identify critical facilities within avalanche paths in other sections of the Wasatch Range.

Mechanical models of snowpacks under the increased stress of ground shaking will improve through further work. The tasks proposed herein will focus on straightforward tests of stability. More rigorous records of avalanching induced by other external triggers will help delineate the mechanical response of various snowpack structures. The construction of shaking frames, to simulate ground motions, could then be applied to these snowpack structures for more accurate determination of earthquake efficiency in triggering avalanches. These results could be applied to mechanical models that would prove valuable for earthquake and avalanche researchers in other parts of the world.

Mapping proposed herein will focus only on the Salt Lake City segment of the Wasatch Fault. If work in this area suggests that the snow avalanche hazard from earthquake-induced shaking is high, it will be appropriate to continue this effort in other areas of the fault, such as the Provo Canyon-Mt. Timpanogos area and Weber Canyon. This mapping will also be at 1:24,000 scale; this is not adequate for detailed study of individual paths (Mears, 1976). Recurrence intervals of paths, through tree ring analysis, will need to be calculated.

The work proposed herein does not address the possible programs that could be undertaken to remedy avalanche hazards. These programs would become the realm of engineering, political, and planning agencies. Engineering solutions might include the construction of snow retention structures in crucial starting zones, diversion structures, or building reinforcement designs. Planning responses might include programs to zone hazardous lands. Political forces will determine what, if any, ultimate actions will need to be taken. The data gathered in this proposed work will be crucial, however, to the decisions that will need to be made for any hazards identified.

The need for real-time data in crucial snowpack parameters in areas with difficult access is another important factor in study of snowpacks. Although probably not related to any USGS project, ESL/UURI is interested in developing instrumentation to conduct such monitoring, as an outgrowth of our instrumentation development efforts in landslide monitoring.

Objectivity and Evaluation

Objectivity will be assured by internal ESL reviews of the work in progress. Such reviews have proven to be a valuable management tool in assuring quality compliance with contracted tasks. A consultant (Dr. Ed LaChapelle) will be retained to evaluate both the mechanical and mapping portions of this study. Reviews by outside avalanche professionals have also been arranged.

RELATED EFFORTS

The proposed tasks are part of the ongoing efforts of Foley in geologic hazard identification, and Ferguson in snowpack studies. Foley, during the time of this proposal, will continue to teach a class on geologic hazards at the University of Utah, and will be involved in the preparation of additional proposals related to earthquakes, avalanches, and geologic hazards. Ferguson will continue (without time or funding conflict) to be an avalanche forecaster for the U.S. Forest Service. She also will be preparing additional proposals for further snowpack stability studies. Foley is co-principal investigator on another proposal responding to this RFP, to map bedrock traces of the Wasatch Fault. Work on this other proposal will not conflict with efforts proposed herein.

The researchers on this program have extensive experience in avalanche mechanics and the identification of geologic hazards. To insure objectivity, however, regular communications will be maintained with other snow workers in the Wasatch. These will include U. S. Forest Service, Utah Department of Transportation, ski area, helicopter skiing, and backcountry tour personnel. Cooperation with these personnel has already been established.

Relevance to emergency personnel will be determined through conversations with both emergency and land use planners. These conversations will insure that the final product from the mapping phase will be able to meet the needs of the planners. Initial contact has already been established with Salt Lake County, Park City and State of Utah planners.

FINAL REPORT

The final report to the USGS will consist of a technical discussion of the methodologies, data bases, data collection, and interpretations of both the mechanical stability of the snowpack under shaking and the colocations of lifelines, critical facilities, and avalanche paths. This report will be delivered within 90 days of the completion of the contract.

The mechanical study of snowpack stability will be suitable for publication in a technical journal (Journal of Geophysical Research?). The geological aspects of avalanche hazard identification will be prepared for publication in a suitable geological journal (Geological Society of America Bulletin?) A series of maps will be prepared for the use of emergency and land-use planners, depicting both avalanche paths and the locations of lifelines and critical facilities. These maps will be accompanied by a non-technical text, for use by planners, so they may evaluate the maps for their needs.

PERSONNEL AND INSTITUTIONAL QUALIFICATIONS

Two professionals are assigned by ESL/UURI to this program. Dr. Duncan Foley has worked at ESL/UURI for more than seven years, in geological investigation and program management roles. He has emphasized field-oriented studies. Currently, Dr. Foley is teaching a class on geologic hazards at the University of Utah. Dr. Sue Ferguson is an employee of the U. S. Forest Service, where she is heavily involved in backcountry avalanche forecasting. She has a career appointment, with a flexible tour of duty. The work proposed herein for her will not be conducted at the same time as her Forest Service efforts. Some of the data she now collects on snowpacks will be useful on this project, but the compilation, integration, and modeling of the data will be made during the summer months, when she is not forecasting. She is also a research associate at ESL/UURI. Brief resumes for these professionals are found in Appendix A.

Dr. Ed LaChapelle is identified as a consultant in this proposal. Dr. LaChapelle recently retired from teaching geophysics at the University of Washington. He was an active researcher at the Alta Avalanche Studies Center until it was disbanded, has been an avalanche forecaster for the U. S. Forest Service in the Wasatch Mountains, and has participated in land use planning analyses. Dr. LaChapelle presently is a worldwide consultant in snow and avalanches.

The University of Utah Research Institute (UURI) is a self-supporting corporation organized in December 1972 under the Utah Non-Profit Corporation Association Act. Under its charter the Institute is separate in its operations and receives no financial support from either the University of Utah or the State of Utah. The charter includes provisions for UURI to conduct both public and proprietary scientific work for governmental agencies, academic institutions, private industry, and individuals. In this work UURI has a close technical association with the University and is able to draw upon the talents of faculty and students. When such activities are proprietary UURI may be taxed on income as determined by IRS codes.

The Earth Science Laboratory (ESL) is a division of the University of Utah Research Institute (UURI) which provides consulting and contracting services in a broad range of scientific areas that include field programs, data interpretation, research and technique development, geochemical analytical services, custom computer software, development of electronic instrumentation, and training seminars and workshops. ESL emphasizes the integration of scientific disciplines and techniques in solving problems in the earth sciences. An optimum, cost-effective combination of techniques from the fields of geology, geochemistry, geophysics, and hydrology can be applied by in-house experts to solve specific problems.

The ESL professional staff is broad and diversified in education and experience. Even though the main portion of a given project may be done by a few scientists, the expertise of the entire staff can be made available as required, and personnel assigned to a project are free to draw upon the talents of other personnel at ESL.

As a federal contractor, the Earth Science Laboratory has developed financial accounting procedures that assure integrity during the execution of a program. Technical accountability is managed through regular reviews of project progress by higher levels of management within ESL.

Professionals in the Geology Group will be the key pesonnel on this proposal. They have extensive experience in applied research, field studies, and interpretation and integration of results with other disciplines. Many reports in refereed journals, to federal agencies, and to private sector companies have been prepared by the Group. These personnel have also been heavily involved in technology transfer, through both public workshops and seminars, and workshops for private industry explorationists. Geology Group members have extensive experience in project management, and have the ability to deliver high quality technical products on time and within budget.

ESL geologists recognize that geologic studies form only a portion of the overall program required to adequately characterize the geologic environment. They therefore have developed expertise in the integration of geologic data with geochemical studies and geophysical surveys, through working with other professionals. These studies have led to integrated reports that have been well received in both the public and private sectors.

The ESL/UURI library is specifically targeted toward geoscience. Personnel at ESL have full privileges in the library system of the University of Utah, and are familiar with the holdings of the Utah Geological and Mineral

Survey. Nationwide resources are available through interlibrary loan, and USGS resources are available through the Salt Lake City Public Information Office.

ESL/UURI support personnel have the facilities and experience to support the publication and drafting needs of the technical staff. These staffers are familiar with the requirements of producing high quality technical documents.

PROJECT MANAGEMENT PLAN

Dr. Foley will be project manager and will coordinate geological aspects of the investigation. He will also be in charge of coordination with planning agencies and the preparation of planning documents at the conclusion of the project. Dr. Ferguson will be in charge of mechanical studies of snowpacks and will coordinate efforts with other professionals in the field. Upper level management of ESL/UURI would oversee the work on the proposal.

Foley will spend approximately 30% of his time on data compilation, 15% on field studies of snowpacks, 40% on field studies of avalanche paths, and 15% on meetings with planners, project management, and report preparation. Ferguson will spend approximately 45% of her time doing studies of snow mechanics, 20% doing data compilation, 10% doing path identification, and 20% on meetings and reports.

Figure 2 is an outline of the project schedule. The work is proposed for 17 months, with a desired start date of August 1, 1985. Although this start date is prior to the suggested date in the RFP, it is preferred to allow the literature, historical record, and lifeline and critical facility data compilation and field preparation tasks to be completed prior to the first major snowfall. Late summer-early fall data compilation will also allow selection of optimum sites for study, where the impacts of avalanches on lifelines is likely to be greatest. If an October start is required by USGS funding, it will mean that the compilation and preparation phases will overlap the field work, and therefore will not be accomplished in as short a time as presently proposed. Winter studies will emphasize mechanical analysis of the snowpack, and identification of paths that slide. Field work in the following summer will refine path analysis, evaluate mechanical and path models, and allow time for preparation of reports.

FIGURE 2

PROPOSED SCHEDULE

EARTHQUAKE-INDUCED AVALANCHES ALONG THE WASATCH FRONT, UTAH

	1985					1986											
Task	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Program Management	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Literature Survey	——	——	——														
Compile historical records, existing maps	——	——	——														
Field work preparation		——	——														
Snow mechanics study																	
identify snowpack structures				——	——	——	——	——	——	- -	- -	- -					
develop composite profiles				——	——	——	——	——	——	- -	- -	- -					
develop models for snow release;		——	——	- -	- -												
refine, integrate results										——	——	——	——	——			
Path Identification																	
compile lifeline and facility data	——	——	——														
map paths; photos, active slides				——	——	——	——	——	- -	- -	- -						
calculate run-out and impact data						- -	- -	- -	- -	- -	——	——	- -	- -			
geologic mapping											——	——	- -	- -			
Reports																	
management				Δ		Δ			Δ			Δ			Δ		
project summary						Δ						Δ					
technical reports												Δ					
final report																	Δ
technical articles																	Δ
meeting abstracts															Δ		Δ
planners data																	Δ

Progress reports will be presented to the USGS on a quarterly basis, with a summary semi-annually. A comprehensive final report will be delivered to the Survey. Technical reports will be presented to the geological, snow science, and planning communities. The proposed cost schedule is shown on page vii.

OTHER SUPPORT AND APPLICATIONS

Work on this proposal would not interfere with the other tasks of either of the researchers. Foley has been involved in the preparation of another proposal in response to this RFP. His tasks on both proposals are complementary and adequate time exists during the summer season for him to accomplish both. He has been supported in the past by Department of Energy and private sector work; it is anticipated that this effort will continue, but at an unknown level, on these projects.

Ferguson's work with the U.S. Forest Service Utah Avalanche Forecast Center is directly compatible with the proposed work herein. Collecting information on avalanche paths, snowpack structures, and avalanche occurrences will aid the operational program of the forecasting center through the winter. In addition, observers for the forecasting program may be used to collect the more specific information needed for this proposed project with no conflict of interest, thereby substantially increasing the data base. A network of mountain observers is well established through the forecast center's computer and telephone system. This will make collecting and processing the incoming data efficient and operationally useful. The forecasting season typically lasts for six months through the winter, leaving the summer months to concentrate on related projects and data analysis.

This proposal is part of an ongoing effort of UURI in environmental studies. It is anticipated that further avalanche proposals will be submitted to such agencies as the Utah Department of Transportation, the National Science Foundation, and the Army Research Office (particularly with the re-establishment of the U. S. Army 10th mountain division).

GOVERNMENT PROPERTY

Primarily low-cost field items are required for this study. Prior permission will be obtained should any U. S. Forest Service equipment be used by Dr. Ferguson.

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Appendix A

Resumes

RESUME

Sue A. Ferguson

POSITION: Avalanche Forecaster, Project Leader, Utah Avalanche Forecasting Center

EDUCATION: B. S., Physics, 1976, University of Massachusetts/Amherst; Ph.D., Geophysics, 1984, University of Washington, Seattle, Washington; emphasis on avalanche mechanics and data analysis.

PROFESSIONAL AFFILIATIONS:
American Geophysical Union
American Association for the Advancement of Science
International Glaciological Society
National Field Hockey Association
Women Business Owners

COURSES AND WORKSHOPS:
1981, USDA-FS National Avalanche School, Reno, Nevada
1978, Northwest Avalanche School, Longmire, Washington

PROFESSIONAL EXPERIENCE:

1985-present	Research Associate, Earth Science Laboratory/University of Utah Research Institute
1985-present	Guest Lecturer, Avalanche Mechanics, University of Utah and Utah State Univesity
1984-present	Avalanche Forecaster, Project Leader, Utah Avalanche Forecasting Center
1983-present	National Avalanche School instructor.
1982-present	Founder and Owner of The Avalanche Review, a monthly publication for avalanche professionals
1981-present	Alaska Avalanche Workshop instructor.
1981-1983	University of Washington research associate; project supported by Alaska Council on Science and Technology to investigate snowpack features in Alaska and Washington; develop quantitative collection, transmission, and analysis routines for snowpack structure; devise objective methods of stability analysis; mathematically define the mechanical state of unstable snow.
1981	USDA-FS Avalanche Center Meteorological Technician - Avalanche Forecaster; forecasted mountain weather and avalanche hazard in South Central Alaskan mountains for public and agency dissemination; coordinated field observations with forecast center; instituted data transmission and data storage systems.

1980-83	Supported by NSF to conduct snowpack investigations in New Zealand South Alps and Washington Cascades; data analysis and snow research performed in cooperation with Dr. Walter Good at the Swiss Federal Institute for Snow and Avalanche Research in Davos, Switzerland, Feb.-Mar., 1983.
1979-80	USDA-FS Avalanche Center Meterological Technician; recorded daily snow and weather observations; helped distribute mountain weather and avalanche forecasts, avalanche advisories, and avalanche bulletins over state and federal circuits; weekly excursion to the Cascades to gather snowpack information and relay to forecast center.
1976-1980	University of Washington research assistant, part-time; recorded and analyzed seismic records. Shift Manager for monitoring erupting Mt. St. Helens.
1979	Supported by the University of Washington W. W. Stout award and the American Alpine Club to conduct snowpack investigations in New Zealand's South Alps; cooperated with the University of Canterbury, University of Otago and Mt. Cook National Park to test field equipment and discuss hazard assessment programs for the South Alps.
1977-79	University of Washington research associate; supported by Washington State Transportation Research Project to investigate snowpack structure and evaluate stability.
1977	University of Alaska research assistant; operated magnetometer to locate buried magnetics for velocity and mass balance determination of the Variegated Glacier.
1976	University of Massachusetts research assistant; collected oriented field samples for paleomagnetic survey.
1971-73	University of Oregon Alpine and Nordic Ski Team
1969-71	National Ski Patrol, Mt. Pilchuck, Washington

PAPERS AND PUBLICATIONS:

"The Role of Snowpack Structure in Avalanching", Ferguson, S. A., Univ. of Washington Ph.D. Dissertation (1984).

"Incorporating Snowpack Structure in Regional Avalanche Hazard Forecasting", Ferguson, S. A., Interim Report, ACST #NH-3-80 (1982).

"Computer Systems for Snowpack Stratigraphy", Ferguson, S. A., Montana State University, Bozeman, Montana, International Snow Science Workshop (1982).

"Interpreting Snowpack Structure", Ferguson, S. A., NRC Associate Committee on Geotechnical Research, Technical Memorandum No. 133, pp. 62-65 (1981).

"Snow Pack Structure: Stability Analyzed by Pattern Recognition Techniques", LaChapelle, E. R., and S. A. Ferguson, Journal of Glaciology, v. 26, no. 94, pp. 506-511 (1980).

"Central Avalanche Hazard Forecasting", LaChapelle, E. R., S. A. Ferguson, R. T. Marriott, M. B. Moore, F. W. Reanier, E. M. Sackett, and P. L. Taylor, Washington State Highway Department Implementation Report, Research Project Y-1700 Phase 3 (1978).

"Magnetic Markers for Glacier Mass Balance and Velocity Measurements", Harrison, W. D., Peter MacKeith, and S. A. Ferguson, Geophysical Institute, University of Alaska, Report UAG R-254 (1978).

RESUME

Duncan Foley

POSITION: Geologist, Project Manager, Earth Science Laboratory, University of Utah Research Institute, Salt Lake City, Utah

EDUCATION:
B.A., Geology, 1971, Antioch College, Yellow Springs, Ohio
M.Sc., Geology, 1973, Ohio State University; emphasis on environmental geology
Ph.D., Geology, 1978, Ohio State University; emphasis on volcanic geology

PROFESSIONAL AFFILIATIONS:

1982,	American Association of Petroleum Geologists
1980,	Utah Geological Association (Secretary, 1981-1982)
1979,	American Geophysical Union
1978,	Geothermal Resources Council (President, Basin and Range Section, 1980-1982)
1976,	Society of Sigma-Xi
1972,	Geological Society of America

PROFESSIONAL EXPERIENCE:

1/84-present	Division of Continuing Education, University of Utah. Teaching "Geology and the Environment" which focuses on identification of and strategies for coping with geologic hazards (earthquakes, landslides, avalanche, floods) and geologic aspects of toxic and nuclear waste disposal.
6/79-present	Geologist, Project Manager, Earth Science Laboratory, University of Utah Research Institute, Salt Lake City, Utah. Management and technical duties on Federal and private sector projects. Program Manager for U.S. Department of Energy funded low- and moderate-temperature goethermal resource assessment programs in 16 western states, including coordination with U.S. Geological Survey resource assessment programs. Served as technical advisor to DOE, and directed production of geothermal resource maps. Technical tasks include geologic mapping, studies of geothermal systems in Utah, Idaho and Texas (including drilling a deep well); evaluation of exploration techniques in different geologic environments, and assessment of geothermal resource potential at federal facilities and wilderness areas.
1979-present	Instructor, Yellowstone Institute, for "Calderas and Hydrothermal Systems," a week long lecture and field course that emphasizes interpretation of ash-flow tuff stratigraphy, caldera evolution, and the geological nature of hydrothermal systems in calderas; taught in Yellowstone National Park.
1/78-6/79	Associate Geologist, Earth Science Laboratory. Assisted in management of U. S. Department of Energy funded program of low-temperature geothermal resource assessment in western U. S. Environmental geologist for overview of southern Utah Known

	Geothermal Resource Areas.
9/73-1/78	Research and Teaching Associate, Department of Geology and Mineralogy, Ohio State University. Teaching and research in volcanology, environmental studies, K-ar geochronology, field geology in central Utah, stratigraphy, and strip mine reclamation.
6/71-9/71	Field Assistant, U. S. Geological Survey, Western Mineral Resources Branch, Menlo Park, California. Geologic mapping near Goldfield, Nevada, with emphasis on volcanic stratigraphy.
4/69-8/69	Physical Science Aide, U. S. Geological Survey, Pacific Mineral Resources Branch, Menlo Park, California. Mineral separations lab; geochemical sampling of alteration assemblages and detailed geologic mine mapping in Goldfield and Silver Peak, Nevada.

PROFESSIONAL ACTIVITIES:

Presented talks on geologic parameters of geothermal energy to American Association for the Advancement of Science (1980), Industrial Development Research Council (1980), National Rural Electric Cooperative Association (1980), National Water Well Association (1979), U. S. Department of Energy Contractors (1978, 1979, 1980), Intermountain Institute of Food Technologists (1982), and Snake River Section of American Institute of Mining Engineers (twice in 1982). Talks on environmental geology to local groups in Salt Lake City (1984).

Coleader of Geothermal Systems of the Yellowstone Caldera field trip, Geothermal Resources Council (1980); leader of Wyoming Geological Association field trip to hydrothermal systems of northern Yellowstone National Park (1982); leader of field trip for Audubon Society on environmental geology of the Wasatch Front.

Courses and workshops attended: International Snow Science Workshop (1984); Delineation of landslide, flash flood and debris flow hazards in Utah (1984); Governors Conference on Geologic Hazards, avalanche work group (1983); Backcountry Avalanche Seminar (1982); Geothermal energy in the Cascades (1981); Geochemical fundamentals for geothermal exploration and reservoir evaluation (1980); Fission-track age dating (1979), "Direct Utilization of Geothermal Energy: Development of Four Educational Reports" (1979), Geothermal Geology of Yellowstone (1978); Volcanic rocks and their vent areas (1978); Direct utilization of geothermal energy (1978).

RELEVANT PUBLICATIONS:

"Environmental geology and land-use planning on the Big Darby Creek, Ohio, watershed," Foley, D., unpub. M.Sc. thesis, Ohio State University (1973).

"Geology and Land-Use Planning on the Big Darby Creek, Ohio, Watershed," Foley, D. and McKenzie, G. D., Geol. Soc. of Am., Abstracts with Programs, 6, No. 6, 508 (1974).

"The geology of the Stonewall Mountain Volcanic Center, Nye County, Nevada," Foley, D. and Sutter, J. F., Geol. Soc. of Am., Abstracts with Programs, *10*, No. 3, 105 (1978).

"The Essence of Urban Environmental Geology," McKenzie, G. D., Utgard, R. O., Foley, D. and McKenzie, D. I., Journal of Geological Education, *26*, 32-37 (1978).

"Geology in the Urban Environment," Utgard, R. O., McKenzie, G. D. and Foley, D., eds., Burgess Pub. Co., Minneapolis, Minn., 355 p. (1978).

"Geology Effects," *Environmental Overview Report on Utah Geothermal Resource Areas*, Foley, D., *in* White, K. L., Hill, A. C. and Ursenbach, W. O., eds., Lawrence Livermore Lab UCRL-13955, *1*, 6.1-6.13 (1978).

"Low-temperature Geothermal Resources in the Central and Eastern United States," Sorey, M. L., Reed, M. J., Foley, D., Renner, J. L., *in* Reed, M. J., ed., Assessment of low-temperature geothermal resources of the United States-1981: U. S. Geological Survey Circular 892, p. 51-65 (1983).

Appendix B

Rate Agreement

RATE AGREEMENT
NONPROFIT ORGANIZATIONS

ORGANIZATION:
University of Utah
Research Institute
Suite 100
420 Chipeta Way
Salt Lake City, Utah 84108

DATE: September 11, 1984

FILING REF.: The preceding Agreement was dated July 7, 1983

The rates approved in this Agreement are for use on grants, contracts and other agreements with the Federal Government, subject to the conditions in Section II.

SECTION I: RATES

Type	Effective Period From	To	Rate	Locations	Applicable To
INDIRECT COST RATES*					
Final	10/1/82	9/30/83	14.0%	All (2)	General and Administrative Rate
Final	10/1/82	9/30/83	85.5%	All (2)	Utah Biomedical Test Lab
Final	10/1/82	9/30/83	45.0%	On-Site (2)	Applied Technology Division
Final	10/1/82	9/30/83	24.0%	Off-Site (2)	Applied Technology Division
Provisional	10/1/83	9/30/84	13.5%	All (2)	General and Administrative Rate
Provisional	10/1/83	9/30/84	85.0%	All (2)	Utah Biomedical Test Lab
Provisional	10/1/83	9/30/84	43.0%	On-Site (2)	Applied Technology Division
Provisional	10/1/83	9/30/84	28.0%	Off-Site (2)	Applied Technology Division
Fixed	10/1/83	9/30/84	41.0%	All (3)	Fringe Benefit Rate Salaried Employees
Fixed	10/1/83	9/30/84	9.5%	All (3)	Fringe Benefit Rate Hourly Employees

SECTION I CONTINUED ON ATTACHED ADDENDUM.

SECTION II: GENERAL

A. LIMITATIONS: The rates in this Agreement are subject to any statutory or administrative limitations and apply to a given grant, contract or other agreement only to the extent that funds are available. Acceptance of the rates is subject to the following conditions: (1) Only costs incurred by the organization were included in its indirect cost pool as finally accepted; such costs are legal obligations of the organization and are allowable under the governing cost principles; (2) The same costs that have been treated as indirect costs are not claimed as direct costs; (3) Similar types of costs have been accorded consistent accounting treatment; and (4) The information provided by the organization which was used to establish the rates is not later found to be materially incomplete or inaccurate.

B. ACCOUNTING CHANGES: If a fixed or predetermined rate is in this Agreement, it is based on the accounting system purported by the organization to be in effect during the Agreement period. Changes to the method of accounting for costs which affect the amount of reimbursement resulting from the use of this Agreement require prior approval of the authorized representative of the cognizant agency. Such changes include, but are not limited to, changes in the charging of a particular type of cost from indirect to direct. Failure to obtain approval may result in cost disallowances.

C. FIXED RATES: If a fixed rate is in this Agreement, it is based on an estimate of the costs for the period covered by the rate. When the actual costs for this period are determined, an adjustment will be made to a rate of a future year(s) to compensate for the diference between the costs used to establish the fixed rate and actual costs.

D. USE BY OTHER FEDERAL AGENCIES: The rates in this Agreement were approved in accordance with the authority in Office of Management and Budget Circular A-122, and should be applied to grants, contracts and other agreements covered by this Circular, subject to any limitations in A above. The organization may provide copies of this Agreement to other Federal Agencies to give them early notification of this Agreement.

ORGANIZATION: University of Utah Research Institute

AGREEMENT: September 11, 1984

E. SPECIAL REMARKS: NONE.

BY THE ORGANIZATION:

(ORGANIZATION)

(Signature)

(Name)

(Title)

(Date)

BY THE COGNIZANT AGENCY
ON BEHALF OF THE FEDERAL GOVERNMENT:

DEPARTMENT OF HEALTH AND HUMAN SERVICES
(Agency)

(Signature)

Henry J. Bomba
(Name)

Director
Division of Cost Allocation/RASC
(Title)

September 11, 1984
(Date)

HHS Representative: Frank T. McKune

Telephone: (303)844-5566

ADDENDUM TO RATE AGREEMENT
NONPROFIT INSTITUTIONS

September 11, 1984
Agreement Reference Date

University of Utah Research Institute
Organization

Suite 100, 420 Chipeta Way
Address

Salt Lake City, Utah 84108

SECTION I: (Cont'd)

Type	Effective Period From	To	Rate	Locations		Applicable To
Provisional	10/1/84	9/30/85	45.0%	All	(1)	Applied Technology Division
Provisional	10/1/84	9/30/85	14.5%	All	(1)	General and Administrative Rate
Fixed	10/1/84	9/30/85	39.0%	All	(3)	Fringe Benefit Rate Salaried Employees
Fixed	10/1/84	9/30/85	9.5%	All	(3)	Fringe Benefit Rate Hourly Employees

* Base: (1) Total direct costs less individual items of equipment in excess of $1,000, subcontracts and subgrants in excess of the first $25,000 for each award, and alterations and renovations.

(2) Total direct costs less individual items of equipment in excess of $1,000, subcontracts and subgrants in excess of $5,000, and alterations and renovations.

(3) Direct salaries and wages excluding fringe benefits.

Treatment of fringe benefits: This organization uses a fringe benefit rate for both budgeting and charging purposes. The following fringe benefits are included in the fringe benefit rate for salaried employees:

SECTION I: *(Cont'd)*

1. FICA
2. State Unemployment Insurance
3. Health and Disability Insurance
4. Retirement - State and TIAA/CREF
5. Workmen's Compensation Insurance
6. Vacation Pay
7. Holiday Pay
8. Sick leave and other paid absences
9. Life and Accident Insurance

The following fringe benefits are included in the fringe benefit rate for hourly employees:

1. FICA
2. Workmen's Compensation Insurance
3. Unemployment Insurance

[Companion NSF proposal]

→ Mike

McCarter - 8603

LANDSLIDE MONITORING, PREDICTION AN

A Proposal

to

~~State of Utah~~
~~Division of Comprehensive Emergency Management~~
~~Department of Public Safety~~

by

University of Utah Research Institute
Earth Science Laboratory
391 Chipeta Way, Suite C
Salt Lake City, UT 84108

FUNDS REQUESTED: $465,265

DURATION: 2 Yrs. - Initial R&D Phase

Policy and Evaluations Division
Federal Emergency Management Agency
500 C Street SW
Washington, D.C. 20472

15 December 1984

CONTENTS

LIST OF FIGURES

EXECUTIVE SUMMARY

During the past two years, landslide hazards in Utah have received national attention. The Utah Division of Comprehensive Emergency Management (CEM) has estimated that the Thistle landslide of 1983 caused more than $200 million in damage. Although other landslides have not been of such magnitude, they have caused many problems. This is particularly true along the highly populated Wasatch Front, where damage in Farmington during 1983 and 1984 has been estimated to be more than $1 million, and along the Wasatch Plateau in central Utah.

Geologic studies show that landslides have been a common phenomenon in Utah for many thousands of years, and it is apparent that they will continue to occur in the future. Even though no comprehensive assessment of the landslide hazard has been made for Utah, more than a hundred potentially hazardous slide areas are known, and many hundreds of partially detached slide blocks exist. Sliding seems to occur more frequently during years of high precipitation, but significant landslides also occur in relatively dry years, as exemplified by the Manti slide during the mid-1970s. With mounting population, especially along the Wasatch Front where slide potential is great, we can only conclude that landslides will cause increasing damage in the future unless steps are taken to mitigate the problem. Consequently, CEM has requested studies to assess landslide hazards in Utah and to develop means to cope with these hazards. This proposal is in response to that request.

It is clear that present technology is not sufficiently advanced to identify, monitor, predict and mitigate hazards arising from mass earth movement. Under what conditions will a landslide occur? How can one tell if a potential slide area is stable? Are there precursor indications, useful for timely prediction that sliding is imminent? What quantities should be measured to predict sliding? How much damage will be caused if a slide actually occurs? How can hazards to life, property and commerce from slides be mitigated? The first step in determining answers to these questions is to begin to gather field data on landslides, especially just before, during and after movement. These data would be immediately useful to state and local agencies charged with dealing with slide hazards, and are necessary to geoscientists and engineers in trying to develop methods to monitor, predict and mitigate slide hazards.

In November, 1983, a team of scientists from the University of Utah (UU), CEM, and the Utah Geological and Mineral Survey (UGMS), ~~and~~ the University of Utah Research Institute (UURI) installed experimental instruments in Rudd Canyon east of Farmington and in Reynolds Gulch in Big Cottonwood Canyon to monitor earth movement. The equipment operated successfully throughout the winter and during spring snowmelt and detected small movements that proved to be precursors to much larger debris flows in both areas.

With this highly successful feasibility effort concluded, the University of Utah Research Institute, along with the Departments of Mining and Civil Engineering of the University of Utah, propose a more detailed program of instrumentation, remote monitoring, and engineering studies on selected high-risk landslide areas of Utah. At least two known slide sites will be instrumented and studied before the 1984-85 slide season, and four additional sites will be studied during the 1985-86 slide season. Data on earth movement will be provided to CEM for dissemination to state and local personnel on a real-time basis for use in dealing with potential emergencies, and these data will also be used by UURI and UU to further our understanding of ways to monitor, predict and mitigate mass earth movement.

Work under this proposal will be carried out over the next two years. It will be imperative to receive funding as quickly as possible in order to allow adequate time for construction and deployment of the instrumentation before snowfall later this year. Any instruments left undeployed this fall will not be in place before the 1985-86 slide season.

The products of this study will be (1) the development, installation and operation of 6 slide monitoring systems with data being provided to CEM, (2) geoscientific and engineering studies aimed at better understanding of processes of mass earth movement and of prediction and mitigation measures, and (3) recommendations for a system to monitor slides that is simple, reliable and inexpensive enough to be deployed on a wide basis and operated by local personnel.

The tasks outlined in this proposal form the first phase of a two-phase, five-year comprehensive program to develop landslide monitoring, prediction and mitigation techniques. A phased approach is indicated because of the many scientific and engineering unknowns at the present time. At the conclusion of the five-year program, it is anticipated that we will have a comprehensive understanding of the geological nature of slides, optimized design of slide monitoring, telemetry, and data handling equipment and mitigation techniques that will permit CEM and other state and local entities to identify, monitor and correct mass earth movement hazards before they occur. In order to support the full five-year program, we will seek federal funds to supplement those that may be provided by CEM.

During the course of the program, we intend to work closely and cooperatively with CEM, the UGMS, the U.S. Geological Survey (USGS) and other state and local entities as appropriate. It is our understanding that the work proposed herein does not overlap the charter of the UGSM, which does not have the engineering research and technology development mandate that this project will require.

Results of the work carried out under this proposal will benefit both state and local emergency management personnel in Utah. The understanding of and ability to respond to emergencies from landslides will be greatly increased. The development of a monitoring system, and the results of the geoscience and engineering studies, may also be applicable to monitoring of earthfill dams, several of which have failed in Utah in the past few years, and to the study of avalanches, which have caused more loss of life than any other geologic hazard in Utah.

INTRODUCTION

Landslides constitute only one of the several damaging natural, geologic hazards that have significant potential for occurrence in Utah. Among the other hazards are earthquakes, floods, rising and falling lake and groundwater levels, surface collapse over excavations and volcanic eruptions. To the present time, relatively little has been done to assess, predict or find methods to mitigate the potentially disasterous effects of any of these hazards. Actual occurrences of one of the above events can be relatively infrequent, being governed by the time scale of nature rather than of man, and so the public becomes lulled into a false sense of security that such events will not happen. Yet the geologic record is clear--such events as earthquakes, large landslides, floods, rising lake levels and volcanic eruption have taken place in Utah in the recent past and, without doubt, will take place in the future. To ignore development of means to cope with these events is to invite disaster in terms of loss of life, property or commerce.

Landslides have caused significant disruption in communities and commerce in Utah during the past decade, and have made national news. Although the public has been more aware of landslide hazards during this time, the effects of mass earth movement have been evident in Utah since early geological studies. The present wet climatic cycle has aggravated the landslide problem, but major movements, such as the Manti Canyon slide during the mid-1970s, have occurred during relatively dry years. Expansion of urbanization into range-front slope, alluvial fan and canyon areas has placed increasingly more people at peril from these geologic hazards.

Nature of Landslides

Landslides have always been viewed with a mixture of fascination and respect. Together with earthquakes and volcanoes, they represent one of the few natural geologic events with the speed and power to affect the course of man.

Landslides are usually defined as perceptible downward sliding or falling of a relatively dry mass of earth, rock or a mixture of the two. By contrast, debris flows are a general designation for all types of rapid flowage involving debris of various kinds and conditions (American Geological Institute, 1976). In some contexts, debris flow has been the term used for water saturated, or at least water lubricated, flows. We will use both terms in this proposal. Landslides result from unbalanced mechanical forces. These forces are the weight of the material in the slide, which is tending to move the mass downslope, and the internal resistance of the soil or rock, which is tending to oppose that motion. Landslides occur when the weight increases or when the internal resistance (strength) of the soil or rock decreases. Infiltration of water into soils both increases the weight and decreases the soil strength.

For a geotechnical engineer, a large landslide is simply the extreme event in the spectrum of slope stability hazards that he must consider in engineering design. More often he is concerned with the analysis of much smaller man-made slopes in such projects as highway cuts, earth dams, or open pit mines. The physical concepts and failure mechanisms that underlie slope stability analysis hold on both natural slopes and man-made slopes (Terzaghi, 1950; Zaruba and Mencl, 1969; Freeze and Cherry, 1979). They are equally valid for large potentially catastrophic landslides and for simple embankment slipouts. The influence of groundwater conditions is significant in most cases, and there are significant differences between the analysis of soil slopes and the analysis of slopes in rock.

The hydrologic response of a hillslope to water infiltration from snowmelt or rainfall involves a complex, transient, saturated-unsaturated interaction that usually leads to a water-table rise, albeit one that may be very difficult to predict. The amount of rise, the duration of the rise, and the time lag between the infiltration event and the resulting rise may vary widely depending on the hillslope configuration, the precipitation duration and intensity, the initial moisture conditions, and the saturated and unsaturated hydrogeologic properties of the hillslope materials. It is a very common observation (Terzaghi, 1950) that slope failures occur during the wet season, or following major rainfall or snowmelt events. The triggering mechanism of such failures is the increase in pore pressures along potential failure planes.

Landslides in Utah

Early studies on the geology of Utah identified many areas of landslide activity (Goode, 1970; Schroder, 1971). No geologic province of the state is free from slide activity. Low population density in the early history of the state meant that hazards from any particular landslide event were limited. The population of the state has increased, however, and people are living more and more in areas of high landslide hazard. There has been a resultant increase in damage from and awareness of landslide activity. In particular, the Thistle slide in 1983, and the Farmington debris flow in 1983 created great public awareness of the problem. Damage from landslides in 1983 and 1984 has been estimated to be hundreds of millions of dollars. Two governor's conferences on geological hazards and one speciality conference have noted some of the problems of landslides (Goode, 1970; Atwood and Mabey, 1983).

High hazards from landslides exist in many parts of the state, but the hazard is particularly acute along the highly populated area of the Wasatch Front. Hazards presently exist in the form of many partially detached landslide starting zones (Wieczorek et al., 1983) that represent areas of high potential for catastrophic sliding. Continued wet years would be expected to cause some of these incipient landslides to move, and a moderate to strong earthquake could trigger sudden sliding in many areas.

The increase in hazards from mass movements implies that at least two areas of study are needed: development of simple and inexpensive monitoring systems, and geoscientific and engineering studies aimed at predicting movement in advance and mitigating its effects. The work proposed herein is directed toward these goals.

Rudd Canyon and Reynolds Gulch -- 1983-84 Monitoring

Two potential slide areas were instrumented during the fall of 1983--Rudd Canyon near Farmington in Davis County and Reynolds Gulch in Big Cottonwood Canyon, Salt Lake County (figure 1). Experimental equipment designed by UU and UURI specifically for this monitoring was used. The purpose of this effort was to determine if year-around monitoring was possible under the severe climatic conditions of snow pack, potential snow slides, animal activity and other problems present in high mountain terrain. In addition, the data were to be analyzed for any patterns which might be useful in predicting onset of sliding. Even though the monitoring systems were acknowledged as experimental, all systems were designed to provide maximum reliability in an effort to produce a first-generation warning system. Actual performance demonstrated that (1) year-around monitoring is feasible, (2) consistent earth movement patterns do exist, (3) precursory events ~~were~~ could be detected prior to landslide activity in both areas and (4) development of reliable warning systems appears to be a distinct possibility.

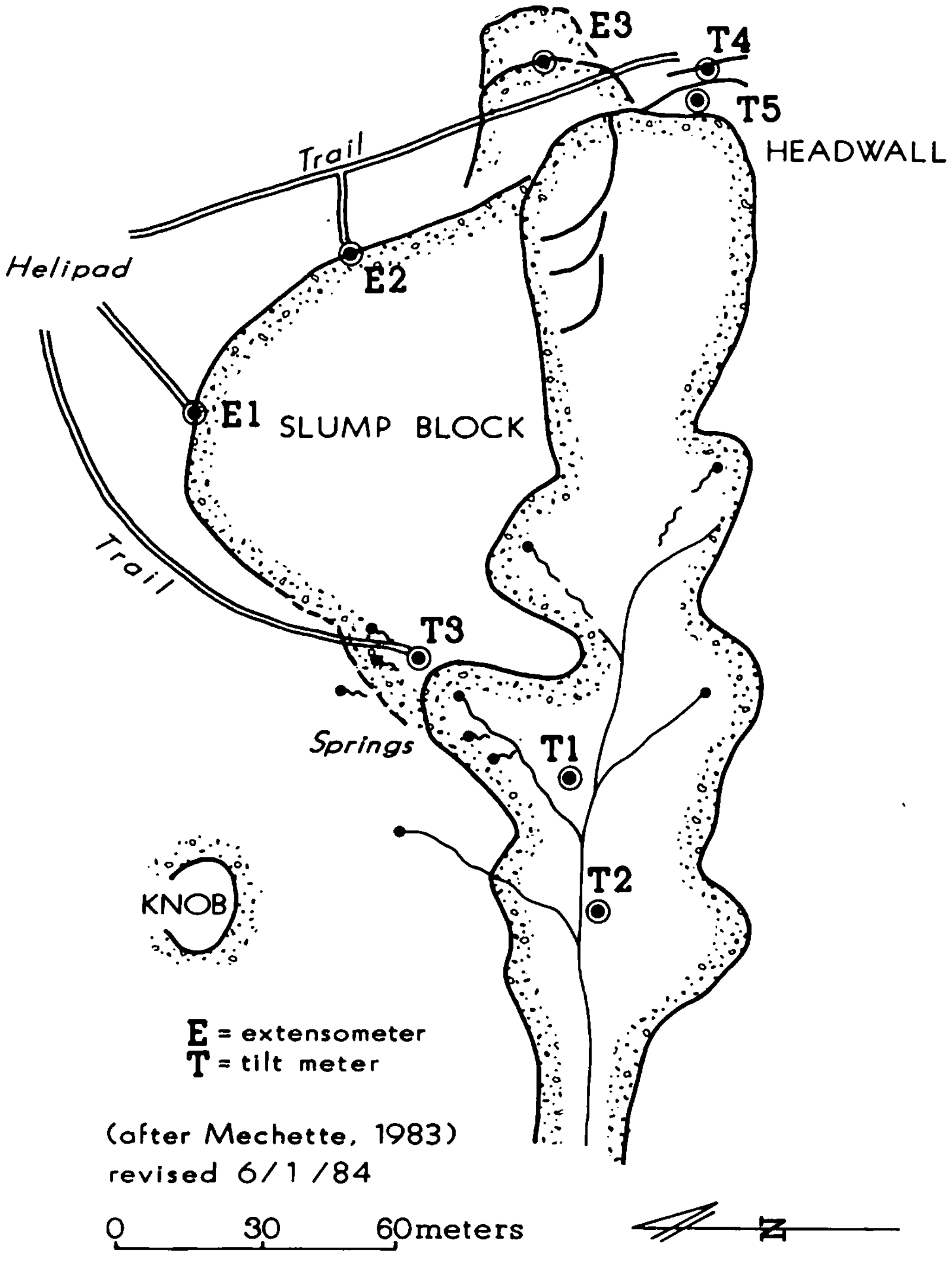
Instrumentation. The experimental landslide monitoring system consisted of three major components. The first component was sensor instrumentation on the slide, which included extensometers to measure the amount and rate of offset across the upper portion of a slide, inclinometers (tilt meters) to measure changes in slope angle, and piezometers to measure changes in groundwater pressure, as well as a weather station. The second component was a telemetry network to radio data from remote landslide sites to appropriate local facilities. The third component was the receiving and data display and recording equipment, placed in a local emergency response center, such as a sheriff's office. Telemetered data were automatically monitored and displayed on a computer screen to identify landslide events, and were simultaneously stored on computer tape for further detailed analysis.

In both the Rudd Canyon and Reynolds Gulch study areas, extensometers were placed across fractures that had resulted from slow earth movements in the potential slide block. One end of the extensometer was anchored to the relatively stable uphill side and the other was attached to the slide mass. The extensometers used in Rudd Canyon were bidirectional, i.e. they were capable of resolving movement into vertical and horizontal components. Those used in Reynolds Gulch were unidirectional, i.e. they measured only the change in slope distance between the two anchor points. Inclinometers were used only at the Rudd Canyon site. Three inclinometers were buried just below the surface of the ground, and two were placed on the surface in the stream channel immediately below the slide area. The purpose of the surface-mounted inclinometers was to indicate if and when debris entered the stream channel. The locations of the extensometers and inclinometers in Rudd Canyon are shown on Figure ~~1~~2, and the locations of the extensometers in Reynolds Gulch are shown on Figure ~~2~~3.

In addition to ground displacement, weather data were also collected. A weather station, consisting of a tipping-bucket rain-gauge and a temperature recorder, was stationed at the helipad in Rudd Canyon. This station provided continuous precipitation and temperature data. In Reynolds Gulch, no continuous weather information was actually obtained on site. Two weather stations, however, were located in the vicinity, and data from these stations were used in the study. Additionally, periodic snow surveys were carried out in the slide areas to measure water content in the snow pack.

Figure ~~3~~4 outlines the basic components of the telemetry system used at Rudd Canyon. The sensors represent movement detection devices. The analog signal from each sensor was presented to a multiplexer which sequentially converted it into an equivalent digital representation. The digital signal was then sent to a modem, which converted it to a series of tones to be broadcast by a radio transmitter to a repeater station, located at Lagoon resort. The signal was then relayed to the receiver station located at the Davis County Sheriff's office. After reconversion to digital format by another modem, the digital signal was processed by a Commodore C-64 home computer. The computer compared data from each sensor with lower and upper thresholds and displayed the results on a video monitor. The video display was updated three times per minute and a permanent record was printed every ten minutes. If the signal fell within the safe band, no response was

LANDSLIDE MONITORING SYSTEM
RUDD CANYON
FARMINGTON AREA



E = extensometer
T = tilt meter

(after Mechette, 1983)
revised 6/1/84

Figure ~~1~~ 2

LANDSLIDE MONITORING SYSTEM
REYNOLDS GULCH
BIG COTTONWOOD AREA

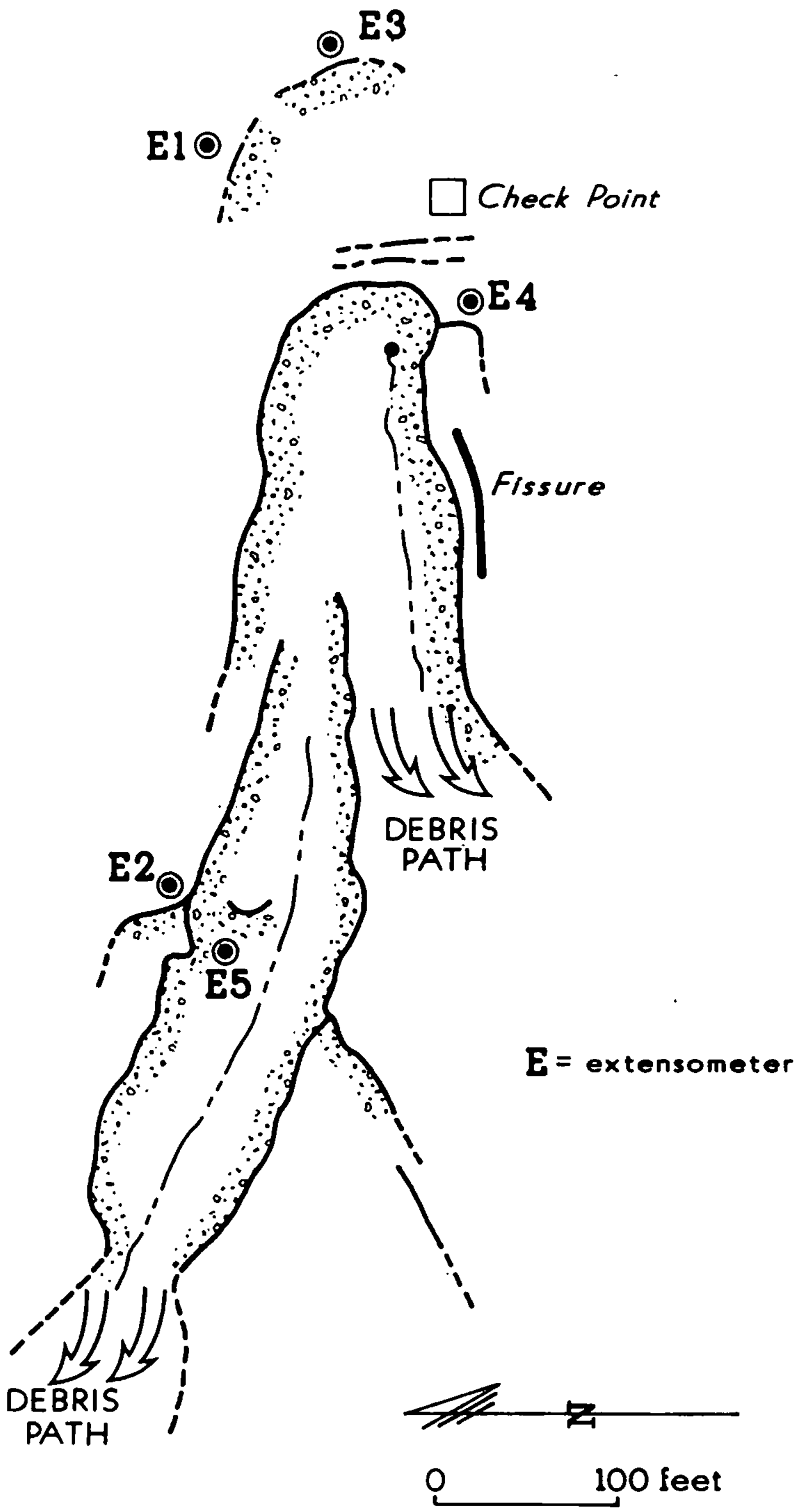


Figure 23

TELEMETRY
RUDD CANYON MONITORING SYSTEM

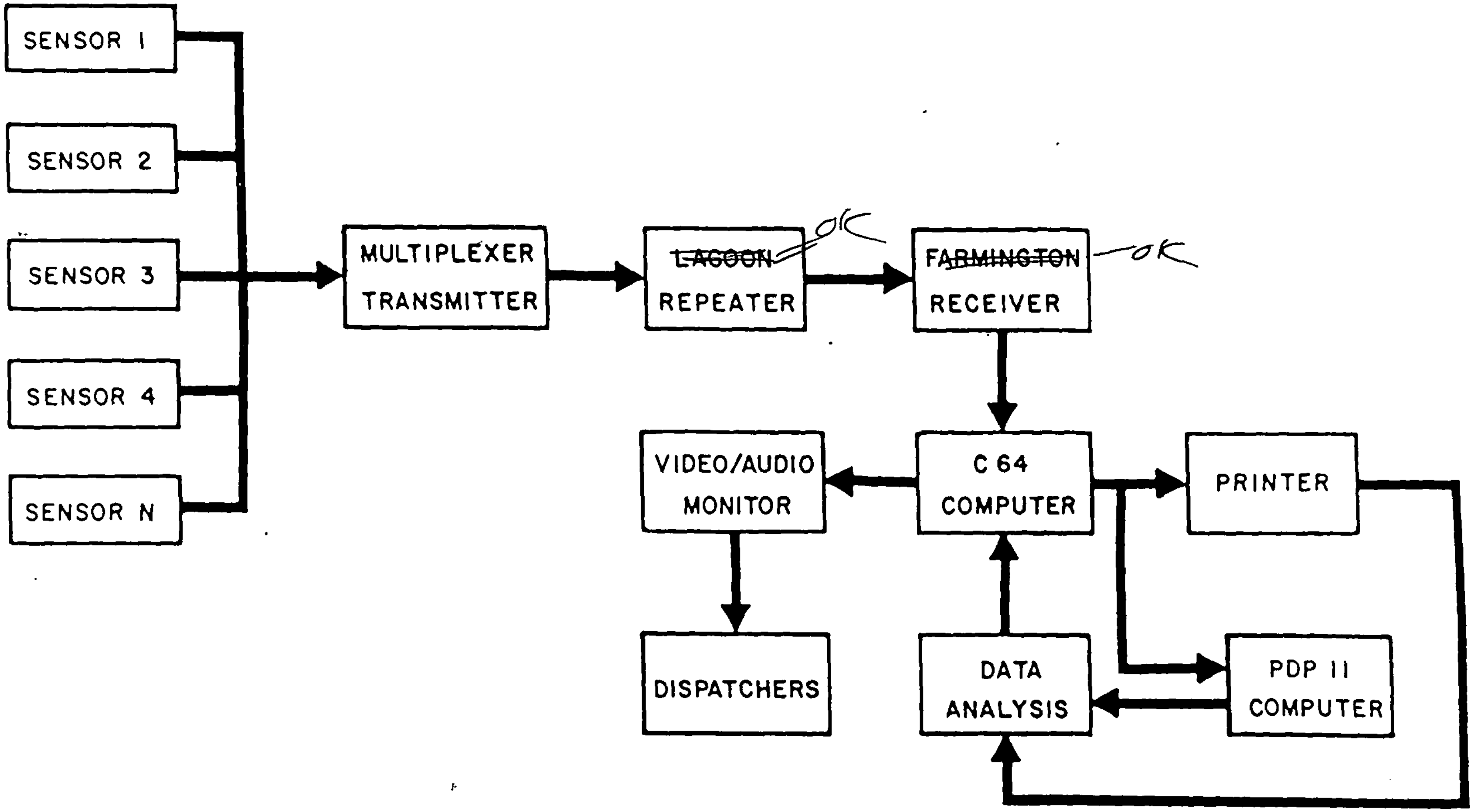


Figure ~~3~~ 4

generated by the computer. If the signal fell outside of the safe band, audible and visual signals were generated. The computer also served to store hourly averages for each sensor and the weather station. The monitoring system automatically called a larger computer located at the Department of Mining Engineering at the University of Utah once each day and transferred the hourly averages. The accumulated data were then available for analysis and modification of threshold limits if necessary.

Results. At 10:33 pm on May 15, Farmington dispatch reported an alarm from the extensometer in Rudd Canyon designated as E3 on Figure 1. The data indicated that fractures opened 7 mm between 4:00 pm, May 15, and the time of the alarm. A second alarm was received at 1:00 am, May 16. Data analysis indicated an accumulated displacement of 11 mm between 4:00 pm, May 15, and the time of the second alarm. Additional alarms from E3 were reported through 6:56 am on May 16. At this time, the alarm capability for this device was deactivated to allow detection of alarms on other channels should movement spread to adjacent areas in the slide zone.

Movement in the vicinity of E3 continued at various rates. The alarm capability was reactivated after analysis of the data, and alarm thresholds were reset every 12 hours to accomodate consistent trends while retaining ability to detect anomalous increases.

At 12:16 pm on May 16, Farmington dispatch received alarms from inclinometers T1 and T3. Two Farmington City personnel were immediately dispatched to the debris basin to observe and report any adverse occurrences. In addition, radio contact was made with a Forest Service helicopter which was in the area. Forest Service personnel arrived in time to confirm a debris flow issuing from the spring area at the lower limit of the slide area. The initial flow from the slide area itself was described as very small, but the volume of the flow increased substantially as debris was mobilized within the canyon.

A similar pattern was observed at Reynolds Gulch. In this case all data were obtained from the sensors through periodic interrogations rather than continuous monitoring. On May 13, an anomalous trend was detected in the data for extensometer E3 (Figure 2). County and other officials were notified and the frequency of readings was increased to verify the trend in the movement curve. On the morning of May 23, field inspection disclosed the development of a debris slide issuing from the unstable area below E3. The volume of debris was small, and the event dissipated before reaching the canyon drainage or the road. In both Rudd Canyon and Reynolds Gulch, movement subsided quickly following development of the debris flows.

OBJECTIVES OF PROPOSED WORK

Although landslide hazards to people, property and commerce presently exist and have existed all during development of Utah, little has been done in the past beyond noting potentially dangerous landslide areas. The present wet climatic cycle has apparently caused movement on more slides than would be expected in more normal years, and has served to focus the eye of the public and of state personnel charged with causing for the public, on this hazard. We must recognize that landslides have been a continuous phenomenon and that they will occur in the future no matter about the weather does. We must also realize that with growth in population, an increasing amount of damage come to be expected from landslides. Now is the time for steps to begin to understand landslide and debris flow phenomena and learn to deal with them.

The work proposed herein has three primary objectives:

~~1~~ 2. To deploy instrumentation to monitor earth movements at six sites that have high potential for landslides, and provide the data to CEM for dissemination to appropriate state and local entities for use in dealing with potential hazards; and,

~~2~~ 3. To analyze and study the data generated from the monitoring and any subsequent mass earth movement for the purpose of learning to monitor potential landslides in optimum fashion, predict sliding in advance and to mitigate sliding and/or its effects. ~~and~~

~~3~~ 1. To develop a landslide monitoring and prediction system that is simple to operate and inexpensive enough that it can be deployed widely throughout the State and used effectively by local personnel under CEM guidance;

STRATEGIES

Several items of strategy are clearly indicated for success ~~on~~ in the proposed project. First, an interdisciplinary team approach will be needed. Engineers to build, install and operate the instrumentation are required; geoscientists and geotechnical engineers are needed to analyze the data and perform needed technology and instrumentation development and personnel from state and local agencies must be integrated to learn to use the data to help prevent disasters. We propose to ~~form~~ use an interdisciplinary scientific team to accomplish these tasks, and to work closely with FEMA and CEM in coordinating data dissemination and use.

Second, it is equally clear that field data collection of is required. Data on earth movement and on precursors to rapid mass movement are needed at a number of ~~potential~~ slide sites. We need to have not only data on the way that earth movement begins and proceeds, but also basic geologic data on the slide area. These data are needed to ~~enable us to form~~ facilitate formation of a descriptive model of the sliding process and to identify variables that affect when and how extensively a landslide will move. From such a model, we will be able to (1) determine exactly what quantities to monitor and from this be able to specify the design of an appropriate monitoring system, and (2) form predictive criteria for onset and extent of slide movement.

Third, a multi-year program will be needed to solve the many problems of landslide monitoring, prediction and mitigation that exist today. The state of the art is relatively primitive in these topics, as it is in the area of most geologic hazards. It will require significant time, effort and money to reach an adequate level of understanding of landslide mechanisms so that they can be predicted in time to avert loss of life and mitigated to avoid property damage. This proposed project is viewed as the first phase of a continuing effort to solve these problems. We intend to seek other sources of funding at the national and State levels to supplement funds that might be available through ~~CEM~~ FEMA. ~~so that the required work may be done to reach a successful conclusion in terms of ability to predict and mitigate slide hazards.~~

PROJECT DESCRIPTION AND APPROACH

Geologic studies of the nature of slides, and monitoring slides to provide needed data to emergency personnel, are two important aspects of hazard mitigation. The basic mechanisms of landslides need to be understood better, and the technology for monitoring remote sites that may be hazardous needs to be improved. The work proposed herein will allow the development of six remote-telemetry slide-monitoring systems, installation of these systems in areas with identified high hazards, operation of these systems through one or two slide seasons, and geoscientific and engineering study on the nature of landslide problems through analysis of the monitoring data and other geologic data to be collected.

The work in this proposal covers the first two years of a potential five-year program. These two years will be mainly devoted to the further development of monitoring techniques and improvement in understanding of geological and engineering mechanisms of landslides. Further work, beyond this proposal, would focus on application of techniques to as many as 50 additional sites in Utah. The ultimate goal of this program is to provide state and local emergency response personnel with a low cost, reliable monitoring system, and the geoscientific information and techniques appropriate to interpret the monitoring data. Both the monitoring system and techniques developed to apply it would provide key input to the design of mitigation strategies.

Summary of Proposed Project

The components of the proposed project are (1) modify present instrument designs and construct new units to monitor and measure surface displacement, soil water content, electrical resistivity and weather information at potential landslide zones; (2) deploy these instruments in crucial locations; (3) monitor data especially thoughout the snowmelt season when tendency to slide is greatest; (4) provide monitoring data to CEM for their use in dealing with potential emergency or hazardous situations; (5) perform the data analysis, research, engineering and technology development needed to identify precursor indications of sliding for prediction purposes; and (6) develop an optimum low-cost monitoring system for future use. Figure 4 summarizes the activities proposed, and is relevant to the description on the next several pages. ~~These tasks form the first two years of the overall five-year program.~~

Site Selection

The selection of sites to be monitored will be very important. Sites should be in areas where potential for significant damage is great. They should also have a high probability of sliding and have reasonable access. Selection of the first two sites has tentatively been made. These will be at Rudd Canyon near Farmington and Reynolds Gulch in Big Cottonwood Canyon, the same sites that were instrumented during the 1983-84 slide season. Continued monitoring of these areas is desirable to establish a longer-term baseline. Both of these areas present a moderate level of hazard to human activities. At Rudd Canyon, the landslide hazard is presently greatest from a slump block (Fig 1). The presence of a debris basin at the bottom of the canyon provides a mechanism for trapping debris that may move downslope. At Reynolds Gulch, slippage has the potential for blocking the highway and Big Cottonwood lc creek. By utilizing instruments already in place, adding selected new instruments, and providing new background geoscientific and engineering studies, these sites can be much better understood.

LANDSLIDE MONITORING, PREDICTION AND MITIGATION SURVEY

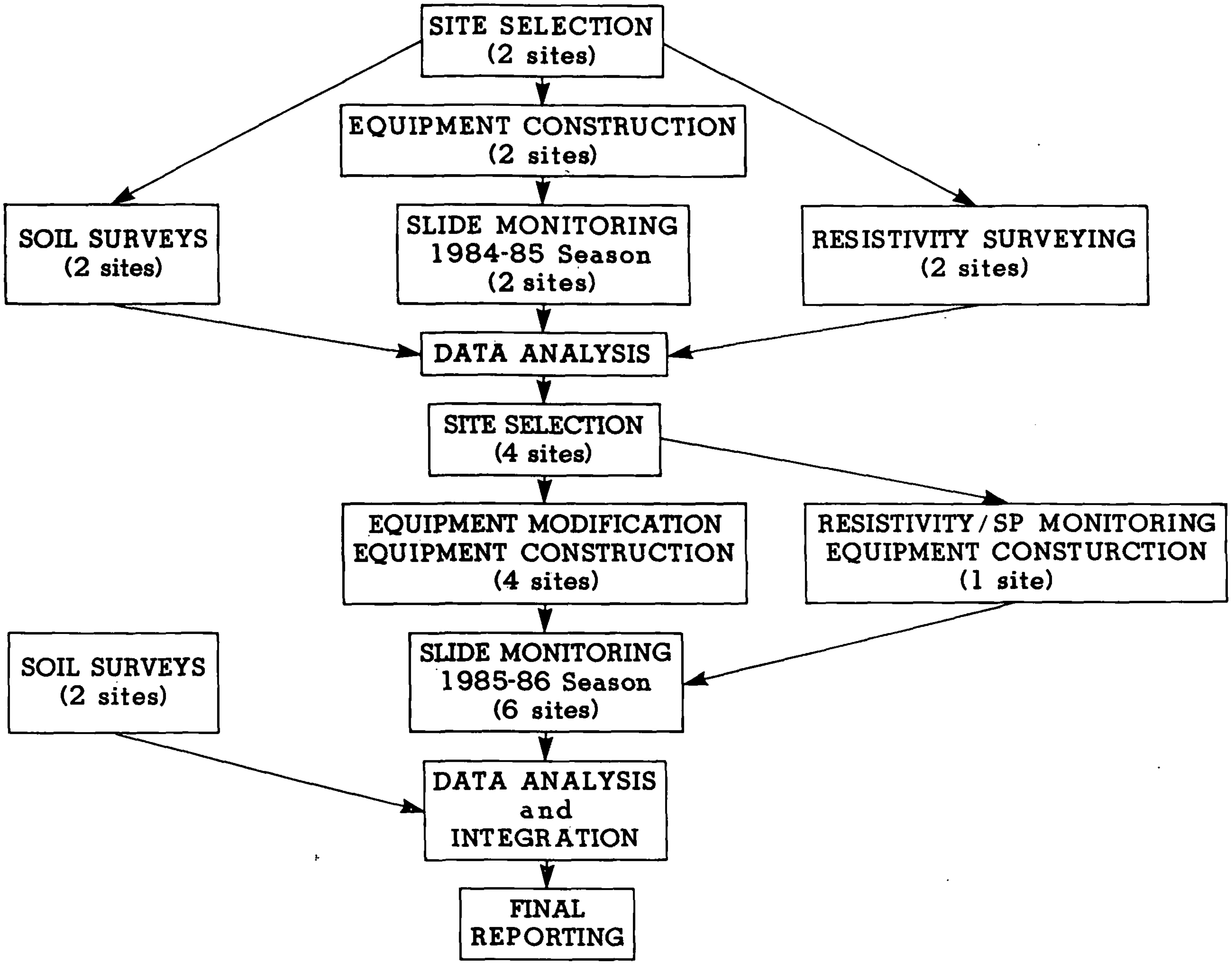


Figure ~~4~~ 5

Selection of additional sites will ~~need to~~ be done in close cooperation with FEMA, CEM and other entities that CEM designates. We anticipate that the Utah Geological and Mineral Survey (UGMS) ~~UGMS~~, the U.S. Geological Survey (USGS) ~~USGS~~, affected local governments, and perhaps other federal, state, and local agencies and private companies would participate.

Instrumentation

The first generation of equipment, used to monitor Rudd Canyon and Reynolds Gulch in 1983-84 was clearly experimen~~ted~~al. However, it performed reasonably well. UURI and UU are currently pursuing the possibility of patenting the design of this equipment and would also pursue patenting any improvements or other design changes. It is our desire to offer the equipment for use by others while reserving rights in the equipment.

For purposes of the current proposed project, construction of new equipment, with minor design improvements, will be needed. Design improvements, construction and deployment of instruments will take several months. Installation must be made before snowfall, when access to slide sites is still possible. Because it is already late in the year, we anticipate being able to instrument only a limited number of sites prior to the 1984-85 slide season. It is very important to begin work on the instrumentation at the earliest possible time. Delay until the next state or federal budget cycle will mean that funding will not be available until the summer of 1985, and an entire slide season will be lost, meaning one year's delay in results.

The existing electronics module in use at Rudd Canyon was designed for that specific site to match sensors already emplaced. Our experience has shown that the basic design is sound but should be improved. A more generalized system design is proposed that can be easily adapted to a wide variety of monitoring situations and sensors is contemplated.

Approximately one third of the field sensors were lost in Rudd Canyon as a result of the May 23 debris flow. New field instrumentation needs to be constructed and redeployed prior to onset of winter. This task will involve construction of at least two new extensometers; repair of E3, which was damaged by snow loading; replacement of three inclinometers lost in the slide; addition of a snow pillow to measure snow pack, and addition of at least two piezometers to measure groundwater conditions near E3 and the springs area. During or subsequent to deployment of field instrumentation, the multiplexer developed by UURI will be examined to determine the effect of long-term operation, and modified if necessary for another field season. In addition, recently acquired radio equipment must be tested and packaged for field operation.

All five extensometers positioned in Reynolds Gulch were extensively damaged by snow loads. They will all be replaced with extensometers similar to those now in Rudd Canyon. In addition to extensometers, at least four piezometers, a precipitation gauge, temperature recorder, and a snow pillow will be added to the system. Since water infiltration appears to be an important factor in initiating sliding, a simple device similar to a rain gauge will be developed to measure water infiltration and added to the system. All data for the 1983-84 slide season were obtained by periodic interrogation of the sensor system. A telemetry system will be added to insure proper data acquisition during the critical spring period.

The basic shapes of cumulative ground displacement curves as a function of time for both areas monitored during 1983-84 were the same. During the midwinter months little or no movement occurred. The onset of movement in the spring was abrupt and decelerated rapidly following debris flow activity. The onset of movement correlated well with melting of the snow pack and presumed rise in groundwater levels. The deceleration also correlated well with presumed decrease in groundwater levels attending liquification of soils immediately preceeding debris flows. The most logical explanation for coincidence of fracture dilatation and debris flows is, therefore, a temporary reduction in effective soil strength caused by increasing groundwater pressure, but this assumed explanation has not been verified. If the assumption is correct, monitoring fracture dilatation is only an indirect means of measuring pore pressure, and perhaps a more direct approach would provide a superior monitoring strategy. Therefore, before committing all of the resources to building additional monitoring systems of the type used during 1983-84, additional investigations will be conducted in Rudd Canyon, Reynolds Gulch and any other sites instrumented before snowfall this winter to evaluate probable correlations between melting of the snow pack, water infiltration, groundwater levels, fracture dilatation, and occurrence of debris flows. This information will help insure development of the most reliable monitoring methods and eventual development of the most effective warning systems.

Monitoring and Data Distribution Data

We propose to telemeter the monitored data to a central location for continuous display in real time. Present plans would be to use a local sheriff's office or similar facility that is operated around the clock. Data would also be transferred to UURI and UU periodically, probably on a daily basis. CEM would have access to the data either at the telemetry receiver site or at UURI. UURI would perform no data distribution functions. CEM would distribute the data and any real-time analysis as it sees fit to local, other state and federal agencies and the public. After the data are collected, UURI's primary interest will be in their scientific analysis, which, of course, will be provided to CEM on both an informal and formal basis.

Geoscientific Studies

Geology. Geological studies will include geologic and limited topographic mapping and mineralogic work on the slide block and its environs. Although it is often reported that selected geologic units are the most prone to sliding along the Wasatch Front (e.g. the Arapeen Formation and the Farmington Canyon Complex), detailed studies of the stratigraphy of these formations to identify the most slide-prone units and their characteristics have not yet been carried out. This is particularly true for the Farmington Canyon Complex, which has so far been treated by landslide investigators as a homogeneous mass of rock. Identification of stratigraphy in much of the area of the Farmington Canyon Complex has been hampered by deep weathering and extensive vegetative cover; there is no reason to expect, however, that the rock unit is any less diverse in slide areas than in areas where it is better exposed (e.g. Hansen, 1980). Stratigraphic controls are probably important in determining which portions of the range front are likely to slide, but these controls are not yet documented. Geologic structures such as faults, fractures and folds within these rocks are also known to be extensive and diverse. It is entirely possible that unrecognized controls, such as traces of the Wasatch Fault or older faults, may help localize slide activity.

If any of the monitored slides move during the course of this program, the slide area will be revisited, and a detailed geologic map will be made to compare with the previous map. This map will supplement the earlier map by noting detail of changes, and identifying newly exposed characteristics of the rocks and soils.

A second geologic aspect that will be investigated is the mineralogy of slide areas, particularly the clay assemblage in starting and slipping zones. Clay minerals that have formed from the weathering of the underlying bedrock may be important in both the slide break and small-scale but important hydrologic effects. To date, no such studies have been done. These mineralogic studies will prove useful to design of mitigation strategies.

Documentation of landslide starting and sliding zones through multiple sequences of aerial photography can greatly increase understanding of the geological and hydrologic conditions of the slides. Aerial photographs allow determination of changes in topography before and after slide events, documentation of additional zones of weakness, which may extend beyond the portion of a slide that has been instrumented, and detection of conditions appropriate for further imminent sliding, without having to get to the slide area on the ground. Aerial photographic monitoring of slide areas will nominally consist of three flights over selected sites. The first will be timed to accompany or slightly post date the installation of the slide monitoring instruments. The second flight will be made when the snowmelt line reaches the starting zone of the slide, when the probability of movement of the slide will probably be at its highest. The third will be after the snow has melted, but prior to full growth of vegetation, to identify any new fractures or partially detached zones left after the slide. If the slide has moved significantly, this third overflight will also document the nature and extent of movement.

Both natural-color and infrared photographs will be made. Natural-color photography is particularly applicable to help understand geologic conditions, whereas infrared photography is best suited to detecting changes in water content of the ground and determination of anomalous zones of vegetation.

Geophysics. Mapping water-saturated or clay horizons in slide areas can, in some instances, be assisted by performing electrical resistivity surveys, and the thickness of a potential slide block may possibly be determined in this way. Usually soils with high water or clay content exhibit lower electrical resistivity than bedrock or soils without high water or clay. The presence of clays and the variation in water content along planes of slippage are also targets for the technique. We propose to determine how well the electrical resistivity method will work in this application by performing surveys at two locations during the 1985 summer field season.

Resistivity and self-potential electrical geophysical surveys together have the capability of mapping the moving inflow of water into a slide block. Water movement not only lowers the electrical resistivity but also produces self-potential anomalies via the electrokinetic effect. Quantitative interpretation of both data sets has been used by Sill (1982a,b; 1983a,b) to indicate fluid flow into and out of fractured and porous media. These data may well provide an early warning of slippage. Such warning could occur ahead of the warning from the extensometers and telemeters.

We propose to instrument at least one slide for the 1985-86 season with a continuously monitoring resistivity/self potential system. This system will follow the design of that used by Morrison et al. (1977) to monitor movement on the Hayward Fault southeast of San Francisco. The monitoring will extend from early October through June of the following year, until cessation of slide movement.

Soil Stability. Geotechnical engineering studies will be undertaken to measure relevant soil strengths and perform analyses to identify mechanisms and conditions leading to landslides. The primary activities will include sampling of soils for strength determination in the field and laboratory and an analysis of the stability of the slopes. During site visits, the cohesive strength of the soils will be measured using a Torvane shear device. It is anticipated that strength tests will include unconfined compression and triaxial tests as appropriate. The testing will assist not only in defining soil strength characteristics as a function of moisture content, but also in indicating the degree to which moisture varies within the potential slide areas.

The lateral extent of a potential slide area is often relatively easy to delineate in areas where movement has previously occurred. However, a complete understanding of the potential for movement requires a knowledge of the volume or mass of material which will participate in the landslide. Consequently, a profile of movement with depth is necessary. To obtain such information, geotechnical engineers have successfully used systems known as slope indicators to profile ground movement as a function of depth. These systems consist of flexible plastic pipe with continuous slots in the inner wall parallel to the pipe axis. The pipes are placed in boreholes to a depth below which movement is believed to be occurring. Movement of the pipes is detected by passing through the pipe a torpedo-shaped device, which contains inclinometers at right angles to each other, and which rides on wheels in the slotted pipe to maintain alignment. Reduction of the inclinometer data enables one to establish soil movement. By periodically running the torpedo through the pipes the location of the sliding surface can be determined as well as a profile of movement with time. We will make such soil movement analyses at selected sites on the instrumented slides.

Integration and Analysis of Data

An integrated, interdisciplinary analysis of the data generated by this study will be undertaken using the full range of techniques developed by the geotechnical engineering profession. A geologic description of the slide areas and of the results if any sliding that occurs will form the basis of further analysis. Data on soil type and mineral content, variations in soil water content and observed earth movement will be subjected to slope stability analyses using methods devised, for example, by Patton and Hendron (1974), Piteau and Peckaur (1978), Bishop (1955), Bishop and Morganstern (1960), Morganstern and Price (1965), Coats (1977) and Terzaghi and Peck (1967). The results of such analyses will enable us to identify phenomen that occur prior to, during and after slide movement and to form a model for landslide movement. From such a model we will be able to:

1. Specify parameters that can be measured during monitoring of potential slide areas. Measuring actual ground movement, as the current monitoring system data, may not be the most desirable. It may be simpler and less expensive to measure degree of water saturation using piezometers or electrical resistivity using conventional geophysical techniques. Before an optimum, simple, reliable monitoring system can be specified, a number of important questions must be answered by the data analysis;
2. Specify the precursor indications that sliding is imminent and approximately when. Ideally, we would be able to show that precursors exist which would give enough warming to take mitigation measures. At the very least we hope to develop techniques that yield enough warning

of a slide to provide time for evacuation of people. The nature of precursors, the quantities which indicate that sliding is imminent and the length of the warning period are all now unknown.

3. Describe better the sliding process, including how water-saturated debris flows pick up much additional material down-channel and thus grow in size as they move along. The goal of such analysis would be to relate slide size to the amount of debris that may ultimately be deposited when the flow comes to rest;
4. Begin to describe potential mitigation measures that might be undertaken to prevent slide damage. In some cases, it may be possible to drill a number of wells into a potential slide and pump out excess water as a stabilizing measure. In other cases, soil mineralogy might be changed chemically to effect stabilization. In still other cases, perhaps a bigger debris basin or avoiding construction development in the area are the best answers.

EXPECTED RESULTS

The proposed work will be an important first step to providing a comprehensive system to monitor, predict and mitigate landslide hazards in Utah. Although we cannot expect to solve these problems completely with the present project, the level of effort suggested herein is believed to be appropriate given the large number of unknowns. Certainly, for example, we could not propose a larger program of instrumenting slides because we are not sure that the present monitoring system is optimum, or even that the best parameters are being monitored.

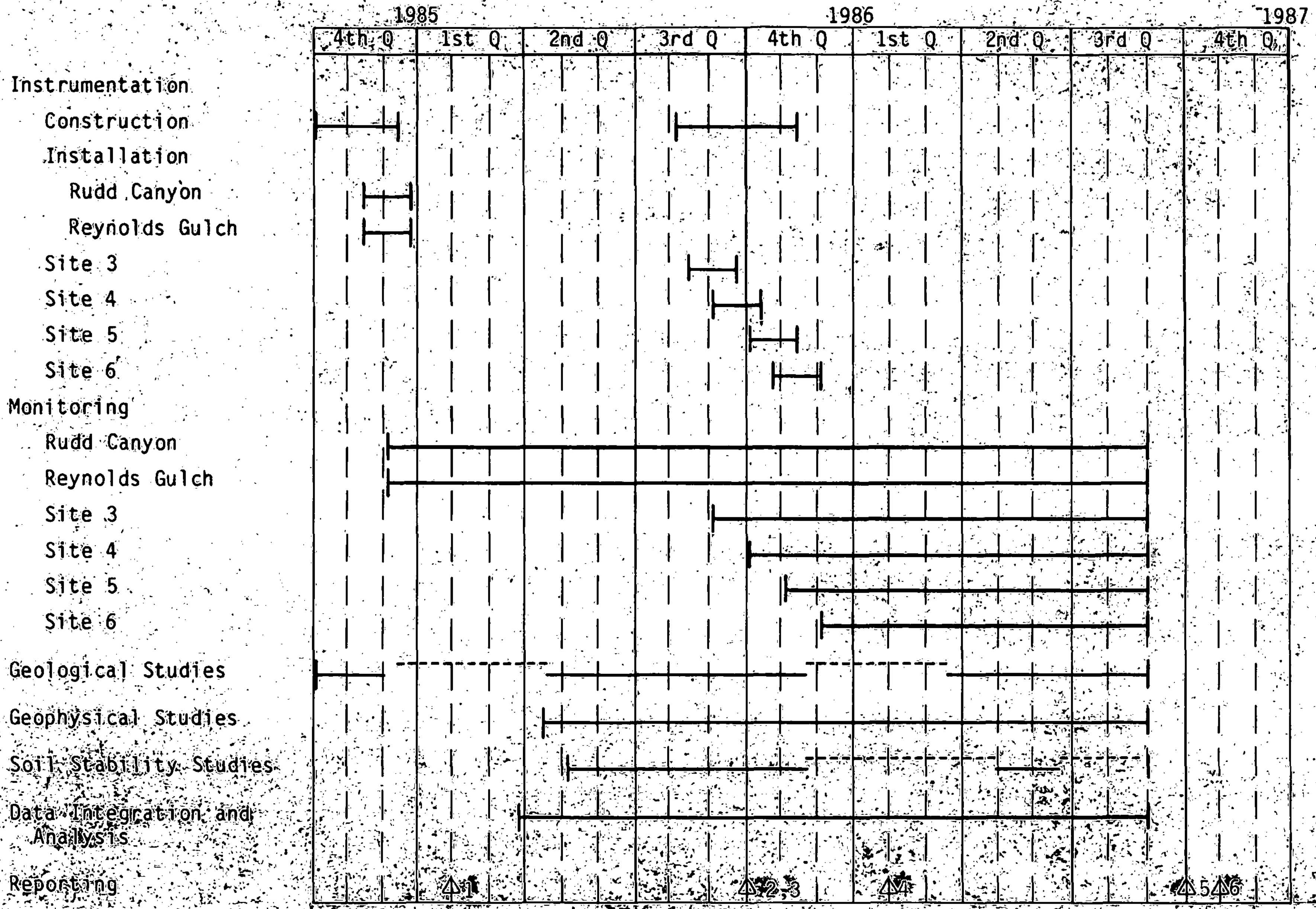
At the completion of this first phase of the project, we expect to be able to:

1. Develop a reliable, hopefully low-cost landslide monitoring system, including instrument design and determination of the critical parameters to measure;
2. Specify the precursor signatures in the monitored data that indicate that sliding is imminent and perhaps even the amount of time before rapid sliding begins;
3. Specify the geologic conditions that tend to facilitate development of a slide;
4. Develop a preliminary model of the mechanical mechanism of the sliding process;
5. Suggest potential mitigation procedures that may be effective for the sites studied.

SCHEDULE

The proposed schedule for this project is given in Figure 5. The schedule assumes that the project can be started on 10 October 1984, i.e. that notification of funding and contract negotiation between UURI and CEM takes place in September, 1984. As we have stated previously, UURI will need as much lead time as possible in order to get equipment installed before snowfall. Time is already very short. If funding is not available soon enough, then monitoring for the anticipated 1984-85 slide season will not be possible--the schedule is not merely stepped forward by one month for each month delay in funding.

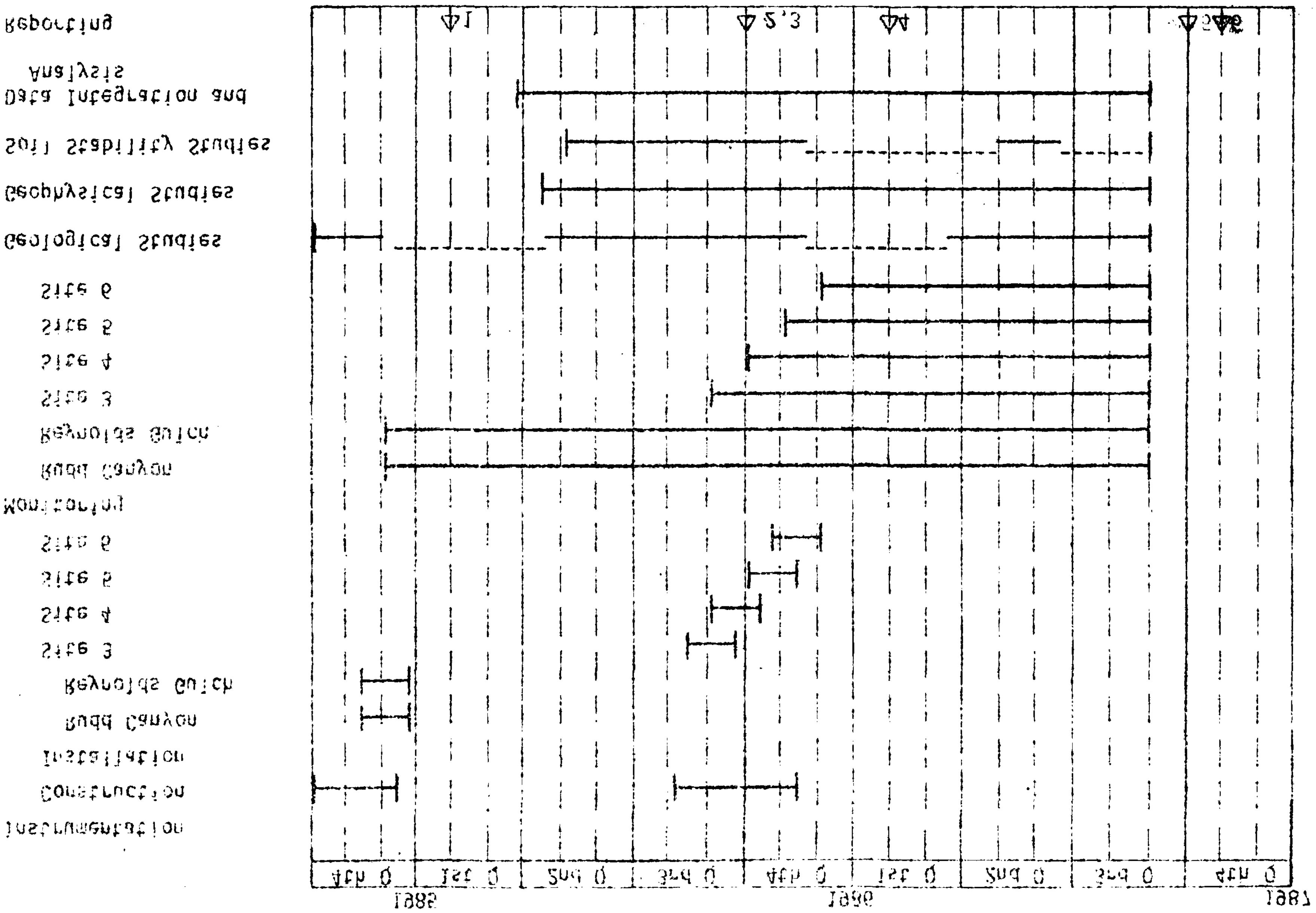
SCHEDULE†



† See next page for explanation of reports.

FIGURE 5

SCHEDULE



† See next page for explanation of reports.

FIGURE 5

EXPLANATION OF REPORTS

1. Interim report documenting monitoring installations.
2. Annual technical and progress report on results of 1984-85 slide season monitoring.
3. Report on selection of four sites.
4. Interim report documenting new monitoring installations.
5. Annual technical and progress report on results of 1985-86 slide season monitoring.
6. Final report with recommendations for monitoring, predicting and mitigating landslides in Utah.

PROPOSED BUDGET

A summary of the proposed budget for this project is given below. It is broken out by units so that the cost of each of the proposed components can be identified. Budget details are given on the following page.

MONITORING EQUIPMENT		
Instrumentation on Site		$ 58,515
Telemetry		57,620
MONITORING (Data Acquisition)		125,315
GEOLOGICAL STUDIES		46,420
GEOPHYSICAL STUDIES		73,970
SOIL STABILITY STUDIES		45,115
DATA INTEGRATION AND ANALYSIS		58,310
	TOTAL	$465,265

Several considerations should be brought out in discussing this budget. First, it is, of course, very much larger than the amount spent for 1983-84 monitoring at Rudd Canyon and Reynolds Gulch. There are several reasons for this, and chief among these are:

1. The present proposal includes monitoring at six sites, rather than two;
2. The present proposal includes a significant engineering and technology development effort that was not included in the past work and without which neither the problems of landslide prediction and mitigation nor of developing our optimum and cost-effective monitoring system will be solved; and
3. The 1983-84 effort involved a very considerable expenditure of unreimbursed personal time on the parts of UU and UURI personnel, whereas in the current proposal we have planned to pay salary time

much more in line with time that will actually be worked on the project. No project as large as the present one would be possible using the same proportion of volunteer, free time as has been donated in the past.

Second, there are a number of opportunities for cost saving in the proposed budget, as follows:

1. There is approximately $13,000 in helicopter charges included. If helicopter time could be donated by the State or the U.S. Forest Service, all or part of this cost could be deducted;
2. Costs for installation and maintenance of monitoring equipment are based on the assumption that most of the areas will have fairly difficult access. Rudd Canyon is considered to be such an area. If some of the 4 new sites have easier access, costs could be brought down, but because these sites are not now known, there is no good way to predict this cost;
3. Other opportunities for decreasing costs may become apparent during the course of the project. We intend to work with CEM to keep costs to a minimum. If cost cutting measures can be found, they will be applied.

Figure 6

BUDGET

MONITORING EQUIPMENT (Construction and Installation)			
Instrumentation on Site			$ 58,515
Professional Salaries	7 days	$ 3,685	
Support Salaries	35 days	6,505	
Travel and Helicopter		19,595	
Equipment (6 sites)		28,730	
Telemetry System			57,620
Professional Salaries	22 days	10,035	
Support Salaries	3 days	495	
Travel		5,500	
Equipment (6 sites)		41,590	
MONITORING (Data Acquisition)			125,315
Professional Salaries	85 days	34,740	
Support Salaries	155 days	57,265	
Student (1 year)		6,700	
Travel		2,515	
Equipment		24,095	
GEOLOGICAL STUDIES			46,420
Professional Salaries	90 days	33,615	
Support Salaries	16 days	3,150	
Travel		2,635	
Supplies		1,500	
X-Ray Diffraction Patterns		5,520	
RESISTIVITY MAPPING			21,175
Professional Salaries	5 days	3,585	
Support Salaries	35 days	6,655	
Travel		6,415	
Supplies		2,010	
Equipment		2,510	
RESISTIVITY MONITORING			52,795
Professional Salaries	78 days	30,150	
Support Salaries	62 days	12,500	
Travel		3,950	
Supplies		1,170	
Equipment		5,025	
SOIL STABILITY			45,115
Professional Salaries	9 days	6,280	
Student Salary	1/2 year	6,280	
Travel		2,250	
Supplies		5,695	
Equipment		24,610	

DATA INTEGRATION AND INTERPRETATION			58,310
Professional Salaries	110 days	46,530	
Support Salaries	63 days	6,280	
Computer Costs		2,500	
Reporting		1,500	
Travel		1,500	
TOTAL			$465,265

STAFFING AND MANAGEMENT

Overall administration of the program proposed herein will be under the Utah Division of Comprehensive Emergency Management (CEM). However, UURI will be deemed and treated as an independent contractor for the proposed work. CEM will be responsible for all coordination aspects of the project with other entities, and will be UURI's point of contact for the project. Although management of an interdisciplinary, integrated program such as this one needs to be centralized in one organization, success of a such study can best be achieved by involving expertise from several organizations. We suggest that advice and guidance to this program be obtained from a steering committee, composed of representatives to be designated by CEM and drawn from CEM, UURI, UU, UGMS and perhaps the USGS.

Overall management of the proposed technical work will be by the University of Utah Research Institute. UURI personnel will perform geotechnical and electrical engineering aspects of the study. Personnel of the Departments of Mining and Civil Engineering, University of Utah, will provide geotechnical engineering expertise. Other University of Utah personnel can also be involved if appropriate. Resumes of principal UURI and UU personnel are in Appendix A.

Day-to-day operation of the monitoring receiving stations will be the responsibility of the local government unit to which they are assigned with assistance and direction from CEM. Maintenance and insuring that the monitoring and telemetry equipment are operating will be the responsibility of UURI.

Personnel from agencies of the State of Utah will be involved in the program. These will include the Utah Geological and Mineral Survey, which will aid in site selection and will assist in evaluation of results. Limited no-cost participation, guidance and advice will be sought from other appropriate groups such as the U.S. Geological Survey and the U.S. Forest Service.

FOLLOW-ON PROGRAM

The presently proposed effort is for the initial two years of a five-year total program. The following three years would be devoted to:

1. Development and deployment of landslide monitoring instrumentation on a wide basis throughout Utah. The monitoring system would be as inexpensive as possible and would be suitable for operation by relatively unskilled, local personnel with advice and administration from CEM. We anticipate that as many as 60 potential slide areas may ultimately be monitored;
2. Development of a comprehensive scientific and engineering understanding of landslides and of methods for predicting their occurrence and the potential damage that might result therefrom;
3. Development of mitigation recommendations and procedures for various landslide hazards. Such mitigation procedures are expected to be a complex function of at least the following variables; location of the slide relative to developments, size of the slide, geology of the slide block and its environs, yearly weather in the slide area, how reliably the slide can be monitored, and other factors.

The cost of the follow-on three years is difficult to estimate at this time. By making the assumption that monitoring would be provided for 60 areas at an equipment cost of $6000 per area, an installation cost of $4000 per area, and that the technology development team would consist of two full-time equivalent scientist/engineers and two full-time technicians/students, the three-year follow-on program is very roughly estimated to be $1,400,000.

We would plan to seek federal funds to provided part or all of this amount.

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PROTOTYPE INSTRUMENTATION AND MONITORING PROGRAMS
FOR
MEASURING SURFACE DEFORMATION ASSOCIATED WITH LANDSLIDE PROCESSES

by: Michael K. McCarter and Bruce N. Kaliser

ABSTRACT

Extensometers and inclinometers were deployed in three areas of the Wasatch Front to measure surface soil deformation during the 1983, winter-spring transition. Resulting displacement vs. time plots disclose similar response patterns for each site which may be useful in identifying high risk periods for gross instability or debris flow development.

INTRODUCTION

During the spring of 1983, melting of an unusually heavy snow pack resulted in numerous debris flows and other forms of rapid slope movement in the mountainous terrain of northern and central Utah. Because of the high potential for reoccurring movement, geotechnical monitoring of recognized landslide areas appeared to be a reasonable step to help mitigate adverse impacts on down-slope communities.

Carl Terazagi (1950), well-known pioneer in soil mechanics and slope stability, expresssed the opinion that few, if any, landslides occur without warning. This warning may be in the form of adverse hydrologic, lithologic, topographic, or meteorologic conditions, or warnings of a more immediate nature which are manifested in the displacement history of the affected slope. Displacement histories have been sucessfully used in the mining industry to help insure safe working conditions (Kennedy et al., 1969; Ko and McCarter, 1975; McCarter, 1976; Larocque, 1977; Campbell and Shaw, 1979). Application of this technology may provide practical benefits for communities located in the path of potential debris flows. For this reason, the Utah Geological and Mineral Survey and the University of Utah engaged in a joint effort to deploy several monitoring devices on the Weber Bench in Weber County, in Rudd Canyon in Davis County, and in Reynolds Gulch in Salt Lake County. The goal of this effort was to provide quantitative data on climatic conditions and relatively long-term slope movement for several sites and to evaluate the possible existence of precursory events indicating a high potential for landslide activity.

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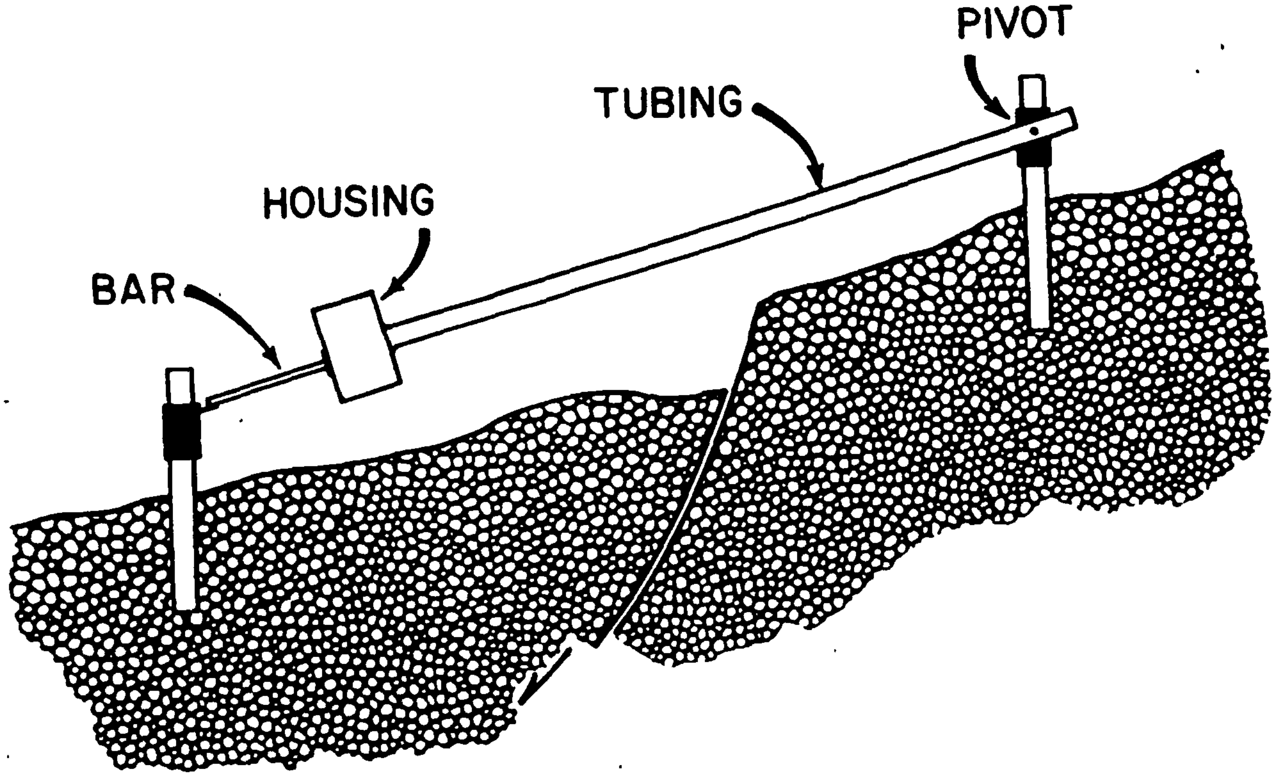
INSTRUMENTATION

Numerous devices have been developed to measure processes associated with slope failure. Some are commercially available while others must be constructed to fit individual site requirements. One of the major challenges in this project was to develop devices capable of measuring soil deformation at or near the surface during the winter-spring transition. Specifically, equipment must be robust enough to survive heavy snow loads while remaining sensitive to soil movement. The following paragraphs will provide a brief description of the transducers used to detect slope movement, equipment deployed to measure climatic conditions, and systems used to collect data.

EXTENSOMETERS

Prototype extensometers were constructed using two different designs. The most successful is referred to as the Rudd extensometer (see Figure 1). It consists of a 3.7 m (12 ft) length of 2.54 x 5.08 cm (1 x 2 in) rectangular steel tubing and a 1.3 m (51 in) length of 1.9 x 1.9 cm (0.75 x 0.75 in) steel bar. As shown in the figure, one end of the tube is anchored to the uphill (relatively stable) side of a fracture using a 1.07 m (42 in) length of standard 2-inch steel pipe. The tubing is attached using a bracket which allows the extensometer to pivot in a vertical plane. The bar is positioned within the tubing at the downhill end and is free to move in or out of the tubing on roller guides. The exposed end of the bar is attached to a bracket and pipe similar to the uphill anchor.

FIGURE 1 Rudd Extensometer



The lower surface of the bar contains a milled grove which provides a longitudinal recess for a 1 m (39 in) precision gear rack. This rack serves to rotate a 32 D.P. spur gear as the rod slides in or out. This gear is held in contact with the rack by a spring and rotates a 10-turn, 2K ohm, precision potentiometer. This device provides a change in resistance proportional to the change in position of the bar relative to the end of the tube. The diameter selected for the spur gear provides an output of approximately 2 ohms per millimeter. The data collection system, however, incorporated the potentiometer as a voltage divider, and the ratio of the wiper arm potential to the applied voltage was, therefore, nearly equal to the extension in meters.

The spur gear and potentiometer are housed in a weatherproof enclosure mounted on the end of the tube. This enclosure also contains an inclinometer (Humphrey* CP17-0601-1 pendulum potentiometer) with the same electrical characteristics as the 10-turn potentiometer previously described. The inclinometer has a range of ±45°, and the mounting configuration permits measurement of extensometer attitude from horizontal to vertical in a downward direction about the pivot. Capability of measuring extension and attitude permits calculation of horizontal and vertical components of movement for the downhill anchor relative to the uphill anchor. The device is sensitive to a change in position of as little as 2 mm (0.08 in) over the 1 m (39 in) range.

The Reynolds extensometer is very similar in design to the Rudd extensometer but with several notable exceptions. The overall length, 4.6 m (15 ft), is longer, and the housing used to protect the potentiometer and facilitate electrical connection is positioned at 1.5 m (5 ft) from the downhill end. This housing is attached by welding the enclosure directly to the tubing after suitable openings are machined in the tubing to accept the potentiometer and drive linkage.

The Rudd extensometer was found to be much easier to service in the field and less susceptible to damage caused by rough handling in transit to the installation site. The Reynolds extensometer is more compact, but the welded construction and machined openings in the tube, along with the additional length, severely limit the ability of this device to withstand the snow loads encountered during this study. All of the extensometers constructed with the Reynolds design experienced excessive bending at the enclosure, and it was necessary to reinforce the welded area with an additional length of tubing which was attached in the field after readings disclosed the bending problem.

Five extensometers were constructed using the Reynolds design, and 4 were constructed using the Rudd Design. Eight of the nine survived to produce data during the spring snow melt. Midwinter maintenance was necessary and only three devices survived without some bending.

INCLINOMETERS

Individual inclinometers were used only at one site (Rudd Canyon) to detect gross movement. Some were buried at shallow depth to detect pro-

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*Identification of brand names in this paper does not imply endorsement.

gression of slide boundaries in an uphill direction while others were mounted on the surface below the potential source of slide debris. Surface mounted inclinometers were intentionally placed where they would be destroyed or disrupted in the event of a debris flow immediately above the installation.

In all cases, inclinometers consisted of the Humphrey pendulum protected by a suitable enclosure. Readings from each inclinometer were expressed as the ratio of the wiper contact potential to the applied voltage. Positive changes in the ratio indicated a rotation of the inclinometer housing in a forward or downhill direction about the pendulum pivot. Negative changes indicated the reverse motion. The range was ±45° with respect to the direction of gravity with a detection threshold of approximately 10 min of arc.

Buried inclinometers provided consistent data throughout the test period. The attitude of surface mounted inclinometers, however, was affected (up to 7.8°) by snow creep, saturation of surface soil, and accumulation of debris. The surface mounted inclinometers also exhibited an undesirable sensitivity to temperature changes. This sensitivity did not affect data accuracy for this project but may complicate design considerations should the same device be used with other data collection systems.

WEATHER STATIONS

Only two monitoring sites (Rudd Canyon and Weber Bench) were equipped with instrumenation to monitor precipitation, and only one (Rudd Canyon) was equipped to continuously measure temperature. All other climatic data were obtained from nearby established weather stations.

The Weber Bench installation included a U.S. Weather Bureau rain gage which was manually read following precipitation events. Thermometer readings were obtained at the time of instrument readings, but maximum and minimum daily temperatures, along with precipitation data, were obtained from the Hill Field Weather Station, approximately 7.2 Km (4.5 mi) away.

The Rudd Canyon installation was equipped with a Qualimetrics P501-AE rain gage and a YSI 44004 thermistor which provided continuous data from May 5 through June 30. On April 14, a snow survey was conducted to establish the water content of the snow pack in the vicinity of the weather station.

The sources of meteorological information for Reynolds Gulch were the Argenta Station, located approximately 2 Km (1.2 mi) down canyon and 244 m (800 ft) lower in elevation, and the Brighton Station, located approximately 7.3 Km (4.5 mi) up canyon and 180 m (590 ft) higher in elevation. The Argenta Station provided precipitation data while the Brighton Station was used for temperature measurements. In addition, snow surveys were conducted especially for this study by the Salt Lake Water Department to provide direct measurements of the water content in the snow pack at the instrument site.

DATA COLLECTION

Three different methods were employed to collect data. Direct interrogation was used at Weber Bench since the site was located near a residence and the homeowner was willing to read the instruments on a daily or more frequent basis. Remote interrogation was employed at Reynolds Gulch where a 670 m (2200 ft) cable was used to activate a stepping relay and sequentially couple each of the transducers to measuring equipment. Finally, radio telemetry was used at Rudd Canyon to relay information from the field site to the Davis County Sheriff's Dispatch Center. The following paragraphs will provide a brief outline of each system.

DIRECT INTERROGATION

Data acquisition was accomplished by connecting a 1.5 V alkaline battery across the resistive element of each displacement transducer. The potential of the wiper contact and applied voltage were then measured relative to the negative side of the battery using a 3 ½ digit portable multimeter. The two readings were used to calculate the ratio to 3 significant figures. The alkaline battery, multimeter, and cable connectors were incorporated in a single package for ease of operation, and the resulting data were independent of temperature and repeatable within ±2 mm (0.08 in) and ±10 min of arc for the extensometers and inclinometers, respectively. Direct interrogation was used at both Rudd Canyon and Reynolds Gulch until communication links were established.

REMOTE INTERROGATION

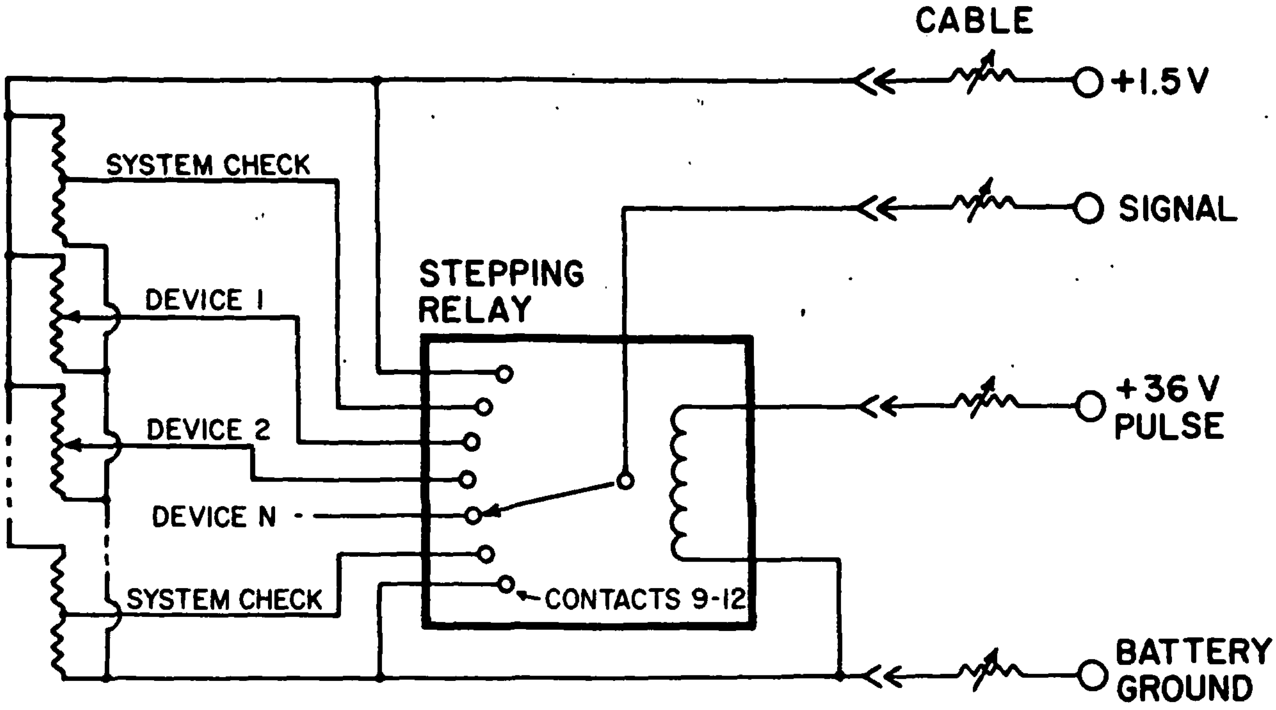
Following an earlier attempt which failed due to severe weather conditions, a 4-conductor cable was successfully installed on March 31, 1984, between the field site in Reynolds Gulch and a check point near the main road in Big Cottonwood Canyon. This cable enabled activation of a 12 VDC, stepping relay and sequentially established electrical contact with each extensometer and two internal reference resistors used to check system calibration. The equivalent circuit diagram is presented on Figure 2. As shown, all potentiometers were connected in parallel and the wiper contact of each was connected to one of 12 contacts on the relay. The first contact provided the potential applied to the potentiometer array by the 1.5 V battery located at the check point. This voltage (V_a) was less than the battery voltage because of the cable resistance which was not constant but a function of ambient temperature. All unused contacts were connected in common to the ground side of the parallel combination of potentiometers and reference resistors. The indicated potential (V_g) of this point in the system was above battery ground by an amount related to the resistance of the cable. Assuming an infinite impedance for the multimeter, the ratio of wiper contact potential to applied voltage, corrected for temperature and cable resistance, is given by:

$$R_i = \frac{V_i - V_g}{V_a - V_g}$$

where V_i is the indicated wiper potential for a given potentiometer.

Data acquisition was not continuous, and each point on the displacement vs.. time record represents a single interrogation result. The frequency of

FIGURE 2 Remote Interrogation System



visits to the check point was a function of rate of movement inferred by connecting a straight line between consecutive readings. The field data show that readings were made from the check point with a precision of about ±2 mm (0.08 in).

RADIO TELEMETRY

The telemetry system established at the Rudd Canyon site consisted of two basic components: a multiplexer and radio transmitter. The multiplexer was designed and constructed especially for this application by the Earth Science Laboratory, University of Utah Research Institute. The multiplexer consisted of a sequencer, A to D converter, modulator, and ancillary circuitry for signal amplification and data serialization. The sequencer served to excite each measuring device and connect the return signal to an analog to digital converter. The digital data were then serialized and presented to a modulator where the value of each data bit was converted to a high or low frequency. The data string was then broadcast continuously by a field transimitter.

The horizontal distance from the Rudd Canyon site to the Davis County Sheriff's Office is approximately 1.6 Km (1 mi). Given this distance and the rugged terrain, economy and reliability favored selection of radio communication over other alternatives. The high relief of the mountain front, however, prevented a direct line of sight to Farmington, and to overcome this difficulty, a repeater was established at the Lagoon Stadium 3 Km (1.9 mi) westward from the field transmitter.

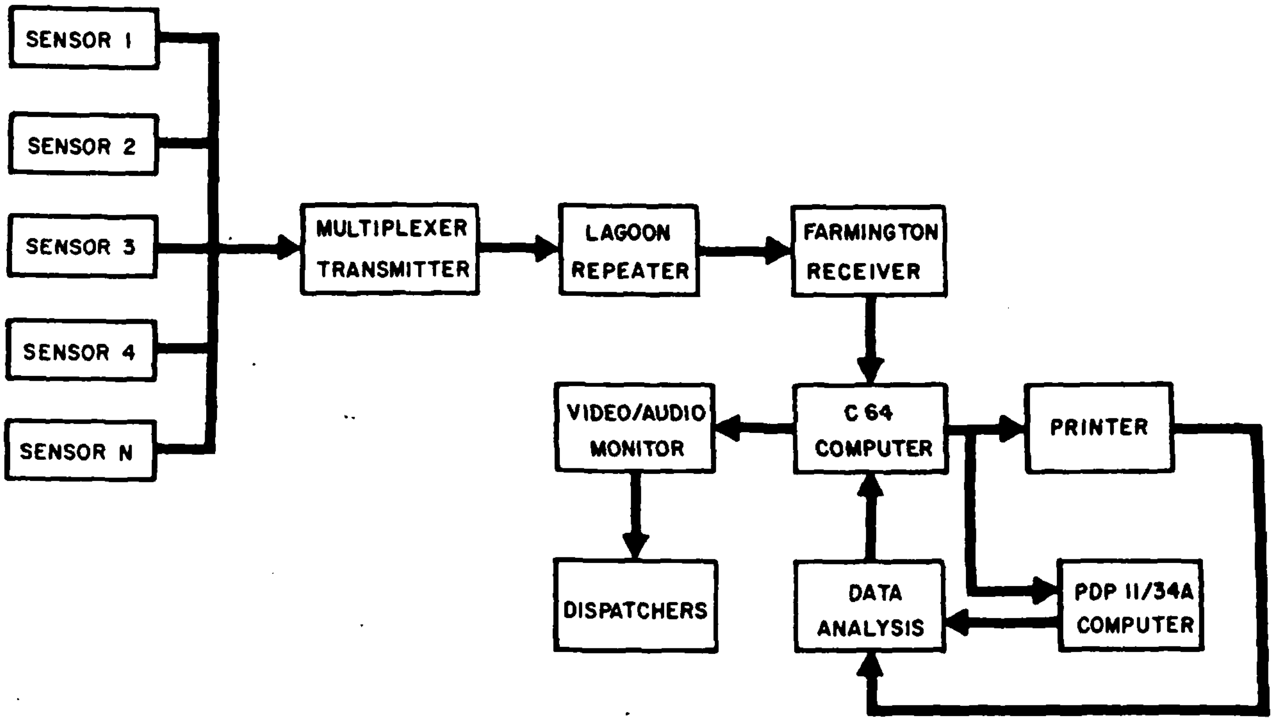
The base station employed a 145 mw Motorola transmitter and a directional antenna. A Bearcat 250 Scanning Radio was used to receive the signal at the repeater, and the signal was rebroadcast by a transmitter identical to the base station but operating at 11.55 MHz lower in frequency. This signal was, in turn, received by a second scanner at the Sheriff's Office.

The multiplexer and base station transmitter were powered by five, 1100 ampere-hour, Carbonaire batteries. The current drain was approximately 80 ma, providing an estimated life of 13,750 hours or 573 days. The repeater operated on 12 VDC provided by a 110 VAC power supply with a battery backup.

Figure 3 illustrates the basic components of the telemetry system including the "real-time" monitoring capability provided by the C64 computer incorporated in the system. The signal received from the Lagoon repeater was demodulated and processed by the computer. Processing included comparing the status of each instrument to an upper and lower limit. If the reading was above the upper limit or below the lower limit, an audible alarm was activated and the offending device was identified by a reverse video image. The dispatchers on duty responded to the alarm by immediately notifying emergency personnel and contacting designated individuals at the Utah Geological and Mineral Survey and/or the University of Utah.

The video display consisted of a listing of 12 channels representing the 11 transducers and a system checking device. This display included the channel designation, lower limit, upper limit, and current value. In addition, the temperature, precipitation, battery voltage, battery current, reference voltage, Julian date and time were displayed below the channel tabulation.

FIGURE 3 Rudd Canyon Monitoring System



New values for all parameters were updated 3 times per minute, and a sample of all values was printed every 10 minutes. Individual readings were accumulated in the memory, and average values printed every hour. The averages were also stored and automatically transferred over telephone lines to a PDP 11/34A computer located at the University of Utah. The hard copy provided the only record for 10 minute intervals and established a backup for hourly averages in the event of power outages and consequent loss of memory. Power failures were infrequent and did not substantially interfere with system operation.

The PDP 11/34A stored the hourly averages in a two-dimensional array defined by device number and time. Auxilliary software permitted review and plotting (video image or hard copy) of any desired device for any desired window in time. This capability permitted ongoing analysis of trends and resetting of limit values to prevent triggering of alarms due to predictable, cumulative trends. Initial thresholds were set at approximately ±5° for the inclinometers and approximately ±1.0 cm (0.4 in) for extensometers. Diurnal variation in readings appeared to be well within 0.5% of the indicated value.

FIELD SITES

The following paragraphs will describe each of three sites selected for instrumentation and resulting data acquired during the 1984 winter-spring transition. The three sites include the Weber Bench in South Ogden, Reynolds Gulch located in Big Cottonwood Canyon east of Salt Lake City, and Rudd Canyon east of Farmington.

WEBER BENCH - SITE DESCRIPTION

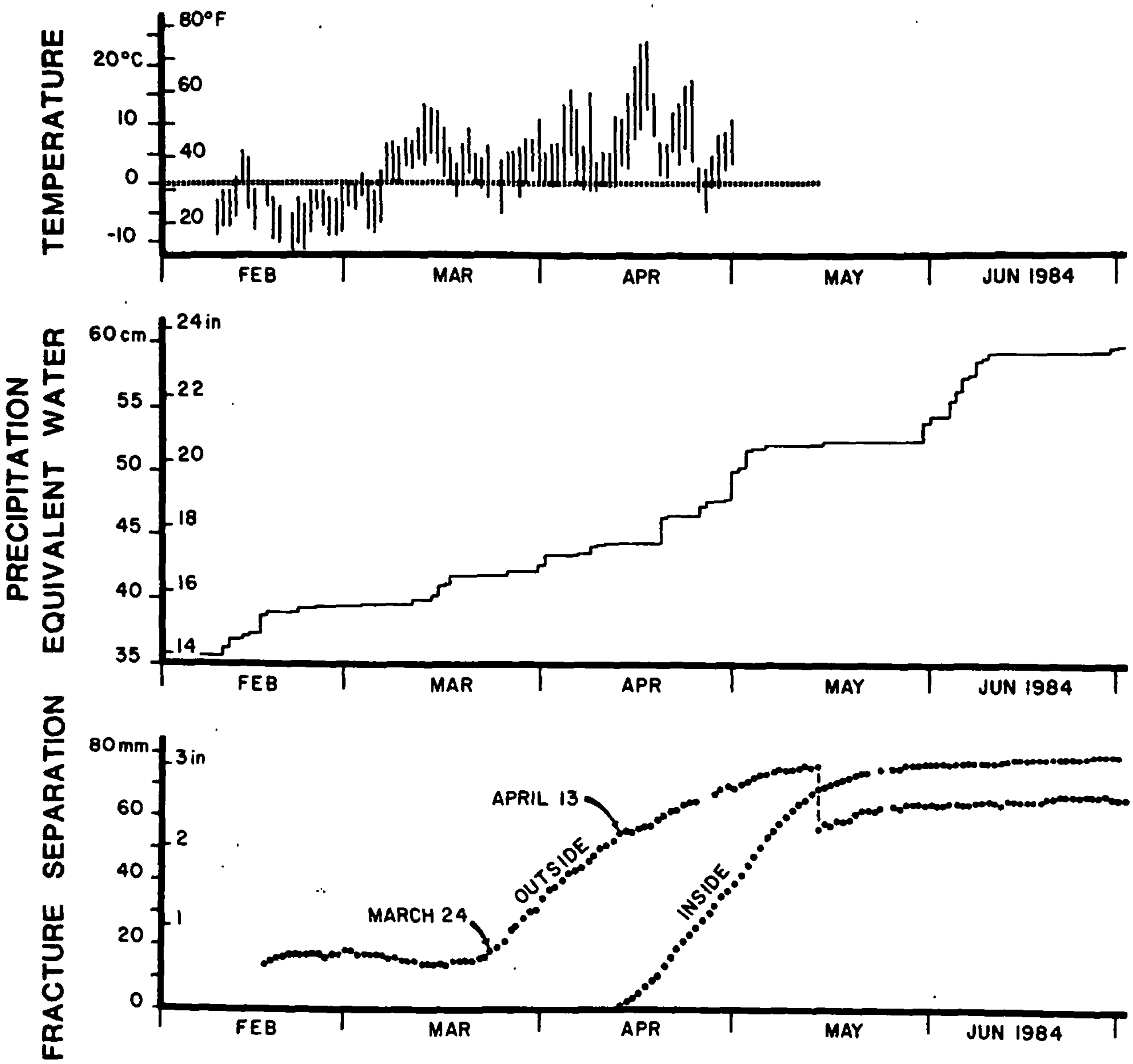
The unstable area is located on a north-facing terrace above the Weber River. The material is of late Quaternary age and consists of lacustrine silts and fine sands with little clay. Aerial photographs and field inspection disclose a well-defined headwall scarp and indistinct toe. The current slide is approximately 490 m (1600 ft) wide by 180 m (600 ft) long and is situated in elevation between 1340 m (4400 ft) and 1390 m (4560 ft).

Two extensometers were positioned 67 m (220 ft) apart near the northwestern extremity of the headwall. One instrument was located across the headwall scarp where the fracture passed through the crawl space under a house. The other was located on the same tension fracture, outside and to the east of the home. The installation provided an excellent opportunity to compare the readings from an extensometer located in a protected, nearly constant temperature environment with one exposed to the elements.

WEBER BENCH - FIELD DATA

Figure 4 represents a summary of individual readings taken between February 17 and June 9. As can be seen, temperatures basically remained below freezing until about March 6. Warmer temperatures began melting the snow cover, and by March 24, nearly all traces of snow had disappeared. The displacement history for the outside extensometer shows a slight downward trend (contraction) for this same period which is probably due to reduction of the snow load on the extensometer. This trend is interupted by a distinct inflection in the curve, indicating reactivation of the dormant slide, which occurred on March 24. By April 1, homeowners situated in the toe area began to notice widening of fractures in pavement and foundations. The continuing upward trend of the curve indicates a more or less uniform rate of movement until about April 13, at which time there is a noticeable decline in the rate

FIGURE 4 Meteorologic and Extensometer Data for the Weber Bench Site



continuing through May 1. This apparent reduction is due to development of a sympathetic headwall fracture and subsequent displacement of the uphill anchor. The extensometer was repositioned on May 14, and the dotted line of the graph connects coincident points on the displacement history curve.

The inside extensometer was not installed until April 13. Its curve, however, is notably more regular than the one developed by the outside extensometer. The smooth appearance is due to the fact that the transducers used for the inside device are approximately ten-times more sensitive than those used for the outside device. The irregularities in the outside curve, for the most part, reflect the ±2mm (0.08 in) repeatability for the device.

The precipitation history is cumulative from the beginning of the water year. It is presented here to allow the reader to infer approximately how much water was contained in the snow pack. The onset of fracture separation, recorded on March 24, is apparently the result of rapid melting of the snow cover which probably contained less than 33 cm (13 in) equivalent water. In addition, the record shows that a substantial amount of rain which began to fall at the end of May [6.9 cm (2.73 in) from May 30 to June 8] is not reflected in the displacement history. The precipitation estimates are based on data accumulated at the Hill Field Weather Station and may not precisely represent this specific site due to local relief and canyon effects.

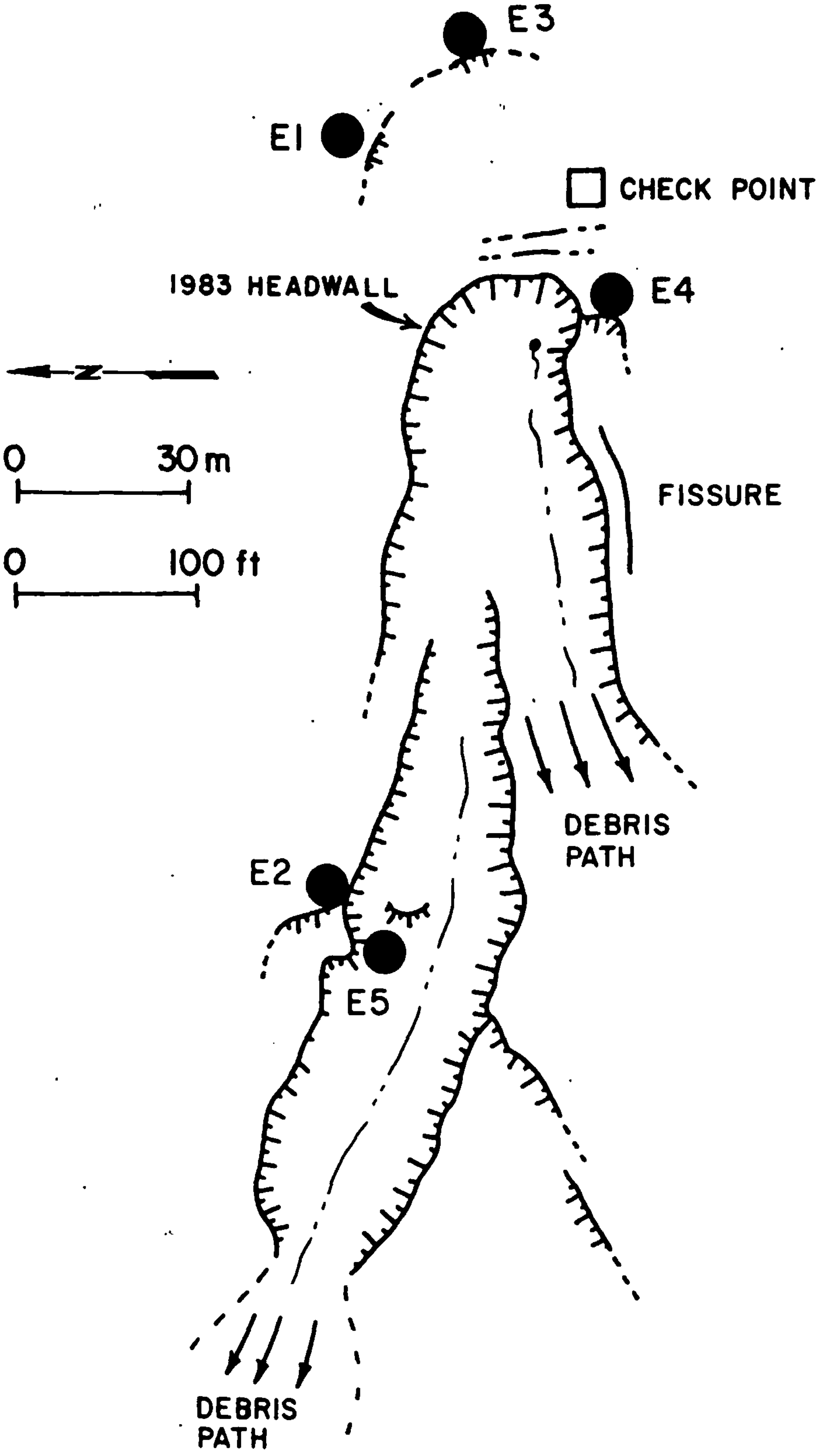
Slide activity is characterized by a period of little or no movement (dormant), followed by a period of increasing displacement, up to about 4 mm (0.16 in) per day, and then a return to the dormant state. No debris flow or rapid slope failure occurred at this site, nor was any expected.

REYNOLDS GULCH - SITE DESCRIPTION

Reynolds Gulch is a north-trending tributary of Big Cottonwood Creek and is situated approximately 14.5 Km (9 mi) from the mouth of the canyon. It was the site of an earlier debris flow which occurred in June 1983. The source area for this event is located on a west-facing mountain slope (slopes range from 26° - 30°) just below the 2438 m (8000 ft) elevation. The disturbed area consists of two superimposed slide zones with detached masses near the toe and above the 1983 headwall (Figure 5). Material covering the slope includes a well-developed organic soil and at least 3 m (10 ft) of rocky colluvium. The fine fraction of the colluvium is plastic and very slippery when wet. Colluvium is derived from Mississippian formations, but no bedrock outcrops were observed in the area, and the depth of cover is uncertain. Numerous springs and seeps are located along the northern margin and drain ground of higher topographic relief to the northeast.

Relative locations for the five extensometers established in the slide area are shown on Figure 5. Devices indicated as E2 and E5 were placed across the north lateral scarp of the slide to detect potential reactivation of debris remaining in the disturbed zone. E4 was located across a fracture bounding a detached block on the south side near the headwall, and E1 and E2 were placed across fractures well above the headwall but in the path of potential uphill progression of the zone of evacuation.

FIGURE 5 Reynolds Gulch Landslide Area, Big Cottonwood Canyon



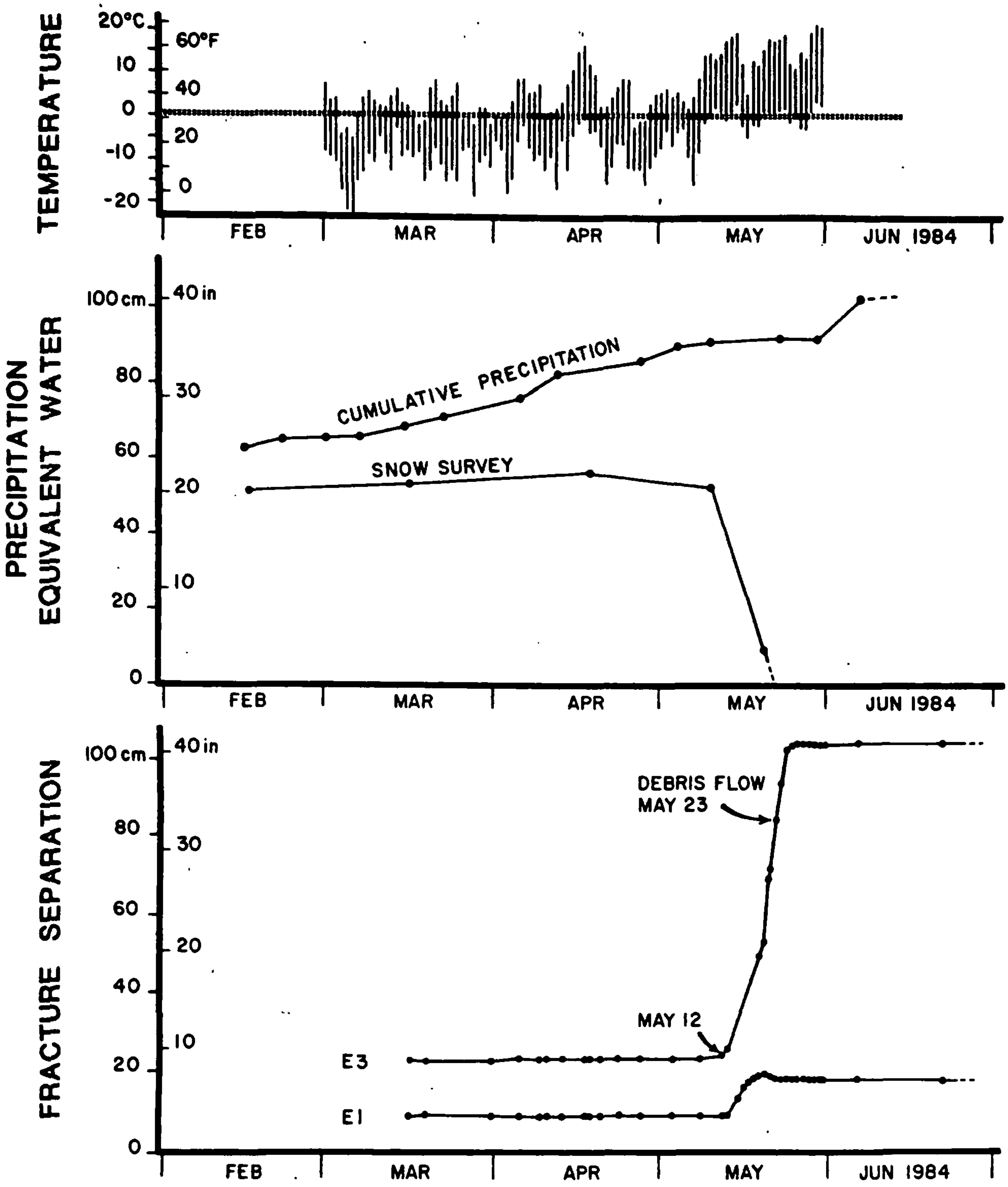
REYNOLDS GULCH - FIELD DATA

The extensometer sites were established on November 17, 1983 and preliminary readings were made on this date and on November 30. Heavy storms prevented access to the site until January 7, 1984. Readings on this date disclosed an apparent extension of 70 mm (2.76 in) on E5 with little or no movement at the remaining installations. On January 21, the site was visited and the snow removed from E5. Inspection disclosed excessive bending of the extensometer tube. Damage was attributed to snow creep and the fact that this extensometer was positioned at an oblique angle to the down-slope vector. All other devices were located nearly parallel to this vector and, therefore, were not subjected to transverse loading. In order to insure proper functioning of the extensometers, a short length of structural tubing was bolted to the existing tube to form a composite beam with greater depth. In addition, snow was periodically removed to limit the load supported by the span. This procedure was employed for all extensometers except E4. This site was left undisturbed so that the full effect of snow loading could be assessed.

Figure 6 summarizes climatic and deformation history during the winter-spring transition. As can be seen the temperatures were predominantly below freezing up until about May 9. (Temperatures shown on this figure are those for the Brighton Station.) Subsequent to this date the temperatures were essentially above freezing. Between May 10 and May 20, rapid melting of the snow pack occurred as indicated by the snow surveys conducted on site for these dates. Anomalous rates of movement at both E1 and E3 were detected subsequent to May 12. No significant movement was indicated by either E2, E4 or E5. Interrogation of E3 disclosed a progressive increase in the rate of deformation beginning at 0.7 mm/hr (0.03 in/hr) on May 13, up to a maximum of 7.2 mm/hr (0.28 in/hr) recorded on May 20. Fractures in the snow were observed from the air on May 16, confirming reactivation of the slide. Interrogation of E1, however, disclosed a decreasing rate beginning on May 16, and continuing to May 20. On this date the rate of movement was negative indicating contraction of the extensometer which suggested that the uphill anchor for E1 was no longer stationary. On May 23, E3 was repositioned to provide additional range, and at the same time, conditions at E1 were investigated. Inspection disclosed that the fracture at E3 had extended northward isolating a block of ground which included both anchors for E1. Upon leaving the area at 7:30 a.m., masses of earth and vegetation measuring several cubic meters in volume were observed sliding down the southern flank of the upper slide. This event was the initiation of a small debris flow, the runout of which was largely confined to the preexisting landslide scar.

The deformation history disclosed by Figure 6 is very similar to that shown in Figure 4. Prior to melting of the snow pack, little or no fissure separation is indicated. Onset of movement lagged significant reduction in the snow pack by at least two days. Abrupt cessation of movement followed the debris flow also by about two days. The period of active fissure separation spanned approximately 13 days from May 12 to May 25. No further separation was measured at E3 even though significant precipitation occurred during the first part of June [10.7 cm (4.2 in) from May 30 to June 6].

FIGURE 6 Meteorologic and Extensometer Data for Reynolds Gulch



RUDD CANYON - SITE DESCRIPTION

Rudd Canyon is located immediately east of the community of Farmington and extends eastward into the Wasatch Range. The source area responsible for the 1983 debris flow is located at a prominent inflection in the main drainage of the canyon where a wedge of unconsolidated material, likely an ancient landslide mass, is situated (perched) at an elevation of about 2110 m (6925 ft) (Kaliser, 1983). The upper surface of the wedge dips as little as 5° to 7° to the west while undisturbed slopes in the source area typically range from 27° to 38°. The unconsolidated wedge consists of permeable, granular soils derived from the metamorphic rocks of the Farmington complex. These soils present ideal conditions for infiltration of melting snow and development of high piezometric pressures.

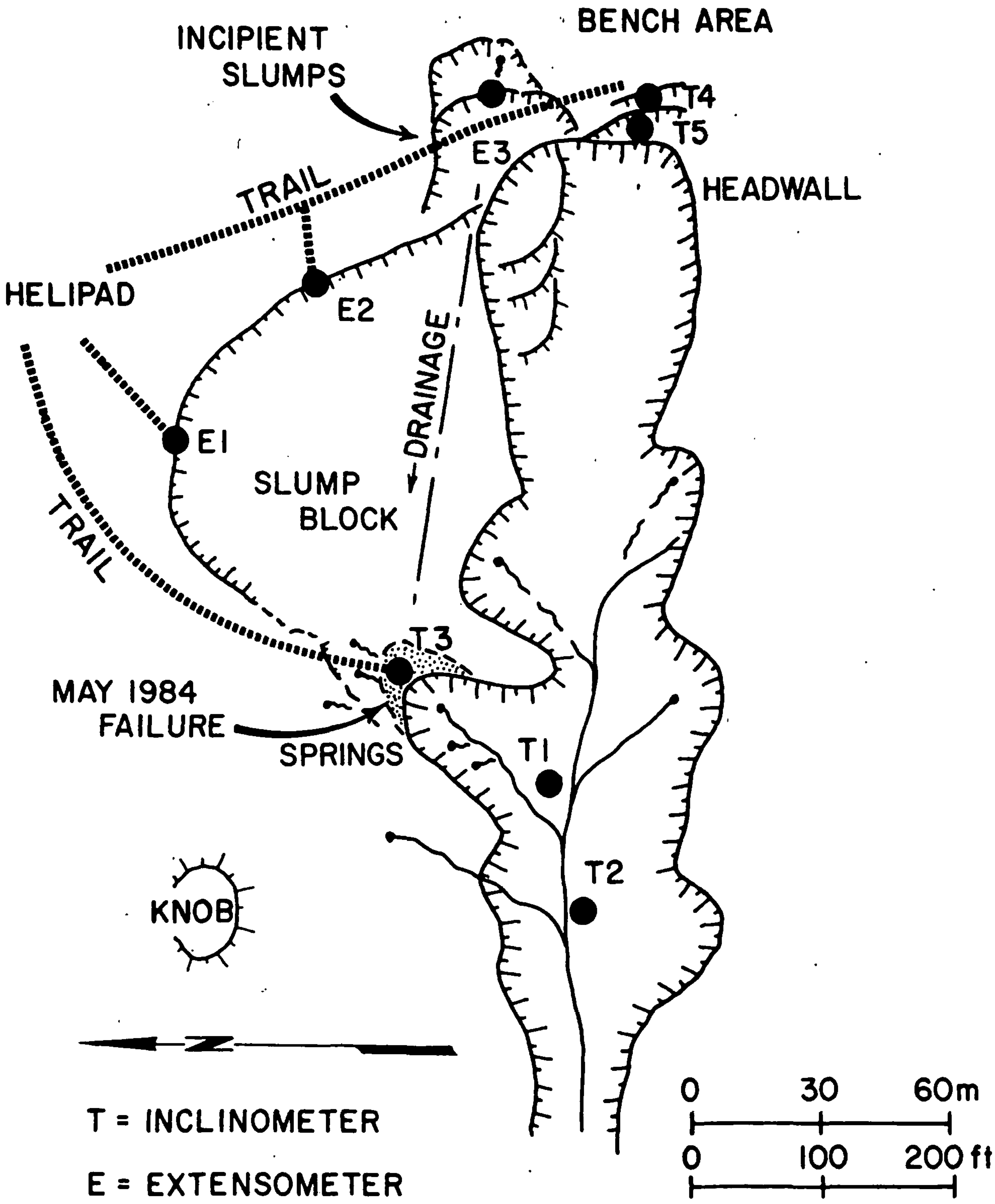
As shown on Figure 7, a series of incipient slumps are located above and to the north of the headwall and extend westward along the northern boundary of the scar. A less conspicuous, continuous tension fracture extends from the headwall area northwestward in a circular arc terminating above an area of natural seeps and flowing springs. This fracture defines the slump block which contains at least 6100 m^3 (8,000 yd^3) (Vandre, 1983) and perhaps significantly more (Wieczorek et al., 1983).

A topographic depression exists in a nearly straight line between the sites marked E3 and T3. Precipitation falling on the slopes above E3 and on or above the slump block flows to this drainage, either on the surface or underground, and feeds the perennial springs in the vicinity of T3, T1 and T2 located on Figure 7. Near-surface springs were observed (May 12, 1984) discharging directly into headwall fractures located at the apex of the drainage. Similar conditions were also observed in the spring of 1983 (Machette, 1983) and will probably reoccur in the future.

On November 16, 1983, installation of eight earth movement detection devices was begun and completed on November 19. Three extensometers (designated E1 through E3) and two inclinometers (designated T4 and T5) were placed in the upper area of the scarp. T4 and T5 were buried at a depth of approximately 30 cm (12 in) immediately behind the headwall. These devices were positioned to detect potential uphill progression of the 1983 scarp. E3 was positioned across a fissure defining the most prominent incipient slump along the north boundary of the landslide scar. Two extensometers, E1 and E2, were placed across the fracture defining the northern boundary of the slump block.

The remaining instruments were positioned near the bottom of the scar. One inclinometer, designated as T3, was buried in the ground above active springs on the north side of the canyon. The second, indicated as T1, was placed on the surface below the springs and approximately 0.6 m (2 ft) above the stream channel. The third, indicated as T2, was also placed on the surface approximately 1.8 m (6 ft) above the stream channel and about 40 m (130 ft) downstream from T2. Both T1 and T2 were intentionally placed in the channel so they would be swept away in the event of a debris flow.

FIGURE 7 Rudd Canyon Landslide Area, Farmington, Utah (1983 Slide Boundaries after Machette, 1983)



RUDD CANYON - FIELD DATA

Figure 8 summarizes data telemetered from the base station located at the helipad and subsequently plotted by the PDP 11/34A at the University of Utah. As indicated, temperatures remained near or below freezing until Julian date 129 (May 8) which marks the beginning of a significant warming trend. Visual estimates indicated that south-facing slopes were nearly clear of snow by May 12, and most of the snow located at the helipad and bench area melted between May 4 and May 16. The water equivalent in the snow at the helipad was measured at 66.3 cm (26.1 in) on April 18.

At 10:33 p.m., on May 15 (Julian date 136), Davis County dispatch reported an alarm originating from E3. Printed data indicated a cumultive downslope movement of 7 mm (0.28 in) between 4:00 p.m., May 15 and the time of the alarm. By 1:00 a.m., May 16, the displacement was 11 mm (0.43 in) and by 5:47 a.m., it was 19 mm (0.75 in). From May 16 to May 18, the rate of separation at E3 averaged 1.5 mm/hr (0.06 in/hr) and increased to 2.0 mm/hr (0.08 in/hr) for period May 19 to May 21. Thereafter, the rate began to decline.

At 12:16 p.m., May 23, Farmington dispatch received alarms from T1 and T3. Radio contact was made with a nearby Forest Service helicopter and a request was made to inspect the area. The helicopter arrived in time for personnel to confirm a debris flow issuing from the spring area at the lower limit of the slide area. The initial flow from the slide area was described as very small, but the volume of the flow increased substantially as debris continued down the canyon.

Immediately following the alarms, two Farmington City personnel were dispatched. One individual reported to the aqueduct road and the other to the debris basin below the road. The debris flow was first sighted from the road. At the debris basin, clear water was observed, and then for a period of about 30 seconds, a cessation of all flow occurred. Following this event, a 2 m (6 to 8 ft) wall of debris was observed followed 2 to 3 minutes later by a 3.5 m (10 to 12 ft) wave of coarser material. According to the Davis County Sheriff's log, 6 minutes elapsed from the time of the alarms to sighting of the debris flow from the aqueduct road. An additional 6 minutes elapsed from sighting at the road to a report of debris in the basin. Duration of surging was for a period of approximately 1 hour. A new surge was sighted from the aqueduct road at 3:30 p.m.; at 3:36 p.m. an alarm was received from T2. There was a decrease in water flow at 4:04 p.m. followed immediately by a debris flow surge 4.6 m (15 ft) high. By 4:12 p.m. only muddy water was flowing.

Evaluation of printed data confirms that the alarm thresholds for T1 and T3 were exceeded in the printout interval 12:16 p.m. to 12:26 p.m. The record clearly shows that T1 was disturbed first followed by progressive failure of the bank above the springs in which T3 was buried. This failure process continued at least 30 minutes before the bank collapsed. Printed data also confirm an alarm from T2 for the interval 3:36 p.m. to 3:46 p.m.

Field inspection on May 24, disclosed continued movement in the vicinity of extensometer E3, but no visual indication of movement was evident at the

FIGURE 8 Meteorologic and Extensometer Data for Rudd Canyon

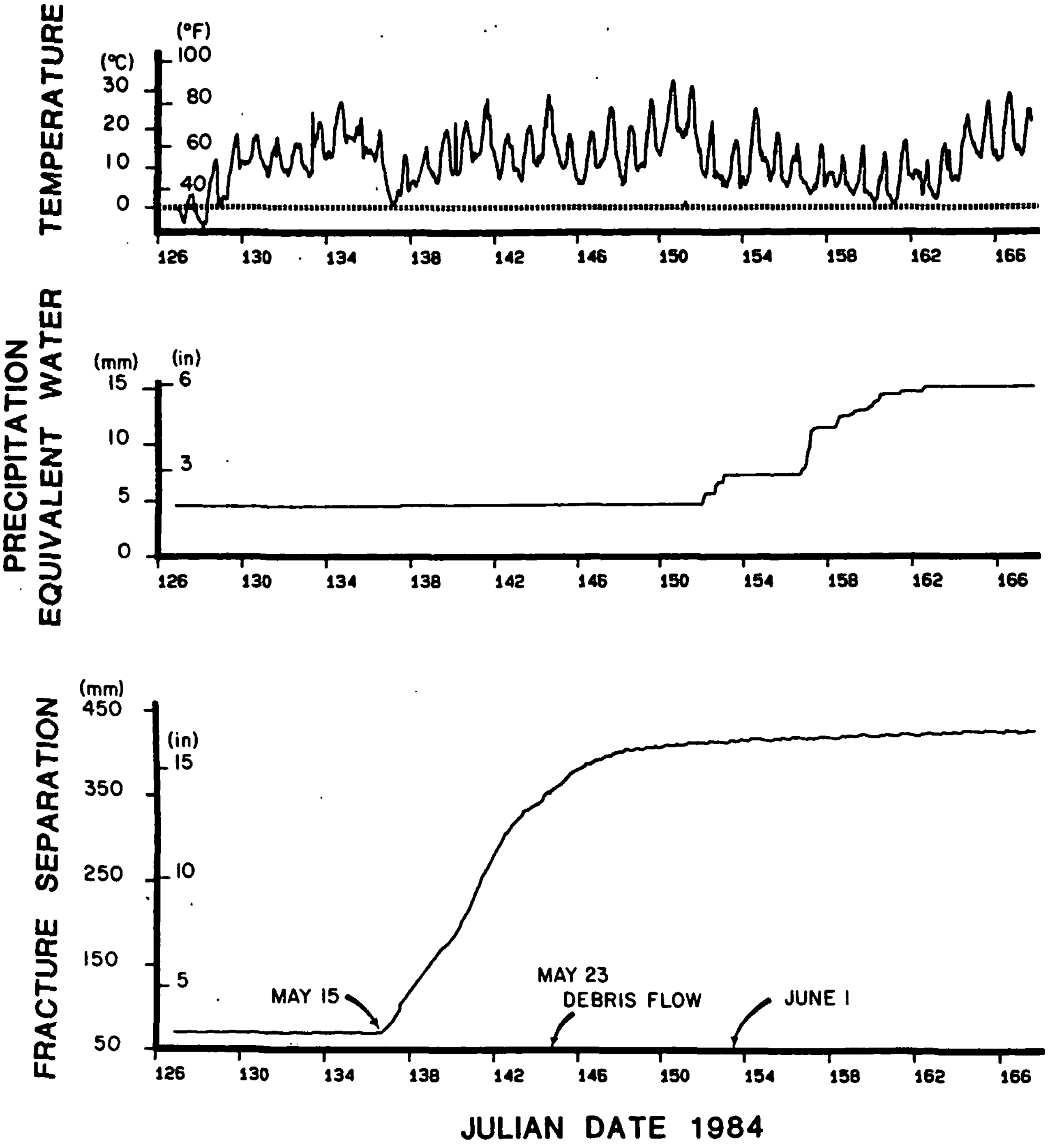
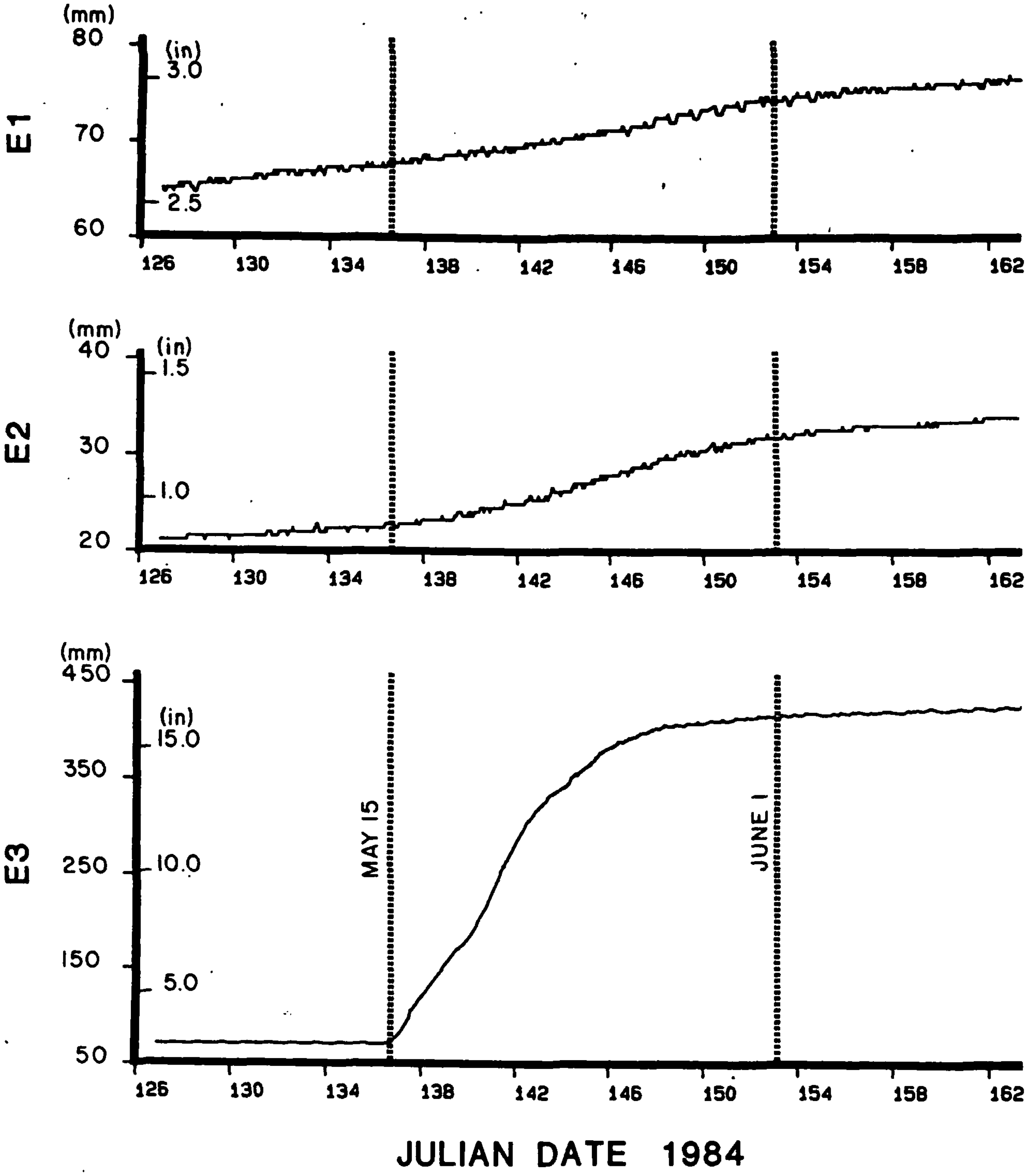


FIGURE 9 Comparison of Extensometer Readings for the Rudd Canyon Site



remaining installations near the top of the slide. Inspection of the lower area confirmed the sequence of events as reported above. The inclinometer T1 was located very near the stream immediately below the spring issuing from the colluvium. In this position it was the first to encounter a discharge of debris from the springs. T3 was located approximately 8 m (26 ft) behind the crest of the steep slope above the springs and responded to subsequent failure of the bank. Apparently, the successive flows were not high enough to reach T2 until the 3:36 p.m. episode. T2 was removed abruptly as indicated by the position of the connecting electrical cable.

It is significant to note that rainfall of 3.8 cm (1.5 in) in a 9-hour period, as recorded in the telemetry data, had no noticeable effect on fissure separation or slide reactivation.

Field estimates indicated that 460 m^3 (600 yds^3) of earth were removed from the north slump block in the vicinity of T3. The volume of material deposited in the basin as of May 24 was approximately 9150 m^3 (12,000 yds^3). These figures indicate that 95% of the debris originated from the stream channel where it had been accumulating over the preceeding 12 mounths (Kaliser and McCarter, 1984).

Telemetry data disclose no movement at either T4 or T5. Data from E1 and E2, however, show a response similar to E3 but much less pronounced (see Figure 9). All three curves disclose a displacement rate transition beginning about May 15. The prominence of the transition appears to be a function of distance to the drainage feature previously identified. As indicated, E3 is located near the apex and within this feature, and it displays the most prominent transition. Abatement of motion at E1 and E2 is not obvious until about June 1. The trend towards improving stability at E3, however, is well developed prior to this date. These observations suggest that the time required for recovery is, in part, related to the volume of the affected mass.

CONCLUSIONS

The objectives of this project were to explore the usefulness of surface deformation measurements in identifying precursory events leading to gross slope failure, to develop instruments capable of surviving the severe climatic environment present in mountainous terrain, and to determine if such instruments can be maintained during the winter-spring transition.

Reactivation of surface extensional fractures is undoubtedly related to a decrease in effective soil strength precipitated by rapid infiltration of snow melt. If the reduction in effective strength is related to a rising phreatic surface, as it appears to be, installation of piezometers may be a more direct method for detecting deteriorating conditions. Strategic placement of these instruments, however, is not obvious. Observations regarding discharge points relative to debris slides, spring fluctuations, soil stratigraphy, and slide morphology made during this study clearly indicate complexities in groundwater distribution that will not be easily comprehended, particularly over any appreciable areal extent. A comprehensive program to identify typical groundwater regimes associated with debris flow source areas would facilitate development of the best strategy for deployment of piezometers. In the meantime, monitoring surface deformation appears to be a viable technique for defining the critical period in which debris flows are most likely to occur. Data from two of the three sites indicate that the beginning of the critical period is defined by the transition from little or no movement to active displacement across extensional fractures. Once displacement returns to the pre-transition rate, danger of a debris flow is apparently over for the season.

The Rudd extensometer developed for this study operates satisfactorily as long as the span is limited to 12 feet, the trend of the extensometer parallels the downslope vector, and the compacted snow cover does not exceed 4 feet at 43% density. Maintenance is possible but difficult in remote mountaineous terrain and is warranted only where monitoring information is needed for scientific purposes or where it is essential to provide added protection for down-slope communities.

ACKNOWLEDGEMENTS

The success of this effort is, in large measure, due to dedicated people in various agencies including the Division of Comprehensive Emergency Management (CEM), Wasatch National Forest, Utah Engineering Experiment Station, University of Utah Research Insitute (UURI), Salt Lake County Commission, Salt Lake Water Department (SLWD), Davis County Commission, Davis County Sheriff's Office and City of Farmington. The authors would like to extend sincere appreciation to the students in the Department of Mining Engineering, University of Utah, specifically Robert Cameron, Jess Kelley, Charysse Menig and Rex Simpson for their dedication to this project. We would also like to acknowledge the active participation of Robert Kistner, formerly of CEM, and Dan Schenck, SLWD. Dale Green and Steve Olsen, UURI, also deserve special recognition for development of innovative telemetry and data processing equipment vital to the success of this project.

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REAL-TIME SLOPE MONITORING USING A DEDICATED HOME COMPUTER

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Abstract. A unique telemetry system was developed to monitor potentially unstable natural slopes above a residential area. Continuous interpretation of data transmitted from remote movement-sensitive devices and immediate communication of signficant changes to emergency personnel were made possible by a readily available "home" computer. Even though the computer based system was originally developed for a non-mining application, it could be used with little or no modification to monitor ground control instrumentation in open pit and underground situations.

Introduction

Unusual climatic events beginning in 1982 and continuing through the spring of 1983 were responsible for the worst statewide disaster in Utah's history. In the mountains east of Salt Lake, seasonal snowfall through May 19, 1983, was recorded at 20.45 m (805 in), well above the average of 12.12 m (477 in). Temperatures rose abruptly in May, sending torrents of water down the canyons and into the population centers along the Wasatch Front. Resulting floods, dam failures, landslides, and debris flows impacted major vehicular roads, rail routes, utilities, agricultural lands, and homes. Damage to these facilities amounted to over $478 million and prompted President Reagan to issue a major disaster declaration covering 22 of the 29 counties in the State (CEM, 1984).

Landslides were numerous and of diverse types, including debris flows. A debris flow is a fluid mass composed of vegetation, gravel, silt, clay, and water, with a consistency of wet concrete. They frequently begin as shallow landslides on steep mountain slopes and travel quickly (1-3 m/sec) (Pierson, 1984) down the stream beds to the valley bench lands below. They occur with little apparent warning and can be very destructive!

The city of Farmington, located approximately 32 km (20 mi) north of Salt Lake City, was inundated by a 1983 Memorial Day debris flow. Cool temperatures produced a one-month delay in melting of the snow pack on the mountain slopes immediately above the community. Late in May, the equivalent water content of the snow pack was 131.6 cm (51.8 in), 400% of normal for this time of year. During the period May 21 to May 30, peak daytime temperatures soared to an average of 84°F, sending a virtual river of mud and boulders down the steep (41%), nearly straight Rudd Canyon directly into the northern subdivisions of Farmington. The first surge destroyed five homes and severely damaged 13 others (Kaliser, 1983; CEM, 1984). Subsequent surges caused damage to an additional 17 homes and deposited 69,000 m^3 (90,000 yd^3) of debris over 78,000 m^2 (19.3 acres) (Jeppson, 1984). Fortunately, no loss of life occurred.

The disastrous events of spring 1983 left little doubt that similar episodes would occur in the future. Erosion, development of deep fissures, and soil deformation surrounding the 1983 landslide sites set the stage for renewed activity in 1984. In addition, unusually high precipitation for the summer and fall months of 1983 indicated that the wet cycle was not over.

In order to help mitigate the consequences of future slides in this area, a debris basin was constructed at the mouth of Rudd Canyon and a system was developed to provide continuous monitoring of a potentially unstable area on the mountain slope above Farmington. The balance of this paper is devoted to a description of the monitoring system and its performance during the 1984 flood season.

Project Description

Project tasks included: designing and constructing suitable devices to detect soil deformation, installing the devices at a remote site, developing a suitable telemetry system and establishing a real-time monitoring technique capable of detecting rapidly changing events. The following paragraphs briefly describe the transducers used to detect slope movement and deployment strategy. A more detailed description is provided concerning the multiplexer, especially designed for this project, and the computer system and software which made real-time monitoring possible.

Field Instrumentation

Monitoring relative movement across surface fractures and anticipated zones of rupture has proven useful in mitigating adverse impacts of landslides (Kennedy, et al., 1969; McCarter, 1976; Larocque, 1977; Campbell and Shaw, 1979). Numerous innovative techniques and devices have been developed and some equipment is commercially available. However, at the beginning of this project no devices were available which could survive the heavy snow loads of an alpine winter and subsequently detect surface soil deformation during the critical winter-spring transition. For this reason, considerable effort was expended in the design and construction of a suitable extensometer (McCarter and Kaliser, 1983). This device consists of a 3.7 m (12 ft) length of rectangular steel tubing, an enclosed rod, and a mechanical linkage connecting the rod to a precision potentiometer. One end of the extensometer is attached to the relatively stable side of a fracture, and the enclosed rod is attached to the unstable side. As movement across the fracture occurs, the rod is extended, resulting in a change in electrical resistance of the potentiometer proportional to the magnitude of separation. The extensometer design also includes a pendulum potentiometer which allows measurement of the inclination of the extensometer and calculation of horizontal and vertical components of movement for the downhill anchor relative to the uphill anchor.

In addition to extensometers, commercially available inclinometers were used to detect gross movement. Some were buried at shallow depth to detect progressive development of slide boundaries while others were mounted on the surface in the path of potential slide debris. The surface-mounted devices were intentionally placed where they would be destroyed or disrupted in the event of a debris flow.

Field Site

The zone of initiation for the 1983 debris flow is located in the drainage channel of Rudd Canyon at an elevation of about 2110 m (6925 ft). This site is approximately 2440 m (8000 ft) east and 600 m (2000 ft) higher in elevation relative to the community of Farmington. The slope in this zone consists of colluvium derived from metamorphic rocks of Pre-Cambrian age covered by a well-developed organic soil. Clay minerals derived from weathered indigenous rock are locally abundant.

The zone of depletion and associated detached masses are shown in Figure 1. Several incipient slumps are located north of the main headwall and extend downward along the northern flank of the excavated zone. An extensional fracture begins in the zone of incipient slumps and terminates in the springs area near the bottom of the slide. This feature defines the arc-shaped boundary of the slump block. This detached mass contains at least 6100 m^3 (8,000 yd^3) and perhaps as much as 76,500 m^3 (100,000 yd^3), depending on the assumed depth. Concern over potential instability of this block provided the primary motivation for the monitoring effort.

Installation of three extensometers and five inclinometers began on November 16, and all devices were deployed with exception of the telemetry system by November 19. The three extensometers (designated as E1 through E3) were established along the extreme uphill boundary of the disturbed zone. Two inclinometers (designated as T4 and T5) were positioned immediately behind the headwall scarp to detect potential uphill progression of the excavated area. Inclinometer T3 was positioned immediately above the northern boundary to detect potential collapse of the escarpment in the springs area. All inclinometers were buried approximately 0.3 m (1 ft) below ground level with exception of T1 and T2. These instruments were mounted on the surface where they would be swept away in the event of a debris flow issuing from the springs area or other location higher in the disturbed zone. Signal cables were routed from each device to the helipad where the multiplexer, radio transmitter, and meteorological equipment were installed in April 1984.

System Components

Figure 2 is a schematic diagram illustrating the components of the telemetry system. As shown, the signal from each remote sensor, meteorological device, or system monitor was processed by a multiplexer and transmitted by a 145 mw radio to a repeater located approximately 3 km (1.9 mi) westward from the field transmitter. The signal was then retransmitted to the Sheriff's Office located in Farmington. The receiver system at the Sheriff's Office incorporated a modem which interpreted the signal and presented the data to a Commodore 64* computer located in the radio dispatch room of the Sheriff's Office. The computer was programmed to compare the signal received from each device with upper and lower threshold limits. If any reading fell outside acceptable limits, audible and visual alarms were generated by the computer. The dispatchers on duty were instructed to respond to alarms by immediately notifying emergency personnel. The computer also served to store incoming data and periodically record the values on a dedicated printer and automatically transfer values via telephone lines to a larger computer at the University of Utah. The following paragraphs provide greater detail concerning the system components and software developed for this process.

Multiplexer Design

Commercial devices are available for acquiring and transmitting data by radio communication links. This particular application, however, required circuitry which could collect data on a continuous basis, present the data in a format suitable for radio transmission and computer interpretation, and operate on limited battery power for extended periods of time (up to 18 months). In addition, a multiplexer was needed which could accommodate long signal cables (500 to 1000 ft), operate in an environment where electrical storms are common, and provide an excitation signal which would inhibit corrosion at electrical junctions. An operating device with all these capabilities was required within a very short period of time and on a limited budget. The University of Utah Research Institute accepted the challenge and met all requirements by designing and constructing the circuit shown in Figure 3.

The diagram shows 2 of a possible 16 remote sensors which are energized by 437 Hz alternating current. The alternating current and transformer isolation are used to reduce direct-current, corrosion effects, and limit damage from nearby lightning strikes. A synchronous rectifier incorporated in the multiplexer converts the signal from the output transformer of each remote sensor to a corresponding direct current value for further processing. All nearby devices, including the rain gage, temperature probe, and system status indicators, are multiplexed directly to the analog-to-digital (A-to-D) converter.

The counter-sequencer serves to sequentially activate and present the analog output of each sensor to the A-to-D converter. After each conversion, an end-of-conversion signal from the A-to-D chip automatically increments the counter sequencer, thus selecting the next sensor. The converter changes the analog signal to an equivalent 12-bit digital representation. The parallel data generated by the A-to-D converter is presented to a universal asynchronous receiver/transmitter (UART). The UART and A-to-D converter are matched units with automatic handshaking control lines to first send the eight least significant bits, then the remaining four most significant bits. After each conversion by the A-to-D, the UART transmits the 12 bits serially to the modulator-demodulator (modem). This device converts the presence or absence of a bit to a low or high tone suitable for radio transmission. A cycle through all sensors is completed three times per minute on a continuous basis.

All circuitry and the radio transmitter were housed in two electrical boxes and sealed in a buried drum along with five 1100 ampere-hour Carbonaire batteries. These batteries provided the 80 ma at approximately 14.5 volts necessary to power the multiplexer and radio transmitter. The buried enclosure protected the circuitry and batteries from temperature extremes.

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* Identification of brand names in this paper does not imply endorsement by the University of Utah or the authors.

Dedicated Computer System

One unique aspect of this project involves the selection of a readily available computer to process vast amounts of data and provide continuous evaluation of the status of several monitoring devices. The selection of a "home" computer system for this purpose incorporates low cost along with tremendous flexibility.

The home computer incorporates several features which makes it ideally suited for monitoring. It has the capability of generating sound and video images especially useful in attracting attention of the user. It can control peripheral devices such as a printer, data cassette, disk drive, or modem to record or transfer data. Most importantly, the home computer can be programmed in BASIC, thus allowing mining and geotechnical engineers to develop processing algorithms tailor-made for specific applications. Furthermore, these algorithms can be changed at will. Once the sensors are established and the computer system is operational, the engineer is free to change the way the system receives, processes, and displays data without redesigning electronic circuitry. This advantage is particularly useful in geotechnical monitoring where complete and practical design of an integrated system is usually not possible until some data is actually recorded and evaluated.

An additional advantage of the home computer in monitoring is that many people now have access to, and regularly use such systems. This familiarity greatly reduces the barriers which previously existed in using nontechnical personnel in the monitoring effort. With a little orientation, dispatchers, security guards, hoist operators, etc., can provide a key role in notifying appropriate personnel when a system detects significant changes in sensor status. The skill of the engineer in developing user-friendly software, of course, has an important bearing on overall success. Properly written software can produce a type of computer "game" with very practical, and perhaps critical consequences.

The home computer system selected for this project consisted of a Commodore 64 computer, model BT120A1 Zenith video monitor, model BX-80 BMC printer, model C2N Commodore Datassette, and a model 1650 Commodore Automodem. The monitor provided a means to visually inspect each data transmission and access various options incorporated in the software. The printer provided a permanent, hard copy for data, and the Datassette contained a tape with a backup copy of the system software. This copy was necessary to boot the system in the event of an interruption in the power. The modem served to transfer stored averages to a larger computer system at the University of Utah. The total cost of the dedicated computer system was under $1,000.

All components were used without modification with exception of the computer. It was necessary to sever the printed circuit traces to the B and C contacts of the user port. Wires were then soldered directly to the severed traces and terminated at a miniature audio plug installed on the computer housing. This modification allowed access to two independent modems. The audio plug served as a port to continuously read data from the radio receiver, and the conventional user port allowed the C64 to periodically write processed data to a host computer.

Data Processing Software

The information displayed on the video monitor is presented in Figure 4. As can be seen, 12 channels are listed representing the three extensometers, three inclinometers attached to the extensometers, and the five independent inclinometers. The remaining channel (#3) was connected to a "dummy" sensor to provide a system check. Four items of information are tabulated for each channel: the low limit, current value, high limit, and alarm status. All data in the tabulation are integers representing the corresponding analog value in digital form. Each integer listed under current value is mathematically related to the magnitude of sensor signals presented to the A-to-D converter. Since the converter outputs each signal in the form of a 12-bit word, the integer may assume any value from 1 to 4096 (2^{12}). The alarm status is either "on" or "off". In the "on" position, any current value which falls outside the acceptance band will activate an audible alarm. In the "off" position, no audible alarm is generated. The "off" position is used to deactivate a given channel without affecting the audible alarm capability of the remaining channels. In addition, precipitation, temperature, reference voltage, battery current, battery voltage, and Julian date and time are displayed below the tabulation. A flowsheet for the software developed to process the data and generate this display is shown in Figure 5.

The flowsheet begins with a block immediately below "START" which generates a seven-part menu. Items on this menu include:

1. RUN PROGRAM
2. SET LOWER LIMITS
3. SET UPPER LIMITS
4. TURN OFF ALARM
5. SET DATE
6. SET TIME
7. TRANSFER DATA

Pressing the corresponding number on the computer keyboard transfers control to the top of one of the seven branches shown on the flowsheet. When completed, all options return the user to the menu with exception of option 1. This option runs continuously until the program is stopped by pressing "RUN/STOP" on the keyboard. To change thresholds, to turn alarms off, to change the date and time, or to manually transfer data, it is necessary to halt the monitoring process and then restart the program.

Before exercising option 1, it is necessary to initialize the date, time, and limit values. For this project, the Julian date (cumulative days since the beginning of the year) was used to simplify the date algorithm. Incrementing dates and restarting the hour designation after 24:00:00 were accomplished automatically. Unfortunately, commands involving the printer and modem interrupted the internal clock and caused a net loss in time. This problem was overcome by adding 6 minutes to the clock reading at midnight of each day.

The limit values are set by selecting 2 or 3 from the menu list. These options ask the user for the channel number and an integer representing the desired analog limit. As shown on the flow diagram, the acceptable range for the lower limit is 43 to 2800. If the user's response to the menu prompt does not fall in this range, the software asks for another limit value. Likewise, if the upper limit does not fall within the interval 43 to 3000, the prompt is repeated.

Important values, such as date, upper and lower limits, hourly averages, alarm settings, etc. are placed in the upper portion of the computer's memory (addresses 49152 - 53247). This portion of memory is not cleared when programs are started. Use of these addresses allows changes to be made in selected values without destroying the remaining settings.

Once all initial values have been specified, the monitoring process is initiated by pressing the digit "1". Control is then shifted to the top of column 1 on the flowsheet. The first time through this branch, the value in address 49284 is zero; consequently, the pointers and accumulation variables are reset to initial values. Execution of the program is then delayed until a "break" character is received from the transmitter indicating the start of a data set. The computer then reads 43 bytes of information and checks to see if bytes 32 and 33 are equal. If not, a transmission error has occurred, and the program waits for the next data set before proceeding. If the two check bytes are equal, the computer is instructed to save the last 38 bytes in upper memory. A sequence of commands is then executed which updates the video screen with the current values of all measured parameters along with the threshold settings. This update is accomplished three times per minute.

If any of the current values for the sensors fall outside of the acceptance band, the sensor value is printed in reverse video. In addition, the current value is combined with previous values received. If the time in minutes is divisible by 10 (i.e., every 10 minutes), all current sensor values are printed. If the data set is the first one received on any given hour, the computer prints the preceding hour's average for each sensor, saves these averages in upper memory, and resets all of the accumulation variables to accept values for the next hour.

As previously indicated, a sensor value which falls outside of the acceptance band generates a visual alarm in the form of a reverse video image. This alarm is not likely to attract attention, so the final process in column 1 is to generate an audible alarm, but only if the acceptance band is violated in two consecutive passes. Should this condition occur, not only will the audible alarm be generated, but a message will be printed giving the channel number, sensor value, and time of the alarm. Finally, the computer looks at its internal clock, and if the current time is 5:00 a.m. (or other specified time) the control is automatically routed to column 7 for data transfer. Once the transfer is completed, the system waits for the next break in the data stream before beginning the process over again.

Column 7 outlines the process of transferring the saved hourly sensor averages over a commercial telephone line to a PDP 11/34A located at the Mining Engineering Department of the University of Utah. As mentioned, transfer of control to this column of the flowsheet is automatic, but it can also be initiated manually. First, the computer halts the data collection sequence if it has automatically entered the transfer mode. Next, it dials a preprogrammed telephone number and waits for an answer. If the computer fails to connect to the host, one of two alternatives occurs. If the computer has automatically entered the transfer mode, it continues monitoring data. If the transfer was initiated through the menu, control is returned to the menu. If the link succeeds, the C64 transfers all stored data, resets the variables which indicate the number of data points to transfer, and returns either to position "A" or "B" on the upper portion of the flowsheet.

The C64 and this version of software have the capability of storing about 100 hours of information. If transfer is not made within this 100-hour window, the pointers will be reset, and all stored data will be lost.

Data Evaluation

The C64 provided the means for continuously monitoring the status of each sensor relative to established limits. Initial selection of these limits was somewhat arbitrary, but development of a data base over a period of a few days permits refinement as suggested in the lower right hand corner of Figure 2. This portion of the figure shows a closed loop involving the C64, the PDP 11/34A, and "DATA ANALYSIS", and illustrates the interactive capability of adjusting system parameters based on trends in the data.

The function of the PDP 11/34A was to store hourly averages in a two-dimensional array defined by device number and time. Auxiliary software permitted review and plotting of this data for any desired device for any desired period of time.

An example of how this capability was utilized is presented in Figure 6. Each data point represents the hourly average total displacement for extensometer E3 (see Figure 1) as a function of time for the period May 20 through May 23. The upper limit of 695 (integer equivalent to 283 mm) for this device for midnight on May 20 was determined by extrapolating the 11 data points acquired between midnight, May 19, and noon, May 20. The limit was actually set just before noon to cover the subsequent 12-hour period. Since no increase occurred in the rate of extension, no alarms were generated before the next update. Just prior to midnight on May 20, an update was obtained yielding 12 additional hourly averages which were used to derive the upper limit of 744 which was established just before midnight for the subsequent midnight-to-noon period. This procedure of reviewing historical data and resetting limit values was followed until the rate of movement at E3 subsided.

Initially, a decision was made to establish cumulative movement as the criteria for generating alarms. This decision proved to be a good one, but the relatively large displacement which occurred at E3 may have been monitored more conveniently by establishing limits based on rate of extension rather than cumulative extension. This provision could be added to the existing system by simply modifying the software.

System Performance

A detailed analysis of data obtained from the Rudd Canyon slide area will not be presented in this paper. Those interested in precursory events leading to instability of natural slopes are referred to a previous publication (McCarter and Kaliser, 1984). It is instructive to note, however, that little or no movement was detected during the winter months. The first indication of instability was detected at 10:33 p.m., on May 15 when the Davis County Sheriff's dispatchers reported an alarm originating from E3. Between May 15 and May 21, rates of separation of up to 2.0 mm (0.08 in/hr) were carefully monitored. At 12:16 p.m. on May 23, additional alarms were received from T1 and T3, indicating the initiation of a debris flow. Radio contact was made with a nearby Forest Service helicopter, and a request was made to inspect the area. At the same time two Farmington City personnel were dispatched to observe conditions at the mouth of the canyon. The helicopter arrived in time to confirm a debris flow issuing from the springs area at the lower limit of the slide zone. Approximately 6 minutes after the alarm, one of the two City employees sighted the debris flow from the mouth of the canyon. An additional 6 minutes elapsed before the second individual reported debris entering the basin previously constructed to protect the community (Kaliser and McCarter, 1984). The basin contained all debris, and no injuries or major property damage were sustained.

Conclusions

The use of a dedicated personal computer is an extremely cost effective and flexible method for monitoring geotechnical data. It allows processing of data as it is received and facilitates immediate interpretation of trends in a form easily comprehended by the user. The computer also provides a convenient tool for storing and transferring data to be used in more detailed professional evaluations. These advantages and the demonstrated success in monitoring stability of natural slopes in Rudd Canyon suggest several applications for the mining industry.

A computer-based monitoring system would be extremely useful in assessing open pit slope stability and stability of mine waste embankments. In both situations, men and equipment work in a constantly changing environment. Early detection of trends towards instability and communication of potential hazards to personnel in affected areas would be useful in maintaining safe working conditions.

A computer-based monitoring system could be immediately applied to a network of ground stress and/or convergence instrumentation in underground operations. Accumulation of data in a readily accessible and user friendly format would allow operational and management personnel to review short- or long-term trends in the integrity of mine openings. This capability would surely aid operational planning and help maintain safe conditions.

With the current economic conditions, improvements in mining methods, mine planning, production management, and safety are certainly needed. Use of readily available personal computers and associated peripheral devices in helping to achieve these improvements is limited only by the imagination and skill of the engineer.

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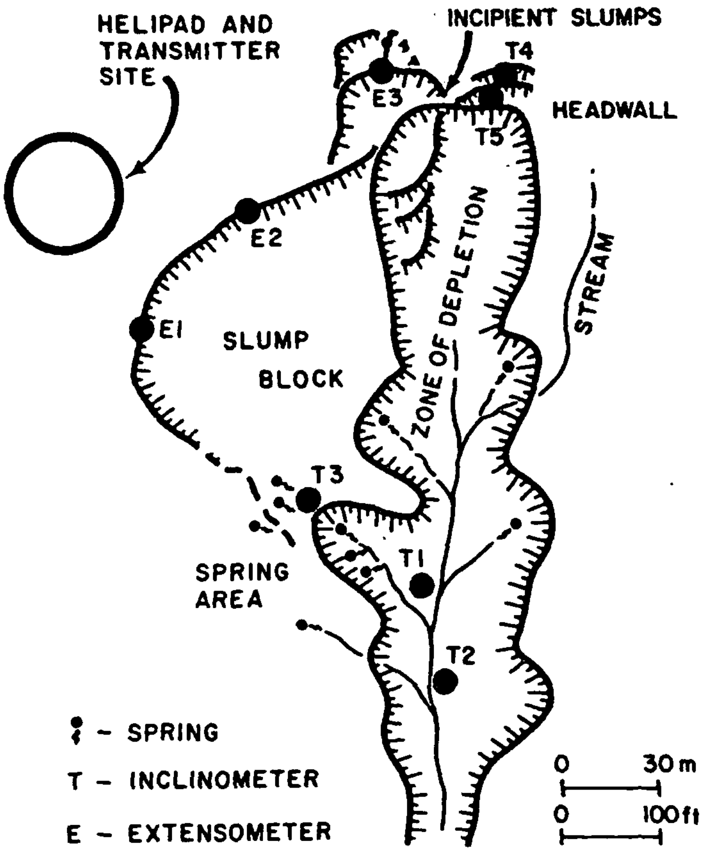


Figure 1. Site of Debris flow initiation, Rudd Canyon, Utah.

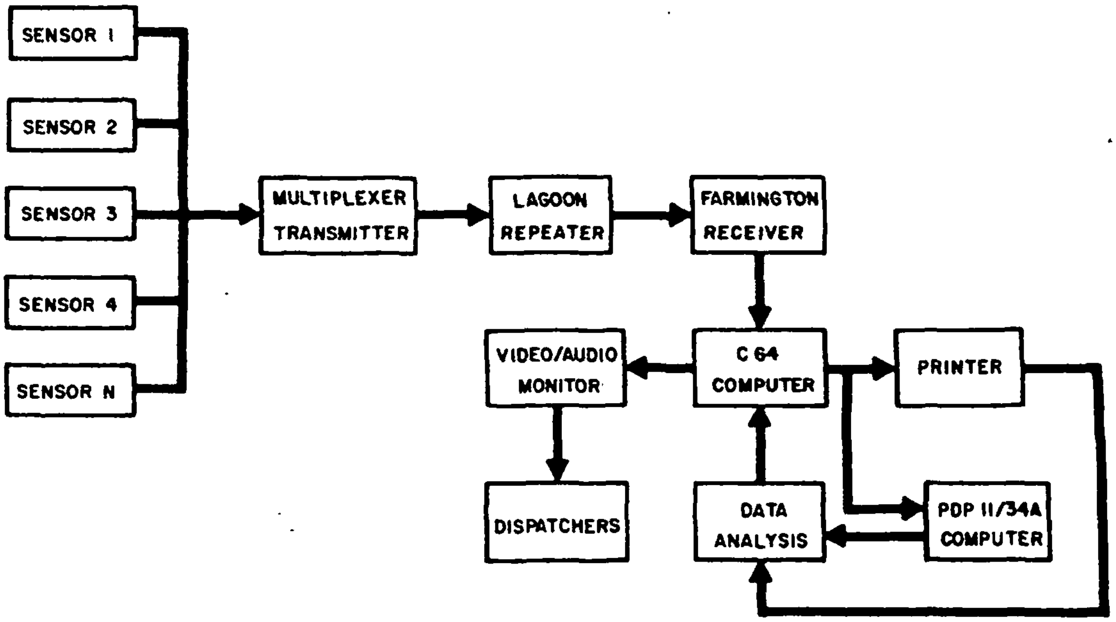


Figure 2. Rudd Canyon monitoring system (after McCarter and Kaliser, 1984).

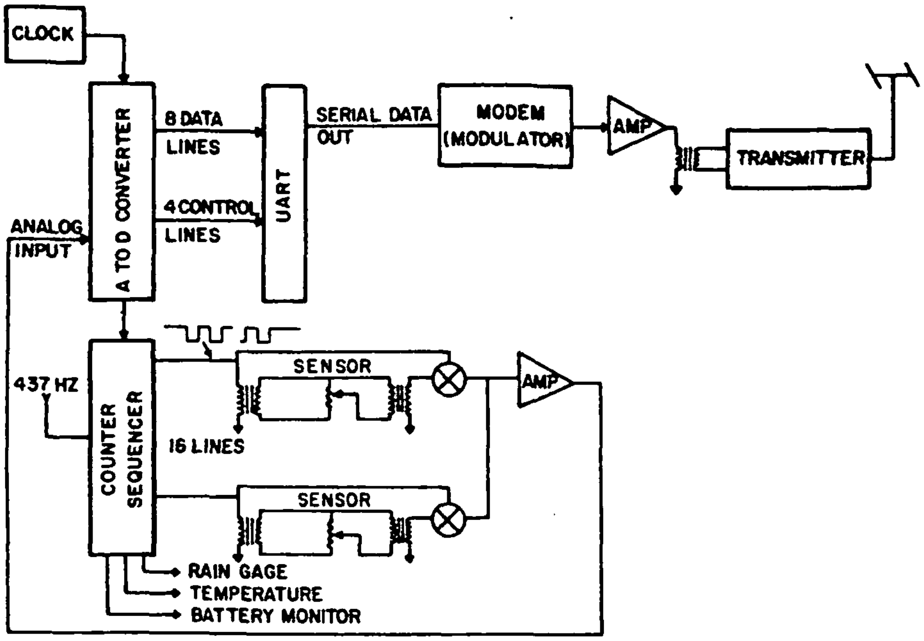
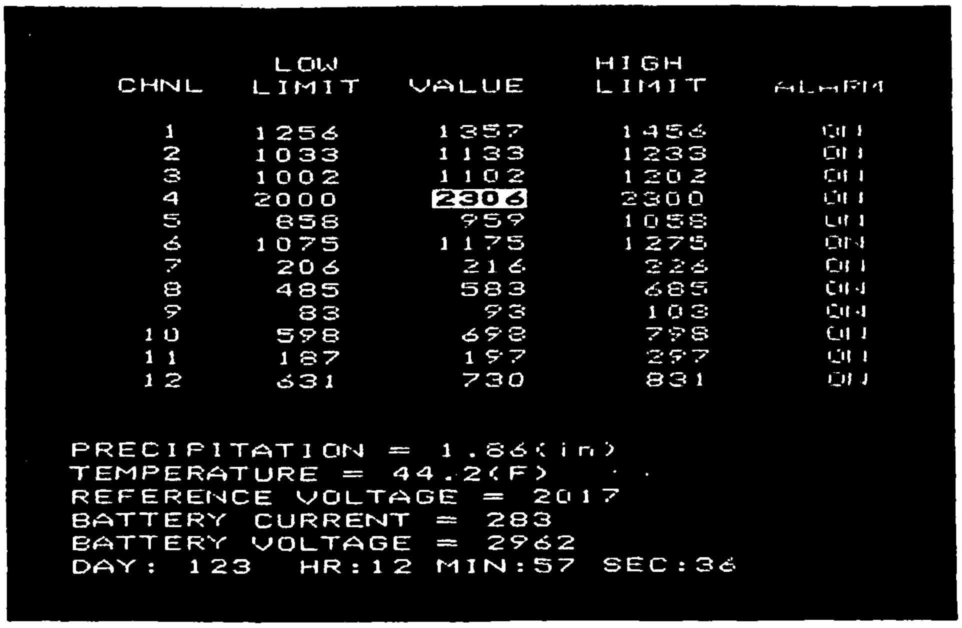


Figure 3. Multiplexer and transmitter functional diagram.



```
           LOW                     HIGH
 CHNL     LIMIT      VALUE        LIMIT       ALARM

   1       1256       1357         1456         ON
   2       1033       1133         1233         ON
   3       1002       1102         1202         ON
   4       2000       2306         2300         ON
   5        858        959         1058         ON
   6       1075       1175         1275         ON
   7        206        216          226         ON
   8        485        583          685         ON
   9         83         93          103         ON
  10        598        698          798         ON
  11        187        197          297         ON
  12        631        730          831         ON


PRECIPITATION = 1.86(in)
TEMPERATURE = 44.2(F)
REFERENCE VOLTAGE = 2017
BATTERY CURRENT = 283
BATTERY VOLTAGE = 2962
DAY: 123  HR:12 MIN:57 SEC:36
```

Figure 4. Video monitor format.

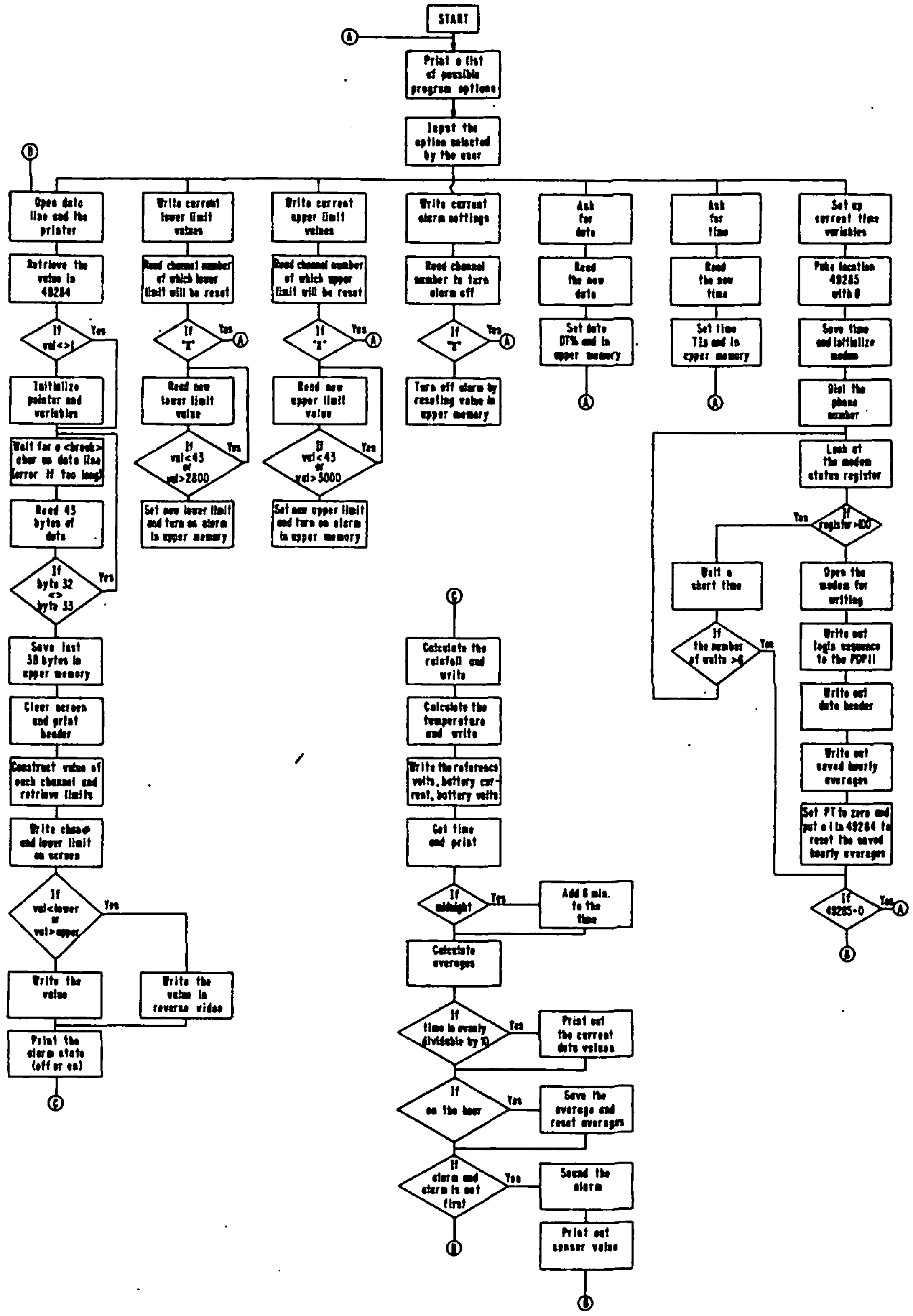


Figure 5. Flow diagram for computer software.

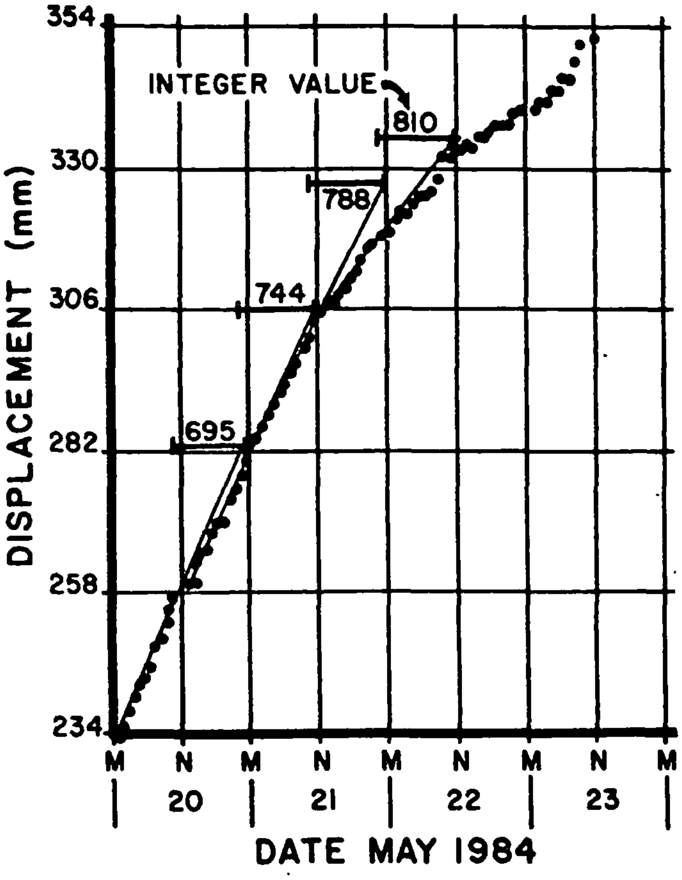


Figure 6. Historical trends used to establish 12-hour upper alarm limits.

Phone Call to Charles Bridges

1. Proposal should come directly his office — if goes thru region, looks endorsed.

   — they may send to region for evaluation — — would look improper.

2. Get it there, assign it to an area of concern
   30 – 90 days for review
   unsolicited proposals not on top priority list for review — usu. ≤ 90 days

Study #2 slide areas

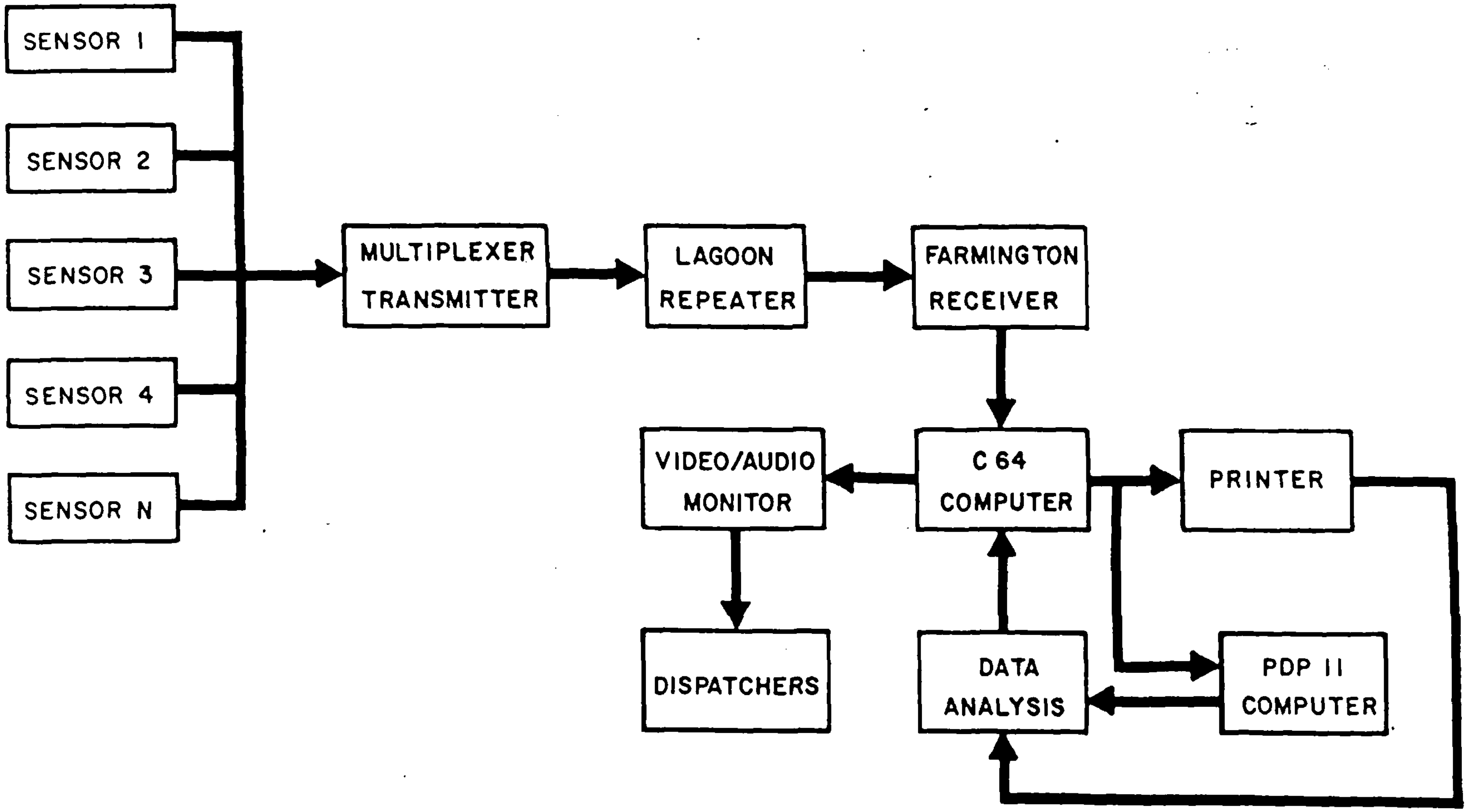
1. what works — what to monitor
2. Improvements to current design —

Green	1/2	Wright	2
McCarter	15		
Sibbett	4		
Nielsen	2		
Foley	~~2~~2		

<u>Bibliographic Search</u>

Landslides
Prediction
Monitoring

TELEMETRY
RUDD CANYON MONITORING SYSTEM



LANDSLIDE MONITORING, PREDICTION AND MITIGATION IN UTAH

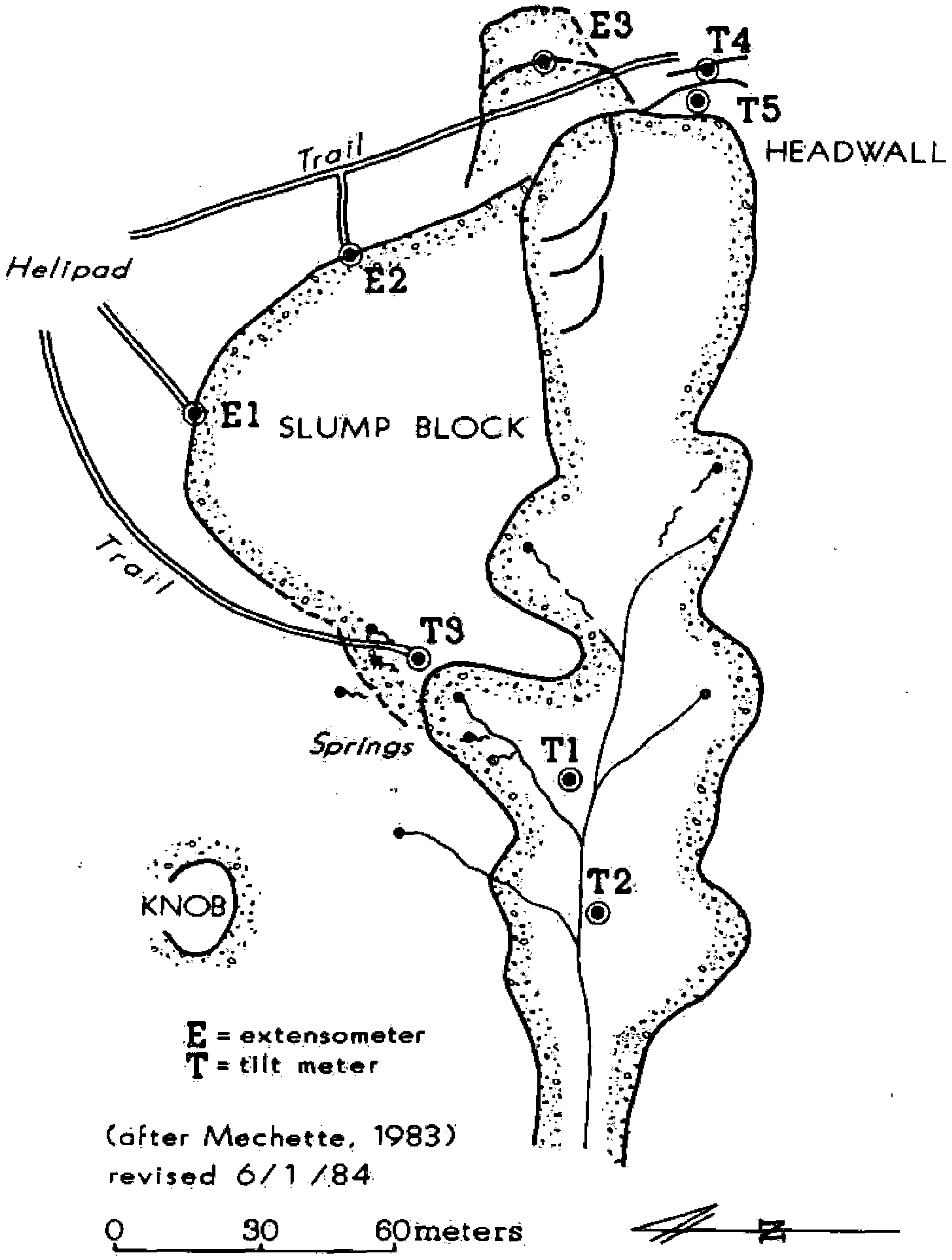
A proposal
to the

State of Utah
Division of Comprehensive Emergency Management
Department of Public Safety

Earth Science Laboratory

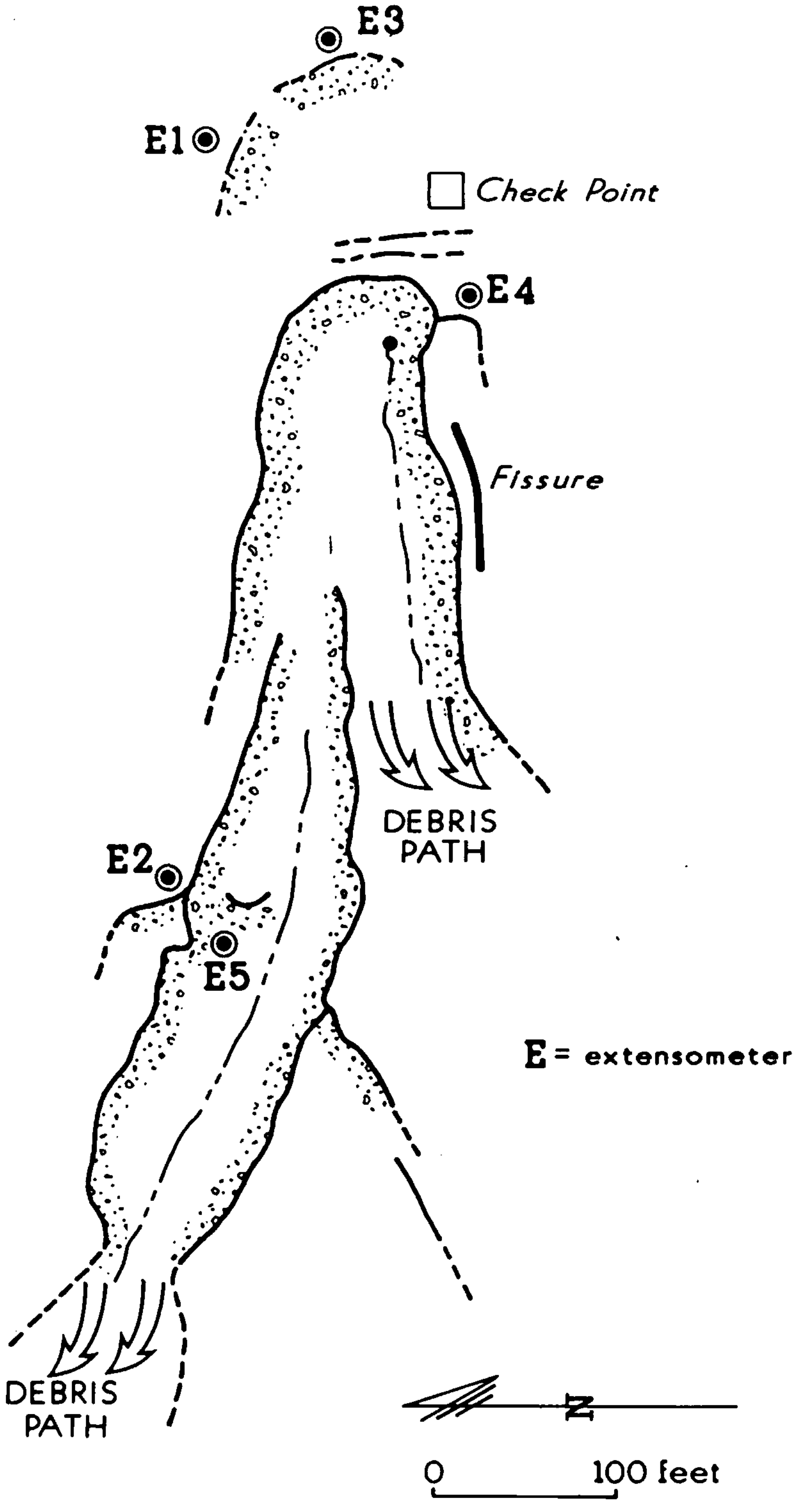
University of Utah Research Institute
391 Chipeta Way, Suite C
Salt Lake City, Utah 84108
(801) 524-3422

LANDSLIDE MONITORING SYSTEM
RUDD CANYON
FARMINGTON AREA

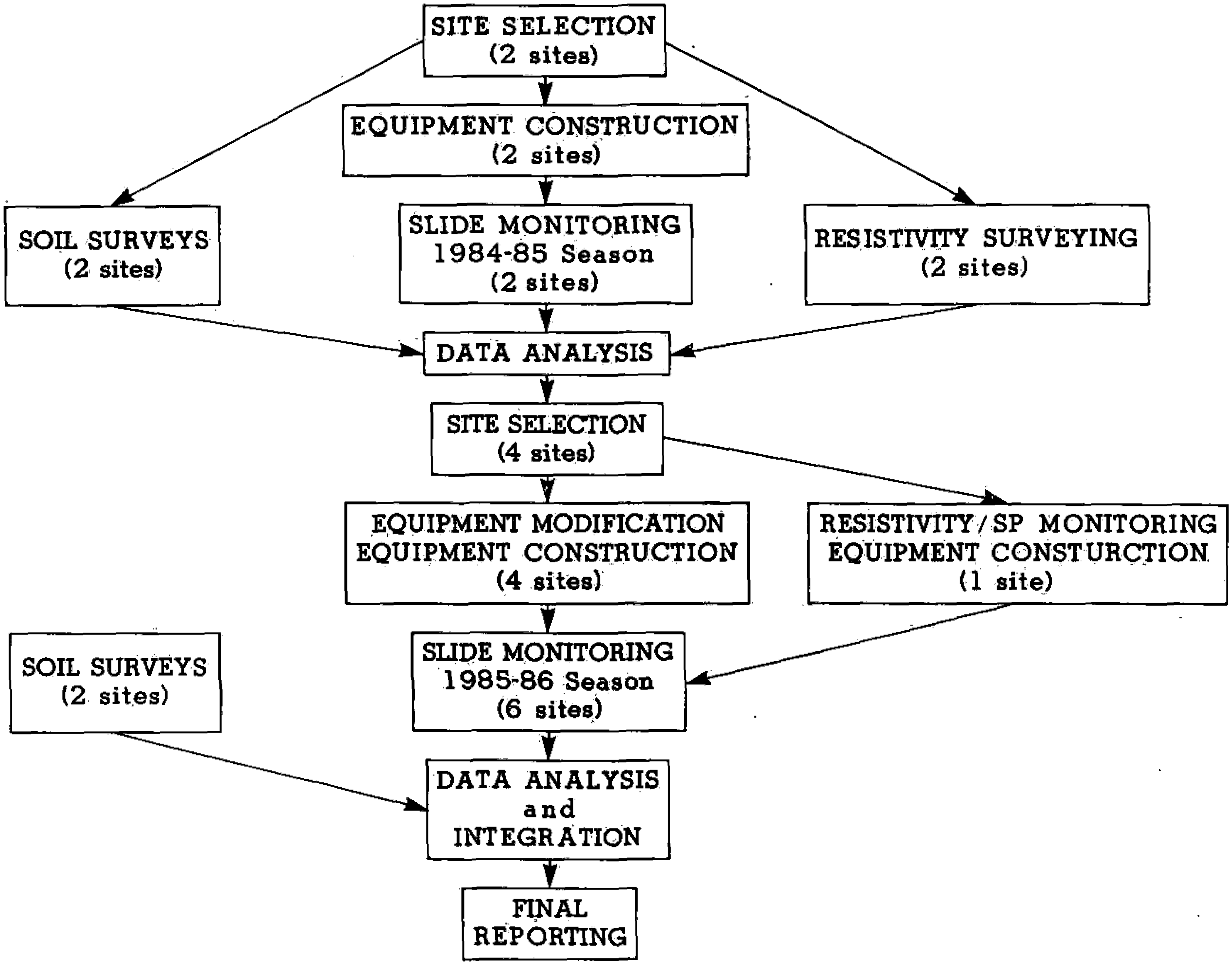


(after Mechette, 1983)
revised 6/1/84

LANDSLIDE MONITORING SYSTEM
REYNOLDS GULCH
BIG COTTONWOOD AREA



LANDSLIDE MONITORING, PREDICTION AND MITIGATION SURVEY



AI's 6 Aug 84

kim - detached blocks left in both?
$ estim. on ls damage (?)
SOW - clean up
tie in geophys better (PMW)
⇒ CHANGES IN OUTYEAR $ W/ CHANGE IN TASK
geol. budget
long term milestone
short term " (review)

clarify who operates

next ed. copies
Rex
Ralph
Joe O.
Dale
Kim
DLN
DF
SHW
PMW
UGMS (who?)

"engineering or non-structural" Joe doesn't like
Text - DLN defns
Joe O. on stabiliz
spell out principal people in text, who's resumes are in back

monitor, then see, then come up w/ more effective way

Budget 50/mo phone lines to computer, unburd.

reference Govs Conf on geol haz more (particularily call for work on ls)

tie many editions together - uniform philos.
mitig.
precursor ident. - pre-mvmt
dynamics

from kim McCarter
5:15 p
2 Aug '84

SCOPE OF WORK FOR 1984/85

The shapes of cumulative displacement curves as a function of time for all areas monitored during 1983/84 are basically the same. During the midwinter months little or no movement occurred. The onset of movement in the spring was abrupt and decelerated rapidly following debris flow activity. The onset of movement correlated well with melting of the snow pack and assumed rise in groundwater levels. The deceleration also correlated well with the assumed decrease in groundwater levels attending liquification of soils immediately preceeding debris flows. The most logical explanation for coincidence of fracture dilatation and debris flows is, therefore, a temporary reduction in effective soil strength caused by increasing groundwater pressure. This is a logical assumtion, but it has not been verified in the field. If the assumption is correct, monitoring fracture dilatation is an indirect means of measuring pore pressure, and perhaps a more direct approach would provide a superior monitoring strategy. Before committing resources to building additional monitoring systems of the type used during 1983/84, additional research should be conducted in Rudd Canyon and Reynolds Gulch to evaluate probable correlations between melting of the snow pack, water infiltration, groundwater levels, fracture dilatation, and occurrence of debris flows. This information should help insure development of the most reliable monitoring methods and eventual development of effective warning systems.

OUTLINE OF TASKS

Phase I Refurbishing existing systems in Reynolds and Rudd
September 1984 - June 1985

1. Approximately one third of the field sensors were lost in Rudd Canyon as a result of the May 23, debris flow. Field instrumentation needs to be constructed and redeployed prior to onset of winter. This task will involve construction of at least two new extensometers, repair of E3 which was dammaged by snow loading, replacement of three inclinometers lost in the slide, addition of a snow pillow to measure snow pack, and addition of at least two piezometers to measure groundwater conditions near E3 and the springs area. During or subsequent to deployment of field instrumentation, the multiplexer developed by UURI should be examined to determine the effect of long term operation and modified if necessary for another field season. In addition, recently acquired radio equipment should be tested and packaged for field operation.

   Required Resources:
   Four inclinometers @ $100 ea
   Three extensometers @ $600 ea
   Four piezometers @ $600 ea
   Snow pillow $500 ?
   Piezometer interface modules $500
   Piezometer cable 2000 ft @ $1/ft
   Modification of existing multiplexer to accept piezometer input. (est. 4 days at Dale Green's rate)

Batteries and misc. hardware $1000
Field installation and spring monitoring
  Dale Green 2 days
  Electronics and computer technician 20 days
  Kim McCarter 6 days @ $400/day
  Field crew of 2 men, 6 days @ $100/man/day
  Helicopter time 10 hours @ $600/hr
  Travel $500

2. All five extensometers positioned in Reynolds were extensively damaged by snow loads. All should be replaced with extensometers similar to those now in Rudd Canyon. In addition to extensometers, at least four piezometers, a precipitation gage, temperature recorder, and a snow pillow should be added to the system. Since water infiltration appears to be an important factor, a simple device similar to a rain gage should be developed to measure water infiltration and added to the system. All data were obtained by periodic interrogation. A telemetry system should be added to insure proper data acquisition during the critical spring period.

   Required Resources:
   Five extensometers @ $600 ea
   Rain gage and temperature probe @ $1000
   Snow pillow @ $500 ?
   Materials for infiltrometers $750
   Materials for telemetry system and computer $?
   Field instrumentation and spring monitoring
   Batteries and misc. hardware $1000
     Dale Green ? days @ rate?
     Electronics technician ? days @ rate?
     Kim McCarter 5 days @ $400/day
     Two man field crew 3 days @ $100/day/man
     Student one year stipend or wage $8000
     Helicopter time 3 hr @ $600/hr
     Travel $500

Phase II Instrument Development and Instrumentation of New Areas

1. Surface mounted extensometers are subject to tremendous loads caused by ice layers within the snow pack. If possible, extensometers (if extensometers prove to be the best choice in instrumentation) should be redesigned to allow burial within the upper soil layers. Development of this device will require construction of a special frame consisting of a split steel shell. One half of the container will be free to move with respect to the other half. The purpose of this device will be to simulate fracture development in unconsolidated geologic materials at a scale approximating actual field conditions. This work will be conducted in the mine Systems Simulation Laboratory and will allow testing and calibration of successful prototypes.

   Required Resources

Materials (Steel plate and structural sections, hydraulic cylinders, pumps etc.) $10,000
Construction labor $6000
Prototype materials $2000

2. The second phase would also include consulting time for siting field instrumentation and supervising extensometer development. Maximum available time is estimated at 15 days at $400 per day.

Budget: First two years (R&D),

1. Consultant : J. M. Olsen	
150 hrs. @ $50/hr.	$ 7,500.
2. Student Time	
1000 hrs. @ $7.50/hr	7,500.
3. Supplies	
Laboratory Supplies	400.
Slope Indicator Tubing	3,000.
4. Computer	3,000.
5. Instrumentation	
Slope Indicator	
Downhole Device & Readout	6,000.
Computer System	12,000.
Portable Soil Sampler	5,000.
Total	$ 44,400.

STATE OF UTAH
DIVISION OF COMPREHENSIVE EMERGENCY MANAGEMENT

DEPARTMENT OF PUBLIC SAFETY
1543 SUNNYSIDE AVENUE
P.O. BOX 8100, SALT LAKE CITY, UTAH 84108
TELEPHONE (801) 533-5271

1896

SCOTT M. MATHESON
Governor

D. P. S.
COMPREHENSIVE EMERGENCY MANAGEMENT
CEM

LARRY E. LUNNEN
Commissioner

LORAYNE TEMPEST
Director

RECEIVED
OCT 1984

October 22, 1984

Dr. S.H. Wood
University of Utah Research Institute
Earth Science Laboratory
391 Chapeta Way, Suite C
Salt Lake City, UT 84108

Dear Dr. Wood:

I have received a response from the Federal Emergency Management Agency Region VIII indicating their action on your proposal for the Landslide Monitoring and Mitigation Program.

As you know, I supported your program and recommended its approval.

I will continue to support your proposal and keep you informed of any developments.

Sincerely,

Lorayne Tempest

Lorayne Tempest,
Director

LT/RFF/eg

"If You Fail to Prepare . . . . . . You Prepare to Fail"

Federal Emergency Management Agency
Region VIII Denver Federal Center, Building 710 Denver, CO 80225

15 OCT 1984

Ms. Lorayne Tempest, Director
Utah Division of Comprehensive
Emergency Management
P. O. Box 8100
1543 Sunnyside Avenue
Salt Lake City, UT 84108

Dear Ms. Tempest:

Thank you for providing me with the proposal, "Landslide Monitoring, Prediction and Mitigation in Utah."

The proposal represents a unique effort beyond the scope of FEMA program funding administered by the Region. Therefore, we are forwarding the proposal to the FEMA National Office for consideration. We will be contacting you as action on the proposal occurs.

We appreciate your continued efforts to address emergency management issues in Utah.

Sincerely,

Alton D Cook

Alton D. Cook
Regional Director

cc: Kenneth Brzonkala, Headquarters
Dr. Art Zeizel, Headquarters

EIVED
OCT 18

1896

SCOTT M. MATHESON
Governor

STATE OF UTAH
DIVISION OF COMPREHENSIVE EMERGENCY MANAGEMENT

DEPARTMENT OF PUBLIC SAFETY
1543 SUNNYSIDE AVENUE
P.O. BOX 8100, SALT LAKE CITY, UTAH 84108
TELEPHONE (801) 533-5271

LARRY E. LUNNEN
Commissioner
LORAYNE TEMPEST
Director

December 10, 1984

Mr. Phillip M. Wright
Technical President
University of Utah Research Institute
391 Chipeta Way
Salt Lake City, UT 84108

Dear Mr. Wright:

Recently we have been contacted by the Federal Emergency Management Agency regarding your proposal for Landslide Monitoring and Mitigation for Utah. They had received the proposal with approval recommendations from this office and the Region Director, FEMA Region VIII.

In order to negotiate directly with the U of U Research Institute, FEMA would like you to submit your unsolicited proposal directly to them. You may restate your proposal to FEMA as it was written, but stated as a proposal to them.

500 C. Street SW

Please address your proposal to the Policy and Evaluations Division, Federal Emergency Management Agency, Washington D.C. 20472, Attn: Mr. Charles Bridges (telephone (202) 287-3822).

We appreciate your interest in this important mitigation effort.

Sincerely,

Lorayne Tempest

Lorayne Tempest
Director

LT/RFF/ecg

LWRIGHT

"If You Fail to Prepare . . . . . . You Prepare to Fail"