Chapter 6

Flood scenarios

6.1 Introduction

This section presents the results of modeling two hypothetical outburst floods from Lake Sarez. These floods are based on the two most probable modes of flood initiation - a breach flood, resulting from overtopping and downcutting of the Usoi landslide dam, and a seiche flood, resulting from a wave generated by a large landslide into the lake. In both cases, arbitrary values for flood volume have been assigned, because existing theory does not permit calculation of an actual probable flood event in either case. Results of an earlier study of the problem conducted by the U.S. Army Corps of Engineers (COE) Waterways Experiment Station in Vicksburg, Missippippi (1998), are presented for purposes of comparison.

6.2 Procedure

Two arbitrary floods were defined for modeling purposes:

- A flood produced by a rectangular breach with width and depth of 500 m. These breach dimensions produce a flood that is in agreement with the COE breach flood at a single point - 200 km downstream from the Usoi landslide dam - where comparison is possible.
- A flood produced by a seiche wave overtopping the dam with an average depth of 50 m over a dam length of 2,000 m.

Two computer software models were used to develop the flood scenarios: 1) the U.S. National Weather Service (NWS) dynamic hydraulic model (Fread, 1984) used by the COE in their flood simulation, and supplied for this study by Dr. Mark Jourdan of COE, and 2) DAMBRK, a commercial version of the NWS software.

Topographic cross sections of the Murgab, Bartang, and Panj River valleys were fabricated based on 1:50,000 Russian Army maps. The locations of the cross sections were largely arbitrary, but generally they were placed as to be reasonably close to villages, as well as to reflect the wide range of cross-sectional topography present in the valleys. The map legends stated that the contour interval for each was 20 m, but inspection showed that some had contour intervals of 40 m. It is assumed that the maps were produced from a smaller-scale series, presumably at 1:250,000 scale, at two different periods, and that contour lines were interpolated from the smaller-scale maps. There are relatively few topographic control points on the maps. The "contour" lines on the Russian Army maps are perhaps more usefully considered as approximations of the actual topography across any given cross section. A Geographic Positioning System (GPS) survey undertaken by the author of this note in June 1999 indicated that valley-floor altitudes and positions of structures, such as bridges, were quite precise. There is no way to evaluate the extent to which this accuracy varies over the total linear extent of the cross section. A total of 19 cross sections was established for the 184 km between the Usoi dam and the village of

Shipad, Tajikistan, the western-most village in the Rushan Rayong (administrative district) of Gorno-Badakshan Province.

The cross sections were measured by opening a scanned version of each map in ArcView 3.1 software. This permitted enlargement of small portions of each map so that individual contour lines could be identified, and followed from the nearest topographic control point. River distance from the crest of Usoi dam to each cross section was measured by the distance measurement function of the ArcView 3.1 software.

6.3 Results

Throughout the 180-km reach of the river system considered in this study, differences between the predicted breach and seiche flood depths are small, relative to the absolute size of each. In either case, the impact of a flood on the villages of the Bartang and Panj valleys, as indicated by the model, would be devastating. Predicted flood depths range from a maximum of nearly 200 m immediately downstream from the Usoi dam to a minimum of approximately 50 m immediately upstream from Shipad for the breach scenario, and approximately 100 m to 30 m for the breach scenario. Perhaps the most significant finding of this study is that the depth of the flood does not decrease continuously with increasing distance from the Usoi dam. For a given flood volume, depth is controlled by valley topography, largely the width of the valley floor and the slope of the valley walls. In the case of the breach flood, a secondary maximum of approximately 160 m occurs in the vicinity of the village of Suponj, approximately 100 km downstream from the Usoi dam, while in the seiche scenario, the maximum flood depth for the entire reach of river considered in this study was at this site.

The cross sections, and the distance to each cross section from the crest of the Usoi Dam are presented in Table 1.

Table 1.

Village	Distance Below Usoi Dam	Elevation Interval (Approx.)	Flood Crest, m (Breach)	Flood Crest, m (Seiche)
Barchidev	16	0-60	73	52
Savnop	23	140	88	82
Nisur	29	50		
Yapshur	31	0-40	95	67
Bardara				
Chadud		0-10		
Basid	65	0-10	113	80
Vorg	71			
Zarjif				
Ajirch	78			
Rajuch	91			
Darjomch	94		96	68
Rawind				
Suponj	102		160	114
Dasht				
Visaw				
Shijez				
Patrud				
Bachu				
Yimptz				
Shojan	138	0-10	55	37
Rushan	147	0-20	67	29
Darushan	153	0-80	67	51

6.4 Discussion

The results of the flood routing of breach and seiche floods from Lake Sarez presented here must be considered indicative, rather than definitive, for several reasons:

- **Debris Flow** — It is probable that a major flood from Lake Sarez will become a debris flow within a distance of a few kilometers or less (Hanisch and Söder, 1999). This will alter the hydraulics of the flood in unpredictable ways.
- **Cross-Section Placement** — Both forms of the dynamic flood-routing model used in this study are sensitive to cross-section placement.

The inclusion or exclusion of a cross section in a model run alters the results in both upstream and downstream directions. While this would not be important in a valley system with relatively uniform topography for extensive river reaches, in the Bartang and Panj valleys the cross-sectional geometry changes considerably over short distances, ranging from narrow gorges a few hundred metres wide to a flood plain more than a kilometre wide

- **Seiche Wave** — At least four methods have been developed for estimating volume and amplitude of a seiche wave (Noda, 1969; Kamphuis and Bowering, 1972; Raney and Butler, 1975, Slingerland and Voight, 1979). These are complex models, with many variables. In general, however, the most important variables considered in each are the kinetic energy of the mass sliding into the water body and the depth of the water body at the point of impact These mathematical models were not used here, due to a lack of information concerning most of the important variables, and are mentioned only to demonstrate the complexity of the problem. For the purposes of this study, it was assumed that the volume of the seiche wave would be approximately equal to the volume of the rock mass entering the lake as a landslide There are at least two major unknowns associated with modeling a seiche wave in Lake Sarez that are not dealt with in the literature: (1) There is no recorded instance of a landslide falling into a water body with a depth of 500 m, (2) A rock slide with a volume of 1 km^3 from the right valley wall above Lake Sarez would, in all probability, form a second major landslide dam approximately 4 km upstream from the Usoi dam (Hanisch and Söder, 1999). This would make the formation of a seiche wave problematical.
- **Breach Development** — The models used in this study simulate erosion-based breaching using a simplified one-dimensional approach by which the shape of breach is predefined as an input parameter (Faeh, 1996). These models are best suited to simulate breaching of man-made earthfill dams, not a complex, heterogeneous landslide dam, such as the Usoi.
- **Embayments** — The flood-routing models do not facilitate the diversion of portions of the flood into embayments, such as would be created by a tributary entering the main river or other major topographic widening within the river system. For this reason, the flood-depth values obtained in this study presumably represent maximum values

6.5 Conclusions

While the results obtained from this preliminary analysis of floods resulting from either an outburst or seiche flood originating from Lake Sarez can be improved considerably by a more detailed definition of the controls on such a flood, it is doubtful that the precision of risk assessment for individual villages in the Bartang and Panj River valleys will show a similar improvement. A fundamental problem is the lack of any empirical data against which to test the results of model scenarios. Values of peak floods will always be driven primarily by assumptions concerning the initiation of the flood, e.g., the height and volume of a seiche wave overtopping the Usoi dam, the rate at which a breach is formed in the dam and the ultimate cross-sectional area of the breach, the extent to which the flood becomes a debris flow, and the dissipation of the flood crest by losses of volume to local embayments The most precise model will be affected by the topographic accuracy of the Russian Army maps used to derive the digital-elevation model used as input. The contour interval of the 1:50,000 maps is given as 20 m This elevational interval is approximately equivalent to the elevation above the flood plain occupied by a majority of the villages of the valleys. Of all the villages in this valley system, only Rorshov and Savnop, near the headwaters of the Bartang River, are clearly above the highest possible flood crest. No amount of improvement in model results will unequivocally demonstrate that all, or portions of, the remaining villages can be considered safe from a flood. Given this fact, it would be irresponsible to base any village-level planning or training on the results of what will continue to be theoretical considerations. The most prudent assumption is that any major flood from Lake Sarez will destroy virtually all villages in the Bartang and Panj River valleys, and extend downstream for at least 1,000 km. Unless additional improvements in flood modeling will prove conclusively that this assumption is incorrect, prudence suggests that the assumption should be the basis for near-term planning for a flood event in the Bartang/Panj valleys.

There is one additional factor that was not considered in this analysis, but which is relevant to continued habitation in these valleys. All considerations to date have been in terms of a flood with an instantaneous peak flow of the order of one million cubic metres per second. It is probable that a simple doubling of the present mean streamflow volume of the Bartang River, perhaps resulting from a small change in the internal structure of the Usoi dam, would destroy portions of the existing road and low-lying villages and agricultural land for more than 100 km below the dam.

Chapter 7
Monitoring and early warning systems

7.1 Introduction

The installation of a monitoring/early warning system for Lake Sarez should be a high priority. In particular, a monitoring system (MS) will alleviate much of the uncertainty that is now associated with the Usoi dam/Lake Sarez hazard. In addition, in case of an outburst flood, an early warning system (EWS) will provide the people living in the villages along the Bartang and the Panj River valleys a better opportunity to save themselves. A definitive approach to the solution of the Lake Sarez problem depends on an efficient EWS, which will be based on the quantity and quality of the field survey data (MS).

Pre-1992 experiences of Soviet scientists and engineers on the Usoi dam/Lake Sarez problem, as well as those since 1992 by representatives of the Government of the Republic of Tajikistan, were presented at a workshop held in Dushanbe on 5 June 1999. The discussion and recommendations presented here stem from information obtained at that meeting and from the field evidence acquired during visits to the site from 6 to 12 June 1999.

7.2 Past experience

Until 1992, studies by Russian and Tajik scientists were directed primarily toward analysis of:

- Geotechnical aspects of the Usoi dam (geology and structural stability).
- Hydrological regime of the lake and of the downstream outflow (seepage flow through the dam to the Murgab River).
- Tectonic/seismic activity of the zone (micro-seismic mapping of the Sarez area).

As a consequence of these studies, new objectives for future activities were developed. However, before these objectives could be implemented, all investigations were brought to a halt by the breakup of the Soviet Union in 1990-1992. During this period, the monitoring, based on visual investigations and some measurements, was not always systematic, due in part to difficult field conditions. The data-acquisition/transmission system was only partially completed. In addition, the early warning system was developed on the assumption that, if there were a breakout of Lake Sarez resulting in a major outburst flood, warning would only be given to people in populated areas along the Amu Darya River, a considerable distance downstream. (Thus, no warning alarm was planned for the villages along the Bartang River immediately downstream from Usoi dam.) Initially, the alarm was to be forwarded to the Moscow headquarters of the Civil Defence Committee. This approach meant that those living in the upper Amu Darya River basin would be informed of the flood by means of telecommunication lines 7 hours after the alarm had been given.

A never-completed alternative to the above early warning system was intended to be installed about 1 km downstream from the first village (Barchidev) on the Murgab River downstream from Usoi dam. (The mathematical model used suggested that the flood wave would reach Barchidev 25-30 minutes after a landslide occurred into Lake Sarez, resulting in overtopping by a seiche wave). The system was supposed to send a signal to the television satellite system "Orbital." This signal would be received at a television center in Dushanbe, and then would be forwarded through a special telecommunication network to the relevant settlements. The effective response time was 2 hours and 54 minutes (54 minutes to warn the population along the river system and 2 hours to evacuate them). The elapsed time obviously would be too great to help the people of Barchidev.

In neither case did the early warning system allow for warning the people of the upper Bartang River, not far downstream from the dam. Instead, the system was designed to warn the population in the reaches farther downstream (along the lower Bartang and the Panj Rivers), as well as to alert the national and Soviet governments of the onset of flooding.

7.3 Current situation

Currently the monitoring system is based on the following two approaches:

- During the summer, and occasionally in the winter, a team of Tajik observers is present at Lake Sarez. In the event of an outburst flood, their responsibilities are to contact the Usoi Master Station (see below) and Dushanbe (Committee on Emergencies of the Republic of Tajikistan) via a radio link. They also monitor the unstable slope on the right bank above the lake and the freeboard at the point of lowest elevation on the crest of the dam (near its right end).
- On the Bartang River (near the village of Nisur) and on the Kudara River (a right tributary to the Bartang) where it enters the Bartang, two hydrometric stations monitor the water levels of these rivers When the rivers rise above a pre-established level, the system sends, via cable connection, an automatic signal to the Usoi Master Station There, a special device receives and analyses the signal to transmit it on to Dushanbe via a robot satellite instrumented for transmission of space data, so that evacuation of downstream villages can be initiated.

The Usoi Master Station, which represents the primary and most complex part of the entire EWS, was originally installed by Russian scientists in 1984, and in 1990 it was improved by adding solar panels and a diesel power supply. The station is situated in a mountainous region (2 km from the village of Savnob and about 30-35 km from Usoi dam) at an elevation of 2,800 m above sea level, which makes it very difficult to access, especially in the winter.

Apart from the satellite transmission system, the Usoi Master Station uses a two-way radio link that connects the Master Station with the Lake Sarez base camp on the left shore of the lake, as well as with the system maintenance centers in Dushanbe and Khorog. The purpose of this element of the system is to assure all staff members that the alarm signal has been received by the control stations.

Near the village of Barchidev, on the Murgab River downstream from the dam, a stream gauge was installed to measure the fluctuation of the volume of streamflow at that point. This gauging station (now abandoned) consisted of both a cableway and staff gauges. It is located immediately adjacent to a footbridge that crosses the Murgab River at Barchidev. A second station was located approximately 400 m upstream from the first. In either case, functioning has now been discontinued or is unknown.

Regarding the above mentioned MS and EWS, the following remarks can be made:

- Visual monitoring performed from the lake base camp cannot provide a continuous and reliable early warning system, and the radio link connection (Lake-Usoi Master Station-Khorog-Dushanbe) is unable to alert the downstream villages in time to allow safe evacuation of the population.

- The automatic system for the detection of the maximum level of the water in the rivers is located too far down-river from the dam. Four villages are located upstream from the system.
- The satellite connection system (10 years old) also is not free of shortcomings. Its main drawback lies in the fact that this connection does not always operate continuously. Thus, there is a possibility that the existing system will fail to alert the immediate downstream population in time for a safe evacuation.

In particular, the existing system will be effective only in the following cases:

- In the case of a relatively insignificant rise in the water level (e.g., up to 5 m) accompanied by spillover of small amounts of water, the warning message ultimately will be received, but will not be followed by a disaster.
- In the case of a catastrophic outburst of the lake waters, only faraway districts (such as Darvaz and Khatlon) will be warned in time.

7.4 Environmental and social conditions

Any planned monitoring and early warning efforts (installation of instruments and equipment, as well as operational and maintenance phases) have to consider the following difficult conditions

- Large size of the phenomena being observed (Usoi landslide dam, Lake Sarez, right-bank landslide).
- Difficulty of access to the field sites (only by helicopter, boat, and/or on foot, all of which will be accomplished under dangerous conditions).
- Severe climate, typical of the high mountains of the Pamir, with cold, dry, long winters (minimum recorded temperature of -39° C) and short, dry summers (maximum recorded temperature of +34°C)
- Difficulty of road access to the Bartang valley (From Khorog to Barchidev the road is approximately 130 km long, with stretches over which it would be impossible for two vehicles to pass). And, above all, the absence of an access road from the Bartang Valley to Lake Sarez.
- Absence of a reliable electric power supply (the electric power line currently extends only part way up the Bartang valley). In particular, at the Lake Sarez base camp, electric power is provided by a diesel generator on a very discontinuous basis.
- For the most part, at present there is no way to communicate among the villages of the Bartang valley, nor between any single village and either Khorog or Dushanbe.
- Continuing seismic activity in the region.

Regarding the potential extension of a new early warning system, the following social aspects must be considered:

- The risk to villages downstream from the Usoi dam varies. Some, such as Roshorv and Savnob, in the upper valley, are located sufficiently high above the river that a flood will probably not directly affect them. However, for most villages – particularly those built on alluvial fans in the Bartang valley – the entire populace appears to be at high risk from a flood, because the villages are situated only slightly above river level.

In planning an emergency response to a potential flood, a critical and primary step is the identification of higher safety areas for all of the people living in the Bartang valley. Very useful information will be provided by both a flood-routing model and detailed topographic mapping of populated flood-prone areas. These efforts should be undertaken as a follow-up to the June 1999 reconnaissance. Installation of a modern monitoring and warning system on Lake Sarez, coupled with initiation of emergency-response training of inhabitants of the valley, should be a first step toward remedying the lack of accessible, organized information on which to base solutions.

7.5 Criteria for design of a new monitoring/early warning system

The early warning system, a partial, but significant, solution to the Lake Sarez problem, depends on the quantity and, above all, the quality of field survey data provided by the monitoring system.

Rational design of the monitoring and warning systems requires that the following conditions be met:

1) Availability of data suitable to characterize the phenomena under observation: right-bank landslide, level of the lake surface, stability of dam crest, seismic activity, and outflow of water from the dam.

2) Management and interpretation of necessary information collected from the monitoring operation, and development of an interpretive model based on these data.

3) Capacity to translate the forecast obtained from the interpretive model into operational decisions.

The first condition (obtaining data) can be realized in three phases:

1) Creation of an explicit scheme for initial reference conditions on the basis of available information;

2) Analysis of the stability of unstable areas, and

3) Installation of a monitoring system for the purpose of checking all of the parameters that characterize the phenomena

The second condition can be achieved by analyzing the functional ratios between the measured quantities and developing an interpretive model (generally numerical) for the phenomena. Such a model allows the prediction of quantitative causes and effects. In addition, it allows examination, by means of risk scenarios, of the possible consequences in evolution of the phenomena.

Finally, the third condition requires that there be in operation an adequate technical structure for management of the monitoring system, updating the data base and model as experience is acquired, and optimization of the decision-making process as input to the early warning system.

This schematic description of the intervention system (MS/EWS) brings to light the necessity for close coordination, and eventually a feedback system, between the various operative phases described above. Further, it shows the different roles and relative importance of the MS and the EWS

The monitoring system enables overall understanding of the landslide/lake/dam behaviour, allowing a continuous view of the relevant measures representative of the evolution of displacements, changes in hydraulic conditions, seismic and acoustic emission activity, meteorological and environmental factors, etc. Automation of the measurement process is an important aspect of the monitoring system. It is obligatory for cases in which the parameters to be measured are numerous, where the sensors are located in inaccessible areas, and/or when the monitoring system must function as an alarm for the safety of the population. The last two conditions are especially applicable in the Usoi dam/Lake Sarez case.

The individual sensors of the monitoring system are connected to the peripheral data-acquisition and transmission units by means of cable or radio; the peripheral units in turn are connected (by radio and/or, even better, by satellite) to a central data-acquisition and recording system. Both are used to manage the measurements, which are acquired at a pre-established rate that can be altered at will at any given moment.

The central data-acquisition and recording unit must be connected via computer to a specialized data-processing base, which, with the help of mathematical modeling techniques, will enable updating of the safety management of downstream valleys and improvement of the early warning system. At the same time, a preliminary early warning system, based on simple representative data of dangerous developing conditions, must be installed as soon as possible in all of the risk cases.

The above-mentioned "ideal scheme" for the monitoring and early warning systems must be considered as a methodological approach. Many questions, relating to type and location of sensors, peripheral power units, data-acquisition and transmitting methods, cable/radio/satellite networks, etc., remain to be answered. The answers will be based on site-specific conditions revealed by field investigations performed during the recent Lake Sarez mission (June 1999) and on past experience of the engineers and scientists involved.

Nevertheless, by considering that an early warning system to alert the inhabitants of the Bartang valley of an outburst flood from Lake Sarez is a priority option, this option must be approached as a special case of a general form of engineering design. The following main aspects and specific requirements are emphasized:

- The most difficult problems to be overcome from an engineering design perspective are the remoteness of the site; the lack of accessibility to the Usoi landslide dam, as well as to potential sites for data transmission repeater stations; and the lack of electrical power.
- The monitoring and early warning systems must be custom-designed to accommodate all of these problems. They must be designed, manufactured, and installed in a manner that will insure that failure of individual components will not compromise operation of the systems.
- The monitoring system should be designed to be multi-purpose so that it can transmit data from the peripheral stations (lake and dam) to the central units (Dushanbe and/or Khorog). The only major design change required will be the capability to both send and receive signals through the transmission network.
- The systems must be able to deliver an unambiguous warning signal to each of the villages, as well as to offices of specific agencies (e.g., the Tajik State Committee of Emergencies). The early warning system must be installed with sufficient simplicity and redundancy to eliminate system failure, to preclude generation of false signals, and to ensure reception of the warning by villagers and responsible government agencies.

Experience in natural-hazards management has shown that good public information and a plan for local involvement make the difference in determining whether or not an early warning is acted upon by the community receiving the warning. The community emergency committee manages local evacuation when necessary, takes the lead in disaster-mitigation measures, and coordinates with the State Committee on Emergencies. Local communities should also be involved in surveillance and routine maintenance of the monitoring and early warning systems as much as is practicable.

7.6 Selection of parameters to be monitored and objectives of the field measurements

Given the considerable concern expressed regarding the hazard represented by Lake Sarez by national and international agencies, a minimum requirement is considered to be an ongoing monitoring program to provide a baseline for conditions at the dam and lake. At a minimum, this should consist of continuous field measurements in order to detect significant and representative parameters that will provide baseline information against which changes in the dam or lake, potential precursors to a dangerous event, can be evaluated.

The parameters to be monitored and the objectives of these measurements are as follows.

- **Water level of the lake** as a function of the cyclic climatic conditions, in order to detect the annual increasing inflow and also to monitor impact waves caused by rock falls or high-velocity rock slides into the lake.
- **Longitudinal profile of the crest of Usoi dam**, in order to monitor settlements of the dam, with particular attention to the minimum freeboard.
- **Slope problems on the right slope (i.e., right bank) above the lake;** in particular, problems related to the large unstable rock mass (~0.9 km^3) about 4 km upstream from the dam. If possible, other parts of the largest potential rock-slope failure (~2 km^3) on the right slope above the lake should be monitored.
- **Seismic activity of the area,** which, in order to define the effective tectonic behaviour (e.g., a deep fault across the lake 9 km upstream of the dam), should be monitored separately on the right and left banks of the lake. A third point of seismic observation should be on the dam itself.
- **Downstream outflow,** in order to monitor the water flow as a function of the climatic conditions for determination of the relationship between through-flow and flow into the lake.

This monitoring system for the Usoi dam and Lake Sarez will allow, in a systematic and continuous way, acquisition of relevant data on the phenomena under observation (active or potentially active phenomena). In this way it will be possible to:

- Integrate the current state of knowledge in order to make it suitable for following development of the phenomena. This should be achieved by preparation of a database, which, supported by adequate methods of analysis and interpretation (numerical models, scenarios, etc.), will allow monitoring of the evolving process in real time.
- After calibration, the monitoring system should allow selection of significant and representative triggering values for automatic activation of the early warning system.

7.7 A new early warning system

Current available data are considered inadequate to design and install a fault-free early warning system. This is true from both the qualitative and the quantitative aspects. All existing data are in analog format (tables, maps, drawings), and their conversion into a digital format should be a must (qualitative aspect). Until a sufficient amount of data are obtained and interpreted, the triggering thresholds for the EWS will have to be periodically revised and updated (quantitative aspect).

The initial early warning system should be based on a preliminary and simple set of triggering thresholds. Keeping these requirements in mind:

- The early warning system must be activated automatically when pre-established values of significant parameters are detected by the monitoring system.

- The alarm signal must be automatically generated by the data-acquisition and transmission unit located at Lake Sarez, and it must simultaneously reach all of the villages in the Bartang valley and the Central Unit in Dushanbe.
- The monitoring-system data collected at the unit on Lake Sarez and in the downstream outflow zone should be transmitted daily to the Central Unit in Dushanbe. In turn, the Central Unit should be able to call the remote station at the lake in order to revise the data-acquisition sequence if some events under observation show significant or dangerous changes.
- This exchange of information between the Central Unit and the remote units (one or more) should be regarded as the best way to update the alarm signals of the early warning system.
- The warning units (horns) located in each village of the Bartang valley should be connected to the remote (Lake Sarez) and the Central Unit by satellite telephones. The warning units should be equipped with oriented antennas, solar panels, and batteries. At the occurrence of dangerous events, two different levels of sound, "get ready" and "run away," will be broadcast by the warning horns to pre-identified safety zones. This standard module could be extended in the future beyond the Bartang valley to the valley of the Panj River.

7.8 Short- and long-term solutions for implementation of the monitoring and early warning systems

A suggested preliminary layout of the monitoring system can be schematically constituted as follows:

7.8.1 On Lake Sarez

- Meteorological station.
- Suspended radar sensors of the water level.
- 3D seismic station.
- Fully automated, laser topographic system to monitor the right-bank landslide (equipped with 8-12 targets) connected by cables to a data-acquisition/transmitting unit located near the Lake Sarez base camp (Unit 1), equipped with solar panels, batteries, and diesel generators.
- Fully automated laser topographic system to monitor the crest of Usoi dam (equipped with 6-10 targets), connected by cables to a data-acquisition/transmitting unit (Unit 2) located on the left bank of the lake near the dam, equipped with solar panels and batteries.

7.8.2 In the canyon nearest the downstream water outflow

- Meteorological unit.
- Instruments to measure streamflow volume and send the data to an appropriately instrumented channel connected by cables to a data-acquisition/transmitting unit (Unit 3) located near the canyon in a protected zone. The unit should be equipped with solar panels and batteries.

7.8.3 Scheduling of unit implementation

Units 1, 2, and 3 should be connected by satellite telephone to the Central Unit at Dushanbe, in order to activate, via the units located in each village of the Bartang valley (from Barchidev to Rushan), the related early warning system, if predetermined thresholds of dangerous parameters are reached.

We estimate that this suggested *"short-term solution"* will require 2 years for design, procurement, and installation of the monitoring and early warning systems, plus 3 years for operations and maintenance. The reasons for the relatively long periods of time required for these actions are:

Monitoring system

- Field tests of the reliability of the satellite communications network (from Lake Sarez along the Bartang valley to Khorog and Dushanbe) have to be planned and carried out before undertaking the final design of the systems.
- Design of the monitoring system, in considering the difficulties of transport and access to the selected points of measurement, must include the necessity of assembling components and much of the equipment before installation.
- Training of local people to enter the needed technical fields (civil end electronic engineers, high-level technicians, diploma-level technologists, etc.) as a function of the skills required (design, field reconnaissance, maintenance, and repair) must be well planned and undertaken in order that these people will be available by the time of installation (3 years after implementation of the MS/EWS).

Early warning system

The warning-system design must consider the following

- Initial village contacts and arrangements for land purchases, as well as local contacts and assistance during system installation and testing, must be part of the evacuation plan. This phase of the effort should also include final selection of the warning-station sites.
- Technical training of selected people from the villages in operating equipment checking/testing, and maintenance of the local warning units (satellite phones, solar panels, batteries, horns) will be provided during installation.
- As part of this process, test horns may have to be activated in each village to determine the area of influence of these horns in order to provide adequate warning to all residents at risk.

In order to acquire additional knowledge on the behaviour of the "Lake Sarez system," as well as to update the monitoring-system data base to mitigate the risk of unexpected modes of failure, the following additional investigations are suggested:

- Seismic refraction profiles on the dam body.
- Aerial photogrammetric/radar satellite views.

Using the criteria mentioned above, installation of additional sensors and instruments should be considered:

- Meteorological unit.
- Long-base extensometers across significant discontinuities on the dam and on the right-bank valley wall above the dam and lake.
- A 3D seismometer station and acoustic emission geophones connected by cables to a remote unit on the right-bank landslide above the lake (Unit 4) and on the dam body (Unit 5);
- Extension of the early warning system units to beyond the Bartang Valley along the Panj River.

At the same time, other long-term efforts should be considered:

- Continuation of theoretical studies using the acquired data.
- Improvement of the efficiency and reliability of the early warning system.

The implementation of these "long-term solutions" will require development in a "staged" effort over a period of several years.

7.9 Conclusions

The development of a monitoring and early warning system for the Usoi landslide dam and Lake Sarez as part of an emergency-response plan for the region in the event of a catastrophic outburst flood from the lake is an important aspect of the large problems that face the Province of Gorno-Badakshan and eastern Tajikistan.

From a technical point of view, the main difficulties in installing a monitoring and early warning system in this region are due to the extreme conditions of the mountain environment: the Usoi dam and Lake Sarez provide extreme examples of a class of problems found in most mountain environments – tectonic activity, slope instability, and the formation of large lakes that are impounded by unstable masses of either earth, rock, or ice. Nevertheless, the installation of a monitoring/early warning system for Lake Sarez should be a high priority. This early warning system will be a prudent form of insurance for villagers living downstream from Lake Sarez.

The monitoring and early warning system suggested for Lake Sarez in this paper will serve two purposes

- It will provide information on the stability of the Usoi landslide dam and Lake Sarez, and will alert observers to any precursors to dam failure.
- It will increase the contacts between villagers and representatives of international organizations associated with installation of the monitoring/early warning system, ending what has been a 70-year period with virtually no contact between the villagers of the Bartang and Panj valleys and the non Soviet world. Such contacts will greatly assist in defining and prioritizing the needs of the people of the Pamir

Two other very important aspects must be considered.

- An emergency-response plan for the Bartang-Panj-Amu Darya River system to be implemented in the event of a catastropnic flood, involving representatives of all countries and interest groups to be impacted by a possible flood, should be developed simultaneously with the installation of an early warning system.
- Villagers should be involved in surveillance and routine maintenance of the monitoring and early warning system. This action, in conjunction with training in a wide range of emergency response, basic mountain-survival, and economic-enhancement activities, should be initiated especially for the inhabitants of the villages of the Bartang valley