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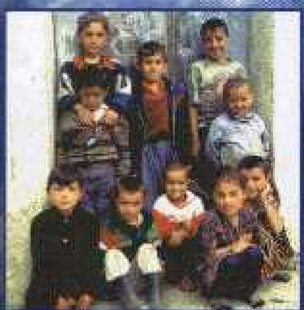
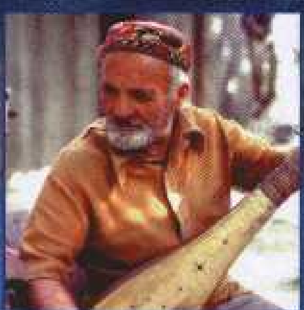
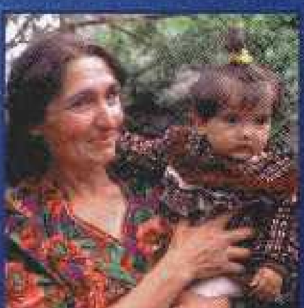
USOI LANDSLIDE DAM AND LAKE SAREZ







An Assessment of Hazard and Risk in the Pamir Mountains, Tajikistan

UNITED NATIONS

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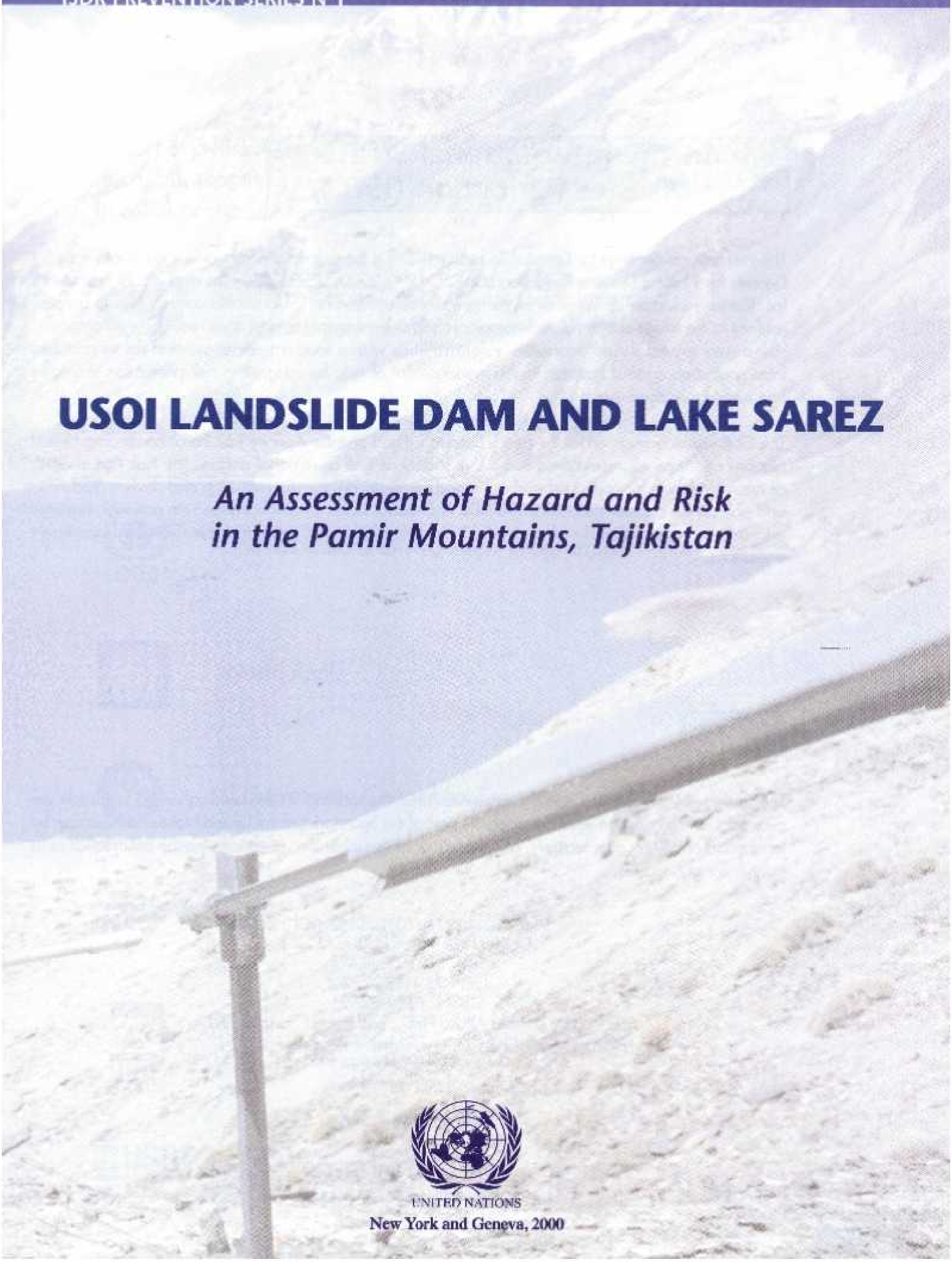

USOI LANDSLIDE DAM AND LAKE SAREZ

An Assessment of Hazard and Risk in the Pamir Mountains, Tajikistan

UNITED NATIONS
New York and Geneva, 2000

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The International Strategy for Disaster Reduction (ISDR) is the successor arrangement to the International Decade for Natural Disaster Reduction (IDNDR, 1990-2000). The ISDR serves as a global framework for disaster reduction efforts at all levels. Its main objectives are: (a) to enable communities to become resilient to the effects of natural, technological and environmental hazards, thus reducing the compound risk posed to social and economic vulnerabilities within modern societies; and (b) to proceed from protection against hazards to the management of risk, by integrating risk prevention strategies into sustainable development

The ISDR works through an Inter-Agency Secretariat and an Inter-Agency Task Force comprising United Nations agencies, representatives of the civil society as well as regional entities The Task Force serves as the main forum for continued and concerted emphasis on disaster reduction and devises guidelines and policies for disaster reduction. The ISDR Secretariat works in collaboration with national, regional and international networks of partners, including National Committees for ISDR and academic institutions

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United Nations Office for the Coordination of Humanitarian Affairs

United Nations Development Programme

UNEP

United Nations Environment Programme

World Bank

CIS Interstate Council for Emergency Situations

Focus Humanitarian Assistance

USAID

US Agency for International Development

USGS science for a changing world

US Geological Survey

List of contributors

Dr. Donald Alford	Chapter 1 and 6
Dr. Robert Schuster	Chapter 1 and 2
Dr. Jörg Hanisch	Chapter 3
Dr Carl-Olaf Söder	Chapter 3
Mr. Gerard Le Claire	Chapter 4
Dr. Teiji Watanabe	Chapter 5
Mr Attilio Zaninetti	Chapter 7
Mr. Bruno Periotto	Chapter 8
Dr. Jack Ives	Chapter 9
Dr. Goulsara Pulatova	Chapter 9
Dr. Svetlana Vinnichenko	Chapter 10

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Foreword

Lake Sarez, which is located in the Pamir Mountains in Tajikistan, was created in 1911 when a massive landslide, triggered by an earthquake, blocked the Murgab River valley, creating a natural dam This dam, which was named Usoi after a village buried by the landslide, retains Lake Sarez, a water basin roughly one half the volume of Lake Geneva. Due to the high seismicity of the region and because the Usoi dam is not an engineered structure designed to withstand the large volume of water it confines, several questions have been raised regarding the conceivable threat of its collapse.

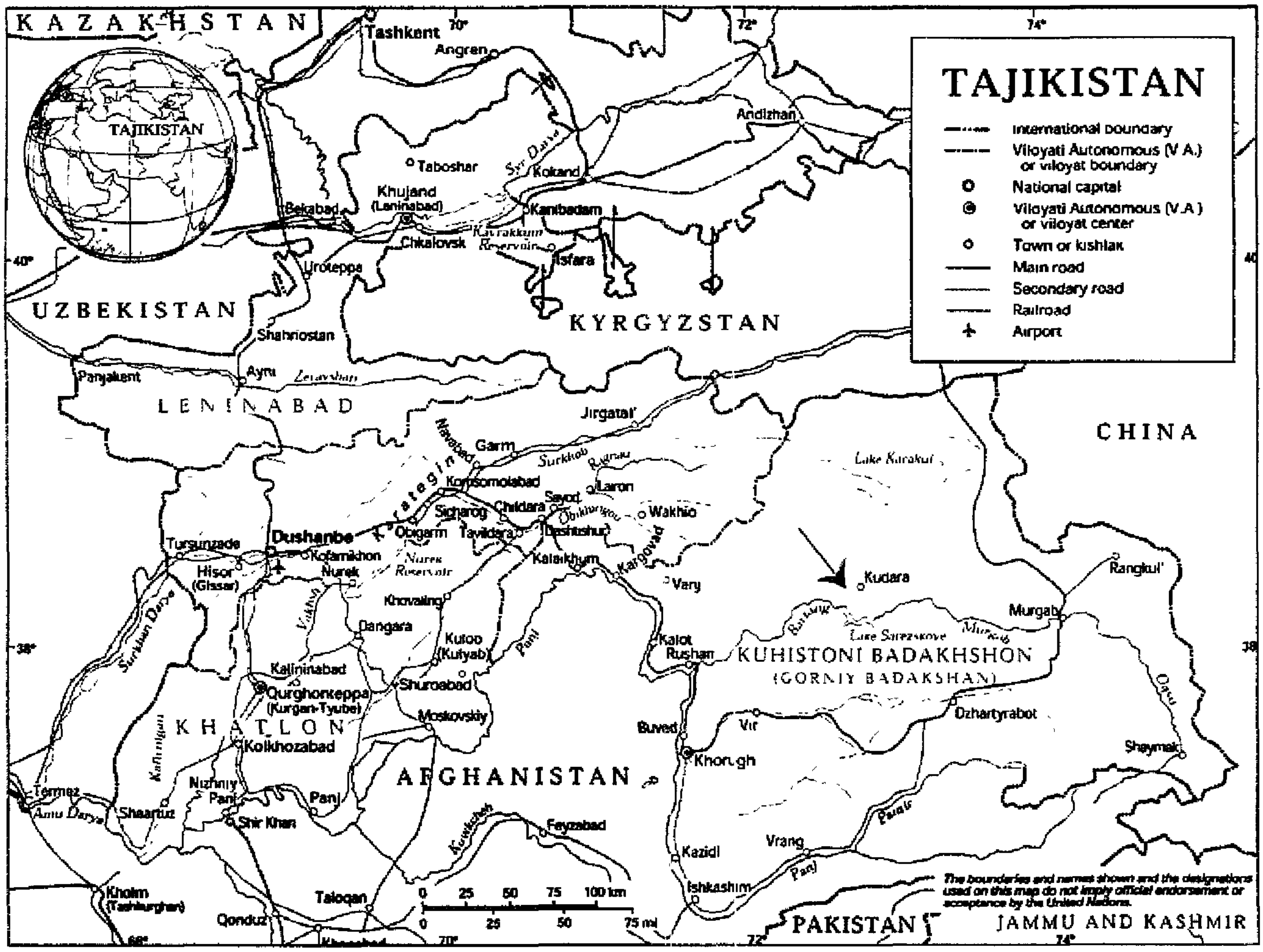
The potential danger of Lake Sarez and Usoi landslide dam was brought to the attention of the Secretariat for the International Decade for Natural Disaster Reduction (IDNDR) in 1997, during the annual meeting of the Interstate Council for Emergency Situations of the Commonwealth of Independent States (CIS), held in Chisinau, Moldova During this meeting, countries of the CIS called upon the IDNDR Secretariat to lead an effort to raise international awareness of this problem and to coordinate initiatives to reduce the risk of an overtopping or collapse of the dam. The Government of Tajikistan also raised the issue of Lake Sarez during the visit of the Under-Secretary-General for Humanitarian Affairs, Mr Sergio Vieira de Mello, in 1998. As a follow-up to these discussions, an inter-agency mission, led by IDNDR, took place in June 1999. The mission consisted of renowned international and national experts in the assessment of risk and impacts of natural phenomena in mountain environments.

This report presents the final results of the inter-agency risk assessment mission, including practical recommendations for further action. It is clear that any solution to make Lake Sarez and, its downstream villages safer, would require coordinated international and regional collaboration. The recommendations given in this report may assist donor governments as well as international agencies in mobilizing funding to make Lake Sarez and the Usoi dam secure

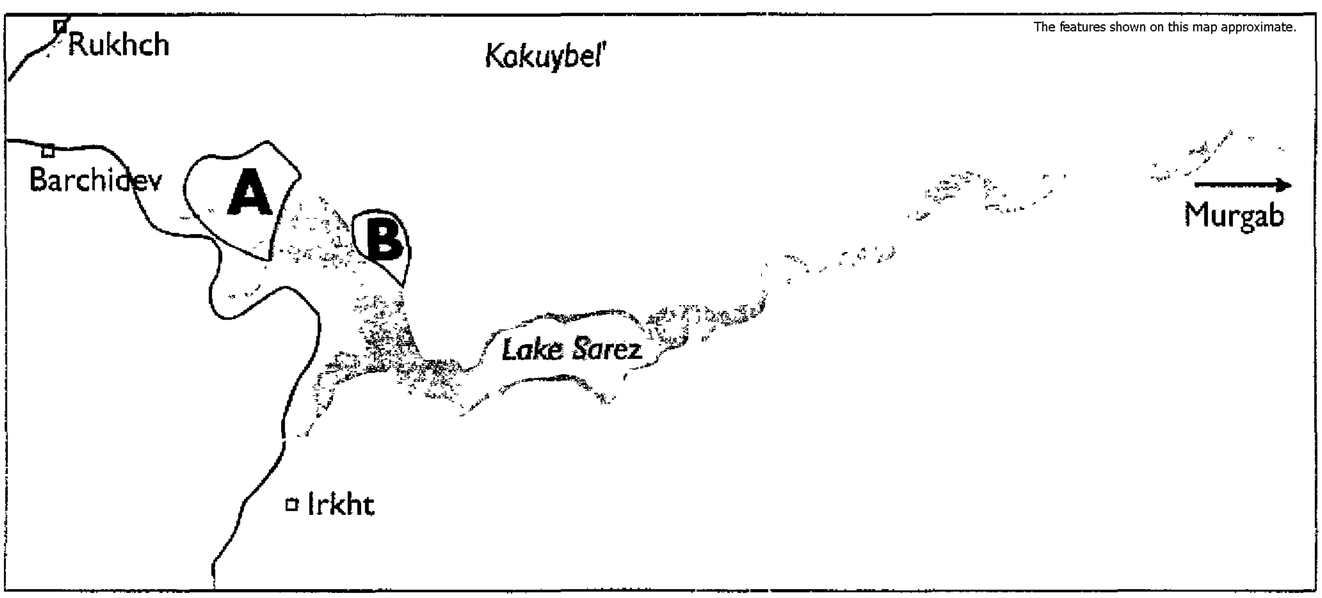
The Secretariat for ISDR wishes to acknowledge all those donor organizations that made this mission possible, in particular, the Office of Foreign Disaster Assistance, the US Agency for International Development (OFDA/USAID), the World Bank, and the United Nations Development Programme (UNDP) We are also grateful to Focus Humanitarian Assistance as well as to the OCHA country office in Tajikistan for their precious assistance.

Secretariat for the International Strategy for Disaster Reduction (ISDR)
United Nations

Location of Lake Sarez and the Usoi landslide dam



Tajikistan and surrounding areas. The arrow indicates location of lake Sarez.
Source: Map No. 3765 Rev. 9 United Nations, Department of Public Information Cartographic Section.



Lake Sarez.
A) Location of the Usoi landslide dam.
B) Location of dangerous right bank landslide zone.

Chapter 1
Introduction and summary

1.1 Introduction

1.1.1 Lake Sarez and the Usoi landslide dam

In the winter of 1911, a massive rock slide in the Pamir Mountains of southeastern Tajikistan completely blocked the valley of the Bartang (Murgab) River, a headwater tributary to the Amu Darya River basin. The Usoi landslide dam, named after the village of Usoi, which was completely buried by the slide, has a total volume estimated at approximately 2 km^3, with a maximum height above the original valley floor of 500-700 m. A lake quickly formed behind the Usoi dam, rising at a rate of approximately 75 m/yr during the first few years. This lake was named for the village of Sarez, drowned by the rising water. Lake Sarez is now more than 60 km long, with a maximum depth in excess of 500 m and a total volume of approximately 17 km^3. Today, the surface of the lake is more than 3200 m above sea level (asl), surrounded by peaks rising to more than 6,000 m asl. At present, there is approximately 50 m of freeboard between the lake surface and the lowest point on the crest of the Usoi dam, and the water level of the lake is now rising at an average of 20 cm/yr, based on the most recent measurements.

The Usoi dam is the highest dam, natural or man-made, on Earth (see chapter 2, figure 1). In a worst-case scenario, a catastrophic outburst flood from Lake Sarez would destroy the villages and infrastructure in the Amu Darya River basin between the lake and the Aral Sea, a distance of over 2,000 km, inhabited by more than 5 million people.

The Usoi dam is the highest dam, natural or man-made, on Earth. In a worst-case scenario, a catastrophic outburst flood from Lake Sarez would destroy the villages and infrastructure in the Amu Darya River basin between the lake and the Aral Sea, a distance of over 2,000 km, inhabited by more than 5 million people.

The Usoi landslide dam and Lake Sarez have been the subjects of observation and technical studies for several decades. These studies, conducted primarily by Russian and Tajik scientists, but effectively discontinued at the time of the breakup of the Soviet Union, were directed primarily toward analyses of the geotechnical and hydrological aspects of the Usoi dam, Lake Sarez, and the adjacent mountain slopes. An early warning system was developed, designed to alert Moscow and Dushanbe to an outburst flood from the lake. However, little attention was given to the safety of the people living in the river valley downstream from the lake. Few of the results of these studies were generally available to scientists or government officials in the West until the breakup of the Soviet Union. Even today, most of the information that has been gathered describing the geotechnical environment of the dam and lake is in the Russian language and is archived in Moscow and Dushanbe, the capital of Tajikistan, in government institutes and agencies that may be virtually nonfunctional. This makes the task of developing a proper perspective on the problem difficult for disaster management experts.

1.1.2 Development assistance initiatives

The Usoi landslide dam and Lake Sarez present a major dilemma to the governments of the riparian Republics along the Amu Darya River basin, as well as to international development assistance agencies. The major engineering programmes proposed to lessen the hazard posed by the dam and lake, and advocated by most of the Central Asian Republics, have been judged by development agencies to be far too expensive to establish. Papers presented at a regional conference on the Lake Sarez problem, convened in Dushanbe, Tajikistan, in late 1997 by the International Organization for Migration and Focus Humanitarian Assistance (FOCUS) and attended primarily by representatives from the Central Asian Republics, reflected a pro-engineering agenda. A second conference, convened by Focus Humanitarian Assistance USA in Washington, DC, in the summer of 1998 and attended by Western geoscientists and representatives from the U.S. Agency for International Development (USAID), the U.S. Geological Survey (USGS), and the World Bank, concluded that insufficient information was available concerning many aspects of the problem, and recommended a reconnaissance of the landslide dam, the lake, and the Bartang valley. This reconnaissance, undertaken in October 1998, led to the conclusion that the Usoi landslide dam showed no obvious signs of instability. It was recommended that installation of a monitoring program for the dam and lake and an early warning system for the downstream villages should be high priorities (Alford, 1998). In early 1999, the World Bank began preliminary planning to implement these recommendations.

In June 1999, a second reconnaissance mission was organized by the UN Secretariat for the International Decade for Natural Disaster Reduction (IDNDR). This mission, fielded with assistance from the Office of Foreign Disaster Assistance, US Agency for International Development (OFDA/USAID); the World Bank; and the United Nations Development Program (UNDP), consisted of a combined group of Tajik and expatriate scientists (see p.113) who studied the dam and lake, as well as the in habitants and environment of the Bartang valley for approximately 200 km downstream. The members of this reconnaissance team concluded that the probability of a massive outburst flood from Lake Sarez was low in the near- to mid-term, but, should such a flood occur, the impact on the downstream valleys would be devastating.

Lake Sarez and the Usoi landslide dam. Right-bank extensometers are in the foreground.
Photo credit. Jorg Hanisch

Irrespective of such an outburst flood, it was concluded that virtually all human habitations in these mountains are subject to hazards associated with earthquakes, slope instability, and flooding. These are the common elements linking the hazard represented by Lake Sarez with the hazards faced by individual villages. These hazards are extremes on a continuum ranging from *high-magnitude, low-frequency* events, as represented by Lake Sarez, to *low-magnitude, high-frequency* events, such as rock falls and seasonal flooding, faced by virtually all villages. For a more detailed discussion of mountain hazards and risks, the reader is referred to Hewitt (1997). An excellent discussion of the general plight of mountain peoples can be found in Messerli and Ives (1998).

A high-magnitude, low-frequency event, such as a major earthquake or an outburst flood, will overwhelm the existing response capabilities of the region and require assistance from the international community. On the other hand, the low-magnitude, high-frequency events can often be dealt with at the local or regional level with minimal assistance, consisting of enhancement of the rudimentary emergency-response infrastructure that currently exists. While the possibility of a major outburst flood from Lake Sarez has received sufficient attention to produce at least gross estimates of the social and economic damages that would result, the cumulative costs of the annual cycle of rock falls, avalanches, and flooding in the Pamir Mountains remain unstudied and unquantified.

The members of the UN reconnaissance mission, organised by IDNDR Secretariat, concluded that the probability of a massive outburst flood from Lake Sarez was low in the near- to mid-term, but, should such a flood occur, the impact on the downstream valleys would be devastating.

The consensus of the members of the UN reconnaissance team was that there are no simple technical solutions to the hazard presented by Lake Sarez. It was concluded that, in the near-term, the most appropriate activities could involve:

1) design and installation of an early warning system to warn inhabitants of the upper Amu Darya River basin of an outburst flood,
2) initiation of a monitoring program at Lake Sarez to provide continuous information on the hydrology of Lake Sarez and stability of the Usoi dam and the slopes surrounding the lake,
3) development of a series of flood scenarios to determine the degree of risk and the vulnerability of downstream villages and infrastructure, and
4) assemblage, organization, and analysis of existing information using Geographic Information System (GIS) technology.

A catastrophic outburst flood from Lake Sarez has international implications. Depending upon the distance travelled by such a flood in the Bartang-Panj-Amu Darya river system, and the magnitude of such a flood, those portions of the countries of Tajikistan, Afghanistan, Uzbekistan, and Turkmenistan located along the continuous river valley are potentially at risk. In the event of such a flood, large irrigation systems, on which the economies of several of these countries are based, could be destroyed. This makes the potential for a flood one of the major concerns uniting the countries of the region, and solutions at any scale should be approached in this light.

The CIS (Commonwealth of Independent States) republics of the region - Tajikistan, Uzbekistan, Kyrgyzstan, Kazakhstan, and Turkmenistan - were all created in this century by the Soviet Union to administer a region formerly controlled by a series of Khanates located along the ancient "Silk Road," plus territories with no clear political allegiance, but contested for by Imperial Russia, Great Britain, China, and Afghanistan during the days of the so-called "Great Game" (Hopkirk, 1992). The region is defined by some of the highest mountain ranges on earth - the Pamir, Tien Shan, Karakoram, and Hindu Kush Mountains - and by the problems these ranges represent in terms of the social, economic, and political isolation of the peoples living in them. The topographic complexity and general inaccessibility of these large mountain ranges, coupled with the many political and economic problems associated with the transition from Soviet control, also create problems for the development-assistance community. The political, social, and economic marginalizations of mountain peoples make it difficult to design assistance programs while working through a central government in a distant lowland. In addition, the complex, three-dimensional environmental mosaic of large mountain ranges makes the application of generic solutions difficult, and their success problematical.

The following sections present the preliminary conclusions reached by individual team members. Here, and in the main body of the report, only minimal editorial changes have been made to the original material prepared by each author. An attempt has been made to standardize English usage and the transliterations of Russian place names to English. Beyond this, the individual reports contained in this document are essentially as prepared by each team member or members Questions concerning geotechnical aspects of each report should be referred to the individual author(s).

1.2 A worldwide perspective on landslide dams[1]

Landslide dams are formed by various types of landslides, and they occur in different physiographic settings, ranging from rock slides and avalanches in steep-walled narrow valleys to slumps and flows of sensitive clays in flat river lowlands. These natural dams range in height from a few metres to hundreds of metres. As reported here, the world's largest and highest (550-700 m) historic landslide dam was formed by the 1911 earthquake-triggered 2- to 2.5-km^3 Usoi rockslide, which dammed the Murgab River in eastern Tajikistan.

Casualties from individual landslide-dam failures have reached into the many thousands. The world's worst recorded landslide-dam disaster occurred when the 1786 Kangding-Louding earthquake in Sichuan Province, China, triggered a huge landslide that dammed the Dadu River. After 10 days, the landslide dam was overtopped and breached; the resulting flood extended 1,400 km downstream and drowned about 100,000 people.

A landslide dam differs from an engineered embankment dam in consisting of a heterogeneous mass of poorly consolidated earth material, in addition, unless they are modified as a mitigation measure, landslide dams do not have protected spillways or other outlet structures. Because of the lack of an erosion-resistant outlet, landslide dams commonly fail by overtopping, followed by rapid surface erosion that progresses from the toe of the dam toward the crest. Because of "self armoring" of the eroding outlet (a process involving removal of fine material by the flowing water, leaving coarser, erosion-resistant blocks and fragments to line the channel), the breach often does not erode down to pre-dam channel level

Before breaching, landslide dams may exist for a few minutes or hours, or for thousands of years, depending on many factors, including:
1) volume and rate of water and sediment inflow to the newly formed lake,
2) size and shape of the dam,
3) character of geologic materials comprising the dam, and
4) rates of seepage through the dam. Landslide dams create the potential for two very different types of flooding: (1) upstream (backwater) flooding as the lake fills, and (2) downstream flooding due to dam failure. Lake Sarez, as it currently exists, provides an outstanding example of upstream flooding.

Landslide dams can affect valley morphology in the following ways.
1) deposition of lacustrine, alluvial, or deltaic

sediments in the reservoir, resulting in changes of stream gradient, surface morphology, and surficial geology upstream from the dam,

2) local downstream channel erosion due to outburst flooding,
3) formation of shifting channels downstream by introduction of high sediment loads from erosion of the landslide deposits during breaching of the dam or due to "bulking" (entrainment of loose materials from the downstream canyon), and/or
4) secondary landsliding along the shore of the reservoir due to reservoir filling or to rapid drawdown when the dam fails. These factors must be considered when siting engineered structures, such as hydroelectric dams, roads, or bridges, in valleys in which landslide dams have occurred or have the potential to occur.

The simplest and most commonly used method of improving stability of a landslide dam has been the construction of protected spillways either across adjacent bedrock abutments or over the crest of the dam. In a few cases, large-scale blasting has been used to excavate new stream channels across landslide dams. Other methods of preventing overtopping of landslide dams by stabilizing lake levels include drainage by means of siphon pipes, pump systems, and tunnel outlets and diversions

Not all landslide dams pose hazards; some have proved beneficial to mankind A few landslide dams that have proved to be stable over long periods of time have been used to provide hydroelectric power. Lake Waikaremoana, the largest landslide-dammed lake (volume· 5.2 billion m^3) in New Zealand, is an outstanding example of a landslide-dammed lake that provides water and hydraulic head for production of hydropower.

1.3 Geotechnical assessment of the Usoi landslide dam and the right bank of Lake Sarez[2]

This study consisted of a one-week field visit to the dam and the slope above the western shore of the lake accompanied by two local experts, Prof. Anatoly Ischuk and Col Yusuf Akdodov. Existing data were compared with visual observations in the field. The most important features studied were:

- The general stability condition of the dam and especially its vulnerability to overtopping
- Any signs of major settlement in the dam since it formed in 1911.
- The right part of the dam, which has minimum freeboard against overtopping.
- Leakage through the dam, which has eroded a canyon on the downstream face
- Instability of the slope above the right bank of Lake Sarez, approximately 3 km upstream from the dam, where previous instability has been verified.

1.3.1 Current state of knowledge

The dam and the slope above the right bank of the lake have been mapped extensively by geologists and surveyed to obtain the topography of the areas. The topographic survey has been extended to the area that has been submerged beneath the lake. Hydrological observations, which began in 1939, have included attempts to determine the locations of the inflow zones of the dam, as well as the flow paths and velocities through the dam At present, the slope above the right bank of the lake is kept under observation from a camp on the opposite side of the lake. A few extensometers were installed at open cracks in the surficial deposits on this right-bank slope in August 1998 The instruments are read annually and have hitherto showed slow movements (on the order of 1-2 cm/yr). Earlier observations between 1985 and 1990 reported maximum displacements of 10 cm/yr.

2. Jorg Hanisch, Ph D., German Federal Institute for Geosciencies and Natural Resources, and Carl-Olaf Soder, SWECO INTERNATIONAL AB.

1.3.2 Observations during the UN mission

The following observations were made at the Usoi dam:

- The right and left parts of the dam (at the surface) consist of very large blocks of rock. The middle part of the dam includes much more fine material and lacks huge blocks. A visit to the dam makes the enormous volume of the 1911 landslide comprehensible.
- The right part of the dam has a lower freeboard than the remainder.
- Downstream from the dam, the valley narrows abruptly, and thus effectively confines the dam, which is advantageous for its large-scale, long-term stability.
- The formation of the canyon on the down-stream face of the dam, by erosion due to leakage water, is restricted to a debris-flow deposit built up by fine materials from a right-bank tributary. The erosion of this material is not considered to influence the stability of the dam. The areas where the water leaks out of the dam in slow turbulent flow show no signs of active erosion and, although no measurements were made, the water seemed to be totally free from sediment, i.e., no "piping" was occurring.
- The springs where the leakage water emanates from the dam are all located roughly at the same level, which is 130-140 m below the level of the lake. This points to the existence of an impermeable layer in the lower part of the dam body.

At the slope above the right bank of the lake, the observations revealed at least three different types of mass movements:

- Rock fall, which occurs regularly each day on the steep cliffs along the shorelines. The volumes vary, but can reach several thousand cubic metres per incident.
- Slow, but continuous, sliding of the colluvial debris of the slopes. This sliding is caused by rock falls that produce overburden loads on the colluvial debris.
- A process, that is called "mountain splitting" (sackungen), has been caused by stress release in the rock of the valley flanks upon retreat of Pleistocene glaciers from the valleys. The deformations caused by these phenomena are currently extremely slow.

Clear evidence of a deep-seated sliding surface in the rock mass could not be found. On the other hand, there are numerous indications of relatively shallow slope movements.

Part of the 1999 UN research team in the Bartang Valley. Photo Credit. Jack Ives

1.3.3 Recommendations for additional work

- ***It is necessary to define the location and size of the zone of low permeability in the dam in order to analyze the stability of the downstream face. This can be accomplished by means of a geophysical survey, using refraction seismic techniques.***
- ***Discharge flow from the lake through the landslide dam should be monitored and compared with earlier measurements. Results of earlier experiments to determine the flow velocity through the dam should be reviewed at the original archives.***
- ***A safety manual for the dam and the right-bank slope should be developed. The manual should contain information regarding, for example, data on the dam and the right-bank slope, check lists for inspections, alarm levels for various parameters, a contact list of individuals and organizations, inspection protocols, inspection intervals, and responsible institutions. The manual should be updated regularly as new information becomes available. From the use of this manual, the assessment of risks can be improved.***
- ***Monitoring of the right-bank slope needs to be improved by installation of additional and more-refined instruments. This instrumentation should also, at least in part, be implemented as a component of the early warning system.***

1.4 Environmental impact assessment: the ecology of South-Eastern Tajikistan[3]

The range of possible flood scenarios represents significant threats to biodiversity, land use, and geomorphologic processes. It is vital that any hazard assessment of Lake Sarez take into account the importance of the local, national, and regional environmental implications.

1.4.1 Sources of information

Natural sciences study is extremely well developed in the region, and there is a wealth of background information and local expertise available. Significant strides have been taken in the cataloguing of biodiversity. The first Tajik Red Data Book (catalogue of biological species) was published in 1988 by the World Conservation Union (IUCN). In addition, several nature reserves (Zapovedniks) and national parks have been implemented in the country, although these designations have been threatened by the civil war. The Tajik Ministry for Nature Protection is the lead government agency and there are many local non-governmental organizations (NGOs), such as the Pamir Biological Institute, the Association of Guards, Woods and Wild Animals of Tajikistan and the Kuhistan International Foundation.

1.4.2 Local description

Because Lake Sarez is a geologically young feature, it is not an ecologically rich habitat in itself. However, the surrounding mountain and valley features are extremely important and would meet national criteria for biological conservation protection. The Bartang valley has been researched since at least 1882, and more than 1200 plant species have been recorded in the valley. Researchers at the Pamir Biological Institute report that the Tajik Province of Gorno-Badakshan alone includes some 166 endemic plant species. Key endemic plant species, which could be affected, include *Clematis saresica*, *Betula murgabica*, *Pleurospermum badachschanicum*,

A lady and her small daughter from Shipad, a small village on the Panj River the confluence with the Bartang River.
Photo Credit. Jack Ives

Kudrjaschevia pojarkovae, K. nadinae, and *Acantholimon hilariae.*

Land use in the valley is restricted by the geomorphology of the area, with both human settlements and the widest range of biodiversity being found on the stable soils of the alluvial fans and river terraces.

At the confluence with the Bartang River, the Panj River valley is generally wider, with greater lateral distance between the river and the valley walls. There are more extensive areas of sediment, providing suitable conditions for both humans and a wide range of wildlife. The following broad land-use valley transect was recorded: River - Bank habitat - Agricultural Area - Road - Homes/Agricultural Area - Marginal Agricultural Slopes - Slope Habitat - Rock Wall.

There are no specifically protected wildlife habitats in the study area, although many localities would meet national criteria for protection. There is relatively little human interference in natural habitat and the Ministry for Nature Protection reports that it tries to concentrate resources in areas of potential conflict between conservation and human uses.

1.4.3 National description

There are currently only three Zapovednik Nature Reserves in Tajikistan, and two of these are in the direct flood path of a possible failure of the Usoi dam. The Dashtidzhumsky mountain forest reserve on the bank of the Panj River occupies 53,400 ha. It includes pistachio, juniper, and maple forests, and provides habitats for key faunal species such as the Markhor Capra falcon, snow leopard, brown bear, and Persian otter. The low-lying areas of this reserve would be affected by a major flood. The Tigrovaya Balka reserve protects the largest tugai forests in Central Asia. With a surface area of 49,786 ha, this Zapovednik was the main habitat of the Turan tiger, which was last seen in Tajikistan in 1954. It remains the key habitat of several Red Data Book species, such as the Bukhara Red Deer, and fish species such as the Shovelnose - Pseudoscaphirhynchus spp.

There do not appear to be potential polluting sources on the upper reaches of the Bartang and Panj Rivers. Fertilizer use is reported as low, although this has not been confirmed independently. There appear to be no factories, power stations, or waste facilities, that, if present, could present significant pollution threats. However, there are mines high in the mountain areas, reportedly for wolfram, gold, and uranium. While the mines would be safe if flooding occurred, it is possible that access routes to these strategic economic resources could be jeopardized.

1.4.4 Regional description

This review does not extend beyond Tajikistan, but it is vital to consider the potential regional implications of a major flood. Termez, on the Amu Darya River, is the nearest major town that could be flooded in the worst-case scenario. Farther downstream across the five nations that would be affected by the worst-case flood scenario, it is very likely that significant pollution would result from

1.5 Environmental impact assessment: geomorphology of the Bartang and Kudara valleys[4]

1.5.1 Previous studies

Local experts have conducted some geomorphologic studies in these valleys, including studies of slope instability related to tectonic activity. However, the impacts of the flood on the geomorphology of downstream valleys have not been assessed thus far. Moreover, relationships between landforms and fauna and flora should be examined in these valleys. The field observations, therefore, were conducted along the Bartang and Kudara Rivers, immediately downstream from the lake.

1.5.2 Environmental impacts

The precise impact assessment will be possible only after the flood calculation is carried out. Nevertheless, the Environmental Impact sub-team found the following important aspects that should be considered regardless of the size of the flood:
The landforms in the valleys are classified into:
1) alluvial fans/cones, which are defined as features formed by frequent debris flows from tributary valleys,
2) river terraces,
3) glacial moraines,
4) talus slopes, which are formed from rock-fall debris on steep slopes,
5) flood plains, including the one covering the old lake deposits, and
6) bedrock cliffs/walls.

Among these, landform elements (1) to (4) are especially important in terms of debris (mixture of rock fragments, sand, and mud) to be transported downstream by the outburst flood from the lake. Because the soft, loose deposits comprising such landforms are distributed from the present valley bottom to the higher slopes, these deposits could easily be incorporated into the flooded water in any flood scenario. This could lead to a debris flow, which could increase damage downstream. Also, the toes of the slopes would become much more unstable after erosional removal of the debris from the valley floor. As a result, continuous, slow retreat of the toes of the terraces and the fans/cones, on which most fauna and flora are found, would be expected.

Most fauna and flora, as well as most human settlements, are observed either on the alluvial fans/cones or on the younger river terraces that formed about 3,000-5,000 years ago. Only two settlements are located on the glacial moraines. The alluvial fans/cones and younger terraces have formed near the valley bottom These depositional landforms, serving as homes for most fauna, flora, and human settlements, could easily be washed away by an outburst flood from Lake Sarez. Downstream transport of the deposits would also lead to high suspended sediment loads, which could damage fish populations in the lower reaches, as described elsewhere in the Himalayas for glacial-lake outburst floods

Revegetatation would be possible only after the stabilization of the new landforms Geomorphologic response would start immediately after the flood. However, redevelopment of the landforms, such as alluvial fans/cones and river terraces, may require hundreds to thousands of years

1.6 Flood scenarios[5]

Two arbitrary floods were defined for modeling purposes:
- A flood produced by a rectangular breach with a length and depth of 500 m These breach dimensions produce a flood in agreement with the U.S Army Corps of Engineers (COE) breach flood at the single point - 200 km downstream from the Usoi dam - where comparison is possible.

1.5 Environmental impact assessment: geomorphology of the Bartang and Kudara valleys[4]

1.5.1 Previous studies

Local experts have conducted some geomorphologic studies in these valleys, including studies of slope instability related to tectonic activity. However, the impacts of the flood on the geomorphology of downstream valleys have not been assessed thus far. Moreover, relationships between landforms and fauna and flora should be examined in these valleys. The field observations, therefore, were conducted along the Bartang and Kudara Rivers, immediately downstream from the lake.

1.5.2 Environmental impacts

The precise impact assessment will be possible only after the flood calculation is carried out. Nevertheless, the Environmental Impact sub-team found the following important aspects that should be considered regardless of the size of the flood:
The landforms in the valleys are classified into:

1) alluvial fans/cones, which are defined as features formed by frequent debris flows from tributary valleys,
2) river terraces,
3) glacial moraines,
4) talus slopes, which are formed from rock-fall debris on steep slopes,
5) flood plains, including the one covering the old lake deposits, and
6) bedrock cliffs/walls.

Among these, landform elements (1) to (4) are especially important in terms of debris (mixture of rock fragments, sand, and mud) to be transported downstream by the outburst flood from the lake. Because the soft, loose deposits comprising such landforms are distributed from the present valley bottom to the higher slopes, these deposits could easily be incorporated into the flooded water in any flood scenario. This could lead to a debris flow, which could increase damage downstream. Also, the toes of the slopes would become much more unstable after erosional removal of the debris from the valley floor. As a result, continuous, slow retreat of the toes of the terraces and the fans/cones, on which most fauna and flora are found, would be expected.

Most fauna and flora, as well as most human settlements, are observed either on the alluvial fans/cones or on the younger river terraces that formed about 3,000-5,000 years ago. Only two settlements are located on the glacial moraines. The alluvial fans/cones and younger terraces have formed near the valley bottom These depositional landforms, serving as homes for most fauna, flora, and human settlements, could easily be washed away by an outburst flood from Lake Sarez. Downstream transport of the deposits would also lead to high suspended sediment loads, which could damage fish populations in the lower reaches, as described elsewhere in the Himalayas for glacial-lake outburst floods

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- A flood produced by a seiche wave overtopping the dam with an average depth of 50 m over an arbitrary dam with a length of 2,000 m.

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

Throughout the 180-km reach of the river system considered in this study, differences between the 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. Modeled flood depths range from a maximum of nearly 200 m immediately downstream from the Usoi dam to a minimum of approximately 50 m upstream from Shipad for the breach scenario, and approximately 100 m to 30 m for the seiche 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 a 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 depth for the entire reach of river considered in this study was at this site.

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 considered 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 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 elevation 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 Rorshorv 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 in the order of one million cubic metres per second. It is probable that a simple doubling of the present mean streamflow volume of 2,000 m^3/sec of the

Bartang River, measured by Soviet geoscientists at Barchidev (Kazakov, 1997), 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 downstream from the dam.

1.7 Monitoring and early warning systems[6]

The installation of a monitoring system (MS)/early warning system (EWS) for Lake Sarez should be given a high priority. In particular, the MS could alleviate much of the uncertainty that now is associated with the hazard from Lake Sarez. The EWS could give the people living in the villages along the Bartang and Panj valleys a reduction in risk. Therefore, a single and clear approach to the solution of the Lake Sarez problem, in terms of an EWS, depends on the quantity and, above all, on the quality of the field-monitoring data (MS).

1.7.1 Past experience

Until 1992, efforts of Russian and Tajik scientists were directed primarily toward analysis of the geotechnical aspects of the Usoi landslide dam. Monitoring, based on visual investigations and some measurements, was not always systematic (due in part to the harsh environmental conditions). The resulting EWS was developed and designed to alert Moscow and Dushanbe to the occurrence of an outburst flood from the lake Little attention was given to the people living in the river valley downstream from the lake. The warning system, in fact, was able to alert only some of the villages and these only after an elapsed time of about 7 hours from the onset of the flood.

1.7.2 Current situation

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

- During summer, and occasionally in winter, a team of Tajik observers is resident at the lake. The responsibilities of the team are to contact Dushanbe, Khorog, and the Usoi Master Station (2 km away from Savnob village), via a radio link, in the event of a flood They also monitor the unstable slope on the right bank of the lake.
- On the Bartang River and on the Jzgulomdara River (a right tributary to the Bartang), near the village of Nisur, two hydrometric stations would monitor the level of the flood crest. If the flood levels rise above the levels of the hydrometric stations, the system will send, via cable connection, an automatic signal to the Usoi master station. This, in turn, will be connected via satellite to Dushanbe and Khorog.

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

- Visual monitoring cannot provide a reliable EWS, and the radio-link connection (Lake-Master Station-Khorog-Dushanbe) cannot alert the villages in time to facilitate evacuation in the event of a flood.
- The automatic system for the detection of the maximum level of the water in the rivers is too far downstream from the lake (four villages are located between the hydrometric stations and the lake).
- The satellite connection system (10 yrs old) is not free from shortcomings, mainly that this connection is not continuous As a result, the existing system will fail to alert the population in time.

1.7.3 Environmental conditions

All of the activities (installation of instruments and equipment, operational and maintenance phases) have to consider the following difficult environmental conditions. large scale of the phenomena under observation; difficulty of access to the sites, climatic conditions (especially during the winter); absence of an access road from the Bartang valley to the lake; and absence of an electrical power supply (at the Lake Sarez camp, electricity is provided by a diesel generator on a very discontinuous basis).

1.7.4 Parameters to be monitored

Necessary field measurements and the related parameters to be monitored are as follows:

- Surface level of the lake.
- Longitudinal profile of the crest of the Usoi landslide dam.
- Movement of the right-bank landslide.
- Seismic activity of the area, which, in order to define the effective tectonic behaviour (a deep fault exists across the lake 9 km upstream from the dam), should be monitored independently in the right and left banks of the lake A third seismic point of observation should be established on the dam itself.
- Discharge of water from the dam.

1.7.5 Criteria for design of a new monitoring system

The MS for Lake Sarez must measure the critical properties and processes defining the Usoi landslide and Lake Sarez, in order to provide a continuous record of changes in these properties and processes with time. This aim must be addressed by means of two basic tasks:

- Integration of 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 data base, which, supported by adequate methods of analysis and interpretation (numerical models, scenarios, etc.), will allow monitoring of the evolving situation in real time.
- After calibration of the system, selection of significant and representative data to determine triggering values for automatic activation of the EWS.

1.7.6 Criteria for design of a new early warning system

Present data are considered inadequate to design and install a default-free EWS. This is true from both qualitative and quantitative standpoints. All existing data are in analogue format (tables, maps, drawings), and their conversion into digital format should be a requirement (qualitative aspect). Until sufficient data are obtained and interpreted, the triggering thresholds for the EWS will have to be periodically revised and updated (quantitative aspect). Consequently, the initial EWS should be based on a preliminary and simple set of triggering thresholds. Keeping these aspects in mind:

- The EWS must start automatically when pre-established values of significant parameters are detected by the MS.
- An alarm signal must be generated automatically by the data-acquisition and transmission unit located at the lake. This signal must reach all of the villages in the Bartang valley and the Central Unit at Dushanbe simultaneously.
- MS data collected at the unit on the lake should be transmitted daily to the Central Unit in Dushanbe, which should be able to call the remote station at the lake in order to revise the data-acquisition sequences if certain events under observation show significant or dangerous changes.

- This exchange of information between the Central and the Remote Units (one or more) should be regarded as the means of updating the alarm signals of the EWS.

- The warning unit located in each village of the Bartang valley should be connected to the remote and central units by satellite telephones. These units should be built according to a standard design.

- The satellite units should be equipped with oriented antennas, solar panels, and batteries. In case of the occurrence of dangerous events, two different levels of sound should be emitted by sirens (1) "get ready" and (2) "run away" to pre-identified safety zones.

- This standard module could be extended in the future to the Panj River valley

1.8 Accessibility of the Bartang River valley and Usoi Dam/Lake Sarez[7]

1.8.1 Background

The accessibility assessment had two objectives.

- To determine the feasibility of completing the existing track from Barchidev to the Usoi dam, in order to move heavy engineering equipment needed for proposed modifications of the dam.

- To determine the modifications to the existing track in the Bartang valley from Rushan to Barchidev that are necessary to ensure the all-year accessibility necessary for establishment and maintenance of monitoring and early warning systems

An accessibility assessment was considered necessary to evaluate the feasibility of any structural intervention aimed at preventing the risk of a breakout of Lake Sarez. Such measures would require heavy construction equipment to reach the lake and operate there reliably for a substantial period of time An access road for this purpose would require a paved surface, structurally adequate bridges, radius of curvature of not less than 25 m, and slopes not exceeding 9 percent Such an endeavour would require structural works (bridges, culverts, retaining walls, etc.) in order to construct a road in the local mountainous terrain

Accessibility to the Usoi landslide dam is not only a local problem, it involves the general conditions of transport in Tajikistan. The situation of road travel in Tajikistan is normally very poor: the roads are unreliable and most of the vehicles are obsolete. The Province of Gorno-Badakshan, where Lake Sarez is located, can be reached from the capital Dushanbe by means of two alternate routes:

- Via Osh, Kyrgyzstan, to the north and east of the Pamir and then south to Khorog. This is a very high and difficult route, closed for some months in wintertime. However, it currently is the primary access road to Gorno-Badakshan.
- The alternative road, presently under construction, reaches the city of Kuliab and then, following the Panj River upstream, arrives at Khorog. This route, due to its crude design and to the rough construction criteria, is even more unreliable and inaccessible to heavy traffic than the route through Osh.

1.8.2 Accessibility of Lake Sarez

It has always been thought that the easiest way to reach the Usoi dam is from downstream through the Bartang valley or the Kudara valley The accessibility from both of these valleys is very arduous because the geomorphologic conditions are difficult and the existing roads are absolutely inadequate. The required works to make these roads usable would impact substantially on both the environment and the social conditions of the local population. In addition to this, the enormous investment that this option would require strongly discourages consideration of the construction of a road suitable for heavy traffic along these valleys.

An alternative route for movement of heavy construction equipment to the dam crest that should be investigated is along a route, which, departing from the city of Murgab in the direction Khorog-Osh-Karakorum, follows the Murgab River downstream, passes over rolling hills, and reaches the upper end of Lake Sarez. If this route were found to be feasible, construction equipment could then be transported by ferry to the dam crest. The topography of the valley of the Murgab River between Murgab and Lake Sarez has yet to be well defined and is worthy of careful study.

1.8.3 Accessibility of the Bartang Valley

In addition, the accessibility of the Bartang valley from the outside is a problem that needs to be faced. The installation of communication apparatus connected with the early warning system requires the possibility of safe travel along the existing road in every season, both for operations and for maintenance. The road has the characteristics of a single-lane track: steep, bumpy, with tight, dangerous curves. It is positioned across landslides, steep rocky hillsides, alluvial fans, and torrents. Improving the general geometric characteristics of the road to make it safe and suitable for light vehicles would require an investment, which, in the best of cases, can be estimated at between US$ 300,000/km and US$ 600,000/km. These figures conflict with the extreme poverty of the valley population. In addition, an improved road built according to common construction procedures would impact the environment negatively and the economy of the valley that is based on a delicate balance of villages located over highly erodible lands, primordial but sophisticated irrigation systems, raging rivers, and unstable slopes.

1.8.4 Recommendations

The quality, performance, and economics of a road into Lake Sarez can be greatly enhanced if it is engineered using proper planning, design, construction, and maintenance strategies. Every effort should be made to develop structural designs that are consistent with local construction capabilities. Construction standards can be achieved by means of labor-intensive technologies, such as construction of retaining walls consisting of steel-meshed gabions, paved fords, and grouted rubble-paved waterways. Involvement of the local population in construction of the road would probably result in reduction of costs to below the lower bound of estimated construction costs given above (say, below US$ 300,000/km). Such basic refurbishment works would improve the rural economy of the valley.

In addition an accessible road would make contacts between villages easier, which would induce the introduction of communication systems, and improve sanitary assistance. Basic development activities (irrigation, rural electrification, radio communication, etc.) are being promoted by non-governmental organizations (notably Focus Humanitarian Assistance) in the Bartang valley. Improving the road to meet the above-described basic standards would render such development efforts more reliable and sustainable. Presently, this is the only type of road activity that promises to have a meaningful cost-benefit ratio. The same cannot be said for any higher standard road required for the transit of heavy vehicles aimed at structural interventions at the lake.

1.9 Human geography/demography[8]

The purpose of this sub-project was to investigate the population structure, location, and well-being, as well as attitudes, of the people in regard to the Lake Sarez problem and people's ability and/or willingness to respond to introduction of an early warning system.

Children of Shipad, a small village on the Panj River below its confluence with the Bartang River.

1.9.1 Prior state of knowledge

Work supported by FOCUS had already provided a much better data base than previously available, e.g., nearly twice as many villages (kishlaks) are located in the Bartang valley as had been identified previously by Russian/Tajik studies. Valuable data on the nutritional status and overall food self-sufficiency level of the inhabitants of the Province of Gorno-Badhakshan, together with much local data, are now being collected by FOCUS.

1.9.2 Current investigation

Apart from the short time spent in the town of Khorog, the work of the team was restricted to one day along the Panj River valley downstream to Shipad, one day in the Bartang River valley, and general observations during the drive out along the Panj gorge. Only a very small sample (10) of interviews with villagers could be completed. These took the form of standard questions with the aid of interpreters, followed by questions relating to attitudes and possible reactions to a catastrophic outburst flood from Lake Sarez. The situation, based on the interviews and general observations, showed that the Panj valley settlements probably should be distinguished from those in the Bartang valley.

Due to the small number of interviews, this report must depend upon the introduction of a series of working hypotheses that will need to be tested by future research:

- The older inhabitants are less concerned about the threat of Lake Sarez than the younger ones, especially those with small children. Thus the older people are much less likely to respond.

  Those living closer to the lake (especially those in the Bartang River valley) are much more sensitive to the potential dangers than those living farther away.

- Government and NGO discussions of the Lake Sarez problem in recent years have artificially increased fear of the lake hazard.

1.9.3 Present situation

Given the alertness, understanding, and willingness of the villagers to respond, there appear to be excellent prospects for successful introduction of an early warning system. The people's sense of belonging to their "homeland" is very high; in general, they want to remain in their mountain valleys. Despite this, they all agree that they cannot become self-sufficient because of the severe shortage of cultivatable land, and that they depend upon humanitarian aid, just as outside food was provided during the Soviet period. The overall nutritional level is very low. Similarly, the level of unemployment in Gorno-Badhakshan, as a whole, is very high (90 percent, according to FOCUS), although this statement needs to be balanced against the fact that the rural families all have access to some land, however insufficient. From Rushan downstream in the Panj valley, it is significant that alternative village sites have already been selected in preparation for a move to higher ground once funds are provided (US$ 5,000 per household) and more-reliable simulation models have become available. Another interesting finding is that the entire village of Basid (Bartang) organized itself and effected a total, if temporary, evacuation in 1998 in response to rock falls and mudflows caused by heavy rains.

1.9.4 Recommendations

In general, great care is needed in discussing this complex issue of Lake Sarez to avoid unnecessary increase in the degree of local alarm. Nevertheless, and, in addition, the many villages on the Afghan side of the Panj River need to be taken into consideration.

- ***Introduction of an early warning system is feasible from the point of view of human response and ability of the local people to be trained;***
- ***A much fuller human geographic/demographic investigation is needed. Such an investigation could be undertaken in two stages:***

Stage 1:

1) Detailed interviewing of a statistically significant sample of families, home units, and settlements;

2) Incorporation of data into a GIS system;

3) Types of data from open-ended questionnaires should include:

- ***a) standard anthropological data and techniques***
- ***b) attitudes toward risk***
- ***c) willingness of local people to respond to perceived possible dangers***

Stage 2:

After completion of the simulation models, the various scenarios so developed should be introduced to the original interviewees, and their specific responses to each should be ascertained.

Together, the two stages will lay a valuable basis for training and development of village-level and regional hazard-response organizations.

In conclusion, the degree of commitment to the area and the level of traditional Pamiri culture that is evident emphasize the importance of maintaining cultural diversity as a complement to the obviously important biodiversity of the region. The proposed research will also lead to improvement of the local inhabitants' abilities to respond to the already numerous and frequently occurring mountain hazards.

1.10 Social and economic conditions in the valley of the Bartang River[9]

From 2-12 June 1999, a preliminary assessment of natural, climatic, and socio-economic conditions was conducted in the valley of the Bartang River downstream from the Usoi landslide dam and in the lower part of the Kudara River valley (a right tributary of the Bartang River valley).

In contrast to the valleys of the Vanj, Gunt, and Shakhdara Rivers, which have been fashioned by glaciers and have wide, flat bottoms, the valley of the Bartang River is the result of erosive and tectonic processes. It is characterized by a series of narrow, meandering bottoms and a large number of deep gorges. The modern riverbed is bordered by steep, bare hillsides; the bare and dissected hillsides are composed largely of shifting talus deposits and rock debris. There are many landslides that periodically narrow the valley bottom and occasionally dam the river

The valley of the Bartang River is still poorly developed. At present, there are only 28 settlements, four of which have come into being within the last 4 to 5 years.

The settlements are situated irregularly in the valley. The 11 largest villages are concentrated in the downstream 60 km of the valley (the so-called Siponj inhabited area)

Potatoes and cereals are the most common crops in the valley. Unfortunately, the growing season is short; thus, in some years there is not enough warm weather for cereals to ripen. As a result, the population of the upper and middle parts of the valley often is without bread for 2, or even 3 months before the new harvest. In addition, because there is no reliable transport to the villages of Ajirv and Barchidev, goods from the outside are delivered there only occasionally, which makes them very expensive.

There is no doubt that the present poor economic state of the inhabitants of the Bartang valley and the ensuing lack of well-targeted and proper development are to a certain extent the result of the threat associated with the Usoi landslide dam and Lake Sarez. It is also clear that the present situation will remain unchanged until the problem of the stability of the Usoi dam is solved. However, it is still possible – and what is more, it is necessary – to improve socio-economic conditions in the region, threat or no threat.

Recommendations

In order to improve socio-economic conditions in the region, it will be necessary to:

- ***Exercise control over future settlement in the Bartang valley.***
- ***Encourage further development of the high mountainous plateaus of Basid-Ajirf and Roshorf-Nisur-Ten.***
- ***Reinforce and reconstruct separate parts of the main automobile road, especially the stretches from Emu to Ajirf and from Basid to Yavshorv.***
- ***Build reliable suspension bridges across the dangerous streams along the stretch of automobile road that connects the villages of Basid and Vijravi.***
- ***Organize emergency one-time assistance in the form of food and clothing supplies to help the inhabitants of the villages of Vijrav, Garjiv, Yapshorv, Roshorv, and Barchidev in the Bartang valley and the village of Rukhch in the Kudara valley, taking into account the financial conditions of the families in these villages.***
- ***Organize periodic humanitarian assistance consisting of supplying all villages in the middle and upper parts of the Bartang valley with flour and new varieties of fast-ripening potatoes, rye, and other grain crops.***
- ***Encourage the development of traditional national trades, which may become one of the most important sources of income in many villages.***

Chapter 2

A worldwide perspective on landslide dams

2.1 Introduction

Landslide dams are formed by various kinds of landslides, and occur in differing physiographic settings, ranging from rock slides and avalanches in steep-walled narrow valleys to slumps and flows of sensitive clays in flat river lowlands. They have occurred to heights as great or greater than the world's largest constructed dams.

The earliest recorded landslide dams occurred in Hunan Province in central China in 1737 B.C. when earthquake-triggered landslides dammed the Yi and Lo Rivers (Xue-Cai and An-ning, 1986). Two of the earliest recorded flooding disasters from failure of landslide dams occurred in Switzerland in A.D. 563 (Eisbacher and Clague, 1984) and in Central Java in A.D. 1006 (Holmes, 1965, pp. 485-487). In the disaster in Java, the southwestern part of the cone of Merapi volcano failed as a large rock slide that created a dam behind which a flourishing countryside, famed for its Hindu temples and monuments, was submerged by a deep and extensive lake.

A landslide dam and its impoundment may last for several minutes or for several thousand years, but sooner or later most landslide dams are overtopped by their impounded lakes. Many then fail catastrophically, causing major downstream flooding. Casualties from individual landslide-dam failures have reached into the many thousands. The world's worst recorded landslide-dam disaster occurred when the 1786 Kangding-Louding earthquake in Sichuan Province, China, triggered a huge landslide that dammed the Dadu River. After 10 days, the landslide dam was overtopped and breached; the resulting flood extended 1,400 km downstream and drowned about 100,000 people.

2.2 Types of landslides that form dams

In a study of more than 500 landslide dams worldwide, Costa and Schuster (1991) and Schuster (1995) found that about one half of the dams were caused by rock and earth slumps and slides, about one quarter by debris or mud flows, and about one fifth by rock or debris avalanches. The remaining few have resulted from sensitive-clay failures and rock and earth falls. Often large landslide dams are caused by complex landslides that start as slumps or slides, and deteriorate into rock or debris avalanches. An outstanding example of this process was the 2.8-km^3 rockslide/debris avalanche (the world's largest historic landslide) associated with the 1980 eruption of Mount St. Helens, United States. This high-velocity landslide travelled 24 km down the North Fork Toutle River valley, impounding three large lakes by damming the headwaters and two tributaries of the river.

2.3 Size and geometry of landslide dams

Landslide dams range in height from only a few metres to hundreds of metres. As reported here, the world's largest and highest (550-700 m) historic landslide dam was formed by the 1911 earthquake-triggered 2- to 2.5-billion m^3 Usoi rockslide, which dammed the Murgab River in Tajikistan. Other examples of very large landslide dams are the 1933 earthquake-triggered Deixi dam (255 m high) of the Min River in central China (Li et al., 1986), the 1974 Mayunmarca landslide dam (170 m high) of the Mantaro River in Peru (Hutchinson and Kojan, 1975), and the 1985 Bairaman River landslide dam (200 m high) on the island of New Britain, Papua New Guinea (King et al., 1989).

The cross profiles of the Usoi and Bairaman River landslide dams are compared in figure 1 to that of Oroville Dam, California, one of the world's largest embankment dams. The Usoi dam is nearly twice as high as the world's largest constructed dam, 300 m high Nurek Dam, also in Tajikistan. As indicated in figure 1, landslide dams usually are much wider (dimension parallel to the stream) than embankment dams of the same height, and thus involve considerably larger volumes.

2.4 Modes of failure of landslide dams

A landslide dam differs from an engineered embankment dam by having been formed of a heterogeneous mass of poorly consolidated earth material; in addition, unless modified, landslide dams do not have protected spillways or other outlet structures. Because of the lack of an erosion-resistant outlet, landslide dams commonly fail by overtopping, followed by rapid surface erosion that progresses from the toe of the dam toward the crest. Because of "self armoring" of the eroding outlet (a process involving removal of fine material by the flowing water, leaving coarser, erosion-resistant blocks and fragments to line the channel), a breach often does not erode down to pre-dam channel level.

Landslide dams often are porous. Dams that consist mainly of broken rock often have few fine materials, thus, the voids between the rock blocks and fragments result in high permeability. Dams consisting of soils without much rock are commonly poorly compacted, thus, they, too, can be quite pervious. Resulting seepage through these dams (particularly soil dams) can lead to failure by internal erosion ("piping"). Examples of failure of dams by piping are:

1) the 1966 breach of the landslide dam that had impounded Lake Yashinkul in today's Republic of Kirgizstan 131 years earlier (Glazyrin and

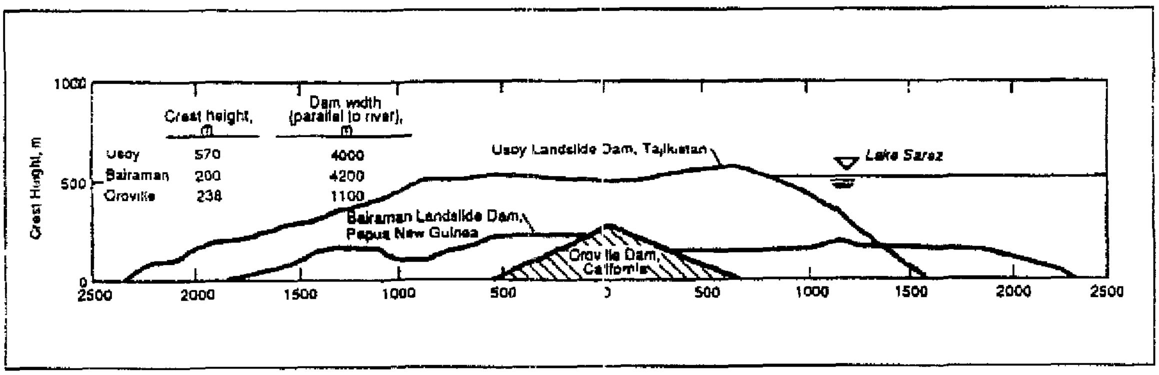


Figure 1. Comparative cross sections (parallel to stream) through the Usoi landslide dam (V.Adushkin, Institute for Dynamics of the Geosphere, Moscow, personal communication), the 1986 Bairaman River landslide dam, Papua New Guinea (King et al., 1989), and the large constructed embankment dam at Oroville, California. Crest heights and dam widths for the three dams are indicated at the left, and the approximate current relative height of the surface of Lake Sarez, the impoundment for the Usoi landslide dam, is shown at the right.

Reyzvikh, 1968; Pushkarenko and Nikitin, 1988); and

2) the 1973 failure of a 90-m-high rock avalanche dam on the Buonamico River in the Province of Calabria, southern Italy (Guerricchio and Melidoro, 1973).

2.5 Longevity of landslide dams

Landslide dams may last for a few minutes or hours, or for thousands of years, depending on many factors, including:

1) volume and rate of water and sediment inflow to the newly formed lake,
2) size and shape of the dam,
3) character of geologic materials comprising the dam, and
4) rates of seepage through the dam.

There are a few known cases in which landslide dams have failed after having been stable for many years. The A.D. 1191 rock-avalanche/debris-flow dam of the Romanche River in alpine France failed after 28 years because of erosion of its downstream face. The failure caused a disastrous flood that destroyed one half of the city of Grenoble (Montandon, 1933). The 1683 landslide dam on the Ojik River, Tochigi Prefecture, Japan, failed after 40 years, causing extensive flood damage downstream. The previously noted 1835 rock- and debris-fall dam that formed Lake Yashinkul on the Tegermach River in the Republic of Kirgizstan failed in 1966 by piping, after having been stable for 133 years (Glazyrin and Reyzvikh, 1968; Pushkarenko and Nikitin, 1988).

In some cases, landslide dams have not been overtopped because inflow to the lake is about equal to losses due to seepage, evaporation, and/or withdrawals for irrigation. The equilibrium shown by Lake Sarez is based on the first two of these factors. Another notable example is Bitang Lake in Qinghai Province, central China, which, because of irrigation, evaporation, and seepage has stabilized at a level considerably below the crest of the landslide dam (Li et al., 1986).

2.6 Floods from landslide dams

Landslide dams create the potential for two very different types of flooding: (1) upstream (backwater) flooding as the lake fills, and (2) downstream flooding due to dam failure. Lake Sarez, as it currently exists, provides an outstanding example of upstream flooding.

Although less common than upstream flooding, downstream flooding due to dam failure is usually more serious. An outstanding example of catastrophic flooding resulted from the 1515 failure of a rock-avalanche blockage of the Brenno River, a tributary of the Tocino River, in southern Switzerland. The flood engulfed the city of Biasca with an explosive surge of water and debris that continued down the Ticino valley for 35 km to Lake Maggiore on the Italian border; about 600 people died in the flood (Montandon, 1933).

2.7 Long-term effects of landslide dams on valley morphology

Landslide dams can affect valley morphology in the following ways:

(1) deposition of lacustrine, alluvial, or deltaic sediments in the reservoir, resulting in changes of stream gradient, surface morphology, and surficial geology upstream from the dam,
(2) formation of shifting channels downstream by introduction of high sediment loads from erosion of the landslide deposits during breaching of the dam, and/or
(3) secondary landsliding along the shore of the reservoir due to reservoir filling or to rapid drawdown when the dam fails. These factors must be considered when siting engineered structures, such as hydroelectric dams, roads, or bridges, in valleys in which landslide dams have occurred or have the potential to occur.

Sediment from landslide dams can significantly influence design and construction of future facilities in a river valley. In the case of the 1941 Tsao-Ling landslide dam on the Chin-Shui-Chi (river), central

Taiwan, thick sediment deposited in the backwater pool behind the dam caused severe siting problems for a proposed power project (Chang, 1984). Because of the 50 m thick deposits, a wide and deep foundation will be necessary if a dam is to be constructed at that site. (Interestingly, earthquake-induced reactivation of the Tsao-Ling landslide dammed the river again in September 1999. As of January 2000, the 50-m-high blockage has not been overtopped). The partial failure in July 1992 of a 100-m-high landslide dam on the Rio Toro (river) in Costa Rica deposited 10 m of sediment at the site of a proposed penstock outlet and powerplant 700 m downstream from the landslide dam (Mora et al., 1993).

Erosion of the stream channel downstream from the dam can adversely affect existing downstream structures, such as hydroelectric plants, bridges, and irrigation works. Such downstream erosion would be expected locally if the Usoi dam were to fail.

Secondary landsliding due to rapid drawdown of the lake after failure of a landslide dam can prove hazardous to any of the aforementioned structures or lifelines along the shore of the lake. For Lake Sarez, this currently poses no significant problem because there is no development along the lake shore

2.8 Engineered control measures for landslide dams

The simplest and most commonly used method of improving stability of a landslide dam has been the construction of protected spillways either across adjacent bedrock abutments or over the crest of the dam An example of a carefully engineered spillway across a landslide dam was constructed by the U.S. Army Corps of Engineers on the Madison Canyon landslide dam, Montana, U.S.A., in 1959. The 75-m-wide spillway was designed for a discharge of 280 m^3/sec and velocities that would only slowly erode the rock sizes that comprised the landslide dam and spillway (Harrison, 1974).

In a few cases, large-scale blasting has been used to excavate new stream channels across landslide dams This technique was used in 1964 to open a channel across a 15-million-m^3 landslide that dammed the Zeravshan River in Tajikistan, upstream from the ancient city of Samarkand (Engineering News-Record, 1964). The dam was 220 m high, 400 m long (across the river), and more than 1800 m wide (parallel to the river) Two blasts, utilizing 250 tons of conventional explosives, excavated 230,000 m^3 of landslide material in forming a 40- to 50-m-deep drainage channel through the blockage.

Other methods of preventing overtopping of landslide dams by stabilizing lake levels include drainage by means of siphon pipes, pump systems, and tunnel outlets and diversions. An excellent example was provided by the stabilization of the level of Spirit Lake, which was impounded by the 1980 Mount St. Helens debris avalanche. As a short-term measure, a system of 20 large pumps, with a maximum total capacity of 5 m^3/sec was used to temporarily prevent overtopping (Sager and Chambers, 1986). The lake was then lowered to its permanent level by means of a 2590-m-long, 3.4-m-diameter gravity-flow tunnel driven through volcanic tuffs and breccias in the right abutment of the dam by the TBM (tunnel-boring-machine) method. A similar procedure was used to stabilize the lake formed by the 1987 damming of the Adda River in northern Italy by the 35-million m^3 Val Pola rock slide/avalanche (Govi, 1989) As a temporary measure, siphons and pumps prevented overtopping. In 1988, Adda River flow was diverted through two bedrock tunnels (6.0 m and 4.2 m in diameter) constructed through the left abutment of the dam (Cambiaghi and Schuster, 1989).

2.9 Beneficial aspects of landslide dams

Not all landslide dams pose hazards, some have proved beneficial to mankind A few landslide dams that have proved to be stable over long periods of time have been used to provide hydroelectric power. Lake Waikaremoana, the largest landslide-dammed lake (volume: 5.2 billion m^3) in New Zealand, is an outstanding example of a landslide-dammed lake that provides water and hydraulic head for production of hydropower. Lake Waikaremoana was impounded about 2,000 years ago by a 2.2-billion-m^3 rockslide (about the same size as the Usoi rockslide), and is still stable (Read et al., 1992).

Chapter 3

Geotechnical assessment of the Usoi landslide dam and the right bank of Lake Sarez

3.1 Introduction

Lake Sarez in the Pamir Mountains of Tajikistan was created in 1911 when an enormous landslide (volume: approximately 2 km^3) blocked the Murgab River valley. The landslide was triggered by one of the strong earthquakes typical of this region of active tectonism. The natural dam, which was named Usoi after a village buried by the landslide, impounded Lake Sarez. This lake has a surface elevation of 3265 m, is 60 km long, and has a volume of approximately 17 km^3, roughly one half the volume of Lake Geneva. With a height of about 600 m, the Usoi landslide dam is the highest dam, natural or man-made, in the world. Because it is not an engineered structure and because of the large volume of water it impounds, significant concern has to be given to the stability of this natural dam and to the slopes along the shore of the lake.

The studies of Lake Sarez and the Usoi landslide dam discussed here were conducted during a one-week field visit to the dam and the western part of the lake accompanied by two local experts, Dr. Anatoly Ischuk (Deputy Director, Tajik Institute of Earthquake Engineering and Seismology, Dushanbe) and Col. Yusuf Akdodov (Sarez Directorate, Tajik Committee on Emergencies, Dushanbe). Existing data were compared with visual observations in the field.

3.1.1 Terms of reference and targets of the hazard assessment mission

The "Disaster Hazard Assessment" sub-team had the task of assessing at a reconnaissance level the likelihood of a collapse of the Usoi landslide dam and the general vulnerability of the Usoi dam at a reconnaissance level. The team consulted with Tajik seismologists and Usoi dam experts in Dushanbe before departing for the lake, and during their field visits.

The duties of the team experts were the following:

- *Assessment of the overall stability of the Usoi dam,*
- *Assessment of the current state of water filtration through the dam and the threat that it poses due to possible internal erosion or "piping";*
- *Assessment of the threat posed by the right-bank landslide-prone slope above the lake;*
- *In consultation with Tajik seismological experts, assessment of the seismicity of the region and the probable impact of future earthquakes on the dam and the lake.*

The following scenarios had to be considered by the experts when performing their risk assessment studies:

- *Failure of the dam due to seismic shaking;*
- *Collapse of the dam due to internal erosion;*
- *Breaching of the dam due to overtopping following possible collapse of the right-bank*

slope into the lake or due to the formation of seiches (waves due to seismic shaking);

- *Instability of the dam due to the excessive pressure of the water in the lake on the dam structure;*
- *Instability of the upstream and downstream slopes of the dam;*
- *Progressive loss of stability of the dam and other areas due to renewed landslides or debris flows in proximity to the lake.*

3.1.2 Former studies

Extended investigations were carried out on the Lake Sarez problem by Russian and Tajik scientists and engineers from 1915 through 1992. Upon the independence of Tajikistan in 1992, all installations and investigations were abandoned. In August 1998, the Tajik State Committee for Emergencies began to install new monitoring systems.

The original Russian reports and publications are generally inaccessible. One English-language paper was found in the Proceedings of the 1984 International Symposium on Landslides in Toronto (Gasiev, 1984). Therefore, the reports and opinions obtained at the beginning of the mission are not always fully verifiable (State Committee on Emergencies, 1997, 1999).

3.1.3 Geological framework

The Pamir is part of the Himalaya - Hindukush - Karakoram - Pamir mountain belt, which is one of the tectonically most active in the world. It is dominated by a series of active thrust faults and associated wrench faults (State Committee on Emergencies, 1997, 1999). The Lake Sarez area lies within one of these major thrust faults (fig. 1). As a consequence of this high tectonic stress, the area is affected by continual earthquakes, some of which attained Richter magnitude values of 8 or 9 (fig. 2).

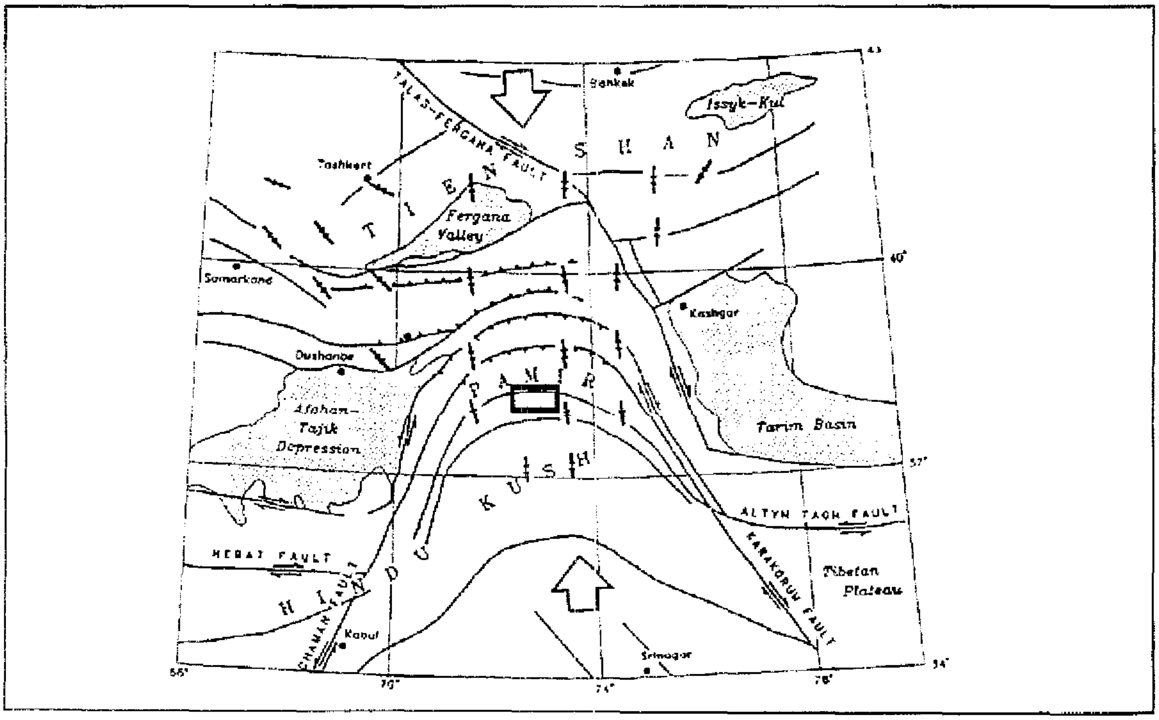


Fig. Tectonic framework of the Pamir Mountains including the Lake Sarez area (from Lukk et al.) Lake Sarez is situated in the EW rectangle near the centre of the map.

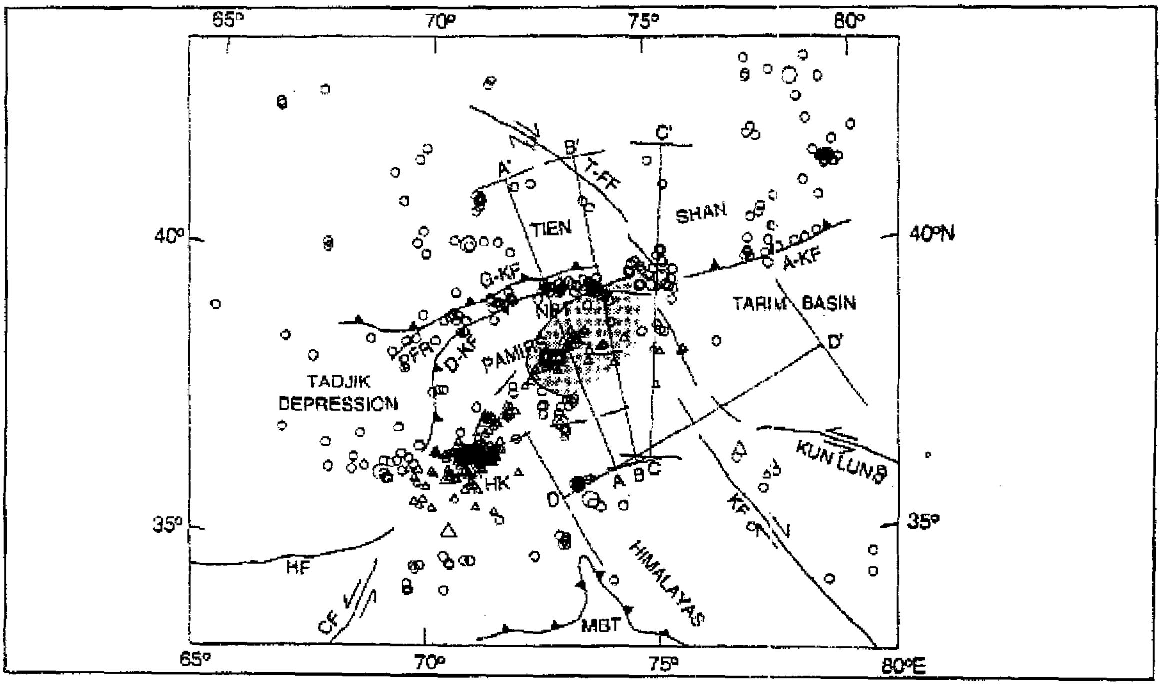


Fig. 2. Epicentres of earthquakes in the surroundings of the Pamirs with location of the Lake Sarez area (from Fan et al., 1994).

3.2 Field visits

Six days were spent in the field with Tajik colleagues, Dr. Anatoly Ischuk and Col. Yusuf Akdodov. The Usoi dam was studied for three full days; the critical unstable slope ("Pravoberezhny slope") on the right bank of the lake, just opposite the base camp, was ascended to an elevation of about 3,900 m; and other slopes along the western part of the lake were inspected visually from a boat. Boat transport was an irreplaceable help in reaching critical locations quickly. The discussions held during the field visits and during two meetings organized in the camp were highly objective and fruitful.

3.3 Findings

3.3.1 General geotechnical conditions

The highly active tectonic regime causes intense stress in the rock mass, resulting in excessive fracturing and the formation of abundant shear zones, mega-joints, and cleavage (photo 4). In extreme cases, the rock mass is completely crushed or mylonitized. For geotechnical assessment of slope stability, this signifies the following:

- The high degree of fracturing has led to continuing rock fall and extreme talus formation along the slopes (photo 5). These talus slopes have an angle of repose of 35-40 degrees, which represents the approximate angle of internal friction of the fragments constituting the talus mass;
- The structure of the rock, with its original bedding or foliation planes, is of secondary importance only because, apart from the potential failure surfaces along the bedding, there are always sufficient other internal surfaces available to serve as foci of rupture for landslides. Therefore, principally all steep slopes are more or less landslide-prone;
- In many cases it is rather difficult (if not impossible) to distinguish between disturbed and crushed rock resulting from (1) tectonic stress and (2) former large-scale landsliding processes. This could be the reason for

controversy on the size of old landslide bodies along the flanks of Lake Sarez (State Committee on Emergencies, 1997, and Prof. Anatoly Ischuk, Institute of Earthquake Engineering and Seismology, personal communication).

3.3.2 Usoi landslide dam

3.3.2.1 Dam formation

The Usoi landslide dam was formed in 1911 by a huge earthquake-triggered rock slide ("Bergsturz," as defined by Heim, 1932), which blocked the valley of the Murgab River. The total volume of the slide has been estimated at about 2 km^3, and the maximum height of the dam above the valley floor is about 600 m. The main constituents in the visible parts of the dam consist of quartzites and schists (Carboniferous age) and marbles and shales (Permian-Triassic age) with some secondary gypsum, anhydrite and dolomite.

The location of the source of the Usoi rock-slide failure was apparently determined by the combination of a series of very unfavourable tectonic factors:

(1) The generally high degree of rock fracturing from former tectonic movements,
(2) The presence of a major thrust fault (photo 6),
(3) The presence of a series of intensive shear zones forming the necessary geometric setting for a typical wedge failure (fig.7 and photo 8), and
(4) The presence of a SW-NE-trending active wrench fault in the innermost corner of the wedge (photo 8)

3.3.2.2 Physical characteristics of the dam

The landslide has been divided into several parts consisting of individual massifs, each of which has its special features in regard to structure, size of blocks, amount of fines, etc. (State Committee on Emergencies, 1997, 1999). These massifs are

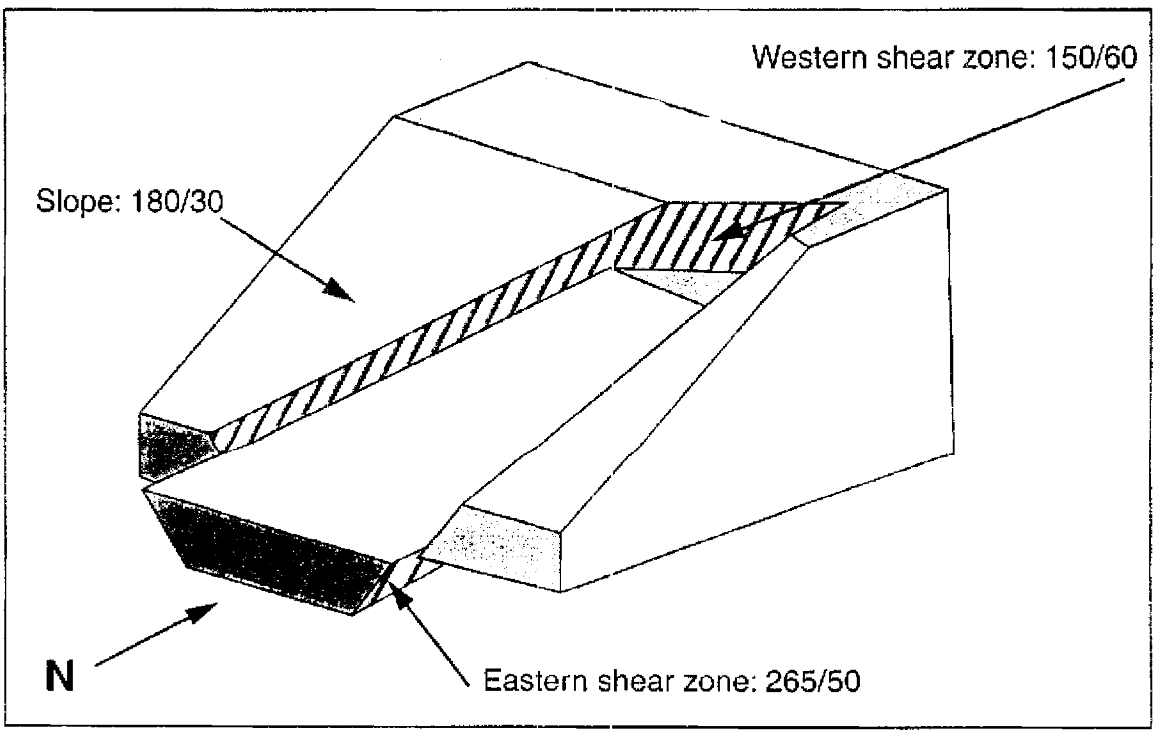


Fig. 7. Simplified scheme of initial wedge failure of the huge Usoi landslide ("Bergsturz"). Tow shear zones form a wedger with intersection line oriented 214/38. The baseline of the wedge is not shown in this model.

interpreted to represent several short intervals during the landslide catastrophe. The upstream area of the dam has been divided into three sectors with different physical characteristics:

- *Southern sector:* This is the highest part of the dam with a maximum height of about 270 m above lake level. The surface is covered by blocks of various sizes, the largest with a diameter as great as 20 m. Almost no fines are visible on the surface.

- *Central sector:* This part rises on the average approximately 100 m above lake level and has a distinct border towards the right part, where the surface is lower. The surface in this central part differs from that of the rest of the dam in that there are no large blocks, and the surface includes a large amount of fines (silt) There are clear indications that this material originated from surficial colluvial deposits on the slopes before the landslide occurred. The surface is extremely irregular and several cracks or openings in the ground exist. The downstream part includes large fragments of more-or-less undisturbed rock (photo 9).
- *Northern sector:* This is the lowest part of the dam, with a minimum freeboard of approximately 50 m. A continuous surface from the lake to the downstream side is covered by large blocks; the largest diameter of these blocks is approximately 20 m and the average diameter is estimated at 2-5 m (photo 10). Practically no fines are visible. In the area closest to the source of the old landslide there are active rock avalanches, debris flows, and mudflows (photo 10). Today, these flows are directed towards the lake. One of the rock avalanches apparently has diverted sediment transport from the slope above the downstream side towards the lake

Along the downstream face of the dam, a large flood plain of fine debris-flow material has been deposited since formation of the dam (photo 11). This deposit of debris-flow material is resting partly on the blocky dam material; the depositional mass is terminated by a local canyon on the downstream face of the dam, which has developed due to erosion by the seepage springs that flow from the dam.

Finally, it should be emphasized that the enormous proportions of the dam and its various features can be comprehended only by an extended visit to the area.

3.3.2.3 Geotechnical stability of the dam

There are two types of stability that need to be addressed: (1) the stability of the entire dam mass and (2) the local stability of its slopes

3.3.2.3.1 Safety against sliding of the entire mass of the dam

The entire dam mass is subjected to the hydrostatic load of 500 m of reservoir water. This load could cause a sliding failure along a sub-horizontal surface beneath the dam, either between the base of the dam and the original ground surface or at greater depth. The controlling factors are the hydrostatic load acting on the dam and the frictional resistance beneath the dam. The hydrostatic load can act on the upstream face as in a CFRD (concrete-faced rockfill) dam or on the central core, as in a traditional earthfill dam. Because the internal structure of this landslide dam is unknown, the simple CFRD case is used here in a rough stability estimation: the longitudinal cross section of the dam can be simplified as a triangle with a baseline 5,000 m long and a height of 550 m, impounding a lake with a depth of 450 m (fig. 12). The specific weight of the dam material is estimated at 22 KN/m^3.

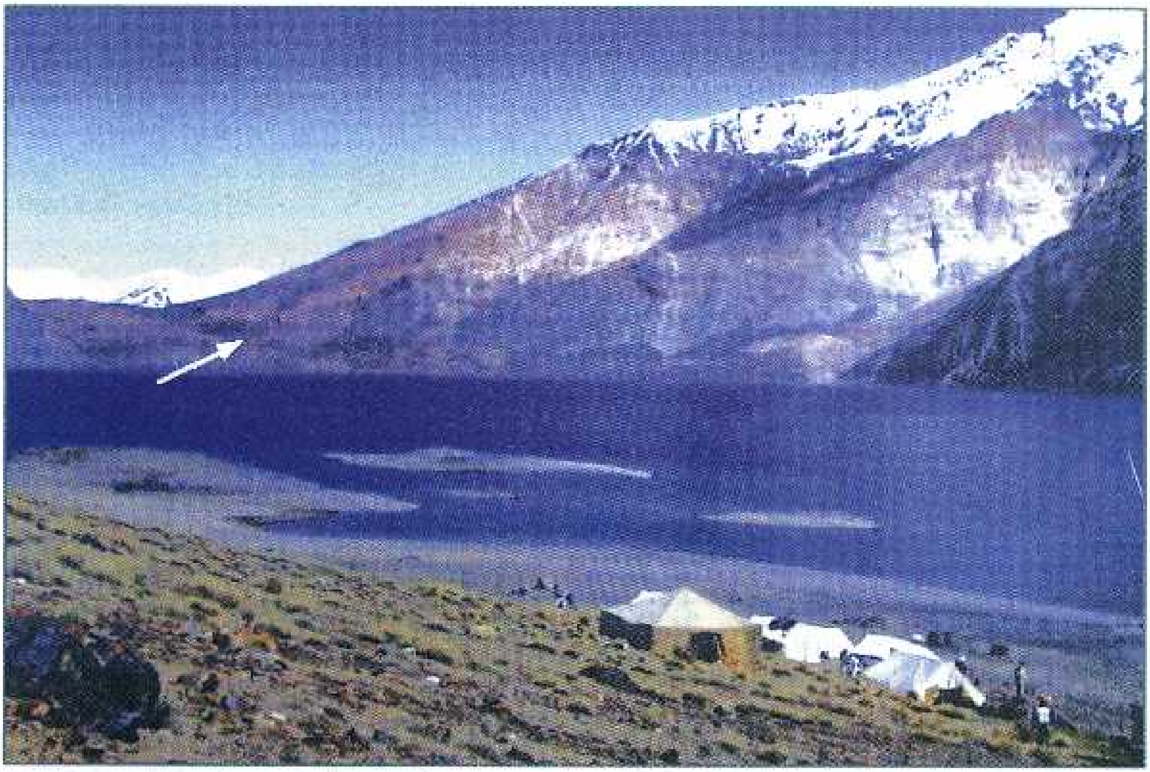


Photo 3. General view of western Lake Sarez showing the base camp in the foreground, the enormous damming landslide mass (arrow), and the huge scarp of the 1911 landslide in the background to the right. Photo credit: Jörg Hanisch

Photo 4. Example of intensely fractured rock (within the "Rushan-Pshart Thrust Fault Zone"). Photo credit: Jörg Hanisch

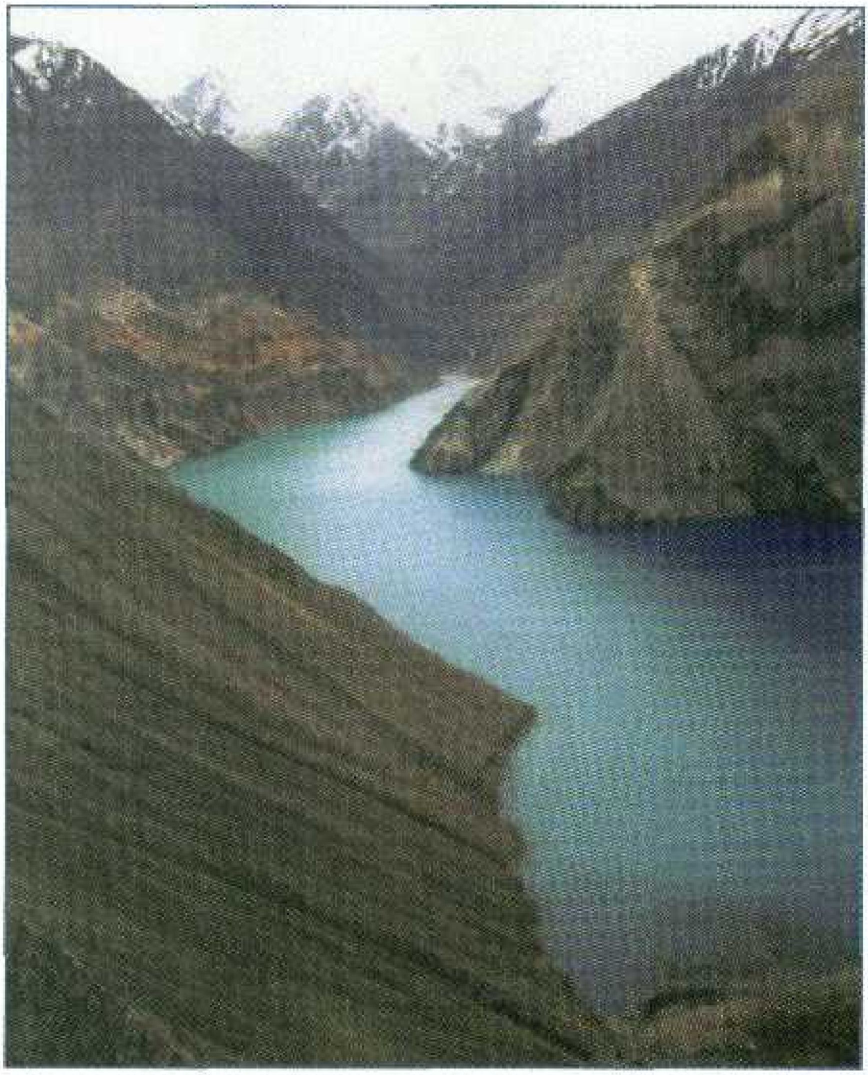


Photo 5. Extensive talus formation (lower left) at Lake Shadau, a tributary lake dammed by the Usoi landslide. The "Shadau Thrust Fault" is in the background (marked by reddish-brown, "bright" zone to the left). Photo credit: Jörg Hanisch

Photo 6. Westernmost part of the Usoi landslide scarp with a regional thrust fault (arrow) between Carboniferous schists and quartzites (below) and Permian-Triassic shales (above). Blocky material of the northern part of the dam in the foreground abuts against finer material of the middle part (left). Photo credit: Jörg Hanisch

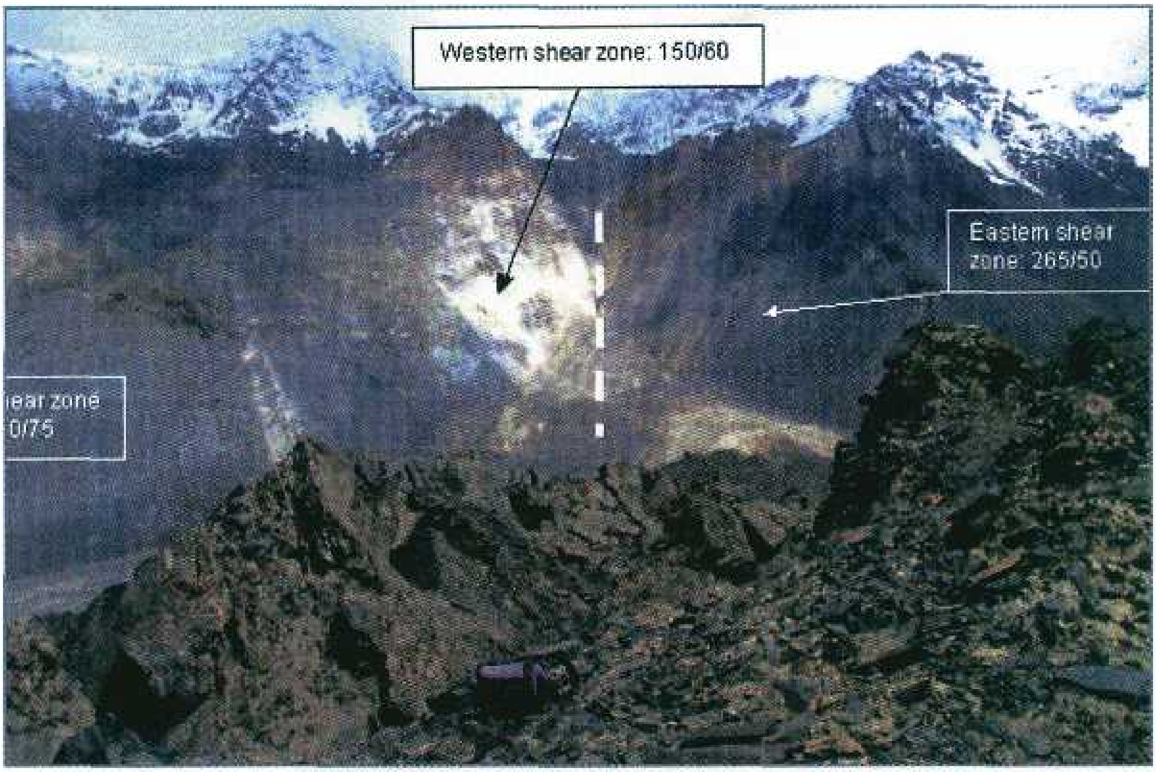


Photo 8. View from the high central part of the Usoi dam (camera bag for scale) to the scarp from which the huge landslide originated. Two shear zones to the left and right of an active wrench fault (subvertical line) form a wedge of failure. A huge debris cone has formed since the landslide occurred in 1911. Another pronounced shear zone follows to the left. Photo credit: Jörg Hanisch.

Photo 9. Huge, rather undisturbed rock block (dashed line) within the central part of the dam. This block was displaced by a secondary landslide (scarp is immediately behind the blocky material near the crest line of the dam). Photo credit: Jörg Hanisch

Photo 10. Rock avalanche deposit lying upon a debris-flow cone (in the foreground) and abutting against blocky, dark grey dam material to the left. The scarp of the 1911 landslide is in the background. Photo credit: Jörg Hanisch

Photo11. View to the downstream side of the dam (dashed line) with the debris-flow "flood plain" in the centre. The erosional channel ("canyon") at the terminus of this flood plain cuts partly into these recent fluvial deposits (left arrow) and slightly into the dam material itself (right arrow). Photo credit: Jörg Hanisch.

The effective weight, W_D, of a 1-m-thick slice of the dam can be calculated as follows:

$$
\begin{aligned}
W_D &= W_{D1} + W_{D2} \\
&= (F_1 \times \gamma_{eff} + F_2 \times \gamma) \times 1\ \text{m} \\
&= (1.1 \times 10^6\ \text{m}^2 \times 12\ \text{KN/m}^3 + \\
&\quad 0.275 \times 10^6\ \text{m}^2 \times 22\ \text{KN/m}^3) \times 1\ \text{m} \\
&= 13{,}200\ \text{MN} + 6{,}050\ \text{MN} \\
&= 19{,}250\ \text{MN}
\end{aligned}
$$

where γ = unit weight above the water table
γ_{eff} = unit weight below water table
K = thousand
M = million
N = Newton

The friction force, F, which resists the force of the water, acts along the base of the dam. This force depends on the weight of the dam and the resisting angle of internal friction, φ, between the dam and its base, which is assumed (conservatively) to be 25°; cohesion is considered to be minor, and is neglected.

$$
\begin{aligned}
F &= W_D \times \tan \varphi \\
F &= 19{,}250\ \text{MN} \times 0.466 \\
&\approx 9{,}000\ \text{MN}
\end{aligned}
$$

The water load, L_W, on a slice 1 m thick averages (as a rough estimate) 2.25 MN/m² between the lake surface and a depth of 450 m. This force acts against the vertical component of the slope area of 450 m² (fig. 13) as follows:

$$
\begin{aligned}
L_W &= 2.25\ \text{MN/m}^2 \times 450\ \text{m}^2 \\
&\approx 1000\ \text{MN}
\end{aligned}
$$

The factor of safety, FS, is the quotient of the resisting friction force and the horizontal water load:

$$FS = F / L_W \approx 9$$

Seismic shaking due to a strong earthquake could reduce this safety factor by as much as 50 per cent (cf. next paragraph), resulting in what is still a high safety factor of 4.5.

The Usoi landslide dam thus has a more than satisfactory stability against sliding of the entire dam. Furthermore, the previous morphology of the valley had pronounced surface relief because of the tributary valley from the south, which is now filled by Lake Shadau (photo 5). Therefore the supporting foundation for the dam is undoubtedly quite rugged, a factor that will resist sliding along the foundation. In addition, the valley narrows considerably at the downstream face of the dam; thus, each of these topographic factors will considerably increase the force that resists sliding. Altogether, the stability of the dam as a whole is very high. In addition, future earthquakes will tend to readjust the dam material, leading to a somewhat higher degree of compaction.

From a geological point of view, the long-term stability of landslide dams can be assessed from the evidence of geological records. As mentioned by the State Committee on Emergencies (1997, 1999), there is evidence of several former major landslide dams in the Murgab valley. Terraces of former lake sediments existing at various levels along the flanks of the valley demonstrate that some of these dams persisted for several thousand years and that the lakes had totally filled with sediment.

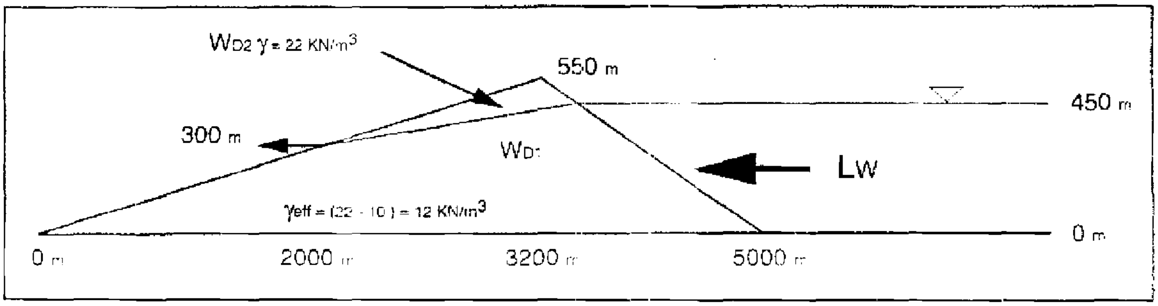


Fig. 12 Scheme for the formulation of the general stabily of Usoi landslide dam against the hydrostatic force (water load) of Lake Sarez.

Another well-documented example has been reported from the Kali Gandaki Valley in Nepal. There, about 55,000 years before the present (Pohl, 1997), a natural dam of similar size to the Usoi dam was formed from a huge landslide (Hanisch, 1995). The lake had a maximum depth of about 600 m and a length of as much as 35 km. It silted up totally; the remains of the lake sediments now exist as widespread horizontal terraces (Fort, 1976; Iwata et al., 1982).

3.3.2.3.2 Safety against internal sliding processes

The second type of failure of earthfill dams normally occurs as sliding within the body of the dam, i.e. between the two faces (Newmark, 1965: photo 5). The controlling factor in this case is the internal water pressure in the dam that decreases the effective stresses in the material. Internal erosion in a dam can cause the maximum water pressures within the mass to migrate downstream; if this process continues, the stability will gradually decrease, and finally sliding can occur within the dam. A large slide of this type could also affect the large-scale stability of the dam because the mass of the dam would decrease.

For this reason, a preliminary calculation of the internal slope stability of the upstream face of the Usoi dam has been performed using Gussman's method of "Kinematic Elements" (Gussmann, 1982). Differing from classic methods, this technique is able to consider the movements between blocks defined arbitrarily by the analysis of the kinematics of landslide movement (fig. 13). The couples of friction/cohesion can be defined separately for each interface between elements or at the bases of the elements.

In the present analysis (fig. 13), the following parameters have been applied:

Specific weight of the dam material:
$\gamma = 22\ KN/m^3$

Property values for interfaces near the bottom of the dam:

Angle of internal friction:	$\varphi = 25°$
Cohesion:	$c = 10\ KN/m^2$

Property values for interfaces between individual elements:

Angle of internal friction:	$\varphi = 40°$
Cohesion:	$c = 0\ KN/m^2$

The influence of a heavy earthquake has been estimated using the pseudostatic approach, adding to the vertical acceleration, g, a horizontal component of as much as 0.5 g, which is an extreme value. (In future studies the more accurate dynamic approach by Newmark (1965) and Jibson (1993) should be applied.)
Note that the curve of potential failure has to be considered as a first estimate until better understanding of the internal structure of the dam becomes available.

The following safety factors have been obtained from these analyses:

FS = 2.48 (water table at elevation 3263 m; no horizontal acceleration)
FS = 1.15 (water table at elevation 3263 m; horizontal acceleration = 0.5 g)
FS = 2.53 (water table at elevation 2800 m; no horizontal acceleration)
FS = 1.43 (water table at elevation 2800 m; horizontal acceleration = 0.5 g)

This signifies that, even under the worst circumstances, the stability of the dam against slope failure towards the lake is fairly high, based on the knowledge that a horizontal acceleration of 0.5 g is an extreme value to assume in a pseudostatic earthquake analysis (Newmark 1965).

The local slope stability of the downstream face cannot be estimated in this report because the internal structure of the dam is not known. As described in the next section, all of the observed leakages of water from the dam emanate at roughly the same level, approximately 140 m below the lake level (about 350 m above the base

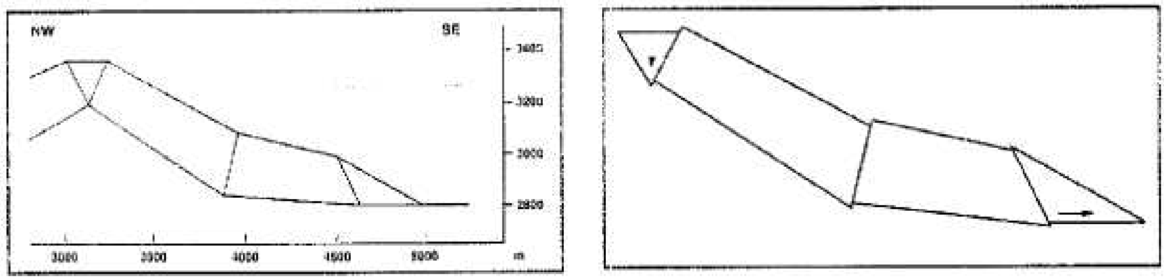


Fig. 13. Kinematics of a potential slide failure of the upstream side of the Usoi landslide dam using the "Method of Kinematic Elements" of Gussmann (1982, 1992). The angle of internal friction between the elements is assumed to be 40° and the cohesion to be zero. It is further assumed that the angle of internal friction between the base of the dam and the underlying geologic material is 25° and the cohesion along this contact is 10 KN/m². For further explanation, see the text.

of the dam). This indicates that (at least for the downstream part of the dam) the lower two thirds of the dam have a very low permeability. The horizontal extension of this material is not known at present; therefore, the water table, the degree of saturation, and the internal water pressure of the dam cannot be estimated. Our present understanding of the water-pressure distribution and drag effects of the flowing water is inadequate to draw final conclusions on the internal stability. This configuration, however, is critical for the stability because the presence of such a zone controls the water-pressure distribution in the dam; this should be the subject of future studies.

At the downstream slope, along the line of seepage springs, a small canyon has formed, with a depth of approximately 20 m (photos 14 and 15). This canyon has developed partly in the dam material at its toe but mainly in a flood plain of debris-flow deposits that are resting on the downstream slope of the dam. The amount of erosion of the dam foot is absolutely minor, so that worries about the influence of dam stability are not justified (cf. State Committee on Emergencies, 1997).

Photo 14. Seepage springs on the downstream side of the dam causing erosion of the debris-flow (i.e. flood-plain) deposits lying on the blocky dam material to the right (bottom of photo). Photo credit: Jörg Hanisch.

3.3.2.4 Seepage

Lake Sarez drains only by seepage flow through the dam. At the top of the dam no indications of a former natural spillway channel (i.e. a surface outlet) have been detected and the dam has never been overtopped. The annual fluctuations of lake level are reported to be ± 6 m.

Seepage measurements began on a regular basis in 1943; since then, the discharge has overaged a constant value of 45 m^3/s (State Committee on Emergencies, 1997) The annual variation has been 35-80 m^3/s, with 28 m^3/s and 84 m^3/s as the extremes The area in the vicinity of the springs on the downstream slope shows no signs of ongoing erosion, and from a visual inspection no sediment transport can be detected. No firm conclusion can be drawn as to possible sediment erosion and transport by piping from this brief inspection. However, because the discharge through the dam has remained constant during the period from 1943 until today, the rate of internal erosion must be very low and not apt to create a major problem. It is important, however, to continue monitoring the seepage.

One important feature of the leakage is that the springs are all located on more or less the same topographic level, which is approximately 140 m below lake level (photo 15). This indicates that the lower part of the dam, with a height of about 350m, has a very low permeability. On the contrary, the upper part of the dam is very permeable. The blocky dam material visible in large parts of the dam surface should be responsible for this high permeability.

The reported extremely high flow velocities through the dam of as much as 5 m/s (State Committee on Emergencies, 1997) are questionable Such tremendous and highly turbulent flow conditions would require large open, and continuous, channels through the interior of the dam. Because the seepage springs emanate quietly and the water-table difference is 140 m between inflow and outflow, build-up of considerable water pressures somewhere in the interior of the dam should be a consequence (with the effect of substantial erosion at the seepage springs). Therefore, the given hydrologic data should be carefully examined and additional testing using markers should be conducted.

Last, but not least, it should be noted that the dam with its controlled normal seepage minimum of 35 m^3/s, plays an important role in the seasonal water regime downstream from the dam. The lake-level fluctuations reflect the function of the dam as a buffer to downstream flow. The lake is thus supplying a rather constant discharge during the long dry season.

Photo 15. Line of seepage springs along one topograpic level forming the post-dam Murgado River. Photo credit. Jorg Hanisch

3.3.2.5 Potential damage from overtopping by surge waves

One very important question is the possibility for the dam to withstand an overtopping wave without severe damage A study of the granulometric composition of the dam has been conducted (State Committee on Emergencies, 1997) with the purpose of estimating the vulnerability against erosion due to overtopping. The results from this study could be very useful in a sensitivity analysis. The other part of the problem is to estimate the features of a landslide-generated displacement wave when it reaches the dam. Several attempts have been carried out to model such a wave; however, the results have been controversial (State Committee on Emergencies, 1997). The studies have provided estimates of waves up to 180 m high following a mega landslide of 2 km³ rushing into the lake near the dam (State Committee on Emergencies, 1997,1999). It is beyond the scope of this reconnaissance report to judge these scenarios. However, the probability of occurrence of landslides this large will be discussed in section 3 3.2.7.2. Despite the difficulties in defining the vulnerability of the dam to an overtopping wave, some general comments from the observations during the mission can be made:

- The northern part of the dam (at least at its surface) consists of blocks of various, but large, sizes with large open voids between them. This composition is advantageous to the dissipation of the energy of an overtopping wave (the blocky material would be ideal for the construction of breakwaters or large-scale riprap), thus offering high resistance to erosion;

- The central part of the dam (at the surface) does not have very large blocks, and the voids are mainly filled with fines. However, this negative aspect of the surface structure is counterbalanced by the considerably greater height of this part of the dam;

- The southern part of the dam is by far the highest, having a freeboard of up to 270 m. Additionally, the dam material consists mainly of the same extremely blocky material as in the northern part of the dam. Thus, this part of the dam is considered to be, by far, the most stable part

- The mechanism of dam failure by overtopping surge waves has to be well understood before judging the possibility of such an event.

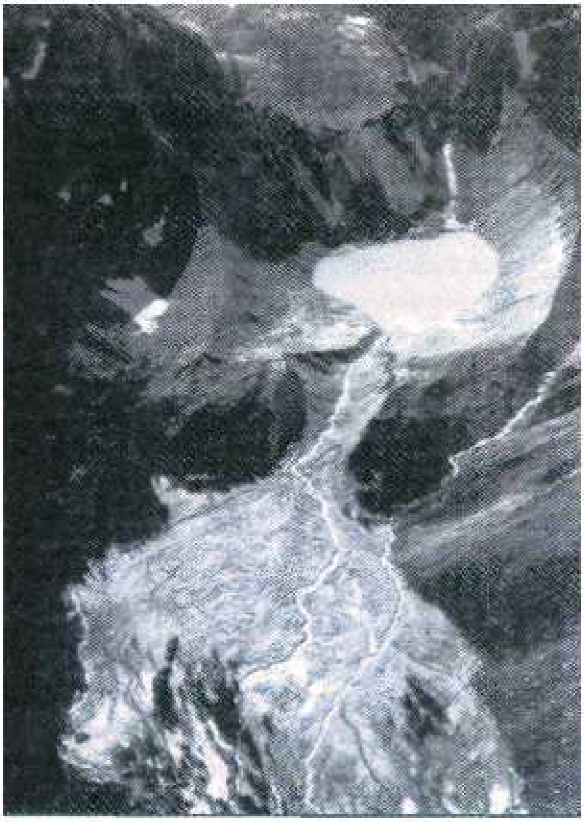


Photo 16. Typical outburst of a moraine-dammed glacier lake: A displacement wave generated by a huge ice fall overtopped the terminal moraine, surged down the steep outer face, and began eroding a narrow breach into the dam by retrogressive erosion. The lake emptied in several hours, resulting in a devastating debris flow (From Evans and Clague, 1994).

The State Committee on Emergencies (1997) refers to outbursts of moraine-dammed glacier lakes. However, the mode of failure of moraine-dammed lakes may be quite different from overtopping failure of landslide-dammed lakes. In most cases of overtopping of a moraine-dammed lake, the surge wave rushes down the steep outer face of the moraine and starts eroding the dam at its toe (photo 16). By retrogressive erosion, a narrow and steep breach is formed which, when reaching the lake itself, leads to emptying in only a few hours (Lliboutry et al., 1977; Evans and Clague, 1994; Hanisch et al., 1998). Because of the comparably flat outer face of the Usoi dam, this mechanism of failure is extremely unlikely in the present case.

3.3.2.6 General observations

Most of the rock mass around Lake Sarez is heavily fractured from older and ongoing compressive tectonic activity This has led to deep weathering, and the formation of thick colluvial soil layers on the slopes. The consequence is - as a result of the generally steep slopes of the region - development of many kinds of permanent downslope mass movements (cf. Watanabe's chapter 5).

A new situation was created with the formation of the lake and the rise of the water level to parts of the slopes that historically have been almost dry. The lake water has infiltrated the soils and the underlying fractured rock, leading to reduced friction angles, buoyancy effects, and potentially to pore and joint water-pressure development during lake-level fluctuations. These effects are apt to destabilize the slopes Another negative influence comes from wave action along the shore lines, which leads to undercutting of the slopes.

3.3.2.7 Unstable slope at the right bank opposite the base camp

3.3.2.7.1 Background

From the very beginning of the Lake Sarez investigations, the "right bank" slope has attracted the concern of researchers. The unstable slope in question lies about 5 km east of the dam and has a width at its foot of about 1 km (photo17). Numerous open cracks are present in the slope; these have been monitored for many years by Russian observers. Movements of up to 10 cm/year have been noted (State Committee on Emergencies, 1997).

Since August 1998, a set of modern, robust extensometers has been installed. One of these is a wire extensometer; the other six are rod extensometers, each equipped with two protractors that are able to register slope movements in three dimensions. The accuracy of these extensometers is about 0.5 cm and 1°.

Photo 17. Unstable slope above the right bank of Lake Sarez opposite the base camp. Lower right part of photo: scarp of active rock fall, consisting of a face of solid rock covered with about 60 m of colluvial soil. Lower middle part, dashed line: landslide that moved downslope about 100 m in 1911, but for some reason stopped at its present location. Visible part immediately above water level: landslide material, volume ~ 150,000 m³. Lower left part, stippled line: probably an older landslide of the same type as in the middle, but much more deteriorated and eroded. Upper right part: smooth slope surface with thick colluvial cover intersected by numerous cracks as much as 3 m wide (arrow), most of which are monitored by extensometers. Hatch-stippled line: approximate extension of maximum possible landslide as estimated by Tajik workers (State Committee on Emergencies, 1997). Photo credit: Jörg Hanisch

Many more cracks are being monitored by sets of two bolts with conical tops that are fixed on each side of open cracks. The accuracy of these installations is not greater than 1 cm. Some of these installations are not well positioned because they measure movement approximately perpendicular to the direction of slope movement.

Two of the rod extensometers have registered movement: one indicated movement of 1 cm in 9 months, and the other showed 2 cm for the same period. However, the nearby wire extensometer, did not register any movement (according to reports, it was out of order for some time).

3.3.2.7.2 Former landslide scenarios on the right bank

The hypothesis that a substantial part of the right bank could slide into the lake - such as happened in 1963 at Vajont, Italy (Mueller-Salzburg 1987) - and could generate a disastrous displacement wave able to overtop the Usoi dam has led to a series of disaster scenarios (State Committee on Emergencies, 1997, 1999). The volumes of landslide masses involved in these disaster scenarios range from 0.35 km^3 through 2.0 km^3. The heights of possible waves were calculated by a "mathematical" and a "physical" model. These heights ranged from 55 m to 180 m, and volumes of water overtopping the dam ranged from 16 million m^3 to 225 million m^3. These calculations showed that a landslide volume of up to 350,000 m^3 would not cause an overtopping wave, and thus would not harm the dam.

The original files of these calculations were not accessible to the authors. Thus, it is not known on what basis estimates regarding the depth and shape of sliding surface (surface of rupture), water depth, underwater morphology, and velocities of sliding were used in these computations. However, the values of these parameters are crucial to the entire hazard assessment and should be re-assessed by specialists.

3.3.2.7.3 New findings

Our one-day climb up the unstable slope revealed several observations that provide a different view of the stability of the right bank slope:

- At an elevation of about 3400 m, a series of cracks, at least 100 m long, are present. These cracks show no extensional behaviour, but clearly indicate compression. This means that, at least at this place, the cause of the landslide movement does not come from the foot of the slope (e.g., undercutting by wave action, water infiltration), but the stress comes from higher parts of the slope above the cracks;

- Most of the observed open cracks parallel to the contour lines of the slope show only minor vertical displacement, i.e., the movements have gone parallel to the gradient of the slope. This points to a rather shallow sliding surface (surface of rupture);

- In the middle part of the slope (marked by M in photo 17), there are clear indications of a long-lasting, but slow, sliding process of the thick colluvial cover. The landslide area lies about 20 m deeper than the immediate upslope area and is separated by a pronounced lateral escarpment. According to Tajik colleagues, the seismic-reflection studies carried out during former Russian investigations revealed a thickness of the colluvial debris of up to 60 m;

- The driving force for these slope movements seems to be loading by the permanent rock-fall activity from the cliffs at the top of the slope at nearly 5,000 m elevation;

- To the west of the slope, at about 4,000 m elevation, an approximately 500-m-long slope-parallel crack has been mapped. Another open crack is present as a westward continuation of this large crack, but within a rock cliff. The slope below this crack down to the shoreline seems to be free of open cracks. This could be an indication that this long and straight crack is caused by a process called "mountain splitting"or Sackung. This is a stress-release effect along valley walls, especially those that have previously been occupied by glaciers. Typically, this mountain splitting results in no well-defined, deep surfaces of rupture; instead, the differential movements are compensated by very slow creep movements. This interpretation should be scrutinized during forthcoming investigations;

- The one drill hole by Russian scientists at the foot of the unstable slope provided "evidence" for a deep-seated surface of rupture at a depth of about 175 m. The (simplified) records of this bore hole reveal "sand" at this depth with rock above and below. According to engineering-geologic drilling practice, this is likely a misinterpretation of drilling results. The "sand" could be the result of core destruction during drilling.

To summarize: there is a series of uncertainties in the description of the indications of slope movements on the right bank. From the impressions gathered during our one-day field visit, slope instabilities on the right bank can be subdivided into three different types of movements:

- Rock falls/slides along the steep shore line (fast movements);

- Debris slides and debris flows along the entire slope (relatively slow movements);

- Mountain splitting (cracks due to stress release along the valley flanks; extremely slow movements).

These slope movements on the right bank should be carefully examined, applying modern engineering-geological methods and experience. At the moment, it seems to be extremely unlikely that there is a deep-seated surface of rupture able to create a disastrous landslide with a volume of even 1-2 km^3. Compared, for example, to the well-investigated 1963 Vajont disaster in Italy (e.g., Mueller-Salzburg, 1987), in which a well-defined pre-existing bedding plane served as a deep-seated surface of rupture, we have found no evidence that the right-bank slope above Lake Sarez has such a potential surface of sliding. The open cracks on the slope seem to have quite different origins from those at Vajont. However, these cracks and the depths of the surfaces of rupture should be investigated in much greater detail.

3.4 Summary and conclusions

The most important features of this study were:

- The general stability of the dam and especially its vulnerability to overtopping leading to erosion;

- The right part of the dam with a minimum freeboard against overtopping;

- The seepage through the dam, which has formed a canyon on its downstream side;

- The right slope above Lake Sarez, approximately 5 km upstream from the dam where instability has been verified.

The macro-scale stability of the dam is considered to be high because the enormous mass of mainly rock debris forms a huge plug in the valley. No signs of former overtopping have been observed. No evidence of piping caused by the seepage through the dam could be detected. Erosion at the seepage outlets is strictly restricted to the young and loose sediments from river and debris-flow action of a tributary stream that reaches the downstream side of the dam from the north.

The slope instabilities on the right slope above the lake (i.e., on the right bank opposite from the base camp) have been divided into three types of movements:

- *Rock fall/slides along the shore line (fast movement);*

- *Debris slides and debris flows along the entire slope (relatively slow movement);*

- *Mountain splitting (cracks due to stress release along the valley flanks); extremely slow movement; probably stable at present.*

From the discussions held and the observations made during the six days spent in the field, the following conclusions can be drawn:

- The most important conclusion of the field visit is that there is no danger of a general dam failure from the pressure of the lake against the upstream face. Even under the worst imaginable circumstances of an extremely heavy earthquake with horizontal accelerations of 0.5 g, the estimate of the safety factor still results in a safe value;

- Both the dam area and the "right bank" problem need a modern strategy of hazard prevention and hazard mitigation. An attempt is made in figure 18 to show the synergetic correlations of the two approaches. For a short-term strategy, both approaches should be pursued independently. In the long term, however, the mitigation approach, including its major component of a well-elaborated early warning system can never work satisfactorily. If, for example, a serious dam failure should happen after 30 or 40 years, the chance that the warning system would still be in function is very low. Additionally, the people living in the hazardous area wouldn't react properly because there certainly would have been several false alarms before.

This signifies that the disaster-prevention works should be finished within a reasonable time span. During this time – and especially during the practical implementation of any kind of prevention measures – the mitigation approach with its combination of monitoring, early warning, and training of the local people for preparedness is a prerequisite. Once the prevention work has been implemented, long-term monitoring of the entire Lake Sarez system has to be conducted on the basis of spot checking to ensure that nothing unforeseen will occur. In case of any unforeseen development, the strategy of hazard prevention/mitigation must be re-established;

- The partially confusing conglomeration of opinions, fears, controversial results of former experiments, and in most cases inaccessible original data of former investigations need urgently to be reviewed thoroughly. A geo-scientist – preferably an engineering geologist or a geotechnical engineer – able to read the Russian originals should have at least three full months for the study of sources;

- For the judgement of hazards along the shore lines of the lake and the corresponding risk assessment, an experienced engineering geologist with a good understanding of modern field techniques and analytical methods will be needed to work with local experts for at least two months in the field.

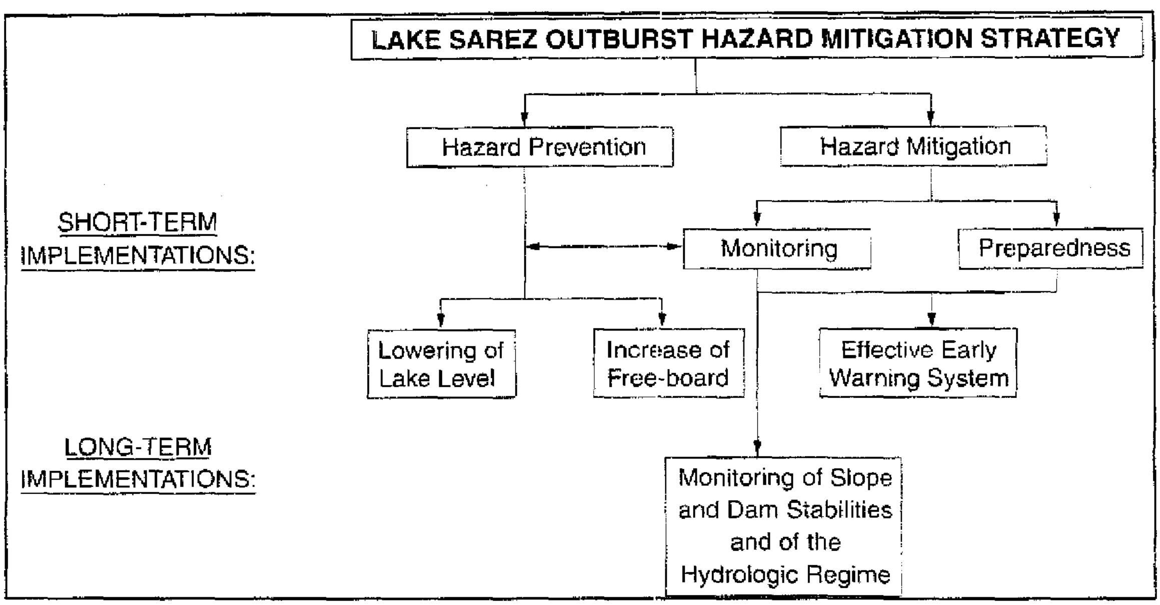


Fig. 18. Scheme of the proposed mitigation strategy: parallel work of disaster prevention and mitigation with interaction from the monitoring for a certain period and – once the hazard of overtopping of the dam by huge displacement waves will have been cleared (either by lowering the lake level or by increasing the freeboard) - the sophisticated early warning system can be abandoned and the monitoring of the dam and of the unstable slopes can be reduced to "spot" checks.

3.5 Recommendations

Based on the above conclusions, the following recommendations are made:

3.5.1 Usoi dam

- A search for and a review of publications that relate to the dam and the lake should be performed. Much of this material is expected to exist in Moscow and will be in the Russian language. Of particular interest are results from measurements that have been made over a longer period of time, such as the leakage through the dam and movements in the right bank. In general, the information on the dam before the establishment of Tajikistan as a sovereign State does not seem to be complete, and, for a hazard assessment to be conducted, it is essential to have access also to older information. A risk assessment is generally greatly improved if data exist over a long period of time.
- Seepage through the dam should be measured on a regular basis; this measurement should include determination of the presence of suspended sediments and an inspection of the downstream slope to detect possible new springs and changes in the existing ones.
- A hydrologic station should be installed near the foot of the dam to exclude influences from tributary rivers between the dam and Barchidev where the present station is located.
- The lower part of the dam, with apparent low permeability, should be further investigated. This seems to be possible only by using geophysical methods because drilling through the blocky material will be almost impossible. It is understood that this is not an easy task because, for example, seismic refraction data can be difficult to interpret for the very blocky parts of the dam.
- A manual for the dam should be set up and maintained. This manual should contain the basic information regarding the geology of the dam, data from earlier and ongoing measurements, inspection protocols, alarm levels for critical parameters, intervals and checklists for inspections, dam-safety organization, responsible persons, etc. The manual should be updated continuously when new information and data are available. Based on this, the hazard assessment can be improved and necessary measures can be planned. A crucial part is the organization and the distribution of responsibilities within this group.
- Earlier calculations of generated waves from a landslide into the lake should be reviewed and possibly repeated using advanced methods. Possible effects on the dam by the waves should also be included in the analysis.
- A feasible way of heightening the crest of Usoi Dam at its lower northern part should be considered The concept of doing this by well-calculated controlled blasting of one of the two steep flanks of the wedge-like escarpment immediately north of the dam should be considered. Special experience in this method of building dams was developed in the former Soviet Union (e.g., at the Medeo debris-retention dam north of Almaty, Kazakhstan, and at Nurek Dam, Tajikistan, the world's highest man-made dam).

3.5.2 Slope above the right bank

- The monitoring stations along the cracks on the slope should be improved. All simple distance-measuring stations should be replaced by 3D gauges or should at least be altered to triangular layouts. Some five additional wire extensometers should be incorporated into the monitoring scheme, with a 50-100-m array across the entire set of open cracks at any specific location.

- To determine the depth(s) of the surface(s) of rupture in the middle part (cf. photo 17) of the slope, two to three drill holes are required, followed by installation of inclinometers.
- Based on existing data and new findings, a totally new assessment of slope movements should be performed applying modern geotechnical methods and experience. The slope movements have to be divided into different classes of landslide activity (e.g., rock slides, rock falls, rock avalanches, debris slides, and Sackungen).
- For the interface to the new early warning system, the thresholds of slope movements, and especially the critical acceleration and velocity values, have to be defined properly.
- For the worst-case scenario, dealing with potential landslides with volumes of up to 1 or 2 km^3, the calculation of the potential height of overtopping and the displacement wave should be recalculated. It should be kept in mind that such an event could create a huge new landslide dam about 5 km upstream from the existing one. For this case, the water volume available to flood the Murgab and Bartang valleys after a potential breaching of the Usoi dam would be reduced considerably.

3.5.3 General recommendations

- For long-term monitoring of the dam and the slopes, it should be determined whether the so-called SAR (Synthetic Aperture Radar) system might be a useful tool. In this system, a radar satellite, which flies over the area every 2 weeks, is able to compare the images of successive flights. If some part of the morphology has changed between flights (horizontal accuracy approaching 0.2 m), the area in question is automatically printed in red. In this way, ground movements could be obtained automatically for an early warning system.
- A new set of stereographic aerial photos of the entire Lake Sarez area is required for the slope stability studies. Prior to this photography, benchmarks (with targets large enough to be registered on the photos) should be installed at crucial points.
- A seismic station should be installed near the Usoi landslide dam to obtain primary data on earthquake activity.

3.5.4 General remarks

Some additional remarks are made here that cover issues beyond the direct tasks of the geotechnical experts:

- It seems irresponsible to keep the base camp at its present location opposite the potential huge landslide (outlined so dramatically in the existing reports of the State Committee on Emergencies 1997,1999). A rock fall with a volume of only several tens of thousands of cubic metres could create a displacement wave able to wash away the camp installations. Preferably it should be removed to the top of the terrace behind the camp where the former Russian camp was situated;
- Any future calculation on the possible propagation of a potential outburst flood should keep in mind that such a flood would soon convert into a debris flow because of the abundantly available loose material comprising the dam and along the Murgab and Bartang valleys. The devastating forces and the reach of such a flow would be considerably greater than that of a high-water flood. Since no practical computer model for such a calculation is yet available (theory in Iverson, 1997), the model developed by Faeh (1996) seems to be the most appropriate because it includes the erosional effects of a flood. The most-used DAMBRK model by Fread (1984) should be used only as a first approach because it does not consider the very high densities (up to 2.4 ton/m^3) observed in debris flows.

Chapter 4

Environmental impact assessment: the ecology of South-Eastern Tajikistan

4.1 Introduction

4.1.1 Background and methodology

In addition to the obvious potential humanitarian implications, the range of possible flood scenarios also presents significant threats to biodiversity, land use, and geomorphological processes at local, national, and regional levels. These will have both short- and long-term impacts.

This chapter summarises the findings of an initial assessment mission, bringing together results from field interviews and surveys, along with published information. It is important to recognise that this presentation represents only a starting point in coming to terms with the enormous possible implications of any breach in the environment of large areas of Central Asia.

In assessing environmental impacts, this chapter highlights key issues of biodiversity and pollution risks. It considers mainly the implications of a breach of the Usoi landslide dam in the context of the effects on Tajikistan, but also identifies potential regional concerns that will require additional research. Geomorphological and landscape impacts are covered in the chapter by Dr. Teiji Watanabe (Chapter 5).

The aim of this study was to produce a broad overview that will provide a context for policy decision-making and a starting point for continued research to refine the understanding of the implications of a flood in the Bartang and Panj River valleys, originating from Lake Sarez.

Interviews were held during the mission with government specialists, NGO representatives, and scientists. Although the mission had the task of reviewing the potential implications of a breach of the Usoi dam and uncontrolled release of water from Lake Sarez, it is important to recognise that this is not an isolated phenomenon. Landslide- and glacier-dammed lakes such as Lake Sarez are found in many mountain areas, and it is possible that risks similar to those faced at Sarez are equally applicable to other locations within Tajikistan and in other mountain nations.

4.1.2 Sources of information

Natural sciences studies are well developed in the region, and there is a wealth of background information and local expertise available. Significant strides have been taken in the cataloguing of biodiversity, the best example of this effort being the first Tajik Red Data Book (Tajikistan Academy of Sciences, 1988). The Ministry for Nature Protection is the lead government agency in this field, but considerable academic expertise exists in the Academy of Sciences of Tajikistan, as well as in active local environmental NGOs, such as Man & Nature, the Pamir Biological Institute (including the Khorog Botanical Gardens), the Association of Guards, Woods and Wild Animals of Tajikistan, and the Kuhiston International Foundation. Therefore, there is adequate baseline information within Tajikistan to provide an initial assessment of potential impacts.

The author has reviewed the Red Data Book for Tajikistan (Tajikistan Academy of Sciences, 1988) to identify potentially affected species of national and international significance. Annex 4-1 provides a full listing of animals and plants found along the river valleys, which could be significantly affected in the event of an overtopping or breach of the Usoi dam. This book is currently in the process of being updated and, although a revised copy was not available at the time of the mission, it is inevitable that the level of understanding will have improved over the last 10 years. The analysis of the existing book should therefore be seen as illustrative rather than definitive

4.1.3. Scenario assumptions

Two failure scenarios are considered here: the worst case scenario of a total breach of the Usoi dam and the alternative scenario of overtopping of the dam without a total breach. If the worst-case scenario occurs, on the basis of available information, impacts are likely to occur as far downstream as the Amu Darya River and into the Aral Sea Basin. Therefore, this report has been divided into local, national, and regional contexts Both scenarios assume that the prime impact driver would be a large-scale debris flow.

4.2 Local description - the Bartang valley

4.2.1 General Description

The Bartang River valley winds for some 150 km from the Usoi landslide dam to the confluence with the Panj River valley at Rushan.

Lake Sarez is a relatively young feature and is not an ecologically rich habitat in itself; however, the surrounding mountain and valley features are extremely important habitats, providing a range of niches that, like many remote mountain areas, could provide suitable conditions for high levels of endemism (Blagoveschenskaja, 1999). The Ministry for Nature Protection has confirmed that the area surrounding Sarez would meet national criteria for conservation protection (Latifi, 1999).

The Bartang valley has been described by Rachkovskaja et al. (1997) as being primarily "Mid-Mountain semi-arid open woodland with leaved forests and shrubs" in the basin of the valley, with "Mid Mountain Juniper Forest" and then "High Mountain Cryophytic Friganoid" habitats farther upslope.

The river varies in width along the valley depending on the slope profiles. Where steep rock cliffs are the main geological features, the river is deep and constrained in movement, with little opportunity for vegetation to grow along the sides and on the unstable talus slopes at the base of the slopes. At some lower reaches of the valley, the flood plain widens to more than a kilometre wide. The river meanders considerably and significant deposits of silt and sand have been deposited in these areas, providing limited opportunities for stable sediments to be produced. However, many of the low-lying areas of riverine and wind-blown silt are subject to flooding in the summer, thus restricting potential long-term niche development in the river bed.

Areas that are more stable sustain low scrub vegetation. The largest range of floral diversity appears to be concentrated in the areas surrounding tributary alluvial fans and on old river terraces. In these areas, soil has started to form and a relatively wide range of vegetation can be found

These areas also are the sites of the human settlements in the valley; so natural biodiversity is also enriched with anthropogenic planting, including crops such as wheat, potatoes, and trees, such as poplar, which is widely used in construction.

4.2.2 Key features

The entire Pamir region is extremely important in biological, geological, and cultural terms. Like many mountain regions, the environment can provide unique pressures and opportunities with which species must evolve to exploit. Therefore, it is not surprising that there are many examples of endemic flora that by definition are of enormous value at the international level (Blagoveschenskaja, 1999).

The value of the Pamirs is well recognised within the scientific community in Tajikistan. Recommendations have been put forward by the Ministry of Nature Protection to designate areas as UNESCO Biosphere Reserves. In addition, plans are well advanced to declare a large area in the northern Pamirs as a National Park. NGOs are pushing to establish larger areas as National Parks (Kasirov, 1999), but the Government has noted that while much larger areas would meet criteria for establishing such protection measures, the resources available to implement such policies are modest and are being targeted to key sites only (Latifi, 1999). Therefore, the Bartang valley must be seen in the broader context of a very large area of Tajikistan being of national and possibly international environmental significance.

The Bartang valley has very rich floral resources. The site has been studied since 1882, and more than 1200 plant species have been recorded in the valley. Researchers at the Pamir Biological Institute have reported that some 166 endemic plant species can be found in the Province of Gorno-Badakshan. Key endemic plant species include *Clematis saresica, Betula murgabica, Pleurospermum badachschanicum, Kudrjaschevia pojarkovae, K. nadinae*, and *Acantholimon hilariae* (Navrouzshoev, 1999).

There are no specifically-protected wildlife habitats in the valley, although some areas would meet the national criteria. There is relatively little human interference in natural habitat and the Ministry for Nature Protection report that they try to concentrate their resources in areas of potential conflict between conservation and human uses (Latifi, 1999).

4.2.3 Risks of impact

Any breach in the Usoi landslide dam has the potential for significant impacts in the Bartang valley. In addition to the large amount of material comprising the dam, the valley contains large amounts of loose and unstable slope debris; both of these masses would be carried by the flood, forming an extensive debris flow. Depending on the height of the flow, it is almost certain that the main areas of both human habitation and richest floral diversity would be devastated.

4.2.3.1 Short-term impacts

- Complete destruction of habitats, human settlements, and infrastructure.

4.2.3.2 Long-term impacts

- Some endemic species may become extinct.
- Erosion of the toes of rock walls could leave the entire valley system unstable, resulting in new rock falls and mud flows in unpredictable places.
- Agricultural land would be destroyed and the surface covered with the associated debris of the flow.
- In broad terms, entire valley areas would probably be rendered uninhabitable for generations.
- Revegetation will proceed slowly, depending on the level and type of sediment deposited, speed of stabilisation of the sediments, and time of year. Opportunistic species will probably predominate in the early phases,

and it is likely that the species composition will change. Food -web impacts will also be likely, e.g , because prey species such as rodents on the valley floor will be greatly affected by the floods, predators such as raptors will be forced to move to find alternative prey sources.

Annex 4-1 highlights the Red Data Species that are found within the Bartang valley and therefore will be most affected by a breach of the Usoi dam. It also highlights the possible Red Data Species that are found along the route of the Panj River. However, while these data highlight the most endangered or rare species in the country, they do not reflect the enormous richness that habitats represent. From this basic analysis of the Red Book, it suggests that some 7 animal species and 13 plant species found in the Bartang valley would be affected by flooding. In total, for the worst case scenario, it is likely that some 13 invertebrates, 3 fish, 9 reptile, 3 bird, 14 mammal, and 65 plant species would be affected in varying degrees. Therefore, more than 100 Red Data Species could be impacted by a worst-case flood scenario, ignoring the thousands of other species that would also be impacted upon.

4.3 National description — Panj River valley

4.3.1 General description

The Bartang River meets the Panj valley at Rushan The Panj River then forms the Tajik/Afghan border for more than 500 km west of Rushan

The Panj valley is generally wider than the Bartang valley, with greater distance between the river and the valley walls. There are also more extensive areas of sediment that provide suitable conditions for both humans and a wide range of wildlife

The following land-use trend (table 1) was recorded during field surveys, and illustrates the range of land uses within settled areas on the valley floors that would be impacted by flood scenarios

Within the village areas there is limited opportunity for development of natural habitats, given that the villagers try to make the best use of available resources. Main wildlife habitats are therefore on the village margins and on inaccessible or uncultivable land.

Table 1. Observed Land Use in the Upper Panj River Valley

Features	Comment
River	Width varies considerably: from 30m - >1km
Bank habitat	Variable: from rock cliffs to gently sloping silt/sand beaches and agricultural terraces.
Agricultural Areas	Wheat and potato fields, fields small, generally < 1 ha; some extensive grazing land noted.
Road	Good quality, two-lane tarmac road close to Rushan; then increasingly rugged, single track with passing zones downstream.
Homes/Agricultural Areas	Many small villages noted; houses are small and often laid out in linear patterns following the road. Homes often include small fields/vegetable patches and poplar trees for construction purposes, along with walnut and mulberry trees for food.
Marginal Agricultural Slopes	Above the villages, as the slope increases, there appears to be relatively marginal land, often requiring irrigation from channels cut into the slopes. Best use appears to be made of all available cropland.
Slope Habitat	Varies from gently rising slopes to solid rock cliffs; most common appear to be high-angle talus slopes providing possible high-frequency/low-impact hazards to homes, especially during the rainy season.

Table 2. Relationship between altitude and vegetation belts in the Rushan area
(source Patchadjanov et al., 1997)

Altitude	Vegetation Belt
1800-2700 m above sea level	Mountain Deserts with *Artemisia sp.*
2700-3700 m	Mountain Steppe-Deserts with *Artemisia Korzinskii*
3700-4200 m	Deserts with *Artemisia Lemanni* and Pamir Prickly Thrift *Acantholimon pamiricu*
4200-4800 m	Belt of Pulvinates

4.3.2 Habitats

The Panj River valley includes a number of important habitat features, these vary, depending on the extent of human influence, altitude, and geological conditions. The broad vertical variation of vegetation types in the mountainous areas around Rushan and Shugnan is indicated in table 2.

Patchadjanov et al. (1997) described the habitats subject to human influence as "Anthropogenic Landscapes," where species composition will vary depending on the degree of human activity as well as the natural conditions. It is likely that large portions of the Panj River valley can be described as this "Anthropogenic Landscape."

The broad habitat description along the Panj valley moving downstream from the confluence with the Bartang River is described in Patchadjanov et al. (1997) as starting out as "Mid Mountain Semi-Arid Open Woodland with Leaved Forests and Shrubs". Approximately 80 km from the confluence, the habitat changes to "Mid and Low Mountains with Arid Open Woodland Pistachio Forests." This continues for an additional 200 km, interspersed with a further section of "Mid Mountain Semi-Arid Open Woodland." In the lower reaches of the river, before reaching the border with Uzbekistan, the habitat changes to "Piedmont Savannoids" with a small but extremely important section of "Tugai" complex and then a section of "Piedmont Desert." Throughout these broad habitat descriptions there are large areas that can be classified as "Anthropogenic Landscapes" in that the base habitat has been subject to considerable human influence, through agriculture, road and infrastructure development, and settlements. The general faunal species composition of the anthropogenic areas in the river valleys of southern Tajikistan include the following: Water Frog *Rana ridibunda*, Green Toad *Bufo viridis*, Water Snake *Natrix natrix*, Rapid Fringe-Toed Lizard *Eremias velox*, Glass Lizard *Pseudopus apodus*, Tree Sparrow *Passer montanus*, Spanish Sparrow *Passer hispaniolensis*, Common Myna *Acridotheres tristis*, Eurasian Rook *Corvus frugilegus*, Jackdaw *Corvus monedula*, Magpie *Pica pica*, Rufous-Backed Shrike *Lanius schach*, Blue Cheeked Bee-eater *Merops superciliosus*, and Common Swift *Apus apus* (Patchadjanov et al., 1997).

4.3.3 Key features

The Panj River valley includes two of the three Zapovednik Nature reserves established in all of Tajikistan. The Zapovednik designation is the highest form of conservation designation. It is reserved for the most important natural habitats where human interference is banned. Usually the only human presence is that of scientists. Unfortunately, during the recent Tajik civil war, some areas of nature reserve were seriously damaged, but the designation remains a reflection of their potential significance (Blagoveschenskaja, 1999)

a) **Dashtidzhumsky** mountain forest reserve on the bank of the Panj River occupies 53,400 ha; it includes pistachio, juniper, and maple forests, as well as providing habitats for key faunal species such as the Markhor *Capra falconeri*, Snow Leopard *Pantera unica unica*, Jungle Cat *Felis chaus oxiana*, Brown Bear *Ursus arctos* Siberian Ibex *Capra siberica*, and Otter *Lutra lutra seistanica*. Reptiles found in the reserve include several species of gecko and the Himalayan Rock *Agama Stelio himalayanus*. Birds in the reserve include White-Caped water Redstart *Chaimarrornis leucocephalus*, Little Forktail *Enicurus scouleri*, and Chuckar Partridge *Alectoris chukar* (Patchadjanov et al., 1997).

b) ***Tigrovaya Balka*** reserve protects one of the largest remaining tugai forests in Central Asia. The tugai ecosytem in Tajikistan is extremely important because the remnants of this florally-rich habitat located farther downstream on the Amu Darya River have been significantly degraded by the impacts of hydrological and pollution conditions in the Aral Sea basin. The tugai habitat typically contains some 576 superior plants, including 29 endemic to Central Asia. Owing to desertification downstream, 54 species have been reported as being on the verge of extinction, and remaining remnants of the habitat are highly stressed. (Glazovsky, 1995). Tigrovaya Balka, with an area of 49,786 ha, is therefore extremely significant. This Zapovednik was the main habitat of the Turan Tiger *Panthera tigris virgata*, which was last seen in Tajikistan in 1954 It remains the key habitat of several Red Data Book species, such as the Bukhara Red Deer *Cervus elaphus bactrianus*, Pheasant *Phasianus cochicus bianchii*, Goitred Gazelle *Gazella subgutturosa*, and fish species, such as the Shovelnose - *Pseudoscaphirhynchus* spp. Amphibians in the reserve include the Green Toad *Bufo viridis* and Water Frog *Rana ridibunda*. Reptiles include the Turkestan Plate-Tailed Gecko *Teratoscincus scincus*, Toad-Headed Agama *Phrynochalus mystaceus*, Desert Monitor *Varanus griseus*, Rapid Fringe-Toed Lizard *Eremias velox*, Sand Racerunner *Eremias scripta*, geckos *Teratoscincus sp* and *Alsophylax sp*, Steppe Ribbon Snake *Psammopnis lineolatus*, Oxus (Central Asian) Cobra *Naja oxiana*, Levantine Viper *Vipera lebetina* and Saw-Scaled Viper *Echis carinatus* Other mammals in the reserve include the Wild Boar *Sus scrofa*, Striped Hyaena *Hyaena hyaena*, Jackal *Canis aureus*, Marbled Polecat *Vormela peregusna*, Tolai hare *Lepus tolai*, and Indian Crested Porcupine *Hystrix leucura satunini* (Patchadjanov et al., 1997).

4.3.4 Risks of impact

Both reserves are extremely important habitats at both national and international levels. Damage to the sites would be a disastrous loss of biodiversity. Although the sites have been damaged by the civil war and reportedly as a result of neighbouring agricultural and hunting activities, the importance of these areas must not be compromised if at all possible (Blagoveschenskaja, 1999).

These reserves would be affected by a full breach of the Usoi landslide dam, and species dependent on water quality would be seriously affected by an overtopping if high sediment loads were released into the Panj River.

The basic impacts would be similar to those for the Bartang valley (above), but, in addition, there is the potential for some pollutants to be released along the length of the valley. Although current pesticide and nitrate usage is reportedly low because of the economic difficulties in the region, historically there have been records of considerable pesticide and fertilizer loadings. Glazovsky (1995) noted that both fertilizer and pesticide usage was higher in the Central Asia areas than in the remainder of the former USSR DDT, now banned, was widely used in the region until 1982, and high DDT concentrations remain within the soils. Furthermore, the use of chemical fertilizers grew enormously from 1960 to 1985. In 1960, Tajikistan, on average, applied fertilizer at a rate of 78.2 kg/ha; by 1985 this had risen to

249 kg/ha (Glazovsky, 1995). However, it is likely that, while the levels of fertilizer application have fallen dramatically given the security and economic conditions in the country over the last 10 years, there remains potential for pollution.

Any remaining soil contamination could possibly be released and spread by a flood reaching this far downstream. This could provide an acute pollution shock compared to the historical chronic releases with which such intensively farmed areas normally have to cope.

There appear to be no major human settlements, factories, power stations, pipelines, chemical stores, or waste facilities along the flood route that could present a significant pollution threat. However, there are mines high in the mountain areas, reportedly for wolfram, gold, and uranium. While the mines would probably be sufficiently high above the river to escape any initial flood, it is possible that damage to deep mines as well as access routes would need to be considered.

It is not known if there are any major military facilities along the possible flood route, but large military facilities often contain potentially contaminating materials, such as fuel, ammunition, chemicals, etc , that would need to be taken into account in any national contingency plan.

4.4 Regional description - Aral Sea basin

This review is not intended to extend beyond Tajikistan, but it is vital to consider the potential regional implications of a major flood scenario. In addition to downstream impacts, it is also important to recognise that the Panj River forms the border with Afghanistan and, although beyond the scope of this assessment, impacts across the border along the entire length of the Panj River flood path would need to be considered in any regional context.

Tajikistan, and particularly the areas potentially affected by a breach of the Usoi landslide dam, are major contributors to the water balance in Central Asia. It is inevitable that any problems experienced in the riverine regime in Tajikistan will be transmitted across borders, potentially affecting even more vulnerable communities farther downstream.

The Amu Darya River, together with the Syr Darya River, is a major contributor to the Aral Sea basin. The problems specifically associated with the Aral Sea are well documented (e.g., Glazovsky, 1995; Kobori and Glantz, 1998; Shestakov and Streletsky, 1998). In addition to the reductions in water supplies reaching the Aral Sea as a result of massive increases in cotton crop irrigation over the last 60 years, downstream water quality is a key regional issue. Problems include contamination from agrochemicals, increasing salinisation, and impacts on groundwater, as well as surface water. The system is already extremely stressed, people living downstream of the Amu Darya are reported as saying: "people at the entry of the "pipe" drink water, but we Karakalpaks, at its exit, drink a poison" (Shestakov and Streletsky, 1998). Ecological resources are also highly stressed; reports note that, in some areas around the Aral Sea, diversity of mammal species has dropped from 60 to 30 species and the number of bird species from 319 to 168 (Glazovksy, 1995)

Under the most likely failure scenario presented for Lake Sarez, due to overtopping of the dam, the immediate downstream cross-border impacts would probably not be very significant. It is predicted that a debris flow would travel as far as the Rushan district. However, although the flow front might not travel past the border downstream, any sediment load and contamination that is collected will be flushed downstream, making an already-stressed water-supply system even more difficult to manage.

However, in the worst-case scenario, it is possible that a debris flow would reach beyond the Tajik border and affect downstream countries as far as the Aral Sea basin itself. In addition to the immediate damage such a flow would cause to settlements and infrastructure in the path of the flood, it is important to recognise the potential for secondary disaster impacts. These could include the destruction of strategic resources, such as oil pipelines, chemical plants, factories, and agrochemical warehouses. In such a scenario, there is a very real threat of a "cocktail" of chemicals being released, which could further complicate recovery from the debris-flow impact by polluting water sources, irrigation systems, agricultural land, and habitat areas.

Furthermore, the impact of a catastrophic debris flow could change the course of river flows in low-lying areas where there might be more room to change flow patterns. This could affect areas that had already been dried out and had become heavily salinised, thereby re-releasing the salts into the changed hydrological regime.

4.5 Conclusions

The areas that are potentially at risk from a flood from Lake Sarez are extremely important natural habitats of local, national, and international significance. The area exhibits a high level of endemism, and it is possible that important species would be endangered by any of the flood scenarios. It is vital that the habitats be given the recognition and protection they deserve, and that every effort be made to protect those species that can be seen as a common heritage of mankind. The concerns are more than just of national-level conservation The species and habitats under threat are unique and irreplaceable. Damage to people and infrastructure from any disaster would be appaling enough; at least people can be given early warning and infrastructure can be rebuilt. If and when rare and endangered species and habitats are expunged, they are gone forever and there can never be recovery from the impact of the disaster. There are basic measures that can be undertaken to identify and protect these habitats and species both in-situ and ex-situ. It is important that all such measures be undertaken if the riches of this area of the Pamirs are to be protected for the international community and future generations.

4.6 Recommendations

The following recommendations are based on the gaps in information available to the current assessment. Anticipated costs are not provided for these items because it is felt that much of the work can be carried out by national and regional authorities and by NGOs. It would benefit such work if it could be conducted under the direct supervision and management of the UN family to ensure that full levels of objectivity are assured.

4.6.1 Regional priorities

Further attention must be given to the identification of potential pollution sources in the region downstream from Tajikistan, including the border areas of Afghanistan along the Panj River. This will require a regional perspective to examine the full route of the Amu Darya River basin in regard to the following issues:

- Baseline survey of settlements, infrastructure, socio-economic resources, and habitat characteristics.
- Comparison of the baseline against the developing flood-path analysis.
- Identification of key points of concern where primary and secondary impacts are most likely, or where impacts would be most significant.
- Estimation of the possible value of flood damage along the entire length of the vulnerable area. This would allow cost/benefit comparison of flood prevention and mitigation schemes to be seen in the appropriate context that potential donors can appreciate.
- Review of opportunities to prepare national/regional contingency plans to cope with the threat scenarios.

These operations could be completed relatively quickly by an organisation with a regional mandate.

4.6.2 Tajikistan priorities

- Risk assessments for any mineral and military establishments near the flood route should be carried out. This would be a national governmental responsibility.

- Key habitat areas, such as those in the Pamirs, should be given the full legal and practical protection their international conservation value warrants. This could help the Government of Tajikistan make the case for international assistance under the various UN conventions to which the nation is signatory. It would possibly make the donor community more amenable to assist if it is clear that internationally-important habitats are afforded the full level of available national protection, yet remain significantly endangered.

- Ecological monitoring programmes should be expanded to ensure that the best possible level of scientific information is available against which policy decisions can be taken. Local and international NGOs should work with Governmental agencies to provide the most effective approaches to covering this large area of outstanding work. The World Wide Fund for Nature (WWF) has worked with local experts to produce a range of biodiversity projects outlined in their report *"Biodiversity Conservation* *of Tajikistan: analysis of recent situation and project portfolio"* (Patchadjanov et al., 1997). Such efforts would be endorsed by the author. Even though none of these projects has been specifically targeted to impact the Sarez issue, the information and infrastructure that could be provided from such efforts would aid more-targeted studies. It appears that the level of technical expertise is very high in Tajikistan, like many countries, the key limiting factor for environmental research is access to resources. In a nation recovering from a civil war and the implications of the relatively new political situation in Central Asia, it is perhaps not surprising that resources that would assist in nature conservation have been channelled elsewhere. However, it is important to note that cutting environmental research will have possibly significant long-term implications in terms of sustainable management of limited resources. Assistance from the international community should be sought to ensure that joint research projects can be developed to re-establish the vital monitoring and protection work that sustainable development requires.

- As a contingency measure, consideration should be given to ex-situ conservation methods for those endemic species that are especially endangered by flooding. This would at least preserve the gene pool of such species. This could be carried out locally, e.g., at the Pamir Botanical Gardens, or internationally, if required. The Pamir Botanical Garden in Khorog works under the Pamir Biological Institute of the Tajikistan Academy of Sciences. The Garden is undertaking important botanical conservation measures and warrants support in developing possible ex-situ conservation projects, such as establishing seed banks. One of the key researchers on the botany of the Bartang valley is the Director of the Gardens, and he is in an ideal position to ensure that such activities are targeted to key species and sites.

- Tajikistan is a signatory to the UN Convention on Biological Diversity. This Convention provides, *inter alia*, for mechanisms to cope with impact assessment threats. It is recommended, without prejudice, that the Government of Tajikistan should explore the possibilities of gaining financial support to undertake measures to secure necessary biological studies under the terms of the Funding Mechanism of the UN Convention on Biological Diversity.

Article 14 of this Convention says that each Contracting Party, as far as possible and appropriate, shall:

"In the case of imminent or grave danger or damage, originating under its jurisdiction or control, to biological diversity within the area under jurisdiction of other States or in areas beyond the limits of national jurisdiction notify immediately the potentially affected States of such danger or damage, as well as initiate action to prevent or minimise such danger or damage; and promote national arrangements for emergency responses to activities or events, whether caused naturally or otherwise, which present a grave and imminent danger to biological diversity and encourage international cooperation to supplement such national efforts and where appropriate and agreed by the States or regional economic integration organisations concerned, to establish joint contingency plans "

There is, therefore, a clear obligation for Tajikistan to take action on this very real threat to biodiversity. However, Article 20 of the Convention states that:
"The developed country Parties shall provide new and additional financial resources to enable developing country Parties to meet the agreed full incremental costs to them of implementing measures which fulfill the obligations of this Convention. .The developed country Parties may also provide, and developing country Parties avail themselves of, financial resources related to the implementation of this Convention through bilateral, regional and other multilateral channels....Consideration shall also be given to the special situation of developing countries, including those that are most environmentally vulnerable, such as those with arid and semi-arid zones, coastal and mountainous areas "

Chapter 5

Environmental impact assessment: geomorphology of the Bartang and Kudara valleys

5.1 Introduction

The Environmental Impact Assessment Sub-team, focusing on landforms and biodiversity, worked in two different geographic areas in determining the environmental impact of possible breaching of the Usoi landslide dam leading to an outburst flood. One area was the upper stretch of the Bartang and Murgab River valleys, immediately downstream from the lake, and the lower end of the Kudara River valley where it enters the Bartang. These stretches of these river valleys would experience the most direct impact of a flood from Lake Sarez, regardless of the size of the flood. The other area was downstream along the Panj River, which would be impacted in the worst-case scenario. The lower part of the Vanj River basin, a tributary basin of the Panj River, could also be damaged; however, because of time constraints, the sub-team was unable to visit this basin.

5.2 Geomorphology and biology of the upstream area (Bartang, Kudara, and Murgab River basins)

The Murgab River meets the Kudara River near the village of Bartang (elevation ca. 2,660 m); at that point, the river name changes to Bartang River. Lake Sarez is located in the Murgab River basin. Lake Sarez and the Bartang, Kudara, and Murgab River basins are situated in a typical dry alpine area. According to Yablokov (1997), the mean annual ambient temperature at the Irkht hydrometeorological station at Lake Sarez (elevation 3,290 m) is 1.0 °C, and the annual precipitation at the station is 108 mm, with little snowfall (average annual maximum snow depth ~ 58 cm).

In order to assess the direct environmental impacts that could be created by a Lake Sarez outburst flood, it is necessary to examine landforms, fauna, and flora in the Bartang, Kudara, and Murgab River basins, immediately downstream from the lake

5.2.1 Previous environmental studies

Local experts have conducted general geomorphic studies in the valleys, including studies of slope instability related to tectonic activity. However, the impacts of an outburst flood on the geomorphology of the downstream valleys had not been assessed thus far. Moreover, relationships between landforms and fauna and flora were yet to be assessed in these valleys. For these reasons, the field observations of the Environmental Impact Assessment Sub-team were conducted along the Bartang, Kudara, and Murgab Rivers.

5.2.2 Environmental impacts

The precise impact assessment will be possible only after a potential outburst-flood analysis is completed. Nevertheless, the sub-team found the following important aspects that have to be considered regardless of the size of the flood.

5.2.2.1 Geomorphology

The landforms observed in the valleys were classified into the following six elements:
(1) glacial moraines,
(2) river terraces,
(3) alluvial fans/cones,
(4) flood plains,
(5) talus slopes, and
(6) bedrock cliffs/walls

On the slopes at higher elevations, glaciers and rock glaciers were observed. However, these features have been excluded from this discussion because they would not be impacted by a flood. Figure 1 is a schematic diagram showing the major landforms observed in the valleys. Among these, landform elements (1) to (5) are especially important in terms of debris (mixture of rock fragments, sand, and mud) to be transported downstream by an outburst flood from the lake.

1) Glacial moraines — Moraine deposits can be found extensively in the Bartang, Kudara, and Murgab River valleys A terminal moraine is located near the confluence of the Bartang and Panj Rivers. This is correlated with the maximum advance of the QII stage of glaciation some 400,000-600,000 years ago. In the upper reaches of these valleys, an ice cap had covered a wide area, and the deep valleys had not been formed at that time. Younger moraines from the tributary valleys are located at the higher altitudes. The chronological correlation of the glacial moraines and the relationships between the moraines and river terraces should be studied in detail.

2) River terraces — Eight to ten river terraces have been formed in the uppermost valley of the Bartang River. Although the results of local studies of the ages of these terraces seem to be contradictory, one study has suggested that some of the terraces were formed about

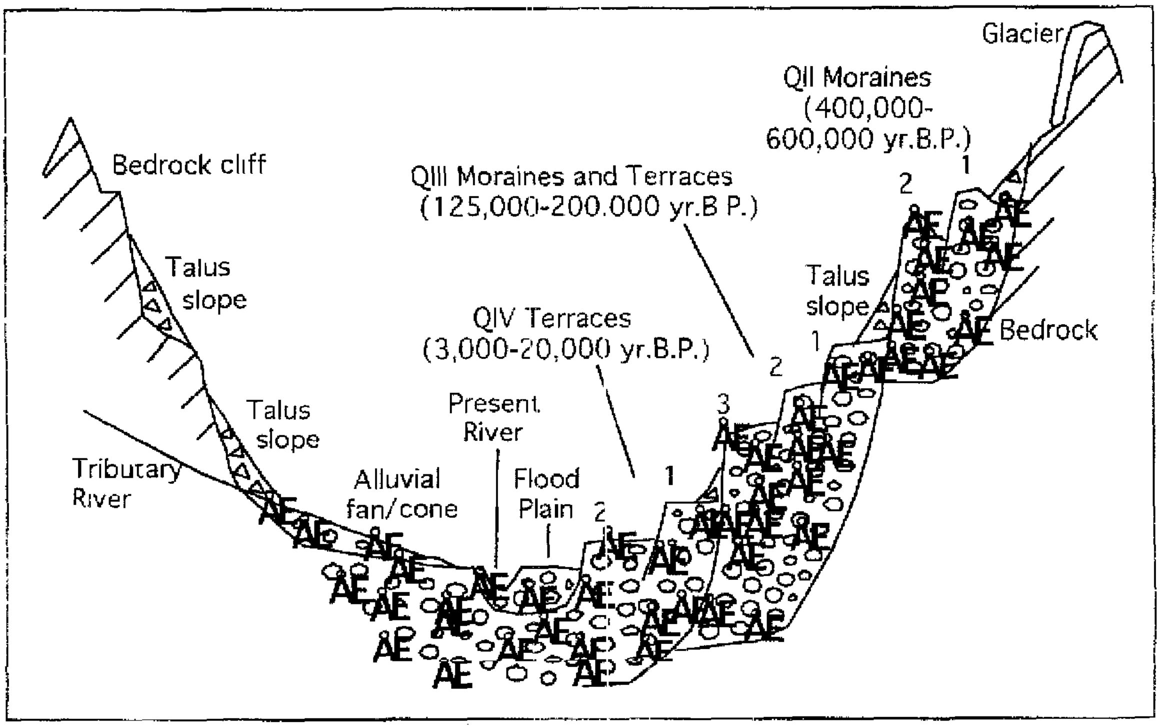


Figure 1. Schematic diagram showing the major landforms in the Bartang, Kudura, and Murgab valleys.

400,000-600,000 years ago (QII). Terraces formed about 125,000-200,000 years ago (QIII terraces) were deposited when glaciers covered the upstream half of the Bartang River. The QIV terraces (photo1) were formed between 3,000 and 20,000 years ago.

modern flood-plain deposits when the old deposits are located on the valley bottom. The depths of such deposits are not known. At least four to five old lake deposits have been recognized on the valley floor of the Bartang River.

3) Alluvial fans/cones — An alluvial fan or cone can be defined as a fan-shaped landform created by frequent debris flows from a tributary valley. A fan has a gentler surface slope than that of a cone. Some parts of the fans and cones are still active (photo 2).

Photo 1: A river terrace formed about 3.000-5.000 years ago. Darjmozh village (elevation about 2.170 m) is located, which is 0-40 m higher thant the present riverbed. Photo credit: Teiji Watanche.

Photo 2. An alluvial cone. The village of Misau is located on the cone, parts of which are still covered by fresh debris. Vetation covers the superface.

4) Flood plains — Flood plains, including those covering the old lake deposits, can be observed in the valleys. Vinnichenko (1997) stated that the downstream stretch of the Kudara River has been fully dammed six times and partially dammed four times. The Murgab River has been blocked at six sites The Bartang River has been dammed at least three to five times. Some of these old flood deposits are covered by

5) Talus slopes — Rock fragments derived from rock falls have been deposited on the slopes that form the valley walls. These rock fragments commonly originated from fallen bedrock (i.e., from rock falls). Most talus slopes are currently active.

These five depositional landform elements are composed of soft, loose geologic materials. The origins of most of these deposits can be divided into two parts. The first group of deposits was formed by glacial erosion. The area hosted large glaciers in the past; these produced enormous amounts of debris that was available to be transported down-valley. In the QII stages (400,000 – 600,000 years ago), the glacier in the Murgab-Bartang valley reached the confluence with the Panj River valley In the QIII stages (125,000 – 200,000 years ago), the deposits formed as glacial moraines at the higher elevations, and as river terraces at lower elevations. The second group of deposits has been attributed to rock fall. Talus slopes have developed as a result of frequent freeze-thaw cycles combined with continuing tectonic activity. Moreover, because this area is extremely dry, the ground surface is not heavily vegetated. As a result, the surfaces of the slopes remain unstable.

These deposits could easily be incorporated into the flood waters/debris flows because they consist of loose, unconsolidated materials. Because these deposits are distributed from the present river beds to the higher slopes, even a small flood could transport the lower-elevation deposits. It should be noted that the deposits are extremely thick near the confluence of the Murgab and Kudara Rivers (photos 3 and 4). In addition, old lake deposits on the valley bottom would probably be eroded away and transported downstream by a Lake Sarez outburst flood. All of these valley-bottom materials could be incorporated into a debris flow, causing damage downstream. Also, the toes of the talus slopes and alluvial cones would become much more unstable as a result of removal of downslope debris. Thus, continuous, slow retreats of the toes of terraces and fans/cones, on which most fauna and flora live, are expected.

Photo 3. Thick alluvial deposits near Yapsho (lower center of the photo) on the uppermost reaches of the Bartang river.

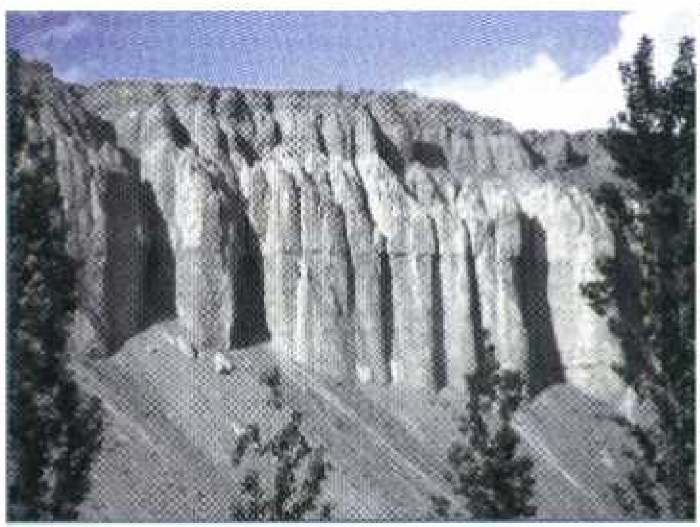


Photo 4. A close-up view of the thick deposits (more than 100 m thick) near Yapsho.

5.2.2.2 Fauna and flora

Most fauna and flora, as well as most human settlements, have been observed either on the alluvial fans/cones or on the younger river terraces formed about 3,000-5,000 years ago (photos 1 and 2). Only two settlements, Dasht and Nisur, are located on the glacial moraines. The alluvial fans/-cones and younger terraces have formed near the valley bottoms. These depositional landforms, serving as homes for most fauna, flora, and human settlements, could easily be washed away.

According to the director of the local botanical gardens in Khorog, there are 166 endemic floral species in Gorno-Badakshan Province and the surrounding Pamir mountains. Among these, some 70 species are found only in Gorno-Badakshan Province.

The major types of vegetation in the Bartang, Kudara, and Murgab River basins are *Artemisia vachanica, A. lehmaniana, A. korshinski, Acantholimon sp.*, and *Carex pachystylis. Acanthlimon Hilun, Kobresia pamiroalaica*, and *Allium fedchencoii* characterize elevations above 3,000 m.

Some of the flora, especially *Climates saresica* and *Pleuraspermum Badackschanica*, are endemic species. Endangered species in the valleys include *Climates saresica, Pleuraspermum Badackschanica, Betula muroabica, Kudrjascheva pojarkovi, K. nadinae, Cousinie rajkovii, Acantholimon Hiluri*, and *Populus pamirica*. These species, and others, could be devastated by an outburst flood.

Wild animals and birds in the valleys include ground squirrels, mountain goats, snow leopards, bears, hares, and magpies. Mountain goats and snow leopards are included in the Red-Data Book. Downstream transport of the deposits would also lead to high suspended-sediment loads, which could damage fish populations in the downstream reaches, as described elsewhere for glacial-lake outburst floods in the Himalaya (Watanabe and Rothacker, 1996).

5.2.2.3 Geomorphology and settlements

Most settlements have developed on either alluvial fans/cones (10 settlements confirmed) or on the younger terraces (eight settlements confirmed). Two settlements are located on glacial moraines. Figure 2 illustrates a cross-sectional profile of a geologically young terrace, on which the village of Darjomzh (elevation about 2,170 m) is located. The relative elevation difference between the present river bed and the houses and agricultural field ranges from 5 to 38 m. This demonstrates that even small-scale flooding could damage fauna and flora as well as settlements.

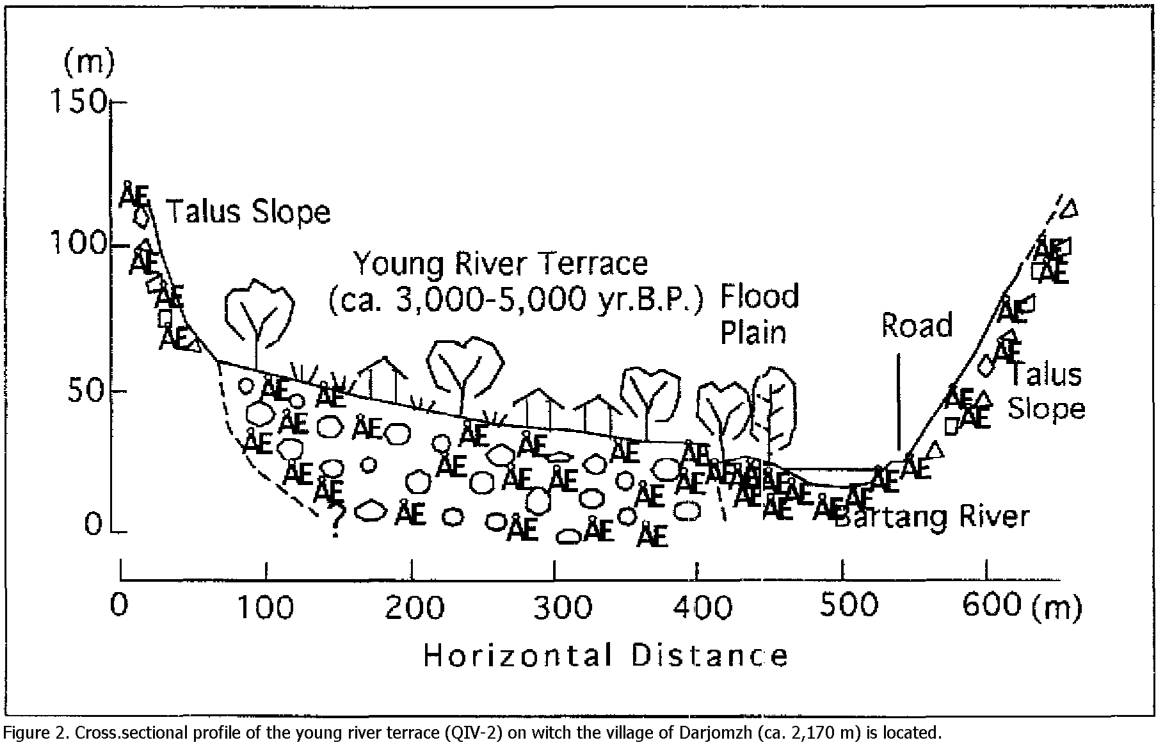


Figure 2. Cross.sectional profile of the young river terrace (QIV-2) on witch the village of Darjomzh (ca. 2,170 m) is located.

5.2.2.4 Long-term response and recommendations

Revitalization of fauna and flora is strongly related to geomorphic stabilization. Revegetation following an outburst flood will be possible only after stabilization of the new landforms. Geomorphic response will begin immediately after the flood. However, full development of landforms, such as new alluvial fans/cones and river terraces, may require hundreds to thousands of years.

Biodiversity in the area largely depends upon the availability of water on the landforms. Most fauna and flora are distributed on the landforms near the present river bed. In addition, conservation of biodiversity will depend on protection of habitats from flooding.

It is important to examine impacts of debris-rich water to the lower reaches of these valleys. Detailed distribution of the deposits should be mapped and the volumes of the deposits should be estimated

5.3 Geomorphology of the downstream area (Panj River basin)

The Panj River basin would very possibly be impacted by an outburst flood if the lake were to drain completely in a short period of time. The Panj River from Rushan to Shuroabad has dissected the mountains and formed a narrow V-shaped valley. The river has deposited an enormous amount of debris on the flat surface downstream from Shuroabad, mainly in Khatlon Province.

The floodwater would flow rapidly down the narrow Panj valley. Then, the water would erode and transport the low-lying alluvial and terrace deposits, which would be deposited farther downstream.

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, Missisippi (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 pre-determined 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

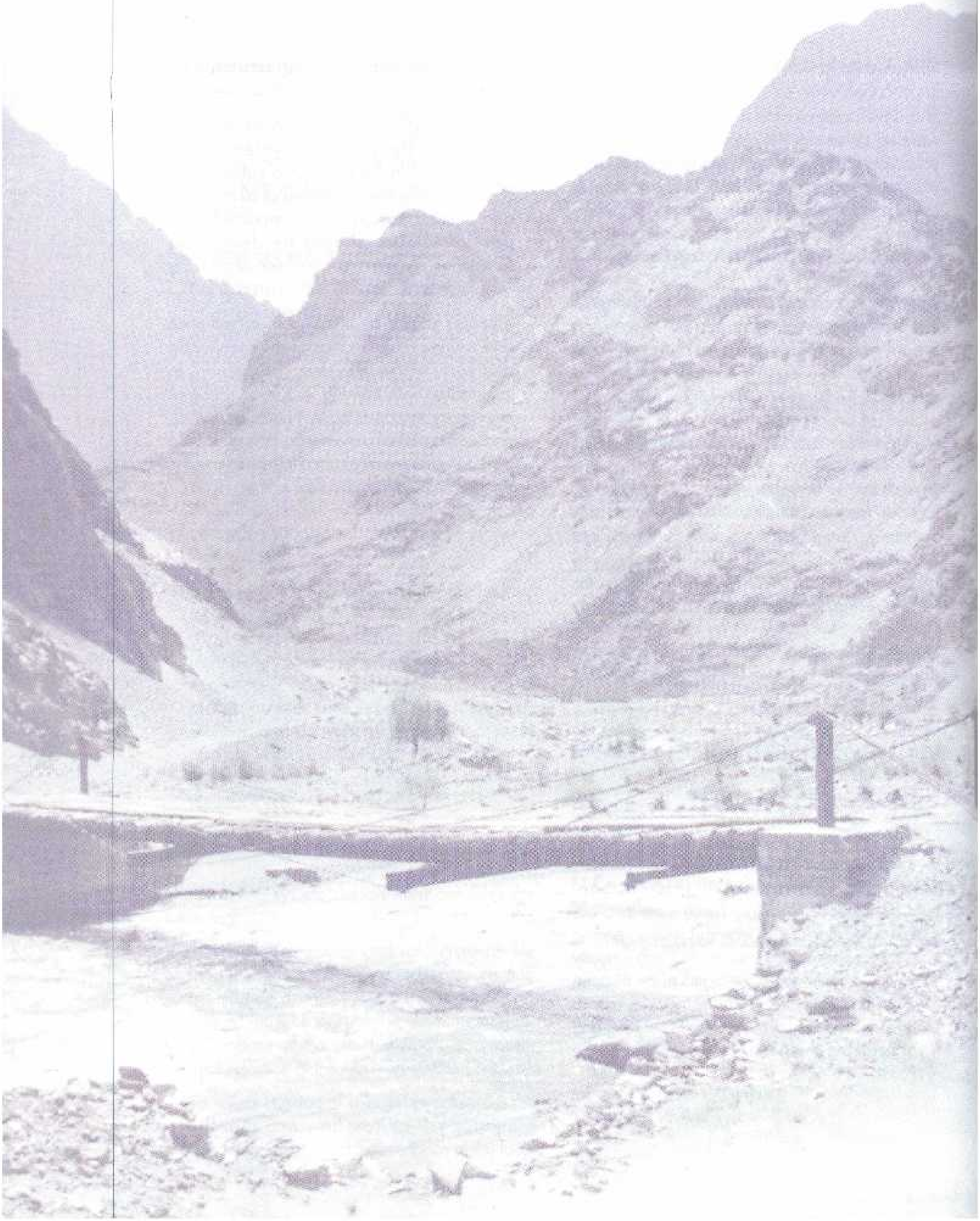
- It will provide information on the stability of the Usoi landslide dam and Lake Sarez, and will alert observers to any precursors to dam failure.

- 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



Chapter 8

Accessibility of the Bartang River valley and the Usoi Dam/Lake Sarez

8.1 Introduction

8.1.1 Objectives of the accessibility sub-project

- Determine the degree of accessibility of the Usoi dam for heavy equipment.
- Investigate the existing road infrastructure.
- Identify methods and route to construct/improve a road in the Bartang River valley.
- Assess project costs.
- Assess capabilities of local contractors to perform the work.

8.1.2 Carrying out of the above tasks

The sub-team carried out the above tasks by:

- Walking downstream from Usoi dam to the village of Barchidev.
- Travelling by car through the Bartang and Panj River valleys from Barchidev to Khorog.
- Travelling by car through the Kudara valley from Rukç to Kudara.
- Travelling by car along the major route from Khorog to Dushanbe, via Kulyab.
- Conferring with Tajik experts.

8.2 Accessibility to Gorno-Badhakshan Province and the Usoi landslide dam

8.2.1 Overall status of accessibility

The problem of the accessibility to Gorno-Badhakshan Province and the Usoi dam is not a local problem, it reflects the generally poor condition of transport in Tajikistan The condition of roads in Tajikistan is normally very poor; they prove unreliable from season to season, and most vehicles are obsolete.

8.2.2 Main routes from Dushanbe to Gorno-Badakshan

The Province of Gorno-Badhakshan, where Lake Sarez is located (fig. 1), can be reached from the capital, Dushanbe, by two routes:

- The first, via Osh, Kyrgyzstan, to the north and east of the Pamir Mountains and then south to Murgab and Khorog, is a high, difficult route, but represents the primary access road to Gorno-Badhakshan.
- The alternate route, currently under construction, reaches the city of Kulyab, and then follows the Panj River upstream along the Tajik-Afghar border to Khorog. This road, due to difficult terrain, limited design standards, and crude standards of construction, is even more unreliable and inaccessible to heavy traffic than the above route through Kyrgyzstan.

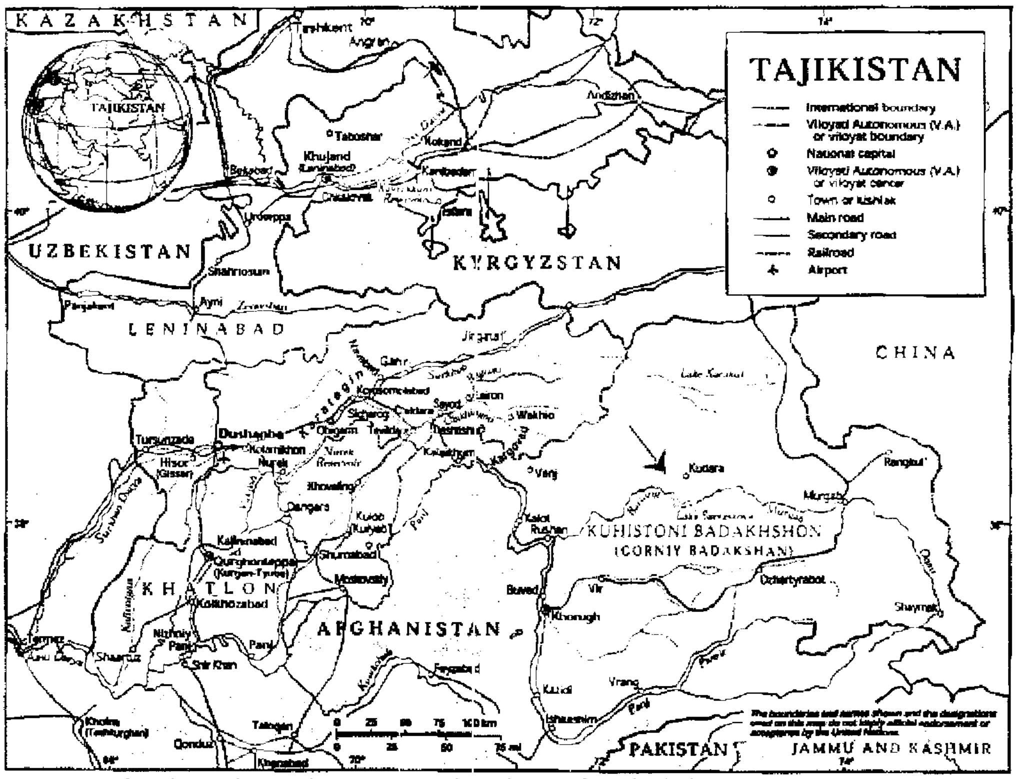


Figure 1. Map of Tajiskitan and surrounding area. Arrow indicates location of usoi dam/ Lake Sarez.
Source: Map No. 3765 Rev. 9 United Nations, Departament of Public Information Cartographic Section.

Place names mentioned in text:

Barchidev:	First village downstream from Usoi dam.
Bartang River:	Trunk river formed by joining of the Murgab and Kudara Rivers downstream from Usoi dam. Flows into the Panj River.
Dushanbe:	Capital city of Tajikistan.
Khorog:	Main city of Gorno-Badhakshan Province.
Kudara River:	Tributary stream that joins the Murgab River at the point where the two streams form the Bartang River.
Kulyab (Kuliab):	Main city located approximately midway on the route from Dushanbe to Khorog.
Gorno-Badhakshan:	Administrative region (oblast or province) on the main road from Khorog to Osh to Dushanbe.
Lake Sarez:	Lake impounded by the 1911 Usoi landslide.
Murgab River:	The river that feeds Lake Sarez and continues downstream to its confluence with the Kudara River to form the Bartang River.
Murgab (town):	Town in Gordo-Badhakshan on the main road from Khorog to Osh to Dushanbe.
Osh:	City in the Republic of Kyrgyzstan on the northern route from Dushanbe to Gordo-Badhakshan.
Pamir Mountains:	Major mountain range in southeastern Tajikistan; it roughly corresponds to the area of Gordo-Badhakshan.
Panj River:	River into which the Bartang River flows; it forms the border between Tajikistan and Afghanistan.
Rushan:	Town at the confluence of the Bartang and Panj Rivers.
Usoi:	Name of the 1911 landslide that buried the village of Usoi, formed the Usoi landslide dam, and impounded Lake Sarez.

At present the most likely route to Gorno-Badhakshan from Dushanbe is the first alternative given above, which circles the Pamir Range from the north and east through the city of Osh, Kyrgyzstan, which has international railway connections If travelling non-stop by means of a modern, 4WD light vehicle, the 350-km-long road between Kulyab and and Khorog requires about 14 hours The entire Province of Gorno-Badhakshan can be considered to be very inaccessible for heavy vehicles and totally inaccessible to trucks with trailers.

8.2.3 Accessibility to Usoi dam

There are two traditional routes to Usoi dam and Lake Sarez:

1) upstream along the Bartang River valley, and
2) via the Kudara River valley

Access through the Kudara valley, which entails entering the upper Kudara valley after leaving the main Osh-Khorog road at Lake Karakul, was previously supported by the Soviet Union. Because the Kudara valley route is longer and more tortuous than that through the Bartang valley, this option has lost favor in recent years.

Accessibility via both routes is very difficult, topographic conditions are extreme, and the existing roads are absolutely inadequate for transport of heavy equipment. An access road for the purpose of mitigative construction at Usoi dam would require a paved surface, structurally adequate bridges, radius of curves of not less than 25 m, and gradients not exceeding 9 percent. Such an endeavour would require structural works (bridges, culverts, retaining walls, etc.) to deal with problems imposed by the local mountainous terrain. The required construction would impact substantially both the environment and the social conditions of the local population. Precious portions of usable terrain would be subtracted from human settlements In addition, road construction would encounter erosion and slope instability along the right-of-way.

Both routes pass through the village of Barchidev, about 20 km downstream from Usoi dam. However, no road exists between Barchidev and Usoi dam. On-site investigations have ascertained that construction of an access road from Barchidev to the dam crest is technically feasible, but would require a greater investment in money and time than the value of the structural intervention at the dam for which purpose the road would be constructed.

The only route that seems feasible for a Barchidev-Usoi dam road is along the lower slopes south of the Murgab River, from Barchidev upstream to the springs (seepage from the lake) at the base of Usoi dam, and then crossing the debris-flow deposit at the right end of the dam in a deep, wide trench leading to the dam crest. Construction and maintenance costs of such a road would be considerable. Local contractors would be unable to carry out construction works and, at international prices, costs could exceed US$ 800,000 per kilometre. Thus, construction of a road suitable for heavy traffic along the Bartang or Kudara River valleys upstream to the village of Barchidev and from Barchidev to the dam crest, would require such an enormous amount of investment as to strongly discourage this option.

8.2.4 Alternative routes to Usoi dam

Two additional possible access routes have been discussed.

- The first access alternative turns north from below the outlet from Lake Yashulkul on the Khorog-Osh-Dushanbe road. This route crosses a mountain range with passes exceeding elevations of 4,000 m, and ultimately enters a valley descending to Lake Sarez The terminus of this route is a bench, about 100 m above lake level, located immediately to the east of the existing base camp on the left (south) shore of the lake This bench, formed by an ancient landslide, is composed of a mixture of rock fragments and soft mud. During an on-site inspection, tracks of trucks could be observed on the soft terrain. This observation indicates that heavy vehicles have traversed this high-elevation route, but there is no knowledge of the path taken by the road, which promises to be very high and difficult. The length of this possible route is about one third of that following the lower part of the Bartang valley, but the accessibility and engineering problems could be more difficult.

- The second route proceeds east from the town of Murgab. This route is probably the key to access of heavy equipment to the dam crest and, realistically, is the only possible alternative to transport of this equipment by helicopter. This route leaves the Khorog-Osh-Dushanbe road at Murgab and proceeds down the course of the Murgab River to the upper end of Lake Sarez. Heavy equipment could then be transported by ferry from this point on the lake to the vicinity of Usoi dam. This route is considerably shorter than the one in the Bartang valley. In addition, inspection of available maps suggests that the topography crossed by this route is more favourable for construction of a road suitable for transport of heavy equipment than that of the connecting route from the Khorog-Osh-Dushanbe road. Other important advantages are offered by the possibility of reaching Lake Sarez directly from Murgab, saving at least a two-day trip, as compared to the Murgab-Khorog-Rushan-Lake Sarez route.

8.3 Rehabilitation of existing road in the Bartang Valley

8.3.1 Present situation

The installation of communication lines, equipment, and facilities connected with the early warning system in the Bartang River valley will require safe and efficient travel in every season along the existing road in terms of both operations and maintenance. Guaranteed access to the Bartang valley is essential for this to be possible

The topography and geomorphology of the Bartang valley are extremely difficult and unstable. Erosion and landslides are common

Bridge in the Bartang valley. Photo credit: Bruno Periotto.

phenomena, and the right-of-way of the road frequently encounters critical situations where it crosses alluvial fans and/or torrents, or where it is immediately adjacent to the Bartang River. At present, the road is a rough track in such poor condition that it can barely be traversed using 4WD light vehicles. Average practical vehicle speed does not exceed 15 km/h, and, in the presence of snow or ice, the road cannot be travelled at all. The basic location of the route is adequate, but the alignment and longitudinal profile should be revised along 100 km of the 130 km connecting the villages of Rushan, at the confluence of the Bartang and Panj Rivers, and Barchidev. However, the first (i.e., downstream) 30 km of the road are in acceptable condition. The road also requires application of adequate gravel surfacing.

8.3.2 Summary description of needed rehabilitation of Bartang Valley road

The design criteria for this road will be determined by the complex morphology of the valley and by the limited abilities of local contractors. Geometric criteria and construction procedures commonly adopted in road construction would impact negatively the environment and the economy of the valley, as a result of the delicate environmental and cultural balance of villages that are located on highly erodible river terraces, alluvial fans, banks of raging rivers, at the toes of unstable slopes, and adjacent to primordial but sophisticated irrigation systems. Under such conditions, it is necessary to adopt pragmatic standards for design and construction. Rehabilitation of the road in the Bartang valley should be done so as to have minimum impact on the valley. Design standards should reflect the specific use for which the road is intended. The level of service to be aimed for, in terms of vehicle speed and maneuverability, traffic interruption, safety, and economy, should be consistent with the primary needs of continuous accessibility and minimal environmental impact. In addition, because of the considerable road lengths involved, any significant upgrading of design standards could lead to an enormous, unjustified increase of costs.

The principal parameters that should determine the road design standards are:

- Low, light traffic flow.
- Low design speed.
- Minimum impact to the road surface.
- Minimum cost of road-related structures.

Design criteria for the above elements are presented in annex 8-1.

The most typical feature of the existing road is its single-lane track. This single-lane roadway, a necessary choice at the time of original construction, must not be considered a limiting condition in future plans. Accessibility and capacity of the road can be increased by a proper number of turnouts placed alongside the single-lane track at regular intervals, together with required widening on curves. With these modifications, a single-lane roadway offers a satisfactory level of service, affords several technical and economic advantages during construction of the road and makes maintenance much easier than for the original single-track road.

In addition to adding turnouts and widening curves, priority should be given to improving the existing roadway. This can be achieved by construction of retaining walls made of steel-mesh gabions, in order to allow the road to follow the contour of the slopes as much as possible. Gabions should also be constructed to protect embankments from erosion where the road runs adjacent to the river and to protect the road across unstable slopes. Gabions and dry masonry walls (i.e., stone walls) will help to minimize slope excavation.

Crossings of most tributaries of the Bartang River, at locations without bridges, can be achieved by installing pipe or box culverts to serve as drains for average stream flow. At these sites, flood discharge can be controlled by installation of erosion-resistant, stone-paved overflow sections across the surfaces of the road embankments. Paved fords at stream level are recommended for crossing minor streams Paved fords are preferred to bridges for minor streams because:

1) they do not reduce the flow cross section; thus, they are not as subject to erosion during flood discharge as are bridge abutments;
2) they can be installed using local materials; and
3) they are easy and economical to maintain.

The suggested labor-intensive structural construction is consistent with local construction capabilities and requires limited use of heavy mechanical equipment. Training will be required for all personnel to ensure that construction is carried out properly, with minimal social and environmental impacts.

8.3.3 Estimation of costs for rehabilitation of Bartang Valley road

Improvement of the general alignment of the Bartang valley road to make it safe and comfortable for light vehicles, as well as adopting uniform design standards and construction procedures, will require investments estimated to be between US$ 300,000 and US$ 600,000 per kilometre. These high figures are justified by the very difficult terrain in the Bartang valley, as well as by the difficulty of access to Gorno-Badakshan, where the Bartang valley is located. These costs conflict with the extreme poverty of the local population. Adopting the suggested design standards and labor-intensive technologies, and involving the local population, will lower the estimated costs to approximately one fifth of those given above. Time required for reconstruction is estimated at approximately 36 months.

8.3.4 Maintenance of the Bartang Valley road

Maintenance of the Bartang valley road should be supported technically and financially primarily by the oblast (provincial) government, but carried out by local authorities and communities. Involving local communities and populations as much as possible in building and maintaining the road will make them able to assume primary responsibility for the road, creating considerable local employment, as well as pride in their accomplishment

8.4 Environmental and social aspects of reconstruction of the Bartang valley road

8.4.1 Existing environmental/social conditions in the Bartang valley

The morphology of the Bartang River valley is characterized by the alternation of narrow rocky canyons and wider valley floors with unstable slopes along the margins. The Bartang valley is very dry; rainfall does not exceed 100 mm/year. The Bartang River and its tributaries, which are fed by abundant snowmelt during the warm season, provide water for human activities and for agriculture. The only green oases of vegetation present in the valley are concentrated on alluvial terraces formed by deposition of debris, sand, and mud inside the meanders of the Bartang River or at its confluences with tributaries. Human settlements and agricultural activities are located on these oases Sophisticated irrigation systems divert river and tributary water to the fields by means of trenches excavated on the mountain slopes at slight gradients. The irrigation channels feeding water to the villages often cross or run parallel to the road without protection.

8.4.2 Potential environmental impacts

Planning for the rehabilitation of the existing road in the Bartang valley should consider the following potential risks:

- Road embankments running alongside the river could reduce the cross section of river flow, resulting in bank erosion, and thus causing retreat of inhabited landforms, particularly those prone to erosion.
- Increase in vehicular traffic could damage irrigation systems if the channels are not protected.
- Dust raised from the road and blown by vehicles could damage crops along the side of the road and pose a health hazard to local inhabitants.
- Deep cuts in steep slopes could increase slope failures.
- Blasting should be limited or avoided wherever possible. Because of the high incidence of slope instability, indirect impacts of blasting could be disastrous.

8.4.3 Social and economic impacts

Distances between individual villages in the Bartang valley vary from 4 to 28 km. The largest town, Rushan, is located approximately 130 km downstream from the village of Barchidev and 155 km downstream from the Usoi dam. Because of these distances, contacts between people of different villages are limited. People often walk from village to village, sometimes covering very long distances, because they lack efficient means of transportation or communication. There is no postal service in Tajikistan.

The installation of an early warning system in each village of the Bartang valley, based on a network of satellite telephones, which will also be usable as normal telephones, will raise the demand for transport in the valley. This communication, in fact, undoubtedly will induce

- Increased opportunity for inhabitants of the valley to trade and sell agricultural products and cattle to neighboring villages.
- Improved access to markets of the region.

A bridge in the Bartang valley. Photo credit Bruno Periotto.

- Possibility of developing new craft activities because marketing of these products will be improved.
- Possibility of introducing money-producing tourist activities, such as hiking/trekking/climbing and canoeing/rafting.
- Possibility of more easily accessing sanitary facilities, including disposal of village waste materials
- Improvement of social contacts among the different villages

Basic village development activities (irrigation, rural electrification, radio communication, etc.) are being promoted by NGOs (notably, the Aga Khan Development Network and Focus Humanitarian Assistance) in the Bartang valley. Improving the road to meet the above-described basic standards will help such development efforts to be more reliable and sustainable. Presently, this plan for rehabilitation of the Bartang valley road is the only proposed road activity that promises to have a meaningful benefit-cost ratio. The same cannot be said for any higher standard required for the transit of heavy vehicles aimed at structural interventions at the lake.

8.5 Road infrastructure in Tajikistan

Transport facilities in Tajikistan suffer from poor condition and relative inefficiency Seventy-five per cent of the paved roads require reconstruction or some rehabilitation Mountain roads are cut into landslide-prone slopes and are under permanent risk of destruction during the rain and flood season, mostly because of the absence of any kind of structural works.

8.5.1 Current status of mountain roads in Tajikistan

The process of construction of roads in Tajikistan, and particularly in the area of the Pamir Range, generally reflects the difficult economic situation in the country. Information supplied by Col. Sultan (State Committee on Emergencies), from road engineers on his staff in Khorog, and from the road maintenance personnel responsible for the roads in the vicinity of the village of Nusur in the Bartang valley, emphasize the scarcity of equipment and resources available for road construction and maintenance. Construction and maintenance of roads are carried out by state construction enterprises of national, oblast and rayon (regional and provincial) status, depending on the size and complexity of the works.

Engineers involved in road design, construction, and maintenance look unfavorably on road construction by private contractors. Roads are designed according to Soviet Union standards and norms, but, in actual construction and maintenance, standards and norms are generally ignored.

The vague information acquired from those responsible for transportation facilities in Gorno-Badhakshan indicates that construction, rehabilitation, and maintenance works are carried out without particular attention to design standards and with no regard for costs. Unit prices for most common road workings were not available

Engineers, mainly operations and maintenance staff, currently have limited design experience. They should receive training that will enable them to carry out high-quality and environmentally friendly methods of mountain road design, construction, and maintenance.

Traffic is normally occasional and, in secondary valleys like the Bartang Valley, is practically non-existent, mostly because of the very poor condition of the roads. Most of the vehicles are obsolete and lack maintenance. Trucks with trailers are very rare and only the main roads in relatively non-mountainous areas are accessible to such vehicles

Geomorphological and hydrogeological conditions in Pamir are critical to the transportation system. The roads are often located on steep talus slopes, on rocky sidehills, or across unstable landslides and seasonal torrents. Rainfall is meager, but the high seismicity of the region and the abundant snowmelt provoke rockfalls, landslides, and debris flows that negatively impact the transportation system.

Mountain roads - or, more appropriately, mountain tracks - are built without use of any structural facilities Because the constructors have available only earthmoving methods and equipment, the resulting alignments are extremely tortuous and bumpy. Sidehill cut-and-fill roads are built simply by cutting the slopes and placing the material in fills without installing retaining walls Thus, these roads have no protection from failure of either cut or fill slopes.

Roads usually have a single carriageway, and the average width does not exceed 3-4 m; in addition, roads often have no shoulders. Very tight and steep hairpin curves are common, and the gradient, for short stretches, can be as great as 15 per cent. Unpaved fords are common.

No gravel surfacing is used The road surface is simply that resulting from cutting of the terrain Roads have no curbstones; short walls made by dry stone masonry protect only a limited number of dangerous curves. Road signs are crude and rare.

Only 4WD light vehicles can travel these roads in relative safety; the average speed is, in most cases, about 15-20 km/h

8.5.2 Construction techniques

Plants and machinery used for road construction and maintenance date back to the period in which Tajikistan was part of the Soviet Union. This equipment commonly suffers from a general lack of maintenance, and much of it is out of commission because of a lack of spare parts.

Road construction methods have been observed by the author at construction sites along the major Khorog-Kulyab highway. Earthmoving makes intensive use of blasting techniques with the intent of displacing huge masses of rocks and, at the same time, to establish the approximate road section. The broken rock mass is then shaped into a roadway by 16-to-20 ton bulldozers. The surface of the resulting road, lacking any prepared base or a gravel surfacing, is extremely rough. Very large bumps are formed in the blasting process. The roads are also prone to local settlement, and the highly fractured rocks often are susceptible to local sliding activity.

8.5.3 Maintenance of mountain roads

Single workers from the village communities commonly carry out maintenance of mountain roads individually; the stretches assigned to each worker are usually 10-15 km long. This work is carried out mostly manually because there is no mechanized maintenance equipment or transport facility available. Where landslides occur, the resulting obstructions and damages cannot be removed or repaired, the road path is simply modified to cross over the debris.

8.6 Needed studies – assessment of accessibility to Lake Sarez

The most appropriate road route to the Usoi dam and Lake Sarez has not yet been identified. Therefore, the following studies are needed:

The topography and geology of the valley of the Murgab River upstream from Lake Sarez - and of a parallel valley between Murgab and Lake Sarez - are currently not well understood and are worthy of careful investigation. Adequate topographic maps of the area should be obtained, at a scale of at least 1:50,000.

An on-site study is needed to evaluate the feasibility of a road to Usoi dam and to estimate the cost of constructing such a road. Costs of transport on Lake Sarez by means of ferries should also be assessed Further investigations should be carried out to determine the accessibility to the region of Gorno-Badakshan using different means of transport, such as by road, railroad, or aircraft. A cost assessment of the transport of heavy machinery and equipment from other countries also would provide needed basic information.

Chapter 9
Human geography/demography

9.1 Introduction

The purpose of this sub-project was to assess the geographic/demographic situations of the settlements below Lake Sarez in the Bartang valley, downstream to its junction with the Panj River at the village of Rushan, and, from there, downstream along the Panj River to include the villages of Dehrushan, Barushan, and Shipad. This approach neglects the villages on the Afghanistan side of the Panj River, in part because of inaccessibility. The assessment also attempts to determine the number of people at risk in the event of any major natural catastrophe emanating from Lake Sarez, and to indicate the existing local ability to respond to, as well as to participate in, the introduction of an early warning system.

9.2 Prior state of knowledge

Earlier Russian/Tajik studies (over the last several decades) on the stability of the Usoi landslide dam/Lake Sarez did not consider the risk to inhabitants of the valleys downstream from the lake. Work in Gorno-Badakhshan Province, in general, supported by FOCUS - Humanitarian Assistance, has provided a much-improved data base on the actual number of villages, size of populations, and locations in relation to the rivers. Information on nutritional status, level of employment, and degree of food self-sufficiency has also been acquired. In terms of the Bartang valley itself, much of the specifically relevant data were collected by Donald Alford during his reconnaissance in October 1998, and which he is currently entering onto a GIS.

9.3 Current investigation

Apart from the short time spent in Khorog, work was restricted to one day along the Panj River between Khorog and Shipad, parts of two days in the Bartang valley with an overnight stay at Basid, and general observations during the drive out from Khorog downstream along the Panj. The severe restriction of the period of field observation was in large part due to transportation difficulties. Thus, the results are best classed as supplementary to those of Alford (1998).

Only a very small number of interviews (10) could be completed in the time available for this study. These took the form of standard questions with the aid of interpreters, followed by open-ended discussions relating to attitudes and locally perceived responses to the prospect of a disaster that might result from an outbreak flood from Lake Sarez. The general situation, based both on the interviews and on personal observations, indicates that the Panj River valley settlements, including Rushan, should be considered separately from those of the Bartang River valley.

Due to the small number of interviews this report is largely anecdotal and will depend upon the introduction of a series of working hypotheses that will need to be tested by future research:

- The older inhabitants are less concerned about the threat of Lake Sarez than the younger ones, especially those with small children. From this it would follow that the older inhabitants are less likely to respond to any disaster-response plan;

- People living closer to the lake (especially in the Bartang Valley) are much more sensitive to the potential dangers than those living farther away;

- Government and NGO discussions of the Lake Sarez problem in recent years have contributed to a degree of artificially increased fear of a possible catastrophe.

This Shipad lady was born in the house where her parents lived at the time of the 1911 earthquake that created the Usoi Dam and Lake Sarez. She has no fear of any flood arising from a possible outbreak of the lake. Photo credit: Jack Ives

9.4 Present situation

While some of the older residents maintained that they had lived all their lives downstream from Lake Sarez, as had their parents, and they did not believe that any significant danger existed, at the local government level some serious steps were being taken to prepare for a substantial threat. The villages along the Panj River had already identified sites to which existing houses and community buildings should be moved as a mitigative measure. Such a move would depend on completion of the anticipated flood-routing map and, equally important, on the provision of financial subsidies. It was stated that any such relocation would be planned in stages, and many of the existing buildings were probably already in safe positions. Thus, the latter could be used for emergency shelter in the event of a disaster occurring prior to the completion of any relocation action.

Throughout the area of the investigation, it is apparent that the overall level of education is remarkably high. Very intelligent discussions were possible concerning the difficulties of living in a hazardous mountain environment. As we have long since come to expect of people who inhabit such places, the local understanding of the many hazardous phenomena, such as seasonal floods, mud and debris flows, slides of various types, rock falls, and avalanches, is extremely high. Individual accounts of village response to mud and debris flows and slides of various types reinforced this view and left the impression that informal response systems already exist in the Bartang villages.

Equally important is the impression that the local people have a very close attachment to their environment – in simple terms: they love their mountains – and it should be clearly understood that one possible response to the assumed danger of Lake Sarez – relocation out of the area – may not be a responsible option. Despite this attachment to the local environment, the prevailing state of poverty, under-employment, malnutrition, and dependency on outside aid is very evident and is an apparent contradiction.

Most of the villages visited along the Bartang River (none farther upstream than Basid) are located on alluvial cones. These cones, built by a combination of geomorphic processes, including snow-melt floods, mud and debris flows, and slides of various types, are very active. It is assumed that sections of the fields on the alluvial cones are subject to annual damage, at least. This is borne out by anecdotes related by villagers. At least this would indicate that the inhabitants are familiar with these processes and are accustomed to dealing with them – both in terms of responsive evacuation and subsequent repair.

Some of the larger villages have sections that are higher than the level of any predicted flood/debris flow in the Bartang. Thus, groups of buildings would be available to constitute initial safe havens. However, it must be emphasized that this would only provide refuge against initial loss of life. Any significant outbreak flood/debris flow, even of much lower magnitude than any worst-case scenario, would obliterate many entire villages and long sections of interconnecting road. In such an event, severe loss of cropland would raise the prospect of a massive evacuation programme. The route out of the Bartang valley on foot would be extremely hazardous and helicopter assistance would be necessary.

Data collected by Goulsara Pulatova indicate that in the Bartang valley some 30 villages with more than 7,000 inhabitants would be at risk in the occurrence of an outburst flood. Much of the town of Rushan (population more than 4,000) would be in danger, and, depending on how far the effects of such a disaster would extend down the Panj River valley, a total of more than 35,000 people would be under serious threat from a "moderate" flood event from Lake Sarez. The potential "back-water" area upstream from Rushan should also be taken into consideration.

One conclusion of this investigation is that the local inhabitants should prove to be very able participants in a training programme for early warning system operation and maintenance in response to actual hazard occurrence. Another conclusion is that systematic research on the human geography of the area is needed to build on these advantages.

Boys of the Bartang River valley. Their homes would be endangered only minutes after any landslide wave were to overspill the Usoi landslide dam and flood the Bartang. Photo credit: Jack Ives

9.5 Recommendations

1) It is urged that great care be taken in discussing the complex issue of Lake Sarez to avoid any unnecessary increase in degree of local alarm. Nevertheless, and in addition, many of the villages on the Afghan side of the Panj River, opposite and downstream of Rushan, need to be taken into consideration;

2) From the point of view of ability and intelligence of the local inhabitants, introduction of an early warning system should be feasible - there appears to be a high level of talent that would lend to training and operation;

3) Similarly, ability to accommodate training for emergency response, establishment of safe havens, and management of local people in a crisis situation, appears to be considerable;

4) Items (1) through (3) above would be greatly augmented if a systematic study of the human geography/demography were to be carried out. See Annex 9-1 for an outline of a possible research approach.

Chapter 10

Social and economic conditions in the valley of the Bartang River

10.1 Introduction

From 2-12 June 1999, a preliminary regional assessment of the natural, climatic, and socio-economic conditions was conducted in the valley of the Bartang River, downstream from the Usoi landslide dam, and in the lower part of the Kudara River (right tributary of the Bartang River) valley. (Note: In this chapter, all references to "right" or "left" are taken as looking downstream.)

Human development of mountainous areas is usually limited to the valleys of mountain rivers. The territory of the Pamirs offers a dramatic illustration of this tendency; the entire national economic activity is concentrated within the mountainous valleys of six rivers: the Vanj, Yazgulem, Bartang, Gunt, Shakhdara, and Panj, the last of which is not only the main river artery of Tajikistan, but also serves as the southern boundary of the republic. The valleys of these rivers provide sufficiently favourable conditions for development of housing and infrastructure. At the same time, each of the valleys has numerous hazards associated with complicated geological conditions and large-scale manifestations of modern geological processes.

10.2 Development in the Bartang valley

The valleys of the Bartang and Yazgulem Rivers can be regarded as exceptions, when compared to the other river valleys. In contrast to the valleys of the Vanj, Gunt, and Shakhdara Rivers, which have been fashioned by glaciers and demonstrate wide and sufficiently flat bottoms, the valleys of the Bartang and Yazgulem Rivers have resulted from erosive and tectonic processes. They are characterized by narrow, meandering floodplains and a large number of deep gorges. Their modern riverbeds are bordered by steep, bare mountainsides; the surfaces of these bare and dissected slopes are studded with shifting talus deposits and rock debris. In addition, there are many landslides that narrow, and periodically dam, the bottoms of the valleys.

These special conditions have always hampered the development of the Bartang valley. Inhabited areas are scattered irregularly along the broader sections of the valley, mainly in its lower part. Generally favourable, relatively flat-lying plateaus, which can be found at elevations of 2,600 to 3,200 m, have not been developed because of climatic difficulties and lack of transportation into the areas.

The valley of the Bartang River is still poorly developed. At present it can boast of only 28 settlements, four of which have come into existence in the last 4 to 5 years. The settlements are situated irregularly along the valley. The 11 largest villages are concentrated in the downstream 60 km of the valley (the so-called Siponj inhabited area).

The villages lie at distances of 4 to 28 km from each other. There are often "pairs" of villages that face one another from the two banks of the river.

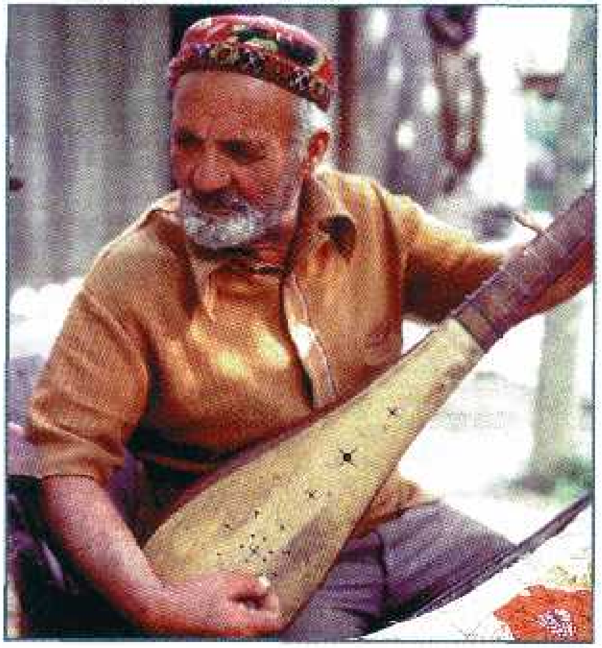
The villages are situated on high terraces of the right bank of the Bartang River above the flood plain, and on debris cones and low terraces of the left bank, which also lie above the flood plain. Arable lands lie either within the villages or nearby.

10.3 Regional transportation

An unpaved automobile road, which runs mainly along the right bank, connects the villages with the district center, Rushan. The bridges and the main automobile road are controlled by the Mountain Societies Development Special Programme (MSDSP), a programme of the Aga Khan Development Network. The most difficult sections of road are those from Shudzhait to Emu and from Hijlis to Bisav. In these stretches, the road undercuts shifting talus deposits, which hamper vehicular travel at all times of the year.

Another inhabited area – the Basid region – occupies a 35-km-long sector in the middle stretch of the valley. It consists of six villages, three of which have come into existence within the last 3 to 4 years. All of these villages, except Chagib, are situated on the left bank of the Bartang River. Only the village of Basid has direct access to automobile communication, because the main road from Rushan to Barchidev passes through this village. Other villages are connected with this road by suspension footbridges.

Areas serving as cropland, both within and outside the villages, are shrinking in size because of encroaching development. As a future prospect, it will be possible to develop a separate outlier of the ancient valley of the Bartang River – the ancient alluvial plateau known as Qll, which lies above the villages of Ajirf and Basid at an elevation of 2,800 to 3,200 m. This plateau lies 250-300 m above the bottom of the valley and the currently inhabited areas, and is practically



without water. Its development can begin only after construction of water-supply channels and redistribution of inhabited areas. The construction of the channels on the plateau above the villages of Basid and Ajirf has already begun with the help of MSDSP, but progress is very slow because of lack of transport, construction equipment, and fuel. Also, the annual construction season is very short. Construction can be undertaken only in summer and – for a short time – in autumn.

Until 5 years ago, the six villages of the Basid region in the central Bartang valley had no automobile connection with the lower part of the valley. Since then, the road has been constructed within a very short period of time by local workers, mainly by hand and with the help of local resources. The condition of the road is controlled by the Hukumat (a provincial government office) of the Rushan district and by the MSDSP. All of the maintenance efforts are conducted by the villagers.

The third inhabited area, from Roshorv to Barchidev, is situated in the upper part of the Bartang River valley. It occupies an area of about 10 km^2 and includes six villages. One of these villages – Vijravsh – is made up of only nine households; it came into being only 3 years ago. Roshorv, the largest village, and the village of Savnob lie on the aforementioned ancient plateau of alluvial and moraine origin at an elevation of 2,800 to 3,200 m. The villages of Barchidev, Nushor, and Yapshorv are situated on the bottom and lower sides of the valley.

The villages are connected between themselves and with the district center of Rushan by an automobile road that has been functioning normally for only the past 5 years. At present, this road is controlled by the Tajik Committee on Emergencies. The most difficult sections of the road from Rushan to Barchidev lie between the villages of Chadud and Vijrav. This stretch of road crosses several active landslides and is traversed by several lateral streams. In summer, it is almost impossible to wade across these streams, and make-shift footbridges are washed away every year. During the time of this very mission, two women from the village of Roshorv drowned when attempting to cross Bardara Creek, 5 km upstream from where it enters the Bartang River. They had already made a 49-km downhill trek, when they met their death.

From the village of Savnob, the road passes through the valley of the Kudara River and farther on to Murgab in the eastern Pamir Range.

10.4 Socio-economic conditions in the Bartang valley

The economic and social conditions in the villages in the Bartang valley depend, as the above-mentioned geological and geographical features would suggest, directly upon the following factors:

- Presence and condition of automobile roads through the valley and within the inhabited areas;
- Availability of arable lands;
- Geographic position and climatic conditions of the inhabited areas;

Summarizing all three of these factors, we can see that the farther down the valley, the better the social situation, and vice versa

Potatoes and cereal grains are the most common crops in the region. However, in some years the growing season is too short for the cereals to ripen, and the people of the upper and middle parts of the valley remain practically without bread for 2, or even 3, months before the new harvest. Because there is no all-year transport to the villages of Ajirv and Barchidev, goods are delivered there only occasionally, which makes them very expensive. The high cost of gasoline sends the prices in the village markets even higher. For example, if a liter of gasoline can be purchased in Khorog for 400 Tajik roubles, in the village of Nisur it will cost 1,300 roubles. It is no wonder, then, that food prices in Nisur are three to four times as high as in Khorog. In all villages upstream from the village of Sinoj, individual families have only a small supply of homemade rye flour, and some don't even have that. Most of the villagers eat plant roots and herbs at least some time during the year. Everyone looks forward to this year's (1999) harvest, but there is little hope that the harvest time will come soon because of abnormally low temperatures and extremely heavy precipitation in 1998-1999. During our visit, inhabitants of the villages of Ajirv, Basid, Chadud, Vijrav, Yapshorv, and Roshorv in the Bartang valley, and Rukhch in the valley of the Kudara River, looked even more emaciated than the people in other villages, and their houses were pitiful sights. All of the people were very poorly dressed, and had no fuel of any kind to heat their houses.

10.5 Recommendations for improving the socio-economic status of the people of the Bartang valley

There is no doubt that the present poor state of the inhabitants of the Bartang valley is to a certain extent the result of widespread knowledge of the hazard associated with Lake Sarez and the ensuing lack of well-targeted and proper development. It is also clear that the present situation will remain unchanged until the problem of the stability of Usoi dam is solved. However, it is still possible – and, what is more, necessary – to improve the socio-economic conditions in the region in spite of the threat from the lake. To do so, will require the following actions:

- The government (local, regional, or national) must exercise control over future settlement of the Bartang valley, allowing enlargement of inhabited areas to an elevation of no more than 50 m above the present floor of the valley.
- Encouragement of further development of the high-elevation Basid-Ajirf and Roshorf-Nisur-Ten plateaus.
- Repair and reconstruction of sections of the main automobile road in the Bartang valley, especially in the stretches from Emu to Ajirf and Basid to Yavshorv.
- Construction of reliable suspension bridges across the dangerous streams in the section of the road that connects the villages of Basid and Vijravi.
- Organization of emergency one-time assistance in the form of food and clothing supplies to aid the inhabitants of the villages of Vijrav, Garjiv, Yapshorv, Roshorv, and Barchidev in the Bartang valley, and the village of Rukhch in the Kudara valley, taking into account the financial positions of the families.
- Organization of periodic humanitarian assistance to all of the villages in the middle and upper parts of the Bartang valley, consisting of flour, as well as new kinds of fast-maturing potatoes, rye, and other grain crops.
- Encouragement of the development of traditional national trades, which may become one of the most important sources of income generation in many villages.

Lake Sarez in the Pamir Mountains of Tajikistan was created in 1911 when an enormous landslide (approx. 2km^3) blocked the Murgab River valley. The landslide was triggered by one of the strong earthquakes typical of this region of active tectonism. The natural dam, which was named Usoi after a village buried by the landslide, impounded Lake Sarez. With a height of about 600 m, the Usoi landslide dam is the highest dam in the world. Because the Usoi dam is not an engineered structure and because of the large volume of water it retains, questions have been raised both nationally and internationally regarding the stability of this natural dam.

This report presents the results of the reconnaissance mission to Lake Sarez, organised by the UN Secretariat for the International Decade for Natural Disaster Reduction (IDNDR) in June 1999. This mission, fielded with assistance from OFDA/USAID, the World Bank, UNDP, consisted of a combined group of Tajik and expatriate scientists who studied the dam and lake, as well as the inhabitants and environment of the Bartang valley. The members of this reconnaissance team concluded that the probability of a massive outburst flood from Lake Sarez was low in the near- to mid-term, but, should such a flood occur, the impact on the downstream valleys would be devastating.

For more information, please contact:
Secretariat for the International Strategy for Disaster Reduction (ISDR)
Palais des Nations
1211 Geneva 10, Switzerland
Tel: (41 22) 917 90 00
Fax: (41 22) 917 90 98/99
Internet: www.unisdr.org
E-mail: isdr@un.org