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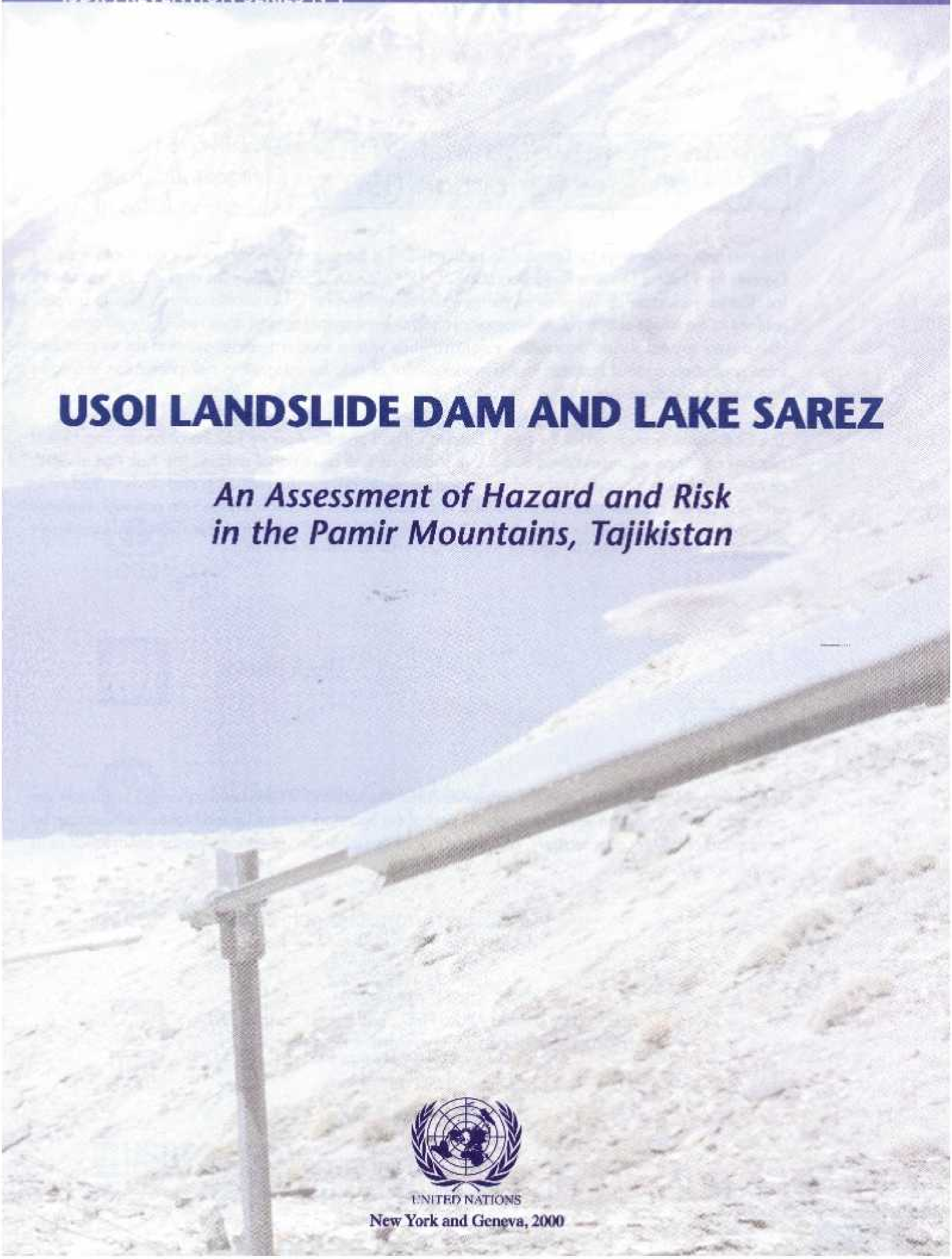

USOI LANDSLIDE DAM AND LAKE SAREZ

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

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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

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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.

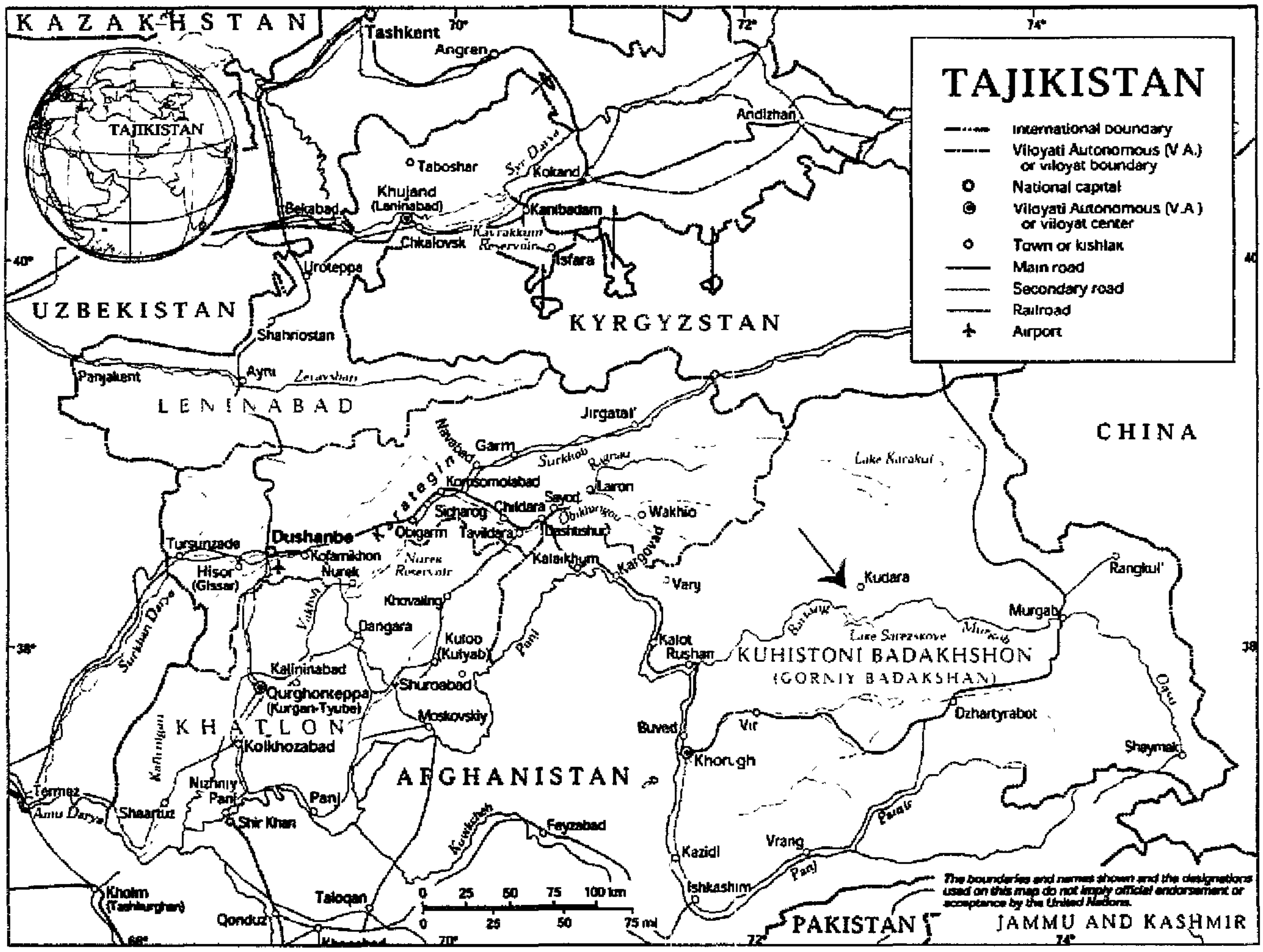
The potential danger of Lake Sarez and Usoi landslide dam was brought to the attention of the Secretariat for the International Decade for Natural Disaster Reduction (IDNDR) in 1997, during the annual meeting of the Interstate Council for Emergency Situations of the Commonwealth of Independent States (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

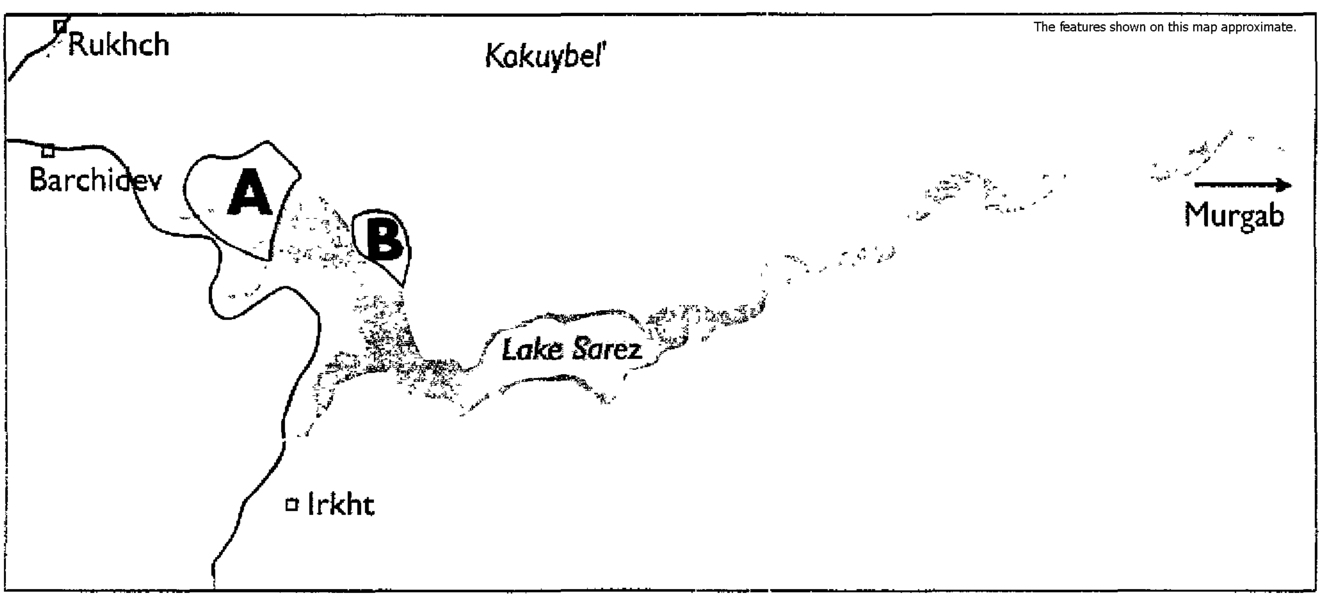
The Secretariat for ISDR wishes to acknowledge all those donor organizations that made this mission possible, in particular, the Office of Foreign Disaster Assistance, the US Agency for International Development (OFDA/USAID), the World Bank, and the United Nations Development Programme (UNDP) We are 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. 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 (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 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 m³) 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.