Chapter 8
The Inventory of Glacial Lakes

8.1 Brief Description of Glacial Lake Inventory

The inventory of glacial lakes has been systematically carried out using topographic maps. As not all the topographic maps for the country are available and most of the topographic maps of the glaciated region are photocopies of poor quality, for identification, classification, and evaluation of the dangerous stage of glacial lakes, different types of satellite images have been used vigorously. The spatial inventory is based entirely on the topographic maps on a scale of 1:50,000 published in the 1950s–1970s by the Survey of India. The information gap resulting from the unavailability of topographic maps is filled by the printed Land Observation Satellite (LANDSAT) Thematic Mapper (TM) images on a scale equivalent to the topographic maps and all the projection parameters of the topographic maps are incorporated in the images to make the prints compatible with the topographic maps. The spatial distribution and aerial extension of the glacial lakes were obtained with the help of geographic information systems (GIS).

8.2 Glacial Lakes—Their Numbering, Type, and Characteristics

A glacial lake is defined as a water mass existing in a sufficient amount and extending with a free surface in, under, beside and/or in front of a glacier and originated by glacier activities such as the retreating processes of a glacier.

For the purpose of the inventory, the numbering of the lakes started from the outlet of the major stream and proceeded clockwise round the basin.

It is obvious to note that the lakes associated with perennial snow and ice originate from glaciers. But the isolated lakes found in the mountains and valleys far from the glaciers may not have a glacial origin. Due to the rapid rate of ice and snow melt, possibly caused by global warming, accumulation of water in these lakes has been increasing rapidly. The isolated lakes above 3,500 masl are considered to be the remnants of the glacial lakes left due to the retreat of the glaciers.

The lakes are classified into erosion lakes, valley trough lakes, cirque lakes, blocked lakes, lateral and end moraine-dammed lakes, and supraglacial lakes.

Erosion lakes

Glacial erosion lakes are the water bodies formed in a depression after the glacier has retreated leaving the lakes isolated from the glaciers (Figure 8.1). They may be cirque type and trough valley type lakes and are generally stable lakes.

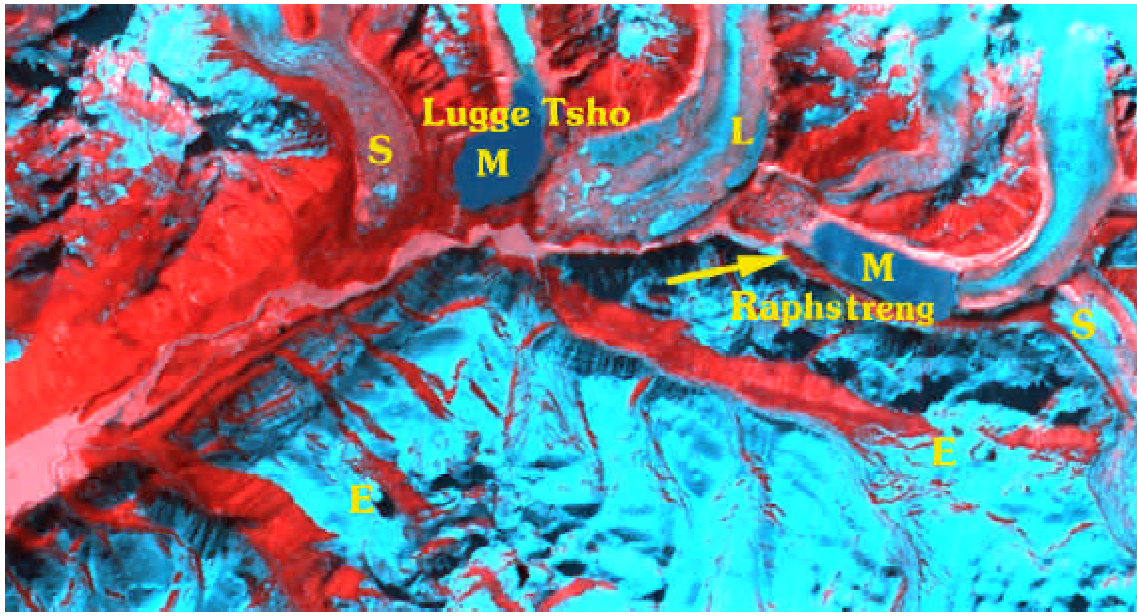

Figure 8.1: Raphstreng area in the Pho Chu Basin showing the types of lakes. S—supraglacial lake, M—end moraine-dammed lake, L—lateral moraine-dammed lake, E—erosion lake

Supraglacial lakes

The supraglacial lakes are small and change their position in the glacier. The Lanzhou Institute of Glaciology and Geocryology (LIGG)/the Water and Energy Commission Secretariat (WECS)/the Nepal Electricity Authority (NEA) study (LIGG/WECS/NEA 1988) did not consider such lakes in their classifications. However, the history of past glacial lake outburst flood (GLOF) events of moraine-dammed lakes indicates that they are initially derived from supraglacial lakes. As the target of the project is to identify and monitor the potentially dangerous glacial lakes with the help of time series' satellite images, aerial photographs, and topographic maps, it will be helpful to know the activity of supraglacial lakes. If supraglacial lakes are situated at the tongue of a valley glacier, larger in size, or grouping rapidly to expand their size, then they are potentially dangerous and may burst out in the near future.

These lakes develop within the ice mass away from the moraine with dimensions of from 50 to 100m. These lakes may develop in any position of the glacier but the extension of the lake is less than half the diameter of the valley glacier. Shifting, merging, and draining of the lakes characterise the supraglacial lakes. The merging of lakes results in expansion of the lake area and storage of a huge volume of water with a high potential energy. The tendency of a glacial lake towards merging and expanding indicates the danger level of the GLOF. Most of the potentially dangerous lakes are advanced forms of supraglacial lake.

Moraine-dammed lakes

A typical example of a moraine-dammed lake is Raphstering Tsho formed on the tongue of the Raphstering Glacier in the Pho Chu Sub-basin of the Lunana region (Figure 8.1). In the retreating process of a glacier, glacier ice tends to melt in the lowest part of the glacier surrounded by lateral and end moraines. As a result, many supraglacial ponds are formed on the glacier tongue. These ponds sometimes enlarge to become a large lake by interconnecting with each other which is accompanied no deepen further. A moraine-dammed lake is thus born. The lake is filled with melt water and rainwater from the drainage area behind the lake and starts flowing from the outlet of the lake even in the winter season when the flow is minimum.

There are two kinds of moraine-dammed lakes, end moraine-dammed lakes and lateral moraine-dammed lakes, depending on the position and morphology of the damming conditions (Figure 8.1). The moraine material may be ice-cored or ice-free. Before the ice body of the glacier completely melts away, glacier ice exists in the moraine and beneath the lake bottom. The ice bodies cored in the moraine and beneath the lake are sometimes called **dead ice** or **fossil ice**. As glacier ice continues to melt, the lake becomes deeper and wider. Finally when ice contained in the moraines and beneath the lake completely melts away, the container of lake water consists of only the bedrock and the moraines.

Ice-dammed lakes

An ice-dammed lake is produced on the side(s) of a glacier, when an advancing glacier happens to intercept a tributary/tributaries pouring into a main glacier valley. Since the glaciers in the Bhutan Himalayas produce relatively rich debris, thick lateral moraines are deposited on both sides of the glacier tongue. As such an ice core-dammed lake is usually small in size and does not come into contact with glacier ice. This type of lake is less susceptible to GLOF than a moraine-dammed lake.

A glacial lake is formed and maintained only up to a certain stage of glacier fluctuation. If one follows the lifespan of an individual glacier, it is found that the moraine-dammed glacial lakes build up and disappear with a lapse of time. The moraine-dammed lakes disappear once they are fully destroyed or when debris fills the lakes completely or the mother glacier advances again to lower altitudes beyond the moraine dam position. Such glacial lakes are essentially ephemeral and are not stable from the point of view of the life of glaciers.

8.3 Glacial Lakes of Bhutan

As in the inventory of glaciers, the inventory of glacial lakes was carried out by dividing the country into six basins with further division into thirteen sub-basins. The sub-basins are Amo Chu, Ha Chu, Pa Chu, Thim Chu, Mo Chu, Pho Chu, Dang Chu, Mangde Chu, Chamkhar Chu, Kuri Chu, Dangme Chu, Nyere Ama Chu, and Northern Basin.

Altogether 2,674 lakes have been identified above 3,500 masl, which cover an area of 106.8 sq.km (Table 8.1 and Figure 8.2). The details of the lake inventory database are given in Annex II. In 1998 Ageta and co-workers inventoried 30 glacial lakes in the northern and northwestern parts of the country for GLOF risk assessments and future monitoring (Ageta and Iwata 1999).

Table 8.1: Distribution of lakes in the basins and Sub-basins of the Bhutan Himalaya

S. No.	Sub-basin	Basin	Lake number	Area (km^2)
1	Amo Chu	Amo Chu	71	1.83
2	Ha Chu	Wang Chu	53	1.83
3	Pa Chu		94	1.82
4	Thim Chu		74	2.82
5	Mo Chu	Puna Tsang Chu	380	9.78
6	Pho Chu		549	23.49
7	Dang Chu		51	1.81
8	Mangde Chu	Manas Chu	521	17.59
9	Chamkhar Chu		557	21.03
10	Kuri Chu		179	11.07
11	Dangme Chu		126	5.82
12	Nyere Ama Chu	Nyere Ama Chu	9	0.076
13	Northern Basin	Northern Basin	10	7.81
	Total		2674	106.8

The Amo Chu basin

In the Amo Chu Basin a total of 71 lakes has been identified. As no glaciers exist in the basin within Bhutan, these lakes are not associated with any glaciers (Figure 8.3). The lakes in this region have been classified into three types: erosion, valley, and cirque lakes (Table 8.2). There are 46 erosion lakes, 21 valley lakes, and four cirque lakes. The cumulative surface area of the lakes in the basin is 1.83 sq.km.

Table 8.2: Types of lake in the Amo Chu Basin

Type	Number		Area (m^2)		Area of largest lake (m^2)
	Number	%	Area	%	
Erosion	46	64.79	542,982.00	29.67	61,614.69
Valley	21	29.58	881,665.37	48.18	243,538.30
Cirque	4	5.63	405,346.14	22.15	141,970.64

The Wang Chu basin

In the Wang Chu Basin there are 221 lakes. Most of the lakes are small in size and only a few are associated with glaciers. At present these lakes do not pose any danger from GLOF.

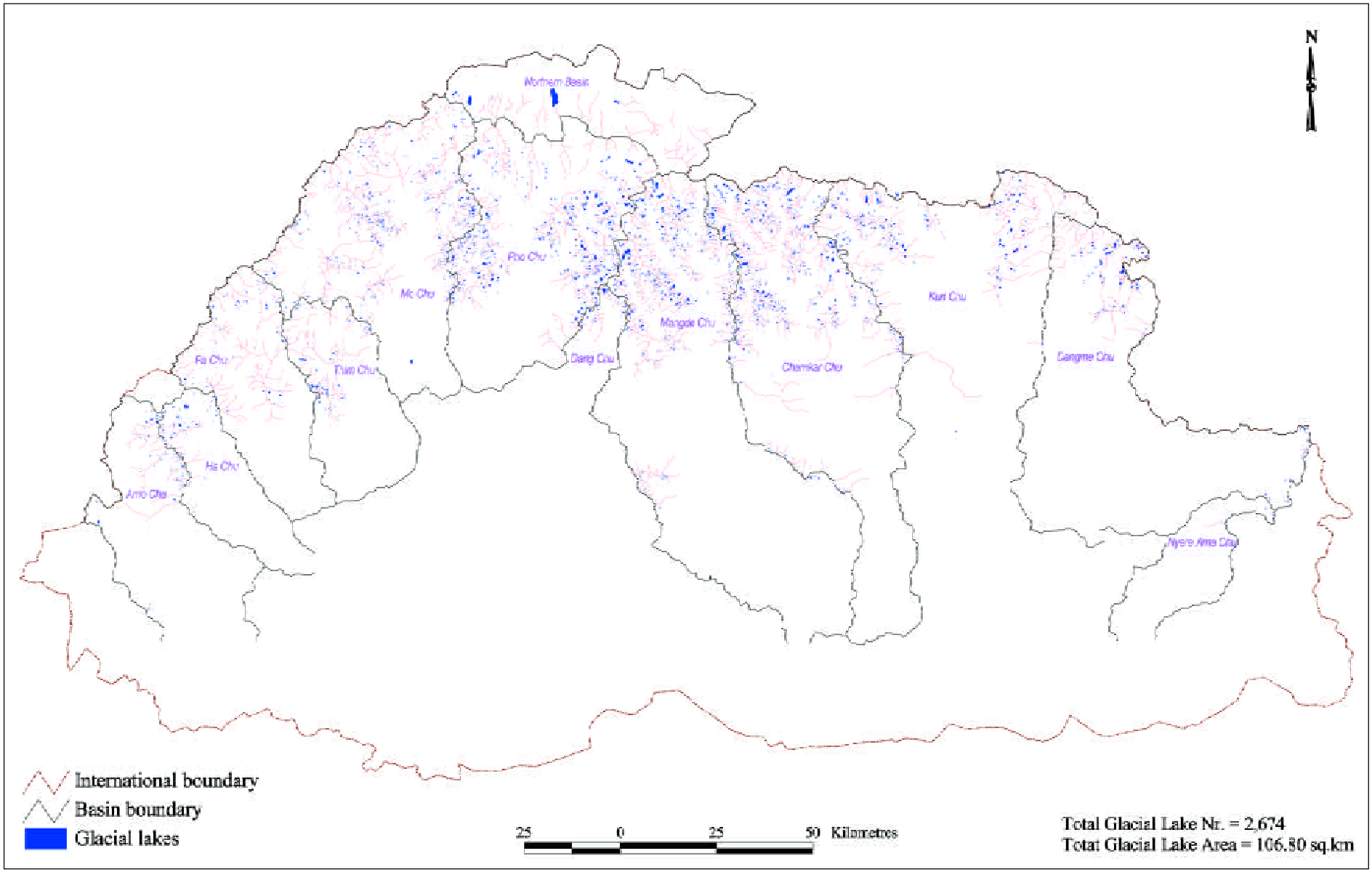

Figure 8.2: Glacial lakes of Bhutan

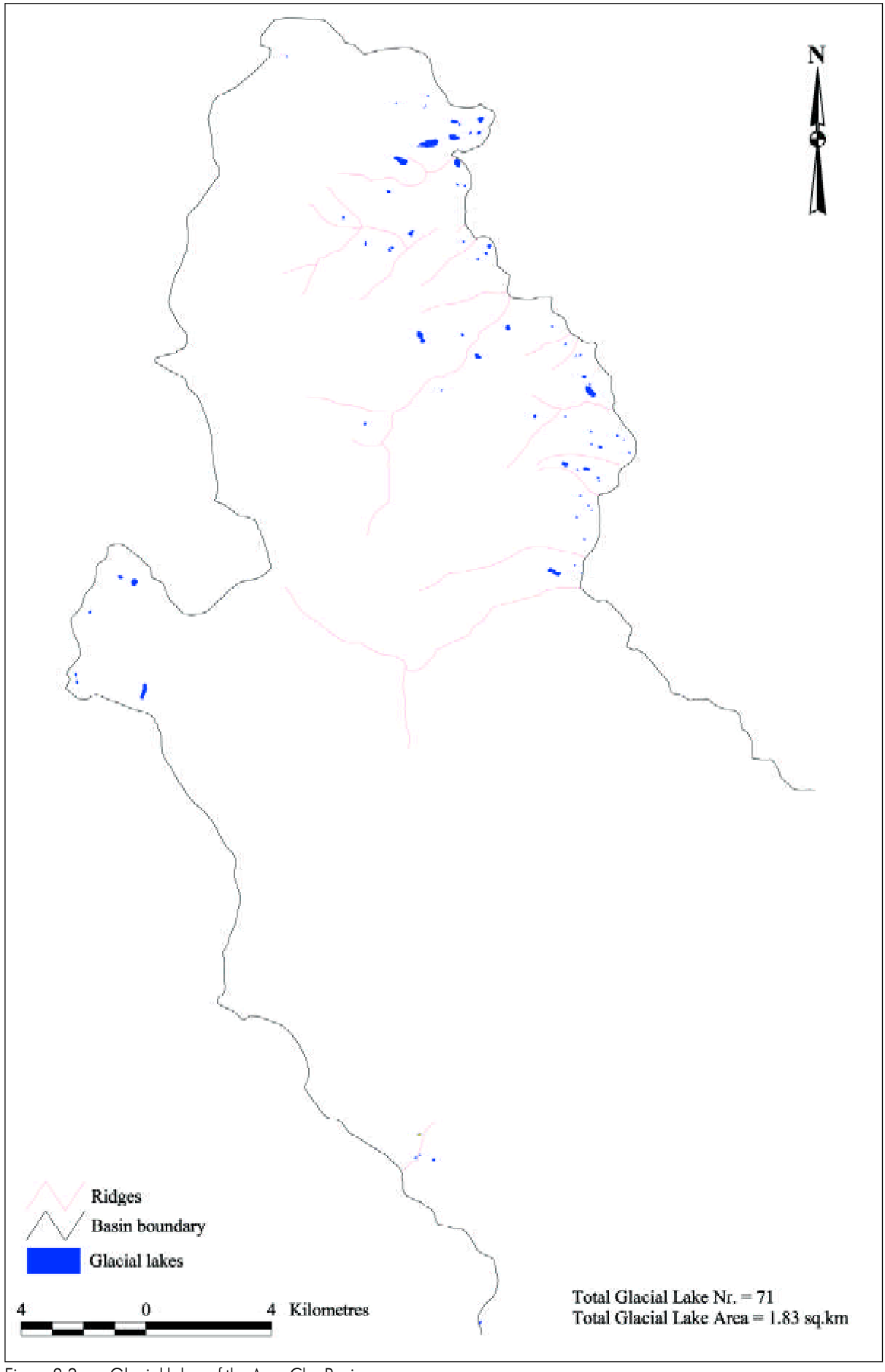

Figure 8.3: Glacial lakes of the Amo Chu Basin

The Wang Chu River Basin consists of three sub-basins—they are the Ha Chu, the Pa Chu, and the Thim Chu Sub-basins from west to east.

The Ha Chu Sub-basin

A total of 53 lakes has been identified in the Ha Chu Sub-basin (Table 8.3 and Figure 8.4) and none of them are associated with glaciers. Lake Ha_gl 37 is the largest lake with an area of 0.47 sq.km and has an average length of 520m. It is classified as a cirque lake and lies at an elevation of 4,430 masl.

Table 8.3: Types of lake in the Ha Chu Sub-basin

Type	Number		Area (m^2)		Area of largest lake (m^2)
	Number	%	Area	%	
Erosion	37	69.81	958,356.91	52.32	234,770.75
Valley	10	18.87	188,061.51	10.27	49,476.66
Cirque	6	11.32	68,530.62	37.41	467,172.06

The Pa Chu Sub-basin

In the Pa Chu Sub-basin a total of 94 lakes has been identified. The majority of these are erosion lakes (Table 8.4 and Figure 7.2) and 16 of them are associated with glaciers. Among the lakes associated with glaciers, five have been identified as major lakes (Table 8.5). Lakes Pa_gl 41 and 42 are directly in contact with Glacier Pa_gr 8, and Lake Pa_gl 44 with Glacier Pa_gr10. These glacial lakes, although small at present, have the potential to expand into large lakes in the future. The Lake Pa_gl 41 is a moraine-dammed lake 110m in length, whereas Lakes Pa_gl 44 and Pa_gl 10 are supraglacial lakes with lengths of 40 and 90m respectively (1960s topomap, Survey of India). Lhabu Tsho Lake (Pa_gl 35) is located about 570 masl southeast of Glacier Pa_gr 6. It is a cirque lake, 325m x 124m in area lying at an altitude of 4,750 masl. The largest lake in the region is Darkey Pang Tsho Lake (Pa_gl 80) which has dimensions of 525m x 435m and lies at an altitude of 4,240 masl. It is a cirque lake with no visible outlet.

Table 8.4: Types of lake in the Pa Chu Sub-basin

Type	Number		Area (m^2)		Area of largest lake (m^2)
	Number	%	Area	%	
Erosion	54	57.45	648,004.38	35.58	60,611.94
Valley	25	26.60	583,946.67	32.06	172,070.30
Cirque	7	7.45	487,271.08	26.76	228,503.08
Supraglacial	3	3.19	16,617.52	0.91	20,493.73
Blocked	4	4.26	64,808.09	3.56	7452.26
Moraine-dammed	1	1.06	20,493.73	1.13	34,353.47

Table 8.5: Major glacial lakes associated with glaciers in the Pa Chu Sub-Basin

Lake	Elevation (masl)	Type	Area (m^2)	Associated glacier	Remarks
Pa_gl 41	4320	moraine-dammed	20 494	Pa_gr 8	in contact with large glacial lake
Pa_gl 42	4520	supraglacial	7452	Pa_gr 8	in contact with large glacial lake
Pa_gl 44	4470	supraglacial	5278	Pa_gr 10	in contact with large glacial lake
Lhabu Tsho (Pa_gl 35)	4750	cirque	40 384	Pa_gr 6	lies 570m southeast of the glacier
Darkey Pang Tsho (Pa_gl 80)	4240	cirque	228 503		largest lake in the basin

The Thim Chu Sub-basin

In the Thim Chu Sub-basin 74 lakes have been identified, out of which erosion and valley lakes are more or less in equal number and there are five cirque lakes (Table 8.6 and Figure 7.3). Among them only one lake (Thim_gl 58) is associated with a glacier (Thim_gr 8). The lake is located 205m southwest of the associated glacier at an elevation of 4,640 masl. The largest lake in this sub-basin is the Santo Tsho Lake (Thim_gl 29) which has a surface area of 483 126 m^2, a mean length of 1,250m and lies at an altitude of 4,320 masl (Table 8.7).

Table 8.6: Types of lake in the Thim Chu Sub-basin

Type	Number		Area (m^2)		Area of largest lake (m^2)
	Number	%	Area	%	
Erosion	35	47.30	1 007 094.14	35.75	258 780.13
Valley	34	45.95	1 581 797.00	56.14	483 126.11
Cirque	5	6.76	61 228 458.12	8.11	62 036.37

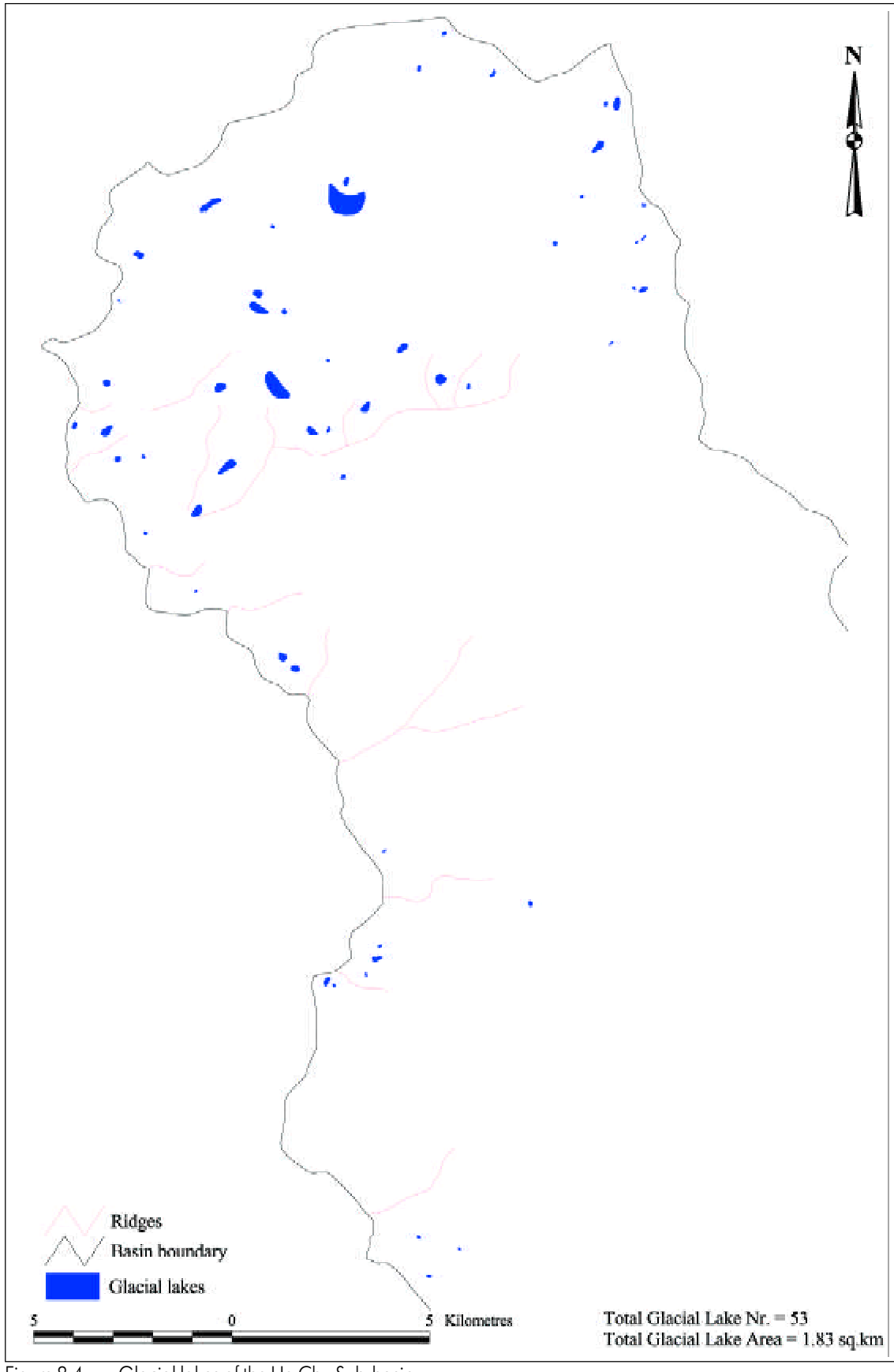

Figure 8.4: Glacial lakes of the Ha Chu Sub-basin

Table 8.7: Major glacial lakes associated with glaciers in the Thim Chu Sub-basin					
Lake name/ number	Elevation (masl)	Type	Area (m^2)	Associated glacier	Remarks
Thim_gl 58	4,640	erosion	3,825	Thim_gr 8	smallest lake
Santo Tsho (Thim_29)	4,320	valley	483,126		largest lake in the sub-basin

The Puna Tshang Chu (Sankosh) basin

The Puna Tshang Chu (Sankosh) Basin consists of the Mo Chu and Pho Chu Sub-basins which contain glaciers and the Dang Chu Sub-basin which does not.

There are 980 lakes with a cumulative area of 35.2m^2 in the Puna Tshang Chu Basin. Of the sub-basins, the Pho Chu is the largest with the highest number of lakes. Some of the lakes are large in size and are associated with glaciers.

Table 8.8: Types of lake in the Mo Chu Sub-basin					
Type	Number		Area (m^2)		Area of largest lake (m^2)
	Number	%	Area	%	
Erosion	209	55.00	3,857,822.19	39.45	291,766.76
Valley	130	34.21	4,041,660.47	41.33	495,757.66
Cirque	23	6.05	1,622,627.58	16.594	210,015.07
Supraglacial	8	2.10	33,815.03	0.344	5,949.88
Blocked	6	1.57	93,327.28	0.955	38,008.97
Moraine-dammed	3	0.79	96,109.73	0.983	52,090.11
Lateral moraine-dammed	1	0.47	34,287.76	0.35	34,287.76

The Mo Chu Sub-basin

In the Mo Chu sub-basin a total of 380 lakes has been identified. Most of them are erosion and valley lakes (Table 8.8 and Figure 7.4).

Seventy-seven lakes are associated with glaciers. The erosion lakes are highest in number followed by the valley lakes. Generally the erosion, valley, and cirque lakes are not susceptible to outburst, but the supraglacial, blocked, moraine-dammed, and lateral moraine-dammed are susceptible to outburst causing flooding downstream. Ten lakes of these types have been identified in the Mo Chu Sub-basin. The largest lake, Hoka Tsho (Mo_gl 1) is an erosion lake located at an elevation of 2,240 masl.

Lakes that are not associated with any glacier even if they are large in size do not pose any danger of GLOF. It is those lakes that are associated with large glaciers that pose a threat of flooding as they have the potential to grow in size as the glaciers recedes. The Lakes Mo_gl 200, 201, 202, 234, and 235 are associated with large glaciers (Table 8.9).

Table 8.9: Major glacial lakes associated with glaciers in the Mo Chu Sub-basin					
Lake name/ number	Elevation (masl)	Type	Area (km^2)	Associated glacier	Remarks
Kab Tsho (Mo_gl 200)	4280	moraine-dammed	52 090	Mo_gr 47	small lakes associated with large glaciers—they have the potential to grow into large lakes
Mo_gl 201	4080	moraine-dammed	30 864	Mo_gr 51	
Mo_gl 202	4380	lateral moraine-dammed	34 288	Mo_gr 52	
Setang Burgi Tsho (Mo_gl 234)	4480	valley	232 775	Mo_gr 84	the lake lies 50m northwest of the glacier
Mo_gl 235	4960	valley	150131	Mo_gr 87	in contact with glacier and needs to be monitored

The Pho Chu Sub-basin

In the Pho Chu Sub-basin 549 lakes have been identified, 53.92% of the lakes are erosion lakes and 33.33% are valley lakes. Supraglacial, blocked, moraine-dammed, and lateral moraine-dammed lakes together constitute 6.56% of the total lake area (Table 8.10 and Figure 7.5).

Several potentially dangerous lakes exist in the Pho Chu Sub-basin. It is in this sub-basin that most of the monitoring and mitigation work of glacial lakes has been undertaken. Some of the well-known glacial lakes in the sub-basin are Tarina Tsho, Raphstreng Tsho, Lugge Tsho, and Thorthormi Tsho Glacial Lakes. The glacial lakes that are associated with the glaciers and posing danger are given in Table 8.11 and described below.

Table 8.10: Types of lake in the Pho Chu Sub-basin					
Type	Number		Area (m^2)		Area of largest lake (m^2)
	Number	%	Area	%	
Erosion	296	53.92	7,908,139	33.66	723,672.60
Valley	183	33.33	10,200,084	43.41	468,690.32
Cirque	34	6.19	3,156,923	13.44	455,024.10
Supraglacial	14	2.55	47,795	2.03	145,948.56
Blocked	8	1.46	202,455	0.86	64,946.45
Moraine-dammed	9	1.64	1,396,854	5.95	769,799.72
Lateral moraine-dammed	5	0.91	152,520	0.65	70,675.33

Table 8.11: Major glacial lakes associated with glaciers in the Pho Chu Sub-basin					
Lake name/ number	Elevation (masl)	Type	Area (m^2)	Associated glacier	Remarks
Pho_gl 84	5,040	valley	214,078	Pho_gr 8	The lake is directly in contact with the glacier.
Pho_gl 148	4,880	valley	454,510	Pho_gr 21	The lake is 1.3 km long and is in contact with the mountain glacier.
Pho_gl 163	4,280	valley	369,572	Pho_gr 41	The lake is quite large and is situated 603m southeast of the glacier.
Tarina Tsho (Pho_gl164)	4,320	Moraine-dammed	280,550	Tarina Pho_gr 44 /49	The lake is over 1 km long; it has breached in the past.
Pho_gl 172	4,310	supraglacial	33,522	Pho_gr 49	Large valley glacier with other supraglacial lakes forming in it.
Pho_gl 206	4,260	supraglacial	44,194	Bechung Pho_gr 79	Severak supraglacial lakes are forming; needs to be monitored.
Pho_gl 207	4,320	supraglacial	15,463	Bechung Pho_gr 79	
Rapshtreng Tsho (Pho_gl209)	4,360	moraine-dammed	145,949	Rapshtreng (Pho_gr80)	Mitigation measures carried out.
Lugge Tsho (Pho_gl210)	4,600	moraine-dammed	769,800	Lugge (Pho_gr82)	Still attached to glacier; terminal moraine has ice core; breached in 1994.

Tarina Tsho (Pho_gl 164) consists of two lakes, one above the other. The outlets of both the lakes are clear and drain into the Pho Chu western branch. The lower lake is rectangular in shape and is about 500m long and 300m wide. This lake has breached in the past, which is evidenced by breached end moraine and a large debris fan in the downstream area. Although at present the lake has a well defined outlet and is detached from the glacier tongue, the size of the lake and the presence of glacier ice on the steep, rocky cliff directly above the lake causes some concern.

The second lake lies directly above the lower lake and is in the shape of a boomerang. It has dimensions of approximately 2 x 0.3 km and is in contact with the glacier tongue resting on a rocky cliff. The outer slope of the end moraine through which the lake is drained is vegetated and has a gentle slope, therefore no immediate danger from this lake is anticipated.

Glacial Lakes Pho_gl 187, 188, and 189 are supraglacial lakes in the large Wachey Glacier (Pho_gr 68). Although these lakes are small at present, they have the potential to grow into large lakes as this glacier recedes.

Raphstreng Tsho glacial lake

Raphstreng Tsho (Pho_gl 209) lies at an elevation of 4,360 masl. On the 1960s map this lake has an area of 0.15 sq.km. In 1986 the lake was 1.65 km long, 0.96 km wide, and 80m deep (GSI; GSB 1986). Nine years later in 1995 (WAPCOS 1997) the maximum length measured 1.94 km, the width 1.13 km and the depth 107m. Figure 8.5 shows the expansion of Raphstreng Tsho glacial lake from 1956 to 1996 (Ageta et al. 1999).

Prior to the 1994 flood from Lugge Tsho, the left lateral moraine was 295m to 410m wide (Indo-Bhutan Expedition 1995). Toe erosion of the moraine initiated by the flood has reduced the width to 178m. This weakening of the lake barrier and the large size of the lake caused grave concern to the Bhutanese

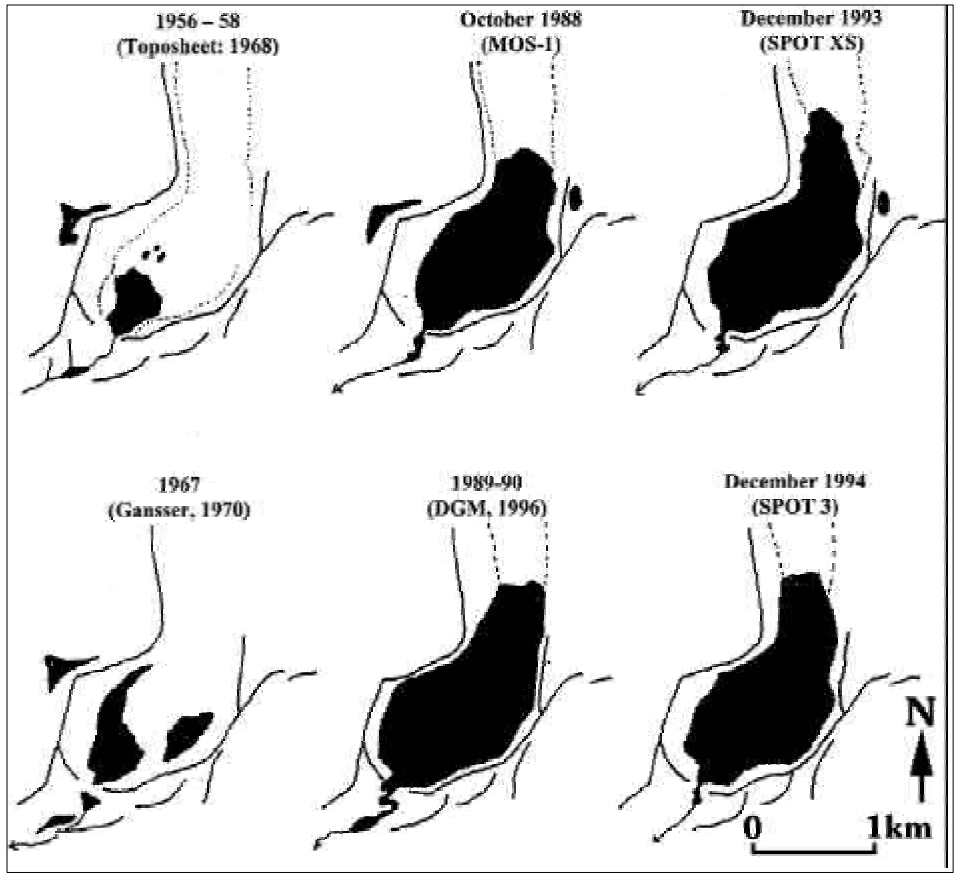

Figure 8.5: Expansion of Raphstreng Tsho Glacial Lake from 1956 to 1994 (Ageta et al. 1999)

Government. Immediate investigation on the stability of the lake was carried out in 1995. Lowering of the lake by 4m (WAPCOS 1997) commenced in 1996 and was completed in 1998.

Thorthormi Tsho glacial lake

On the 1960s map no lakes were seen in Thorthormi Glacier. At present several of supraglacial lakes have been observed within this large glacier. The largest of the lakes is called Thorthormi Tsho. Thorthormi Tsho Glacial Lake is not visible on the toposheet of 1958; some supraglacial lakes are visible on the map as reported by Gansser (Figure 8.6). The Thorthormi terminal moraine acts as a dam between Thorthormi Tsho and Raphstreng Tsho Lakes and has a width of 30m at its crest. Thorthormi supraglacial Lake is 65m higher than Raphstreng Tsho Lake and lies directly above it. This lake is separated from the Pho Chu by a thin left lateral moraine, which is continuously eroding. Considering the present scenario in which the lake is at a higher elevation than Raphstreng Tsho Lake, and that the terminal and left lateral moraine are narrow and unstable, this lake and glacier need to be continuously monitored.

Lugge Tsho glacial lake

This lake is a rectangular-shaped, pro-glacial, moraine-dammed lake. On 7 October 1994 this lake breached at the junction of its left lateral moraine and terminal moraine causing damage to lower valleys downstream and to the Punakha Dzong. The lake is still increasing in size due to the retreat of the glacier tongue as shown in Figure 8.7. The lake was not visible in the topographic map of 1958 and appeared in 1967 in the form of supraglacial lakes (Gansser 1970). The outlet channel is at the same level as the lake surface and has a gentle slope. The terminal moraine has and ice core which is evidenced by the bumpy topography of the terminal moraine. Due to the continuous sliding of the left lateral moraine at the outlet and the presence of ice core in the terminal moraine, the breached outlet may get blocked and cause another GLOF.

Supraglacial Lakes Pho_gl 206 and 207 associated with Bechung Glacier, although small in size at present, will grow in size in the future. Regular monitoring of their expansion is required. A small supraglacial lake in the Tshoju Glacier was observed with no surface outlet, but from the middle of the terminal moraine a substantial amount of outflow was seen.

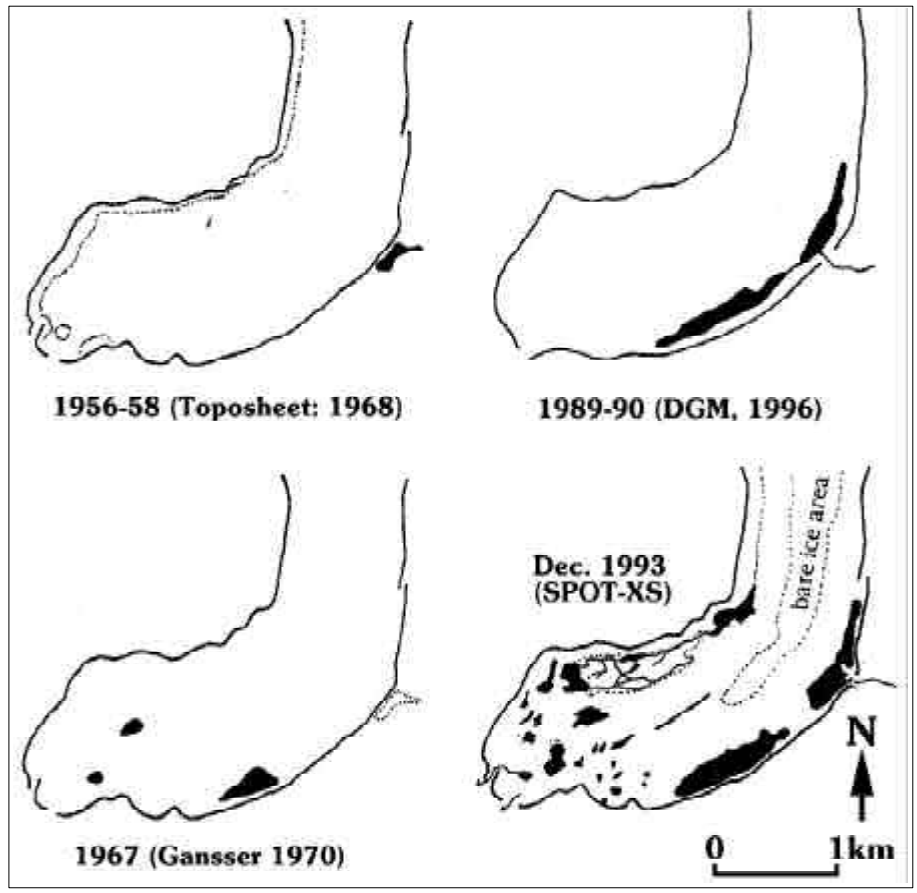

Figure 8.6: Expansion of Thorthormi Tsho Glacial Lake from 1956 to 1990 (Ageta et al. 1999)

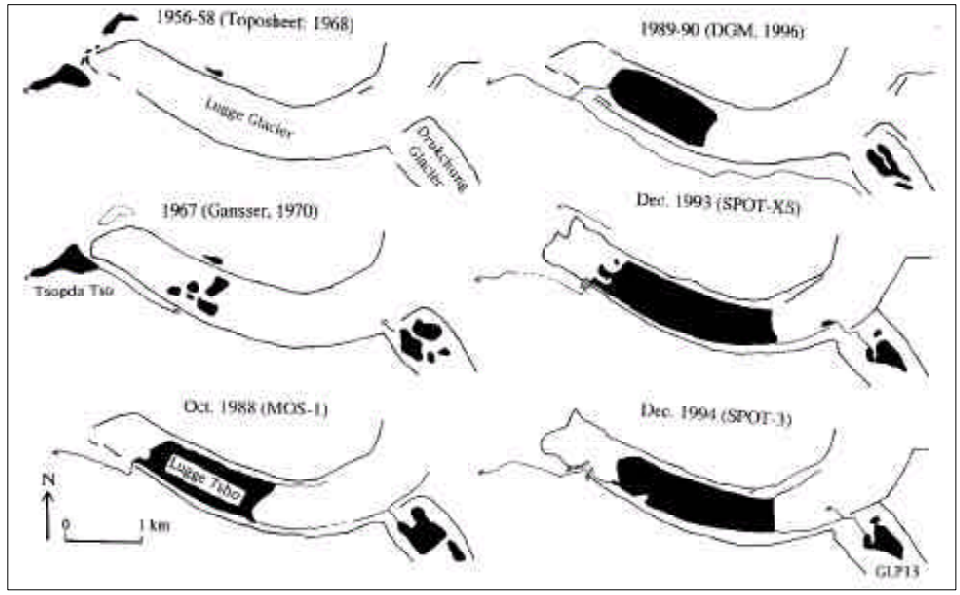

Figure 8.7: Expansion of Lugge Tsho, Tsopda Tsho, and Drukchung Tsho Glacial Lakes from 1956 to 1994 (Ageta et al. 1999)

The Dang Chu Sub-basin

The lakes in the Dang Chu Sub-basin have been classified into three types, erosion, valley, and cirque. There are 34 erosion lakes, 14 valley lakes, and three cirque lakes. The area covered by the valley lakes is 66.98% of all the lakes in the region (Table 8.12). The largest lake is Dang_gl 31. It is 1.56 km long and located at an elevation of 4,730 masl with a surface area of 7.9 sq.km. None of the lakes of this sub-basin is associated with glaciers (Figure 8.8).

Table 8.12: Types of lake in Dang Chu Sub-basin

Type	Number		Area (m^2)		Area of largest lake (m^2)
	Number	%	Area	%	
Erosion	34	66.67	431,284.48	23.77	65,654.74
Valley	14	27.45	1,215,368.76	66.98	789,373.64
Cirque	3	5.88	167,835.20	9.25	100,492.03

Table 8.13: Types of lakes in the Mangde Chu Sub-basin

Type	Number		Area (m^2)		Area of largest lake (m^2)
	Number	%	Area	%	
Erosion	202	38.58	2,511,787.46	14.34	288,133.99
Valley	250	47.98	10,304,174.80	58.83	868,294.42
Cirque	35	6.27	1,993,290.86	11.38	217,085.14
Supraglacial	25	4.80	362,275.27	2.07	146,451.70
Blocked	5	0.96	746,305.17	4.26	466,125.34
Moraine-dammed	4	0.77	1,598,214.37	9.12	710,226.90

The Manas Chu basin

The Manas River is formed by joining two rivers of similar catchment area within Bhutan. They are the Mangde Chu and the Dangme Chu. Each of these two sub-basins has a tributary of substantial size. These are the Chamkhar Chu and the Kuri Chu respectively.

The Mangde Chu Sub-basin

A total of 521 lakes has been identified in this sub-basin (Figure 7.6). Valley lakes and erosion lakes are dominant, numbering 250 and 202 respectively. The valley lakes have an area of 10.3 sq.km, that is, 58.83% of the total area occupied by the lakes of the sub-basin (Table 8.13). The largest lake is Mangd_gl 106. It has a surface area of 0.87 sq.km and lies at an elevation of 5,040 masl. It is directly in contact with Glacier Mangd_gr 10 (Table 8.14).

Table 8.14: Major glacial lakes associated with glaciers in Mangde Chu

Name/number	Elevation (masl)	Type	Area (m^2)	Associated glacier	Remarks
Mangd_gl 99	4960	moraine dammed	192607	Mangd_gr 8	in contact with glacier
Mangd_gl 104	5000	valley	521081	Mangd_gr 9	1.2 km long
Mangd_gl 106	5040	valley	868294	Mangd_gr10	1.5 km long; in contact with glacier
Mangd_gl 270	5280	valley	239778	Mangd_gr 51	850m long; 200m east of glacier
Mangd_gl 307	5240	valley	767429	Mangd_gr 65	1.8 km long; in contact with glacier
Mangd_gl 308	4193	moraine dammed	710227	Mangd_gr 70	1.2 km long; 30m from glacier
Mangd_gl 310	5200	valley	200746	Mangd_gr 76	0.5 km long; in contact with glacier
Mangd_gl 366	5160	valley	150806	Mangd_gr 101/102	0.8 km long; in contact with glacier
Mangd_gl 398	5182	erosion	288134	Mangd_gr 117	0.8 km long; 20m away from glacier

No field visits have been carried out in this region. Out of the 521 lakes in the the Mangde Chu Sub-basin, 200 lakes are associated with glaciers. Although there have been no reports of any GLOFs in the region it is necessary to study this sub-basin in detail as there are many lakes (large and small) attached to glaciers.

Table 8.15: Types of lake in the Chamkhar Chu Sub-basin

Type	Number		Area (m^2)		Area of largest lake (m^2)
	Number	%	Area	%	
Erosion	161	28.90	3,416,929.39	16.34	624,669.81
Valley	306	54.95	12,723,820.30	60.85	437,816.58
Cirque	28	5.03	2,471,170.51	11.82	802,938.10
Supraglacial	55	9.87	2,138,650.25	10.23	1,035,131.51
Blocked	1	0.18	32,401.00	0.15	32,401.23
Moraine-dammed	5	0.90	128,774.10	0.62	47,247.94

The Chamkhar Chu Sub-basin

In the Chamkhar Chu Sub-basin a total of 557 lakes was identified (Figure 7.7). The majority of the lakes fall into the class of valley lakes (306 lakes). The valley lakes occupy 60.85% of the total lake area in the sub-basin (Table 8.15). The largest lake is Cham_gl 383 (supraglacial lake). It has a surface area of 1.03 sq.km and is 2.6 km long (Table 8.16). No field visit has been carried out in the glaciated region of this sub-basin.

The valley Glacier Cham_gr 71 was named Chubda Glacier (Karma 1999). Within this glacier, several supraglacial lakes were observed during the expedition in August 1999. Five major glacial lakes associated with glaciers (Table 8.16) were identified in this sub-basin.

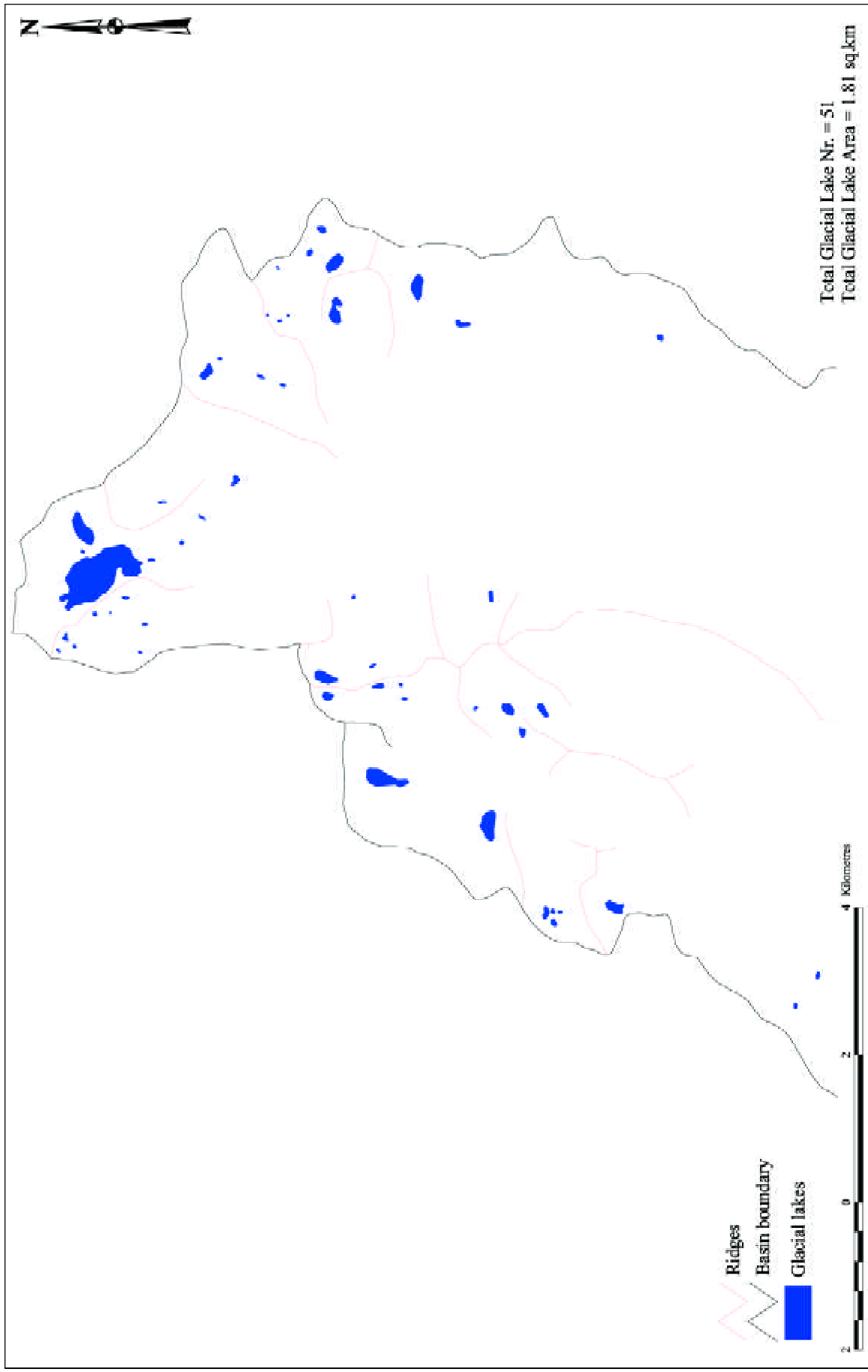

Figure 8.8: Glacial lakes of the Dang Chu Sub-basin

Table 8.16: Major glacial lakes associated with glaciers in the Chamkhar Chu Sub-basin					
Name/ number	Elevation (masl)	Type	Area (m^2)	Associated glacier	Remark
Cham_gl 163	4,766	cirque	802,938	Cham_gr 2	1.5 km long; 425m away from glacier; a number of supraglacial lakes are forming
Cham_gl 198	5,046	erosion	624,670	Cham_gr 9	1.5m long; directly in contact with glacier
Cham_gl 232	5,200	supraglacial	205,146	Cham_gr 15	0.6 km long; needs to be urgently studied as this has the potential to grow even larger
Cham_gl 242-284	4,680-5,160	supraglacial		Cham_gr 25	Numerous small supraglacial lakes in the glacier; needs to be monitored as these may join and become one large lake.
Cham_gl 383	4,840	supraglacial	1,035,132	Cham_gr 71	Very large lake, 2.6 km long within the glacier; needs to be studied in detail.

Kuri Chu

In this sub-basin 179 lakes have been identified (Figure 7.8). Erosion lakes occupy 50.88% of the total lake area in the sub-basin and valley lakes 32.26% (Table 8.17). The largest lake in the sub-basin is a cirque lake (Kuri_gl 102) having an area of 0.918 sq.km lying at an elevation of 4,774 masl. The lake is 1.95 km long. In the headwaters of the Kuri Chu there are 11 lakes associated with glaciers. Details of a few of the larger lakes associated with glaciers are given in Table 8.18.

Table 8.17: Types of lake in the Kuri Chu Sub-basin					
Type	Number		Area (m^2)		Area of largest lake (m^2)
	Number	%	Area	%	
Erosion	84	46.93	5,635,093.37	50.88	421,298.90
Valley	73	40.78	3,573,598.03	32.26	258,827.12
Cirque	20	11.17	1,818,881.01	16.42	918,538.74
Supraglacial	2	1.12	48,575.96	0.44	30,379.50

Table 8.18: Major glacial lakes associated with glaciers in the Kuri Chu Sub-basin					
Lake name/ number	Type	Area (m^2)	Latitude/ longitude	Associated glacier	Remarks
Kuri_gl 129	erosion	132,967	28° 02' 35.47" 91° 17' 49.66"	Kuri_gr 16	0.72 km long; 485m away from glacier
Kuri_gl 142	erosion	361,758	27° 55' 53.22" 91° 16' 20.88"	Kuri_gr 23	0.75 km long; 875m away from glacier
Kuri_gl 172	valley	161,706	27° 55' 47.56" 91° 18' 08.77"	Kuri_gr 33	0.85 km long; in contact with glacier

Table 8.19: Types of lake in the Dangme Chu sub-basin					
Type	Number		Area (m^2)		Area of largest lake (m^2)
	Number	%	Area	%	
Erosion	77	61.11	2,815,766.11	48.38	642,108.68
Valley	38	30.16	1,806,838.53	31.05	373,285.22
Cirque	11	8.73	1,196,905.60	20.57	232,524.25

The Dangme Chu Sub-basin

A total of 126 lakes has been identified in this sub-basin, most of them are small compared to the lakes in other basins (Figure 7.9). There are 77 erosion lakes, 38 valley lakes, and 11 cirque lakes (Table 8.19). The largest lake in the region is Dangm_gl 59 which has a surface area of 0.64 sq.km and a length of 1.3 km. It lies at an altitude of 4,560 masl. In this sub-basin there are no prominent lakes associated with the glaciers. Only the minor lakes in this sub-basin are associated with the glaciers. They are Dangm_gl 10, 14, and 15.

The Nyere Ama Chu basin

In this basin there are only nine lakes (Figure 8.9) of two types. There are five erosion lakes and four valley lakes (Table 8.20). All these lakes are small in size, the largest is only 185m long.

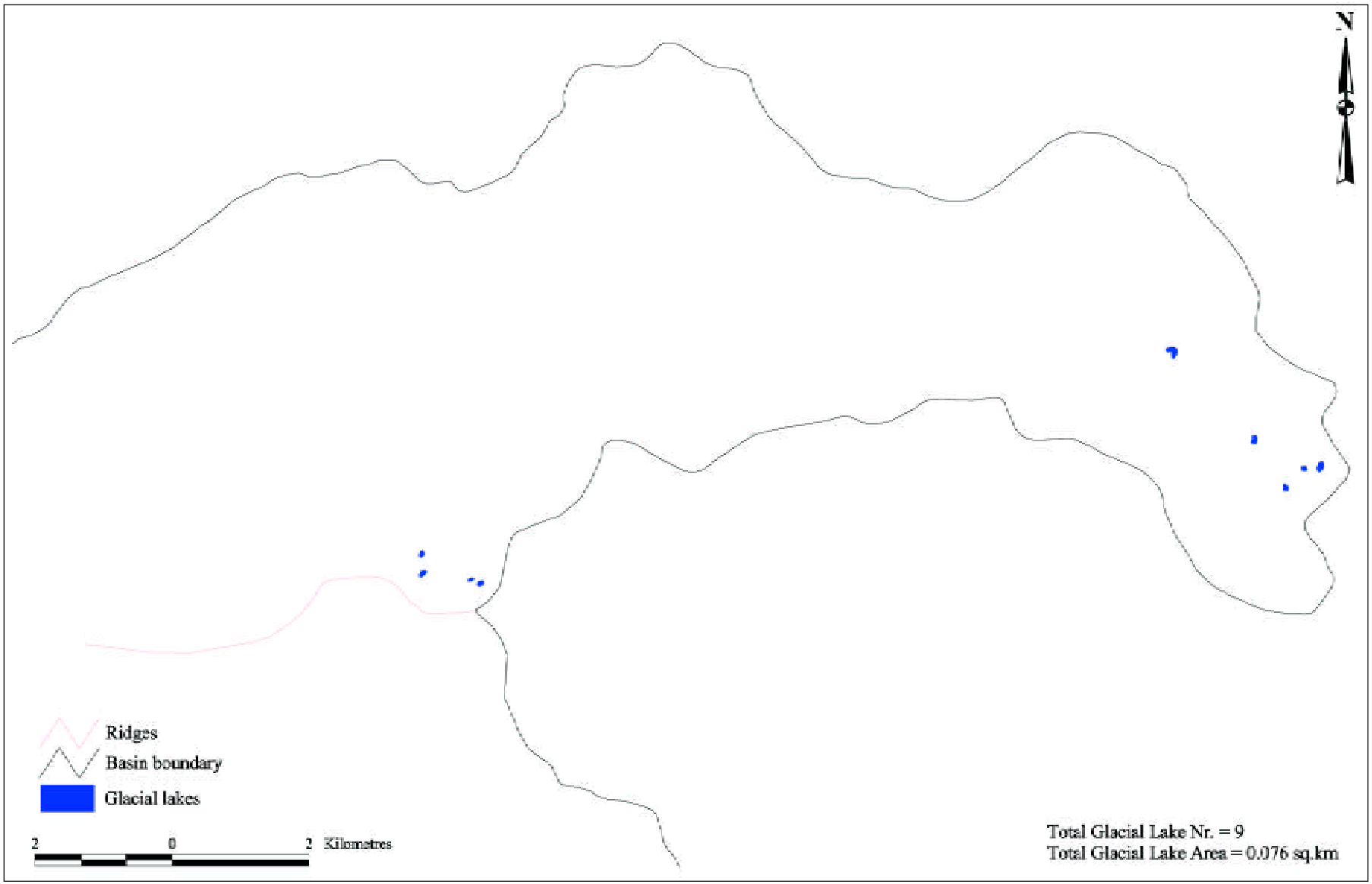

Figure 8.9: Glacial lakes of the Nyere Ama Chu basin

Table 8.20: Types of lake in the Nyere Ama Chu Basin					
Type	Number		Area (m^2)		Area of largest lake (m^2)
	Number	%	Area	%	
Erosion	5	55.56	50,903.68	66.78	17,841.96
Valley	4	44.44	25,321.13	33.22	8,559.00

The Northern basin

The Northern Basin comprises the rivers originating from the watershed of Bhutan. All these rivers flow north towards Tibet (Figure 7.10). There are 10 glacial lakes in this basin covering a total area of 7.81 sq.km (Table 8.21). Most of the glacial lakes are erosion lakes. There are two moraine-dammed and two supraglacial lakes. Only one valley lake exists in this basin. Details of the lakes associated with the glaciers are given in Table 8.22.

Table 8.21: Types of lake in the Northern Basin					
Type	Number		Area (m^2)		Area of largest lake (m^2)
	Number	%	Area	%	
Erosion	5	50	508,199	6.50	219,072
Moraine-dammed	2	20	7,125,098	91.19	5,640,910
Supraglacial	2	20	164,567	2.11	151,160
Valley	1	10	15,634	0.20	15,634

Table 8.22: Major glacial lakes associated with glaciers in the Northern Basin				
Name/ Number	Type	Area (m^2)	Associated glacier	Remark
Out_gl 1	erosion	219,072	Out_gr 26	470m away from the glacier
Out_gl 2	erosion	49,712	Out_gr 26	85m away from the glacier
Out_gl 3	moraine-dammed	5 640,910	Out_gr 34	largest glacial lake in contact with the glacier
Out_gl 4	supraglacial	151,160	Out_gr 50	in contact with the glacier
Out_gl 5	valley	15,634	Out_gr 51	280m away from the glacier
Out_gl 6	supraglacial	13,407	Out_gr 51	in contact with the glacier
Out_gl 7	moraine-dammed	1,484,188	Out_gr 57	in contact with the glacier
Out_gl 8	erosion	33,111	Out_gr 58	315m away from the glacier
Out_gl 9	erosion	129,144	Out_gr 58	815m away from the glacier
Out_gl 10	erosion	77,160	Out_gr 58	150m away from the glacier