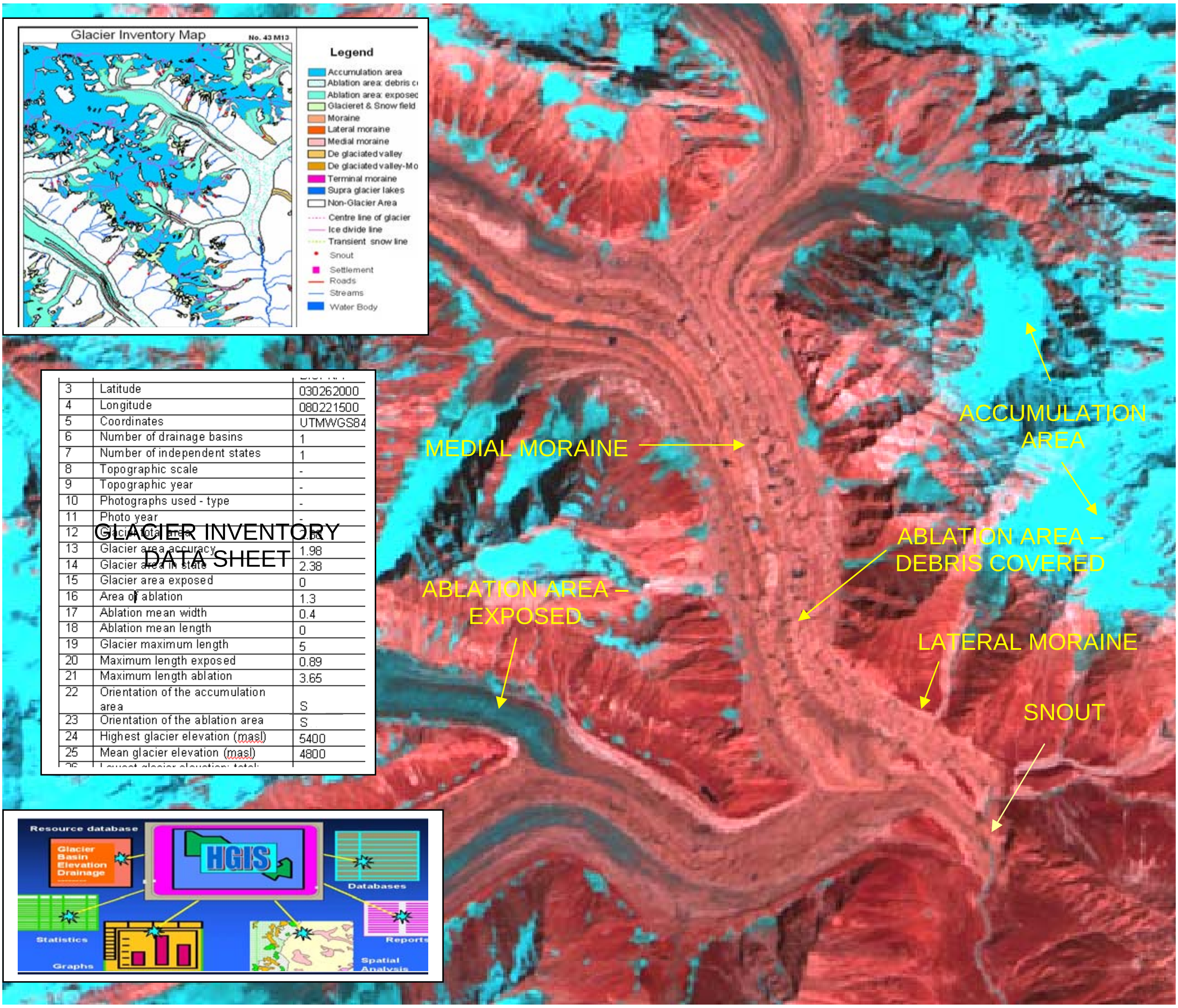
TECHNICAL GUIDELINES FOR HIMALAYAN GLACIER INVENTORY

(INDUS, GANGA AND BRAHMAPUTRA BASINS)



Space Applications Centre (ISRO)
Ahmedabad - 380 015

December 2006

Technical report SAC/RESIPA/MESG-SGP/TN 27/2006

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10. Abstract	Using Indian Remote Sensing Satellite (IRS) LISS III Data and GIS Techniques Glacier Inventory maps and data sheets are prepared at 1:50,000 scale for the three river basins, namely the Indus, the Ganges and the Brahmaputra in the Himalayas. The modified UNESCO-TTS data format has been followed. A structured GIS database creation for Glacier Inventory has been proposed. Detailed procedures are discussed.
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Contents

1.0 Introduction

Systematic inventory of glaciers is required for a variety of applications such as a) Planning and operation of mini and micro hydroelectric power stations, b) disaster warning and c) estimation of irrigation potential, etc. needed for the overall development of the Himalayan region.

But glaciological studies in high altitude terrains and under inclement weather conditions as in higher Himalayas become difficult by conventional means. Thus remote sensing techniques play much greater role in mapping and monitoring of permanent snowfields and glaciers. Therefore, use of satellite data is finding wide acceptance in glacial inventory (Anon., 2003)

Inventory data is generated for individual glaciers in a well-defined format as suggested by United Nations Temporary Technical Secretariat (UNESCO/TTS) and later modified with few additional parameters. Additional parameters contain information related to de-glaciated valleys and glacier lakes. These parameters are not recommended by UNESCO/TTS. According to this system, the methodology that has been developed for inventory has following components:

A period of the year i.e. from July to end of September, when seasonal snow cover is at its minimum and permanent snow cover and glaciers are fully exposed, is selected for the glacier mapping using remote sensing data. Topographical maps and corresponding multi-temporal geocoded FCC's of standard band combination such as 2 (0.52-0.59 μm), 3 (0.62-0.68 μm) and 4 (0.77-0.86 μm) of IRS LISS III sensors at 1:50,000 scale have been used for interpretation. Altitude information is generated from standard Digital Elevation Model (DEM) available from satellite data of Shuttle Radar Terrain Mapping Mission (SRTM) or CARTOSAT data.

One of the important outcome of glacier inventory is identification and mapping of moraine-dammed lakes. Glacier outburst floods caused by the moraine-dammed lakes are a common phenomenon in the glaciated terrain of the world. These floods can cause extensive damage to the natural environment and human property; as it can drain extremely rapidly and relatively small lake can cause flash floods. These events could be cyclic and can occur periodically. In the Indian Himalaya, no systematic record of flash flood due to moraine-dammed lake is available.

The information generated will be in the form of designed and structured digital database which can be easily assessed, updated, analyzed and retrieved for hydrological applications.

This report provides the details of the procedure and other guidelines for preparation of glacier inventory maps, standard data sheet and digital database as envisaged for the glacier inventory project taken up at Space Applications Centre (ISRO), Ahmedabad.

1.1 Objectives

The main objective is systematic inventory of the glaciers occurring in the Indus, Ganga and the Brahmaputra basins. The study will result in following :

- Preparation of glacier inventory maps at 1:50,000 scale
- Preparation of glacier inventory data sheet
- Creation of (spatial / non spatial) digital database in GIS

The above input will be used for the envisaged Himalayan Snow and Glacier Information System (HGIS). The database will also be used for the Natural resources database (NRDB).

1.2 Study Area

The study area (Fig. 1) is the glaciated part of the three Himalayan Basins, the Indus, the Ganges and the Brahmaputra.

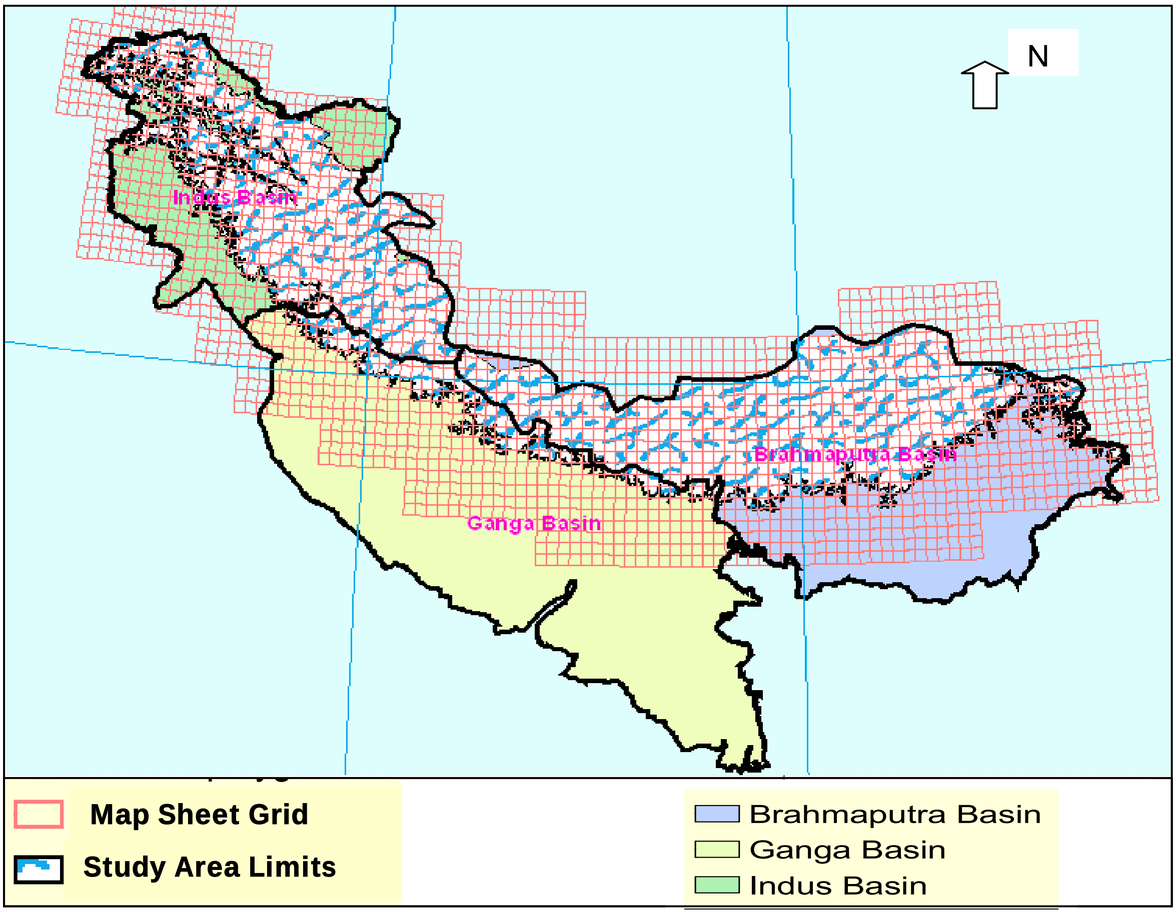

Figure-1 Study area parts of Indus, Ganga and Brahmaputra Basins (Himalaya)

It is estimated that about 1586 Survey of India (SOI) topographic maps on 1:50,000 scale cover the Himalayan area for the three basins. However, the glaciated area, which generally occurs at 3500 m above mean sea level, is estimated to be restricted to about 1250 maps only. The study area also covers some parts of Nepal, Bhutan, Tibet and China from where these rivers either originate or have major tributaries which flow into India.

1.3 Data Required

1.3.1 Satellite data

Geocoded IRS LISS III data on 1:50,000 scale, from period July to end of September for the glacier inventory seasons is procured in the form of FCC paper prints and digital format. The hard copy geocoded FCC's of standard band combination such as 2 (0.52-0.59 μm), 3 (0.62-0.68 μm) and 4 (0.77-0.86 μm) and in digital data the standard bands with additional SWIR band (1.55-1.70 μm) will be procured from National Data Centre (NDC), National Remote Sensing Agency (NRSA), Hyderabad.

1.3.2 Collateral data

Following collateral data will be required / referred

- Drainage maps from Irrigation Atlas of India.
- Basin Boundary maps from Watershed Atlas of All India Soil and Land Use Survey (AIS&LUS).
- Available Snow and Glacier maps (at 1:250,000 and other scales from intrernet. (Anon. 1990, Bahuguna et. al. 2001, Kulkarni et. al. 1999 and 2005, Kulkarni and Buch. 1991, www.glims on internet 2006).
- Elevation information from DEM generated initially from SRTM data. Later on DEM from CARTOSAT data will be used to replace the elevation information from SRTM data.
- Road, trekking routes and guide maps
- Political and Physiographic maps
- Published literatures on Himalayan glaciers

2.0 Approach

The main aim is to generate a glacier morphological map based on multi temporal IRS LISS III satellite data and ancillary data. Specific measurements of mapped glacier features will be the inputs for generating the glacier inventory data sheet (Annexure-1) with 37 parameters as per the UNESCO/TTS format and 11 additional features associated with the de-glaciated valley. The data sheet provides glacier wise details mainly related to the glacier identification in terms of number and name, glacier location in terms of coordinate details, information on the elevation, measurements of dimensions and orientation, etc. A Table showing statistics summarizing the essential glacier features is also generated.

The glacier inventory map with details of the glacier features is prepared by visual on screen interpretation by using soft copy of multi-temporal IRS LISS III satellite data and ancillary data. Earlier field studies and results derived using satellite data suggest that spectral reflectance's of the accumulation area are high in bands 2, 3 and 4 of IRS LISS II and TM data. On the other hand, reflectance in band 2 and 3 are higher than the surrounding terrain but lower than vegetation in band 4. These spectral characteristics are useful to differentiate between glacial and non-glacial features (Dozier, 1984; Hall et al., 1988).

The broad approach for the preparation of glacier inventory map, data sheet and digital data base is given in flow chart below (Figure- 2)

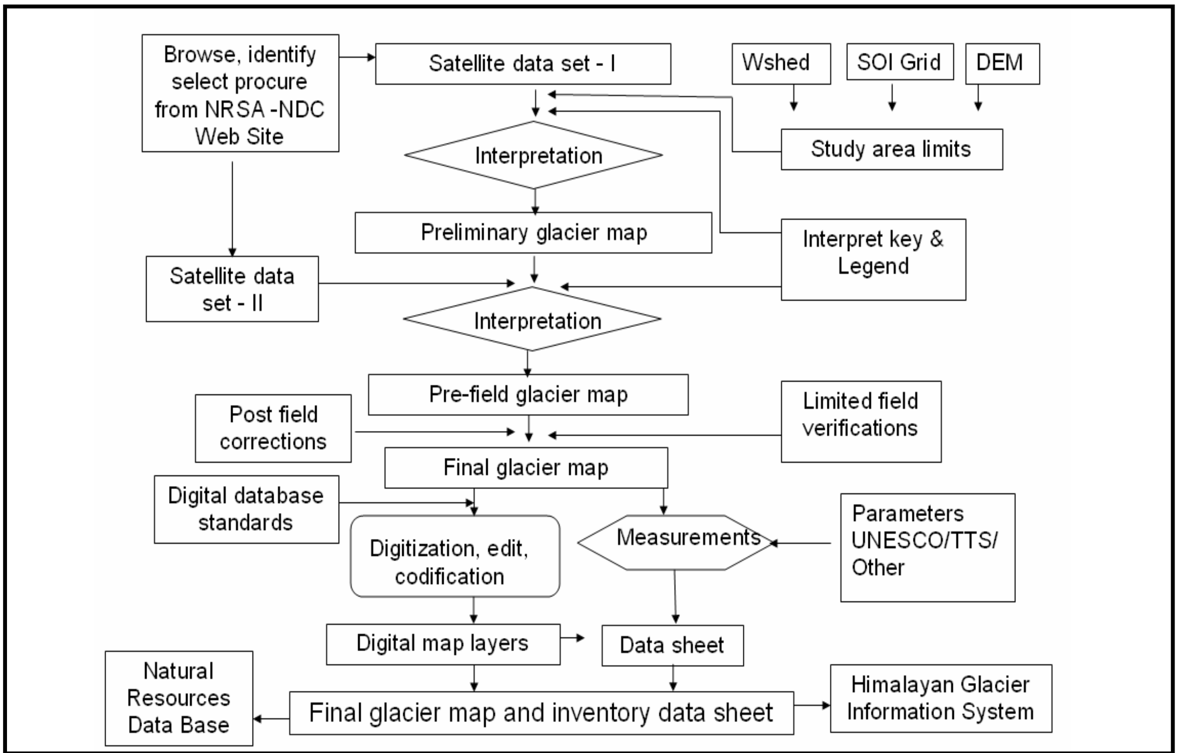

Figure-2 Broad approach for glacier inventory map and data sheet preparation

In practice the preparation of glacier inventory map involves preparation and integration in GIS of primary theme layers. The primary theme layers can be grouped into three categories i) Base information ii) Hydrological information iii) Glacier and De-glaciated valley features (Table-1).

Table-1 Theme layers for glacier inventory map and data sheet creation

Sr. No.	Theme	Remarks/ Contents
A] Base Map		
1	Frame work	5' * 5' latitude-longitude tic points (background for all layers)
2	SOI map reference	15'*15' latitude-longitude grid and SOI reference no.
3	Country Boundaries **	Country
4	State boundaries **	State
5	District Boundary**	District
6	Taluk Boundary**	Taluk
7	Roads	Metalled/unmetalled road, foot-path, treks, etc.
8	Settlement extent	Extent of habitation
9	Settlement location	Location of habitation
10	Elevation DEM*	Image grid
B] Hydrology		
11	Drainage lines	Streams with nomenclature
12	Drainage poly	Water body, river boundary with nomenclature
13	Watershed Boundary	Watershed boundary and alphanumeric codes
C] Glacier		
14	Glacier boundary	Ablation, accumulation, snow cover areas, supra-glacial lake, de-glaciated valley, moraine dammed lake, etc
15	Glacier lines	Ice divide, transient snow line, centre line, etc.
16	Glacier point	Point locations representing coordinates for glacier, glacier terminus/snout, moraine dam lake, supra-glacier lakes, etc.
17	Glacier elevation point locations	Glacier elevation point locations. highest/lowest values for glacier, moraine dam lake, supra-glacier lakes.

** Will be kept directly in the final database by SAC

Initially the small scale ancillary data (drainage, watershed, roads, settlements, etc.) is used to prepare preliminary digital maps corresponding to the base and hydrology themes. These preliminary theme layers are modified and finalized by using multi-temporal satellite data.

A preliminary glacier inventory map has been prepared using the first set of satellite data. Subsequently, it is modified as pre-field glacier inventory map using second set of satellite data to include all the essential glacier features. Limited field visits are to be carried out to verify the pre-field glacier inventory map. Corrections, if any, are to be incorporated to prepare the final glacier inventory map. Measurements carried out on the glacier inventory map result in generating the glacier data sheet.

2.1 Preparation of theme layers

The published Irrigation Atlas, Watershed Atlas, small and large scale maps like political/ physical maps from reliable source have been identified for utilization for base map and hydrology theme layers. The information like administrative boundary, transportation features and settlement locations, drainage, watershed, etc., are identified on these maps. The maps are then scanned as raster images and registered / projected with the satellite data based on common control features. These scanned images are used in the background for extracting the base information on separate vector layers.

The information content of each of the primary theme layers and the procedure for their preparation is discussed below :-

2.1.1 Base map layers

The base map comprises of the four types of layers like the administrative boundary layer, transportation network, settlement locations and elevation information (DEM) layer.

Administrative boundary layer

Major administrative boundaries like the Country, State, District and Taluk are obtained from published Political maps (or SOI open series maps). In digital data base these boundaries are identified, delineated, codified and are stored as separate layers with corresponding look-up tables (Tables-2, 3, 4, 5 and 6). The country codes as identified by UNESCO/TTS /Muller may be followed. The codes for the State, District and Taluk may be taken as given in Census (Census, 2001) data.

The satellite data does not have any role in creating these administrative layers. However, these are significant reference layers essential for understanding the distribution of glaciers within the political boundaries. It is envisaged that the layers will be directly procured from SOI as open series digital maps. The administrative maps will be directly incorporated in the data base at SAC.

Table-2 Attribute tables for Country: COUNTRY.LUT

COUNTRY-CODE	COUNTRY-NAME
IN	India
CH	China
NP	Nepal
BH	Bhutan
TB	Tibet

Table-3 Structure of table-COUNTRY.LUT

Field Name	Field Type	Key Field- Y/N
COUNTRY-CODE	2,2,C	Y
COUNTRY-NAME	10,10,C	N

Table-4 Structure of table-STATE.LUT

Field Name	Field Type	Key Field- Y/N
STATE-CODE	2,2,C	Y
STATE-NAME	30,30,C	N
Code's and names as per NIC Scheme		

Table-5 Structure of table-DISTRICT.LUT (NRIS)

Field Name	Field Type	Key Field- Y/N
D-CODE	4,4,C	Y
D-NAME	30,30,C	N
Code's and names as per NIC Scheme		

Table-6 Structure of table-TALUK.LUT (NRIS)

Field Name	Field Type	Key Field- Y/N
T-CODE	6,6,C	Y
T-NAME	30,30,C	N
Code's and names as per NIC Scheme		

Transportation network

As majority of the glaciated areas in the Himalayas are not easily assessable, the meager transportation features that are available become all the more significant for any glacier related study. The information on the transportation features occurring in the area is represented in a separate layer called the Roads layer.

The road maps published by the state or other transportation network maps like road atlas, tourist/track maps, etc., containing the required information on various types of roads are used. The road network comprising of various types of metalled, un-metalled roads, foot paths, cart tracks, track on glacier, etc. leading to the glacier or across the glacier, if any, are to be identified and delineated on to the vector layer. This information is then compared and updated based on satellite data and field visit. The layer is digitized and appropriately codified to create a final ROADS layers. The corresponding look up tables (ROADS.LUT) and structure of the table are as given in Tables-7 and 8 given below.

Table-7 **Attribute Table for Roads: ROADS.LUT (NRIS)**

RD- CODE	ROAD TYPE	SUB-TYPE
01-00	Metalled Black Topped (BT) or Bitumen Roads	
01-01	National Highway	
01-02	State Highway	
01-03	District Road	
01-04	Village Road	
02-00	Unmetalled Water Bound Macadam (WBM) or Concrete/ Cement Roads	
02-01	National Highway	
02-02	State Highway	
02-03	District Road	
02-04	Village Road	
03-00	Tracks	
03-01		Pack Track in Plains
03-02		Pack Track in hills
03-03		Track follows stream
03-04		Cart Track in plains
03-05		Cart track in desert/ wooded/ hilly area
03-06	Footpath	
03-07	Footpath in hill	
04-00	Route Over glacier	
05-00	Pass	
06-00	Pass in permanent snow	
07-00	Road on dry river bed	
08-00	Road under construction	
08-01		National Highway
08-02		State Highway
08-03		District Road
08-04		Village Road
09-00	Others	Earthen/Gravel, Flyover etc.

Table-8 **Structure of the table - ROADS.LUT (NRIS)**

Field Name	Field Type	Key Field - Y/N	Remarks
RD-CODE	4, 4, C	Y	Feature Code
TYPE	30,30, C	N	Road Type
SUB-TYPE	30,30, C	N	Sub-Type

Settlement location

The lower reaches of the basins are inhabited and presence of small settlements common. The extents of such village/town are first delineated based on available published maps and stored as a polygon (SETTLEA) layer or the habitation mask. The village/town settlement extent (polygon) is updated using multi-date satellite data and corresponding codification is done as per look-up table SETTLEA.LUT (Table- 9). The centeroid of the delineated polygon for settlement is marked as the settlement location point (SETTLEP) and all relevant information can be attached with this point in the look-up table SETTLEP.LUT (Table-10). The SETTLEP codification for each of the village will be as per the codes given in Census (2001).

The settlement layers will be used as habitation location mask that will be overlaid on the glacier inventory map while generation of the hardcopy output during the preparation of the A3 size Atlases for each of the three basins.

Table-9 Attribute Table for Settlement (Polygons): SETTLEA.LUT (NRIS)

SETA-CODE	SET-TYPE
01	Towns/ Cities (Urban)
02	Villages (Rural)

Table-9.1 Structure of the Table DRAINL.LUT (NRIS)

Field Name	Field Type	Key (Y/N)	Remarks
SETA-CODE	4,4, C	Y	Feature Code
SET-TYPE	30,30,C	N	Code Description

Table-10 Attribute Table for Settlements (Points): SETTLEP.LUT (NRIS)

Field Name	Field Type	Key Field Y/N	Remarks
SCODE	8,8,C	Y	
LOCATION	25,25,C	N	Village Name
V –TYPE	25,25,C	N	
SCODE is the system link CODE			
SCODE	V -TYPE		
00009000	Village		
00009001	Forest		
00009002	Town		
9004	Others		

Elevation information (DEM) *layer*

The DEM generated based on Shuttle Radar Terrain Mapping (SRTM) Mission with vertical resolution of 30 m will be used for collecting the elevation information. The point location layer can be overlaid on the DEM and significant elevation measurements required as input for the data sheet can be obtained. In future, the DEM from SRTM may be replaced with higher resolution DEM prepared based on CARTOSAT data.

2.1.2 Hydrology

The hydrology layer with information on all the minor, major drainage, water bodies and watershed with their corresponding identification numbers and names is to be created. The published small scale Irrigation Atlas of India will be used as input for generating the preliminary drainage line and water bodies layers. The watershed Atlas of India (Anon., 1990) will be used as input for generating the preliminary watershed layer.

The drainage layer will be generated as two separate layers the *drainage line layer* (DRAINL) and the drainage polygon layer (DRAINP). All streams up to fifth order are numbered in an inverse manner as per the Strahlars streams ordering procedure and the corresponding codes are assigned to the streams. The Strahlars ordering is done on a standard map at 1:20 m scale wherein the originating streams as seen on the map are given the highest order of 5^{th} and subsequently the two 5^{th} order streams when join make the 4^{th} order stream and when two 4^{th} order streams join they make the 3^{rd} order stream and so on The stream identification numbering scheme as suggested by Muller (1970) is followed and each stream is numbered accordingly (Figure-3).

Drainage line layer

The drainage line layer is prepared to represent all the streams arising from the snow and glacier feed area and which can be represented only as single line due to mapping scale (DRAINL.LUT) Table-11.

Table-11 Attribute Table for Water Body Polygons: DRAINL.LUT (NRIS)

DRNL-CODE	DISCR
01	Perennial
02	Dry
03	Tidal*
04	Undefined/ Unreliable
05	Perennial - Unreliable
06	Tidal creek*
07	Water channel in dry river
08	Broken Ground/ ravines

*may not exist in glacier areas.

Table-12 Structure of the Table DRAINL.LUT (NRIS)

Field Name	Field Type	Key (Y/N)	Remarks
DRNL-CODE	2,2,C	Y	Feature Code
DISCR	30,30,C	N	Code Description
STREAM ORDER	2,2,I	N	Stream Order

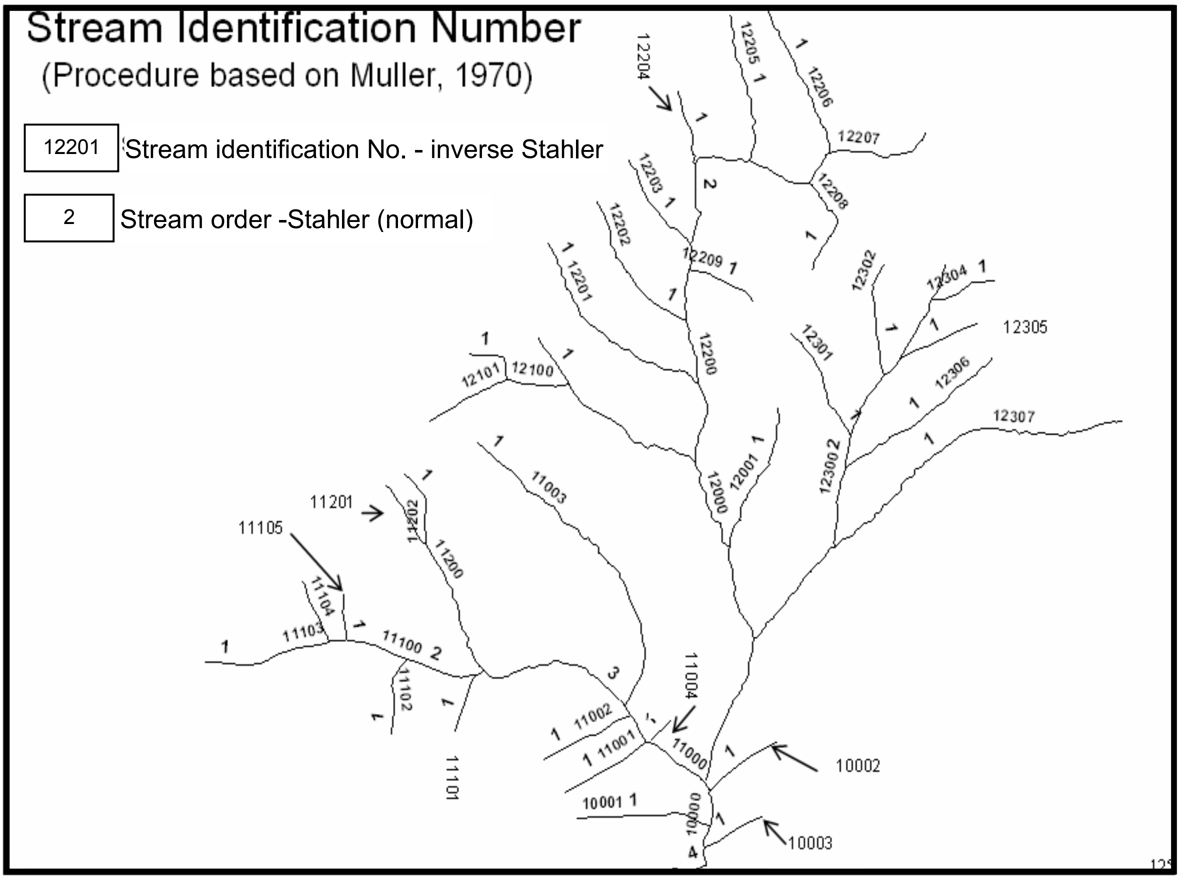

Figure-3 Stream Identification - Inverse Stahler Stream identification Method

Drainage poly layer

This layer provides information on all the major streams and the waterbodies which can be mapped as polygons at this scale. The dry and wet parts of the drainage are identified and delineated with appropriate codification. The sand area, which is seasonally under water during occasional flooding caused by snow melt, should also be appropriately identified and mapped.

The moraine dammed lakes and the supra-glacial lakes should be delineated and appropriately classified (DRAINP.LUT) (Table-12). Names of large waterbodies and rivers are identified from published maps and stored in the associated record in look-up table.

Both the preliminary drainage line and polygon layers prepared using small scale maps as input are updated using multi-date satellite data. All changes in stream/river courses and presence of new waterbodies are incorporated in the final drainage layers.

Table-13 Attribute Table for Water Body Polygons: DRAINP.LUT (NRIS)

DRNP-CODE	DISCR
01	River
02	Canal*
03	Lakes/ Ponds
04	Reservoirs
05	Tanks
06	Cooling Pond/ Cooling Reservoir*
07	Abandoned quarries with water*
08	Bay*
09	Cut-off Meander*
10	Supra-glacial lake
11	Moraine dammed lake

* may not exist in glacier areas

Table-14 Structure of the Table DRAINP.LUT (NRIS)

Field Name	Field Type	Key (Y/N)	Remarks
DRNP-CODE	2,2,C	Ŷ	Feature Code
DISCR	30,30,C	N	Code Description

Watershed boundary layer

The hierarchical (preliminary) watershed boundary information as delineated from the small scale watershed maps as available in the Watershed Atlas (Anon., 1990). The delineated boundaries in the preliminary map are modified using multi-date satellite data. The ridges, ice divide and stream/river features representing the watershed boundaries as seen on the image are carefully interpreted and are refined at 1:50,000 scale to prepare the final watershed map layer. The alphanumeric codification associated with the watersheds (WS-CODE) is retained without change (WSHED.LUT) as given in Table-15.

The delineation and codification of watershed is limited up to watershed level only in the 16 digit code (ws-lcode). The sixteen digit link code ws-lcode comprises of RB-BB-CB-SC-WB-SW-MN-MI representing the boundary for the Region (RB), Basin (BB), Catchment (CB), Sub-catchment (SC), Watershed (WB), Sub-watershed (SC), Mini-watershed (MN) and Micro-watershed (MI). The codes representing the Sub-Watershed Boundary (SC), Mini-Watershed Boundary (MN), Micro-Watershed Boundary (MI) will be kept as zero value. The structure of the table WSHED.LUT and a sample watershed look-up table are given in Tables-15 and 16 respectively.

Table-15 Structure of the Table WSHED.LUT (NRIS)

Field Name	Field Type	Key (Y/N)	Remarks
WS-LCODE	16,16,C	Y	Link code with attribute table
WS-CODE	8,8,C	N	AISLUS Code
REGION	40,40,C	N	Description
BASIN	40,40,C	N	Description
CATCHMENT	80,80,C	N	Description
SUBCATCHMENT	80,80,C	N	Description
WATERSHED	80,80,C	N	Description

Table-16 Sample WSHED.LUT

WSHED_LCODE	WSCODE	RB	BB	CB	SC	WB	STREAM NAME
01-06-03-03-01-00-00-00	1F3C1	01	06	03	03	01	R B Shyok
01-06-03-03-02-00-00-00	1F3C2						Chorbat
01-06-03-03-03-00-00-00	1F3C3						Malakohu
01-06-03-03-04-00-00-00	1F3C4						Tharu Lungpa
01-06-03-03-05-00-00-00	1F3C5						Paizamplu
01-06-03-03-06-00-00-00	1F3C6						Khardung
01-06-03-03-07-00-00-00	1F3C7						R B Shyok

2.1.3 Glacier

The glaciers in the Himalayas are mainly of the Mountain and valley glacier type. The available archive information on glaciers in the form of glacier maps / Atlas on the Himalayan Glacier Inventory at 1:250,000 scale (Kulkarni and Buch, 1991) is referred before the mapping is initiated to get an idea of the glacier occurrences and distribution in the past.

Using multi-date satellite data the required glacier morphological features are mapped. However, for convenience of generating statistics from digital layers, these morphological features are stored separately as line point and polygon layers.

The glacier inventory map is prepared in two steps; first the preliminary glacier inventory map is prepared using the first set of satellite data and all glacier features (Figure-4) are mapped. Later, the dynamic features like snow line, permanent snow covered area, moraine extent, etc., are modified and new glacier features, if any, are appended based on the subsequent year satellite data to prepare the pre-field glacier inventory map. The pre-field glacier inventory map is then verified in the field wherever possible and final glacier inventory map is prepared after including the modifications.

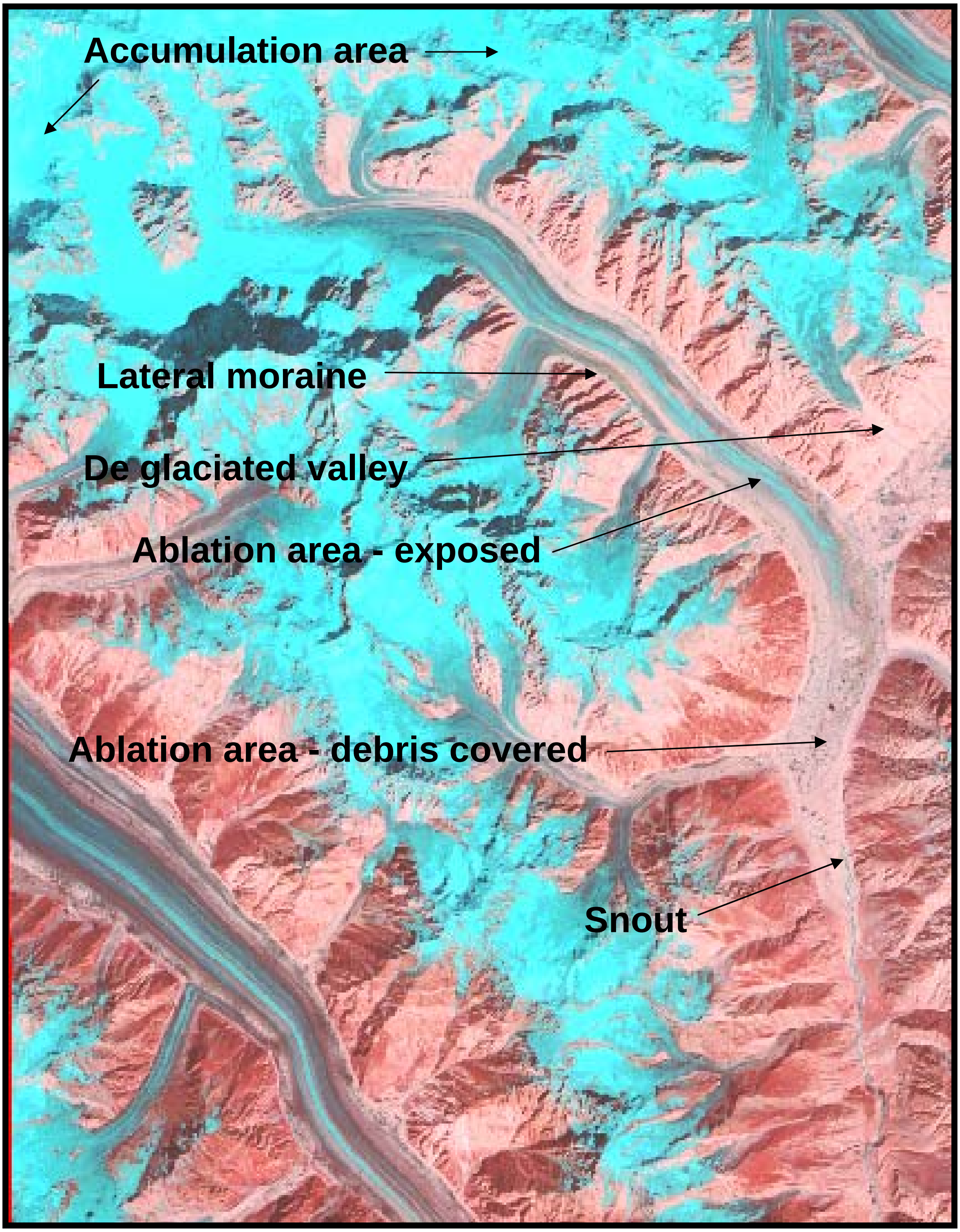

Figure-4 Glacier Features as seen on IRS LISS III FCC (Sep. 2005)

The mapped glacier features comprise of the permanent (for 2 or more glacial inventory season) snow covered areas/snow fields, the boundary of smaller glacieret, the glacier boundary for accumulation and ablation area with the transient snow line separating the two areas. The ice divides line at the margin of glaciers and other features like cirique, horn the glacial outwash plain areas, the glacier terminus / snout, etc. are delineated. The ablation area is further classified as ice exposed or debris covered.

The extent of the de-glaciated valley and the associated various types of moraines and moraine dammed lake features are delineated. These features are appropriately stored in GIS as point line and polygon layers.

Glacier features layers

Using multi-date satellite data, the extent of the perennial snow covered areas, the glacieret, the glacier accumulation and ablation area, cirques, horn, etc., associated with the glacier are delineated as polygon features (GLACIER) and appropriately codified (GLACIER.LUT).

The transient snow line which separates the accumulation and ablation areas and the ice divide line at the margins of two or more glaciers are identified and delineated as line features in a separate cover. The centre line running along the maximum length/longitudinal axis of the glacier and dividing it into two equal halves is delineated and stored as line feature (GLACIERL). The position of the glacier terminus or snout is delineated as point feature in a separate cover (GLACIERP). The associated look-up tables for the glacier poly, line and point features are created as GLACIER.LUT, GLACIERL.LUT and GLACIERP.LUT along with corresponding structure for each of these are respectively given in Tables-17, 18, 19, 20, 21and 22.

As per the TTS format the glacier position as represented by the latitude /longitude and coordinate system is essential. Similarly, various point locations representing the coordinate point for de-glaciated valley, supra-glacier lake, snout, moraine dam lake, etc. are essential for tabular representation and future reference. The layer GLACIERP with point location (coordinates in latitude /longitude) is to be created for this purpose.

De-glaciated valley feature

The de-glaciated valley and associated features are significant to determine the health of the glacier. The dimensions of the valley and the type of moraines deposits reflect upon the retreat pattern of the glacier. The multi-date satellite data is used to identify and delineate the extent of the de-glaciated valley features.

Mainly the de-glaciated valley and associated features that are mapped include the glacial valley, moraines like the terminal, medial, lateral moraine, outwash plain, moraine dammed lake, etc. (Figure-5). The moraines can occur both as polygon as well as line features depending upon their width at the mapping scale. The information is stored in polygon vector (GLACIER) layer. Some of the lateral and terminal moraines which can be delineated only as the lines are separately kept in a line vector layer the de-glaciated valley line (GLACIERL) layer.

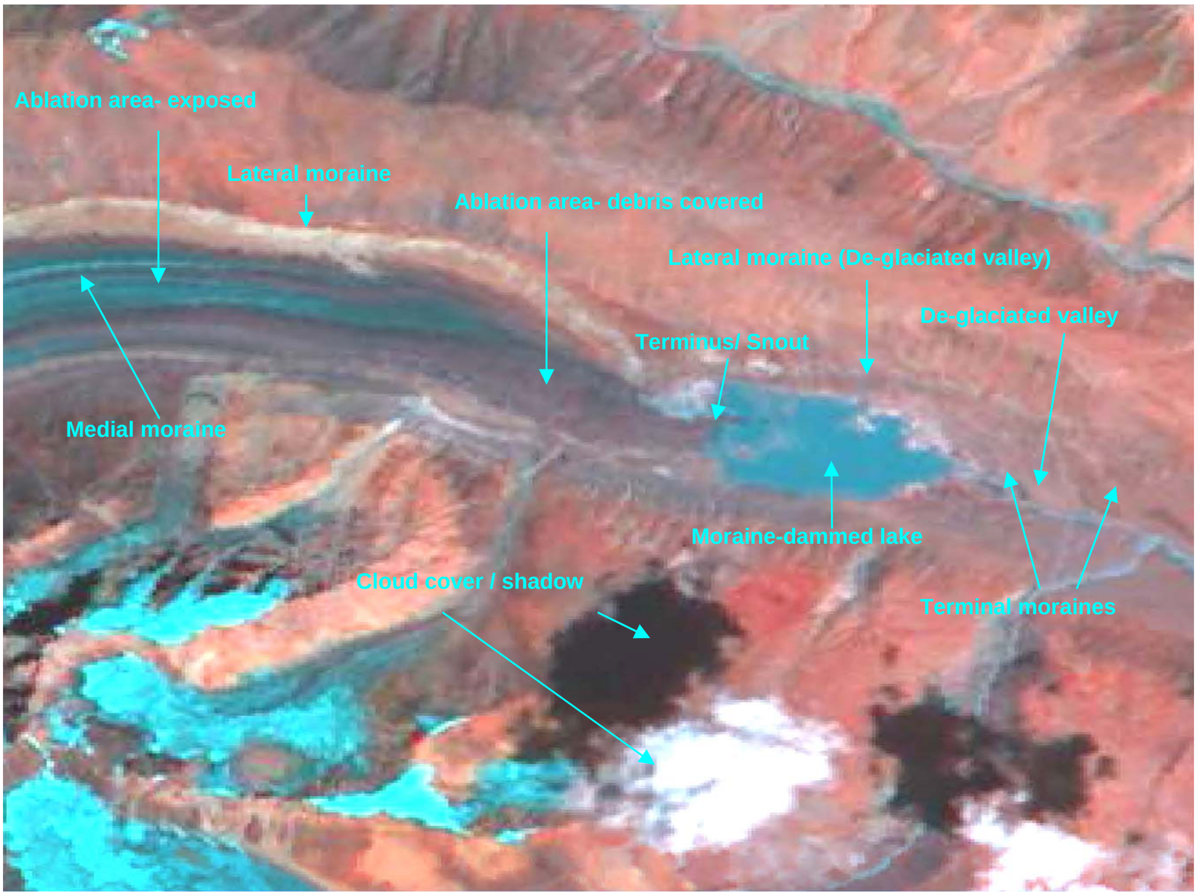

Figure-5 Glacier and De-glaciated valley Features - IRS LISS III FCC

The elevation information, particularly the highest and lowest elevation of glaciers, de-glaciated valley, the supra-glacial and moraine dam lakes are significant as these are to be incorporated in the TTS format. A point layer (ELEVP) will be created to store all the locations of these elevation points and their elevation values. The attribute table and the structure of the ELEVP is given in Table-23. The elevation information for these locations will be obtained by intersecting this layer with the DEM layer created using SRTM data.

Table-17 Attribute Code Table for Glacier Polygon Layer: GLACIER.LUT

GL-Code	Discr-L1	Discr-L2	Discr-L3
01-00-00	Glacier		
01-01-00		Accumulation area	
01-02-00		Ablation area	
01-02-01			Ablation area: debris cover
01-02-02			Ablation area: exposed
01-03-00		Moraine	
01-03-01			Terminal moraine
01-03-02			Medial moraine
01-03-03			Lateral moraine
01-04-00		Supra glacier lakes	
02-00-00	De glaciated valley		
02-01-00		Moraine	
02-01-01			Terminal moraine
02-01-02			Lateral moraine
02-02-00		Outwash plain	
02-03-00		Moraine dammed lake	
03-00-00	Glacieret & Snow field		
88-88-88	Non glaciated area		

Table-18 Structure of the Table GLACIER.LUT

Field Name	Field Type	Key Field - Y/N	Remarks
GL-Code	6, 6, C	Y	Feature Code
GLAC_ID	15, 15, C	Y	Glacier identification number
Discr-L1	50,50, C	N	Glacier Unit at very small scale
Discr-L2	50,50, C	N	Glacier Unit at large (1:50k) scale
Discr-L3	50,50, C	N	Glacier Unit at large (1:50k) scale with next level of (hierarchy) details

Table-19 Attribute Code Table for Glacier Line Layer: GLACIERL.LUT

GLL-Code	Discr-L1
01	Ice divide line
02	Lateral Moraine glaciated area (trace)
03	Median Moraine in glaciated area (trace)
04	Terminal Moraine in glaciated area (trace)
05	Lateral Moraine in de-glaciated area (trace)

06	Terminal Moraine in de-glaciated area (trace)
07	Transient snow line
08	Centre line of total glacier (max. length)
09	Centre line of glacier (2) smallest (min. length)
10	Centre line of total de-glaciated valley (max. length)
11	Centre line of exposed glacier (max. length-exposed)
12	Centre line of ablation area (max. length)
13	Mean width line for accumulation area - maximum length
14	Mean width line for accumulation area - minimum length
15	Mean width line for ablation area – maximum length
16	Mean width line for ablation area – minimum length

Table-20 Structure of the Table GLACIERL.LUT

Field Name	Field Type	Key Field - Y/N	Remarks
GLL-Code	2, 2, C	Y	Feature Code
GLAC_ID	15, 15, C	Y	Glacier identification number
Discr	50,50, C	N	Glacier line feature at large (1:50k) scale

Table-21 Attribute Code Table for Glacier Point Layer: GLACIERP.LUT

GLP-Code	DESCRIPTION
01	Terminus / snout
02	Glacier coordinate point
03	Supra-glacial lake coordinate point
04	De-glaciated valley coordinate point
05	Moraine dam lake coordinate point
06	Snowline coordinate point

Table-22 Structure of the Table - GLACIERP.LUT

Field Name	Field Type	Key Field - Y/N	Remarks
GLP-Code	2, 2, C	Y	Feature Code
GLAC_ID	15, 15, C	Y	Glacier identification number
Discr	50,50, C	N	Glacier co-ordinate point location

Glacier elevation point layer (ELEVP)

The elevation information, particularly the highest and lowest elevation of glaciers, de-glaciated valley, the supra-glacial and moraine dam lakes are significant as these are to be incorporated in the TTS format. A point layer (ELEVP) will be created to store all the locations of these elevation points and their elevation values. The attribute table and the structure of the ELEVP is given in Table-23. The elevation information for these locations will be obtained by intersecting this layer with the DEM layer created using SRTM data.

Table-23 Attribute Code Table for Elevation Point Layer: ELEVP.LUT

ELEV-CODE	DESCRIPT
01	Highest glacier elevation point
02	Lowest glacier elevation point (same as snout location)
03	Lowest supra-glacial lake elevation point
04	Lowest moraine dam lake elevation point
05	Snowline elevation point / high elevation ablation area / low elevation of accumulation area

Table-24 Structure of the Table - ELEVP.LUT

Field Name	Field Type	Key Field - Y/N	Remarks
ELEV-CODE	2, 2, C	Y	Feature Code
GLAC_ID	15, 15, C	Y	Glacier identification number
ELEV-VAL	5,5,I	N	Glacier elevation value in meters
Discr	50,50, C	N	Various glacier elevation point

2.2 Steps in preparation of glacier inventory map and data sheet

For preparing the glacier inventory map and data sheet, analysis of satellite data is carried out using FCC paper print at 1:50,000 scale as well as corresponding soft copy digital image. Along with the satellite data following thematic layers prepared earlier are also used.

- Frame work (FRAME) comprising of tic marks at interval of 5’ x 5’ representing the latitude and longitude for the study area with datum and projection in WGS84 corresponding to open series maps (OSM) will be created and provided. The codification for the tic ids will be DDMMSSDDMMSS (12 digits) corresponding to the longitude and latitude for the tic location.

- SOI layer comprising of polygons Grid obtained by joining the tics located at interval of 15’ x 15’ and representing the boundary of 1:50,000 scale map sheet. The information of the map sheet number the minimum and maximum values of latitude and longitude associated with the sheet will be stored in the associated look-up table (SOI.LUT) Table-25.

- Watershed boundary (WSHED) based on small scale maps and codification as per AIS&LUS procedure (Anon., 1990).

- DEM based on SRTM data. Raster image with elevation information.

Table-25. Attribute Table for Survey of India Toposheets: SOI.LUT

Field Name	Field Type	Key Field- Y/N
SOI-CODE	6,6,C	(Y)
SOI-NAME	8,8,C	N
LAT-MIN	10,10,C	N
LONG-MIN	10,10,C	N
LAT-MAX	10,10,C	N
LONG-MAX	10,10,C	N
Explanation for SOI-CODE (nn-qq-ss)		
Nn	Toposheet Number at 1:1million level i.e 01, 02.....	
Qq	Quadrant number	
	01	A
	02	B
	----------	-----------
Ss	16	P
	Segment Numbers from 01 to 16	
	For Example SOI-CODE for Toposheet 56/E/2 will be 56-05-02	

- The administrative boundary of COUNTRY, STATE, DISTRICT and TALUK will be generated and will be finally integrated with the data base. The corresponding look-up tables will be prepared for these layers COUNTRY.LUT, STATE.LUT, DISTRICT.LUT and TALUK.LUT

The details of steps involved in the preparation of the glacier inventory map (Fig. 6) and data sheet (Annexure-1) are given below

The geocoded satellite data along with the above layers that are provided are appropriately loaded on to the computer system.

A new vector layer is created with the projection and datum system as defined in the standards (section 3.3.1). Copies of this layer can be made and appropriately renamed as DRAINL, DRAINP, WSHED, GLACIER, GLACIERL, GLACIERP, etc.

The coverage topology can be built as poly, line or point as required. For distinction between the preliminary and final maps the preliminary maps are prefixed with a _P for e.g. WSHED_P, DRAINP_P, etc. The prefix (_P) can be removed once the coverage is finalized.

DRAINL

- To create the drainage line layer activate a new line vector layer and name it DRAINL_P
- Superimpose the vector layer on the available scanned small scale drainage map. Delineate all the drainage features as seen on the map as single line. A preliminary drainage line layer is prepared.
- Now superimpose the preliminary drainage line layer on the satellite image and match drainage seen on satellite data with the drainage mapped from small scale map.
- The small scale map does not contain the required details and needs to be modified using satellite data. New drainage lines not mapped from small scale map may now be visible on satellite data and should be mapped. The courses of drainage may be modified as seen on the satellite data to finalize the drainage line layer. The lines may be suitably codified as given in DRAINL.LUT.
- Proper care should be taken to delineate all drainage which emanate from the snow and glacier area. Care should be taken to see that all the drainage lines are joined properly upstream with the glacier feature from which these emanate and down stream with the other line or polygon drainage / water body feature. None of the drainage should be left hanging unless it really shows the characteristic of a hanging drainage.
- Once finalized, the drainage line layer is saved as DRAINL in the workspace.

DRAINP

- Superimpose a new blank vector layer DRAINP_P on the displayed small scale drainage map. Delineate all the drainage as well as water body features as seen on the map as double line. A preliminary drainage polygon layer is prepared.
- As explained above (for DRAINL), superimpose the drainage polygon layer on satellite data and delineate all the new drainage polygon and water body features. Modifications are to be carried to include the changed courses of drainage features.
- The extent of dry sections of channel / water body should be appropriately delineated and codified.
- Proper care should be taken to maintain the continuity of drainage features within the drainage polygon as well as with line drainage features mapped earlier.

WSHED

- Superimpose a new vector layer WSHED_P on the displayed small scale preliminary watershed map.
- Correlate the boundaries given in the preliminary watershed map with the features on satellite data like the ridges or courses of major stream, ice divide, etc. which represent watershed limits.
- Adjust and redraw the boundaries of the preliminary map to match the satellite data watershed features. The refinement is done to follow distinctly seen watershed features on the satellite data. Particularly watershed boundary should be coterminous with the ice divide, streams, etc. and should not cut across them.
- The stream name and watershed hierarchical codification is verified with the corresponding plate from Watershed Atlas (Anon., 1990). The watershed layer (WSHED) is thus finalized.

ROADS

- The preliminary ROAD_P layer is superimposed on the satellite data and the road features on map and satellite data are correlated.
- The new road features are delineated and any other changes with respect to road features as seen on the satellite data are incorporated on to the map.
- Care should be taken to see that the roads are not left hanging and are appropriately connected with the other roads in the area.
- The delineated road features are codified as per the codification scheme
- In the absence of roads in the area a blank line layer need not be created.

GLACIER

- Blank polygon, line and point vector layer named GLACIER_P, GLACIERL_P and GLACIERP_P respectively are created as per the required standards.
- The glacier inventory map is prepared in two stages using two set of satellite data.
- The preliminary layers which are intermediate layers are stored in the database with a _P as suffix for e.g. GLACIER_P, GLACIERL_P and GLACIERP_P respectively to distinguish these from the final layers GLACIER, GLACIERL and GLACIERP.

Preliminary Glacier inventory map (pre-field glacier inventory map)

- First the preliminary glacier inventory map is prepared using the first set of satellite data by superimposing the glacier poly layer on the satellite data and delineating the area features like the extent of the snow fields and glacierets. The glacier boundary with separate accumulation and ablation area are delineated as polygon features and appropriately codified (GLACIER_P.LUT) and stored in preliminary coverage (GLACIER_P).

- Next the glacier line vector layer (GLACIERL) is activated and the line features like the transient snow line which separates the accumulation and ablation areas and the ice divide line at the margins of two or more glaciers are identified and delineated as line features. The centre line running along the maximum length/longitudinal axis of the glacier and dividing it into two equal halves is identified, delineated, codified and stored as line feature (GLACIERL_P) and stored in the database. Besides these, other line features are also delineated as required to fill the standard TTS glacier inventory data sheet. These lines mostly are drawn to represent width of the glacier (mean width line) for ablation and accumulation areas. In practice, two lines are drawn for width estimation, one representing the maximum width and other representing the minimum width of the feature (viz. ablation area / accumulation area). These lines are only meant for recording the measurements for the purpose of the TTS data sheet.

- Similarly the point vector glacier layer GLACIERP is created by delineating the glacier terminus or snout as point feature.

- The coordinate point for glacier features such as glacier, de-glaciated valley, supra-glacier lake, moraine dam lake, etc. are delineated. The corresponding latitude and longitude values are obtained against these locations for further use in TTS form and others.

- These points are appropriately codified and stored as GLACIERP_P layer in the database.

- The various elevation points like the lowest/highest glacier elevation are identified using the SRTM data within the glacier boundaries (ELEVP).

- It is important to note that some of the point features as required for the TTS form may be common during digitization. Like the lowest glacier elevation point may be lowest elevation point for ablation area and may also represent the location for the snout position. The same point representing more than one feature may also occur in both the GLACIERP as well as the ELEVP layers.

Final glacier inventory map

- The second date satellite data is used to verify and, if necessary, modify the previously delineated boundaries of glacier features.
- The preliminary glacier layer is superimposed onto the second set of satellite data.

- The previously delineated features are verified and doubts, if any, regarding the delineation of extent or location or the classification of feature are cleared by comparison between the two sets of satellite data.
- The snout position is taken as in the latest data set. The snow extent and snow line is taken as the minimum extent of the two set of data.
- The associated look-up tables for the glacier poly, line and point features are created as GLACIER.LUT, GLACIERL.LUT and GLACIERP.LUT respectively.
- The maps are edge matched/ mosaicked and stored in database.
- The final outputs as hard copy atlas are to be prepared basin-wise.

Field verification

- The final glacier inventory map layer will be prepared only after limited field verification exercise is carried out for few specific glaciers.
- The specific glaciers will be selected judiciously from among a set of basins geographically well distributed and showing definite variation of observed geomorphological parameters.
- The accessibility to the regions will have to be ascertained while identifying the glaciers for field validation.
- Based on the field expeditions to different glaciers, the glacier inventory map will be verified and corrections if any will be incorporated.

ELEVP

- The elevation locations are delineated as points in a separate layer.
- The elevation locations mainly represent the highest glacier elevation, lowest glacier elevation, lowest supra-glacial lake elevation, lowest moraine dam lake elevation, snowline elevation, etc.
- All elevations measurements (as applicable) are taken along the centre line of the glacier.
- The point locations are provided codes/attributed as given in ELEVP.lut. The actual elevation values are obtained by overlaying the ELEVP on the DEM layer in GIS using identity function for the points.

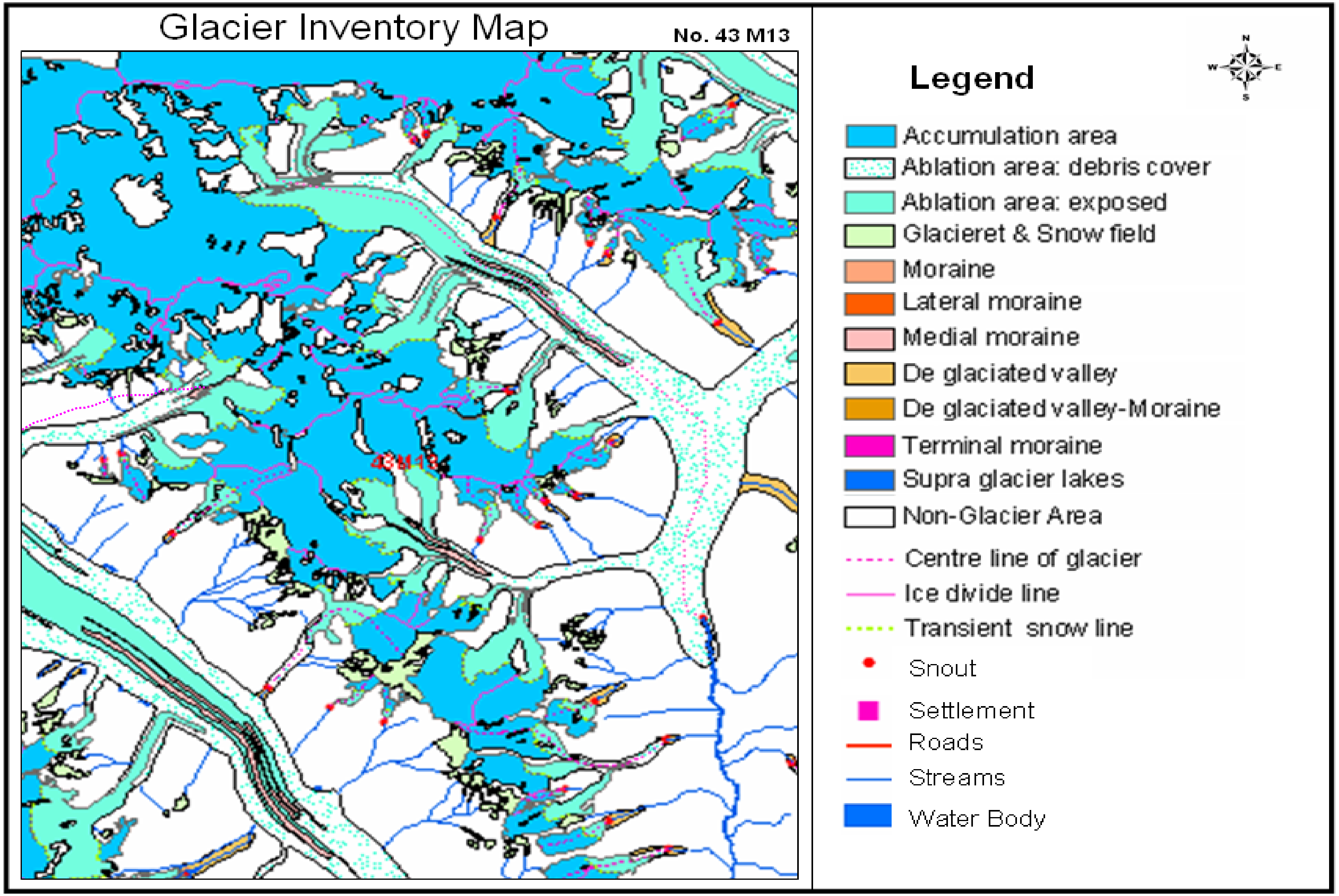

Figure-6 Glacier Inventory Map

3.0 Database design, creation and organisation

As the project envisages the preparation of digital database, it is essential to systematically digitize and store the data in a pre-designed fashion for ease of accessibility for all future hydrological applications. Arc GIS software is to be used for database creation, organization and analysis. In order to create and organize spatial database of glacier, for the entire Himalaya at 1:50,000 scale using satellite data, tasks as detailed below need to be carried out.

3.1 Detailed tasks

- Identification, preparation and collection of the input data sets
- Design, organization and creation of an integrated database (spatial as well as non-spatial database) at 1:50,000 scale.

3.2 Data sources

3.2.1 Satellite data

Details of the data to be acquired for the study area are given in Table-26. Various combinations of this data are to be used for the preparation of thematic maps like drainage, watershed, transportation network, glacier features, de-glaciated valley features, etc.

Table-26 Details of satellite data used

Sr. No	Satellite	Acquisition date/period
1.	IRS P6/IC/ID LISS III (Digital data + Paper prints)	July to September 2004 / 2005/2006 (If suitable data not available then 2002 /2001 periods)
2.	SRTM DEM	2003

3.2.2 Collateral data

- Drainage maps from Irrigation Atlas of India
- Watershed maps from Watershed Atlas of India (Anon., 1990).
- Political and Physiographic maps
- Road maps / guide maps
- Census information (Anon., 2001)
- Climate data for nearby stations from Indian Meteorology Department (IMD).
- Available DEM for elevation information

3.3 Database Contents and Design

Basically the database will have two components. i.e. spatial and non-spatial data. The Geographic Information system (GIS) package with *ArcGIS* software is to be employed as the main tool for design, organization, storage, retrieval, analysis and generation of cartographic outputs. The database design and creation standards suggested in '*NRIS node design and standards, February 2000'* (Anon., 2000)and '*NNRMS standards 2005'* (Anon., 2005)are to be adopted for database creation and organization. The design specifications and database specifications are given in Table-27.

Table-27 Database Design Specifications

Sr. No.	Element	Specification
Input Specifications		
1	Location reference	Latitude-longitude
2	Scale	1:50,000
3	Projection/Map standard	WGS84 (with reference to available SOI map base)
4	Thematic Accuracy	
	MSU (2mm)	0.01 sq km. or 1.0 ha
	Mapping Accuracy	90/90 (unverified)
Database Specifications		
1	Spatial framework	
	Registration scheme	Lat.-Long. Graticule 5' x 5'
	Projection / Coordinate system	WGS84 / UTM
	Coordinate units	Meters
2	Accuracy/Error limits	
	Registration accuracy (rms)	6.25 m
	Area	0.3%
	Weed tolerance	6.25 m

The database design is such that it not only helps for a systematic database organization but also provides a level of flexibility for enhancement / up gradation / improvement. There are three major elements of database design a) generation of spatial framework b) spatial data and c) non-spatial data. The element-wise design considerations adopted for the project are given below.

3.3.1 Generation of spatial framework

This is the most important task prior to database creation due to the fact that entire study area is covered in multiple map sheets and the inputs are available on single map sheet basis. The study area of three basins in the Himalaya is covered in

1250 (15’ x 15’ grid) map sheets of 1:50,000 scale. Based on extent and map sheet graticule, the spatial framework for the GIS database is worked out. which involves:

- Definition/selection of a coordinate system
- Identification of registration tic marks at longitude - latitude crossings of 5 minute interval.
- Decision on coordinate units chosen as true distance in meters.
- Calculation of coordinate values (projection) for selected registration points using UTM projection with following corresponding UTM Zones.

The projection and zones covering the study area are

- *Projection:* UTM
- *UTM Zones:* Four zones viz. 43, 44, 45, 46 and 47 which cover parts of India. The central meridian and range of longitude are given below Table-28
- *Spheroid: WGS84*
- *Unit: meters*

Table-28, WGS84 zones for India

Zone	Central Meridian	Longitude Range
43	75E	72E - 78E
44	81E	78E -84E
45	87E	84E -90E
46	93E	90E -96E
47	99E	96E -102E

To create the digital database, the prescribed NRIS/NNRMS standards are to be used. The four corners of the 15’ x 15’ grid are taken as the tics or registration points to create spatial database of each map taking master grid as the reference.

As the main data source is geocoded LISS-III products (of 1:50,000 scale), a 15’ x 15’ grid coverage is generated with reference tics at interval of 5’ x 5’ interval. This grid will be used for creation of sheet-wise thematic database. The template consisting of entire spatial framework is finalized and made compatible to accept the data at 15’ x 15’ grid basis. The spatial framework created for the entire study area and covering the three basins in the Himalaya is shown in Figure-7.

Administrative boundaries e.g. district mask, taluka boundary, are to be registered with this framework using transformation techniques in GIS.

3.3.2 Spatial data

The spatial data is mainly derived from remotely sensed data and ancillary sources. Most of the spatial data sources follow the WGS84 / UTM co-ordinate system. Thus, the spatial database needs to follow the standards graticule. Hence it is essential to create the spatial database commensurate to 1:50,000 scale selected as identified for the study. The entire study area is covered in 1250 Grids (15’ x 15’) of 1:50,000 scale. A standard registration procedure is to be adopted. The registration points are four corners of graticule. Each 15’ x 15’ graticule covers an area of about 700 sq. km.

Digital database is to be created for all the thematic maps required for generation of glacier inventory map using the spatial framework. The data sets required to be prepared for the study area are given in Table-29. All the data set are to be designed and organized as per NRIS / NNRMS standards. Sheet-wise thematic layers are to be mosaicked / edge-matched and integrated with database.

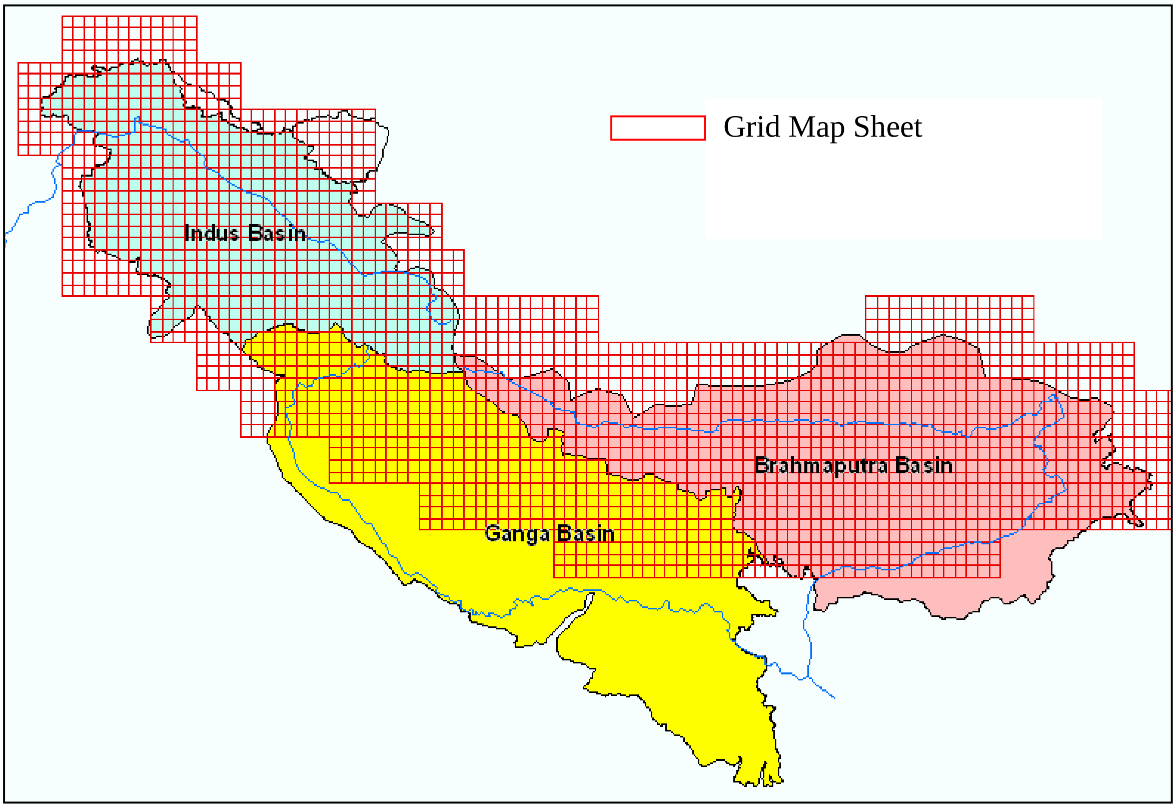

Figure-7 Spatial framework for Himalayan Region (Indus, Ganga and Brahmaputra basins)

Table-29 List of spatial data layers

THEME	LAYER NAME	FEATURE TYPE	MAIN SOURCE	REMARKS
1. Base Map				
Graticule / grid	FRAME	Point	SOI open series maps	5’ 5’ latitude-longitude tic points
SOI map reference	SOI	Poly	SOI open series maps	15’ 15’ latitude-longitude grid and SOI reference no.
Country Boundary	COUNTRY	Poly	SOI and admin. Maps	Country
State Boundary	STATE	Poly	SOI and admin. maps	State
District Boundary-	DISTRICT	Poly	SOI and admin. maps	District
Taluk Boundary	TALUK	Poly	SOI and admin. maps	Taluk
Block/Mandal Boundary	BLOCK	Poly	SOI and admin. maps	Block/Mandal
Roads	ROADS	Line	Satellite data & Published maps	Metalled/unmetalled road, foot-path, treks, etc.
Settlement	SETTLEA	Point	Satellite data & Published maps	Extent of habitation
Settlement	SETTLEP	Point	Satellite data & Published maps	Location of habitation
Elevation DEM	DEM	Grid	SRTM data	Image grid
2. Hydrology				
Drainage lines	DRAINL	Line	Irrigation Atlas & Satellite Data	Streams – nomenclature
Drainage poly	DRAINP	Poly	- DO -	Water body, river boundary
Watershed Boundary	WSHED	Poly	Watershed Atlas, Satellite data	Watershed boundary and alpha numeric codes
3. Glacier				
Glacier boundary	GLACIER	Poly	Satellite data	Ablation, accumulation, snow cover areas, etc
Glacier lines -Snow Line / Ice divide	GLACIERL	Line	Satellite data	Dividing line between accumulation/ablation area
Glacier point - Snout location	GLACIERP	Point	Satellite data	Glacier terminus point and glacier coordinate point.
Glacier elevation locations	ELEV	Point	Satellite data & DEM	Glacier elevation location points like highest or lowest elevation of glacier, etc.

3.3.3 Non-spatial data

The non spatial information like glacier name, identification number, and classification of glacier, elevation and other information is stored in a dat file (GLACIER.DAT) and linked with spatial data using the key field. The glacier identification number (GLAC_ID) is to be used to link non-spatial data with spatial data. This linkage resulted in identifying a polygon, line or point glacier feature with the corresponding record in the dat file.

3.4 Database creation

There are several input sources for data. The main source of data is the thematic maps created from remotely sensed data. The best method for GIS database creation is manual digitization. An alternative to manual digitization is raster scanning followed by raster vector conversion and topology creation. As described earlier the input data could be the existing maps, point sample data, classified remote sensing data etc. The technique for encoding the various types of spatial data is similar to manual digitization. Using these techniques, all thematic layers are to be created and organized in GIS environment.

Non-spatial database creation: The data corresponding ho the data sheet as per standard TTS procedure is collected and stored in GLACIER.DAT which is a dat file (dBase files). These data files are reformatted and organized in ArcGIS environment (Annexure 3).

3.5 Database organisation

Organization of the database (Figure-4) recognizes the fact that the system has to support information retrieval in terms of spatial units, which are generally used by the planners at various levels. These units are invariably the hydrological units like either watershed or administrative units like State, District or Taluk.

Furthermore, the information presentation has to be categorized into functional components, for various planning sectors. The input data is in form of maps, where hydrological and administrative unit may include, partially or fully, more than one map sheet. Spatial database will be created and organized in ArcGIS at Watershed, State, District and Taluk level.

4.0 Integration of Layers and Preparation of Final Glacier Inventory Map

The various layers prepared by interpretation of multi-date satellite data are digitized, appropriately codified and stored in the digital database in GIS environment. These layers are then systematically integrated in GIS to prepare the final glacier inventory map (pre-field). Limited field verification is carried out to verify the delineated features. The post-field modification, if any, are incorporated in the map to prepare the final glacier inventory map. Cartographic maps are composed by overlaying the various layers in GIS and by using appropriate symbology for each of the features related to the base map, hydrology and glacier features layers. The final glacier inventory map is thus composed is ready for printing and binding into Himalayan Glacier Atlas (A3) size.

5.0 Generation of glacier inventory data sheet

Inventory data (Annexure-2) is generated for individual glaciers in a well-defined format as suggested by UNESCO/TTS and later modified. It is divided into two parts. First part comprises all 37 parameters recommended by UNESCO/TTS. Second part contains additional information on 15 parameters related to remote sensing and de-glaciated valleys and glacier lakes. These parameters are not recommended by UNESCO/TTS. However, by considering usefulness of this information in glaciological studies, these are also included in the investigation.

By using the glacier inventory map layers in GIS environment, systematic observations and measurements are made on the glacial feature and recorded in tabular form in the Inventory data sheet The observations and features measured and recorded are mainly related to the data (age / year) used, location, dimensions, elevations and directions, etc. for the glacier. Majority of the measurements can be directly obtained through GIS functions. The table thus generated is linked to corresponding glacier inventory map feature in GIS through the unique glacier identification number.

5.1 Data fields description

The World Glacier Inventory data sheet contains the following data fields. Not all glaciers have entries in every field. Explanations for various Data fields in the standard Data Sheets are as below

1. Glacier identification number: The glacier identification number as defined by the World Glacier monitoring Service's convention. It is based upon inverse STRAHLER ordering of the stream. To achieve uniform classification a base map of 1:20,000 scale was used. On this map the smallest river gets, by definition, order five and when two rivers of the same order meet together; they make a lower order river. Each order is assigned a fixed position in the numbering scheme, which has a total of 12 positions. First three positions are reserved for apolitical and continent identification; fourth position for first order basin and code Q and O is assigned for Indus and Gang rivers, respectively. Next three positions are reserved for 2nd, 3rd and 4th order basins, respectively. In order to identify every single glacier, remaining five positions from 8 to 12 are kept at the disposal of local investigators. In the local system of identification, glaciers are first identified with map number and then numbered in the individual basins.

In present investigation the identification of major basin is to be done by using map supplied by UNESCO/TTS. Present investigation is done on large scale maps; therefore, to make full utilization of inventory information it would be necessary to further subdivide major basin into smaller sub basins. This will make it possible to provide glacier inventory information for small stream and thus improving utility in water resources management. To facilitate this, smallest stream is given, by definition, order eight, instead of four as given by UNESCO/ TTS. This can cause change in number from order five to eight and no change is necessary for positions between four and one. This makes data completely compatible with UNESCO/ TTS data base. To get number for stream order between eight and five; the map of watersheds is taken from Watershed Atlas of India (Anon., 1990).

2. Glacier name: The name of the glacier. Note that not every glacier has a name within the database. Often the name is the glacier's numerical position within its particular drainage sub-region.

3. Latitude: The latitude of the glacier, in decimal degrees North.

4. Longitude: The longitude of the glacier, in decimal degrees East.

5. Coordinates: Local coordinates in UTM (or other nationally determined format)

6. Number of drainage basins: Number of drainage basins

7. Number of independent states: The number of independent states

8. Topographic scale: The scale of the topographic map used for measurements of glacier parameters.

9. *Topographic year:* The year of the topographic map used for measurements of glacier parameters.

10 Photo / image type: The year of the photograph/image used for measurements of glacier parameters.

11. Photo year: The year of the photograph/image used.

12. Total area: The total surface area of the glacier, in square kilometers.

13. Area accuracy: The accuracy of the area measurements on a percentile basis.

14. Area in state: The total area in the political state reporting.

15. Area exposed: The area of open ice, in square kilometers.

16. Area of ablation (total): The total surface ablation area of the glacier, in square kilometers.

17. Mean width of glacier: The mean width of the glacier, in kilometers.

18. Mean length (total): The mean glacier length, in kilometers

19. Max length: The maximum glacier length, in kilometers.

20. Max length exposed: The maximum length of exposed ice, in kilometers.

21. Max length ablation: The maximum length of ablation area, in kilometers

22. Orientation of the accumulation area: The aspect of the accumulation area in degrees in direction of flow. The value -360 indicates an ice cap.

23. Orientation of the ablation area: The aspect of the ablation area in degrees in direction of flow. The value -360 indicates an ice cap.

24. Max / highest glacier elevation: The maximum glacier elevation, in meters.

25. Mean elevation: The mean glacier elevation, in meters.

26. Min / lowest elevation: The minimum glacier elevation, in meters.

27. Min / lowest elevation exposed: The minimum elevation of exposed ice, in meters.

28. Mean elevation-accumulation: The mean elevation of accumulation area, in meters (along the centre line mean of max. elevation and min. elevation)

29. Mean elevation ablation: The mean elevation of the ablation area, in meters. (along the centre line mean of max_elevation_ablation and min. elevation_ablation)

30. Classification: Is the six digit form morphological classification of individual glaciers (UNESCO/IASH guidelines) as detailed in Table-30 below :-

Table-30 Classification System for Glaciers

	Classification					
	Digit 1	**Digit 2**	**Digit 3**	**Digit 4**	**Digit 5**	**Digit 6**
	Primary Classification	**Form**	**Frontal Characteristics**	**Longitudinal Profile**	**Major Source Of Nourishment**	**Activity Of Tongue**
0	**Uncertain or Misc.**	**Uncertain or Misc.**	**Normal or Misc.**	**Uncertain or Misc.**	**Uncertain or Misc.**	**Uncertain**
1	Continental ice sheet	**Compound basins**	**Piedmont**	Even; regular	Snow and/or drift snow	Marked retreat
2	**Ice field**	**Compound basin**	**Expanded foot**	Hanging	Avalanche ice and /or avalanche snow	Slight retreat
3	Ice cap	**Simple basins**	Lobed	Cascading	Superimposed ice	Stationary
4	Outlet glacier	**Cirique**	**Calving**	Ice-fall		Slight advance
5	**Valley glacier**	**Niche**	**Coalescing, non-contributing**	Interrupted		Marked advance
6	**Mountain glacier**	**Crater**				Possible surge
7	**Glacieret and snow field**	Ice apron				Known surge
8	Ice shelf	**Group**				Oscillating
9	**Rock glacier**	**Remnant**				

Descriptions of each of the above classification are given below

Digit 1 Primary classification

0 Uncertain or Misc. - Any not listed
1 Continental ice sheet - Inundates areas of continental size
2 Ice field - Ice masses of sheet or blanket type of a thickness not sufficient to obscure the surface topography
3 Ice cap - Dome shaped ice mass with radial flow
4 Outlet glacier - Drains ice sheet or ice cap, usually of valley glacier form; the catchment area may not be clearly delineated
5 Valley glacier - Flows down a valley; the catchment area is well defined
6 Mountain glacier - Cirique, niche or crater type; includes ice aprons and groups of small units
7 Glacieret and snow field - Glacieret is a small ice mass of indefinite shape in hollows, river beds and on protected slopes developed from snow drifting, avalanching and / or especially heavy accumulation in certain years; usually no marked flow pattern is visible and therefore no clear distinction from snow fields is possible. Exists for at least two consecutive summers.
8 Ice shelf - A floating ice sheet of considerable thickness attached to a coast, nourished by glaciers(s); snow accumulation on its surface or bottom freezing

9 Rock glacier - A glacier-shaped mass of angular rock in a cirique or valley either with inertial ice, firn and snow or covering the remnants of a glacier, moving slowly down slope

Digit 2 Form

1 Compound basins - Two or more individual valley glaciers issuing from tributary valleys and coalescing (Fig. 8-a and Fig. 10).
2 Compound basin -Two or more individual accumulation basins feeding one glacier system (Fig. 8-b and Fig. 11).
3 Simple basin - Single accumulation area (Fig. 8-c and Fig. 12a).
4 Cirque - Occupies a separate, rounded, steep walled recess which it has formed on a mountain-side (Fig. 8-d and Fig. 12b).
5 Niche - Small glacier formed in initially V-shaped gulley or depression on mountain slope; generally more common than the genetically further developed cirque glacier (Fig. 8-e).
6 Crater - Occurring in extinct or dormant volcanic craters which rise above the regional snow line.
7 Ice apron - An irregular, usually thin, ice mass plastered along a mountain slope or ridge.
8 Group - A number of similar small ice masses occurring in close proximity and too small to be assessed individually.
9 Remnant -An inactive, usually small ice mass left by a receding glacier.

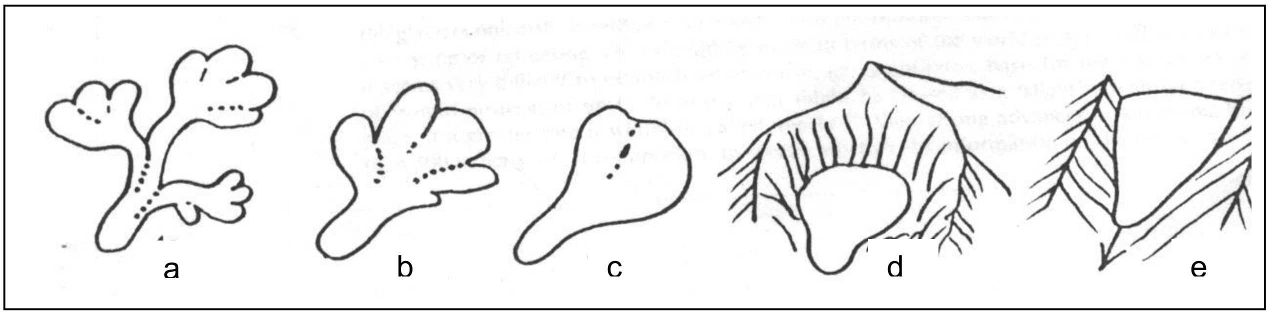

Figure-8 Glacier Classification- Form a) Compound basins, b) Compound basin c) Simple basin d) Cirque e) Niche (After Muller, 1970)

Digit 3 Frontal characteristics *(Fig. 9)*

1 Piedmont (glacier) -Ice-field formed on lowland by the lateral expansion of one or the coalescence of several glaciers. (Fig. 9a and 9b)
2 Expanded foot - Lobe or fan of ice formed where the tower portion of the glacier leaves the confining wall of a valley and extends on to a less restricted and more level surface (Fig. 9c and Fig. 13).
3 Lobed - Part of an ice sheet or ice cap, disqualified as outlet or valley glacier.

4 Calving - Terminus of glacier sufficiently extending into sea or occasionally lake water to produce icebergs; includes-for this inventory-dry land calving, which would be recognizable from the 'lowest glacier elevation.
5 Coalescing, non contributing (Fig. 9d).

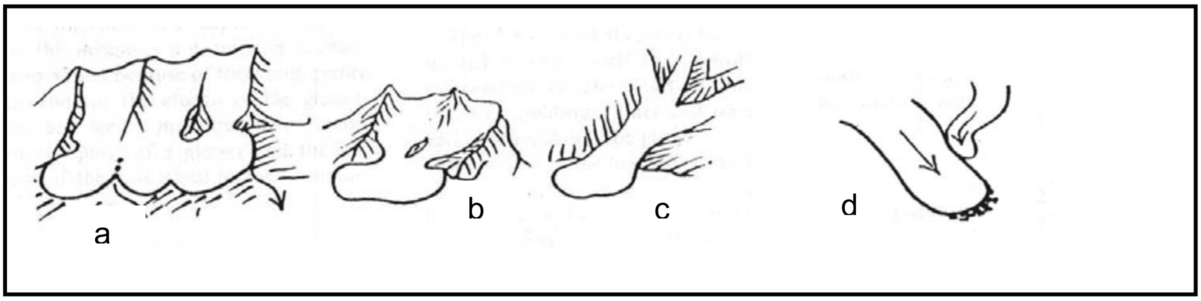

Figure-9 Glacier Classification - Frontal characteristics (After Muller, 1970)

Digit 4 Longitudinal profile

1 Even -Includes the regular or slightly irregular and stepped longitudinal profile.
2 Hanging (glacier) - Perched on a steep mountain-side or issuing from a hanging valley.
3 Cascading - Descending in a series of marked steps with some crevasses and seracs.
4 Ice-fall - Break above a cliff, with reconstitution to a cohering ice mass below.

Digit 5 Nourishment

Self-explanatory.

Digit 6 Tongue activity

A simple-point qualitative statement regarding advance or retreat of the glacier tongue in recent years, if made for all the glaciers on earth, would provide most useful information. The assessment for an individual glacier (strongly or slightly advancing or retreating, etc.) should be made in terms of the world picture and not just that of the local area; however, it seems very difficult to establish an objective, i.e. quantitative basis for the assessment of the tongue activity. A change of frontal position of up to 20 m per year might be classed as a 'advance or retreat. If the frontal change takes place at a greater rate it would be called 'marked'. Very strong advances or surges might shift the glacier front by more than 500 m per year. It is important to specify whether the information on the tongue activity is documented or estimated.

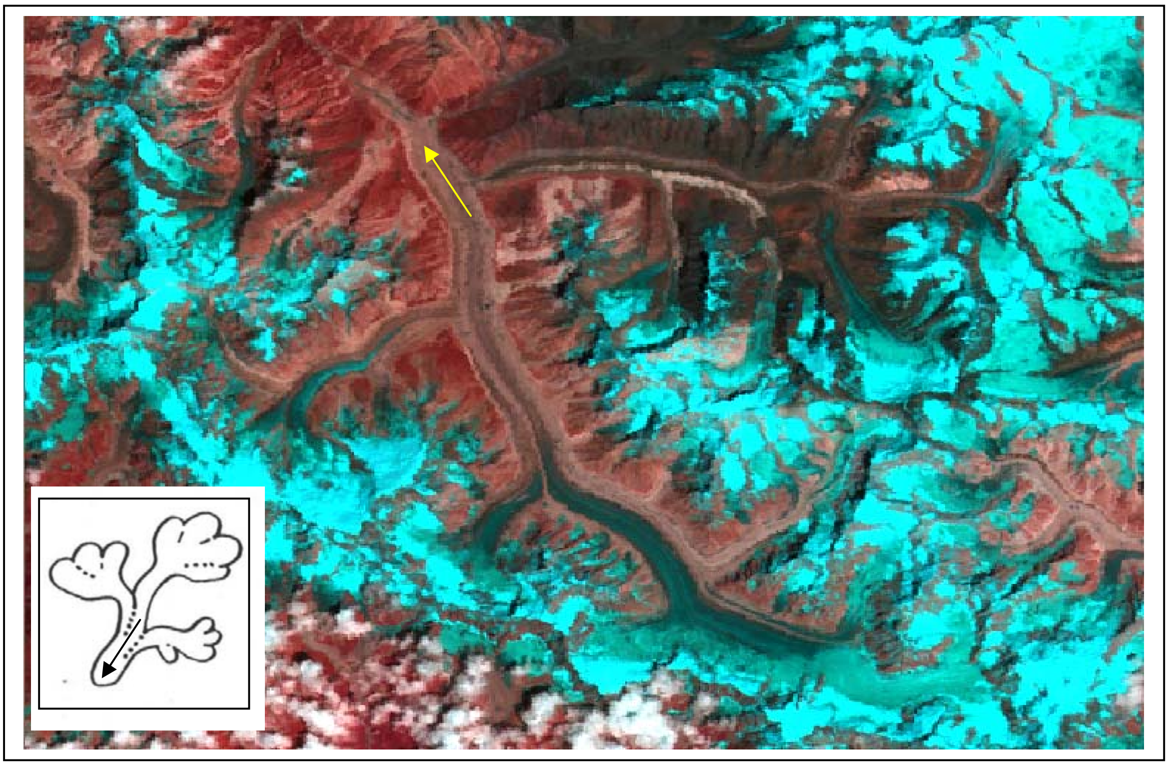

Figure-10 Glacier Classification – Compound Basins as seen on satellite data

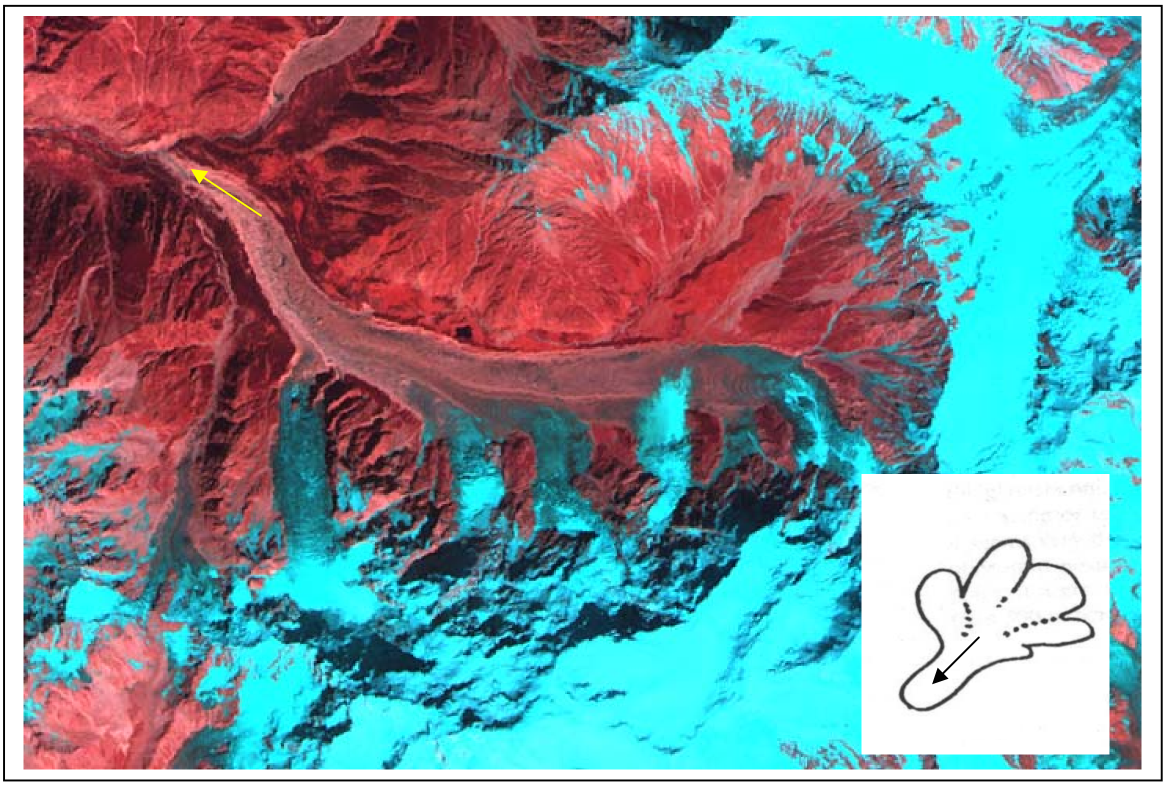

Figure-11 Glacier Classification – Compound Basin as seen on satellite data

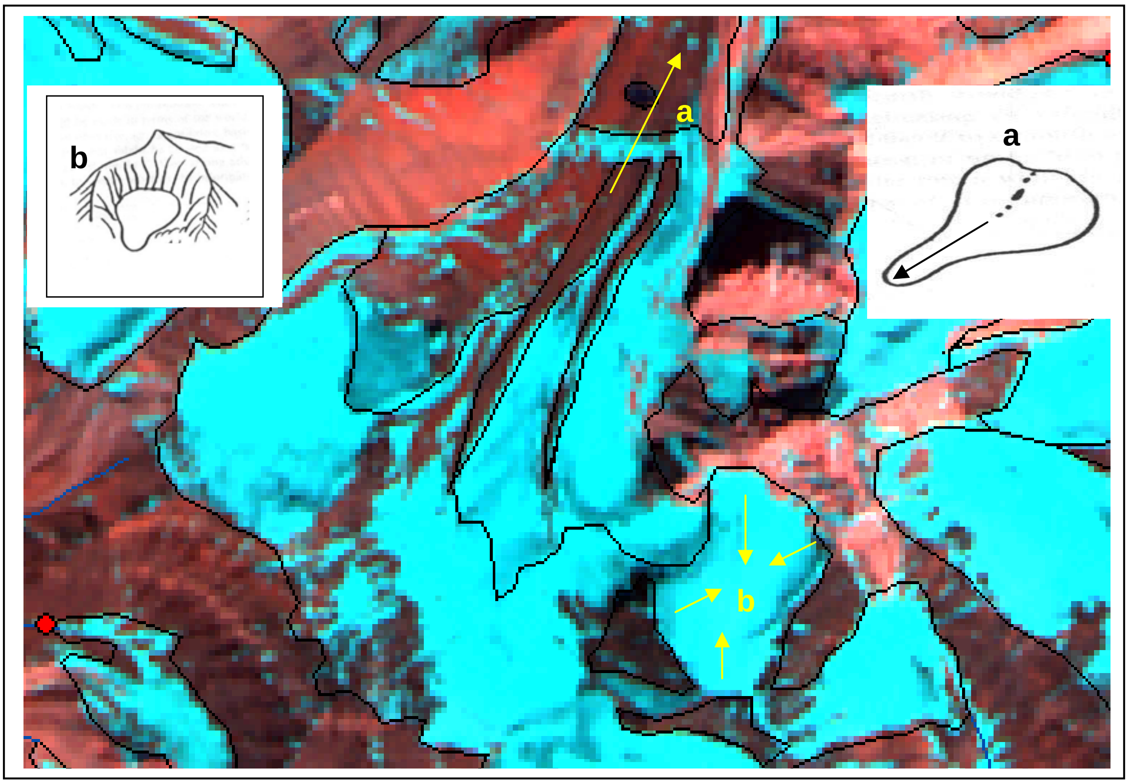

Figure-12 Glacier Classification - a) Simple Basin b) Cirque as seen on satellite data

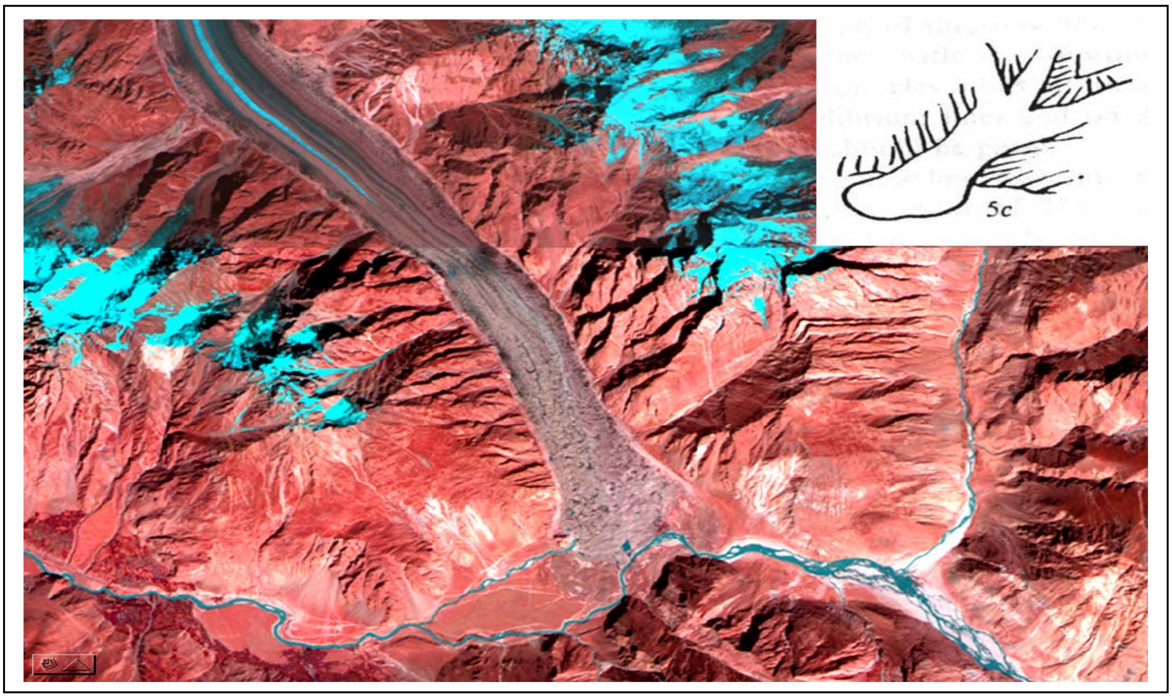

Figure-13 Glacier Classification - Frontal Characteristics-Expanded Foot as seen on satellite data

31. Period for which tongue activity assessed: Period of activity for which the tongue activity was assessed.

32. Moraine code: 1st digit refers to moraines in contact with present-day glacier. The 2nd digit refers to moraines farther downstream. Both the above digits use the same coding system (Table 31).

Table-31 Coding Scheme for Moraine

Code	Description		Code	Description
Code	**Description**		**Code**	**Description**
0	**No moraines**		5	Combinations of 1 and 3
1	**Terminal moraine**		6	Combinations of 2 and 3
2	**Lateral and/or medial moraine**		7	Combinations of 1, 2, and 3
3	Push moraine		**8**	**Debris, uncertain if morainic**
4	**Combinations of 1 and 2**		**9**	**Moraines, type uncertain or not listed**

33. Snow line elevation: The observed or calculated location of the snow line for the total glacier in meters above mean sea level (masl).

34. Snow line accuracy: The snow line accuracy rating is high as snow line based on the two set of satellite data (SAT_DATA) can be entered in the Proforma.

35. Snow Line Date: The date of observation of the snow line or the method of calculation of the snow line. The date of observation can range from a precise day (e.g. 1/7/06) to an individual year (e.g. 2006).

36. Mean Depth: The physical depth of the glacier, in meters. This is estimated based on Table-32.

Table-32 Mean glacier depth estimates (after Muller, 1970)

Glacier Type		Area km^2	Depth (m)
Valley glaciers	Compound basins	1-10	50
		10-20	70
		20-50	100
		50-100	100
	Compound basin	1-5	30
		5-10	60
		10-20	80
		20-50	120
		50-100	120

	Simple basins	1-5	40
		5-10	75
		10-20	100
Mountain glacier, cirque		0-1	20
		1-2	30
		2-5	50
		5-10	90
		10-20	120
Glacieret and snow fields		0-0.5	10
		.05-1	15
		1-2	20

37. Depth Accuracy rating: The accuracy rating of the depth measurement on a percentile basis is given as shown in Table-33.

Table-33 Accuracy rating of the depth measurement

Index [A]	Area, length % [B]	Altitude (m)
1	0-5	0-25
2	5-10	25-50
3	10-15	50-100
4	15-25	100-200
5	> 25	> 200

6.0 Derivation of dimensions (length / width / area), altitude and azimuth information of glacier features in GIS

The glacier polygon, line and point layers are designed for providing easy access to important information for filling the glacier inventory data sheet. The glacier inventory map layers are used to obtain various details for filling the datasheet as per modified UNESCO/TTS format and additional parameters. Using standard GIS tools, area can be found out for the polygon features like total glacier, the ablation zone, accumulation zone, de-glaciated valley, moraine-dammed lakes, etc. By measurement in GIS of various stored line features information for length and width can be obtained. By using GIS function the altitude information can be derived from DEM generated by SRTM data of corresponding scale. The data thus generated is stored in a structured digital data sheet (GLACIER.DAT) with 65 entries corresponding to the modified UNESCO/TTS format. A sample data sheet with the defined database structure (GLACIER.DAT) is given in Annexure-2.

7.0 Preparation of hard copy Atlas in A3 Size

- The atlas will be prepared basin-wise one each for the Indus, Ganga and Brahmaputra basin.
- The map sheets corresponding to a particular basin will be identified based on the watershed boundary.
- These map sheets will be individually composed as maps with the required symbology and printed on A3 size paper. The maps will have corresponding legend associated with the map sheets.
- The inventory statistics will be provided along with the map sheets at appropriate place in the Atlas.
- In the beginning of the Atlas, the mosaic for the entire basin will be shown in reduced scale. Appropriate uniform legend and symbology will be decided and used.

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www.glims web site Global Land Ice Measurements from Space

Annexure - 1
GLACIER INVENTORY DATA SHEET

UNESCO/TTS PARAMETERS

1. Identification number:
2. Glacier name:
3. Latitude:
4. Longitude:
5. Co-ordinates:
6. Number of drainage basins:
7. Number of independent states:

8. Topographical map used: Scale
9. : year
10. Photographs used : type
11. : year

12. Surface area : total (sq. km)
13. : accuracy
14. : total in the state (sq. km.)
15. : exposed (sq. km)
16. Area of ablation (sq. km) :
17. mean width (km) :
18. mean length (km) :

19. maximum length : total (km)

20. : exposed (km)

21. : ablation area (sq. km.)

22. **Orientation :**accumulation area (sq. km.)

23. : ablation area (sq. km.)

24. Highest glacier elevation (masl) :

25. Mean glacier elevation (masl) :

26. Lowest glacier elevation: total; (masl)

27. : exposed (masl)

28. Mean elevation accumulation area (masl):

29. Mean elevation ablation area (masl):

30. Classification:

31. Period for which tongue activity was assessed:

32. Moraines:

33. Snowline for total glacier : elevation (masl)

34. : accuracy

35. : date (day/mo./yr.)

36. Mean depth (m) :

37. accuracy:

REMOTE SENSING PARAMETERS / ADDITIONAL PARAMETERS

1. Satellite data : Name
2. : Sensor
3. : Date (day/mo./yr.)
4. : Type
5. : Bands

6. Deglaciated valley : length (km)
7. : area (sq km)
8. : lowest elevation (m)

9. Glacier lake : Type
10. : Areal extent
11. : Elevation

12. Data compiled by:
13. Date (day/mo./yr.) :
14. Organization:
15. Remarks:

Annexure – 2

STRUCTURE OF GLACIER.DAT WITH SAMPLE DATA (MODIFIED TTS FORMAT)

SR NO.	ITEM NAME (WIDTH, OUTPUT, TYPE, NO. OF DECIMALS)	SAMPLE DATA	REMARKS
[A] TTS Parameters			
1	GLAC_ID (15,15,C,-)	IN5Q62B07008	Glacier identification number
2	GLAC_NAM (25,25,C,-)	BIOFNA	Glacier name
3	LAT (9,9,C,-)	030262000	Latitude
4	LON (9,9,C,-)	080221500	Longitude
5	CORDINAT (15,15,C,-)	UTMWGS84	Coordinates
6	NUM_BASINS (2,2,I,-)	1	Number of drainage basins
7	NUM_STATES (2,2,I,-)	1	Number of independent states
8	TOPO_SCAL (9,9,C,-)	-	Topographic scale
9	TOPO_YEAR (9,9,C,-)	-	Topographic year
10	PHOTO_TYP (9,9,C,-)	-	Photographs used - type
11	PHOTO_YEAR (9,9,C,-)	-	Photo year
12	TOTAL_AREA (10,10,N,2)	2.38	Glacier total area (km^2)
13	AREA_ACU (10,10,N,2)	1.98	Glacier area accuracy
14	AREA_STATE (10,10,N,2)	2.38	Glacier area in state (km^2)
15	AREA_EXP (10,10,N,2)	0	Glacier area exposed (km^2)
16	AREA_AB (10,10,N,2)	1.3	Area of ablation (km^2)
17	WID_ME_AB (10,10,N,2)	0.4	Ablation mean width (km)
18	LEN_ME_AB (10,10,N,2)	0	Ablation mean length (km)
19	LEN_MAX (10,10,N,2)	5	Glacier maximum length (km)
20	LEN_MIN (10,10,N,2)	4	Glacier minimum length (km) comp. basin(s)
21	MEAN_LEN (10,10,N,2)	4.5	Glacier mean length (km)
22	LEN_MAX_EX (10,10,N,2)	0.89	Maximum length exposed (km)
23	LEN_MAX_AB (10,10,N,2)	3.65	Maximum length ablation (km)
24	ORIENT_AC (3,3,C,-)	SW	Orientation of the accumulation area
25	ORIENT_AB (3,3,C,-)	SW	Orientation of the ablation area
26	MAX_ELEV (10,10,I,0)	5400	Highest glacier elevation (masl) (m)
27	MEAN_ELEV (10,10,I,0)	4800	Mean glacier elevation (masl) (m)
28	MIN_ELEV (10,10,I,0)	4200	Lowest glacier elevation: total; (masl) (m)
29	MIN_EL_EXP (10,10,I,0)	0	Lowest glacier elevation: exposed; (masl) (m)
30	MEAN_EL_AC (10,10,I,0)	5200	Mean elevation accumulation area (masl) (m)
31	MEAN_EL_AB (10,10,I,0)	4400	Mean elevation ablation area (masl) (m)
32	CLASS (2,2,C,-)	5	Primary classification
33	FORM (2,2,C,-)	3	Classification - form
34	FRONT (2,2,C,-)	0	Classification - frontal characteristic
35	LONG_PROF (2,2,C,-)	0	Classification - longitudinal profile
36	SOURCE (2,2,C,-)	1	Classification - major source of nourishment
37	TONGUE_ACT (2,2,C,-)	0	Tongue activity
38	PERIOD1 (10,10,C,-)	02/07/2004	Tongue activity - period of observed activity, from
39	PERIOD2 (10,10,C,-)	15/08/2005	Tongue activity-period of observed activity, to
40	MORAIN1 (2,2,C,-)	0	Moraine code - moraine type 1
41	MORAIN2 (2,2,C,-)	2	Moraine code - moraine type 2
42	EL_SNLIN (10,10,I,0)	4800	Snowline for total glacier: elevation (masl)

43	SNLINE_ACU (2,2,I,-)	1 SAT_DATA	Snowline for total glacier : accuracy (masl)
44	DATE_SNLIN (10,10,C,-)	15/08/2005	Snowline for total glacier : date(dd/mm/yyyy)
45	MEAN_DEPTH	40	Mean snow depth (m)
46	DEPTH_ACRC (2,2,I,-)	1	Depth accuracy
47	COUNTRY (2,2,C,-)	IN	Country code
48	CONTINENT (2,2,I,-)	5	Continent number
49	BASIN_CODE (16,16,C,-)	0202011105	Basin_code
[B] Additional Parameters (Satellite data & Deglaciated valley)			
50	SAT_NAME (10,10,C,-)	IRS P6	Satellite name
51	SAT_SENSOR (10,10,C,-)	LISS III	Satellite sensor
52	SAT_PASS (10,10,C,-)	15/08/2005	Satellite Date of pass (dd/mm/yyyy)
53	SAT_DATA_TY (9,9,C,-)	DIGITAL	Satellite data : Type
54	SAT_BANDS (10,10,C,-)	2,3,4&5	Satellite data : Bands
55	DGV_LENT (10,10,N,-)	2.3	Deglaciated valley : length (km)
56	DGV_AREA (10,10,N,-)	3.28	Deglaciated valley : area (km^2)
57	DGV_MIN_EL (10,10,I,-)	4000	Deglaciated valley : lowest elevation (m)
58	LAKE_TYPE (2,2,C,-)	2	Glacier lake : Type
59	LAKE_AREA (10,10,N,-)	0.88	Glacier lake : Areal extent (km^2)
60	LAKE_ELV (10,10,I,-)	4100	Glacier lake: Elevation (m)
61	COMPIL_NAM (25,25,C,-)	FIXED	Data compiled by: name
62	ORGANISA (25,25,C,-)	SAC	Date (day/mo./yr.)
63	DATE (10,10,C,-)	10/6/2006	Organization
64	REMARKS (25,25,C,-)		Remarks specific to glacier

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December 15, 2006
Ahmedabad

Earth Sciences & Hydrology Division
Marine and Earth Sciences Group
Space Applications Centre (ISRO)

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Glossary of Some Important Glacier Terms

A

ablation
In glaciers, refers to melting, erosion and evaporation which reduces the area of the ice.

ablation area or zone
The region of a glacier where more mass is lost by melting or evaporation than is gained.

accumulation area or zone
Where snow falls on a glacier, commonly on a snowfield or cirque.

avalanche
A large mass of snow, ice or rock moving down a steep part of the glacier under the influence of gravity. The first sound of an avalanche is often a hissing like sand falling through a small hole. The Snow and Avalanche Center, reports that "Avalanches equal snowpack + terrain + weather."

B

basal slip also basal sliding
Subglacial meltwater lubricates and separates the ice and the subsurface which results in the glacier sliding over the subglacial surface.

breccia, ice
Large angular ice fragments embedded in finer ice or snow record abrupt changes.

C

calving
Ice sheets calve by breaking off flat pieces when the walls of crevasses give way or chunks fall off the front of an ice sheet. The results are called ice bergs, bergy bits and crevasse wall breakaways.

cirque (corrie or cwm)
A steep-walled semicircular basin in a mountain caused by glacial erosion. After glaciation, the depression may contain a lake.

compressive flow
The body of the glacier is shortened and thickened (not elastically compressed) in reaches where velocity is decreasing.

convergence
Where two ice streams or glaciers flow together, convergence occurs.

continental glaciers and ice sheets
Glaciers which cover continent size masses, for example, Greenland and Antarctica. In the Pleistocene, vast portions of the Americas and Eurasia were covered by continental glaciers.

corrie glaciers
Larger than niche glaciers, smaller than valley glaciers, they occupy hollows on bedrock faces in mountain regions.

corrie glaciation
The development of ice fields between peaks, the growth and coalescence of mountain ice caps into regional ice caps, and the growth of these regional caps into ice sheets.

crevasse
Elongated open cracks in glacial ice, usually nearly vertical, and subject to change at any moment. Crevasses form due to extensional changes in velocity or gradient. They can be oriented to the glacier transverse, longitudinal or oblique and occur in marginal, central or terminal positions on the ice. A crevasse which causes an ice block to displace has caused calving. Crevasses cannot exceed 50 meters (165 feet) deep because they are closed by plastic flow below that depth.

cuesta
A ridge with a gentle slope on one side and a steep slope on the other, often resulting from the movement of a glacier over a rock outcrop. Cuestas are large scale features analogous to rock knobs (roche moutonne).

D

discharge
In glaciers, the total volume of ice passing through a specified cross section of the glacier during a particular unit of time.

dropstones
Rock pieces trapped in icebergs and released (dropped) when the iceberg melts.

drumlins
Poorly understood, streamlined, symmetric hills of drift which may have been formed by reworking of older glacial sediments, or cut from sediments confined by floating ice.

E and F

end moraine
Unlike terminal moraines which mark the furthest advance of the ice sheet or lobe,

end moraines record the continuing retreat of the ice.

equilibrium line
The boundary between the accumulation area and the ablation area.

esker
A narrow, sinuous ridge of sorted sands and gravels deposited by a supraglacial, englacial or subglacial stream.

esker fan
A small plain of sand and gravel built at the mouth of a subglacial stream and associated with an esker formed simultaneously.

false ogives
Light and dark bands on the glacier formed by rock avalanching.

fissure
A deep, long and narrow opening such as a crevasse in a glacier.

firn limit
The dividing line between old ice and new snow at the end of the melting season.

flow
Glacial ice flows in two ways. (a) Ice behaves as a brittle solid until the pressure is equal to the weight of 50 meters (165 feet) of ice; then it becomes plastic and flow begins. (b) The whole mass of ice can slip along the ground, or along shear planes in the ice.

flutes
Long grooves gouged by englacial debris on subglacial pavement parallel to the direction of glacial movement.

furrow
Long grooves in subglacial till or pavement gouged by englacial debris.

G

glacial (glaciation)
(1) Period of time during an ice age when glaciers advance because of colder temperatures. (2) Involving glaciers and moving ice. Usually pertaining to processes associated with glaciers.

glacial budget
The annual relationship between accumulation and wastage. Not equivalent to fluctuations in terminus position.

glacial drift (also see outwash)
A general term for all material transported and deposited directly by or from the ice, or by water running off the glacier.

glacial ice
Consolidated, relatively impermeable ice crystal aggregates with a density greater than 0.84.

glacial lake
Proglacial lakes form the angle of the land and the angle of the glacier are opposite or in the superglacial/englacial environment. Enormous quantities of fine particles are transported by glacial meltwater, leading to the milky or cloudy appearance of many glacial lakes. After glacial melting, tarn lakes, kettle lakes and Pater Noster lakes remain.

glacial outburst flood
A sudden release of melt water from a glacier or glacier-dammed lake sometimes resulting in a catastrophic flood, formed by melting of a channel or by subglacial volcanic activity.

glacial portal
Cavernous openings in subglacial ice and debris above meltwater streams.

glacial retreat
The backwards movement of the snout of a glacier.

glacial surge
A rapid forward movement of the snout of a glacier. Others describe it as rapid, wavelike downglacial ice movements which cause sudden advances of the ice margin.

glacial trough
Glaciers transform v-shaped stream valleys to u-shaped glacial troughs by erosion.

glacier
A large long lasting accumulation of snow and ice that develops on land. Most glaciers flow along topographic gradients because of their weight and gravity. Also defined as: A mass of snow and ice flowing mostly down gradient due to gravity.

glacial deposit
Sedimentary material carried by the glacier and left behind when the ice melts.

glacier terminus
Where the glacier ends, the leading edge of the glacier, also called the glacier nose.

glacier trough
Steep U-shaped valley with a flat bottom caused by glacial scour and erosion.

glaciofluvial
Geomorphic feature whose origin is related to the processes associated with glacial meltwater.

glaciology
The study of the physical and chemical propeties of snow and ice.

grooves/grooving

As the glacier moves forward, rocks imbedded in the ice scratch the underlying materials. If small, these linear features are called striations. Grooves are larger features which may be regular or irregular and may be helpful in establishing direction of glacial flow.

ground moraine

A gently rolling ground surface underlain by till deposited beneath a glacier and usually bordered by terminal moraines.

H

hanging glacier

Ice moving out of high cirques can carve hanging valleys unconnected to a lower glacial mass on steep slopes.

hanging valleys

Tributary glaciers are often smaller than the main glacier and do not cut as deeply. When the ice melts, these shallower glacial troughs lead into the deeper main trough, leaving hanging valleys. Waterfalls are common features of hanging valleys (e.g. Bridal Veil Falls in Yosemite).

headwall

The steep rock at the top edge of the cirque.

horn

A peak or pinnacle thinned and eroded by three or more glacial cirques. The Matterhorn of the Swiss Alps was formed in this manner.

I

ice

The solid form of water is called ice.

ice age

Reoccuring periods in Earth history when the climate was colder and glaciers expanded to cover larger areas of the Earth's surface.

ice breccia

Large angular ice fragments embedded in finer ice or snow record abrupt changes.

ice caps

Smaller ice sheets which cap many islands in the Arctic Ocean and in and near Iceland.

ice cliff

Walls of ice where glaciers meet the sea, such as at the edge of land or the edge of an ice shelf.

ice contact deposit

The multiple types of accumulated stratified sediment left behind when meltwater flows over, within, and at the base of a motionless, melting terminus. See kame, kame terraces and eskers.

ice crystals

Ice crystals are hexagonal in internal structure. The basal plane is weak and permits slip.

ice fall

The reaction of glacial snow and ice to subglacial changes in gradient. The icefall is broken by crevasses and moves constantly when conditions are favorable. Downglacier from icefalls are ogives.

ice quakes

The beginning of the formation of a crevasse or moulin is often accompanied by shaking ice and a hissing or cracking sound.

ice sheets (see continental glaciers)

ice shelf

A large flat-topped sheet of ice that is attached to land along one side and floats in an ocean or lake. More ice is added from the flow of ice from land and is removed by calving and/or melting.

ice streams

In glaciers, ice flows in lineaments which, if they encounter other ice streams, do not mix. River inflow streams eventually mix, although they may remain discrete in their early encounter. Ice streams gouge their bases and carry till. The sides of ice streams may be marked by lateral moraines and where two streams flow, there may be medial moraines of till dividing the ice streams. Ice streams may reach terminus; or may melt away before then leaving lobate terminal moraines.

interglacial periods

Times between recognized advances of the ice. Sea level can be hundreds of feet higher in interglacials than in glacial periods. The present time is the latest interglacial period.

J, K and L

kame

A low, but steep-sided hill or mound composed of poorly sorted sands and gravels deposited in strata by meltwater plunging into crevasses near the melting edge of an ablating glacier.

kame-terrace

Flat-topped ridges built of stratified sand and gravel deposed by a melt water stream between an ablating glacier or a stagnant ice lobe and a higher wall or lateral moraine. The ridge remains after the ice melts away.

kettle

A shallow basin or bowl shaped depression formed when a large block of ice is buried in outwash or diamicton during ablation. Upon melting and dewatering of the sediment the hole left by the block may become a kettle-lake or a kettle-depression.

lateral moraines

A moraine which forms on the side of the ice stream, often where the ice meets the rock wall. Also described as: Piles of loose unsorted rocks along the side margins of a glacier which may fallen there, been pushed there by the ice or dumped from the rounded upper surface of the glacier.

M, N and O

mass balance

The balance of glacial input (accumulation), throughput (transport), and output (ablation) of snow and ice.

medial moraines

Concentrations of till in septa dividing ice streams deposits as medial moraines after complete ablation. Also described as: Where two mountain glacier lateral moraines unite, a dark band of rock forms along the centerline.

moraine

Unsorted till (diamicton) deposited either along the sides (lateral moraine) or the ends of an ablating glacier (end or terminal moraine); or the material below a retreating glacier (ground moraine).

mountain glaciers

Glaciers which form in the mountains.

net balance

The change in the amount of mass of a glacier from one year to the next.

neve

The upper area of accumulation in a glacier where firn is found.

ogives

A series of ice waves or bands of lighter and darker material formed below ice falls in some glaciers. Also called Forbes bands, true band ogives are laid down one per year and represent different flow rates through the steep, narrow ice falls.

outlet glaciers

Valley glaciers which permit ice to move from accumulation areas through mountainous terrain to the sea.

outwash

Stratified sands and gravels washed out from glaciers by meltwater streams and deposited in the proglacial environment, or beyond the active glacial margin.

outwash plain

Proglacial meltwater deposits unconfined sorted sediments; stream pattern depends upon angle of topography.

P

Pater Noster lakes

A string of glacial lakes along the path of a mountain glacier. The erosion of gaps between roche moutonne leaves behind topographic depressions which (after the melting of the glacier) fill with water. The name comes from the similarity to a string of Catholic Christian prayer beads; the first prayer of which begins "Pater Noster..."

pavement

A rock surface, often eroded or striated, which underlies glacial till and is exposed in sufficient quantity to resemble a sidewalk or open plaza.

periglacial

The area around a glacier often characterized by harsh climate.

permafrost

Soil or rock at or near the ground in Arctic or subarctic regions that has been continuously frozen for a long time.

piedmont glacier

A glacier occurring on the piedmont, the gradually sloping area leading down from a mountain to the plains or to the sea. The Malaspina Glacier is a piedmont glacier. Piedmont glaciers are fed by one or more valley glaciers.

plucking

The process of loosening and lifting pieces of rock by a flowing glacier. Meltwater intrudes joints and cracks in the underlying material. The freeze/thaw contraction/expansion series provides the leverage to release large blocks of rock.

proglacial

The area in front of, or just at the outer edge of a glacier.

proglacial lakes (see glacial lakes)

Q and R

recessional moraines

End moraines created during occasionally stabilization of the ice front during retreat.

rock flour
Pulverized rock of the smaller size sediment classes (silts and clays) produced by glacial milling can give outwash streams a milky appearance.

rock glaciers
A mass of rock (talus) held together by ice that moves down gradient like a glacier.

S

saddle
A depression or sag on the ice sheet between domes.

sheet flow
Unrestricted glaciers including ice caps and ice sheets flow independently of underlying topography. Friction is greatest between the glacier and its base in this form of flow.

streaming flow
Where glaciers are constricted, such as in a valley, the flow may or may not be controlled by underlying topography. Friction is greatest at the center and less towards the margins.

snowfield
The zone of accumulation sometimes a cirque, cwm or corrie; or a large open collecting point between mountains.

snow line
The lower limit of permanent snow cover, below which snow doesn't accumulate.

snowpack
The total ice and snow on the ground, including fresh and older snow and ice.

striations/stria
Gouges in bedrock or on glacial sediments which record abrasion by the moving glacier. If on pavement, stria may reveal direction of glacial movement.

subglacial
The area below the glacier. Subglacial features include deformed sediments, ice caves, and eskers.

supraglacial
The area on top of the glacier which may be snow, ice, rock fragments or covered with soil, plants or forests.

surges
Periods of extremely rapid movements in glacial flow.

T

terminal moraine
A ridge formed by the accumulation of glacial deposits at the point marking the furthest advance of an ablating glacier.

terminus
The end of the glacier. Also called a glacial snout.

till
Many writers use till for any glacial deposit. However some (including ISGS) define till to mean only sediments composed of a mixture of grain sizes which were deposited directly onto the subglacial landscape during basal melting.

till plain
A gently irregular plain of till deposited by an actively retreating glacier.

transient snowline
The line separating transient accumulation and ablation areas, also a transient equilibrium line.

transverse fissure
A vertical crevasse in a glacier which runs in an upslope-downslope direction

trimlines
Sharp boundaries in vegetation abundance or community type showing the upper margin of a former glaciation. For example, ferns colonize recently deglaciated areas and conifers show that the area has been deglaciated longer.

U V W XY and Z

valley glacier
A stream of ice flowing down gradient.

wastage area
On a glacier, the terminal end where ablation results in deposition of till and removal of water.

whalebacks
Elongated mounds or hills shaped by glacier movement may indicate direction of ice flow.

zone of ablation
The termini of glaciers where loss of ice occurs through calving, melting or evaporation.

zone of accumulation
The snowfields or cirques of mountain glaciers and the snowfields of continental glaciers are called the zone of accumulation because it is here than new snow falls to nourish the glacier.