3 Methods

One of the key features of the GHWI approach is the use of remotely sensed satellite data for classification of land use and land cover in order to describe wetland types and area in different detail at each hierarchical level of data collection. Other features of the GHWI approach are

- the production of maps using secondary sources and remotely-sensed data (satellite data);
- the collection and analysis of standardised categories of data including bio-geographical, socioeconomic, and cultural values of the wetland ecosystems;
- the above-stated done within a hierarchical and scalar framework which links the mapping scales and the level of data-detail that it is possible to achieve;
- the use of remotely sensed satellite data for classification of wetlands resources.

3.1 Definition of Wetlands

Wetlands are areas where water is the primary factor controlling the environment and the associated plant and animal life. They occur where the water table is at or near the surface of land or where the land is covered by shallow water. It is not easy to define wetlands, and many definitions exist throughout the world. The definition of wetlands used by the Ramsar Convention (RCS 2006) has gained worldwide recognition and acceptance and is adopted as the basis for this inventory:

> "Wetlands are areas of marsh, fen, peatland, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres."

Article 2.1 of the Ramsar Convention provides that areas defined as wetlands 'may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands'. In this respect the definition adopted provides support for formal national and international purposes associated with the Ramsar Convention, but is sufficiently broad to support other wetland analyses that may use a narrower definition.

The Ramsar typology of wetland habitats and ecosystems (see Box 1) is useful and has been widely used to provide a broad framework for rapid identification of the main wetland habitat types, based on a mixture of vegetation, soil, inundation, and landform features. However, this system is not easily applied in the context of multi-scale classification using Earth observation technology (Jones et al. 2008).

Therefore, it is recommended to use standard hierarchical national/regional land use and land cover classification schemes (whichever exists), which internally can be translated to the Ramsar typology. If these land-use /land-cover schemes are not available, it is suggested to refer to an international standard hierarchical classification system such as the FAO Land Cover Classification (www.fao.org; for example (http://www.fao.org/sd/Eidirect/Eire0019.htm).

3.2 Wetland Delineation

The principal purpose of the GHWI is to delineate and map the region's wetland resources, reaching to the level of specific wetland habitats, and to display this information on base maps (e.g., topographic, thematic) or GIS-based maps, as available. It is intended that this would occur at different scales with the amount of detail being dependent on the explicit purpose of the inventory and the size and importance of the wetland. Thus a hierarchy of four mapping scales, as prescribed in the AWI, is applied, none of which are fixed and any of which can be used, see the example illustrated in Figure 2. Typical mapping scales, for example, could be:

1 1:500,000 to 1:1,000,000 scale maps for major river basins
2 1:250,000 to 1:500,000 scale maps for sub-basins

Box 1: **Ramsar Classification System for Inland and Human-made Wetland Types**

(Source: Ramsar Convention Secretariat 2008)

Inland Wetlands

L	Permanent inland deltas
M	Permanent rivers/streams/creeks; includes waterfalls
N	Seasonal/intermittent/irregular rivers/streams/creeks
O	Permanent freshwater lakes (over 8 ha); includes large oxbow lakes
P	Seasonal/intermittent freshwater lakes (over 8 ha); includes floodplain lakes
Q	Permanent saline/brackish/alkaline lakes
R	Seasonal/intermittent saline/brackish/alkaline lakes and flats
Sp	Permanent saline/brackish/alkaline marshes/pools
Ss	Seasonal/intermittent saline/brackish/alkaline marshes/pools
Tp	Permanent freshwater marshes/pools; ponds (below 8 ha), marshes and swamps on inorganic soils; with emergent vegetation water-logged for at least most of the growing season
Ts	Seasonal/intermittent freshwater marshes/pools on inorganic soils; includes sloughs, potholes, seasonally flooded meadows, sedge marshes
U	Non-forested peatlands; includes shrub or open bogs, swamps, fens
Va	Alpine wetlands; includes alpine meadows, temporary waters from snowmelt
Vt	Tundra wetlands; includes tundra pools, temporary waters from snowmelt
W	Shrub-dominated wetlands; shrub swamps, shrub-dominated freshwater marshes, shrub carr, alder thicket on inorganic soils
Xf	Freshwater, tree-dominated wetlands; includes freshwater swamp forests, seasonally flooded forests, wooded swamps on inorganic soils
Xp	Forested peatlands; peatswamp forests
Y	Freshwater springs; oases
Zg	Geothermal wetlands
Zk(b)	Karst and other subterranean hydrological systems; inland

Note: **'floodplain'** is a broad term used to refer to one or more wetland types, which may include examples from the R, Ss, Ts, W, Xf, Xp, or other wetland types. Some examples of floodplain wetlands are seasonally inundated grassland (including natural wet meadows), shrublands, woodland, and forests. Floodplain wetlands are not listed as a specific wetland type herein.

Human-made wetlands

1	Aquaculture (e.g., fish/shrimp) ponds
2	Ponds; includes farm ponds, stock ponds, small tanks; (generally below 8 ha)
3	Irrigated land; includes irrigation channels and rice fields
4	Seasonally flooded agricultural land (including intensively managed or grazed wet meadow or pasture)
5	Salt exploitation sites; salt pans, salines, etc
6	Water storage areas; reservoirs/barrages/dams/impoundments (generally over 8 ha)
7	Excavations; gravel/brick/clay pits; borrow pits, mining pools
8	Wastewater treatment areas; sewage farms, settling ponds, oxidation basins, etc
9	Canals and drainage channels, ditches
Zk(c)	Karst and other subterranean hydrological systems; human-made

3 1:25,000 to 1:250,000 scale maps for wetlands complexes
4 1:50,00 to 1:25,000 scale maps for wetland habitats

The four hierarchy scales will provide different information for wetland management. As the data fields for each scale are interlinked, it will be possible to compile the inventory in either a top-down or bottom-up approach, depending on the purpose. The information at each scale can also serve different reporting purposes.

The GHWI is built on the use of river basins as the basis for a geographical framework for Himalayan wetlands because they are topographically and hydrologically distinct. The GHWI also aims to promote the use of remotely sensed data for delineating wetland resources. Various satellite data can be used depending upon the size of the mapping unit and desired level of detail of the land-cover class. Table 1 provides a summary of satellite data that can be useful at different mapping scales as suggested above.

Table 1: **Summary of potential satellite data types applicable for wetlands resources mapping** (based on van Valkengoed 2007)

Area of site (km^2)	Preferred (minimum scale of map)	Minimum mapping unit	Satellite data type		Spatial resolution	Tentative cost (in US$)
10,000	1:1,000,000	–	Low resolution	SPOT-vegetation NOA	1 km	Available for free down-loading
1,000 to 10,000	1:500,000	–		MERIS	250-500m	
500 to 1000	1:250,000	20 ha (450 x 450m)			250-500m	
250 to 500	1:100,000	–	MODIS		30m	0.01¢ to $3.50 per km^2
100 to 250	1:50,000	5 ha (225 x 225m)	Low resolution	MERIS	30m	
10 to 100	1:25,000	3 ha (170 x 170m)	MODIS		15-30m	$3.50 to $80.00 per km^2
<10	1:5,000		Medium resolution	Landsat TM/ ETM+	5-10m	
				Landsat 7 (ETM+)	0.6-4m	
			ASTER			

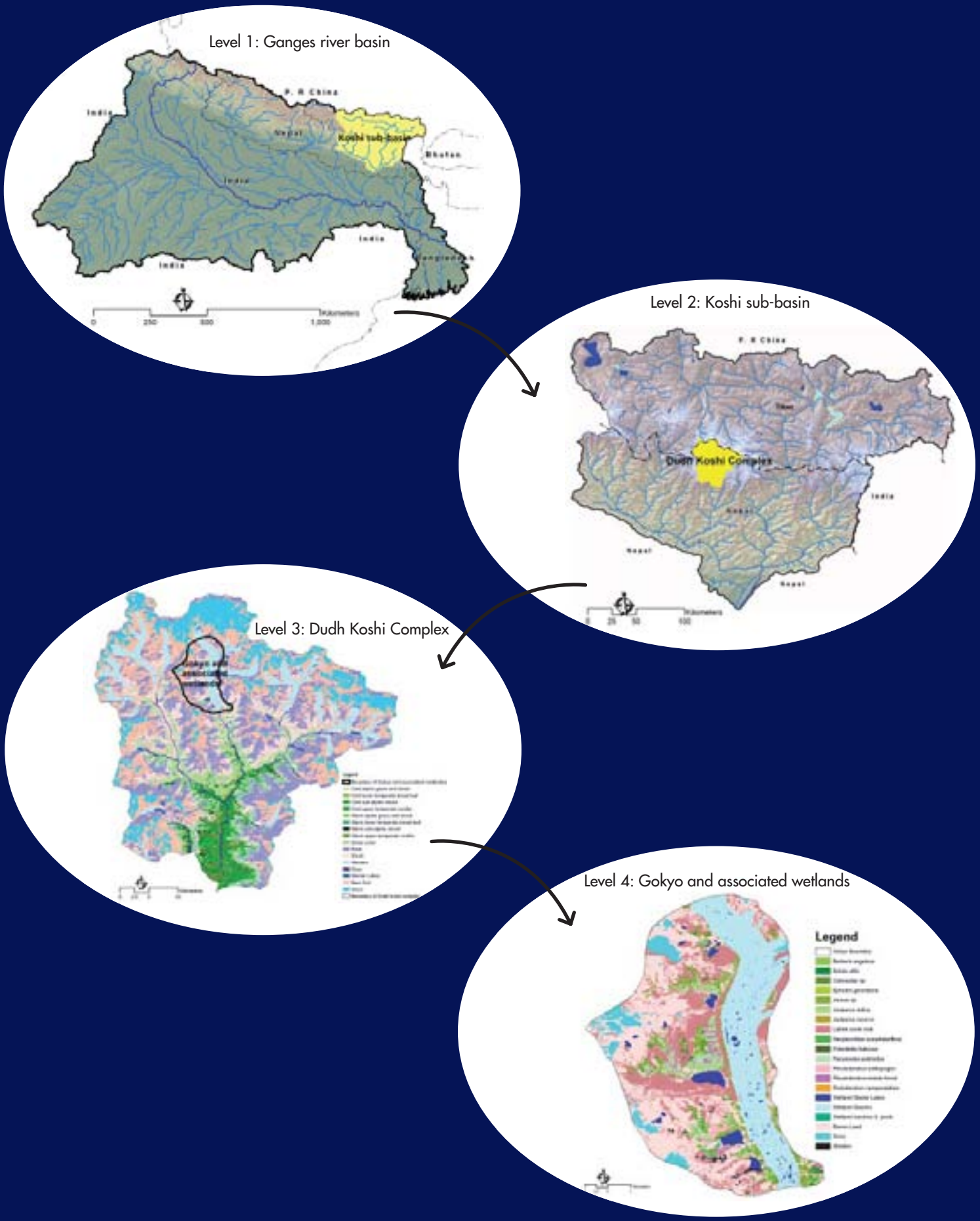
The geographical extent (basin boundary) of major river basins of the Himalayan region (see Figure 1) would be indicated on the basis of existing map-based products in ICIMOD. A text description and maps of the major geological, climatic, and vegetation features will accompany each river basin. An area within each river basin that shares common landforms and water regimes as determined by topographic and hydrologic features will be further delineated and presented on maps (i.e., sub-basin). These maps will provide the basis for delineating and mapping the complexes (or aggregations) of wetlands within the same sub-catchment, which can be further distinguished by topographical features into individual habitats or a wetland site for specific management purposes (e.g., Ramsar site).

3.3 Wetland Description

Another purpose of the GHWI is to describe the wetland resources of the greater Himalayan region using core data sets. For example, the initial analyses at Level 1 (river basins), comprise a broad-based description of river basins' wetlands from existing global and Asia regional maps. It further encompasses a description of geological, climatic, and ecological features based on existing information and presented in a geographic information system (GIS), making it possible to overlay layers with national borders, and geographic and demographic information as required.

The distribution and occurrence of sub-basins within each river basin is then described on the basis of similar characteristics for Level 2 (sub-basins), such as climatic, geological, hydrological and vegetation features. Each of the sub-basins can be further sub-divided for Level 3 (wetland complex/es) that comprise wetlands with broadly similar ecological characteristics and values. The most detailed data collection then focuses on Level 4 (wetland habitat or site) and describes the ecological character of the habitats of a wetland defined at Level 3.

Figure 2: **The four-tiered landscape (multi-scale) approach for wetland inventory. The level of detail varies with spatial scale in the four-level hierarchy from river basin to wetland habitat**



The descriptions outlined above should be undertaken by people with appropriate skills and access to the required resources, and in conjunction with relevant institutes and agencies, for accurate identification of information sources. The usefulness of all information will need to be assessed and then used as a basis for determining the extent of further analysis and data collection, including fieldwork. The methodology used at each level is in general as follows:

- Level 1 – desk study using existing information to describe each major river basin;
- Level 2 – desk study using available information to identify and describe the sub-basins;
- Level 3 – fieldwork and analysis to identify and describe wetland complexes within each sub basin; and
- Level 4 – detailed field work and analysis to delineate and describe habitats within each wetland complex.

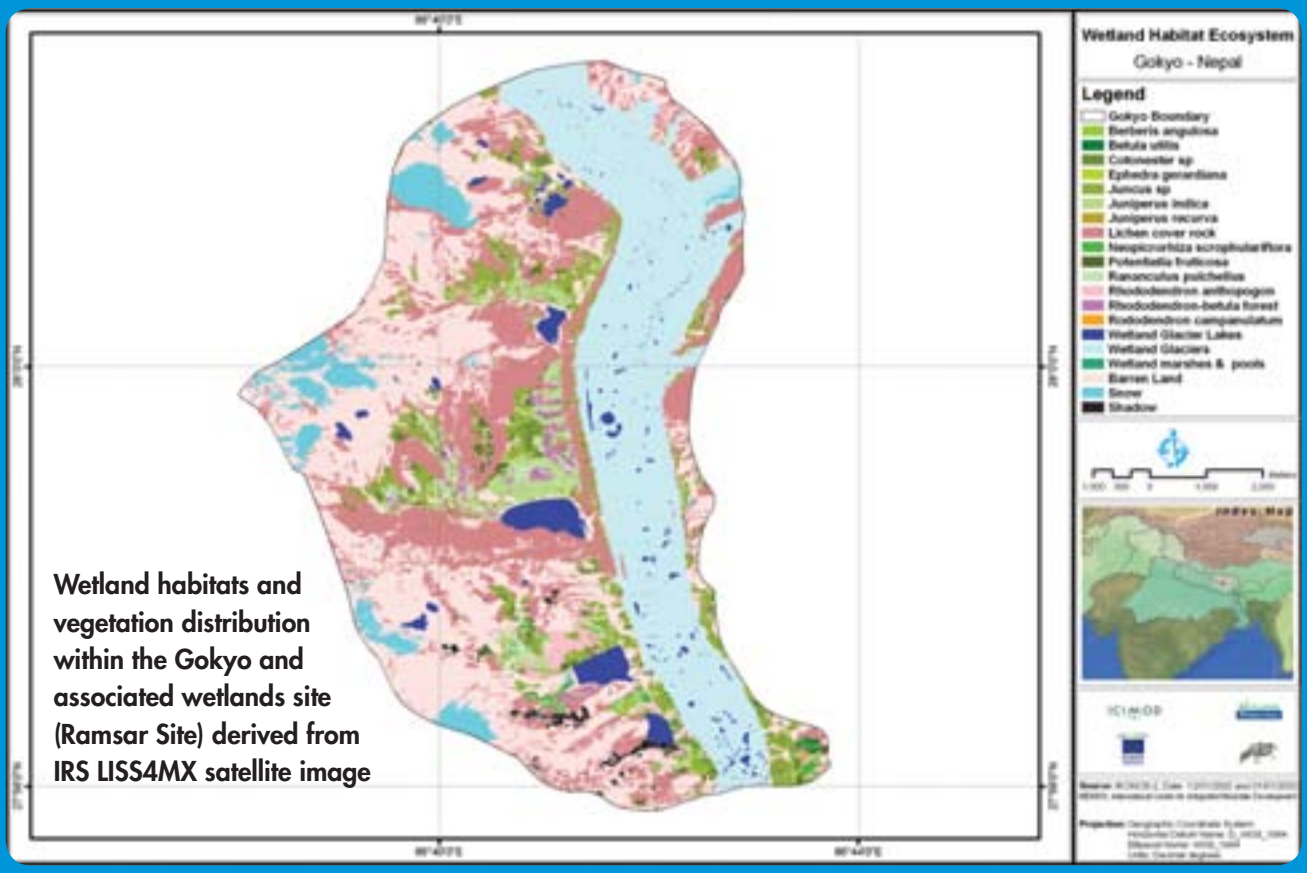
Data collection sheets have been developed together with a GIS-integrated database system for each level of the hierarchy (see Section 4 below). The data sheets indicate the core data that is considered necessary for each level of delineation and description of wetlands and provide a standardised format for recording and presenting this information.

A site-specific wetland description can be developed in consultation with local experts. An example of this is provided in Table 2. This shows the site-specific characteristics of a high altitude wetland in Nepal, where information was collected using local expert knowledge and developed with ICIMOD expertise.

Level 3 and Level 4 datasheets should be accompanied by a GIS-based vegetation map and detailed wetland habitats map (Figure 3). Other maps which could complement the data collection sheets and that are relevant for wetland monitoring and management purposes are change detection (land use land cover) and water cycle regime maps

Figure 3: **Example of the production of a wetland habitat map at Level 3/4**

High resolution satellite images (IRS LISS4MX, IKONOS) were used for detailed classification of the wetland habitats and associated dominant vegetation at Level 4. A field survey was conducted in the Koshi Tappu area to gather training samples for image classification. Training samples were generated based on local experts' knowledge and secondary information for Gongga township and Gokyo and associated wetlands. Using digital image processing techniques, the satellite data were classified to describe wetland habitats within the wetland sites.



Wetland habitats and vegetation distribution within the Gokyo and associated wetlands site (Ramsar Site) derived from IRS LISS4MX satellite image

(Jones et al. 2008). A change detection map will provide an overview of the main permanent changes in the wetland and its surroundings over a selected time period due to natural and anthropogenic factors, which allows the identification of (potential) threats affecting the area.

The water cycle regime (or hydroperiod) map provides information on the dynamics of the surface water of the wetland (Figure 4). When generated over several years, the production of such maps could serve as an important monitoring tool for the area's water cycle and help identify water regime variations that may affect the wetland system and its surroundings.

Table 2: **Land use and land cover classification scheme developed for the Gokyo and associated wetlands site (Ramsar site), Nepal**

Major land use		Level 3 – Wetland complex	Level 4 – Wetland habitat
1	Forest	a. Warm sub-alpine mixed	*Juniperus indica* (f)
		b. Cold upper temperate coniferous	*Betula utilis* (a)
		c. Warm upper temperate coniferous	*Abies spectabilis* (c)
		d. Cold lower temperate broad-leaf	*Prunus sp* (d)
		e. Warm lower temperate broad-leaf	*Rhododendron arboreum* (e)
		f. Cold sub-alpine mixed	*Rhododendron-Betula* forest (e)
2	Shrubland	a. Warm (moist) alpine grass and shrub	*Rhododendron anthopogon* (b)
		b. Cold (dry) alpine grass and shrub	*Rhododendron lepidotum* (a)
		c. Shrub mixed	*Bistortia milletii* (a)
			Ephedra gerardiana (b)
			Berberis angulosa (a)
			Cotoneaster sp (b)
			Salix sikkmensis (a)
			Rhododendron campanulatum sp (a)
3	Grassland	Grassland *Imperata* type	Grassland *Imperata* type
4	Herbs	Herbs	*Juncus sp*
			Neopicrorhiza scrophulariflora
			Meconopsis horridula
			Parnesia nubiculla
			Aster himalayca
			Rananculus pulchellus
			Potentiella fruticosa
			Juniperus recurva
			Primula sp
			Senecio sp
5	Agricultural land	Agriculture	
6	Urban / built up	Settlement	
7	Wetland	a. Permanent river	a. Permanent river
		b. Seasonal river	b. Seasonal river
		c. Glacial lakes	c. Glacial lakes
		d. Permanent freshwater marshes and pools	d. Permanent freshwater marshes and pools
		e. Snow and glaciers	
8	Barren land	Bare soil	Bare soil
9	Rock	Rock	Lichen covered rock of the forest belt
10	Other	Shadow	Shadow

Figure 4: **Example of the production of a water cycle regime map (Level 3/4)**

The distribution and extent of wetland habitats is dependent on the seasonal dynamics of the water cycle. The water cycle regime provides information on the annual variations of the surface water over the wetland area. Temporal, time-series satellite images can be used in deriving and mapping a water cycle regime. However, in practice it can be basically only be done with radar images, as optical images often fail in the wet season due to cloud cover.

It is important to acquire information on the extent of open water during very specific times of the season. These would normally include the high water and low water cycles. In the case of the Koshi Tappu Wildlife Reserve, three radar images – pre-monsoon, monsoon, and post-monsoon (2006) were acquired. A 'synthetic' image was produced by combining these three multi-dated radar images, and this was further classified into three general classes to depict permanent land, permanent water body, and seasonally inundated lands. Figure 1 represents the water cycle regime in the Koshi Tappu Wildlife Reserve area derived from ASAR data.