# Mapping to Support Snow Leopard Landscapes Management Planning

## Advice Document Addendum to the General Guidelines for Climate Smart Snow Leopard Landscape Management Planning

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# 1. Background

In 2013, the twelve Snow Leopard Range Countries made a groundbreaking pledge to "protect and recover snow leopard populations and their fragile habitats" (Snow Leopard Working Secretariat 2013a).

A number of strategies outlined in the Bishkek Declaration on the Conservation of the Snow Leopard and subsequent work streams are spatially explicit. For example, countries resolved to "map the current status of key snow leopard populations and habitats to set baselines and indicators against which to assess future change". They unanimously agreed to secure 20 snow leopard landscapes by the year 2020 (the definition of which has spatially explicit components) (Snow Leopard Working Secretariat, 2013b). At a meeting in the Kyrgyz Republic in June 2014, countries further agreed to seven criteria of secure snow leopard landscapes. Among these criteria are designated "critical wildlife areas and corridors, where damaging land use is minimized" and "multiple use zones", where a broader array of stakeholders and development opportunities are allowed (GSLEP, June 2014) (see Appendix 1).

The implementation of these strategies necessitates GIS mapping. In order to produce meaningful management insights, it is necessary to map:

- snow leopard habitats and movement areas
- ecosystem services and their long term vulnerability
- areas at risk from climate change and human development

These and other layers (on prey, sensitive habitats, future development plans, etc.) can inform the delineation of management zones.

The following document provides optional guidance for producing GIS layers for the management zoning process in snow leopard landscapes. There are numerous approaches that can be used, and this provides a grab bag of suggestions that can be customized based on needs and capacity in a given landscape. A sample work plan is provided as Appendix 2.

*Photo 1. Snow leopard landscape. Photo Credit: Nature Conservation Foundation / Snow Leopard Trust*

## 2. Required Resources

1. **Advanced GIS expertise**: expert familiar with data processing, advanced raster analysis, mapping standards, and some cartography
2. **Any GIS software**: which can be ArcGIS, Q-GIS, or any other modern software as preferred by the GIS-expert, including computer resources (data storage)
3. Guidance from GSLEP network in **mapping standards**, in order to communicate consistently on snow leopard conservation throughout the snow leopard range
4. **Support from experts** on wildlife behavior, habitat modeling, ecosystem services, water resources, and climate change projections
5. **Time allowance** to be working on the maps: depending on the availability of data, this allowance can range to a couple of days, to weeks or even months

## 3. Summary of GIS Layers to Inform Snow Leopard Landscape Management Planning

1. The extent or boundaries of:
    a. the snow leopard landscape for GSLEP (i.e., the management landscape)
    b. the snow leopard habitat analysis (present and under climate change)
    c. the water analysis (present and under climate change)
2. Snow leopard habitat and movement between habitat blocks (ecological maps)
3. Ecosystem services, such as water provision, carbon, etc.
4. Climate change layer for snow leopards (climate envelope) or biodiversity (land facets)
5. Climate change layer for ecosystem services, i.e. how services will change with projected increase in temperature or change in precipitation patterns.
6. Current human pressures (roads, settlements, and others as availability)
7. Future human pressures, such as planned infrastructure and projected population growth
8. Current and proposed management zones (protected, community etc.)
9. Other wildlife, biodiversity and ecological values

Once all layers are available, they can be overlain in a GIS. Raster approaches or manual delineation can be used to create ecological and/or physical zone maps of the region, based on aspects such as ecological sensitivity. An ecological zonation can then inform a management map (see Figure 1 and Appendix 3).

**Critical Wildlife Areas** – Areas with higher wildlife, snow leopard, and/or biodiversity values than surrounding areas within the landscape. These areas also have low human density or a community willing to collaborate in conservation. This area would largely be a no-go zone for new infrastructure development.

**Multiple Use Zones** – Areas with lower wildlife density and greater human footprint than Critical Wildlife Areas, but still possible for snow leopards and other wildlife to live in and/or cross.

While communities here are willing to collaborate in conservation, other stakeholders may be engaged as well, in the appropriate development of 'smart green infrastructure" and other conservation activities. Other stakeholders include businesses and government departments typically focused on human development, infrastructure, and service provision.

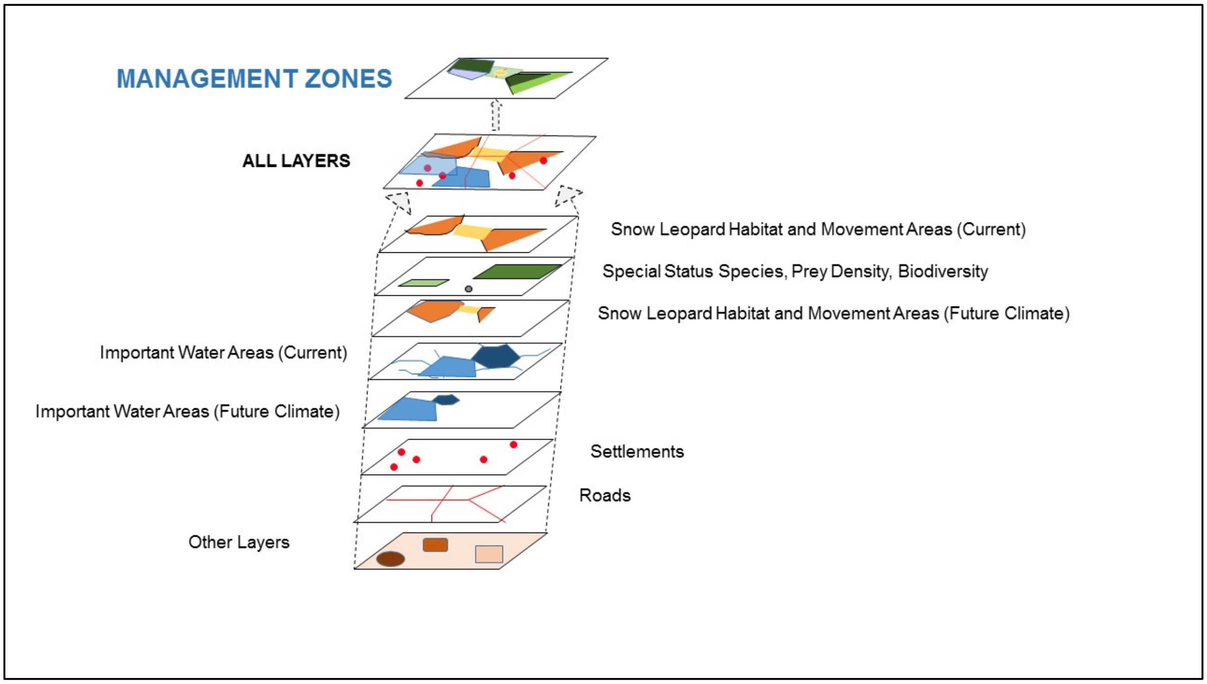


*Figure 2. An assortment of ecological and physical data layers feed into a delineation of management zones.*

# 4. Guidance and Resources for Producing GIS Layers

The following tools and methodologies can be used to create GIS layers to feed into the management planning process. Key layers include maps of snow leopard and other wildlife core habitats and movement zones, climate envelope models to predict changes in species habitats, other guidance for planning climate resilience into landscapes, and water provision services. We also provide guidance on ways to assign management zones based on multiple ecosystem values. These are just a subset of tools and approaches to get started – other tools and approaches may also exist. Innovating new approaches, and customizing model outputs, also may be appropriate.

## 4.1 Habitat Modeling

The following set of tools can be used to map species habitats. Approaches can also be modified to produce future projections of habitat under changing infrastructure or climate.

- **MaxEnt: Maximum Entropy Modeling Tool** [https://www.cs.princeton.edu/~schapire/maxent/] This software takes as input a set of layers or environmental variables (such as elevation, precipitation, etc.) as well as a set of georeferenced species occurrence locations, and produces a model of the niche of the given species. This tool can also be used to do future projections of habitat based on changing environmental inputs such as land cover, infrastructure or climate.
- **The Smart Infrastructure Planner**

[http://www.worldwildlife.org/publications/smart-infrastructure-planner-beta]
The Smart Infrastructure Planner is a GIS toolbox that uses a habitat suitability modeling approach (USFWS 1981) to enable GIS practitioners and stakeholders to evaluate the effects of future infrastructure development and landscape changes on wildlife. Inputs include things like landcover/land use, roads, mines and settlements. Climate change would presumably be incorporated by utilizing future models of landcover, land use and water as these are expected to be impacted by climate variables. The tool is built and tested for ArcGIS 10.0 and 9.3. The user manual provides an overview of process that can be implemented in other software types.

- **Resource Selection Technique**
  Uses observation data, GIS, and statistical analysis to define good and fair habitat based on snow leopard habitat use frequency by habitat type (Neu et al. 1974, Shrestha and Wegge 2008).

## 4.2 Corridor Design

The following tools can be used to model connectivity or potential for wildlife movement between core habitat patches.

- **GIS Tools for Designing Wildlife Corridors**
  [http://corridordesign.org/]
  Conceptual and technical resource on how to design wildlife corridors. There is also an ArcGIS toolbox called Corridor Designer that is available for download. The tool facilitates the process of building a cost raster, running cost distance, and applying a slice for the corridor (Beier et al. 2007, 2008).
- **CircuitScape, Linkage Mapper, and Gnarly Landscape Utilities** [http://www.circuitscape.org/]
  This site is home to Circuitscape, Linkage Mapper, and Gnarly Landscape Utilities, all of which are free and open source. Circuitscape borrows algorithms from electronic circuit theory to predict connectivity in heterogeneous landscapes (McRae 2008). Linkage Mapper uses least-cost corridor analysis, circuit theory, and barrier analysis to map corridors, detect pinch-points and restoration opportunities within them, and identify important core areas and corridors. Gnarly Landscape Utilities automates the creation of core area maps and resistance layers needed for connectivity modeling. This set also includes **Climate Linkage Mapper** to help map corridors following climatic gradients to facilitate species range shifts under climate change (Nuñez et al. 2013).

## 4.3 Coarse Filter Approaches to Conserve Biodiversity under Climate Change

There are two types of approaches that have been proposed for conserving species under climate change: coarse and fine filter. Climate envelope models are an example of a fine filter approach. These aim to project how niches for one or a few species might shift in response to a changing climate. Fine filter approaches are data intensive and often only suitable for a few well known species. The models, however, have been criticized as being subject to a high degree of error resulting from future emissions scenarios, future climate models, environmental inputs, and the niche modeling algorithms. Coarse filter approaches have been proposed as an alternative or complement to fine filter approaches. Coarse filter approaches aim to conserve representation of geomorphological types or climate zone connectivity in hopes of preserving the number of species that occupy the cross-section of these zones.

- **Land Facet Mapping Tools**
  [http://corridordesign.org/downloads]
  Representing land facets (or major geomorphological types in the landscape) and ensuring their future connectivity in conservation plans has been argued as a means of preserving landscape biodiversity under a changing climate, as a complement to focal species mapping approaches. A land facet mapping tool for ArcGIS 10.x and other information is available on this site (Anderson and Ferree 2010, Beier and Brost 2010, Beier 2012, Beier and Brost 2012, Brost and Beier 2012).
- **Climate Corridor based on Climate Gradient Data**
  Climate corridors that connect 2 areas of different temperature through a unidirectional temperature gradient (Nunez 2012 approach). See **Climate Linkage Mapper** at http://www.circuitscape.org/

## 4.4 Mapping Water Provision Functions, An Ecosystem Service Value of Landscapes

The following summarizes an approach tested to map the water provision functions of several snow leopard landscapes. For each snow leopard landscape, four different primary functions were selected that represent different aspects of water provision. Four were selected since the relative importance of each of these functions for water provision differs by landscape. These functions were mapped out at the broader sub-basin context in order to assess the role that the snow leopard landscape plays in providing water as an ecosystem service.

- **Local runoff** is the amount of water in the landscape that ends up in a river or stream and then flows downstream. Source areas of runoff are often called "water towers"; these are often located on the mountain slopes in the upstream reaches of river systems. Local runoff can be modelled by looking at *rainfall* and then subtracting the component that is "consumed" by vegetation and soils (*actual evapotranspiration*) (See Figure 2). Local runoff must be considered in monthly timing over the course of a year, and in spatial patterns throughout the landscape. In regional contexts, water provision arguments should not only show positive associations with larger quantities of water, since floods are severe and abundant.

  **Data sources:** Current Mean Monthly Precipitation Historical Averages at 30s resolution (Hijmans et al. 2005); Current Mean Monthly Actual Evapotranspiration, based on historic Global Soil-Water-Balance, CGIAR, 30s resolution (Trabucco and Zomer 2010).

- **Snowmelt**. Downstream of mountainous regions, the seasonality of water provision is under direct influence of the annual *snowmelt* cycles. In many locations, the snowmelt cycle has a different timing from that of rainfall (or local runoff), often providing essential amounts of water just before, or at the end of the dry season. Global climate change may cause increased temperatures and changing amount, timing and distribution of snow and snowmelt. Such changes may lengthen the downstream dry season and/or exacerbate floods. For example, precipitation that historically would have been stored in the landscape over the winter might now run off and coincide with the flood season.

**Data sources:** Monthly data on snowmelt from 2006-2015 at 0.25 degree resolution (NOAH-GLDAS V.2.0 2015)

- **Aridity** concerns the extent to which water is the limiting factor in vegetation growth. Often-in a single landscape and over the seasons- local water balances can range on a gradient from humid to arid; where a chronic level of aridity indicates a trend toward desertification. In terms of water provision, it helps to see where in the landscape or its larger sub-basin there is enough water to sustain vegetation or provide water downstream, and where there is a demand for extra water. Aridity is calculated as the amount of *precipitation* divided by the amount of potential evapotranspiration. Potential evapotranspiration is calculated as the amount of evaporation that soils and vegetation would consume if water were not a limiting factor.

  **Data sources:** Current Mean Monthly Precipitation Historical Averages at 30s resolution (Hijmans et al. 2005); Current Mean Monthly Actual Evapotranspiration, based on historic Global Soil-Water-Balance, CGIAR, 30s resolution (Trabucco and Zomer 2010).

- **River system layout** can determine to what extent a location has the capacity to provide water to its downstream. In addition, it displays the capacity of downstream areas to receive water from upstream.

  **Data source:** HydroSHEDS 15s drainage directions (Lehner et al. 2008)

Additional water provision functions listed below are recognized for their importance to water provision, and can be mapped out. Currently, there is a high degree of scientific uncertainty about the way these processes work, and insufficient data to properly assess them systematically across the snow leopard range as water provision functions.

- **Presence of glaciers.** Similar to snowmelt, *glaciers* provide essential water provision outside of the seasonal precipitation. *Regelation* is an important process that lies at the basis of this: it refers to the water that melts from a glacier under the pressure of the thick overlying ice layers, regardless of surface temperature. Modelling quantities of glacial melt has been a challenge; each single glacier acts as a reservoir where water melts, or snowfall accumulates, according to many local factors that underlie the existence of each glacier. In general, glaciers cannot be considered to be renewable water resources without taking into account the rate at which they accumulate new snowfall, or considering the overall temperature-melt balance through which they have existed for centuries. Under a changing climate, these balances shift, though there is no real rule of thumb to determine whether a specific glacier is growing or shrinking.

  **Data sources:** GLIMS glacier database (GLIMS and NSIDC 2012)

- **Permafrost presence**. The *presence of permafrost* (Figure 2) has a direct influence on local hydrology. Seasonal shifts in the depth of permafrost are at the base of local hydrology, for example, in determining the seasonal water levels in wetlands. Often, the permafrost layer is impermeable, and soil-water interactions take place on top of the permafrost layer; the so-called *active layer*. Naturally, the thickness of the active layers is a very local soil characteristic, where issues of soil temperature, aspect, and vegetation cover are all of influence. Any change to these, as well as changes in air temperature will all trigger a chain of events, which often leads to permafrost degradation. There is a high correlation between the presence of permafrost, and the larger snow leopard landscape. At the moment, however, there is limited research on how locally and region-wide permafrost degradation is likely to change under climate change, and how exactly it would affect snow leopard habitat.

**Data source:** Global permafrost database, Permafrost Zonation Index (PZI) (Gruber 2012)

- **Snow cover and frost line**. The seasonal *presence of snow* (figure 2) and the coinciding frost line (temperatures below zero 0°C) are important landscape characteristics that guide the seasonality of most landscape processes, including hydrology. Under changing temperatures, it is important how much the frost line would shift, when and where. Seasonality will change when the frost line changes, though this change might not always happen linearly; a shorter winter will result in earlier spring snowmelt, or also possibly in an extended flood season at the start of winter.

  **Data sources:** Current Mean Monthly Temperatures, based on historic WorldClim, 30s resolution (Hijmans et al. 2005); MODIS/TERRA Monthly Snowcover L3 at 5km (0.05 degree) resolution (Hall et al. 2006)

- **Lakes, wetlands, floodplains** are freshwater entities that form a relevant part of the river system layout and the overall water provision context. As with glaciers, the typical hydrology of each these freshwater entities are often too complex to be modelled in detail, yet for each landscape, they should nevertheless be described and characterized.

  **Data sources:** GIEMS D15 Database, Fluet-Chouinard et al. 2015.

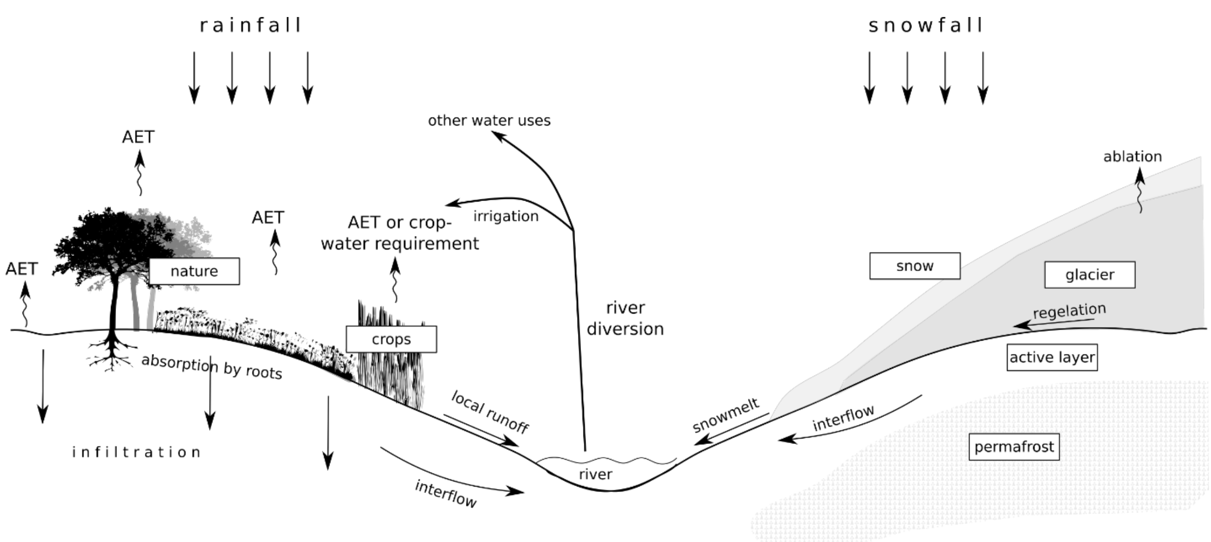


*Figure 2. A simplified water balance including the components of rainfall, actual evapotranspiration, and local runoff. To the right: a simplified water balance of the cryosphere, including the components of snowfall, snowmelt, glaciers and permafrost.*

## 4.5 Management Zones

Once all layers are available, it is necessary to consolidate the information to produce a single management zone map. There are often challenges to how to summarize overlaying information. The following are a few approaches that have been used in the past.

- **Ecological sensitivity mapping:** All spatial data layers are assigned an ecological sensitivity ranking and overlain in GIS. A given plot of land is assigned to the most sensitive ecological class of the species/features located in that place. Management guidance is then assigned accordingly (see Appendix 3 and Forrest 2011).
- **NatureServe Vista:** A GIS tool designed for land use planning [http://www.natureserve.org/conservation-tools/natureserve-vista]

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# Appendices

## Appendix 1: Secure 20 Landscapes by 2020

"The goal of GSLEP is for the 12 range countries, with support from interested organizations, to work together to identify and secure 20 snow leopard landscapes across the big cat's range by 2020, or, in shorthand—"Secure 20 by 2020". Secure snow leopard landscapes are defined as those that:

a) contain at least 100 breeding age snow leopards conserved with the involvement of local communities,
b) support adequate and secure prey populations,
c) have functional connectivity to other snow leopard landscapes, some of which cross international boundaries.

"Secure 20 by 2020" will lay the foundation to reach the ultimate goal: ensuring that snow leopards remain the living icon of mountains of Asia for generations to come." *(Snow Leopard Working Secretariat 2013, p. 15)*

Range countries agreed to the following 7 criteria for secure snow landscapes:

1. Snow leopard landscapes designated as 'ecologically fragile' zones that have defined 'values' and biodiversity-sensitive land-use and development planning for various zones within the landscape. Critical wildlife areas and corridors designated within the landscapes where damaging land use is minimized.
2. Stable or increasing population of snow leopards and sufficient prey populations maintained in the landscapes.
3. Sustainable and socially responsible development achieved through community based efforts and business models to enhance livelihoods of local communities within the ecologically fragile zones (landscapes).
4. Industry encouraged to aid local communities in the multiple-use zones within the snow leopard landscapes (chipping in funds for conservation and livelihood activities).
5. Local community involvement in conservation planning and implementation through community-based conservation efforts, provisioning of economic and other incentives, and policy and legal support.
6. Policy initiatives and strengthening of laws to effectively address traditional and emerging threats including climate change.
7. Sustainability of Global and National snow leopard programs through capacity building, technology, research, resource mobilization, multi-country information exchange and cooperation among the range countries.
8. Monitoring efforts involve two groups of activities: impact and process oriented activities. *(GSLEP, Issyk Kul, Kyrgyz Republic, June 2014, pp. 9-10)*

## Appendix 2: Sample Work Plan for Producing Relevant Maps to the GSLEP Landscape Management Planning Process

### Preparation

1. Evaluate existing maps or data on essential features for management planning in snow leopard landscapes: snow leopard habitat and movement areas, water resources, and climate vulnerability for water and snow leopards.
2. Identify other map/spatial data needs for landscape planning (ie, wildlife density, human infrastructure, future human infrastructure)
3. Define extents: snow leopard landscape for GSLEP (ie, the management landscape), snow leopard habitat analysis (present and under climate change), water analysis (present and under climate change)
4. Define data needs and availability
5. Acquire best-available data to support the mapping
6. Pre-process data and form an organized database

### Snow Leopard Habitat and Movement

1. Evaluate existing maps and data on core snow leopard habitat and movement zones [as above]
2. Snow leopard core habitat: If a need to model new or improve existing:
   - Determine approach (Maxent, habitat suitability modeling, manual other)
   - Identify key criteria for determining snow leopard distribution
   - Prepare data for entry into model [as above]
   - Run analysis
   - Interpretation and thresholding
   - Assess accuracy
   - Convert to GIS data
   - Write up methods and describe any assumptions and limitations
3. Movement areas: Determine best source of existing data. Or, to produce new:
   - Identify key criteria
   - Determine mapping approach (Threshold of maxent model, least cost corridor, circuitscape, manual delineation)
   - Prepare data for entry into model [as above]
   - Run analysis
   - Interpretation and thresholding
   - Assess accuracy
   - Convert to GIS data
   - Write up methods and describe any assumptions and limitations
4. Bottlenecks: Determine definition and relevance in this landscape
   - Identify key criteria
   - Determine mapping approach
   - Prepare data
   - Analysis
   - Interpretation and thresholding
   - Assess accuracy

- Convert to GIS data

## Climate Smart Landscape Planning for Snow Leopards

1. Refer to research to understand conceptually likely climate changes in this landscape and potential responses by vegetation, prey and snow leopards
2. Identify what information, data, or approach will be most useful to assure 'climate smart' conservation planning for snow leopards and/or biodiversity in snow leopard landscapes (ie, climate smart conservation principles? Niche models of snow leopards or their habitats, land facets? A combination?)
3. Identify what data exists and priorities for new analysis
4. For fine filter (niche modeling) approach:
   - EX. Use existing or produce new model on snow leopard/treeline shift using new downscaled data from Columbia & Worldclim
5. For coarse filter (land facet or geophysical representation):
   - Prepare input layers for land facet map. DEM derived topographic position index, soil map, etc.
   - Produce 'land facet' layer using land facet tool (http://corridordesign.org/downloads) or an isocluster algorithm.
   - Assess accuracy with expert opinion and ground data.
   - Run successive iterations
   - Interpret how to incorporate into land use planning (how much of each 'land facet' should be 'protected' and what 'protection' means, how to ensure connectivity of land facets). It may be necessary to run successive analyses, such as with Marxan which plans representation.
6. For climate smart approach
   - Determine criteria to include in core areas and multiple use zones, and approach
   - Prepare data
   - Use GIS based methods to implement approach

## Climate Vulnerability of Important Water Areas

1. Using Columbia methodologies on broader sub-basin context n order to project climate futures and uncertainties.
2. Apply Columbia projections on selected water provision functions, identify critical thresholds and spatial shifts.
3. Combine historic, future waterscapes, relate to changes in landscape and changes to water use locations.

## Mapping Management Zones

1. Engage stakeholders in creating definitions of ecological and management zones nested within the vision of the Bishkek Declaration, "20 by 2020", and 7 Criteria of Secure Snow Leopard Landscapes (Snow Leopard Secretariat 2013, GSLEP 2014).
2. Use data layers and GIS based approaches to delineate management zones
3. Review by experts and other stakeholders

4. Revise
5. Relevant stakeholders should approve
6. Seek government approval

## Appendix 3: Sample Management Zonation

This map shows an example of a management zonation based on multiple conservation values. First, mapped conservation values were overlayed. Next, ecological zones with similar characteristics and values were delineated. Zones were assigned the ecological sensitivity score of the most sensitive ecological value present in a given place. Subsequently, each zone was assigned management protocols based on the ecological values present and their level of sensitivity.