Appendix C: Final Report

GIS Mapping and Spatial Analysis

Upper Trishuli-1 Hydropower Project, Nepal

Prepared for

NWEDC NEPAL WATER & ENERGY DEVELOPMENT COMPANY

IFC International Finance Corporation World Bank Group

Prepared for:

Nepal Water and Energy Development Company
&
International Finance Corporation

Appendix C: GIS Mapping and Spatial Analysis

Supplemental ESIA-

Upper Trishuli-1 Hydropower Project

December 2014

Cover Photo:

Trishuli River downstream from the proposed powerhouse site, facing upstream. October, 2013. [Photo: P. de la Cueva]

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Table of Contents

List of Figures

List of Tables

1 Overview

This report summarizes ESSA's GIS Mapping and Spatial Analysis work for the Upper Trishuli-1 Hydropower Project. Figure 1 displays a detailed work plan (for both Phase I and Phase II) of the GIS Mapping and Spatial Analysis task. ESSA Technologies Ltd. led this task and maintained close collaboration with local team members at Nepal Environmental and Scientific Services (NESS). The team includes a Project Lead/Spatial Modeller, Local GIS and Remote Sensing Expert, GIS Analyst, Sr. Statistician, and Sr. Systems Ecologist.

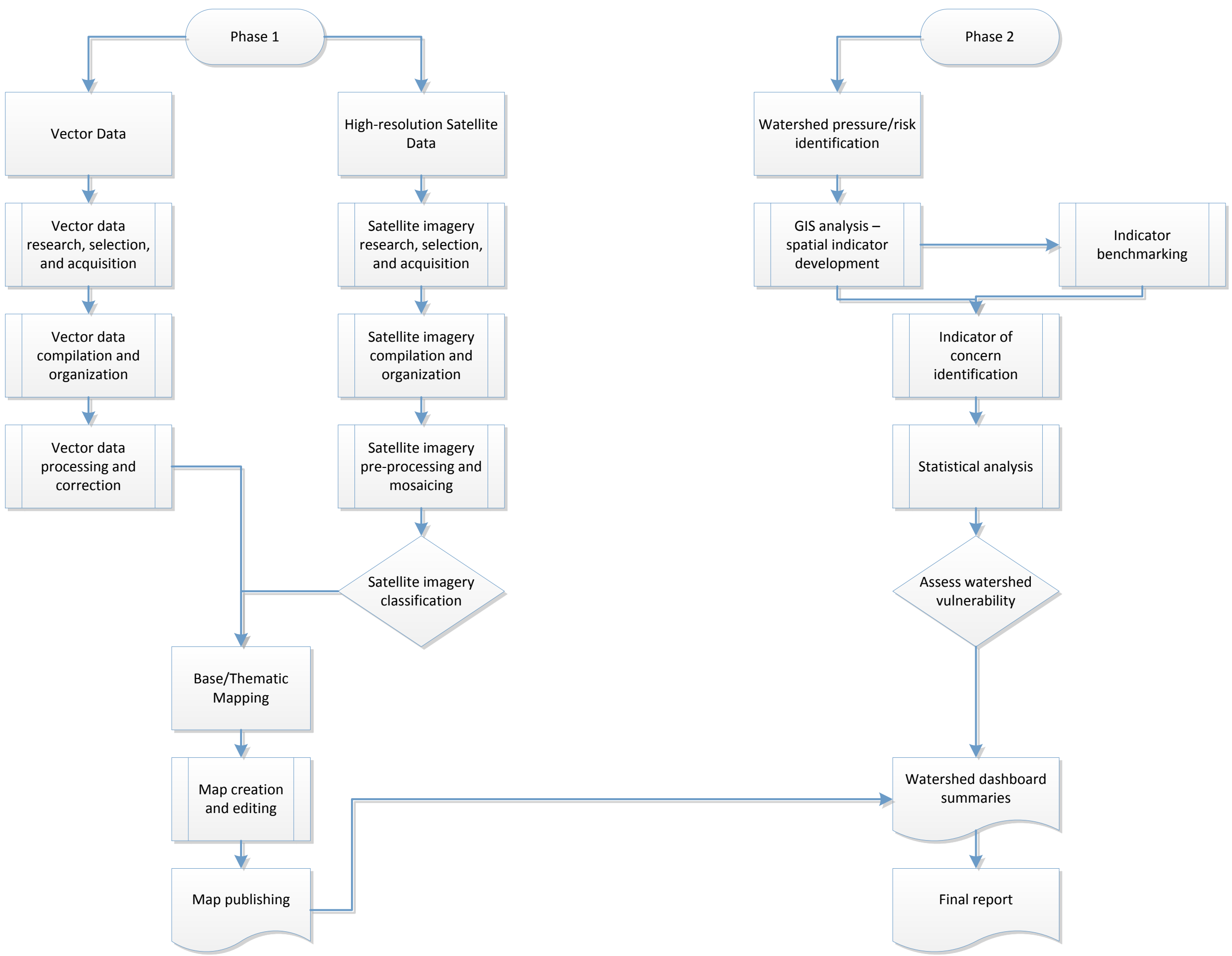

Figure 1-1: Project work plan for the GIS Mapping and Spatial Analysis task

The areas of interest related to this report are:

- Trishuli watershed (~4000km²) – primary watershed of concern containing the bulk of current and planned hydroelectric development in Nepal
- Gandaki basin (~32000km²) – larger basin containing many smaller watersheds, including the Trishuli (see Figure 2 for a map of the Gandaki basin)

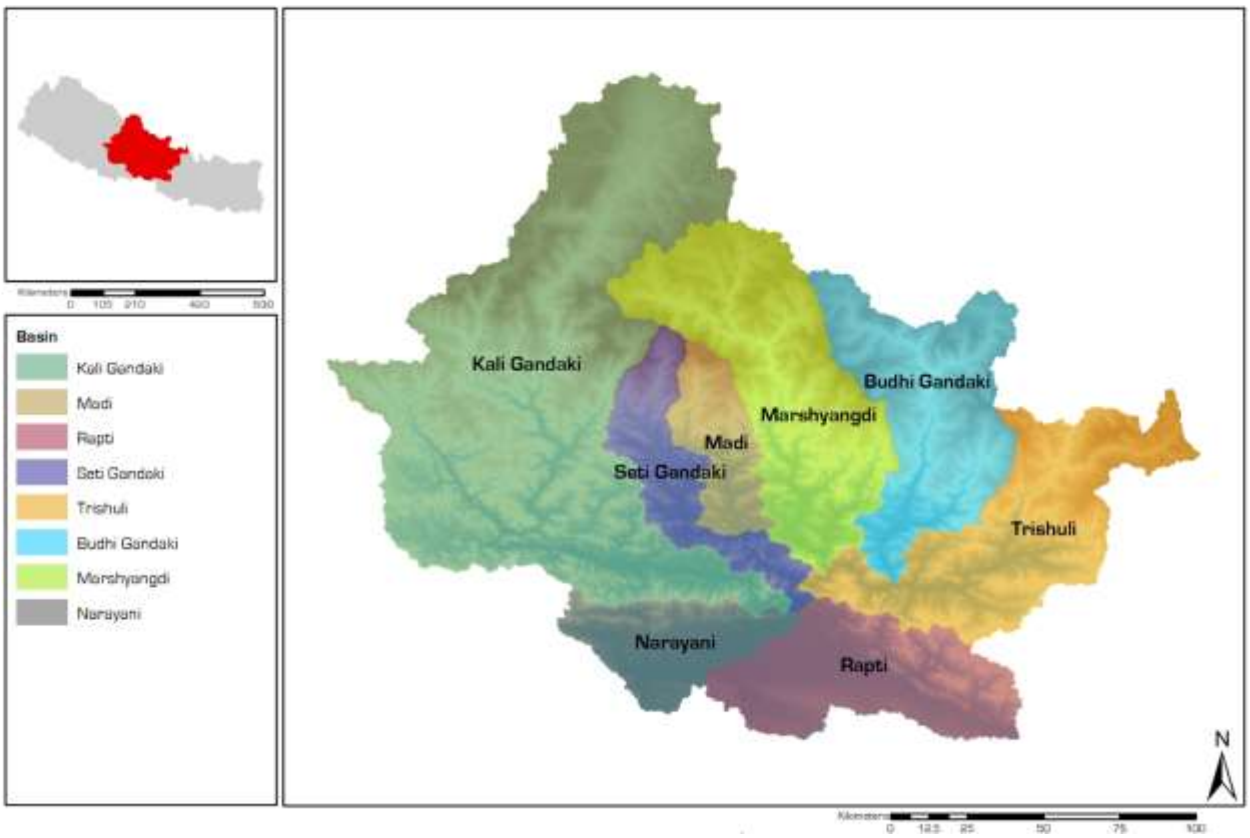

Figure 1-2: Gandaki basin and its eight constituent sub-basins

The spatial information generated during Phases 1 and 2 of this task has also informed and contributed to the identification and assessment of impacts in the Trishuli watershed, as part of the Cumulative Impacts Assessment (CIA) task under Phase II of the Environmental and Social Consulting Services (Appendix D of the Supplemental Environmental and Social Impact Assessment).

Table 1-1: Summary of watersheds and their area (km2) in the Gandaki basin

Watershed name	Watershed area (km²)	Gandaki basin area (% of total)
Budhi Gandaki	3,621	11%
Kali Gandaki	11,846	37%
Madi	1,254	4%
Marshyangdi	4,786	15%
Narayani	1,664	**5%**
Rapti	3,031	9%
Seti Gandaki	1,739	5%
Trishuli	4,036	13%

1.1 Phase I: Trishuli Watershed Maps

Phase I of the GIS Mapping and Spatial Analysis task is concerned with spatial data collection/review, GIS analysis, and base/thematic mapping.

This task addresses a problem wherein large data and knowledge gaps pertaining to spatial information prevent a thorough understanding of the Upper Trishuli-1 Hydropower and similar projects' effect on natural environments in the Trishuli watershed as well as the whole of the Gandaki basin. The purpose of this work was to effectively understand the current and future state of critical watersheds in Nepal, especially given the recent increase in hydroelectric development. This report addresses questions at different spatial scales.

At the most basic level, thematic maps of the study area are essential to understanding the state of the environment. In order to produce appropriate and accurate, up-to-date maps it was necessary to process the collected data and in some cases digitize new spatial information from satellite imagery. Collection of much of the data involved engaging with stakeholders 'on-the-ground' in Nepal.

The primary research questions that were addressed in Phase I were the following:

What is the current state of geospatial data in the Trishuli watershed?

i. What organizations (government, non-profit organizations, private industry) currently collect and store geospatial data?
ii. Is geospatial data easy to access (e.g. available online)?
iii. How up-to-date is the existing geospatial data?
iv. What, if any, standards are in place to ensure data integrity?

How can existing geospatial data be supplemented and/or improved?

v. What existing data need to be updated?
vi. Can existing data be extended/improved (e.g. adding new road networks)?
vii.

How can new geospatial data be created or derived from existing data sources?

viii. What data sources can be used to create new geospatial (e.g. satellite imagery, tabular data)

Another goal of Phase I was to provide critical supplementary information to ESSA's other, work activities including:

- Complementary Environmental and Social Baseline;
- Cumulative Impacts Assessment and Watershed Management;
- Minimum Ecological Flow Assessment;
- Environmental and Social Management Plan for Construction.

Nepal has a severe deficiency of available spatial information that required addressing in order to allow for a comprehensive understanding of the state of the environment. During Phase I we determined the most versatile, cost-effective remote sensed/GIS methods/datasets available for capturing watershed information. At the most basic level this involved a thorough search for available data; in cases where data gaps or deficiencies existed it was necessary to determine the best way to supplement it (e.g. classification of new satellite imagery). Once appropriate data were found and/or created, base maps covering a variety of critical themes were created. These maps represent the primary deliverables for this task.

1.2 Phase II: Analysis of watershed pressures and risks across the Gandaki basin

The goal of Phase II is to provide stakeholders with a means of assessing and comparing the status of watershed health across the sub-watersheds in the Gandaki river system. For example, conservation in one watershed can be used to offset development in another. During Phase II, criteria were established for assigning watershed condition rankings based on the GIS/remote sensed data collected in Phase I. Additionally; there was an assessment of further needs for field data collection for condition ratings at this spatial scale. Finally, empirical methods were developed for reliably linking and validating watershed condition. In order for an efficient and balanced evaluation of individual watersheds, a series of watershed pressure/risk indicators (see Table 2) were developed, which can be used by stakeholders to compare watershed health.

Phase II focused on the development of a detailed overview of watershed pressure/risk for all 8 watersheds in the Gandaki System. A detailed GIS-based methodological approach was developed in order to achieve this objective. A number of spatial indicators of watershed health (Table 1-2) were selected. These indicators represent watershed condition in a landscape-scale habitat "pressure" model, and have been adapted from previous watershed assessment procedures (Porter *et al*. 2013, MOF 2003) to the existing GIS information in the Gandaki basin. A simple ranking system was used as a preliminary means of comparing watersheds based on pressures/risk derived from the computed spatial metrics.

The following activities were undertaken during Phase II:

- Indicator (broad) and metric (narrow) selection and refinement;
- Spatial data processing and metric calculation;
- Watershed ranking;
- Map production;
- Summary and reporting.

Table 1-2: Pressure/risk indicators developed for Phase II

Pressure Indicators	Acronym	Units	Required Data
Hydro licenses (total area vs. watershed area; total area by class vs. watershed area)	HYDRO	km2, %	Hydro license polygons by class
Road density	ROAD_DEN	km/km2	Road network
Road density near streams (e.g. within 100m)	ROAD_STREAM	km/km2	Road network, stream network
Road density on unstable slopes	ROAD_SLOPE	km/km2	Road network, DEM
Stream/road crossing density	ROAD_CROSS	#/km2	Road network, stream network
Population density (based on villiage development committees)	POP_DEN	#/km2	Major Cities
Change in glacier extent	GLACIER	km2, %	Land cover (1990, 2000, 2010)
Forest cover change (1990-2010)	FOREST	km2, %	Land cover (1990, 2000, 2010)
Agriculture change (1990-2010)	AGRICULTURE	km2, %	Land cover (1990, 2000, 2010)
Moderate or high slide potential (total area vs. watershed area)	SLIDE	km2, %	DEM

2 Methodology and data collection

2.1 Phase I: Trishuli Watershed Maps

2.1.1 Data Collection and Review

There were three primary goals to the data collection and review process:

1. Identify available data that can be used to create critical base maps;
2. Narrow down the data that can be used to create watershed indicator categories (e.g. total land cover alteration, riparian disturbance, water allocation) for Phase II;
3. Identify data that can be acquired again at a later date in order to update the watershed evaluations as a means of assessing change.

Table 2-1: GIS Data sources

Government of Nepal	WWF Nepal	ICIMOD	Miscellaneous
Digitized from 1990's aerial imagery	DEM	Contours	Soil/terrain database (SOTOR)
Landuse - 1990's	Settlements	District	Soil degradation
Protected Areas	Boundary	District Headquarters	Rural water supply and sanitation districts
Buildings	Cities	Ecology	VDC (Village development committee)
Contours	Forest Patches	Elevation	Conserved land (national parks)
Settlements	Geology	Grid Lines	Sacred sites
Watersheds	Landuse (1990, 2000, 2010)	National Park	Wind power
Roads	Major Rivers	Precipitation	Table of major hydropower
Major Rivers	Major Rivers and Tribs	Rivers	Admin boundaries
Districts	Rivers - detailed	Roads	Inland waters
Geology	Major Roads	Settlements	Roads
Grid Sheet	Roads - detailed	Zone	Railroads
Spot Height	Physiographic Zones	Spot Height	Elevation
VDC	Political Boundaries	Development Region	Elevation mask
Department of Energy Development	Protected Areas and Buffer Zones	Country Boundary	Land cover
Existing Hydro Projects	Sub-watersheds	District (Line)	Land cover mask
Future Hydro Projects	Topo/contours	Ecology Region	Population
Hydro Projects Under Construction	Towns	Elevation Zone	Population mask
UT-1 Project Site	Transmission lines	Airports	Gazetteer
		Soil	
		Physiography	

The following questions were addressed during the data collection and review process:

- What remote sensed/GIS data are available (e.g. topographic maps, air photos, high-resolution satellite imagery, etc.)?
- How frequently and for what dates are data available (e.g. annually, once every 5 years, etc.?)
- At what spatial scale (e.g. 1:20K, 1:50K, etc.)?
- How much does it cost to obtain data (e.g. cost of coverage for entire Gandaki system or parts of the system (i.e. Trishuli))?
- How much does it cost to process data (e.g. how many person hours)?

- How much processing effort is involved (e.g. are the data manually processed or is the procedure automated)?
- What interpreted information can the data provide us (e.g. vegetation layers, road density, etc.)?

Vector data

A comprehensive data review was completed in order to identify all available sources of vector GIS data. The data currently available from the Survey Department within the Government of Nepal was found to be approximately 20 years out of data and often required improvement – in some cases, improved data was found to already be available from other sources, such as international GIS consortiums (e.g. ICIMOD Mountain GeoPortal). This data review included both simple (e.g. administrative boundaries, roads) and complex (e.g. physiography, soils) geometries. This comprehensive research into data providers and associated available data was a first for Nepal and is integral for developing modern spatial analysis and environmental assessment capabilities.
Following the data source review, appropriate data was identified and acquired by direct download (where available), through point-of-contact acquisition provided by the source GIS metadata, and via working with stakeholders in person in Kathmandu.

Satellite imagery

The primary area of interest is the Trishuli watershed – recent coverage of this area was found to be available from a combination of high-resolution optical, panchromatic, and near-infrared (NIR) satellites, including Landsat-8, IKONOS, GeoEye, Worldview, and Quickbird. Landsat-8 imagery was chosen and used to identify varying land-use classes found throughout the watershed (e.g. forest, agriculture, glaciers). Landsat-8 was chosen because it offered the most cost-effective and up-to-date imagery that allowed for the calculation of the Normalized Difference Vegetation Index (NDVI), which is critical to land cover composition and vegetative health in natural ecosystems.

It was not found to be cost-effective to acquire high-resolution data for the entire Gandaki basin due to its size and number of images required to comprehensive coverage.

2.1.2 Data Processing

Vector Data

The data received from providers was in various formats (e.g. shapefile, geodatabase, ArcInfo E00, open-source vector) and in differing Coordinate Reference Systems (CRS). All data was converted to the ESRI geodatabase format and projected to the WGS 1984 Universal Transverse Mercator (UTM) Zone 44N projected coordinate system with a central meridian of ‘84’ to account for the fact that Nepal is split between two UTM zones. This procedure improved data storage capabilities and processing speed.

Some data contained geometry errors. Topological correction using tools provided by the ESRI ArcGIS 10.1 software was used to correct these issues.

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Satellite Imagery

For all imagery, pre-processing was necessary. Where required, mosaicking, atmospheric correction, and optical distortion corrections was performed using the ENVI software package.

Supervised image classification was performed using the Idrisi remote sensing software package. Object-based maximum likelihood classifiers were applied and classification results were fed into a series of confusion matrices to evaluate and report on classification accuracy. The output of image classification was base map layers representing land cover, with a focus on development, sensitive areas, critical habitat, and hazards.

In addition to watershed-level (1990, 2000, 2010) and basin-wide (2010) land cover maps a project site-level map was digitized from 2010 Google Earth imagery. The land cover classes used in this classification were matched to the larger-scale classifications for consistency.

2.2 Phase II: Analysis of watershed pressures and risks across the Gandaki basin

2.2.1 Research on watershed assessment

It has been suggested by many authors that the most effective way to approach cumulative impacts affecting fish and other aquatic values is to consider them at the "watershed" level, where the fundamental connection among all components of the landscape is the network of streams and associated water bodies that define the basin (Reid et al 1996; Williams et al. 1997; NRC 1999; Sedell et al. 1990, Newbold 2002; Smith et al. 2005; as cited in Potyondy and Geier 2011). Watersheds are integral parts of broader ecosystems and can be incorporated into integrated evaluations at a variety of spatial scales. Watersheds are spatially located landscape features that are easily identified on maps and on the ground and their boundaries do not change much over time which makes them ideal for consistent, long term monitoring exercises. Watersheds also resonate with much of the public as a logical way to frame local management issues. Conditions existing within a watershed represent an integration of the effects of all activities that are occurring (or have occurred) within the watershed; therefore a formal assessment of watershed condition should provide an ideal mechanism for representing the cumulative effects/impacts over time of a multitude of human-mediated actions on key watershed processes (Potyondy and Geier 2011).

Watershed condition can be considered as the state of the physical and biological characteristics and processes within a watershed. Watersheds considered to be in “properly functioning condition” (aka “healthy”) have terrestrial, riparian, and aquatic systems that capture, store, and release water, sediment, wood, and nutrients within the range of natural variability for these processes. They create and sustain functional habitats capable of supporting diverse populations of native aquatic and riparian dependent species (Potyondy and Geier 2011). Williams et al. (1997) identified five important characteristics of properly functioning, healthy watersheds:

1. They provide for high biotic integrity; habitat that supports adaptive animal and plant communities that reflect natural processes
2. They are resilient and recover rapidly from natural and human disturbances
3. They exhibit a high degree of connectivity along the stream, laterally across the floodplain and valley bottom, and vertically between surface and subsurface flows
4. They provide important ecosystem services such as high quality water, recharge of streams and aquifers, the maintenance of riparian communities, the moderation of climate variability and change
5. They maintain long-term soil productivity.

Cumulative watershed effects are environmental changes that affect watershed condition and that often involve more than one land-use activity. Almost all environmental changes represent potential cumulative effects, and almost all land-use activities can contribute to cumulative effects to some extent. The concern is that while several activities may conceivably have fairly minor impacts by themselves, the combined effects of all activities may lead to a degradation of the ecosystem as a whole. Evaluating cumulative effects of disturbances on watershed condition can be problematic however. The sensitivity of aquatic habitats and their dependent biota to the threats represented by ongoing and future landscape-scale disturbances will be influenced by a variety of natural and anthropogenic-generated factors operating within a watershed that could either exacerbate or ameliorate the severity of potential disturbance effects on hydrologic processes/functions. Such factors could include precipitation and evapotranspiration rates, vegetation cover, seasonal distribution of water inputs, organic and mineral soil depths, soil and subsoil permeability, bedrock type, topography, slope aspect and gradient, and topographic convergence (influences hillslope water accumulations and consequent rates and magnitude of water contribution to the stream network) (Smith and Redding 2012).

2.2.2 Watershed indicators

Indicators can be defined as relatively simple quantifiable or qualitative measures of the condition or dynamics of broader, more complex (and generally difficult to assess) attributes of ecosystem health. Indicators act as surrogates for the underlying ecological processes that maintain watershed functionality and condition (Potyondy and Geier 2011). As simple surrogates for complex ecological processes watershed habitat indicators are unlikely to accurately represent direct cause-and-effect relationships. For example, road density has been correlated with increasing sediment load to streams in many studies and is a commonly used indicator of the risk of aquatic habitat impairment. Yet the full set of factors that produce sedimentation is highly complex, with other factors such as soil type, geology, slope, land use and road condition all having an influence on actual sediment yield (Potyondy and Geier 2001). Consequently a single habitat indicator like road density is unlikely to be a consistent predictor of environmental response in a watershed, as indicators will have different influences in different environmental settings.

While recognizing that there are uncertainties inherent in indicator-based approaches a comprehensive multi-stressor evaluation can present a viable approach for framing an assessment of the potential for cumulative effects on aquatic habitats across a suite of local or regional scales. Key watershed indicators can be developed as standard, quantified metrics by which habitat status can be measured or judged, and compared over time and space to determine condition or the risk of adverse effects. Within a pressure-state response (PSR) framework (Bertram and Stadler-Salt 2000, Ironside 2003, Newton 2007), two types of habitat indicators ("pressure" and "state") are typically developed to inform two scales of decision making and management action: regional and local scales. Pressure (aka stressor) indicators (e.g. road density, land cover alteration, etc.) are intended to provide information on the relative degree of potential stress across watersheds sufficient to identify initial regional-scale priorities for habitat protection and restoration. A next level of decision is intended to be informed by information on state indicators – more detailed descriptions (generally based on field measurement) of the actual "on-the-ground" condition (i.e., physical, chemical, biological) of habitats within watersheds (e.g. water temperature, water chemistry, aquatic invertebrates, riparian condition, etc.). State indicators (generally more difficult and more expensive to obtain) describe habitat condition at a much more localized scale and are intended for more focused monitoring in areas where initial broad assessment of pressure indicators has identified a higher risk of potential problems.

After a thorough investigation of available data, 5 indicator categories indicative of pressures on watershed health were selected: Surface Erosion, Mass Wasting, Land Cover Change, Hydropower Development, and Impacts from Human Populations. Associated with these indicators are 10 spatial metrics; descriptions, analyses, and results are described in Section 3.2.

Table 2-2: Pressure/risk indicators developed for Phase II

Pressure Indicators	Acronym	Units	Required Data
Hydro licenses (total area vs. watershed area; total area by class vs. watershed area)	HYDRO	km2, %	Hydro license polygons by class
Road density	ROAD_DEN	km/km2	Road network
Road density near streams (e.g. within 100m)	ROAD_STREAM	km/km2	Road network, stream network
Road density on unstable slopes	ROAD_SLOPE	km/km2	Road network, DEM
Stream/road crossing density	ROAD_CROSS	#/km2	Road network, stream network
Population density (based on villiage development committees)	POP_DEN	#/km2	Major Cities
Change in glacier extent	GLACIER	km2, %	Land cover (1990, 2000, 2010)
Forest cover change (1990-2010)	FOREST	km2, %	Land cover (1990, 2000, 2010)
Agriculture change (1990-2010)	AGRICULTURE	km2, %	Land cover (1990, 2000, 2010)
Moderate or high slide potential (total area vs. watershed area)	SLIDE	km2, %	DEM

3 Results

3.1 Phase I: Thematic maps

Map creation and editing: Maps were based on data from the original providers, updated vector sources, and classified satellite imagery. All maps conform to standard cartographic principles.

Map publishing: Maps were published as images, PDFs and in ArcGIS MXD format. All data associated with each map is stored and linked via metadata so that it can be referenced and utilized in the future.

These thematic maps have served as critical spatial information inputs for the other activities under this consultancy, especially for the baseline characterization of the Trishuli watershed as part of the Cumulative Impacts Assessment. Indicators and spatial metrics based on these base maps will be developed as part of Phase II of GIS Mapping and Spatial Analysis.

Due to the size and desired quality of the maps created for Phase I these products are provided as PDFs and therefore are not included within this report. See Appendix 1 for map descriptions and associated data sources.

3.2 Phase II: Analysis of watershed pressures and risks across the Gandaki basin

The results of Phase II are presented in both tabular and map format. The tables simply display the calculated values for each metric, for example, the Trishuli watershed has a road density of 0.48 based on a total road length of 1923km and a watershed area of 4036 km^2. The maps associated with each metric were created using a simple ranking system wherein the watershed with the most amount of pressure, based on an individual metric, receives a rank of 8, and the watershed with the least amount of pressure receives a rank of 1. The final watershed ranking map is based on the cumulative rank across all metrics. Therefore, the watershed that scored the highest (most pressure) across all metrics receives the highest overall rank and is, for the purpose of this simple analysis, the watershed facing the most pressure and risk of damage to the local environment.

3.2.1 Surface erosion

Metric: Road density for entire watershed (km/km^2)

How is road density for entire watershed calculated?
Road density is defined as the total length of roads divided by the total watershed area (km/km^2). Relevant roads were selected types using the descriptor column in the attribute table (e.g. highway, major arterial roads). For this analysis, roads types such as 'walking trail' and 'cart track' were removed. Clipped the roads layer within the confines of the watershed polygons. Within each watershed, summed the total length of all road segments and divided this length by the total watershed area.

How are results interpreted?
High road densities within a watershed indicate a greater risk to fish habitat disturbance. Increases in road density may also lead to magnified surface erosion and landslide risk, with associated increases in stream turbidity and potential disruptions to aquatic functions.

Table 3-1: Road density for watersheds in the Gandaki basin

Watershed Number	Watershed Name	Watershed Area (km2)	Road Length (km)	Density (km/km2)
1	Budhi Gandaki	3621	580.32	0.16
2	Kali Gandaki	11846	2945.99	0.25
3	Madi	1254	840.44	0.67
4	Marshyangdi	4786	1303.19	0.27
5	Narayani	1664	307.61	0.18
6	Rapti	3031	1136.74	0.38
7	Seti Gandaki	1739	1095.72	0.63
8	Trishuli	4036	1923.76	0.48
	TOTAL	31977	10133.77	0.32

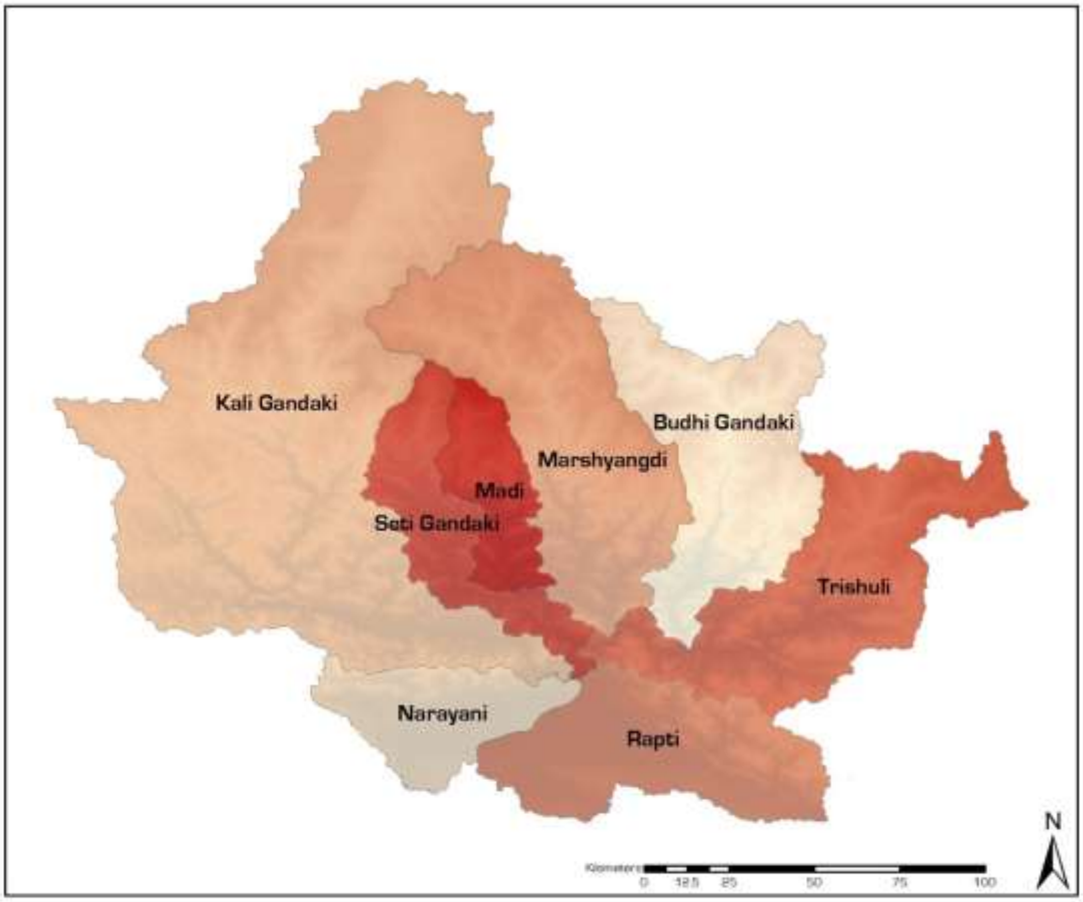

Figure 3-1: Watersheds rankings based on road density. Darker red represents a higher ranking (more pressure based on the associated metric).

Metric: Road density <100m from a stream (km/km^2)

How is road density <100m from a stream calculated?

This metric is calculated as the length of roads within 100m of a stream, divided by total area of the watershed. To calculate this metric, a stream network, provided by the Survey Department (Government of Nepal), and a road layer (see road density above) are used. Both layers were clipped within the confines of the watershed boundary. Buffered the streams by 100 m, and calculated the total length of roads within this 100 m buffer area, then divided this figure by the total watershed area.

How are results interpreted?

Roads situated in close proximity to streams (< 100 m) can pose serious threats to stream channel stability. Road construction and maintenance can be very disruptive to streams, with frequent incidences of channel disturbance and point-source pollution. Roads within 100m of a stream also contribute to surface erosion and mass-transport of sediment. Increases in sediment deposition as a result of higher road density can have serious health implications to fish and their ecosystems. A buffer distance of 100 m is usually identified in the literature[1] as the area where most of the road impacts will concentrate and has been selected as indicator for watershed health assessments[2].

Table 3-2: Road density within 100m of streams for watersheds in the Gandaki basin

Watershed Number	Watershed Name	Watershed Area (km2)	Road Length (km)	Density (km/km2)
1	Budhi Gandaki	3621	269.3	0.07
2	Kali Gandaki	11846	1353.28	0.11
3	Madi	1254	387.6	0.31
4	Marshyangdi	4786	620.2	0.13
5	Narayani	1664	45.26	0.03
6	Rapti	3031	543.72	0.18
7	Seti Gandaki	1739	403.76	0.23
8	Trishuli	4036	1060.87	0.26
	TOTAL	31977	4683.99	0.15

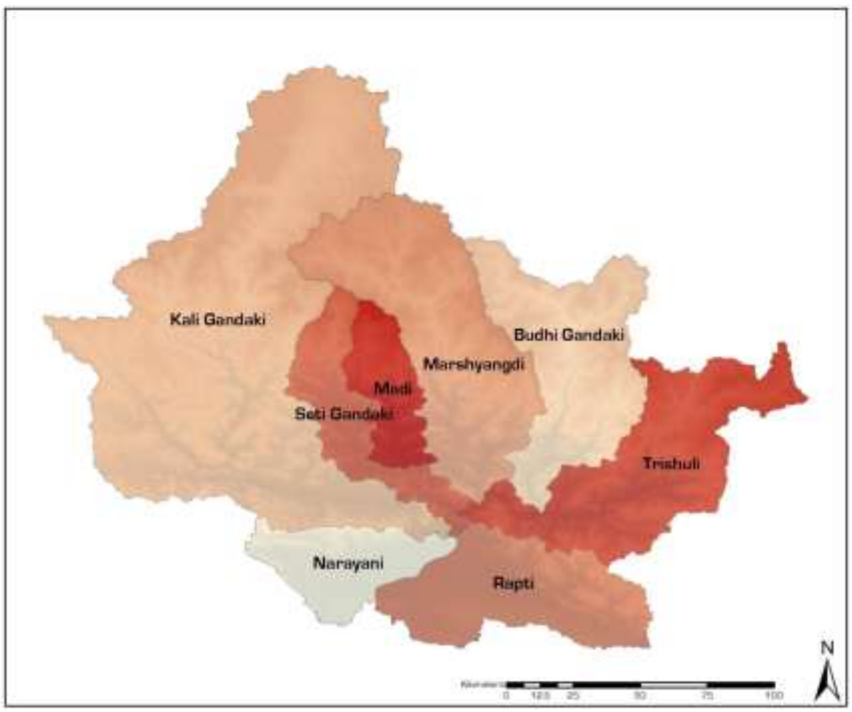

Figure 3-2: Watersheds rankings based on road density near streams. Darker red represents a higher ranking (more pressure based on the associated metric)

[1] http://owpubauthor.epa.gov/lawsregs/lawsguidance/cwa/tmdl/recovery/upload/RP2wshedroaddens1109.pd

[2] http://www.for.gov.bc.ca/tasb/legsregs/fpc/fpcguide/iwap/iwapp9.htm

Metric: Stream Crossing Density (no./km^2)

How is stream crossing density calculated?

Intersected the roads layer (see road density above) with the streams layer and returned the resulting intersections as points. Divided the number of road-stream crossings in the watershed by the total area of the watershed.

How are results interpreted?

Stream crossings at road intersections represent potential focal points for fine sediment input and intercepted flow delivery, as well as potential physical impediments to fish movements. In general the greater the density of road-stream crossings on forest land, the greater the potential risk to fish and their habitats. It is important to note that some stream crossings may not have an effect on the proximate river as the infrastructure used to traverse the river is sometimes minimally invasive (i.e. bamboo bridge). Care was taken to select road types that do have a stronger effect, such as highways and major roads that require larger bridges.

Table 3-3: Stream crossing density for watersheds in the Gandaki basin

Watershed Number	Watershed Name	Watershed Area (km2)	Crossings (count)	Density (Xing per km2)
1	Budhi Gandaki	3621	663	0.18
2	Kali Gandaki	11846	3456	0.29
3	Madi	1254	843	0.67
4	Marshyangdi	4786	1541	0.32
5	Narayani	1664	81	0.05
6	Rapti	3031	1079	0.36
7	Seti Gandaki	1739	831	0.48
8	Trishuli	4036	2698	0.67
	TOTAL	31977	11192	0.35

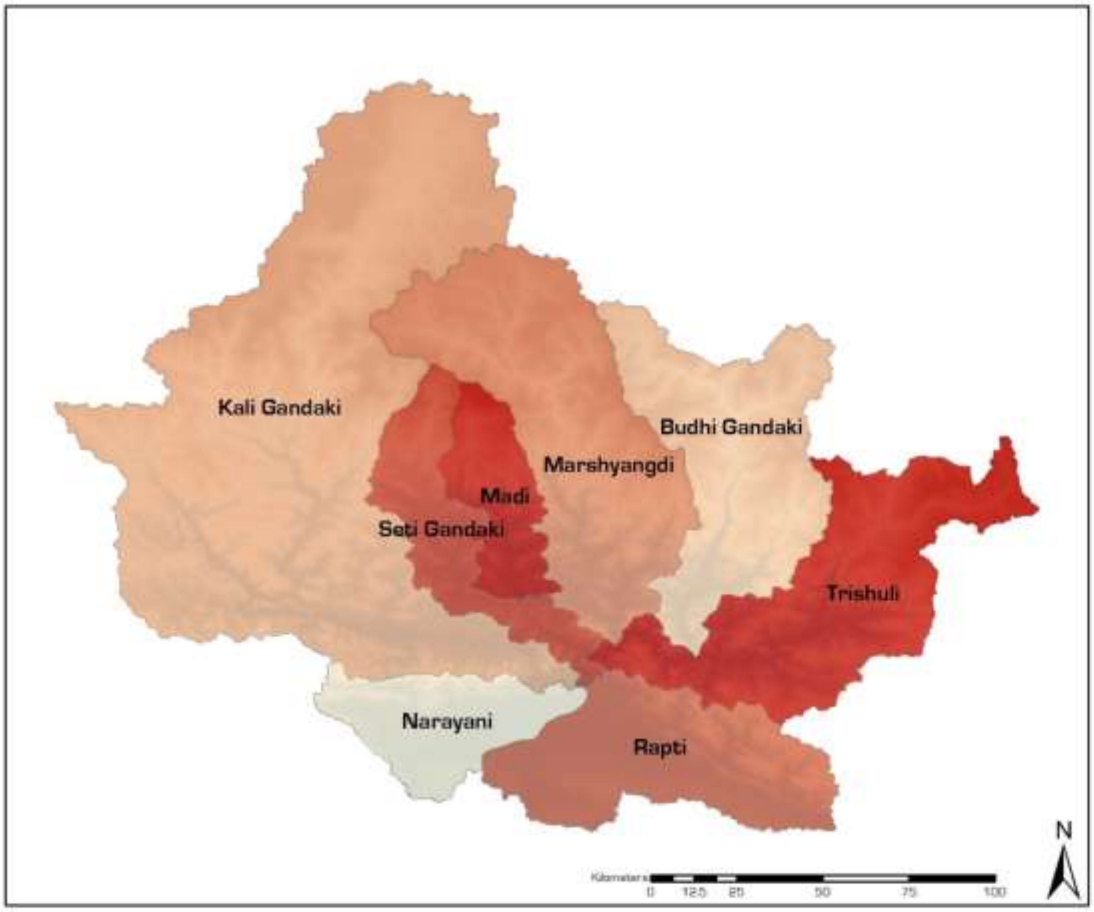

Figure 3-3: Watersheds rankings based stream crossing density. Darker red represents a higher ranking (more pressure based on the associated metric)

Metric: Road Density on unstable slopes (km/km^2)

How is road density on unstable slopes calculated?

Available datasets limit the inferences we can make currently about unstable slopes in watersheds. As an interim default we assumed that all slopes >45% are unstable or potentially unstable. Using the DEM, we first isolated the areas within the watershed that are located on steep slopes >45%. To do this we ran a slope analysis and reclassified the resulting raster file to only those areas that represent slopes >45%. Converted the reclassified slope raster to polygon features, and used this to calculate the total road length within the >45% polygon. Divided this road length by the total watershed area.

How are results interpreted?

Roads located on unstable slopes can be major contributors to surface erosion and increase risk of mass wasting events. A higher road density on unstable slopes generally indicates a greater risk to watershed health.

Table 3-4: Road density on unstable slopes for watersheds in the Gandaki basin

Watershed Number	Watershed Name	Watershed Area (km2)	Road Length (km)	Density (km/km2)
1	Budhi Gandaki	3621	21.54	0.0059
2	Kali Gandaki	11846	69.62	0.0059
3	Madi	1254	17.28	0.0138
4	Marshyangdi	4786	35.87	0.0075
5	Narayani	1664	0	0.0000
6	Rapti	3031	10.62	0.0035
7	Seti Gandaki	1739	11.66	0.0067
8	Trishuli	4036	40.84	0.0101
	TOTAL	31977	207.43	0.0065

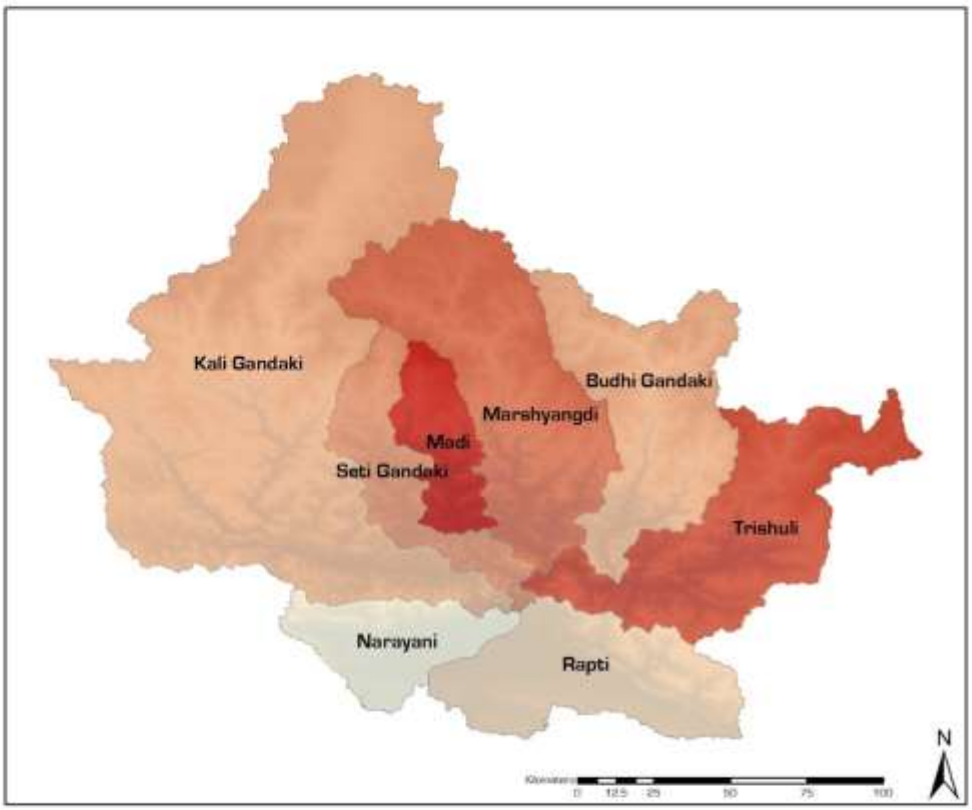

Figure 3-4: Watersheds rankings based on road density on unstable slopes. Darker red represents a higher ranking (more pressure based on the associated metric)

3.2.2 Mass wasting

Metric: Landslide potential (km^2/km^2)

How is landslide potential calculated?

Available datasets limit the inferences we can make currently about unstable slopes in watersheds. As an interim default we assumed that all slopes >45% are unstable or potentially unstable. Using the DEM, we first isolated the areas within the watershed that are located on steep slopes >45%. To do this we ran a slope analysis and reclassified the resulting raster file to only those areas that represent slopes >45%. Converted the reclassified slope raster to polygon features, and calculated the total area of unstable slopes. Divided to unstable slope area by the total area of the watershed to derive the total area of each watershed considered to contain unstable slopes.

How are results interpreted?

Mass wasting events can be both beneficial and detrimental to watersheds. Landslides can transport woody debris into streams, adding to stream channel complexity which is favorable for spawning. Landslides can also harm fish-bearing stream networks by introducing large quantities of coarse and fine sediment and creating passage blocks. Landslide density should be monitored closely and in conjunction with many of the indicators that focus on soil erosion, riparian logging, and unstable slopes.

Table 3-5: Landslide potential for watersheds in the Gandaki basin

Watershed Number	Watershed Name	Watershed Area (km2)	Slide Potential (km2)	Slide (% of total area)
1	Budhi Gandaki	3621	491.75	13.58%
2	Kali Gandaki	11846	685.04	5.78%
3	Madi	1254	54.04	4.31%
4	Marshyangdi	4786	409.39	8.55%
5	Narayani	1664	4.71	0.28%
6	Rapti	3031	23.63	0.78%
7	Seti Gandaki	1739	75.8	4.36%
8	Trishuli	4036	243.44	6.03%
	TOTAL	31977	1987.8	6.22%

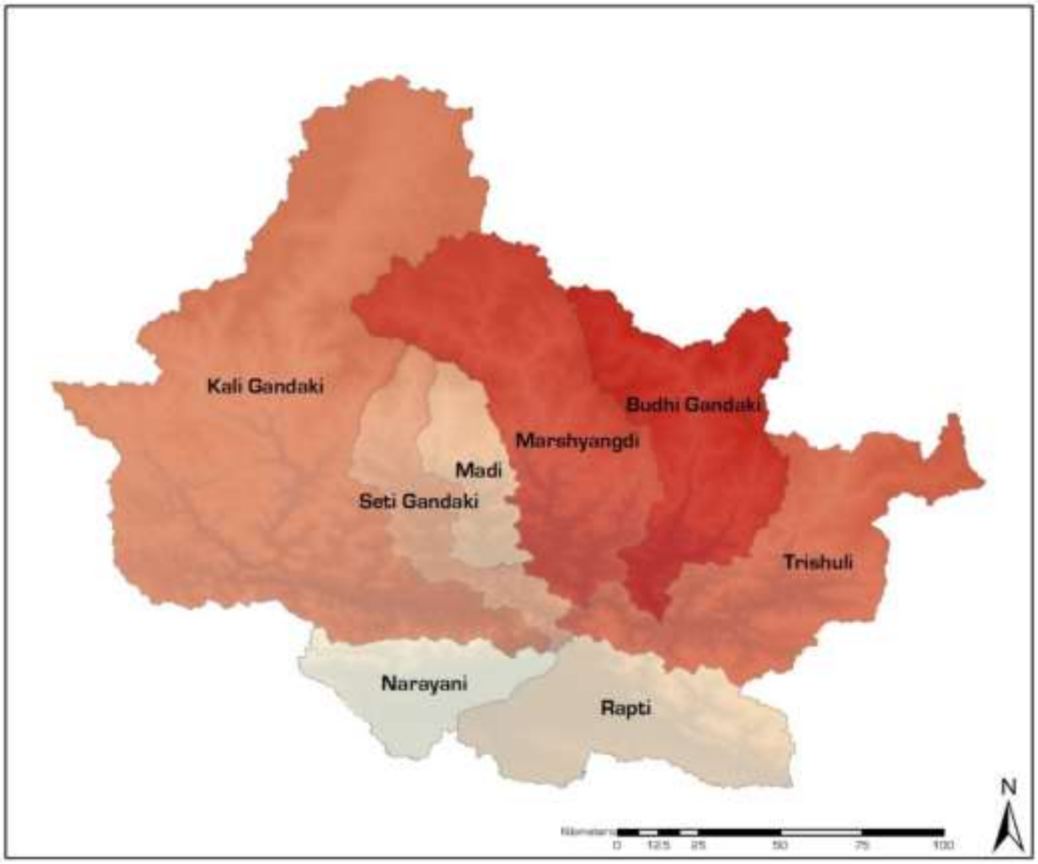

Figure 3-5: Watersheds rankings based on slide potential. Darker red represents a higher ranking (more pressure based on the associated metric)

3.2.3 Impacts from Human Populations

Metric: Population density (persons/km^2)

How is population density calculated?

Population density is based on village development committee population counts, which is derived from the national census. All villages with a population >100 persons were included. The population layer (as points) was clipped to each watershed boundary. The number of persons in each watershed was divided by the total watershed area to produce a density value.

How are results interpreted?

Population density within a given watershed can provide insight into the effects of development on local communities. It's important to note that for this analysis the total population density for the entire watershed was calculated, but some areas with be denser than others. Further investigation is required to determine the effects of individual projects on local communities.

Table 3-6: Population density for watersheds in the Gandaki basin

Watershed Number	Watershed Name	Watershed Area (km2)	Population (count)	Density (persons per km2)
1	Budhi Gandaki	3621	218204	60
2	Kali Gandaki	11846	1310203	111
3	Madi	1254	283870	226
4	Marshyangdi	4786	404590	85
5	Narayani	1664	217986	131
6	Rapti	3031	807492	266
7	Seti Gandaki	1739	473338	272
8	Trishuli	4036	523576	130
	TOTAL	31977	4239259	133

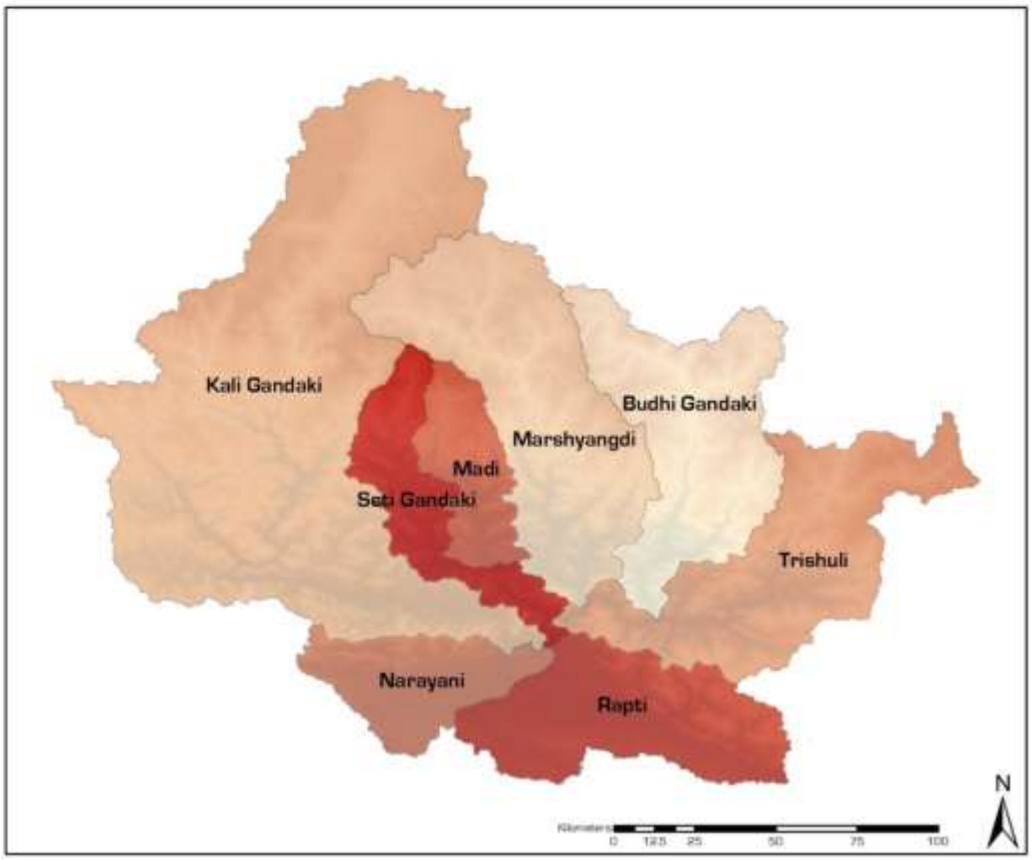

Figure 3-6: Watersheds rankings based on population density. Darker red represents a higher ranking (more pressure based on the associated metric)

3.2.4 Hydropower Development

Metric: Hydropower development (km^2, % of watershed)

How is hydropower development calculated?

Hydropower project footprints were created using tables provided by the Department of Energy Development (Government of Nepal), which list the corner boundaries of each hydro license. Licenses were divided into classes: 1) Operating, 2) Under Construction, 3) Survey: >100MW, 4) Survey: 25-100MW, 5) Survey: 1-25MW. For each project footprint the total area was calculated and compared, by class, to the total area of each watershed.

How are results interpreted?

Hydropower development has a direct effect on the river ecosystems in which they are constructed. Refer to the Cumulative Impacts Assessment (ERP-07D-P06 - DFG# E0720044) for a detailed analysis.

Hydropower Development Scenarios

In the Hydropower Development Scenarios below, 'low' indicates that only **operating** and **under construction** licenses were used in the analysis. 'High' indicates that all licenses (operating, under construction, and all survey licenses) were used in the analysis.

Table 3-7: Area of hydropower licenses in the Gandaki basin for 2 development scenarios (high/low)

Hydropower Development Scenarios						
Watershed Number	Watershed Name	Watershed Area (km2)	Low (km2)	Low (%)	High (km2)	High (%)
1	Budhi Gandaki	3621	8.70	0.24%	150.65	4.16%
2	Kali Gandaki	11846	317.53	2.68%	566.53	4.78%
3	Madi	1254	38.25	3.05%	89.20	7.11%
4	Marshyangdi	4786	235.59	4.92%	288.93	6.04%
5	Narayani	1664	0.00	0.00%	0.00	0.00%
6	Rapti	3031	56.64	1.87%	76.58	2.53%
7	Seti Gandaki	1739	33.63	1.93%	130.34	7.50%
8	Trishuli	4036	225.82	5.60%	600.85	14.89%
		31977	916.16	2.87%	1903.08	5.95%

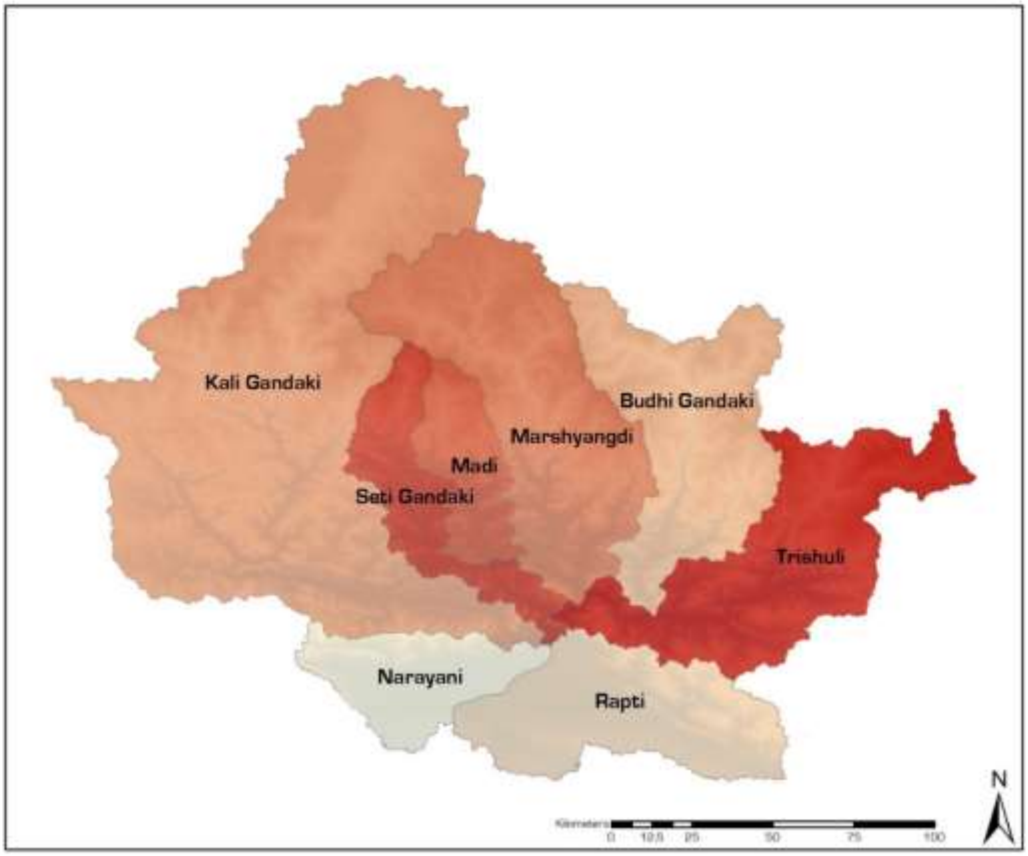

Figure 3-7: Watersheds rankings based on hydropower development ("high" development scenario). Darker red represents a higher ranking (more pressure based on the associated metric)

Hydropower Development by Class

Table 3-8: Area of 'operating' hydropower licenses for watersheds in the Gandaki basin

			Operating		
Watershed Number	Watershed Name	Watershed Area (km2)	HYDRO (km2)	HYDRO (%)	HYDRO (count)
1	Budhi Gandaki	3621	0.00	0.00%	0
2	Kali Gandaki	11846	227.55	1.92%	7
3	Madi	1254	0.00	0.00%	0
4	Marshyangdi	4786	137.24	2.87%	4
5	Narayani	1664	0.00	0.00%	0
6	Rapti	3031	35.36	1.17%	1
7	Seti Gandaki	1739	14.03	0.81%	3
8	Trishuli	4036	67.27	1.67%	5

Table 3-9: Area of 'under construction' hydropower licenses for watersheds in the Gandaki basin

			Under Construction		
Watershed Number	Watershed Name	Watershed Area (km2)	HYDRO (km2)	HYDRO (%)	HYDRO (count)
1	Budhi Gandaki	3621	8.70	0.24%	1
2	Kali Gandaki	11846	89.98	0.76%	8
3	Madi	1254	38.25	3.05%	5
4	Marshyangdi	4786	98.35	2.05%	8
5	Narayani	1664	0.00	0.00%	0
6	Rapti	3031	21.28	0.70%	1
7	Seti Gandaki	1739	19.60	1.13%	1
8	Trishuli	4036	158.55	3.93%	10

Table 3-10: Area of '100+MW' hydropower survey licenses for watersheds in the Gandaki basin

			100+MW		
Watershed Number	Watershed Name	Watershed Area (km2)	HYDRO (km2)	HYDRO (%)	HYDRO (count)
1	Budhi Gandaki	3621	136.56	3.77%	1
2	Kali Gandaki	11846	61.80	0.52%	1
3	Madi	1254	0.00	0.00%	0
4	Marshyangdi	4786	14.43	0.30%	1
5	Narayani	1664	0.00	0.00%	0
6	Rapti	3031	0.00	0.00%	0
7	Seti Gandaki	1739	0.00	0.00%	0
8	Trishuli	4036	21.74	0.54%	1

Table 3-11: Area of '25-100MW' hydropower survey licenses for watersheds in the Gandaki basin

			25-100MW		
Watershed Number	Watershed Name	Watershed Area (km2)	HYDRO (km2)	HYDRO (%)	HYDRO (count)
1	Budhi Gandaki	3621	0.00	0.00%	0
2	Kali Gandaki	11846	16.69	0.14%	1
3	Madi	1254	0.00	0.00%	0
4	Marshyangdi	4786	8.30	0.17%	1
5	Narayani	1664	0.00	0.00%	0
6	Rapti	3031	0.00	0.00%	0
7	Seti Gandaki	1739	34.12	1.96%	2
8	Trishuli	4036	238.84	5.92%	5

Table 3-12: Area of '1-25MW' hydropower survey licenses for watersheds in the Gandaki basin

			1-25MW		
Watershed Number	Watershed Name	Watershed Area (km2)	HYDRO (km2)	HYDRO (%)	HYDRO (count)
1	Budhi Gandaki	3621	5.39	0.15%	1
2	Kali Gandaki	11846	170.51	1.44%	16
3	Madi	1254	50.95	4.06%	3
4	Marshyangdi	4786	30.61	0.64%	5
5	Narayani	1664	0.00	0.00%	0
6	Rapti	3031	19.94	0.66%	3
7	Seti Gandaki	1739	62.59	3.60%	3
8	Trishuli	4036	114.45	2.84%	14

3.2.5 Watershed Ranking Summary

The maps associated with each metric were created using a simple ranking system wherein the watershed with the most amount of pressure, based on an individual metric, receives a rank of 8, and the watershed with the least amount of pressure receives a rank of 1. The final watershed ranking map is based on the cumulative rank across all metrics. Therefore, the watershed that scored the highest (most pressure) across all metrics receives the highest overall rank and is, for the purpose of this simple analysis, the watershed facing the most pressure and risk of damage to the local environment. Based on this analysis, the Madi and Trishuli watersheds rank the highest.

Table 3-13: Watershed ranking summary based on a cumulative assessment of all 7 metrics

Watershed Number	Watershed Name	Roads	Road Streams	Road Slope	Road Crossing	Slide Potential	Population Density	Hydro Development	Summary	Rank
1	Budhi Gandaki	8	7	5	7	1	8	6	42	2
2	Kali Gandaki	6	6	6	6	4	6	5	39	3
3	Madi	1	1	1	1	6	3	3	16	8
4	Marshyangdi	5	5	3	5	2	7	4	31	5
5	Narayani	7	8	8	8	8	4	8	51	1
6	Rapti	4	4	7	4	7	2	7	35	4
7	Seti Gandaki	2	3	4	3	5	1	2	20	6
8	Trishuli	3	2	2	2	3	5	1	18	7

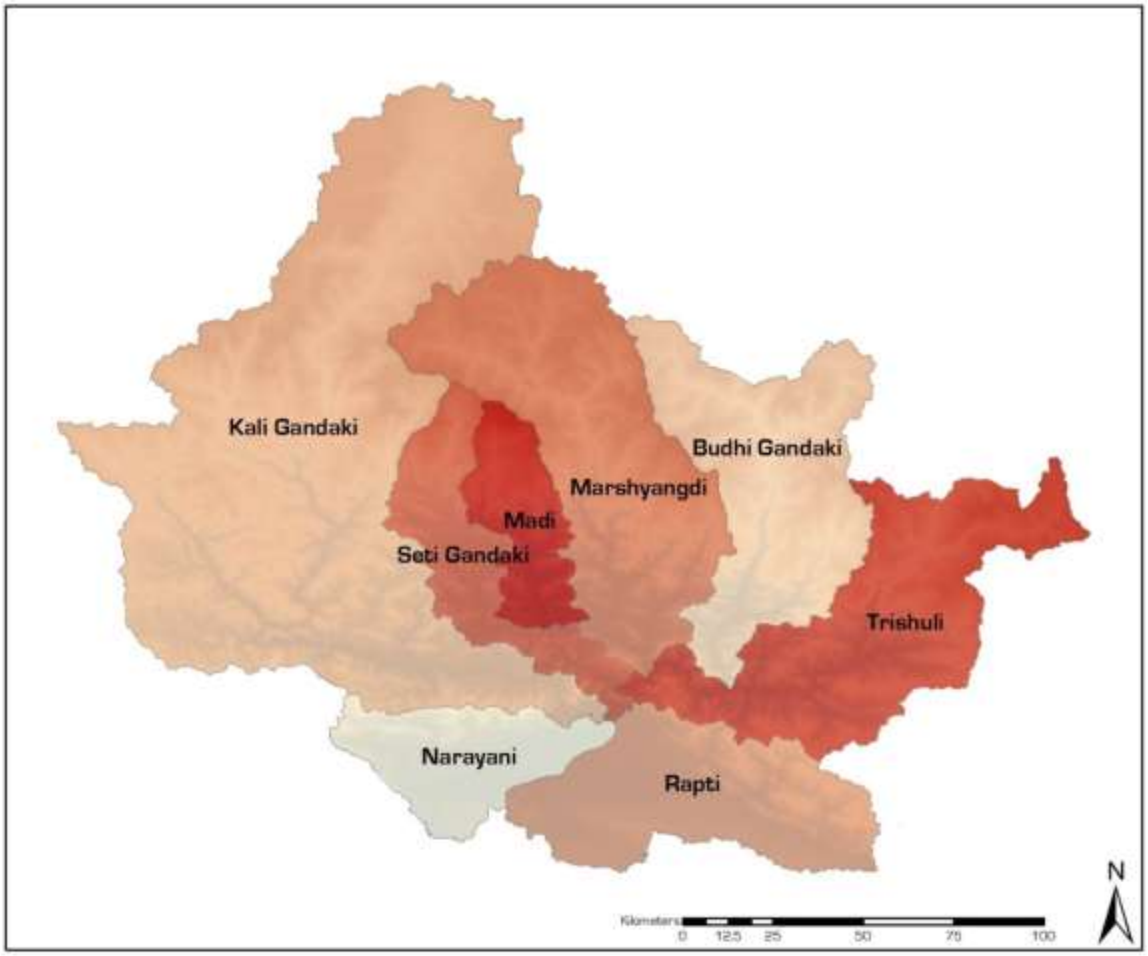

Figure 3-8: Final watershed ranking based on a cumulative assessment of all 7 metrics. Darker red represents a higher ranking (more pressure based on the associated metric)

3.2.6 Land Cover Change

Land cover change was assessed separately from the previous metrics as the results require additional data and further analyses in order to derive significant conclusions. The provided maps simply show net gain (green) and loss (red) of individual land cover types during the assessment period (1990-2010).

Metric: Forest cover change (1990 – 2010) (km^2)

How is forest cover change calculated?

Land cover classifications are available for the years 1990, 2000, and 2010. For each of these years, land cover classes pertaining to forest cover were selected and exported as a polygon shapefile. The total area of forest cover was calculated for each year and within each watershed.

How are results interpreted?

Change in forest cover can often be attributed to anthropogenic influence, such as clearing for agriculture or infrastructure development. Forest health and connectedness can be directly related to terrestrial habitat quality within the watershed. In addition to these immediate impacts, the clearing of forest cover can lead in an increase in surface erosion and unstable slopes, potentially threatening habitat and infrastructure stability.

Table 3-14: Forest cover change (1990-2010) for watersheds within the Gandaki basin

Watershed Number	Watershed Name	1990 (km2)	2000 (km2)	2010 (km2)	Plot
1	Budhi Gandaki	955.74	952.72	969.78	
2	Kali Gandaki	3736.78	3801.42	3713.59	
3	Madi	711.68	719.25	712.96	
4	Marshyangdi	1288.22	1297.59	1304.66	
5	Narayani	896.07	938.26	937.22	
6	Rapti	1846.13	1822.28	1832.95	
7	Seti Gandaki	764.66	765.89	777.48	
8	Trishuli	1095.34	1036.86	1077.89	
	TOTAL	11294.62	11334.27	11326.53	

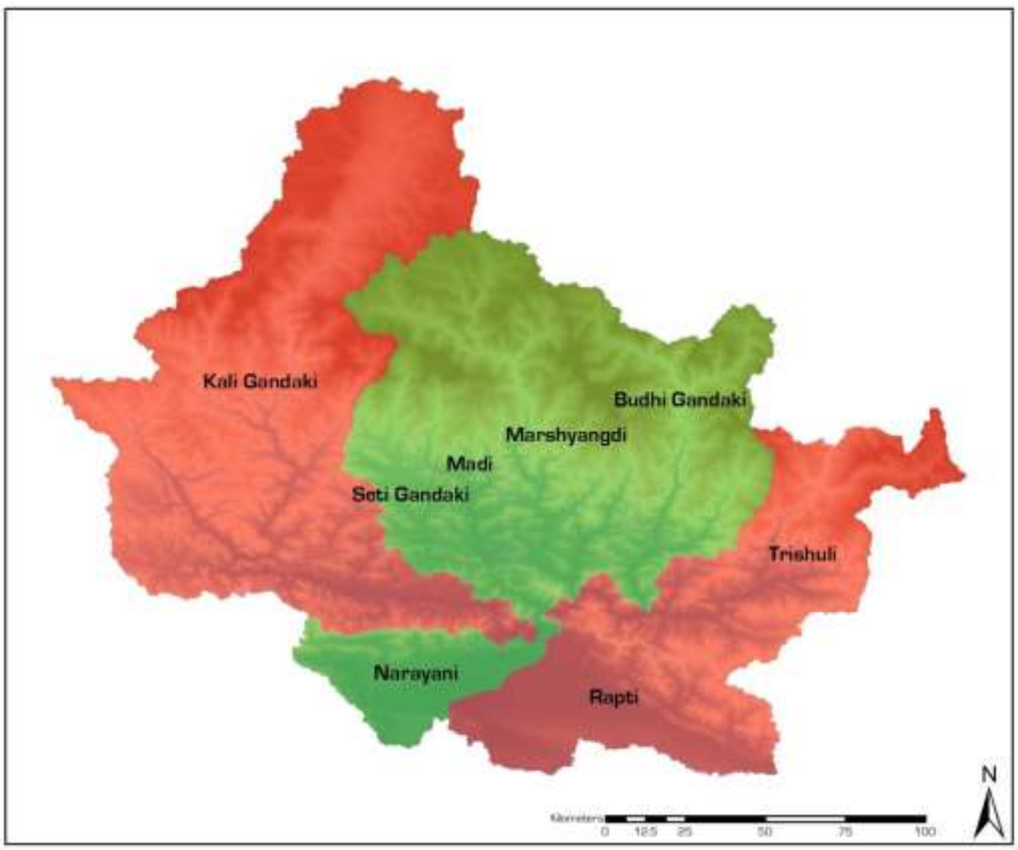

Figure 3-9: Forest cover change in the Gandaki basin (1990-2010). Green watersheds saw a net increase in forest cover and red watersheds saw a net decrease

Metric: Agriculture change (1990 – 2010) (km^2)

How is forest cover change calculated?

Land cover classifications are available for the years 1990, 2000, and 2010. For each of these years, land cover classes pertaining to agriculture were selected and exported as a polygon shapefile. The total area of agriculture was calculated for each year and within each watershed.

How are results interpreted?

Change in agriculture can indicate the presence and extent of human habitation within a watershed. An increase in agriculture can be used to predict future movement of people into previously uninhabited areas. It can also be linked to forest cover loss and therefore habitat degradation.

Table 3-15: Agriculture change (1990-2010) for watersheds in the Gandaki basin

Watershed Number	Watershed Name	1990 (km2)	2000 (km2)	2010 (km2)	Plot
1	Budhi Gandaki	468.53	495.44	494.43	
2	Kali Gandaki	2230.36	2282.16	2299.62	
3	Madi	287.43	289.29	289.19	
4	Marshyangdi	674.49	676.37	674.41	
5	Narayani	384.78	368.14	366.52	
6	Rapti	745.61	762.64	763.44	
7	Seti Gandaki	556.57	560.24	560.47	
8	Trishuli	1262.19	1296.17	1302.86	
	TOTAL	6609.96	6730.45	6750.94	

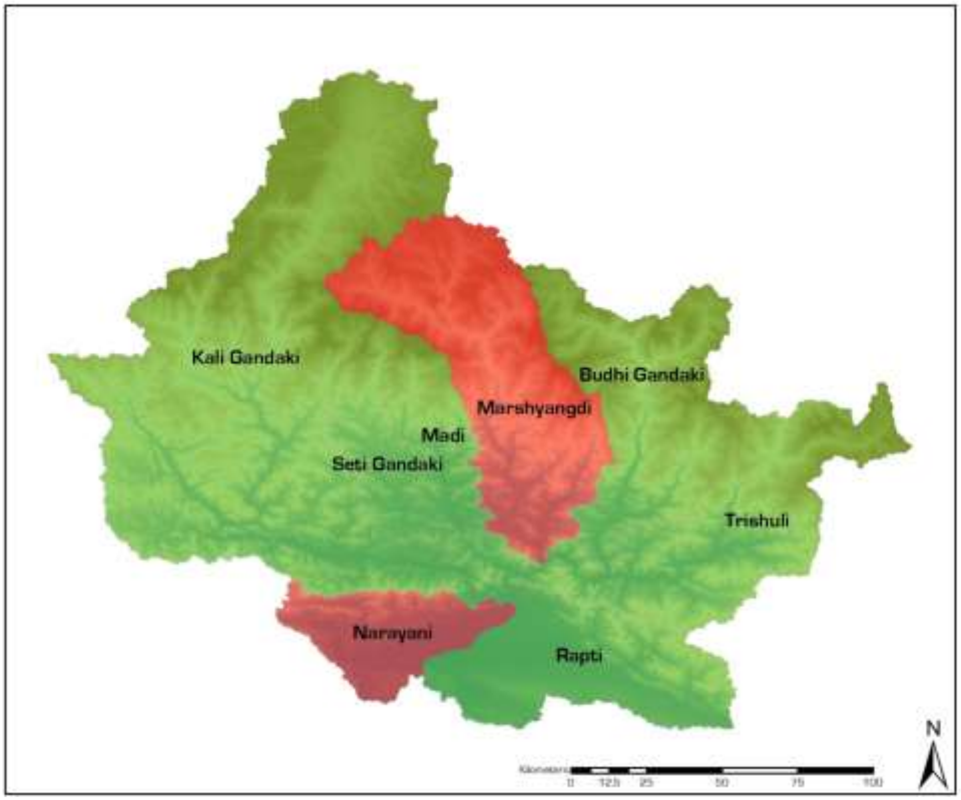

Figure 3-10: Agriculture cover change in the Gandaki basin (1990-2010). Green watersheds saw a net increase in forest cover and red watersheds saw a net decrease

Metric: Change in glacier extent (1990 – 2010) (km^2)

How is change in glacier extent calculated?

Land cover classifications are available for the years 1990, 2000, and 2010. For each of these years, the land cover class pertaining to glaciers was selected and exported as a polygon shapefile. The total area of glaciers was calculated for each year and within each watershed.

How are results interpreted?

Change in glacial extent is often used as an indicator for climate change monitoring and is a good predictor of flows, especially in mountainous regions where the water supply often substantially consists of melting snow and ice.

Table 3-16: Glacier cover change (1990-2010) for watersheds in the Gandaki basin

Watershed Number	Watershed Name	1990 (km2)	2000 (km2)	2010 (km2)	Plot
1	Budhi Gandaki	36.58	21.79	41.44	
2	Kali Gandaki	61.57	22.89	53.93	
3	Madi	2.76	0.50	3.42	
4	Marshyangdi	47.24	10.04	49.30	
5	Narayani	0.00	0.00	0.00	
6	Rapti	0.00	0.00	0.00	
7	Seti Gandaki	12.23	2.14	12.93	
8	Trishuli	34.25	41.56	36.09	
	TOTAL	194.63	98.92	197.11	

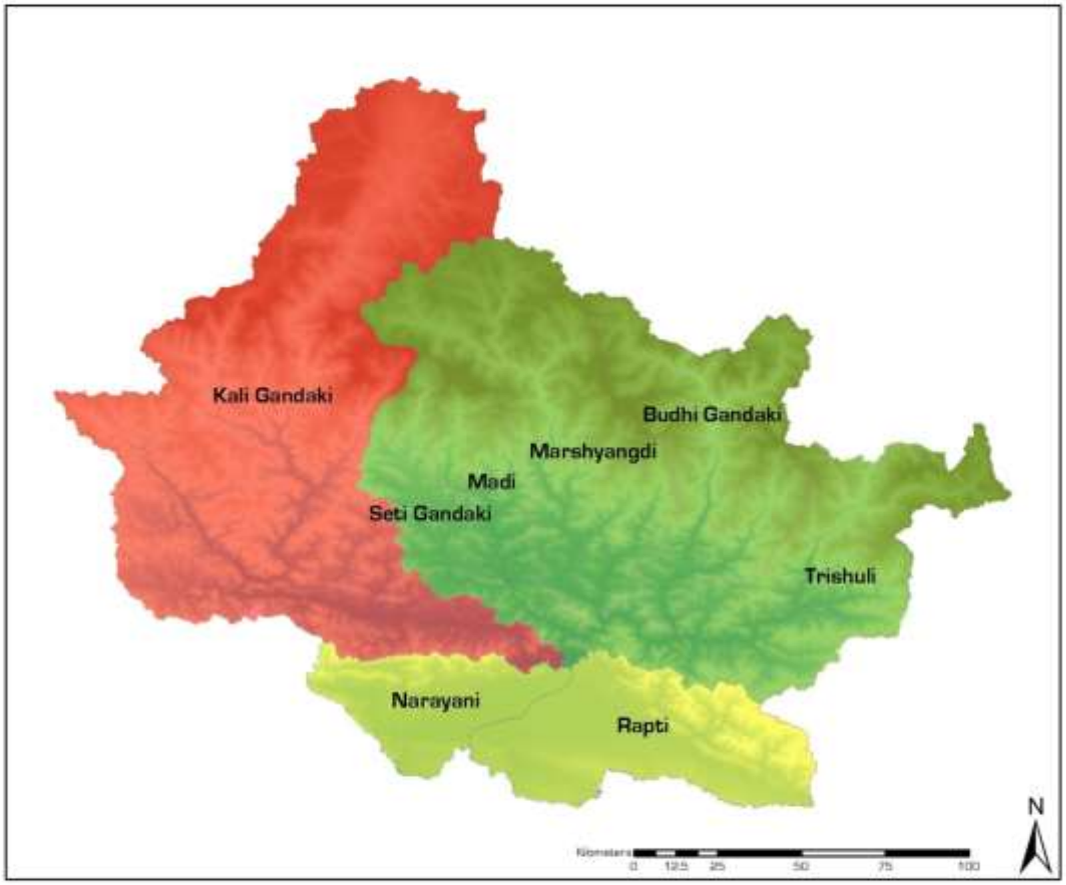

Figure 3-11: Forest cover change in the Gandaki basin (1990-2010). Green watersheds saw a net increase in forest cover and red watersheds saw a net decrease. Yellow watersheds contain no glaciers and therefore saw no change

4 Conclusions

The collection, review, and analysis of available spatial information at the watershed scale and the generation of multiple thematic maps looking at different environmental and social variables has contributed to creating a spatial knowledge base of the Trishuli watershed that facilitates the understanding of the Upper Trishuli-1 Hydropower and similar projects' effect on natural environments in the Trishuli watershed.

At the scale of the Gandaki river system, the exercise of comparing watershed pressure/risk indicators (e.g. roads, population density, hydropower development, etc.) across sub-basins provides valuable information that can support regional planning efforts, as these indicators show the different level of development, and therefore of associated impacts or environmental problems, across the region.

The Trishuli watershed came as second, after the Madi basin, for the highest level of stress/pressure for the selected indicators. The Trishuli has the highest level of hydropower development of all the sub-basins in the Gandaki system. Road density, with its associated impacts on erosion and aquatic habitats, is also a significant pressure in the Trishuli in comparison with the other sub-basins.

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Appendix 1: Trishuli Watershed Thematic Maps

The following section provides a description, list of layers and data sources, and the GIS methodology associated with each map created via the previously described process. All maps are provided in Portable Document Format (PDF). MXD (ArcMap) files are provided for each map and all layers are provided in ESRI geodatabase (10.x) format.

Map 01: Roads & Rivers

- Description: The major roads and rivers found in the Trishuli watershed.
- Layers & Data Sources
  - Roads - World Wildlife Fund Nepal – 2010 Data
  - Rivers - Survey Department (Government of Nepal) – 1996 Data
  - Digital Elevation Model – ASTER – 2000 imagery
- Methodology (if applicable): Trails and cart tracks were removed from the road layer. 4th order and higher streams were removed from the river layer.

Map 02: Hydro Licenses (Point)

- Description: Current point locations of hydro licenses (operating, under construction, survey) in the Trishuli watershed. Data is up-to-date as of November 2013.
- Layers & Data Sources
  - Hydro license locations – Department of Electricity Development (Government of Nepal)
- Digital Elevation Model – ASTER – 2000 imagery
- Methodology (if applicable): Data was downloaded in tabular format from the DOED website (http://www.doed.gov.np/). The provided coordinates were used to locate the center location (point) of the license area. Note – there are some discrepancies in the naming of these licenses in the source data.

Map 03: Hydro Licenses (Polygon)

- Description: Current areal locations of hydro licenses (operating, under construction, survey) in the Trishuli watershed. Data is up-to-date as of November 2013.
- Layers & Data Sources
- o Hydro license locations – Department of Electricity Development (Government of Nepal)
- o Digital Elevation Model – ASTER – 2000 imagery
- • Methodology (if applicable): Data was downloaded in tabular format from the DOED website (http://www.doed.gov.np/). The provided coordinates were used to locate the outer bounds (rectangular) of the license. Note – there are some discrepancies in the naming of these licenses in the source data.
-

Map 04: Land Cover (1990)

- Description: Land cover map of the Trishuli watershed (1990).
- Layers & Data Sources

o Land Cover - Survey Department (Government of Nepal) – 1996 Data

o Land Cover - World Wildlife Fund Nepal – 1990 satellite-derived data

• Methodology (if applicable): Merged land covers classes where necessary to accommodate watershed scale.

Map 05: Land Cover (2000)
• Description: Land cover map of the Trishuli watershed (2000).
• Layers & Data Sources
o Land Cover - World Wildlife Fund Nepal – 2000 satellite-derived data
o Land Cover – ESSA Technologies – updated using 2000 Landsat ETM+ imagery
• Methodology (if applicable): A new classification was performed by ESSA Technologies in order to improve the existing classification provided by WWF Nepal. The resulting land cover classifications were merged.

Map 06: Land Cover (2010)
• Description: Land cover map of the Trishuli watershed (2010).
• Layers & Data Sources
o Land Cover - World Wildlife Fund Nepal – 2010 satellite-derived data
o Land Cover – ESSA Technologies – updated using 2000 Landsat-8 imagery
• Methodology (if applicable): A new classification was performed by ESSA Technologies in order to improve the existing classification provided by WWF Nepal. The resulting land cover classifications were merged.

Map 07: Communities
• Description: Point locations of major communities (population >100).
• Layers & Data Sources
o Communities - Survey Department (Government of Nepal) – 1996 Data xxx
o Digital Elevation Model – ASTER – 2000 imagery
• Methodology (if applicable): N/A

Map 08: Districts
• Description: Political districts of the Trishuli watershed.
• Layers & Data Sources
o Districts - Survey Department (Government of Nepal) – 1996 Data
• Methodology (if applicable): N/A

Map 09: Protected Areas
• Description: Protected areas, including buffer zones, of the Trishuli watershed.
• Layers & Data Sources
o Protect Areas - Survey Department (Government of Nepal) – 1996 Data
o Digital Elevation Model – ASTER – 2000 imagery
• Methodology (if applicable): N/A

Map 10: Cultural & Religious Sites
• Description: Cultural & religious sites of the Trishuli watershed.
• Layers & Data Sources

o Buildings - Survey Department (Government of Nepal) – 1996 Data
o Digital Elevation Model – ASTER – 2000 imagery
• Methodology (if applicable): A selection process was used to identify various cultural and religious sites (e.g. temples, crematoriums). These locations were extracted from the original building layer and used to create a new layer representing just these sites.

Map 11: Forest Patches (2010)
• Description: Forest patches within the Trishuli watershed.
• Layers & Data Sources
o Land Cover - World Wildlife Fund Nepal – 2010 satellite-derived data
o Land Cover – ESSA Technologies – updated using 2000 Landsat-8 imagery
o Digital Elevation Model – ASTER – 2000 imagery
• Methodology (if applicable): The forest land cover class was extracted from the classification created from the merging of WWF Nepal and ESSA Technologies 2010 land cover data.

Map 12: Forest Change (1990-2010)
• Description: The addition and removal of forested land cover between 1990 & 2010 within the Trishuli watershed.
• Layers & Data Sources
o Land Cover - Survey Department (Government of Nepal) – 1996 Data
o Land Cover - World Wildlife Fund Nepal – 2010 satellite-derived data
o Land Cover – ESSA Technologies – updated using 2000 Landsat-8 imagery
o Digital Elevation Model – ASTER – 2000 imagery
• Methodology (if applicable): The forest land cover class was extracted from the classifications created from the merging of Survey Department, WWF Nepal, and ESSA Technologies 1990 & 2010 land cover data. The difference between the 1990 & 2010 data is displayed.

Map 13: Agriculture Change (1990-2010)
• Description: The addition and removal of agricultural land cover between 1990 & 2010 within the Trishuli watershed.
• Layers & Data Sources
o Land Cover - Survey Department (Government of Nepal) – 1996 Data
o Land Cover - World Wildlife Fund Nepal – 2010 satellite-derived data
o Land Cover – ESSA Technologies – updated using 2010 Landsat-8 imagery
o Digital Elevation Model – ASTER – 2000 imagery
• Methodology (if applicable): The agriculture land cover class was extracted from the classifications created from the merging of Survey Department, WWF Nepal, and ESSA Technologies 1990 & 2010 land cover data. The difference between the 1990 & 2010 data is displayed.

Map 14: Ecological Regions
• Description: Ecological regions (dominant forest type) of the Trishuli watershed.
• Layers & Data Sources

- o Ecology – ICIMOD – 2000 data
- • Methodology (if applicable): N/A

Map 15: Parent Materials

- • Description: Dominant parent material of the Trishuli watershed.
- • Layers & Data Sources
- o Soil Terrain Database (SOTOR) – 2009 data
- • Methodology (if applicable): N/A

Map 16: Soils

- • Description: Dominant soils of the Trishuli watershed.
- • Layers & Data Sources
- o Soil Terrain Database (SOTOR) – 2009 data
- • Methodology (if applicable): N/A

Map 17: Fire Events (2003-2011)

- • Description: Fire events (points) occurring between 2003 & 2011 in the Trishuli watershed.
- • Layers & Data Sources
- o Fire events – Department of Forests (Government of Nepal) – 2013 data
- o Digital Elevation Model – ASTER – 2000 imagery
- • Methodology (if applicable): Fire events are classified into categories by year.

Map 18: Surface Slope (Degree)

- • Description: Topological surface slope in degrees for the Trishuli watershed.
- • Layers & Data Sources
- o Digital Elevation Model – ASTER – 2000 imagery
- • Methodology (if applicable): The surface slope was derived from the input DEM using bilinear interpolation (using the Slope tool in ArcMap 10.1).

Map 19: Surface Slope (Percent Rise)

- • Description: Topological surface slope as percent rise for the Trishuli watershed.
- • Layers & Data Sources
- o Digital Elevation Model – ASTER – 2000 imagery
- • Methodology (if applicable): The surface slope was derived from the input DEM using bilinear interpolation (using the Slope tool in ArcMap 10.1).

Map 20: Topological Aspect

- • Description: Topological aspect (orientation of the surface of the terrain) in degrees for the Trishuli watershed.
- • Layers & Data Sources
- o Digital Elevation Model – ASTER – 2000 imagery
- • Methodology (if applicable): The surface aspect was derived from the input DEM (using the Aspect tool in ArcMap 10.1).

Map 21: Slide/Erosion Potential Analysis

- Description: Slide/Erosion potential for all areas within the Trishuli watershed.
- Layers & Data Sources
  - Slope (degrees) derived from: Digital Elevation Model – ASTER – 2000 imagery
  - Land Cover - World Wildlife Fund Nepal – 2010 satellite-derived data
  - Land Cover – ESSA Technologies – updated using 2010 Landsat-8 imagery
- Methodology (if applicable): Areas representing slope of 45-90 degrees were intersected with land cover classes susceptible to erosion and slides (bare soil, agriculture, sand, cliff). High slide potential was determined based on steeper slopes, proximity to water sources (within 1km) and land cover type (probability of loose surface materials). Moderate slide potential is found in drier areas within more moderate slopes.

Map 22: Solar Exposure (May-Oct 2013)

- Description: Solar exposure in W/m² per day for the 6-month summer period (May-October 2013).
- Layers & Data Sources
  - Digital Elevation Model – ASTER – 2000 imagery
- Methodology (if applicable): Solar exposure was derived from the input DEM (using the Solar Exposure tool in ArcMap 10.1).

Map 23: Detailed Terrain

- Description: Detailed topological terrain for the Trishuli watershed.
- Layers & Data Sources
  - Digital Elevation Model – ASTER – 2000 imagery
  - Solar Exposure model derived from: Digital Elevation Model – ASTER – 2000 imagery
- Methodology (if applicable): The Digital Elevation Model (DEM) and solar exposure model were intersected to create a visual contrast map of the terrain within the Trishuli watershed.

Map 24: Gandaki Basin - Land Cover (2010)

- Description: Land cover map of the Gandaki Basin (2010).
- Layers & Data Sources
  - Land Cover - World Wildlife Fund Nepal – 2010 satellite-derived data
  - Land Cover – ESSA Technologies – updated using 2000 Landsat-8 imagery (for Trishuli watershed)
- Methodology (if applicable): A new classification was performed by ESSA Technologies in order to improve the existing classification provided by WWF Nepal (only for Trishuli watershed area). The resulting land cover classifications were merged.

Map 25: Gandaki Basin - Hydro Licenses (Polygon)

- Description: Current areal locations of hydro licenses (operating, under construction, survey) in the Gandaki Basin. Data is up-to-date as of November 2013.
- Layers & Data Sources
  - Hydro license locations – Department of Electricity Development (Government of Nepal)

o Digital Elevation Model – ASTER – 2000 imagery

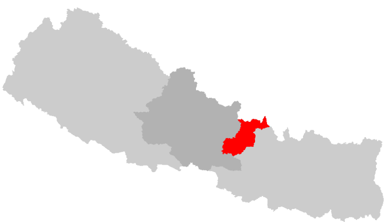
• Methodology (if applicable): Data was downloaded in tabular format from the DOED website (http://www.doed.gov.np/). The provided coordinates were used to locate the outer bounds (rectangular) of the license. Note – there are some discrepancies in the naming of these licenses in the source data.

Map 26: Gandaki Basin - Roads & Rivers

• Description: The major roads and rivers found in the Gandaki Basin.
• Layers & Data Sources
o Roads - World Wildlife Fund Nepal – 2010 Data
o Rivers - Survey Department (Government of Nepal) – 1996 Data
o Digital Elevation Model – ASTER – 2000 imagery
• Methodology (if applicable): Trails and cart tracks were removed from the road layer. 4th order and higher streams were removed from the river layer.

Map 27: Project Site - Land Cover (2010)

• Description: Land cover map of the UT-1 Hydropower Project site (2010).
• Layers & Data Sources
o Land Cover – NESS – Manually digitized from 2010 Google Earth imagery
• Methodology (if applicable): A new manual classification was performed by NESS. Land cover classes were matched to those of the other, larger scale, classifications (watershed, basin).



Kilometers 0 105 210 420 630

UT-1 Hydropower Project

Roads

Trishuli River

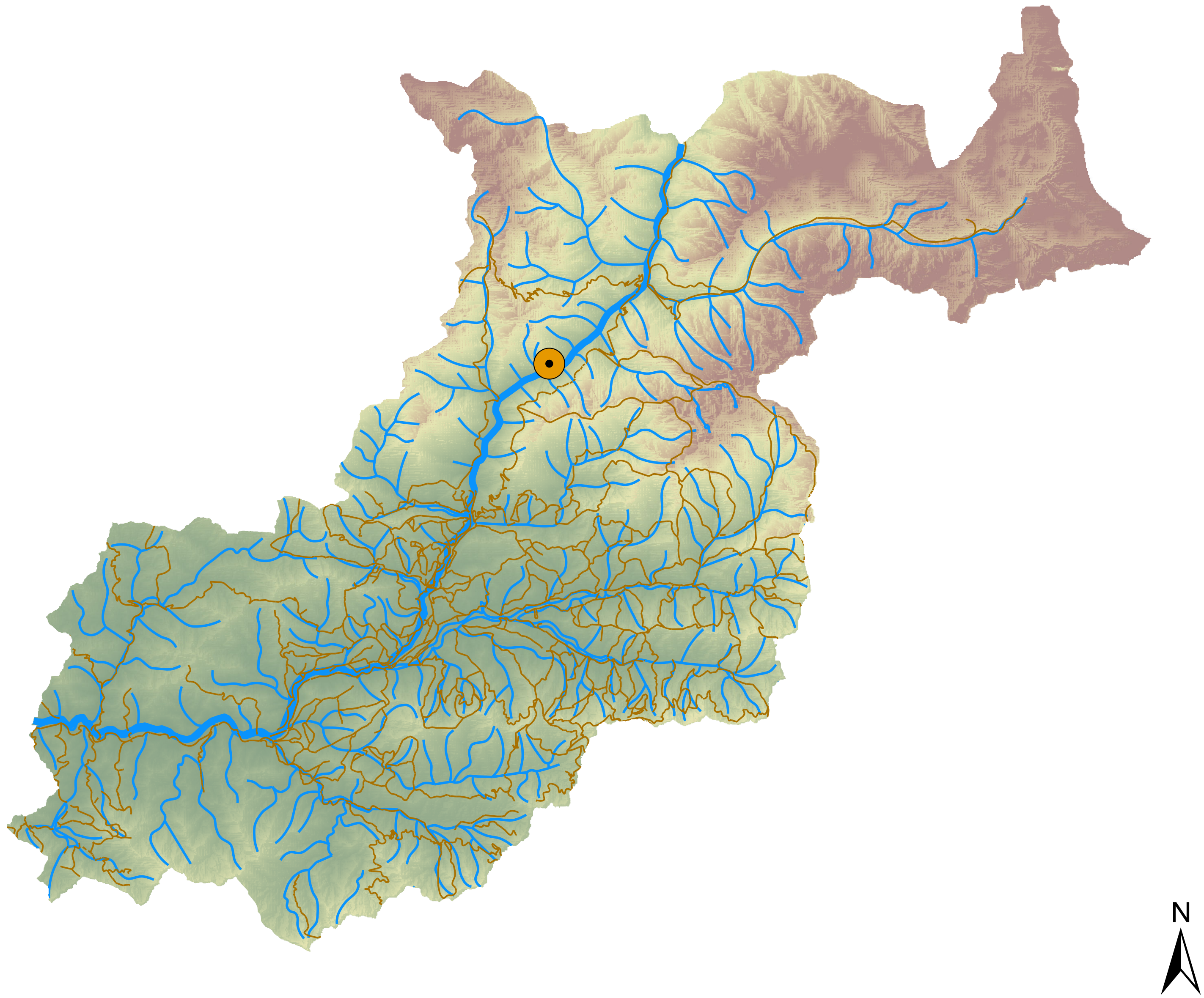
Minor Rivers

Digital Elevation Model

Elevation

High : 7203m

Low : 329m



Kilometers 0 5 10 20 30 40

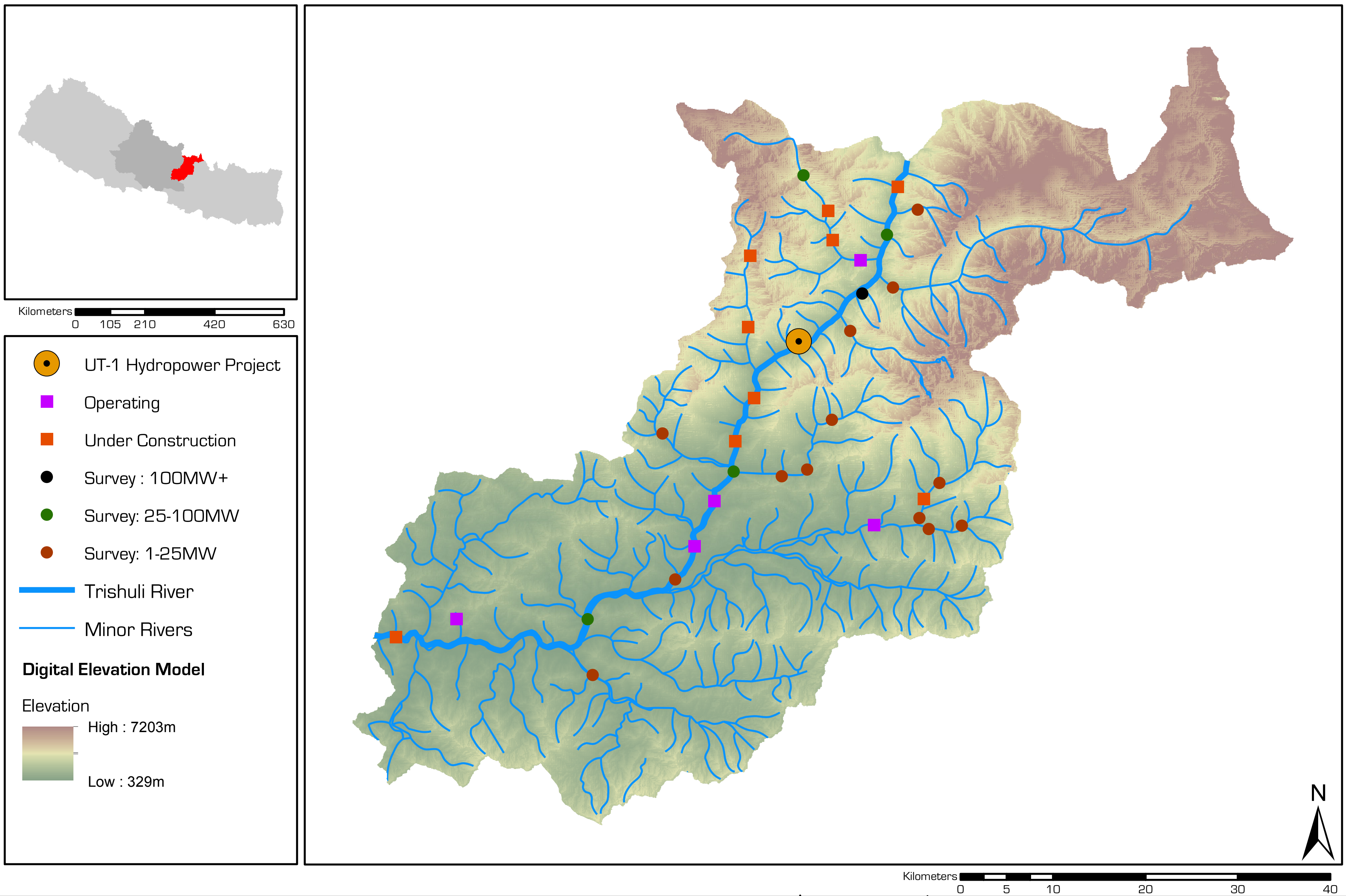
Trishuli Watershed
Major Roads and Rivers

Map 01

ESSA Technologies Ltd.

Created by: Nick Ochoski, M.Sc.

Upper Trishuli-1
Hydropower Project



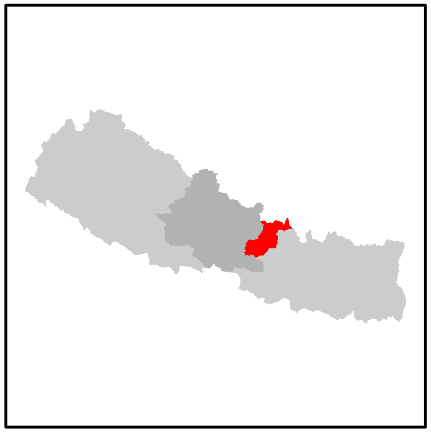
Trishuli Watershed Hydro Licenses

Map 02

ESSA Technologies Ltd.

Created by: Nick Ochoski, M.Sc.

Upper Trishuli-1 Hydropower Project



Kilometers
0 105 210 420 630

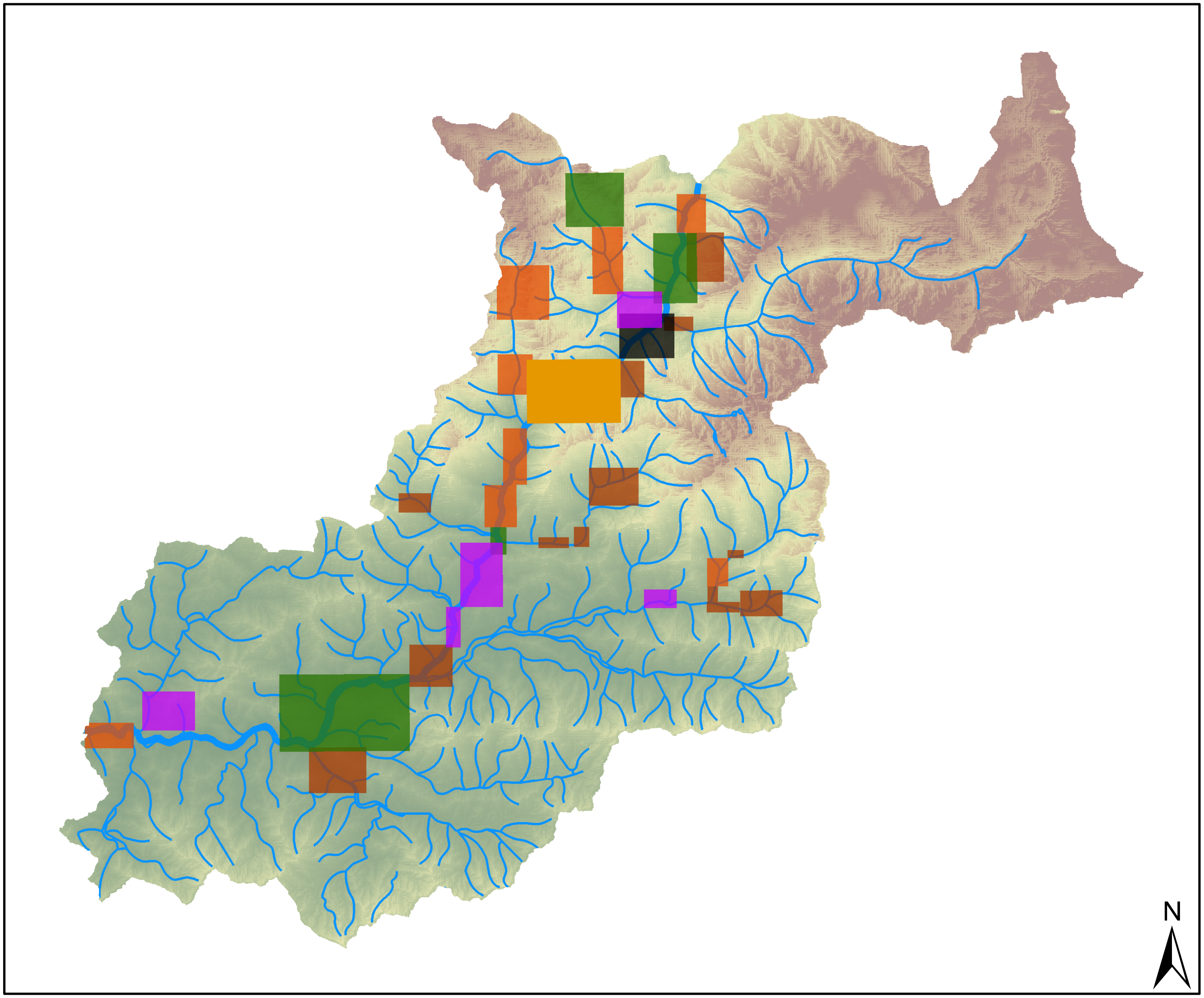
- UT-1 Hydropower Project
- Operating
- Under Construction
- Survey: 100MW+
- Survey: 25-100MW
- Survey: 1-25MW
- Trishuli River
- Minor Rivers

Digital Elevation Model

Elevation

High : 7203m

Low : 329m



Kilometers
0 5 10 20 30 40

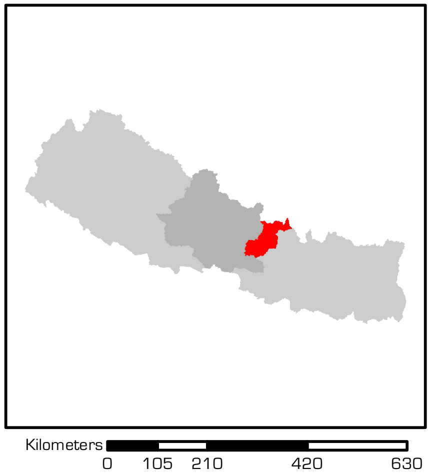
Trishuli Watershed Hydro Licenses

Map 03

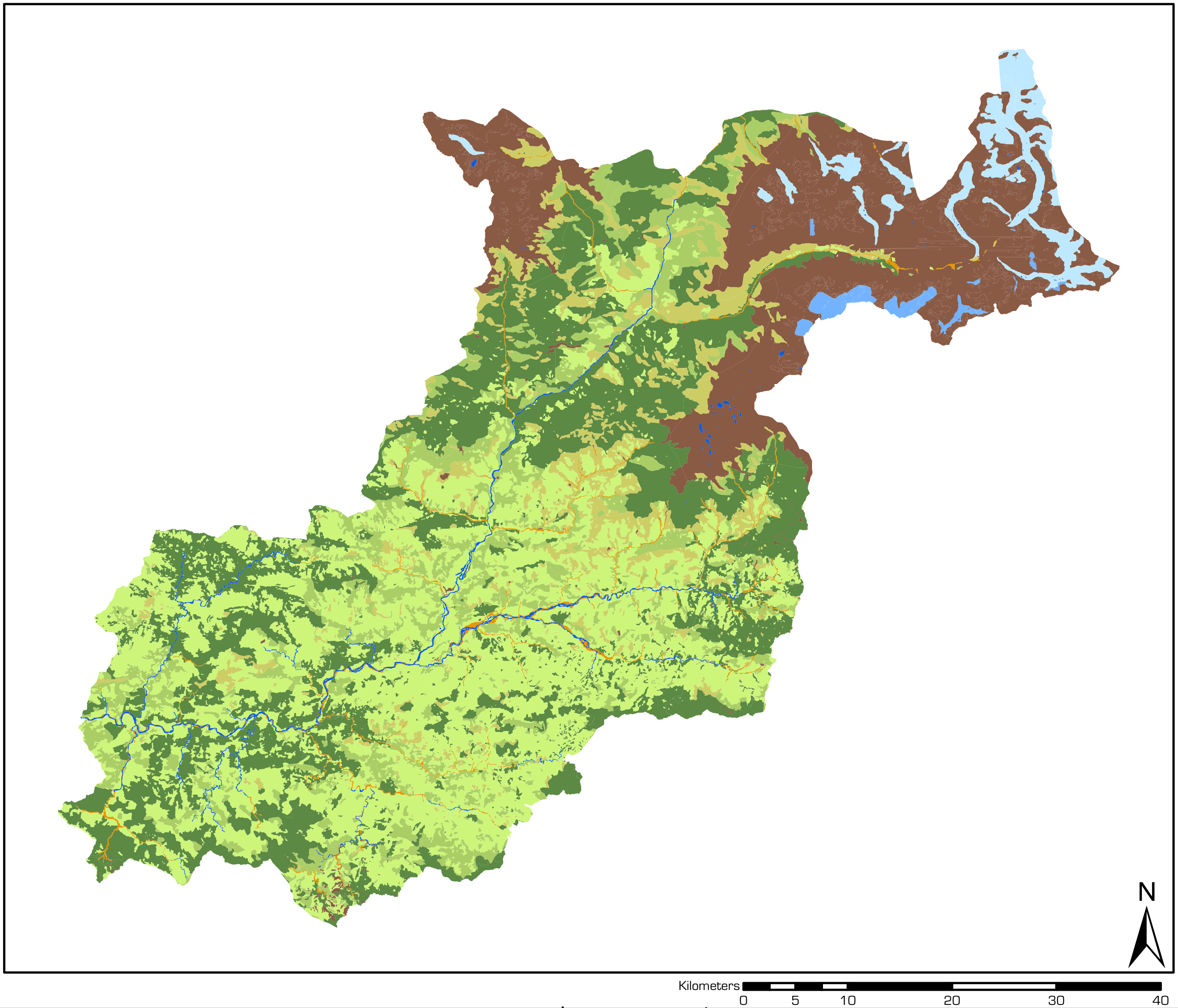
ESSA Technologies Ltd.

Created by: Nick Ochoski, M.Sc.

Upper Trishuli-1 Hydropower Project



- Forest
- Scrub
- Agriculture
- Grass
- Sand
- Barren Land
- Glacier
- Snow
- Waterbody



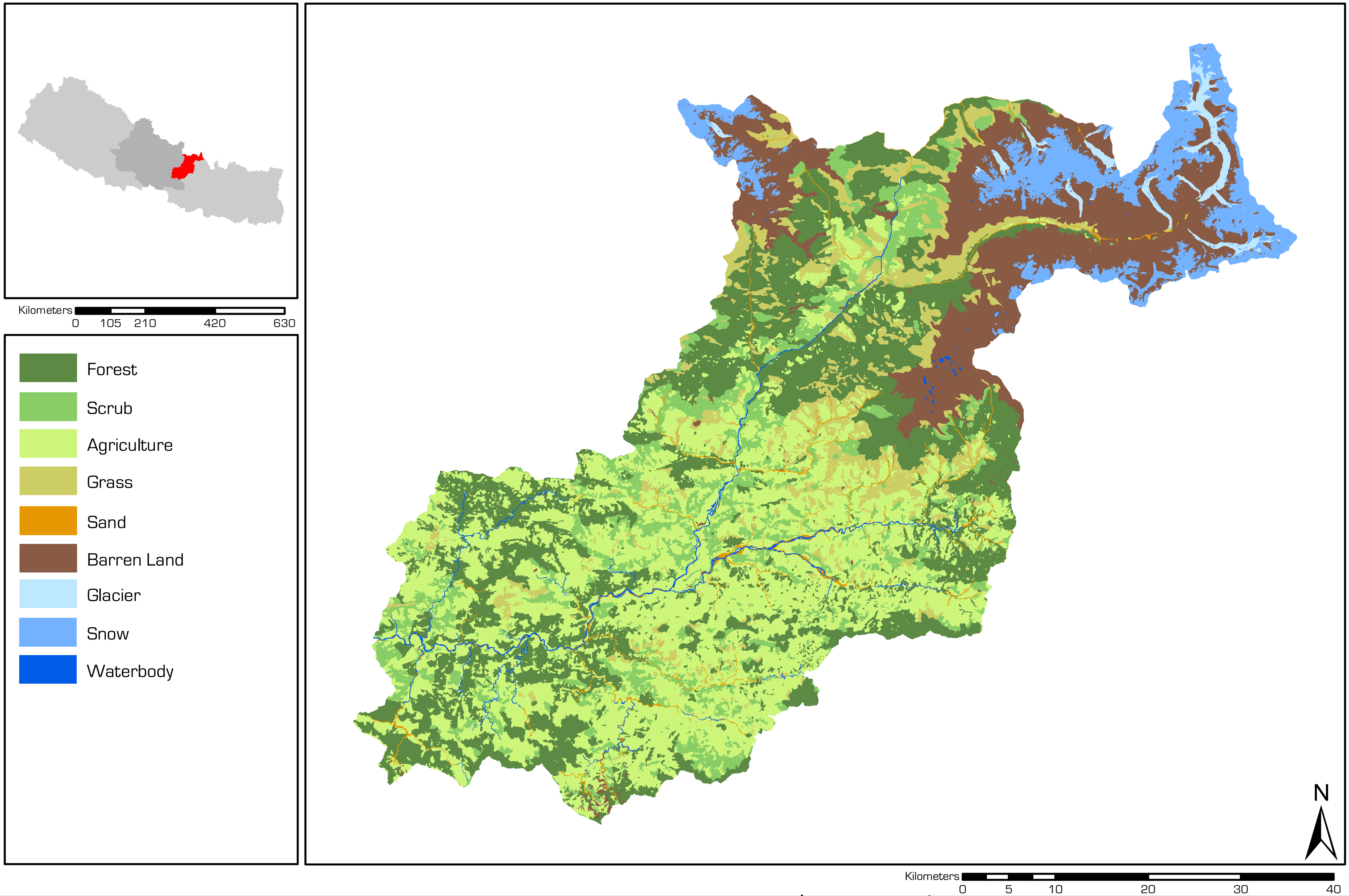
Trishuli Watershed Land Cover (1990)

Map 04

ESSA Technologies Ltd.

Created by: Nick Ochoski, M.Sc.

Upper Trishuli-1 Hydropower Project



Trishuli Watershed Land Cover (2000)

Map 05

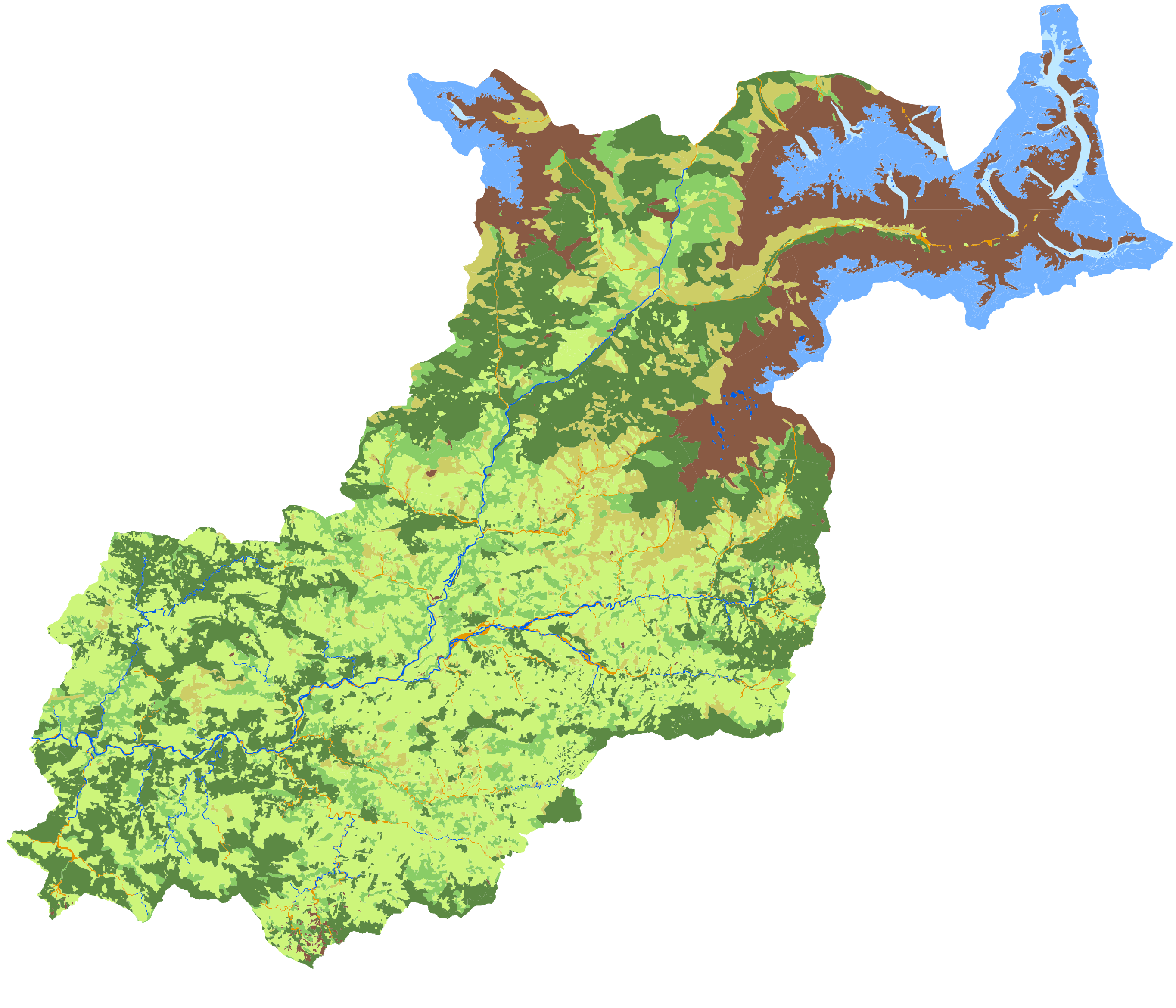
ESSA Technologies Ltd.

Created by: Nick Ochoski, M.Sc.

Upper Trishuli-1 Hydropower Project

Kilometers
0 105 210 420 630

Forest
Scrub
Agriculture
Grass
Sand
Barren Land
Glacier
Snow
Waterbody



Kilometers
0 5 10 20 30 40

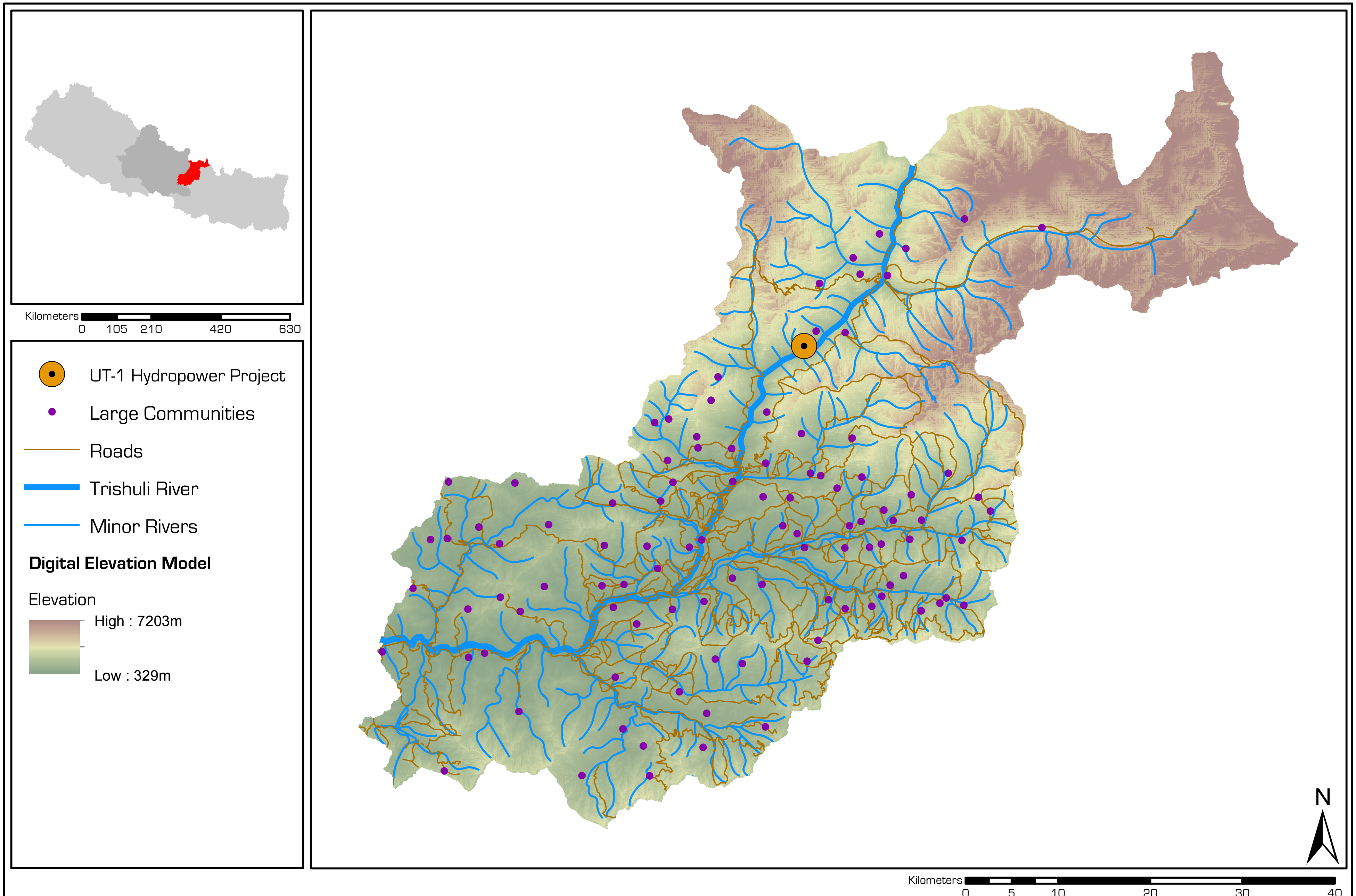
Trishuli Watershed
Land Cover (2010)

Map 06

ESSA Technologies Ltd.

Created by: Nick Ochoski, M.Sc.

Upper Trishuli-1
Hydropower Project



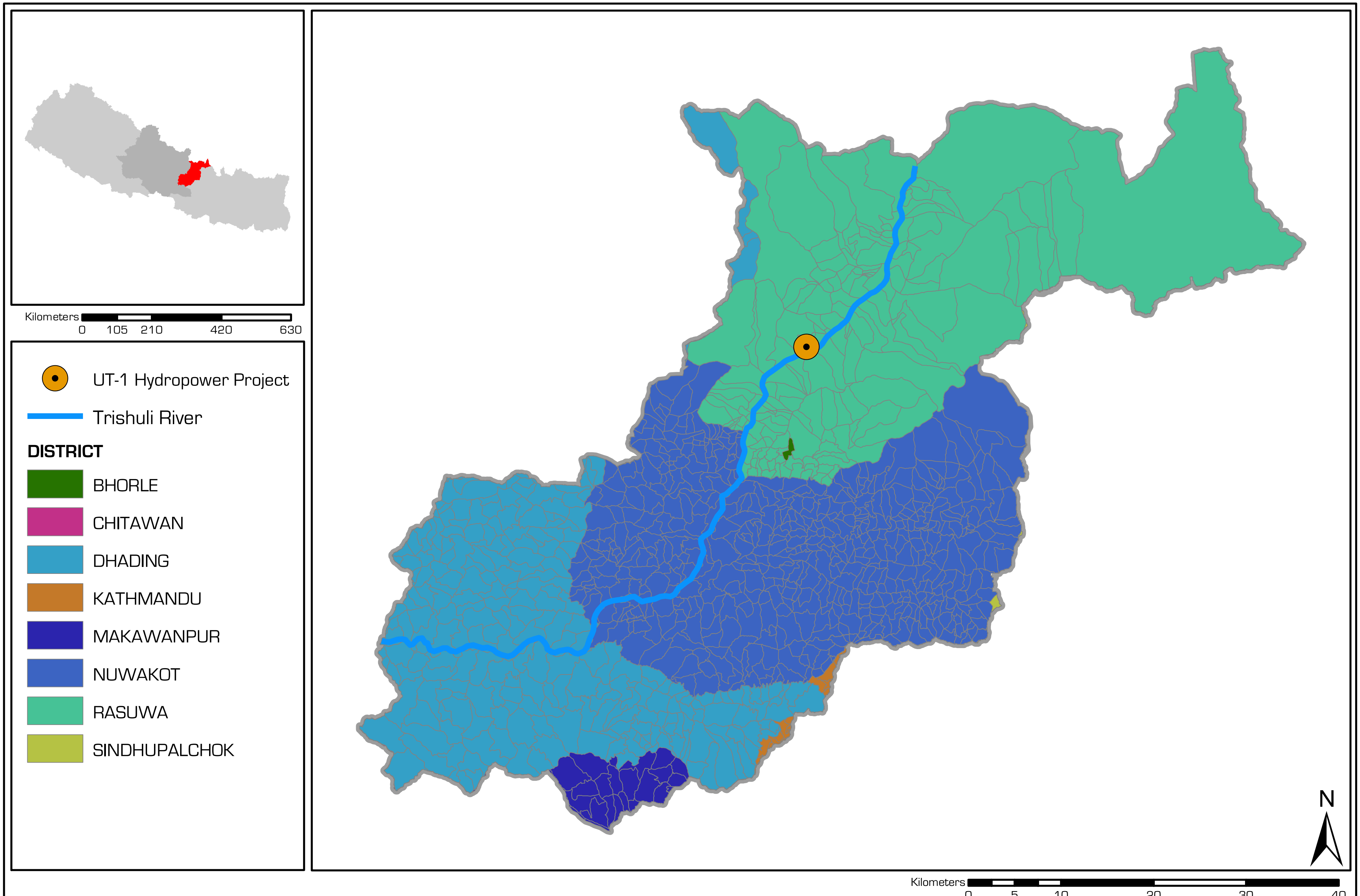
Trishuli Watershed
Large Communities

Map 07

ESSA Technologies Ltd.

Created by: Nick Ochoski, M.Sc.

Upper Trishuli-1
Hydropower Project



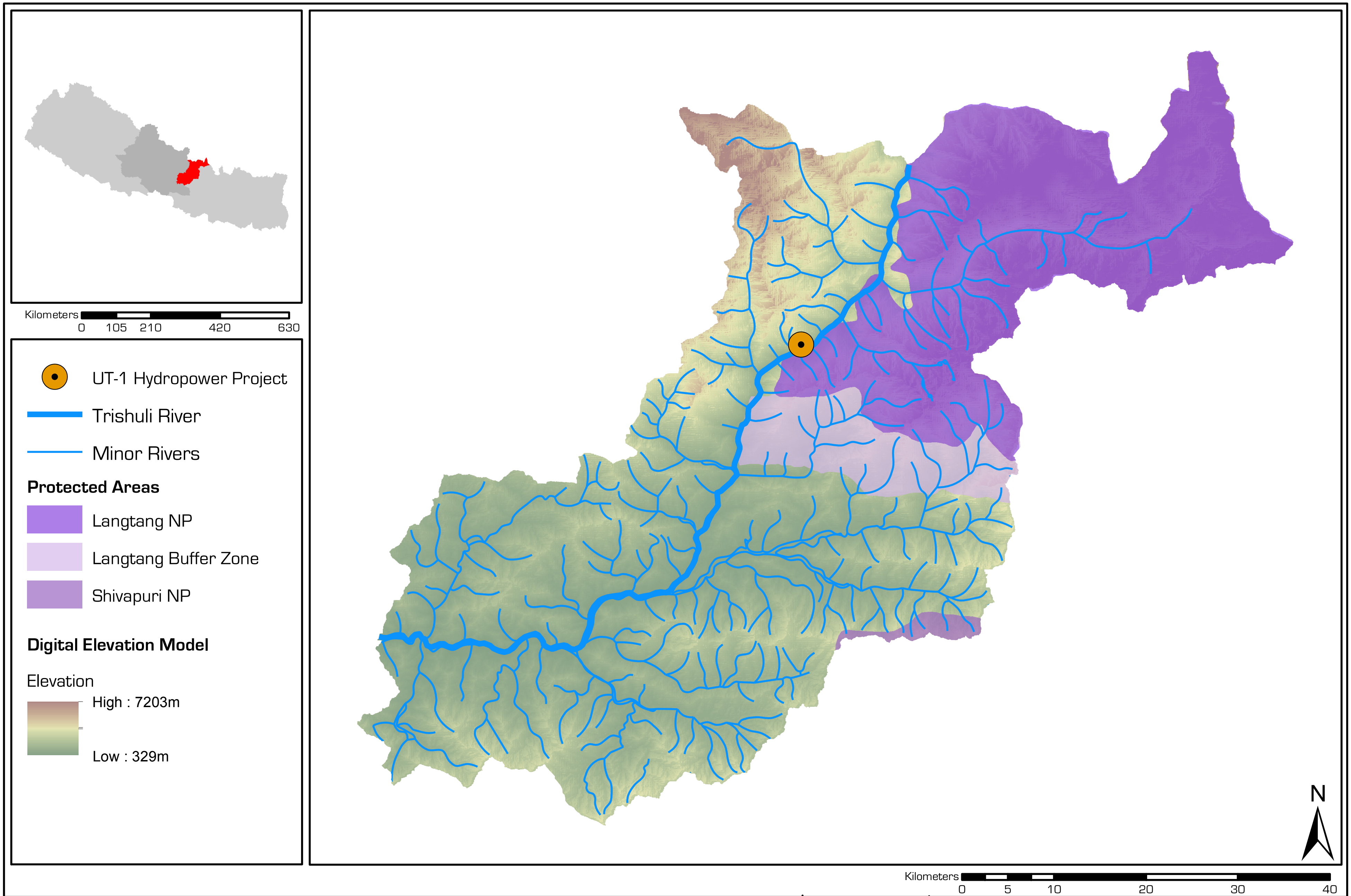
Trishuli Watershed
Political Districts

Map 08

ESSA Technologies Ltd.

Created by: Nick Ochoski, M.Sc.

Upper Trishuli-1
Hydropower Project



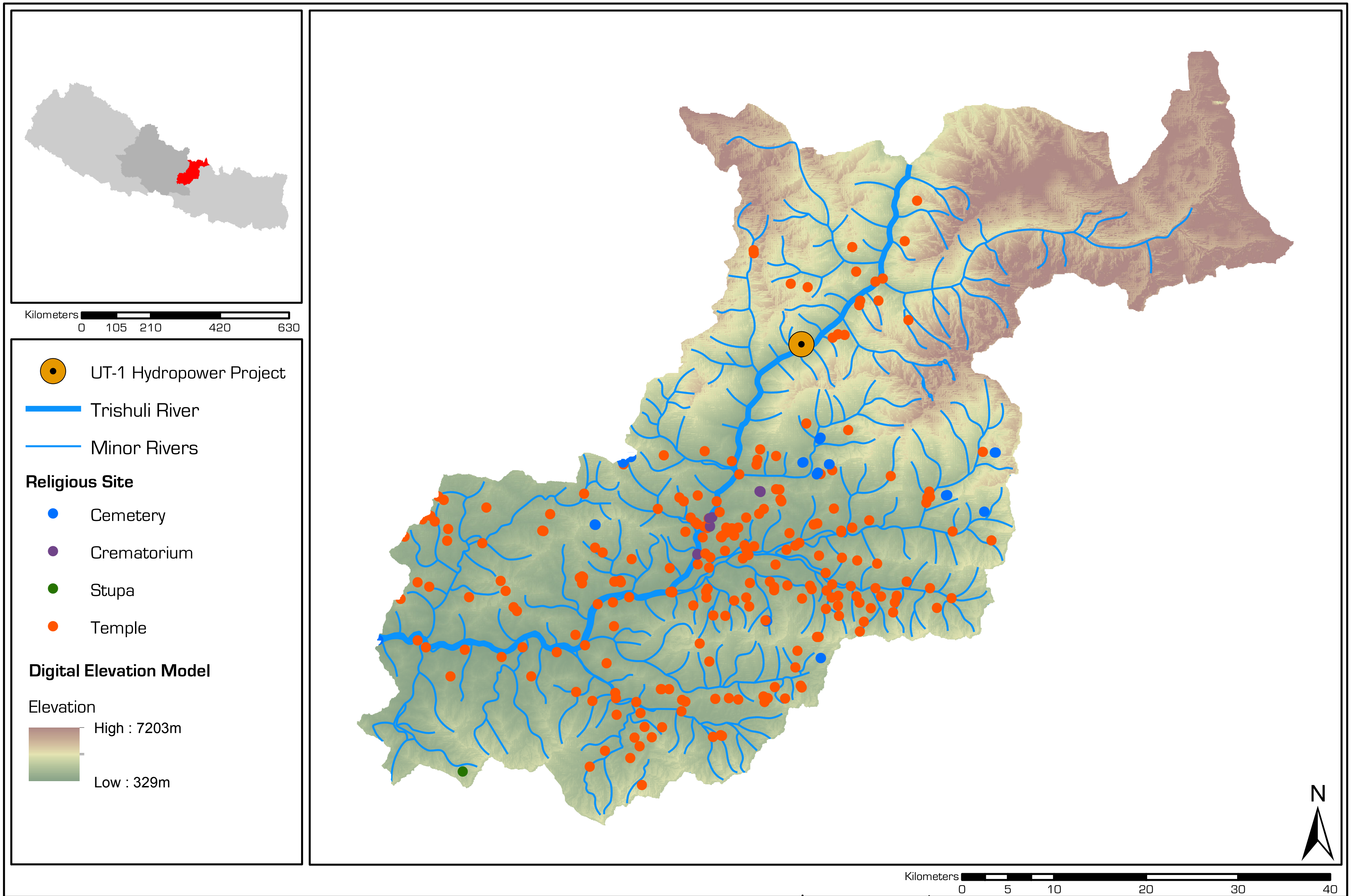
Trishuli Watershed
Protected Areas and Buffer Zones

Map 09

ESSA Technologies Ltd.

Created by: Nick Ochoski, M.Sc.

Upper Trishuli-1
Hydropower Project



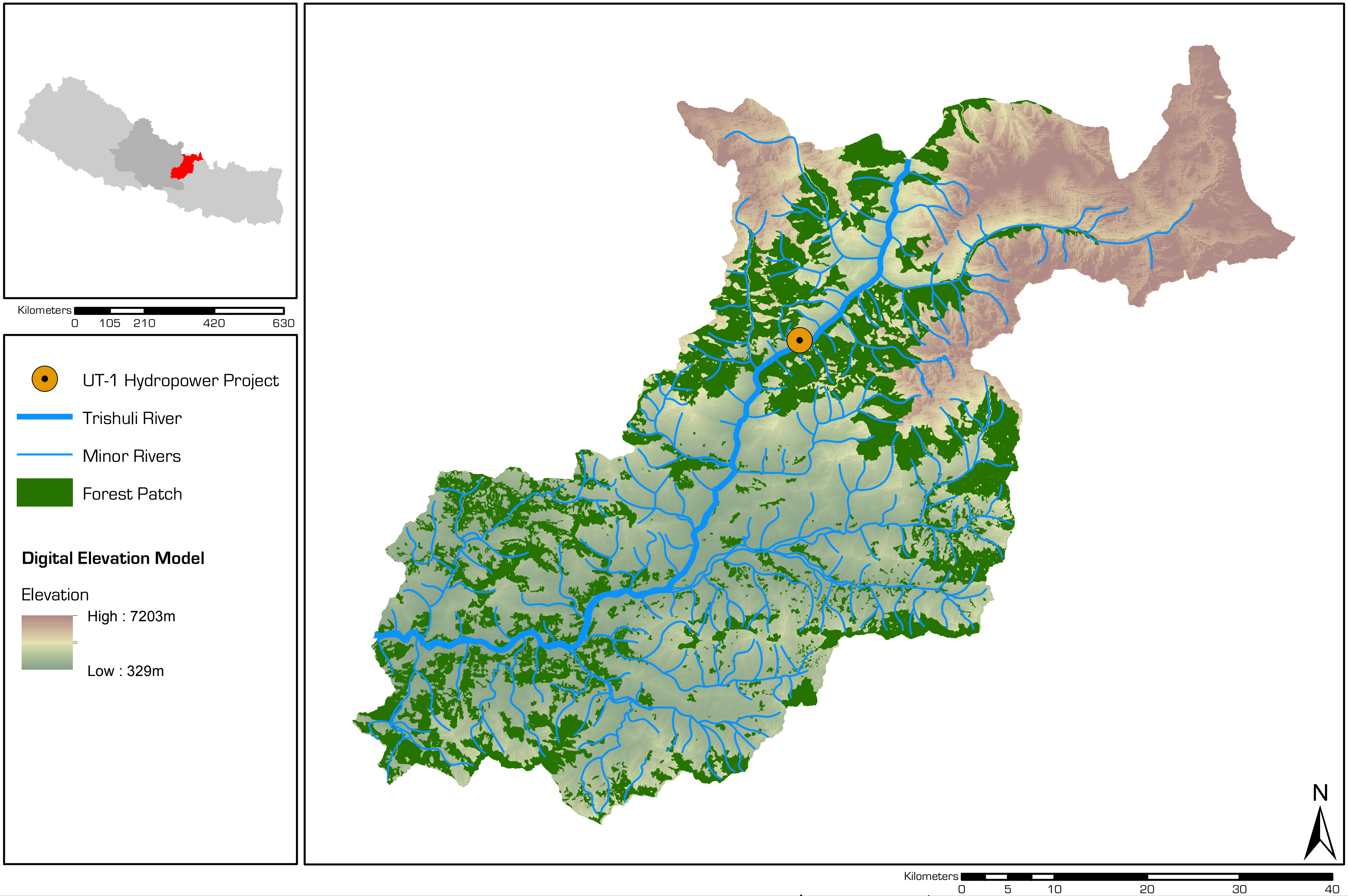
Trishuli Watershed Religious Sites

Map 10

ESSA Technologies Ltd.

Created by: Nick Ochoski, M.Sc.

Upper Trishuli-1 Hydropower Project



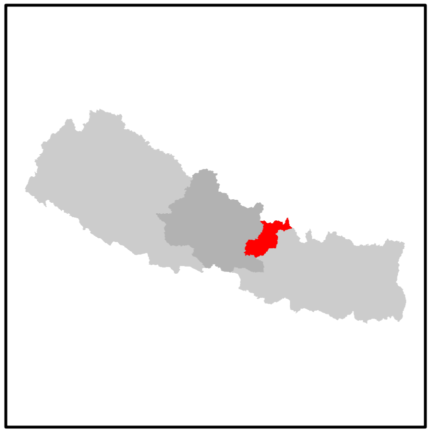
Trishuli Watershed
Forest Patches

Map 11

ESSA Technologies Ltd.

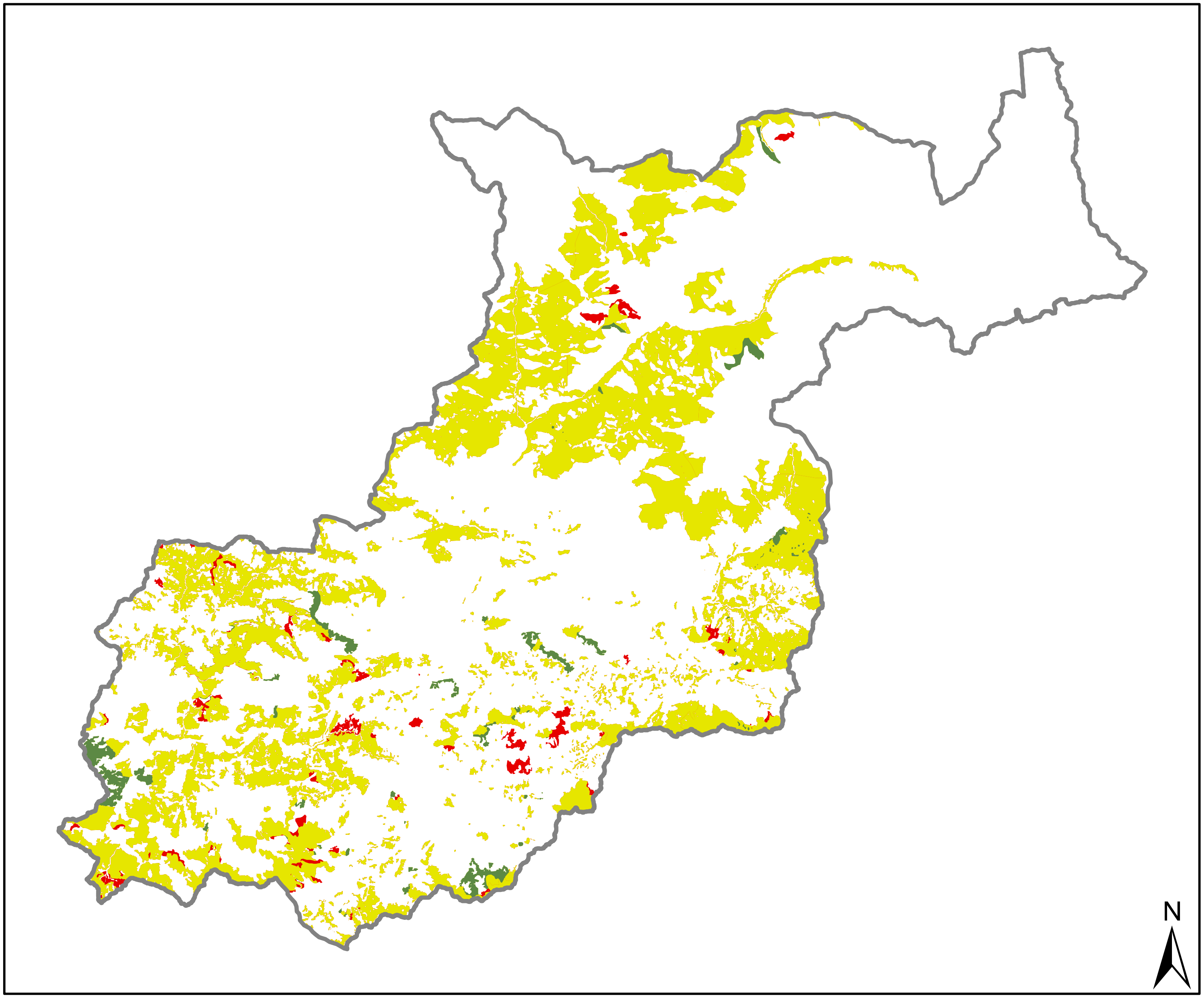
Created by: Nick Ochoski, M.Sc.

Upper Trishuli-1
Hydropower Project



Kilometers
0 105 210 420 630

Forest Gain
No Change
Forest Loss



Kilometers
0 5 10 20 30 40

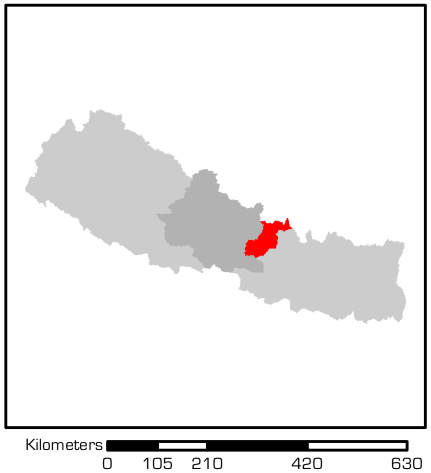
Trishuli Watershed
Forest Change (1990 - 2010)

Map 12

ESSA Technologies Ltd.

Created by: Nick Ochoski, M.Sc.

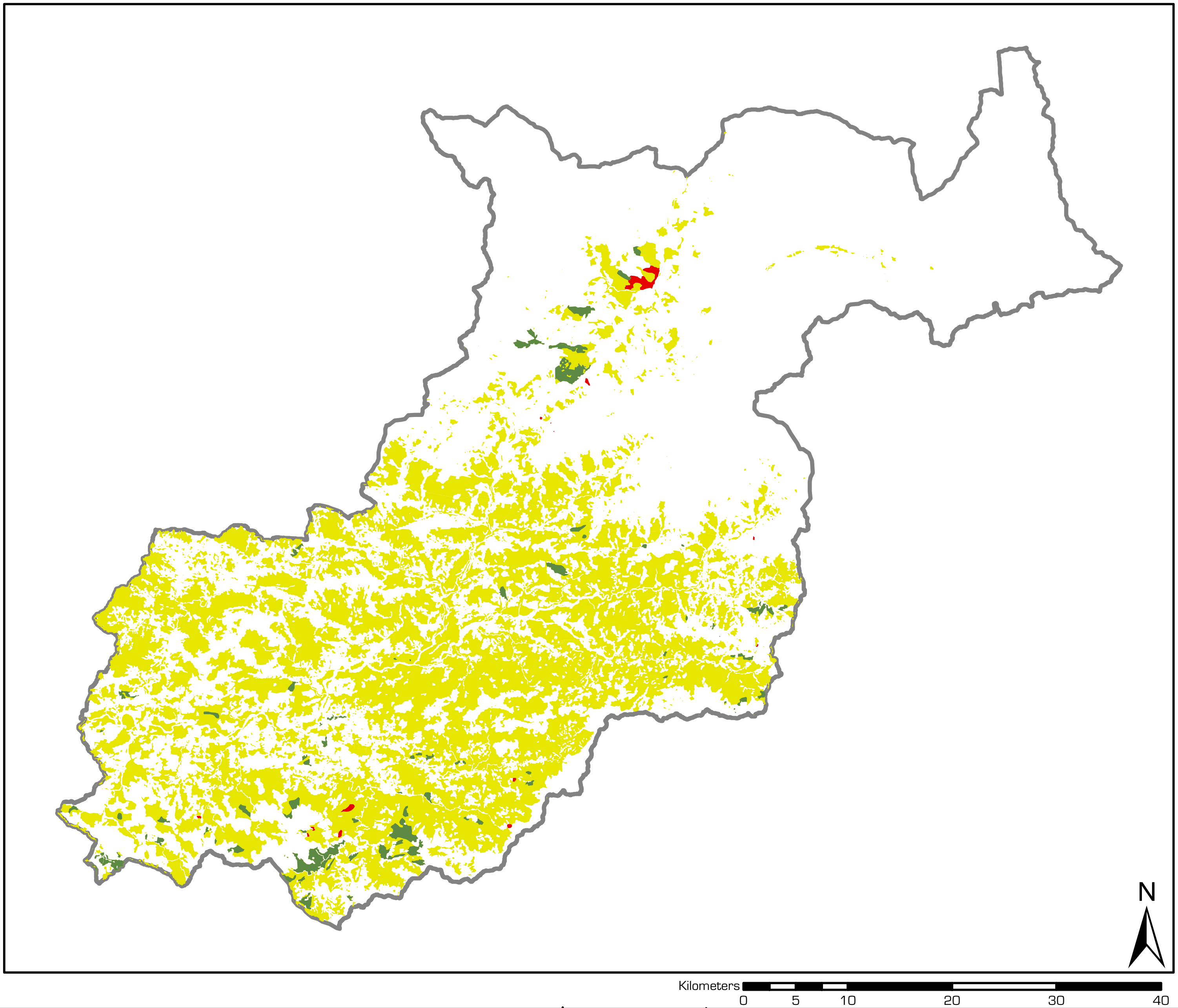
Upper Trishuli-1
Hydropower Project



Agriculture Gain

No Change

Agriculture Loss



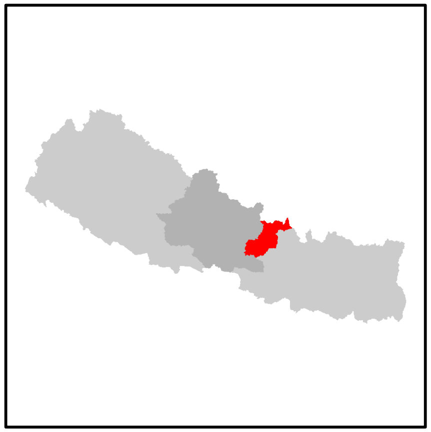
Trishuli Watershed
Agriculture Change (1990 - 2010)

Map 13

ESSA Technologies Ltd.

Created by: Nick Ochoski, M.Sc.

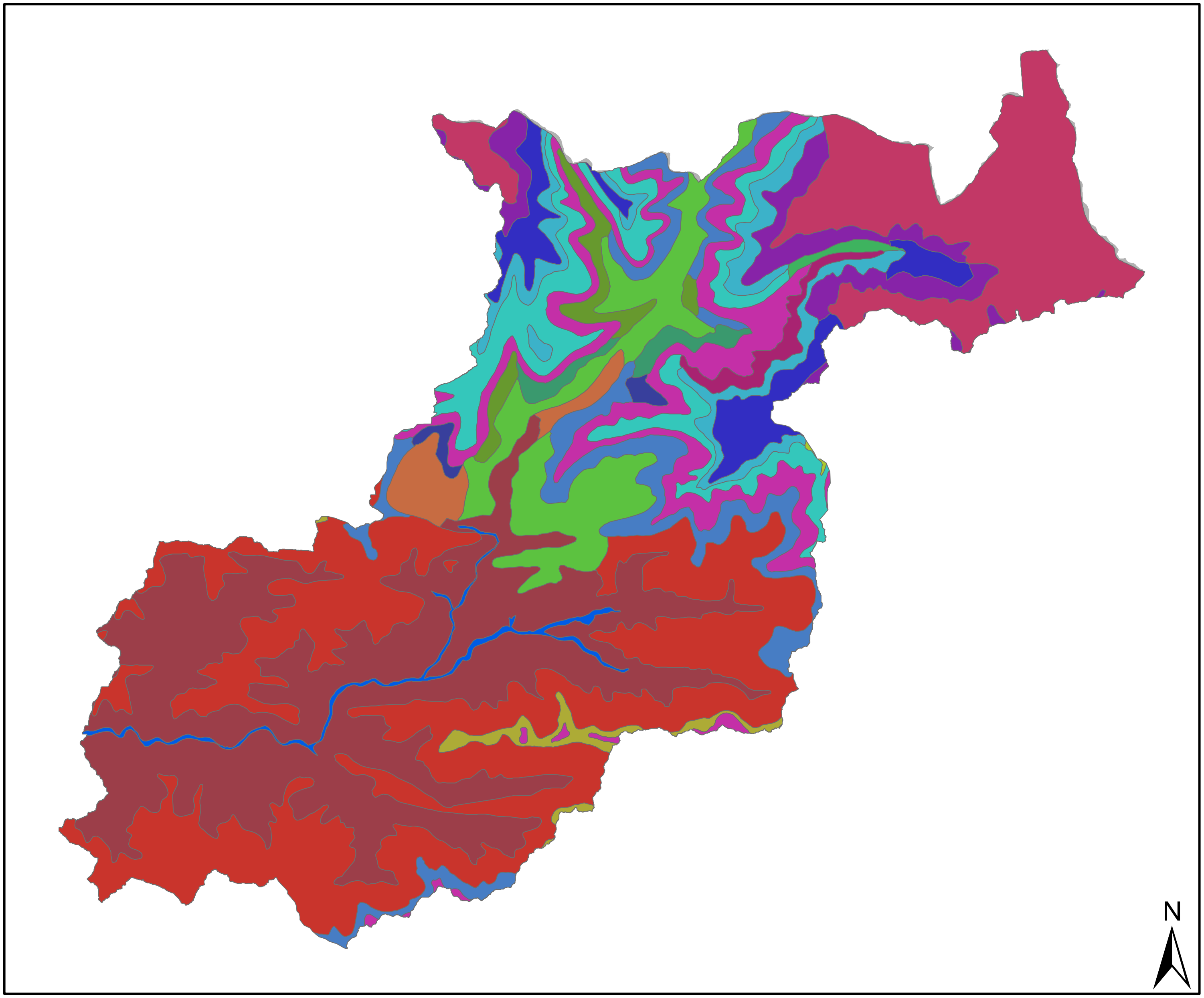
Upper Trishuli-1
Hydropower Project



Kilometers 0 105 210 420 630

Forest Type

- Alpine Pasture
- Birch-Rhododendron Forest
- Chir Pine Forest
- Chir Pine-Broad Leaved Forest
- Dwarf Rhododendron Scrub
- East Himalayan Oak-Laurel Forest
- Fir Forest
- Hill Sal Forest
- Juniper Scrub
- Larch Forest
- Lower Temperate Oak Forest
- Mixed Blue Pine-Oak Forest
- Mixed Oak-Laurel Forest
- Nival Zone
- Schima-Castanopsis Forest
- Temperate Mountain Oak Forest
- Trans-Himalayan Steppe
- Upper Temperate Blue Pine Forest
- Water Body



Kilometers 0 5 10 20 30 40

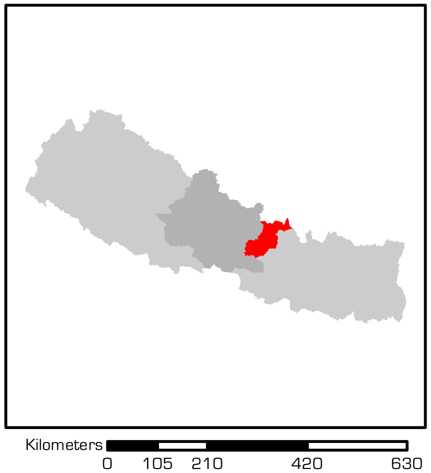
Trishuli Watershed Dominant Forest Type

Map 14

ESSA Technologies Ltd.

Created by: Nick Ochoski, M.Sc.

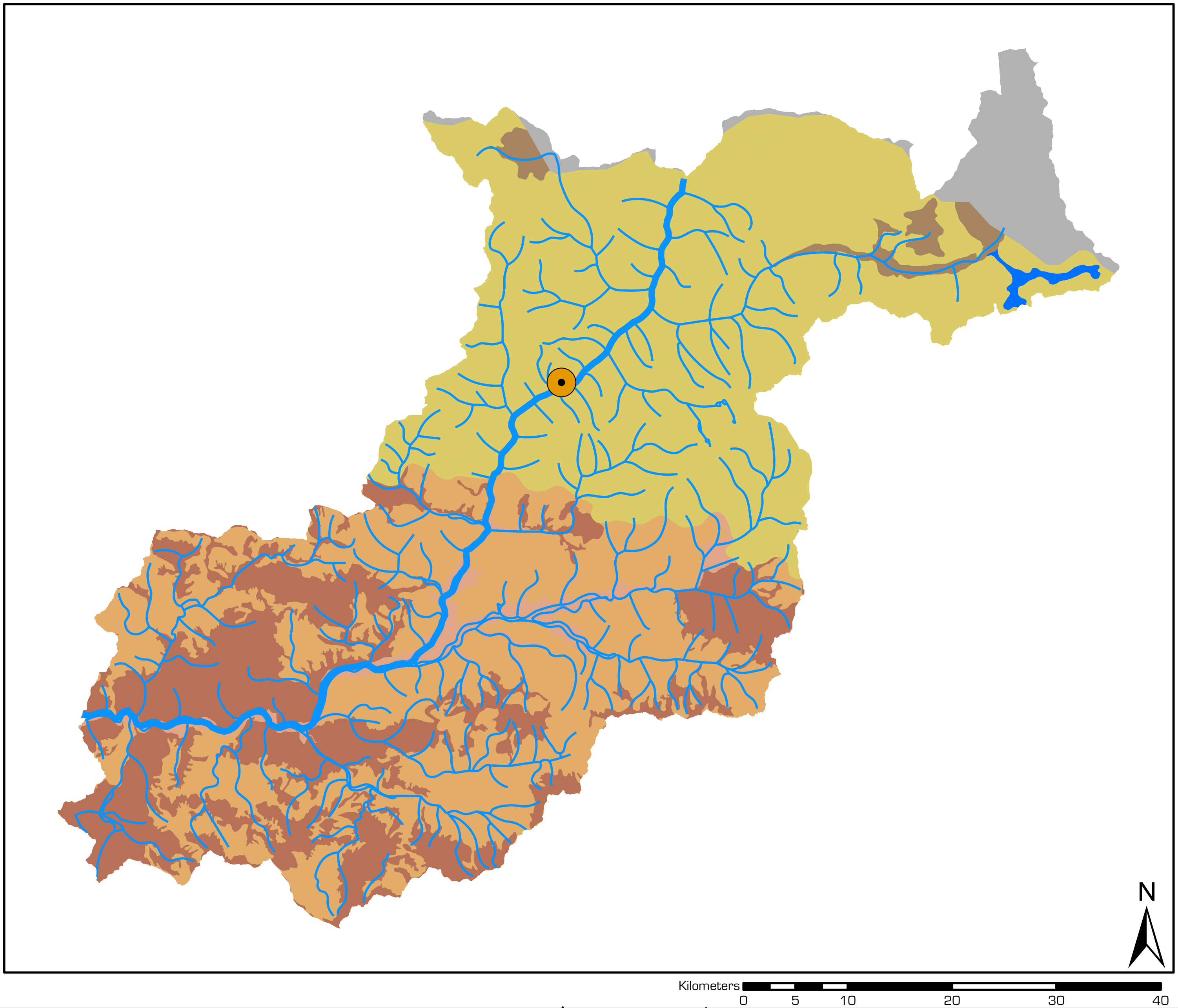
Upper Trishuli-1 Hydropower Project



UT-1 Hydropower Project
Trishuli River
Minor Rivers

Dominant Parent Material

- Quartzite
- Gneiss, migmatite
- Slate, phyllite
- Colluvial, calcareous
- Fluvial, non-calcareous
- GG - Glacier, inland ice



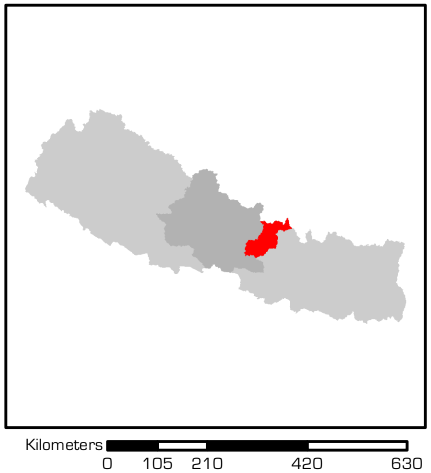
Trishuli Watershed
Dominant Parent Materials

Map 15

ESSA Technologies Ltd.

Created by: Nick Ochoski, M.Sc.

Upper Trishuli-1
Hydropower Project



UT-1 Hydropower Project

Trishuli River

Minor Rivers

Dominant Soil Type

CMe - Eutric CAMBISOLS

CMg - Gleyic CAMBISOLS

CMu - Humic CAMBISOLS

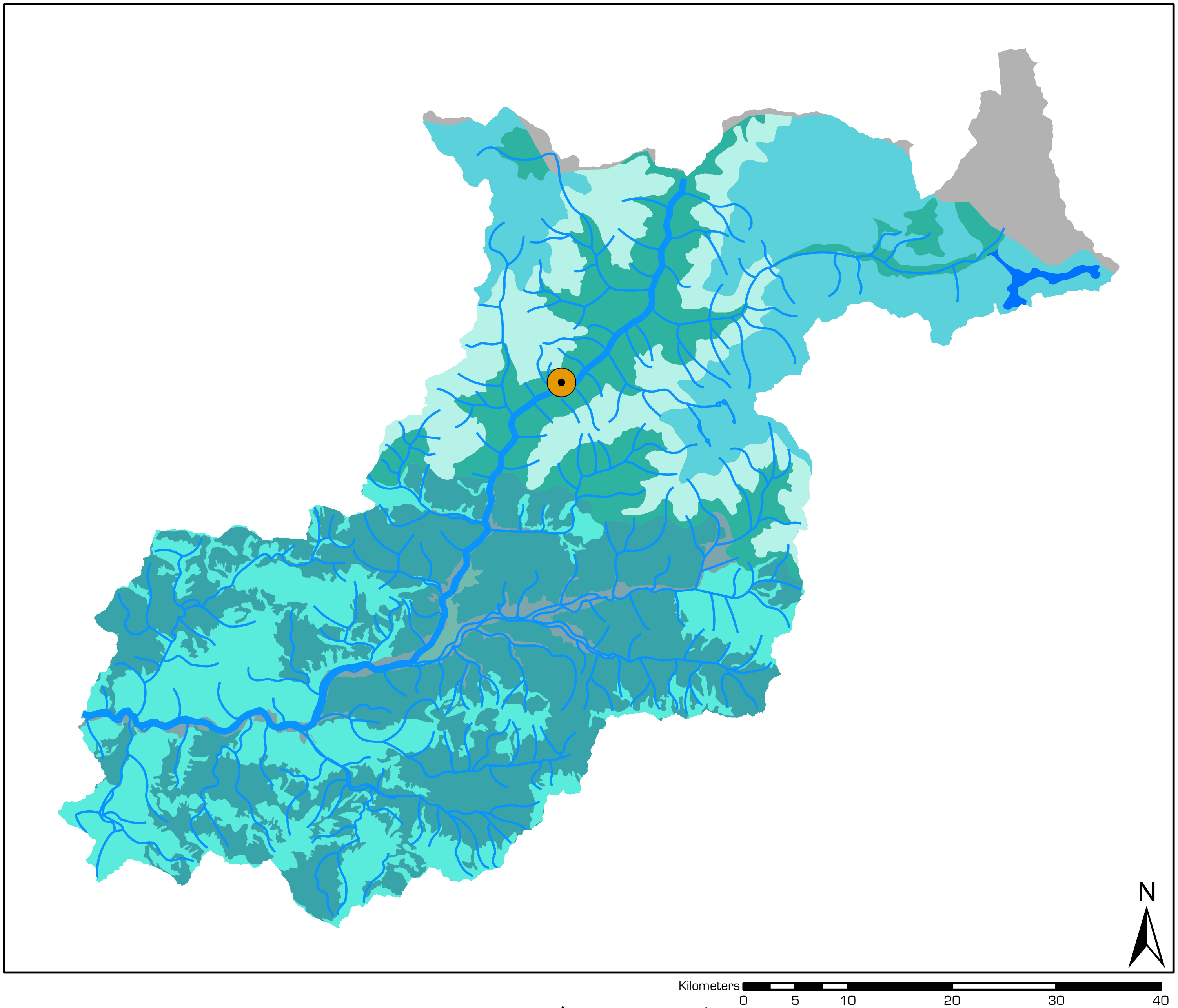
CMx - Chromic CAMBISOLS

LPi - Gelic LEPTOSOLS

LVx - Chromic LUVISOLS

RGe - Eutric REGOSOLS

GG - Glacier, inland ice



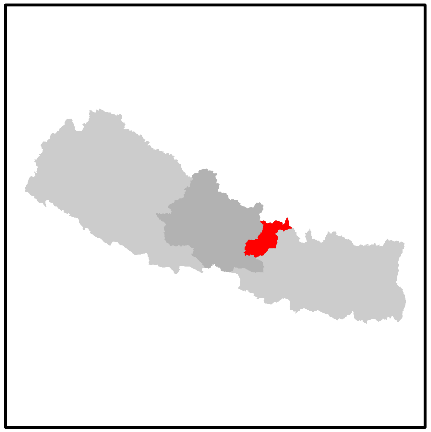
Trishuli Watershed Dominant Soils

Map 16

ESSA Technologies Ltd.

Created by: Nick Ochoski, M.Sc.

Upper Trishuli-1 Hydropower Project



Kilometers
0 105 210 420 630

UT-1 Hydropower Project

Trishuli River

Minor Rivers

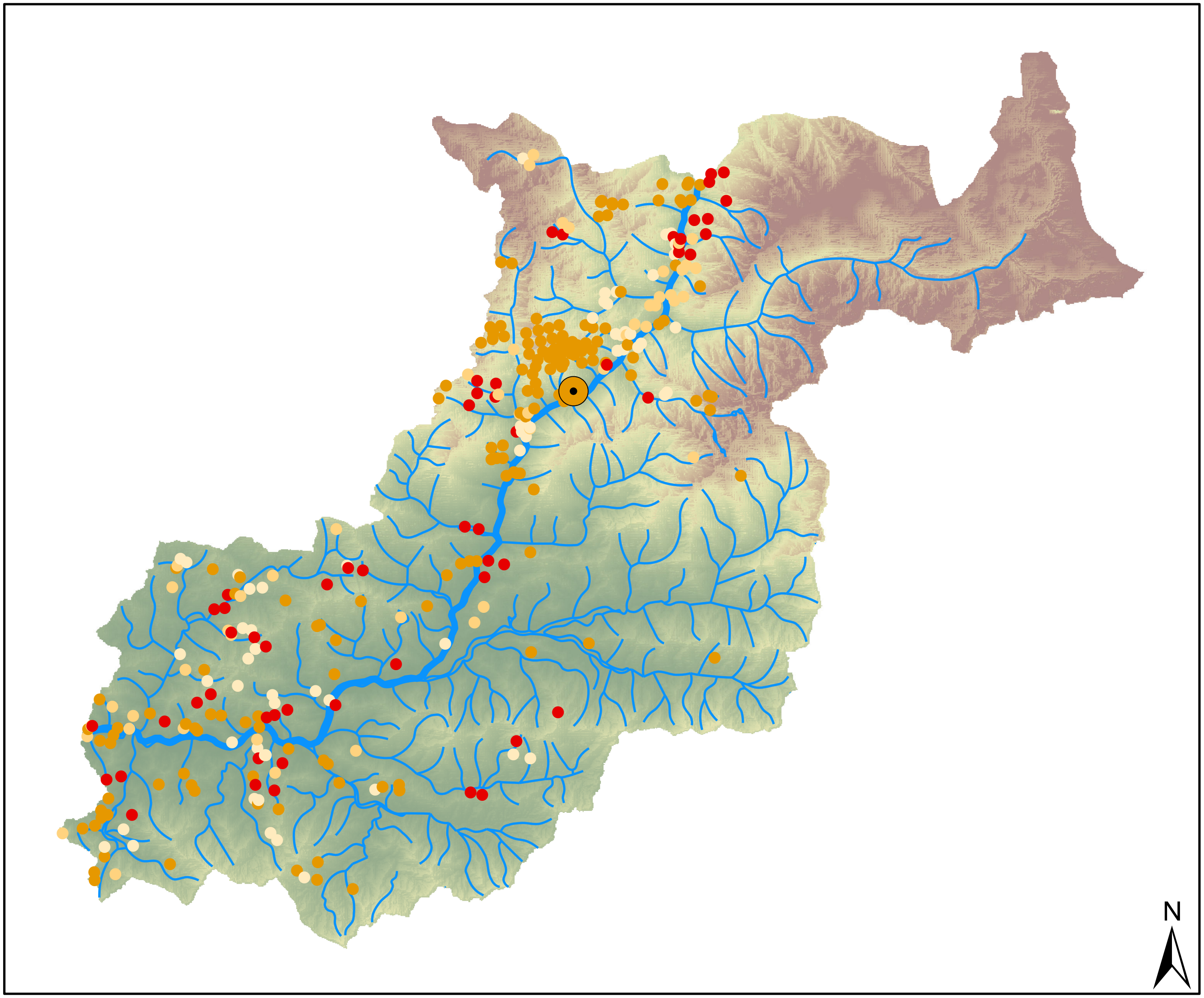
Fire Year

2003 - 2005

2006 - 2007

2008 - 2009

2010 - 2011



Kilometers
0 5 10 20 30 40

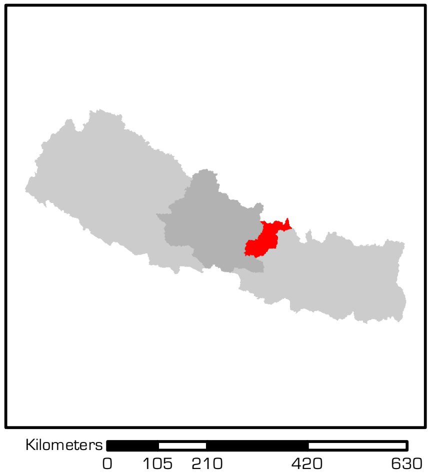
Trishuli Watershed
Fire Events (2003-2011)

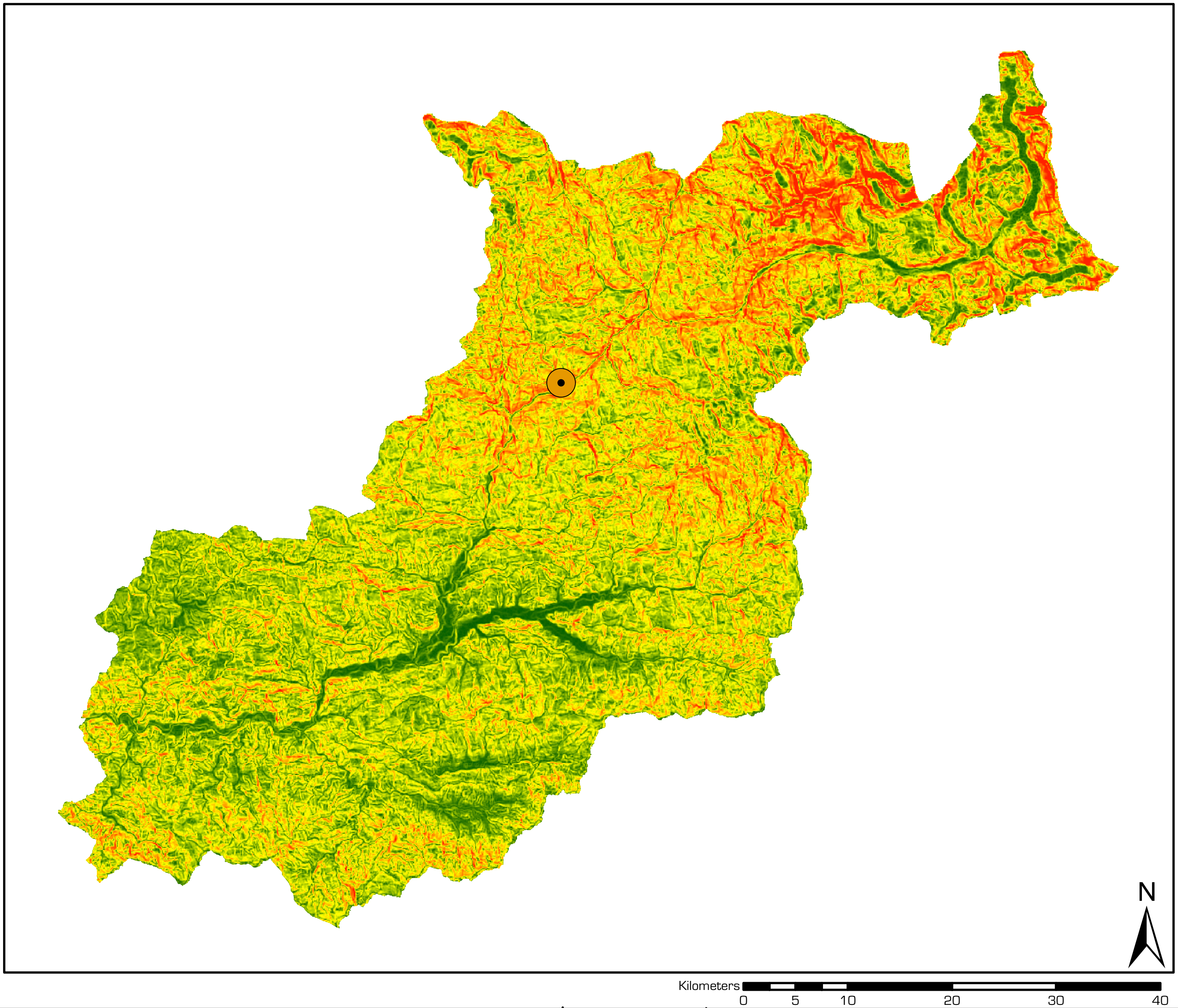
Map 17

ESSA Technologies Ltd.

Created by: Nick Ochoski, M.Sc.

Upper Trishuli-1
Hydropower Project





UT-1 Hydropower Project

Slope (Degree)

High : 85 degrees

Low : 0 degrees

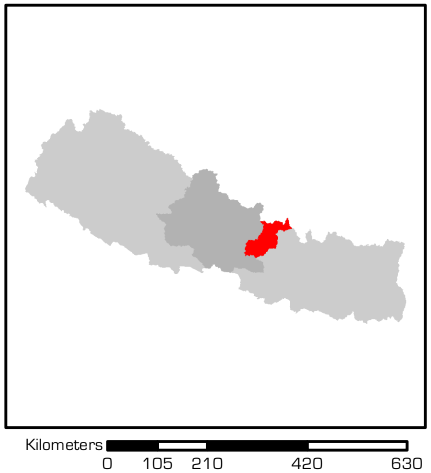
Trishuli Watershed
Slope (Degree)

Map 18

ESSA Technologies Ltd.

Created by: Nick Ochoski, M.Sc.

Upper Trishuli-1
Hydropower Project

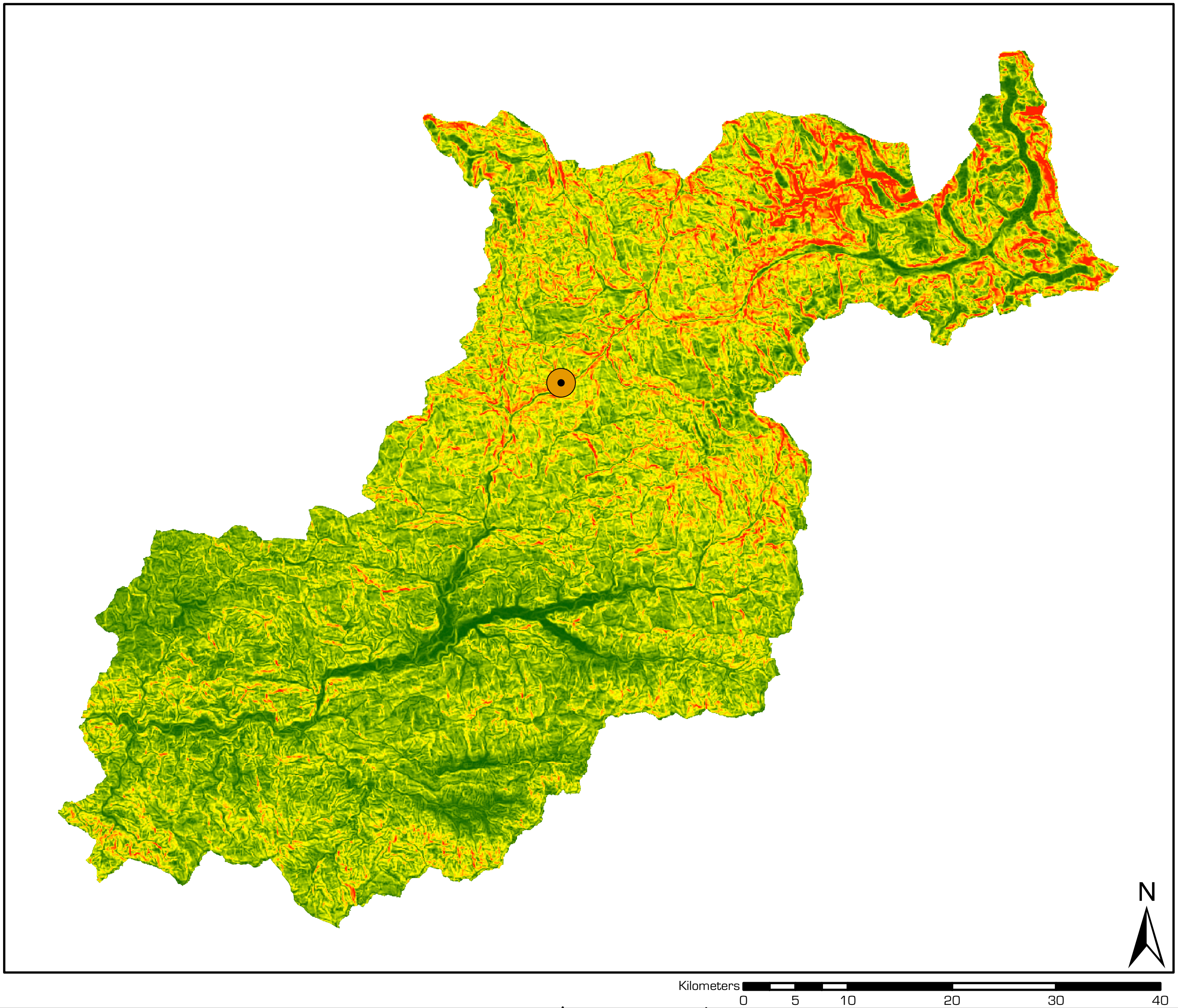


UT-1 Hydropower Project

Slope (Percent Rise)

High : 2000%

Low : 0%



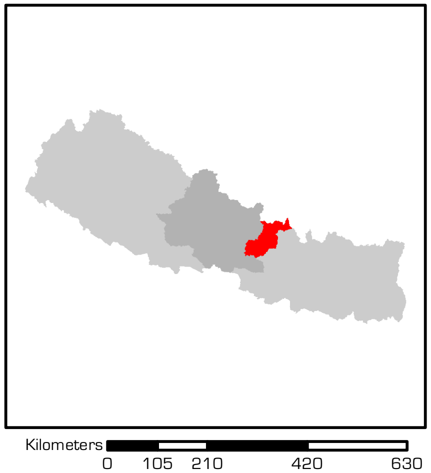
Trishuli Watershed
Slope (Percent Rise)

Map 19

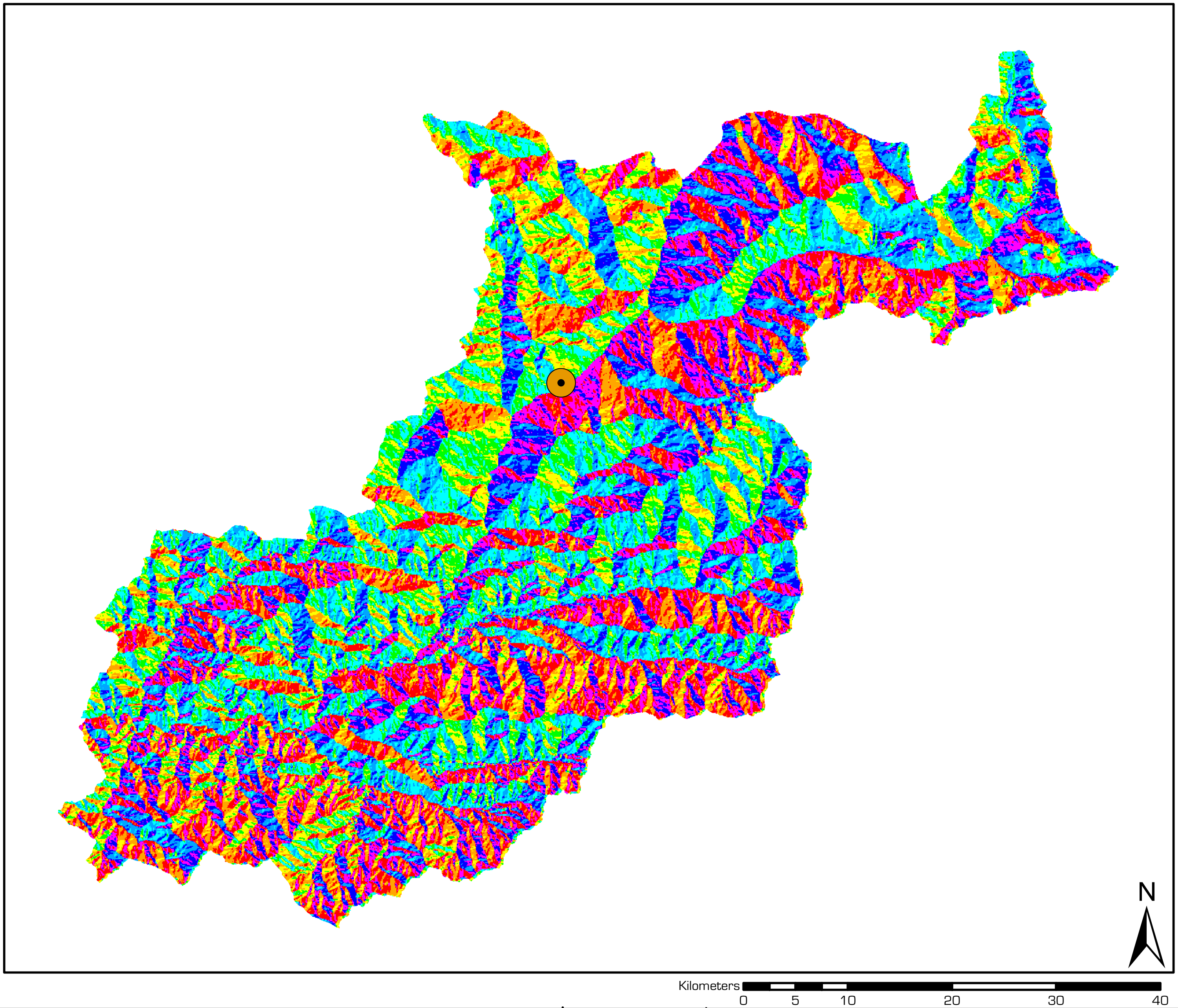
ESSA Technologies Ltd.

Created by: Nick Ochoski, M.Sc.

Upper Trishuli-1
Hydropower Project



UT-1 Hydropower Project
Flat (-1)
North (0-22.5)
Northeast (22.5-67.5)
East (67.5-112.5)
Southeast (112.5-157.5)
South (157.5-202.5)
Southwest (202.5-247.5)
West (247.5-292.5)
Northwest (292.5-337.5)
North (337.5-360)



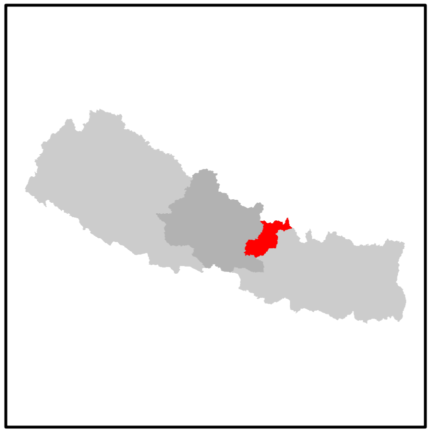
Trishuli Watershed
Aspect

Map 20

ESSA Technologies Ltd.

Created by: Nick Ochoski, M.Sc.

Upper Trishuli-1
Hydropower Project



Kilometers 0 105 210 420 630

UT-1 Hydropower Project

Trishuli River

Minor Rivers

High Slide Potential

Moderate Slide Potential

Digital Elevation Model

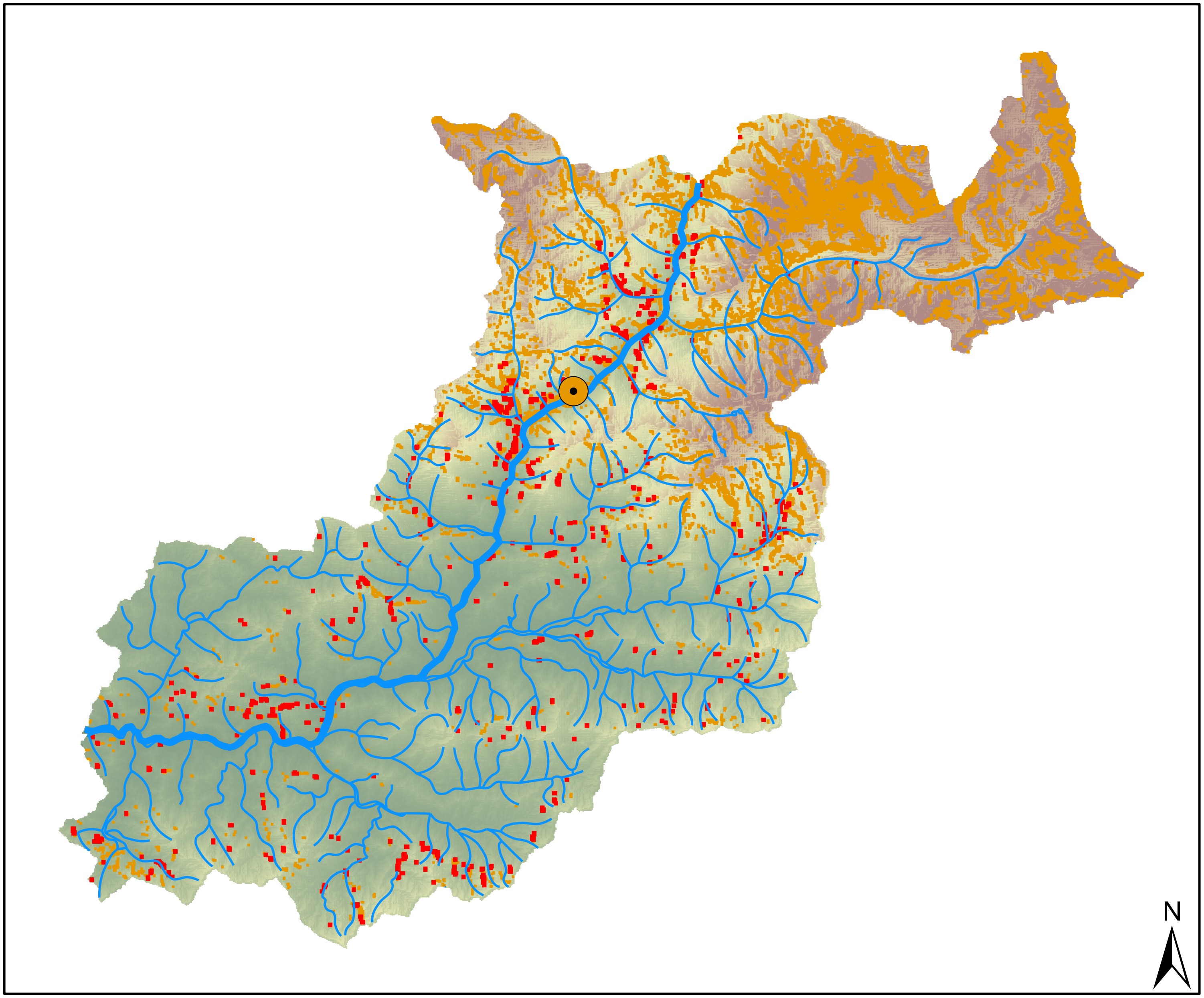
Elevation

High : 7203m

Low : 329m

High Slide Risk: Slope > 45 degrees & located in a disturbed (cultivated, deforested) area

Moderate Slide Risk: Slope > 45 degrees & located in a non-disturbed or barren area



Kilometers 0 5 10 20 30 40

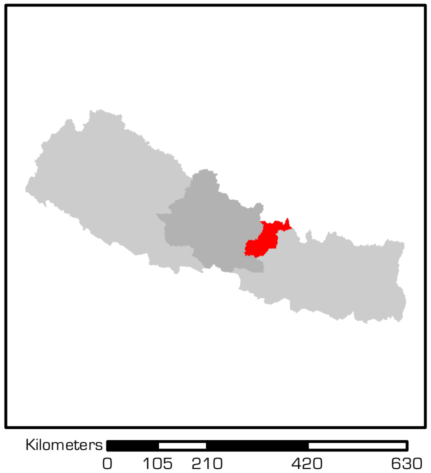
Trishuli Watershed Slide Potential

Map 21

ESSA Technologies Ltd.

Created by: Nick Ochoski, M.Sc.

Upper Trishuli-1 Hydropower Project



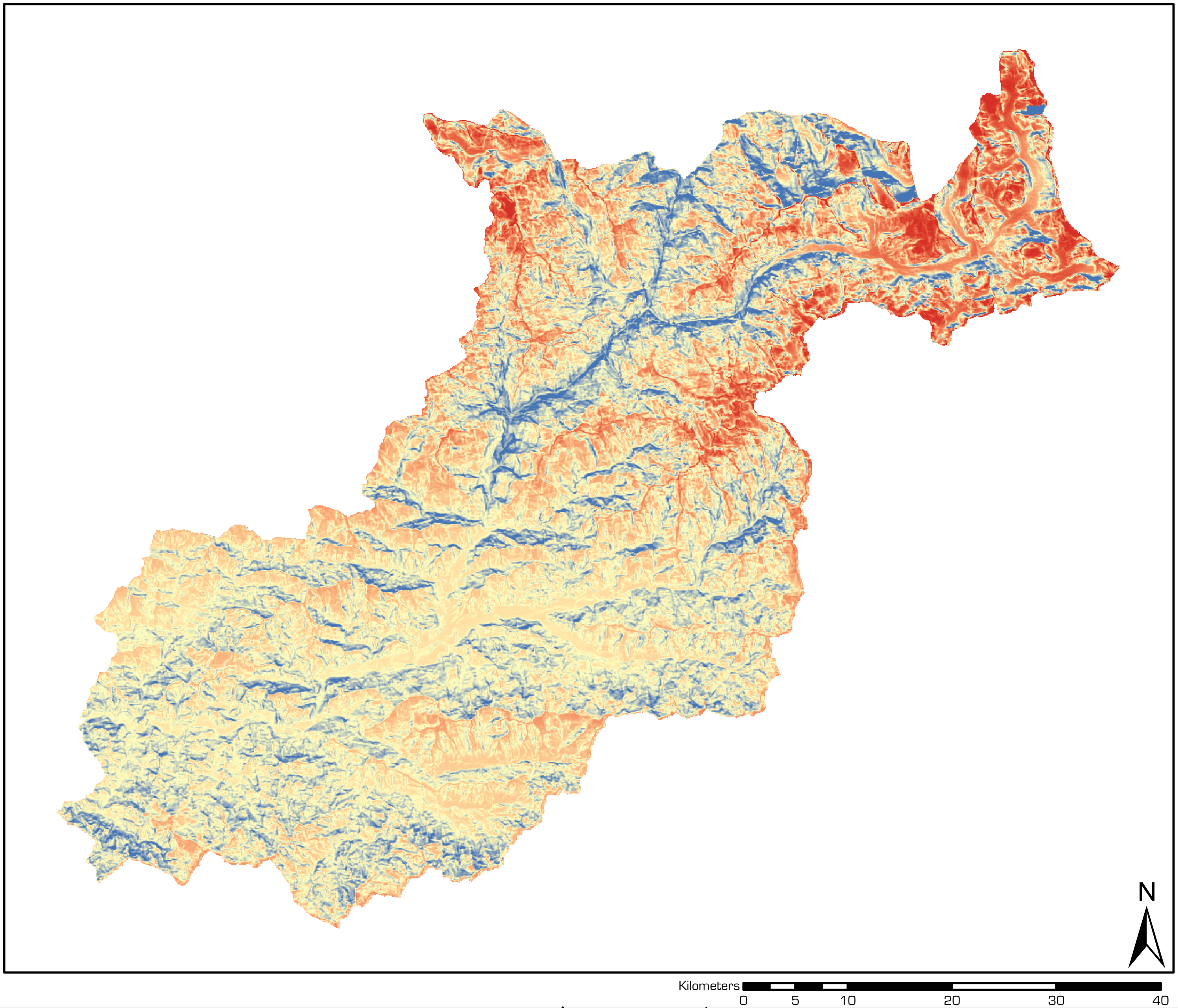
Solar Exposure

W/m^2

High : 1100

Low : 10

Values represent average W/m^2 per day



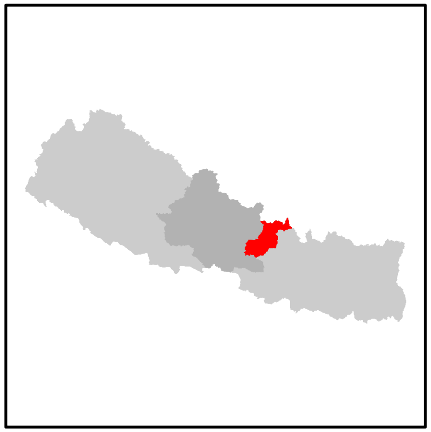
Trishuli Watershed
Solar Exposure (May - October)

Map 22

ESSA Technologies Ltd.

Created by: Nick Ochoski, M.Sc.

Upper Trishuli-1
Hydropower Project



Kilometers
0 105 210 420 630

Direct Solar Radiation
May - October
High
Low

Terrain derived from hillshade
and solar insolation model

Kilometers
0 5 10 20 30 40

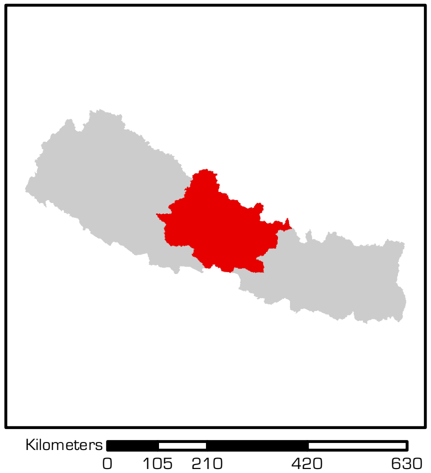
Trishuli Watershed
Detailed Terrain

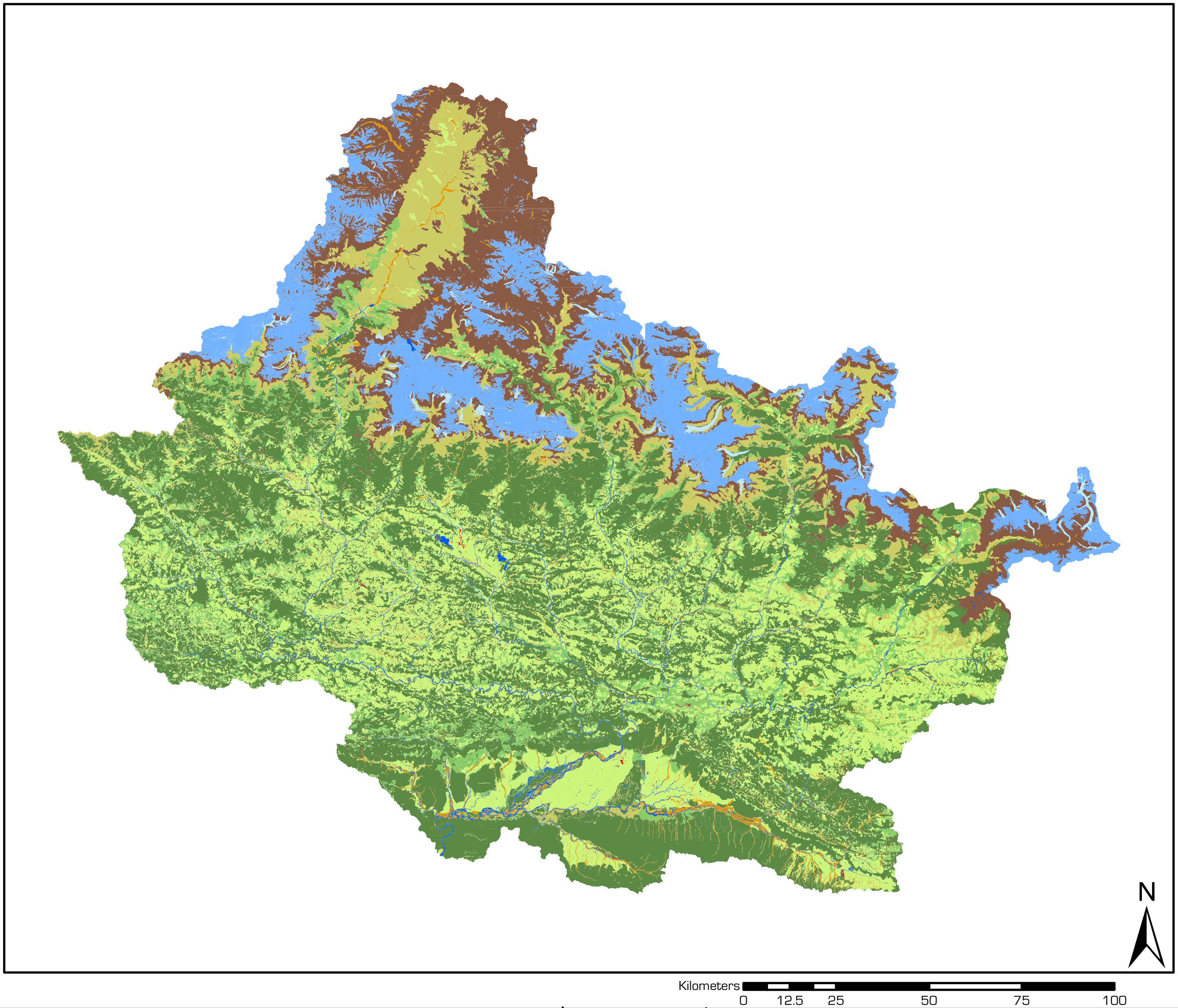
Map 23

ESSA Technologies Ltd.

Created by: Nick Ochoski, M.Sc.

Upper Trishuli-1
Hydropower Project





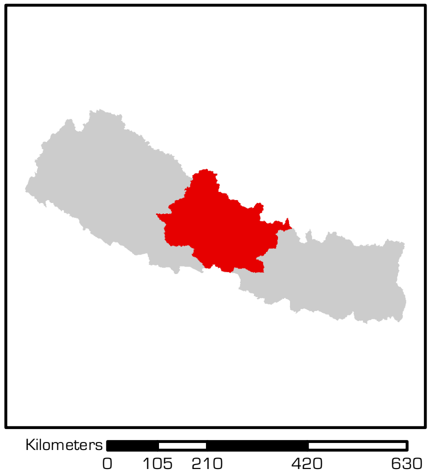
Gandaki Basin
Land Cover (2010)

Map 24

ESSA Technologies Ltd.

Created by: Nick Ochoski, M.Sc.

Upper Trishuli-1
Hydropower Project



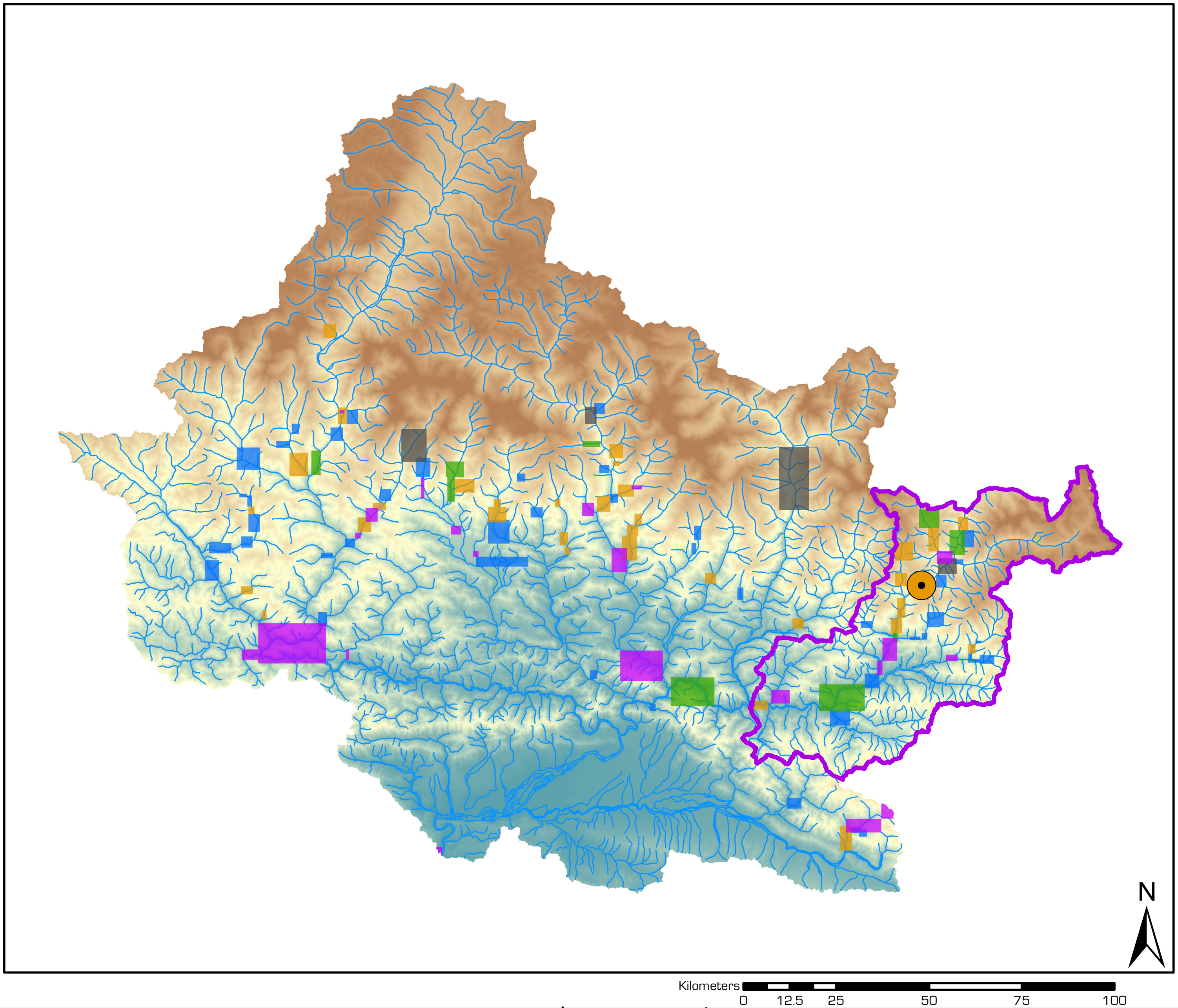
UT-1 Hydropower Project
Trishuli Watershed
Operating
Under Construction
Survey: 100MW+
Survey: 25-100MW
Survey: 1-25MW
Major Rivers

Digital Elevation Model

Elevation

High : 8147m

Low : 112m



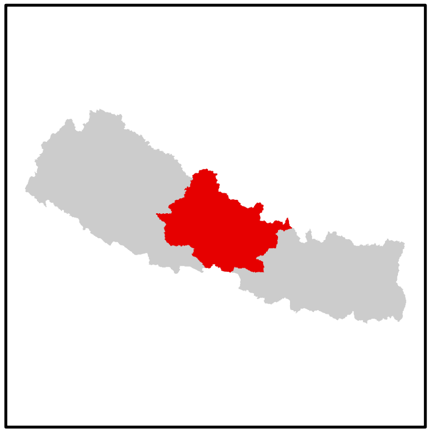
Gandaki Basin Hydropower Development

Map 25

ESSA Technologies Ltd.

Created by: Nick Ochoski, M.Sc.

Upper Trishuli-1 Hydropower Project

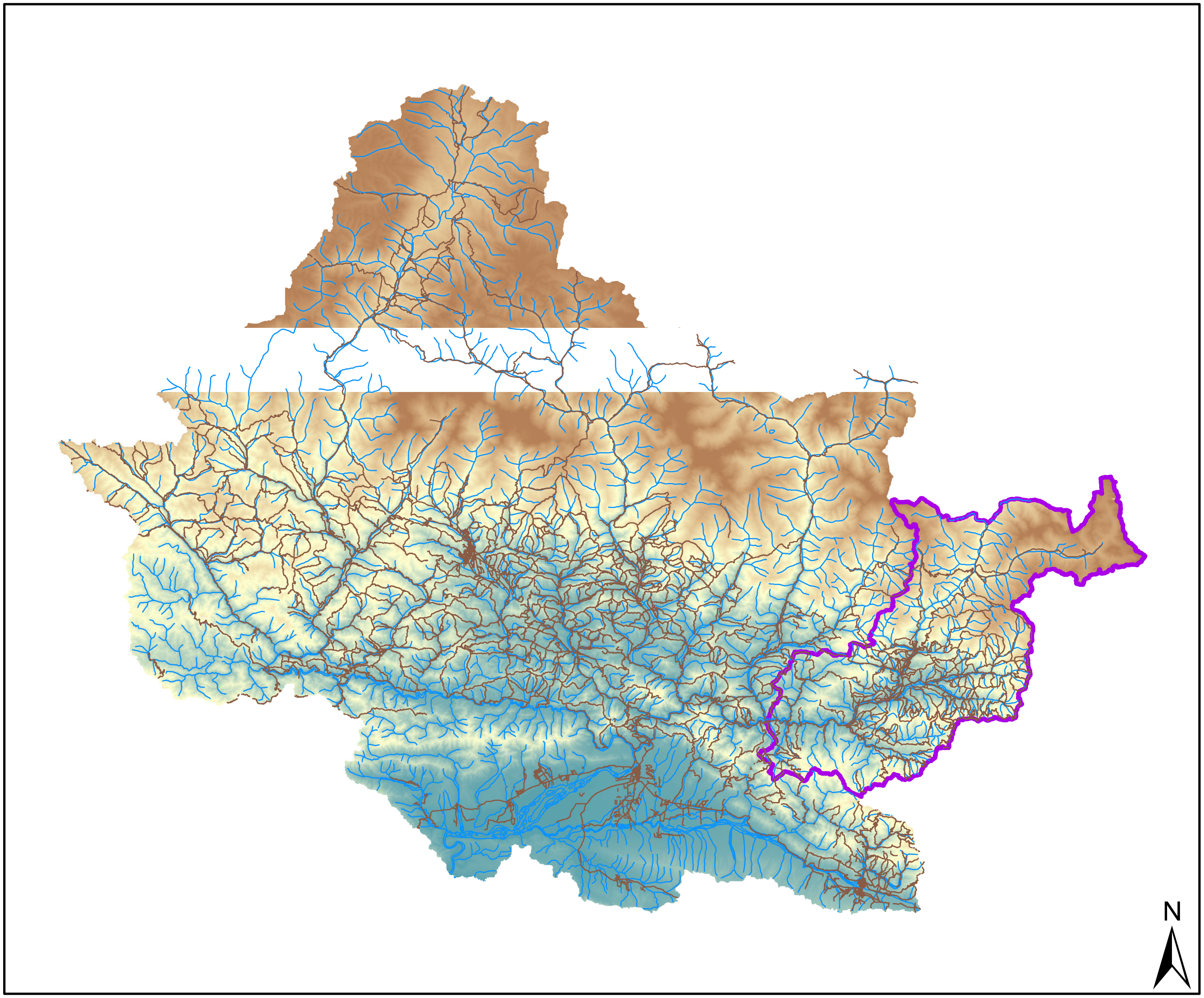


Kilometers
0 105 210 420 630

Roads
Major Rivers
Trishuli Watershed

Digital Elevation Model

Elevation
High : 8147m
Low : 112m



Kilometers
0 12.5 25 50 75 100

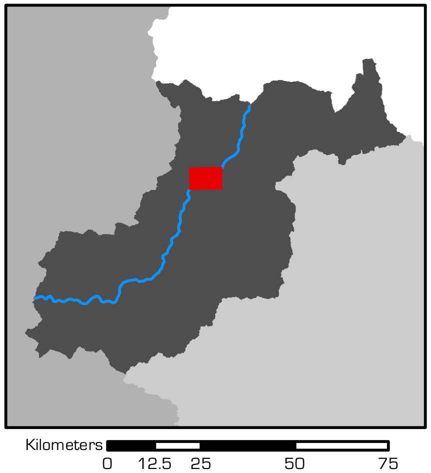
Gandaki Basin
Major Roads and Rivers

Map 26

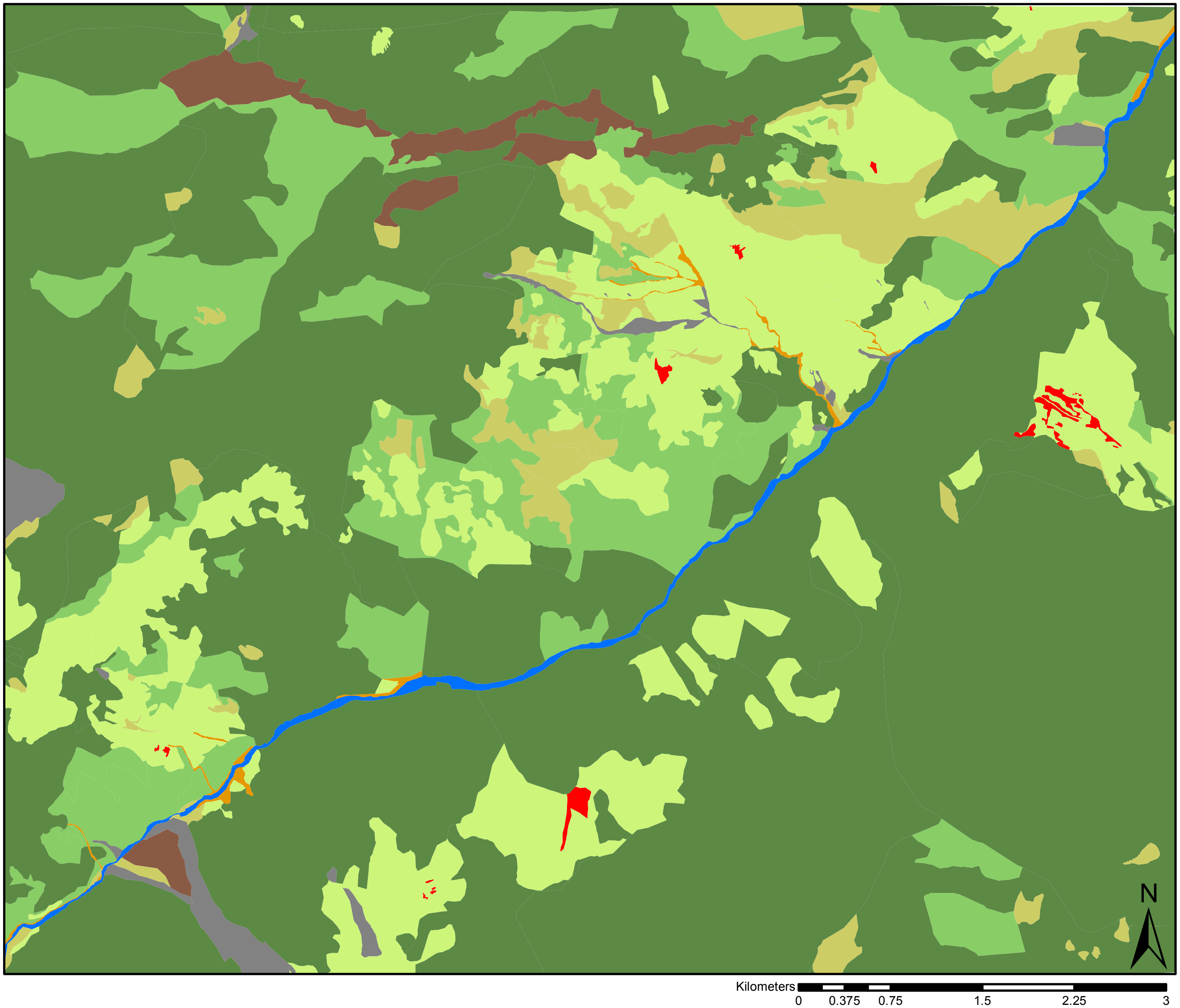
ESSA Technologies Ltd.

Created by: Nick Ochoski, M.Sc.

Upper Trishuli-1
Hydropower Project



Forest
Scrub
Agriculture
Grass
Barren Land
Sand
Cliff/Slide
Waterbody
Settlement



Upper Trishuli-1 Hydropower Project Site
Land Cover (2010)

Map 27

ESSA Technologies Ltd.

Created by: Nick Ochoski, M.Sc.

Upper Trishuli-1
Hydropower Project

Appendix C: Final Report