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ESMAP
Energy Sector Management Assistance Program

Small Hydro Resource Mapping in Madagascar

PREFEASIBILITY STUDY: MAHATSARA

[ENGLISH VERSION]

April 2017

This report was prepared by SHER Ingénieurs-Conseils s.a. in association with Mhylab, under contract to The World Bank.

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This document is an **interim output** from the above-mentioned project. Users are strongly advised to exercise caution when utilizing the information and data contained, as this has not been subject to full peer review. The final, validated, peer reviewed output from this project will be a Madagascar Small Hydro Atlas, which will be published once the project is completed.

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Phase 2 – Ground Based Data Collection

PREFEASIBILITY STUDY OF THE MAHATSARA HYDROELECTRIC SCHEME

Renewable Energy Resource Mapping: Small Hydro – Madagascar [P145350]

April 2017

ENGLISH VERSION

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FINAL OUTPUT

Correspondence Table between the terms of reference and reporting and the ESMAP phases:

ESMAP General Phasing	Correspondence with ESMAP-Small Hydro Madagascar ToR
Phase 1 Preliminary resource mapping output based on satellite and site visits	**Activity 1** - Data collection and production of Hydro Atlas, review and validation of small hydro potential **Activity 2** - Small hydro electrification planning **Activity 3** - Small hydro prioritization and workshop
Phase 2 Ground-based data collection	**Activity 4 -** Data collection and final validation (from the REVISED TERMS OF REFERENCES FOR THE ACTIVITY 4) : A - Review of previously studied small hydropower sites B - Data collection and final validation C - Pre-feasibility study of two priority sites for small hydropower development
Phase 3 Production of a validated resource atlas that combines satellite and ground-based data	D - Support to the Ministry of Energy to build capacity and take ownership of the created GIS database for hydropower E - Updated Small Hydro Mapping Report for Madagascar

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In case of discrepancy, the French version prevails

ABRÉVIATIONS AND ACRONYMS

ADER	Agence de Développement de l'Electrification Rurale
AO	Appel d'Offre
APD	Avant-Projet Détaillé
APS	Avant-Projet Sommaire
DGE	Direction de l'Energie
DGM	Direction Générale de la Météorologie
ENR	ENergie Renouvelable
ESMAP	Energy Sector Management Assistance Program
EU	European Union
FTM	FOIBEN-TAOSARINTANIN'I MADAGASIKARA
GRDC	Global Runoff Data Centre
GWh	Giga Watt heure, Milliards de kWh ou Millions de MW
INSTAT	Institut National de la Statistique
IPP's	Independent Power Producer's
IRENA	International Renewable Energy Agency
JIRAMA	Jiro sy Rano Malagasy (Société d'électricité et d'eau de Madagascar)
kW	kilo Watt
kWh	kilo Watt heure
LCOE	Levelized Cost Of Electricity
MEH	Ministère de l'Energie et des Hydrocarbures
MNS	Modèle numérique de surface
MW	Mega Watt
MWh	Mega Watt heure
ORE	Office de Régulation de l'Electricité
ORSTOM	Office de la recherche scientifique et technique outre-mer
PIC	Projet Pôles Intégrés de Croissance
PPP	Partenariat Public Privé
SAPM	Système des Aires Protégées de Madagascar
SE	Système Electrique
SIG	Système d'Information Géographique
SNAT	Stratégie Nationale d'Aménagement du Territoire
TWh	Tera Watt heure
WB	World Bank

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1 EXECUTIVE SUMMARY

The key features of the Mahatsara hydroelectric scheme are summarized in Table 1 below.

Table 1. Key features of the proposed Mahatsara hydroelectric scheme

FEATURE	PARAMETER	VALUE	UNITS
Location	Region	Vatovavy Fitovinany	-
	River	Besana	-
Hydrology	Watershed area	125	km²
	Median streamflow ($Q_{50\%}$)	6.6	m³/s
	Firm streamflow ($Q_{95\%}$)	2.9	m³/s
Weir and intake	Watershed closure	Overflowing weir + flushing gates (3 bays)	-
	Type	Concrete gravity	-
	Average height	3.5	m
	Crest elevation	237.5	m
	Crest length	46.50	m
Spillway	Type	Overflowing Ogee-type weir	-
	Crest elevation	237.5	m
	Design flood (100 years)	514	m³/s
	Water head at design flood	3.0	m
Waterways	Intake structure		
	Invert elevation	235.0	-
	Design flow	6.2	m³/s
	Number of bays	2	-
	Canal		
	Length	21m (following the sand trap)	m
	Average slope	0.05	%
	Tunnel		
	Length	480	m
	Average slope	2.20	m
	Surge chamber / forebay	Equipped with an emergency spillway	-
	Surge chamber / forebay operating water level	237.20	m
	Penstock		
	Number	1	-
	Diameter	1.40	m
	Length	280	m
Hydropower Plant	Type	Surface type structure	-
	Location	Right river bank	-
	Number of bays	5	-
	Tailwater level	85.0	m
	Floor elevation	90.0	m
	Available gross head	146.70	m
	Number of turbines and type	4 Pelton turbines	-
	Rated output of each turbine	1.85	MW
	Rated discharge	7.30	MW
	Installed capacity	47.8	GWh
Economics	Average annual energy generation	15.92	M€
	Capital expenditure costs (CAPEX) – *Without transmission lines and existing access roads to be rehabilitated*	0.0497	€/kWh
	Levelized Cost of Energy (LCOE) - *Without transmission lines and existing access roads to be rehabilitated*	33.45	M€
	Capital expenditure costs (CAPEX) – *Incl. transmission lines and existing access roads to be rehabilitated*	0.0983	€/kWh

2 INTRODUCTION

2.1 OVERVIEW OF THE ESMAP PROGRAMME

ESMAP (Energy Sector Management Assistance Program) is a technical assistance program managed by the World Bank and supported by 11 bilateral donors. ESMAP launched in January 2013 an initiative to support the efforts of countries to improve the knowledge of renewable energy resources (REN), establish appropriate institutional framework for the development of REN and provide "free access" to geospatial resources and data. This initiative will also support the IRENA-GlobalAtlas program by improving data availability and quality, consulted through an interactive atlas.

This study "Renewable Energy Resource Mapping: Small Hydro Madagascar", is part of a technical assistance project funded by ESMAP, implemented by the World Bank in Madagascar (the "Client"), which aims to support mapping resources and geospatial planning for small hydropower. It is conducted in close coordination with the Ministry of Energy, the Electricity Regulation Office (ERO), Development Agency of Rural Electrification (DARE) and JIRAMA.

2.2 OBJECTIVES, RESULTS AND ACTIVITIES OF THE STUDY

The objectives of the Study are:

- To improve the quality and availability of the information related to hydropower resource in Madagascar ;
- To undertake a detailed review and update of the small hydropower potential (1-20 MW) ;
- To formulate recommendations regarding where small hydro can be implemented in regards to energy sector planning in the country.

The expected results of the Study are:

- A consolidated data in a Geographical Information System (GIS) ;
- A thematic Atlas on Hydropower in Madagascar with an emphasis on Small Hydro (1-20 MW) ;
- Recommendations to develop the small hydropower sector in Madagascar.

The ESMAP Study is divided into three phases:

- **PHASE 1 :** Preliminary resource mapping based on spatial analysis and site visits
- **PHASE 2 :** Ground-based data collection
- **PHASE 3 :** Production of a validated resource Atlas that combines cartographic and ground-based data

In the specific context of the Small Hydro Resource Mapping Study in Madagascar, those 3 phases have been broken down into 4 Activities;

- **Activity 1** : Data collection and production of Hydro Atlas, review and validation of small hydro potential
- **Activity 2** : Small hydro electrification planning

- **Activity 3** : Small hydro prioritization, site visits and workshop
- **Activity 4** : Data collection and final validation (HydroAtlas update / hydrological monitoring campaign / additional geological and environmental field investigations)

2.3 CONTEXT AND SCOPE OF THE PREFEASIBILITY STUDY

This report is delivered in the context of PHASE 2 (Ground-based data collection). In accordance with our Terms of References (Revised Terms of References for the Phase 2 (Activity 4) of the Project, 16 April 2015), the prefeasibility study covers the following aspects:

- Review of the existing data and GIS information ;
- Additional site visit to the two sites and main load centers / national grid connection by relevant sector experts ;
- Additional topographic and geotechnical surveys, update of the hydrology, and assessments of environmental and social impact to reach study results at pre-feasibility level;
- Preparation of a conceptual design and drawings at pre-feasibility level; Schematic Layout of Hydro Powerhouse, weir or dam (when applicable), waterways and Transmission Lines to the main load centers / national grid connection;
- Preparation of a Budgetary Cost Estimate, including costs for environmental and social costs, and Electricity Generation Estimate for a range of installed capacities;
- Preliminary economic analysis.

Access track to Mahatsara, Intsaka River valley

3 CONTEXT OF THE MAHATSARA HYDROELCTRIC SCHEME

3.1 PROJECT AREA

The Mahatsara site is located on the Besana River approximately 16.5 km upstream of the confluence with the Intsaka River (tributary of the Mananjary River). The geographical coordinates (WGS1984) of the proposed weir location are 21.0322°South and 47.9177° East.

At the proposed intake weir location, the watershed of the Besana River drains an area of 125km². Figure 1 presents the exact location of the proposed site in Madagascar.

Table 2. Administrative data

Site code (Small Hydro Atlas)	SF196
Site name	Mahatsara
River	Besana
Major river basin	Mananjary
Province	Fianarantsoa
Region	Vatovavy Fitovinany
District	Mananjary
Commune	Ambodinonoka
Village	Mahatsara
Reference topographic map	IGN Q52 Sud (scale 1:50,000)

3.2 SITE ACCESS

Access to the site is from RN25 at Vohilava. Then follow a track along the Intsaka River to the village of Ambodivandrika and continue approximately 7km to the village of Mahatsara (Figure 2 et Figure 3). These two tracks as well as part of the RN24 will have to be rehabilitated for the development of the site. The rehabilitation and new access works are detailed in Section 8.2.9 of the chapter describing the proposed hydroelectric scheme and its design.

Figure 1. Study area

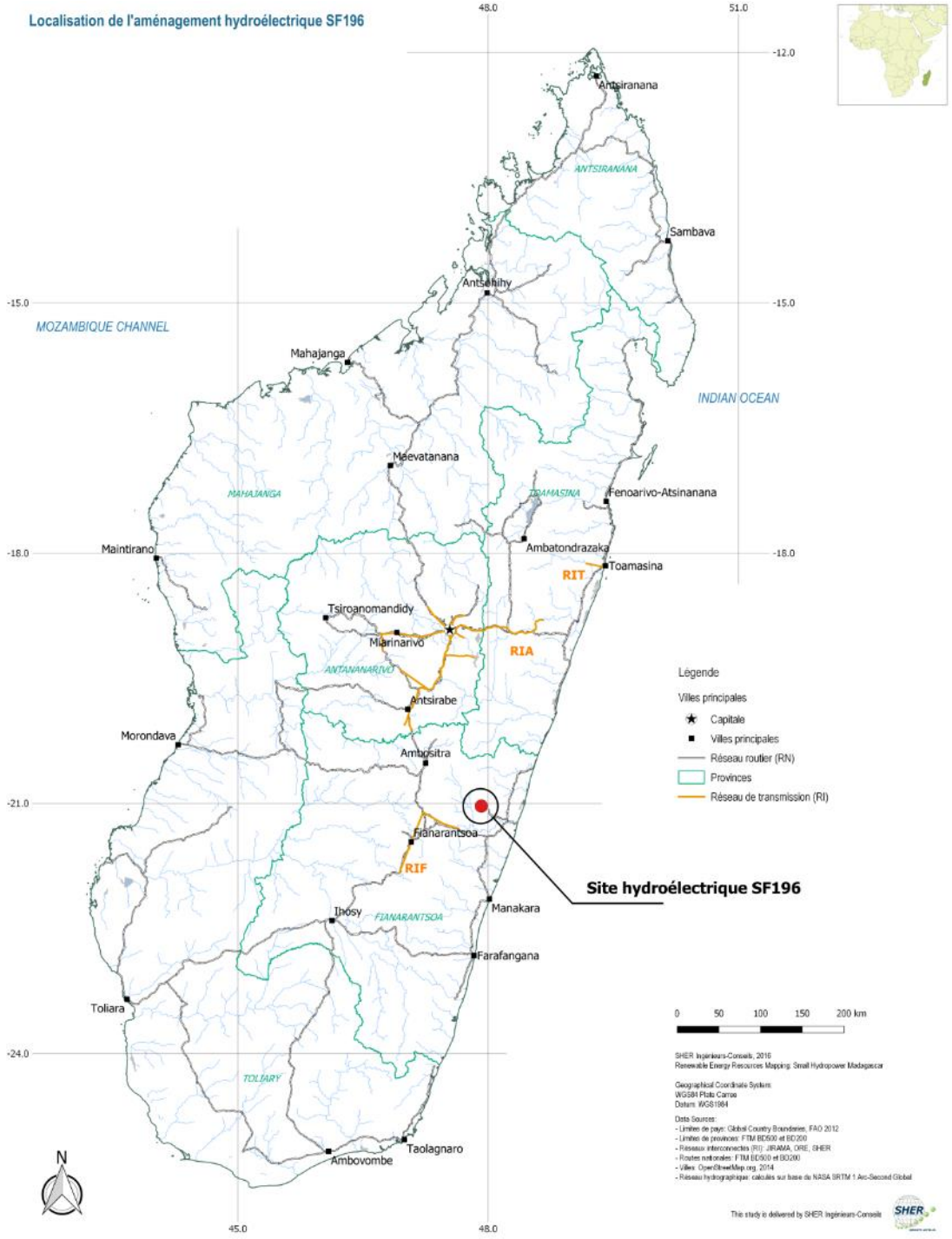


Figure 2. Access to the Mahatsara site from RN25 and RN24 (road map)

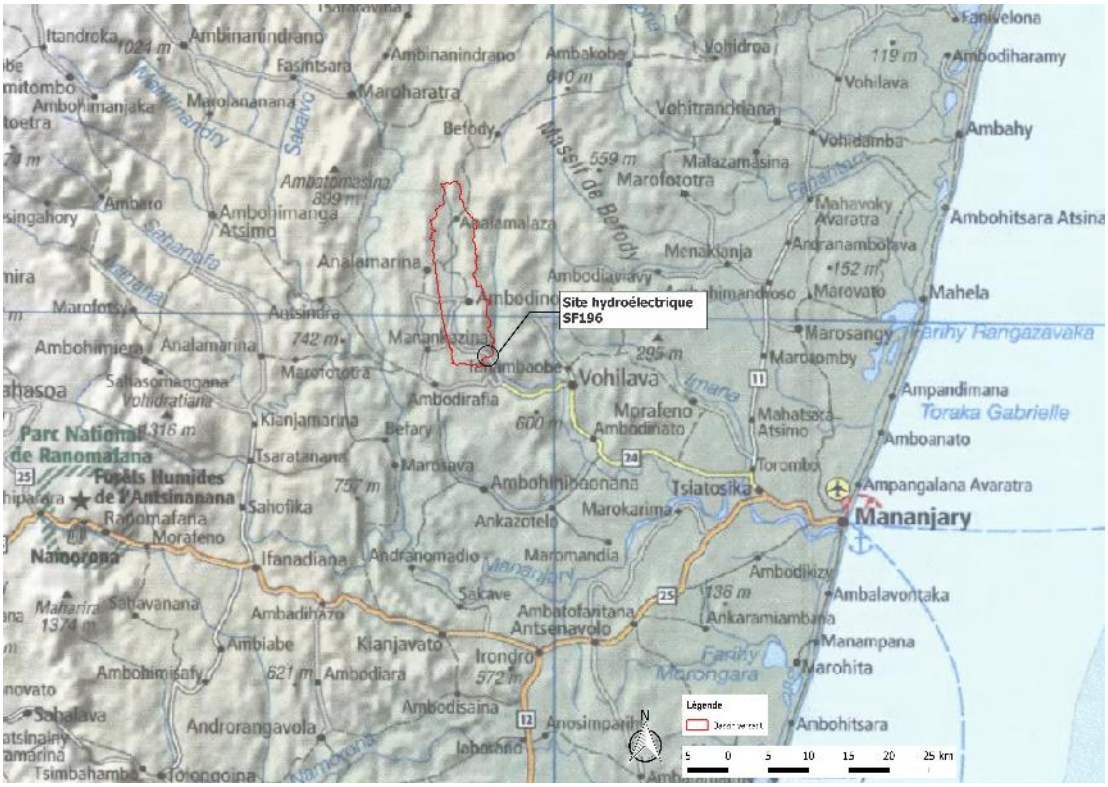
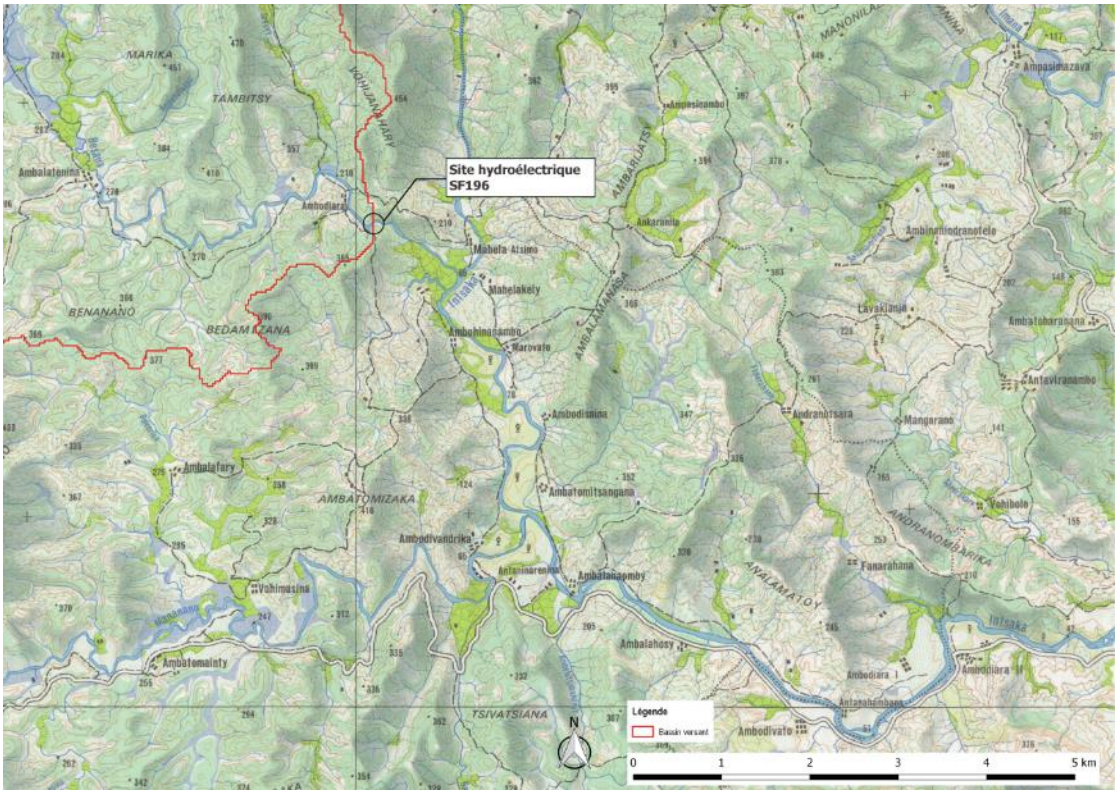


Figure 3. Access to the Mahatsara site (details on topographic map 1:50 000)



3.3 GENERAL SITE DESCRIPTION

The site features a ~150m high waterfall on the Besana River in the South-East direction. The river planform has changed in the past, as can be seen by comparison of the topographical map (scale 1:50 000) and the recent satellite image (Figure 3 et Figure 4). There are currently no hydroelectric or hydro-agricultural developments at the proposed site.

Figure 4. Overview of the main waterfall (Landsat image, Google Earth)

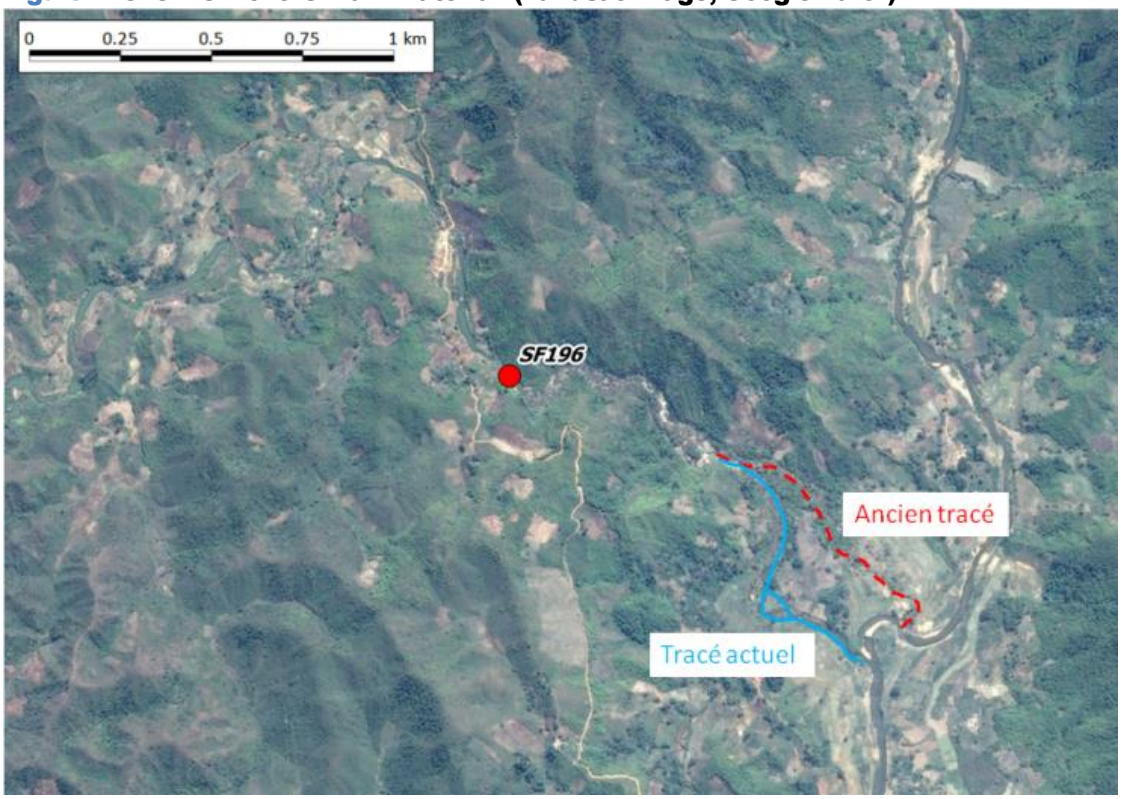


Figure 5. Upstream view of the proposed weir location

Figure 6. Downstream view of the proposed weir and intake location

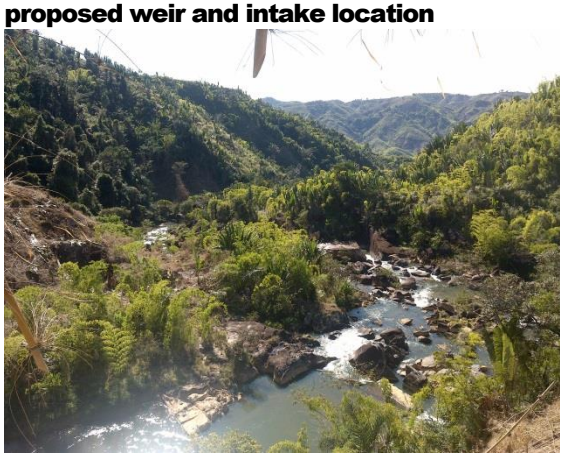


Figure 7. View of the penstock alignement and tailrace

Figure 8. Proposed powerhouse location

3.4 PREVIOUS STUDIES

To the best of our knowledge, there are no previous studies of the site.

4 TOPOGRAPHY AND MAPPING

4.1 EXISTING MAPPING

4.1.1 Topographic mapping

The JPEG format (not georeferenced) 1:50,000 scale topographic maps have been acquired from the *"Institut Géographique et Hydrographique de Madagascar"* (Foiben-Taosarintanin' i Madagasikara - FTM) in order to cover the entire site of the Fanovana hydroelectric scheme. The JPEG format (not georeferenced) 1:100,000 scale topographic maps have been also obtained from the FTM. The 1:50,000 scale map of interest is the sheet Q52 Sud – AMBOHINIHAONANA 1 :50,000, 1972. The contour lines interval is 25m. All the topographic maps have been georeferenced as described in section 4.2.

4.1.2 Thematic Mapping

Thematic maps and their key features, sources and format are presented in Table 3 below.

Table 3. Collected thematic maps

THEMATIC	FORMAT	KEY FEATURES	SOURCES
Administrative boundaries	Vector	Country / Provinces / Regions / Districts / Communes	Institut Géographique et Hydrographique de Madagascar (FTM) FTM BD500, FTM BD200
Main cities	Vector	32 cites and towns	Open Street Map, 2014
Landuse	Vector	11 classes d'occupation du sol	Schéma National d'Aménagement du Territoire (SNAT)
Protected areas	Vector	SAPM / sites prioritaires / sites potentiels	Atlas numérique du système des aires protégées de Madagascar (SAPM) http://atlas.rebioma.net/
Geology	Raster	1:1,000,000	Schéma National d'Aménagement du Territoire (SNAT)
	Vector	Digitalisation des planches au 1 :500,000	Service Géologique 1969
Soils map	Raster	1:1,000,000	ISRIC-WISE, 2006
Pedology	Raster	1:1,000,000	Schéma National d'Aménagement du Territoire (SNAT)
	Raster	1:10,000,000	
Gemorphology	Raster	1:1,000,000	Schéma National d'Aménagement du Territoire (SNAT)
Mines	Raster	-	Bureau Du Cadastre Miniers de Madagascar (BCMM)
Satellite imagery	Raster	Landsat 1999	Google Earth
	Raster	Landsat 2005	Google Earth
Hydrometric stations	Vector	Location	GRDC, Direction Générale de la Météorologie de Madagascar, ouvrage « Fleuves et Rivières de Madagascar, 1992 »
Rainfall and temperature	Raster	Spatial resolution ~ 1km	WorldClim, v1.4 http://www.worldclim.org/
Roads	Vector	National roads, provincial roads and tracks	FTM BD500, FTM BD200
Transmission network (RI)	Vector	Build up from various sources	JIRAMA, ORE, SHER

4.1.3 Digital Surface Model

The digital surface model (DSM) used in the hydrological study is based on the "Shuttle Radar Topography Mission" (SRTM, version 1 arc-second). These data were acquired in February 2000 by the United States

Space Agency (NASA) through radar measurements from space shuttle Endeavor. These data have a spatial resolution of 1 arc-second (about 30 m at the equator). The MNS of the study area is illustrated in Figure 12 of the chapter describing the Hydrological Study.

4.2 MAPPING CARRIED OUT AS PART OF THE STUDY

4.2.1 Digitization and geo-referencing

The 1:50,000 scale topographic maps were geo-referenced using the Quantum GIS software and the following projection parameters:

- Projection Laborde Madagascar (Gauss Laborde)
- Latitude of origin = 49
- Longitude of origin = -21
- Scale factor = 0.9995
- False Easting = 800 000
- False Northing = 400 000
- Ellipsoïde de Hayford 1909

4.2.2 Additional Surveying

A topographical survey of the site was carried out by triangulation of aerial images taken from a specially equipped light aircraft (Figure 9).

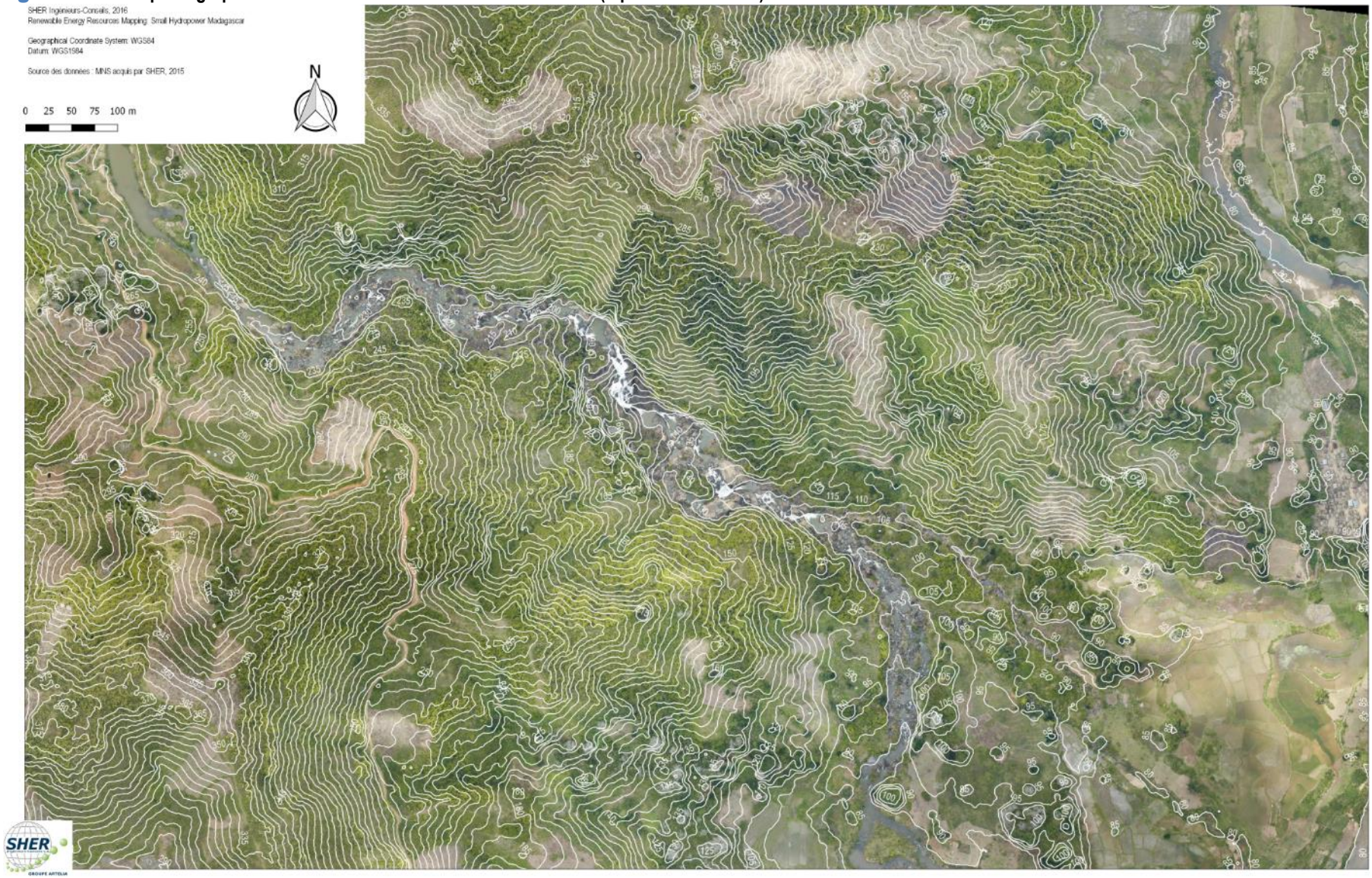
Figure 9. Aircraft and dedicated survey equipment

The topographic survey is characterized by a density greater than 5 points / m² and a relative accuracy of 2%.

The results of the survey are, on the one hand, a digital surface model (DSM) which includes vegetation. It nevertheless provides an excellent representation of the topographic context of the site and an ortho-photography of the site whose pixel size is between 0.20m and 0.40m. The ortho-photography as well as contour lines deduced from the digital surface model are presented at Figure 10.

Elevations resulting from this topographic survey are relative to each other and have not been linked to the national system. Consequently, the elevations of the works mentioned in this report are not the absolute altitudes of the Malagasy national system.

Figure 10. **Ortho-photographie du site de Mahatsara et courbes de niveau (équidistance de 5m)**



5 HYDROLOGICAL STUDY

5.1 OBJECTIVES AND LIMITS

The objective of the hydrological study is to establish and quantify the climatological and hydrological characteristics of the study area in order to determine the hydrological parameters and time series required for the design of the Mahatsara hydroelectric project as well as for the economic analysis of the pre-feasibility study.

5.2 DESCRIPTION OF THE STUDY AREA

5.2.1 Physical Context

The Besana orginates in the Haut Plateaux at an elevation over 600m. Then, the elevation decreases quickly and 70% of the watershed lies between 400 m and 300 m (Figure 12). The Besana River flows mainly north to the south and flows into the Intsaka River downstream from the waterfall used in the proposed hydroelectric development, a tributary of the Mananjary River that flows into the Indian Ocean.

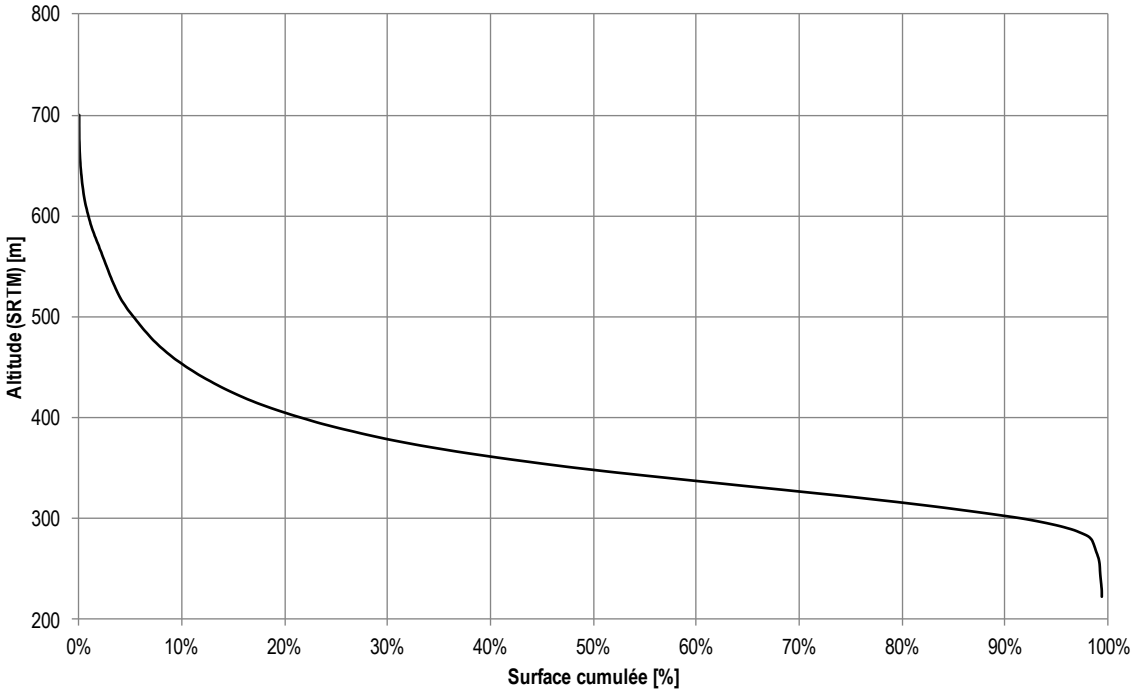
As shown in Figure 12, the Besana watershed at the proposed hydroelectric project site has marked relief with elevations between 222 m et 699 m (365 m on average). The drainage basin of the Besana River at the proposed intake site is 125.1 km² (delimitation based on the SRTM DTM of spatial resolution 1 arc-second, i.e. approximately 30 m). The main physical and morphological characteristics of the watershed are presented in Table 4.

he hypsometric curve of the watershed is shown in Figure 11. This curve shows the percentage of the watershed area above a given elevation. It shows that slopes are important in the upstream and downstream parts of the watershed and that 70% of the watershed flows on a plateau characterized by a gentle slope (between elevations 400m and 300m). This is clearly observed in Figure 11 and Figure 12.

Table 4. Physical and morphological characteristics of the watershed

PARAMETER	VALUE	UNIT
Area	125.1	km²
Average elevation	365	m a.s.l.
Maximum elevation	699	m a.s.l.
Maximum elevation (quantile 5%)	505	m a.s.l.
Minimum elevation	222	m a.s.l.
Minimum elevation (quantile 95%)	294	m a.s.l.
Slope index	5.2	m/km
Elevation difference	208	m
Perimeter	86.4	km
Gravelius index	2.18	-
Equivalent length	40.8	km

Figure 11. Hypsometric curve of the Besana watershed



5.2.2 Land use and protected areas

Data from the CCI Land Cover project (© ESA Climate Change Initiative - Land Cover project 2016) is a widely accepted source of information for land use around the world. These data are freely available and are derived from satellite images acquired by the MERIS instrument of the European Space Agency. The land cover includes 5 years of satellite imagery acquisition between 2008 and 2012. The information is provided in raster format with a spatial resolution of 300 m and allows defining the land use classes shown in Figure 13.

Figure 13 and Table 5 shows the land cover of the Besana watershed is mainly agriculture.

Table 5. Land cover in the Besana watershed

CODE	LEGEND	AREA	
		[%]	[HA]
10	Agriculture, non-irriguée	83.0%	10378
30	Mosaïque agriculture (>50%) / végétation naturelle (<50%)	7.9%	992
40	Mosaïque végétation naturelle herbacée, arbustive ou arborée (>50%) / agriculture (<50%)	1.5%	183
50	Forêt, arbres de type feuillus, sempervirente, couverture ouverte à fermée (>15%)	7.6%	954
	TOTAL	**100%**	**12507**

The Digital Atlas of the System of Protected Areas of Madagascar (Atlas Numérique du Système des Aires Protégées de Madagascar - SAPM) highlights existing protected areas, protected areas with a temporary protection status and new protected areas identified by the "Promoters". The Besana watershed does not feature any protected area under the SAPM.

Figure 12. **Besana watershed and Digital Elevation Model**

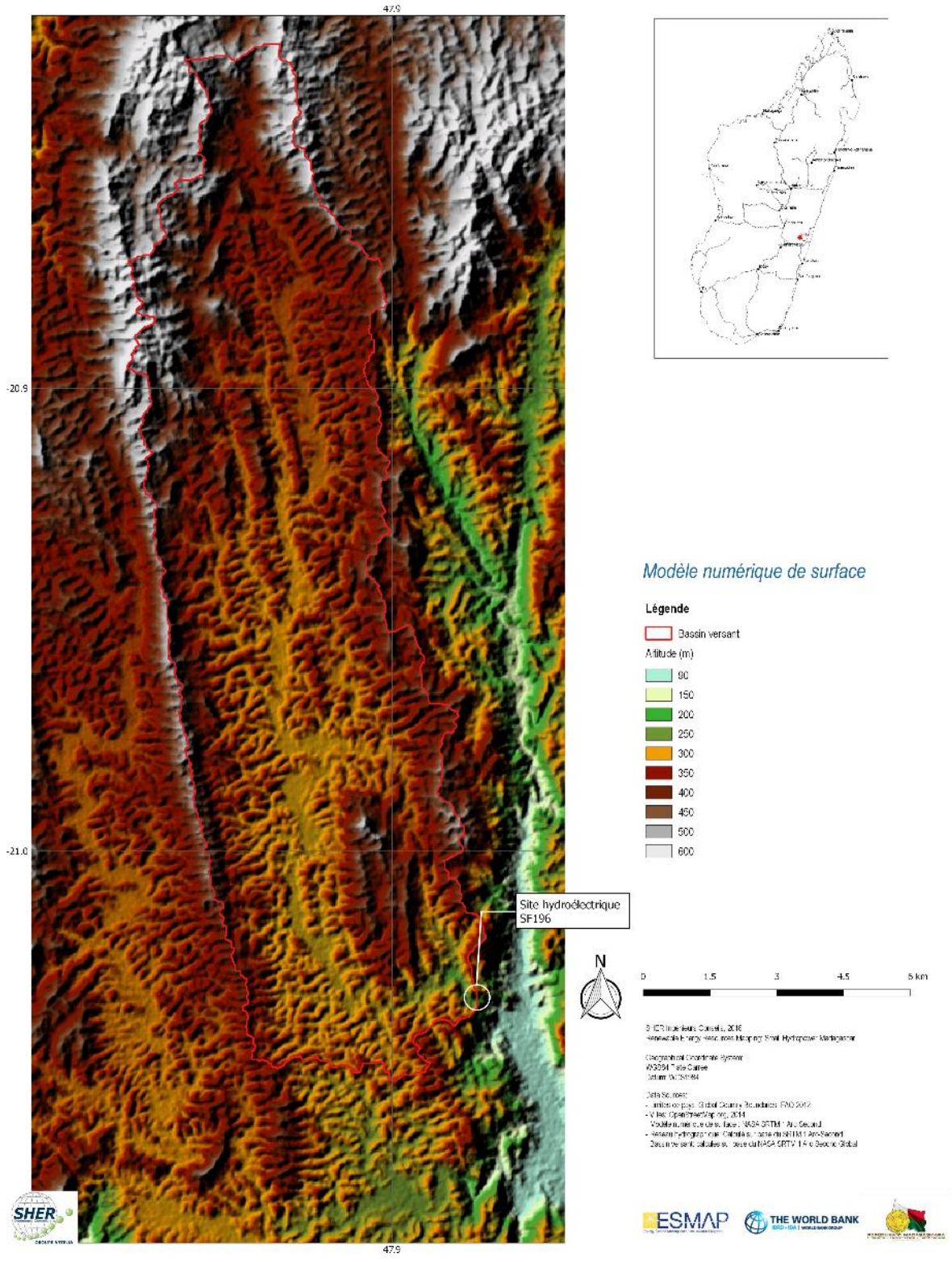
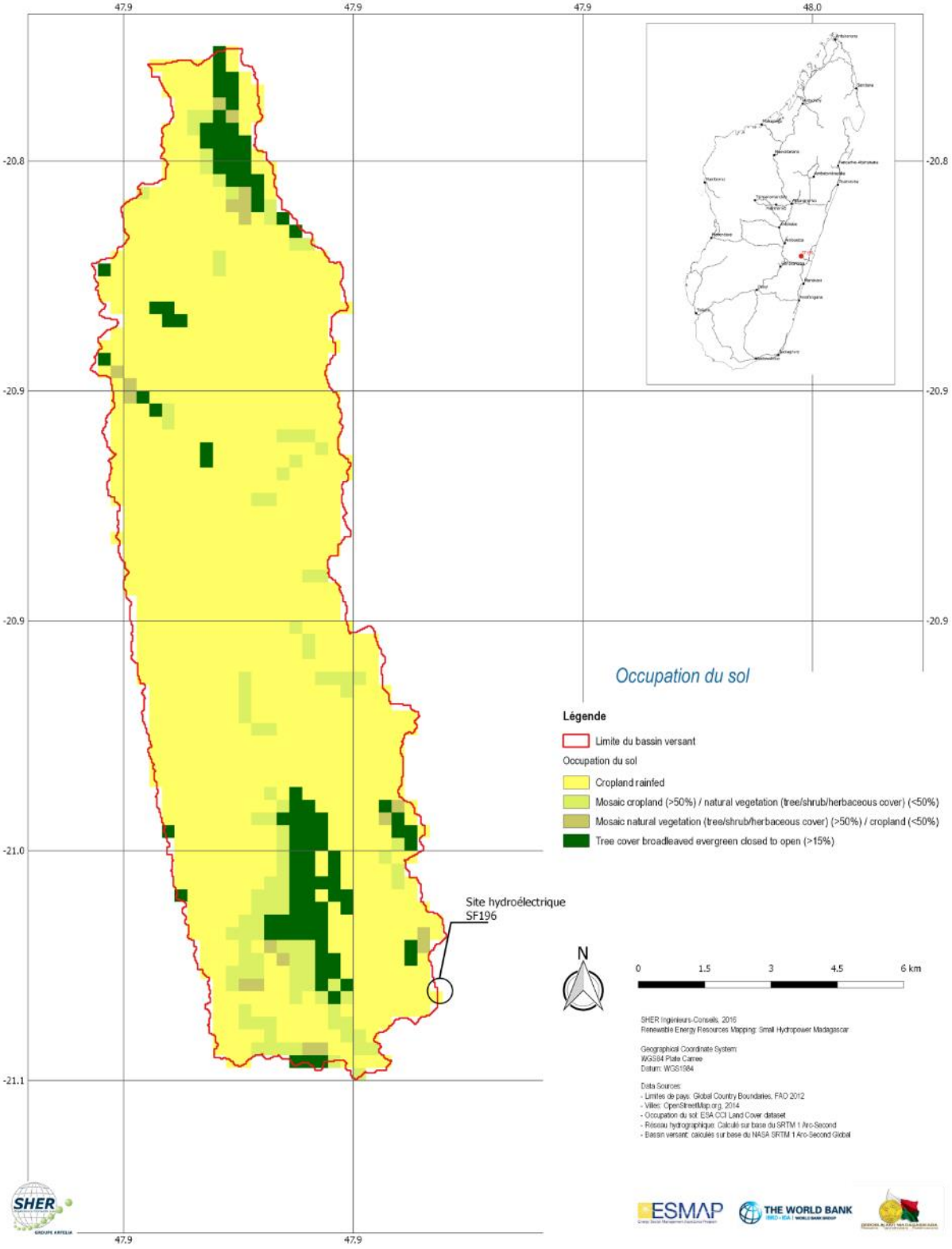


Figure 13. Land cover in the Besana watershed



5.2.3 Climate

According to the Köppen classification based on rainfall and temperature, the study area (Besana River watershed) is characterized by a warm temperate climate with no dry season (oceanic) and warm summer (Cfa class). Köppen defines the temperate climate «C» by the following characteristics:

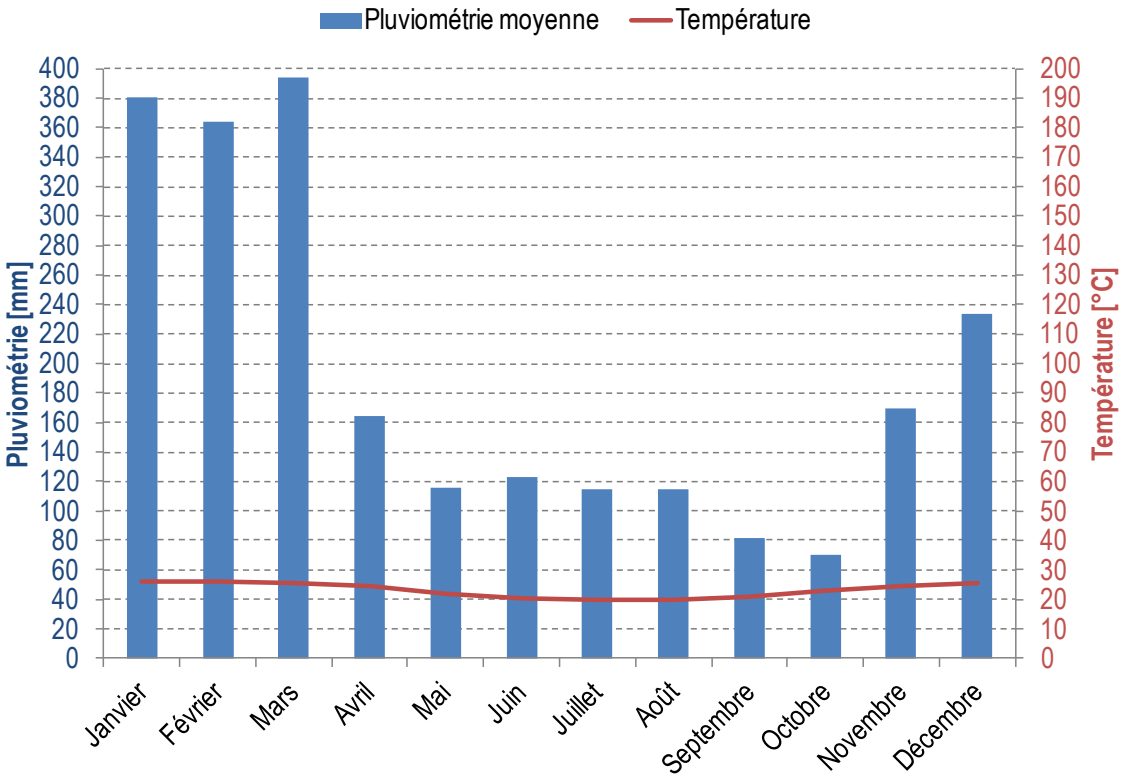
- Average temperature of the 3 coldest months between -3 °C and 18 °C ;
- Average temperature of the warmest month > 10°C ;
- Winter and summer seasons are well defined.

The rainfall regime « *f* » (humid climate) is defined by precipitation spread over every month of the year, with no dry season.

Finally, the amplitude of the annual cycle of « *a* » type temperatures means a hot summer with an average temperature of the hottest month above 22 °C.

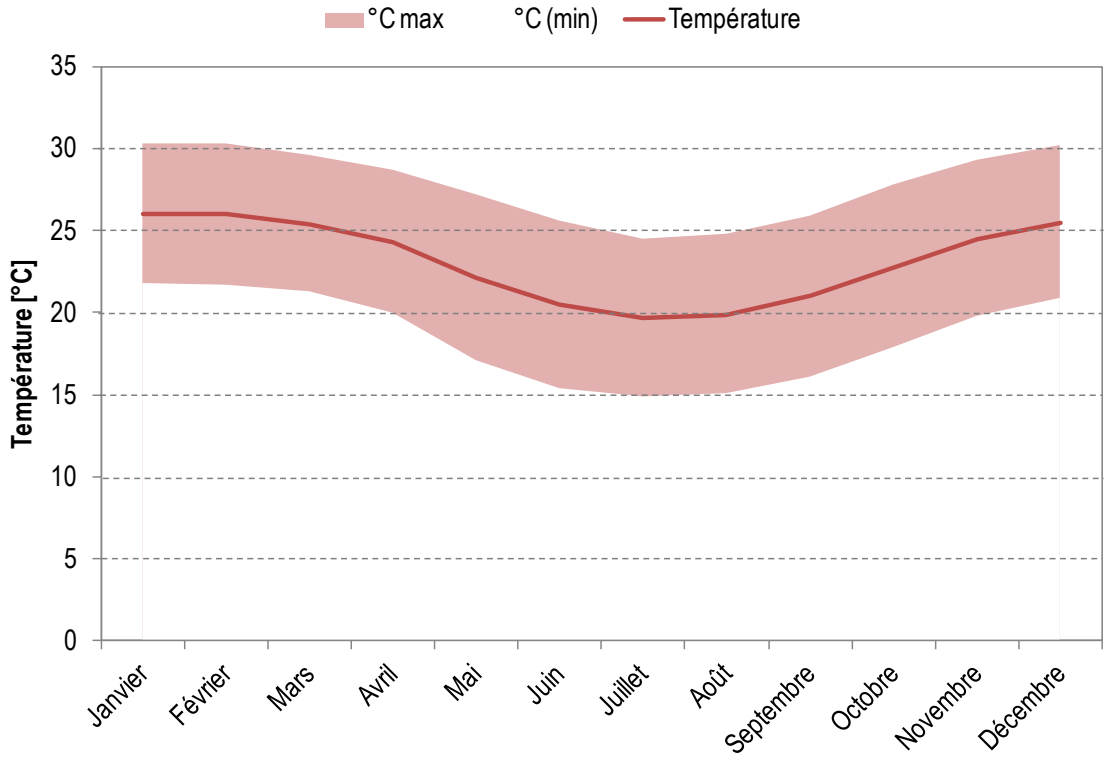
Figure 14 shows the climatic diagram as well as the temperature curve for the Vohilava meteorological station. Precipitation is very high during the summer months (December to March) but remains significant during the winter season. October is the driest month with 70mm of precipitation whereas the wettest month is March with 394 mm on average. The average annual precipitation is 2328 mm in Vohilava.

Figure 14. Climatic diagram at the Vohilava meteorological station



It is observed that the average annual temperature is 23.1°C. Temperature varies significantly during the seasons with an average amplitude of 6.3°C. The warmest month is February with 26°C and July is the coldest, with an average temperature of 19.7°C.

Figure 15. Temperature curve at the Vohilava meteorological station



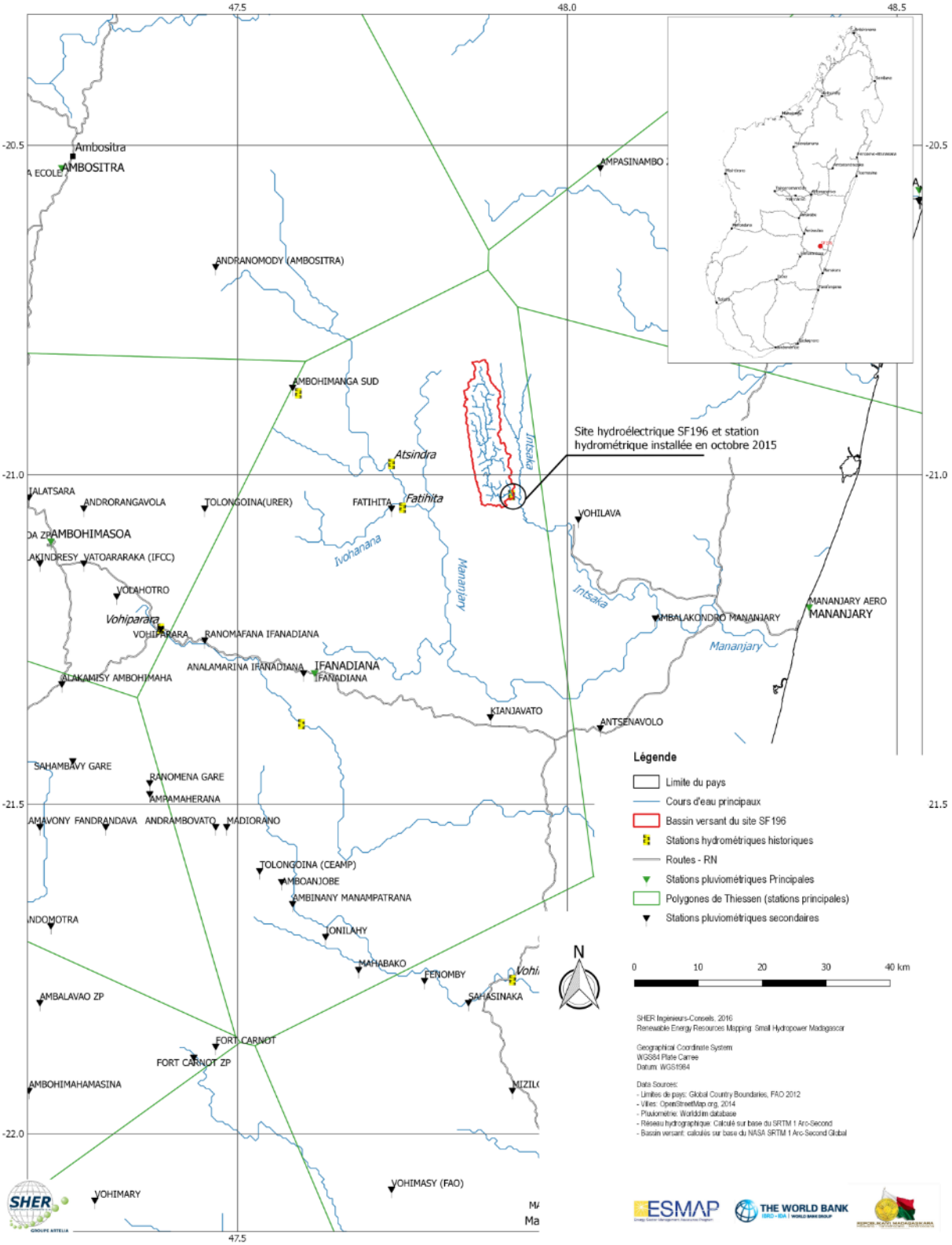
5.3 HYDRO-METEOROLOGICAL DATABASE

Figure 16 shows the location of hydrometric and rainfall stations where historical records exist. Two types of rainfall stations exists:

- stations where long-term measurements allowed an advanced statistical analysis and thus the determination of probability of occurrence of extreme rains (main stations). The Thiessen polygons of these stations are shown in Figure 16;
- rainfall stations where smaller records exist.

As noted in Figure 16, there is no rain gauge or hydrometric station in the catchment area of the proposed Mahatsara hydroelectric site.

Figure 16. Location of the hydrometric and rainfall stations



5.3.1 Rainfall and meteorological data

There is no meteorological station in the Besana watershed nor in its immediate vicinity. The closest rainfall gauges are in Vohilava and Fatihita.

Table 6. Available precipitation data

STATION	LONG	LAT	ALTITUDE	PERIOD	SOURCE
Vohilava	48°01'	-21°04'	~220m	1949-1978	ORSTOM, 1992
Fatihita	47°44'	-21°03'	~400m	1960-1985	ORSTOM, 1992

Beyond the data available at agro-meteorological ground stations, rainfall and temperature data from the WorldClim climate database were used in this study. WorldClim is a set of global data representative for the period ~1950-2000 available with a spatial resolution of about 1 km and at a monthy timestep. The spatial resolution is obtained by interpolation of ground-measured data.

5.3.2 Hydrological data

Historical data were obtained from three sources of information : (i) « Fleuves et Rivières de Madagascar» reference book published by ORSTOM in 1993 (FR)[1], (ii) Global Runoff Data Center database (GRDC)[2] and (iii) Meteorological Service of Madagascar (Direction Générale de la Météorologie de Madagascar - DGMET). All the data were compiled and consolidated into a single database. The location of the hydrological stations is presented in Figure 16.

The reference hydrometric station for this study is the Fatihita station on the Ivohanana River. At that location, historical streamflow records from various sources covers the period from 1956 to 75 (19 years) with daily data. The Ivohanana River watershed at the Fatihita hydrometric station is 835 km². It has a 15% catchment area ratio with the Besana River at the Mahatsara site.

pour laquelle un historique de mesures provenant de sources diverses couvre la période de 1956 à 1975 (soit 19 années consécutives) avec des données journalières. Le bassin versant de l'Ivohanana à la station hydrométrique de Fatihita est de 835km² et présente dès lors un rapport de superficie de bassin versant de 15% avec la Besana au site de Mahatsara. This ratio is low, but it is the nearest hydrometric station to the site of interest in the same larger watershed. Indeed, the Antsidra station on the Mananjary River drains a watershed that is too large (2260 km²) to be representative of the hydrological behavior of the Besana.

As part of the ESMAP Small Hydropower Resource Mapping study, a hydrometric station was installed in October 2015 at the potential hydroelectric site of Mahatsara. The preliminary rating curve has been established during the hydrological year 2015-2016. Given the limited length of the records, it will only be used to validate the hydrological study carried out based on the data from the Fatihita station on the Ivohanana River.

5.4 RAINFALL AND STREAMFLOW DATA ANALYSIS

5.4.1 Annual and Monthly Rainfall

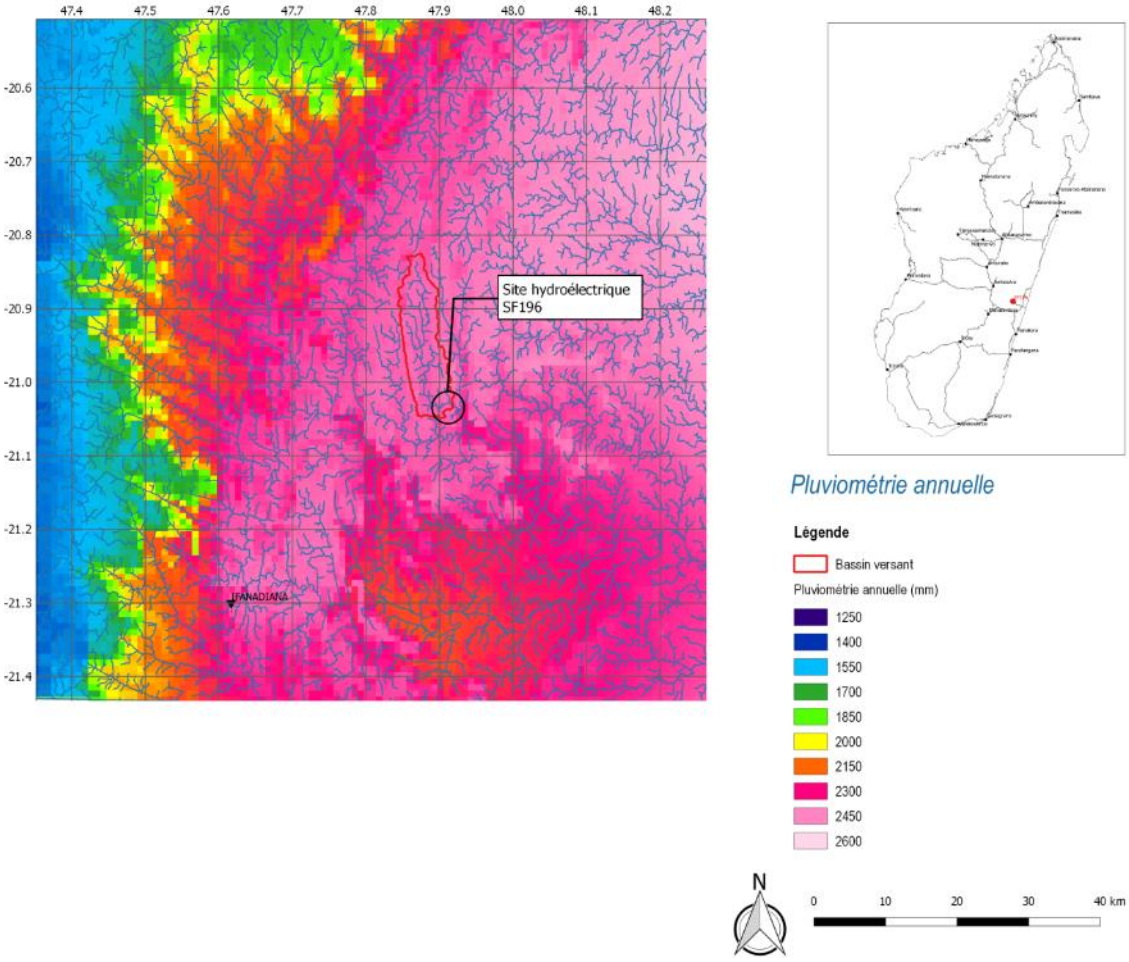
5.4.1.1 Spatial Distribution

The analysis of the spatial variation of rainfall within the study area is based on the WorldClim dataset, presented in section 5.3.1. As illustrated in Figure 17, the spatial variation of average annual rainfall within the watershed is low. The mean annual rainfall calculated on the catchment area is 2414 mm with a minimum of

[1] Caperon P., Danloux J. et Ferry L., Fleuves et Rivières de Madagascar, ORSTOM Editions, Paris, 1993.
[2] http://www.bafg.de/GRDC/EN/Home/homepage_node.html

2349 mm and a maximum of 2543.5 mm. The standard deviation is 11.23mm. This Figure shows that the rainfall gradient in the region is clearly oriented from East to West as one moves from the coast to the high plateaus where the rainfall is less abundant.

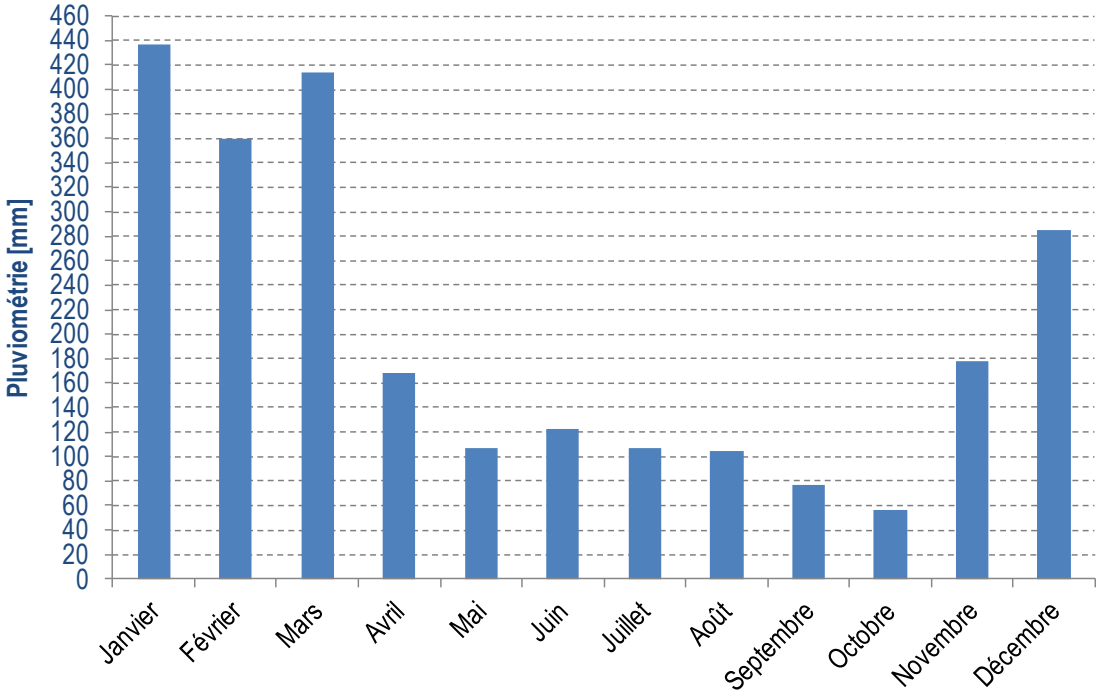
Figure 17. Spatial distribution of rainfall



5.4.1.2 Temporal Variation

Given the absence of rainfall stations in the catchment area and / or its immediate vicinity, the analysis of the temporal variation of rainfall is also based on the global data of the WorldClim database and is therefore only indicative. The seasonal variation in rainfall over the watershed (WorldClim source) is shown in Figure 18 hereunder. It is observed that the first precipitations become significant as from November, intensifying until January to March and then decreasing sharply in April.

Figure 18. **Monthly average precipitations on the Besana watershed (WorldClim data)**



5.4.2 Daily streamflow data

5.4.2.1 Preliminary note

As mentioned earlier, the reference hydrometric station for this study is the Fatihita station on the Ivohanana River. The rating curves (relationship between the measured water levels and the corresponding streamflows) and any other information relating to the quality of the measurements have not been made available to us. Moreover, it is important to note that the historical data cover the period 1956-1975 and are therefore representative of the hydrological conditions of more than 40 years ago. Therefore, some caution should be taken in the interpretation and use of these data.

5.4.2.2 Quality control and gap filling

Data from different sources and covering different time periods were compiled into a single consistent time series. The data were subjected to a few quality control checks. First visual screening showed a few mistyped numbers with two decimal points or misplaced decimal point. These data were corrected in the database.

5.4.2.3 Transposition des débits au site d'intérêt

La transposition des débits observés à la station de Fatihita sur l'Ivohanana vers le site de Mahatsara a été faite sur base du rapport des superficies de bassins versants, ajusté par le rapport des pluviométries annuelles sur les bassins versant. En effet, cette dernière correction s'est avérée nécessaire afin de prendre en compte le fait que la moitié du bassin versant drainé par la station de Fatihita se trouve à une altitude plus importante, nettement moins arrosée que le reste du bassin versant, tel qu'illustré à la Figure 17. Les résultats sont décrits dans les sections ci-dessous.

5.4.2.4 Adapted streamflow series

Figure 19 presents the hydrograph of the adapted streamflows at the Mahatsara potential hydropower site. The hydrology of the river is characterized by two seasons:

- Dry season from May to November where the average streamflow is below 5 m³/s;
- Wet season from December to April where the average monthly streamflow in February peaks at 15.1 m³/s.

Figure 19. Hydrograph of the Besana at Mahatsara

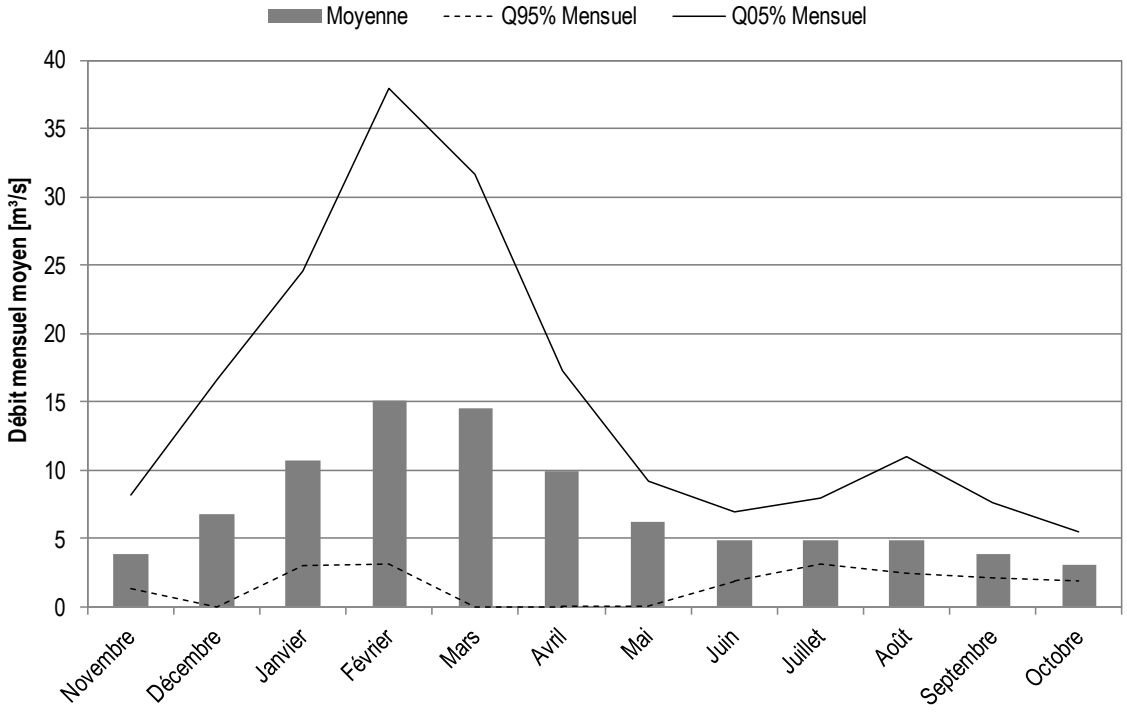


Figure 18 shows that the monthly hydrograph is very well correlated with the average monthly rainfall over the watershed.

Figure 20. Comparison of the hydrograph of the Besana River at Mahatsara (spatial extrapolation from Fatihita) and average monthly precipitations (WorldClim)

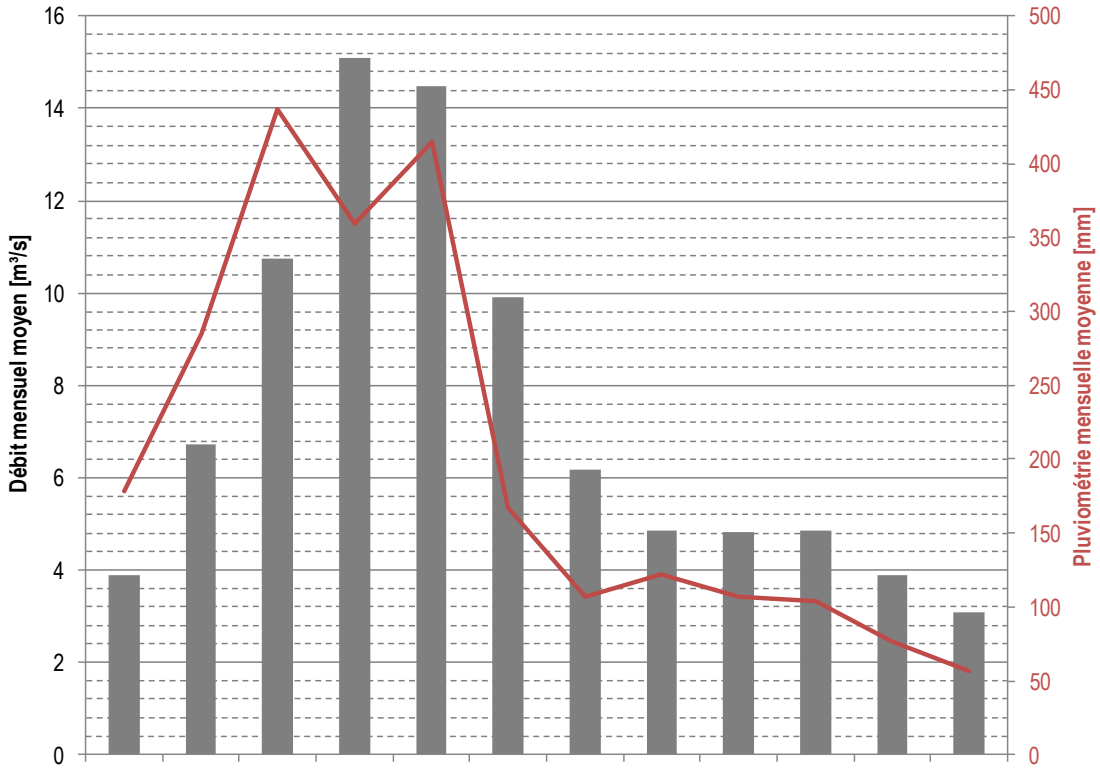


Table 7 and Figure 21 show the flow duration curve as well as the main quantiles. We observe that the streamflow of the Besana River is less than 5.1 m³/s 50% of the time and that it is higher than 13.9 m³/s only 10% of the time (over a year period). The flow guaranteed 95% of the time (347 days per year) is estimated at 2.3 m³/s.

Table 7. Flow duration curve of the Besana at Mahatsara

Exceedance Probability	Streamflow	
[-]	[m³/s]	[L/s/km²]
$Q_{95\%}$ -(débit garanti)	2.3	18.08
$Q_{90\%}$	2.6	20.60
$Q_{80\%}$	3.2	25.63
$Q_{70\%}$	3.8	30.06
$Q_{60\%}$	4.4	34.97
$Q_{50\%}$ (débit médian)	5.1	40.96
$Q_{40\%}$	6.2	49.46
$Q_{30\%}$	7.6	60.96
$Q_{20\%}$	10.0	80.12
$Q_{10\%}$	13.9	110.75

Figure 21. Flow duration curve of the Besana at Mahatsara

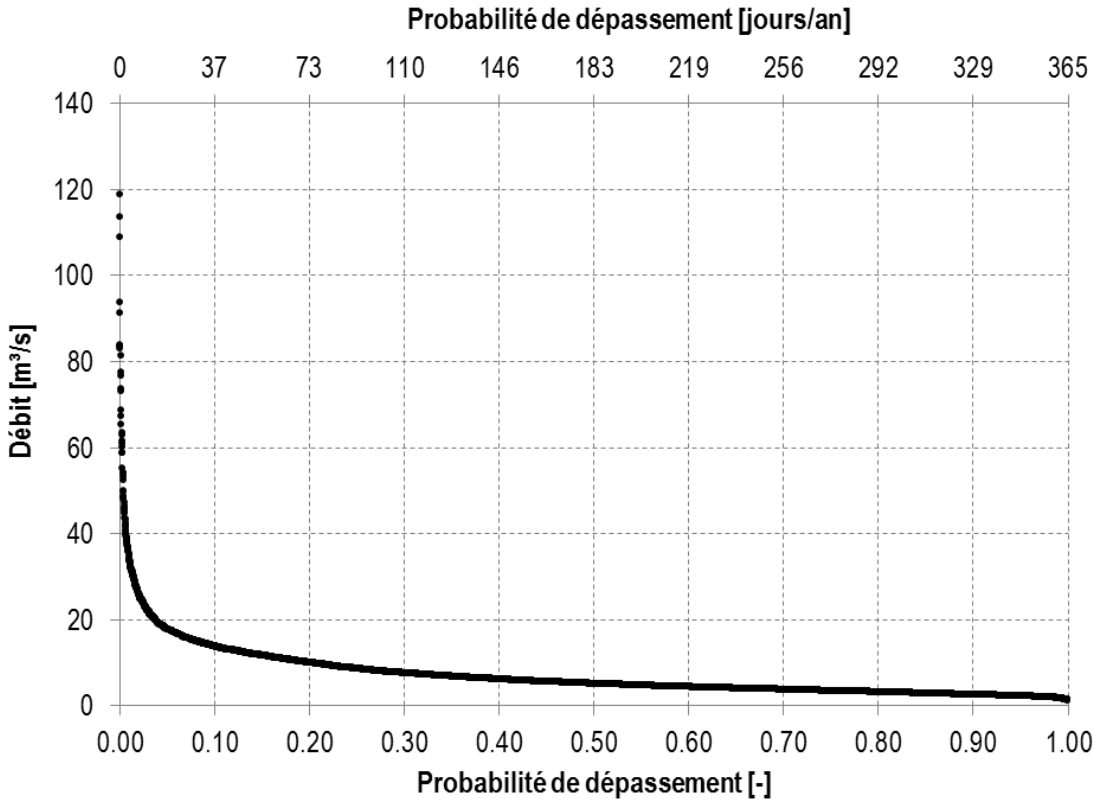
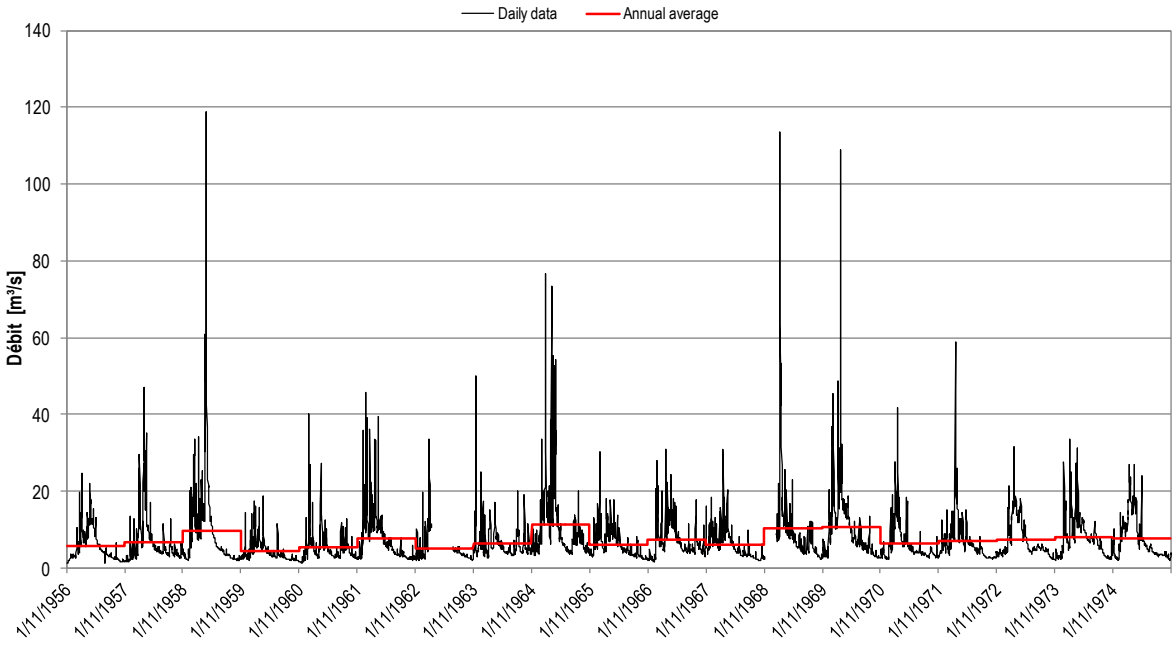


Figure 22 show a downward trend in average annual streamflow over the period considered. The feasibility study should investigate whether this observation is real or whether it is a problem in the quality of the recorded data.

Figure 22. Time series of average monthly streamflow of the Besana at Mahatsara



5.4.3 Recent daily streamflow analysis

5.4.3.1 ESMAP hydrometric station: Hydrological year 2015-2016

As mentioned earlier, a hydrometric station was installed in October 2015 at the Mahatsara potential hydroelectric site as part of the ESMAP Small Hydropower Resource Mapping study funded by the World Bank. The station is equipped with a pressure sensor (capacitive sensor with thermal and atmospheric compensation OTT PLS) for automatic water level measurement, an integrated recording and communication solution (OTTNetDL500) and a staff gauge read daily by an observer.

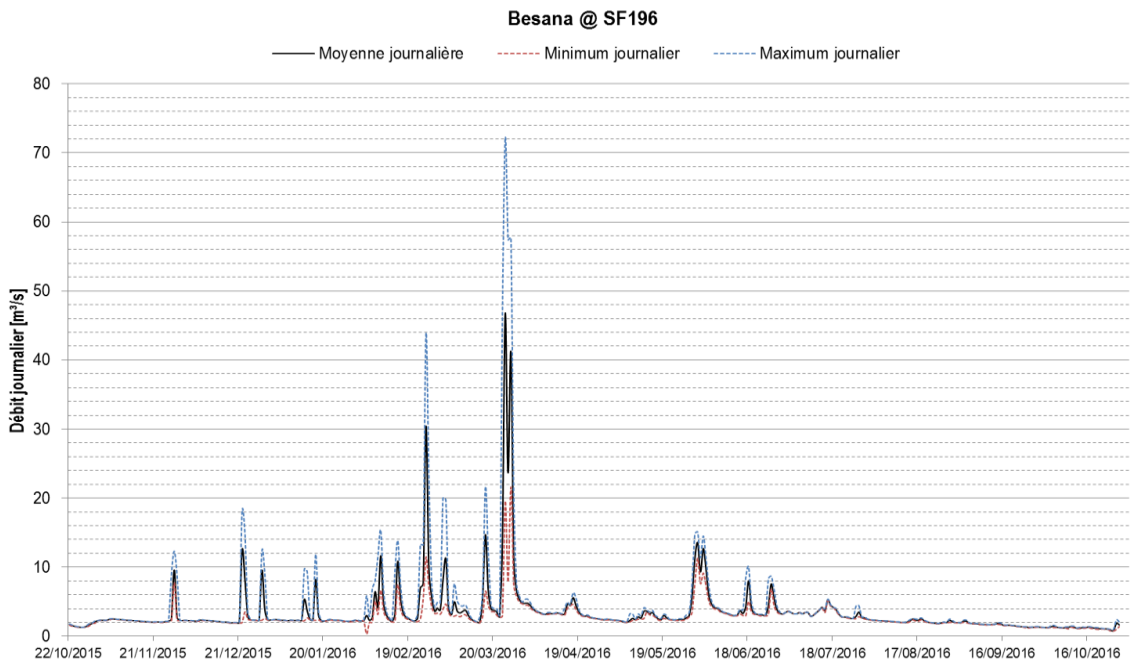
The measurement campaign took place during the hydrological year 2015-2016, from October 2015 to October 2016.

A preliminary rating curve was established on the basis of 11 gauging carried out with an ADCP (Accoustic Doppler Current Profiler). Those gauging cover a range of streamflow measured between 1.08 m³/s and 10.63 m³/s and have been done in good conditions. The preliminary rating curve covers an interesting range of water level but will have to be completed, especially in the water level above 0.30m. Indeed, few floods occurred in 2015-2016 on the Besana and the seasonal variability of its water level was very low during the hydrological year 2015-2016. Additional gauging operations will aim at validate and improve the accuracy of the curve.

The streamflows calculated using the preliminary rating curve are presented below. Figure 23 shows the average daily streamflows during the hydrological year 2015-2016. It is observed that the winter of 2015-2016 (corresponding to the rainy season and cyclones) is characterized by only few floods between November and February and no floods in April and May. The winter season has not been clearly visible in 2015-2016.

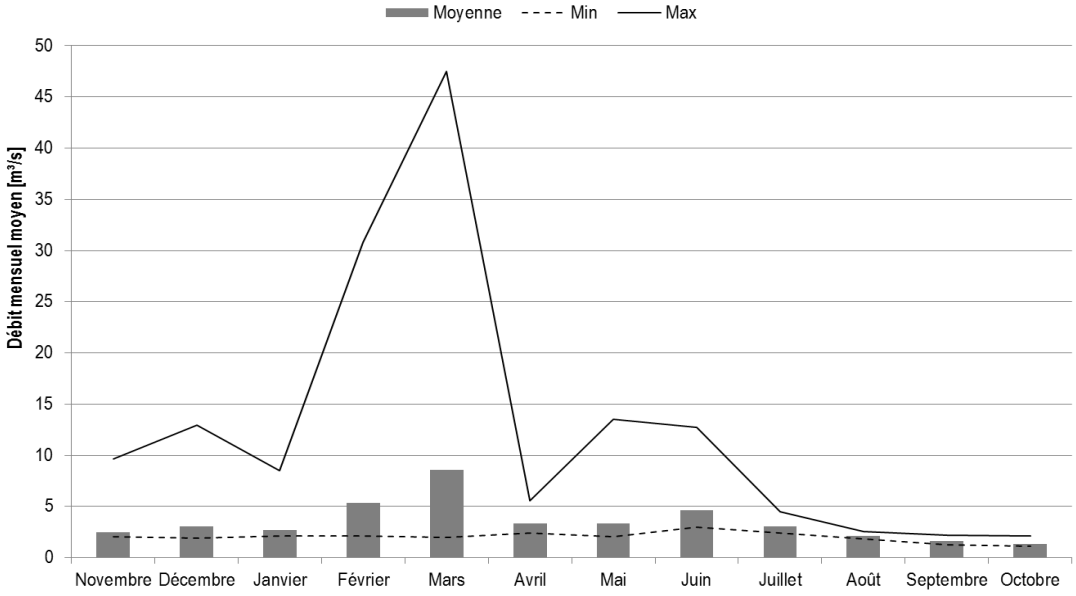
The graph in Figure 23 also shows the recorded daily maximum and minimum flows. We note that the peaks are generally high during the winter, but have a very limited duration in time (a few tens of minutes). Indeed, the latter have a limited impact on the daily average.

Figure 23. Daily streamflow on the Besana (2015-2016)



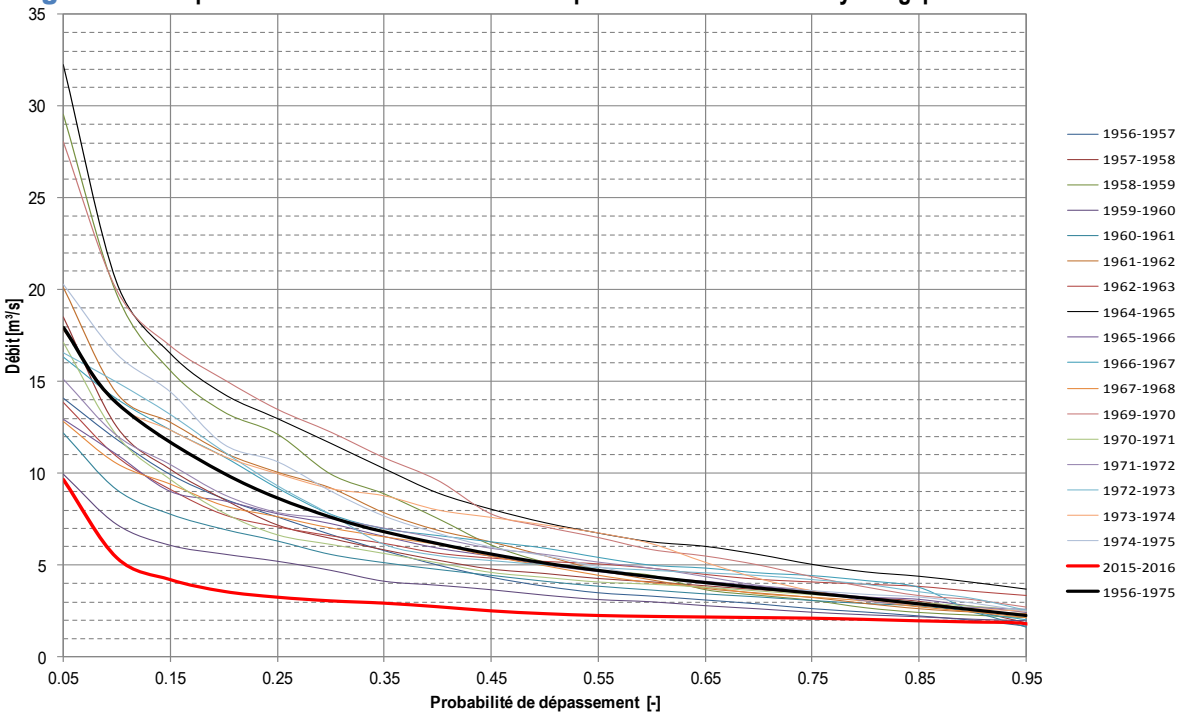
The monthly hydrograph is shown in Figure 24. It represents the monthly averages of the daily flows shown in Figure 23. It is observed that the largest daily peaks occurred during the month of March corresponding to the month with the higher flow rate on average.

Figure 24. Monthly hydrograph of the Besana (2015-2016)



The consequence of these observations is that the flow duration curve measured during 2015-2016 is characterized by low flows compared to the other hydrological years transposed from the Fatihita station (Figure 25). In addition, the curve 2015-2016 has a guaranteed flow rate of 95% close to the median flow rate $Q_{50\%}$. This is a consequence of the absence of major floods during the rainy season.

Figure 25. Comparaison des courbes des débits classés pour les différentes années hydrologiques



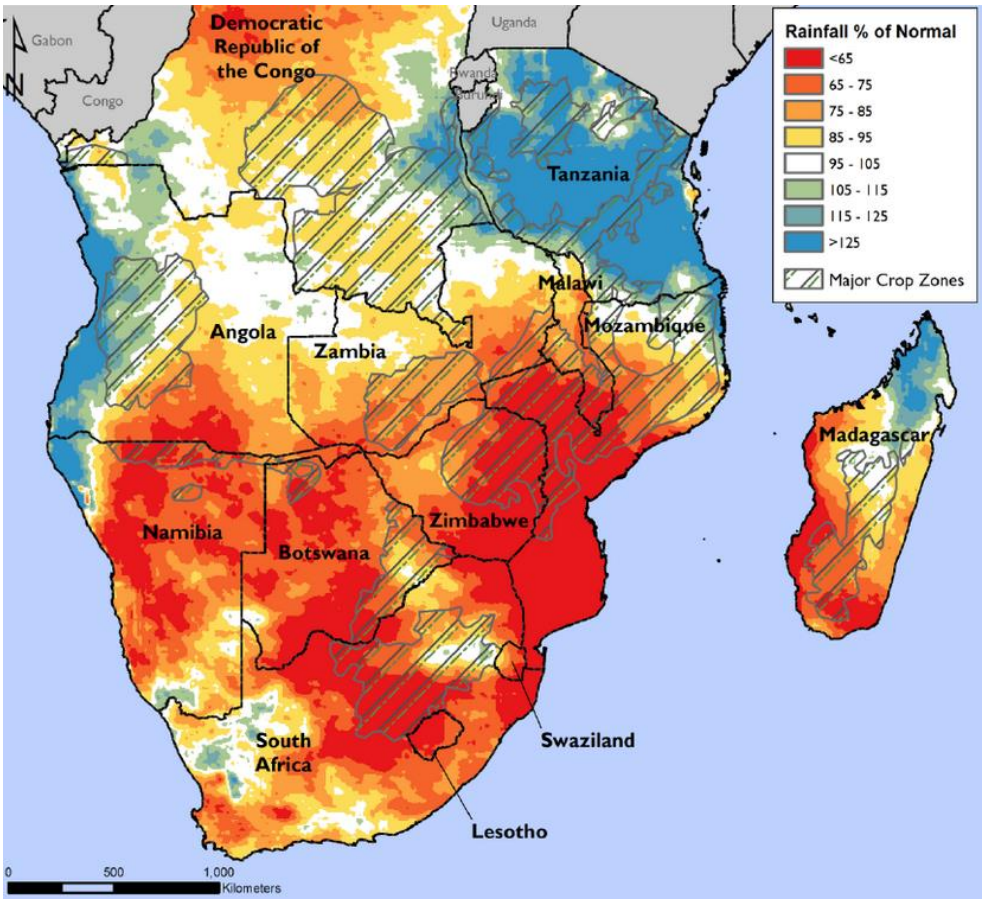
5.4.3.2 Comments on the hydrological year 2015-2016

El Niño is a natural phenomenon characterized by the abnormal warming of sea surface temperatures (SST) in the central and eastern regions along the equatorial Pacific Ocean. On average, it occurs every 2 to 7 years and can last up to 18 months. El Niño has significant environmental and climate impacts at the global scale. In some areas, this can lead to reduced rainfall and drought, while other areas are subject to intense rainfall and flooding. Climatologists have announced that the event El Niño 2015-2016 could be the most severe ever recorded.

In Madagascar, an extreme drought hit the south of the country directly affecting agriculture production and access to water, which led to severe problems on human health and nutrition. Four southern districts recorded below-average precipitation that occurs statistically every 20 years prior to April 2016 and precipitation since April 2016 in two districts arrived too late for the June crop harvest. The northern part of the country has been affected by extreme precipitation, causing numerous floods.

The map below (Figure 26) shows the differences in precipitation that occurred between October 2015 and February 2016 compared to the 1982-2011 average. It is observed that the watersheds studied in this hydrological monitoring campaign are all in the zone where precipitation deficits are more or less severe.

Figure 26. October 2015 - February 2016: Abnoral precipitations (% of average 1982-2011)[3]



[3] Source: FEWS NET/USGS

5.5 FLOOD STUDY

5.5.1 Introduction

The flood study is essential for design calculations of structures and equipment such as spillways or floodgates but also for temporary infrastructure such as cofferdams and temporary diversions during the construction period.

The flood study will focus on 10 years and 100 years return period. These floods will be used respectively for the construction and exploitation phases. A detailed justification for these return periods can be found in section 8.1.4 of this report.

5.5.2 Methodology

Floods were estimated using the Duret method that allows estimating the maximum flood of a river, for a given return period, based on the morphological characteristics of the watershed and the daily precipitations of the same return period falling on this watershed. This method was established in the 1970's to respond to a need for a practical flood-determining tool for any river in Madagascar, given the lack in historical data. The method has been established mainly for watersheds with a surface area of more than 150 km². An adapted version exists however to extend its validity to a watershed area down to 5 km².

The Duret method (1973) is based on the following equation:

$$Q(T) = k\, S^{\alpha}\, I^{0.32}\; H(24,T)\,(1 - 36/H(24,T))^2$$

Where I is the average slope of the watershed (m/km), S is the watershed area (km²), T is the return period of the event (year), $H(24,T)$ is the daily precipitation heigth (over 24h) on the watershed for a return period T *(year)*, k and α are variables depending on S and H.

For $S \geq 150$ km², $k = 0.025$ and $\alpha = 0.8$. Hence, the general equation becomes:

$$Q(T) = 0.025\, S^{0.8}\, I^{0.32}\; H(24,T)\,(1 - 36/H(24,T))^2$$

5.5.3 Daily precipitation estimations

In his book, Duret presents daily rainfall (over 24 hours) for different return periods for a set of 105 stations spread over Madagascar. Those data were estimated from a frequency analysis of available 30 to 40 years-long time series.

Given the size of the Sahatandra River watershed, application of the Duret method requires taking into account the spatial variability of precipitation. The Thiessen polygon method is a simple method for interpolating point measurements of rainfall stations on a territory. Thiessen polygons are formed by mediators of straight lines joining adjacent rainfall stations as shown in Figure 16. Hence, weighted average precipitation on the watershed surface is calculated by the arithmetic sum of precipitation from each station, weighted by the area of the corresponding Thiessen polygon in relation to the total area of the watershed area.

We observe that the entire Besana watershed is location within the Thiessen polygon associated with the Ifanadiana rainfall gauge.

5.5.4 Flood estimates

Ten years and hundred years return period flood estimates at the Mahatsara hydroelectric scheme are presented in the following table.

Table 8. Ten years and hundred years return period flood events

Atlas Code	Site Name	Daily precipitations H(24,T) [mm]		Floods [m³/s]	
		T = 10 years	T = 100 years	T = 10 ans	T = 100 ans
SF196	Mahatsara	205	325	279	514

5.6 Study of the Erosion Hazard in the Besana Watershed

5.6.1 Objectives

No information on solid transport in the river is available at this stage. Solid transport is strongly linked to land use conditions, agricultural practices in the catchment area and to extreme rainfall events.

The objective of this study is to map the actual erosion hazard (taking into account the land use) for non-artificialized area (crops, grasslands, forests, savannas, etc.) based on the soil losses estimates resulting from water erosion. The objective is not about estimating the solid transport in the river but rather mapping the areas where erosion is potentially important in order to appropriately manage the issue, in particular by the development of watershed management policies that include conservation soil measures.

5.6.2 Methodology

Soil losses resulting from erosion by water were estimated using the RUSLE model (Revised Universal Soil Loss Equation), widely used and accepted across the scientific community. RUSLE is an empirical model based on five determining factors that impacts soil loss (Wischmeier et Smith, 1978[4]).

$$E = R \cdot K \cdot LS \cdot C \cdot P$$

Where *E* expressed the soil losses [t.ha^{-1}.y^{-1}], *R* is the rainfall-runoff erosivity factor [MJ.mm.ha^{-1}.h^{-1}.y^{-1}], *K* is the soil erodibility factor [t.h.mm^{-1}.MJ^{-1}], *L and S* are the slope length and slope steepness factors (dimensional), *C* is the cover-management factor (dimensional) and *P* is the support practice factor (dimensional).

The use of RUSLE is justified by its simplicity, in particular due to the relatively small number of parameters taken into account, its clarity and its easy integration into a GIS. However, this model has a number of limitations both in terms of limits of applicability and design. These limitations, which are inherent to the conceptual model, must be taken into account when analyzing the model outputs. A literature review of the limits of the RUSLE is presented below (Yoder et al., 2001[5] et Roose, 1994[6]):

- Many factors influencing soil erosion are taken into account, but the interaction between these parameters is sometimes overlooked.
- The model calculates long-term average erosion rates. It is not valid at the timescale of the rainfall event nor a year.
- The model is only valid for slopes steepness below 35% and slope lengths less than 300 m. Beyond that the results are uncertain and indicative only.
- Calibration data are taken from plots not exceeding a few hundred m². The results obtained at the watershed scale are only indicative.

[4] Wischmeier W. H., Smith D. 1978. Predicting rainfall erosion losses, a guide to conservation planning, Agriculture Handbook 537, Washington D. C.
[5] Yoder D. C., Foster G. R., ., Weesies G. A., Renard K. G., McCool D. K., Lown J. B. 2001. Evaluation of the RUSLE Soil Erosion Model, in Agricultural Non-Point Source Water Quality Model: Their use and application, Parsons et al., Southern Cooperative Series Bulletin 398.
[6] Roose E. 1994. Introduction à la gestion conservatoire de l'eau, de la biomasse et de la fertilité des sols (GCES), Bulletin pédologique de la FAO 70.

- Only detachment and transport of soil are taken into consideration. The deposition of eroded sediments due either to the topography or to the carrying capacity of the runoff water is not taken into account.

The model outputs that quantify the soil losses are therefore to be considered with caution. However, the model is extremely interesting to map the relative intensity of erosion hazard over large areas.

5.6.3 Potential and actual soil erosion harzard

Potential soil erosion reflects the erosion related to the physiographic properties of the environment (rainfall, soil type, topography) irrespective of land use or possible anti-erosion measures. The results are presented in Figure 27. Due to the limitations of the method used to calculate soil losses but also due to the quality and resolution of the input data, it is preferable to classify the absolute erosion values into potential intensity of the erosion hazard. Five classes of erosion hazards were defined based on the statistical distribution of the absolute values of potential erosion calculated over Madagascar:

- Low hazard : quantiles 0 - 25 ;
- Medium hazard : quantiles 25 - 50 ;
- High hazard : quantiles 50 - 75 ;
- Very high hazard : quantiles 75 - 95 ;
- Extreme hazard : quantiles 95 - 100.

The mapping of the potential erosion hazard in the Sahatandra watershed is presented in Figure 28. It is observed that the potential erosion hazard is relatively high over the entire watersged area, particularly in the downstream part of the watershed where the slopes are the steepest.

On the other hand, the calculation of the actual erosion takes into account the land use. This is illustrated in Figure 29.

As mentioned earlier, it is not the absolute values of soil loss that are of interest here but the comparison between potential erosion and actual erosion. This comparison highlights the positive impact of land use in the Sahatandra River watershed, particularly the positive impact of the protected areas on the erosion rates. The latter are drastically reduced in the vast majority of the watershed but remain important in the downstream part of the watershed due to the steep slopes and a mainly agricultural land use.

These findings suggest that the Mahatsara site could potentially have significant solid transport, particularly during flood events, which would cause operational and maintenance problems for the hydroelectric power station.

It is important to note that the results obtained below can not be transposed directly into sediment inputs into rivers. Indeed, the above analysis is valid for pixel-by-pixel mapping of potential and effective erosion and does not take into consideration the transport of soil particles between pixels. Consequently, a large part of these soil particles will not be found in the watercourses because they will have been sedimented on their way to the watercourses because of changes in slope intensities, land use, etc.

Figure 27. Potential soil losses

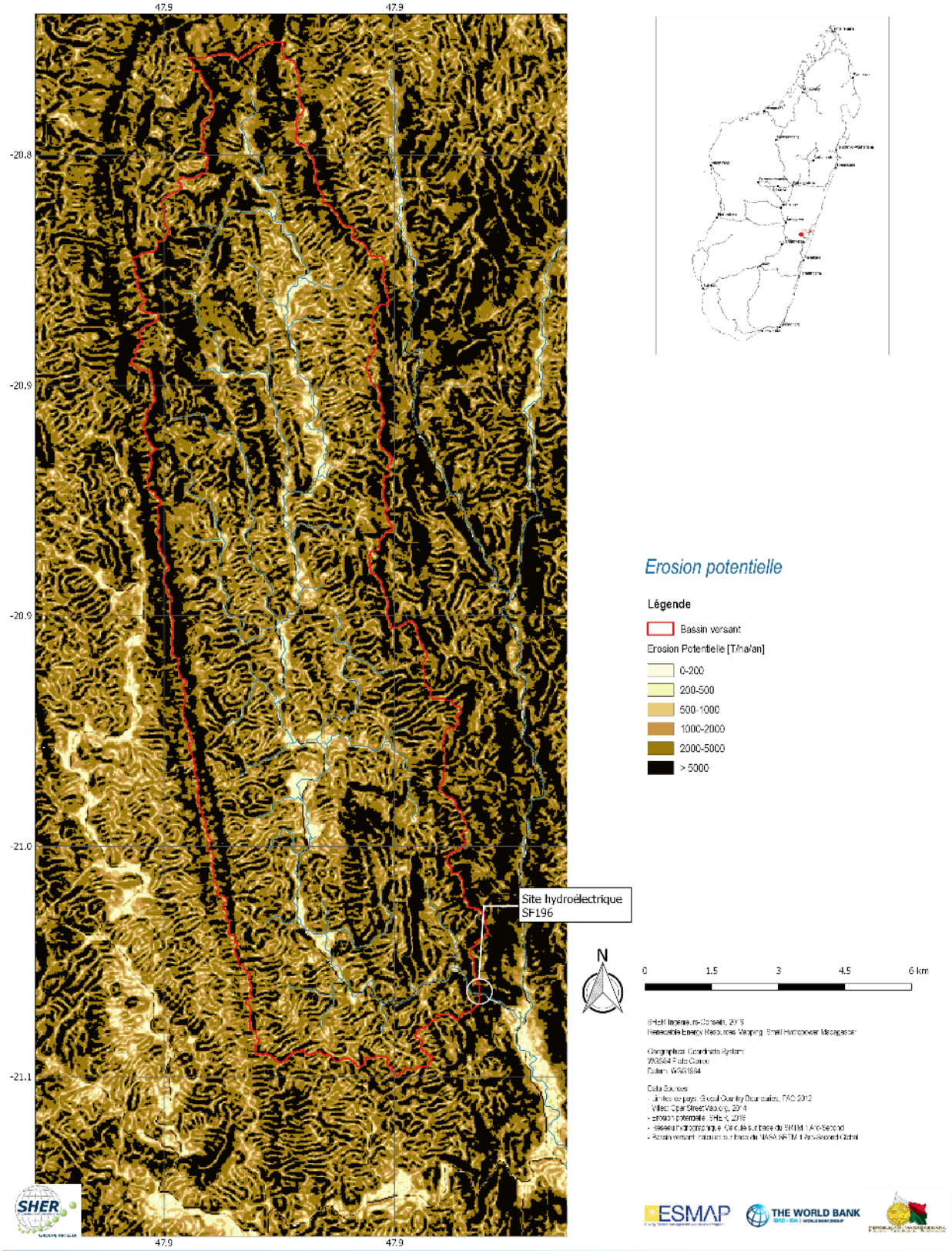


Figure 28. Potential relative erosion hazard

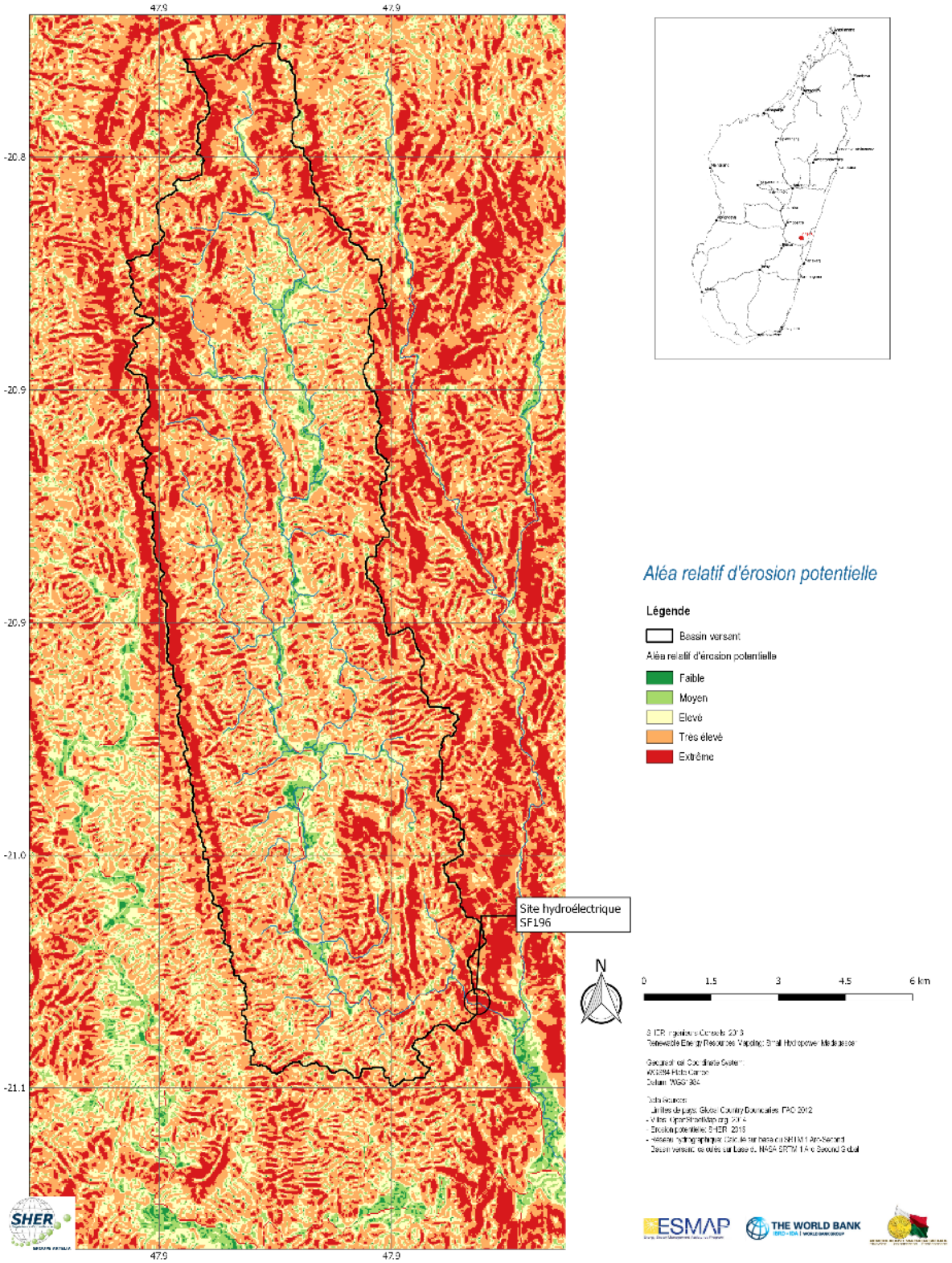
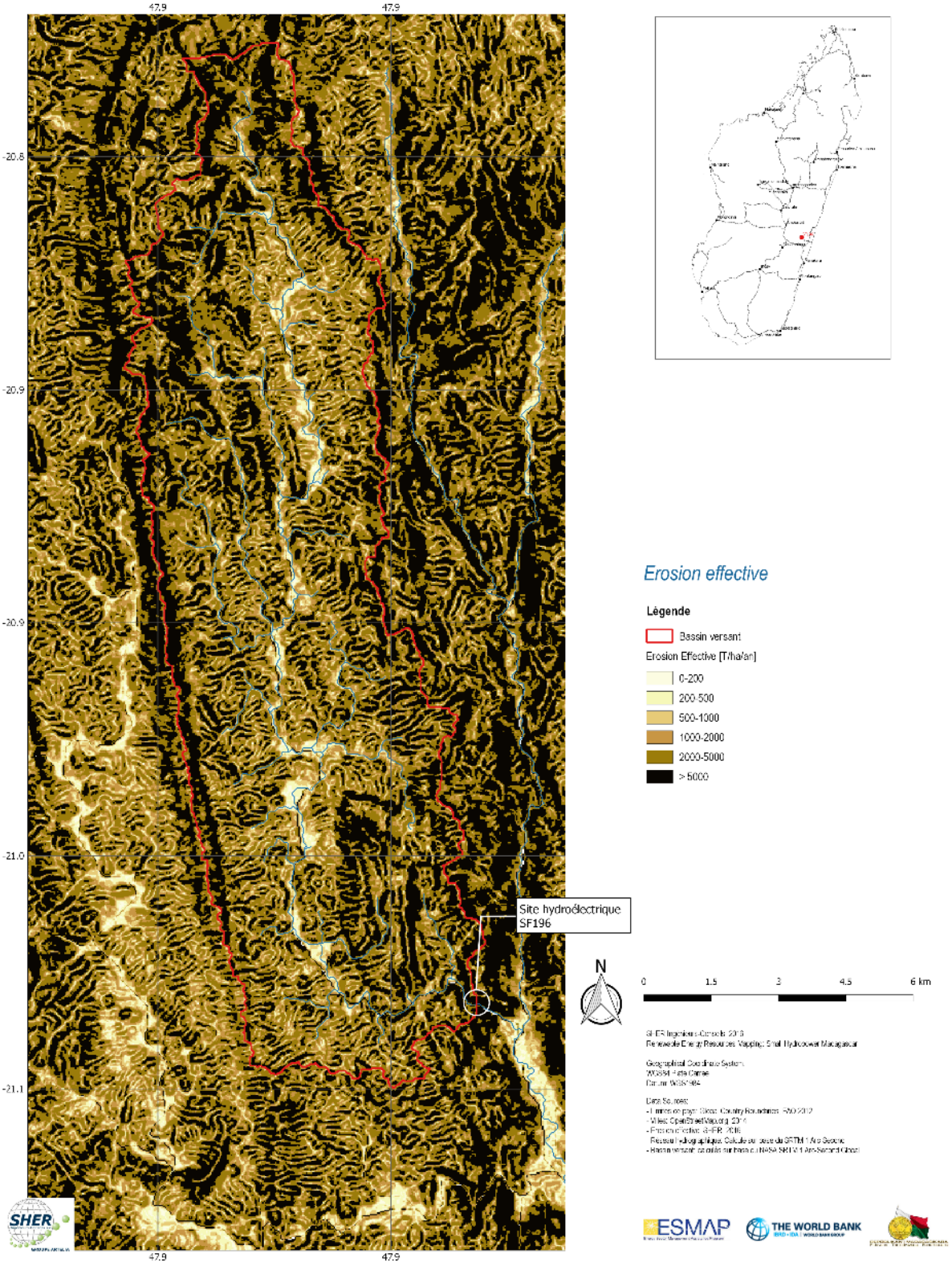


Figure 29. Actual relative erosion hazard



5.7 KEY HYDROLOGICAL PARAMETERS OF THE MAHATSARA SITE

The key hydrological characteristics of the Mahatsara hydroelectric project on the Besana River are summarized in Table 9 ci-below.

Table 9. Key hydrological characteristics of the site

CHARACTERISTIC	PARAMETER	VALUE	UNIT
Watershed	River	Besana	-
	Area	125	km²
	Mean elevation	365	m a.s.l.
	Maximum elevation	699	m a.s.l.
	Minimum elevation	222	m a.s.l.
	Average slope	5.2	m/km
Rainfall	Average (WorldClim)	2414	mm/a
Natural inflows	Average	7.3	m³/s
	Average specific	58.3	L/s/km²
	Median	5.1	m³/s
	Median specific	40.9	L/s/km²
Floods (Duret approach)	10 years	279	m³/s
	100 years	514	m³/s

5.8 CONCLUSIONS AND RECOMMENDATIONS

The hydrological study is based on hydrological data from the station of Fatihita on the Ivohanana River. On the basis of the measurements carried out during the year 2015-2016, it is observed that the latter is particularly dry and characterized by the absence of major floods. It is important, however, to bear in mind the following, sources of uncertainty:

- The hydrological year 2015-2016 is an El-Nino year. This global climatic phenomenon has a significant impact on hydrology in Madagascar by reducing inputs. This is confirmed by the absence of cyclones during this season.
- The hydrological reference data used for spatial extrapolation (Fatihita station on Ivohanana) are very old (1956-1975) and come from a catchment much larger than that of the Besana (area ratio of 15%).
- The flows for the year 2015-2016 were calculated on the basis of a preliminary rating curve established during the year 2015-2016.

The flow duration curve obtained by extrapolation is therefore to be used with caution and it is strongly recommended to continue the hydrological monitoring of the Besana beyond the year 2015-2016 in order to confirm the hydrological deficit observed during the year 2015 -2016.

The hydrological study also found that the Mahatsara site could potentially feature a significant solid transport, particularly during flood events, which would cause problems of operation and maintenance of the hydroelectric power station. This risk is due to the combination of the following factors: predominantly agricultural land cover in the catchment area, presence of steep slopes and significant annual rainfall over the entire catchment area.

Beyond the development of the Mahatsara hydroelectric project, it is strongly recommended that the Government of Madagascar set up a hydrological monitoring network for its rivers with high hydropower potential in order to better understand the available water resources and thus promote the development of hydroelectric projects across the country. It is only in a context of reduced uncertainties through reliable, recent and long-term records (more than 20 years) that technical parameters and economic and financial analyzes of hydroelectric developments can be defined accurately, enabling optimization of their design and their flood control infrastructure (temporary and permanent).

5.9 REFERENCES

1. Fleuves et Rivières de Madagascar, ORSTOM 1993
2. Food and Agriculture Organization of the United Nations (FAO) : http://www.fao.org/emergencies/crisis/elnino-lanina/intro/en/
3. Unicef : http://reliefweb.int/sites/reliefweb.int/files/resources/UNICEF%20Madagascar%20Humanitarian%20SitRep%20-%20Sep%202016.pdf
4. Famine Early Warming Systems Network (FEWS NET) : http://www.fews.net/southern-africa/special-report/march-2016

6 GEOLOGY

6.1 INTRODUCTION

The purpose of this chapter is to generate preliminary geological datasets and other important baseline information at the proposed site that will be used for the design of the hydroelectric scheme at the pre-feasibility study level. These data and information will also be used to define the geotechnical investigations that will have to be carried out at next stages of the study.

This study aims to inform about the geological conditions and the types of materials existing in the region, as well as to give an initial overview of the geotechnical properties of these materials. Recommendations are also formulated regarding the need for further studies and investigations if necessary.

6.2 GEOLOGICAL REFERENCE MAP

The reference map is Sheet Mananjary QRS 52-53 (1962) 1 :200,000 scale.

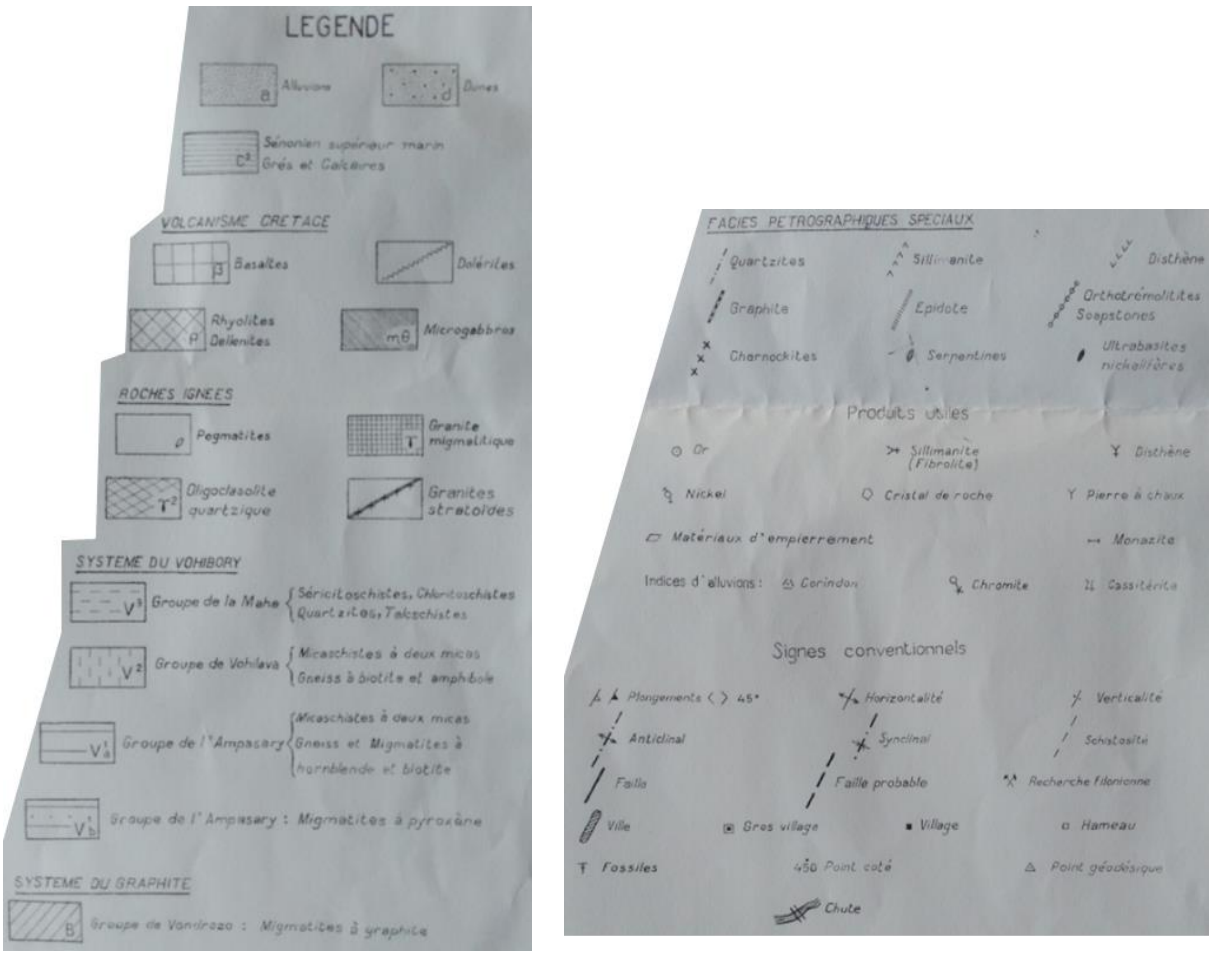
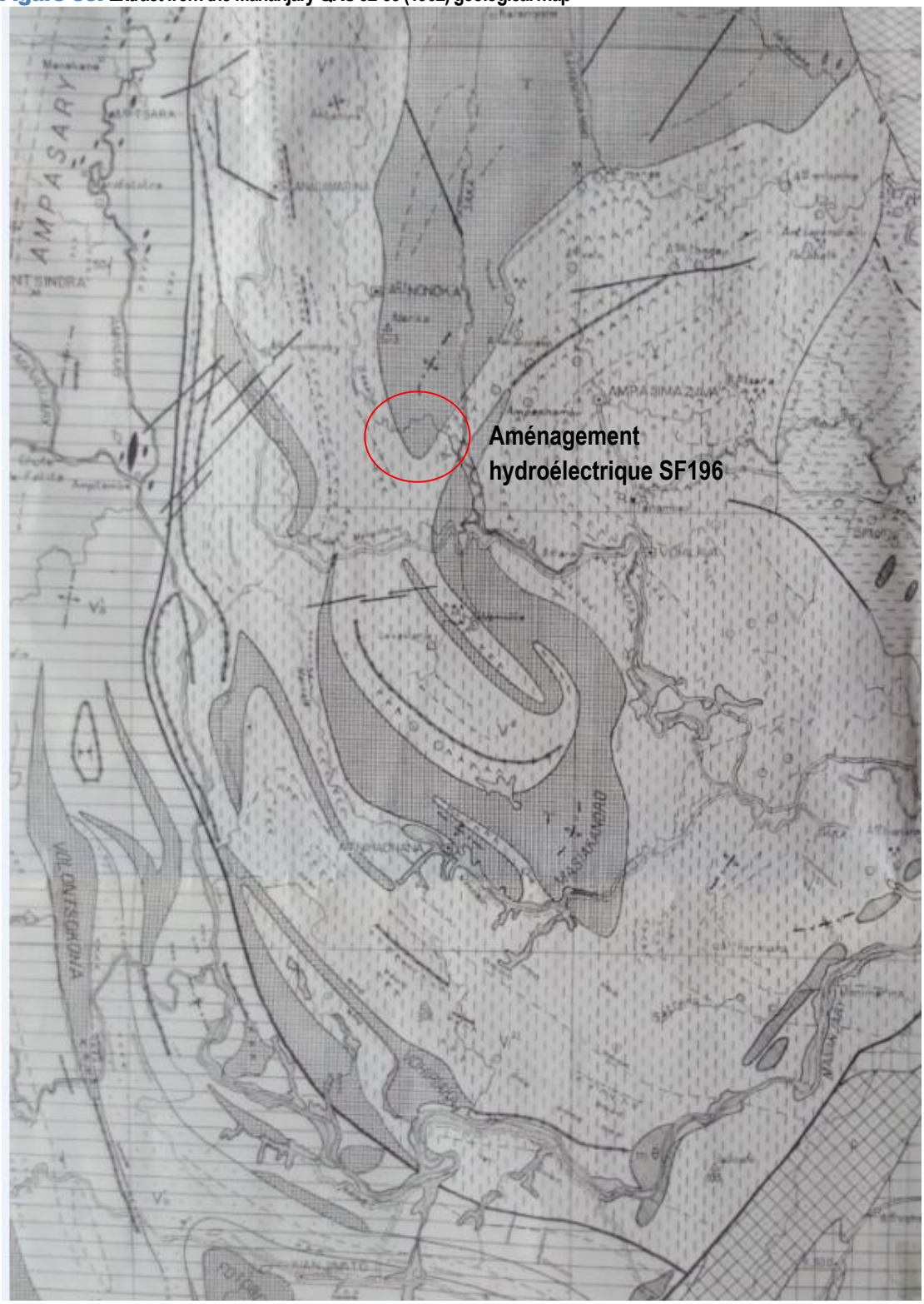


Figure 30. Extract from the Mananjary QRS 52-53 (1962) geological map



6.3 REGIONAL GEOLOGICAL SETTING

The study area is located on the *Precambrian* Madagascar rocks. Existing formations belong to the *Vohibory system* with predominant *metamorphic rocks*.

The region is characterized by two groups:

- the group of Vohilava formed of *micaschiste and gneiss*.
- the Ampasary group formed of *migmatite*.

These two formations are intersected by the *Befody granite eruptive rock* formed of *granite and granite - migmatitic*.

The formations are organized in vast systems of syncline and anticline of axis north / south in general.

The region is characterized by intense tectonic activity. This is related to the Great Eastern Fault, which resulted in the formation of secondary fault systems throughout the area. These faults have a north / south direction. The eruption of the granite gave the multidirectional faults.

The region is in the form of hills of medium altitude up to mountains up to 1000m. Depending on the nature of the soils, erosion has shaped different forms of mountains with narrow valleys.

6.4 LOCAL GEOLOGICAL AND PETROGRAPHIC SETTINGS

6.4.1 Geological setting of the study area

The project area lies between two mountains of medium elevation. The river flows into a narrow valley between the mountains. On the surface, the formations encountered are the *laterites* resulting from the alteration of the *gneisses*, the *micaschists* and the *substratum*.

The *laterite* is red to brown in color, it appears compact and indurated on the surface. On the road embankments, the cut shows a thickness of about ten meters. *Structured laterite* is seldom seen.

Under the cover, the rock of the *granite substrate* with *migmatitic granite* with *low foliage* is encountered. The *granite* is light colored and consists of *quartz*, strongly *feldspathic* and a few *micas*. The grains are coarse giving a grainy texture. The thickness of the surface alteration is small: less than 10 cm.

On the right bank, the *granite* appears on a sliding plane having a dimension of about ten meters. On the left bank, the rock outcrops at the foot of a hill in massive form with extensions towards the river bed.

Downstream of the main waterfall we find mainly *granite boulders* of different dimensions (metric). These boulders cover the bed of the river.

The tectonics that affected the eastern region resulted in cracks in the rocks. The cracks have two preponderant directions:

- direction 180N and dip 70W
- direction 320N and subvertical dipping

The second is oriented in the flow direction.

Figure 31. View of the intake and weir site

6.4.2 Geological characteristics of the proposed scheme

6.4.2.1 River bed at weir location

On each river bank, the foundation is formed by elongated flat outcrops of *granite or migmatitic granite*, having a grainy texture. The material is slightly altered on the surface.

The rocks have cracks of centimetric width along the general directions. Sometimes the crack is clogged by a vein of white quartz. Cracks are simple fracture without change of direction or dip. The rock material is hard.

The water level in the river was shallow at the time of the visit (September 2016). In the middle of the river, it is not possible to observe the nature of the river bed. Centimeter boulders can be observed in places.

Due to the presence of cracks, permeability tests will be necessary. In addition, further investigations have to be carried out on the submerged area in subsequent studies.

Figure 32. Rocks at the proposed weir location

6.4.2.2 Right bank support

The right bank support has a subvertical sliding plane of length between 15 and 20 m and a height of about 10 to 12 m. The cross section shows, at the top, a layer of compact pink laterite and below a massive outcrop

of granite with migmatitic granite, with granitic rock boulders at the base. The granite has coarse grains of quartz and feldspar, mica is rare. The texture is grainy.

The rock has fissures and diaclases oriented in the two dominant directions. The breaks do not cause a change of direction.

Figure 33. Rocks under thin laterite layer

The outcrops extend horizontally into the bed of the river with migmatitic granite with low foliage. The rock is cracked in both directions. Fractures could cause leakage by bypassing the intake structure. Further investigations will have to be carried out to determine the level of fracturing of the rocks and their permeability. On the surface the altered layer is thin. The rock has a grainy texture and appears to be hard.

Figure 34. Cracks in the rocks

6.4.2.3 Left bank support

The lateritic layer is thin and indurated. There is no structured laterite in contact with the rock. The natural slope of 50 ° appears stable.

From the bed of the river one encounters horizontal outcrops elongated which extend to the foot of the mountain. The rock is formed of medium grained migmatitic granite or granite. The outcrops have breaks of centimetric width oriented along the general directions. The superficial alteration is thin. Sometimes pegmatitic segregations, large crystals of feldspar and quartz are encountered.

Figure 35. Fractured elongated outcrop

At the foot of the slope there is a massif in place of granite to medium to coarse grains. The texture is grainy. Outcrop to one metric dimension. It is not very fractured. This outcrop reappears on the opposite bank of the river in the form of a vertical bedrock.

This set of hard rock, large in size, can be used as a support for the structure.

6.4.2.4 Intake structure

The intake area the catch is the same type of rock: granite with migmatitic granite. The outcrops in the river are flat. Cracks exist. The rock is slightly altered on the surface. On the other hand, at the foot of the embankment there are rock blocks displaced. The stable rock is not visible under the vegetation.

An area with moved blocks limits the intake area.

Figure 36. Rocks at the proposed intake location

6.4.2.5 Inundated area

The inundated area is not visible because of the presence of water. But there are a few isolated blocks of rock.

Figure 37. Rocks in the inundated area

6.4.2.6 Tunnel

The tunnel will probably cross the extension of the massive rock of granite, whose characteristics are mentioned above. Investigations will be carried out on the soft materials and the rocks: Auger borings will have to be carried out to determine the thickness and compactness of the soil as well as the level of the rock roof. Rock sampling is required to obtain samples for hardness, cracking and permeability tests.

Figure 38. Departure area of the tunnel

6.4.2.7 Penstock

Along the course of the penstock, laterite is observed on a strong natural slope. Geophysics will be required to determine the level of the bedrock for anchoring the foundations.

6.4.2.8 Powerhouse

The planned powerhouse location is on a steep mountain slope. On the surface is a soil with gray humus used for cultivation after clearing. There are metric boulders of granite. On one of the slopes of a thalweg, an outcrop elongated in a vertical position is observed. It probably indicates the presence of massive rock beneath the laterite.

Surveys and geophysics will be carried out to find the substratum.

At the foot of the mountain, on the edge of the major bed of the river, are displaced blocks of granite. In the bottom of the lavakas, the blocks are in clusters.

Figure 39. Proposed powerhouse location

6.4.3 Construction materials

For filling and riprap materials, migmatitic granite or granite metric blocks can be used in riprap, rubble and gabion.

For concrete aggregates, boulders and blocks can provide aggregates for concrete after manual crushing and sorting of dimensions.

For river sand, the only exploitable area is located on meanders located well downstream of the site.

For soils: certain categories of laterite can be exploited as backfill material.

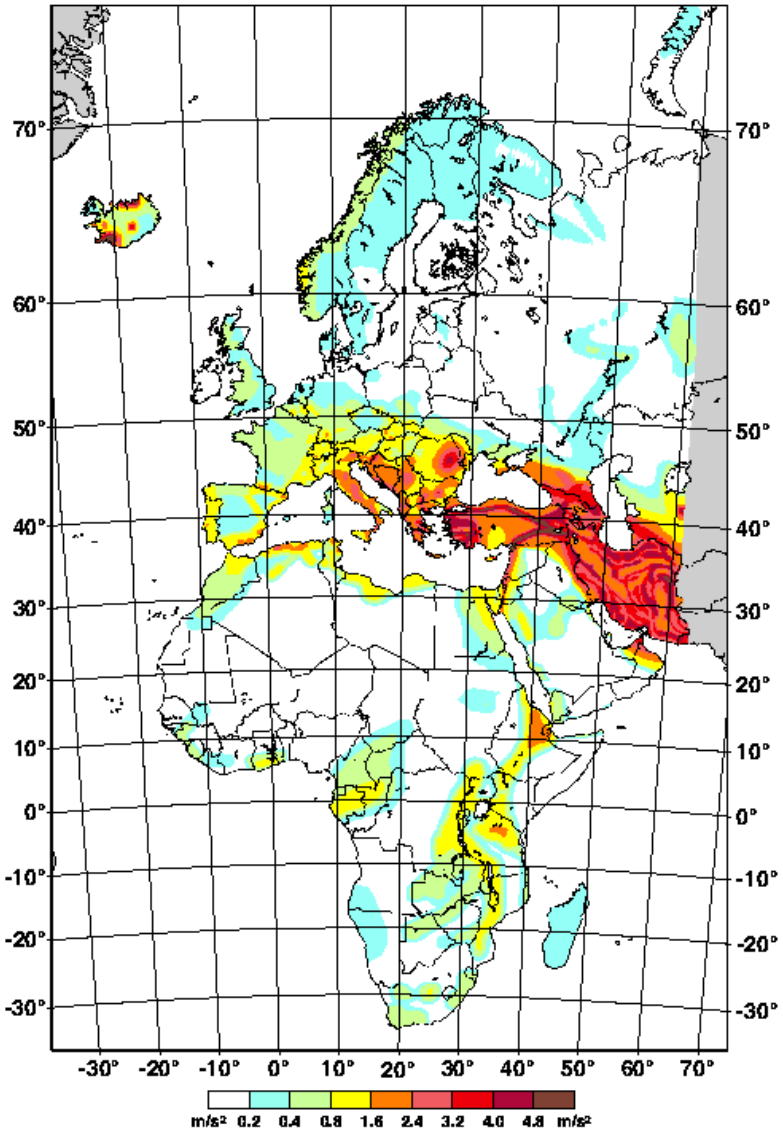
6.5 SEISMICITY

Madagascar is characterized as a stable area. This very old plateau is still characterized by some tectonic activities. Seismicity in this area is relatively unknown, mainly due to the lack of historical data. Within the framework of the Global Sismic Hazard Assessment (GSHAP), the assessment of the seismic hazard in West Africa was carried out on the basis of two data sources:

- The catalog of the British Geological Survey (Musson, 1994), containing quakes of magnitude greater than 4 from 1600-1993 (this is assumed to be complete for magnitudes greater than 5 beyond the year 1950 and for Magnitudes greater than 6 since the beginning of the 20th century),
- The NEIC catalog for more recent events (1993-1998).

A statistical method was used to determine the horizontal acceleration values due to earthquakes. The map below shows the distribution of seismic acceleration coefficients for the entire African continent. It can be seen that the project area is characterized by horizontal accelerations of less than 0.4 m / s². This value will of course have to be confirmed by additional studies.

Figure 40. Horizontal acceleration du to seismicity (source : GSHAP[7])



6.6 RECOMMENDATIONS

For the stability of the supports and foundations:

- On rocks: rock drilling tests to determine the thickness of the surface deterioration and degree of cracking.
- Sampling of rock cores for hardness and compressive strength tests.
- Geophysics on the layout of the tunnel and the penstock to determine the characteristics of the bedrock.
- 2 or 3 rock drill holes will be planned to calibrate the geophysics along the alignment of the tunnel.

For the permeability of the inundated area and tunnel:

[7] http://www.seismo.ethz.ch/static/GSHAP/eu-af-me/euraf.html

- On soils: digging by hand auger to determine the thickness and nature of the layers, and sampling soil samples to determine the stability characteristics of the layers.
- Measurements of permeability on cracked rocks and soils.

The table presented hereunder summarizes the uncertainties to be removed and the type of investigations to be carried out to remove them.

ELEMENT	UNCERTAINTIES TO REMOVE	INVESTIGATION
Bed at weir	✓ Existence of a fault along the river axis ✓ Leakage through fractures	✓ Permeability test. ✓ Dewatering of the riverbed for investigations
Right and left banks supports	✓ Leakage through fractures	✓ Percolation tests in situ, grout injections for sealing.
Intake	✓ Type of rocks ✓ Multiple cracks on the slope	✓ Clearing of the vegetation ✓ Detailed study of the cracks with percolation tests in situ, grout injections for sealing.
Waterway	✓ State of internal fracturing of the rock structure under influence of the regional fault. ✓ Leakages within the tunnel ✓ Exact location of the bedrock	✓ The level of rock with appropriate compactness should be determined by seismic reflection geophysical survey ✓ Core drilling at some chosen points along the waterway to characterize the fracturing condition and to conduct percolation tests
Penstock	Location of the bedrock	✓ Geophysics.
Powerhouse	Location of the bedrock	✓ Auger drilling or seismic reflection geophysical survey to determine the level of the bedrock

6.7 CONCLUSIONS

Superficial investigations led to the following conclusions:

- The rock is made of granite with homogeneous migmatitic granite. The rock is in massive form in place or displaced blocks. The rock is cracked but there is no variation in direction. The cracks and boulders are due to the intense activity of brittle tectonics in the eastern region.
- The hard rock ensures stability of the weir anchors.
- Covering soils have a stable natural slope.
- The following drill holes are recommended: manual auger, coring and geophysical testing, and permeability measurement.
- The search of sand for construction is to be continued.

From a geological point of view, the site is favorable for the realization of the project. The site has no major problems of stability and leakage. Further studies will, however, have to be undertaken in subsequent studies.

7 PRELIMINARY ENVIRONMENTAL AND SOCIAL ANALYSIS

The Environmental and Social Impact Assessment (ESIA) is the procedure for prior analysis of the impacts that a project may have on the environment. It ensures the integration of environmental concerns into project planning and allows for consideration of likely environmental measures from the design stage of the project.

7.1 DESCRIPTION OF THE BIOPHYSICAL CONTEXT

7.1.1 Relief

The Mahatsara postential hydropower site is in located in the South East of Madagascar. It is surrounded between two hills: Vohijanahary in the North at 454m of altitude and Bedamizana in the South at 390m of altitude. The relief of the area is relatively hilly but the valleys are quite developed allowing the development of lowland crops such as rice growing.

The hydrographic network is dense as in most parts of the eastern coast of Malagasy but it is the river Besana which constitutes the main river that crosses the zone. It flows first from North to South, then takes a West-East direction before flowing into the Intsaka. The latter is a tributary of the Mananjary.

7.1.2 Vegetation

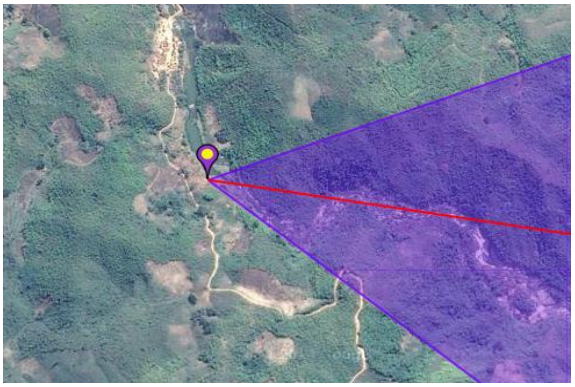
The floristic landscape of the area is formed by:

- Secondary formation in *bamboo* and *ravinala*, as well as in the form of *ericoic* bush, low vegetation and grasslands (*ferns, Rubus, Lantana, Tridax, Psidium, Imperata, ...*);
- Riparian formation with *Raphia farinifera, Pandanus, Typhonodorum*;
- Plantations: *coffee, banana, jackfruit, lychee, breadfruit, raffia*;
- Crops: *rice, dry crops (eg cassava) and vegetable crops*;
- Forest shrubs with characteristic species such as *Weinmania, Humbertia, Albizzia*.

The secondary *bamboo* formations ("*savoka*") occupy a very large area in the area. These formations succeed the primary formations after clearing and passage of fire (*brulis*).

Figure 41. Representative pictures of the vegetation at Mahatsara

Cultivated river bank and *Savoka* with bamboo upstream of the proposed location of the weir



S21°1'53.36" E47°54'56.55"

Ericoid bush and *Savoka* with bamboo at the weir location

S21°1'54.50" E47°54'58.97"

Agricultural landscape downstream of the site

S21°2'30.08" E47°55'7.82"

Figure 42 below gives an overview of land use and land use in the area.

Figure 42. Landcover in the area

7.1.3 Observations

The *tavy* (culture on *brulis*) is a common practice for the local population and impacts on the landscape in the study area: bare soils, secondary vegetation.

7.1.4 Sensibilities

The Mananjary River, in which Besana flows through Intsaka, is defined as a potential conservation site.

The area downstream of the site has a relatively developed agrarian landscape. Indeed, it opens up on a vast shallow land made up of plots of crops and arboricultural plantations. The slopes are also partly converted into terraced plots.

7.2 SOCIO-ECONOMIC CONTEXT

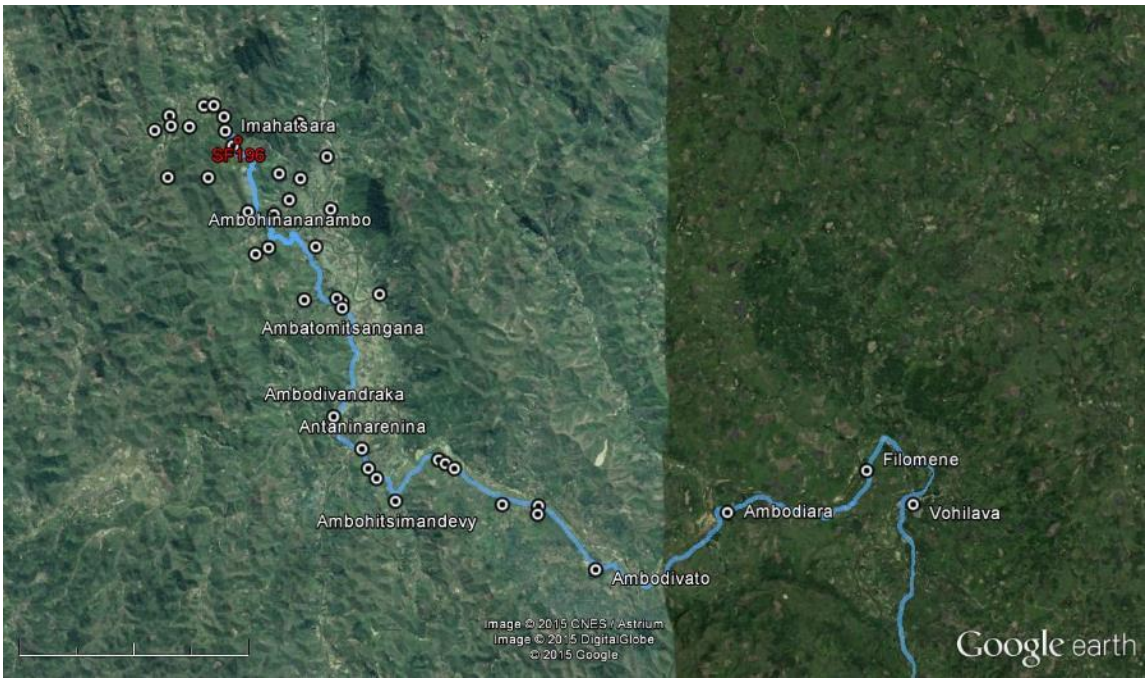
7.2.1 Local area

The site belongs to the Rural Commune of Ambodinonoka. It covers about 350 km² and is subdivided into 8 fokontany. The population in 2009 was 13285 which represents an average of just over 1600 inhabitants per fokontany.

In terms of infrastructure, the Commune has 23 EPPs and 20 community schools. However, in terms of health, it has only one CSB 1 and one CSB 2. The population obtains water from sources of water and rivers. The villages are not supplied in electricity.

The village of Imahatsara is the closest from the site. It is less than 400m on the right bank above the proposed weir location. Other villages are located within a radius of 1 km around the site, particularly along the access road to the site. Some of these villages have more than twenty roofs.

Figure 43. Villages and neighborhood



7.2.2 Activities

Agriculture is the main activity of the local population. This activity boosted by the abundant local hydrographic network and the existence of a relatively large cultivable areas. The inhabitants manage to produce rice twice a year, sometimes three if they simultaneously exploit the plots on slopes. Rice is usually associated with subsistence crops (cassava, maize) and frequently vegetable crops. Apart from the shallows

and the slopes, the banks of the watercourses are also arranged in plots of vegetable cultivation but also in rice fields.

7.2.3 Others

The ethnic groups in the area are the *Antambahoaka, Tanala* and *Antemoro*.

Mining activities, particularly gold, are observed along the access to the site and to the rivers. Operators use either crafts or simple craft tools (mainly used by local miners). Indeed, the site is located on mining sites subject to gold mining permits. Similarly, the area crossed by the access road is located on mining squares belonging to companies or individuals with permits to search for and exploit gold, but also other minerals (crystal, emerald, etc.).

Figure 44. Mining activities along the access to the site

7.3 APPLICABLE WORLD BANK OPERATIONAL SAFEGUARD POLICIES

This section summarizes the World Bank's safeguard policies that contribute to the sustainability and effectiveness of development within the Bank' s projects and programs by helping to avoid or mitigate the impacts of these activities on people and society, environment

OP 4.01 – Environmental assessment ☒

OP 4.04 – Natural habitats ☒

The Besana River is an habitat for halieutics species.

PO 4.11 – Patrimoine culturel ☐

Le site n'est pas connu pour contenir des ressources culturelles matérielles particulières.

OP 4.11 – Cultural Heritage ☐

The site is not known to contain particular material cultural resources.

OP 4.12 – Involuntary resettlement of people ☒

The inundated area may affect agricultural cropped area. The village of Mahatsara is the closest village to the proposed weir location

OP 4.37 – Dam safety ☐

Application of standard dam safety measures as the weigh height is lower than 15m.

7.4 REFRENCES

1. CREAM 2009, Monographie de la Région Analanjirofo

8 PROPOSED SCHEME AND DESIGN

8.1 PROPOSED SCHEME DESCRIPTION

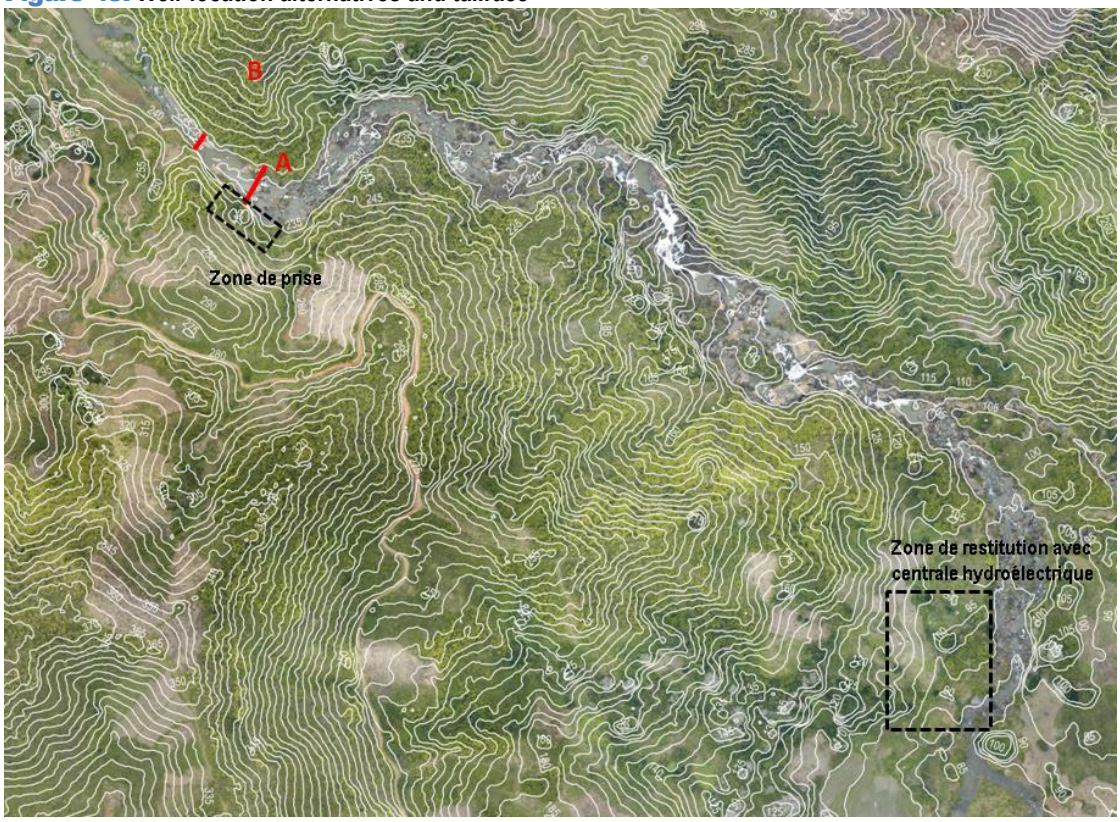
8.1.1 Weir, intake, waterway and powerhouse

As illustrated in Figure 45, two alternatives for the positioning of the weir and the intake structure were identified. Alternative *"A"* was eventually chosen for the following reasons:

1) The village of Mahatsara is located on the right bank upstream of the proposed site. The amplitude of the floods is such that a sufficient length of spillway is necessary in order to minimize the raising of the water level. The "*B*" axis, located about 50m upstream of the axis illustrated in Figure 45 below (Axis "A"), is very narrow, it does not allow to evacuate the design flood without putting at risk the village of Mahatsara. In addition, the reduced length of the spillway in axe "*B*" would imply a very an excessive hydraulic head on the spillway.

2) During the construction phases, location "*B*" would be more complicated to implement because the work in the rivers could only take place during the low-flow season (no place to install a temporary diversion) and would therefore generate a longer duration of the construction phase.

Figure 45. Weir location alternatives and tailrace



Following the axis *"A"*, the weir will benefit from rock supports on both banks. The total weir crest length is estimated at 47m with an average height of approximately 3.5m.

The intake, waterway and the powerhouse will be located on the right bank of the river. The intake will be equipped with a gravel trap and sand trap to remove solid particles suspended in the water and gravel and stones carried by the flow that have a negative effect on the proper operation of the hydroelectric scheme.

Flushing gates will be required to prevent the accumulation of sediments in front of the intake.

The sandtrap will be located after the intake before entering the tunnel that will lead to the surge chamber that will connect the penstock to the powerhouse.

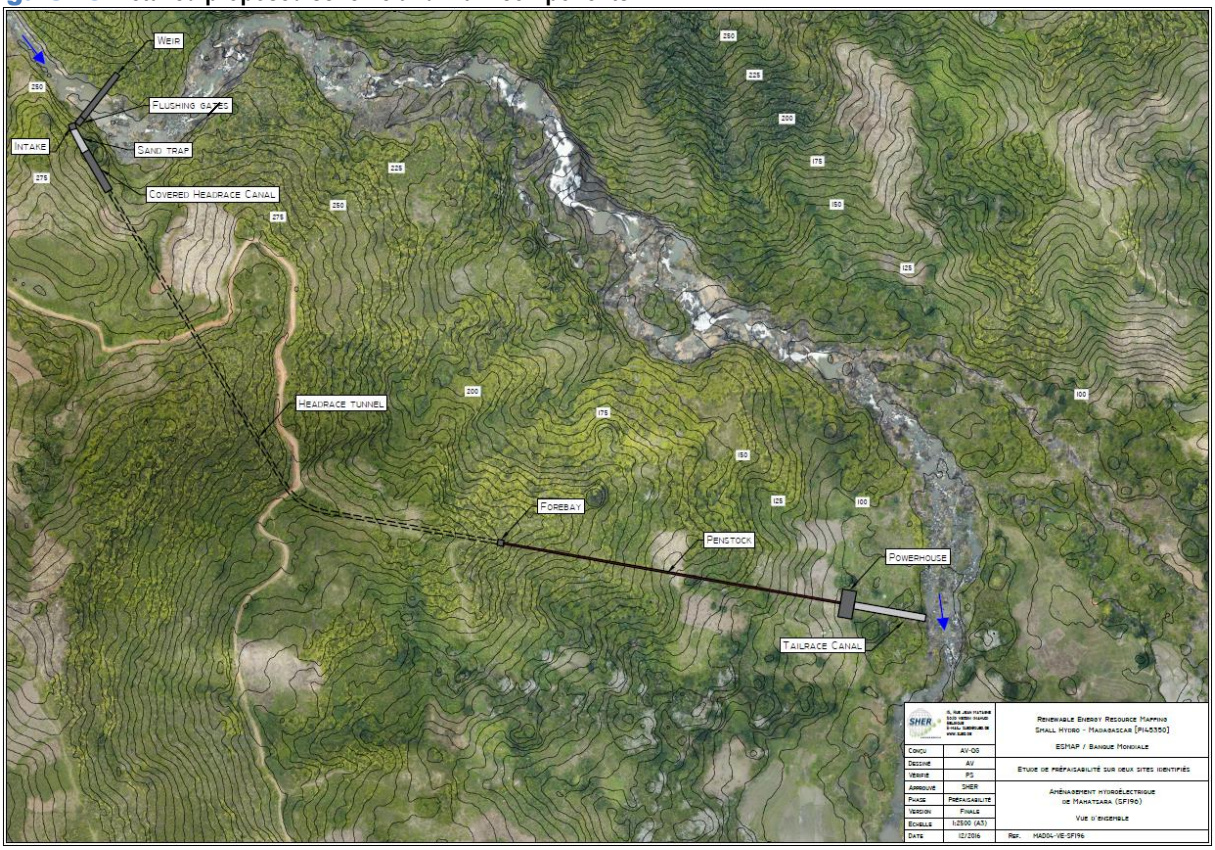
Geographical coordinates of the main structures are presented in the table below:

STRUCTURE	LATITUDE*	LONGITUDE*
Weir	-21.032°	47.917°
Intake	-21.032°	47.917°
Hydropower plant	-21.036°	47.923°

* Decimal degree, WGS1984

The tailrace elevation is 85m and the proposed layout for the hydropower scheme is presented in Figure 46 below.

Figure 46. Detailed proposed scheme and main components



8.1.2 Type of scheme

The proposed Mahatsara scheme is a run-of-the-river hydropower type of scheme without regulation capacity.

8.1.3 Design flow

At this stage of the study, and taking into account the uncertainties on the hydrology of the Besana as revealed by the hydrological study (Chapter 5), it seems appropriate to be careful in choosing the design flow. Measurements carried out during the year 2015-2016 show that a flow rate of 3 m³/s is guaranteed 35% of the time (i.e. 128 days per year) and that a flow rate of 2m³/s is guaranteed 90% of the time (328 days a year).

In this context of hydrological uncertainties, it seems reasonable to make the technical choices to develop the site in two stages in terms of electromechanical equipment:

- the civil works (intake, canal, sand trap, tunnel, penstock and the civil works of the powerhouse) will be sized for an design flow of 6.2 m³/s corresponding to the $Q_{40\%}$ of the flow duration curve extrapolated from the Fatihita hydrometric station;

- the site will however be equipped initially only with electromechanical equipment corresponding to a guaranteed equipment flow rate of 3.1 m³/s.

These choices will make it possible to add the necessary electromechanical equipment when the hydrological regime of Besana will be better understood through hydrological measurements over longer and more recent periods.

The final choice of design flow should be made at the feasibility study stage on the basis of an economic analysis of alternatives. The flow duration curve should also be validated by the additional hydrological data that will be available in the future at the hydrometric station located at the site (Mahatsara village).

8.1.4 Design flood

The Besana River watershed is located on the eastern slope of Madagascar, which is characterized by steep slopes and exposure to the numerous cyclones coming from the Indian Ocean. This results in strong floods despite significant forest cover.

Several national bodies have examined the problem of defining the relevant design flood to be considered for the design of spillway and other associated flood structures. Only US and French methods are developed below.

According to USACE (United States Army Corps of Engineers) in *Recommended guidelines for safety inspection of dams*, dam are classified in accordance with 2 characteristics: (i) the size of the structure and (ii) the potential hazard. The tables below present the classifications.

Table 10. Size classification (USACE)

CATEGORY	STORAGE (AC-FT – HM³)	DAM HEIGHT (FT – M)
Small	< 1000 Ac-ft < 1.2 hm³	< 40 Ft < 12.19 m
Intermediate	> 1000 Ac-ft et < 50 000 Ac-ft >1.2 hm³ et < 61.7 hm³	> 40 Ft et < 100 Ft 12.19 m et < 30.48 m
Large	> 50 000 Ac-ft > 61.7 hm³	> 100 Ft > 30.48 m

In the table above, the height of the dam is calculated from the lowest point of the structure to the maximum level of the reservoir. The category is defined either by the storage capacity of the reservoir or by the height of the dam, depending on the characteristic that classify the dam into the less favorable category.

The proposed weir on the Besana will be less than 12m high and the storage volume or the reservoir will be less than 1.2 hm³. Therefore, the proposed weir is classified as being *"Small"*.

As far as potential hazard is concerned, it can be considered as *"Low"* according to the table below: there is no risk of loss of human life in the event of failure or misoperation of the dam or appurtenant facilities. There is no significant industry or cultivated area have been identified downstream of the proposed weir.

Table 11. Hazard potential classification (USACE)

CATEGORY	LOSS OF LIFE (EXTENT OF DEVELOPMENT)	ECONOMIC LOSS (EXTENT OF DEVELOPMENT)
Low	None expected (No permanent structures for human habitation)	Minimal (undeveloped to occasional structures or agriculture)
Significant	Few (No urban development and not more than a small number of inhabitable structures)	Appreciable (Notable agriculture, industry or structures)
High	More than a few	Extensive community, industry or agriculture

Table 12 presents the USACE's recommendations for the design flood to be considered as a function of the potential hazard that may occur in the event of failure or misoperation of the dam or appurtenant facilities and the size of the structure. The flood is expressed either by its return period (or frequency) or by the PMF. The PMF (Probable Maximum Flood) is the largest possible flood that can occur through the most severe combination of critical meteorological, geographic, geological and hydrological conditions reasonably possible in a watershed.

Table 12. Recommended spillway design floods (USACE)

HAZARD	SIZE	SPILLWAY DESIGN FLOOD
Low	Small	50 to 100-year frequency
	Intermediate	100-year to ½ PMF
	Large	½ PMF to PMF
Significant	Small	100-year to ½ PMF
	Intermediate	½ PMF to PMF
	Large	PMF
High	Small	½ PMF to PMF
	Intermediate	PMF
	Large	PMF

Following the aforementioned guidelines of the USCA, the recommended design flood for the Besana hydroelectric scheme is from 50-years to 100-years frequency. The hydrological study presented in Section 5.5 estimates the 100-year return period flood to be 514 m³/s (4112 L/s/km²).

8.2 STRUCTURES DESIGN

8.2.1 Type of weir and characteristics

Given the nature of the foundations as well as the estimated water head on the weir for the design flood, a concrete gravity-overflow weir (spillway) seems the most appropriate structure. As mentioned in Section 8.1, it is recommended that the hydraulic profile of the weir be profiled in order to minimize the impact of the weir on the upstream water level. A concrete structure is also particularly recommended for submersible structures. This choice is motivated by the following elements:

- The local geology shows that the rock is of good quality, adapted to the foundations of a concrete weir;
- Given the magnitude of the design flood, the weir must be as low as possible in order to minimize the impact of the upstream water level rise (presence of the village).

- An ungated weir/spillway will be easier to build and safer in design since there is no risk of dysfunction or misoperation of the gates, particularly during flood events.

The weir will be equipped with flushing gates on the right bank to flush the sediments that would have accumulated in front of the water intake (see section 8.2.3).

The main function of a spillway is to allow the passage of normal (operational) and/or exceptional flood flows in a manner that protects the structural integrity of the structures and / or its foundations.

For the Mahatsara scheme, given the proximity of the village, it is recommended to minimize the raise of the water level during extreme flood events. Therefore, the Mahatsara hydroelectric scheme will be equipped with ogee-shaped type of spillway. The profile of this type of weir is close to the hydraulic profile of the nappe springing freely from a sharp crested weir. The advantage of such a profile is that, at an equivalent discharge, the ogee-shaped spillway is characterized by a lower rise in the water level compared to a broad-crested weir. Similarly, considering the same hydraulic head on the spillway, a longer crest length is required for a broad-crested weir than for an ogee-shaped weir.

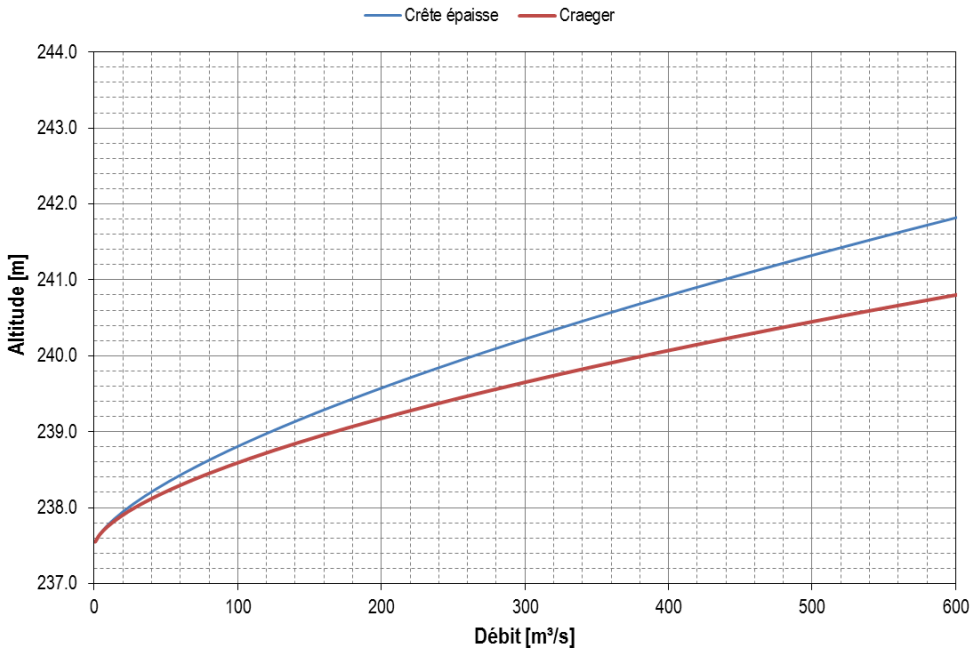
The discharge flowing over a spillway is calculated based on the following equation:

$$Q = C_d L h^{\frac{3}{2}} \sqrt{2g}$$

Where Q is the discharge [m³/s], C_d the spillway coefficient [-], L the length of the overflowing crest [m], h is the total hydraulic head (static and dynamic head) over the crest [m] and g is the gravitational acceleration [m/s²].

The comparison of the spillways capacities is based on spillway coefficients of 0.325 and 0.4806 for the ogee-shape and broad-crest type of spillway respectively (for the design flood). It is worth mentioning that the spillway coefficient of the ogee-shape spillway varies according to the hydraulic head (which is taken into consideration in the calculations). The difference of the spillways capacity is presented in Figure 47. For the design flood (514 m³/s), an ogee-shaped reduces the hydraulic head on the crest by approximately 1 m compared to a broad-crest spillway.

Figure 47. Comparison of the spillway capacity



Given the elevation of the village (elevation 242.50) and a safety margin of 2.0 m above the hydraulic head over the spillway corresponding to the design flood (3.0 m), the spillway crest is set at elevation 237.50 m. The apron of the flushing gates is set at elevation 234.50 m. The spillway crest will have a length of 46.5 m to evacuate safely the design flood.

The impact of the proposed weir on the water level rise upstream is shown in Figure 45 for the normal operation level and the design flood level.

The stability of the weir results from its shape. The upstream face of the weir will be vertical at this stage of pre-feasibility study but will have to be confirmed during the feasibility study based on a more detailed topography. The crest of the spillway will have a hydraulic profile that meets the US Army Waterways Experimental Station (WES) standards and recommendations to minimize the risk of to the spillway structure due to negative pressure and cavitation under the nappe.

The main features of the spillway are presented in Table 13 and a typical cross section of the profile is shown in Figure 48.

Table 13. Spillway characteristics

PARAMETER	UNIT	VALUE
Railway flooding elevation at the weir location	m	237.5
Safety margin	m	242.5
Water elevation at design flood	m	2.0
Flushing gate apron elevation	m	240.5
Hydraulic head at design flood	m	234.5
Design flood (100-year return period)	m	3.0
Required crest length	m³/s	514
Crest elevation	m	46.5
Weir height	m	3.5

Figure 48. Typical cross section of an ogee-shape type spillway

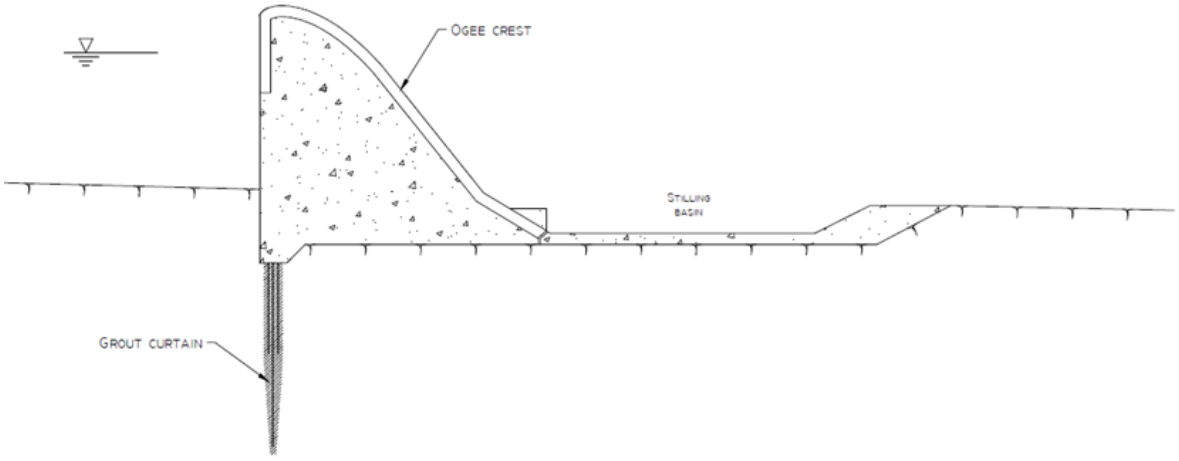


Figure 49. Inundated area by the proposed scheme

8.2.2 Temporary diversion

The purpose of the temporary diversion is to dry up part of the river to allow the construction of the weir and appurtenant structures described in the previous section. The temporary diversion will be implemented consecutively on the right bank in order to construct the flushing gates and the intake, then on the left bank.

It will consist of a cofferdam in compacted embankments or, if the ground conditions are favorable, a sheer of piles cut off.

8.2.3 Outlet structures

The outlet structure is designed to allow inspection of the weir and intake. Also, the outlet structure while open can create a strong current with the effect of flushing the accumulated sediments close to the intake structure.

The flushing will be done by flushing gates (radial gates) of which the invert is positioned at an elevation close to the elevation of the natural riverbed. The gates will be located on the right side of the weir, next to the intake structure to allow an effective purge of the accumulated sediments.

The number of bays and their size were calculated to ensure that the water level at the intake structure could be below its invert at least 90% of the time, i.e. 329 days a year. This objective is achieved with the installation of two 1.80m wide gates of square section.

Table 14. Flushing gates characteristics

PARAMETER	UNIT	VALUE
Water elevation at design flood	m	240.5
Crest elevation	m	237.5
Flushing gates apron elevation	m	234.5
Flushing gates max elevation	m	236.7
Number of bays	-	2
Discharge coefficient (submerged)	-	0.6
Discharge coefficient (free surface flow)	-	0.35
Width	m	1.80
Height	m	1.80
Discharge from VC @ $Z_{intake\ –\ free\ flow\ surface}$	m³/s	10.1
Discharge from VC @ $Z_{CRT\ –\ submerged}$	m³/s	34.9
Discharge from VC @ $Z_{RWS\ -\ submerged}$	m³/s	45.9

8.2.4 Waterway

8.2.4.1 Intake structure

The intake will be located on the right bank in the continuity of the weir. The intake will be followed by a sand trap before entering the tunnel. The headrace canal from the sand trap to the tunnel will be covered.

Flushing gates will be located on the right side of the weir, next to the intake structure to allow an effective purge of the accumulated sediments in front of the intake. The design of the flushing gates is detailed in section 8.2.3.

The intake structure will be equipped with a flushing gate in the transition zone to the canal to allow for sediment removal that would eventually have entered the intake. The intake will also be equipped with a screen and an automatic screen cleaning system upstream of the intake gates, to prevent floating debris or large stones from obstructing the intake gates. The section of the bars and their spacing will be determined at the feasibility study stage.

The intake is designed taking into account the following constraints:

- The invert elevation will be set 1m above the bottom of the flushing gates;
- The velocity of water at the entrance of the screen should not be greater than 0.8 m/s to minimize turbulence and facilitate screening of debris. That will also minimize head losses.

- A safety spillway will be integrated into the forebay / sucge chamber in order to spill the excess water in a controlled manner to the river if necessary. The suitability of an surge chamber or a forebay will be calculated during detailed studies.

Hence, the intake will consist of 2 bays of square section (2.0m x 2.0m), followed by a free inlet that will guide the current lines gradually towards the sand trap. The invert of the intake will be set at elevation 235.0 m. Details are presented in Table 15 below.

Table 15. Intake characteristics

PARAMETER	SYMBOL	UNIT
Intake invert elevation	m a.s.l.	235.0
Intake top elevation	m a.s.l.	237.0
Design flow $Q_{40\%}$	m³/s	6.2
Required total area for $Q_{e\text{-}v1}$ et v_{max}	m²	11.4
Number of bays	-	2
Bay width	m	2.0
Bay height	m	2.0
Discharge coefficient (submerge)	m/s	0.8

The free inlet will which will have the objective of converging the current lines to the headrace canal will, for hydraulic reasons, be approximately 2.5 times the width of the intake, i.e. 10 m. The feasibility study will study the hydraulic behavior of the intake in detail and adapt its design accordingly.

8.2.4.2 Gravel trap, sand trap and headrace canal

The study of the soil losses quantification carried out in section 0 concludes that the Besana River may feature heavy solid transport due to its agricultural land cover. If not taken into account at the design stage, it would result in operational and maintenance problem of the hydroelectric plant.

The sediments that would accumulate in front of the intake will be flushed by frequent flushing operations using the flushing gates designed for this purpose.

The intel of the sand trap will have a sufficient slope in order to guide the solide particules to the sand trap.

The geometry of the sand trap is defined on the basis of:

- Topographic constraints: elevation of the invert, outflow, maximum depth, ...

- Hydraulic and sedimentary constraints: inflow, mean solid transport in the river, maximum diameter of the particules to be sedimented, maximum speed in the structure, ...

- Operational constraints: frequency of drainage.

At the pre-feasibility study stage, the constraints considered are defined in the following table:

Table 16. Preliminary design criteria for the sand trap

PARAMETER	UNIT	VALUE
Invert elevation	m a.s.l.	235.0
Outlet elevation	m a.s.l.	234.9
Design flow	m³/s	6.2
Average solid inflow	kg/m³	0.3

Minimum diameter of the particles	mm	0.5
Drag velocity of the particles	m/s	0.06
Volumetric weight of the particles	kg/m³	1300
Maximum horizontal velocity	m/s	0.4
Maximum flush frequency	hours	24

The width of the sand trap B_{min} is determined in such a way that the horizontal speed is less than the maximum horizontal speed $V_{h,max}$. The height of drag h_{chute} is fixed by the water level in the downstream structure (the tunnel in this case) and is estimated at 2.5m at the entrance to the sand trap. Therefore the sand trap will have a minimum width B_{min} of 6.20m.

The length of the sand trap is determined in such a way that a particle located on the surface can be deposited in the reservoir of the sand trap. The horizontal and vertical velocity ratio is proportional to the ratio of the falling length to the falling height. The drag speed is the difference between the rate of drop of the grains and the turbulent mean root velocity given by $u * = 4.2\% V_{h,max}/R_h^{1/6}$ où R_h is the hydraulic radius of the sand trap.

In this case the length L_{min} of the sand trap will be 23.0m.

The sand trap will therefore have a hydraulic width of 9.10m and will be composed of 2 sub-basins each 3.20m wide and will have a sedimentation length of 23.0m. To this must be added the transition zones upstream and downstream of the settling tank of the sand trap. The sandblaster will therefore have a total length of 35.40m and a total width of 7.60m and a maximum depth of 5.30m.

These dimensions offer a storage capacity of 340.10m³ and are sufficient to contain the maximum solid flow decanted in 24h, namely 159.51m³.

The channel will be covered as soon as it leaves the sand trap until it enters the tunnel.

8.2.4.3 Tunnel

The supply of water from the sand trap to the penstock will be through a circular tunnel of 2.20m diameter (2m being the minimum dimension allowing an easy construction of the gallery) and of 0.05% of slope. The proposed alignment of the tunnel is such that the thickness of the rock above the roof of the gallery is sufficient. According to this layout, the tunnel will have a length of 480m. The final alignment of the tunnel will be determined by detailed geological and geotechnical studies to ensure the good quality of the rock along the route.

The flow type in the tunnel will be free surface flow and lead to the surge chamber or forebay which will be the departure of the penstock.

8.2.4.4 Penstock

The tunnel and the pressure penstock meet at the forebay. The forebay will be equipped with a purge gate in order to drain the channel as well as the particles that would have sedimented in the latter back to the river. The forebay will be equipped with a safety spillway in the event of excessive inflows coming from the headrace canal or allowing the spill of the water in excess during variations flow through the turbines (production decrease, shutdown of a group, etc). ...). The relevance to construct a channel to redirect water from the safety spillway to the river or the waterfall will be studied during subsequent studies.

The penstock departure will be integrated into an adequate structure comprising a trashrack and suitable grooves for the stoplogs in order to be able to isolate the penstocks during the maintenance operations.

The Mahatsara site will be equipped with a single penstock to maintain the head losses to an acceptable level (less than 2% of the gross load) and to minimize the number and diameter of the pipes. The internal diameter will be 1.40m.

The pressure penstock will be overground and 280 m long. The penstock will be supported by reinforced concrete support blocks. Anchoring blocks will be placed at each elbow to balance the forces related to the change of direction of the flow. A suitable system allowing the thermal expansion of the penstock should be defined at the feasibility study stage.

8.2.5 Electromechanical equipment

8.2.5.1 Basic data

The following basic constants are considered for all calculations and considerations related to the electromechanical equipment:

CONSTANT	SYMBOL	UNIT	VALUE
Gravity acceleration	g	m/s^2	9.787
Average water temperature	T_{eau}	°C	20
Water density at 20°C	ρ	kg/m^3	998.2

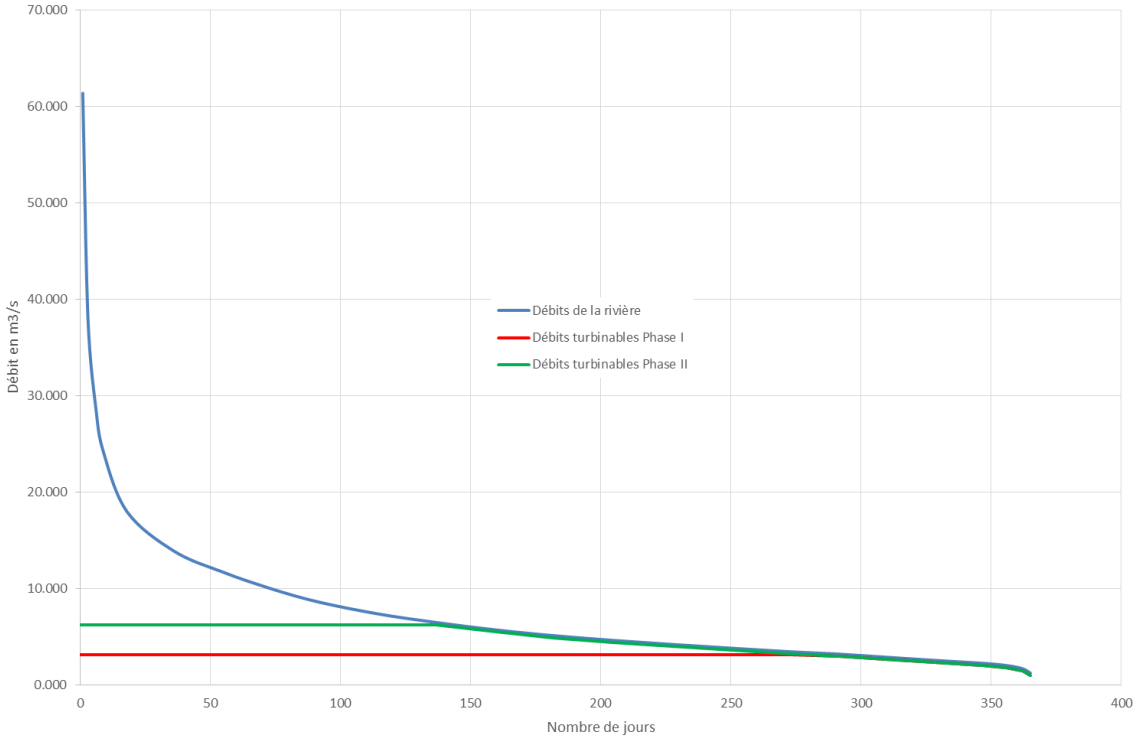
8.2.5.2 Usable Flow Duration Curve

The flow duration curve was determined in Chapter 8.1.3 of this report. It does not, however, correspond directly to the flow available to the equipment. Indeed, the Besana River will be by-passed over a length of approximately 1km. An ecological flow guarantee at all times is required for environmental and ecological reasons.

In the absence of standards, the ecological flow is set at 220 L/s, which corresponds to approximately 10% of the guaranteed flow ($Q_{95\%}$) of the river. Since this flow is not available for the turbines, it is necessary to subtract it from the flow duration curve of the river.

The flow duration curve that can actually flow through the turbines is finally obtained by considering the design flow rate of equipment chosen at the pre-feasibility stage, namely 3.1 m^3/s during stage 1 and 6.2 m^3/s during stage 2. The choice of the design flow should be optimized in the feasibility study stage considering technical and economic aspects.

Figure 50. Usable flow duration curve of the Besana at Mahatsara



8.2.5.3 Selection of the type of turbine

The available gross head and the design flow rate of equipment are within the scope of the Pelton turbines. Francis turbines could also be an alternative option.

The section below briefly compare the two alternatives:

- The entrance of the penstock will be protected by a trashrack whose spacing will be determined at the detailed studies stage and a manual cleaning is planned. These operating conditions make it impossible to exclude the passage of solid materials, plants or other fibers into the penstock and ultimately into the turbine. The geometry of the Francis turbines makes them sensitive to the presence of plants and bundles which can lead to the blockage of the wheel, which requires complete dismantling and cleaning.

  The Pelton is much less sensitive to the presence of plants, while being easier to clean if needed (access via the tailrace for example).

- The Francis turbine require a shaft seal, a wear piece, whereas a Pelton turbine with a vertical axis does not need it. This reduces maintenance and the need for spare parts.

- Generally speaking, the operation of the Pelton turbines is simpler than that of the Francis turbines.

- Pelton turbines have automatic jet deflectors that deflect the jet of the wheel so that in the event of disconnection of the network the machine does not runaway. In addition to the intrinsic safety that this gives the unit, it is thus possible to slowly close the injectors of the turbine, which makes it possible to limit the overpressure in the pipe to a maximum of 1.2 x the static pressure due to the gross head. This is an effective protection against water hammer. If it is impossible to close an injector (due, for example, to a possible obstruction by a solid or by a defect in the operating mechanism), it is then possible to shut off the remaining flow rate by closing the guard valve of the turbine.

- The maximum efficiency level of the Francis turbines is about 2 points higher than that of the Pelton turbines. The performance of the Pelton is, however, better than that of the Francis when partially loaded.

- The rotation speed of the Francis turbines for this type of flow and head will be high (750 rpm or more), while that of the Pelton turbines will be low (of the order of 500 rpm).

- In phase I, the flow variation factor between the full load and the minimum load is in the order of 2.5. The Francis turbines do not make it possible to respond optimally to these variations, their efficiency at partial load being relatively low. In contrast, Pelton turbines with multiple injectors allow the flow variations to be monitored while maintaining a stable level of performance.

The table below summarizes the various elements mentioned above.

Table 17. Comparison of the Pelton and Francis Turbines

	PELTON	FRANCIS
Flexibility to flow variations	excellent	Meidum
Flow control device	Yes	yes
Startup and synchronization	easy	Easy
Sensitivity to plants and others floating elements	Low	Medium
Sensitivity to solid elements	Low	High
Robustness and reliability	Excellent	Good
Minimum number of bearings	2	2
Possibility of a cantilevered wheel	Yes	Yes
Complexity of alignment	Low	Low
Shaft seal	No	Yes
Risk of runaway	No	Yes
Risk of water hammer	Low	Medium
Maximum efficiency	0.89 - 0.92	0.92 – 0.94
Rotation speed in the present context	Low	High

Considering that the new Mahatsara hydropower plant will represent a significant proportion of the available power on the isolated grid to which it will be connected, great flexibility will be needed to follow the evolution of demand. This key element, as well as the argument related to the ease of operation and maintenance, lead to retaining the Pelton turbine for this project.

8.2.5.4 Selection of the number or turbines and rated flows

If the flexibility required to follow the energy demand can be achieved by a single Pelton multijet turbine, it is proposed to install two identical groups.

The first reason is technical and economic. A single group would lead to a very slow rotation speed (375 rpm), involving heavy and bulky equipment, which is therefore expensive. Moreover, such a speed requires choosing a non-standard alternator with what this implies in terms of delivery times, costs and maintenance difficulty.

The second is that it is often advantageous to have several groups for reasons of security of supply and maintenance. With two groups, for example, it is possible to plan maintenance operations during low demand periods and to rotate only with one machine during the maintenance of the second.

The third concerns the relative site access difficulties favoring the installation of several groups more easily transportable and installable than one large group. This is also reflected in the infrastructure of the plant, particularly with regard to the overhead travelling crane which may be of lower capacity, the loads being lower.

All of these reasons lead, at the prefeasibility stage, to selecting a configuration with two identical turbines each using 1.55 m³/s. The exact number can be refined as part of a technical and economic comparative analysis in feasibility study.

8.2.5.5 Net Head Calculation

The Pelton turbine is an impulse type of turbine whose main characteristic is to use the energy of the water essentially in kinetic form. Its wheel rotates in the air and its operation requires to guarantee at all times a minimum level of dewatering, whatever the downstream level. For a vertical shaft machine, the gross head is defined as the elevation difference between the upstream water level (surge chamber / forebay) and the median plane of the wheel and of the injectors.

The floor elevation of the power plant being at 90.0 m, the median plane of the wheel, for a machine with a vertical axis, can therefore only be above this level. Based on the observation of similar projects, it can be considered that the median plane of the wheel will be approximately 91.0 m above sea level. The exploitable gross head would thus be **146.7 m**.

The net head for impulse type machine is calculated using the following equation:

$$H(Q) = \Delta Z(Q) - H_{rc}(Q) \quad [m]$$

Avec:

H(Q): Net head as a function of the turbined flow [m]

ΔZ(Q): Gross Head [m]

$H_{rc}(Q)$: Head losses due to pipe frictions [m]

g = 9.787 [m/s²]

Further optimization of the various elevations may be done in later phases of the project.

8.2.5.6 Overview of the units operation

The turbines will be controlled by the upstream water level measured in the forebay. The foreseen operation of the scheme is as follows:

- As long as the available flow is less than the minimum rated flow of one turbine, the power plant is stopped;
- As long as the available flow is between the minimum and maximum rated flows of one turbine, all the water passes through a single hydroelectric unit;
- As soon as the available flow exceeds the maximum rated flow of one turbine, the second unit starts. The first unit reduces its opening, while the second increases its own, until the two turbines operate at the same opening;
- The two units are then adjusted in parallel until each one operates at full opening according to the total available flow;
- As soon as the available flow exceeds the maximum rated flow of the two turbines, the surplus is discharged over the spillway of the forebay;
- When the flow rate decreases, the control system reduces the opening of the two turbines in reverse sequences.

If one or two groups are shut down, the flow in excess is discharged from the forebay over the spillway.

8.2.5.7 Pelton Turbines

The following indications correspond to pre-designed units from the consultant's database. They are indicative only and may vary according to the manufacturer. The performance and characteristics of the turbines (speed, efficiency, reliability, etc.) correspond to machines for which the manufacturer can indisputably prove the origin of his guarantees. Thus, the announced characteristics are realistic, provided that the turbines are constructed in accordance with a hydraulic profile resulting from developments in the laboratory.

The calculation based on the specific energy, the rotation speed and the maximum flow allow to determine the following characteristics and dimensions of the turbines:

Design flow phase I	$Q_{inst\ I}$	m^3/s	3.1
Design flow phase II	$Q_{inst\ II}$	m^3/s	6.2
Unit rated flow	Q_{max}	m^3/s	1.55
Gross head	ΔZ	m	146.7
Net head at design flow phase I	$H_{n\ I}$	m	146.1
Net head at design flow phase II	$H_{n\ II}$	m	144.2
Type of turbine	-	Vertical shaft Pelton	
Number of jets	Z_i		5
Unit mechanical power	$P_{méc}$	kW	2000
Total mechanical power phase I	$P_{méc\ I}$	kW	4000
Total mechanical power phase II	$P_{méc\ II}$	kW	8000
Rotation speed	N	t/min	500
Maximum rotation speed	N_e	t/min	950
External diameter of the wheel	D_{ext}	mm	1260
Injection Diameter	D_1	mm	960
Paddle width	B_2	mm	285
Diamètre du cuvelage	D_c	mm	3100
Jet diameter	D_i	mm	290
Minimum dewatering height	Ha	mm	1200
Jet type	-	Avec déflecteur, commande hydraulique	

The selection of a vertical shaft arrangement and cantilevered wheels is made to simplify the assembly and alignment operations and to simplify the disassembly of the machines during the maintenance operations. This configuration makes it possible to limit the number of bearings of the unit to one bearing and one thrust bearing, both located in the generator, which has the effect of increasing the reliability.

The injectors will be controlled by means of an oil-hydraulic system. They will be equipped with a deflector.

Figure 51. Example of a vertical shaft Pelton turbine with 5 jets

8.2.5.8 Generators

Generators for this power range are generally available at standard voltages of 690V or 5.5 kV. The main characteristics of the generators are as follows:

Type	Synchrone triphasé
Axe	Vertical avec roue de turbine en porte à faux
Fréquence en Hz	50
Puissance en kVA	2'100
Cos φ	0.9
Surcharge	110% de S_n pendant 2h (Echauffement selon classe F)
Tension de service en V	690 V ou 5.5 kV
Vitesse de rotation en t/min	500
Vitesse d'emballement en t/min	1'100
Axe	Vertical avec roue de turbine en porte-à-faux
Protection	IP 23
Isolation	Classe F, exploité en classe B

8.2.5.9 Butterfly Safety Valve

Each turbine will have a safety valve DN 1200 PN 10. It allow to isolate the turbine in case of maintenance and ensures safety in the event of emergency stop or shutdown of the distributor. It will be of the eccentric butterfly type. Its opening will be managed by oil-hydraulic cylinder while its closing by counterweight.

8.2.5.10 Hydraulic control unit

Each unit will have an oil-hydraulic high-pressure control unit that will allow the needle to be maneuvered from the turbine injectors, the deflectors and the guard and safety valve. It will be equipped with a battery to ensure safety in the event of high pressure pump failure.

8.2.5.11 Control and monitoring system

Since the power plant is designed to operate fully automatically, its control and operation must be simple in order to minimize human interventions.

The flow will be controlled by the water level in the forebay, which will be measured by a probe connected to the plant by optical fiber. Each generation unit will have a dedicated control system. A plant controller will also be installed to manage both units.

If required to maintain the frequency of the network, the installation will be equipped with a speed control sytem.

Each turbine must be able to operate either automatically or manually. A key to prevent misoperation will lock the manual operation.

In the event of a network trip, the restart will be automatic. For safety reasons of plant operating personnel and the power grid, the automatic restarting following an alarm, even if turned off without human intervention, should not be authorized.

The electrical switchboards will include the following: Control of the distributor with display of the opening, Cos , voltage and frequency setting, inverters.

The following indicators are provided: grid and generators voltmeters, wattmeter, frequency meter, Cos measurement, synchroscope, rev counter, upstream water level indicator, hour counter, starts counter, alternator bearing and winding temperatures, emergency stop, load indicator for emergency power supply.

The following alarms should be considered: insufficient upstream water level, insufficient upstream pressure, generator overload, overspeed, emergency stop, start fault, bearing fault, winding faults, current feedback, battery overloads, and battery faults.

A remote control could be installed.Une commande à distance pourra être installée

8.2.5.12 Emergency power unit

A 48 or 110 V DC back-up power supply, including batteries, chargers, inverters, load indicators, protections, etc., is provided to ensure safety in the event of network loss. The battery fault and battery overload alarms must be relayed in the control command unit. In normal operation, the backup power supply will be powered by the LV network. It is also planned to install a 100 kVA thermal generator. Its exact power will be defined in a later stage.

8.2.5.13 Transformers

Each group will be connected to a three-phase transformer immersed in oil 2100 kVA (or of a minimum power compatible with the power of the generator, according to the standard ranges of the market) making it possible to raise the output voltage of the generators to 63 kV. It is also planned to install a 100 kVA 63 / 0.4 kV transformer supplying ancillary services. A block of 63 kV cells (group arrival, network start) will also be installed. These equipment will be defined according to market standards.

8.2.5.14 Overhead travelling crane

The plant will be equipped with an overhead traveling crane and electric lifting which will allow all assembly and dismantling of the units, valves and accessories.

8.2.5.15 Abrasion

The proposed scheme does not include sand trap facilities as solid transport is assumed to be limited. Should future investigations reveal the opposite, it would then be necessary to protect the turbines against excessive abrasion, for example by applying a specific coating to the distributor blades and the runner.

8.2.6 Power and Energy Generation Performance Assessment

The annual energy generation is calculated by the integration of the power duration curve using the following equation:

$$E_{etot} = 10^{-3} \int \rho \, g \, Q_t \, \eta(Q_t) \, H(Q_t) \, dt \quad [kWh/an]$$

where E_{etot} = annual energy generation [kWh/an]

ρ = water density (998.2 at 20 °C) [kg/m^3]

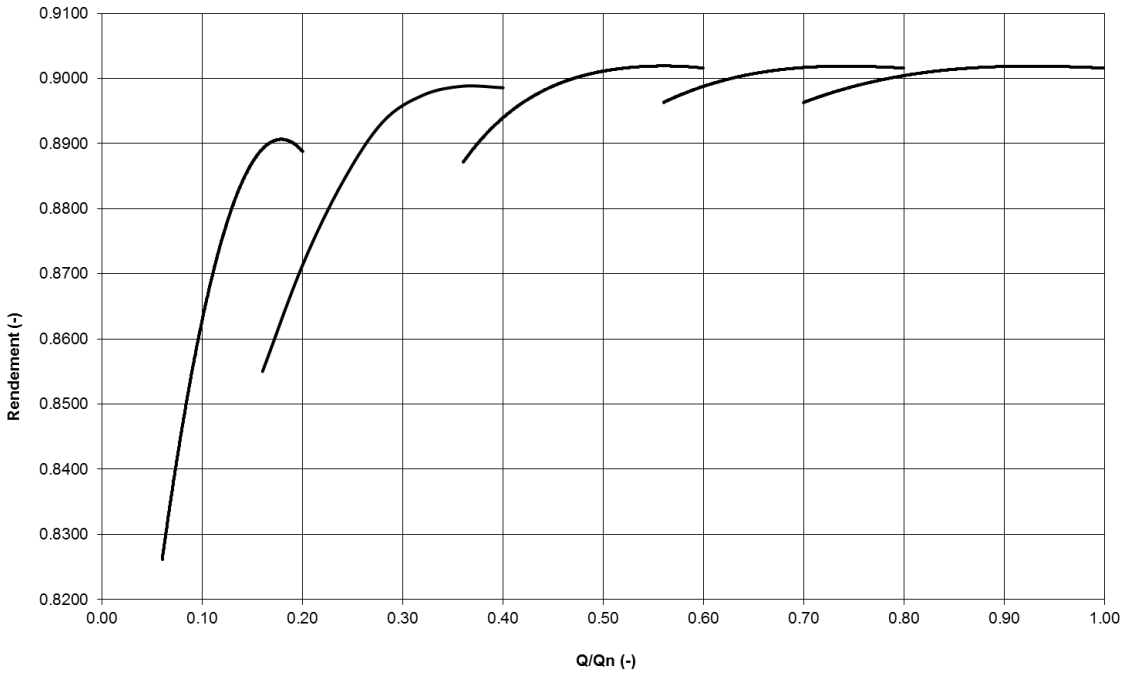
g = gravitational acceleration (9.786) [m/s^2]

$\eta(Q_t)$ = global efficiency of the equipment, product of the turbine and generation as a function of the turbined flow [-]

$H(Q_t)$ = Net head as a function of the turbined flow [m]

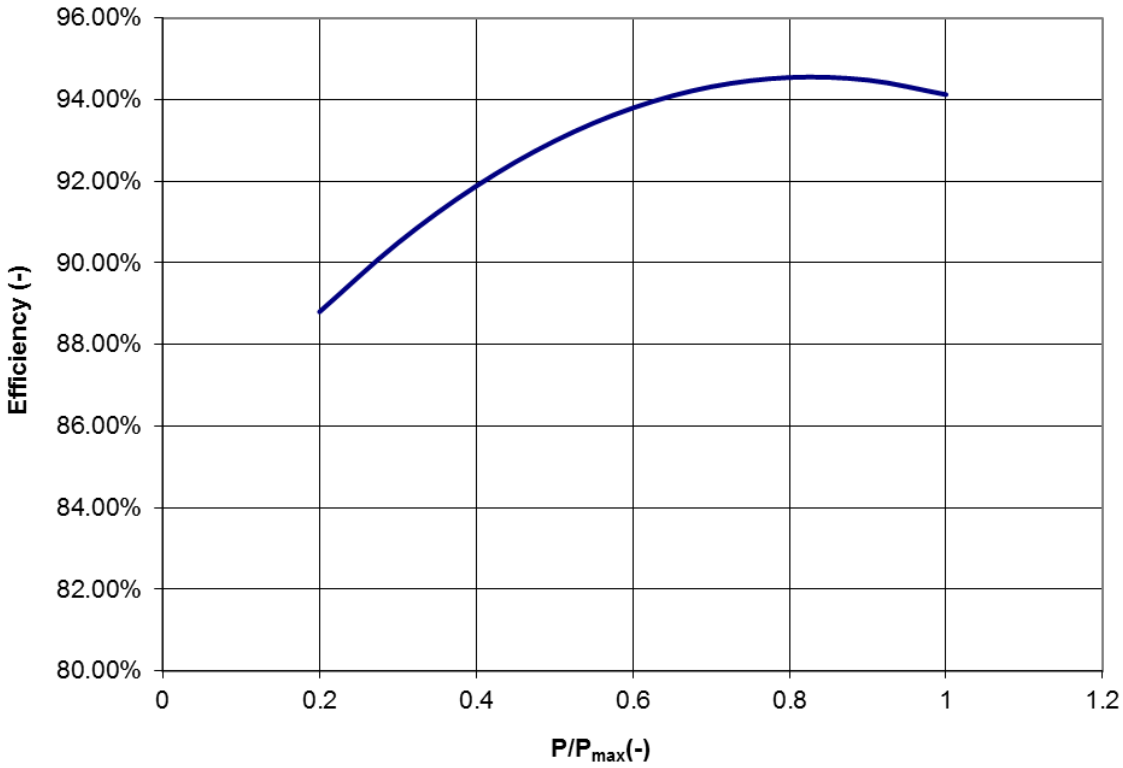
The turbine efficiencies are coming from statistical relationships corresponding to Francis turbines of similar size and power, based on models tested in the laboratory.

Figure 52. Typical efficiency curve of a Pelton turbine with 5 injectors developed in laboratory



The efficiency of the generator (given as a percentage of the relative power), is coming from the characteristics of a similar standard machine, available on the market, as shown in the figure below.

Figure 53. Typical generator efficiency curve



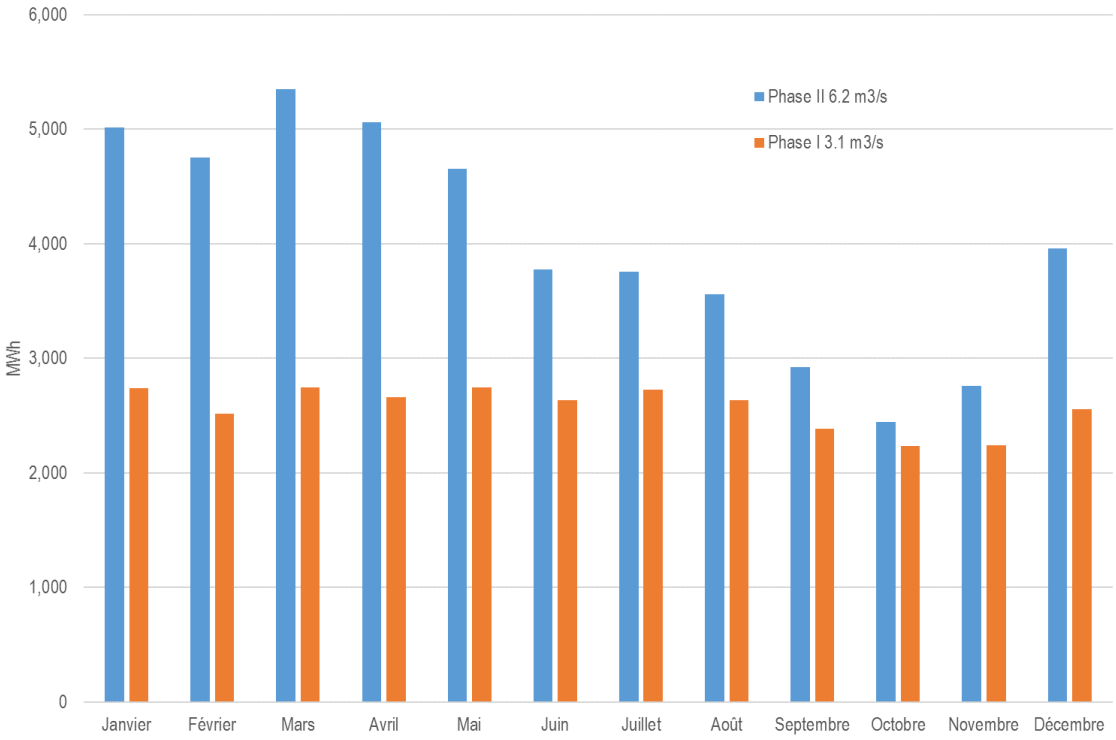
The efficiencies of the transformers are assumed constant at 98.5%.

The table below presents the results of the energy generation modelling:

PARAMETER	PHASE I	PHASE II
Design flow of the scheme [m^3/s]	3.1	6.2
Number of units	2	4
Unit rated flow [m^3/s]	1.55	1.55
Gross head [m]	146.7	146.7
Net head at design flow [m]	146.1	144.2
Maximum Power before transformer [kW]	3750	7400
Maximum Power after transformer [kW]	3700	7300
Annual producible [GWh]	30.7	47.8
Average annual power [kW]	3505	5463
Average power / installed capacity [%]	94.8	74.8
Equivalent number of hours at full power	8306	6556

The average potential monthly production is shown in the figure below. This production corresponds to the simulation of the production of the power plant over the period 1957-1975 corresponding to the available hydrological record, as presented in section 5.3.

Figure 54. Average monthly generation (period 1957-1975)



8.2.7 Powerhouse

The hydropower plant will be positioned downstream of the main waterfall on the right riverbank. A truck access road should be provided to allow the delivery of the turbine / generator units (even if the equipment is transported by train to the vicinity of the site, it must be possible to transport them from the railway to the plant). A platform will also have to be constructed to allow the maneuvering of long vehicles.

The floor elevation of the powerplant is fixed in order to ensure that it remains flood-free and that the electromechanical equipment is sufficiently high with respect to the water level in the river bed (tailwater level increased by the maximum flood level of (~ 4m) to which is added 1m of safety margin). The tailrace canal will have a length of 50m.

The plant will consist of 5 + 1 bays, one per unit and one bay for assembly / dismantling. One floor is provided for offices, toilets, control room and meeting room. The area under the offices will allow the storage of tools and spare parts. A backup generator will also be placed there. The height of the plant will be governed by the size of the highest of the parts to be handled and by the characteristics of the crane. The dimensions of the plant, estimated at 16m wide, 40m long and 10m high, will have to be refined in subsequent studies.

For safety reasons (fire hazard) the transformers will be positioned in the immediate vicinity of the plant in a separate room.

The characteristics of the plant are given in the following table:

Table 18. Characteristics of the powerhouse

PARAMÈTRE	SYMBOLE	UNITÉ	VALEUR
Floor elevation	Z_{rad}	m a.s.l.	90.0
Minimum tailwater level	$Z_{restitution}$	m.a.s.l.	85.0
Powerhouse length	$L_{Centrale}$	m	40.0
Powerhouse width	$B_{Centrale}$	m	16.0
Powerhouse height	$H_{Centrale}$	m	10.0
Tailrace canal length	L_{canal_fuite}	m	50

8.2.8 Transmission lines and substation

The energy produced from Mahatsara will be evacuated by a ~70km transmission line to the isolated grid of Manajary (currently served by a thermal group of 1.3 MW), serving on its route the communes of Vohilava and Tsiatosika. Connection to the existing network will require the installation of a step-up station and a substation. A 63kV power line is foreseen.

Given that the village of Mahatsara and its surroundings are currently not served by the power grid, detailed studies will need to analyze the technical and economic feasibility of a medium-voltage departure from the Mahatsara power station to serve the surrounding communities.

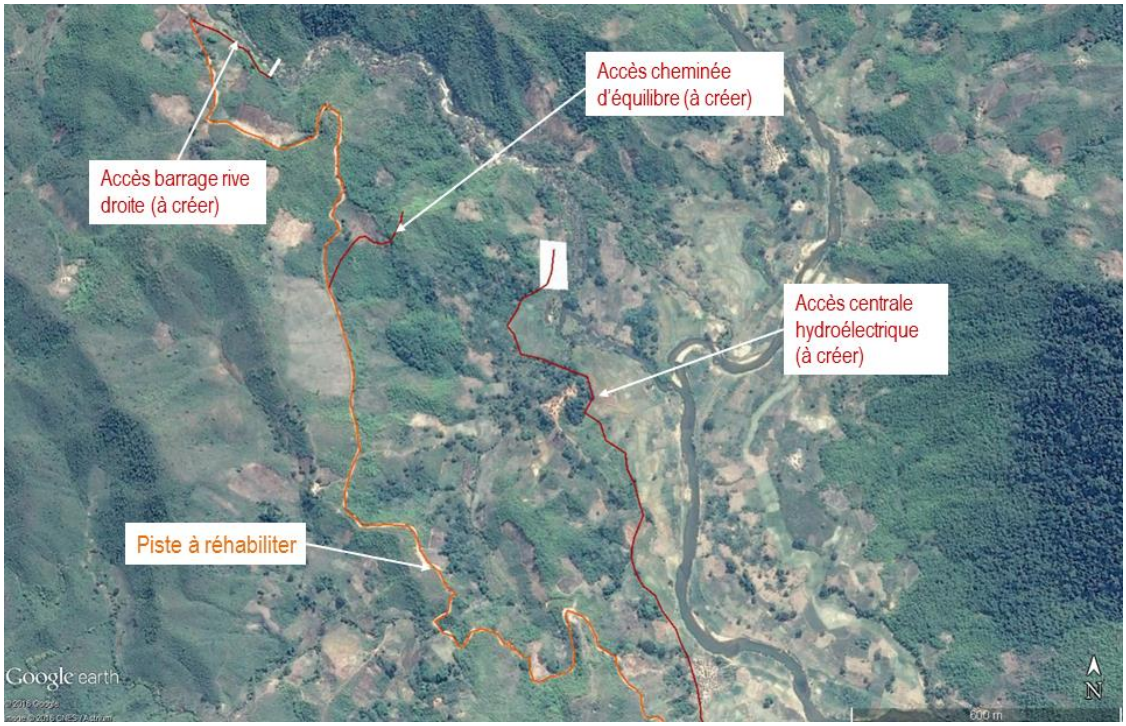
The exact alignment and the technical characteristics of the power line shall be defined during the next phases of the study.

8.2.9 Access

A comprehensive description of existing access is presented and illustrated in Section 3.2 of this report.

Access to the weir and intake will require the creation of a 500m access road on the left bank from the bridge over the river to the right of the village of Mahatsara. Access to the hydroelectric power plant site will be through the creation of a 2.5 km trail along the current trail path leading to the village of Ambohinanambo. In addition, a 300m access to the surge chamber / forebay should be created. The project will also require the rehabilitation of the track between Vohilava and the village of Ambohinanambo (21.9 km) and the village of Mahatsara (4.7 km extra). Additional studies should analyze the need to rehabilitate the whole or part of the RN24 from its intersection with the RN 25 (an additional distance of about 37 km). These different accesses to be rehabilitated and to create are illustrated in Figure 55 below.

Figure 55. Site access to be created and rehabilitated (Google Earth background)



8.2.10 Temporary infrastructure during the construction period

Temporary infrastructure includes:

- Construction camp.
- Construction works areas (e.g. concrete batching plant, cable crane plant).
- Quarry locations.
- Site access roads

The construction camp is intended to accommodate allochthones workers working on the site. It will consist of accommodations, all the necessary sanitary facilities, a water treatment station and a wastewater treatment plant. This will serve both for the construction camp and for the permanent camp.

8.2.11 Permanent Camp

The permanent camp will be located near the power station. It will consist of accommodations for the operators of the power plant as well as for the plant manager. The water treatment plants, constructed for the temporary camp, will also ensure the treatment of the waters of the permanent camp and the power plant.

8.3 KEY PROJET FEATURES

Table 19 below summarizes the key features of the proposed layout of the Fanovana hydroelectric scheme.

Table 19. Key features of the proposed scheme

PARAMETER	UNIT	PHASE 1	PHASE 2
		VALUE	
Power and Energy			
Design flow	m³/s	3.10	6.20
Gross head	m	154.00	154.00
Number of units	pce	2	4
Unit rated flow		1.55	
Installed capacity	MW	1.85	
Annual producible	MW	3.70	7.30
Power and Energy	GWh/an	30.7	47.8
Weir, flushing gates and intake			
Type of weir	-	Creager	
Weir length	m	46.50	
Weir height	m	5.00	
Crest elevation	m	237.50	
Number of flushing gates	Pce	2	
Flushing gates dimensions (h x b)	m x m	1.8 x 1.8	
Intake : number of gates	Pce	2	
Intake : gate dimensions (h x b)	m x m	2.0 x 2.0	
Tunnel and penstock			
Tunnel length	m	480	
Tunnel diameter	m	2.20	
Penstock length	m	280	
Penstock diameter	m	1.40	
Powerhouse and tailrace canal			
Powerhouse slab elevation	m	90.0	
Minimum tailrace elevation	m	85.0	
Powerhouse length	m	40.0	
Powerhouse width	m	16.0	
Power house heigth	m	10.0	
Tailrace canal length	m	50	

9 COSTS AND QUANTITIES ESTIMATES

9.1 ASSUMPTIONS

At the prefeasibility study stage of a hydroelectric development, the assumptions detailed in the following paragraphs are commonly accepted.

9.1.1 Units Costs

The list of unit prices comes from the Consultant's database which includes prices of contractors competent in hydraulic works and which can prove similar works carried out to international standards. This database is based on unit prices valid in Africa for infrastructure projects and updated for Madagascar.

Table 20. Unit prices (2016 USD)

STRUCTURE	DESCRIPTION	UNITS	COST
Weir	Rockfill	$/m³	55.00
	Rip-Rap	$/m³	55.00
	Grout curtain	$/m³	165.00
	Massonry	$/m³	126.50
	Random fill	$/m³	55.00
Route	Access road (new)	$/m	330.00
	Access road (rehabilitation)	$/m	88.00
	Excavation (rock)	$/m³	33.00
	Excavation (soil)	$/m³	5.50
	Excavation (tunnel)	$/m³	440.00
Concrete	Bedding concrete	$/m³	165.00
	Mass concrete	$/m³	400.00
	Structural concrete	$/m³	550.00
	Concrete lining for tunnel (30cm thickness)	$/m³	935.00
	Compacted earthfill	$/m³	13.20
Steel	Gates (2m x 2m)	$/pce	16,500.00
	Gates (1.8m x 1.8m)	$/pce	12,000.00
	Gates (0.8m x 0.8m)	$/pce	5,000.00
	Penstock	$/kg	13.20
	Roof	$/m²	16.50
	Trashrack	$/kg	30.00
	Laminted steel	$/kg	6.60
	Structure	$/kg	1.65
Massonry	Stones	$/m³	115.00
	Bricks	$/m³	110.00
Miscellaneous	Automatic trashrack cleaning machine	$/pce	100,000.00
	Overhead travelling crane	$/T	1,000.00

9.1.2 Reinforcements and concrete

The reinforcements necessary for the realization of the structural concrete are taken into account in the concrete costs (at 250 kg of steel per m³). No reinforcement is foreseen in mass concrete (mainly used for the spillway).

9.1.3 Indirect Costs

Indirect costs were estimated using rates applied on different sub-totals of costs, as enlightened in the table below. Rates applied to Civil Works are higher than rates applied to Electrical and Mechanical Works as more uncertainties remain until the works have started. They are shown in the table below.

Table 21. Indirect costs

INDIRECT COSTS	APPLIED RATE
Civil works contingencies	20% of civil works costs
Electrical and mechanical works contingencies	10% of E-M costs
Engineering (including ESIA), administration and supervision of works	10% of total costs
Owner's development costs	2% of total costs

9.1.4 Site Facilities

Costs for the Contractor site facilities and housing depend on the size of the project. Hence, this cost is taken as 10% of the total civil works costs.

9.1.5 Environmental and Social Impact Assessment Mitigation Costs

At this stage of the study and given the conclusions of the preliminary socio-environmental study, 3% of the total project costs are planned for the Environmental and Social Impact Assessment and mitigation (ESIA costs). This amount shall cover:

- Expropriation costs (compensation or allocation of new land);
- Mitigation cost of environmental impacts.

These costs should be specified in the full Environmental and Social Impact Assessment Study which will be carried out at a later stage of the project development. The costs of this study are taken into account in the indirect engineering costs presented in the previous section (section 9.1.3).

9.2 BILL OF QUANTITIES

Details of the quantities required for civil works, electromechanical equipment and other requirements are given in the following table.

Table 22. Bill of Quantities (BOQ)

SUBJECT		QUANTITY	UNIT	TOTAL COST (US $)
Site Access				**990,000**
	Création accès chantier	3.00	km	990,000
Concrete gravity weir (spillway) - 3.5 m high and 47 m long				**446,447**
	Concrete	1005.9	m³	374,724
	Excavation (soil)	104.66	m³	575
	Excavation (rocks)	788.20	m³	26,004
	Fill material	820.80	m³	45,144

Flushing gates				**107,465**
	Structural concrete	143.82	m³	79,101
	Excavation (soil)	6.90	m³	38
	Excavation (rocks)	131.10	m³	4,326
	Gates (1.8m x 1.8m)	2.00	pce	24,000
Intake and automatic trashrack cleaning system				**373,992**
	Structural concrete	414.75	m³	228,112
	Gates (2m x 2m)	2.00	pce	33,000
	Trashrack	312.00	kg	9,360
	Automatic trashrack cleaning machine	1.00	pce	100,000
	Excavation (soil)	25.60	m³	141
	Excavation (rocks)	102.40	m³	3,380
Sand trap - 35.4 m long ; 7.6 m width and 2.8 m high (2 basins)				**279,160**
	Structural concrete	343.02	m³	188,659
	Gates (2m x 2m)	4.00	pce	66,000
	Gates (0.8m x 0.8m)	2.00	pce	10,000
	Excavation (soil)	376.66	m³	2,072
	Excavation (rocks)	376.66	m³	12,430
Tunnel (partially lined with concrete) - 480m long and 2.2 m diameter				**968,509**
	Revêtement en béton tunnel (30cm d'épais)	177.19	m³	165,669
	Excavation tunnel et ancrage	1,824.64	m³	802,840
Penstock - 280 m long ; 1.4 m diameter and 11.9 mm thicknexx ; anchor blocks (4) and support blocs (47)				**1,740,025**
	Steel	115,315.20	kg	1,522,160
	Structural concrete	276.50	m³	152,075
	Masonry (stones)	352.80	m³	40,572
	Excavation (soil)	655.00	m³	3,602
	Excavation (rocks)	655.00	m³	21,615
Surge chamber 7 m diameter and 9.7 m high				**84,320**
	Structural concrete	133.52	m³	73,435
	Excavation (soil)	282.74	m²	1,555
	Excavation (rocks)	282.74	m³	9,331
Powerhouse - 40 m long ; 16 m width and 10 m high				**861,214**
	Structural concrete	704.00	m³	387,200
	Masonry (bricks)	336.00	m³	36,960
	Masonry (stones)	302.40	m³	34,776
	Door (large)	12.25	m²	1,225
	Door (steel)	1.00	pce	350
	Door (wood)	2.00	pce	240
	Window	11.00	pce	1,650
	Sheet metal	768.00	m²	12,672
	Laminated steel	26,880.00	kg	177,408
	Excavation (soil)	8,533.33	m³	46,933
	Excavation (rocks)	4,266.67	m³	140,800
	Overhead travelling crane	21.00	T	21,000
Tailrace canal - 50 m long ; 3.5 m width and 1 m high				**279,500**
	Masonry (stones)	2,000.00	m³	230,000
	Excavation (soil)	3,000.00	m³	16,500
	Excavation (rocks)	1,000.00	m³	33,000
Electromechanical equipment				**5,570,000**
PHASE 1				
	Turbine	2	pce	1 100 000
	Generator	2	pce	750 000

	Control system + transformers + electrical board and protections	1	pce	500,000
	HPU	1	pce	40 000
	Backup energy supply	1	pce	30 000
	Transport	1	pce	160 000
	Installation	1	pce	180 000
	Commissioning	1	pce	25 000
	Training of personal	1	pce	15 000
PHASE 2				
	Turbine	2	pce	1 100 000
	Generator	2	pce	750 000
	Control system + transformers + electrical board and protections	1	pce	500,000
	HPU	1	pce	40 000
	Transport	1	pce	160 000
	Installation	1	pce	180 000
	Commissioning	1	pce	25 000
	Training of personal	1	pce	15 000
Others				**17,530,000**
	Transmission line	70.00	km	12,250,000
	Rehabilitation of existing access roads	60.00	km	5,280,000
TOTAL				**29,230,635**

9.3 TOTAL COSTS (CAPEX)

The costs presented in the previous section (Table 22) have been consolidated based on the thematic in Table 23 below. This table also presents indirect costs related to studies, site supervision, project administration and environmental and social mitigation measures.

Table 23. Estimated total project costs

CATEGORY		PRIX [USD]
Civil Works		**6,632,000**
Mobilization, installation, demobilization		500,000
Access roads		990,000
Weir, flushing gates and intake		928,000
Waterway (sand trap, canal, tunnel, forebay and penstock)		3,073,000
Powerhouse and tailrace canal		1,141,000
Electromechanical equipment phase 1		**2,800,000**
Turbine		1,100,000
Generator		750,000
Control system + transformers + electrical board and protections		500,000
HPU		40,000
Backup energy generation		30,000
Transport		160,000
Installation		180,000
Commissioning and training of personal		40,000
Electromechanical equipment phase 2		**2,770,000**
Turbine		1,100,000
Generator		750,000
Control system + transformers + electrical board and protections		500,000
HPU		40,000
Transport		160,000
Installation		180,000
Commissioning and training of personal		40,000
Total		**12,202,000**
Contingencies		**1,884,000**
Civil works	20%	1,327,000
Electromechanical equipment phase 1	10%	280,000
Electromechanical equipment phase 2	10%	277,000
Indirect costs		**1,833,000**
Environmental and social mitigation costs	3%	367,000
Development costs	2%	245,000
Engineering (incl. ESIA) and works supervision	10%	1,221,000
Total project costs (including contingencies and indirect costs)		**15,919,000**
Other costs		**17,530,000**
Rehabilitation of existing access roads		5,280,000
Transmission line		12,250,000

10 ECONOMIC ANALYSIS

10.1 METHODOLOGY

The economic analysis is based on the results of the field investigations and various studies presented in the previous chapters, which includes an estimate of the quantities and the construction costs of the project (Chapter 9) and the definition of the installed capacity and power output. Based on these results, the Consultant estimated the cost of to deliver energy for the development of the Fanovana hydropower scheme.

The energy production alternatives (currently thermal units) will be compared based on their costs per kWh, the latter being expressed in terms Levelized Cost Of Energy (LCOE) which is a stream of equal payments, normalized over expected energy production periods that would allow a project owner to recover all costs, an assumed return on investment, over a predetermined life span.

The LCOE is defined from investment costs (CAPEX – Capital Expenditure), operating costs (OPEX – Operational Expenditure) and the expected production of energy.

Investment costs are:

- Study and work supervision costs, hereafter called “Studies and engineering costs” which include:
    - Civil works study and supervision costs
    - Electromechanical works study and supervision costs
    - Owner’s development costs
- Civil works and equipment costs, hereafter called “HPP costs”
- Resettlement and environmental impact costs, hereafter called “ESIA costs”

Annual operating costs are:

- Operation and maintenance costs, hereafter called “O&M costs” which include:
    - Fixed operation and maintenance costs (annual scheduled maintenance)
    - Costs related to interim replacement and refurbishments of major items in the course of the project’s life
    - Insurance costs

The LCOE is then calculated based on expected production and costs from the following formula:

$$LCOE = \frac{NPV(CAPEX + OPEX)}{NPV(Energy\ production)}$$

Where NPV is the Net Present Value which is obtained by: $NPV(value) = \sum_i \frac{valuer_i}{(1+n)^i}$ where *n* is the discount rate.

10.2 ASSUMPTIONS AND INPUT DATA

10.2.1 Economic modelling assumptions

The main economic assumptions for the economic modeling of the *LCOE* calculation for the Fanovana hydroelectric project are presented in Table 24 below.

Table 24. Economic modelling assumptions

Economic lifespan of the project	50 years
Decommissioning cost at the end of the economic life	10% of civils works and equipment costs
Engineering (incl. ESIA) and works supervision **Owner's development costs**	10% of civils works and equipment costs 2% of civils works and equipment costs
Environmental and social impact mitigation costs	3% of civils works and equipment costs
O&M costs **Interim replacement** **Fixed operation costs**	 0,25%/year of civils works and equipment costs 10 USD/kW/year
Insurance costs	0,10% of civils works and equipment costs per year
Distribution of costs over the project implementation process	 Year -3 = 20% Year -2 = 45% Year -1 = 35% Year 0 = Commissioning
Reference date for economic analysis	2016
Costs are expressed in constants	(2016) USD
Escalation costs (inflation)	No escalation costs were applied to capital costs or operating costs.
Financing costs etc.	Financing costs, tax, duties or other Government levees are ignored at this stage but shall be included in the financial analysis that will be done during the detailed studies.
Discount rate	10%

The economic analysis is carried out by considering that all the energy produced is absorbed by the electricity grid. In other words, the analysis assumes that there is a demand for all the energy generated by the Mahatsara hydroelectric scheme.

It is considered that the development of Phase 2 (upgrade from 3.7MW to 7.3MW) will take place 5 years after the commissioning of phase 1.

10.3 ECONOMIC ANALYSIS AND CONCLUSIONS

Table 25 presents the levelized costs of energy (LCOE) for the Mahatsara site.

Table 25. Levelized Cost of Energy (LCOE)

	ANNUAL ENERGY [GWH]	INSTALLED CAPACITY [MW]	DESIGN FLOW [M³/S]	CAPEX [M USD]	LCOE [USD / KWH]
Without Transmission lines and access roads to be rehabilitated	**year 1 to 5: 30.7 GWh from year 6: 47.8 GWh**	**7.3**	**6.2**	**15.92**	**0.0497**
With Transmission lines and access roads to be rehabilitated	year 1 to 5: 30.7 GWh from year 6: 47.8 GWh	7.3	6.2	33.45	0.0983

The economic analysis highlights that the Mahatsara hydroelectric scheme is an economically attractive project with a LCOE of 0.0497 $US/kWh (excluding the cost of transmission lines and the rehabilitation of the existing access roads). This figure should be compared with the cost of energy production by the thermal power plants currently in service since the development of the Fanovana hydroelectric project would replace the production of thermal energy by hydroelectricity. The cost of generating thermal power plants depends largely on the fuel costs.

Given a cost per kWh estimated between 0.180 to 0.250 $US/kWh for the HFO thermal and between 0.300 and 0.340 $US/kWh for the thermal GO (statistics from JIRAMA 2011), the Mahatsara site has production costs significantly lower than production costs by existing thermal units. These JIRAMA statistics are confirmed by the diagnosis of the energy sector in Madagascar carried out by WWF in 2012, which mentions a cost of production of thermal power plants between 0.3 US$/kWh for diesel-fired plants and 0.2 US$/kWh for fuel-fired plants, according to the ORE calculation.

It is important to note that the conclusions of this economic analysis are conditioned to the validation of the flow duration curve estimated in the hydrological study. This validation can only be done by pursuing the hydrological monitoring of the Besana River at the hydrometric station installed in October 2015 in Mahatsara.

11 CONCLUSIONS AND RECOMMENDATIONS

The hydrological study revealed the existence of uncertainties on the hydrology of the Besana River. Hence, it seems relevant to be careful in the choice of the design flow and it seems reasonable to make the following technical choices:

- the civil works (intake, canal, sand trap, tunnel, penstock and the civil works of the powerhouse) will be sized for an design flow of 6.2 m³/s corresponding to the $Q_{40\%}$ of the flow duration curve extrapolated from the Fatihita hydrometric station;
- the site will however be equipped initially only with electromechanical equipment corresponding to a guaranteed equipment flow rate of 3.1 m³/s.

These choices will make it possible to add the necessary electromechanical equipment when the hydrological regime of Besana will be better understood through hydrological measurements over longer and more recent periods. The final choice of the design flow should be made at the stage of detailed studies on the basis of an economic analysis of alternatives. The flow duration curve should also be validated by the additional hydrological data that will be available in the future at the hydrometric station located at the site (Mahatsara village).

The hydrological study also found that the Mahatsara site could potentially present a significant solid transport, particularly during flood events, which would cause problems of operation and maintenance of the hydroelectric power station.

The preliminary investigation of the surface geology concludes that from a geological point of view the site is favorable for the construction of the project as long as the appropriate mitigation measures are put in place. The site has no major problems of stability and leakages. Further studies will however have to be undertaken in further studies.

Preliminary socio-environmental studies show that the development of the Fanovana site has no major impacts that can not be mitigated by adequate measures.

The economic analysis reveals that the costs of rehabilitating existing access roads and the construction of the transmission line to Mananjary is high. The proposed hydroelectric development is an economically attractive site with a total LCOE (excluding transmission line and rehabilitation of existing access roads) of 0.0497 US$/kWh. The Mahatsara site features a production costs significantly lower than production costs by thermal units (0.18 to 0.25 US$/kWh for HFO and 0.30 to 0.34 US$/kWh).

It is therefore recommended that:

- the rehabilitation of the track between Vohilava and the village of Ambohinanambo (21.9 km) and up to the village of Mahatsara (additional 4.7 km) and (part or all) the RN24 from its intersection with RN 25 An additional distance of about 37 km)
- the construction of the 63kV transmission line

are carried out and financed under the structuring projects of the Malagasy Government with the objective of opening up the Vohilava region and consequently developing the local economy.

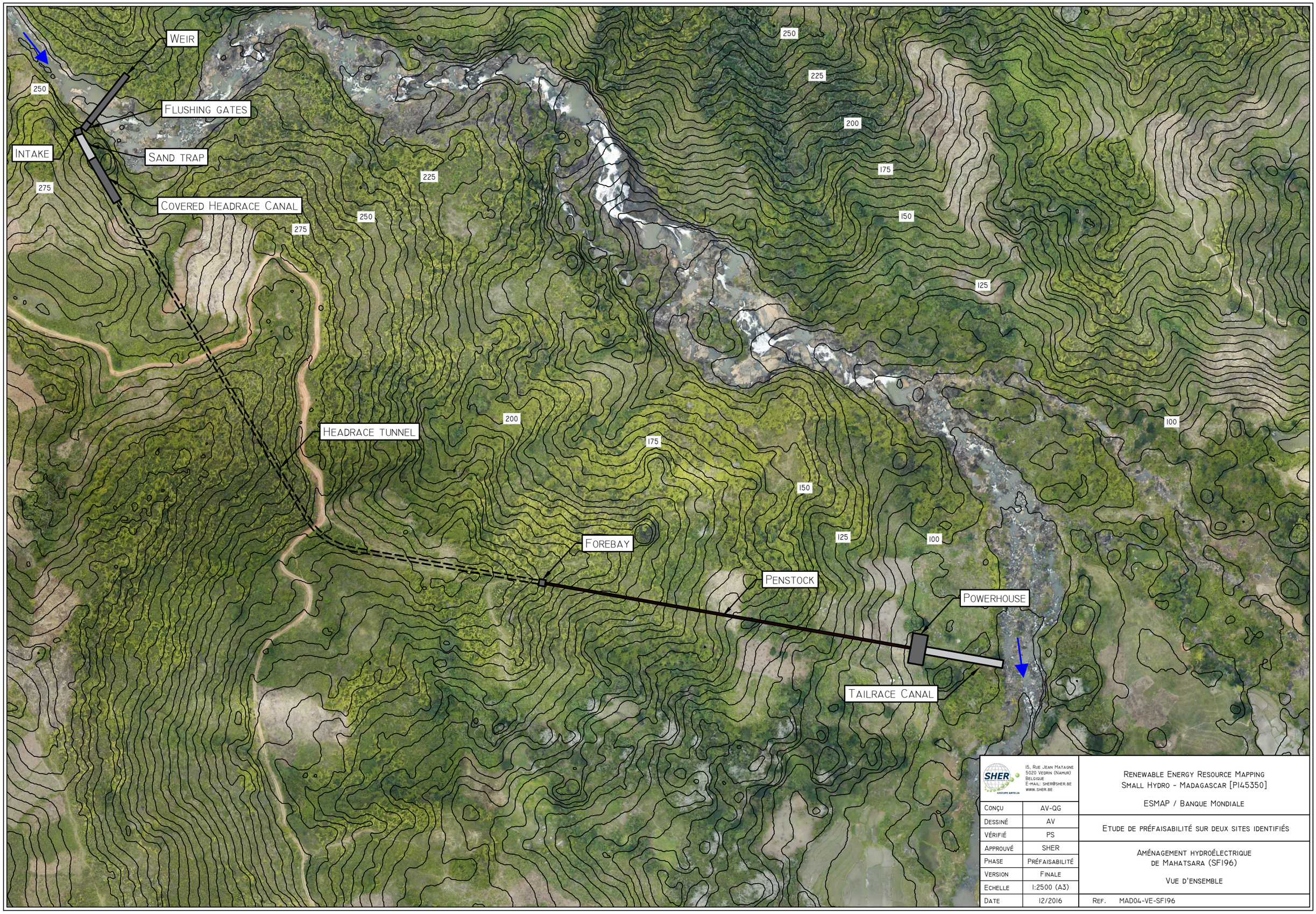
The Mahatsara Project could be developed via a Public Private Partnership (PPP), in particular in accordance with the law of 9 December 2015 organizing PPPs. The modalities of selection and invitation to tender must be very clearly defined and a firm specialized in PPPs must be recruited to accompany the tendering process.

It is important to note that the conclusions of this economic analysis are conditioned to the validation of the flow duration curve estimated in the hydrological study. This validation can only be achieved by pursuing the hydrological monitoring of the Besana River at the hydrometric station installed in October. This hydrological monitoring should include not only the continuation of the water level monitoring but also the continuation of the gauging operations of the river for the establishment of a validated rating curve.

Beyond the development of the Fanovana hydroelectric project, it is strongly recommended that the Government of Madagascar set up a hydrological monitoring network for its rivers with high hydropower potential in order to better understand the available water resources and thus promote the development of hydroelectric projects across the country. It is only in a context of reduced uncertainties through reliable, recent and long-term records (more than 20 years) that technical parameters and economic and financial analyzes of hydroelectric developments can be defined accurately, enabling optimization of their design and their flood control infrastructure (temporary and permanent).

12 APPENDICES

12.1 APPENDIX 1 : PROPOSED LAYOUT



SHER
GROUPE ARTELIA
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Conçu	AV-QG
Dessiné	AV
Vérifié	PS
Approuvé	SHER
Phase	Préfaisabilité
Version	Finale
Echelle	1:2500 (A3)
Date	12/2016

Renewable Energy Resource Mapping
Small Hydro - Madagascar [PI45350]

ESMAP / Banque Mondiale

Etude de préfaisabilité sur deux sites identifiés

Aménagement hydroélectrique
de Mahatsara (SF196)

Vue d'ensemble

Ref. MAD04-VE-SF196

12.2 APPENDIX 2 : HYDROLOGICAL DATA – IVOHANANA AT FATIHITA

Jour	Mois	1956-1957	1957-1958	1958-1959	1959-1960	1960-1961	1961-1962	1962-1963	1963-1964	1964-1965	1965-1966	1966-1967	1967-1968	1968-1969	1969-1970	1970-1971	1971-1972	1972-1973	1973-1974	1974-1975
1	11	9.3	11.6	29.5	15.0	11.4	15.6	14.5	22.9	33.0	22.2	13.8	48.6	14.7	17.3	16.9	18.4	27.7	14.6	33.8
2	11	9.2	11.4	30.0	14.6	11.1	15.6	19.5	27.8	41.7	21.8	13.3	47.4	15.9	17.9	16.7	22.5	26.5	14.4	42.7
3	11	9.2	11.3	33.5	14.4	10.9	16.0	16.6	36.2	33.4	21.6	13.3	107.0	17.9	19.0	17.4	22.0	28.8	14.2	47.9
4	11	9.1	11.6	30.1	15.2	10.8	19.3	14.6	30.7	31.9	27.1	13.3	55.3	19.1	20.2	17.3	21.8	25.9	14.0	41.5
5	11	9.1	12.7	26.9	17.5	10.6	16.2	13.4	25.9	36.0	33.2	13.1	42.5	15.8	22.7	17.2	21.4	24.3	13.8	41.0
6	11	9.0	13.9	27.3	20.7	10.5	15.9	14.4	25.7	69.0	29.7	13.2	42.0	14.9	35.4	23.2	20.8	23.2	15.1	68.8
7	11	8.9	13.0	24.5	20.9	10.3	15.7	26.6	36.6	41.9	30.8	16.5	37.7		31.0	29.0	20.1	22.6	23.3	54.2
8	11	9.5	11.9	21.1	20.3	10.2	15.8	24.6	35.0	35.1	24.9	15.5	32.7		50.0	32.3	19.6	21.7	27.9	45.2
9	11	13.3	11.3	20.5	20.2	10.2	15.4	20.0	35.6	30.9	26.4	13.5	30.2		40.0	23.5	19.1	21.0	32.8	35.6
10	11	13.8	11.1	19.6	23.1	10.0	16.3	25.6	95.3	29.2	32.3	12.6	28.9		43.8	21.3	21.5	20.3	31.1	29.8
11	11	13.6	11.1	20.6	16.9	10.0	18.6	67.6	98.0	27.6	31.8	13.8	28.3		36.0	19.9	30.2	19.6	28.5	25.4
12	11	13.4	11.0	23.8	15.3	9.9	17.1	62.3	64.8	41.2	26.0	14.6	25.5		31.9	18.6	28.6	19.0	26.3	22.2
13	11	13.2	11.6	18.3	15.0	9.8	19.1	22.1	73.9	42.8	24.0	18.0	25.4		22.1	17.4	25.8	18.7	24.2	19.6
14	11	12.9	15.0	19.3	14.8	9.7	20.3	19.6	334.0	30.5	22.4	33.2	24.6		20.1	17.1	27.4	23.6	21.9	18.4
15	11	12.6	21.3	25.2	14.8	9.6	22.0	17.9	248.0	27.6	21.0	21.2	29.8		24.4	18.5	27.9	27.0	19.7	17.8
16	11	13.6	20.9	24.5	14.9	9.6	21.8	18.2	155.0	24.0	20.6	16.2	30.3		45.3	20.0	26.1	25.6	17.8	20.4
17	11	13.4	16.4	18.3	15.8	9.5	29.2	16.1	88.3	23.9	21.1	15.2	40.7		30.9	36.1	25.6	24.2	16.9	22.6
18	11	13.0	14.5	18.4	16.4	9.4	46.6	15.8	64.3	23.1	23.8	22.9	31.8		23.4	31.8	25.8	23.5	18.8	22.1
19	11	12.9	12.8	17.4	19.1	9.4	30.1	16.1	36.7	21.9	23.8	16.1	32.8		21.6	28.6	25.8	27.9	21.0	19.5
20	11	14.0	11.6	15.3	29.3	9.3	24.4	14.4	30.9	21.5	21.1	15.4	54.1		20.8	27.3	30.1	30.4	19.1	17.0
21	11	14.2	11.2	15.0	23.7	11.7	20.8	13.6	26.8	21.1	20.3	15.6	45.4		20.3	44.4	83.6	31.3	19.1	16.1
22	11	16.0	11.2	15.1	20.5	20.2	17.5	13.5	24.0	22.5	20.8	15.5	43.5		20.1	45.6	73.2	31.8	17.6	15.9
23	11	17.6	11.1	16.2	19.3	16.1	16.1	13.5	22.2	23.5	23.1	19.4	74.9		29.7	36.8	56.3	29.2	16.7	16.3
24	11	22.1	10.9	15.2	26.1	12.1	15.9	14.1	20.7	24.1	29.5	16.9	79.2		28.3	26.4	51.5	26.8	16.2	17.1
25	11	25.1	10.9	15.0	31.4	11.1	15.5	14.0	22.0	39.2	88.8	18.5	52.9		24.7	23.6	48.0	25.9	16.6	18.4
26	11	25.1	12.0	15.1	35.5	10.6	15.0	24.5	24.3	58.2	63.4	19.1	40.7		23.0	21.4	44.1	25.1	17.4	19.3
27	11	24.4	14.3	14.7	95.6	10.5	17.3	35.0	27.5	50.7	84.5	16.6	37.8		21.6	19.0	40.8	24.3	21.2	19.3
28	11	24.1	12.8	14.5	40.0	11.9	31.5	42.2	31.2	37.9	61.5	14.7	36.4		19.8	18.0	35.8	23.2	22.0	18.5
29	11	23.1	12.2	14.7	26.9	15.5	24.2	36.9	31.7	31.2	72.8	13.9	35.4		19.0	17.9	33.7	25.2	18.3	17.3

30	**11**	22.9	12.1	14.6	31.9	22.9	25.9	27.4	29.5	28.7	43.7	13.3	38.1		19.9	17.6	31.1	24.4	17.0	16.4
1	**12**	24.8	12.4	14.6	37.4	24.5	62.2	18.5	27.9	29.1	37.8	14.4	74.2		31.3	17.1	45.9	23.2	17.0	15.5
2	**12**	23.0	13.1	14.2	23.5	25.7	30.5	52.9	27.4	40.1	41.5	12.5	71.4		26.4	16.9	50.8	22.5	18.5	14.8
3	**12**	21.5	27.3	13.8	19.1	29.9	28.9	50.0	33.4	56.1	33.8	12.0	124.0		19.2	16.5	47.7	22.2	17.1	14.1
4	**12**	20.2	90.3	13.6	24.1	17.6	35.9	22.2	34.5	65.2	34.2	12.0	58.3		17.4	16.4	45.1	21.7	16.7	13.6
5	**12**	19.9	80.2	13.4	22.4	13.3	44.0	19.9	33.4	47.7	43.6	11.7	59.0		18.9	18.7	59.8	21.2	18.1	13.6
6	**12**	19.4	50.9	13.1	19.4	13.1	51.5	21.8	36.2	37.4	33.1	11.6	86.3		37.2	17.6	54.8	21.1	17.0	15.8
7	**12**	18.8	36.9	13.0	16.7	12.5	239.0	24.6	47.2	37.0	32.0	11.5	64.7		26.6	16.6	51.7	20.8	16.1	22.6
8	**12**	18.2	27.1	16.2	15.6	16.1	97.2	30.0	49.6	30.5	36.8	11.8	55.1		22.1	16.0	48.8	20.3	15.4	28.2
9	**12**	17.6	21.0	33.3	14.9	18.6	64.3	27.3	39.3	40.4	76.1	12.8	54.7		21.6	15.7	44.2	23.6	17.4	33.3
10	**12**	17.0	15.6	23.0	14.5	27.1	48.5	23.1	42.4	33.6	58.2	13.6	53.3		40.4	15.5	41.6	26.7	28.6	40.8
11	**12**	16.6	16.3	17.8	14.5	35.2	50.5	16.9	42.6	41.0	48.3	14.5	82.0		65.7	15.4	38.6	31.3	26.3	36.9
12	**12**	17.3	16.0	20.4	16.7	42.0	56.2	14.8	51.7	34.8	55.0	12.8	52.2		79.9	15.3	34.7	27.5	21.6	33.8
13	**12**	22.7	19.7	26.2	26.9	51.5	146.0	15.3	63.6	30.8	60.4	11.9	43.1		70.0	15.1	32.2	28.2	19.3	31.7
14	**12**	23.3	17.1	67.6	21.1	88.1	140.0	17.2	43.7	26.2	58.9	11.6	46.9		137.0	15.0	28.8	29.2	18.7	28.7
15	**12**	23.0	23.0	134.0	15.8	38.1	129.0	34.9	46.6	24.5	51.8	12.2	43.0		100.0	14.9	27.2	28.1	17.9	28.8
16	**12**	22.4	22.7	105.0	16.8	36.0	135.0	132.0	166.0	25.2	45.5	23.6	40.2		96.1	14.8	35.0	26.3	17.7	52.2
17	**12**	22.0	31.3	83.6	15.5	24.3	114.0	90.1	137.0	40.0	39.5	17.7	38.0		98.0	14.8	49.1	28.5	17.1	68.7
18	**12**	21.5	45.9	72.5	14.5	33.8	87.0	44.2	88.6	36.2	34.1	16.7	43.6		84.6	17.1	59.0	32.9	17.5	78.8
19	**12**	20.9	41.3	140.0	14.2	48.1	80.4	23.0	38.5	57.1	32.1	16.3	68.4		58.3	20.5	52.5	32.3	21.3	86.0
20	**12**	20.6	29.8	77.6	14.2	32.4	70.6	24.3	32.8	56.0	34.6	32.0	54.7		49.0	19.3	53.0	31.3	38.8	96.4
21	**12**	20.4	25.7	43.0	14.1	27.3	65.4	23.8	32.5	45.7	48.8	43.3	68.6		44.6	17.5	52.0	30.6	26.0	75.3
22	**12**	22.0	20.4	35.5	13.7	22.3	87.8	22.8	35.4	48.8	87.5	64.0	58.1		52.1	16.2	79.7	27.5	30.9	68.1
23	**12**	22.0	17.2	34.8	13.6	17.8	77.4	21.1	48.1	69.0	112.0	139.0	51.1		46.1	15.5	102.0	25.6	34.6	64.9
24	**12**	21.5	15.9	35.7	16.4	16.1	61.2	23.7	44.3	118.0	95.3	68.3	70.4		41.2	15.9	85.1	24.8	61.3	62.1
25	**12**	21.2	16.5	42.2	32.1	15.1	89.5	23.8	36.8	85.8	82.8	89.3	65.5		95.5	27.8	76.1	31.9	92.1	59.2
26	**12**	20.6	21.4	48.8	28.8	18.5	306.0	23.4	33.7	86.0	59.0	50.9	43.7		89.5	42.5	51.2	36.5	123.0	51.7
27	**12**	20.3	38.1	51.4	20.2	29.9	166.0	21.8	35.5	66.9	48.2	72.7	43.2		62.2	42.9	40.5	34.5	160.0	48.8
28	**12**	20.0	40.4	47.0	17.8	43.2	121.0	17.6	50.1	53.2	55.2	97.1	50.8		59.4	43.6	37.5	31.0	184.0	47.1
29	**12**	19.4	80.0	57.4	17.0	83.2	92.3	17.0	71.0	47.4	69.5	162.0	51.9		152.0	44.1	34.8	27.1	141.0	56.6
30	**12**	18.8	85.7	66.1	26.8	43.5	198.0	15.7	94.5	42.0	62.7	187.0	56.7		204.0	43.0	32.3	35.2	86.7	77.1
31	**12**	18.5	60.4	123.0	66.0	34.8	262.0	16.4	116.0	40.7	55.1	98.0	86.7		108.0	37.6	38.1	32.4	78.5	83.1

1	**1**	26.7	78.1	73.7	35.2	70.0	173.0	72.0	26.2	41.0	127.0	91.8	68.6		89.1	37.2	37.4	29.1	71.6	75.5
2	**1**	35.2	51.3	63.8	32.1	268.0	123.0	57.9	28.7	111.0	202.0	97.0	66.9		245.0	41.2	33.5	26.7	62.1	70.9
3	**1**	69.2	33.7	81.5	47.9	126.0	98.6	41.7	27.2	143.0	99.4	107.0	66.6		195.0	62.6	29.5	27.0	55.6	67.9
4	**1**	69.2	24.2	109.0	36.9	81.8	88.1	36.8	25.7	223.0	74.1	95.8	76.3		172.0	105.0	26.1	25.5	112.0	77.1
5	**1**	63.2	22.4	89.2	25.7	61.1	84.3	33.1	24.6	137.0	60.0	98.8	58.6		153.0	47.6	24.4	29.2	103.0	89.4
6	**1**	57.2	21.2	100.0	33.9	57.8	76.4	80.8	23.8	84.8	56.0	142.0	51.0		127.0	32.0	22.7	39.2	102.0	84.7
7	**1**	50.7	18.6	116.0	40.8	78.4	69.8	58.3	22.4	85.6	50.9	80.5	45.5		159.0	37.8	23.3	44.6	116.0	79.6
8	**1**	46.0	17.9	129.0	59.3	112.0	65.5	47.9	20.6	106.0	49.7	86.4	43.6		304.0	50.8	50.7	43.3	92.5	79.4
9	**1**	42.3	17.8	120.0	78.3	181.0	61.2	38.4	21.8	92.3	57.9	59.3	44.0		241.0	42.3	47.7	52.5	79.5	76.4
10	**1**	39.3	17.0	151.0	94.1	120.0	58.3	36.5	45.9	129.0	94.2	47.0	47.1		227.0	31.2	38.2	72.3	73.3	74.3
11	**1**	34.8	16.3	198.0	49.6	73.2	57.0	37.4	46.7	113.0	74.9	41.7	42.2		167.0	26.2	58.3	86.8	65.9	72.4
12	**1**	30.0	16.3	195.0	35.2	51.8	52.9	36.8	92.6	135.0	60.0	41.7	39.0		120.0	32.3	52.1	106.0	60.1	76.9
13	**1**	26.3	18.5	225.0	28.7	49.5	52.3	33.7	91.4	99.2	59.1	37.9	40.6		108.0	65.9	44.7	104.0	53.4	72.0
14	**1**	23.4	20.3	153.0	24.7	49.1	52.7	35.5	67.9	88.0	80.9	39.4	35.5		124.0	75.7	38.2	143.0	50.7	68.2
15	**1**	26.8	27.9	112.0	35.1	50.8	66.7	31.9	58.2	82.3	52.0	39.4	44.7		126.0	127.0	34.5	105.0	59.4	72.1
16	**1**	47.0	67.0	94.0	55.3	39.6	53.7	29.9	43.7	132.0	45.7	46.8	50.6		136.0	117.0	43.9	70.0	54.9	65.9
17	**1**	35.9	30.0	85.2	37.5	39.7	47.6	31.5	37.8	109.0	45.1	45.3	47.4	58.4	126.0	106.0	39.7	58.4	44.9	60.3
18	**1**	26.9	23.1	78.9	33.3	50.7	47.0	34.7	34.7	86.8	42.2	57.8	49.2	53.8	101.0	89.5	33.9	56.2	45.1	64.3
19	**1**	26.5	23.5	72.5	34.8	41.5	69.5	27.5	32.1	79.5	41.9	44.1	42.8	69.6	95.2	80.9	32.2	72.1	57.1	59.6
20	**1**	30.0	21.5	66.7	28.1	53.5	155.0	34.2	28.9	79.7	41.5	36.3	41.8	53.3	95.6	72.4	76.1	63.8	54.9	54.2
21	**1**	61.0	30.8	63.8	25.4	46.3	241.0	86.5	27.4	73.7	37.3	38.7	37.1	51.9	82.6	60.9	60.3	64.0	50.6	58.5
22	**1**	64.7	41.7	81.3	32.4	36.5	114.0	80.4	26.7	83.9	37.7	48.3	35.2	93.6	75.3	57.6	51.6	73.8	44.2	79.7
23	**1**	131.0	56.6	147.0	40.3	39.0	140.0	62.8	33.9	137.0	38.9	66.9	33.5	55.9	74.4	50.6	53.3	61.3	38.9	76.9
24	**1**	110.0	57.3	82.6	65.1	62.3	150.0	214.0	31.3	140.0	36.0	77.0	29.7	45.9	72.5	43.8	67.2	57.1	35.5	72.3
25	**1**	62.0	59.7	62.0	117.0	68.5	139.0	224.0	27.4	278.0	33.9	81.0	53.1	69.5	68.2	44.4	79.0	53.8	33.1	76.4
26	**1**	46.5	52.3	63.7	68.3	80.3	92.6	105.0	25.1	361.0	32.1	134.0	99.0	61.2	75.6	93.8	98.9	48.2	30.0	76.4
27	**1**	38.9	74.1	94.4	80.3	115.0	76.9	104.0	23.1	437.0	32.8	73.5	84.3	60.2	73.9	79.6	84.5	52.5	33.8	71.9
28	**1**	41.5	97.3	94.3	96.2	56.4	69.0	75.6	21.4	512.0	30.0	54.4	44.3	73.5	88.6	68.7	70.8	43.7	38.3	66.9
29	**1**	43.5	173.0	74.7	73.2	46.1	61.7	166.0	20.1	402.0	29.3	48.3	35.5	75.6	84.4	77.2	59.0	42.4	36.7	64.2
30	**1**	38.2	129.0	66.4	81.2	38.1	78.6	160.0	18.8	279.0	27.2	46.4	33.6	148.0	78.3	95.8	57.7	40.0	37.5	63.4
31	**1**	38.5	85.1	61.9	107.0	33.6	74.3	146.0	18.5	202.0	27.2	43.1	33.1	69.9	85.3	108.0	87.9	43.0	34.8	79.7
1	**2**	50.0	69.7	67.4	64.3	31.9	127.0	97.4	17.4	87.4	28.0	40.8	67.6	52.8	82.0	148.0	99.0	64.3	35.4	86.7

2	**2**	95.7	111.0	63.7	44.9	30.4	77.3	81.4	21.1	89.9	30.3	42.8	106.0	47.9	73.5	172.0	74.6	90.5	51.4	86.5
3	**2**	87.3	198.0	54.5	40.4	28.5	87.5	65.9	20.7	89.8	33.5	40.8	82.8	55.7	67.3	185.0	67.7	82.5	70.3	98.4
4	**2**	161.0	144.0	50.7	37.1	27.9	84.1	79.5	19.9	92.9	39.4	37.4	81.0	242.0	93.3	157.0	60.0	86.6	98.1	93.9
5	**2**	164.0	105.0	48.1	37.0	27.6	86.7	99.0	19.4	101.0	47.4	34.1	71.2	491.0	101.0	126.0	53.1	90.5	224.1	107.0
6	**2**	118.0	77.7	47.8	39.8	28.5	76.5	77.1	22.2	109.0	59.3	31.1	70.5	560.0	203.0	118.0	48.2	100.0	150.0	118.0
7	**2**	94.2	67.1	48.3	38.2	25.7	67.9	74.1	39.6	115.0	38.2	31.8	51.5	626.0	254.0	108.0	51.5	109.0	120.0	115.0
8	**2**	83.2	82.9	63.6	40.1	25.1	63.3	77.4	67.3	98.8	30.5	30.6	45.1	758.0	232.0	131.0	50.3	116.0	106.0	118.0
9	**2**	77.3	87.4	82.5	45.2	27.6	62.8	75.2	67.4	79.1	28.4	31.2	43.8	558.0	184.0	123.0	51.2	114.0	89.5	133.0
10	**2**	63.8	103.0	99.5	38.1	26.7	109.0	69.5	72.2	99.1	27.7	30.8	44.6	424.0	324.0	110.0	52.0	98.3	88.6	168.0
11	**2**	56.3	76.5	228.0	37.9	30.4	111.0		81.0	109.0	29.9	28.7	66.5	320.0	164.0	101.0	48.0	96.3	127.0	179.0
12	**2**	51.9	56.5	122.0	34.2	29.7	88.3		87.4	124.0	46.9	35.0	69.8	298.0	117.0	91.9	57.6	102.0	167.0	169.0
13	**2**	52.8	49.3	86.7	49.6	25.5	77.1		89.5	133.0	116.0	47.3	56.6	283.0	104.0	86.3	141.0	95.2	146.0	162.0
14	**2**	65.9	44.7	121.0	66.5	23.9	74.2		102.0	126.0	120.0	45.2	48.0	356.0	122.0	81.3	393.0	106.0	114.0	154.0
15	**2**	62.5	42.9	92.6	60.2	22.1	70.2		100.0	125.0	88.3	43.4	42.9	292.0	115.0	80.3	393.0	115.0	102.0	149.0
16	**2**	55.8	47.6	73.5	42.6	23.6	70.4		91.8	120.0	86.4	36.2	46.3	306.0	188.0	173.0	256.0	210.0	91.3	145.0
17	**2**	48.3	46.2	64.8	36.4	43.4	64.7		74.3	140.0	84.1	42.8	58.0	272.0	159.0	280.0	219.0	192.0	82.7	159.0
18	**2**	44.9	39.3	59.2	40.5	34.0	89.8		50.8	143.0	94.4	120.0	206.0	211.0	209.0	253.0	194.0	180.0	71.4	159.0
19	**2**	42.9	35.8	54.0	45.4	25.7	112.0		42.8	143.0	78.3	207.0	103.0	178.0	138.0	215.0	163.0	169.0	65.4	152.0
20	**2**	45.2	37.0	52.0	40.8	25.3	106.0		38.9	111.0	57.4	103.0	90.0	153.0	131.0	166.0	142.0	136.0	60.3	145.0
21	**2**	50.8	58.6	50.9	67.8	23.0	108.0		37.2	86.2	89.4	109.0	83.0	141.0	180.0	117.0	126.0	120.0	57.5	138.0
22	**2**	58.6	81.8	50.3	58.5	20.7	225.0		36.2	71.5	79.3	114.0	55.3	90.4	410.0	97.0	114.0	114.0	55.9	124.0
23	**2**	62.5	57.3	52.0	106.0	19.0	221.0		35.3	54.3	55.8	73.6	122.0	104.0	543.0	76.9	112.0	111.0	87.3	117.0
24	**2**	63.8	47.0	64.6	103.0	18.5	190.0		34.8	47.8	65.2	64.3	75.9	118.0	727.0	76.2	173.0	107.0	83.9	111.0
25	**2**	54.3	43.8	62.5	59.9	19.7	133.0		34.3	41.5	76.3	54.8	66.1	122.0	518.0	124.0	156.0	108.0	76.2	102.0
26	**2**	50.3	69.5	71.0	52.6	20.6	112.0		33.9	41.0	73.6	50.5	59.7	100.0	258.0	108.0	124.0	115.0	70.8	102.0
27	**2**	47.6	149.0	103.0	55.3	21.8	104.0		33.7	48.0	57.4	57.1	53.8	90.8	212.0	74.7	113.0	120.0	59.5	98.6
28	**2**	44.9	183.0	153.0	71.3	23.2	93.3		33.4	74.9	48.5	77.3	49.3	84.1	186.0	69.2	106.0	125.0	57.1	95.0
29	**2**				50.2				33.4				53.9				104.0			
1	**3**	39.5	143.0	83.7	43.4	19.8	89.3		33.7	169.0	48.1	58.4	47.8	78.9	148.0	87.7	101.0	116.0	51.5	96.2
2	**3**	37.3	145.0	133.0	45.6	18.2	83.2		33.9	198.0	51.8	86.0	90.2	76.3	175.0	83.3	81.2	110.0	48.1	93.2
3	**3**	37.6	169.0	124.0	43.1	17.8	78.7		34.4	421.0	46.0	122.0	90.7	73.2	160.0	79.2	69.9	97.6	45.0	101.0
4	**3**	46.0	315.0	162.0	38.2	31.0	70.5		35.2	489.0	45.6	150.0	63.1	72.9	215.0	73.0	65.9	94.1	43.4	95.0

5	**3**	55.4	208.0	168.0	35.5	29.5	71.6		36.3	155.0	52.5	85.9	72.0	75.5	173.0	68.9	59.7	95.5	46.5	125.0
6	**3**	72.6	187.0	118.0	35.7	31.8	67.7		38.2	107.0	70.0	62.0	60.9	74.5	119.0	65.7	55.6	101.0	55.4	120.0
7	**3**	57.5	205.0	94.0	35.2	33.8	65.8		41.1	87.6	55.5	91.2	78.4	86.8	120.0	63.5	51.2	92.8	75.3	113.0
8	**3**	55.3	178.0	101.0	35.5	29.4	61.2		44.5	89.8	52.6	105.0	87.9	88.1	114.0	61.6	46.6	94.4	87.2	110.0
9	**3**	52.3	151.0	92.4	39.7	53.8	64.4		50.4	73.8	48.4	97.1	105.0	78.8	106.0	57.7	44.1	89.3	95.0	103.0
10	**3**	50.9	123.0	88.7	43.1	75.3	65.1		59.5	89.2	114.0	67.0	111.0	79.3	102.0	54.3	52.3	87.9	112.0	99.1
11	**3**	57.2	107.0	104.0	44.6	45.7	94.6		72.4	80.1	118.0	62.4	91.0	145.0	110.0	58.8	73.5	85.7	147.0	113.0
12	**3**	96.7	102.0	112.0	36.0	32.5	263.0		86.7	71.6	86.0	88.7	73.7	171.0	121.0	58.3	85.9	82.3	182.0	136.0
13	**3**	93.2	103.0	93.3	31.4	61.7	135.0		115.0	95.5	69.4	93.4	110.0	107.0	118.0	53.3	81.1	79.8	151.0	181.0
14	**3**	80.0	124.0	85.6	32.3	53.1	127.0		104.0	126.0	66.9	84.5	136.0	77.1	114.0	50.3	74.0	87.4	117.0	179.0
15	**3**	57.4	236.0	81.2	36.9	59.3	102.0		95.8	182.0	82.7	85.9	86.4	61.4	105.0	47.6	77.8	85.5	106.0	166.0
16	**3**	52.4	155.0	82.0	42.1	110.0	87.0		90.7	369.0	58.6	95.1	72.6	62.3	100.0	44.7	75.5	80.3	97.2	136.0
17	**3**	51.7	113.0	102.0	38.2	182.0	82.2		86.5	300.0	59.4	73.9	67.5	68.3	101.0	41.2	71.2	78.2	85.1	126.0
18	**3**	57.8	103.0	167.0	43.5	120.0	78.8		80.2	148.0	76.1	100.0	62.9	78.8	102.0	41.0	66.4	97.0	79.5	119.0
19	**3**	59.0	90.0	407.0	34.7	98.8	78.0		68.8	128.0	64.5	94.1	63.2	74.7	110.0	42.8	65.9	96.2	72.8	110.0
20	**3**	74.9	82.2	325.0	53.4	87.0	73.8		61.6	271.0	56.6	101.0	66.3	92.9	119.0	40.1	86.4	87.5	69.8	104.0
21	**3**	84.9	76.1	249.0	46.8	91.8	67.3		55.6	351.0	55.9	89.9	68.1	136.0	95.4	38.0	80.7	85.3	133.0	97.1
22	**3**	75.1	72.4	214.0	57.2	82.8	70.9		52.0	243.0	60.9	83.3	60.9	80.1	102.0	46.0	70.0	83.0	180.0	93.5
23	**3**	92.5	69.4	201.0	126.0	91.0	71.9		49.5	191.0	75.9	130.0	55.6	71.2	97.7	43.9	64.8	100.0	209.0	106.0
24	**3**	92.0	67.6	309.0	56.3	60.7	67.7		51.3	144.0	57.4	117.0	58.1	66.7	90.4	40.5	60.0	95.1	189.0	106.0
25	**3**	106.0	66.8	459.0	48.4	50.2	65.4		54.3	121.0	52.1	109.0	52.2	57.8	95.7	39.3	54.2	107.0	153.0	109.0
26	**3**	127.0	73.8	555.0	46.7	48.0	61.6		53.5	216.0	50.0	116.0	59.8	61.0	92.8	38.4	49.4	106.0	129.0	122.0
27	**3**	139.0	70.9	793.0	43.8	64.4	63.1		49.5	213.0	73.4	163.0	55.3	69.9	94.7	37.1	70.5	101.0	117.0	117.0
28	**3**	148.0	66.5	610.0	39.7	56.2	60.3		47.9	239.0	59.7	97.6	56.5	74.3	87.6	41.3	73.5	95.6	108.0	111.0
29	**3**	133.0	69.2	449.0	38.8	42.6	66.8		46.5	198.0	96.8	81.0	54.6	68.2	113.0	38.3	80.3	106.0	97.4	104.0
30	**3**	111.0	66.0	332.0	38.6	38.9	89.6		44.2	257.0	119.0	76.0	53.1	63.0	93.1	37.9	86.9	108.0	89.2	98.4
31	**3**	118.0	62.3	289.0	38.5	37.1	84.9		42.7	362.0	82.0	70.6	54.5	70.6	85.8	59.3	97.0	121.0	80.2	77.1
1	**4**	112.0	57.7	246.0	36.4	35.1	79.9		51.0	209.0	65.5	101.0	53.1	64.2	85.1	59.4	94.7	118.0	71.6	72.5
2	**4**	97.6	54.8	226.0	33.7	38.7	92.1		60.0	109.0	56.7	83.9	50.3	55.8	88.0	52.4	81.8	108.0	69.4	67.1
3	**4**	86.1	52.6	214.0	35.9	47.5	87.6		60.7	98.1	54.9	78.0	48.1	52.0	90.4	49.1	70.4	102.0	97.3	63.2
4	**4**	79.4	51.3	196.0	34.7	57.0	80.0		57.3	98.6	78.3	74.5	47.0	64.5	85.8	47.7	64.0	97.8	91.4	59.8
5	**4**	76.5	49.8	183.0	34.8	60.9	71.7		52.6	103.0	65.0	80.5	43.9	77.9	110.0	45.4	59.9	92.5	85.9	55.7

6	**4**	78.5	51.4	165.0	32.9	54.1	64.1		48.8	91.4	52.0	68.6	44.3	59.3	111.0	43.3	55.3	87.5	81.4	58.0
7	**4**	78.2	50.4	154.0	31.6	34.1	69.4		45.6	93.8	60.0	68.9	43.9	51.5	108.0	41.5	50.5	79.0	76.9	53.8
8	**4**	77.0	49.5	144.0	31.1	31.7	60.0		43.3	105.0	52.6	69.1	43.1	66.0	105.0	52.2	45.9	73.1	73.1	47.8
9	**4**	77.5	47.7	140.0	32.3	34.2	54.8		41.2	93.5	69.6	84.5	42.5	81.2	126.0	55.0	41.3	67.0	74.1	44.8
10	**4**	86.5	47.1	143.0	29.0	82.5	53.6		39.9	79.4	78.7	121.0	44.0	62.2	120.0	123.0	38.2	60.5	72.2	43.1
11	**4**	83.5	62.6	131.0	27.2	69.4	63.4		41.3	71.5	61.7	114.0	73.5	88.3	113.0	80.3	29.9	60.3	67.5	41.7
12	**4**	84.3	114.0	125.0	27.1	60.2	53.9		44.4	73.3	52.0	86.6	47.1	113.0	99.0	57.7	27.6	64.8	72.0	40.0
13	**4**	79.6	66.0	123.0	28.3	46.9	50.5		47.1	88.1	51.6	79.1	43.8	77.6	88.5	49.0	47.2	64.5	71.7	38.4
14	**4**	77.1	49.9	119.0	33.2	43.0	51.9		46.4	88.1	48.0	77.5	48.5	69.5	84.8	43.4	43.2	61.0	69.6	35.6
15	**4**	78.0	46.7	112.0	29.8	54.4	49.4		44.3	97.8	45.4	69.6	41.6	63.6	89.2	45.2	40.6	57.4	66.2	33.0
16	**4**	92.3	46.9	105.0	26.5	46.0	47.0		41.3	110.0	43.9	63.5	40.9	77.3	86.8	81.3	36.6	51.6	64.2	35.0
17	**4**	103.0	55.2	100.0	25.5	38.3	42.7		39.1	100.0	41.4	64.2	45.6	94.2	81.7	116.0	31.5	46.4	61.3	44.4
18	**4**	96.2	58.8	95.3	26.1	42.4	42.0		37.6	84.6	42.0	114.0	44.6	90.6	76.8	74.7	55.1	54.9	71.2	55.7
19	**4**	83.2	57.2	90.8	38.2	42.7	58.4		36.2	69.9	40.3	102.0	43.2	73.0	74.6	53.5	52.5	61.7	81.9	77.7
20	**4**	75.9	48.6	87.6	33.2	68.9	54.5		34.9	63.1	43.0	82.2	37.8	74.1	75.2	44.7	50.7	73.4	80.2	71.8
21	**4**	71.4	47.8	85.5	29.6	48.7	43.8		33.8	60.2	92.3	67.8	37.8	56.5	79.2	40.8	53.5	80.1	88.2	65.2
22	**4**	69.1	46.4	83.7	29.5	39.5	41.4		33.0	51.4	53.1	53.8	37.4	58.4	74.4	38.9	65.1	84.0	86.9	60.3
23	**4**	67.2	43.9	82.2	27.7	51.8	41.8		32.7	53.0	43.0	52.8	36.6	65.6	72.6	37.6	100.0	71.3	83.9	55.4
24	**4**	65.3	41.7	80.9	26.5	41.5	42.0		34.7	47.4	39.1	54.4	35.9	59.1	69.0	39.3	101.0	65.7	79.9	52.8
25	**4**	61.1	39.8	80.1	24.8	36.2	41.5		39.8	45.8	37.3	51.8	33.9	53.6	67.5	38.3	88.6	62.5	87.3	51.2
26	**4**	59.1	39.4	83.2	24.4	32.4	42.2		48.7	68.1	37.9	55.5	32.7	51.5	67.1	39.9	79.3	71.2	84.2	49.0
27	**4**	56.3	38.8	90.3	24.7	32.2	39.3		48.1	71.0	38.6	107.0	35.7	57.0	67.8	38.5	69.8	74.7	80.3	49.7
28	**4**	54.6	37.0	83.2	24.5	31.0	36.3		42.6	66.0	49.0	55.1	34.1	153.0	65.7	36.8	61.4	72.8	78.3	141.0
29	**4**	59.1	36.6	79.0	25.5	29.5	36.2		38.8	71.3	57.5	54.3	37.1	86.8	61.6	35.9	58.3	63.6	82.6	160.0
30	**4**	79.8	36.2	75.9	24.9	29.5	36.4		36.4	76.1	48.4	50.2	32.9	66.1	73.2	34.7	53.9	60.9	74.7	124.0
1	**5**	87.3	39.0	74.1	23.0	32.1	37.9		35.2	72.7	56.8	45.7	32.3	60.3	70.6	33.8	52.1	58.0	68.3	61.7
2	**5**	81.4	41.4	71.3	22.5	34.8	42.8		33.9	65.1	51.3	45.7	32.7	51.1	65.5	33.2	49.4	55.1	66.2	50.8
3	**5**	69.4	39.0	68.9	24.6	30.1	42.4		33.9	57.9	49.5	45.2	31.4	47.5	60.6	34.2	47.2	54.0	66.8	49.1
4	**5**	59.2	36.0	66.0	27.2	29.1	39.4		39.0	53.6	53.5	45.7	30.2	46.5	58.8	34.8	42.9	51.9	66.1	47.3
5	**5**	56.0	34.8	63.9	28.4	28.2	38.2		38.9	50.7	59.7	44.8	29.9	45.9	56.6	34.5	41.0	47.8	66.2	47.0
6	**5**	53.1	33.8	62.6	28.8	26.9	35.8		37.2	50.4	70.3	43.7	28.9	45.4	53.2	40.7	47.2	47.4	65.1	47.3
7	**5**	50.4	32.9	61.9	27.4	26.2	39.3		35.9	51.0	52.8	50.3	28.3	44.6	50.3	34.0	49.3	46.6	64.0	49.1

8	**5**	48.8	31.9	61.1	27.5	25.7	46.0		35.8	50.0	46.1	62.7	28.0	45.2	47.7	31.4	48.0	45.9	63.7	51.0
9	**5**	48.1	31.0	59.8	23.8	26.0	44.1		33.8	52.6	47.8	51.7	28.1	47.3	45.5	30.8	45.5	44.9	63.0	53.4
10	**5**	47.6	30.3	57.6	20.8	25.5	42.4		31.1	50.4	44.8	46.3	27.0	49.7	52.4	33.6	43.7	43.9	61.5	51.9
11	**5**	46.8	32.1	56.2	21.9	24.9	39.2		29.3	47.6	41.5	49.8	27.0	58.8	49.6	30.2	41.6	43.2	61.1	49.9
12	**5**	45.0	39.8	55.5	21.6	24.3	37.1		28.1	45.1	42.8	50.5	26.3	55.0	46.3	28.9	39.9	41.4	60.6	48.6
13	**5**	43.6	39.7	55.3	20.9	24.0	35.0		28.1	43.8	39.4	45.9	26.2	50.8	43.8	28.9	42.9	35.8	59.8	47.0
14	**5**	43.5	33.6	54.7	20.3	23.5	33.4		27.4	43.1	37.2	46.0	25.9	49.7	49.1	31.4	45.0	35.0	58.9	45.0
15	**5**	42.3	31.4	53.6	20.0	24.3	31.6		27.6	43.7	36.3	43.9	26.5	49.1	51.4	41.9	50.2	33.9	59.1	43.3
16	**5**	41.6	31.9	52.9	20.2	26.5	41.8		26.5	41.0	35.5	42.6	28.3	47.2	53.3	37.1	54.1	33.0	57.7	41.6
17	**5**	40.6	32.3	52.0	22.6	26.7	42.7		26.9	40.0	34.5	43.7	27.3	44.0	52.0	34.3	49.8	32.8	54.5	39.8
18	**5**	39.6	31.7	51.7	19.6	32.0	43.3		26.4	39.5	36.7	45.6	26.9	47.0	49.9	30.2	45.6	32.0	53.4	39.8
19	**5**	39.0	30.5	50.4	20.0	28.3	52.2		26.7	39.3	34.0	50.8	25.9	45.0	64.3	28.9	45.1	31.8	52.5	41.6
20	**5**	38.6	32.1	49.6	21.0	25.4	53.4		26.2	40.6	32.4	51.1	26.8	42.5	81.1	28.9	43.2	33.3	52.2	43.0
21	**5**	38.1	31.8	48.2	24.8	25.4	46.0		25.6	39.6	34.0	53.7	34.6	41.5	75.5	30.7	40.1	32.5	50.8	42.3
22	**5**	37.6	28.5	47.0	29.6	25.5	43.5		25.4	39.2	36.3	50.2	29.8	39.7	72.0	37.9	39.0	31.9	49.3	41.8
23	**5**	37.8	28.4	46.1	29.9	25.1	40.8		26.1	41.8	34.0	45.2	26.5	38.5	71.5	35.8	45.8	31.5	48.2	41.4
24	**5**	40.9	30.4	45.4	24.9	24.2	39.2		26.3	40.1	31.9	42.4	25.9	37.2	65.1	30.7	48.7	31.3	48.0	39.2
25	**5**	37.5	37.6	44.4	22.3	22.9	39.8		27.0	40.8	29.9	41.0	26.2	36.3	58.8	29.6	45.1	30.5	48.3	38.2
26	**5**	35.0	34.7	43.4	20.8	22.4	46.2		27.4	40.1	29.7	39.6	29.3	35.8	53.9	29.0	41.8	29.3	51.6	37.6
27	**5**	34.2	29.8	42.7	20.3	22.3	42.9		27.3	39.3	28.2	38.5	46.5	35.8	49.5	27.6	39.7	28.9	50.8	37.4
28	**5**	33.3	28.3	41.8	22.1	21.9	41.2		29.4	37.8	26.5	36.6	55.1	36.1	47.1	26.6	39.0	28.9	49.3	38.8
29	**5**	32.6	27.6	41.0	24.3	21.9	37.7		28.4	36.9	28.6	43.5	39.3	36.1	44.1	26.4	38.7	29.6	48.8	39.0
30	**5**	35.5	27.6	40.0	26.4	22.3	38.9		27.7	35.2	30.0	42.8	33.3	37.8	43.7	25.9	38.5	30.0	48.6	38.6
31	**5**	34.9	27.9	39.1	27.5	22.3	49.8		27.6	35.5	31.9	35.8	35.2	38.0	43.4	26.1	38.2	29.9	48.0	38.0
1	**6**	33.8	27.9	38.6	24.0	21.5	51.7		26.3	34.7	35.4	33.8	38.3	36.9	41.3	25.5	39.0	29.3	47.1	36.7
2	**6**	32.5	28.2	38.2	22.3	21.0	44.8		25.0	33.0	31.7	33.0	29.3	35.2	39.7	25.1	43.9	28.9	46.4	35.2
3	**6**	31.4	29.7	38.0	21.1	20.8	42.3		24.4	31.9	28.8	32.6	26.3	35.5	39.1	25.4	43.7	28.7	45.6	34.0
4	**6**	30.2	31.2	37.7	20.3	20.1	38.9		25.7	31.0	28.9	33.0	25.5	35.3	37.4	25.3	42.3	28.0	45.9	33.7
5	**6**	30.0	38.0	37.6	19.7	19.7	37.0		24.9	30.1	28.0	32.2	24.6	35.8	36.9	25.7	41.0	27.4	45.4	33.3
6	**6**	30.0	36.6	37.5	19.3	19.4	35.0		26.3	30.0	27.5	32.4	24.2	40.0	38.4	27.1	39.6	26.5	44.5	32.5
7	**6**	29.8	33.1	37.2	19.3	19.1	33.5		32.2	29.6	28.9	30.4	24.4	45.1	45.5	26.6	39.0	25.6	44.0	32.3
8	**6**	30.3	28.8	37.1	19.4	18.8	31.0		34.0	29.3	29.4	29.9	23.6	51.2	41.1	26.5	38.0	25.2	45.0	31.4

9	**6**	30.1	27.2	36.7	18.7	18.8	33.2		30.4	29.3	31.6	29.4	22.8	56.2	38.2	27.9	36.9	24.9	46.6	30.5
10	**6**	30.0	26.8	36.1	18.2	18.5	32.5		28.7	30.4	28.3	30.1	22.4	60.7	39.1	27.7	36.7	26.5	49.1	29.4
11	**6**	29.6	27.0	35.3	17.9	18.3	31.7		30.3	33.9	31.2	31.0	22.1	61.1	42.1	28.3	36.5	28.3	50.8	29.2
12	**6**	28.8	28.6	34.8	17.8	18.5	30.5		33.5	37.8	29.6	29.3	21.8	54.1	44.7	29.2	35.0	30.3	52.3	28.7
13	**6**	28.4	30.8	34.3	18.2	19.4	31.8		33.7	36.5	33.4	28.3	21.6	43.9	48.3	29.8	34.7	33.8	53.8	27.8
14	**6**	28.9	27.4	33.8	20.9	24.4	30.2		29.0	31.6	30.2	29.7	21.7	41.2	50.0	28.8	34.2	34.6	56.6	28.2
15	**6**	29.8	26.4	33.3	26.2	23.2	29.3		33.0	32.3	27.7	30.2	21.5	38.5	46.5	27.9	33.0	33.9	59.1	28.4
16	**6**	29.2	26.9	33.0	35.2	20.6	28.9		29.5	30.5	28.7	30.9	21.2	36.3	44.5	27.0	32.4	33.3	59.9	29.3
17	**6**	28.3	27.9	32.8	71.0	19.6	29.0		34.5	28.9	30.2	30.2	20.9	32.7	54.6	25.5	31.9	32.8	59.5	30.8
18	**6**	27.5	27.0	32.5	77.2	19.6	27.9		42.3	30.2	32.7	36.3	20.7	30.7	78.0	26.0	31.0	31.9	53.5	33.3
19	**6**	26.9	26.6	32.3	74.9	19.4	26.9		35.4	27.6	33.0	37.2	20.9	29.0	47.9	29.0	30.1	31.1	52.9	34.0
20	**6**	26.5	25.6	32.0	58.5	18.9	26.5		29.9	26.8	28.7	41.3	21.4	27.6	41.7	28.9	30.2	31.0	52.3	37.9
21	**6**	26.2	24.6	31.8	41.1	18.8	28.0		26.9	26.3	26.3	37.2	21.5	37.9	37.1	28.6	31.9	33.9	50.9	38.2
22	**6**	26.1	24.1	31.5	29.2	21.5	28.0		26.2	26.2	25.2	30.4	22.5	34.6	43.2	27.6	33.9	35.0	50.0	38.6
23	**6**	25.3	24.0	31.4	26.7	36.7	26.4		25.8	25.8	28.9	30.6	29.7	38.8	51.5	27.1	35.6	36.8	47.9	41.0
24	**6**	25.5	24.2	31.1	26.1	24.1	25.5		25.5	25.2	46.5	32.6	28.6	51.3	62.7	26.5	33.5	36.7	47.0	40.0
25	**6**	28.7	24.0	30.9	24.8	20.4	24.8	36.9	25.0	24.9	50.6	32.8	27.6	42.7	86.9	26.2	29.7	36.2	47.2	38.7
26	**6**	29.1	25.8	30.1	23.8	20.9	25.3	35.6	23.2	24.6	51.6	32.4	25.6	36.7	71.6	26.3	28.7	35.7	53.5	38.0
27	**6**	8.3	27.6	30.0	22.2	20.3	25.0	33.9	22.5	24.2	42.5	34.3	25.0	33.0	61.2	26.9	27.4	34.8	53.5	36.8
28	**6**	27.5	25.3	29.7	23.8	21.1	24.9	32.4	22.4	23.7	38.9	33.2	22.0	30.0	49.2	26.7	25.4	33.9	52.0	36.1
29	**6**	26.8	26.3	30.7	24.8	22.9	24.7	31.2	22.4	25.8	34.0	31.2	21.8	28.5	44.2	27.3	24.6	33.3	50.9	34.9
30	**6**	26.2	40.2	36.9	23.5	23.6	24.8	30.3	22.3	30.8	33.2	30.1	22.6	27.3	71.3	26.9	24.3	32.5	47.3	34.2
1	**7**	25.5	60.1	34.3	22.2	23.0	24.7	29.3	21.9	29.8	33.5	29.9	28.8	29.2	53.0	26.5	24.7	32.0	45.0	33.4
2	**7**	24.9	77.8	32.9	22.9	28.1	24.6	29.6	21.7	27.2	27.4	29.2	36.6	29.0	45.8	25.8	29.0	31.8	43.7	32.8
3	**7**	24.0	67.9	31.9	22.5	27.2	23.5	30.0	21.4	28.7	26.8	28.2	32.7	26.3	41.5	25.4	32.3	31.4	41.8	32.0
4	**7**	23.1	48.0	30.6	21.4	23.2	24.6	33.2	21.8	29.8	25.9	26.3	26.3	25.2	38.6	28.8	34.7	30.7	42.1	31.4
5	**7**	24.5	39.5	29.8	20.5	20.5	24.4	30.3	22.8	29.2	25.2	25.4	26.0	25.6	47.9	48.6	35.6	31.2	50.6	30.5
6	**7**	35.4	36.4	28.4	20.4	19.4	23.1	29.0	23.7	26.6	24.8	25.8	25.1	25.8	42.3	60.6	33.2	31.3	58.9	29.7
7	**7**	29.5	35.1	30.0	21.0	19.2	22.7	28.6	23.1	26.1	25.6	27.6	23.1	25.5	38.1	64.2	31.8	32.7	81.1	29.3
8	**7**	25.1	35.0	31.9	20.3	20.8	23.7	28.2	22.9	25.7	26.6	25.9	22.1	24.6	35.8	50.6	30.1	33.3	70.7	29.2
9	**7**	24.6	31.5	31.1	21.4	19.8	23.4	28.6	22.4	26.0	24.8	26.0	23.0	26.5	34.4	40.5	29.2	33.7	67.7	29.2
10	**7**	24.2	29.9	30.5	27.5	17.6	24.5	29.0	22.9	25.0	22.1	28.5	23.6	54.1	33.7	37.1	28.2	33.9	66.6	28.8

11	**7**	23.2	29.7	30.3	27.5	18.4	33.2	29.8	29.8	24.3	21.9	40.7	22.1	51.9	32.9	31.6	26.7	34.3	65.7	28.4
12	**7**	22.9	36.2	31.6	22.4	18.9	33.5	31.5	36.2	23.6	27.5	77.2	21.8	48.3	33.7	26.8	26.4	35.2	64.5	28.2
13	**7**	22.2	33.3	31.0	23.2	20.0	30.1	31.4	39.4	23.0	30.8	52.2	21.9	36.4	31.7	24.4	25.6	38.2	63.1	27.5
14	**7**	21.8	31.4	30.2	25.7	20.5	26.9	34.7	42.5	25.6	27.2	37.0	20.9	28.6	33.5	23.1	24.9	39.3	61.3	26.9
15	**7**	21.5	31.8	30.3	27.3	18.9	24.2	32.2	47.6	44.9	25.3	30.6	19.9	27.0	34.2	22.4	24.3	41.3	60.1	26.5
16	**7**	21.4	31.4	29.2	22.8	17.8	23.1	29.2	38.6	49.7	26.8	28.9	20.2	27.5	34.0	22.1	24.3	41.0	59.9	25.9
17	**7**	22.5	28.3	27.9	21.3	20.5	22.9	28.6	33.3	45.0	41.6	30.4	21.6	27.3	38.7	22.0	33.3	40.0	59.7	25.5
18	**7**	22.4	26.9	26.3	20.1	29.8	22.4	28.5	30.6	40.7	39.0	41.1	23.5	26.0	42.8	25.3	54.8	38.7	58.6	25.2
19	**7**	21.8	26.2	25.5	19.7	36.7	21.9	28.1	26.7	42.7	30.9	32.8	22.7	25.2	38.5	29.3	48.5	38.1	57.1	25.2
20	**7**	21.5	25.6	24.7	19.1	35.1	21.9	27.4	25.5	42.6	28.2	29.2	23.1	24.8	39.0	29.2	37.2	37.6	54.4	24.9
21	**7**	21.2	25.2	24.3	18.7	64.3	22.3	27.1	24.9	58.3	28.0	27.3	23.7	26.4	37.8	28.1	34.3	36.8	53.0	24.6
22	**7**	20.8	25.0	23.6	18.2	79.7	21.8	26.8	24.6	67.5	26.5	28.0	22.7	28.7	35.0	26.0	33.7	36.1	51.6	24.5
23	**7**	21.4	25.2	23.3	17.8	55.5	21.5	26.5	26.4	73.5	26.0	27.4	26.3	28.9	34.1	25.2	37.3	35.2	49.0	25.5
24	**7**	21.2	25.1	24.5	17.6	40.4	20.9	26.5	29.1	81.3	24.3	26.7	49.7	28.0	33.5	24.4	37.1	34.7	48.0	26.5
25	**7**	20.6	24.0	25.0	17.9	48.0	20.1	26.2	29.8	85.2	22.9	29.3	66.2	26.9	36.4	24.0	38.3	36.5	46.5	27.3
26	**7**	20.6	23.1	24.3	17.9	51.7	20.6	27.5	47.2	92.6	22.9	32.4	47.1	26.6	40.9	24.0	38.0	37.3	45.0	26.5
27	**7**	23.6	23.0	23.4	19.5	48.8	24.1	35.2	42.4	92.4	22.5	30.6	35.6	63.0	43.0	23.7	36.6	36.3	43.8	25.8
28	**7**	23.0	22.9	22.7	31.8	37.2	25.2	37.6	36.8	79.0	22.3	31.1	32.2	72.7	44.5	23.9	35.0	35.4	42.6	24.9
29	**7**	21.5	22.5	22.6	26.4	30.7	27.7	36.0	57.5	48.6	22.3	30.1	34.9	47.5	43.5	23.6	34.4	35.5	41.2	24.3
30	**7**	19.9	23.1	24.6	21.3	31.1	31.7	33.1	64.6	41.1	24.6	30.2	40.1	34.3	37.8	23.3	34.2	34.8	40.0	24.3
31	**7**	19.5	25.6	30.0	19.2	46.6	48.0	31.1	68.5	62.0	23.9	33.2	33.0	33.5	34.4	23.2	33.9	33.8	38.7	25.6
1	**8**	19.9	24.9	32.0	18.2	71.8	52.5	30.1	68.3	86.7	23.7	33.1	25.3	38.1	32.4	22.5	33.6	33.0	38.0	25.7
2	**8**	19.7	24.0	28.7	17.6	48.0	49.3	30.5	64.2	84.0	22.3	33.2	22.7	35.9	33.2	22.6	31.9	32.4	36.7	25.2
3	**8**	19.2	24.5	28.8	17.4	34.7	32.1	32.4	78.0	74.8	21.6	30.8	24.2	33.3	35.8	25.1	30.0	31.9	35.2	24.3
4	**8**	19.2	21.9	25.6	17.3	30.2	25.1	35.6	135.0	60.7	21.5	32.2	24.0	28.5	32.4	25.9	28.3	31.4	34.0	23.4
5	**8**	20.6	21.1	24.0	17.5	28.0	23.4	37.8	125.0	51.2	20.3	30.3	23.0	26.8	29.1	26.5	26.4	31.0	33.7	23.3
6	**8**	24.9	20.4	23.1	17.9	26.6	24.4	35.5	85.6	47.3	20.6	28.9	22.1	26.8	26.9	27.2	25.5	33.6	33.3	23.0
7	**8**	25.7	20.1	22.5	17.4	27.2	23.2	29.6	63.8	42.9	21.3	27.4	21.5	37.3	25.8	25.9	24.7	35.8	32.4	22.4
8	**8**	23.0	20.8	22.4	16.7	34.2	22.9	26.9	55.2	39.8	20.9	33.2	20.9	60.4	40.3	25.2	24.6	38.4	33.0	21.9
9	**8**	21.2	24.1	22.4	16.5	42.3	22.7	25.5	59.5	39.1	20.9	42.6	20.5	65.9	37.2	24.6	24.6	39.6	41.9	21.8
10	**8**	19.8	26.5	22.1	16.3	35.4	26.4	23.9	57.7	42.4	25.3	38.3	20.7	68.6	32.1	24.3	24.3	40.8	44.1	22.0
11	**8**	19.1	30.0	21.8	16.0	29.8	22.3	23.8	64.9	61.2	24.5	31.0	20.1	72.1	32.5	24.0	23.9	40.1	46.9	22.9

12	**8**	18.5	40.1	21.6	15.9	28.9	20.3	23.5	56.2	55.9	21.1	29.6	19.7	74.9	29.7	23.6	23.1	39.4	49.1	23.2
13	**8**	18.1	46.4	22.1	15.7	32.9	22.2	23.5	43.8	45.9	22.5	29.5	19.4	80.2	27.8	23.0	22.5	38.2	50.8	22.6
14	**8**	17.4	46.5	22.9	15.6	43.9	30.2	23.8	43.0	42.5	24.8	32.9	19.1	81.2	28.9	22.2	22.4	37.6	51.8	21.1
15	**8**	17.0	84.5	23.2	15.4	57.2	29.2	23.8	39.7	45.4	24.2	34.6	18.8	75.9	27.3	21.8	22.1	37.1	49.3	20.7
16	**8**	16.8	85.6	22.9	15.8	71.1	26.8	23.2	37.4	51.2	21.0	33.6	18.8	71.2	27.2	21.5	21.8	37.9	47.1	22.4
17	**8**	16.7	60.8	21.7	15.6	52.2	27.9	23.2	36.5	57.0	19.7	29.4	18.8	69.0	28.0	21.2	21.8	35.2	45.3	22.4
18	**8**	16.8	43.2	21.2	15.4	39.5	28.5	24.2	34.8	98.5	18.9	30.4	19.0	53.1	28.9	20.9	21.7	33.8	42.7	22.8
19	**8**	17.2	36.6	21.4	15.7	34.1	25.3	23.0	33.1	126.0	18.4	26.7	20.4	45.4	36.0	20.3	20.9	33.0	40.0	24.8
20	**8**	18.3	36.6	22.7	15.4	31.8	25.0	22.6	32.4	135.0	17.5	24.8	20.8	42.1	51.0	19.7	20.3	32.3	37.8	24.9
21	**8**	18.2	34.2	22.6	15.2	31.6	22.7	23.4	32.0	84.6	21.7	24.3	20.3	41.2	61.6	19.4	20.0	31.5	36.4	24.6
22	**8**	17.8	32.5	21.8	15.0	30.5	21.4	22.9	31.9	74.2	39.9	30.8	19.4	53.5	90.4	19.2	19.7	31.0	33.6	24.6
23	**8**	17.1	38.0	20.8	15.1	33.8	20.4	22.8	31.6	64.5	54.5	34.5	18.6	53.0	67.8	19.7	19.4	30.6	32.3	24.3
24	**8**	16.7	36.2	19.6	16.0	52.5	21.5	22.3	29.5	57.6	39.4	35.2	18.2	49.5	51.4	20.3	19.3	30.4	33.0	24.3
25	**8**	16.6	33.0	19.1	16.0	86.2	21.1	22.0	28.7	53.5	39.6	37.8	17.9	44.8	43.5	20.9	18.8	30.1	29.7	24.3
26	**8**	16.4	30.6	18.6	15.4	79.6	19.8	21.7	27.7	54.6	49.0	68.1	17.9	46.4	38.4	21.6	18.5	30.0	28.3	24.0
27	**8**	16.0	31.0	18.5	15.3	53.8	20.6	21.4	27.5	48.6	43.0	90.9	17.6	82.0	35.6	20.9	18.0	29.7	27.5	24.0
28	**8**	16.1	27.3	18.4	15.2	46.4	20.0	21.5	27.1	44.9	35.9	79.2	17.3	79.1	34.2	20.1	17.9	29.6	26.8	24.2
29	**8**	18.0	25.8	17.9	14.9	44.8	19.5	23.9	26.8	44.7	28.3	87.2	17.0	52.9	32.8	19.7	17.6	29.6	26.2	24.0
30	**8**	18.8	25.0	17.5	14.2	43.0	19.4	27.1	26.8	46.0	25.7	118.0	17.0	41.1	30.7	19.4	17.3	29.3	25.6	23.9
31	**8**	18.9	24.6	18.3	14.2	42.2	19.3	25.6	26.5	60.0	26.6	92.9	16.8	41.2	28.8	18.8	17.1	29.3	25.7	23.5
1	**9**	18.1	24.2	17.9	13.8	38.6	18.8	24.9	26.4	72.3	25.1	67.5	16.8	39.7	27.4	18.3	17.3	29.6	25.5	24.2
2	**9**	17.7	23.4	17.6	13.6	35.2	18.5	24.3	25.8	58.7	23.9	54.4	16.6	38.7	26.3	18.2	17.3	30.4	24.9	24.3
3	**9**	16.5	22.7	17.1	13.5	34.4	18.2	24.3	25.3	55.4	22.5	48.7	16.5	36.0	25.5	18.2	17.3	33.1	24.3	24.0
4	**9**	16.1	22.1	17.0	13.3	37.3	18.0	23.5	25.8	50.7	21.4	44.0	16.6	34.8	25.5	18.4	17.6	34.5	24.0	23.4
5	**9**	20.7	21.8	16.8	13.3	38.6	18.4	22.7	29.6	50.6	21.4	41.3	17.1	33.8	24.8	21.4	17.8	33.9	23.8	23.0
6	**9**	43.9	21.4	16.6	13.2	38.3	18.3	21.8	30.9	65.9	20.9	42.2	18.2	32.4	24.5	24.1	17.4	33.3	22.6	22.7
7	**9**	33.7	20.3	16.4	13.3	42.7	17.4	21.1	26.2	63.1	20.3	41.1	22.1	31.1	24.0	25.7	17.3	33.0	22.1	22.4
8	**9**	22.8	20.8	16.2	15.1	35.8	18.4	19.7	26.0	46.8	21.7	40.5	27.8	30.0	25.2	26.5	17.0	32.8	22.0	22.4
9	**9**	19.0	24.0	16.0	14.3	32.4	18.5	18.9	34.8	41.1	22.8	45.1	23.8	29.3	38.2	27.2	16.8	32.3	21.5	22.1
10	**9**	17.2	41.6	16.0	13.5	30.3	17.2	18.9	44.3	42.9	22.4	45.2	19.6	28.8	41.2	28.4	16.8	31.4	21.2	22.1
11	**9**	16.4	28.7	15.8	13.4	29.4	17.0	19.8	51.2	41.5	22.4	45.1	16.9	28.3	37.1	30.4	16.8	30.6	20.9	21.8
12	**9**	16.0	27.3	15.8	13.0	27.9	16.7	22.0	59.3	47.4	27.7	40.0	16.2	27.9	33.5	34.6	17.5	30.4	20.4	21.5

13	**9**	15.7	39.8	15.8	13.0	26.3	16.6	21.1	46.0	51.2	38.3	37.1	15.8	27.5	29.8	37.5	17.9	30.0	20.3	21.5
14	**9**	16.1	28.1	15.6	13.8	25.6	16.3	20.5	38.9	59.5	26.0	34.9	15.6	26.8	27.0	36.8	18.2	29.4	20.0	21.3
15	**9**	16.0	30.2	15.6	15.5	25.5	16.2	20.1	61.0	65.2	19.9	33.0	15.2	26.2	25.4	36.0	18.8	29.6	19.4	21.5
16	**9**	16.0	26.2	15.4	18.3	25.6	16.0	20.4	127.0	62.8	19.8	32.2	15.0	25.6	24.6	34.0	19.4	30.0	19.1	21.9
17	**9**	16.0	25.8	15.6	24.9	24.7	16.0	19.7	118.0	61.1	19.4	33.8	14.8	25.2	24.1	33.2	19.6	30.6	18.8	22.8
18	**9**	16.2	24.6	17.2	22.9	24.2	15.8	19.1	78.5	59.5	18.8	40.2	14.6	25.9	23.6	31.9	19.4	31.6	18.8	24.3
19	**9**	16.4	28.1	20.8	17.6	23.1	15.7	19.1	54.8	58.4	18.4	41.8	14.4	32.4	23.2	30.5	18.9	33.1	18.8	25.5
20	**9**	15.7	28.6	21.5	19.0	22.8	16.0	18.9	45.2	56.8	19.0	40.2	14.2	38.0	22.6	28.9	18.7	30.5	18.5	26.5
21	**9**	15.1	30.2	18.2	19.7	22.9	16.2	24.0	39.7	56.8	21.0	39.5	14.2	34.5	22.3	27.7	18.2	27.8	18.2	27.5
22	**9**	15.1	31.8	16.5	17.8	22.4	16.5	21.6	35.9	44.4	21.4	40.3	14.0	28.6	22.1	27.4	17.9	26.4	18.2	28.0
23	**9**	15.5	27.1	15.6	15.9	21.8	16.3	19.5	34.0	39.3	19.0	46.7	14.0	26.4	21.5	26.5	17.9	24.5	17.9	26.5
24	**9**	15.1	23.6	15.6	14.6	21.7	16.2	18.8	33.7	35.3	17.7	43.4	13.8	25.8	22.2	25.3	17.9	23.3	17.6	24.3
25	**9**	15.0	22.2	15.5	13.9	27.1	16.7	18.5	35.2	33.8	17.1	43.5	13.8	25.5	22.2	24.3	17.6	22.5	17.6	22.3
26	**9**	14.8	21.5	15.0	14.1	46.2	19.5	18.4	34.0	33.3	17.0	36.8	13.6	24.9	21.8	23.9	17.6	22.4	18.8	21.5
27	**9**	14.4	21.2	14.6	14.7	54.8	19.5	17.5	33.2	34.5	16.6	32.6	13.6	24.3	21.4	24.7	17.6	22.1	18.8	20.9
28	**9**	14.0	23.1	14.4	17.6	36.9	19.3	17.4	32.1	34.2	16.2	32.4	13.4	23.7	21.1	24.6	17.6	22.1	18.5	20.6
29	**9**	13.8	25.8	14.3	16.9	27.4	18.6	17.2	31.8	33.4	16.0	30.3	13.4	23.3	20.5	24.1	17.3	21.8	18.8	20.3
30	**9**	13.4	25.7	14.4	17.0	24.3	16.9	17.9	28.7	33.5	17.1	28.7	13.2	22.5	21.1	23.9	17.0	21.2	21.2	20.5
1	**10**	13.0	22.8	14.2	14.4	23.0	16.6	18.3	27.6	30.8	17.8	28.0	13.2	21.3	23.4	23.6	16.8	20.7	20.3	23.9
2	**10**	11.7	21.5	14.0	13.8	22.9	16.0	17.4	26.5	29.2	16.7	26.9	13.0	20.1	26.7	23.3	16.6	19.7	19.0	28.2
3	**10**	11.5	20.7	13.8	13.8	22.2	15.8	17.1	26.3	28.0	16.4	26.4	12.9	21.0	30.7	23.2	16.6	19.3	17.9	23.8
4	**10**	11.4	20.8	13.6	13.7	21.8	19.4	17.0	25.9	27.3	16.6	26.2	12.7	22.5	23.8	22.8	16.4	19.0	17.1	21.4
5	**10**	11.2	22.4	13.6	13.1	20.6	17.4	16.8	24.8	28.1	15.9	25.5	12.7	22.2	22.4	22.7	16.2	18.9	16.6	20.8
6	**10**	11.2	23.7	14.1	13.0	20.7	16.0	16.8	25.5	27.6	15.9	25.4	12.9	22.1	21.4	22.5	16.2	18.3	16.2	19.3
7	**10**	11.1	21.8	16.0	12.8	21.1	15.3	16.7	33.1	37.2	15.5	24.1	13.6	21.7	19.6	22.4	16.1	17.5	15.8	18.7
8	**10**	11.1	21.1	16.7	12.8	20.3	14.9	16.7	47.0	39.4	14.8	27.7	16.3	21.0	18.8	22.1	16.4	17.0	15.6	17.9
9	**10**	10.9	20.1	17.5	12.8	20.2	15.3	16.5	45.6	31.3	16.2	29.0	16.0	19.9	18.2	21.8	17.3	16.8	15.4	17.3
10	**10**	10.8	19.4	16.3	13.7	21.3	15.2	16.5	77.8	28.2	15.9	24.7	15.2	19.7	17.9	21.7	18.3	16.4	15.6	17.3
11	**10**	10.5	18.8	15.1	15.7	24.5	14.7	16.5	73.0	26.2	15.5	29.6	14.6	20.0	17.6	21.2	18.2	16.2	17.0	17.5
12	**10**	10.3	18.3	14.6	16.8	20.5	14.5	16.5	51.6	27.5	14.7	33.1	14.3	20.0	17.6	21.0	18.2	16.0	19.6	19.5
13	**10**	10.2	18.4	14.4	20.8	19.0	14.1	16.3	43.6	36.9	14.6	37.8	14.3	19.4	17.4	20.3	17.7	15.8	20.2	23.4
14	**10**	10.0	19.3	14.2	16.6	18.8	16.0	16.8	44.0	40.3	14.5	46.3	15.4	18.8	17.3	19.5	18.9	15.6	19.2	23.8

15	**10**	9.9	19.8	14.0	14.5	18.2	39.2	22.9	48.9	44.3	14.4	39.4	21.3	18.0	17.1	19.0	19.1	15.4	17.1	21.1
16	**10**	10.5	18.8	14.1	14.4	18.0	29.5	21.6	43.6	38.5	14.3	74.5	42.5	17.9	17.0	18.4	19.1	15.2	15.7	18.8
17	**10**	14.2	17.8	14.3	13.3	18.0	22.2	18.0	35.6	32.7	16.0	52.1	36.5	17.6	16.9	20.6	19.5	15.0	15.0	17.1
18	**10**	14.0	18.1	14.2	12.7	18.3	19.2	16.1	35.1	30.4	20.0	36.0	28.0	17.3	16.8	54.1	20.0	16.1	14.7	16.0
19	**10**	16.1	21.5	14.1	13.1	28.1	22.1	16.0	31.0	27.5	21.8	33.8	23.2	17.0	18.4	33.7	20.3	22.0	15.1	15.1
20	**10**	16.2	23.0	15.5	13.5	26.4	17.6	16.0	35.8	33.4	18.8	29.5	20.1	16.6	21.0	24.3	19.8	27.0	17.4	14.8
21	**10**	14.3	24.9	21.4	13.8	22.2	16.8	16.0	29.6	31.7	16.8	27.7	17.8	16.4	22.3	22.1	19.3	20.7	22.2	14.4
22	**10**	14.8	43.8	21.8	13.4	19.9	15.5	15.5	27.4	28.3	18.1	27.9	16.7	16.2	21.4	21.3	18.7	17.8	25.8	14.2
23	**10**	13.6	33.1	21.2	12.7	19.7	14.7	15.0	26.6	29.0	17.2	26.8	16.5	16.2	19.6	21.0	18.5	16.8	31.3	14.0
24	**10**	13.2	43.5	20.6	12.4	18.4	19.1	14.7	24.1	34.6	16.2	25.2	19.1	17.0	18.2	20.3	18.2	16.4	54.8	13.6
25	**10**	12.9	29.0	20.0	12.4	17.8	15.1	14.2	23.7	30.5	16.4	23.0	21.7	21.5	17.9	19.7	17.8	16.0	37.3	13.5
26	**10**	13.0	29.0	19.3	12.4	16.8	16.8	14.1	23.6	30.6	16.8	20.2	20.0	24.4	18.3	19.1	17.6	15.8	26.3	14.7
27	**10**	14.1	26.4	17.7	12.3	16.6	17.4	15.4	23.6	25.2	15.6	21.4	17.5	20.8	18.2	19.1	18.2	15.4	22.6	20.0
28	**10**	12.7	24.7	16.7	12.0	16.3	15.9	15.4	23.1	23.6	14.7	27.1	16.0	18.7	17.9	18.6	18.2	15.2	21.9	25.3
29	**10**	11.8	28.8	16.2	11.9	16.1	15.2	15.1	25.2	22.9	14.1	33.9	15.1	17.7	17.6	18.2	18.7	14.8	21.1	25.4
30	**10**	11.6	27.6	15.5	11.7	15.7	14.3	15.0	32.3	22.3	14.1	40.5	14.5	17.5	17.2	17.9	28.6	14.6	26.9	23.9
31	**10**	11.6	29.5	15.0	11.5	15.6	14.5	22.9	29.9	22.2	13.8	48.6	14.3	17.3	16.9	18.4	26.7	14.6	33.8	#N/A