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ESMAP
Energy Sector Management Assistance Program

Small Hydro Resource Mapping in Madagascar

SITE INVESTIGATION REPORT

[ENGLISH VERSION]

May 2016

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

It is one of several outputs from the small hydro resource mapping component of the activity " Renewable Energy Resource Mapping and Geospatial Planning – Madagascar" [Project ID: P145350]. This activity is funded and supported by the Energy Sector Management Assistance Program (ESMAP), a multi-donor trust fund administered by The World Bank, under a global initiative on Renewable Energy Resource Mapping. Further details on the initiative can be obtained from the ESMAP website.

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.

Phase 2 – Ground Based Data Collection

SITE INVESTIGATION REPORT

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

May 2016

English Version

IN ASSOCIATION WITH

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 prioritisation 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 resources atlas that combine 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 Hydropower Hydro Planning and Mapping Reports for Madagascar

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Abbreviations and acronyms

ADEME	Agence de Maîtrise de l'Energie
ADER	Agence de Développement de l'Electrification Rurale
AO	Appel d'Offre
APD	Avant-Projet Détaillé
APIPA	Autorité pour la Protection contre les Inondations de la Plaine d'Antananarivo
APS	Avant-Projet Sommaire
BAD	Banque Africaine de Développement
BDHM	Banque de Données Hydro pluviométriques de Madagascar
BEI	Banque Européenne d'Investissement
BM	Banque Mondiale
BRGM	Bureau de Recherches Géologiques et Minières
CIRAD	Centre International de Recherche pour l'Agriculture et Développement
DGE	Direction de l'Energie
DGM	Direction Générale de la Météorologie
DGRE	Direction de la Gestion des Ressources en Eau
EDM	Electricité de Madagascar
ENR	ENergie Renouvelable
ERD	Electrification Rurale Décentralisée
ESF	Electriciens Sans frontières
ESMAP	Energy Sector Management Assistance Program
EU	European Union
FAD	Fonds Africains de Développement
FMO	Société néerlandaise pour le financement du développement
FONDEM	Fondation Energies pour le Monde
FTM	FOIBEN-TAOSARINTANIN'I MADAGASIKARA
FWC	Framework Contract
GES	Gaz à Effet de Serre
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GRDC	Global Runoff Data Centre
GRET	Groupe de Recherche et d'Echanges Technologiques
GTE	Groupe de Travail Energie
GTZ/GIZ	Deutsche Gesellschaft für Technische / Internationale Zusammenarbeit GmbH)
GVEP	Global Village Energy Partnership
GWh	Giga Watt heure, Milliards de kWh ou Millions de MW
HFF	Henri Fraise & Fils (société)
IED	Innovation Energie Développement
IEPF	Institut de l'Energie et de l'Environnement de la Francophonie
INSTAT	Institut National de la Statistique
IPP's	Independent Power Producer's
IRENA	International Renewable Energy Agency
JICA	Japan International Cooperation 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
MAP	Madagascar Action Plan
MdE	Ministère de l'Energie
MDE	Maîtrise De l'Energie
MGA	Malagasy Ariary
MIGA	Multilateral Investment Guarantee Agency
MNT	Modèle numérique de terrain
MW	Mega Watt
MWh	Mega Watt heure
NEPAD	NEw Partnership for Africa's Development
NOAA	National Oceanic and Atmospheric Administration
ONE	Office National de l'Environnement
ONG	Organisation Non Gouvernementale
ORE	Office de Régulation de l'Electricité
ORSTOM	Office de la recherche scientifique et technique outre-mer
PADR	Plan d'Action pour le Développement Rural
PAH	Petit Aménagement Hydroélectrique
PIC	Projet Pôles Intégrés de Croissance
PNUD	Programme des Nations Unies pour le Développement
PPP	Partenariat Public Privé
PV	Solaire Photovoltaïque
RFE	Rainfall estimates
RIAED	Réseau International d'Accès aux Energies Renouvelables
RTA	Rio Tinto Alcan
SAPM	Système des Aires Protégées de Madagascar
SE	Système Electrique
SFI	Société Financière Internationale
SIG	Système d'Information Géographique
SNAT	Stratégie Nationale d'Aménagement du Territoire
TWh	Tera Watt heure
WB	World Bank
WWF	World Wildlife Fund

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Introduction

Introduction

1.1 Background information of the ESMAP framework

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 as an initiative to support the efforts of countries to improve knowledge of their renewable energy resources (REN), to establish appropriate institutional frameworks for the development of REN, and to provide "free access" to geospatial resources and data. This initiative will also support the IRENA-GlobalAtlas[1] program by improving data availability and quality, through an interactive atlas.

This study, "Renewable Energy Resource Mapping: Small Hydro Madagascar", is part of a technical assistance project funded by ESMAP and 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.

1.2 Objectives, results and activities of the study

The objectives of the study are:

1. Improving the quality and availability of information about the hydropower resource in Madagascar;
2. A detailed review and update of Madagascar's small hydro potential (1-20 MW), and
3. Recommendations for implementation of small hydro within the framework of energy sector planning.

Expected results from the study are:

1. A geographical database (GIS) of data from the study;
2. A thematic atlas on hydropower in Madagascar with a particular emphasis on small hydro, and
3. Recommendations for developing the small hydro sector in Madagascar.

The three phases of the ESMAP study are:

PHASE 1: Preliminary resource mapping based on satellite and site visits.

PHASE 2: Ground-based data collection.

PHASE 3: Production of validated resource atlas that combines satellite and ground-based data.

[1] http://globalatlas.irena.org/

In the context of this study in Madagascar, those three phases have been broken down into four 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: Ground-based data collection and final validation (HydroAtlas update / hydrological measurements campaign / site investigations for surface geology and socio-economic aspects).

1.3 OBJECTIVES AND LIMITS OF THE REPORT

The Site Investigation Report is delivered in the frame of PHASE 2 (Ground-based data collection) and aims at providing an overview, at reconnaissance level, of the 17 most promising potential small hydropower sites in Madagascar. The selection process for those 17 sites has been carried out during PHASE 1 and results have been validated during the workshop held in Antananarivo in June 2015 at the Ministry of Energy and Hydrocarbons premises.

This selection of the 17 sites is the result of a complex spatial planning exercise based notably on economic, environmental and energy supply/demand balancing criterion. It constitutes the list of priority sites for the short-term development of small hydropower in Madagascar. Of these 17 sites, three (3) have been recommended for the development of remote areas and three (3) other sites come from potential sites previously studied a more or less advanced stage (up to feasibility level) and/or planned in the energy sector development plans by the Ministry of Energy (after site visits of eight potential sites that met the criterion established during Phase 1).

The selection process highlighting the origin of the selected 17 potential hydropower sites is illustrated in Figure 1 and their localization is illustrated in Figure 2 hereafter.

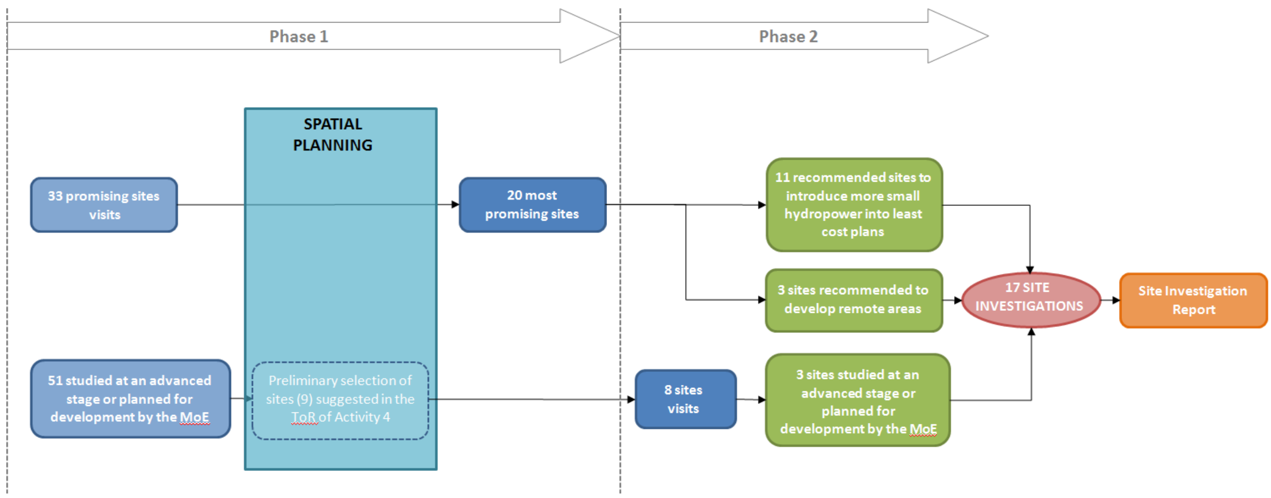

Figure 1. Diagram showing the selection process of the 17 potential small hydropower sites

The findings presented in this report are based on high level technical site investigations that include site visits, topographical surveys (based on the processing of ortho-photogrammetric images acquired by a light airplane), characterization of the surface geology and socio-economic environment and a regional desk-based hydrological study. All the parameters, information, data and recommendations presented in this report are indicative only. They are not intended to be used for design purposes and will need to be confirmed and further analyzed at prefeasibility, feasibility and design stages.

SHER makes its best efforts to ensure that the information presented in this document is reliable and correct. However, SHER does not assume any liability for damage or loss directly or indirectly caused in the misuse or misinterpretation of the data, information or recommendations presented in this report.

Figure 2. Localization map of the 17 potential hydropower sites

Technical description of the visited sites

2 Technical description of the visited sites

This chapter contains the technical descriptions of the 17 most promising potential small hydropower sites in Madagascar. The selection process for those 17 sites has been carried out during PHASE 1 and results have been validated during the workshop held in Antananarivo in June 2015 at the Ministry of Energy and Hydrocarbons premises.

Those are organized as follow:

N° Fiche	Code Atlas	Site Name	River	Site Origin (Selection process from Phase 1)		
				Development of remote areas	**Introduction in the least-cost development plans**	**Promising sites studied/planned by the MoE**
1	AD313	Ampondrokoh	Maheriara			√
2	AD342	Manankazo	Manankazo			√
3	AD411	Ambodimanga	Laroka		√	
4	AD601	Antaralava	Imorona	√	√	
5	AD620	Behingitika	Manandriana	√	√	
6	AD631	Antanjona	Sahanofa		√	
7	AD652	Tambohorano	Faravory		√	
8	AD653	Vohinaomby	Antsakoama	√	√	
9	FR148	Vohibato	Mananara			√
10	G191	Andriamanjavona	Namorona		√	
11	G407	Fanovana	Sahatandra		√	
12	SF011	SF011	Marimbona		√	
13	SF015	SF015	Maningory		√	
14	SF020	SF020	Sandratsiona		√	
15	SF038	SF038B	Namorona		√	
16	SF195	SF195	Namorona		√	
17	SF196	SF196	Besana		√	

The key features of the 17 sites are summarized in Table 1 below.

Table 1. Key features of the 17 potential hydropower sites

			HYDROLOGY				@ $Q_{95\%}$						@ $Q_{50\%}$					
Atlas Code	Site Name	River	Watershed [km²]	Firm discharge Q95% [m³/s]	Median discharge Q50% [m³/s]	Gross head [m]	Power [MW]	Energy [GWh/y]	CAPEX [M$]	LCOE [$/kWh]	CAPEX (without lines & access) [M$]	LCOE (without lines & access) [$/kWh]	Power [MW]	Energy [GWh/y]	CAPEX [M$]	LCOE [$/kWh]	CAPEX (without lines & access) [M$]	LCOE (without lines & access) [$/kWh]
AD313	Ampondrokoh	Maheriara	178	0.9	3.2	18	0.1	1.0	4.01	0.465	1.89	0.220	0.445	3.1	4.99	0.190	2.87	0.110
AD342	Manankazo	Manankazo	140	1.3	2.2	31	0.3	2.4	7.45	0.372	3.69	0.185	0.54	4.2	8.35	0.237	4.59	0.131
AD411	Ambodimanga	Laroka	190	2.6	7.1	100	2.0	15.3	23.00	0.179	9.03	0.071	5.76	41.0	32.17	0.094	18.20	0.054
AD601	Antaralava	Imorona	491	3.1	6.7	34	0.8	6.0	6.96	0.137	4.29	0.085	1.7	12.6	9.14	0.087	6.47	0.062
AD620	Behingitika	Manandriana	289	3.4	9.7	25	0.7	5.0	23.20	0.544	5.03	0.119	1.94	13.9	26.75	0.229	8.58	0.074
AD631	Antanjona	Sahanofa	416	4.8	13.0	100	3.8	29.2	43.49	0.177	18.79	0.077	10.44	75.0	64.56	0.103	39.86	0.064
AD652	Tambohorano	Faravory	460	6.2	17.0	37	1.8	13.9	13.19	0.113	8.45	0.073	4.98	35.7	23.01	0.077	18.28	0.062
AD653	Vohinaomby	Antsakoama	387	2.2	4.7	18	0.3	2.4	8.90	0.435	2.62	0.129	0.66	5.0	9.54	0.229	3.26	0.079
FR148	Vohibato	Mananara	2615	34.1	93.7	21	5.8	45.1	31.75	0.084	21.80	0.058	16.08	116.1	61.73	0.064	51.78	0.054
G191	Andriamanjavona	Namorona	863	8.5	24.4	65	4.3	34.1	20.75	0.073	16.09	0.057	12.78	92.3	43.78	0.057	39.13	0.051
G407	Fanovana	Sahatandra	520	5.4	16.7	68	3.0	23.6	13.30	0.068	9.74	0.050	9.42	66.5	26.52	0.048	22.96	0.042
SF011	SF011	Marimbona	1459	17.1	45.1	95	12.5	96.8	91.39	0.113	66.53	0.082	33.9	244.0	176.75	0.087	151.89	0.075
SF015	SF015	Maningory	8474	8.6	46.9	19	1.3	10.2	19.78	0.229	6.45	0.076	7.11	47.8	39.12	0.098	20.12	0.051
SF020	SF020 (aval)	Sandratsiona	2183	17.9	53.8	83	11.4	88.6	118.83	0.160	39.38	0.054	35.6	251.9	193.75	0.092	114.29	0.055
SF038	SF038B	Namorona	1301	16.9	44.2	20	2.7	20.9	28.21	0.160	10.07	0.058	7.11	51.6	38.88	0.090	20.74	0.049
SF195	SF195	Namorona	828	7.8	23.0	27	1.6	12.9	16.45	0.152	7.20	0.067	4.9	35.0	24.99	0.086	15.74	0.055
SF196	SF196	Besana	125	1.4	4.7	150	1.6	12.2	33.42	0.326	7.86	0.078	5.64	40.3	42.47	0.126	16.91	0.051

Madagascar: Small Hydropower Resource Atlas (1-20MW)
Site Investigation Report

AMPONDROKOH SITE

Maheriara River | Atlas Code : AD313

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In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

1 SITE LOCATION

Geographical coordinates (WGS 84)	Longitude [°]	Latitude [°]
Intake	48.111	-17.780
Powerhouse	48.113	-17.779

1.1 Administrative data

Atlas code	AD313
Site name	Ampondrokoh
River	Maheriara
Major river basin	Maningory
Province	Toamasina
Region	Alaotra-Mangoro
District	Amparafaravola
Commune	Morarano Chrome
Village	Amparafaravola, Ambatondrazaka

1.2 Access

Reliable access to the project site is possible from the RN3a coming from the Morarano Sud and then using the AP33 going West in the direction of Maheriara. The AP33 road is tarred and in good condition. Please note that the road RN44 from Moramanga going North to Lake Alaotra was partially renovated in 2014 but is already damaged which makes the traffic slow and arduous from the RN2 (Antananarivo - Toamasina).

The construction of a small hydropower project involves the rehabilitation of the access road from the AP33 highway a distance of about 1.5 km. Then, the access road to the site and to the powerhouse needs to be created over a total distance of approximately 0.5 km.

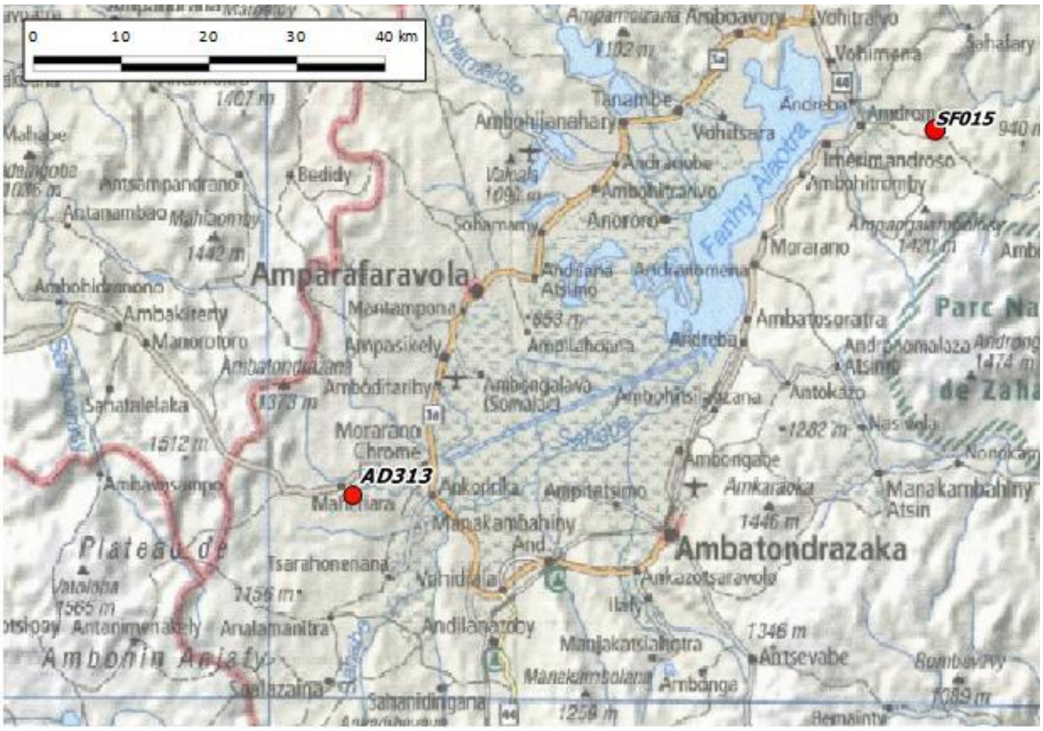


Figure 1. Site access

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

2 GENERAL SITE DESCRIPTION

2.1 Background

The river is characterized by a several small drops. This configuration allows a gross vertical drop of 18 meters for hydropower bypassing a river stretch of 430 m.

At present, there is neither hydro-agricultural nor hydropower scheme at the proposed site location. Nevertheless, there is an on-going project of construction of a hydropower plant (BTEC Nanala company) 2 km upstream from the site AD313.

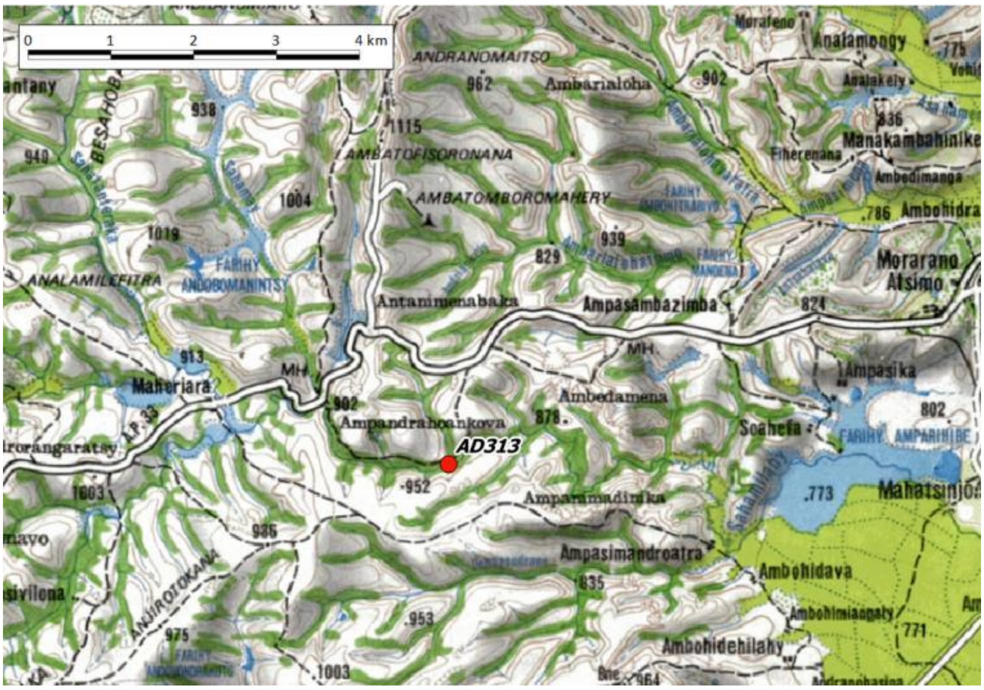


Figure 2. Topographic map (scale 1:50,000)

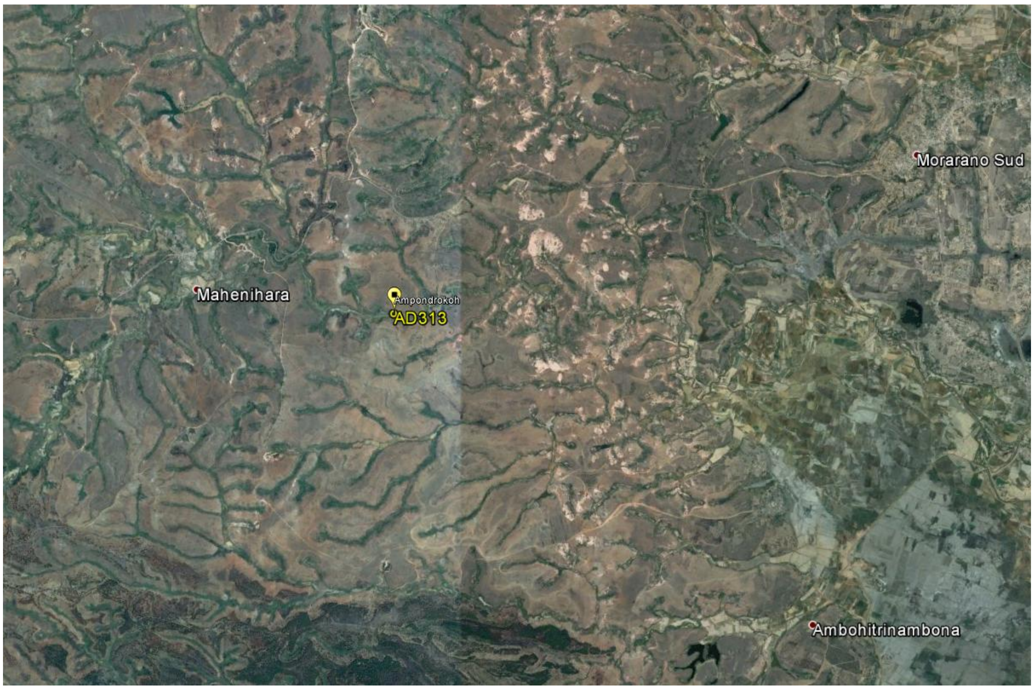


Figure 3. Satellite image (Google Earth)

Figure 4. View of the proposed location of the weir.

Figure 5. View of the river.

2.2 Topography

The topographical survey was achieved through remote sensing. An aircraft was chartered and equipped with optical sensors.

Figure 6. Aircraft and remote sensors container for airborne survey

The topographical survey has a point density of 5 /m² and a relative accuracy of 2%.

Outputs from airborne survey are (1) a high resolution orthophotography (0.2m to 0.4m resolution) and (2) a Digital Surface Model (DSM). The DSM includes the vegetal cover, but it gives an excellent global picture of the site topographical configuration. Results are illustrated in the figures below and the contour lines deducted from the DSM are presented on the detailed proposed scheme layout in section 5.2.

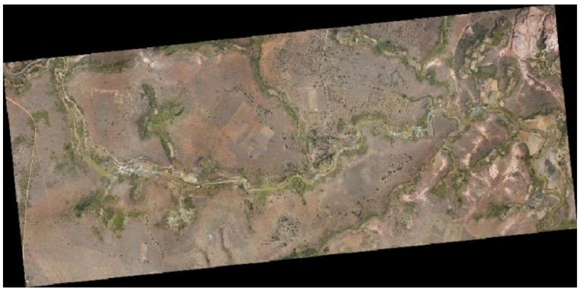


Figure 7. Orthophotography of the site

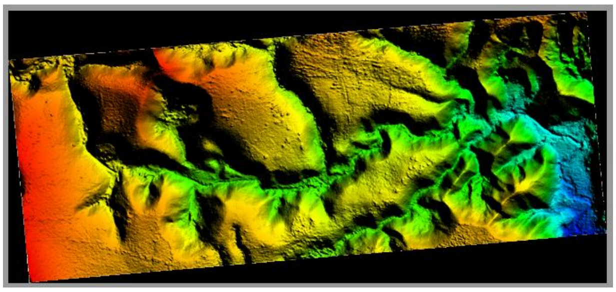


Figure 8. Digital Surface Model of the site

2.3 Preliminary hydrological study

Accurate information on the hydrology of the Maheriara River (tributary of the Maningory River) does not exist. As a consequence, statistical characteristics of the river discharge at the site of interest have been estimated using a regional methodology. This methodology is based on the available information at other hydrometric stations distributed in the country. Given the limited spatial and temporal resolution of the available data, the results of the regional study presented below are indicative only and are not intended to be used for design purposes without further detailed hydrological studies.

Key preliminary hydrological characteristics of the river at the site of interest are presented in the table below.

River	Maheriara
Main river basin	Maningory
Area [km²]	178
Average elevation [m a.s.l]	1 053
Slope index [m/km]	8.1
Specific vertical drop [m]	108
Average annual rainfall [mm/year]	1 183
Average interannual discharge [m³/s]	4.3
$Q_{95\%}$ - firm discharge [m³/s]	0.9
$Q_{50\%}$ - median discharge [m³/s]	3.2
$Q_{30\%}$ [m³/s]	4.8
10yr return period flood [m³/s]	180
100yr return period flood [m³/s]	586

2.4 Sediment transport

The measured turbidity of water was good (below 20 NTU) at the time of the different site visits (June 2015). However the presence of sand deposits demonstrates that significant erosion and deposition processes occur at some period of the year, likely during major flood events.

Adequate sediments and gravels trapping systems will be designed at the feasibility study stage based on an analysis of the sediment load at different river discharges.

2.5 Site geology

2.5.1 Geological context

The study area consists of granite, Migmatite and porphyritic often disposed as massive benches along the river in times of low flow. Two directions of joints predominate: N30W and N270E. These are widely opened and deeply cut into the rock, leading to the presence of isolated massive boulders.

Figure 9 Isolated massive boulders

The lateritic weathering is deep, red, compact and dominant on top of the hills and tends to form "lavaka" (Figure 10). The hill sides contain up boulders that are becoming more and more massive as we approach the foot slope.

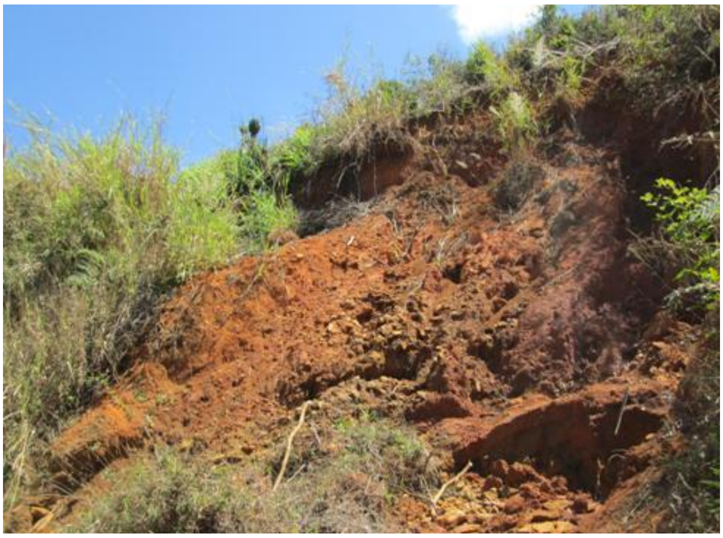


Figure 10 Lavaka on-going process

The whole area has a low hill morphology, with no vegetation, slashed by many small streams.

2.5.2 Technical characteristics

<u>Bed aspect at the projected weir location:</u> Rocky dismantled bottoms by the joints are observed in sub-outcrops at the location for the dam.

<u>Right bank support aspect :</u> The support right side is represented by a low hill including big boulders included in laterite.

<u>Left bank support aspect :</u> The support left side consists of low hill whose base is formed of solid rock slightly disturbed but still in place.

<u>Intake and waterway</u> will be cut into the surface laterite.

<u>Penstock :</u> Penstock will be supported by the laterite soil of the same kind, including boulders or scree.

<u>Powerhouse:</u> The power plant will be installed on a sandy/clay ground. Note the presence of massive rock outcropping near the side of the river.

2.5.3 Recommendations for further investigations

ELEMENT	UNCERTAINTY TO REMOVE	SURVEY TYPE
Bed at weir	- massive rock occupying the river bottom - Possible leakage - Possibility of sandy clay deposits and interstices between the rocks.	- Observation of the river bottom during low flow - Blowing on joints - Permeability tests : important as the rock dip slightly downstream and the joints follow the direction of flow
Left support	- Fear of leaks because of too accentuated openings joints and interbeds despite a visible proper arrangement of rocks	- Permeability tests - Blowing on joints
Right support	- accurate geological formation of the right support - Technical characteristics of laterite which dominates at first sight	- Stripping sloping to update the arrangement of boulders, their size and their status. - Compactness Test of the laterite embedding the boulders.
Intake / waterway	- Technical characteristics of the laterite.	- Auger drillings with sampling, analysis and laboratory tests are necessary to obtain the technical characteristics of the laterite.

Penstock	technical soil on the penstock trace	- Auger drillings with sampling, analysis and laboratory tests are necessary to obtain the technical characteristics of the laterite.
Powerhouse	- Solid rocks in the deep foundation of the Powerhouse	- Auger drilling to study the soil characteristics. - Geophysical survey by seismic reflection
Tailrace canal	- Technical characteristics of the laterite	- Auger drillings with sampling, analysis and laboratory tests to obtain the technical characteristics of the laterite.

2.6 Socio-environmental aspects

The site detailed description sheet is provided in the Appendices.

2.6.1 Socio-environmental background

The site is located on the Maheriara River, Maheriara fokontany, rural community of Morarano Chrome, Amparafaravola District, region of Alaotra Mangoro.

From the environmental perspective, the hills landscape of the area is mainly composed of herbaceous savannah vegetation, with some partially reforested zones (*Pinus and/or Eucalyptus*). Those herbaceous savannahs show the most advanced levels of degradation of the ecosystem due to forest clearings and repetitive fires. Some shrubby species such as guava trees (*Psydium*) and mango trees can be found in the down parts of the hillsides, along with riparian species (for instance *Phragmites, Sporobolus*) next to the river.

Moreover, some « lavaka » phenomena, erosion process of ferralitic soils, can be seen in the area. Water erosion of big hill diggings leads to a lowlands and downstream waters sedimentation.

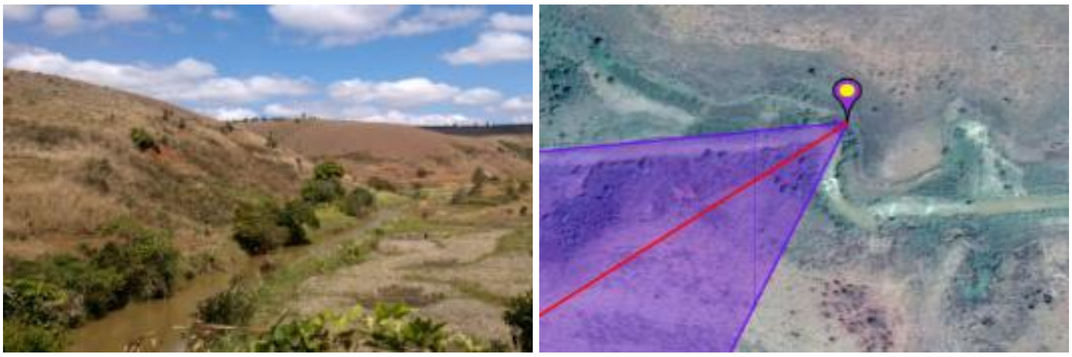


Image 11. Overview of the site vegetation

From the socio-economic perspective, the closest village is Maheriara (~3km away from the site). In the direct neighbourhood, there are only a few hamlets/campsites. Moreover, there is an on-going construction project: a weir and a mini hydroelectric plant. Some infrastructures already exist and others are being built; this was observed in September 2015, during some fields investigations, about 500m upstream of the AD313 point.

The local population are mainly farmers: in particular rice growing associated with subsistence crops (manioc, corn, sugar cane) and vegetable crops. Both banks of the Samilahy river are made for it, divided in crop parcels, in particular on the left bank.

The following image shows a global overview of the land use of the area.

Image 11. Land use of the AD313 site

2.6.2 *Socio-environmental constraints*

Depending on the final conception of the AD313 site, the project could impinge on rural surfaces, for the implementation of the weir, the plant and the penstock pipe. This could lead to loss of resources for the concerned communities.

Moreover, if the implementation of the project leads to an increase of the water level upstream of the weir, some crops, located upstream of the weir could be affected by the magnitude of the flooding.

Some campsites are located in the area, within a radius of 1km from the projected infrastructures The implementation of the project will affect those campsites, especially regarding potential nuisances (noise, traffic, atmospheric emissions…).

2.6.3 *The World Bank Safeguard Policies that could be applicable:*

The World Bank Safeguard Policies that could be applicable for the AD313 site are the following:

- OP 4.01 – The Bank requires Environmental Assessment (EA) of projects proposed for Bank financing to help ensure that they are environmentally sound and sustainable, and thus to improve decision making. However, we can already estimate that the adverse impacts on human populations and environment-linked areas are limited. They are reduced, not irreversible and some measures can prevent, mitigate or minimize them. Moreover, these measures can improve the environmental performance.

- OP 4.12 – Involuntary Resettlement: the hydropower project will require the use of a large space (implementation of the plant, creation of access roads to the site…), which sometimes are crop areas. Moreover, a ponded water upstream of the weir could impact some habitation huts or crop parcels. So the project will have to take into account the concerned people and communities, particularly regarding the restoration of the standards of living due to the loss of resources.

OP 4.11 – Cultural Heritage is not applicable because the site is not known for containing particular cultural material resources. Idem for OP 4.04 – Natural Habitats

The projected weir is classified as a small dam (<15m high); the usual generic safety measures for dams are not appropriate and do not need the OP 4.37 – Safety of Dams (for large dams).

3 PROPOSED SCHEME LAYOUT

3.1 Technical assumptions

The objective is to carry out a high level assessment of the scheme potential in terms of installed capacity, energy generation (firm and average) and the associated capital investment costs (CAPEX) and productions costs (Levelized cost of energy). Hence, at this stage of the study, the technical features of the hydropower scheme are designed in the following sections for both firm and median discharges (respectively $Q_{95\%}$ and $Q_{50\%}$). The actual design flow will be determined during the detailed studies based on economical, financial and technical criterion as well as the future energy and power demand.

The proposed scheme layout is shown in Figure 12 and presented in A3 format in Appendix 5.2 of this report.

Figure 12. Proposed scheme layout for AD313 site (see also annex Erreur ! Source du renvoi introuvable.**)**

Since the site is intended to supply the villages around the Lake Aloatra, the network will operate independently of the three national interconnected networks, but this network could be powered with more energy sources such as the plant under construction upstream of the site or the existing biomass power plant on the East side of the Lake Aloatra.

3.2 Weir and intake

The weir is located upstream of the main drop. This location is suitable to anchor the weir on the bedrock. The fall that follows the weir allows the channel and the sand trap/desander to be out of the floods. The intake will be on the right bank.

The height of the weir will be about 2m and length of 50m.

3.3 Desander

The final location of the desander will be confirmed during the feasibility study, it is indeed necessary to take into account the final topographical and geological condition.

Given the conditions of watershed degradation and water quality observed during the visit, the dimension of the desander will need to be properly designed.

3.4 Waterways

The water supply can be done via a canal on the right bank, although the slopes from the outlet are in the range of 1: 1. From the intake to the channel, it would have a length of 310 m. From PM 0 + 200m, cross slopes leading to significantly reduce slopes of 6: 1. The feasibility study should be particularly attentive to stabilization, reinforcement and drainage slope.

The channel internal dimensions are 1.15 m wide and 0.7 m high operating at Q95 and 2.10 m wide and 1.30 m high for operation at Q50.

3.5 Penstocks and powerhouse

The Penstock length is 90 m and its inner diameter of 0.80 m for the firm discharge to 1.00 m for the median discharge. One Penstock is requested.

The plant will be anchored into the hillside, above the rice fields. A protection zone around the plant will be established to prevent rice crops nearby. A 40m tailrace will lead the water to the river.

3.6 Electromechanical equipments

3.6.1 Design flow taken at $Q_{95\%}$

For a design flow at Q95, there is no need to choose a turbine with a high flexibility regarding discharge variations. As the turbine will be installed in an isolated grid composed of several power generation sources, adaptation to demand variation will be enhanced. Given the available head, a Francis turbine might be chosen as it presents a high performance level and a satisfactory flexibility.

Francis turbine is preferred to Crossflow (or Banki) turbine which is less robust and less resistant to abrasion. Moreover, this type of turbine requires a gearbox that will reduce the global reliability and will increase maintenance works. Although Kaplan turbine offers a higher flexibility, it is not selected for this site as it is a rather sophisticated machine which requires costly maintenances.

It must however be noted that given the low flow, it might be complicated to find, on the market, a turbine corresponding to the site requirements. In such case, the final choice might be a Crossflow turbine.

Given observations formulated about water quality, a particular attention must be paid to the quality of materials used for the construction of the turbine. One should probably consider the need for an anti-abrasion coating.

Electromechanical equipments of the powerhouse will then be composed of:

- Butterfly safety valve with counterweight to ensure its closure in case of emergency of black out.
- A 135 kW horizontal axis Francis turbine running at 1000rpm or 1500 rpm.
- A flywheel, required to operate the powerhouse in an isolated grid.
- A 400V alternator, 125kW/140 kVA.
- Control and monitoring system, including speed regulator and voltage regulator.
- Security system and electrical protection.
- Step-up transformer and electrical cabinet and switchgear.

- Emergency power unit.

Figure 13 Example of a horizontal axis Francis Turbine

Following issues should be studied as well in the next stages of the project :

- Sedimentation problem and the need for anti-abrasion coatings (e.g. Tungsten carbide).
- Technical and economic optimization of the penstock diameter.
- Technical and economic optimization of the number of units and of the design flow, according to the hydrology and the electrical demand.
- The need of a flywheel (for grid stability)
- The set up level and rotational speed of the turbine (Suction height and cavitation issues).
- Grid voltage.
- Preliminary turbine design.

3.6.2 Design flow taken at $Q_{50\%}$

Installed in a local isolated network comprising several sources of production, it is possible to rely on a several power sources that will allow a good adaptation to load changes. It is therefore possible when choosing a moderately flexible turbine dealing with flow variations. Given the drop available, the choice can therefore be focused on the Francis turbine with a high level of performance and a good flexibility. This type of turbine is preferred to Crossflow or Kaplan for the same reasons describe for design flow at Q95.

Other technical considerations also remain valid.

For a design flow at Q50, a Francis turbine is recommended as well. Other considerations exposed for a design flow at Q95 remain valid for a design flow taken at the median discharge (Q50).

The turbine will have a power of 445kW and a rotation speed of 750 rpm or 1000 rpm. The alternator power will be 445kV/495 kVA for a 400V voltage.

3.7 Transmission lines

It is envisaged that the proposed hydropower scheme would be connected to the isolated private grid of the Lake Alaotra using a 10 km long and 35 kV line.

3.8 Key technical features

The key features of the proposed hydropower scheme are summarized in the table below for both firm ($Q_{95\%}$) and median ($Q_{50\%}$) design flows.

		Firm discharge	Median discharge
Installed capacity	[kW]	125	445
Potential annual generation	[GWh/year]	1.02	3.18
Design flow	[m³/s]	0.9	3.2
Gross head	[m]	18	
100yr return period flood	[m³/s]	471	
Weir length	[m]	50	
Weir height	[m]	2	
Desander		Large size	
Tunnel length	[m]	310	
Tunnel diameter	[m]	1.15 x 0.7	2.1 x 1.3
Penstock length	[m]	90	
Penstock diameter	[m]	0.8	1
Number of penstock(s)	[-]	1	1
Number of T/G units	[-]	1	1
Transmission line length	[km]	10	
Line voltage	[kV]	35	
Length of the access road to create	[km]	2	
Length of the access road to upgrade/rehabilitate	[km]	0	

4 ENERGY GENERATION AND COSTS

Based on the assumptions of the economical and hydrological studies presented in the main report, the proposed hydropower scheme would feature the following values:

Gross head	**[m]**	18	
Design flow	**[m³/s]**	0.9 ($Q_{95\%}$)	3.2 ($Q_{50\%}$)
Installed capacity	**[kW]**	125	445
Potential annual generation	**[GWh/y]**	1.02	3.12
CAPEX (excl. access and lines)	**[M$]**	1.89	2.87
LCOE (excl. access and lines)	**$/kWh]**	0.220	0.110
Total CAPEX (incl. access and lines)	**[M$]**	4.01	4.99
Total LCOE (incl. access and lines)	**[$/kWh]**	0.465	0.190

5 Appendices

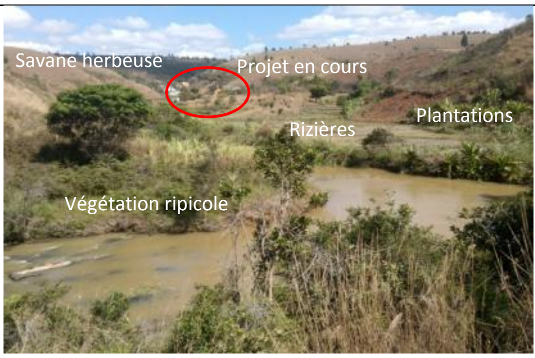
5.1 Socio-environmental description form

A – Site localisation

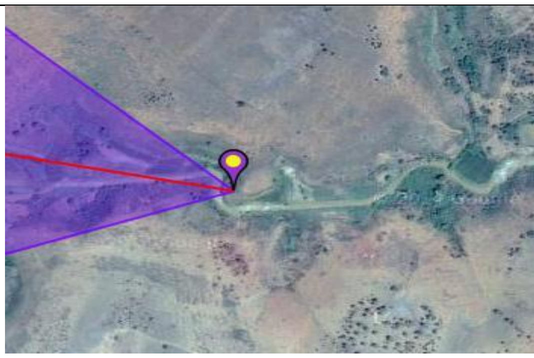
Site reference	:	AD313
Village / Fokontany	:	Maheriara / Maheriara
Community / District/Region	:	Morarano-Chrome / Amparafaravola – Alaotra Mangoro

B - Description of the biophysical background

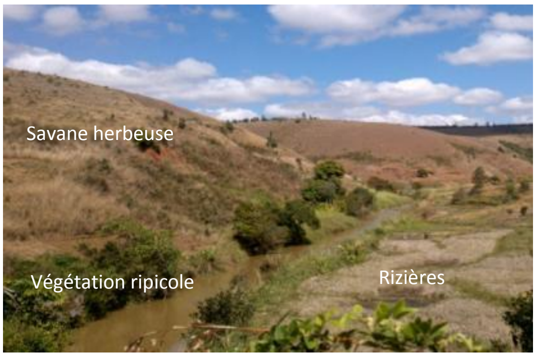
Relief	The AD 313 site is located in the Alaotra Mangoro region, between the « Angavo cliff » (West) and the « Betsimisaraka cliff » (East). The relief's shape is like a basin topped with scarps of mountains. The Maheriara river is the main one. Three small rivers meet near the Maheriara village to create this one.
Vegetation	The vegetation of the area is mainly composed of herbaceous savannah vegetation, with some partially reforested zones (*Pinus and/or Eucalyptus*). Those herbaceous savannahs show the most advanced levels of degradation of the ecosystem due to forest clearings and repetitive fires. Some shrubby species such as guava trees (Psydium) and mango trees can be found the down parts of the hillsides, along with riparian species (for instance *Typhonodorum lindleyanum, Phragmites, Sporobolus*) next to the river.  General overview of the vegetation (S17°46,882 E 48°05,738)



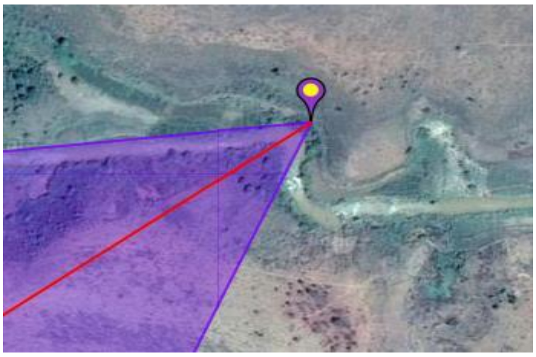
The AD313 point



S17°46'54.53" E48°5'49.79"



Vegetation alongside the river



S17°46'56.17" E48°6'5.51"

OBSERVATIONS

An on-going weir construction and mini hydroelectric plant project (700kWh) upstream of the AD313 (~500m) is running since October 2014.It is co-handled with the support of the EU in the framework of the JIRO KANTO Project, in the Ambatondrazaka and the Amparafaravola communities, with another 1500 kWh site on the Lovoka River (Androkabe). Some connexions infrastructures will be built and they are divided into 20 communities of the Alaotra Mangoro region (17 communities need to have access to electricity and 3 communities need their electric network to be improved.) Moreover, water distribution system infrastructures have been found in the valleys.

Info panel about the on-going mini hydroelectric plant

Meshing of rubble near the weir (S17°46’53.39 E48°5’38,99)

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

Technical-administrative building (work in progress)

Intended location for the plant (S17°46’54,36 E48°5’50,30)

Global overview of the on-going project

Water distribution system (PVC pipe)

For more details about the on-going project, click here :
http://database.energyfacilitymonitoring.eu/acpeu/project/4614/

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

SENSITIVITIES	A potential conservation site was found ~800m West of the AD313 point, next to the weir and the on-going micro-plant project. The vegetation is really poor so the area is affected by the erosion. So, lavaka phenomena, in addition of bush fires, are common and begin to fill the Alaotra lake and the downstream waters.   « lavaka » phenomena in the Alaotra Mangoro Region

B - Description of the socio-economic background

<table>
<tr><td>LOCALITY</td><td><u>Rural community of Morarano South :</u>

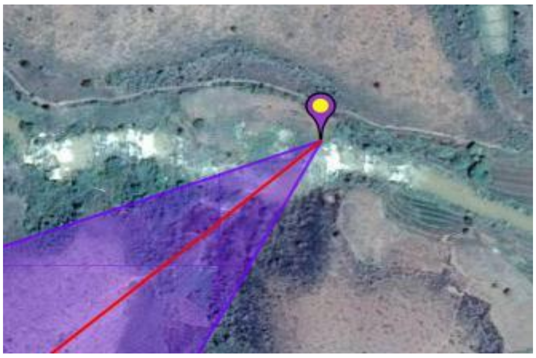
The rural community of Morarano South (Morarano Chrome) spreads on 445 km² and counts 42 127 inhabitants. It is divided into 20 fokontany.

The community is accessible via the NR33 from Vohidiala, which is located on the NR44. The Maheriara village is located on the NR33, coming from Morarano. With the implementation of the current project, a path suitable for vehicles was built alongside the river to access the site from the NR33 to the plant site.

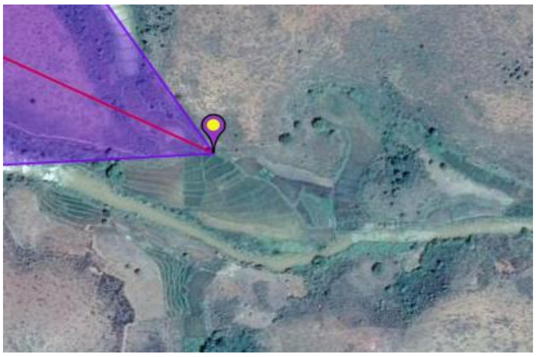
Villages and hamlets:

The main village is Maheriara, ~2,5km away from the current weir. In the direct neighbourhood of the AD313 site, only a few hamlets/campsites can be found.</td></tr>
<tr><td>ACTIVITIES</td><td>The region of Alaotra is one of the biggest rice granary of Madagascar. The main local activity is rice growing. The main subsistence crops on hillsides (« tanety ») are manioc, corn and sugar cane crops. Sometimes fruit crops are associated with hillsides crops (pineapple). We can also find vegetable crops over there. The latter are cultivated during the off-season. Crop parcels (rice, vegetable…) are located on the hillsides and valleys next to/irrigated by waters. They can be terrace crops. Forest clearings and fires linked with rural activities represent a huge pressure for the ecosystem of the area.


Tomato and sugar cane crops, irrigated by the Samilahy river


S17°46’54,39 E48°5’45,88


Rice crops


S17°46’54,74 E48°5’52,07</td></tr>
</table>

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

OTHERS	The community of Morarano South is commonly called Morarano Chrome because of the presence of a chromite deposit in the area, and because of the presence of a train station to convey minerals to the Toamasina harbour. The site is located on mining plots which research authorization expired in 2009.

C – World Bank Safety Policies that can be applicable :

OP 4.01 – Environmental Assessment ☒
OP 4.04 – Natural Habitats ☐
OP 4.11 – Cultural Heritage ☐
OP 4.12 – Involuntary Resettlement ☒
OP 4.37 – Safety of Dams ☐

Land use around the site

Crops on river banks

Lot of earth for irrigation water catchment/ use of rocks to dry manioc

: Riparian vegetation

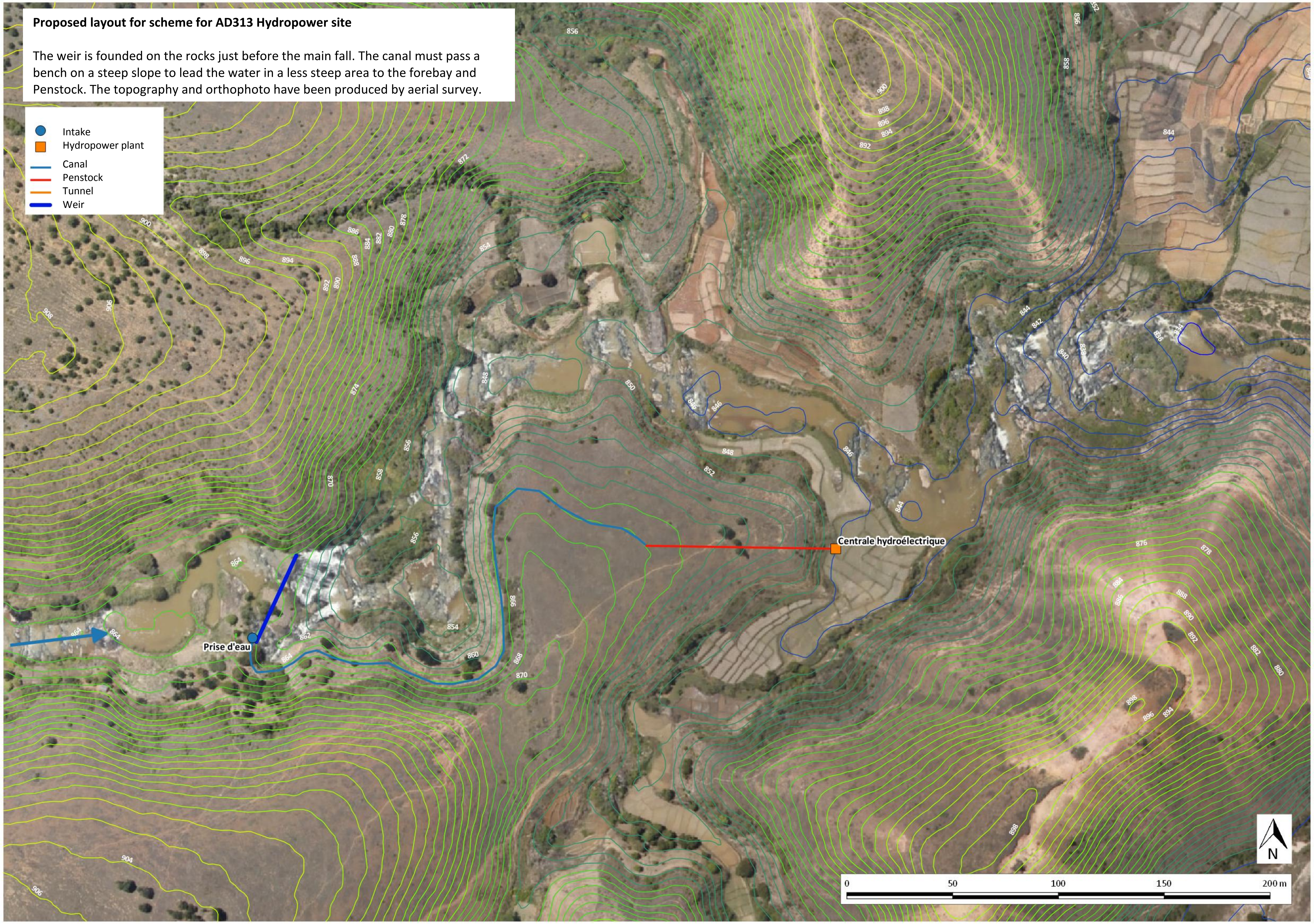
: Crops

: Harbaceous savannah (woody/shrubby)

: Campsites/housings

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

5.2 Proposed scheme layout



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Madagascar: Small Hydropower Resource Atlas (1-20MW)
Site Investigation Report

MANANKAZO SITE

Manankazo River | Atlas Code: AD342

Table of content

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

1 SITE LOCATION

Geographical coordinates (WGS 84)	Longitude [°]	Latitude [°]
Intake	47.210	-18.157
Powerhouse	47.205	-18.155

1.1 Administrative data

Atlas code	AD342
Site name	Manankazo
River	Manankazo
Major river basin	Betsiboka
Province	Antananarivo
Region	Analamanga
District	Ankazobe
Commune	Talata Angavo
Village	Ankazobe

1.2 Access

Access to the site is easy : there is a road in the forest nursery along the river at the site position. This road begins at the RN4 whose bridge is located on the upstream stretch of the site. However, a 2km long road will need to be created to access the plant's infrastructures.

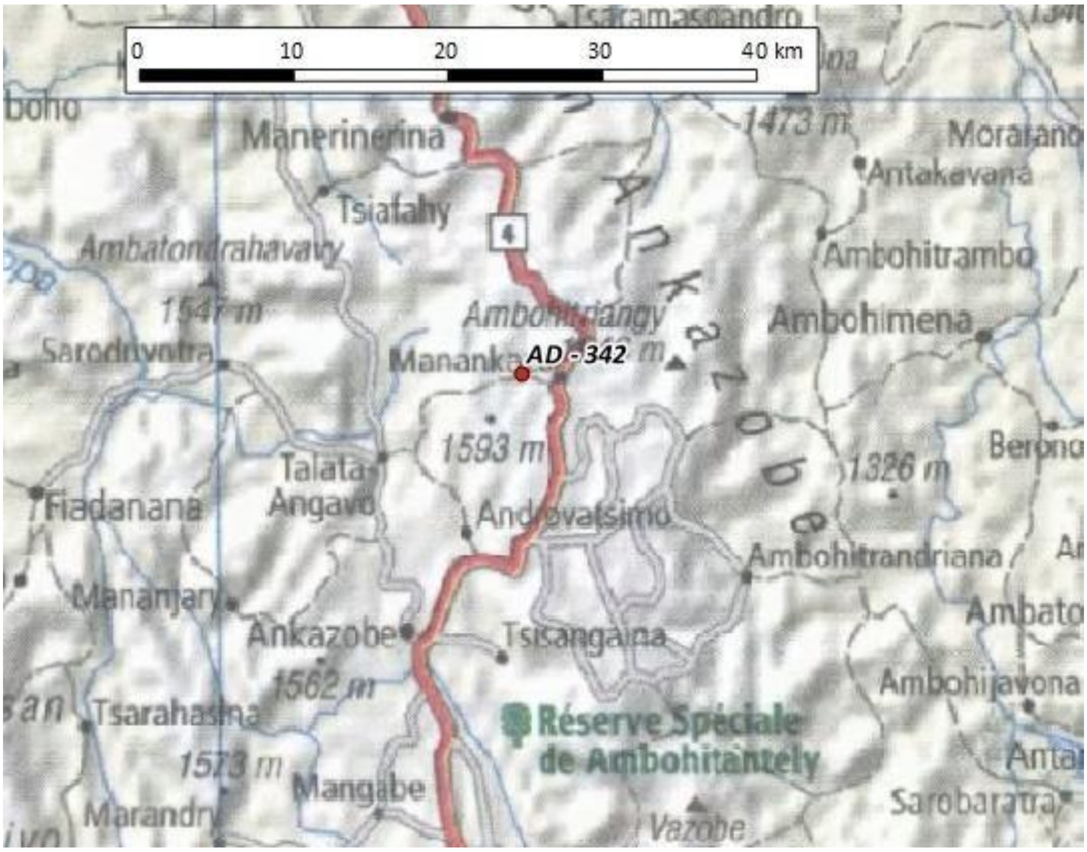


Figure 1: Position of site AD - 342

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

2 GENERAL SITE DESCRIPTION

A rocky outcrop creates a lengthy waterfall at the site position (red frame on the figure below). This rocky outcrop generates a swampy area upstream (green frame on the figure below). The bridge is based on the upstream stretch of the rocky outcrop. The waterfall's length is 680m.

There is an existing hydropower plant (a few kW of power capacity) at the site location. The plant benefits from a very limited part of the available head. It is no longer in use and all equipments have been removed. The proposed scheme detailed below does not use the existing plant's infrastructures because the goal is to use most of the available head.

Figure 2: Aerial view of the site and the upstream swampy area

Figure 3: Upstream stretch of the rocky outcrop that creates the waterfall, where the bridge is based

2.1 Background

The available head is 41m. This value is reached thanks to succession of rapids and small waterfalls all along the rocky outcrop. At this preliminary stage, many possibilities for the scheme exist and depending of the necessary power needed in the area, all or only parts of the available head might be used (just as for the existing pico plant).

Floods are significant and according to some of the forest nursery employees, the highest water level recently observed is about 2-3m high at the bridge position.

Figure 4: Highest water level recently observed according to forest nursery employees

2.2 Topography

The topographical survey was achieved through remote sensing. An aircraft was chartered and equipped with optical sensors.

Figure 5. Aircraft and container of remote sensors for airborne survey

The topographical survey has a point density of 5 /m² and a relative accuracy of 2%.

Outputs from airborne survey are (1) a high resolution orthophotography (0.2m to 0.4m resolution) and (2) a Digital Surface Model (DSM). The DSM includes the vegetal cover, but it gives an excellent global picture of the site topographical configuration. Contour lines might be deduced from the DSM.

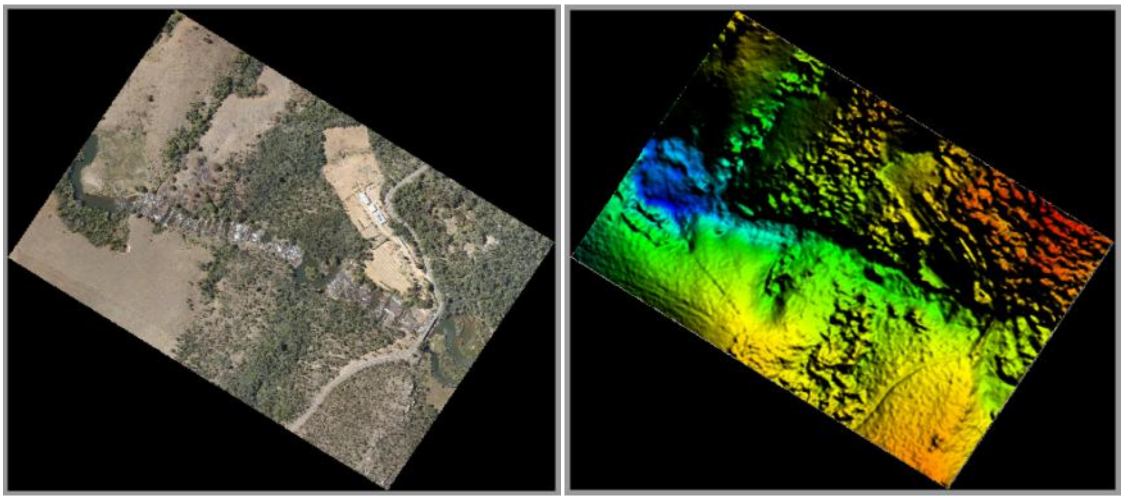


Figure 6. Orthophotography and Digital Surface Model (DSM) from airborne survey

2.3 Preliminary hydrological study

Accurate information on the hydrology of the Namorona River does not exist. As a consequence, statistical characteristics of the river discharge at the site of interest have been estimated using a regional methodology. This methodology is based on the available information at other hydrometric stations distributed in the country. Given the limited spatial and temporal resolution of the available data, the results of the regional study presented below are indicative only and are not intended to be used for design purposes without further detailed hydrological studies.

Key preliminary hydrological characteristics of the river at the site of interest are presented in the table below.

River	Manankazo
Main river basin	Betsiboka
Area [km²]	140
Average elevation [m a.s.l]	1573
Slope index [m/km]	2.9
Specific vertical drop [m]	35
Average annual rainfall [mm/y]	1418
Average interannual discharge [m³/s]	3.2
$Q_{95\%}$ - firm discharge [m³/s]	1.3
$Q_{50\%}$ - median discharge [m³/s]	2.2
$Q_{30\%}$ [m³/s]	2.6
10yr return period flood [m³/s]	91
100yr return period flood [m³/s]	158

2.4 Sediment transport

At the time of site visit (August, 2015), the water was perfectly clear and bed-load almost non existant. According to the site warden, the water becomes heavely loaded only in time of heavy floods. Nonetheless, there are sands strip along the rivers which show the river’s potential solid transport activity. That particular aspect shall be thoroughly investigated during the next phases of the project.

Figure 7: Sands strip along the river

2.5 Existing hydropower plant

The infrastructure of a handmade pico hydropower plant still exists on the site. According to the site warden, it would have been used between October 2009 and May 2015. There would be a rehabilitation project in preparation. It used to be for the forest nursery own needs.

The existing scheme used only a fraction of the available head and available flow. A pressure chamber is located inside the river path and used as an intake. The flow goes directly inside 2 pipes which terminate in the power plant itself.

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

Figure 8: Aerial view of the existing hydropower plant infrastructures

Figure 9: Forebay (intake)

All existing electromechanical equipments have been removed.

Figure 10: Power plant

2.6 Site geology

2.6.1 Geological context

Manankazo site is located in a low hill and high plateau. Exception made of some pine and eucalyptus groces, the area is almost void of greenery. Geologically speaking, the sector is made of heterogranular porphyroid migmatitic granites, on light color (grey to pink), see Figure 11 .

Figure 11. Heterogranular porphyroid migmatitic granite

Two perpendicular joints affect this formation. One follows the river direction while the other crosses it. The joints are largely open and split rock into massive boulders, mainly of parallelepiped shape.

Piano key fractures are found in the area. They are distinctly marked along the river where a succession of super-elevated panels (outcrops) and lower panels (below the water level) are observed (cf. Figure 12).

Figure 12. Geologic fractures.

Lateritic alteration of the granite is one superficial, with reddish to yellowish color.

2.6.2 Technical characteristics

Bed aspect at the projected weir location: rock beds split into massive blocks through the river and might serve as weir foundation (cf. Figure 12). The precise weir location will only depend on the left and right banks characteristics.

Right bank support aspect: it is made of a low height hill slope with granite boulders perceptible along the riverbank. Lateritic cover is reduced. The bedrock, outcropping in the river must extend on the riverbank, below a small and superficial lateritic layer.

Left bank support aspect: on this bank, the bedrock outcropping in the river is clearly extending beyond the reach of the river bank, on a gentle hill slope, under a small and superficial lateritic cover (Figure 13).

Figure 13. clearly Extension of the bedrock under a small and superficial lateritic cover

Intake and waterway: the intake will be founded on massive rock while the canal will be buitl within lateritic layers.

Penstock: it will be placed on a lateritic slope.

Powerhouse: it will be founded on a rather flat area characterized by a lateritic cover without noticeable outcrops.

2.6.3 Recommandations for further investigations

ELEMENT	UNCERTAINTY TO REMOVE	SURVEY TYPE
Bed at weir	✓ Weir water tightness	✓ Analytical study of the deeply open joints within the rock due to the transversal faults. ✓ Compressed air blowing and percolation tests should be conducted
Right support	✓ Existence of the bedrock for support	✓ Mechanical excavation of the laterite until the bedrock is found.
Left support	✓ Fear of possible leakage	✓ Compressed air blowing and grout injections to be planned within the open cracks ✓ Percolation tests
Intake and waterway	✓ Existence of bedrock on which founding the intake ✓ Thickness of the lateritic layer along the canal trace	✓ Mechanical excavation of the laterite until the bedrock is found for intake base. ✓ Auger drilling at some chosen points along the waterway to determine the lateritic layer thickness and to define the geotechnical characteristics of soils.
Penstock	✓ Nature and disposition of the ground ✓ Hill slope stability	✓ More detailed geological reconnaissance to be defined in the next study stages, once the final penstock trace is defined

Powerhouse	✓ Existence of massive rock to serve as powerhouse foundation.	✓ Auger drilling to define the bedrock level (or seismic reflection geophysical survey if need)

2.7 Socio-environmental aspects

The site detailed description sheet is provided in the Appendices.

2.7.1 Socio-environmental background

The site is located on the Manankazo River. It is situated in the fokontany of Manankazo, between the rural communities of Ankazobe and Talata Angavo, Ankazobe District, Analamanga.

From the environmental perspective, the site is located in a *Eucalyptus* and *Pinus* reforesting area of the Manankazo forest station. It covers an area of more than 15 130 ha. Along the left and right banks of the Manankazo River, the forest station can be seen from the RN4 roadside, next to the PK121. It is classified as Reforestation and Restoration Perimeter and was assigned to the Water and Forest Department in 1951 (Decree 1826-DOM, August 8, 1951). It is currently the subject of a 50 years lease management contract with the Madagasco Environnement Company (Ocean Trade Group) by the Ministry for the Environment.

However, steppe areas composed of grasses such as *Andropogon* sp., *Loudetia stipoïdes*, *Heteropogon contortus* (Danga), *Aristida multicaulis* (Kifafa) and *Hyparrhenia rufa* (Vero) which can be observed in the surroundings of the site (+- 1 km).

You can also find some shred forests, adjacent to watercourses, which belong to the centre and eastern region. They are characterised by *Weinmannia* sp., *Cussiona* sp., *Canarium madagascariensis*, *Dracaena* sp. … A particular species has been found in the area (the royal palm or *Dypsis decipiens*). Another endemic species of the area, called Sohisika (*Schizolaena tampoketsana*) is planted in the forest station.

Moreover, the « lavaka » phenomena, usual erosion process on ferralitic soils, can be seen in the area and they lead to the sedimentation of downstream rivers. Those phenomena are increased by local bush and forest fires.

Image 14. Overview of the vegetation around the site

From the socio-economic perspective, the site is located in a reforestation and restoration area. So, rural activities and housings are almost non-existent. The closest and main village is located 4km away from the site, heading North on the RN4.

However, some buildings and breeding grounds of the forest station are located on the right bank of the river, in front of the AD 342 site. The forest station owns a mini hydropower plant for its own electricity needs, based on a catchment place under the RN4 bridge.

Moreover, a thermal power plant from JIRAMA provides electricity for Ankazobe. It requires between 11 400 l and 14 670 l of fuel every month. In 2015, the daily peak was between 213 kWh and 782 kWh. The 670 subscribers consume 20 400 from 30 400 kWh to 40 200 kWh every month for a monthly production which varies between 33 900 kWh and 47 500 kWh. The production is still sufficient for the current subscribers and JIRAMA does not need to apply load shedding yet. However, despite the high volume of connection requests (~350 requests), there is no on-going extension project yet.

To sum up, the following image gives a global overview of the land use in the area.

Image 15. Land use in the AD 342

2.7.2 Socio-environmental constraints

The project may interfere with the activities of the forest station, both during the construction phase and the operational phase, regarding potential nuisances (noise, traffic, atmospheric emissions…). The project may especially interfere with the use of the hydropower plant if it should be upgraded.

Furthermore, existent natural forests represent a potential habitat for endemic species, which, a priori, are a part of the forest station. The development of the hydropower project will require some free spaces, which could impact on shred forests and reforestation.

Finally, the water flow disturbance and the local water resources availability, during the implementation of the facilities, could affect the development of seedlings (especially for the breeding ground).

2.7.3 World Bank operational policies that could be applicable:

The World Bank Safeguard Policies that could be considered for the AD342 site are the following:

- OP 4.01 – The Bank requires Environmental Assessment (EA) of projects proposed for Bank financing to help ensure that they are environmentally sound and sustainable, and thus to improve decision making. However, we can already estimate that the adverse impacts on human populations and environment-linked areas are limited. They are reduced, not irreversible and some measures can prevent, mitigate or minimize them. Moreover, these measures can improve the environmental performance.

- OP 4.04 – Natural Habitats: natural forests represent a habitat for endemic species (for instance, the royal palm aka *Dypsis decipiens*, « sohisika » or *Schizolaena tampoketsana*). However, they are not critical habitats and some mitigation measures could be created during the conception of the project and its implementation.

- OP 4.12 – Involuntary Resettlement: the hydropower project will require the use of a large space (implementation of the plant, creation of access roads to the site…) located in the forest station. So the project will take into account the inconveniences and losses linked to the decrease of spaces used by the station.

The OP 4.11 – Cultural Heritage is not applicable because the site is not known for containing particular cultural material resources.

The projected weir is classified as a small dam (<15m high); the usual generic safety measures for dams are not appropriate and do not need the OP 4.37 – Safety of Dams (for large dams).

3 PROPOSED SCHEME LAYOUT

3.1 Technical assumptions

As detailed above, a potential implementation of this project should consider the socio-environmental aspects which are significant:

Forest along the site. The forest is gazetted and a special attention should be paid to that particular aspect.

Bridge on the RN4. The bridge location is advantageous for the building of the weir because upstream of it the swampy area calms and stabilizes the flow. However the bridge is based at this place, and we consider here to locate the weir and intake just downstream of it, where the impact on the flow does not affect the bridge.

Forest nursery. The forest nursery would benefit from the generated power. However, the scheme would affect some of the parcels belonging to the nursery, and impacts should be weighted during the next stage of the project.

Given the limited power needs in the area, the project size will likely be limited, which will limit the negative impacts.

An assessment of the scheme potential in terms of installed capacity, energy generation (firm and average) and the associated capital investment costs (CAPEX) and productions costs (Levelized cost of energy) is presented in section 4. It is based on the scheme proposed in this section. Hence, at this stage of the study, the technical features of the hydropower scheme are designed for both firm and median discharges (respectively $Q_{95\%}$ and $Q_{50\%}$). The actual design flow will be determined during the detailed studies based on economical, financial and technical criterion as well as the future energy and power demand.

The proposed scheme layout is shown below and presented in A3 format in Appendix of this report.

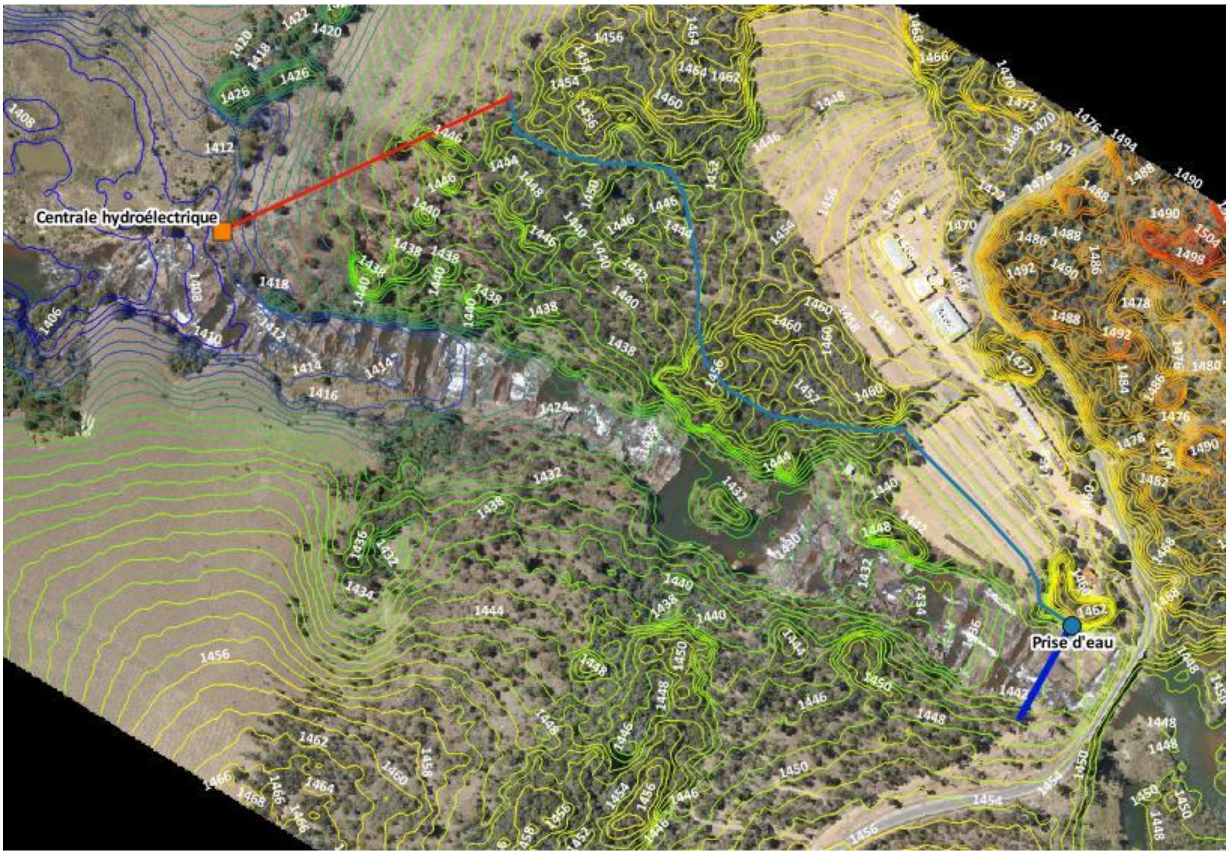


Figure 16. Proposed scheme for AD343

3.2 Weir and intake

In order to avoid disturbances on flood flows at the bridge position, it is proposed to build the weir downstream of the bridge at a sufficient distance.

The weir will be in stone masonry, based on rocky ground, 65m long and max 3-4m high with an intake on the right bank.

3.3 Desander

A desilting basin will be located right after the intake. Its dimensions will depend on the bedload study and the power needs requirements.

3.4 Waterways

A canal will convoy the water to the pressure chamber. The river stretch to be intercepted by the scheme is almost straight lined. The left bank shows that a lavaka is being created. This is the reason why the right bank is chosen, however its long term stability should be properly assessed. The main drawback is the fact that the canal will go through the forest nursery.

The canal will be 530m long, with a rectangular section. Depending on the design flow, it will be [h x b] 0.80 x 1.30 (Q95) or 1.05m x 1.75 (Q50). Flow velocity will be limited to 2 m/s.

3.5 Penstock and powerhouse

The penstock will be located on an unforested area, above ground level, 195m long and 0.80m diameter (Q95) or 1.00m (Q50).

The power plant will be located upstream of a small waterfall, upstream of a small tributary as well and based on rocky round.

3.6 Electromechanical equipments

3.6.1 Design flow taken at Q_{95}

For a design flow at Q95, there is no need to choose a turbine with a high flexibility regarding discharge variations. As the turbine will be installed in an isolated grid composed of several power generation sources, adaptation to demand variation will be enhanced. Given the available head, a Francis turbine might be chosen as it presents a high performance level and a satisfactory flexibility.

Francis turbine is preferred ton Crossflow (or Banki) turbine which is less robust and less resistant to abrasion. Moreover, this type of turbine requires a gearbox that will reduce the global reliability and will increase maintenance works.

Given observations formulated about water quality, there will probably be no need for an anti-abrasion coating.

Electromechanical equipments of the powerhouse will then be composed of:

- Butterfly safety valve with counterweight to ensure its closure in case of emergency of black out.
- A 335 kW horizontal axis Francis turbine running at 1000rpm or 1500 rpm.
- A flywheel, required to operate the powerhouse in an isolated grid.
- A 400V alternator, 315kW/350 kVA.
- Control and monitoring system, including speed regulator and voltage regulator.
- Security system and electrical protection.
- Step-up transformer and electrical cabinet and switchgear.
- Emergency power unit.

Following issues should be studied as well in the next stages of the project

- Sedimentation problem and the need for anti-abrasion coatings (e.g. Tungsten carbide).
- Technical and economic optimization of the penstock diameter.
- Technical and economic optimization of the number of units and of the design flow, according to the hydrology and the electrical demand.
- The need of a flywheel (for grid stability)
- The set up level and rotational speed of the turbine (Suction height and cavitation issues).
- Grid voltage.
- Preliminary turbine design.

Figure 17. Example of a horizaontal axis Francis set

3.6.2 Design flow taken at Q_{50}

Same considerations as those exposed for a design flow at Q95 might be formulated for a design flow taken at the median discharge (Q50). A Francis turbine is recommended as well. Further investigation should examine whether a single turbine offers enough flexibility.

The turbine will have a power of 575kW and a rotation speed of 1000 rpm. The alternator power will be 540kV/600 kVA for a 400V voltage.

A power plant PLC (Programmable Logic Controller) should also be foreseen to manage the two units.

3.7 Transmission lines

The scheme is aimed to provide the neighboring villages with power and the Ankazobe town. The power supply line will be about 24km long.

3.8 Key technical features

The main project's features are presented below.

		Firm discharge	Median discharge
Installed capacity	[kW]	315	540
Potential annual generation	[GWh/y]	2.37	4.17

Design flow	[m³/s]	1.3	2.2
Gross head	[m]	31	
100yr return period flood	[m³/s]	158	
Weir length	[m]	65	
Weir height	[m]	4	
Desander		large size	
Canal length	[m]	530	
Canal section (b x h)	[m]	1.3 x 0.8	1.75 x 1.05
Penstock length	[m]	195	
Penstock diameter	[m]	0.8	1
Number of penstock(s)	[pce]	1	1
Number of T/G units	[pce]	1	1
Transmission line length	[km]	24	
Line voltage	[kV]	35	
Length of the access road to create	[km]	2	
Length of the access road to upgrade/rehabilitate	[km]	0	

4 ENERGY GENERATION AND COSTS

At this very early stage of study, and according to the hypotheses and options taken above, the project would have the following energitical and economical performances as order of magnitude:

Gross head	**[m]**	31	
Design flow	**[m³/s]**	1.3 ($Q_{95\%}$)	2.2 ($Q_{50\%}$)
Installed capacity	**[kW]**	315	540
Potential annual generation	**[GWh/y]**	2.37	4.17
CAPEX (excl. access and lines)	**[M$]**	3.69	4.59
LCOE (excl. access and lines)	**[$/kWh]**	0.185	0.131
Total CAPEX (incl. access and lines)	**[M$]**	7.45	8.35
Total LCOE (incl. access and lines)	**[$/kWh]**	0.372	0.237

The produced power would be evacuated through a 24km long 35kV line towards the neighboring villages and Ankazobe town (southwards, following RN4). At the moment in Ankazobe, power is generated by the Jirama's diesel plant, a few hours a day.

5 Appendices

5.1 Socio-environmental datasheet

A – Site localisation

Site reference	:	AD342
Villages / Fokontany	:	Manankazo
Communities / District-Region	:	Ankazobe & Talata Angavo / Ankazobe - Analamanga

B – Description of the biophysical background

RELIEF	The AD342 site is located in the « Tampoketsa ». This means rolling plains (convex hills) and with a strong topography (15-35° slope) on the central highlands of Madagascar, rising to more than 1300m. More precisely, the AD342 site is located in valleys along the Manankazo River. The Tampoketsa hydrographical network is quite thick and it is linked to the weather conditions of the region and to water dynamics. The site belongs to the Ikopa Basin, which is created by Andranobe and Manankazo rivers. The river flows from East to West. It should be noticed that the « lavaka » phenomena are due to water erosion following the disappearance of the soil cover.  Convex hill with the "lavaka" phenomenon in the background S18°9'19.51 E47°12'16.35

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

VEGETATION

The site is located in the Eucalyptus and Pinus reforestation area of the forest station of Manankazo.

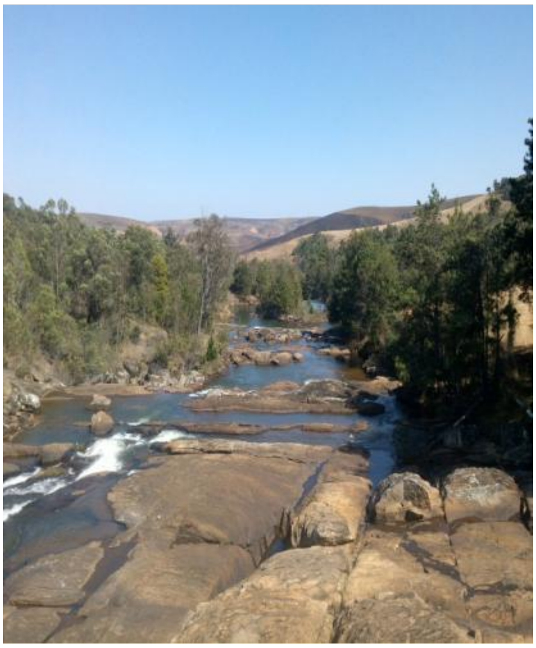
However, steppe areas constituted by grasses such as Andropogon sp., Loudetia stipoïdes, Heteropogon contortus (Danga), Aristida multicaulis (Kifafa) and Hyparrhenia rufa (Vero) which can be observed in the surroundings of the site (+- 1 km).

You can also find some shred forests, adjacent to watercourses, which belong to the centre and eastern region. The woody vegetation seems like an Eastern mid-elevation rainforest, which is characterised by Weinmannia sp., Cussiona sp., Canarium madagascariensis, Dracaena sp. … A particular species has been found in the area (the royal palm or Dypsis decipiens). Another endemic species of the area, called Sohisika (Schizolaena tampoketsana) is planted in the forest station.

Forests alongside the water are sometimes gallery forests, mostly in certain places on the river bank. The canopy meets above the two banks.

Planted Sohisika next to the office of the forest station

Royal palm situated upstream of the site



Vegetation is mainly characterised by *Pinus* and *Eucalyptus,* with steppe in the background

S18°9'28.01" E47°12'37.27"

OBSERVATIONS	The AD 342 site is in the perimeter of the forest station of Manankazo. . It covers an area of more than 15 130 ha. Along the left and right banks of the Manankazo River, the forest station can be seen from the RN4 roadside, next to the PK121. It is classified as Reforestation and Restoration Perimeter and was assigned to the Water and Forest Department in 1951 (Decree 1826-DOM, August 8, 1951). It is currently the subject of a 50 years lease management contract with the Madagasco Environnement Company (Ocean Trade Group) by the Ministry for the Environment. Moreover, Ankazobe is famous for the frequency and the intensity of bush fires. Besides, recent traces of fire have been seen really close to the site.   Traces of fire next to the cottage (near the bridge) — Traces of fire just after the hydropower plant in the forest station
CRITICAL AREAS	In addition of the presence of the forest station, which wants to enter the carbon market, the Ambohitantely special reserve is situated ~7km East of the site. This area has a rich flora and fauna, including lemurs (*Eulemur fulvus, Microcebus rufus, Avahi laniger*), birds (*Lophotibis cristata*) , reptiles reptiles (*Brookesia therezieni, Uroplatus ebenaui* and *Uroplatus fimbriatus*), timber species (*Weinmannia* spp, *Cunoniaceae*, *Kaliphora madagascariensis*, Rhus taratana, *Canarium madagascariensis*, *Diospyros* sp.) , orchids and epiphytich plants (*Bulbophyllum* spp. , *Angraecum* sp, *Plypodium* spp).

B - Description of the socio-economic background

LOCALITY	**<u>Rural communities of Ankazobe and Talata Angavo :</u>** The Manankazo River is the limit between the communities of Ankazobe and Talata Angavo. The AD 342 site is located between the latter. To access the site, you have to take the RN4, less than 100m away from the bridge, alongside the river. ***Villages and hamlets:*** The AD342 site has a special characteristic: it is located inside the forest station. Except from the buildings of the forest station, there is no known housing in the area. The main village, Firarazana, is 4km North, following the RN4.
ACTIVITES	Situated in a forest station, the identified activities of the area are limited: activities of management of the forest station only. The bridge is the only way to cross the Manankazo River. It is an important infrastructure of the RN4. Surveys have shown that, during previous researches on the ground, the Department of Public Works proposed the implementation of a weir upstream of the bridge in order to not make the latter more fragile Besides, the forest station has already implemented a catchment under the bridge to purchase electricity. As a matter of fact, is has its own hydropower plant.

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	 Catchment near the bridge, for the hydropower plant of the forest station S18°9’27.42’’ E47°12’36.86’’  Hydropower plant of the forest station
OTHERS	<u>JIRAMA Ankazobe</u> A survey has been led by the team close to JIRAMA Ankazobe. The data is as follows: • Number of subscribers: 670 households • Daily peak: mini 213 kWh and max 782 kWh (on-going year 2015) • Monthly sales: 30400 to 40200 kWh • Monthly production: 33900 to 47500 kWh • GO consumption: 11440 to 14670 litres/month PD: the production is still highly sufficient (no load shedding) and there is no on-going extension project yet despite the amount of extension requests (350).

C - World Bank operational policies that could be applicable:

OP 4.01 – Environmental Assessment ☒

OP 4.04 – Natural Habitats ☒

OP 4.11 – Cultural Heritage☐

OP 4.12 – Involuntary Resettlement ☒

OP 4.37 – Safety of Dams☐

Land use near the site	
	
Downstream overview of the site	Breeding ground flowerbeds in the forest station
	
Vegetation of the right bank upstream of the site	Type vegetation on the left bank

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

: Restoration and Reforestation

: Riparian forest/Gallery forest

: Shred forest

: Grassy savanna/steppe

: Breeding ground of the forest station

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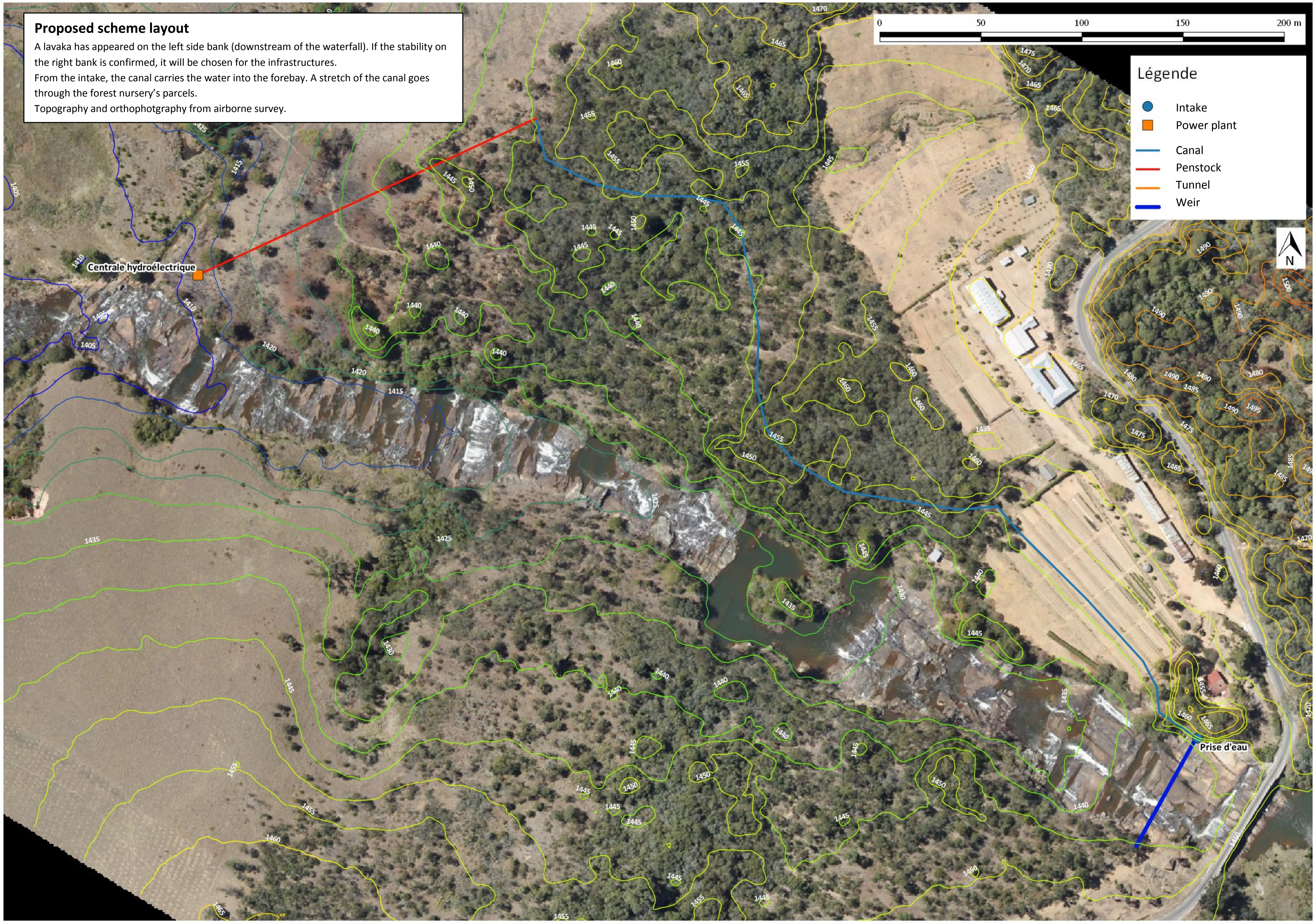
5.2 Proposed scheme layout



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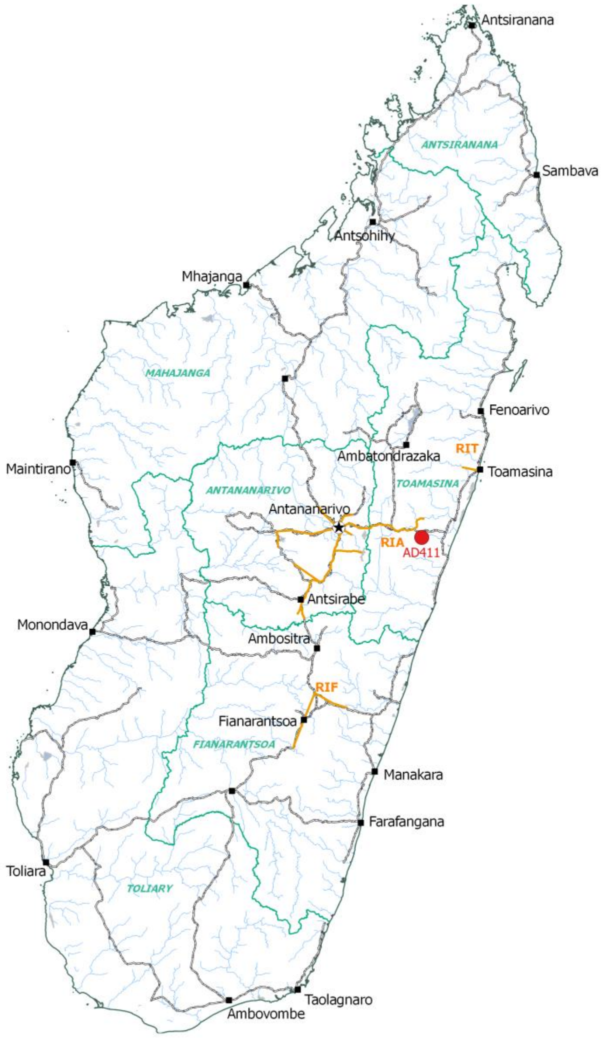
Madagascar: Small Hydropower Resource Atlas (1-20MW)
Site Investigation Report

AMBODIMANGA SITE

Laroka River | Atlas Code: AD411



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1 SITE LOCATION

Geographical coordinates (WGS 84)	Longitude [°]	Latitude [°]
Intake	48.633	-19.050
Powerhouse	48.641	-19.050

1.1 Administrative data

Atlas code	AD411
Site name	Ambodimanga ou Chutes de la Mangorina
River	Laroka
Major river basin	Rianila
Province	Toamasina
Region	Alaotra-Mangoro
District	Moramanga
Commune	Beforona
Village	Ambodimanga
Reference topographical map	Carte topographique n°T47 (échelle 1:50,000)

1.2 Access

Access to AD411 is rather difficult at the moment as it requires taking a 12km long path (by foot) from the RN7. From the end of the path to the site, there is still 1.5km to get to the site.

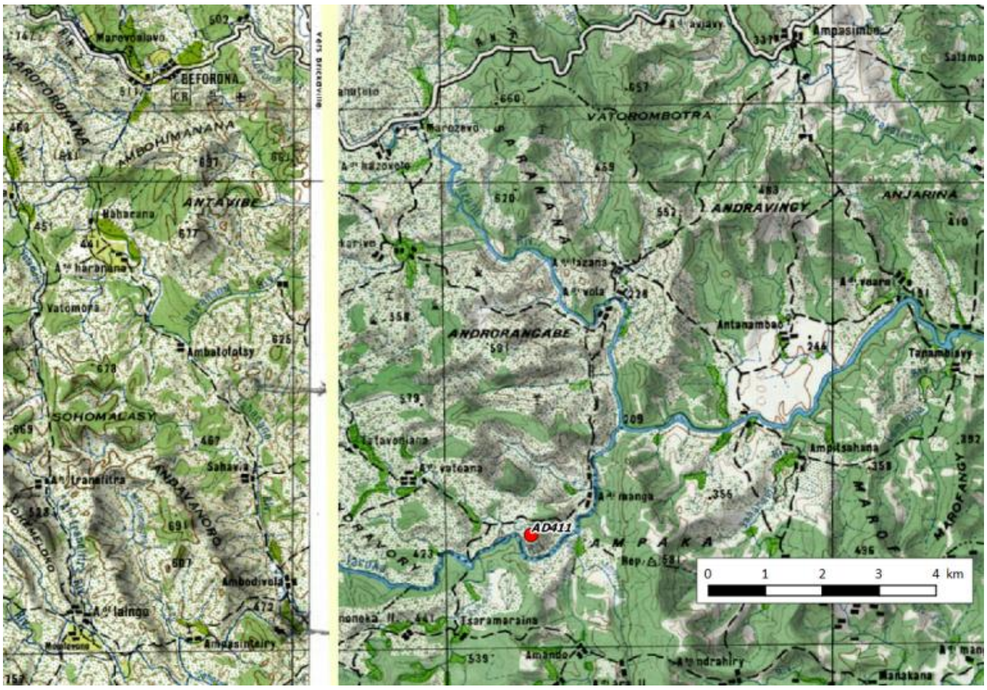

Figure 1. Access to site AD-411.

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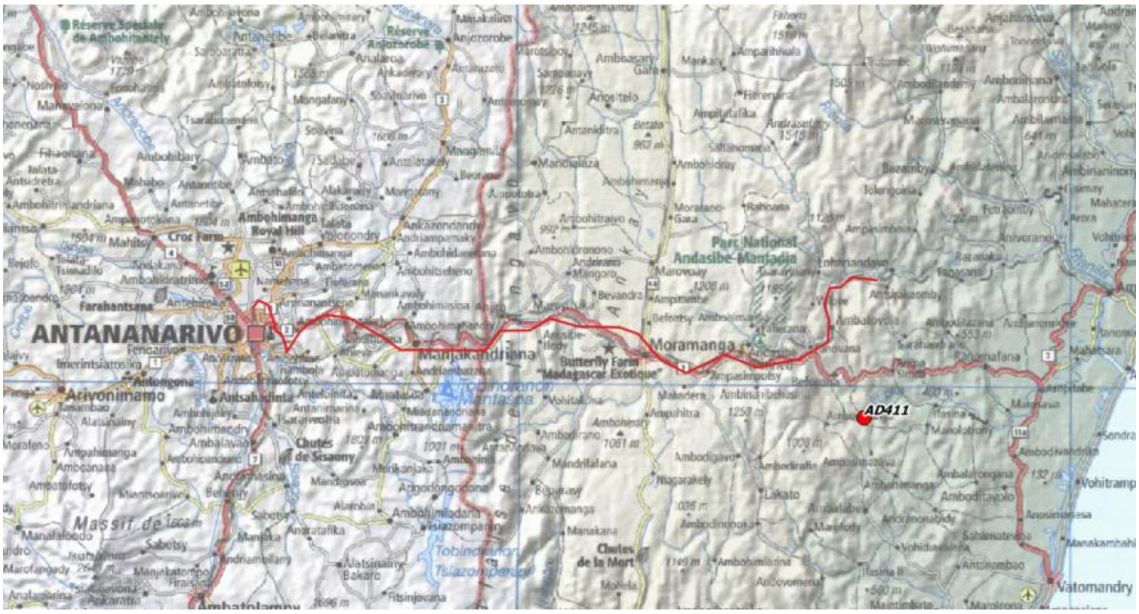


Figure 2. Position of AD411 relative to Antananarivo

2 General site description

2.1 Background

The river drops significantly when going around a hill along a semi-circle. The 100m head is created through a succession of successive waterfalls, the highest of them being located at the south of the semi-circle.

There is currently no hydropower, nor irrigation scheme at the site.

Figure 3. Site overview.

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

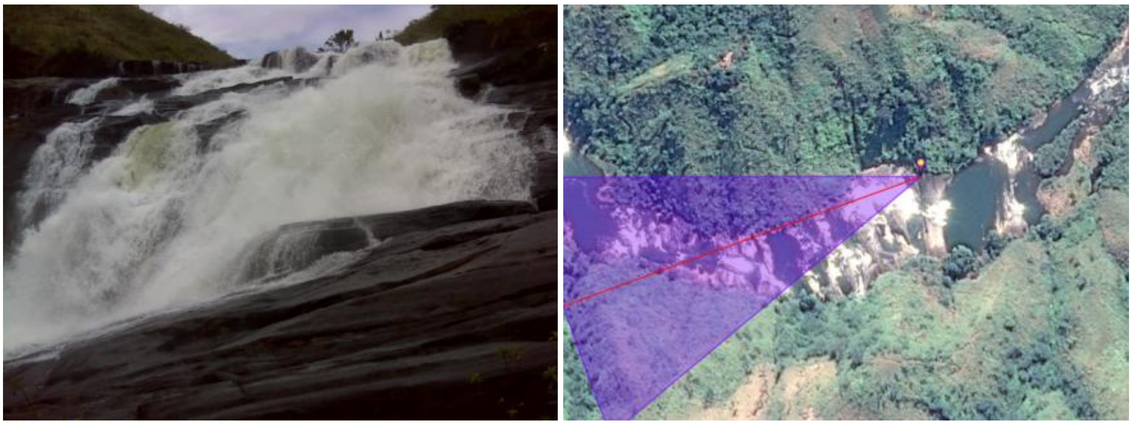


Figure 4. View on the highest waterfall.

2.2 Topography

The topographical survey was achieved through remote sensing. An aircraft was chartered and equipped with optical sensors.

Figure 5. Aircraft and container of remote sensors for airborne survey

The topographical survey has a point density of 5 /m² and a relative accuracy of 2%.

Outputs from airborne survey are (1) a high resolution orthophotography (0.2m to 0.4m resolution) and (2) a Digital Surface Model (DSM). The DSM includes the vegetal cover, but it gives an excellent global picture of the site topographical configuration. Contour lines might be deduced from the DSM.

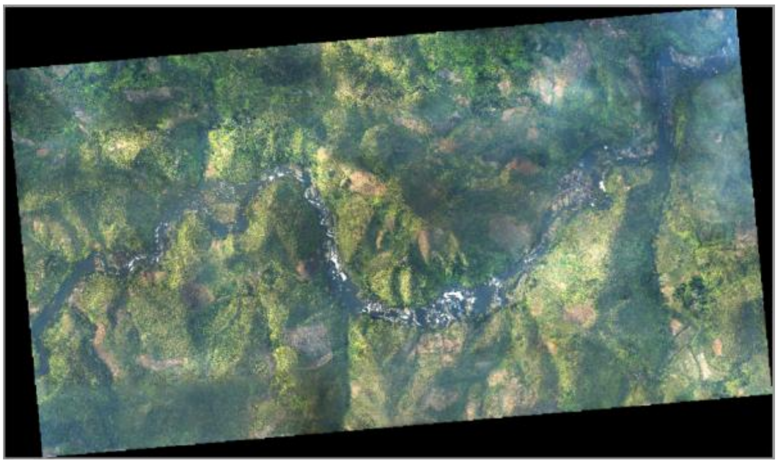


Figure 6. Orthophotography from airborne survey

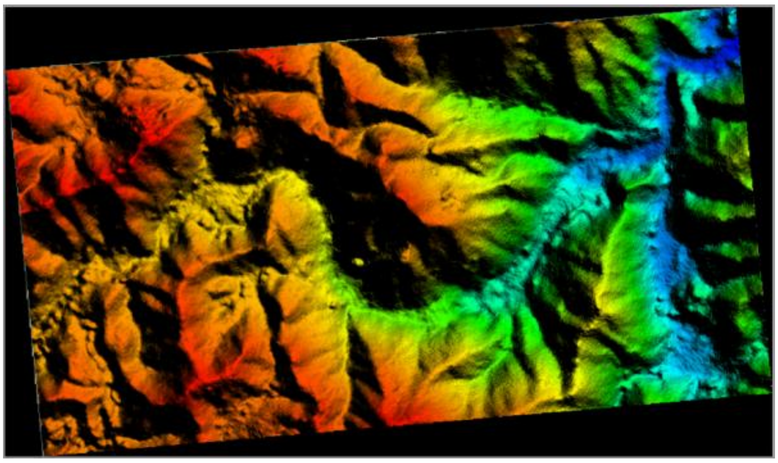


Figure 7. Digital Surface Model from airborne survey

2.3 Preliminary hydrological study

Accurate information on the hydrology of the Laroka River does not exist. As a consequence, statistical characteristics of the river discharge at the site of interest have been estimated using a regional methodology. This methodology is based on the available information at other hydrometric stations distributed in the country. Given the limited spatial and temporal resolution of the available data, the results of the regional study presented below are indicative only and are not intended to be used for design purposes without further detailed hydrological studies.

Key preliminary hydrological characteristics of the river at the site of interest are presented in the table below.

River	Laroka
Main river basin	Rianila
Area [km²]	190
Average elevation [m a.s.l]	789
Slope index [m/km]	13.8
Specific vertical drop [m]	190
Average annual rainfall [mm/y]	2290
Average interannual discharge [m³/s]	9.2
$Q_{95\%}$ - firm discharge [m³/s]	2.6
$Q_{50\%}$ - median discharge [m³/s]	7.1
$Q_{30\%}$ [m³/s]	9.8
10yr return period flood [m³/s]	440
100yr return period flood [m³/s]	888

2.4 Sediment transport

Turbidity was very low at the time of visit (<30 NTU, September 2014). However, there are sand strips along the river banks, and heavy solid transport should be expected during floods. The basin upstream of the site is deforested, most of the area being cultivated and exposed to soil erosion.

Figure 8. Basin upstream : deforested, cultivated and exposed to soil erosion.

2.5 Site geology

2.5.1 Geological context

The area is dominated by medium to fine grain biotite and amphibole migmatite, with quartz, feldspar and mica grains. Interbed quartzic veins are found as well. Some quartzic beds and some black coloured ultramafic lenses appear sometimes as intercalation or overlapping within the miglatites (Figure 9).

Figure 9. Bedrock details

Alteration is poorly marked on the whole sector. It is limited to split in boulders of the rock masses, noticed on the hills sides. Hence, the alteration soil only appears as laterite made of reddish to brownish clayey-sandy silts in surface and in-depth as lateritic granitic sands (resulting from the boulders alteration).

On a structural and tectonic point of view, the rock formation is a component of a sub-horizontal dome characterized by spalling of horizontal layers observed along the river (Figure 10). Joints and fractures with main direction N110E and vertical dip mark the entire rock mass. Fractures filled with quartz vein (direction N20E, dip 70°W) are also observed.

Figure 10. Rock dome

Rocks, of massive appearence or spilted into large boulders crop out along the river, creating remarkable falls.

2.5.2 Technical characteristics

Bed aspect at the projected weir location: the projected weir axis is located on massive but fractured migmatite rock with sub-horizontal dip, crossed by a basalt vein, easily noticeable during low water period, which is responsible of the succession of drops extending on 100m downstream (Figure 11).

Figure 11. Weir axis

Right bank support aspect: it is made of massive but fractured rock with big boulders on the river banks. This area is the base of a hill made of embedded rock boulders under laterization process. Some boulders are partly outcropping on the hill slope (Figure 11).

Left bank support aspect: the left bank is of the same type as the right bank. Boulders are found above of some rock masses observed from place to place along the river. Brownish to reddish laterite of found between the boulders (Figure 11).

Intake and waterway : the tunnel will cross a lateritic high plateau composed migmatite embedding non-fully weathered boulders. This structure is indicated by the observation of outcropping rock boulders in some places.

<u>The penstock</u> : the ground is made of laterite and migmatites including big boulders under laterisation process (particular attention should be paid to the boulders on the hillsides).

<u>The powerhouse :</u> the powerhouse will be located on an area covered by rock boulders that will have to be removed in order to reach the bedrock.

2.5.3 Recommendations for further investigations

ELEMENT	UNCERTAINTY TO REMOVE	SURVEY TYPE
Bed at weir	✓ Precise weir axis	✓ The outcrop should be further analysed during low flow period.
Right support	✓ The weir lifespan is threatened by boulders that might potentially hurtle down the hill during natural disasters (floods, seism, cyclonic storms,...)	✓ A more detailed analysis should be conducted regarding the final weir axis. It should take into account the hillsides slopes and constitution.
Left support	✓ Same as for right bank support	✓ Same as for right bank support
Intake and waterway	✓ Nature, continuity and compactness of the lateritic mass to drill for the tunnel. Boulders, sometimes of huge size, are embedded in laterite.	✓ Taking the land morphology and geology into account ✓ Seismic reflection geophysical survey along the waterway to define the boulders position in-depth ✓ Core drilling and percolation tests to characterize the laterite ✓ Internal rock boulders might cause difficulties for the tunnel drilling as there is a risk to cross a succession of migmatite boulders and laterite with magmatic structure
Penstock	✓ Characterization of the ground, fear of land/rock slides ✓ Existence of boulders embedded in laterite	✓ More detailed geological investigation must be conducted once the penstock axis is established (to check if land/rock slide might occur)
Powerhouse	✓ Characterization of the supporting ground (Massive rock? Boulder in place or not? Depth of laterite?)	✓ Auger drilling or seismic reflection geophysical survey

2.5.4 Main risks

For the tunnel, it is recommanded to avoid creating a bend in the tunnel trace. As this one crosses laterite layers, the risk of erosion due to water velocity in the bend is significant. A canal should be preferred to cross the thalweg and could afterwards be followed by a straight tunnel up to the penstock.

2.6 Socio-environmental aspects

The site detailed description sheet is provided in the Appendices.

2.6.1 Socio-environmental background

The site is located on the Laroka River, close to the « Mangorina Falls ». It is situated next to the village of Ambodimanga, in the fokontany of Antsakarivo, rural community of Beferona, Moramanga District, Alaotra Mangoro.

The local vegetation is mainly composed by Savoka and fallows that correspond to secondary formations, due to forest clearings and burnt cultivated parcels. We can also find, in general, some *Ravenala madagascariensis*. On the other hand, the Savoka and fallows surfaces are composed by a huge ericoid bush. It is mainly composed by herbaceous species, namely *Hyparrhenia rufa*, *Ctenium spp*., *Aristida spp*., *Aframomun angustifolium*. The ericoid bush can also be found alone, in certain areas around the site.

Next to the plant, we can see a cover composed by quite dense tree and shrubby vegetation. The main species in this type of vegetation are composed by *Pandanus* and *Adina microcephala*. Some reforestation species, such as the eucalyptus, can also be observed.

Image 12. Vegetation downstream of the site

From the socio-economic perspective, the main villages are located at ~4km as the crow flies from the site (Ambodivolo and Antskarivo, which is the county seat of the fokontany). However, not less than fifteen hamlets or campsites are counted around the site. Every hamlet or campsite is formed by 1 to 3 habitation huts. In particular, the projected route for the gallery goes under a small 3 habitation huts hamlet.

The agriculture is the main activity in the area. It is mainly rice growing but there are some other subsistence crops (manioc, sweet potato, corn and some vegetable crops).

The agriculture is still based on slash-and-burn cultivation, in particular for hillside parcels (rain crops). The lowlands take the form of rice fields. Furthermore, we can see cash crops in the area (coffee, banana, ginger, sugar cane). The villages are surrounded by tree plantations (banana trees, coffee trees, etc.).

However, fishing is not really used in the area.

The following image shows a global overview of the land use in the area.

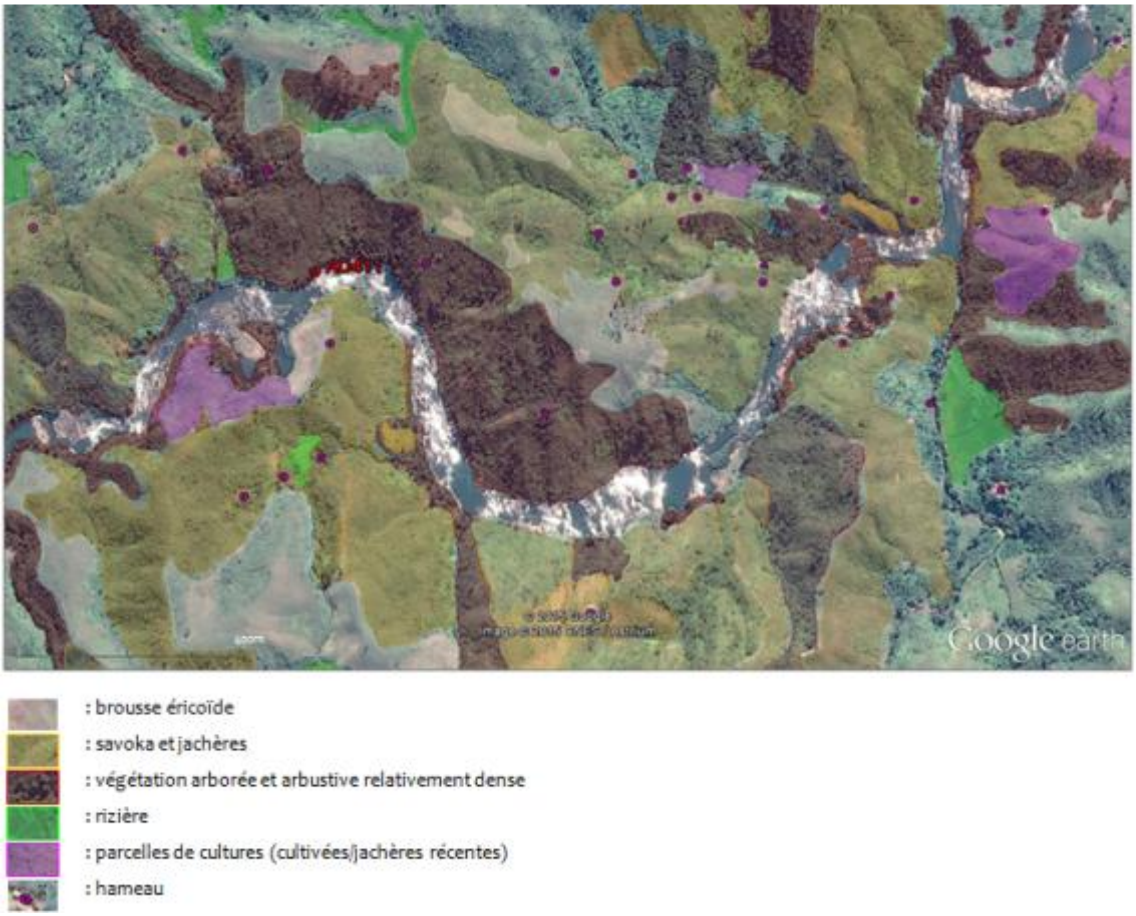


Image13. Land use in the AD 411

2.6.2 *Socio-environmental constraints*

Some hamlets are situated next to development sites (weirs, tunnels, penstock pipes, plants) The implementation of the project will affect those hamlets, especially regarding potential nuisances (noise, traffic, atmospheric emissions…). The short distance between the hamlets and the working site will increase the risk of an accident for the concerned population, especially for a small hamlet situated on the projected route of the gallery.

On the other hand, at the weir site, the presence of small hamlets on both banks (one hamlet is situated 50m upstream of the site and two hamlets are situated between 70 to 100m away from the river, downstream from the site) leads us to think that the river is used, in this section, for the needs of those small villages. The implementation of the project will also affect those hamlets as they may interfere with the water use.

Moreover, if the implementation of the project leads to an increase of the water level upstream of the weir, some crops (situated on the right bank, 175m upstream from the site and some small huts situated 50m upstream of the weir and 70m away from the river) could also be affected, depending of extent of the pond.

2.6.3 World Bank operational policies that could be applicable:

The World Bank Safeguard Policies that could be considered for the AD342 site are the following:

- OP 4.01 – The Bank requires Environmental Assessment (EA) of projects proposed for Bank financing to help ensure that they are environmentally sound and sustainable, and thus to improve decision making. However, we can already estimate that the adverse impacts on human populations and environment-linked areas are limited. They are reduced, not irreversible and some measures can prevent, mitigate or minimize them. Moreover, these measures can improve the environmental performance.

- OP 4.12 – Involuntary Resettlement: the hydropower project will require the use of a large space (implementation of the plant, creation of access roads to the site…), which sometimes are crop areas. Moreover, a ponded water upstream of the weir could impact some habitation huts or crop parcels. So the project will have to take into account the concerned people and communities, particularly regarding the restoration of the standards of living due to the loss of resources.

The OP 4.11 – Cultural Heritage is not applicable because the site is not known for containing particular cultural material resources. Same applies for OP 4.04 – Natural Habitats

The projected weir is classified as a small dam (<15m high); the usual generic safety measures for dams are not appropriate and do not need the OP 4.37 – Safety of Dams (for large dams).

3 PROPOSED SCHEME LAYOUT

3.1 Technical assumptions

Given the potential of the site, it is expected that the project will be connected to the main grid of Antananarivo (the line Andekaleka – Anatananarivo is close).

An assessment of the scheme potential in terms of installed capacity, energy generation (firm and average) and the associated capital investment costs (CAPEX) and productions costs (Levelized cost of energy) is presented in section 4. It is based on the scheme proposed in this section. Hence, at this stage of the study, the technical features of the hydropower scheme are designed for both firm and median discharges (respectively $Q_{95\%}$ and $Q_{50\%}$). The actual design flow will be determined during the detailed studies based on economical, financial and technical criterion as well as the future energy and power demand.

The proposed scheme layout is shown below and presented in A3 format in Appendix 5.2 of this report.

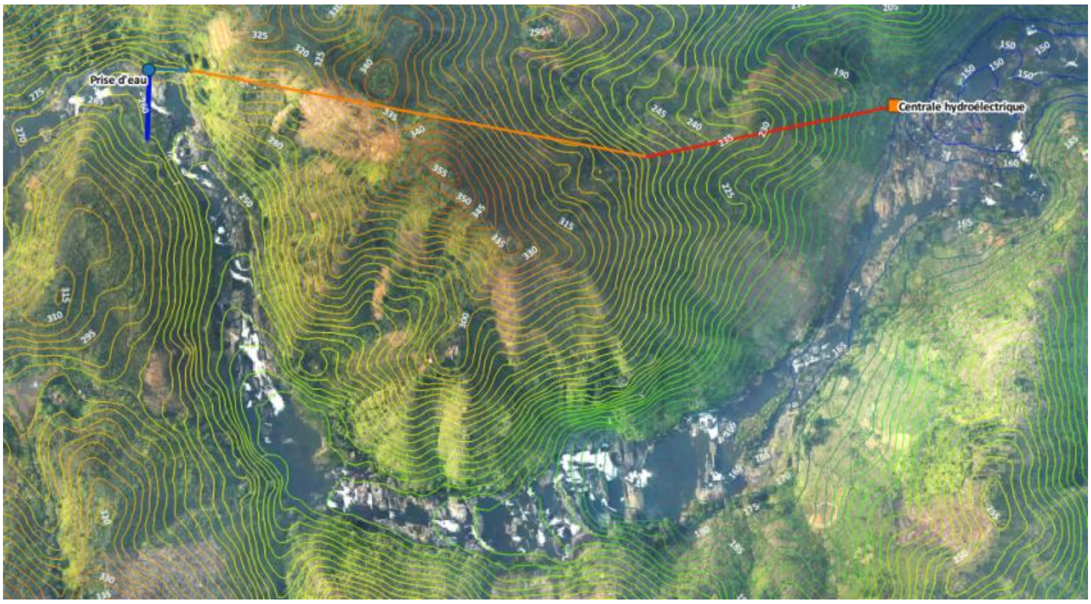


Figure 14. Proposed scheme layout for site AD411

3.2 Weir and intake

The weir will be positioned upstream of a small waterfall, the intake being located on the left bank. This way, the canal will be out of flood range right after the small waterfall.

The weir will be 70m long and 6m high at its highest position.

Figure 15. Situation upstream of scheme

3.3 Desander

Given the possible sediment transport during the rainy season, a desander will be set up and located upstream of the tunnel.

3.4 Waterways

The topography of the site makes it very difficult for a canal to be built. This is the reason why a tunnel is considered below. Between the intake and the tunnel though, a 40m long canal/desander allows to connect both elements. The canal will be (h x b) 0.80m x 1.30m for the firm flow (Q95) and 1.90 x 1.3m for the median flow.

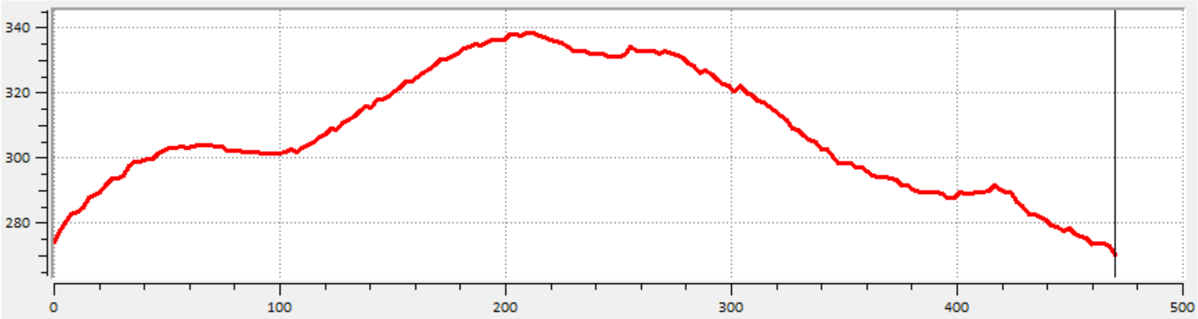


Figure 16. Profile view along the tunnel

3.5 Penstock and powerhouse

Penstock will be 285m long and 0.80m diameter (firm flow) and 1.40m diameter (median flow).

The hydropower station will be located on the left embankment, at the end of the half loop.

Figure 17. View around the plant site.

3.6 Electromechanical equipments

3.6.1 Design flow taken at Q_{95}

In the case of a project aiming at being connected to Antananarivo grid, one must choose a turbine type that enables a maximization of the power output. For a design flow taken at Q95, not much flexibility is required for the turbine as it will work most of the time at nominal power.

Given the head, discharge and foreseen output, a Francis turbine comes as and evidence. It offers a high performance level and a satisfactory flexibility.

Given observations formulated about water quality, a particular attention must be paid to the quality of materials used for the construction of the turbine. One should probably consider the need for an anti-abrasion coating.

Electromechanical equipments of the powerhouse will then be composed of:

- Butterfly safety valve with counterweight to ensure its closure in case of emergency of black out.
- A 2 130 kW vertical axis Francis turbine running at 1000rpm.
- A 690V alternator, 2 000 kW/2 200 kVA.

- Control and monitoring system, including speed regulator and voltage regulator.
- Security system and electrical protection.
- Step-up transformer and electrical cabinet and switchgear.
- Emergency power unit.

Figure 18. Example of 2 set with vertical axis

Following issues should be studied as well in the next stages of the project

- Sedimentation problem and the need for anti-abrasion coatings (e.g. Tungsten carbide).
- Technical and economic optimization of the penstock diameter.
- Technical and economic optimization of the number of units and of the design flow, according to the hydrology and the electrical demand.
- The need of a flywheel (for grid stability)
- The set up level and rotational speed of the turbine (Suction height and cavitation issues).
- Grid voltage.
- Preliminary turbine design.

3.6.2 *Design flow taken at Q_{50}*

For a design flow taken at Q50, it is recommended to install two identical units (Francis turbines) in order to optimize the global efficiency and to increase the plant availability.

Other considerations exposed for a design flow at Q95 remain valid for a design flow taken at the median discharge (Q50).Turbines will have a unit nominal power of 3 100kW and a rotation speed of 1000 rpm. The alternator power will be 2 920 kV/3 250 kVA for a 690V or 5.5 kV voltage.

A power plant PLC (Programmable Logic Controller) should also be foreseen to manage the two units.

3.7 Transmission lines

As discussed above, it is expected to connect the plant to the grid of Tana. A 30km long, 63kV line will be necessary to connect the plant to the Andekaleka segment of the grid.

3.8 Key technical features

The main project's features are presented below for both the firm and the median discharge.

		Firm discharge	Median discharge
Installed capacity	[kW]	2000	5760

Potential annual generation	[GWh/y]	15.26	41.04
Design flow	[m³/s]	2.6	7.1
Gross head	[m]	100	
100yr return period flood	[m³/s]	888	
Weir length	[m]	70	
Weir height	[m]	6	
Desander		Medium size	
Canal length	[m]	40	
Canal section (b x h)	[m]	1.85 x 1.15	3.1 x 1.9
Tunnel length	[m]	480	
Tunnel diameter	[m]	2	2.3
Penstock length	[m]	285	
Penstock diameter	[m]	0.8	1.4
Number of penstock(s)	[pce]	1	1
Number of T/G units	[pce]	1	2
Transmission line length	[km]	30	
Line voltage	[kV]	63	
Length of the access road to create	[km]	13.5	
Length of the access road to upgrade/rehabilitate	[km]	0	

4 ENERGY GENERATION AND COSTS

At this very early stage of study, and according to the hypotheses and options taken above, the project would have the following energitical and economical performances as order of magnitude:

Gross head	**[m]**	100	
Design flow	**[m³/s]**	2.6 ($Q_{95\%}$)	7.1 ($Q_{50\%}$)
Installed capacity	**[MW]**	2 000	5 760
Potential annual generation	**[GWh/y]**	15.26	41.04
CAPEX (excl. access and lines)	**[M$]**	9.03	18.2
LCOE (excl. access and lines)	**[$/kWh]**	0.071	0.054
Total CAPEX (incl. access and lines)	**[M$]**	23	32.17
Total LCOE (incl. access and lines)	**[$/kWh]**	0.179	0.094

5 APPENDICES

5.1 Socio-environmental datasheet

A – Site localisation

Site reference : AD411

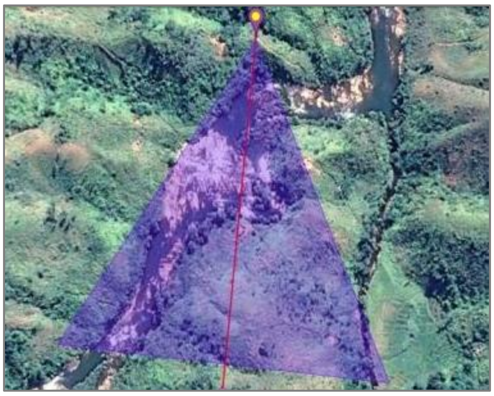
Village / Fokontany : Ambodimanga / Antsakarivo

Community / District : Beforona / Moramanga

B - Description of the biophysical background

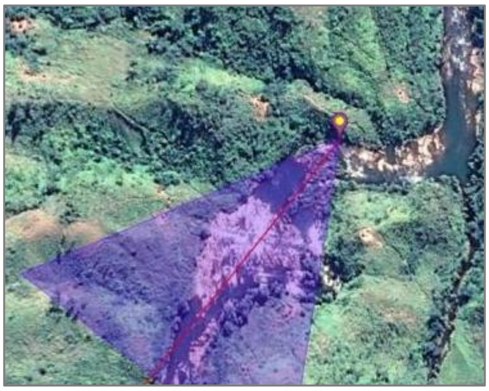
RELIEF	The AD 411 site is close the the "Mangorina Falls", alongside the Laroka River. The latter crosses the curvy relief of the Eastern Malagasy in the area of Beforona, before joining the Rianila. The relief is precipitous, uneven and crossed by little narrow valleys (V-shape). The hillsides are mainly multi-faces and the slopes are steep (from 25% to 56%). The hydrographic network is dense and torrential during the rain season. The Laroka River is rooted in the Vohidrazana forest massif. It flows from West to East to the Mangorina Falls. Then, it heads South – for about 500 m – to finally flows North to the Ilazana River. From there, the Laroka River heads East before joining the Rianila River.
VEGETATION	The Dynamics of vegetation is created by human activities in the studied area. Generally, the vegetation cover is composed by 4 units: - The quite dense vegetation characterised by a tree or shrub gallery represent a natural anti erosion. The main species in thoses formations are composed by *Pandanus* and *Adina microcephala* (soaravina). It should be noted that some shred forests exist on the hills tops. Some reforestation species, in particular the eucalyptus, can also be observed. - Fallows and savoka are secondary plant formations. They come after the forest clearing and the burnt crops. They can be herbaceous or shrubby. Savoka generally contains *Ravenala madagascariensis*, sometimes associated with bamboos. Depending on their age and level of regeneration, the flower composition of the fallows changes: o Shrubby fallows are composed by heliophilious woody species such as *Harungana madagascariensis* (harongana), *Trema orientalis* (tsivakimbaratra) and *Psiadia altissima* (Dingadingana); o Herbaceous fallows are composed by a mix of species (sometimes higher than 2m) such as *Aframomum angustifolium* (longoza) and *Rubus mollucanus* (takoaka). - The surface of the ericoid bush creates a huge plant cover around the site. As a matter of fact, we can find it in the fallows, as mentioned above, but can also be seen in other areas. It is composed by the following: *Hyparrhenia rufa* (vero), *Ctenium* spp. (tenona), *Aristida* spp. (paipaika), *Aframomun angustifolium* (longoza). - Crop patchworks, which can be used as fallows for a couple of crop seasons.

Downstream landscape of the site



S19°2'56.62" E48°38'33.18"

Savoka and riparian vegetation on hillside



S19°2'58.32" E48°38'34.68"

OBSERVATIONS	Despite the close distance with the Vohidrazana forest massif, at the West of the site (less than 10km as a crow flies), the landscape possesses a typical vegetation from a degraded location: savoka, *Ravenala madagascariensis* or even bush. The vegetation recovery after the forest clearing is helped with the wet weather of the area. It should be noted that, on the hills tops, some shred forests exist and that they are generally linked to reforestation species, in particular the eucalyptus.
CRITICAL AREAS	The site is close to some conservation areas: - 10km West from the site: forest corridor called « Ankeniheny – Zahamena », handled by the International Conservation. - 10 km South-West from the site: the new protected area of Ambalabe, handled by the Missouri Botanical Garden (MBG). - A dozen km East from the site: potential conservation site of Takarindaona. The area, which has a weak soil cover and/or plant rootedness, is likely to be touched by potential landslides during the rainy period. Endemic species exist in the area (presence of large-diameter *« Ficus sp »*), but no IUCN classified species.

B - Description of the socio-economic background

LOCALITY	Fokontany Antsakarivo – Rural community of Beforona – Moramanga District (Alaotra Region – Mangoro). You can access to the site from the Ambodihazovelo village (Marozevo) via a 20km road heading South. 5km further, the road crosses the Antsakarivo village, county seal of the fokontany. You can only access to the site by feet. **Rural community of Beforona** The rural community of Beforona is close to the PK 160 on the NR2, linking Antananarivo and Toasmasina. It spreads on about 347km², divided in 13 fokontany. In 2009, the population was about 15 079[1] people, which means about 1 200 people per fokontany. Every basic social infrastructures can be found in the county seal of the community of Beforona: education infrastructures(EPP[2], CEG[3]), health infrastructures (CSB[4] I et CSB II), an electric network since 2007 (presence of a micro thermal diesel power plant) and drinking water supply lines, managed by a private organism Beforona is accessible during the whole year by the NR2. However, the fokontany of the community can only be reached by feet because of muddy and slippery paths. Moreover, they cross hillsides with steep slopes ***Localities et villages*** The site is situated 5km South from Antsakarivo (county seal of the fokontany). It counts about 600 inhabitants divided in more than 100 households. The fokontany is mainly composed by Betsimisaraka. However, about 20% of the population are migrants (Merina, Sihanaka, Antesaka and Betsileo). Antsakarivo, previously called Haranana, used to welcome migrants because of the huge rice fields in the valley. Then, the rise of the ginger crop in the 60s gave birth to the new village name: Antsakarivo, which means “where ginger is”. Because of the population growth, people dispersed in order to create new crop parcels, mostly on hillsides (tanety). Generally, those are temporary crops (sort of campsites): used for 5 years max and inhabited only during a “tavy”. However, close to the irrigable valleys, the huts can be permanent The two main villages around the AD 411 site are Ambodivolo (~4kmNorth from the site) and Ambodimanga (~2km downstream of the site). Those contain more or less 50 households. Identified hamlets or campsites within a distance of 1km are composed by 1 to 3 huts on average. .

[1] CREAM 2013 – Monographie de la Région Alaotra Mangoro / Annexe 1 : Recensement 2009

[2] EPP : école primaire publique

[3] CEG : Collège d’enseignement général

[4] CSB : centre santé de base

	  Ambodivolo Village Ambodimanga Village
ACTIVITIES	The agriculture is the main activity in the area. It is mainly rice growing but there are some other subsistence crops (manioc, sweet potato, corn and some vegetable crops). The agriculture is still based on slash-and-burn cultivation, in particular for hillside parcels (rain crops). The lowlands take the form of rice fields. Furthermore, we can see cash crops in the area (coffee, banana, ginger, sugar cane). The villages are surrounded by tree plantations (banana trees, coffee trees, etc.). The population uses extensive livestock of zebus and some small breeding used for self-consumption and sometimes for sale. The rest of the forest areas represent a timber reserve (construction and energy). However, firewood is found in savoka and shrubby forests. Moreover, the population uses a lot of ravinala, which is a special characteristic of savoka : the dried leaves are used for roofing; falafa (split petioles) are used to create wall panelling: the tree trunk is used as floor. As a housing hut lasts more or less only 10 years, secondary forests allow farmers to periodically renew them at low price. There is no fishing in the area. It is just a game for kids in order to have a different meal.  Ginger producer transporting his yield towards the RN2  Drying coffee in Antsakarivo
OTHERS (IF ANY)	The site is located in mining plots possessing an authorization to look for garnet. Other smaller mining plots possessing an authorization for smallholder farmers (until 2018) are located more than 5km North from the site.

C - World Bank operational policies that could be applicable:

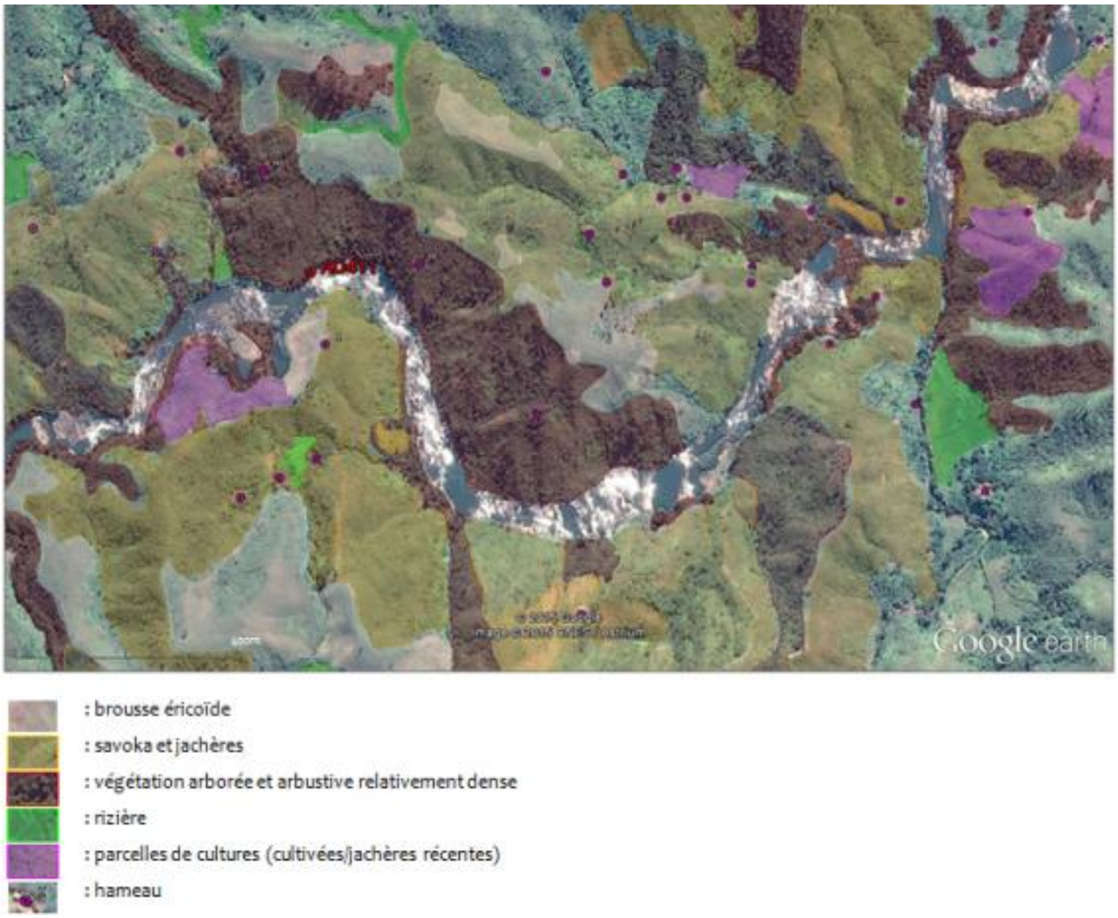
PO 4.01 – Environmental Assessment ☒

PO 4.04 – Natural Habitats

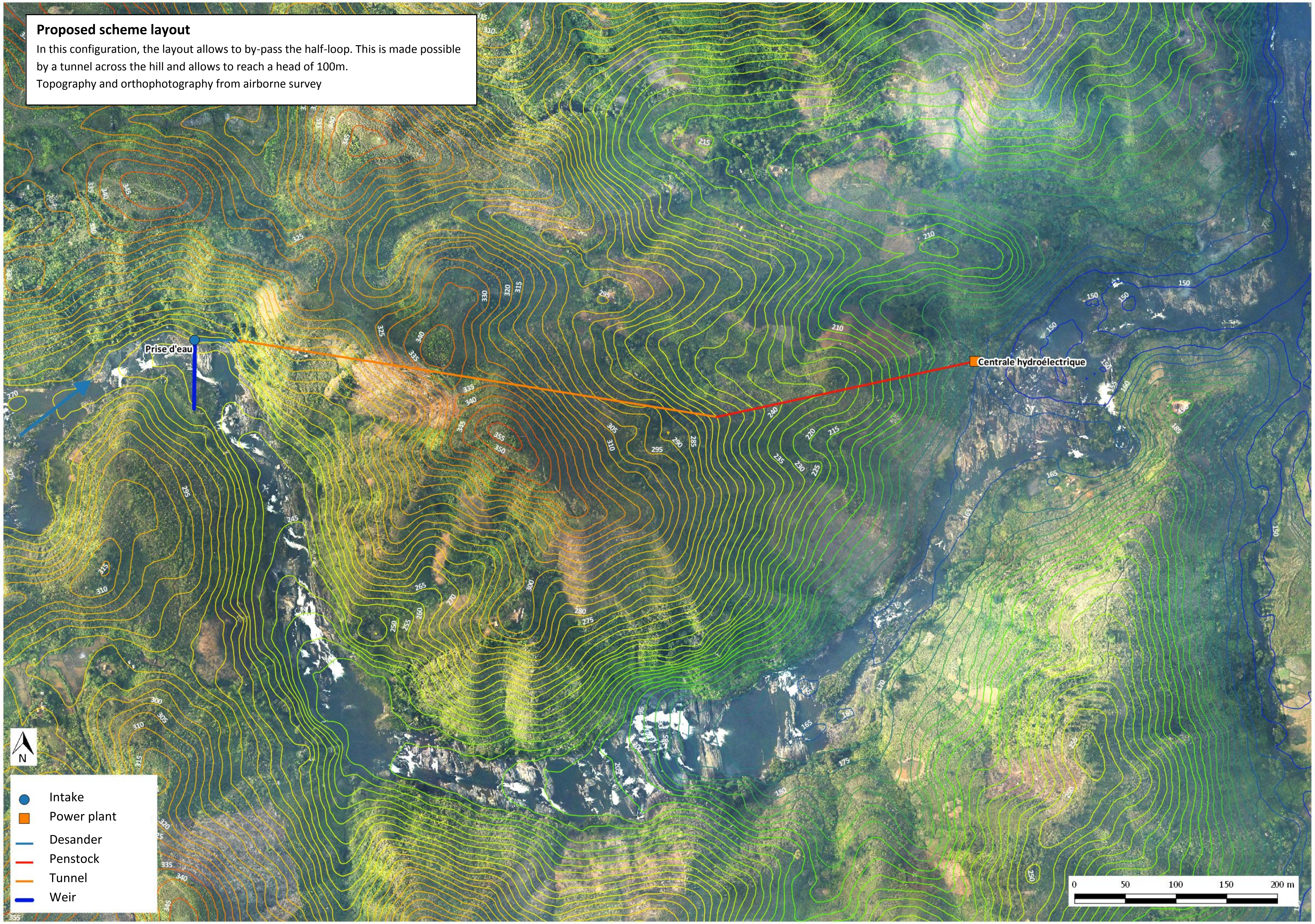
PO 4.11 – Cultural Heritage ☐

PO 4.12 – Involuntary Resettlements ☒

PO 4.37 – Safety of Dams ☐



5.2 Proposed scheme layout



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Madagascar: Small Hydropower Resource Atlas (1-20MW)
Site Investigation Report

ANTARALAVA SITE

Imorona River | Atlas Code: AD601

Table of content

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1 SITE LOCATION

Geographical coordinates (WGS 84)	Longitude [°]	Latitude [°]
Intake	46.711	-20.591
Powerhouse	46.708	-20.594

1.1 Administrative data

Atlas code	AD601
Site name	Antaralava
River	Imorona
Major river basin	Tsiribihina
Province	Fianarantsoa
Region	Amoron'i mania
District	Ambatofinandrahana
Commune	Ambatofinandrahana
Village	Sambalahy à 2km à l'Est du site

1.2 Access

Access to the site is easy given its proximity with road RN35 (120m). However, this road is in poor conditions and one of the bridge is damaged (collapsed bridge deck). Rehabilitation and strengthening of the road should be considered on a distance of 5km. Moreover, access to the scheme's infrastructures will require the lying of 600m of new road.

Figure 1. Site access from Ambatofinandrahana

Figure 2. Villages close to the site

2 General site description

2.1 Background

The total head is created by a succession of small waterfalls. An irrigation scheme is in use at the site location. The proposed scheme layout would partly use the same layout, while requiring heavier infrastructures to carry a higher flow to the powerhouse.

Slopes on the river banks are gentle enough to enable a canal system solution.

Figure 3. Site overview (GoogleEarth)

Figure 4. Global view of the site

2.2 Topography

Figure 5. Aircraft and container of remote sensors for airborne survey

The topographical survey was achieved through remote sensing. An aircraft was chartered and equipped with optical sensors.

The topographical survey has a point density of 5 /m² and a relative accuracy of 2%.

Outputs from airborne survey are (1) a high resolution orthophotography (0.2m to 0.4m resolution) and (2) a Digital Surface Model (DSM). The DSM includes the vegetal cover, but it gives an excellent global picture of the site topographical configuration. Contour lines might be deduced from the DSM.

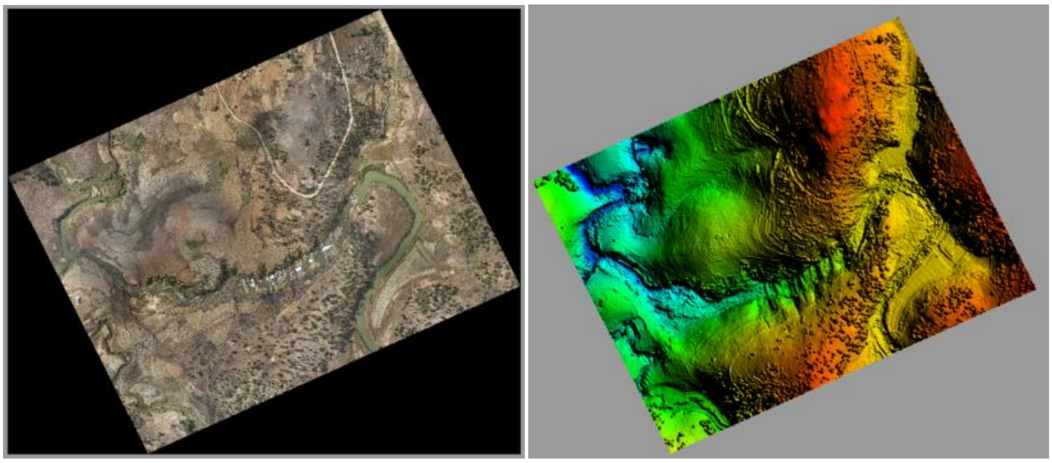

Figure 6. Orthophotography and Digital Surface Model from airborne survey

2.3 Preliminary hydrological study

Accurate information on the hydrology of the Imorona River does not exist. As a consequence, statistical characteristics of the river discharge at the site of interest have been estimated using a regional methodology. This methodology is based on the available information at other hydrometric stations distributed in the country. Given the limited spatial and temporal resolution of the available data, the results of the regional study presented below are indicative only and are not intended to be used for design purposes without further detailed hydrological studies.

Key preliminary hydrological characteristics of the river at the site of interest are presented in the table below.

River	Imorona
Main river basin	Tsiribihina
Area [km²]	491
Average elevation [m a.s.l]	1462
Slope index [m/km]	5.6
Specific vertical drop [m]	124
Average annual rainfall [mm/an]	1331
Average interannual discharge [m³/s]	9.8
$Q_{95\%}$ - firm discharge [m³/s]	3.1
$Q_{50\%}$ - median discharge [m³/s]	6.7
$Q_{30\%}$ [m³/s]	8.6
10yr return period flood [m³/s]	332
100yr return period flood [m³/s]	794

2.4 Sediment transport

Sediment issue is assumed to be important given the sand deposition on the river banks and the apparently active sand strip.

Figure 7. Detail of sand deposition on the river bank

2.5 Existing irrigation scheme

There is an existing irrigation scheme that irrigates both embankments of the river. A 1m high weir and 2 intakes are located upstream of the waterfall.

Figure 8. Existing weir

From satellite images observations we can deduce and assume a irrigation coverage of about 12ha (left bank) and 36ha (right bank). Because of the site topography and the fact that the left bank has only 25% of the total irrigation area, the impact on the irrigation scheme might be limited.

Figure 9. Irrigated area deduced from aerial images (GoogleEarth) and proposed hydropower scheme layout. North heads rightward

The right bank has a steep slopes downstream of the weir. A concrete support allows to cross the most difficult parts of the steep stretch.

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Figure 10. (a) Concrete support for the canal on the steep slopes of the right bank and (b) canal on the left bank

2.6 Site geology

2.6.1 *Geological context*

The area is dominated by leucocratic migmatitic granite with heterogranular facies and of direction N50E 20W. It is a massive rock that outcrops along the river, downstream of the projected weir axis. This rock formation is highly jointed. Moreover, as this rock undergoes surface decompression, spalling occurs and many of the superficial rocks in the area are covered by outcropping boulders.

The granitique texture influences the nature of its weathering laterite : it is leucocratic (white), compact and resistant. But narrow joints associated to surface spalling reduce the compactness and increases the risk of land or rock slides as well as erosion processes. This compact texture is found for the laterite as well as ferruginous ions migrate easily and rapidly at the surface level through the narrow fractures.

On a brittle tectonic point of view, the main directions are few and of minor importance. They are sometimes reduced to simple fractures directing the flows, as the one followed by the concerned river.

2.6.2 *Technical characteristics*

<u>Bed aspect at the exisiting weir location:</u> the existing weir is founded on sound rock. It is set parallel to the rock formations inclination (20°W), what ensures an increased resistance towards flow, even during flood events.

<u>Left and right bank support aspect:</u> the right support is founded directly by compact laterite via a masonry system including the intake (Figure 11). The left support is founded on a superficial part of the granitic rock, not yet weathered (Figure 12).

Figure 11. Right bank support of the existing weir

Figure 12. Right bank support of the existing weir

Waterway: the existing canal on the right bank is excavated in structured laterite as defined above. The water flow is quite and without apparent perturbation. Potential leakage is prevented by the grassing on the canal sides

2.6.3 *Recommendations for further investigations*

ELEMENT	UNCERTAINTY TO REMOVE	SURVEY TYPE
Bed at weir	✓ From the existing weir for irrigation, four series of drops are observed downstream in the river. Sound rock masses crop out in an almost flat direction during low water. Hence, the setting up of a new weir should not induce any particular problem is terms of foundation quality.	✓ Once the final weir axis defined, check the solid nature of the bedrock.
Right and left supports	✓ No lavakas are observed in the surroundings and the compactness of the laterite along the river banks is rather good, hence there should not be any troubles regarding supports.	✓ Once the final weir axis is defined, several observations should be conducted about the nature and arrangement of the support which might be a rock formation (open joints or spalling issues), boulders (in-place or reworked), structured laterite (compact or resulting from a landslide), or just superficial laterite (indurated or not) such as the one on the supports of the existing irrigation weir.
Intake / waterway	✓ The intake and waterway are foreseen on the left bank. They must be excavated in structured laterite, as defined above. The canal slope must remain low so that the flow does not induce perturbations and to preserve the canal from headward erosion. Boulders will probably be found along the canal trace.	✓ A more detailed observation of the intake and waterway trace should be conducted once their final location is defined, as well as the weir axis. Then, areas where tectonic and structural effects could have a negative impact (opening of joints or increased spalling) requiring masonry works should be detected
Penstock	✓ Characterization and state of the supporting ground	✓ More detailed observations of the vertical alteration series, from sound

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		rock at the basis to boulders and lateritic alterations on top.
Powerhouse	✓ Characterization of the supporting ground for the powerhouse foundations (Massive rock? Boulder in place or not? Depth of laterite?)	✓ Auger drilling or seismic reflection geophysical survey

2.7 Socio-environmental aspects

The site detailed description sheet is provided in the Appendices.

2.7.1 *Socio-environmental background*

The site is located on the Imorona River. Is is situated in the Fokontany of Sambalahy, rural community of Ambatofinandrahana, Ambatofinandrahana District, region of Amoron'i Mania.

The vegetation of the area is characterised by Tapia forests (*Uapaca bojeri*) that covers in a sparse way the hillsides. Herbaceous layers are associated with Tapia forests. On the other hand, the penstock pipe will cross large areas, that are irrigated by existing infrastructures.

Downstream, on the non-cultivated banks, we can see some riparian forests. Some *Pinus* forests can also been found, in particular on the right river.

Image 13. Vegetation near the existing weir

From the socio-economic perspective, the main village (Marovoalavo) is situated close to the site (about 500m North). It has about 20 housings and is situated on the edge of the NR35 (~15km from Ambatofinandrahana). Within a radius of 500m around the existing weir, there are two hamlets, one East and one South-East. Moreover, one hamlet is situated less than 500m West from the potential power plant site.

The JIRAMA plant in Ambatofinandrahana is furnished with 4 portable generators but only one is operational and its maximum power capacity is about 135 kW/day. There is electricity only 12hours/day, from noon to midnight. The generator uses about 300L of fuel/day.Draining should be done every 500 hours and the filter has to be changed every 600 hours.

There are currently 400 households linked to the electricity supply network from the JIRAMA plant in Ambatofinandrahana. Among the subscribers we can find the aministration services and the collectivities. About 50 requests of new connexions are on hold, but the JIRAMA plant cannot answer these requests because its production level is low. The town also has 14 public lighting devices (power poles) that work until midnight.

The supply network is composed by a low voltage line (7 600m long). In 2012, the JIRAMA plant thought of transforming the low voltage line into a medium voltage line but, until now, the project has not been realised yet.

According to the JIRAMA spokesmen, some potential hydroelectric sites exist in the area, in particular in Ifasina and in Antsangandrano (a survey was done by EDF in 1999).

The main activity is rice growing. There are two types of rice growing: lowlands cultivation and irrigated terrace rice cultivation, which is the most common one. At the projected weir site, an operational weir supplies two intakes that feeds the 20 ha terrace rice fields in water on both sides of the Imorona River.

The rice growing is generally associated to subsistence crops, which generally depend on the rain (manioc, etc).

Breeding, in particular cattle breeding, is also one importante activity for the local population. The extent of the pastures near the area attracts a lot of migrant farmers.

The following image gives a global overview of the land use in the area.

Image 14. Land use of the AD 601 site

2.7.2 *Socio-environmental constraints*

Some hamlets are situated next to development sites (weir, canal, penstock pipes, power plant) The implementation of the project will affect those hamlets, especially regarding potential nuisances (noise, traffic, atmospheric emissions…). The short distance between the hamlets and the working site (less than 500m) will increase the risk of an accident for the concerned population.

The two existing intakes on the existing weir feed irrigated areas on both banks of the river. The project plans to partly by-pass the irrigation scheme on the left bank of the river and will thus impact the amount of water brought to these areas. About ten hectares are concerned.

Furthermore, the expected route of the penstock pipe crosses fields that are irrigated, on the left bank of the river. This will create a loss of surfaces for the development and the exploitation of the penstock pipe.

2.7.3 *World Bank operational policies that could be applicable:*

The World Bank Safeguard Policies that could be considered for the AD601 site are the following:

- OP 4.01 – The Bank requires Environmental Assessment (EA) of projects proposed for Bank financing to help ensure that they are environmentally sound and sustainable, and thus to improve decision making. However, we can already estimate that the adverse impacts on human populations and environment-linked areas are limited. They are reduced, not irreversible and some measures can prevent, mitigate or minimize them. Moreover, these measures can improve the environmental performance.

- OP 4.12 – Involuntary Resettlement: the hydropower project will require the use of a large space (implementation of the plant, creation of access roads to the site…), which sometimes are crop areas (for example along the penstock). So the project will have to take into account the concerned people and communities, particularly regarding the restoration of the standards of living due to the loss of resources.

OP 4.04 – Natural Habitats is not applicable. Same applies for OP 4.11 – Cultural Heritage.

The projected weir (4m high) is classified as a small dam (<15m high); the usual generic safety measures for dams are appropriate and do not need the OP 4.37 – Safety of Dams (for large dams) to be implemented.

3 PROPOSED SCHEME LAYOUT

3.1 Technical assumptions

The left bank has gentler, more stable slopes and is preferred for the infrastructures of the hydropower scheme. Moreover, perturbations on the irrigation scheme will be less important on that side. Finally, the site for the powerhouse is also better on the left bank. The downside is an access to the left bank (a bridge) needs to be prepared.

An assessment of the scheme potential in terms of installed capacity, energy generation (firm and average) and the associated capital investment costs (CAPEX) and productions costs (Levelized cost of energy) is presented in section 4. It is based on the scheme proposed in this section. Hence, at this stage of the study, the technical features of the hydropower scheme are designed for both firm and median discharges (respectively $Q_{95\%}$ and $Q_{50\%}$). The actual design flow will be determined during the detailed studies based on economical, financial and technical criterion as well as the future energy and power demand.

The proposed scheme layout is shown below and presented in A3 format in the Appendix of this report.

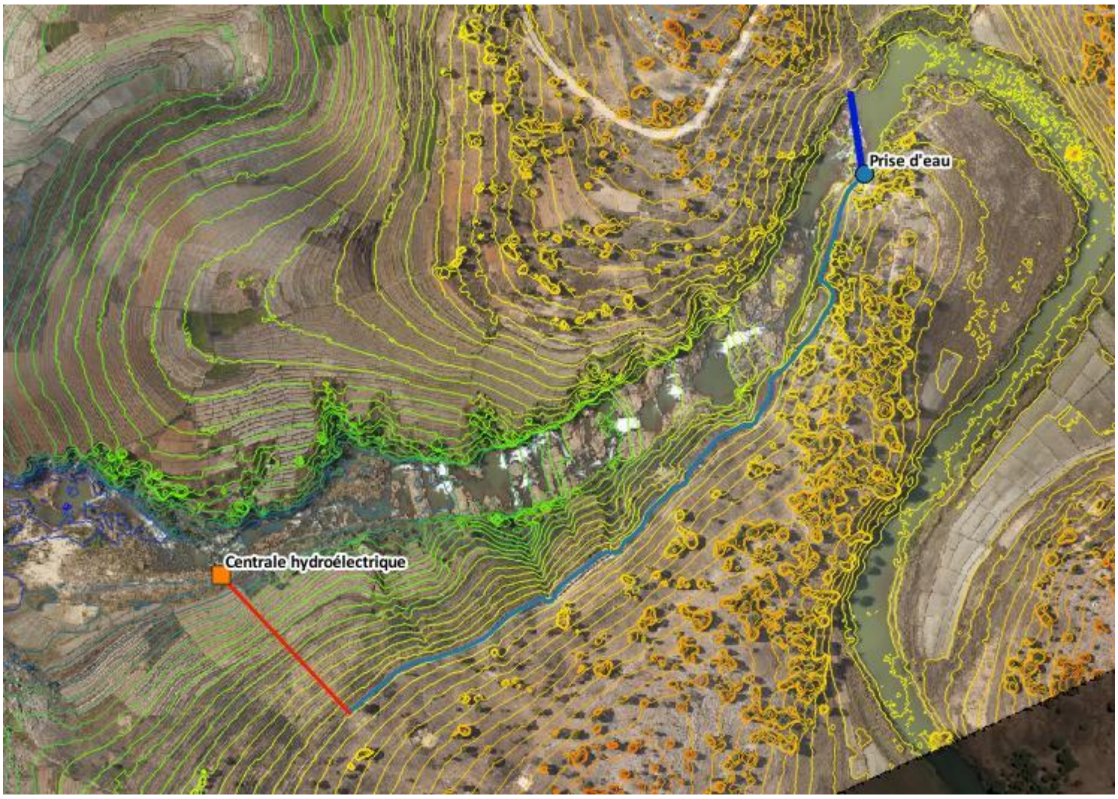


Figure 15. Proposed scheme layout

3.2 Weir and intake

The weir would be 4m high and 65m wide. The weir currently used for the irrigation scheme will not be enough and will probably be completely replaced. A flushing gate will be set up in the weir just beside the intake.

3.3 Desander

A desander will be necessary. 2 options seem feasible at this stage: either upstream or just downstream of the first set of waterfalls.

3.4 Waterways

A canal, lined with stone masonry will carry the water from the intake to the forebay (610m long) on the same alignement that the current canal. Just upstream of the forebay, a flow divider will allow the scheme to secure 200 l/s for irrigation purpose.

3.5 Penstock and powerhouse

The gentle slopes of the left bank allow an easy access to the powerhouse. Penstock will be 145m long and it will have a diameter of 1.00m for the firm flow or 1.20m for the median flow.

Figure 16. Potential site for the powerhouse

3.6 Electromechanical equipments

3.6.1 *Design flow taken at Q_{95}*

For a design flow at Q95, there is no need to choose a turbine with a high flexibility regarding discharge variation. Given the available head, a Francis turbine might be chosen as it presents a high performance level and a satisfactory flexibility with regard to the probable development of connections to Ambatofinandrahana.

Francis turbine is preferred ton Crossflow (or Banki) turbine which is less robust and less resistant to abrasion. Moreover, this type of turbine requires a gearbox that will reduce the global reliability and will increase maintenance works.

Given observations formulated about water quality, a particular attention must be paid to the quality of materials used for the construction of the turbine. One should probably consider the need for an anti-abrasion coating.

Electromechanical equipments of the powerhouse will then be composed of:

- Butterfly safety valve with counterweight to ensure its closure in case of emergency of black out.
- A 830 kW horizontal axis Francis turbine running at 1000rpm.
- A flywheel, required to operate the powerhouse in an isolated grid.
- A 400V alternator, 780kW/ 870 kVA.
- Control and monitoring system, including speed regulator and voltage regulator.
- Security system and electrical protection.
- Step-up transformer and electrical cabinet and switchgear.
- Emergency power unit.

Following issues should be studied as well in the next stages of the project :

- Sedimentation problem and the need for anti-abrasion coatings (e.g. Tungsten carbide).
- Technical and economic optimization of the penstock diameter.
- Technical and economic optimization of the number of units and of the design flow, according to the hydrology and the electrical demand.
- The need of a flywheel (for grid stability)
- The set up level and rotational speed of the turbine (Suction height and cavitation issues).
- Grid voltage.
- Preliminary turbine design.

Figure 17. Example of horizontal Francis set

3.6.2 *Design flow taken at Q_{50}*

For a design flow taken at Q50, it is recommended to install two identical units (Francis turbines) in order to optimize the global efficiency and to increase the plant availability.

Other considerations exposed for a design flow at Q95 remain valid for a design flow taken at the median discharge (Q50).Turbines will have a unit nominal power of 900kW and a rotation speed of 1000 rpm. The alternator power will be 850 kV/ 940 kVA for a 400V or 690 V voltage.

A power plant PLC (Programmable Logic Controller) should also be foreseen to manage the two units.

3.7 New irrigation scheme's organization

Given the power needs in the area (diesel plant in town of 135kW), and the water needs for irrigation purpose on 45ha (180 l/s estimated), power production and irrigation might coexists without exclusion. Indeed, the firm flow has been estimated to 3.1m³/s, which allows a production of 780kW (200 l/s deduced for irrigation purpose).

Irrigation of the area between the canal and the river will be ceased and deep roots vegetation will be set up to protect the stability of the slopes. Including a buffer area around the penstock and the powerhouse, an area of 1.7 ha will be required from the irrigation zone.

3.8 Transmission lines

Power from the plant would be evacuated by a 35 kV, 15 km long line to Ambatofinandrahana town. Indeed, given the limited production capacity, the interest of the site is mainly local.

The JIRAMA currently supplies power a few hours a day with a diesel generator.

3.9 Key technical features

Key technical features are presented below for both the firm flow and median flow.

		Firm flow	Median flow
Installed capacity	[kW]	780	1700
Potential annual generation	[GWh/y]	6.03	12.56
Design flow	[m³/s]	2.9	6.5
Gross head	[m]	34	
100yr return period flood	[m³/s]	794	
Weir length	[m]	65	
Weir height	[m]	4	
Desander		large size	
Canal length	[m]	610	
Canal section (b x h)	[m]	2 x 1.2	2.95 x 1.85
Penstock length	[m]	145	
Penstock diameter	[m]	1	1.2
Number of penstock(s)	[pce]	1	1
Number of T/G units	[pce]	1	2
Transmission line length	[km]	15	
Line voltage	[kV]	35	
Length of the access road to create	[km]	0.6	
Length of the access road to upgrade/rehabilitate	[km]	5	

4 ENERGY GENERATION AND COSTS

The project would have the following economical and energetical performances, with the assumptions detailed above.

Gross head	**[m]**	34	
Design flow	**[m³/s]**	2.9 ($Q_{95\%}$)	6.5 ($Q_{50\%}$)
Installed capacity	**[kW]**	780	1 700
Potential annual generation	**[GWh/y]**	6.03	12.56
CAPEX (excl. access and lines)	**[M$]**	4.29	6.47
LCOE (excl. access and lines)	**[$/kWh]**	0.085	0.062
Total CAPEX (incl. access and lines)	**[M$]**	6.96	9.14
Total LCOE (incl. access and lines)	**[$/kWh]**	0.137	0.087

5 Appendices

5.1 Socio-environmental datasheet

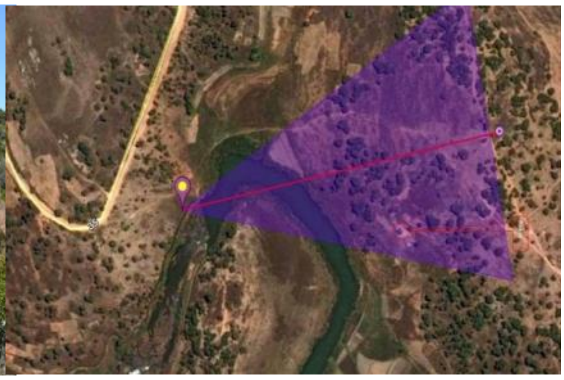
A – Site localisation

Site reference	:	AD 601
Village / Fokontany	:	Marovoalavo / Sambalahy
Community / District-Region	:	Ambatofinandrahana/Ambatofinandrahana-Amoron'i Mania

B - Description of the biophysical background

<table>
<tr><td>RELIEF</td><td>The AD 601 site is located in the central highlands, about 12 km East from Itremo massif. The projected site is at approximately 1200m of elevation and is limited by:
North and East: by the topographic glacis, extension of the Manaforahona crest line (1 459m)
South and West: by the topographic glacis, extension of the Andrianisindika crest line (1 504m)
The close relief is created by a series of valleys. The hillsides have mean/gentle slopes.

Topography defined by gentle slopes
Hydrography: mostly the Imorona River, tributary of the Mania River. Upstream of the weir, the Imorona River receives the Riantsasina River and other temporary waters. Downstream, Antsihobe and Antsiho Rivers go to the Imorona River, close to Marovoalavo.</td></tr>
<tr><td>VEGETATION</td><td>The vegetation in the area is characterised by the presence of sclerophyll forests of Tapia (Uapaca bojeri). Tapia create a sparse cover on the hillsides. Layers of herbaceous are linked with Tapia forests.

Riparian forests are found alongside the waters, on the not cultivated banks. Some Pinus forests can also be seen, in particular on the right side of the Imorona River.
 </td></tr>
</table>

	Sparse vegetation, mostly Tapia S20°35'27.43" E46°42'41.35"   Small Pinus forests on the right bank of the Imorona River; close to the projected site — Riparian bush upstream of the weir site (S20°35'27.00" E46°42'42.17")
OBSERVATIONS	The landscape is composed by crop fields on the hillsides, with a lot of terrace. The site was created to support the town of Ambatofinandrahana and the MAGRAMA marble company (Antaralava data sheet – JIRAMA, APS in 1982). Following the closing of the marble company, the project was said unprofitable.
SENSITIVITIES	There are two sensitive sites in the area: - The Contract-based Management of Forests site(GCF) of the Itremo Community de l'Itremo; - And the SAPM[1] sites composed by : o The NAP (New Protected Area) « Itremo Massif », situated +- 12km West of the site. At first created by the RBG[2] / Kew, the NAP is currently managed by the KMCC[3] and by 8 basic Communities(COBA), embodied by 24 members of the IMPACT (Itremo Massif Protected Area Conservation Team). o 2 potential sites respectively at 10km East and 5km West, suggested by the REBIOMA[4] and the APAPC[5].

B - Description of the socio-economic background

LOCALITY	Fokontany Sambalahy, Sector of Marovoalavo – Community of Ambatofinandrahana – Ambatofinandrahana District (Region of Amoron'i Mania). You can access to the site via the national road 35, 20km West of Ambatofinandrahana. **<u>Community of Ambatofinandrahana :</u>** The site belongs to the community of Ambatofinandrahana. The latter's surface is about 650 km² and counted about 35 000 inhabitants in 2009[6], divided in 21 fokontany. Its is an average of 1 600 inhabitants/fokontany. You can access the county seat of the community via the national road 35 anytime. It has education infrastructures (EPP[7], CEG[8] and school), health infrastructures (CHD[9] II, CSB[10] I and CSB II) and sanitary infrastructures (public toilets and

[1] SAPM : Système d'Aires Protégées de Madagascar (Protected areas system of Madagascar)

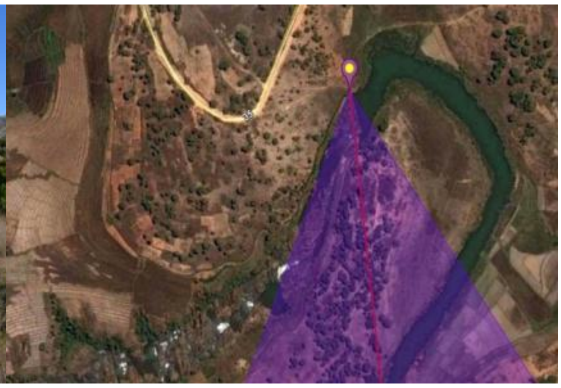
[2] RBG : Royal Botanic Gardens

[3] KMCC : Kew Madagascar Conservation Centre

[4] REBIOMA: Réseau de la Biodiversité de Madagascar (Biodiversity Network of Madagascar)

[5] APAPC : Assessment of Priority Area for Plant Conservation

[6] CREAM 2013, Monographie de la Région Amoron'i Mania / Annexe 1 : Recensement 2009

	laundry). Moreover, it has sport and sociocultural infrastructures. About roads and diverse networks, only Ambatofinandrahana receives electricity and drinking water: - electricity: the thermoelectric plant of JIRAMA provides electricity to the town of Ambatofinandrahana since 1975 ; - water supply: the town possesses an autonomous service via gravity system. The supply is handled by the community via 115 standpipes, 60 of which are operational. ***Localities and villages :*** The closest main village is Maroalavo. It is situated 500m North from the site. There are 20 houses and it is situated on the edge of the NR35 (~15km from Ambatofinandrahana). Two hamlets are in the North-North-East of the site, upstream of the weir. The other is located downstream of the river, heading South. Those three hamlets are situated less than 700m from the site.
ACTIVITIES	The main activity is rice growing. There are two types of rice growing: lowlands cultivation and irrigated terrace rice cultivation, which is the most common one. At the projected weir site, an operational weir supplies two intakes that feeds the 20 ha terrace rice fields in water on both sides of the Imorona River. The rice growing is generally associated to subsistence crops, which generally depend on the rain (manioc, etc). Breeding, in particular cattle breeding, is also one importante activity for the local population. The extent of the pastures near the area attracts a lot of migrant farmers.   Existing weir, with water intakes to irrigate downstream crops S20°35'25.30" E46°42'41.79"

[7] EPP : École Publique Primaire (Public primary school)

[8] CEG Collège d'Enseignement Général

[9] CHD : Centre Hospitalier de District (District Hospital)

[10] CSB : Centre Santé de Base (Basic Health Centre)

<table>
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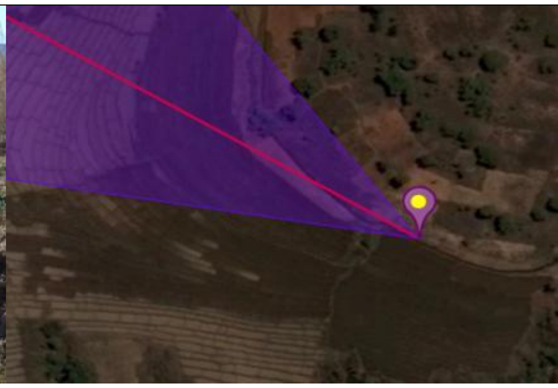
<td></td>
<td>
Irrigation canal in the ground of the right bank (the riversides are partially cultivated)
S20°35'33.27" E46°42'33.59"</td>
</tr>
<tr>
<td>OTHERS (IF ANY)</td>
<td>Most of the local population comes from Betsileo. Moreover, an important part of Antandroy/Bara is present, attracted by the favourable pastures for zebus extensive breeding.

The site is located on mining spots (research authorization expired in 2014). Other mining spots exist, here is what they do:

- marble and gabbro exploitation (authorization until 2044) in Ambatofinandrahana by MAGRAMA company, which is situated 10km and 12km South-East from the site (but this company is currently closed) ;
- research and exploitation, situated 5km South-West (PRE authorization – authorization for research and exploitation reserved to smallholder farmers, until 2017) ;
- research, situated 6km West from the site. (research authorization that expired in March 2015).

JIRAMA Ambatofinandrahana :

The JIRAMA plant in Ambatofinandrahana is furnished with 4 portable generators but only one is operational and its maximum power capacity is about 135 kW/day. There is electricity only 12hours/day, from noon to midnight. The generator uses about 300L of fuel/day.Draining should be done every 500 hours and the filter has to be changed every 600 hours.

There are currently 400 households linked to the electricity supply network from the JIRAMA plant in Ambatofinandrahana. Among the subscribers we can find the aministration services and the collectivities. About 50 requests of new connexions are on hold, but the JIRAMA plant cannot answer these requests because its production level is low. The town also has 14 public lighting devices (power poles) that work until midnight.

The supply network is composed by a low voltage line (7 600m long). In 2012, the JIRAMA plant thought of transforming the low voltage line into a medium voltage line but, until now, the project has not been realised yet.

According to the JIRAMA sposkmen, some potential hydroelectric sites exist in the area, in particular in Ifasina and in Antsangandrano (a survey was done by EDF in 1999).</td>
</tr>
</table>

C - World Bank operational policies that could be applicable:

PO 4.01 – Environmental Assessment ☒

PO 4.04 – Natural Habitats ☐

PO 4.11 – Cultural Heritage ☐

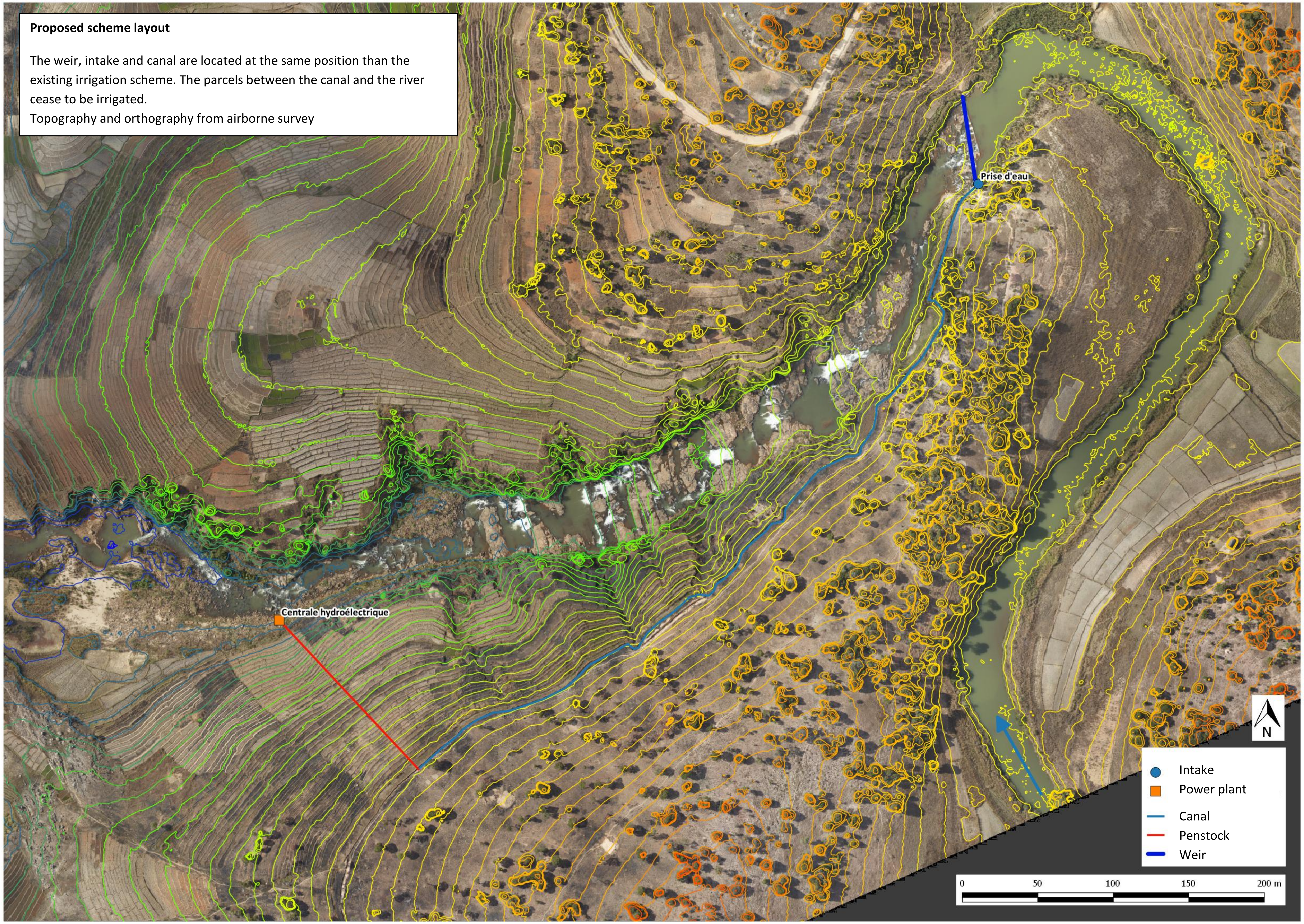
PO 4.12 – Involuntary Resettlements ☒

PO 4.37 – Safety of Dams ☐

Land use around the site

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

5.2 Proposed scheme layout



Madagascar: Small Hydropower Resource Atlas (1-20MW)
Site Investigation Report

BEHINGITIKA SITE

Manandriana River| Atlas Code: AD620

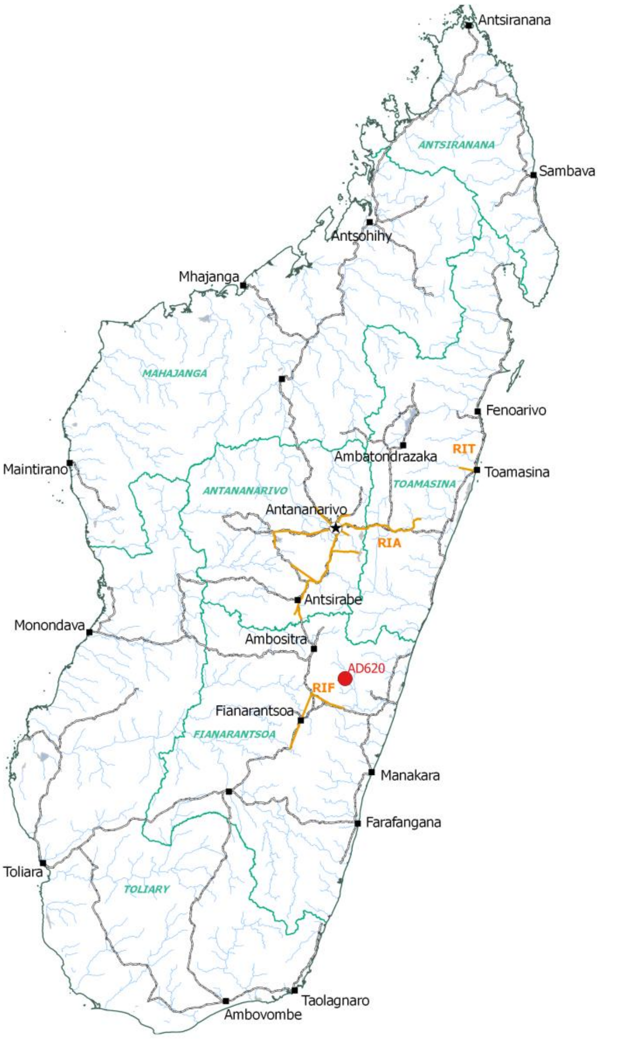


Table of contents

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

1 SITE LOCATION

Geographical coordinates (WGS 84)	Longitude [°]	Latitude [°]
Intake	47.655	-20.907
Powerhouse	47.659	-20.908

1.1 Administrative data

Atlas code	AD620
Site name	Behingitika
River	Manandriana
Major river basin	Mananjary
Province	Fianarantsoa
Region	Vatovavy Fitovinany
District	Ifanadiana
Commune	Ambohimanga Atsimo
Village	Ambilanibe

1.2 Access

Reliable access to the project site is possible from the N25 at Ifanadiana and then using the rural road going North to Ambohimanga du Sud. The N25 road is tarred and in good condition. Please note that the rural road starting from Ifanadiana and going North was partially renovated on the first 15 kilometers to the bridge at Sandrakely but suffered heavy damages due to traffic of heavy vehicles from the mine.

The construction of a small hydropower project involves the rehabilitation of the access road from the Sandrakely Bridge on a distance of about 30 km upon several stretches. Then, the access road to the site and to the powerhouse from Ambohimanga du Sud needs to be created over a total distance of approximately 13 km but on a flat and easy alignment.

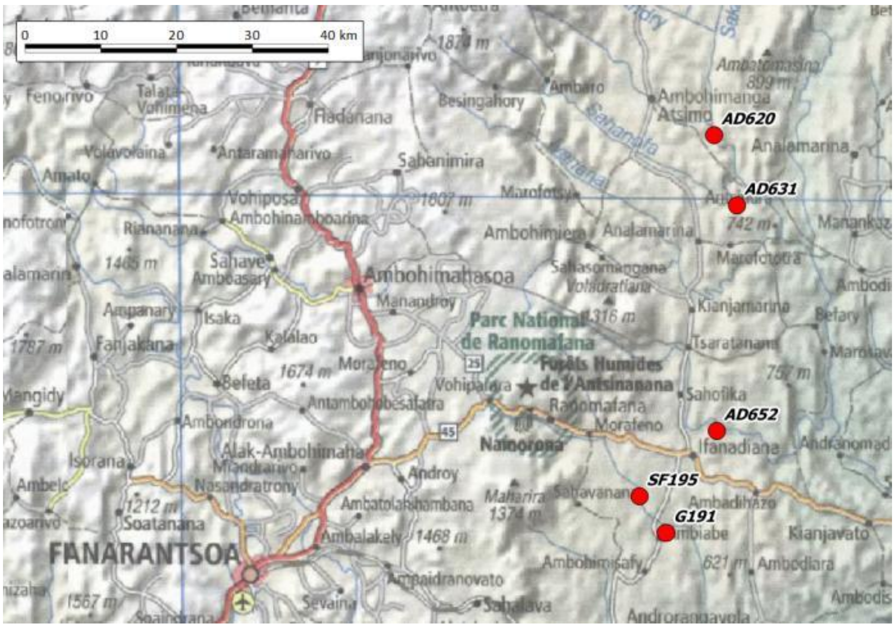


Figure 1. Site access

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

2 GENERAL SITE DESCRIPTION

2.1 Background

The site is characterized by a first drop of approximately 5 m high on a rocky outcrop then several small drops. This configuration allows a gross vertical drop of 25 meters for hydropower bypassing a river stretch of 450 m. The site is interesting for supplying a isolated network powering the town of Ambohimanga du Sud and the surrounding villages.

At present, there is neither hydro-agricultural nor hydropower scheme at the proposed site location. Note that the potential site is followed by a second interesting stretch from a hydraulic point of view with the possibility to reject the water collected in the Manandriana River directly in the downstream Mananjary River. Ultimately, this section could be a possible extension of the project (cascade hydropower plants).

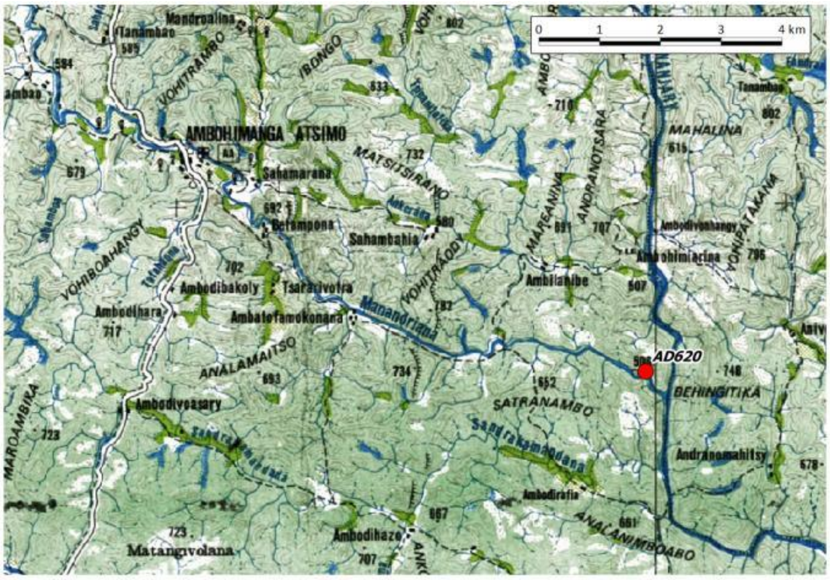


Figure 2. Topographic map (scale 1:50,000)

Figure 3. Satellite image (Google Earth)

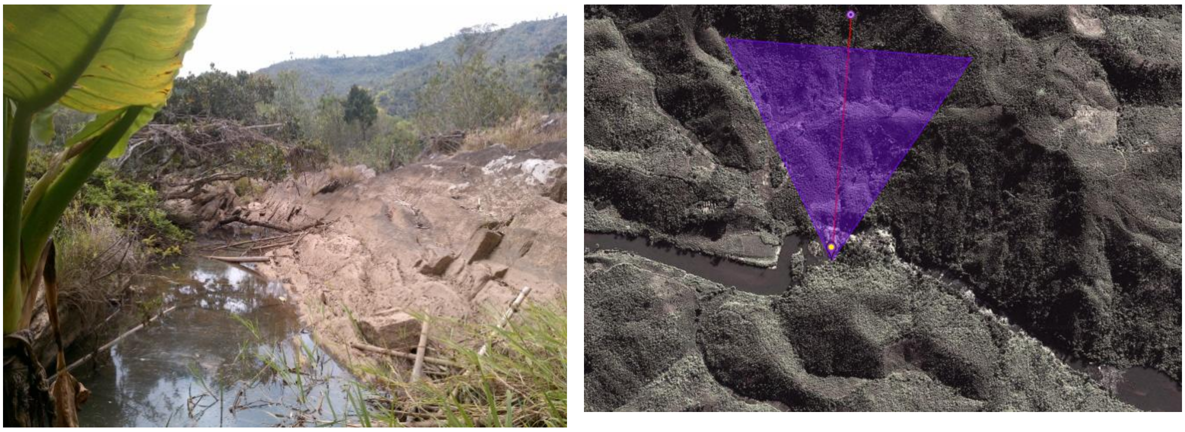


Figure 4. View of the proposed location of the weir.

Figure 5. View of the river.

2.2 Topography

The topographical survey was achieved through remote sensing. An aircraft was chartered and equipped with optical sensors.

Figure 6. Aircraft and remote sensors container for airborne survey

The topographical survey has a point density of 5 /m² and a relative accuracy of 2%.

Outputs from airborne survey are (1) a high resolution orthophotography (0.2m to 0.4m resolution) and (2) a Digital Surface Model (DSM). The DSM includes the vegetal cover, but it gives an excellent global picture of the site topographical configuration. Results are illustrated in the figures below and the contour lines deducted from the DSM are presented on the detailed proposed scheme layout in section 5.2.

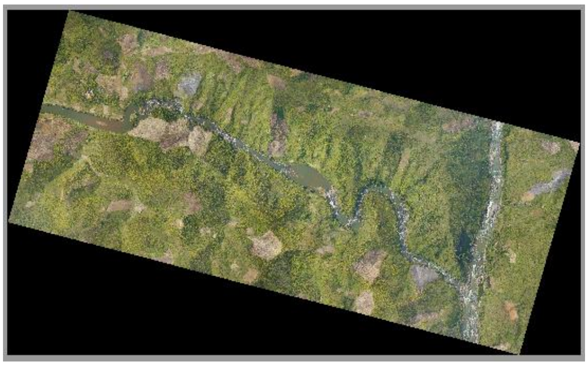


Figure 7 Orthophotography of the site

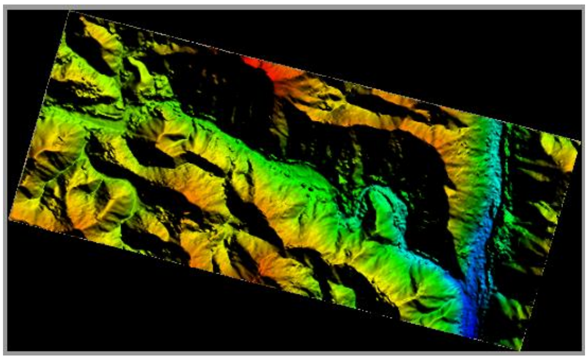


Figure 8. Digital Surface Model of the site

2.3 Preliminary hydrological study

Accurate information on the hydrology of the Manandriana River (tributary of the Mananjary River) does not exist. As a consequence, statistical characteristics of the river discharge at the site of interest have been estimated using a regional methodology. This methodology is based on the available information at other hydrometric stations distributed in the country. Given the limited spatial and temporal resolution of the available data, the results of the regional study presented below are indicative only and are not intended to be used for design purposes without further detailed hydrological studies.

Key preliminary hydrological characteristics of the river at the site of interest are presented in the table below.

River	Manandriana
Main river basin	Mananjary
Area [km²]	289
Average elevation [m a.s.l]	819
Slope index [m/km]	9.7
Specific vertical drop [m]	164
Average annual rainfall [mm/y]	2 018
Average interannual discharge [m³/s]	12.6
$Q_{95\%}$ - firm discharge [m³/s]	3.4
$Q_{50\%}$ - median discharge [m³/s]	9.7
$Q_{30\%}$ [m³/s]	13.6
10yr return period flood [m³/s]	336
100yr return period flood [m³/s]	711

2.4 Sediment transport

The measured turbidity of water was good (below 20 NTU) at the time of the different site visits (June 2015). However the presence of sand deposits demonstrates that significant erosion and deposition processes occur at some period of the year, likely during major flood events.

Adequate sediments and gravels trapping systems will be designed at the feasibility study stage based on an analysis of the sediment load at different river discharges.

2.5 Site geology

2.5.1 Geological context

The study area consists of gneiss migmatitic including porphyroblast foliated texture disposed as benches. The whole structure has a subvertical dip tilted upstream relative to the flow of the river (Figure 10).

Figure 9 Gneiss migmatitic

Very open in surface, the joints intersect perpendicularly the strata; they are sometimes filled with quartz veins. Migmatitic banks also have large planar scales following their foliation planes. This results in a breakdown in parallelepiped boulders. Note that a regional fault of NW-SE direction is followed by the river further downstream. It plays an important role on the opening of the foliation and disturbance of the arrangement of rock strata in this area.

Figure 10 Lateritic strata protected by vegetation cover

The effects of lateritic weathering are relatively large (several meters) caused by the open foliation of surface rocks and subvertical arrangement. It is the red hard laterite (clay and sand), however protected by vegetation cover, it can not turn into lavaka.

Figure 11 Subvertical downstream dip

The whole sector has low hill morphology, devoid of vegetation, slashed by many small streams.

2.5.2 Technical characteristics

<u>Bed aspect at the projected weir location:</u> Covering the bottom of the river, mass rocks will be the foundation of the weir as visible from the banks. These rocks are composed of migmatitic gneiss disposed in subvertical bench, with very open foliation, sometimes cut into blocks.

<u>Right bank support aspect .</u> Masses of rock outcrop appear on the edge of the river during low flow.

The bank left side offers views of massive rocks in place. In fact, the foundation of the dam consists of a mixture of Migmatitic benches in place and dismantled boulders, topped with a thick red hard lateritic accumulation.

Given the importance of the alteration in the sector it is advantageous to limit the height of the dam/weir to a few meters above the river to avoid problems with the lateral anchors on the lateritic weathering.

<u>Left bank support aspect :</u> At the weir location, the right bank is constituted by a relatively soft and poorly vegetated hillside. It reveals on its side big boulders embedded in laterite. On the banks there are also massive blocks from the dismantling of the bedrock in place.

<u>Intake and waterway</u> : Boulders zone : Boulders within an alteration of existing rocks under a rocky roof.

<u>Tunnel</u> : Chance to meet boulders in laterite at a certain depth from the surface before reaching the massive Migmatitic rock. The latter may be only relatively compact due to the influence of the regional fault passing nearby.

Depending on the final layout, special attention should be dedicated to the thalweg located at the center of the gallery and which will be very close to the elevation of the tunnel. A deviation of the tunnel or reinforcement may be considered.

Penstock: The place was not accessible during the reconnaissance mission. On the basis of satellite images it is deducted that we should be on a vegetalized plateau consists of Migmatitic gneiss boulders included in laterite (rockhead). Note that a stream crosses the penstock trace.

Powerhouse: The place was not accessible during the reconnaissance mission. On the basis of satellite images it is deducted that we should be on the sandy ground. The migmatite rock, however, should exist not far below.

2.5.3 Recommandations pour les investigations ultérieures

ELEMENT	UNCERTAINTY TO REMOVE	SURVEY TYPE
Bed at weir	- Existence and position of the bedrock below the riverbed	- Observation to be conducted by using o sensor or after drying the river. Given the rock spalling and foliated state, compressed air blowing and percolation tests should be planned as well.
Left support	- Existence of solid bedrock	- Clearing, removing of boulders and mechanic lateral excavation to find the solid bedrock
Right support	- Existence of solid bedrock	- Clearing, removing of boulders and mechanic lateral excavation to find the solid bedrock
Intake	- Slope instability, possible erosion of the banks foundations	- Major masonry retaining works will be required to stabilize the slopes and prevent the banks from collapsing
Tunnel	- Strata opening and deep foliations, in-depth formation compactness - Leakages due to the sub vertical extension of the beds and the crossing joints (cf. geological context)	- Core drilling at some chosen points along the tunnel trace to characterize the geotechnical properties of the laterite and to conduct percolation tests - Seismic reflection geophysical survey to study the in-depth formation compactness
Penstock	- Characterization of the supporting ground	- Detailed contour lines to better define the penstock trace. - Detailed study to characterize the rock alteration at the downhill slope
Powerhouse	- Existence of solid bedrock for powerhouse foundation	- Auger drilling (DCP) to check whether the area is made of boulders or solid bedrock.

2.6 Socio-environmental aspects

The site detailed description sheet is provided in the Appendices.

2.6.1 Socio-environmental background

The site is located on the Manandriana River. It separates the fokontany of Ambilanibe and the fokontany of Ambodirafia, community of Ambohimanga South, Ifanadiana District, Region of Vatovavy Fitovinany.

The vegetation is the area is mainly savoka. It is secondary vegetation, coming from the degradation of the ecosystem of the forest and from the repetitive forest clearings by fire (« tavy »). Savoka is mainly composed by Ravinala (*Ravenala madagascariensis*) and bamboos (*Nastus*). They are sometimes associated with woody species (*Psiadia, Harungana*) that characterise the open vegetation and the low bushy vegetation (*Aframomum angustifolium*, *Lantana camara*, *Philippia*, *Clidemia hirta*, *Pteridium*). On the lower slopes, alongside the river, riparian species such as *Dracaena, Adina* can be found in the vegetation with woody bases that can reach 10m high.

Image 12. Vegetation near the intake

From the socio-economic perspective, about 10 small hamlets (~3 huts/hamlet) and campsites (~1 temporary hut/campsite) can be found within a radius of 1km around the site. On the hillside, ~250m North-East of the site, there is a village composed by a group of huts, representing 15 households.

Slash-and-burn (or « tavy ») is the main local activity. They cultivate rice, manioc, rice, sugar cane, sweet potato, etc. Nevertheless, some vegetable crops can be found on the banks of the Manandriana River. Lands that were cleared by fire are generally used to be cultivated. Tavy is done on both hillsides and banks (for instance, on the left bank, upstream of the projected weir. Moreover, valley and lowlands are sometimes converted to rice fields.

The following image gives a global overview of the land use.

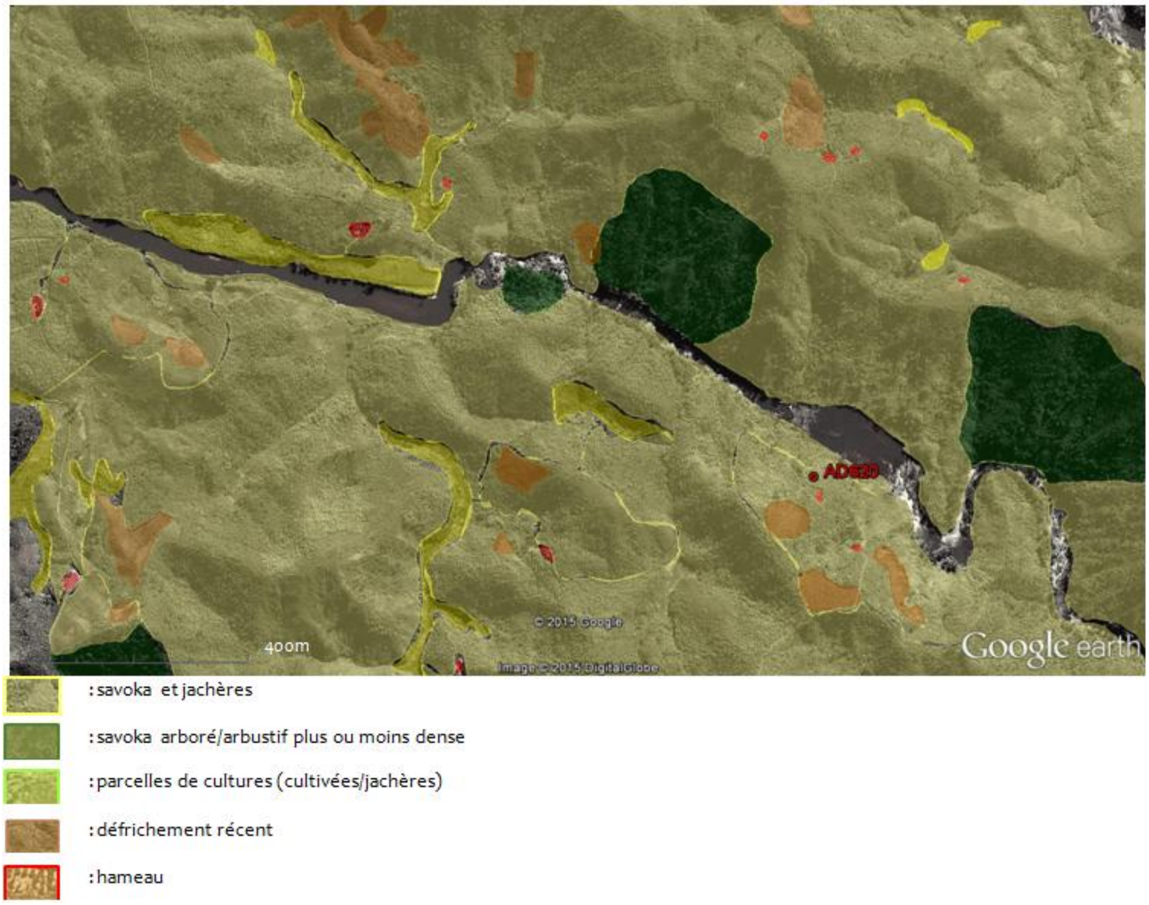


Image 13. Land use in the AD 620 site

2.6.2 *Socio-environmental constraints*

You can find some crops alongside the Manandriana River, in particular upstream of the expected weir. It is mainly tavy of sugar cane, manioc and – sometimes – vegetable crops. Rice fields can also be found in the small valley that is crossed by a watercourse that runs into the river about 50m upstream of the intake. If the implementation of the project leads to an increase of the water level upstream of the weir, some crops, situated on the river banks, could potentially be affected, depending on the magnitude of the provoked flooding. Some crops can be found about 90m upstream of the site and some rice fields are located about 50m upstream of the intake, about 80m away on the left bank.

Some hamlets, campsites and, in particular, a village situated ~250m away from the expected weir can be found near the development sites (weir, power plant….). There could be some problems, especially regarding potential nuisances (noise, traffic, atmospheric emissions…). The short distance between the hamlets and the working site will increase the risk of an accident for the concerned population.

2.6.3 *The World Bank Safeguard Policies that could be applicable:*

The World Bank Safeguard Policies that could be applicable for the AD620 site are the following:

- OP 4.01 – The Bank requires Environmental Assessment (EA) of projects proposed for Bank financing to help ensure that they are environmentally sound and sustainable, and thus to

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improve decision making. However, we can already estimate that the adverse impacts on human populations and environment-linked areas are limited. They are reduced, not irreversible and some measures can prevent, mitigate or minimize them. Moreover, these measures can improve the environmental performance.

- OP 4.12 – Involuntary Resettlement: the hydropower project will require the use of a large space (implementation of the plant, creation of access roads to the site…), which sometimes are crop areas. Moreover, the ponded water upstream of the weir could impact some habitation huts or crop parcels. So the project will have to take into account the concerned people and communities, particularly regarding the restoration of the standards of living due to the loss of resources.

OP 4.11 – Cultural Heritage is not applicable because the site is not known for containing particular cultural material resources. Idem for OP 4.04 – Natural Habitats

The projected weir (4m high) is classified as a small dam (<15m high); the usual generic safety measures for dams are not appropriate and do not need the OP 4.37 – Safety of Dams (for large dams).

3 PROPOSED SCHEME LAYOUT

3.1 Technical assumptions

The objective is to carry out a high level assessment of the scheme potential in terms of installed capacity, energy generation (firm and average) and the associated capital investment costs (CAPEX) and productions costs (Levelized cost of energy). Hence, at this stage of the study, the technical features of the hydropower scheme are designed in the following sections for both firm and median discharges (respectively $Q_{95\%}$ and $Q_{50\%}$). The actual design flow will be determined during the detailed studies based on economical, financial and technical criterion as well as the future energy and power demand.

The proposed scheme layout is shown in Figure 14 and presented in A3 format in Appendix 5.2 of this report.

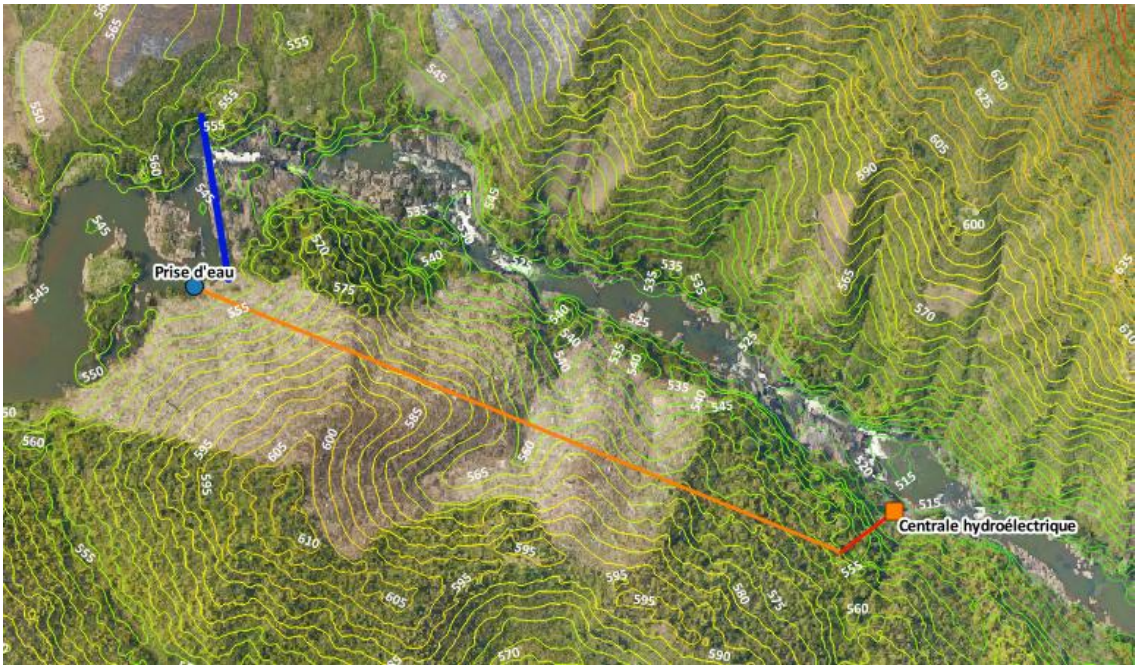


Figure 14. Proposed scheme layout for AD620 site

The site is designed to feed Ambohimanga du Sud city and surrounding villages and will thus work as an isolated grid. In the long run, the site might be connected to the RIF grid (and the powerhouse should be designed for such eventuality).

3.2 Weir and intake

The weir will be located upstream of the main t-drop, a priori on the bedrock. The intake, on the right river bank, will be set a bit more upstream in order to ease access to the tunnel. The weir dimensions would be about 4m of height for about 95m of length.

3.3 Desander

Given the potential sediment load in the river mentioned previously, adequate gravels trap and desander systems will be required. It will be located immediately downstream of the intake. However, little place is available for the desander. This must be taken into account for the design of this infrastructure.

3.4 Waterways

Waterways consist of a straight 2m (assuming the design flow at $Q_{95\%}$) or 2.7m (assuming the design flow at $Q_{50\%}$) diameter and 390m long tunnel in the right bank. However, the tunnel trace crosses a thalweg (less then 5m of elevation difference according to the DSM). Hence, it might be that the tunnel will be modified and would follow a bended trace to avoid the thalweg area. Another possibility would consist of an aerial section between the two hills.

3.5 Penstocks and powerhouse

The penstock will be set on a very steep slope. Similarly, as no alternative location is available, the powerhouse will also be constructed on the slope, in an area difficult to access.

The penstock will be 45m long and will have a diameter of 1.00m (assuming the firm discharge) or 1.60 m (assuming the median discharge).

3.6 Electromechanical equipments

3.6.1 Design flow taken at $Q_{95\%}$

For a design flow taken at Q_{95}, not much flexibility is required for the turbine as it will work most of the time at nominal power.

Francis turbine is preferred to Crossflow (or Banki) turbine which is less robust and less resistant to abrasion. Moreover, this type of turbine requires a gearbox that will reduce the global reliability and will increase maintenance works. Although Kaplan turbine offers a higher flexibility, it is not selected for this site neither as it is a sophisticated machine which requires costly maintenances.

Electromechanical equipments of the powerhouse will then be composed of:

- Butterfly safety valve with counterweight to ensure its closure in case of emergency of black out.
- A 690 kW horizontal axis Francis turbine running at 750rpm or 1000rpm.
- A 400V alternator, 650kW/ 720 kVA.
- Control and monitoring system, including speed regulator and voltage regulator.
- Security system and electrical protection.
- Step-up transformer and electrical cabinet and switchgear.
- Emergency power unit.

Figure 15 Example of a horizontal axis Francis unit

Following issues should be studied as well in the next stages of the project :

- Sedimentation problem and the need for anti-abrasion coatings (e.g. Tungsten carbide).

- Technical and economic optimization of the penstock diameter.
- Technical and economic optimization of the number of units and of the design flow, according to the hydrology and the electrical demand.
- The need of a flywheel (for grid stability)
- The set up level and rotational speed of the turbine (Suction height and cavitation issues).
- Grid voltage.
- Preliminary turbine design.

3.6.2 *Design flow taken at $Q_{50\%}$*

For a design flow taken at Q_{50}, it is recommended to install two identical units (Francis turbines) in order to optimize the global efficiency and to increase the plant availability.

Other considerations exposed for a design flow at Q_{95} remain valid for a design flow taken at the median discharge (Q_{50}).Turbines will have a unit nominal power of 1 030 kW and a rotation speed of 750 rpm. The alternator power will be 970 kV/ 1 075 kVA for a 400V or 690 V voltage.

A power plant PLC (Programmable Logic Controller) should also be foreseen to manage the two units.

3.7 Transmission lines

It is envisaged that the proposed hydropower scheme would be feed the city of Ambohimanga du Sud. using a 7.5 km long and 35kV line.

3.8 Key technical features

Les caractéristiques principales de l'aménagement hydroélectrique sont présentées ci-dessous pour les débits d'équipement correspondants au débit garanti et au débit moyen.

		Firm discharge	Median discharge
Installed capacity	[kW]	650	1 940
Potential annual generation	[GWh/yr]	5.04	13.88
Design flow	[m³/s]	3.4	9.7
Gross head	[m]	25	
100yr return period flood	[m³/s]	711	
Weir length	[m]	95	
Weir height	[m]	4	
Desander		Large size	
Tunnel length	[m]	390	
Tunnel diameter	[m]	2.00	2.70
Penstock length	[m]	45	
Penstock diameter	[m]	1.00	1.60
Number of penstock(s)	[-]	1	1
Number of T/G units	[-]	1	2
Transmission line length	[km]	7.5	

Line voltage	[kV]	35
Length of the access road to create	[km]	13
Length of the access road to upgrade/rehabilitate	[km]	30

4 ENERGY GENERATION AND COSTS

Based on the assumptions of the economical and hydrological studies presented in the main report, the proposed hydropower scheme would feature the following values:

Gross head	**[m]**	25	
Design flow	**[m³/s]**	3.4 ($Q_{95\%}$)	9.7 ($Q_{50\%}$)
Installed capacity	**[kW]**	650	1 940
Potential annual generation	**[GWh/yr]**	5.04	13.88
CAPEX (excl. access and lines)	**[M$]**	5.03	8.58
LCOE (excl. access and lines)	**[$/kWh]**	0.119	0.074
Total CAPEX (incl. access and lines)	**[M$]**	23.2	26.75
Total LCOE (incl. access and lines)	**[$/kWh]**	0.544	0.229

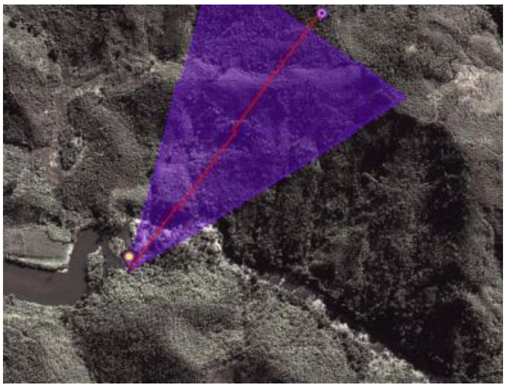
5 APPENDICES

5.1 Socio-environmental description form

A – Site localisation

Site reference	:	AD620 - Behingitika
Village / Fokontany	:	Ambilanibe et Ambodirafia
Community / District/Region	:	Ambohimanga Sud / Ifanadiana / Vatovavy Fitovinany

B - Description of the biophysical background

RELIEF	The water intake is located on a piedmont. The relief of the area is composed by several hills, surrounding a watercourse. A small hill overhangs the West part of the site. The studied area is fed by the Manandriana River, which is a tributary of the Mananjary River. The water intake is located 2km away from the confluence point. The future infrastructures are situated on the West hillside of the watercourse.
VEGETATION	The vegetation in the area belongs to the West domain. Anthropic activities characterise the vegetal landscape of the area (mainly « tavy »: forest clearing, more or less advanced savoka, fallows). Secondary vegetation, composed by fallows and savoka colonize crop parcels after forest clearing or slash-and-burn. This vegetal cover is mainly composed by *Ravenala madagascariensis* and bamboos, sometimes associated with woody or shrubby bases (*Psiadia, Harungana*) and low vegetation, which is more or less bushy. The vegetation alongside the river is characterised by the presence of *Dracaena*, *Adina*. The fallows are composed by several species, reaching 2m high, such as *Aframomum angustifolium, Pteridium aquilinum (*ferns). The lower parts of the slopes and the river banks are mainly crop fields (sugar cane crops, vegetable crops…). The lowlands, which are more or less narrow, are converted into rice fields.  Bamboo savoka and Ravinala savoka associated to a low vegetation (*Pteridium)*  S20°54'25.42" E47°39'18.69"

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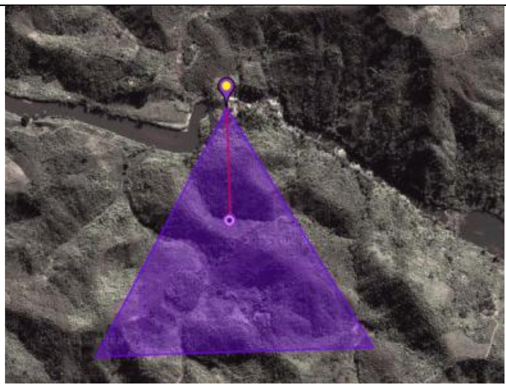
	 Vegetation near the water intake	 S20°54'23.41" E47°39'18.79"
OBSERVATIONS	The vegetation recovery after clearing/slash-and-burn is encouraged by the wet weather of the area.	
CRITICAL AREAS	The closest potential conservation sites are located about 3km East and 10km North from the site (for the extension of the protected area of the Fandriana Vondrozo corridor)	

B - Description of the socio-economic background

<table>
<tr>
<td>LOCALITY</td>
<td>The AD 620 site belongs to the fokontany of Ambilanibe and is close to the fokontany of Ambodirafia, community of Ambohimanga South. The county seat of the fokontany, Ambilanibe, is located about 1,5km North from the expected weir. Within a radius of 1km from the site, some hamlets and villages can be found. In particular, about 250m North-East of the intake, we can find on the hillside a village composed by a group of huts, representing 15 households. Seasonal campsites, composed by two or three houses, are also scattered in this area, next to crops and/or « tavy » fields.

The site is accessible via a route and a path, about 8km long, from the county seat of the community of Ambohimanga South, which is situated about 15km away from the site via the path in the North of Ifanadiana. Crossing the river is compulsory during the trip (S20°56'30.67" E47°34'14.91").


“boat” used to cross the river, in order to reach the site


Crops on both sides of the path leading to the site</td>
</tr>
<tr>
<td>ACTIVITIES</td>
<td>The agriculture is mostly composed by rain and irrigation rice growing. Then there are subsistence crops (manioc, sweet potato, corn) and also some vegetable crops. The main technique is slash-and-burn, in particular on the hillsides. The lowlands are mainly rice fields. On the other hand, cash crops can be found in the area (coffee, banana, ginger, sugar cane). The villages are surrounded by tree plantations (banana trees, coffee plants…).

The fabrication of local rum "Toaka gasy", thanks to homemade stills, is another activity of the area.


Rice fields in the lowlands


Vegetable crops and sugar cane crops on the river banks</td>
</tr>
</table>

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OTHERS (IF ANY)	The main ethnic groups of the Ifanadiana District are the Tanalas and the Sahafatras. The site is located on mining plots, with the authorization to search silver, gold, iron, lead, zinc, beryllium and copper.

C –World Bank Safety Policies applicable :

OP 4.01 – Environmental Assessment ☒
OP 4.04 – Natural Habitats ☐
OP 4.11 – Cultural Heritage ☐
OP 4.12 – Involuntary Resettlement ☒
OP 4.37 – Safety of Dams ☐

Map of the main villages

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Land use around the site

: savoka et fallow land

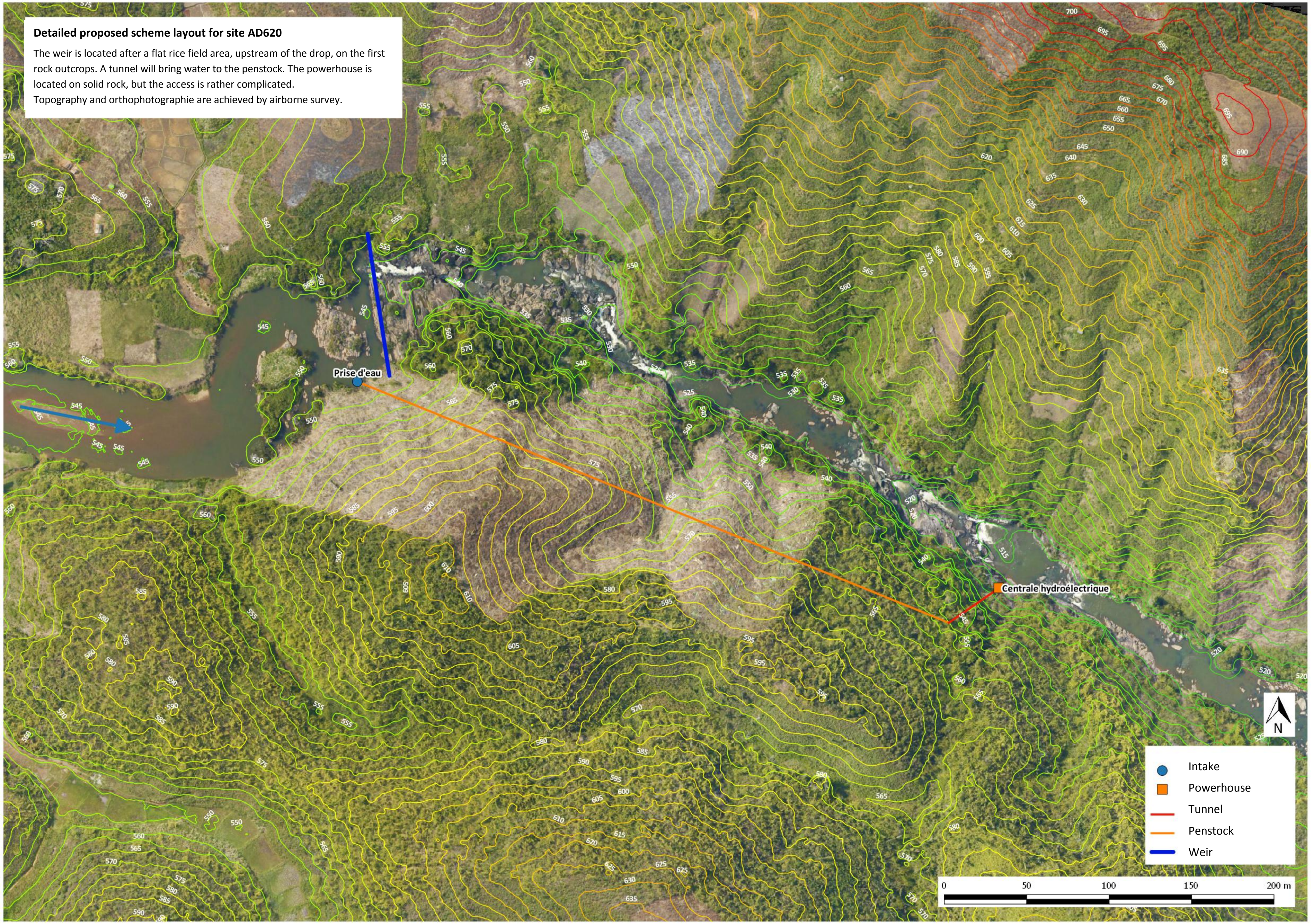
: more or less dense tree/bush savoka

: cultivated parcels (cultivated/fallow)

: recent clearing

: hamlets

5.2 Proposed scheme layout



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Madagascar: Small Hydropower Resource Atlas (1-20MW)
Site Investigation Report

ANTANJONA SITE

Sahanofa River | Atlas Code: AD631

Table of Content

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1 SITE LOCATION

Geographical coordinates (WGS 84)	Longitude [°]	Latitude [°]
Intake	47.688°	-20.992°
Powerhouse	47.691°	-20.977°

1.1 Administrative data

Atlas code	AD631
Site name	Antanjona
River	Sahanofa
Major river basin	Mananjary
Province	Fianarantsoa
Region	Vatovavy Fitovinany
District	Ifanadiana
Commune	Tsaratanana
Village	Antanjona
Reference topographical map	P52 Nord, P52 Sud, Q52 Nord (1:50,000)

1.2 Access

The projected site is accessed from the RN12 at Ifanadiana city by following an all weather conditions track towards Ambohimanga du Sud. The 26 first kilometers of the track (up to Soaniherenanabridge) are drivable the whole year around. The next 20 kilometer are however way more difficult, even with a 4-wheel drive. At Kilometric Point 46km (beyond Sandratsy village), there is a 11km track on the right river bank which includes river crossing with a pirogue at Antanjona village.

For the construction of a hydropower scheme, the track towards Ambohimanga du Sud will require 43km of rehabilitation. 14km of new access road will have to be created to access to the intake and powerhouse area.

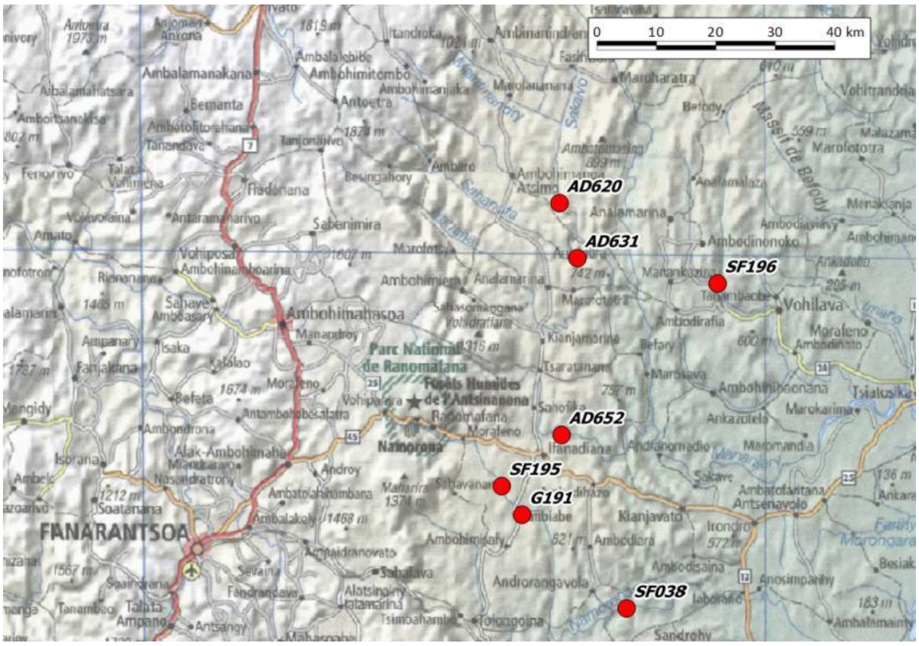

Figure 1. Site access

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2 GENERAL SITE DESCRIPTION

2.1 Background

The site is characterized by several meanders of the river. This configuration enables the use of approximately 100m drop to produce hydropower by by-passing meanders through hills. Upstream of the site, the river has a straight stretch of about 1400m long with North-East direction (very low river slope and approx. 80m large riverbed) followed by a 180°curve with South-West direction. This configuration reduces the flow velocity and consequently favors the sedimentation of suspended particles.

At present, there is neither hydro-agricultural nor hydropower scheme at the proposed site location.

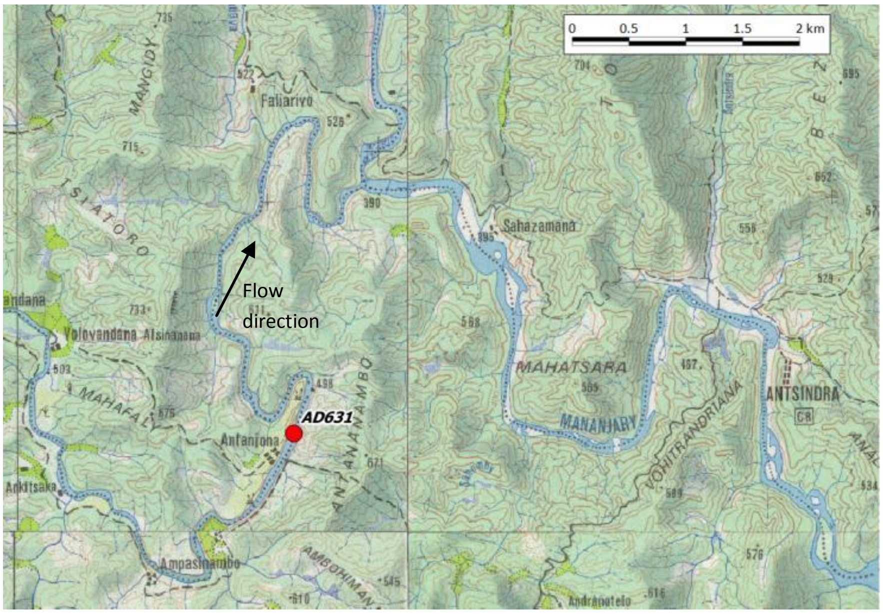

Figure 2. Topographic map of the site

Figure 3. Satellite image (Google Earth)

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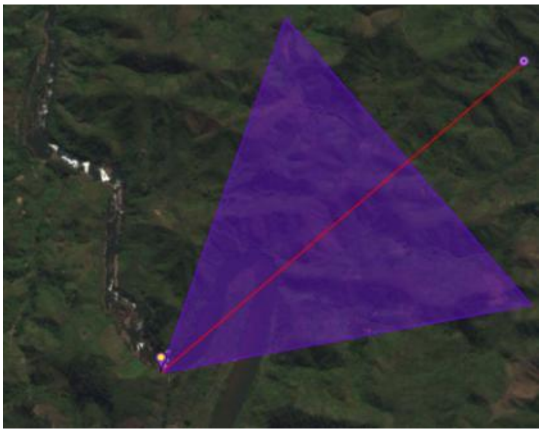

Figure 4 : Proposed site for the weir


Figure 5. View of the straight river stretch before the 180° bend

2.2 Topography

The topographical survey was achieved through remote sensing. An aircraft was chartered and equipped with optical sensors.

Figure 6. Aircraft and remote sensors container for airborne survey

The topographical survey has a point density of 5 /m² and a relative accuracy of 2%.

Outputs from airborne survey are (1) a high resolution orthophotography (0.2m to 0.4m resolution) and (2) a Digital Surface Model (DSM). The DSM includes the vegetal cover, but it gives an excellent global picture of the site topographical configuration. Results are illustrated in the figures below and the contour lines deducted from the DSM are presented on the detailed proposed scheme layout in section 5.2.

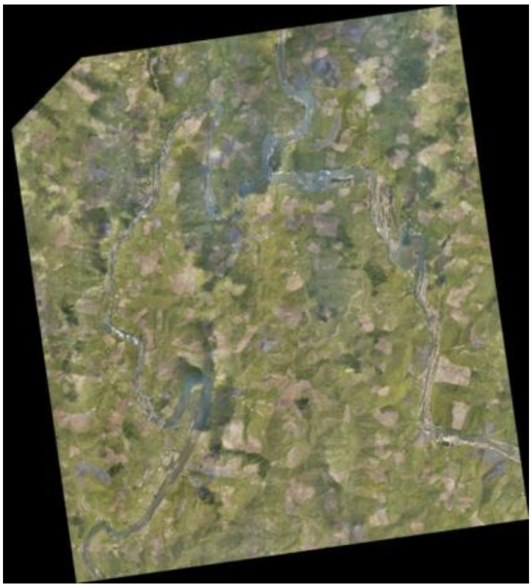

Figure 7. Orthophotography of the site

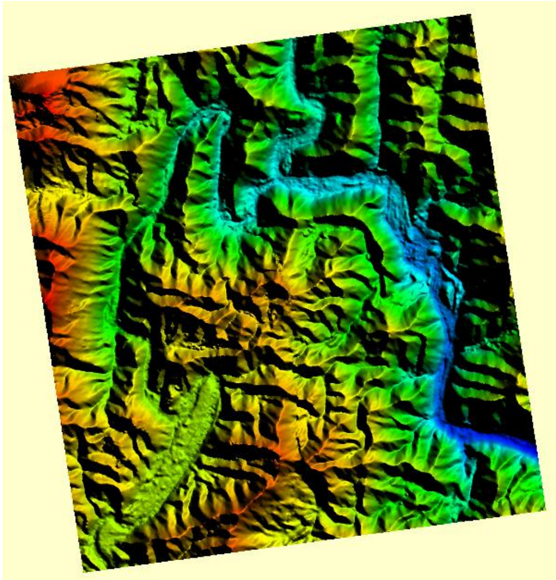

Figure 8. Digital Surface Model of the site

2.3 Preliminary hydrological study

Accurate information on the hydrology of the Sahanofa River does not exist. As a consequence, statistical characteristics of the river discharge at the site of interest have been estimated using a regional methodology. This methodology is based on the available information at other hydrometric stations distributed in the country. Given the limited spatial and temporal resolution of the available data, the results of the regional study presented below are indicative only and are not intended to be used for design purposes without further detailed hydrological studies.

Key preliminary hydrological characteristics of the river at the site of interest are presented in the table below.

River	Sahanofa
Main river basin	Mananjary
Area [km²]	416
Average elevation [m a.s.l]	1040
Slope index [m/km]	9.8
Specific vertical drop [m]	199
Average annual rainfall [mm/an]	1830
Average interannual discharge [m³/s]	16.6
$Q_{95\%}$ - firm discharge [m³/s]	4.8
$Q_{50\%}$ - median discharge [m³/s]	13.0
$Q_{30\%}$ [m³/s]	17.9
10yr return period flood [m³/s]	519
100yr return period flood [m³/s]	1032

2.4 Sediment transport

At the time of the site visit (october 2014), turbidity was good, measured at 40 NTU. However the presence of lateral silt and sand deposits demonstrates that significant erosion and deposition processes occur at some period of the year, likely during major flood events.

Adequate sediments and gravels trapping systems will be designed at the feasibility study stage based on an analysis of the sediment load at different river discharges.

2.5 Site geology

2.5.1 Geological context

The area is located in the Ifanadiana migmatitic variants. Massive heterogranular porphyroblasts outcrops are found, in direct contact with stratiform beds of migmatitic gneisses (Figure 9). At the river and river bank level, they crop out subhorizontaly and plunge slightly towards upstream. The river flows on the rock and usually shows a flat and rocky riverbed. The rocks are always composed of quartz, variants of feldspar and biotite.

Figure 9. Rock of the site

Local faults affect the region but they are poorly defined at the area level. The drop at the proposed weir location is part of these faults whose locations are determined by the surroundings hilly morphology.

The lateritic alteration is relatively low.

2.5.2 Technical characteristics

<u>Bed aspect at the projected weir location:</u> it is characterized by a dismantled rocky bar made of massive blocks. Its presence creates a drop in the river which attests the presence of a local fault (Figure 10).

Figure 10. rocky weir

<u>Right bank support aspect:</u> there are in-place rocky mass, separated by largely open cleavages and surmounted by chaotic blocks.

<u>Left bank support aspect:</u> under vegetal cover, rocky blocks crop out in surface within lateritic formations. On the banks, they appear in mass.

<u>Intake and waterway:</u> the tunnel crosses an area of rugged terrain which is covered by laterite. The rock structure is of the same type as the outcropp observed in the river. The migmatitic rock is compact but regional joins cause sometimes largely open fracturing. This favors the formation of

surface streams (by opening of the massive rock to a deep level) which is at the otrigin of xater circulation within mountains.

Penstock : it is located on a slope where rocky blocks are included in laterite.

Powerhouse : it should be located on a sandy field. The migmatitic bedrock should however be found not too deep below sands.

2.5.3 Recommendations for further investigations

ELEMENT	UNCERTAINTY TO REMOVE	SURVEY TYPE
Bed at weir	Weir water tightness	✓ Observation of cracks and fractures between the rocky boulders ✓ Percolation tests.
Right support	Fear of possible leakages	✓ Anchoring choice depending of the weir height and final location ✓ Clogging of open fractures and between massive boulders in place
Left support	Existence of rock mass for support	✓ Clearing and lateral excavation to find the bedrock at the supporting hill basis.
Intake / waterway	Fear of possible leakages	✓ Core drilling at some chosen points along the waterway to characterize the fracturing condition and to conduct percolation tests
Penstock	No particular issue	-
Powerhouse	Characterization of the supporting ground (Massive rock? Boulder in place or not? Depth of laterite?)	✓ Auger drilling or seismic reflection geophysical survey

2.6 Socio-environmental aspects

The site detailed description sheet is provided in the Appendices.

2.6.1 Socio-environmental background

The site is located on the Sahanofa River, fokontany of Antanjona, community of Tsaratanana, Ifanadiana District, region of Vatovavy Fitovinany.

There is mainly secondary vegetation, characterising a more or less advanced degradation of the environment: it is mainly savoka, shrubby bush : the particular species being *Nastus* (bamboo), *Ravenala madagascariensis* (Ravinala), *Lantana camara, Psidium, Phillipia*. The most affected areas are composed by low vegetation such as *Aframomum angustifolium, Pteridium* (ferns), *Cyperus*,

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Clidemia hirta, Neyraudia. Bases of raffia (*Raphia farinifera*) can also be found alongside the watercourses and gathered in certain valleys (with raffia). Other hygrophilous species (that fundamentally need moisture) such as *Typhonodorum lindleyanum* and Ciperacea species can be found alongside the watercourses.

Nevertheless, even if there are signs of degradation, some shred primary forests can be found in the area. They are found on the crest lines, such as the area crossed by the tunnel alignment. They can also be seen in the lower parts of the hillsides, among riparian vegetation (for example: close to the expected weir site).

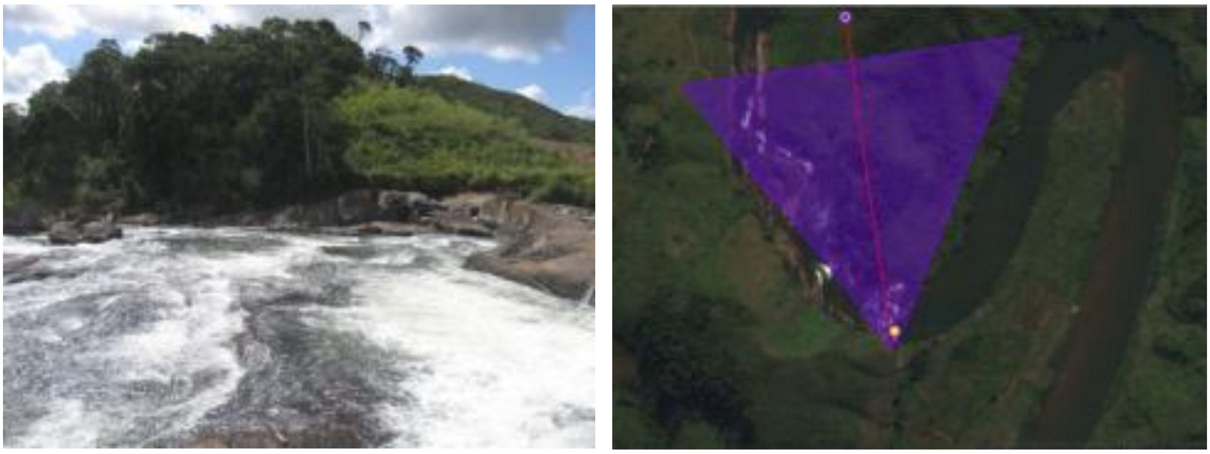


Image 11. Vegetation in the area upstream of the weir site

From the socio-economic perspective, the Antanjona village, county seat of the fokontany, is the main village (~70 households) near the site. It is situated 300m upstream of the water intake, 50m away on the left bank of the river, on a relatively flat ground. Some hamlets/campsites of 2 or 3 huts (sometimes reaching 10) are scattered alongside the river and on both sides of the expected penstock pipe, in the lower parts of the hillsides. In particular, we can find about 10 huts near the projected power plant (250m).

The main local activity is agriculture. The hillsides and the Sahanofa river banks are cultivated using the « tavy » method (slash-and-burn). They are subsistence and/or vegetable crops but also sometimes plantations of banana trees or sugar cane. Moreover, the local population occasionally goes fishing in the river.

Finally, we can find some gold mining activities in the area. Gold miners search the ground from the Sahanofa River to find gold.

The following image gives a global overview of the land use in the area.

Figure 12. Occupation du sol dans la zone du site

2.6.2 Socio-environmental constraints

Some hamlets and campsites are situated near the development sites (weir, penstock pipe, power plant). The implementation of the project could create some problems, especially regarding potential nuisances (noise, traffic, atmospheric emissions…). The proximity of hamlets increases the risk of accident for the concerned population. The Antanjona village (more than 70 households) is located ~250m away from the tunnel opening. About 10 huts are located less than 200m away from the penstock pipe and within a radius of less than 300m from the power plant.

On the other hand, if the implementation of the project leads to an increase of the water level upstream of the weir, some crops on both sides of the projected intake and some parcels between the village and the river could be affected by the pond, depending on its extent.

Finally, the implementation of the project could also impact on the gold mining activities, common in the area, and could also affect the fishing activities. Further studies should evaluate the need for specific works ensuring free passage of fishes.

2.6.3 World Bank Safeguard Policies that could be applicable:

The World Bank Safeguard Policies that could be applicable for the AD 631 site are the following:

- OP 4.01 – The Bank requires Environmental Assessment (EA) of projects proposed for Bank financing to help ensure that they are environmentally sound and sustainable, and thus to improve decision making. However, we can already estimate that the adverse impacts on human populations and environment-linked areas are limited. They are reduced, not irreversible and some measures can prevent, mitigate or minimize them. Moreover, these measures can improve the environmental performance.

- OP 4.12 – Involuntary Resettlement: the hydropower project will require the use of a large space (implementation of the plant, creation of access roads to the site…), which sometimes are crop areas. Moreover, the ponded water upstream of the weir could impact some habitation huts or crop parcels. So the project will have to take into account the concerned people and communities, particularly regarding the restoration of the standards of living due to the loss of resources.

OP 4.11 – Cultural Heritage is not applicable because the site is not known for containing particular cultural material resources. Idem for OP 4.04 – Natural Habitats

The projected weir (3m high) is classified as a small dam (<15m high); the usual generic safety measures for dams are appropriate and do not need the implementation of OP 4.37 – Safety of Dams (for large dams).

3 PROPOSED SCHEME LAYOUT

3.1 Technical assumptions

The project will likely be connected to the Interconnected Transmission Network of Fianarantsoa (RIF) given both the potential energy generation of the proposed scheme and its proximity to the RIF. The objective is to carry out a high level assessment of the scheme potential in terms of installed capacity, energy generation (firm and average) and the associated capital investment costs (CAPEX) and productions costs (Levelized cost of energy). Hence, at this stage of the study, the technical features of the hydropower scheme are designed in the following sections for both firm and median discharges (respectively $Q_{95\%}$ and $Q_{50\%}$). The actual design flow will be determined during the detailed studies based on economical, financial and technical criterion as well as the future energy and power demand.

The proposed scheme layout is shown in Figure 13 and presented in A3 format in Appendix 5.2 of this report.

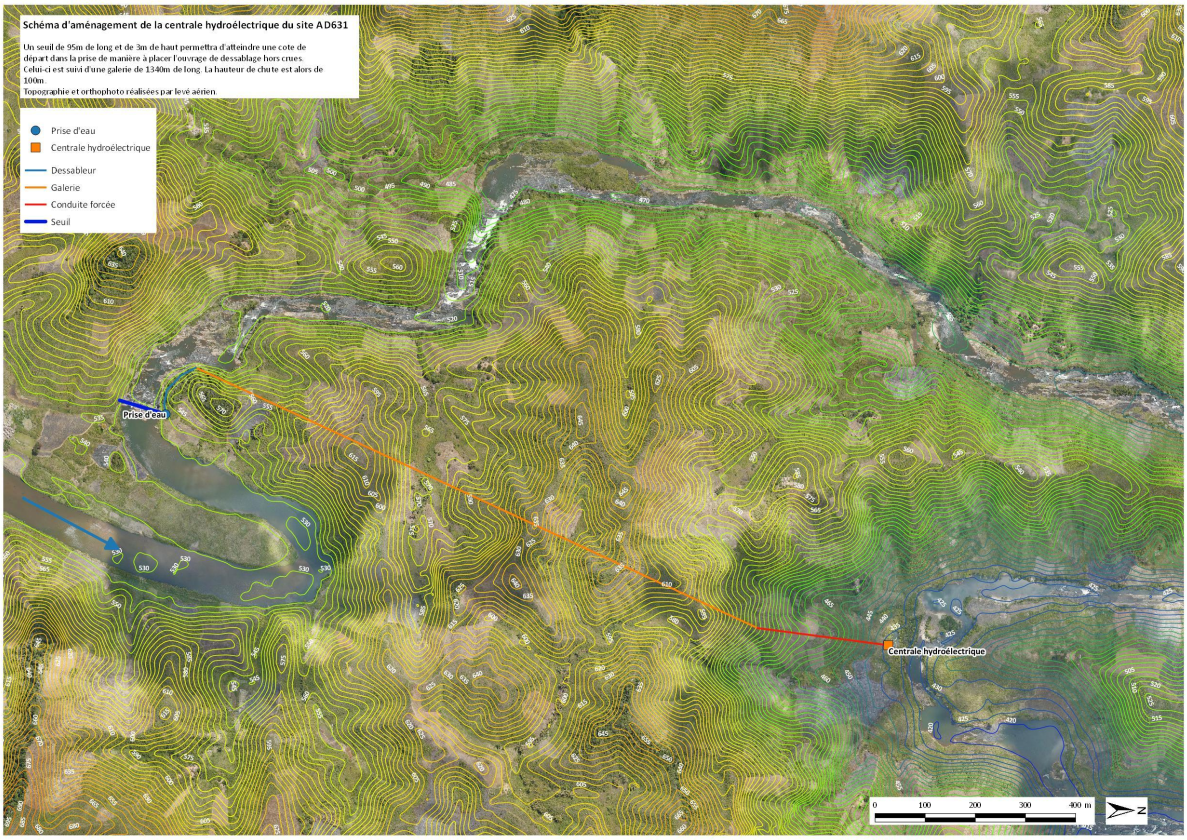


Figure 13. Proposed scheme layout for the site

3.2 Weir and intake

The 95m long and 3m high weir will be founded on the rock in-place (which creates a natural sill of about 2m high). The intake, located on the right riverbank, will be followed by a desander and a short canal arriving in the tunnel.

3.3 Desander

Given the potential sediment load in the river mentioned previously, adequate desander system will be required. It is suggested to implement it on the right river bank, close to the weir. The natural drop at the weir will enable an effective purge of the desander.

3.4 Waterways

Waterway consist of a 50m long canal (including desander) and of a 1340m long tunnel. The elevation profile of the natural ground above the proposed tunnel alignment is illustrated in the figure below. The canal section would be 1.60m x 2.55m (assuming the design flow at $Q_{95\%}$) or 2.6m x 4.20m (assuming the design flow at $Q_{50\%}$). The tunnel diameter would be 2.00m (for $Q_{95\%}$) or 3.50m (for $Q_{50\%}$)

The final tunnel alignment will be determined after the detailed geological and geotechnical surveys to ensure the presence of sufficient thickness of adequate rock around the tunnel. The tunnel will end in a surge chamber/shaft at the junction with the penstock leading to the powerhouse.

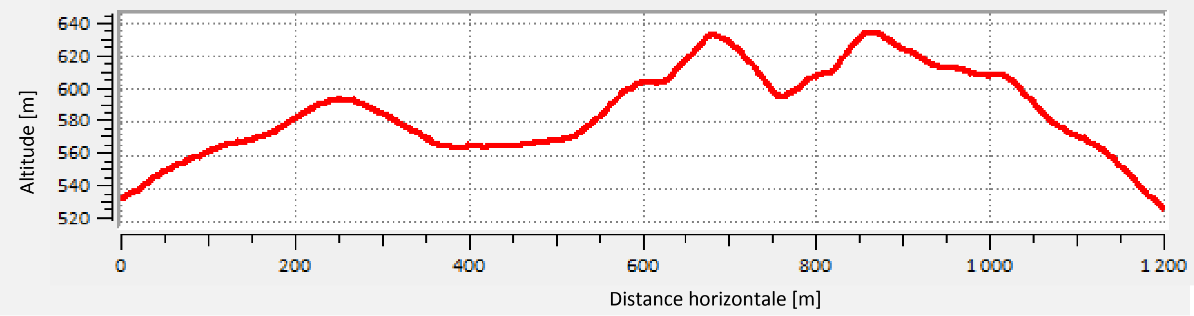


Figure 14. Elevation profile of the natural ground above the proposed tunnel alignment

3.5 Penstock and powerhouse

For the firm discharge as well as for the design flow, a single 300m long penstock will be required. A 1.20m (assuming the design flow at $Q_{95\%}$) or 1.80m (assuming the design flow at $Q_{50\%}$) penstock diameter will ensure that the head losses due to friction in the pipes will be below 5% of the available gross head.

3.6 Electromechanical equipments

3.6.1 Design flow taken at $Q_{95\%}$

Theoretically, the project should be connected to RIF grid. Hence, the chosen turbine type must enable a maximization of the power output. For a design flow taken at Q_{95}, not much flexibility is required for the turbine as it will work most of the time at nominal power.

Given the head, discharge and foreseen output, a Francis turbine comes as and evidence. It offers a high performance level and a satisfactory flexibility.

Given observations formulated about water quality, a particular attention must be paid to the quality of materials used for the construction of the turbine. One should probably consider the need for an anti-abrasion coating.

Figure 15. Example of two vertical axis Francis units

Electromechanical equipments of the powerhouse will then be composed of:

- Butterfly safety valve with counterweight to ensure its closure in case of emergency of black out.
- A 3 990 kW vertical axis Francis turbine running at 1000rpm.
- A 690V alternator, 3 750 kW/ 4 170 kVA.
- Control and monitoring system, including speed regulator and voltage regulator.
- Security system and electrical protection.
- Step-up transformer and electrical cabinet and switchgear.

- Emergency power unit.

Following issues should be studied as well in the next stages of the project :

- Sedimentation problem and the need for anti-abrasion coatings (e.g. Tungsten carbide).
- Technical and economic optimization of the penstock diameter.
- Technical and economic optimization of the number of units and of the design flow, according to the hydrology and the electrical demand.
- The need of a flywheel (for grid stability)
- The set up level and rotational speed of the turbine (Suction height and cavitation issues).
- Grid voltage.
- Preliminary turbine design.

3.6.2 *Design flow taken at $Q_{50\%}$*

For a design flow taken at Q_{50}, it is recommended to install two identical units (Francis turbines) in order to optimize the global efficiency and to increase the plant availability.

Other considerations exposed for a design flow at Q_{95} remain valid for a design flow taken at the median discharge (Q_{50}).Turbines will have a unit nominal power of 5 555 kW and a rotation speed of 750 rpm. The alternator power will be 5 220 kV/ 5 800 kVA for a 690 V or 5.5 kV voltage.

A power plant PLC (Programmable Logic Controller) should also be foreseen to manage the two units.

3.7 Transmission lines

It is envisaged that the proposed hydropower scheme would be connected to the Interconnected Grid (RIF) using a 50 km long and 63kV line to Ifanadiana.

3.8 Key technical features

The key features of the proposed hydropower scheme are summarized in the table below for both firm ($Q_{95\%}$) and median ($Q_{50\%}$) design flows.

		Firm discharge	**Median discharge**
Installed capacity	[kW]	3750	10 440
Potential annual generation	[GWh/yr]	29.15	74.95
Design flow	[m³/s]	4.8	13
Gross head	[m]	100	
100yr return period flood	[m³/s]	1 032	
Weir length	[m]	95	
Weir height	[m]	3	
Desander		Large size	
Tunnel length	[m]	50	

Tunnel diameter	[m]	2.55 x 1.6	4.2 x 2.6
Penstock length	[m]	1 340	
Penstock diameter	[m]	2.0	3.1
Number of penstock(s)	[-]	295	
Number of T/G units	[-]	1.2	1.8
Transmission line length	[km]	1	1
Line voltage	[kV]	1	2
Length of the access road to create	[km]	50	
Length of the access road to upgrade/rehabilitate	[km]	63	
Installed capacity	[kW]	14	
Potential annual generation	[GWh/yr]	43	

4 ENERGY GENERATION AND COSTS

Based on the assumptions of the economical and hydrological studies presented in the main report, the proposed hydropower scheme would feature the following values:

Gross head	**[m]**	100	
Design flow	**[m³/s]**	4.8 ($Q_{95\%}$)	13.0 ($Q_{50\%}$)
Installed capacity	**[kW]**	3 750	10 440
Potential annual generation	**[GWh/yr]**	29.15	74.95
CAPEX (excl. access and lines)	**[M$]**	18.79	39.86
LCOE (excl. access and lines)	**[$/kWh]**	0.077	0.064
Total CAPEX (incl. access and lines)	**[M$]**	43.49	64.56
Total LCOE (incl. access and lines)	**[$/kWh]**	0.177	0.103

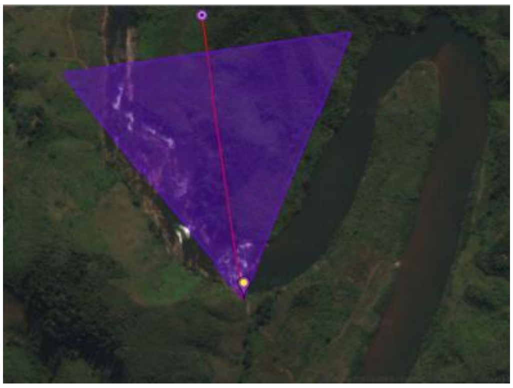
5 APPENDICES

5.1 Socio-environmental description form

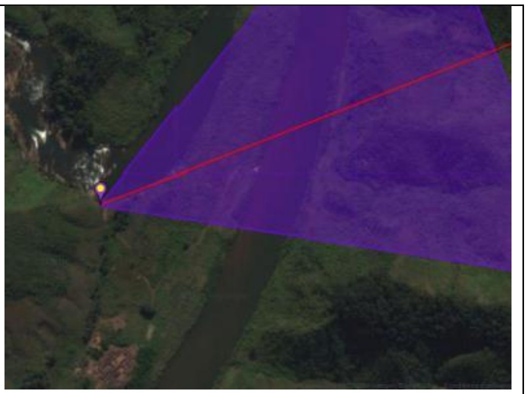
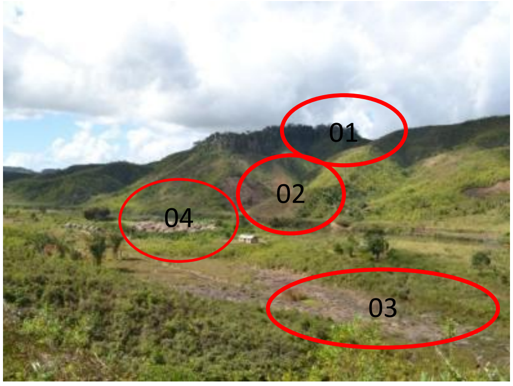
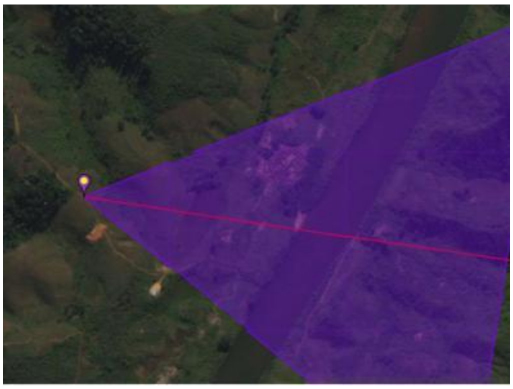
A – Site localisation

Site reference	:	AD631 - Antanjona
Village / Fokontany	:	Antanjona
Community / District/Region	:	Tsaratanana / Ifanadiana / Vatovavy Fitovinany

B - Description of the biophysical background

RELIEF	The relief of the area is composed by a field of hills (Antanamambo and Mahafaly) sinuously crossed by the Sahanofa and Mananjary watercourses. The Sahanofa river is a tributary of the Mananjary River. They meet ~3km upstream of the projected power plant and ~6km downstream of the projectedwater intake. The hydroelectric plant is located on the other side of a mountain massif, East of the water intake (2km as the crow flies). The hillsides are generally steep, including the ones along the Sahanofa River.
VEGETATION	The area has the characteristics of the flora from the West domain. It is mainly secondary vegetation. The savoka, more or less shrubby bushy, characterises the more or less advanced degradation of the environment: *Nastus* (bamboo), *Ravenala m/sis* (Ravinala), *Lantana camara*, *Psidium, Phillipia.* The most degraded areas are composed by low vegetation such as angustifolium, *Pteridium (*ferns*), Cyperacea, Clidemia hirta, Neyraudia.* Bases of raffia *(Raphia farinifera)* can also be found alongside the watercourses and gathered in certain valleys (with raffia). Other hygrophilous species (that fundamentally need moisture) such as *Typhonodorum lindleyanum* and *Ciperacea* species can be found alongside the watercourses. Many traces of "tavy" were identified in the area. Cultivated areas were observed on the hillsides and along watercourses.Nevertheless, some shred primary forests can be found in the area.   Shred forests near the weir S20°59'33.59" E47°41'15.83"

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

	  Bases of raffia, species found in wet environment — S20°59'33.60" E47°41'15.85"   Shred forests on the top of the hillside (01), dry crops on the hillside (02), rice fields (03) near the Antanjona village(04) — S20°59'43.52" E47°41'5.41"
OBSERVATIONS	Slash-and-burn is often used by the local population. It uses fire to clean the lands to be cultivated and the ashes help to fertilize the ground. Traces of fire are common in the area   Traces of fire — Recent fire
SENSITIVITIES	The closest protected area is located 40 km away from the site, as a crow flies (National Park of Ranomafana). Two potential sites (extension of the Fandriana Vondrozo corridor) are located about 5km S-E and about 12km N-W away from the site.

B - Description of the socio-economic background

LOCALITY

The site is located in the community of Tsaratanana, Ifanadiana District. The Antanjona village, seat county of the fokontany,is the most important village close to the site (more than 70 households). It is located about 300m upstream of the projected intake. It is set on the left riverbank, 50m inland, on a rather flat area. Some hamlets/campsites of 2 or 3 huts (sometimes reaching 10) are scattered alongside the river and on both sides of the expected penstock pipe, in the lower parts of the hillsides. In particular, we can find about 10 huts near the projected power plant (in a radius of 250m).

Antanjona village

Hamlet

To access the site, you have to take a track heading North at Infanadiana village, towards Ambohimanga South village. This track, 46km long, is in good condition during the first 26km and then the rest of it is impassable during the wet season. Then you have to follow by foot a 9km long path to arrive close to the weir, crossing the river and the hills.

Path leading to the future infrastructures

Pirogue crossing

ACTIVITIES

The main local activity is agriculture. The hillsides and the Sahanofa river banks use the « tavy » (slash-and-burn) technique. The riverbanks are used for vegetables crops and banana trees plantations. Lowlands and valleys are arranged in ricefields. Villages are frequently encircled by coffee-tree plantations and/or fruit trees plantations.

The local population occasionally goes fishing in the river. Moreover, active gold miners were observed on the Sahanofa River.

	  Rice fields Slash-and-burn   Gold miners (Antobikely) Fishermen(Antanjona)
OTHERS (IF ANY)	The main ethnic groups of the Ifanadiana District are the Tanalas and the Sahafatras. The site is located on mining plots, with the authorization to search silver, gold, iron, lead, zinc, beryllium and copper.

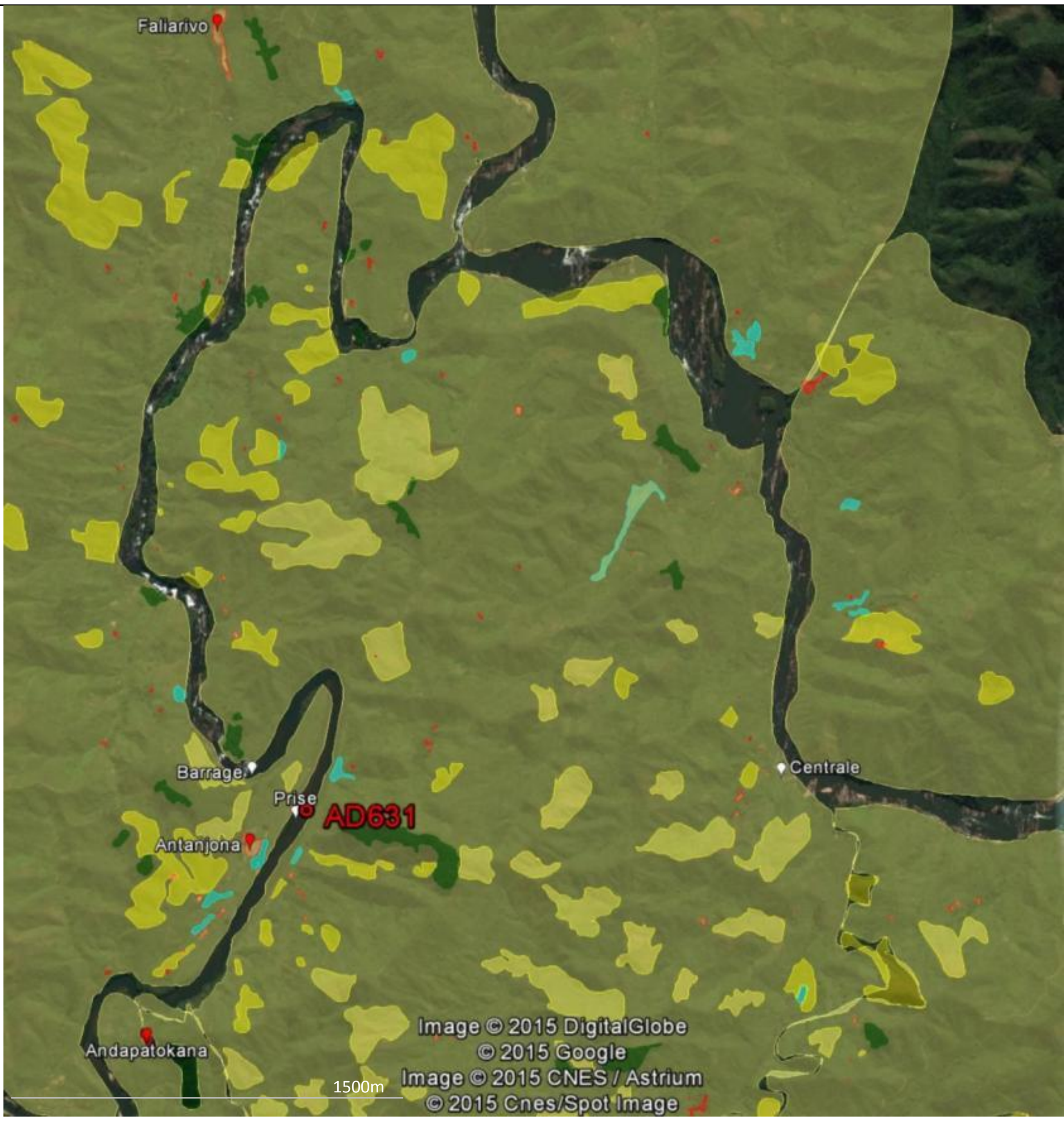
C –World Bank Safety Policies applicable :

OP 4.01 – Environmental Assessment ☒
OP 4.04 – Natural Habitats ☐
OP 4.11 – Cultural Heritage ☐
OP 4.12 – Involuntary Resettlement ☒
OP 4.37 – Safety of Dams ☐

Map of villages/hamlets

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

Land use around the site



: shred forest

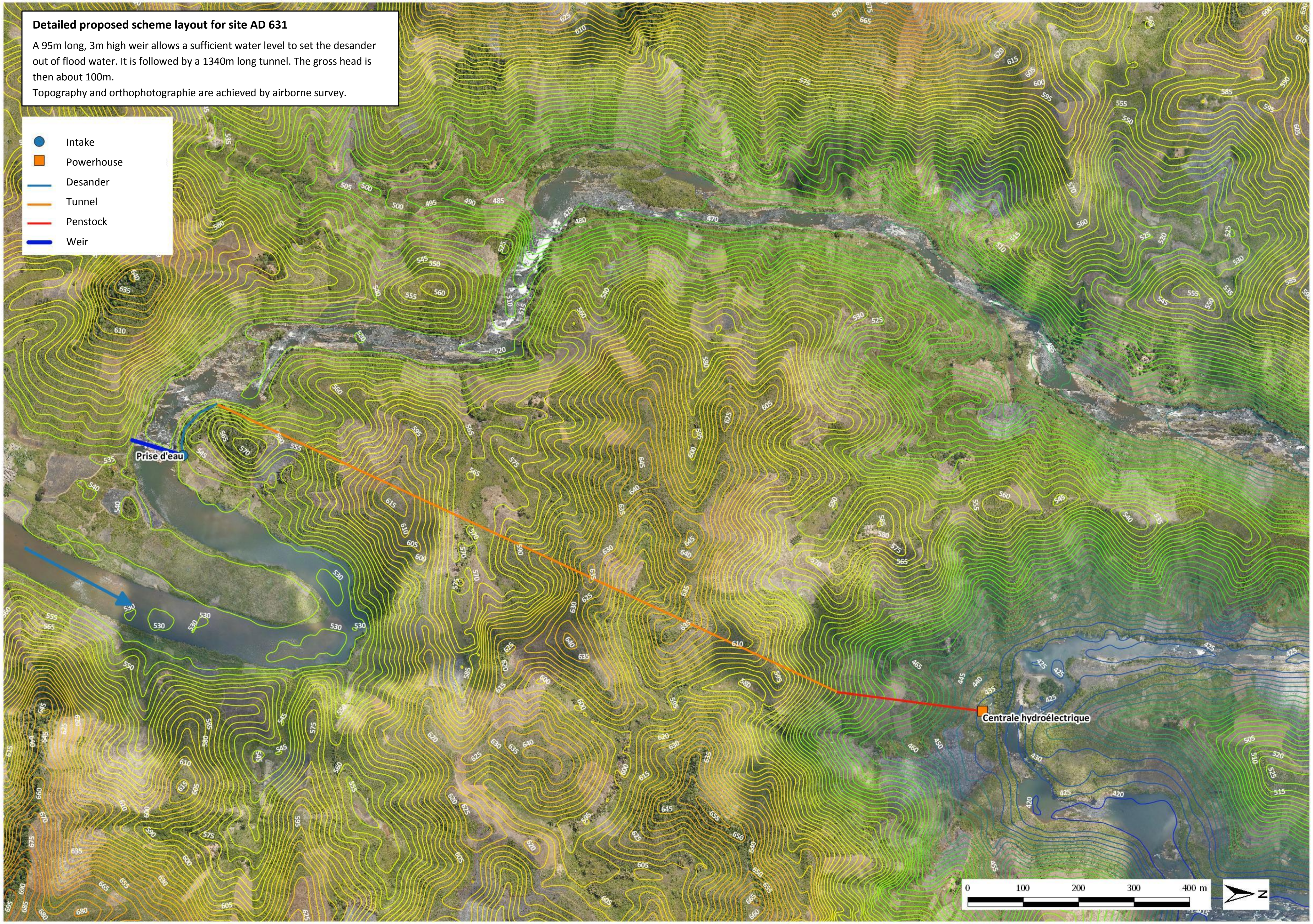
: savoka and fallow

: recent fire

: developped crops parcels

: hamelts

5.2 Detailed proposed scheme layout



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Madagascar: Small Hydropower Resource Atlas (1-20MW)
Site Investigation Report

SITE TAMBOHORANO

Faravory River | Atlas Code: AD652

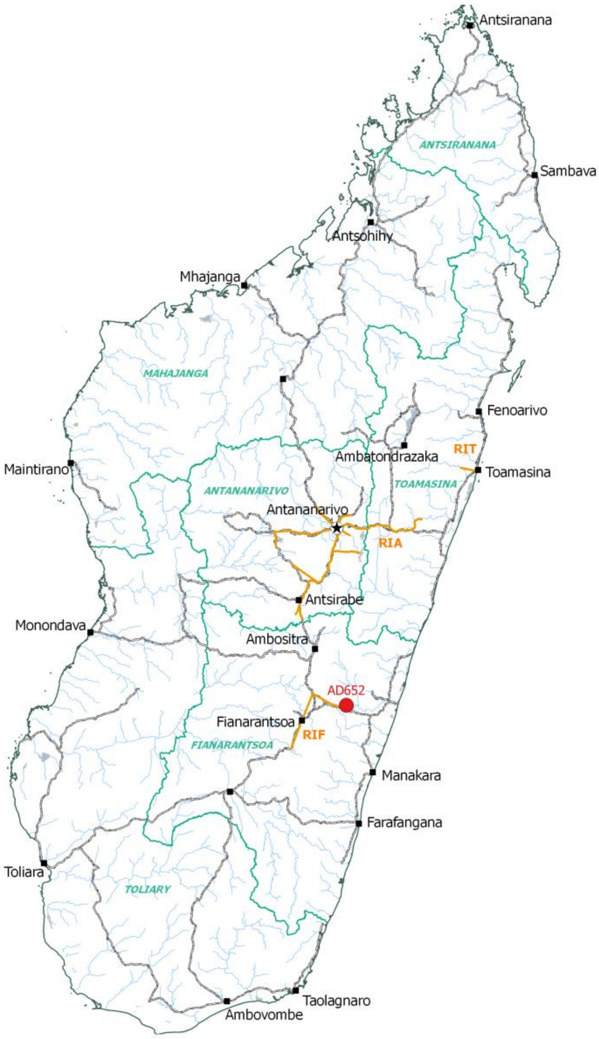

Table of Content

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1 SITE LOCATION

Geographical coordinates (WGS 84)	Longitude [°]	Latitude [°]
Intake	47.664°	-21.262°
Powerhouse	47.671°	-21.261°

1.1 Administrative data

Atlas code	AD652
Site name	Tambohorano
River	Faravory
Major river basin	Mananjary
Province	Fianarantsoa
Region	Vatovavy Fitovinany
District	Ifanadiana
Commune	Ifanadiana
Village	Isolated site, no habitation nearby.
Reference topographical map	P53 Nord (scale 1:50,000)

1.2 Access

The projected site is accessed from the RN12 at Ifanadiana city by following an all weather conditions track towards Ambohimanga du Sud. At kilometric point 2.7km, there is a 6km track on the right river bank which includes river crossing with a pirogue just before arriving at the site in order to continue on the left river bank.

For the construction of a hydropower scheme, the track towards Ambohimanga du Sud will require 3km of rehabilitation. 8km of new access road will have to be created to access to the intake and powerhouse area.

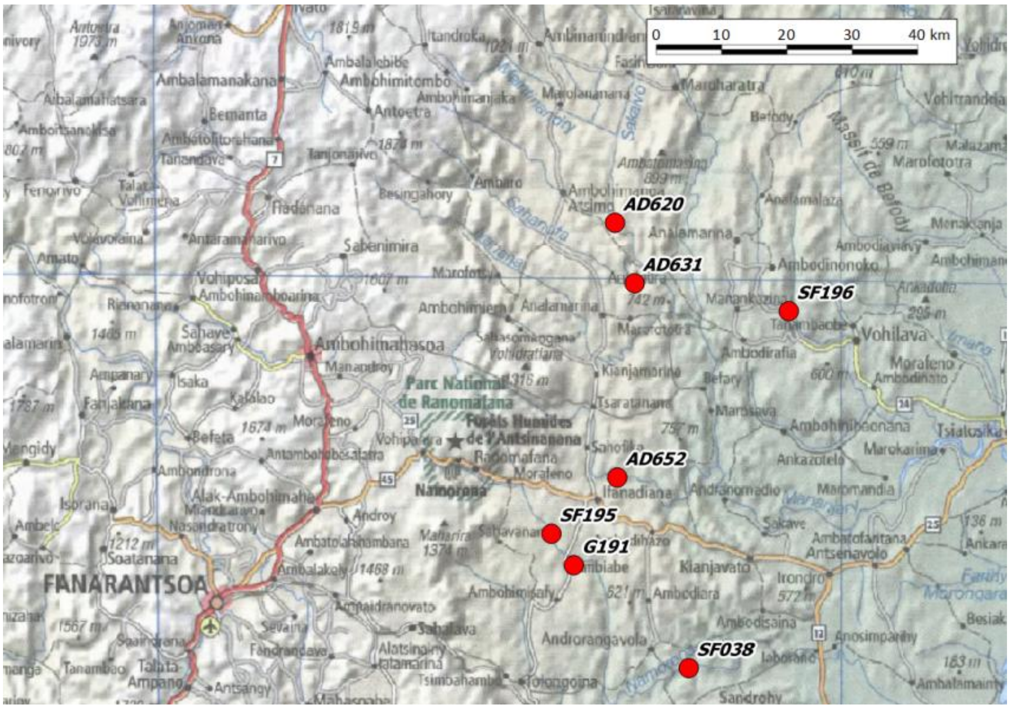

Figure 1. Access to the site

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

2 GENERAL SITE DESCRIPTION

2.1 Background

The site is characterized by a first succession of small drops that ensure a total head about 20m. By using another set of rapids located a little downstream, a total gross head of 37m might be gained.

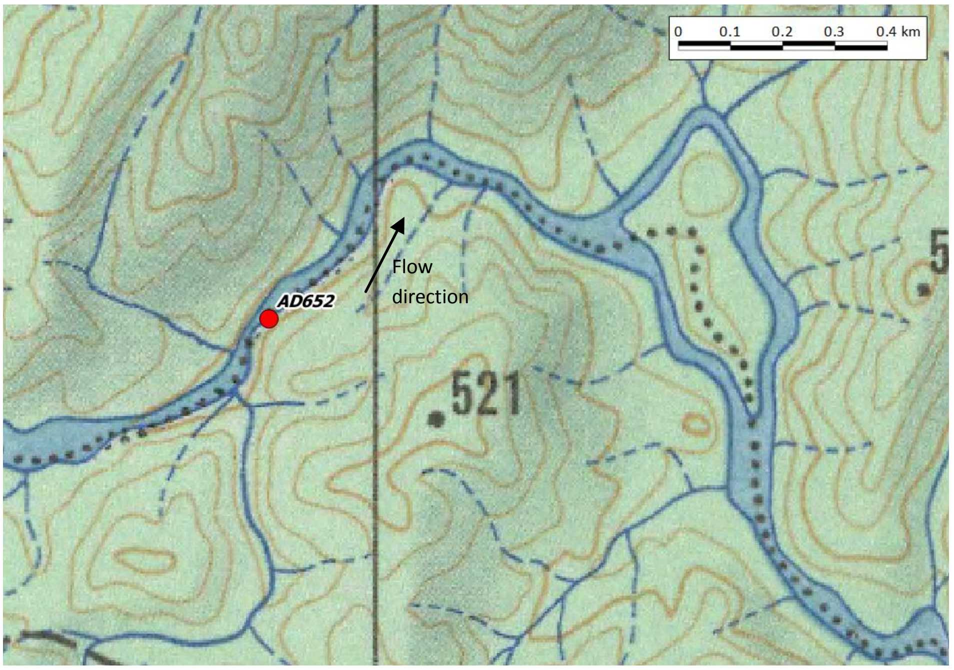

Figure 2. Topographic map (scale 1:50,000)

Figure 3. Satellite image (Google Earth)

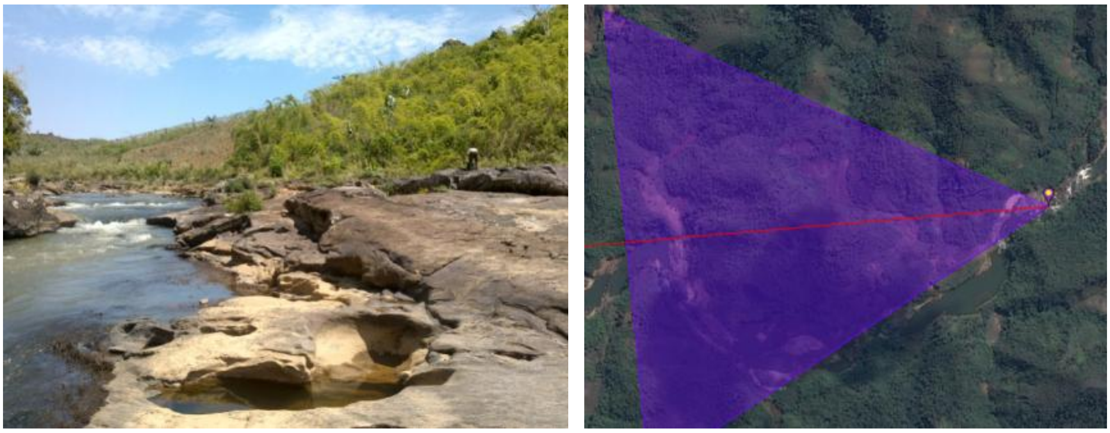

Figure 4. Suggested location of the weir

Figure 5. Suggested location of the intake

2.2 Topography

Figure 6. Aircraft and remote sensors container for airborne survey

The topographical survey was achieved through remote sensing. An aircraft was chartered and equipped with optical sensors.

The topographical survey has a point density of 5 /m² and a relative accuracy of 2%.

Outputs from airborne survey are (1) a high resolution orthophotography (0.2m to 0.4m resolution) and (2) a Digital Surface Model (DSM). The DSM includes the vegetal cover, but it gives an excellent global picture of the site topographical configuration. Results are illustrated in the figures below and the contour lines deducted from the DSM are presented on the detailed proposed scheme layout in section 0.

Figure 7. Orthophotography of the site

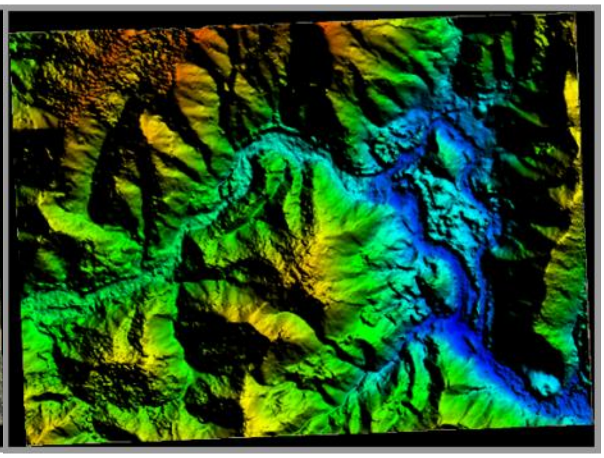

Figure 8. Digital Surface Model of the site

2.3 Preliminary hydrological study

Accurate information on the hydrology of the Fahavory River does not exist. As a consequence, statistical characteristics of the river discharge at the site of interest have been estimated using a regional methodology. This methodology is based on the available information at other hydrometric stations distributed in the country. Given the limited spatial and temporal resolution of the available data, the results of the regional study presented below are indicative only and are not intended to be used for design purposes without further detailed hydrological studies.

Key preliminary hydrological characteristics of the river at the site of interest are presented in the table below.

River	Fahavory
Main river basin	Mananjary
Area [km²]	460
Average elevation [m a.s.l]	713
Slope index [m/km]	7.5
Specific vertical drop [m]	162
Average annual rainfall [mm/y]	2112
Average interannual discharge [m³/s]	21.5
$Q_{95\%}$ - firm discharge [m³/s]	6.2
$Q_{50\%}$ - median discharge [m³/s]	17.0
$Q_{30\%}$ [m³/s]	23.5
10yr return period flood [m³/s]	846
100yr return period flood [m³/s]	1564

2.4 Sediment transport

At the time of the site visit (october 2014), turbidity was good (measured at 30 NTU). However the presence of lateral silt and sand deposits demonstrates that significant erosion and deposition processes occur at some period of the year, likely during major flood events.

Adequate sediments and gravels trapping systems will be designed at the feasibility study stage based on an analysis of the sediment load at different river discharges.

2.5 Site geology

2.5.1 Geological context

Heterogranular migmatitic granite composed of quartz, feldspar and biotite mica with a porphyroblast granitoid texture form the area petrography. Corresponding in place rocks lay in stratiform beds of variable width.

The structure is little fractured and cleavages are few. It results in boulders of various size, depending on the stratum spalling

Figure 9 : Local petrography

The same applies for alteration results : in some areas, they are significant with sandy-clay alterites and granitic sand while in other areas, alterations appear as clearly superficial. The multiplicity of granitic sand on hilly slopes explains the high bed load observed in the river.

2.5.2 Technical characteristics

<u>Right bank support aspect</u>: the right bank offers a hill with a rock structure in-place. It is poorly altered with a heavy vegetal cover. The structure is outcropping on the riverbanks. It is compact but is subject to surface erosion and dismantling in boulders given its easy spalling due to the stratum laying.

<u>Left bank support aspect</u>: fine sand (dune), approximately 4m high. The vegetal cover is about 0.30m thick.

Figure 10: Big boulders within the river bed

The left bank presents an embankment of some meters high, made of finely stratified rock in their arenic shape (easily .breakable). this formation could extend quite far towards West, what make this section unfavorable for support. Further studies will have to confirm this assumpotion based on complementary investigations. If required, an alternative proposal might be needed.

<u>Intake :</u> the area is covered by fine silty sand but massive boulders are found below the dunes and they are apparently reworked. The bedrock should be found deeper.

<u>Waterway :</u> the tunnel will cross a granitoid textured mountain. Structural variability could not be determined but the Petrographic constitution of the rock remains similar as the rock outcropping at the riverside. The nature of the layers plays a key role on the compactness state of the formation from place to place. As no major fault is found, the compactness state is ensured for tens of meters below the surface. The stratiform aspect and the arrangement of the layers could lead to leakage by opening of the layers along potential structural folds.

Penstock: down the hill, the supporting soil for the penstock would be a block field with a similar petrographic nature as that found on the other side of the hill. The size of the boulders is to be determined as it varies a lot, depending on the nature of the layers.

Powerhouse: the overlaying roof rock outcrops on the bottom of the river close to the powerhouse.

2.5.3 Recommendations for further investigations

ELEMENT	UNCERTAINTY TO REMOVE	SURVEY TYPE
Bed at weir	Existence and continuity of a well anchored rock mass within the river.	✓ Drying of the river bed, de sanding and determination whether rocky blocks are in-place or reworked. ✓ Tests to be conducted on the left side by mechanical excavation of drillings
Right support	No major problem for anchoring a weir (depending on the final weir height).	-
Left support	Existence of massive rocks in place.	✓ Mechanical excavation until massive rocky forms are encountered to get rid of boulders set in their granitic sand
Intake / waterway	Given the stratiform state of the formation, compacity of the rock to cross (fear of possible strata opening by spalling and structural movements).	✓ Core drilling at some chosen points along the waterway to characterize the fracturing condition and to conduct percolation tests
Penstock	Stability of hill slope for supports.	✓ More detailed geological reconnaissance to be defined in the next study stages, once the final penstock trace is defined
Powerhouse	Existence of massive rock to serve as powerhouse foundation.	✓ Auger drilling or seismic reflection geophysical survey

2.5.4 Major risks

Given the alteration level on the left river bank, it might happen that nothing else than rock boulders set in their granitic sand shape are found (hence, the river bank will easily break up into sandy elements). In such event, the place is not suitable for weir anchorage.

It should be noted that a little upstream of the proposed site location, there are clear rock outcrops on both riversides and below the river.

2.6 Socio-environmental aspects

The site detailed description sheet is provided in the Appendices.

2.6.1 *Socio-environmental background*

The site is located on the Faravory River, fokontany of Maromena, community of Ifanadiana, Ifanadiana District, Region of Vatovavy Fitovinany.

The main vegetation is savoka, which is a secondary vegetation coming from the degradation of the forest ecosystem and from the repetitive forest clearings by fire (« tavy »). They are Ravinala (*Ravenala madagascariensis*) and bamboos (*Nastus*). We can also find bushy species (*Aframomum angustifolium*, *Lantana camara*, *Philippia*, *Clidemia hirta*, *Pteridium*), and herbaceous species (*Neyraudia*, *Imperata*, *Bidens pilosa*).

Nevertheless, some primary shred forests are present on the crest, even if they show signs of degradation. Sometimes they can also be found in the lower parts of the hillside, among riparian vegetation.

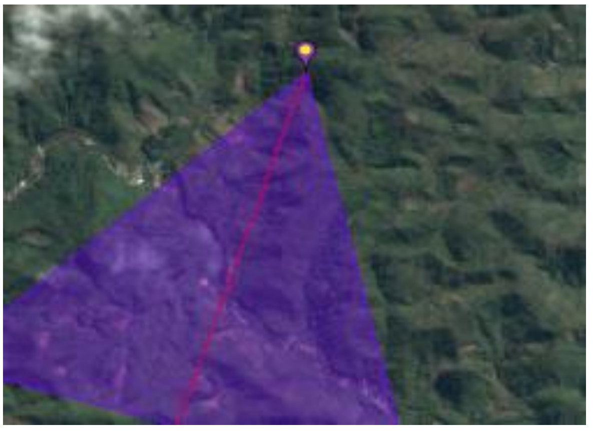

Image 11. Vegetation downstream of the site (central)

From the socio-economic perspective, the main village (Ambalahosy) is located about 1km South from the site. It has about 50 huts. Moreover, about 40 small hamlets (~3huts/hamlet) and campsites (~1 temporary hut/campsite) can be found within a radius of 1km from the site. The closest hamlets are situated on the expected route for the penstock pipe and about 100m away from the weir site.

Tavy (slash-and-burn) is the main local activity. We can find rice, manioc, corn and sugar cane crops. Tavy is used on both hillsides and river banks. Moreover, valleys and lowlands are sometimes arranged as rice fields (for instance: the expected route of the penstock pipe crosses a rice fields).

Some gold mining activities are also noticed in the area. Gold miners create artisanal holes and/or galleries and then filter the ground in the Faravory River to find gold.

The following image gives a global overview of the land use in the area.

Image 12. Land use in the area of the site

2.6.2 *Socio-environmental constraints*

Some hamlets and campsites are situated near the development sites (weir, penstock pipe, power plant). The implementation of the project could create some problems, especially regarding potential nuisances (noise, traffic, atmospheric emissions…). The small distance with those hamlets increases the risk of an accident for the concerned population. In particular, a small hamlet on the expected route of the penstock pipe and another campsite located ~90m away from the weir.

Downstream of the projected intake, a potential drying of the river up to the water restitution zone could affect the hamlets of the area: this could interfere with the use of the water resource. In particular, on this section, a hamlet is located on the left bank, about 50m away from the river and another one on the right bank, about 100m away from the river.

On the other hand, if the implementation of the project leads to an increase of the water level upstream of the weir, some rice fields on the right bank, ~90m upstream of the site/~20m away from the river, and a campsite on the left bank, ~90m upstream of the site/~40m away from the river, could be affected by the provoked flooding, depending on its magnitude.

Finally, the implementation of the project could also impact on the gold mining activities which are common in the area. In particular, several small gold miners who work in the East part of the area.

2.6.3 *World Bank Safeguard Policies that could be applicable:*

The World Bank Safeguard Policies that could be applicable for the AD 652 site are the following:

- OP 4.01 – The Bank requires Environmental Assessment (EA) of projects proposed for Bank financing to help ensure that they are environmentally sound and sustainable, and thus to improve decision making. However, we can already estimate that the adverse impacts on human populations and environment-linked areas are limited. They are reduced, not irreversible and some measures can prevent, mitigate or minimize them. Moreover, these measures can improve the environmental performance.

- OP 4.12 – Involuntary Resettlement: the hydropower project will require the use of a large space (implementation of the plant, creation of access roads to the site…), which sometimes are crops areas. So the project will have to take into account the concerned people and communities, particular regarding the restoration of the standards of living due to the loss of resources.

OP 4.11 – Cultural Heritage is not applicable because the site is not known for containing particular cultural material resources. Idem for OP 4.04 – Natural Habitats

The projected weir (3m high) is classified as a small dam (<15m high); the usual generic safety measures for dams are appropriate and do not need the implementation of OP 4.37 – Safety of Dams (for large dams).

3 PROPOSED SCHEME LAYOUT

3.1 Technical assumptions

The project will likely be connected to the Interconnected Transmission Network of Fianarantsoa (RIF) given both the potential energy generation of the proposed scheme and its proximity to the RIF. The objective is to carry out a high level assessment of the scheme potential in terms of installed capacity, energy generation (firm and average) and the associated capital investment costs (CAPEX) and productions costs (Levelized cost of energy). Hence, at this stage of the study, the technical features of the hydropower scheme are designed in the following sections for both firm and median discharges (respectively $Q_{95\%}$ and $Q_{50\%}$). The actual design flow will be determined during the detailed studies based on economical, financial and technical criterion as well as the future energy and power demand.

The proposed scheme layout is shown in Figure 13 and presented in A3 format in appendix 5.2 of this report.

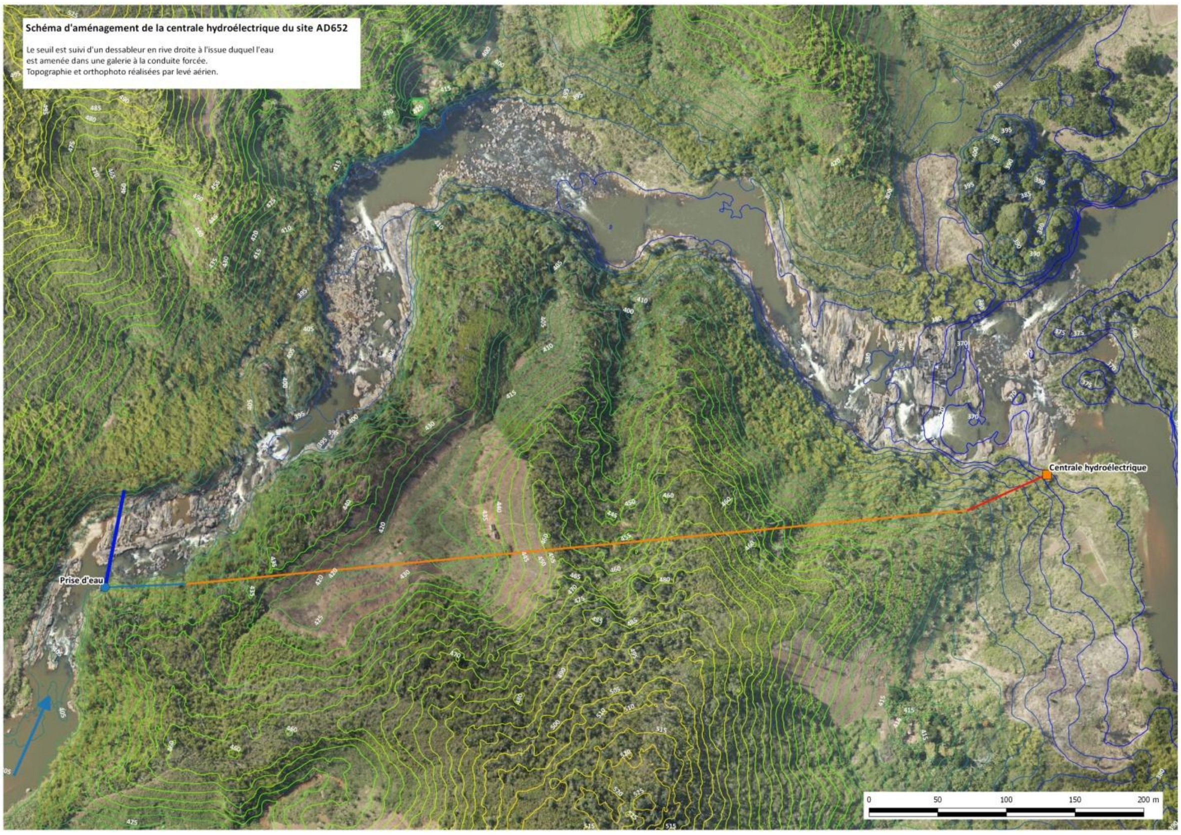

Figure 13. Proposed scheme layout for the site

3.2 Weir and intake

The 65m long and 3m high weir would be founded on the rock in-place, upstream of the waterfall. The intake, located on the right riverbank, will be followed by a desander and a short canal arriving in the tunnel.

3.3 Desander

Given the potential sediment load in the river mentioned previously, adequate desander system will be required. It is suggested to implement it on the right river bank, close to the weir. The natural drop at the weir will enable an effective purge of the desander.

3.4 Waterways

Waterway consists of a short 25m long canal (including desander) and of a 650m long tunnel. The elevation profile of the natural ground above the proposed tunnel alignment is illustrated in the figure below. The final tunnel alignment will be determined after the detailed geological and geotechnical surveys to ensure the presence of sufficient thickness of adequate rock around the tunnel. The tunnel will end in a surge chamber/shaft at the junction with the penstock leading to the powerhouse.

The canal section would be 1.80m x 2.90m (assuming the design flow at $Q_{95\%}$) or 2.95m x 4.80m (assuming the design flow at $Q_{50\%}$). The tunnel diameter would be 2.10m (for $Q_{95\%}$) or 3.50m (for $Q_{50\%}$)

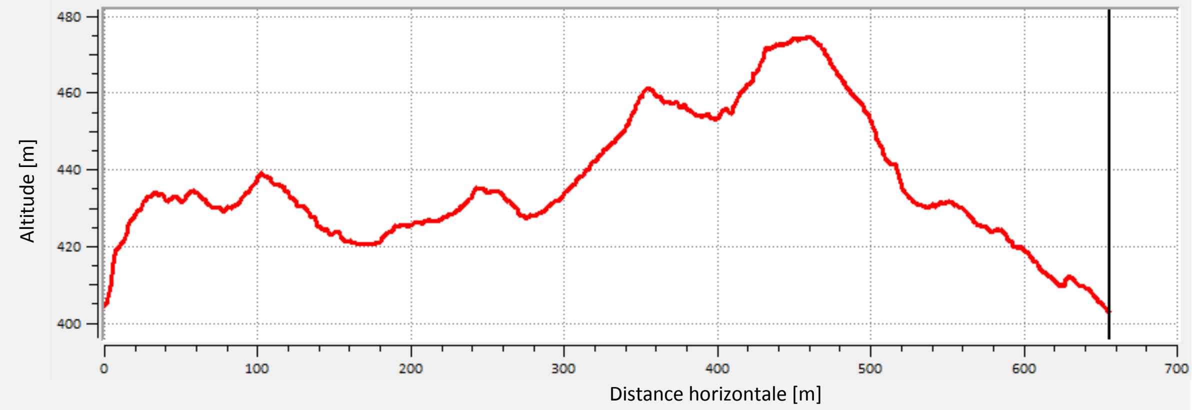

Figure 14. Elevation profile of the natural ground above the proposed tunnel alignment

3.5 Penstock and powerhouse

The penstock will have a total length about 50m and single 1.2 m (assuming the design flow at $Q_{95\%}$) or two 1.6 m (assuming the design flow at $Q_{50\%}$) diameter penstocks will be required to ensure that the head losses due to friction in the pipes will be below 5% of the available gross head.

3.6 Electromechanical equipments

3.6.1 Design flow taken at $Q_{95\%}$

Theoretically, the project should be connected to RIF grid. Hence, the chosen turbine type must enable a maximization of the power output. For a design flow taken at Q_{95}, not much flexibility is required for the turbine as it will work most of the time at nominal power.

Head, discharge and foreseen output allow the choice between a Francis turbine, which offers a high performance level and a satisfactory flexibility, and the double regulated Kaplan turbine which offers a high efficiency on a large discharge range. The final choice is set on a Francis turbine which is simpler and more robust. The suggested solution does not require the use of a gearbox, which is a sensitive and costly component, as well for operation as for maintenance.

Given observations formulated about water quality, a particular attention must be paid to the quality of materials used for the construction of the turbine. One should probably consider the need for an anti-abrasion coating.

Electromechanical equipments of the powerhouse will then be composed of:

- Butterfly safety valve with counterweight to ensure its closure in case of emergency of black out.
- A 1 905 kW vertical axis Francis turbine running at 750rpm.
- A 690V alternator, 1 790 kW/ 1 990 kVA.

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

- Control and monitoring system, including speed regulator and voltage regulator.
- Security system and electrical protection.
- Step-up transformer and electrical cabinet and switchgear.
- Emergency power unit.

Figure 15 : Example of two vertical axis Francis units

Following issues should be studied as well in the next stages of the project :

- Sedimentation problem and the need for anti-abrasion coatings (e.g. Tungsten carbide).
- Technical and economic optimization of the penstock diameter.
- Technical and economic optimization of the number of units and of the design flow, according to the hydrology and the electrical demand.
- The need of a flywheel (for grid stability)
- The set up level and rotational speed of the turbine (Suction height and cavitation issues).
- Grid voltage.
- Preliminary turbine design.

3.6.2 *Design flow taken at $Q_{50\%}$*

For a design flow taken at Q_{50}, it is recommended to install three identical units (Francis turbines) in order to optimize the global efficiency and to increase the plant availability.

Other considerations exposed for a design flow at Q_{95} remain valid for a design flow taken at the median discharge (Q_{50}).Turbines will have a unit nominal power of 1 770 kW and a rotation speed of 750 rpm. The alternator power will be 1 660 kV/ 1 845 kVA for a 690 V voltage.

A power plant PLC (Programmable Logic Controller) should also be foreseen to manage the three units.

3.7 Transmission lines

It is envisaged that the proposed hydropower scheme would be connected to the Interconnected Grid (RIF) using a 8 km long and 33kV line to Ifanadiana.

3.8 Key technical features

The key features of the proposed hydropower scheme are summarized in the table below for both firm ($Q_{95\%}$) and median ($Q_{50\%}$) design flows.

		Firm discharge	Median discharge
Installed capacity	[kW]	1790	4980
Potential annual generation	[GWh/yr]	13.94	35.71
Design flow	[m³/s]	6.2	17
Gross head	[m]	37	
100yr return period flood	[m³/s]	1 564	
Weir length	[m]	65	
Weir height	[m]	3	
Desander		Large size	
Tunnel length	[m]	25	
Tunnel diameter	[m]	2.9 x 1.8	4.8 x 2.95
Penstock length	[m]	650	
Penstock diameter	[m]	2.1	3.5
Number of penstock(s)	[-]	50	
Number of T/G units	[-]	1.2	1.6
Transmission line length	[km]	1	1
Line voltage	[kV]	1	3
Length of the access road to create	[km]	8	
Length of the access road to upgrade/rehabilitate	[km]	33	
Installed capacity	[kW]	8	
Potential annual generation	[GWh/yr]	0	

4 ENERGY GENERATION AND COSTS

Based on the assumptions of the economical and hydrological studies presented in the main report, the proposed hydropower scheme would feature the following values:

Gross head	**[m]**	37	
Design flow	**[m³/s]**	6.2 ($Q_{95\%}$)	17.0 ($Q_{50\%}$)
Installed capacity	**[kW]**	1 790	4 980
Potential annual generation	**[GWh/yr]**	13.94	35.71
CAPEX (excl. access and lines)	**[M$]**	8.45	18.28
LCOE (excl. access and lines)	**[$/kWh]**	0.073	0.062
Total CAPEX (incl. access and lines)	**[M$]**	13.19	23.01
Total LCOE (incl. access and lines)	**[$/kWh]**	0.113	0.077

5 Appendices

5.1 Socio-environmental description form

A – Site localisation

Site reference	:	AD652 - Tambohorano
Village / **Fokontany**	:	Maromena
Community / District/Region	:	Ifanadiana / Ifanadiana / Vatovavy Fitovinany

B – Description of the biophysical background

<table>
<tr><td>Relief</td><td>The site is located on the Faravory River. It receives several watercourses such as the Mangabe (South) and the Sahanaka (North).

In the area of study, there are the mountains massifs of Sahavohikatra, Tambohorano and Analavory. The expected penstocks cross a mountain (~520m high). The relief is mainly precipitous and the hillsides of the Faravory river have quite steep slopes.


DSC 00140 :Localisation of the future infrastructures and general overview of the site


S21°15'20.79" E47°40'35.66"</td></tr>
<tr><td>Vegetation</td><td>The projected sites is in the Eastern domain. The main vegetation is savoka, which is a secondary vegetation coming from the degradation of the forest ecosystem and from the repetitive forest clearings by fire (« tavy »). They are Ravinala (Ravenala madagascariensis) and bamboos (Nastus). We can also find bushy species (Aframomum angustifolium, Lantana camara, Philippia, Clidemia hirta, Pteridium), and herbaceous species (Neyraudia, Imperata, Bidens pilosa). Some quite homogeneous bamboo formations might partly or fully cover the hillsides. Nevertheless, some primary shred forests are present on the crest, even if they show signs of degradation. Sometimes they can also be found in the lower parts of the hillside, among riparian vegetation.

Moreover, we can see traces of fire because of the tavy, for cultures. After a few years of crops, the soils have to rest for a certain amount of time. The frequency and the duration of the tavy/fallow shape the landscape and the local vegetation over the course of time. So we can find in the area different levels of degradation of the forest ecosystem in the West of the domain (forests, savoka (bamboo/ravinala), grasslands, low vegetation…).</td></tr>
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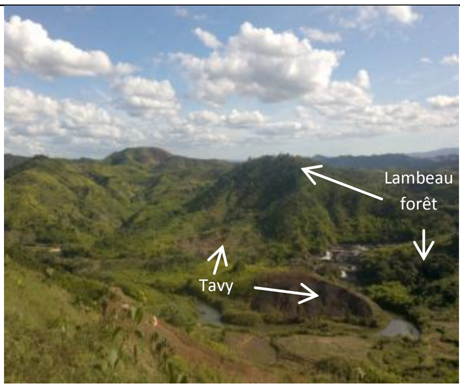
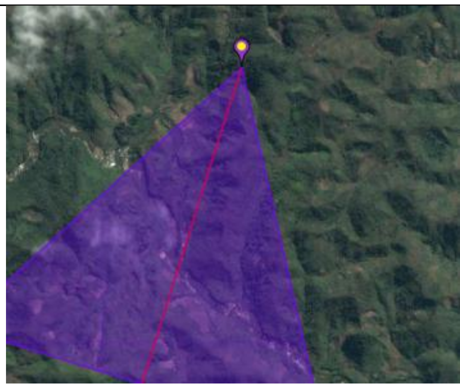
In case of discrepancy between the French language original text and the English language translation, the French text shall prevail



Landscape of the power plant



S21°15'21.46" E47°40'35.81"

Bamboo and woody species savoka

S21°15'48.83" E47°39'41.34"

Mosaic of crops on the right bank of the Faravory River

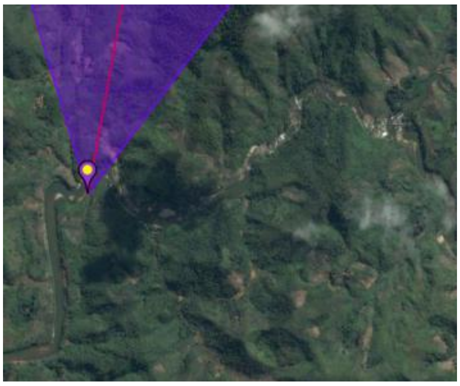
S21°15'49.54" E47°39'21.29"

OBSERVATIONS

Traces of fire can be observed. Slash-and-burn is commonly used to clear crops in the area.

Slash-and-burn

S21°15'51.25" E47°39'34.11"

CRITICAL AREAS	Some conservation sites can be found more than 10km North East and South from the site. The closest protected area, called the Ranomafana National Park, is located more than 12km East of the site, as the crow flies. Certain parts of the river banks suffer from water erosion;   Erosion of the banks S21°15'46.64" E47°39'24.78"

B - Description of the socio-economic background

LOCALITÉ	The site belongs to the fokontany of Maromena. The main village (Ambalahosy) is located about 1km South from the site. It has about 50 huts. Moreover, about 40 small hamlets (~3huts/hamlet) and campsites (~1 temporary hut/campsite) can be found within a radius of 1km from the site. A campsite is called « saha ». Campsite exists for a whole crop period or until the depletion of the soil fertility (slash-and-burn).   Huts S21°15'49.35" E47°39'21.37" The site is accessible by car (4X4) thanks to a secondary road (3km long), from the change of direction heading North near the Ifanadiana village, in the direction of Ambohimanga South. Then you have to walk a 7km long path to reach the site.

ACTIVITIES	Tavy (slash-and-burn) is the main local activity. We can find rice, manioc, corn and sugar cane crops. Tavy is used on both hillsides and river banks. Moreover, valleys and lowlands are sometimes used as rice crops (for instance: the expected route of the penstock pipe crosses rice fields). Some gold mining activities are also noticed in the area. Gold miners create artisanal holes and/or galleries and then filter the ground in the Faravory River to find gold.   Tavy Rice fields   Gold mining activities
OTHERS (IF ANY)	The main ethnic groups of the Ifanadiana District are the Tanalas and the Sahafatras. Some smallholder farmers look for crystal, emerald, corundum, tourmaline, beryl, amethyst, apatite, gold, cordierite and quartz. The research and exploitation authorization expired in 2015 for the main part of the area (Eastern part).

C –World Bank Safety Policies applicable :

OP 4.01 – Environmental Assessment ☒
OP 4.04 – Natural Habitats ☐
OP 4.11 – Cultural Heritage ☐
OP 4.12 – Involuntary Resettlement ☒
OP 4.37 – Safety of Dams ☐

Map of the hamlets

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

Land use around the site

 : Savoka

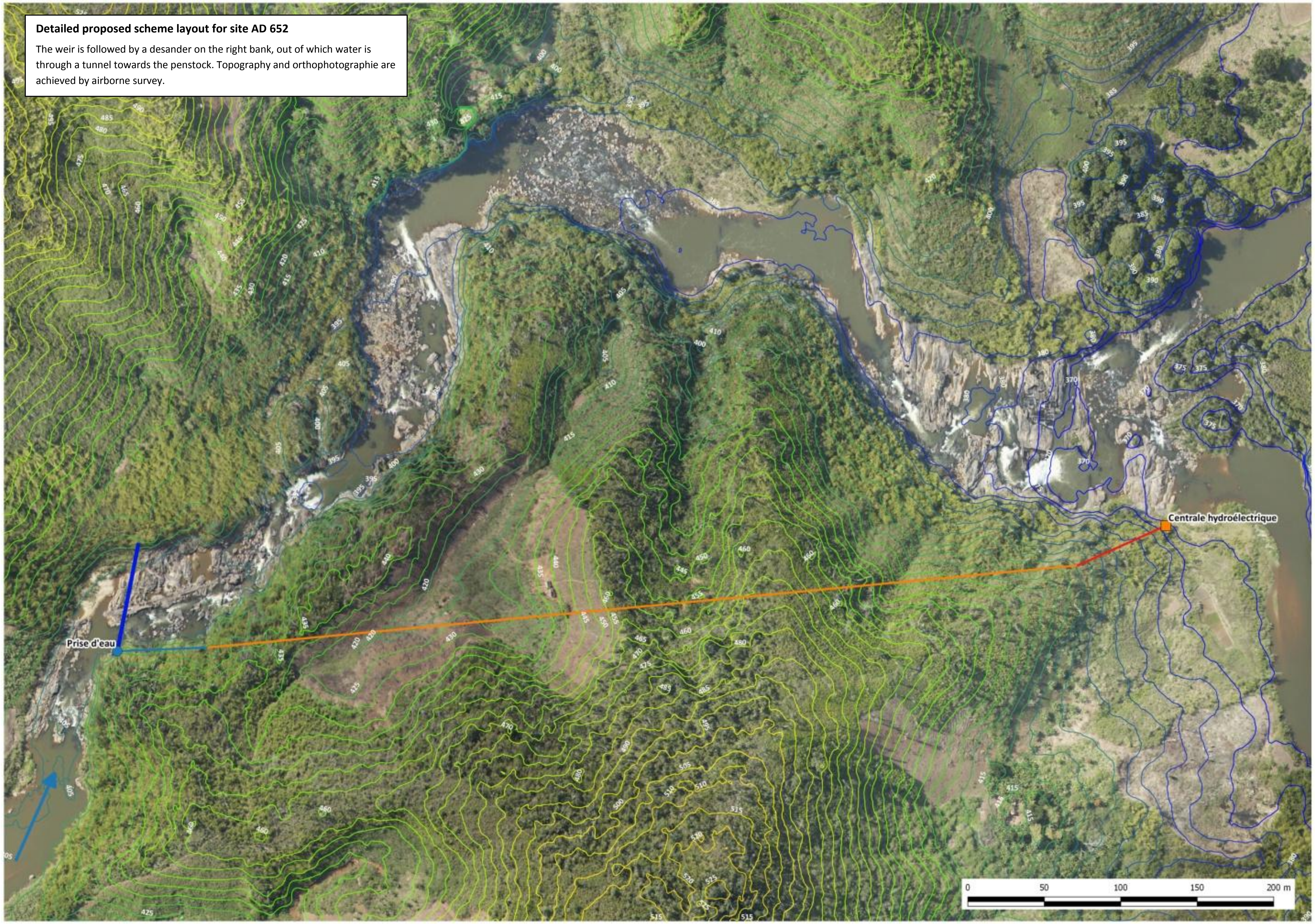
 : Quite dense tree and shrub vegetation

 : Rice fields

 : Recent traces of land clearing/fires

 : Hamlets

5.2 Detailed proposed scheme layout



In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

Madagascar: Small Hydropower Resource Atlas (1-20MW)
Site Investigation Report

VOHINAOMBY SITE

Ivonina Asitonga River | Atlas Code: AD653

Table of content

1 SITE LOCATION

Geographical coordinates (WGS 84)	Longitude [°]	Latitude [°]
Intake	46.682	-21.260
Powerhouse	46.681	-21.262

1.1 Administrative data

Atlas code	AD653
Site name	Vohinaomby
River	Antsakoama
Major river basin	Mongoky
Province	Fianarantsoa
Region	Haute Matsiatra
District	Ikalamavony
Commune	Mangidy
Village	Asitonga
Reference topographical map	Carte topographique n°M53 (échelle 1:100,000)

1.2 Access

Access to the site is possible by taking the dirt road RN42 (Fianarantsoa – Ikalamavony). Given the poor road conditions, 4 hours are currently necessary to cover the 70km from Fianarantsoa. From there, one can reach the site on foot wuth a 2 km long track.

It is expected to rehabilitate 70km of the RN42 and to create 3.2km to access the infrastructure of thesite.

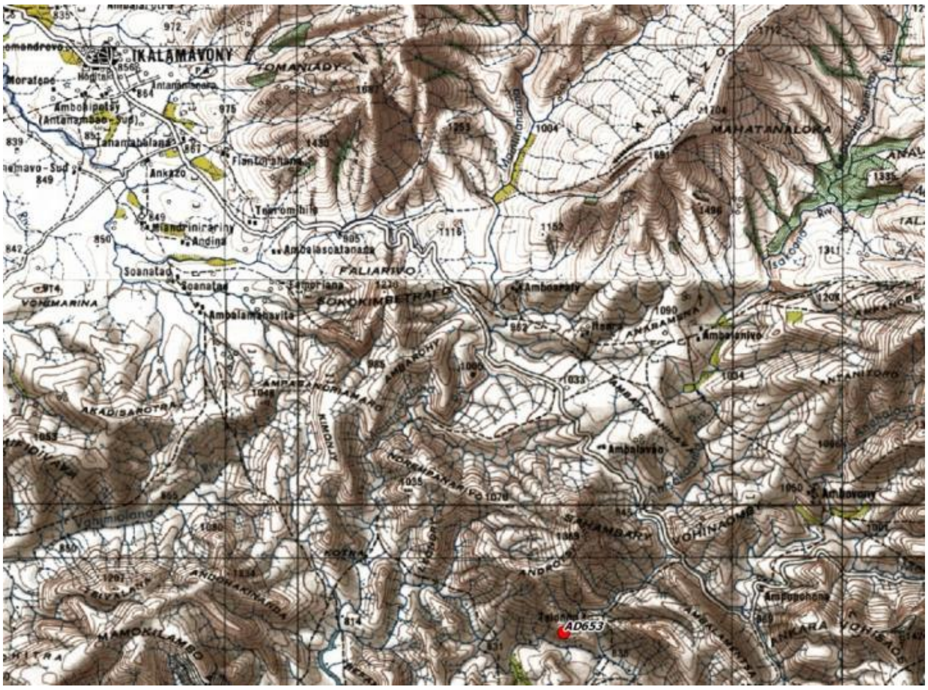


Figure 1. Access to the site from the village of Ikalamavony

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

Figure 2. Site global context and proximity with Ikalamavony town.

2 GENERAL SITE DESCRIPTION

2.1 Background

The site is located in a narrow glen where the river makes a half loop around a hill while losing elevation. On the central hill, lies a village with some 20 houses. An irrigation scheme exists with an intake upstream of the site.

Figure 3. Site overview

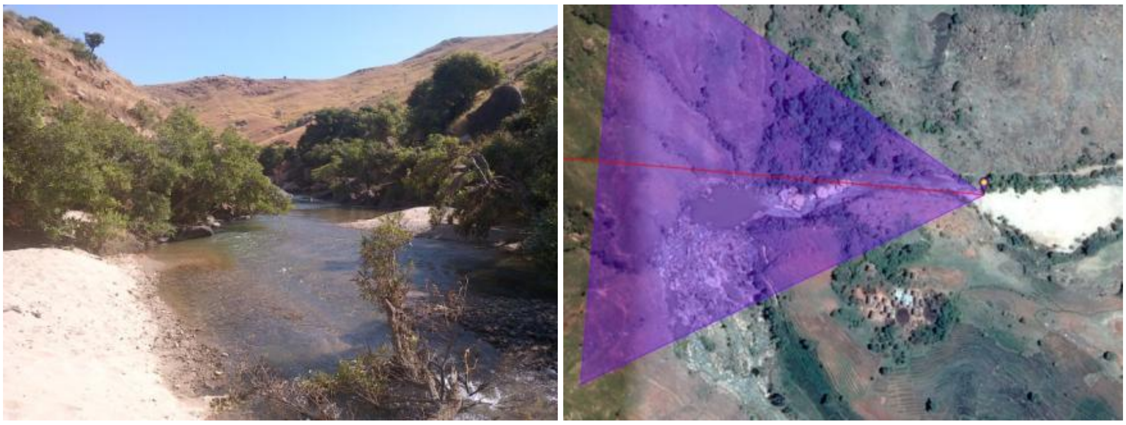


Figure 4. View on the narrow glen

Figure 5. Waterfall from above

Figure 6. Watefall from below

2.2 Topography

The topographical survey was achieved through remote sensing. An aircraft was chartered and equipped with optical sensors.

The topographical survey has a point density of 5 /m² and a relative accuracy of 2%.

Outputs from airborne survey are (1) a high resolution orthophotography (0.2m to 0.4m resolution) and (2) a Digital Surface Model (DSM). The DSM includes the vegetal cover, but it gives an excellent global picture of the site topographical configuration. Contour lines might be deduced from the DSM.

Figure 7. Aircraft and container of remote sensors for airborne survey

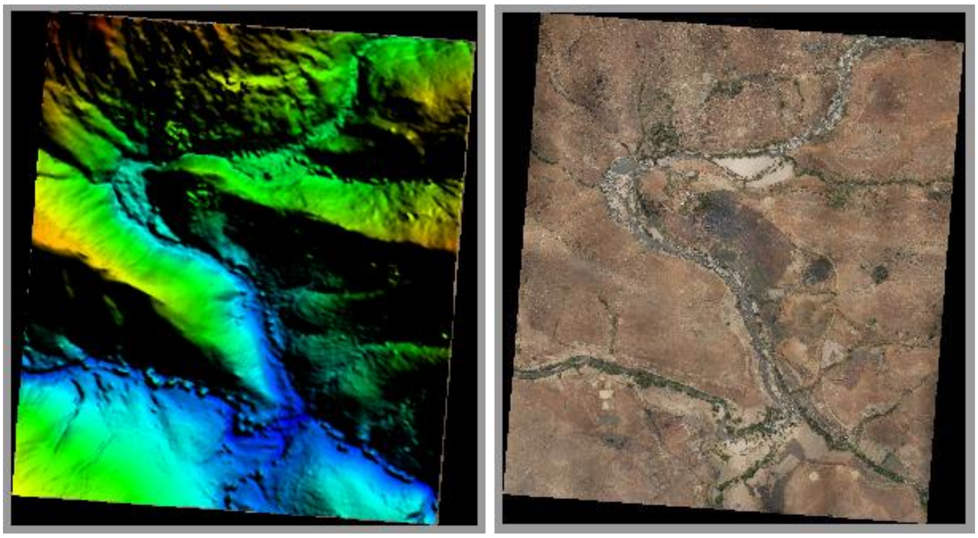


Figure 8. Digital Surface Model and orthophotography from airborne survey

2.3 Preliminary hydrological study

Accurate information on the hydrology of the Antsakoama River does not exist. As a consequence, statistical characteristics of the river discharge at the site of interest have been estimated using a regional methodology. This methodology is based on the available information at other hydrometric stations distributed in the country. Given the limited spatial and temporal resolution of the available data, the results of the regional study presented below are indicative only and are not intended to be used for design purposes without further detailed hydrological studies.

Key preliminary hydrological characteristics of the river at the site of interest are presented in the table below.

River	Antsakoama
Main river basin	Mongoky
Area [km²]	387
Average elevation [m a.s.l]	1353
Slope index [m/km]	8.8
Specific vertical drop [m]	172
Average annual rainfall [mm/yr]	1158
Average interannual discharge [m³/s]	6.9
$Q_{95\%}$ - firm discharge [m³/s]	2.2
$Q_{50\%}$ - median discharge [m³/s]	4.7

$Q_{30\%}$ [m³/s]	6.0
10yr return period flood [m³/s]	344
100yr return period flood [m³/s]	756

2.4 Sediment transport

Sediment issue is expected to be important. Sand and stones strips are visible along the river banks.

Figure 9. Material visible on the left bank, just upstream of the waterfall

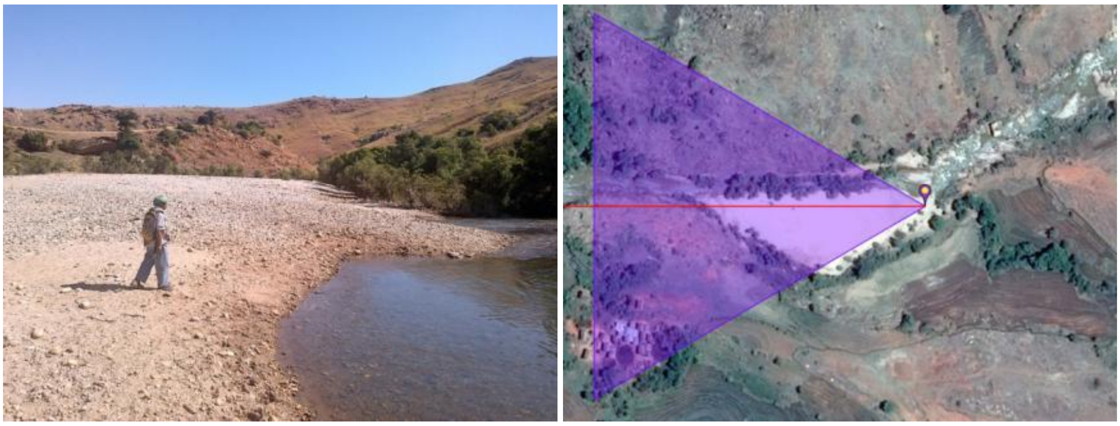


Figure 10. sand strip upstream of the waterfall

2.5 Existing irrigation scheme

An existing irrigation scheme is used by the villagers. The intake is located 1.8km upstream of the waterfall. The irrigation canal crosses the hill to feed parcels behind it.

The impact of the proposed hydropower scheme would be limited because located on the side of the irrigation area. Only 0.3 ha of currently cultivated area should be taken for the hydropower scheme.

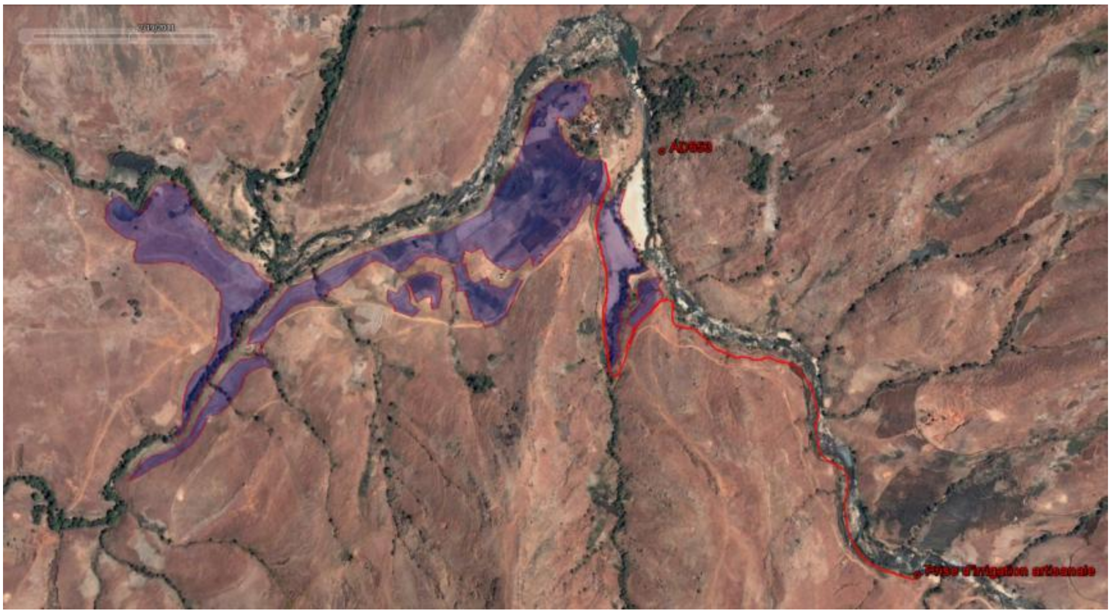


Figure 11. Zones d'irrigation déduites de GoogleEarth: (à confirmer). 20ha. L'ouest pointe vers le haut

There is another irrigation scheme on the right bank whose intake is 3.5km upstream of the intake and it ends 1km upstream of the waterfall.

2.6 Site Geology

2.6.1 Geological context

The whole area is dominated by gneissic migmatite with beds, or even stratum, of quartzite interbedded within migmatites. Some microcline quartzic pegmatite folds of centimetric dimension are randomly observed within the migmatite. All of it composes a sound and compact rock, outcropping on the left bank of the proposed weir axis (Figure 15) and further downstream along the riverbed, where it is observed under the shape of rock slides shredded by the water flow. The formation plunges towards West, between 20° and 30° dip with a variable direction, from N50 E to N 70 E.

Laterisation is not important in-depth (thickness of decimetric to metric order). The area is only marked by thin screes within laterite with scattered noticeable boulders (in place or not) of the same rock type.

On a tectonic point of view, some small cross cutting fractures are noticed on the whole sector. They are especially put in evidence through the land morphology.

An important regional fracturing effect is also noticed. It explaine the difference of elevation observed between the left and right river banks at the proposed weir location. It results from diagonal faults that affect the whole region, causing partial collapsing and important strike slips on bedding rock formations. It is why, at the projected weir location, the river follows a tectonic direction combined with a relative lateral displacement that caused the right bank to drop with regard to the left bank and explains how no equivalent geologic formations are fond on the same elevations on both river banks.

Similarly, there could be a sequence of higher rock protrusion on the right river bank, upstream of the project weir site (this should be checked on site as it was observed based on aerial imagery).

2.6.2 Technical characteristics

Bed aspect at the projected weir location: the river bottom is looking sandy but the bedrock is found not deep below. It would consist is quartzitic migmatite beds with quartzic pegmatite folds. The bedrock might however not be massive rock, due to the probable fracture along the river axis.

Left bank support aspect: the left bank shows migmatite rock mass interbedded with thin quartzic layers. Some quartz and feldspar pegmatite folded intrusions are also found. The in-situ rock formation is hard, very resistant and compact (Figure 12).

Figure 12. View towards upstream, the left bank is on the right on the picture

However, due to its foliated original texture and as the rock is free at the surface, decompression favors spalling of outcropping part. It induces differential alteration, observed under the serrated shape of the outcropping rocks which is especially noticeable along the river, on the downstream part (Figure 13).

Figure 13. Spalling aspect of migmatic rocks on the surface and under water flow effect downstream of the site.

Right bank support aspect: unlike the left bank, no sound rock is found high up on the right bank. Rock found are mainly big reworked boulders of metric dimension over hanging over the river(Figure 14). Hence, it is not advisable to use this section of the right bank for weir support. A bit upstream, there is a portion of projecting geological formation that, although not observed close by, could suit for a run of the river weir.

Figure 14. Boulders not in place on the right bank of the proposed weir axis

Intake and waterway: for this site, a tunnel crossing the sound rock described for the left riverbank would bring water to the penstock. Hence, the detailed characteristics of the rock should be determined in the next stages of the study. From the current study, it might be said that the rock seems compact with few joints. It forms the bedrock on which Vohinaomby village (called Tsitonga by the villagers) is located.

Foliation opening within the migmatitic rock is however feared, it might be induced by decompression on the surface or close by (spalling effect Figure 15). It would follow the layers directions and could ease leakage in the future.

A rather important fracture is observed on the left bank and affects the migmatitc rock (Figure 15). It results in the deviation of the rock formation from N70 20W from the southern part to N50 20W for the northern part. Given its direction and importance, it must continue to the other riverside and hence cross the future tunnel. It is probable that this fracture is not the only one in the area.

Figure 15. Rock constitution of the left river bank and petrographic texture

Canal (if tunnel is not possible): it will be set in structured laterite and laterite formations. In this area, laterite formations are partly converted in rice terrace by the villagers and follow the natural land slope. If such is needed, the conception of the canal should take this parameter into account.

Penstock: same observation as above. Only the lowest part could be made of boulders with more or less important dimension.

Nota : for the canal as well as for the penstock, no lavaka is to feared thanks to the small thickness of laterisation on this area.

Powerhouse : the reduced laterite thickness is an advantage for the powerhouse foundations. Sound rock is found at a low depth (1 to 2 m maximum, depending to the selected location). However, the nature of the rock could be in situ massive bedrock of just boulders as those observed in the riverbed.

2.6.3 Recommendations for further investigations

ELEMENT	UNCERTAINTY TO REMOVE	SURVEY TYPE
Bed at weir	✓ Determine whether the riverbed is made of massive rock or in-situ or heaped boulders	✓ Clearing of the sand layer in the river
Left support	✓ Existence of other important fractures similar to that encountered. ✓ Importance, depth and density of spalling (presented under the shape of rock masses outcropping at the supports as well as at the projected powerhouse area - Figure 15) ✓ Fear of leakages below the weir.	✓ More detailed geological investigation of the existing rock outcrops along the river (before construction, compressed air blowing should be conducted within the fractures or rock openings encountered to enable clogging by cement grout injection) ✓ Percolation tests should be conducted by drillings, before the construction starts.
Right support	✓ Constitution and characterization of the overhanging rock formations located upstream of the support indicated in this report	✓ More detailed geological investigation of the overhanging rock
Intake / waterway	✓ Compactness of the rock mass to drill, given the eventual fractures and spallings	✓ Core drilling at some chosen points for percolation tests.
Canal (if needed)	✓ Crossing of rice terraces	✓ Masonry works might be required
Penstock	✓ Nature and state of the land to cross	✓ More detailed geological reconnaissance to be defined in the next study stages, once the final penstock trace is defined
Powerhouse	✓ Characterization of the supporting ground (Massive rock? Boulder in place or not? Depth of laterite?)	✓ Auger drilling or seismic reflection geophysical survey

2.6.4 *Main risks*

The observed section of the right bank does not offer enough massive rock for weir support and anchoring. This is why the projected weir axis might have to be displaced upstream of this section. This should however be checked during the next stages of the study.

2.7 Socio-environmental aspects

The site detailed description sheet is provided in the Appendices.

2.7.1 *Socio-environmental background*

The site is located in the Isitonga village, in the fokontany of Laobato Atsimondrano, rural community of Mangidy, Ikalamavony District, Haute Matsiatra.

The area is characterised by a small amount of vegetal cover. It is mainly composed by herbaceous savannahs, such as *Hyparrhenia* and *Heteropogon*. Some saplings of mango trees can be observed, in particular near the villages/hamlets.

We can also find vast areas of mosaic of crops. These are terrace and/or hillsides parcels (dry and vegetable crops).

At the bottom of the hillsides, we can find riparian forests (*Breonadia* and *Mangium)*. The vegetation is composed by shrubby and woody species. The riparian forests are the main tree zones of the area.

Moreover, due to the small amount of vegetal cover, bare areas are likely to be affected by water erosion. An important silting can be seen upstream of the projected weir site.

Imahge16. Vegetation at the projected weir

From the socio-economic perspective, the main village is Isitonga, located 100m away from the projected weir and really close from the projected gallery route. It counts about 50 households. Moreover, some small hamlets are located within a radius of 400m from the site. They are on the hills and are separated from the watercourses by crop fields.

About the electricity in the area: the closest electric network is situated in the county seat of the Ikalamavony district and provides electricity only to the latter. The plant, implemented in 1997, works thanks to four power generators having a total capacity of 432 kW (82kW, 50kW, 80kW and 220kW). So far, only the 82 kW generator works and produces only 50 kW. However, this cannot meet the needs of the town because the consumption peak currently represents 160 kW. So, the electricity is only provided during 6hours a day, divided between two neighbourhoods: the first between 12 :00 and 15 :00 and the second between 15 :00 and 18 :00. In 2015, JIRAMA had about 400 subscribers and 30 requests on hold.

The main activity is rice growing. The land use is composed by terrace crops, with multilevel handmade irrigation canals. The intake of this hydro-agricultural scheme is located more than 1km upstream of the site. Water is taken through a small weir which is precariously built with river stones. The irrigations canals are earthen but some portions are suspended next to the difficult place (canyons) and need more resistant and manipulable materials (sheet-metal plates, wood, ….). Canals branch out upstream of the hillsides to irrigate 15ha of crops, located on the left bank of the river. Despite the implementation of handcraft infrastructures for the local population, the water flow is irregular and depends on the quality of the canals, which are skimpily maintained. As a matter of fact, some canal breaches and cracks can be seen, which causes progressives loss of the water flow. Terrace crops are mainly rice crops from October to May. However, some early rice parcels exist (harvest in November). They are used for self-consumption but due to the arrival of the manifolds, farmers tend to produce more and more and to sell a share of the production.

The majority of the households also works in subsistence and vegetable crops (onions, beans, corn, sweet potato, manioc.) and even sometimes cash crops (Tabaco, ricin).

It should be noted that there are a remarkable presence of tombs and headstones. A dozen tombs and headstones can be observed within a radius of less than 700m from the site

The following image gives a global overview of the land use in the area.

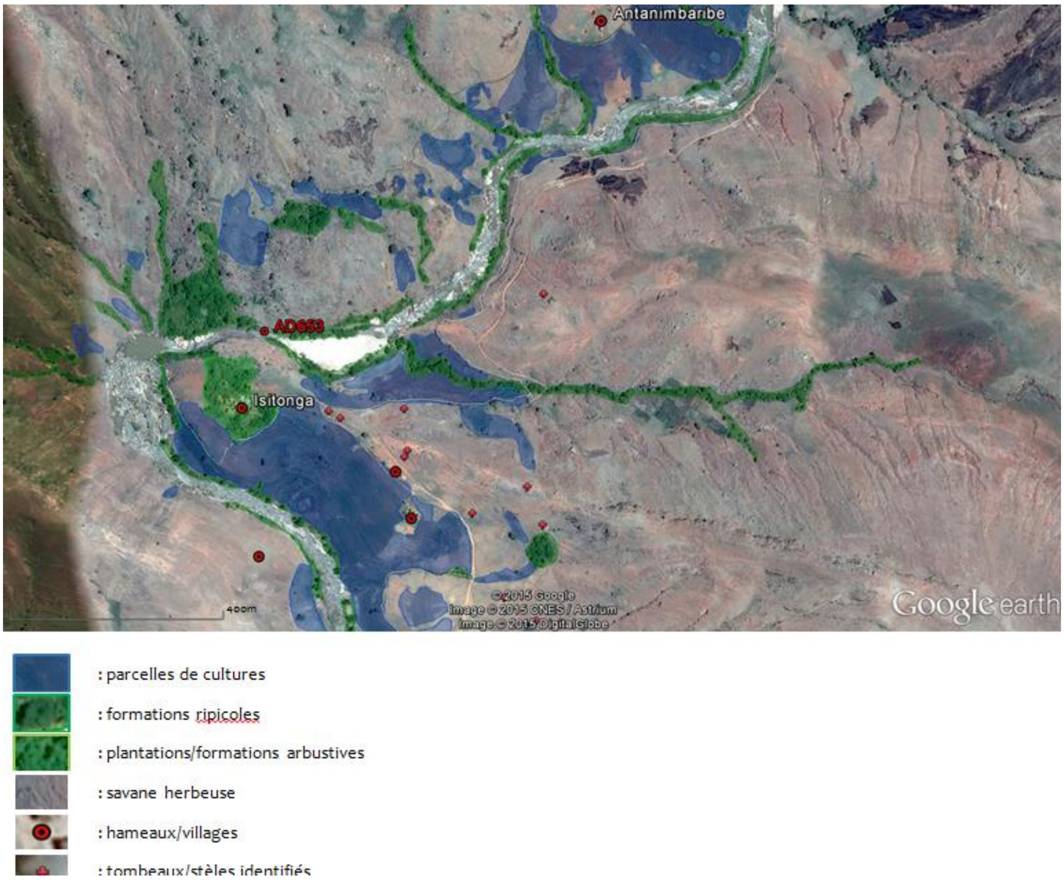


Figure 17. Land use at AD 653 site

2.7.2 *Socio-environmental constraints*

Some hamlets are situated next to development sites (weirs, tunnels, penstock pipes, plants) The implementation of the project will affect those hamlets, especially regarding potential nuisances (noise, traffic, atmospheric emissions…). The short distance between the hamlets and the working site will increase the risk of an accident for the concerned population, especially for the main village (Isitonga), situated on the projected route of the gallery.

On the other hand, next to the water intake, the Isitonga village (~50 households), let us think that the river is used at this point for the needs of the village. The implementation of the project will interfere with the village and its use of water. A drying of this area will have bad impacts on the village. Moreover, it would jeopardize the riparian forests in the area, in particular the one situated on the right bank of the river, downstream of the weir, which has a vast surface in relation with the rest of the area.

Moreover, some tombs and headstones are present near the site (between 100m and 700m). The work (new rights of way, improving the access,) could potentially lead to the destruction of this kind of heritage.

Finally, we can see a lot of vast culture crops in the area. The project might impinge on these fields (in particular the implementation of the powerplant), leading to a loss of resources for the concerned communities.

2.7.3 *World Bank operational policies that could be applicable:*

The World Bank Safeguard Policies that could be considered for the AD653 site are the following:

- OP 4.01 – The Bank requires Environmental Assessment (EA) of projects proposed for Bank financing to help ensure that they are environmentally sound and sustainable, and thus to improve decision making. However, we can already estimate that the adverse impacts on human populations and environment-linked areas are limited. They are reduced, not irreversible and some measures can prevent, mitigate or minimize them. Moreover, these measures can improve the environmental performance.
- OP 4.11 – Cultural Heritage: there are several tombs and headstones on the site.
- OP 4.12 – Involuntary Resettlement: the project needs new use of some areas (implementation of the plant, renovation of the access roads to the site…) that can be crop zones.
- OP 4.04 – Natural Habitats is not applicable.

The projected weir (6m high) is classified as a small dam (<15m high); the usual generic safety measures for dams are appropriate and do not need the implementation of OP 4.37 – Safety of Dams (for large dams).

3 PROPOSED SCHEME LAYOUT

3.1 Technical assumptions

An assessment of the scheme potential in terms of installed capacity, energy generation (firm and average) and the associated capital investment costs (CAPEX) and productions costs (Levelized cost of energy) is presented in section 4. It is based on the scheme proposed in this section. Hence, at this stage of the study, the technical features of the hydropower scheme are designed for both firm and median discharges (respectively $Q_{95\%}$ and $Q_{50\%}$). The actual design flow will be determined during the detailed studies based on economical, financial and technical criterion as well as the future energy and power demand.

The proposed scheme layout is shown below and presented in A3 format in the Appendix of this report.

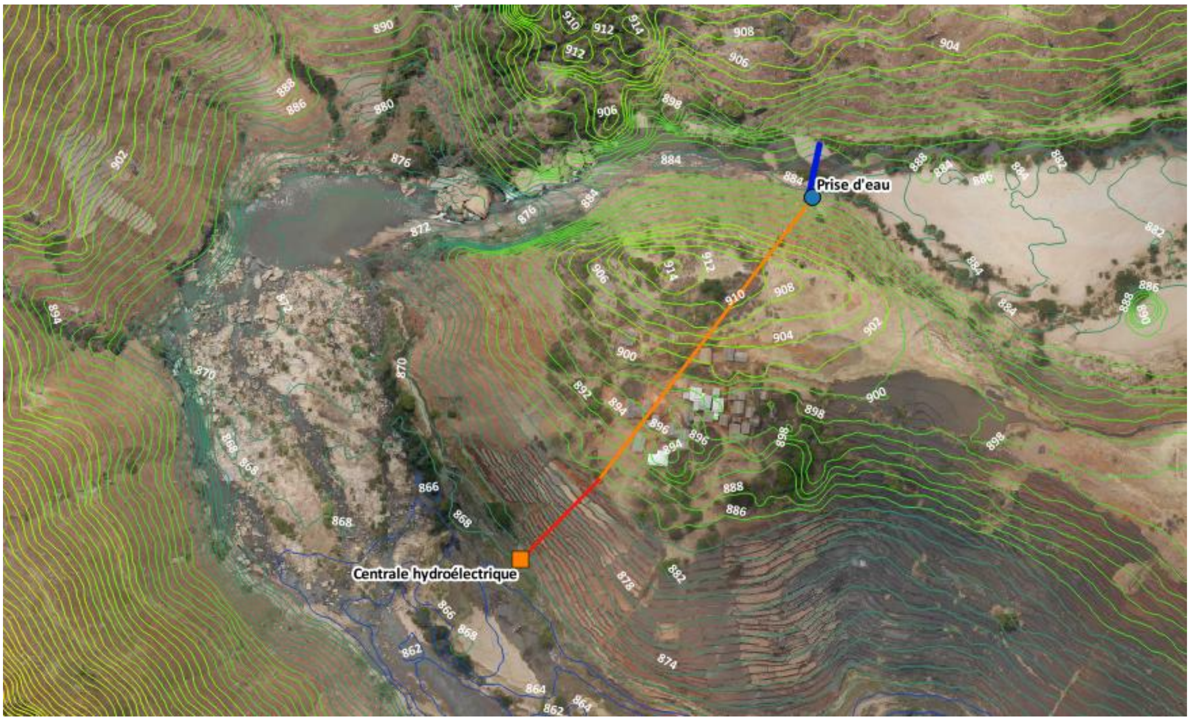


Figure 18. Proposed scheme layout

3.2 Weir and intake

Furthur geological investigations must confirm whether a weir is possible of not. As detailed above, there is a doubt on the right bank soil quality.

Assuming it is geologically possible, the weir would be located somewhere in the narrow glen or upstream of it, where the river bed broadens. The intake would be on the left bank anyway in order to take advantage of the site configuration.

3.3 Desander

Given the sediment issue, it is expected that a desander is necessary. Yet, given the topographical conditions of the site, the feasibility of such a structure without financially jeopardizing the project should be investigated.

3.4 Waterways

A 180m long tunnel allows to cross the hill and to avoid the steep slopes of the left bank. It would be 2m diameter in both cases of firm or design flow (minimal recommended section). The terrain profile on the tunnel alignment is shown below.

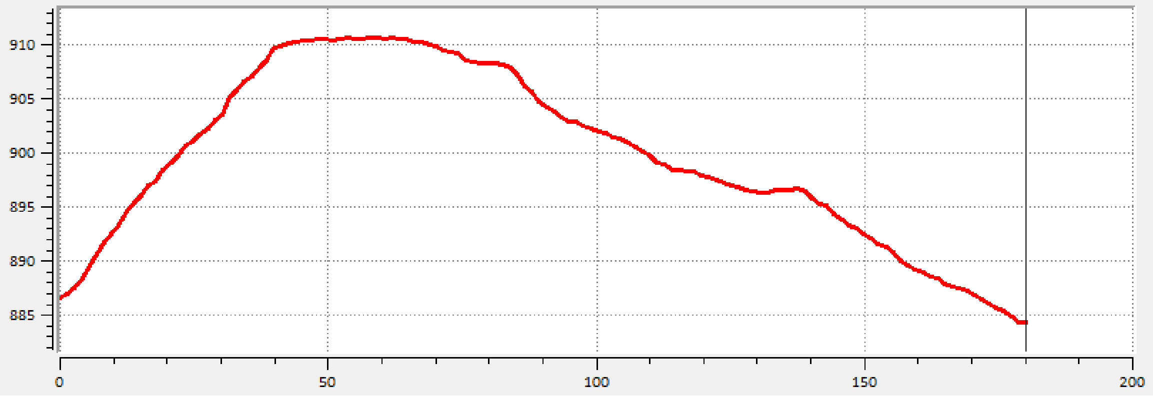


Figure 19. Terrain profile on the tunnel alignment

3.5 Penstock and powerhouse

The penstock would be located in an area which is currently cultivated (irrigated rice). This area will be reallocated to the hydropower scheme infrastructures including a (deep roots) vegetalized buffer zone for stability protection. A loss of 0.3 ha irrigated area is expected.

The penstock would be 75m long (1.00m diameter in case of firm flow design, 1.20m in case of median flow design).

3.6 Electromechanical equipments

3.6.1 Design flow taken at Q_{95}

For a design flow at Q95, there is no need to choose a turbine with a high flexibility regarding discharge variation. Given the available head, a Francis turbine might be chosen as it presents a high performance level and a satisfactory flexibility,

Head, discharge and foreseen output allow the choice between a Francis turbine, which offers a high performance level and a satisfactory flexibility, and the double regulated Kaplan turbine which offers a high efficiency on a large discharge range. The final choice is set on a Francis turbine which is simpler and more robust. The suggested solution does not require the use of a gearbox, which is a sensitive and costly component, as well for operation as for maintenance.

Given observations formulated about water quality, a particular attention must be paid to the quality of materials used for the construction of the turbine. One should probably consider the need for an anti-abrasion coating.

Electromechanical equipments of the powerhouse will then be composed of:

- Butterfly safety valve with counterweight to ensure its closure in case of emergency of black out.
- A 325 kW horizontal axis Francis turbine running at 1000rpm.
- A flywheel, required to operate the powerhouse in an isolated grid.
- A 400V alternator, 305 kW/ 340 kVA.
- Control and monitoring system, including speed regulator and voltage regulator.
- Security system and electrical protection.
- Step-up transformer and electrical cabinet and switchgear.
- Emergency power unit.

Following issues should be studied as well in the next stages of the project :

- Sedimentation problem and the need for anti-abrasion coatings (e.g. Tungsten carbide).
- Technical and economic optimization of the penstock diameter.
- Technical and economic optimization of the number of units and of the design flow, according to the hydrology and the electrical demand.
- The need of a flywheel (for grid stability)
- The set up level and rotational speed of the turbine (Suction height and cavitation issues).
- Grid voltage.
- Preliminary turbine design.

Figure 20. Example of a horizontal-axis Francis set

3.6.2 *Design flow taken at Q_{50}*

Same considerations as those exposed for a design flow at Q95 might be formulated for a design flow taken at the median discharge (Q50). A Francis turbine is recommended as well. Further investigation should examine whether a single turbine offers enough flexibility.

The turbine will have a power of 700 kW and a rotation speed of 750 rpm. The alternator power will be 660 kV / 730 kVA for a 400V voltage.

3.7 Impacts on the existing irrigation scheme

The impacts on the irrigation scheme's organization are very limited since no canal is disturbed by the proposed scheme. Only 0.3 ha would be reallocated as a buffer around the hydropower plant's infrastructures.

3.8 Transmission line

Given the low power generation capacity, the interest of the site is mainly local. The main focus for the energy delivery would be the village of Ikalamavony, 20km away from the site. A 20km long, 35kV line would carry the power to the village.

3.9 Key technical features

The main technical features are presented below for both design possibilities of firm or median flow.

		Firm discharge	Median discharge
Installed capacity	[kW]	305	660
Potential annual generation	[GWh/yr]	2.42	4.95
Design flow	[m³/s]	2.2	4.7
Gross head	[m]	18	
100yr return period flood	[m³/s]	756	
Weir length	[m]	30	
Weir height	[m]	6	
Desander		Large size	
Tunnel length	[m]	180	
Tunnel diameter	[m]	2	2
Penstock length	[m]	70	
Penstock diameter	[m]	1	1.2
Number of penstock(s)	[pce]	1	1
Number of T/G units	[pce]	1	1
Transmission line length	[km]	19	
Line voltage	[kV]	35	
Length of the access road to create	[km]	3.2	
Length of the access road to upgrade/rehabilitate	[km]	20	

4 ENERGY GENERATION AND COSTS

At this early stage of study, and according to the hypotheses and options taken above, the project would have the following energy and economical performances as order of magnitude:

Gross head	**[m]**	18	
Design flow	**[m³/s]**	2.2 ($Q_{95\%}$)	4.7 ($Q_{50\%}$)
Installed capacity	**[kW]**	305	660
Potential annual generation	**[GWh/yr]**	2.42	4.95
CAPEX (excl. access and lines)	**[M$]**	2.62	3.26
LCOE (excl. access and lines)	**[$/kWh]**	0.129	0.079
Total CAPEX (incl. access and lines)	**[M$]**	8.9	9.54
Total LCOE (incl. access and lines)	**[$/kWh]**	0.435	0.229

5 APPENDICES

5.1 Socio-environmental datasheet

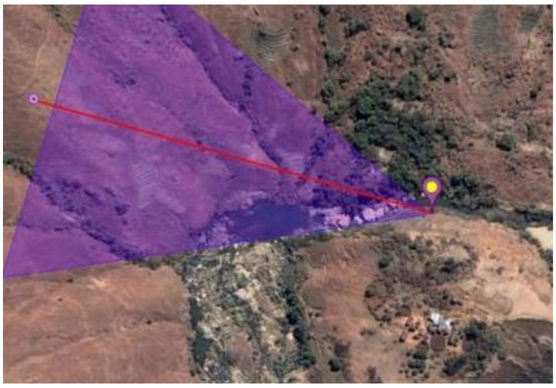
A – Site localisation

Site reference : AD653 - Vohinaomby

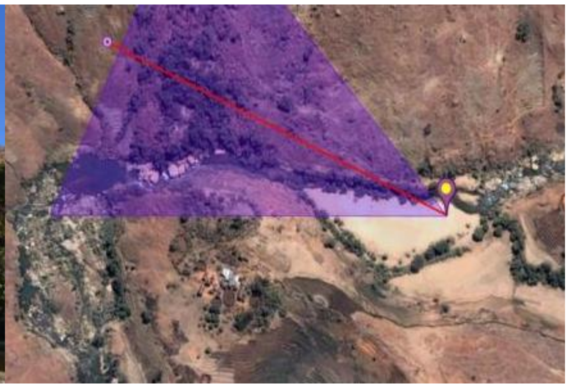
Village / Fokontany : Isitonga

Community / District/Region : Mangidy / Ikalamavony / Haute Matsiatra

B – Description of the biophysical brackground

RELIEF	The relief around the AD 653 site is composed by a series of hills with middle slopes, which is typical of the malagasy Middle West. However, close to the site, the relief is precipitous with steep slopes. (about 25 ° and more). The average elevation is about 900m, the local bases level is about 835m but the peaks can reach more than 1000m, in particular Sahambary in the North (1 369m) and Ambalamentsa in the West (1 049m). The Manambovona River is the main watercourse in the area. It is one of the several tributaries of the Mangoky. It receives the Vozina, the Imandro and the Antsakoamo rivers. It flows from East to West.
VEGETATION	The vegetation is composed by : – Riparian forests (*Breonadia* and *Mangium)* : alongside a river or next to water. The vegetation is composed by woody and shrubby species; – Herbaceous savannahs (*Hyparrhenia* and *Heteropogon) are the main type of vegetation.* We can also see some bases of mango trees; – Mosaic of crops: composed by terrace and/or hillside crops (dry and vegetable crops).  Vegetation in the AD 653 site  S21°15'38.50" E46°40'54.73"
OBSERVATIONS	Traces of fire can be seen on the hillsides. Fire is used to renew the pastures and to clean crops parcels.
SENSITIVITY OF THE AREA	The closest protected areas are more than 100km away from the area: Ranomafana (East) and Makay (West). Riparian forests are the only tree vegetation of the area. Moreover, the area is affected by erosion due to the poor vegetation cover. In particular, bare soils are affected by water erosion: a strong silting can be seen upstream of the site.


Silting in the riparian forest area


S21°15'38.90" E46°41'3.62"

B - Description of the socio-economic background

LOCALITY

Fokontany Laobato Atsimondrano, Rural community of Mangidy – Ikalamavony District(Region ofHaute Matsiatra).

Rural community of Mangidy :

The rural community of Mangidy had about 21 000 inhabitants in 2014, divided in more than 5 000 households. It is subdivided in 8 fokontany (2 500 inhabitants/fokontany). Like the majority of the communities of Madagascar, it possesses basic social infrastructures, in particular education ones (19 EPP[1], CEG[2] and school), health ones (1 CSB[3] 1 and 1 CSB 2)and a community market. Moreover, the seat county has a drinking water supply network (water tower) financed by the catholic Church. It was implemented in 1996, divided in 8 public fountains but only one is currently working.

You can access the site via the NR42 linking Fianarantsoa and Ikalamavony. A route, and then a 2km path heading South South-West near a bridge, lead to the site. Tombs and headstones can be found alonside the path and the route.

Tomb and headstone along the way to the site

Localities and villages:

[1] EPP : Ecole Primaire Publique (public primary school)

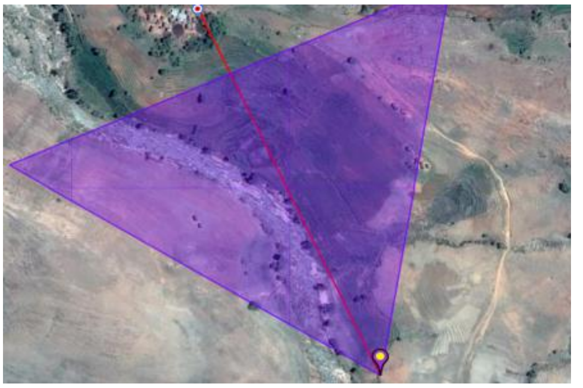
[2] CEG : Collège d’Enseignement Général (college of general education)

[3] CSB : Centre Santé de Base (basic health centre)

	Isitonga is the main village near the site. Less than 1km away from the site, you can find a few hamlets. They all belong to Isitonga (fokontany Laobato Atsimondrano). They are located on the hills, separated by waters and crops. Isitonga has about 50 households and the majority of it is situated in Betsileo. The village does not possess any health, water supply, education infrastructure. Drinking water is taken from water sources (for instance in the valleys).  Isitonga village  Drinking water source
ACTIVITIES	The main activity is rice growing. The land use is composed by terrace crops, with multilevel handmade irrigation canals. Its intake is located more than 1km away from the site. Water is taken through a small weir which is precariously built with river stones. The irrigations canals are earthen but some portions are suspended next to the difficult place (canyons) and need more resistant and manipulable materials (sheet-metal plates, wood, ….). Canals branch out upstream of the hillsides to irrigate 15ha of crops, located on the left bank of the river. Despite the implementation of handcraft infrastructures for the local population, the water flow is irregular and depends on the quality of the canals, which are skimpily maintained. As a matter of fact, some canal breaches and cracks can be seen, which causes progressives loss of the water flow. Terrace crops are mainly rice crops from October to May. However, some early rice parcels exist (harvest in November). They are used for self-consumption but due to the arrival of the manifolds, farmers tend to produce more and more and to sell a share of the production. The majority of the households also works in subsistence and vegetable crops (onions, beans, corn, sweet potato, manioc.) and even sometimes cash crops (Tabaco, ricin).  Terrace crop, on the projected work site (canals, factory)  S21°15'43.76" E46°40'52.62"

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

Irrigation canal and rural landscape



S21°15'58.27" E46°41'5.25"

Suspended irrigation canal

Vegetable crop on the river banks

Tabaco crops on the hill, rice crop down below and vegetable crop in the background

Fabrication of ricin oil

	 Drying of manioc above the Apepigny fall  Preparation of the rice crops
OTHERS	The area has mining plots (authorization to look for gold, crystal, copper, tungsten,… but they expired in 2008 and 2012). ***JIRAMA Ilakalamavony :*** The plant, implemented in 1997, works thanks to four power generators having a total capacity of 432 kWh (82kw, 50kW, 80kW et 220kW). So far, only the 82 kWh generator works and produces only 50 kWh. However, this can not meet the needs of the town because the consumption peak currently represents 160 kWh. So, the electricity is only provided during 6hours a day, divided between two neighbourhoods: the first between 12 :00 and 15 :00 and the second between 15 :00 and 18 :00. EN 2015, JIRAMA had about 400 subscribers and 30 requests on hold.

C – World Bank operational policies that could be applicable :

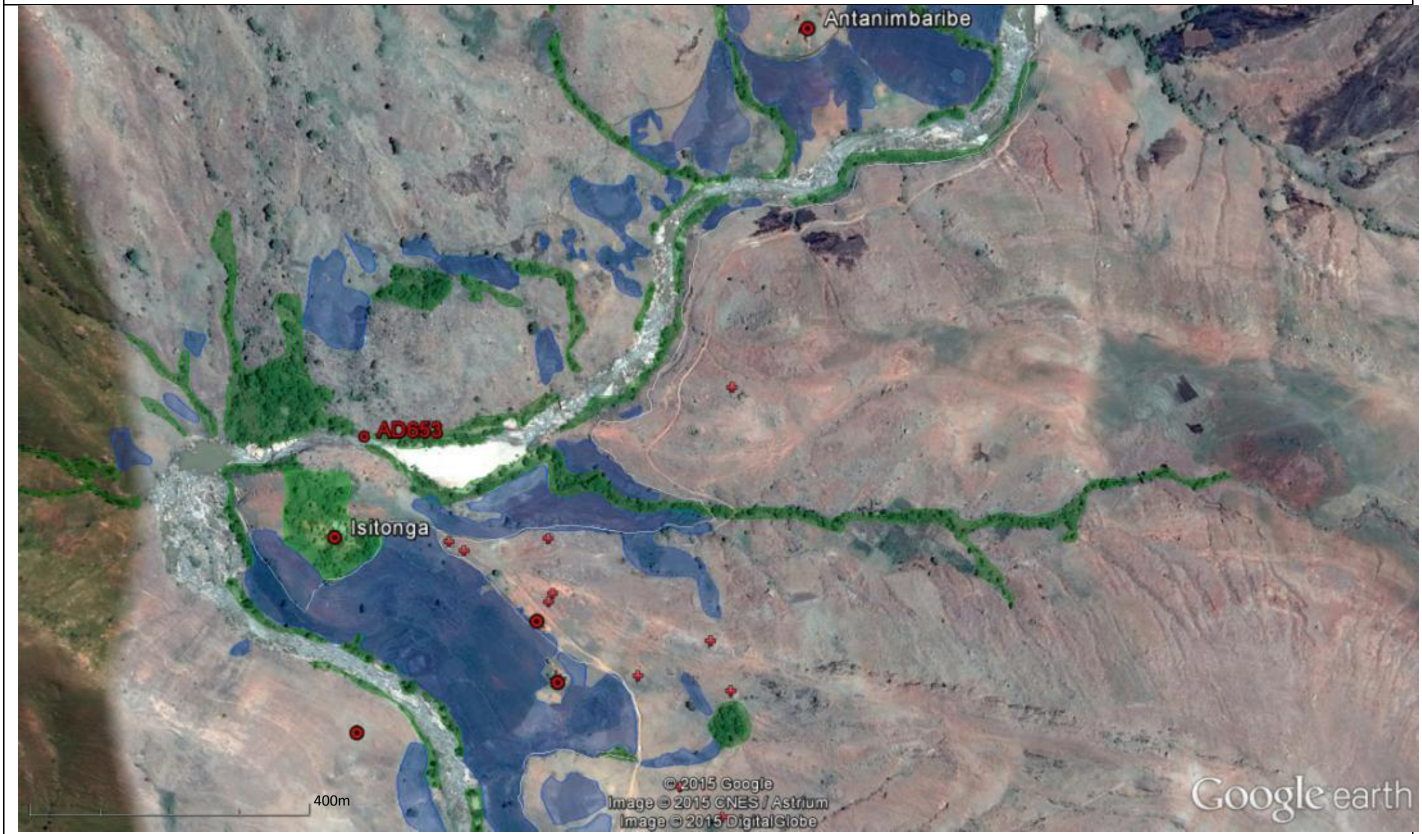
OP 4.01 – Environmental assessement ☒

OP 4.04 – Natural Habitat ☐

OP 4.11 – Cultural Heritage ☐

OP 4.12 – Involuntary Resettlement ☒
.
OP 4.37 – Safety of Dams ☐

Land use of the site



: Culture crops

: Riparian formations

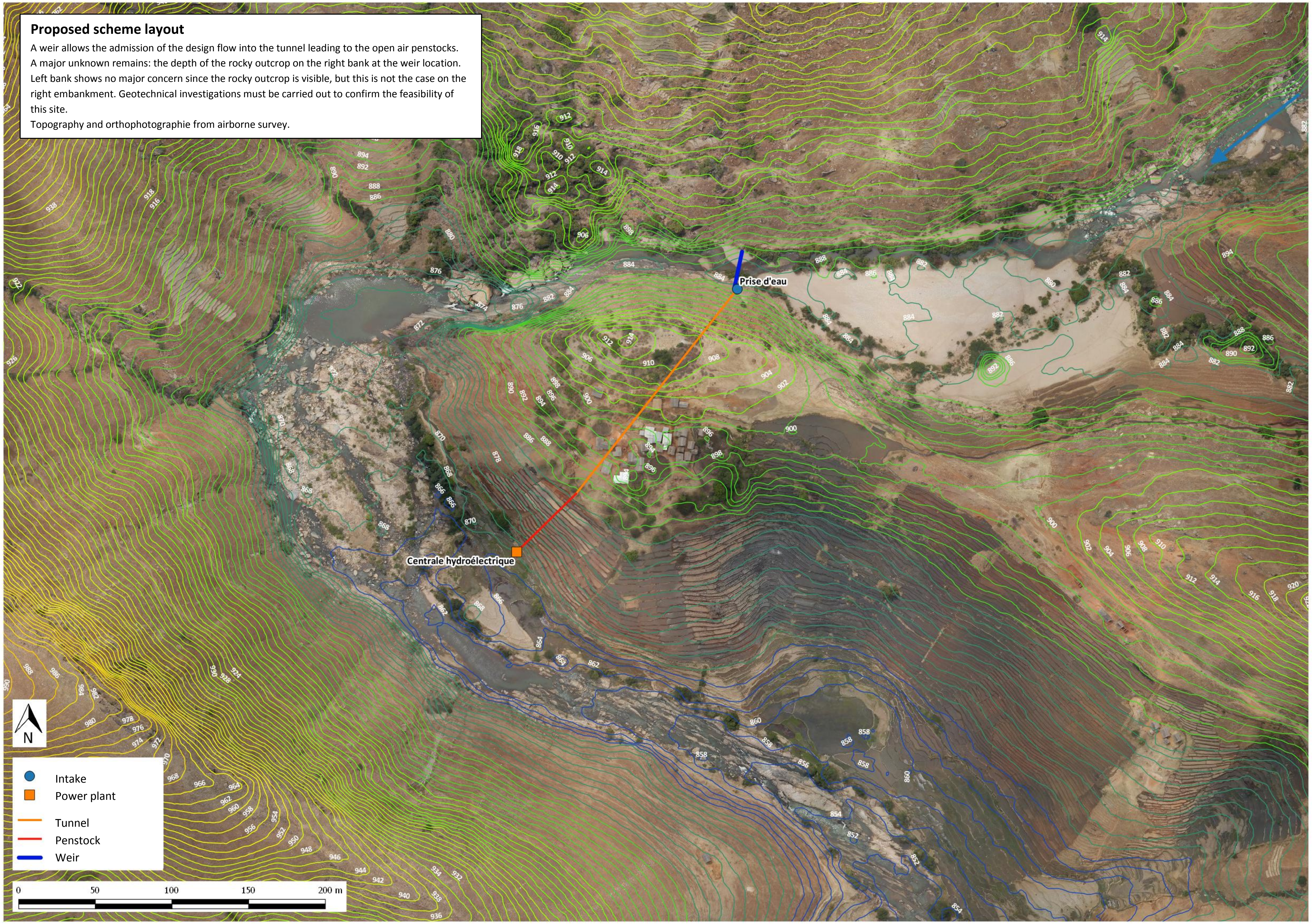
: Plantations/shrub formations

: Grassy savannah

: Hamlets/villages

: Tombs/identified headstones

5.2 Proposed scheme layout



In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

Madagascar: Small Hydropower Resource Atlas (1-20MW)
Site Investigation Report

VOHIBATO SITE

Mananara River| Atlas Code: FR148

SHER GROUPE ARTELIA | ESMAP Energy Sector Management Assistance Program | THE WORLD BANK IBRD · IDA | WORLD BANK GROUP | REPOBLIKAN'I MADAGASIKARA

Table of content

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

1 SITE LOCATION

Geographical coordinates (WGS 84)	Longitude [°]	Latitude [°]
Intake	49.674	-16.200
Powerhouse	49.676	-16.197

1.1 Administrative data

Atlas code	FR148
Site name	Vohibato
River	Mananara
Major river basin	Mananara (Sud)
Province	Toamasina
Region	Analanjirofo
District	Mananara Nord
Commune	Mananara Nord / Ambodivoanio
Village	Ambodiatafana

1.2 Access

It is possible to access the site by taking a 14km long road (paved but in poor conditions) from the mouth of Mananara river. From the road, there is still 4km to walk on a track.

For the works, it is expected to rehabilitate 14km of road and create 9km a new road to access the different parts of the project's infrastructure.

Figure 1. Access to site FR148 from Mananara Town

Given the proximity of Mananara town, where power is produced from a diesel plant, the idea is to feed the city.

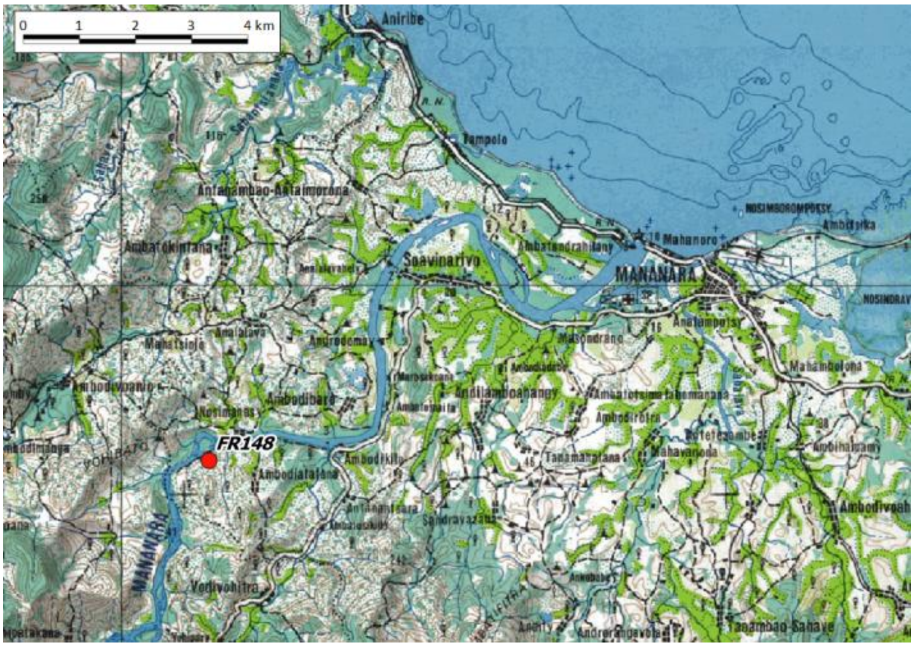


Figure 2. Proximity of site to Mananara town

2 GENERAL SITE DESCRIPTION

2.1 Background

The waterfall is created by a rocky outcrop in a slight bend of the river. Small islets are present in the upstream part of the river, then the river sharpens in the rocky section. There is currently no existing irrigation or hydropower scheme.

Figure 3. Aerial view of site FR148

Figure 4. Topo map of site FR148

2.2 Topography

The topographical survey was achieved through remote sensing. An aircraft was chartered and equipped with optical sensors.

Figure 5. Aircraft and container of remote sensors for airborne survey

The topographical survey has a point density of 5 /m² and a relative accuracy of 2%.

Outputs from airborne survey are (1) a high resolution orthophotography (0.2m to 0.4m resolution) and (2) a Digital Surface Model (DSM). The DSM includes the vegetal cover, but it gives an excellent global picture of the site topographical configuration. Contour lines might be deduced from the DSM.

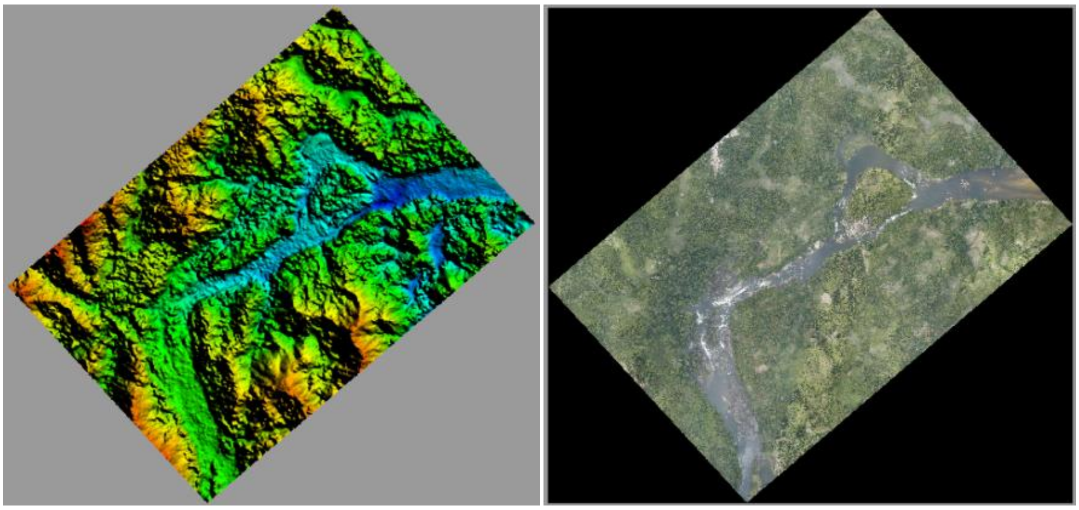


Figure 6. Digital Surface Model and orthophotography from airborne survey

2.3 Preliminary hydrological study

Accurate information on the hydrology of the Mananara River does not exist. As a consequence, statistical characteristics of the river discharge at the site of interest have been estimated using a regional methodology. This methodology is based on the available information at other hydrometric stations distributed in the country. Given the limited spatial and temporal resolution of the available data, the results of the regional study presented below are indicative only and are not intended to be used for design purposes without further detailed hydrological studies.

Key preliminary hydrological characteristics of the river at the site of interest are presented in the table below.

River	Mananara
Main river basin	Mananara
Area [km²]	2615
Average elevation [m a.s.l]	648
Slope index [m/km]	2.3
Specific vertical drop [m]	120
Average annual rainfall [mm/yr]	1779
Average interannual discharge [m³/s]	112.0
$Q_{95\%}$ - firm discharge [m³/s]	34.1
$Q_{50\%}$ - median discharge [m³/s]	93.7
$Q_{30\%}$ [m³/s]	129.4
10yr return period flood [m³/s]	2061
100yr return period flood [m³/s]	4713

2.4 Sediment transport

Given the current conditions of the basin, a heavy solid transport in the river is assumed, especially during floods. Altough water turbidity was very good at the time of visit, many active sand strips are visible along the banks.

2.5 Site geology

2.5.1 Geological context

The area consist of hilly land, with high rocky mountains and a thick vegetal cover.

About the geology itself, the area is made of medium grain migmatitic porphyroid granite (Figure 7) with diffuse foliation and quartz veins are hardly found.

Figure 7. Typical rock of the area

During low water, the corresponding rock crops out under the shape of big size (tens of meters) massive blocks, dismantled by their own joints (Figure 8).

Figure 8. Rock out crop

Alteration is superficial with reddish to yellowish soil cover.

2.5.2 Technical characteristics

Bed aspect at the projected weir location : the projected weir location shows rock boulders within part of the riverbed. They are of metric dimension, based on massive in-situ migmatitic granite who should constitute the riverbed (Figure 8).

Right bank support aspect : the right riverbank is made of a relatively low hill with much vegetal cover and big rock boulders embedded in lateritic soil (Figure 9).

Figure 9. In situ big boulder

Left bank support aspect: as everywhere in the area, the riverbanks (and hence the left riverbank) are characterized by masses of boulders. Most of them are displaced boulders laid on the migmatitic granite bedrock which composes the riverbed. The granitic rock is sub outcropping within the river bed and should appear in surface more inside the bank, in the wooded area before the increasing hill slope. The bedrock of the supporting hill, starting a bit away from the bank, is made of that granitic rock.

Intake: the intake level will depend in the final weir height. As it will be set on the right riverbank, same views and considerations can be done for the intake as for the right bank support.

Waterway: the dense presence of boulders or even rock masses on the hill sides conjugated with a dense vegetal cover do not favor a canal option for waterway. A tunnel would probably fit better given the mountainous morphology of the area. Hence, the structure of the land should mainly consist of rock masses but fractures affecting the rock structure are currently unknown and might negatively impact a tunnel.

Penstock and powerhouse: the penstock trace and the powerhouse location are characterized by undergrowth. The hill slope is rugged by rock boulders of various sizes appearing from time to time between tree roots. They are embedded in yellowish laterite soil (Figure 10). The same type of soil composes the powerhouse superficial ground.

Figure 10. Soil along the penstock trace

2.5.3 Recommendations for further investigations

ELEMENT	UNCERTAINTY TO REMOVE	SURVEY TYPE
Bed at weir	✓ Continuity of the massive bedrock in the riverbed	✓ Clearing of in-surface rock boulders to found the weir on the bedrock ✓ Hand probe testing of the river bottom along the final weir axis to identify the rock formations beneath the surface (which are probably in continuity with the outcropping rocks)
Right support	✓ Characterization of the right bank support (nature and composition)	✓ Soil clearing and lateral mechanical excavations of the lateritic soils to better understand the laying of rock boulders at the hill basis
Left support	✓ Characterization of the left bank support (nature and composition)	✓ Soil clearing and lateral mechanical excavations of the lateritic soils along a corridor from the bank to the woods up to the basis of the hill (characterized by an increasing slope) to better observe the composition and aspect of the intercepted geological formations (cleared boulders, in-situ massive blocks,…)
Intake	✓ Same as right bank support	✓ Same as right bank support
Waterway	✓ Choice of tunnel vs canal and final trace ✓ Fractured state of the bedrock	✓ Check the fracturing level of the bedrock
Penstock and powerhouse	✓ Depth of the bed rock	✓ Auger drilling or seismic reflection geophysical survey to determine the bedrock level

2.6 Socio-environnemental aspects

The site detailed description sheet is provided in the Appendices.

2.6.1 Socio-environmental background

The site is located on the Mananara River, in the fokontany of Ambodiatafana, which is the limit between the rural community of Mananara North and Ambodivoanio, Mananara District, region of Analanjirofo.

From the ecological perspective, the area is homogenous and this is typical of the region. Within a radius of 1km around the site, the vegetation is composed by a mosaic of forests, which are more or less degraded, by plantings (pine trees, cloves…), savoka with or without woody elements (ravinala on the hillsides, bamboos on the banks), grass and epiphyte meadows. Woody species can grow high (>20m). Some walking trees, palms (*Dyspis, Dracaena, Raphia* and *Typhonodorum* sp., *Aframomum angustifolium*, *Phragmites)* and ferns can be seen alongside the river and the relatively wet areas.


Image 11. Overview of the vegetation of the site

From the socio-economic perspective, some villages and hamlets/campsites can be found within a radius of 1km around the FR148 site. The Ambohitsara (700m North of the site) and Nosy Manasy (500m East of the foot of the waterfall and less than 100m from the river) villages are the closest ones of the site. The seat county of the fokontany is located about 1,2km South-East of the site. These villages are composed by about 50 huts and surrounded by more or less important crops.

The main activity is agriculture, in particular rice growing (lowlands and hillsides) and subsistence crops (manioc, sweet potato, corn, sugar cane) on the hillsides. Crops, in particular rice crops, can be developed as terrace crops or can be found on the river banks.

Besides, the local clove production is a key element of the local economy. Except from cloves, other local products intended for exportation or local market are also cultivated (cinnamon, pepper, vanilla…).

The local population also uses woody forest products (precious wood, carbon manufacture, slash-and-burn). This contributes to the degradation of forests.

The following picture gives a global overview of the land use.

Image 12. Land use of the FR 148 site

The site would mainly provide the city of Mananara in electricity. According to the collected data from the investigation team during an interview with the person in charge of JIRAMA, in Mananara North, here is the current situation :

- Subscribers : 1231 households
- Daily peak : 850 kW
- Monthly sale : 167248 kWh
- Monthly production : 192092 kWh
- Fuel consumption : 6600 L/month

The daily production if sufficient, except during the peak hours. There is also a daily electricity blackouts (two and a half hours) for the fuel management (sporadic supply from Maroantsetra, interdiction of loans from local operators).

2.6.2 *Socio-environmental constraints*

Some hamlets, campsites and villages (Nosy Manasy) are located in the surroundings of the site (within a radius of 1km). The implementation of the project will affect these villages and hamlets, especially regarding potential nuisances (noise, traffic, noise, atmospheric emissions…).

There are a lot of plantings in the area (clove, vanilla, coffee…) and crops. The project could impinge on these rural surfaces, leading to a loss of resources for the concerned communities.

2.6.3 *World Bank Safeguard Policies that could be applicable :*

The World Bank Safeguard Policies that could be applicable for the FR 148 site are the following:

- OP 4.01 – The Bank requires Environmental Assessment (EA) of projects proposed for Bank financing to help ensure that they are environmentally sound and sustainable, and thus to improve decision making. However, we can already estimate that the adverse impacts on human populations and environment-linked areas are limited. They are reduced, not irreversible and some measures can prevent, mitigate or minimize them. Moreover, these measures can improve the environmental performance.

- OP 4.12 – Involuntary Resettlement: the hydropower project will require the use of a large space (implementation of the plant, creation of access roads to the site…), which sometimes are crop areas (cloves and other). So the project will have to take into account the concerned people and communities, particularly regarding the restoration of the standards of living due to the loss of resources.

The projected weir is classified as a small dam (<15m high); the usual generic safety measures for dams are appropriate and do not need the implementation of OP 4.37 – Safety of Dams (for large dams).

3 PROPOSED SCHEME LAYOUT

The proximity of a similar site should be noted : AD158 is located 3km upstream of FR148. Subsequent studies should compare both options as well as considering a combined solution.

3.1 Technical assumptions

An assessment of the scheme potential in terms of installed capacity, energy generation (firm and average) and the associated capital investment costs (CAPEX) and productions costs (Levelized cost of energy) is presented in section 4. It is based on the scheme proposed in this section. Hence, at this stage of the study, the technical features of the hydropower scheme are designed for both firm and median discharges (respectively $Q_{95\%}$ and $Q_{50\%}$). The actual design flow will be determined during the detailed studies based on economical, financial and technical criterion as well as the future energy and power demand.

The proposed scheme layout is shown below and presented in A3 format in the Appendix of this report.

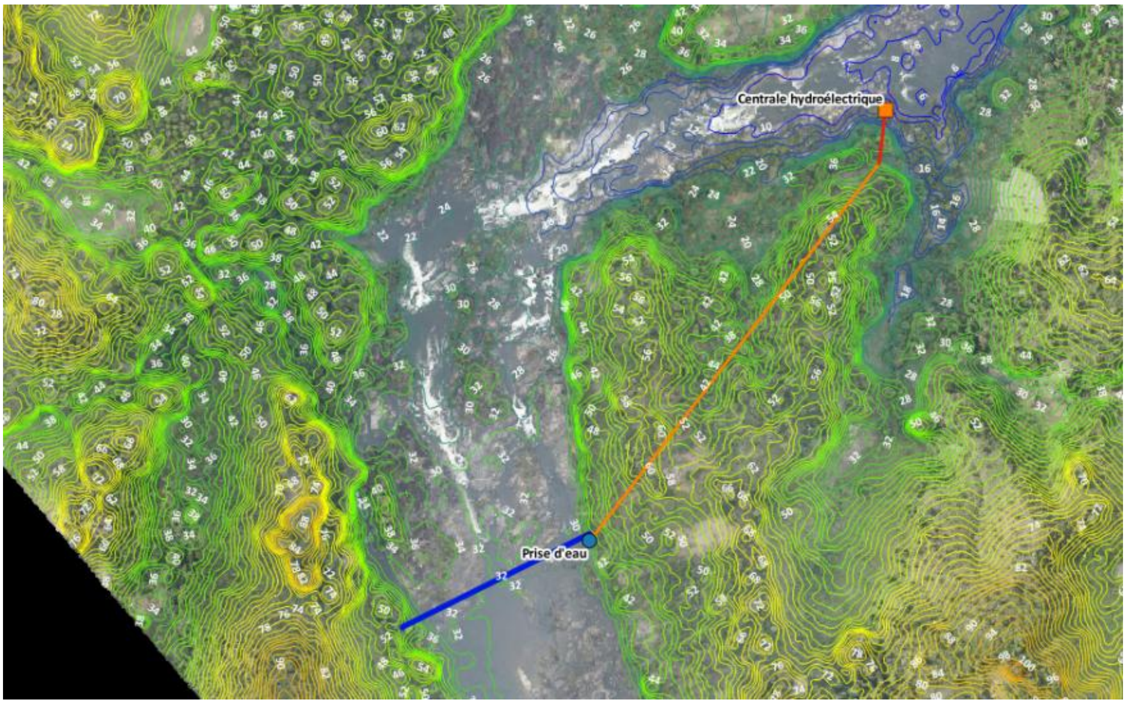


Figure 13. Proposed scheme layout FR148

3.2 Weir and intake

The weir would be located on the upper part of the waterfall, on the rocky outcrop. It would be 140m long and 3.5m high. The intake would be on the right bank, in order to take advantage of the bend.

3.3 Desander

Given the sediment issue detailed above, a desander is necessary.

3.4 Waterways

A 430m long tunnel would carry the water to the penstock. Terrain profile along the tunnel is given at Figure 14. A particular attention should be paid to the low point at KP 0+240m (see profile below). If necessary, the alignment will be modified in order to avoid geological issues.

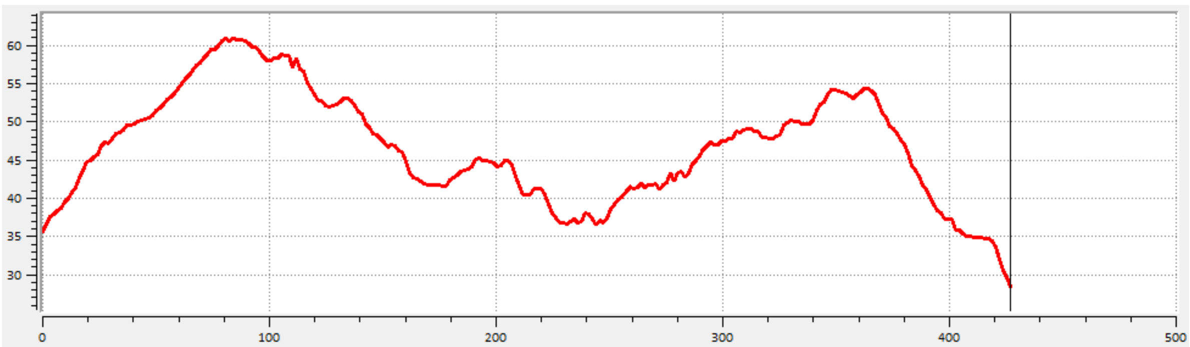


Figure 14. Terrain profile on the tunnel alignement

3.5 Penstock and powerhouse

The penstock will be 55m long (2 pipes of 2.00m diameter in case of design at firm flow, 4 pipes of 2.40m diameter in case of design at median flow).

The powerhouse will be located at a place where the river broadens significantly. This feature has a positive impact on the river water level in times of floods.

3.6 Electromechanical equipments

3.6.1 Design flow taken at Q_{95}

Given its remoteness, the site is foreseen to feed Mananara city. Hence, the chosen turbine type must enable a maximization of the power output while enabling enough flexibility to absorb peaks and ensure production during low demand periods. Given the power potential of the site, it is recommended to install several similar units to optimize the plant efficiency and to enhance its availability and to follow the demand evolution as much as possible.

Head, discharge and foreseen output allow the choice between a Francis turbine, which offers a high performance level and a satisfactory flexibility, and the double regulated Kaplan turbine which offers a high efficiency on a large discharge range. The final choice is set on a Francis turbine which is simpler and more robust. The suggested solution does not require the use of a gearbox, which is a sensitive and costly component, as well for operation as for maintenance.

Given observations formulated about water quality, a particular attention must be paid to the quality of materials used for the construction of the turbine. One should probably consider the need for an anti-abrasion coating.

Given the site characteristics, it is planned to install four identical units, each composed of:

- Butterfly safety valve with counterweight to ensure its closure in case of emergency of black out.
- A 1 535 kW vertical axis Francis turbine running at 500rpm.
- A 690V alternator, 1 440 kW/ 1 600 kVA.
- Control and monitoring system, including speed regulator and voltage regulator.
- Security system and electrical protection.
- Step-up transformer and electrical cabinet and switchgear.
- Emergency power unit.

A power plant PLC (Programmable Logic Controller) should also be foreseen to manage the four units.

Following issues should be studied as well in the next stages of the project :

- Sedimentation problem and the need for anti-abrasion coatings (e.g. Tungsten carbide).
- Technical and economic optimization of the penstock diameter.
- Technical and economic optimization of the number of units and of the design flow, according to the hydrology and the electrical demand.
- The need of a flywheel (for grid stability)

- The set up level and rotational speed of the turbine (Suction height and cavitation issues).
- Grid voltage.
- Preliminary turbine design.

Figure 15. Example of a vertical axis Francis Turbine

3.6.2 Design flow taken at Q_{50}

Other considerations exposed for a design flow at Q95 remain valid for a design flow taken at the median discharge (Q50). In order to increase the plant flexibility and to avoid the use of gearboxes, it is recommended to install at least 8 units.

Turbines will have a unit nominal power of 2 140 kW and a rotation speed of 428.27 rpm. The alternator power will be 2 010 kV/ 2 235 kVA for a 690 V or 5.5kV voltage.

A power plant PLC (Programmable Logic Controller) should also be foreseen to manage the eight units.

3.7 Transmission lines

As explined above, it is likely that the site would be mainly interresting for Mananara town. A 15km long 63kV transmission line would transport the produced power from the plant to the town.

3.8 Key technical features

Key technical features are presented below for both design possibilities: firm flow or median flow.

		Firm flow	Median flow
Installed capacity	[kW]	5 760	16 080
Potential annual generation	[GWh/yr]	45.06	116.05
Design flow	[m³/s]	34.1	93.7
Gross head	[m]	21	
100yr return period flood	[m³/s]	4 713	
Weir length	[m]	140	
Weir height	[m]	3.5	
Desander		Medium size	
Tunnel length	[m]	430	
Tunnel diameter	[m]	5	8.2

Penstock length	[m]	55	
Penstock diameter	[m]	2	2.4
Number of penstock(s)	[pce]	2	4
Number of T/G units	[pce]	4	8
Transmission line length	[km]	15	
Line voltage	[kV]	63	
Length of the access road to create	[km]	9	
Length of the access road to upgrade/rehabilitate	[km]	15	

4 ENERGY GENERATION AND COSTS

At this very early stage of study, and according to the hypotheses and options taken above, the project would have the following energy and economical performances as order of magnitude:

Gross head	**[m]**	21	
Design flow	**[m³/s]**	34.1 ($Q_{95\%}$)	93.7 ($Q_{50\%}$)
Installed capacity	**[kW]**	5 760	16 080
Potential annual generation	**[GWh/yr]**	45.08	116.05
CAPEX (excl. access and lines)	**[M$]**	21.8	51.78
LCOE (excl. access and lines)	**[$/kWh]**	0.058	0.054
Total CAPEX (incl. access and lines)	**[M$]**	31.75	61.73
Total LCOE (incl. access and lines)	**[$/kWh]**	0.084	0.064

5 APPENDICES

5.1 Socio-environmental datasheet

A – Site localisation

Site reference : FR148

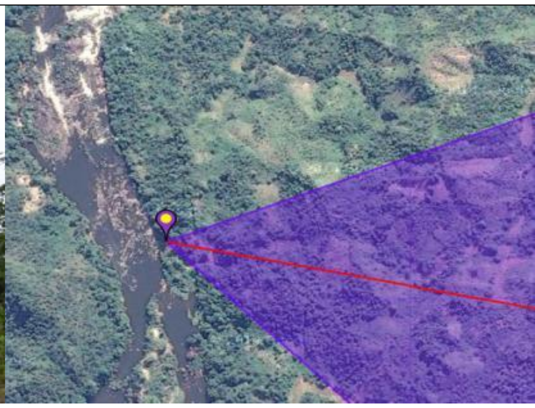
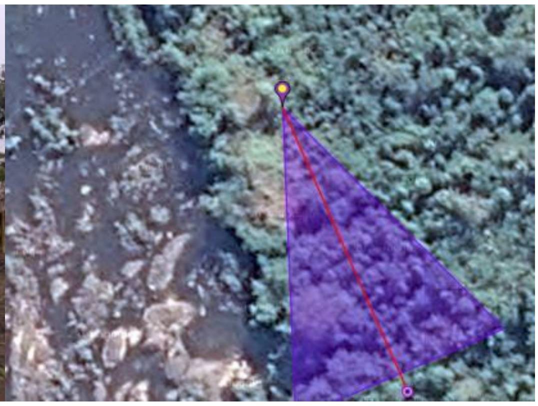
Villages / Fokontany : Andrangibe & Andapibe / Ambodiatafana

Community / District-Region : Mananara-North & Ambodivoanio / Mananara-North - Analanjirofo

A - Description of the biophysical background

RELIEF	The Mananara area has a general precipitous and steep relief. However, this variation is not really marked alongside the Mananara River because the relief is hillier over there. The Mananara River is the main river in the area. It is fed by many watercourses. It flows from West to East and goes into the Indian Ocean in the North of the Mananara city.
VEGETATION	The vegetation is composed by wet forest low altitude vegetation (<800m). It is really heterogeneous. Within a radius of 1km around the site, shred forest, secondary vegetation and degraded bushy vegetation (savoka) are found. There are present due to forest clearings and repetitive fires (slash-and-burn). Plantings of clove, typical of the region of Analanjirofo (meaning “clove forest”), is mixed with the local vegetation. The vegetation is composed by mosaics of forests (more or less degraded) such as plantings (clove, pine trees), savoka with or without woody elements (ravinala on the hillsides, bamboos on the river banks), grass and epiphytes meadows. Woody species can grow high (>20m). Walking species such as *Dyspis*, *Dracaena, Raphia*, *Typhonodorum* sp., *Aframomum angustifolium, Phragmites* and ferns can be seen in the riparian forests alongside the river and in relatively wet areas.  General overview of the vegetation : mosaics of plantings, forests and meadows. S16°11,769 E 49°41,342

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

	  Vegetation stratification — S16°12'10.36" E49°40'31.27"   Riparian vegetation — S16°11'49.18" E49°40'37.18"
OBSERVATIONS	The site landscape is modified by men. The majority of the hillsides is covered by clove, vanilla, rice fields and banana trees. They are the main resources of local incomes. Coal production is important. It is easy to transport coal via the rivers to the towns.   Coal stoves and campsite — S16°12'4,02 E49°40'29,61

	  Coal waiting to be sent S16°12'10,47 E49°40'31,41
CRITICAL AREAS	The region is known for its exportation crops such as vanilla, cloves, pepper and cinnamon. The implementation of the construction project would imply crossing the crops. The same applies for charcoal because coal merchants prefer river transport to supply the Mananara city.

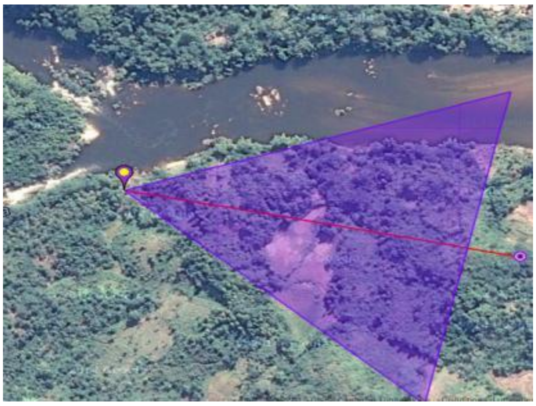
B - Description of the socio-economic background

LOCALITY	**<u>Urban community of Mananara North & rural community of Ambodivoanio :</u>** The Mananara River separates the communities of Mananara North (right bank) and Ambodivoanio (left bank) around the FR148 site. The urban community of Mananara North, which spreads over about 316 ha, had about 23 035 inhabitants in 2007[1]. It is subdivided in 31 fokontany. You can access the site by car via the NR5 or via seaway from Toamasina/Maroantsetra/Soanierana Ivongo/Sainte-Marie and by foot from the western districts. The rural community of Ambodivoanio spreads over 18 411 ha for a population of 14 234 inhabitants in 15 fokontany. ***Villages and hamlets:*** Even if the local population calls the FR148 site « Andrangibe » or « Andapibe », the main villages around are: Ambohitsara (700m North), Nosy Manasy (500m à East of the drop point). The closest Fokontany is Ambodihatafana, which is a village located alongside the crest line (1km East).
ACTIVITIES	The main activity is agriculture, in particular rice growing (lowlands and hillsides) and subsistence crops (manioc, sweet potato, corn, sugar cane) on the hillsides. Crops, in particular rice crops, can be developed as terrace crops or can be found on the river banks. Besides, the local clove production is a key element of the local economy. Except from cloves, other local products intended for exportation or local market are also cultivated (cinnamon, pepper, vanilla…). The local population also uses woody forest products (precious wood, carbon manufacture, slash-and-burn). This contributes to the degradation of forests.

[1] *Plan de Développement du District Mananara-Nord 2007*

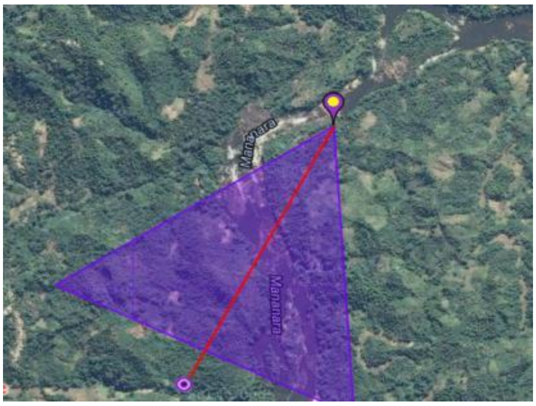
The main activity is agriculture. This activity might be divided in two categories: subsistence crops (rice, manioc, sweet potato, corn, sugar cane, fruit trees) and cash crops (cloves, vanilla, litchi, coffee,...) Other activities conducted by the local population, linked to forest clearing, increase environmental pressures (e.g.precious wood, carbon manufacture, slash-and-burn). This contributes to the degradation of forests, affect and modify the local ecosystem.

Plantations of vanilla tress with support (baby pine tree)



S16°11’39,93 E49°40’54,69

Manioc field



S16°11’50.33 E49°40’36,45

OTHERS

<u>JIRAMA Mananara North</u>

According to the collected data from the investigation team during an interview with the person in charge of JIRAMA, in Mananara North, here is the current situation :

- Subscribers : 1231 households
- Daily peak : 850 kW
- Monthly sale : 167248 kWh
- Monthly production : 192092 kWh
- Fuel consumption : 6600 L/month

Remarque :

– The above values are only averages
– 2 new generators were acquired after the events of 2013 (fire in the office).
– The daily production if sufficient, except during the rush hours.
– There is also a daily electricity cut (two and a half hours) for the fuel management (sporadic supply from Maroantsetra, interdiction of loans from local operators)

C – World Bank Safety Policies that could be applicable :

OP 4.01 – Environmental Assessment ☒

OP 4.04 – Natural Habitats

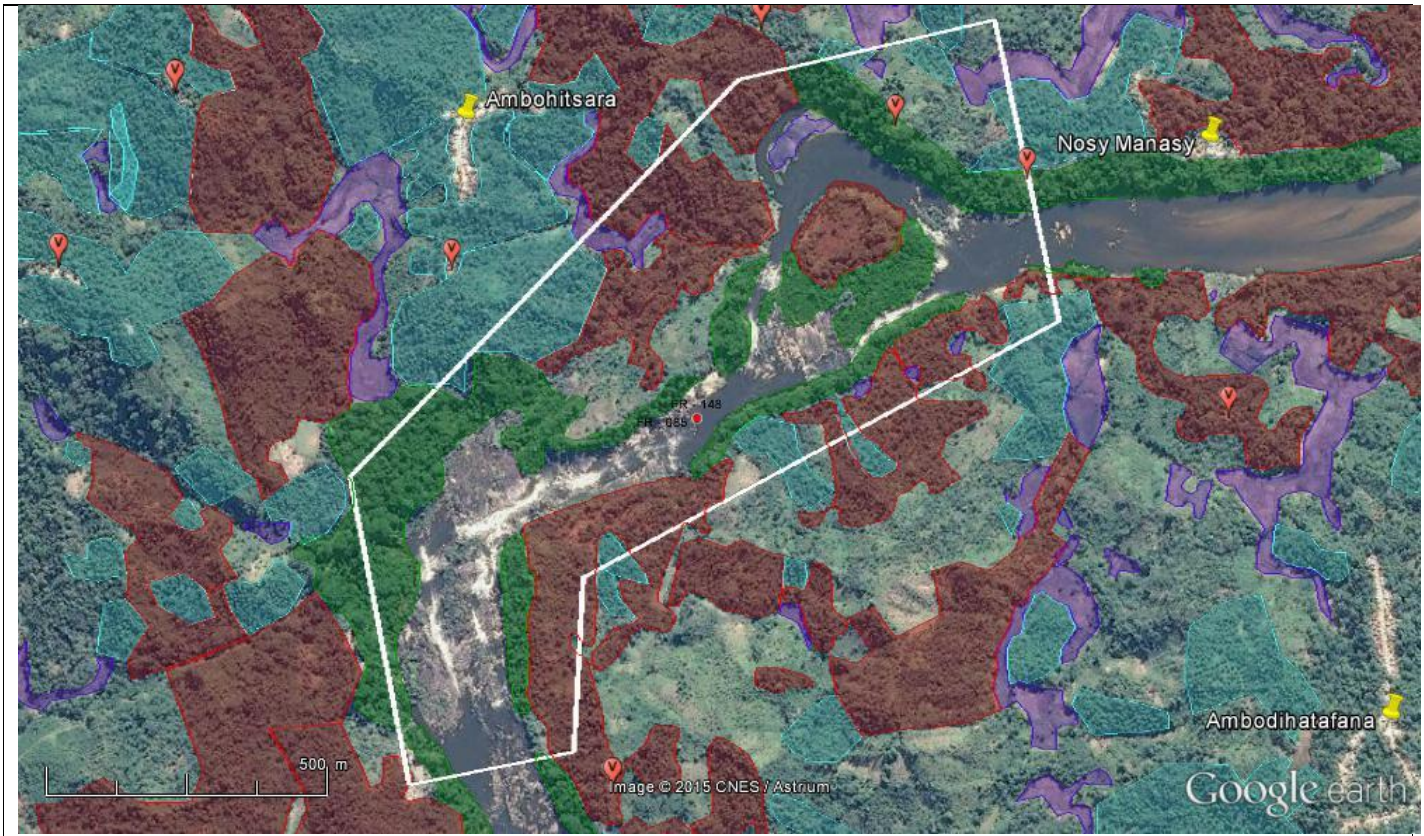
OP 4.11 – Cultural Heritage ☐

OP 4.12 – Involuntary Resetllement ☒

OP 4.37 – Safety of Dams ☐

<table>
<tr><th colspan="2">Land use around the site</th></tr>
<tr><td>
Overview upstream of the site</td><td>
Collection point of coal on the right bank</td></tr>
<tr><td>
Vegetation near the projected weir</td><td>
Savoka (mainly Rivanala on the left bank)</td></tr>
<tr><td>
Drying of the clove on the road</td><td>
Vegetable crops on an old coal stove</td></tr>
</table>

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail



: riparian formation /forest

: savoka/forest mosaic

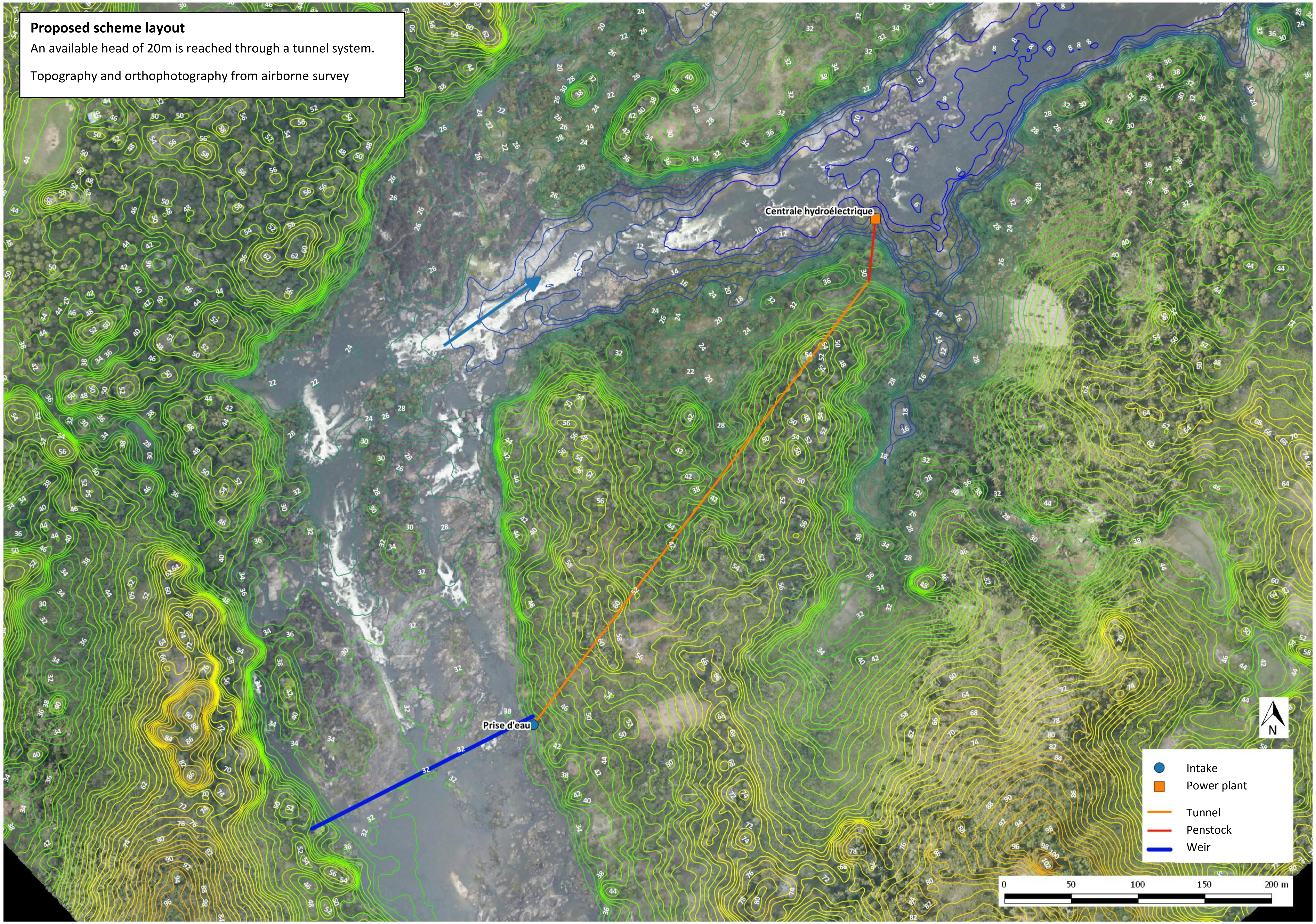
: fields/savoka mosaic

: shrub savoka/meadows

: hamlets/campsites

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

5.2 Proposed scheme layout



In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

Madagascar: Small Hydropower Resource Atlas (1-20MW)
Site Investigation Report

ANDRIAMANJAVONA SITE

Namorona River | Atlas Code: G191

Table of Content

1 SITE LOCATION

Geographical coordinates (WGS 84)	Longitude [°]	Latitude [°]
Intake	47.600°	-21.382°
Powerhouse	47.606°	-21.383°

1.1 Administrative data

Atlas code	G191
Site name	Andriamanjavona
River	Namorona
Major river basin	Namorona
Province	Fianarantsoa
Region	Vatovavy Fitovinany
District	Ifanadiana
Commune	Ambiabe
Village	Isolated site
Reference topographical map	P53 Nord (scale 1:50,000)

1.2 Access

Reliable access to the project site from the RN12 using an approx. 12km long all weather conditions track exists. Junction from the RN12 to the track is located approx. 1km West of Ifanadiana southwards (Figure 1). The proposed intake is located approx. 600m downstream of the bridge of the Namorona River.

A new 2.1km long access road will be required from the existing road system to the intake, dam and powerhouse site. The bridge crossing the Namorona River will likely need upgrading to be capable of carrying heavy loads associated with the carrying of construction materials, equipments and construction machinery.

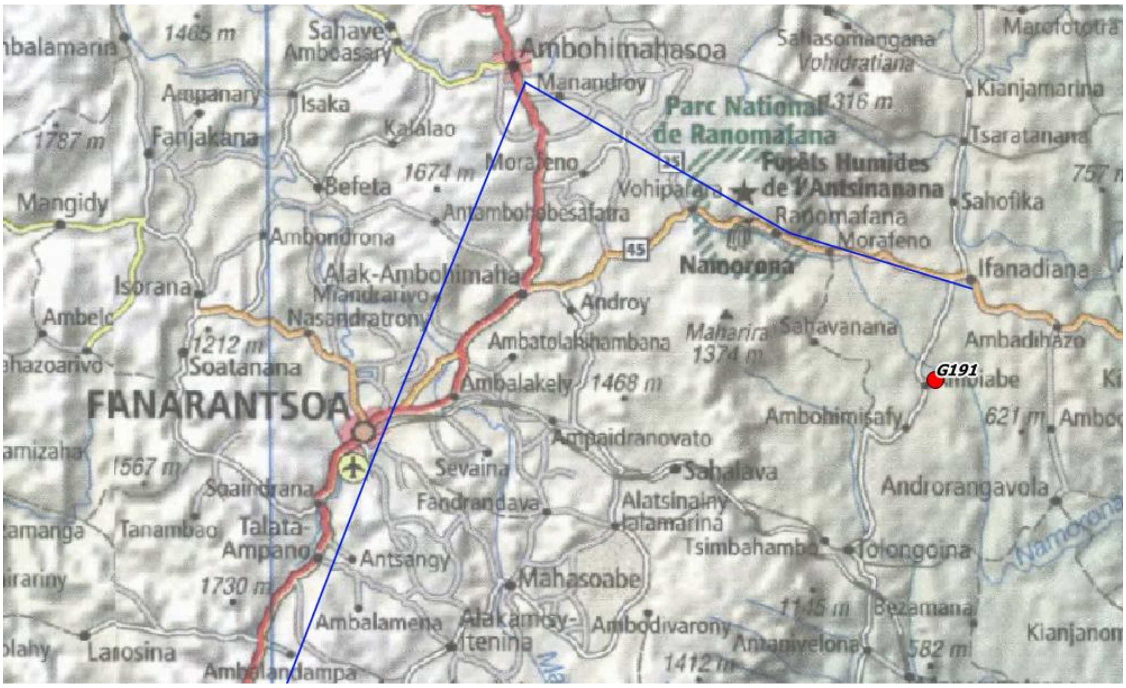


Figure 1. Site access

2 GENERAL SITE DESCRIPTION

2.1 Background

The site is characterized by a major drop of approximately 20m high of the Namorona River on a rocky outcrop (Figure 4 and Figure 5). The river then continues its course through a succession of smaller drops and rapids over a distance of about 700m (Figure 3). This river reach is characterized by the presence of overgrown small islands and blocks around which the Namorona River flows. The steep topography of the river banks is not adequate for the construction of a canal type waterway.

At present, there is neither hydro-agricultural nor hydropower scheme at the proposed site location.

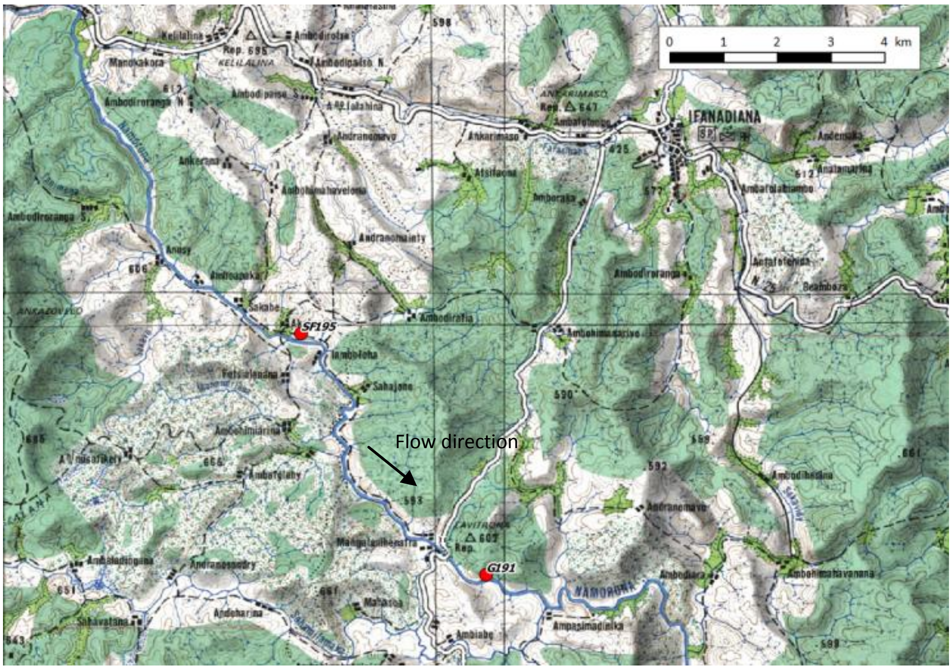


Figure 2. Topographic map (scale 1:50,000)

Figure 3. Satellite image (Google Earth)

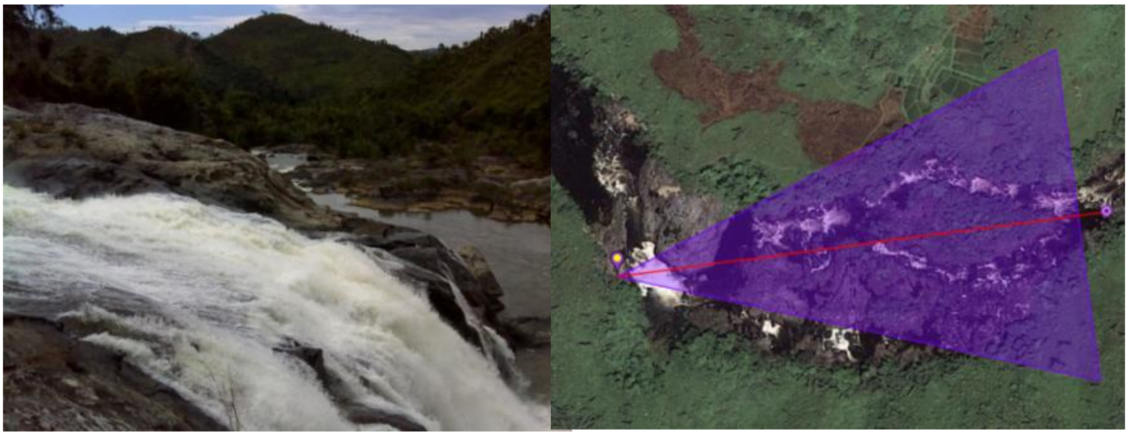


Figure 4. Upstream view of the main waterfall in the river (towards downstream).

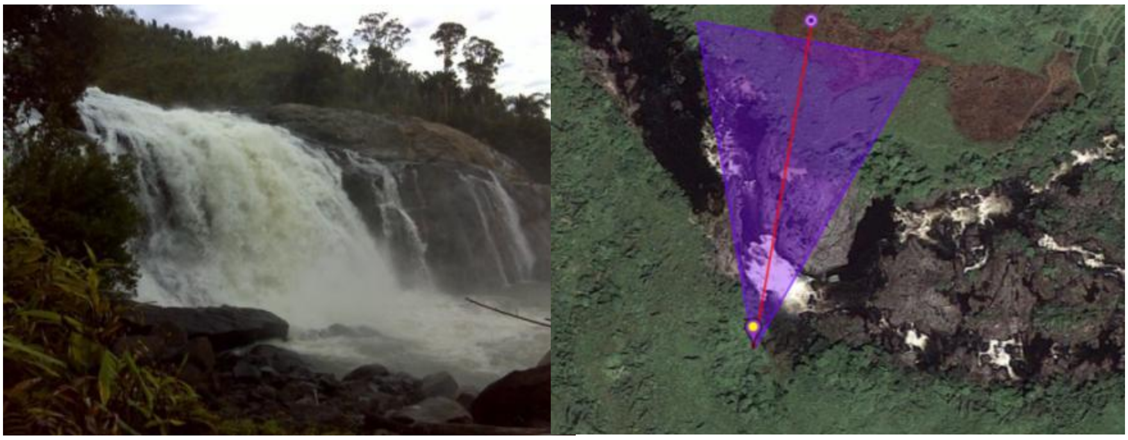


Figure 5. Bottom view of the main waterfall.

2.2 Topography

The topographical survey was achieved through remote sensing. An aircraft was chartered and equipped with optical sensors.

Figure 6. Aircraft and remote sensors container for airborne survey

The topographical survey has a point density of 5 /m² and a relative accuracy of 2%.

Outputs from airborne survey are (1) a high resolution orthophotography (0.2m to 0.4m resolution) and (2) a Digital Surface Model (DSM). The DSM includes the vegetal cover, but it gives an excellent global picture of the site topographical configuration. Results are illustrated in the figures below and the contour lines deducted from the DSM are presented on the detailed proposed scheme layout in section 5.2.

Figure 7. Orthophotography of the site

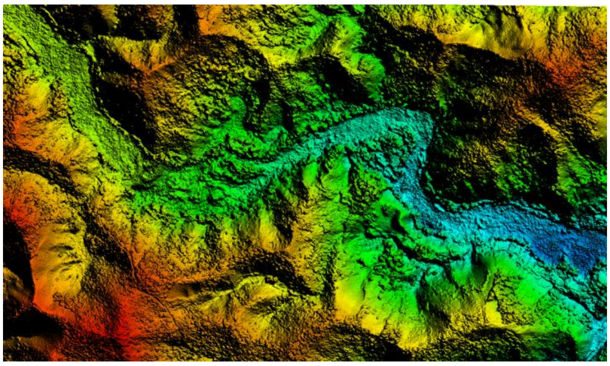


Figure 8. Digital Surface Model of the site

2.3 Preliminary hydrological study

Accurate information on the hydrology of the Namorona River does not exist. As a consequence, statistical characteristics of the river discharge at the site of interest have been estimated using a regional methodology. This methodology is based on the available information at other hydrometric stations distributed in the country. Given the limited spatial and temporal resolution of the available data, the results of the regional study presented below are indicative only and are not intended to be used for design purposes without further detailed hydrological studies.

Key preliminary hydrological characteristics of the river at the site of interest are presented in the table below.

River	Namorona
Main river basin	Namorona
Area [km²]	863
Average elevation [m a.s.l]	1145
Slope index [m/km]	1.0
Specific vertical drop [m]	30.2
Average annual rainfall [mm/yr]	1573
Average interannual discharge [m³/s]	30.6
$Q_{95\%}$ - firm discharge [m³/s]	8.5
$Q_{50\%}$ - median discharge [m³/s]	24.4
$Q_{30\%}$ [m³/s]	34.2
10yr return period flood [m³/s]	536
100yr return period flood [m³/s]	1008

2.4 Sediment transport

The measured turbidity of water was good (below 30 NTU) at the time of the different site visits (October 2014, July 2015, October 2015 and February 2016). However the presence of lateral silt and sand deposits demonstrates that significant erosion and deposition processes occur at some period of the year, likely during major flood events.

Adequate sediments and gravels trapping systems will be designed at the feasibility study stage based on an analysis of the sediment load at different river discharges.

2.5 Site geology

2.5.1 Geological context

Medium to fine grain, granitoid like, biotite migmatite with quartz and feldspar dominates the area (Figure 9). Along the proposed weir axis, foliation direction is along the river axis.

Figure 9. Medium to fine grain, granitoid like, biotite migmatite with quartz and feldspar

Two main cleavage appear in this formation. They are nearly rectangular (N30W and N70E).

Although massive rock appears high in the surrounding hills, the lateritic alteration is relatively low (about one meter) and takes up mainly in surface. With large vegetal covers, their slope ends up barely all the time as riverbank. Lavaka formation is inexistent.

2.5.2 Technical characteristics

Bed aspect at the projected weir location : it is fully made of massive rock in-place, observed through the riverwater. The rocky formation plunges against the river flow. There is an open cleavage, followed by the river in its middle. It is marked on the bottom during low water period (direction N30W).

Right bank support aspect : high mountain-like zone with a migmatitite structure with granitoid tendency, the basis of it is observed as a spread out rocky mass at the river level (Figure 10).

Figure 10. Right bank support: migmatitite rock with granitoid tendency

Left bank support aspect: the left bank support is on a high hill, approximately 50m high, ending up with steep slope close to the river. It is made of granite-migmatitite rocky mass outcropping at its basis and continuing to the river bottom. The lateritic alteration is relatively low (about five meter) and is mainly observed at the summit.

Intake and waterway: the intake and the beginning of the tunnel will be set in a migmatite rocky mass slashed by its joints. This rocky mass forms the plateau structure, which will be crossed by the tunnel. This structure extends towards East. The lateritic alteration is relatively low (about one meter).

Penstock : the land petrographic structure is made of the same rock as described above. Alteration effect is however more important on the East site of the area. High from the river, blockfields with blocks in place are found below structured laterite. At the river, massive formation is found.

Powerhouse : the powerhouse is located in an area made of compact red soil with reworked boulders.

2.5.3 Recommendations for further investigations

ELEMENT	UNCERTAINTY TO REMOVE	SURVEY TYPE
Bed at weir	✓ Possible leakage due to the open cleavage in the middle of the river ✓ Rock plunge against the river flow	Percolation tests. Grout injections recommended for sealing. ✓ To be taken into account during construction as it may increase the strength of the current during flood events
Left and right support	✓ No problem major found	✓ More detailed geological investigation must be conducted once the weir axis is established
Intake / waterway	✓ Level of the bedrock below the lateritic alteration on the waterway trace ✓ Compactness of the rocky structures to cross, influence of the main cleavage and joints ✓ Characterization of the ground at the tunnel outlet	✓ Auger drilling or seismic reflection geophysical survey along the tunnel trace. ✓ Core drilling at some chosen points for percolation tests.
Penstock	✓ Characterization of the supporting ground ✓ Possible landslide or rockslide due to seismicity or cyclonic rainstorms	✓ Geological reconnaissance to be defined in the next study stages ✓ Slope protection measures downhill along the penstock trace
Powerhouse	✓ Characterization of the supporting ground ✓ Level of the bedrock	✓ Auger drilling or seismic reflection geophysical survey

2.6 Socio-environmental aspects

The site detailed description sheet is provided in the Appendices.

2.6.1 Socio-environmental background

The site is located on the Namorona River, near the Andriamanjavona Fall. It is situated in the fokontany of Ambiabe (Mangalahenatra sector), rural community of Ambiabe, Ifanadiana District, region of Vatovavy Fotovinany.

The vegetation in the area is characterised by secondary vegetation, mainly Savoka (Ravinala) and bushy (ericoid) and herbaceous plants. Some degraded forests can be found in the lower part of the hillsides.

Some traces of forest clearings can be seen in the area, in particular on the hillsides.

On the river banks, riparian forests are present discontinuously. They are mainly shrubby (with *Adina*, *Cyperus*) or woody (with bases *Harungana* and *Nuxia*).

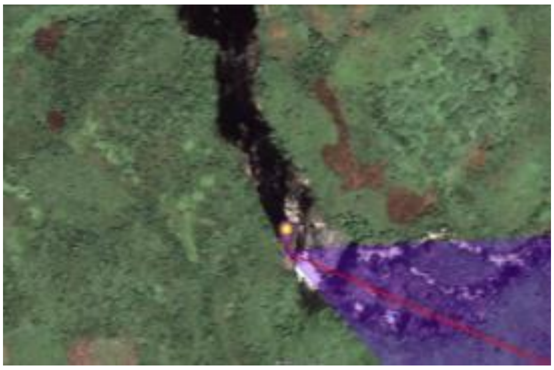



Image 11. Vegetation on the right of the weir site

From the socio-economic perspective, the two main villages (Mangalahenatra Avaradrano and Mangalahenatra Atsimondrano) are located about 1km North-East from site, upstream of the bridge. On the other hand, about 15 small hamlets are located within a radius of 250m South of the penstock pipe route. These hamlets are generally on the hillsides.

The main local activity is agriculture. Rice growing in done in 2 or 3 seasons: 2 for irrigated rice growing and 1 for rain rice growing. The hydro-agricultural infrastructures are composed of hand-dug canals near the rice crops (no irrigation from the Namorona River).

The rural products (rice, manioc, corn, etc.) are mainly used for self-subsistence. Nevertheless, some products are sold: bean, banana, coffee and, more recently, clove). They increase the household incomes.

Young men of the villages in the area go fishing (eels and crayfish). Their products are sold in the seat county of the community of Ambiabe, Kelilalina or Ifanadiana.

The following image gives a global overview of the land use of the area.

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

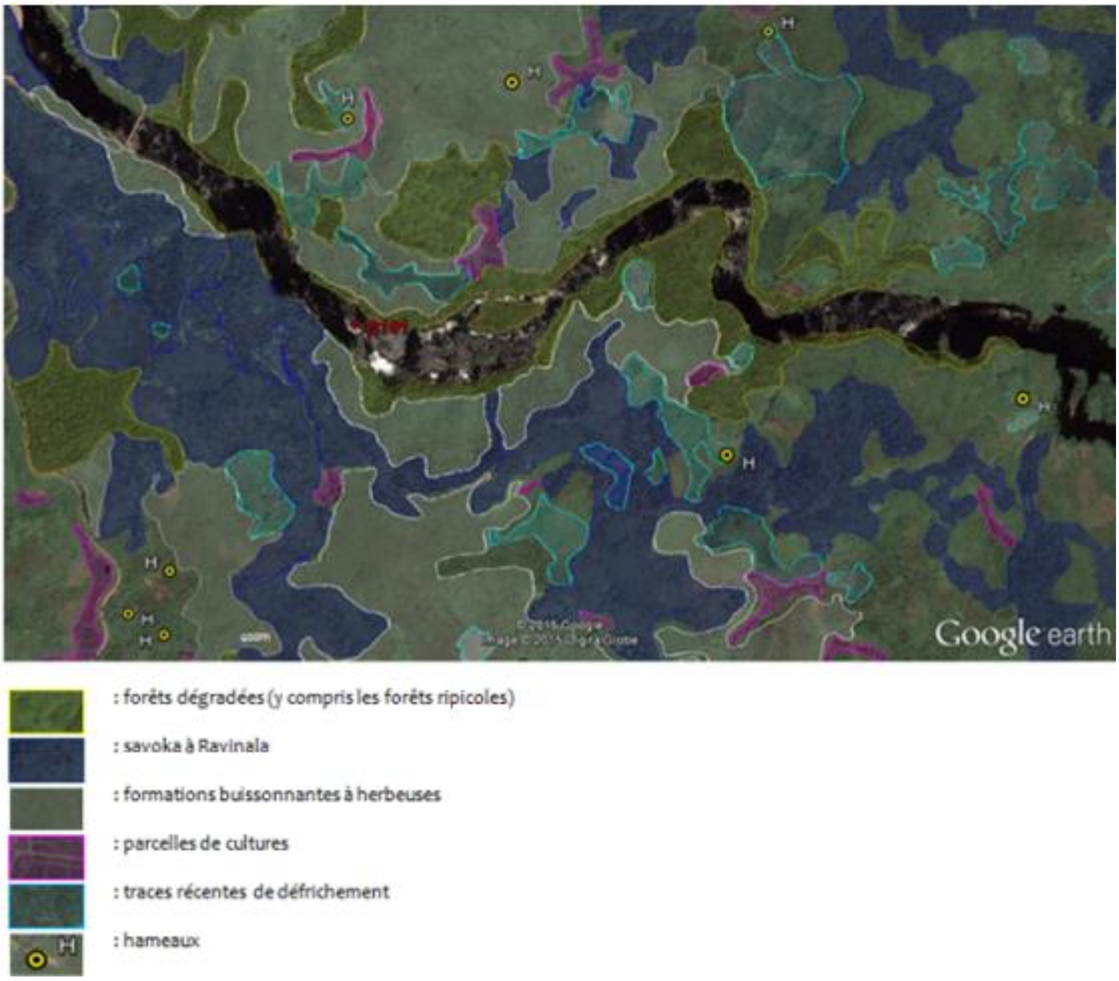


Image 12. Land use in the area of the G 191 site.

2.6.2 *Socio-environmental constraints*

Villages and hamlets are located next to the site (within a radius of 1km): Mangalahenatra Avaradrano and Mangalahenatra Atsimondrano. The implementation of the project will have an impact on those villages, especially regarding potential nuisances (noise, traffic, atmospheric emissions…).

The implementation of the weir could also reduce the socio-economic value of the river, especially on fishing resources (eels and crayfish that travel up the river). Further studies should evaluate the need for specific works ensuring free passage of fishes.

2.6.3 *World Bank Safeguard Policies that might be applied*

The World Bank Safeguard Policies that might be applied for the G191 site are the following:

OP 4.01 – The Bank requires Environmental Assessment (EA) of projects proposed for Bank financing to help ensure that they are environmentally sound and sustainable, and thus to improve decision making. However, we can already estimate that the adverse impacts on human populations and environment-linked areas are limited. They are reduced, not irreversible and some measures can prevent, mitigate or minimize them. Moreover, these measures can improve the environmental performance.

OP 4.12 – Involuntary Resettlement: the hydropower project will require the use of a large space (implementation of the plant, creation of access roads to the site…), which sometimes are crop areas. Moreover, the ponded water of the weir could impact some habitation huts or crop parcels. So the project will have to take into account the concerned people and communities, particularly regarding the restoration of the standards of living due to the loss of resources.

OP 4.04 – Natural Habitats: the Namorona River is the habitat of fish species such as eels and crayfish. However, those habitats are not critical, and mitigation measures might be implemented during the planning studies and the building of the project.

OP 4.11 – Cultural Heritage is not applicable because the site is not known for containing particular cultural material resources.

The projected weir (3m high) is classified as a small dam (<15m high); the usual generic safety measures for dams are appropriate and do not need the implementation of OP 4.37 – Safety of Dams (for large dams).

3 PROPOSED SCHEME LAYOUT

3.1 Technical assumptions

The project will likely be connected to the Interconnected Transmission Network of Fianarantsoa (RIF) given both the potential energy generation of the proposed scheme and its proximity to the RIF. The objective is to carry out a high level assessment of the scheme potential in terms of installed capacity, energy generation (firm and average) and the associated capital investment costs (CAPEX) and productions costs (Levelized cost of energy). Hence, at this stage of the study, the technical features of the hydropower scheme are designed in the following sections for both firm and median discharges (respectively $Q_{95\%}$ and $Q_{50\%}$). The actual design flow will be determined during the detailed studies based on economical, financial and technical criterion as well as the future energy and power demand.

The proposed scheme layout is shown in Figure 13 and presented in A3 format in Appendix 5.2 of this report.

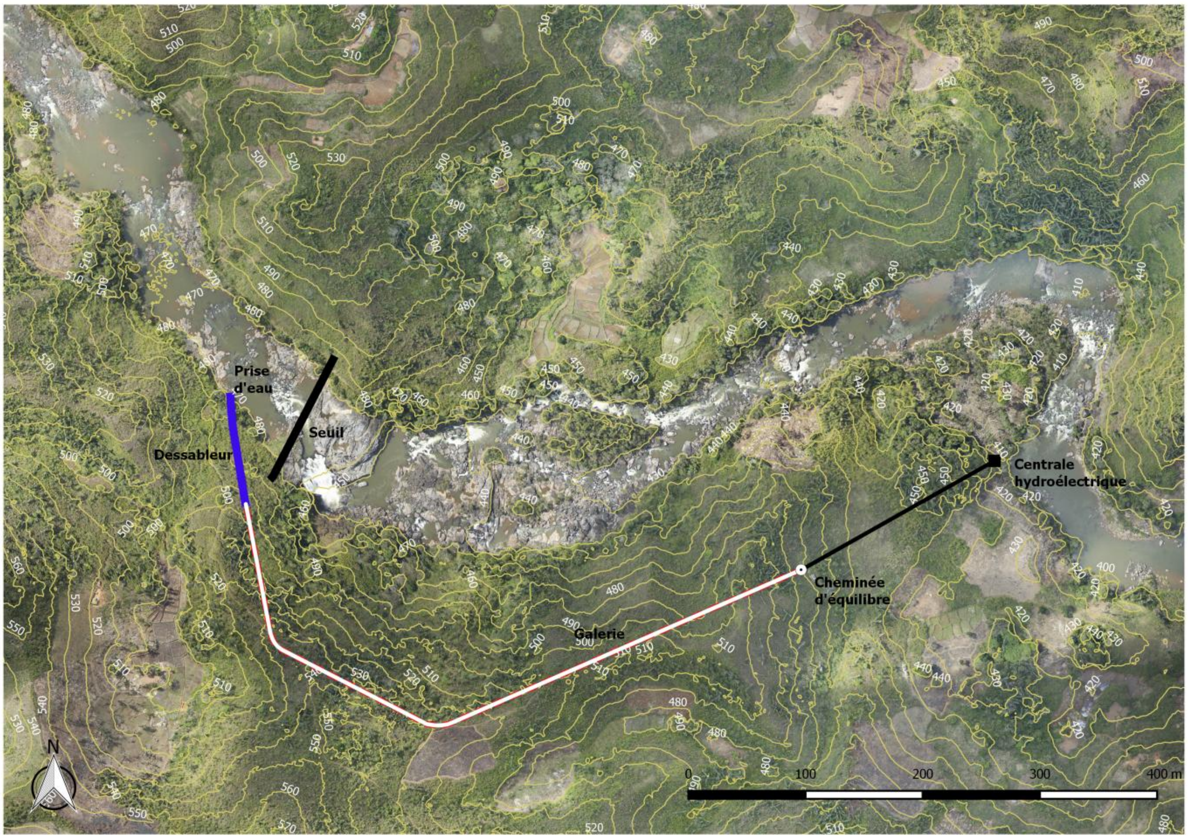


Figure 13. Proposed scheme layout for G191 site

3.2 Weir and intake

The proposed run-of-the river scheme consists of a 5m high and 100m long transversal weir positioned upstream of the main waterfall. The weir will be equipped with a gated bottom outlet in order to flush accumulated sediments, likely at the beginning of the wet season. The intake is located upstream of the weir on the right bank.

Figure 14. Partial view of the proposed weir site.

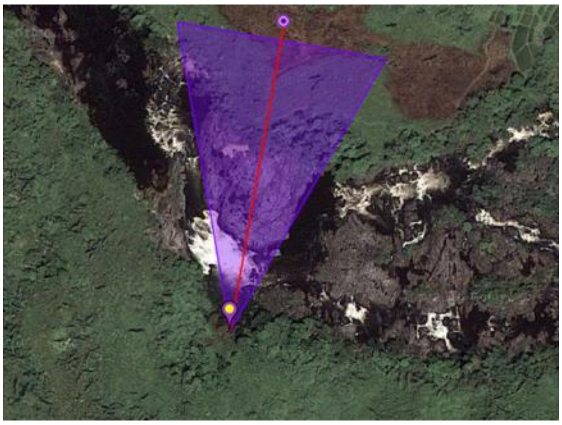



Figure 15. Rocks on the left bank of the main waterfall.

3.3 Desander

Given the potential sediment load in the river mentioned previously, adequate gravels trap and desander systems will be required. Those will be located on right bank of the river before the tunnel entrance. Sediments will be flushed downstream of the main waterfall.

3.4 Waterways

Waterways consist of a 2.5m (assuming the design flow at $Q_{95\%}$) or 4.2m (assuming the design flow at $Q_{50\%}$) diameter and 670m long tunnel in the right bank. The elevation profile of the natural ground above the proposed tunnel alignment is illustrated in the figure below. The final tunnel alignment will determined after the detailed geological and geotechnical surveys to ensure the presence of sufficient thickness of adequate rock around the tunnel. The tunnel will end in a surge chamber/shaft at the junction with the penstock leading to the powerhouse.

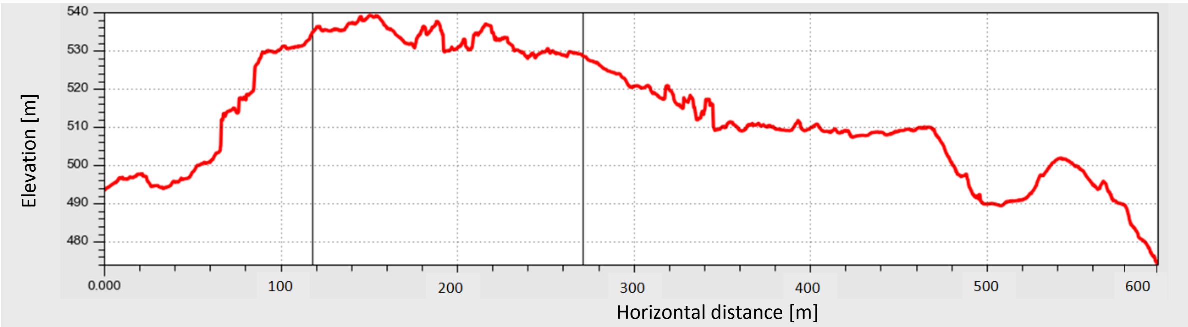


Figure 16. Elevation profile of the natural ground above the proposed tunnel alignment

3.5 Penstock and powerhouse

A single 1.40m (assuming the design flow at $Q_{95\%}$) or two 1.80m (assuming the design flow at $Q_{50\%}$) diameter penstocks will be required to ensure that the head losses due to friction in the pipes will be below 5% of the available gross head. The penstock(s) will be 190m long.

3.6 Electromechanical equipments

3.6.1 Design flow taken at $Q_{95\%}$

Theoretically, the project should be connected to RIF grid. Hence, the chosen turbine type must enable a maximization of the power output while enabling enough flexibility to absorb peaks and ensure production during low demand periods. Given the power potential of the site, it is recommended to install several similar units to optimize the plant efficiency and to enhance its availability and to follow the demand evolution as much as possible.

Figure 17. Exemple de deux groupes Francis à axe vertical

Head, discharge and foreseen output give the Francis turbine as and evidence. It offers a high performance level and a satisfactory flexibility. The suggested solution does not require the use of a gearbox, which is a sensitive and costly component, as well for operation as for maintenance.

Given observations formulated about water quality, a particular attention must be paid to the quality of materials used for the construction of the turbine. One should probably consider the need for an anti-abrasion coating.

Given the site characteristics, it is planned to install two identical units, each composed of:

- Butterfly safety valve with counterweight to ensure its closure in case of emergency of black out.
- A 2 320 kW vertical axis Francis turbine running at 750rpm.
- A 690V alternator, 2 185 kW/ 2 425 kVA.
- Control and monitoring system, including speed regulator and voltage regulator.
- Security system and electrical protection.
- Step-up transformer and electrical cabinet and switchgear.
- Emergency power unit.

A power plant PLC (Programmable Logic Controller) should also be foreseen to manage the two units.

Following issues should be studied as well in the next stages of the project :

- Sedimentation problem and the need for anti-abrasion coatings (e.g. Tungsten carbide).
- Technical and economic optimization of the penstock diameter.
- Technical and economic optimization of the number of units and of the design flow, according to the hydrology and the electrical demand.

- The need of a flywheel (for grid stability)
- The set up level and rotational speed of the turbine (Suction height and cavitation issues).
- Grid voltage.
- Preliminary turbine design.

3.6.2 Design flow taken at $Q_{50\%}$

For a design flow taken at Q_{50}, it is recommended to install two identical units (Francis turbines) in order to optimize the global efficiency and to increase the plant availability.

Other considerations exposed for a design flow at Q_{95} remain valid for a design flow taken at the median discharge (Q_{50}).Turbines will have a unit nominal power of 6 875 kW and a rotation speed of 500 rpm. The alternator power will be 6 460 kV/ 7 180 kVA for a 690 V or 5.5kV voltage.

A power plant PLC (Programmable Logic Controller) should also be foreseen to manage the three units.

3.7 Transmission lines

It is envisaged that the proposed hydropower scheme would be connected to the Interconnected Grid (RIF) using a12km long and 63kV line until Ifanadiana.

3.8 Key technical features

The key features of the proposed hydropower scheme are summarized in the table below for both firm ($Q_{95\%}$) and median ($Q_{50\%}$) design flows.

		Firm discharge	Median discharge
Installed capacity	[kW]	4 318	12 780
Potential annual generation	[GWh/yr]	34.05	92.27
Design flow	[m³/s]	8.5	24.4
Gross head	[m]	65	
100yr return period flood	[m³/s]	1 008	
Weir length	[m]	100	
Weir height	[m]	5	
Desander		Medium size	
Tunnel length	[m]	670	
Tunnel diameter	[m]	2.5	4.2
Penstock length	[m]	190	
Penstock diameter	[m]	1.4	1.8
Number of penstock(s)	[-]	1	2
Number of T/G units	[-]	2	2
Transmission line length	[km]	12	
Line voltage	[kV]	63	
Length of the access road to create	[km]	2.1	
Length of the access road to upgrade/rehabilitate	[km]	5	

4 ENERGY GENERATION AND COSTS

Based on the assumptions of the economical and hydrological studies presented in the main report, the proposed hydropower scheme would feature the following values:

Gross head	**[m]**	65	
Design flow	**[m³/s]**	8.5 ($Q_{95\%}$)	24.4 ($Q_{50\%}$)
Installed capacity	**[kW]**	4 318	12 780
Potential annual generation	**[GWh/yr]**	34.05	92.27
CAPEX (excl. access and lines)	**[M$]**	16.09	39.13
LCOE (excl. access and lines)	**[$/kWh]**	0.057	0.051
Total CAPEX (incl. access and lines)	**[M$]**	20.75	43.78
Total LCOE (incl. access and lines)	**[$/kWh]**	0.073	0.057

5 APPENDICES

5.1 Socio-environmental datasheet

A – Site localisation

Site reference : G 191

Village / Fokontany : Andriamanjavona / Mangalahenatra

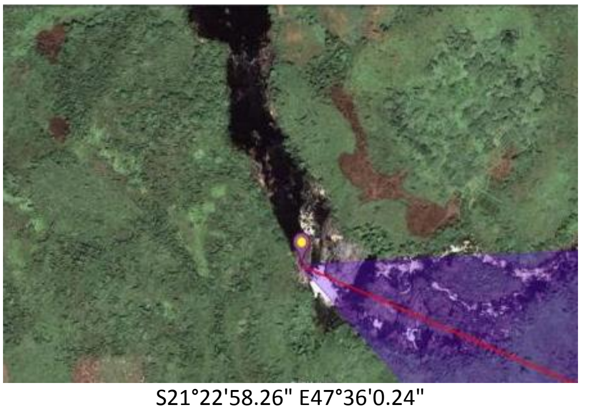
Community / District : Ifanadiana / Ifanadiana – Vatovavy Fitovinany

B - Description of the biophysical background

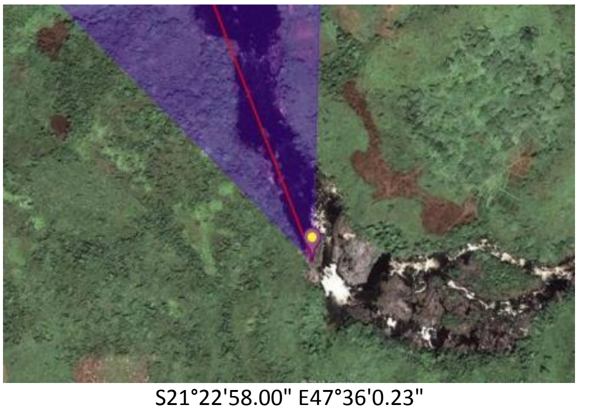
<table>
<tr><td>RELIEF</td><td>The G 191 site is close to the Andriamanjavona fall, ~500m away from the Mangalahenatra bridge. The relief of the site is really precipitous with steep slopes (that can reach 45 °).

The Namorona River is the main watercourse of the area. It comes from the forest massif of Ranomafana (North-West) and flows about 100km before going to the sea. The hydrographic network is really dense. Some tributaries such as the Manandriana, the Sahamilamaka, the Sahavatona Rivers meet the Namora River. The basin of the Namorona is narrow and elongated. It heads West-East and is characterised by a long and precipitous relief (with some falls).


Next to the Andriamanjavona Fall


S21°22'58.26" E47°36'0.24"


View downstream of the G191 site


S21°22'58.00" E47°36'0.23"</td></tr>
</table>

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

VEGETATION	The vegetation cover is characterised by an important diversity due to repetitive forest clearing in the area. Some leftovers of natural forests, relatively degraded, (*Tambourissa* and *Weinmannia*) mix with secondary forests (mainly Savoka, Ravinala). The latter are associated with fallows, in the shape of bushy vegetation (ericoid) and/or mosaic of crops. Riparian forests can be discontinuously found near the river. They can be bushy (*Adina, Cyperus)* or woody (*Harungana* and *Nuxia*) The ecosystem of the area is typical of the Eastern forests, with repetitive forest clearings. The vegetation activity is really active, helped by the weather and the soil conditions of the area.  Forest clearing near the Andriamanjavona Fall (S21°22'52.60" E47°35'54.85")  End of a Savoka (Ravinala) forest
OBSERVATIONS	Forest clearing and/or slash-and-burn are common in the area because of the narrow lowlands and valleys. The hillsides are the main agricultural areas.  Tavy in the middle of a Savoka (Ravinala)
SENSIBILITIES	The G 191 site is located about 15km West of the protected area of Ranomafana. The new protected area « Fandriana – Vondrozo forest corridor » is located about 10km East of the site. The International Conservation NGO is the sponsor.

B - Description of the socio-economic background

<table>
<tr><td>LOCALITY</td><td>
Fokontany Mangalahenatra, rural community of Ambiabe – Ifanadiana District (Region of Vatovavy Fitovinany). You can access the site via a dirt road suitable for vehicles which is about 10km long from the bifurcation of the NR25, near the Ambatotongo village. It is the temporary NR14 linking Ifanadiana – Tolongoina – Ikongo.
<u>Rural community of Ambiabe :</u>
The G 191 site belongs to the rural community of Ambiambe, which was created in 2014. It belonged to the rural community of Ifanadiana until 2012. In 2014, the community had more than 2 000 inhabitants over 18 years old, in 6 fokontany (Ambiabe, Ambinanidranotelo, Ankobaka, Ambalatenina, Ambalafasina, Sahavatana).
The community has currently no office of official document. The social infrastructures are schools and markets. In case of diseases, the population has to go to the Health centres of Ranomafana or Ifanadiana.
Localities and villages :
The two main villages (Mangalahenatra Avaradrano and Mangalahenatra Atsimondrano) are located about 1km North-East from site, upstream of the bridge. On the other hand, about 15 small hamlets are located within a radius of 250m South of the penstock pipe route. These hamlets are generally on the hillsides. The two villages have about 60 households and only one basic social infrastructure (no health infrastructure, the water supply is done via sources in the valleys).
</td></tr>
<tr><td>ACTIVITIES</td><td>
The main local activity is agriculture. Rice growing in done in 2 or 3 seasons: 2 for irrigated rice growing and 1 for rain rice growing. The hydro-agricultural infrastructures are composed of hand-dug canals near the rice crops (no irrigation from the Namorona River).
The rural products (rice, manioc, corn, etc.) are mainly used for self-subsistence. Nevertheless, some products are sold: bean, banana, coffee and, more recently, clove). They increase the household incomes.
Young men of the villages in the area go fishing (eels and crayfish). Their products are sold in the seat county of the community of Ambiabe, Kelilalina or Ifanadiana.
Every household has poultry farm and zebus to help in the rice crops.

Investigation in Mangalahenatra

Trees at the end of the village of Mangalahenatra
</td></tr>
</table>

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	 Housing in Mangalahenatra	 Drying of coffee
OTHERS (IF ANY)	Most of the population is Tanala, but the community of Ambiabe has other ethnic groups, such as Betsileo and Antesaka. It should be noted that, in order to have economical resources quickly, the population participates in gold mining activities along the Namorona River. According to an inhabitant of the village, it is forbidden to use perfumed soap or to bath in the Namorona River after eating pork.	

C - World Bank operational policies that could be applicable:

OP 4.01 – Environmental Assessment ☒

OP 4.04 – Natural Habitats

OP 4.11 – Cultural Heritage ☐

OP 4.12 – Involuntary Resettlements ☒

OP 4.37 – Safety of Dams ☐

Land use around the site

: riparian formation

: savoka / forest mosaïc

: field / savoka mosaïc

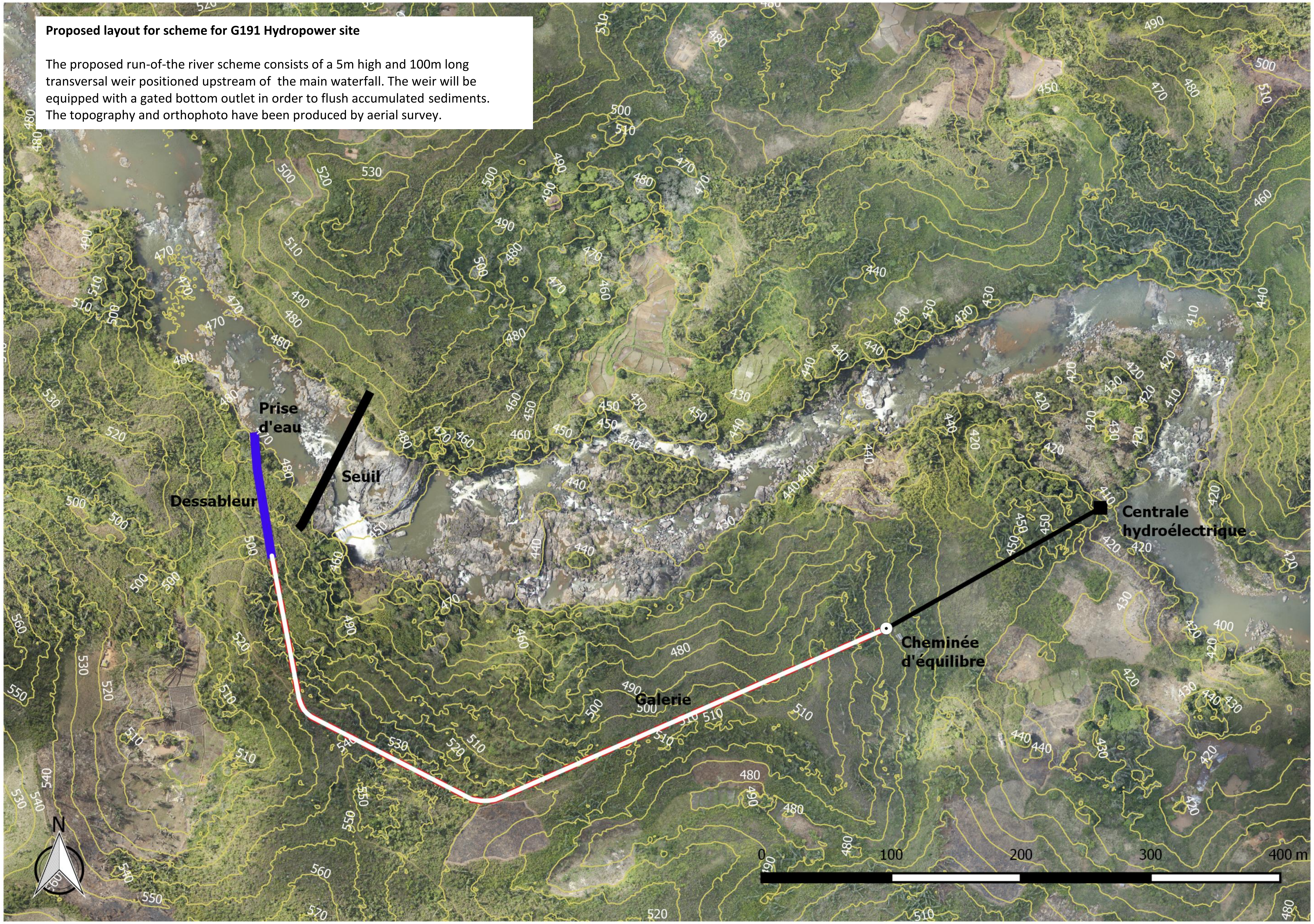
: fields

: clearing

: hamlets / campsites

	
Forest clearing on the left bank of the Namorona River	Muddy track leading to the G191 site

5.2 Proposed scheme layout



Madagascar: Small Hydropower Resource Atlas (1-20MW)
Site Investigation Report

FANOVANA SITE

Sahatandra River | Atlas Code: G407

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REPOBLIKAN'I MADAGASIKARA

Table of content

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1 SITE LOCATION

Geographical coordinates (WGS 84)	Longitude [°]	Latitude [°]
Intake	48.545	-18.915
Powerhouse	48.546	-18.913

1.1 Administrative data

Atlas code	G407
Site name	Fanovana
River	Sahatandra
Major river basin	Rianila
Province	Toamasina
Region	Alaotra-Mangoro
District	Moramanga
Commune	Ambatovola
Village	Fanovana

1.2 Access

Access to the site is easy given the proximity of road RN7 from which a dirt road leads to the train station Fanovana. From there, there is still 2km to walk along the train's tracks.

For the works, 5km of existing dirt road should be rehabilitated, and 3.5km created.

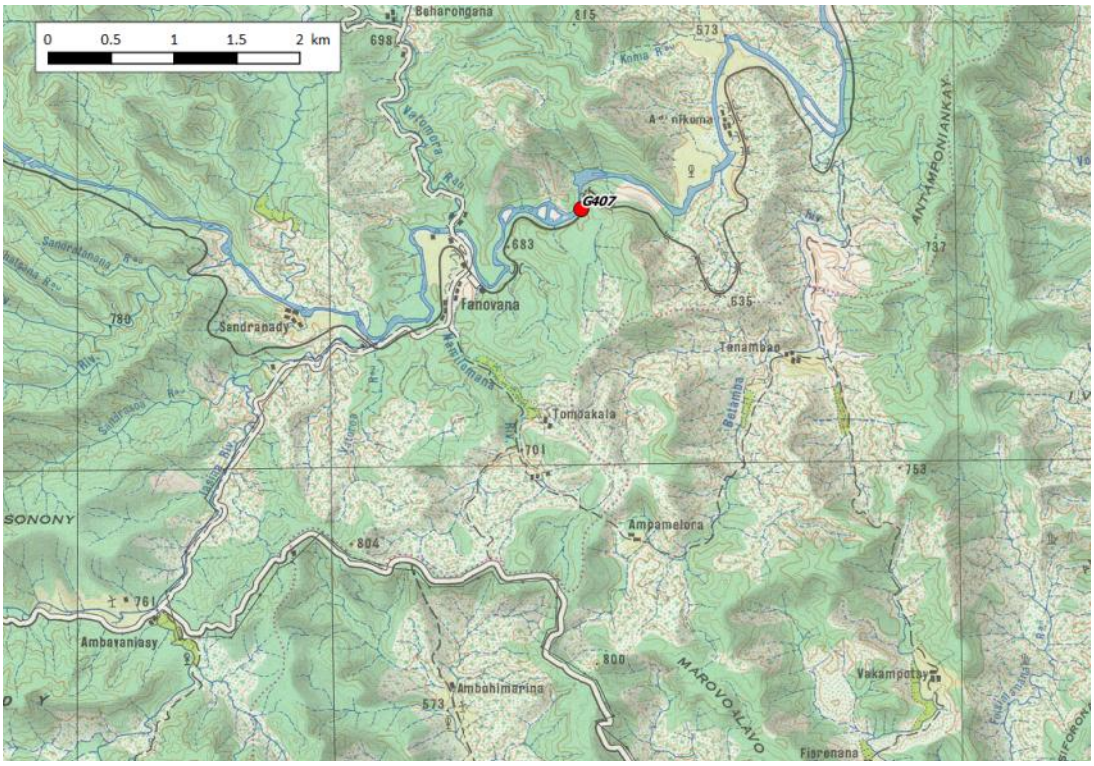

Figure 1. Access to site G-407

The site is located 2km away from the Andekaleka-Antananarive transmission line. It is assumed that a connexion to this segment is possible.

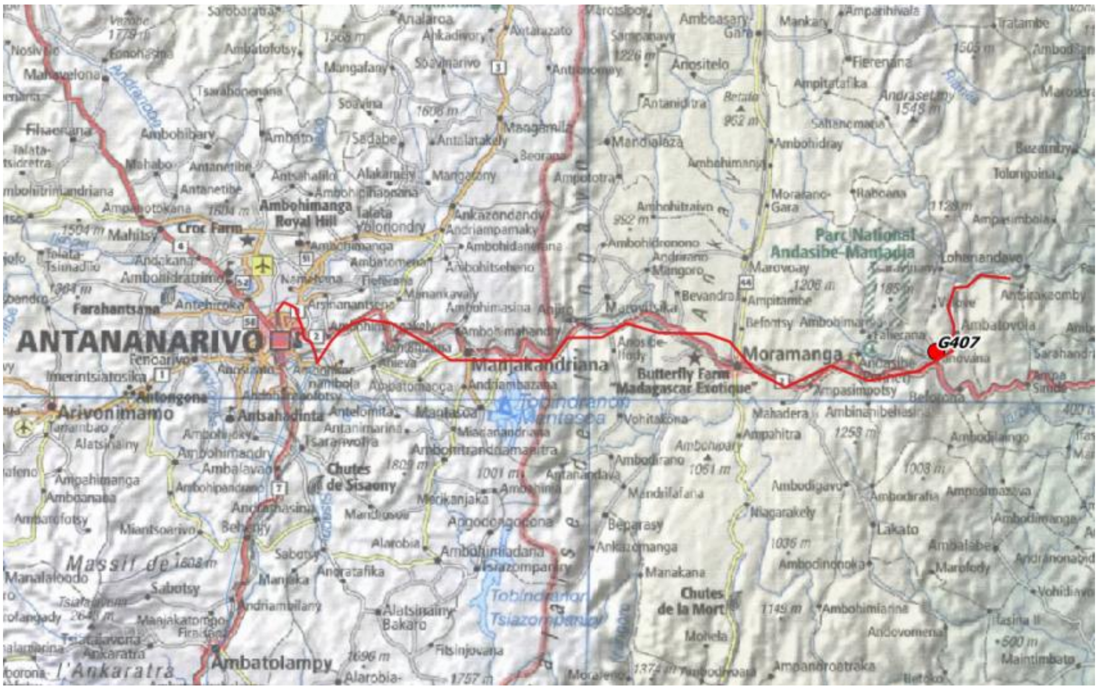

Figure 2. Connexion to the Andekaleka-Antananarive transmission line

2 GENERAL SITE DESCRIPTION

2.1 Background

The waterfall is clear and concentrated on a short segment. There is currently no existing irrigation or hydropower scheme. However, the site is locatedright beside a segment of the Tamatave-Antananarivo railway.

Figure 3. Site overview (GoogleEarth)

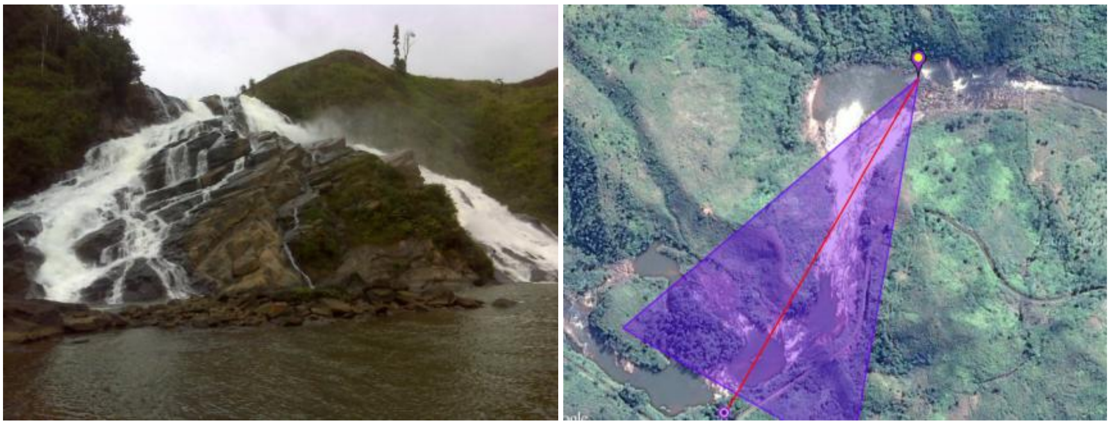

Figure 4. View from below the waterfall

2.2 Topography

The topographical survey was achieved through remote sensing. An aircraft was chartered and equipped with optical sensors.

The topographical survey has a point density of 5 /m² and a relative accuracy of 2%.

Figure 5. Aircraft and container of remote sensors for airborne survey

Outputs from airborne survey are (1) a high resolution orthophotography (0.2m to 0.4m resolution) and (2) a Digital Surface Model (DSM). The DSM includes the vegetal cover, but it gives an excellent global picture of the site topographical configuration. Contour lines might be deduced from the DSM.

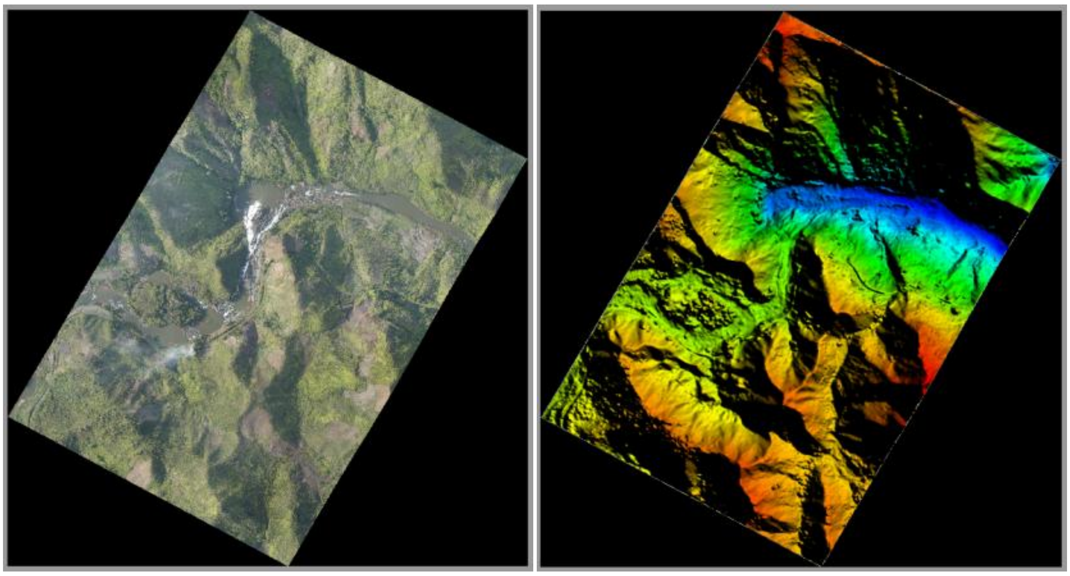

Figure 6. Orthophotography and Digital Surface Model from airborne survey

2.3 Preliminary hydrological study

Accurate information on the hydrology of the Sahatandra River does not exist. As a consequence, statistical characteristics of the river discharge at the site of interest have been estimated using a regional methodology. This methodology is based on the available information at other hydrometric stations distributed in the country. Given the limited spatial and temporal resolution of the available data, the results of the regional study presented below are indicative only and are not intended to be used for design purposes without further detailed hydrological studies.

Key preliminary hydrological characteristics of the river at the site of interest are presented in the table below.

River	Sahatandra
Main river basin	Rianila
Area [km²]	520
Average elevation [m a.s.l]	983
Slope index [m/km]	2.8
Specific vertical drop [m]	64
Average annual rainfall [mm/yr]	1842
Average interannual discharge [m³/s]	21.2
$Q_{95\%}$ - firm discharge [m³/s]	5.4
$Q_{50\%}$ - median discharge [m³/s]	16.7
$Q_{30\%}$ [m³/s]	23.9
10yr return period flood [m³/s]	646
100yr return period flood [m³/s]	1351

2.4 Sediment transport

Sediment transport depends on the discharge in the river. Although turbidity was good at the time of visit (September 2014), a heavy sediment load should be assumed when designing the scheme, as active sand strips are visible upstream of the site (see figure below).

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Figure 7. Historical aerial images of a river stretch just upstream of the site: (a) November 2004, (b) May 2013 and May 2014. (d) Detail on sand deposition in the river

2.5 Site geology

2.5.1 Geological context

The whole area is dominated by migmatitic granite composed of medium grain quartz, feldspar and biotie, with a large portion of feldspar. The general direction of this rock formation is N100E and it is sometimes cut but by basalt veins that may be very large. Quartzic veins N20E plunging at 30°E are observed similarly. Joints and small fractures are multiple and often filled of quartzic intrusions (Figure 8).

Figure 8. (A) Migmatic granite dominating in the area and (B) Joints and small fractures filled of quartzic intrusions.

The morphology is shaped by the influence of twe faults with respective directions N40W and N20E. It results in a serie of plateaus where rock masses dominate in-depth, under a thin alterite layer (of metric order). Widespread outcrops are noticed along the river, sometimes split by fractures into large boulders.

Lateritic alteration is rather low on the whole area. Only reddish to brownish clayey sand alterites are found in surface. A large vegetal cover is only found on steep plateaus slopes.

2.5.2 *Technical characteristics*

Bed aspect at the projected weir location: the projected weir axis crosses a mass of migmatitic granite spreading between the two banks, easily identifiable during low water period. The river follows the direction of one of the main fault in the area (N20E) which alignment, oriented from upstream to downstream; is noticed on field during dry season.

Right bank support aspect: the right bank is characterized as the basis of a high hill with steep slope, formed of massive migmatitic granite which superficial layer is covered by thin lateritic layer with poor vegetal cover. The corresponding rock widely crops out at the riverside.

Left bank support aspect: the left bank has the same aspect as the right bank. The hill slope on the left riverbank is however smoother than that of the right bank.

Intake: the geology of the intake area and tunnel opening is fully made of massive rock with sub-vertical limb, which is suitable for a tunnel opening.

It must be noted that the railway tunnel is only a few meters above the water level in the river and the tunnel for the hydropower scheme will have to be set below the railway tunnel. The level for the tunnel opening will depend on the final weir height.

Waterway: the tunnel alignment crosses a plateau made of a massive migmatitic granite formation. Its opening will rest against the basis of the retaining wall of the railway. The tunnel would be more in depth than the railway tunnel but its alignment would cross the railway tunnel alignment two times on a XY plane. The exit opening would be in the same rock mass as the rest.

Penstock: the ground is composed of granitic mass under a thin metric alterite layer (compact reddish-brownish clayey sand soil).

Powerhouse: the powerhouse woul be founded on the bedrock which is found beneath a thin alluvium deposition (made of scree and lateritic clay) and some reworked boulders.

2.5.3 *Recommendations for further investigations*

ELEMENT	UNCERTAINTY TO REMOVE	SURVEY TYPE
Bed at weir	✓ Fear of leakage due to the pressure induced by the waterpond.	✓ Clogging of the fault below the weir by injection of cement grout or other systems
Right support	✓ No particular issue	✓ Some boulders must be removed
Left support	✓ No particular issue	✓ Some boulders must be removed and the geotechnical capability of lateritic soil should be analyzed
Intake and waterway	✓ Fear of tunnel collapsing due to vibrations resulting from passing trains	✓ Analyze of the rock foundation compactness where the railway crosses the tunnel (horizontal or inclined core drilling)

Penstock	✓ No particular issue	✓ More detailed geological observations of the final penstock alignement after final definition of the tunnel exit opening location
Powerhouse	✓ Nature of the supporting ground (Massive rock? Boulder in place or not? Depth of laterite?)	✓ Auger drilling or seismic reflection geophysical survey

2.5.4 *Main risks*

The rail company may refuse the drilling of a new tunnel close to the existing railway.

2.6 Socio-environmental aspects

The site detailed description sheet is provided in the Appendices.

2.6.1 *Socio-environmental background*

The site is located on the Sahatandra river, near the Koma Fall. It is located in the fokontany of Fanovana, rural community of Ambatovola, Moramanga District, region of Alaotra Mangoro.

From the ecological perspective, the region belongs to the Western domain, characterised by an evergreen vegetation.

Right near the site, the vegetation is mainly savoka without woody elements (mostly *Psiadia altissima* and *Helychrysum)*. Nevertheless, on the left bank, near the expected weir, we can see an evergreen wet forest, more or less degraded (mostly *Weinmannia* and *Tambourissa*).

Image 9. Vegetation : savoka on the right of the weir

Within a radius of 1km around the site, the forest recovering rate is quite small (~25%). The vegetation is quite uniform: the upper part of the hillside is covered by Eucalyptus ; the hillsides are covered by Savoka without woody elements (mostly *Psiadia altissima*, *Aphramomum angustifolium* and *Helychrysum) ;* the lower part of the hillsides is covered by mosaics of crops (banana trees, sugar cane, manioc), just like the rest of the power plant site.

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

Image 10. Mosaic of plantings on the power plant site and on the hillsides around the site

From the socio-economic perspective, the site is located about 1km away from two villages: Fanovana (S-W) and Ambodinikoma (N-E). The Fanovana village has about 1 600 inhabitants and the Ambodinikoma village has about 50 households. Some hamlets and seasonal campsites can be seen around the site.

Generally, the main activities of the local population in the area are agriculture and fishing. They go fishing in the Sahatandra River (eels and crayfish).

On the other hand, the Sahatandra River is a place for kayaking.

The agriculture is mainly rice growing, twice a year: tanety (rain culture) and lowland crops (irrigated by tributaries of the Sahatandra River). Rice growing is generally associated with subsistence crops such as manioc, sweet potato… and cash crops such as coffee and ginger.

In the area of the site, traces of tavy (slash-and-burn) can be found thanks to fallows (grass species which indicate forest clearings and disused fields) and crops on these fallows (banana trees, manioc and sugar cane).

The following image gives a global overview of the land use in the area.

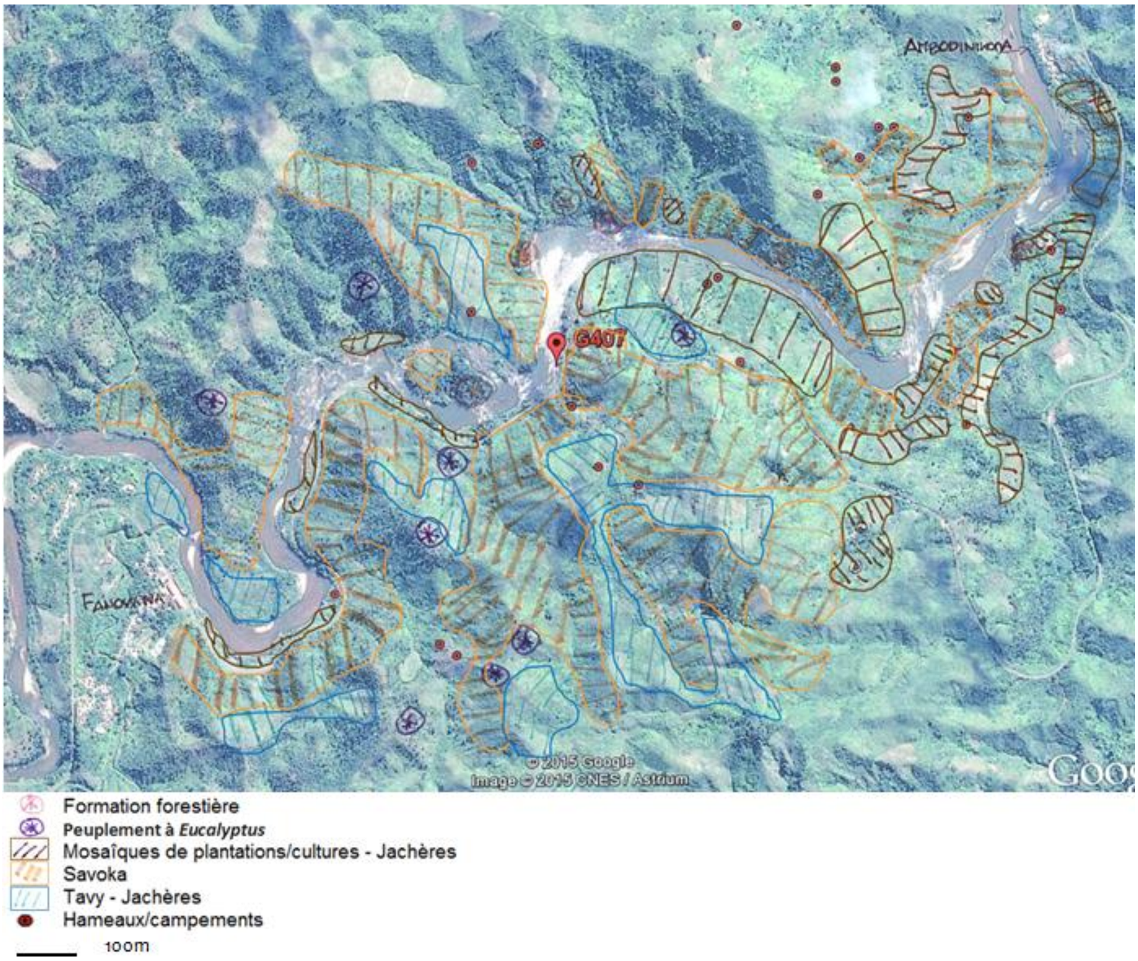


Image 11. Land use in the area of the G 407 site

2.6.2 *Socio-environmental constraints*

The implementation of the weir could reduce the socio-economic value of the Sahatandra River, especially tourism (use of the river to go kayaking) and fishing resources (crayfish that goes up the river).

Moreover, a railroad on the right of the site is a socio-economic constraint that cannot be neglected. A train passes by the site 4 times/week (Moramanga-Toamasina and Moramanga-Ambila) ; the implementation of the works should be well thought in order not to become obstacles to the usual rail traffic, which is strategic for the economy of the region.

Finally, some hamlets/villages are present in the surroundings of the site (within a radius of about 1km around the site), including the seat county of Fanovana and the Ambidinikoma village. The implementation of the project will affect these villages, especially regarding potential nuisances (noise, traffic, noise, atmospheric emissions…).

2.6.3 *World Bank Safeguard Policies that might be applied*

The World Bank Safeguard Policies that could be applicable for the G 407 site are the following :

OP 4.01 – The Bank requires Environmental Assessment (EA) of projects proposed for Bank financing to help ensure that they are environmentally sound and sustainable, and thus to improve decision making. However, we can already estimate that the adverse impacts on human populations and environment-linked areas are limited. They are reduced, not irreversible and some measures can prevent, mitigate or minimize them. Moreover, these measures can improve the environmental performance.

OP 4.04 – Natural Habitats: the Sahatandra River is the habitat of fish species such as eels and crayfish. However, those habitats are not critical, and mitigation measures might be implemented during the planning studies and the building of the project. Further studies should evaluate the need for specific works ensuring free passage of fishes.

OP 4.12 – Involuntary Resettlement: the hydropower project will require the use of a large space (implementation of the plant, creation of access roads to the site…), which sometimes are crop areas. Moreover, the ponded water upstream of the weir could impact some habitation huts or crop parcels. So the project will have to take into account the concerned people and communities, particularly regarding the restoration of the standards of living due to the loss of resources.

OP 4.11 – Cultural Heritage is not applicable because the site is not known for containing particular cultural material resources.

The projected weir (6m high) is classified as a small dam (<15m high); the usual generic safety measures for dams are appropriate and do not need the implementation of OP 4.37 – Safety of Dams (for large dams).

3 PROPOSED SCHEME LAYOUT

3.1 Technical assumptions

An assessment of the scheme potential in terms of installed capacity, energy generation (firm and average) and the associated capital investment costs (CAPEX) and productions costs (Levelized cost of energy) is presented in section 4. It is based on the scheme proposed in this section. Hence, at this stage of the study, the technical features of the hydropower scheme are designed for both firm and median discharges (respectively $Q_{95\%}$ and $Q_{50\%}$). The actual design flow will be determined during the detailed studies based on economical, financial and technical criterion as well as the future energy and power demand.

The proposed scheme layout is shown below and presented in A3 format in the Appendix of this report.

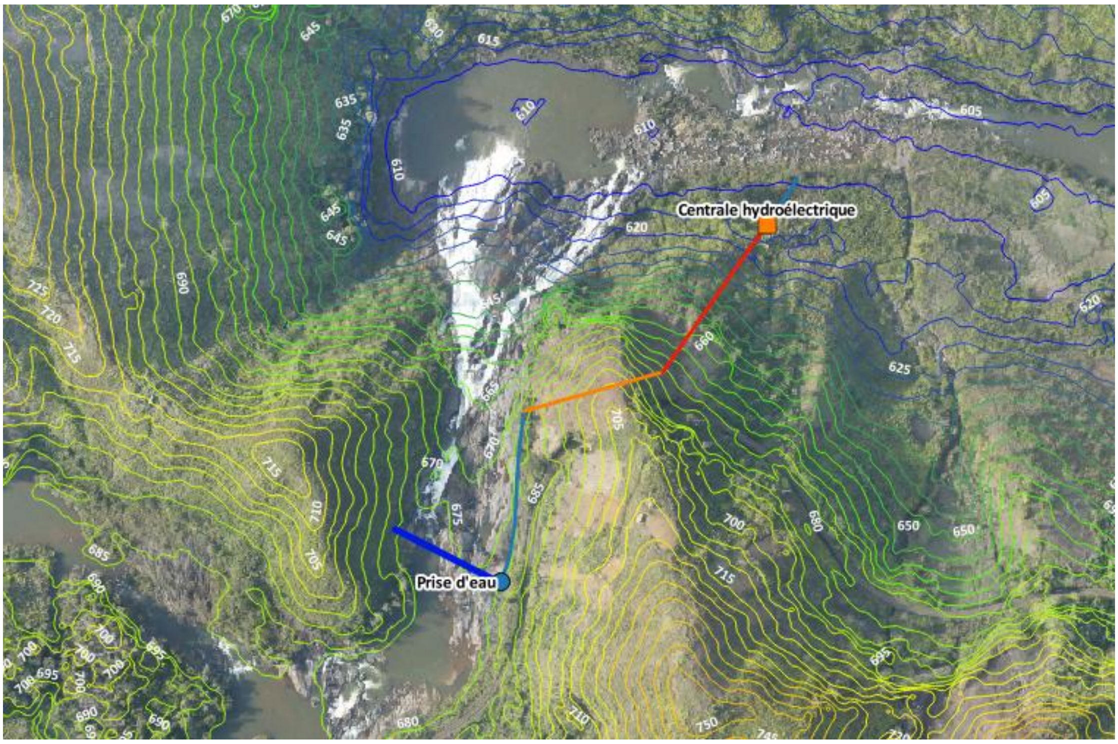


Figure 12. Proposed scheme layout

3.2 Weir and intake

The weir would be positioned at the upstream part of the waterfall, yet at a low enough position to ensure a limited impact of the river flood level on the railroad. It would be 75m long and maximum 6m high.

Figure 13. Proposed weir site

Figure 14. Upstream part of the site next to the railway

3.3 Desander

The desander will be located downstream of the intake, on the channel stretch linking the intake to the gallery.

3.4 Waterways

A 140m long canal would carry the water into a 90m long tunnel. This tunnel would be at a distance of 60m from the railway tunnel. Deeper investigations must confirm that this value is enough in order to avoid to jeopardize the stability of the existing infrastructure.

The tunnel would have a circular section with a diameter 2.0m (firm flow) or 3.5m (median flow). The terrain profile is presented below.

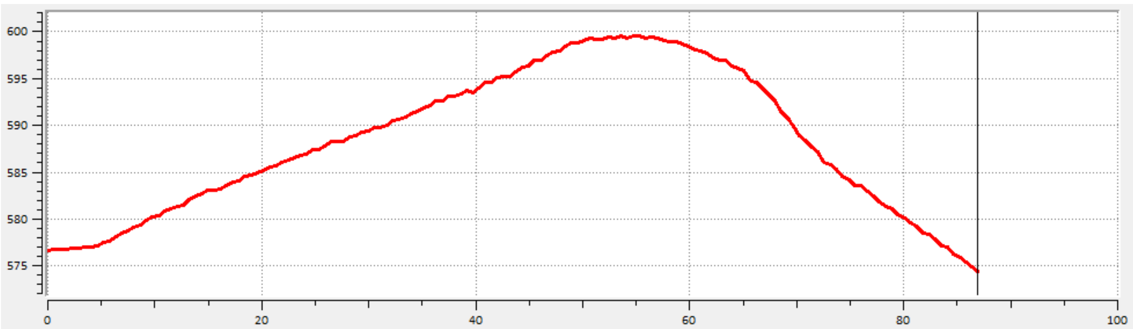


Figure 15. Terrain profile for the tunnel

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

Figure 16. Existing tunnel for the railway adjacent to the site

3.5 Penstock and powerhouse

The penstock will be 130m long (1.20m diameter at firm flow and 2.00m at median flow).

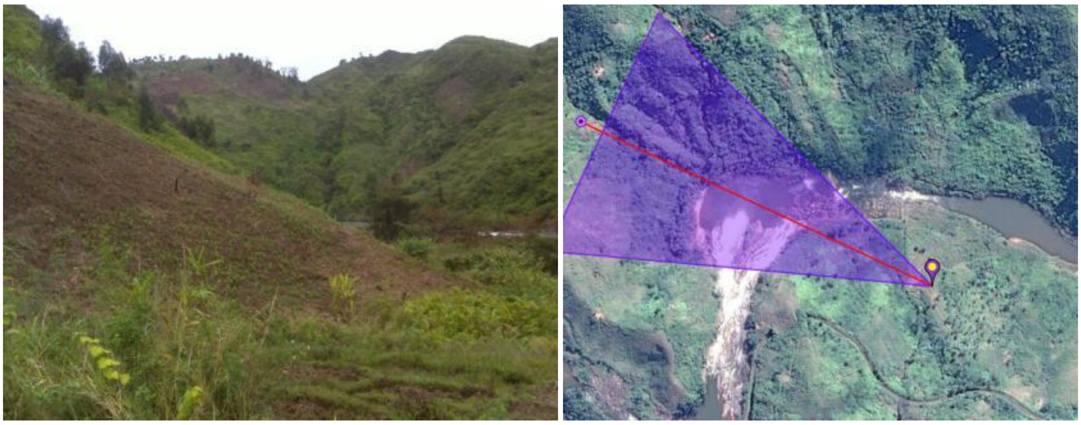


Figure 17. View on the hill hosting the proposed penstock and powerhouse

3.6 Electromechanical equipments

3.6.1 Design flow taken at Q_{95}

Head, discharge and foreseen output give the Francis turbine as and evidence. It offers a high performance level and a satisfactory flexibility.

Given observations formulated about water quality, a particular attention must be paid to the quality of materials used for the construction of the turbine. One should probably consider the need for an anti-abrasion coating.

Electromechanical equipments of the powerhouse will then be composed of:

- Butterfly safety valve with counterweight to ensure its closure in case of emergency of black out.
- A 3 200 kW vertical axis Francis turbine running at 750rpm.

- A 690V or 5.5 kV alternator, 3 010 kW/ 3 345 kVA.
- Control and monitoring system, including speed regulator and voltage regulator.
- Security system and electrical protection.
- Step-up transformer and electrical cabinet and switchgear.
- Emergency power unit.

Following issues should be studied as well in the next stages of the project :

- Sedimentation problem and the need for anti-abrasion coatings (e.g. Tungsten carbide).
- Technical and economic optimization of the penstock diameter.
- Technical and economic optimization of the number of units and of the design flow, according to the hydrology and the electrical demand.
- The need of a flywheel (for grid stability)
- The set up level and rotational speed of the turbine (Suction height and cavitation issues).
- Grid voltage.
- Preliminary turbine design.

Figure 18. Example of 2 vertical-axis Francis sets

3.6.2 *Design flow taken at Q_{50}*

For a design flow taken at Q50, it is recommended to install two identical units (Francis turbines) in order to optimize the global efficiency and to increase the plant availability.

Other considerations exposed for a design flow at Q95 remain valid for a design flow taken at the median discharge (Q50).Turbines will have a unit nominal power of 5 010 kW and a rotation speed of 600 rpm. The alternator power will be 4 710 kV/ 5 235 kVA for a 690 V or 5.5kV voltage.

A power plant PLC (Programmable Logic Controller) should also be foreseen to manage the two units.

3.7 Transmission line

The produced power would be evacuated by a 5km long, 63kV line to the RIA (Anatananarivo'grid) through the segment joining the Andekaleka plant.

3.8 Key technical features

The main technical features are presented below for both design flows: firm and median.

		Firm flow	Median flow
Installed capacity	[kW]	3010	9420
Potential annual generation	[GWh/yr]	23.58	66.52
Design flow	[m³/s]	5.4	16.7
Gross head	[m]	68	
100yr return period flood	[m³/s]	1 351	
Weir length	[m]	75	
Weir height	[m]	6	
Desander		Large size	
Canal length	[m]	140	
Canal section (b x h)	[m]	2.7 x 1.7	4.75 x 2.95
Tunnel length	[m]	90	
Tunnel diameter	[m]	2	3.5
Penstock length	[m]	130	
Penstock diameter	[m]	1.2	2
Number of penstock(s)	[pce]	1	1
Number of T/G units	[pce]	1	2
Transmission line length	[km]	5	
Line voltage	[kV]	90	
Length of the access road to create	[km]	3.5	
Length of the access road to upgrade/rehabilitate	[km]	5	

4 ENERGY GENERATION AND COSTS

At this very early stage of study, and according to the hypotheses and options taken above, the project would have the following energy and economical performances as order of magnitude:

Gross head	**[m]**	68	
Design flow	**[m³/s]**	5.4 ($Q_{95\%}$)	16.7 ($Q_{50\%}$)
Installed capacity	**[kW]**	3 010	9 420
Potential annual generation	**[GWh/yr]**	23.58	66.52
CAPEX (excl. access and lines)	**[M$]**	9.74	22.96
LCOE (excl. access and lines)	**[$/kWh]**	0.050	0.042
Total CAPEX (incl. access and lines)	**[M$]**	13.3	26.52
Total LCOE (incl. access and lines)	**[$/kWh]**	0.068	0.048

5 APPENDICES

5.1 Socio-environmental datasheet

A – Site localisation

Site reference : G 407

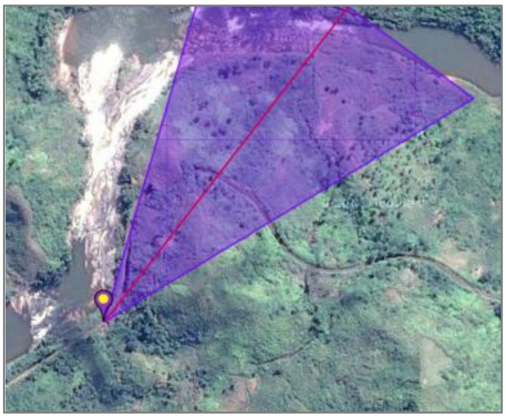
Village / **Fokontany** : Fanovana

Community / District-Region : Ambatovola / Moramanga - Alaotra Mangoro

B - Description of the biophysical background

RELIEF	The G 407 site is located near the Koma Fall. The area is surrounded by hills and is limited by : - The Marovoalavo - Antamponankay – Ambatosoa complex, which altitude is about 800m ; - The Vohidrazana Summit (more than 1 200m high, South) The area has a precipitous relief, characterised by multi-faces hills and steep slopes. The valleys and lowlands are narrow and have a really small surface. The hillsides are generally cleared by « tavy ». The area is crossed by small watercourses that meet the main river: the Sahatandra River. Near the site, the Sahatandra River is located between two hills heading North-South and their peaks are at more than 800m high. The Sahatandra River flows East-North-East, passes near Ambatovola (about 7km) to throw itself in the Vohitra River (about 15km from the site).
VEGETATION	The area belongs to the Western domain, characterised by an evergreen forest. The vegetation in the surroundings of the area is generally composed by Savoka, without woody elements (*Psiadia altissima* and *Helychrysum).* Nevertheless, near the location of the weir, we can see an evergreen deep forest islet, quite degraded, mainly composed by *Weinmannia*, *Tambourissa*. In the 60's, large forest exploitation works were done in the area with the construction of the TCE railway (East Coast Tananarive). The major steps of degradation of the vegetation, associated with a strong exploitation of the hillsides by tavy, lead to the current secondary vegetation composed by bushy and herbaceous species. However, we still can see some degraded wet vegetation (IEFN 2005). Some shred reforestation forests, leftovers of the Fanalamanga society, are spread over the summits and hillsides. These reforestations are generally composed by Eucalyptus. Within a radius of 1km around the site, the forest recovering rate is quite small (~25%). The vegetation is quite uniform: the upper part of the hillside is covered by Eucalyptus ; the hillsides are covered by Savoka without woody elements (mostly Psiadia altissima, Aphramomum angustifolium and Helychrysum) ; the lower part of the hillsides is covered by mosaics of crops (banana trees, sugar cane, manioc), just like the rest of the power plant site. Despite the quite degraded vegetation in the area, some forest massifs are still there, like the Vohidrazana first (~10km as a crow flies, South of the site) and the experimental reserve of Vohimana (3km as a crow flies, West of the site).

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

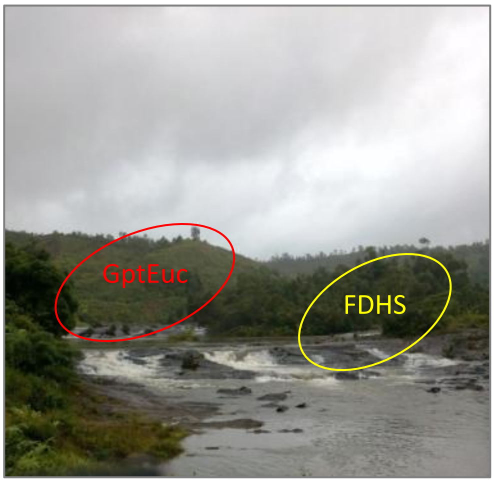


Savoka without woody elements and plantings *Musa* (Svk) in the middle part of a hillside

S18°54'57.71" E48°32'42.48"

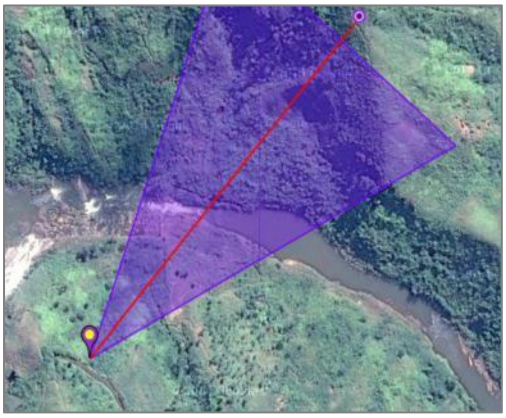
Savoka without woody elements in the upper, middle and lower part of a hillside.

S18°54'57.63" E48°32'42.42"



Degraded wet dense forest islet and group of Eucalyptus sp. In the upper part of a hillside.

S18°54'56.86" E48°32'43.14"

	 Mosaic of plantings (Mospl) (upstream) on the power plant site and on the middle part of a hillside  S18°54'51.91" E48°32'47.59"
OBSERVATIONS	Near the G 407 site, traces of tavy can be seen in the landscape : remaining fallows (grass species indicate clearings and disused fields) and still cultivated crops (banana trees, manioc, sugar cane).
CRITICAL AREAS	The neighbourhood of the site is composed by several protected areas - Andasibe National Park – Mantadia (~7km from the site) - Special Reserve of Analamazaotra (~12km from the site) - Ankeniheny NAP Forest Corridor – Zahamena (~8km from the site) - Vohimana experimental reserve (~3km from the site) These protected sites are only located East of the G407 site. Biodiversity : the Vohimana experimental reserve, which is a leftover of the forest that shares the same characteristics than the ancient forest of Fanovana, still currently has some lemurs species such as the Babakoto ((*Indri indri*), Varika Mena, Matavy Rambo. It should also be noted than a bird species, the « *Newtonia fanovanae* », found in the forest of Fanovana in 1933, is named by the Fanovana village. The lack of woody vegetation on the hillsides encourages landslides, and obviously the sedimentation of the downstream areas.

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

B - Description of the socio-economic background

LOCALITY

Fokontany Fanovana – Rural community of Ambatovola - Moramanga District (Region of Alaotra – Mangoro).

Following the railway, you can access the site (~2km away from the seat county of the fokontany).

Rural community of Ambatovola :

The rural community of Ambatovola has about 10 500 inhabitants[1] spread in 7 fokontany, this is an average of 1 600 inhabitants by fokontany. The community has education infrastructures such as primary public schools (10) and one College of General Education (1). However, there is no High School yet, in the community. Health: the rural community of Ambatovola has a Basic Health Centre II and one private clinic.

Localities and villages :

The site is located near two big villages :

- The Fanovana village, seat county of the fokontany. It has about 1 600 inhabitants in 6 neighbourhoods. Infrastructures : the fokontany has a drinking water network, managed by a private association, with 12 public fountains[2] (only 4 are operational) ; one primary public school and one train station (in the seat county of the fokontany)..

  Accessibility : the fonkontany is linked to the NR2 near the Ambavaniasy village via a track suitable for vehicles, about 5km from the Tombakata village. This track is the access track number 3 of Ambatovy. By train, the Fanovana station is located 4km away from the Vohimana station (East) and about 25km of the Perrinet Andasibe station. The train passes by 4 times a week (round trip Moramanga – Toasmasina, leaving every Monday and returning every Tuesday and Moramanga – Ambila, leaving every Thursday and returning every Friday).

- The Ambodinikoma village is located upstream of the G 407 site, near the Sahatandra River, on the edge of the Koma Fall. It has about 50 housings and is crossed in the East by the railway that links Fanovana to the seat county of the rural community of Ambatovola.

Some hamlets and campsites, locally called « pôtro » are found in the surroundings of the site. These campsites are generally seasonal: from 6 months to 5 years.

Housing in the fokontany/village Fanovana

Fanovana station

[1] CREAM 2009 – Monographie de la Région Alaotra – Mangoro / Annexe 1

[2] CREAM 2009 – Monographie de la Région Alaotra – Mangoro / Annexe 3

<table>
<tr><td></td><td>


Fanovana – operational public fountain

Fanovana – public primary school
</td></tr>
<tr><td>ACTIVITIES</td><td>
The main activities of the G 407 site are fishing and agriculture :

- The agriculture is mainly rice growing, twice a year : tanety (rain crops) and lowlands rice crops (irrigation from small watercourses, tributaries of the Sahatandra River). The narrowness of the relief does not help with the irrigated rice growing. As a matter of fact, the lowlands are really narrow in the area. The local population has technical supports from technicians in Ambatovy in order to improve the production of irrigated rice crops : provision of rural equipment, improved seeds and farm inputs. Rice growing is generally associated with subsistence crops such as manioc, sweet potato… and cash crops such as coffee and ginger.

- The river is also a source of income for the local population, in particular eels and crayfish fishing. They are sold in Ambavaniasy (NR2) or in the big villages (seat county of the fokontany and/or seat county of the community).

Vegetable crop on the Sahatandra bank

Manioc crop on hillside

Banana tree on the edge of the river

Fanovana river – Coffee crop
</td></tr>
<tr><td>OTHERS</td><td>
The majority of the population is from the ethnic groups of Bezanozano and Betsimisaraka.

The closest activity is the mine and the graphite factory in Falierana Andasibe.
</td></tr>
</table>

C – World Bank Safety Policies that could be applicable :

OP 4.01 – Environmental Assessment ☒

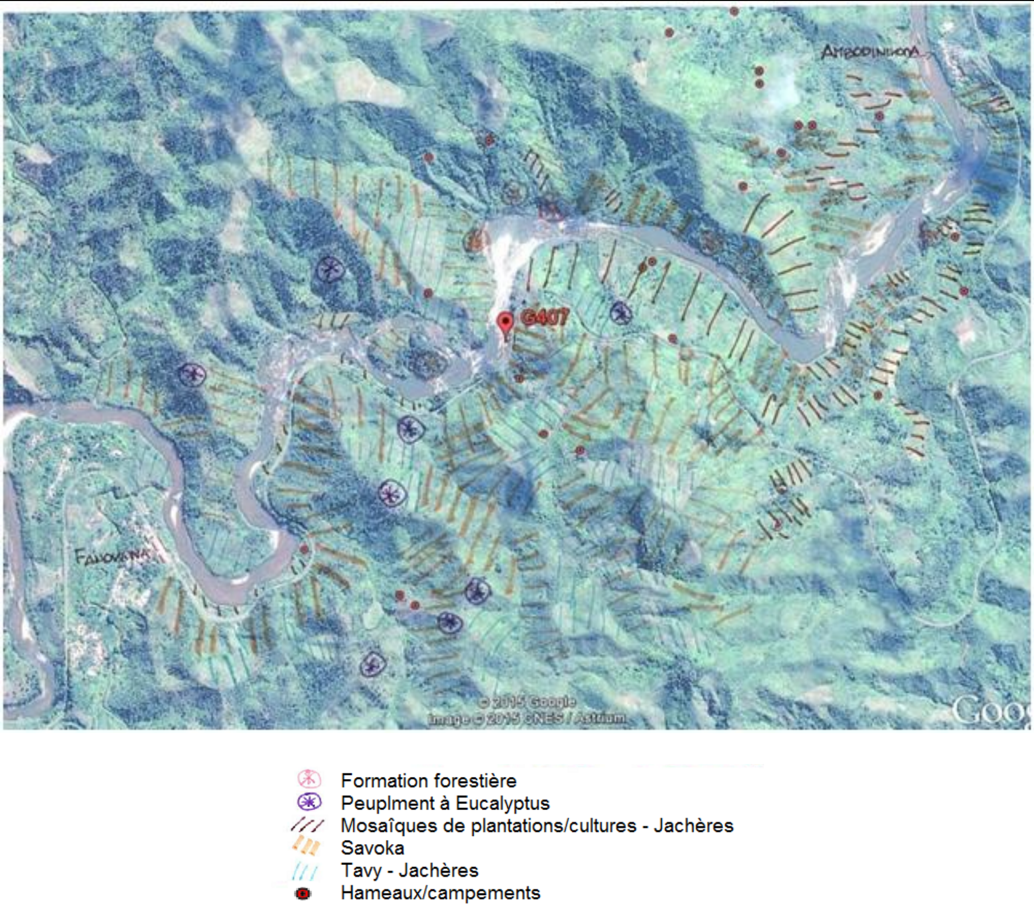
OP 4.04 – Natural Habitats ☒

OP 4.11 – Cultural Heritage ☐

OP 4.12 – Involuntary Resettlement ☒

OP 4.37 – Safety of Dams ☐

Land occupation around the site



100m

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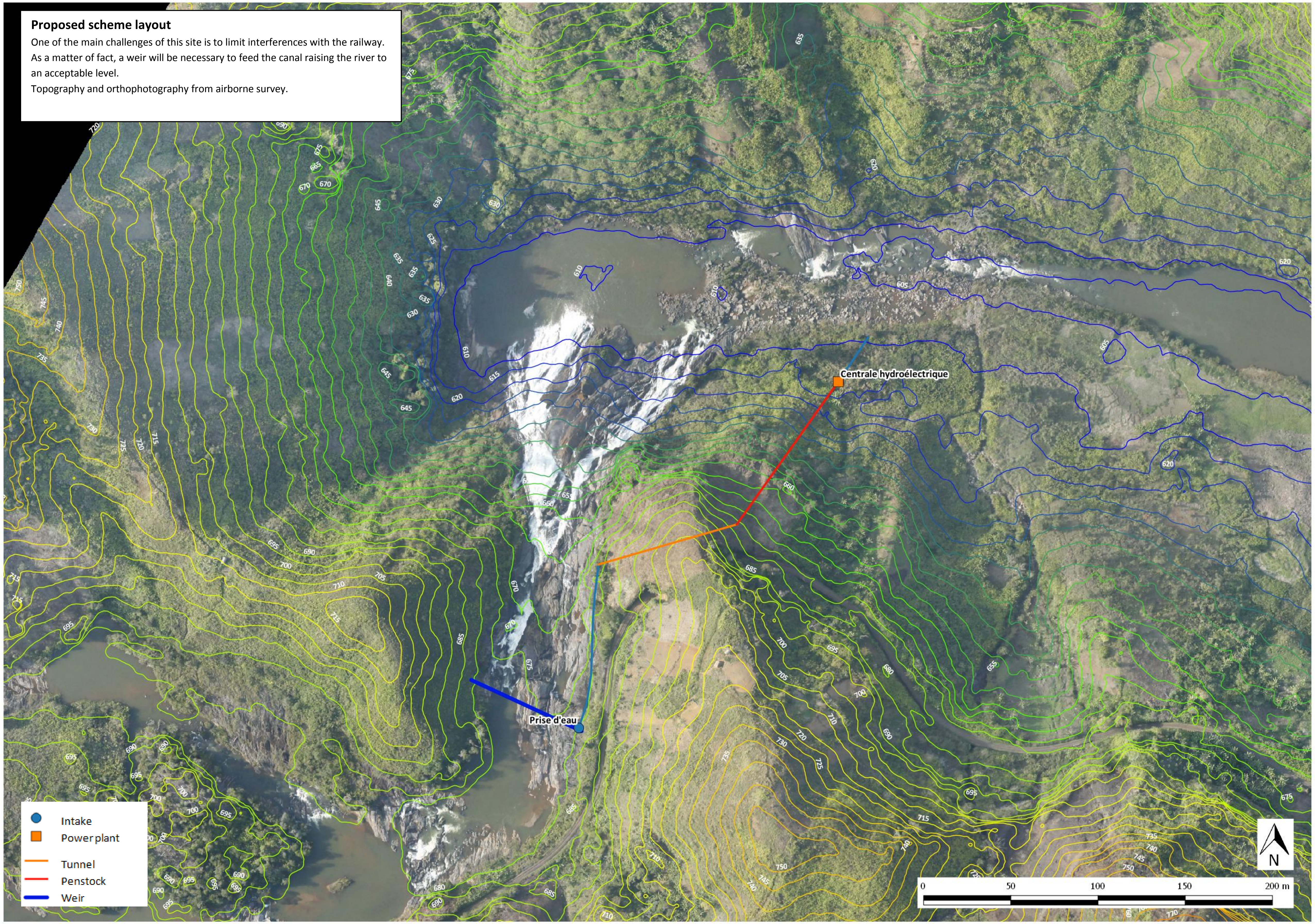
5.2 Proposed scheme layout



Madagascar: Small Hydropower Resource Atlas (1-20MW)
Site Investigation Report

SF011 SITE

Marimbona River | Atlas Code: SF011

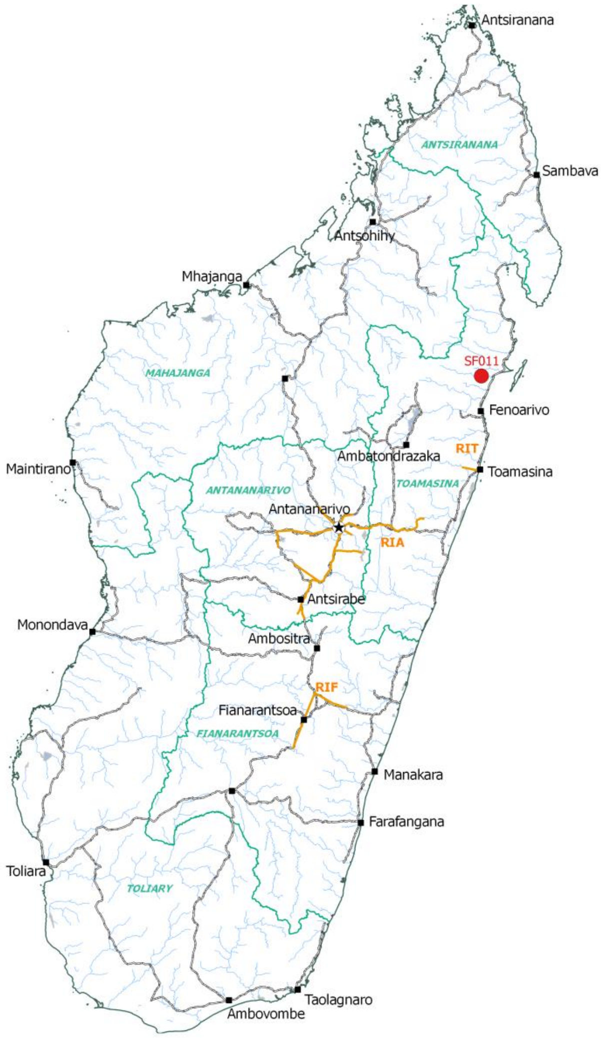


Table of content

1 SITE LOCATION

Geographical coordinates (WGS 84)	Longitude [°]	Latitude [°]
Intake	49.421	-16.912
Powerhouse	49.446	-16.918

1.1 Administrative data

Atlas code	SF011
Site name	SF011
River	Marimbona
Major river basin	Marimbona
Province	Toamasina
Region	Analanjirofo
District	Soanierana-Ivongo
Commune	Andapafito
Village	Fotsialanana/ Marolambo
Reference topographical map	Carte topographique n°V42 (échelle 1:50,000)

1.2 Access

Access to the site is currently possible from Sonierana Ivongo. River boats get as far as Fotsialanana. From there, a wide track leads to Amboninanto (right bank).

For the works, it is probably easier to cross the river at Sonierana Ivongo (with the crossing boat), and then to make an access road from there to the site (33km long).

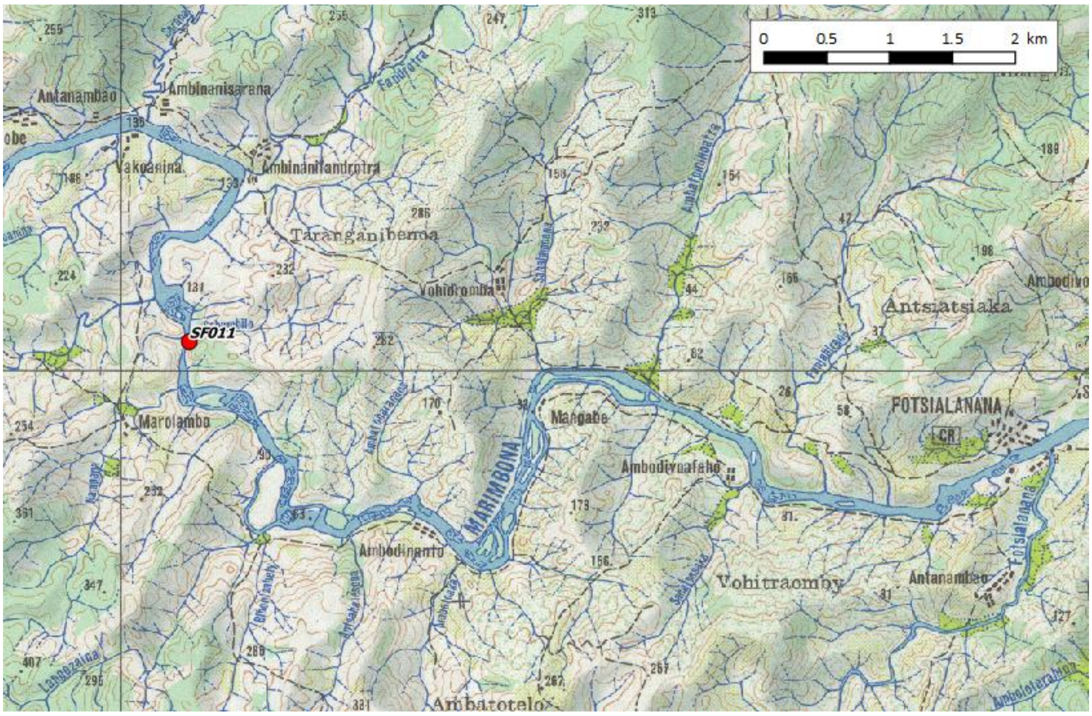


Figure 1. Access to the site from Fotsialanana

Relatively close to this site are the town of Sonierana Ivongo and the neighboring coastal villages. Sonierana Ivongo is currently fed by a diesel plant, mainly during evening time.

Figure 2. The site might feed the town and villages between Sonierana Ivongo and Fenoarivo Atsin

2 GENERAL SITE DESCRIPTION

2.1 Background

A global head of 100m is reached by a succession of rapids (rather than a clear waterfall) in a half loop 5.7km long. The area is steep and hilly, which reduces the possibility of canals. There is no irrigation or hydropower scheme in the area.

Figure 3. Aerial view of the site

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

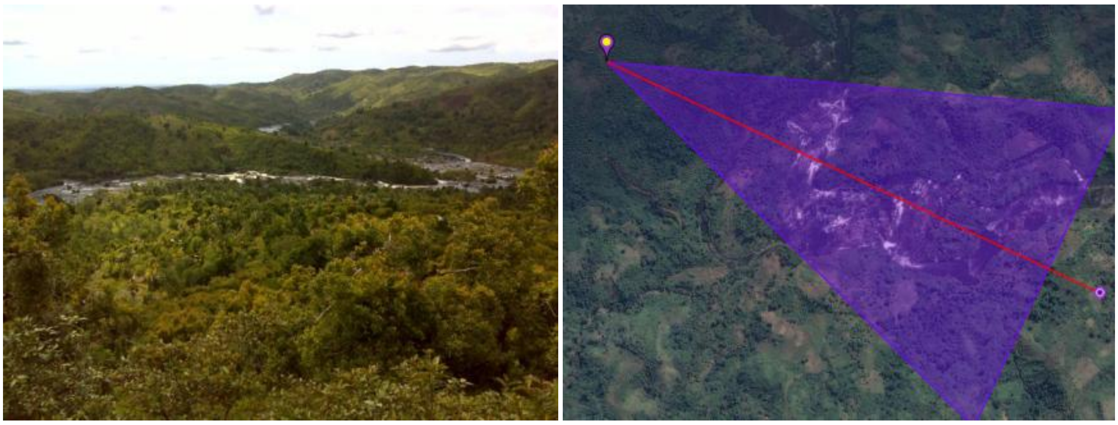


Figure 4. Downstream part of the site overview

Figure 5. Detail of one of the rapids leading to a global head of about 100m on the whole stretch

2.2 Topography

The topographical survey was achieved through remote sensing. An aircraft was chartered and equipped with optical sensors.

Figure 6. Aircraft and container of remote sensors for airborne survey

The topographical survey has a point density of 5 /m² and a relative accuracy of 2%.

Outputs from airborne survey are (1) a high resolution orthophotography (0.2m to 0.4m resolution) and (2) a Digital Surface Model (DSM). The DSM includes the vegetal cover, but it gives an excellent global picture of the site topographical configuration. Contour lines might be deduced from the DSM.

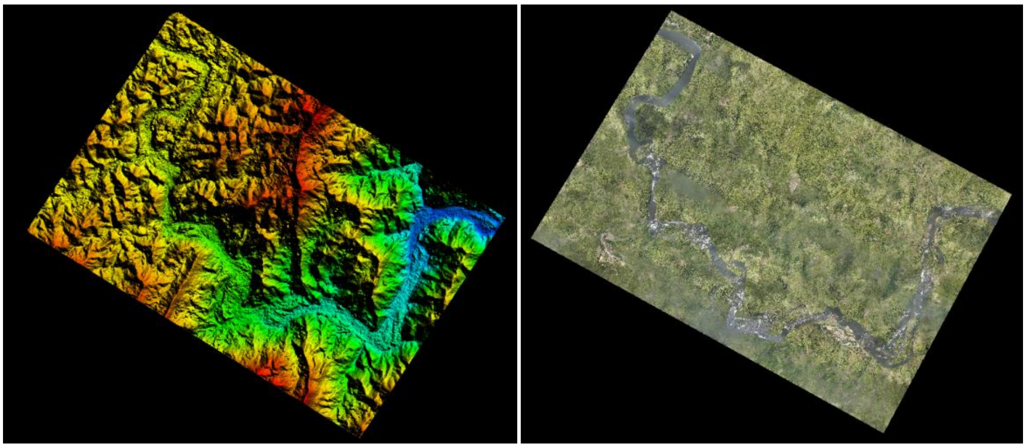


Figure 7. Digital Surface Model and orthophotography from airborne survey

2.3 Preliminary hydrological study

Accurate information on the hydrology of the Marimbona River does not exist. As a consequence, statistical characteristics of the river discharge at the site of interest have been estimated using a regional methodology. This methodology is based on the available information at other hydrometric stations distributed in the country. Given the limited spatial and temporal resolution of the available data, the results of the regional study presented below are indicative only and are not intended to be used for design purposes without further detailed hydrological studies.

Key preliminary hydrological characteristics of the river at the site of interest are presented in the table below.

River	Marimbona
Main river basin	Marimbona
Area [km²]	1459
Average elevation [m a.s.l]	801
Slope index [m/km]	4.5
Specific vertical drop [m]	173
Average annual rainfall [mm/yr]	1631
Average interannual discharge [m³/s]	55.2
$Q_{95\%}$ - firm discharge [m³/s]	17.1
$Q_{50\%}$ - median discharge [m³/s]	45.1
$Q_{30\%}$ [m³/s]	61.5
10yr return period flood [m³/s]	1815
100yr return period flood [m³/s]	3546

2.4 Sediment transport

Sediment is an important issue for the scheme. The basin cover is mainly unforested and most of the area is cultivated, even on steep slopes. High soil erosion is expected. Active sand strips are visible on the banks of the river.

2.5 Site geology

2.5.1 Geological context

The area is dominated by granitoïd migmatite composed of medium to coarse grains of quartz, feldspar and biotite and of heterogranular porphyroblast texture. On the riversides and on the hills sides, it is observed under the shape of massive rock but more often as big rock boulders. Some big gabbro blocks (greenish) are observed along the river.

Lateritic alteration is limited (order of the meter) and lavakisation system is limited. The ground surface is covered by luxurious vegetation.

On a tectonic point of view, important faults are few. Two fracture directions dominate and are related to joints that opened after superficial decompression. They crosscut diagonally (N20 W and N240 E) and both have a vertical dip. One of it is followed by the river flow at the projected weir location.

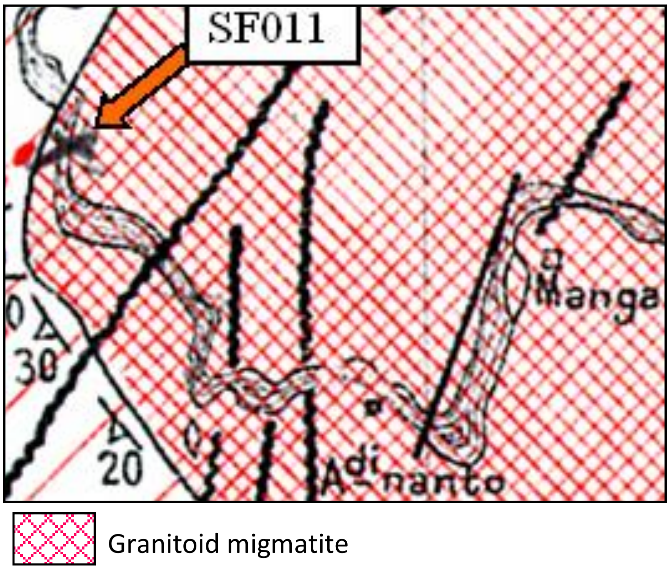


Figure 8. Global geological context

2.5.2 Technical characteristics

Bed aspect at the projected weir location (Figure 9): an in-situ rock mass is immersed beneath the water flow. In this area, in-situ migmatites are sub-horizontal and plunge slightly towards upstream, it will positively impact the weir bed stability. However, some important fracture, such as open joint could be found in the riverbed. This should be analyzed in the next stages of the study.

It should be noted that there exist falls (H ≈ 8m) downstream of those investigated. A narrow section (L ≈ 7 m) with small upstream drop (H ≈ 2m)is also found close to Marolambo village.

Figure 9. Bad aspect

Left bank support aspect (Figure 9): it consist of a high hill, poorly lateritized in surface (order of the meter). At its basis is a large rock mass made of in-situ granitoid migmatite. On the outcropping parts at the hill basis, splitting into boulders is observed. This phenomena is favored by the opening of joints due to superficial decompression.

Right bank support aspect (Figure 10): unlike the left bank, the right bank is characterized by the absence of in-situ massive rock noticeable on field. It is of mountainous nature with an important vegetal cover. Lateritisation is of limited thickness (order of the meter) and includes in-situ boulders appearing from time to time on the hill side. On the hill basis, boulders transported by the river during floods and/or hurtling down the hill during cyclonic periods pile up and cover the riverbank.

Figure 10. Right bank aspect

Intake and waterway: the intake and tunnel opening will be founded on massive in-situ rock (cf. left bank description) with open joints. The tunnel will cross Ambatoharanana (which means « rocky area ») granitic plateau formed of compact and tightly jointed granitoid rock. It is poorly lateritized in surface and has the same petrographic nature as the surroundings (see geological map), i.e. granitoid migmatite described previously.

One should however beware of joints, superficially opened bu decompression that should exist in the intermediary levels, especially at the digitations formed by creeks converging on the Marimbona river (Figure 1).

Penstock: it will be set on a lateritic hill slope that might include in-situ rock boulders.

Powerhouse : massive in-situ rock is outcropping at the river with sparse boulders covering the river side and the hill basis (Figure 11).

Figure 11. Massive rock outcropping downstream of the site

2.5.3 *Recommendations for further investigations*

ELEMENT	UNCERTAINTY TO REMOVE	SURVEY TYPE
Bed at weir	✓ Existence of open joints crossing the bedrock	✓ Geological observations in-the-dry ✓ Percolation test to be conducted afterwards to determine whether a fracture exists and to evaluate the importance of clogging work to be conducted by the mean of injections
Left support	✓ Possible leakages due to open joints on the left bank support	✓ Percolation tests to be conducted, along the supports projected locations, on joints to evaluate the importance of clogging work to be conducted by the mean of injections
Right support	✓ Existence of in-situ massive bedrock under boulders heaps found on the riverside.	✓ Mechanical excavation and core drilling to determine wheter massive bedrock is found below the support on the right bank.
Intake / waterway	✓ Level of Ambatoharanana plateau bedrock ✓ Compactness of the rock to drill and existence of open joints under the shape of fractures	✓ Seismic reflection geophysical survey ✓ Series of core drillings along the projected tunnel alignment to check if open joints exist. If such are found, percolation tests should also be conducted.
Penstock	✓ Nature and state of the land to	✓ More detailed geological reconnaissance to be defined in the

	cross	next study stages, once the final penstock trace is defined
Powerhouse	✓ Level of the bedrock for powerhouse foundation	✓ Mechanical excavations, core drilling or seismic reflection geophysical survey to determine the bedrock level

2.6 Socio-environmental aspects

The site detailed description sheet is provided in the Appendices.

2.6.1 Socio-environmental background

The site is located on the Marimbona River. It is situated in the fokontany of Marolambo, rural community of Andapafito, Soanierana Ivongo District, Region of Analanjirofo.

From the ecological perspective, the region has an evergreen vegetation belonging to the domain of the East, which shows an anthropization process. The direct surroundings of the site are made by a mosaic of savoka and plantings of clove. Savoka are secondary vegetation mainly composed by bamboo (*Nastus*) and/or Ravinala (*Ravenala madagascariensis*), with or without woody elements, due to repetitive forest clearings.

The clove trees, of all different ages, dominate the landscape. New and older plantings can be seen in the area. Some bases of clove trees are also mixed with savoka vegetation. Moreover, some bases of vanilla plants and of coffee trees can be seen in the savoka.

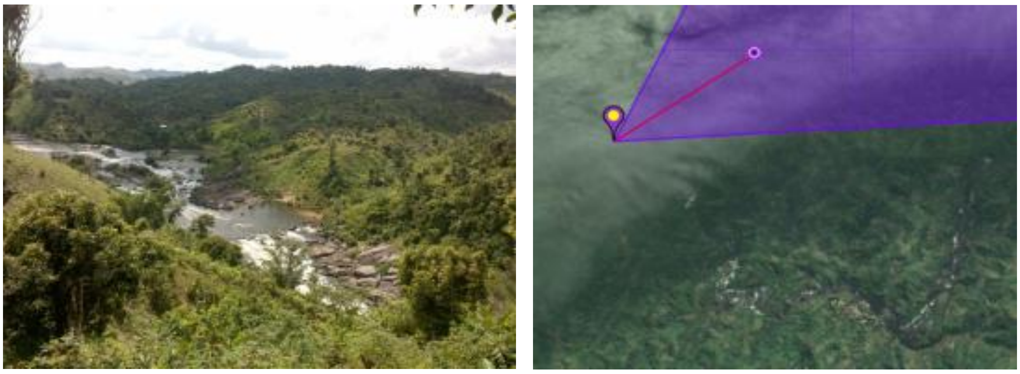


Image 12. Overview of the vegetation near the intake

From the socio-economic perspective, some villages and hamlets/campsites can be seen in the direct neighbourhood of the site. In particular, the Ambodinanto village is located ~500m downstream of the river. This village has more than 100 huts alongside the river. One hamlet is also identified near the route of the gallery. Moreover, some tombs can be found in the area.

The main local activity is agriculture, in particular rice growing (lowlands and hillsides) and subsistence crops (manioc, sweet potato, sugar cane) which are generally terrace crops or bank crops.

Moreover, the local clove production also helps the local economy. Clove is sold as nail or essential oil. Furthermore, some artisanal extraction units can be seen in the area, built with local materials, and one or several handmade stills.

The following image gives a global overview of the land use in the area.

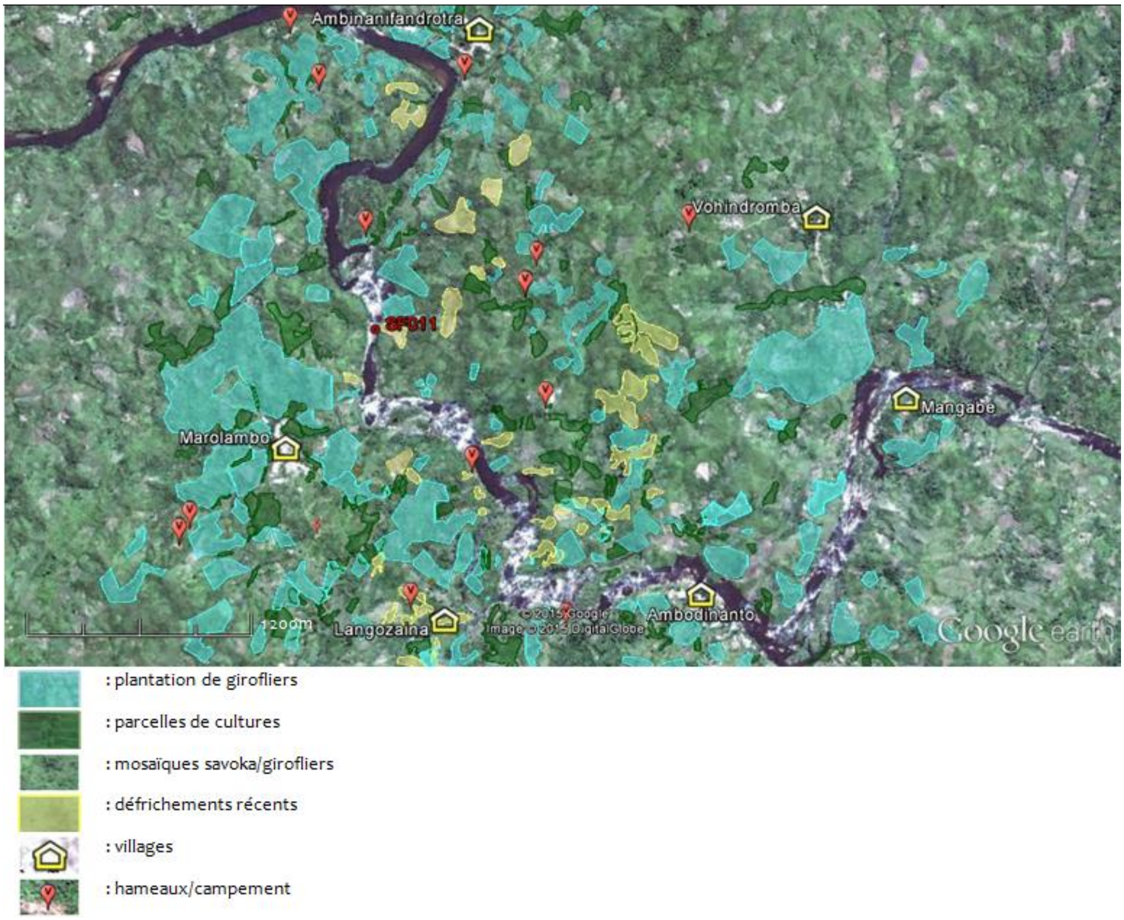


Image 13. Land use in the area of the SF 011 site

2.6.2 Socio-environmental constraints

Some hamlets, campsites and villages (Ambodinanto) can be found in the direct neighbourhood of the site (within a radius of 1km around the site of the expected infrastructures). The implementation of the project will affect these villages and hamlets, especially regarding potential nuisances (noise, traffic, noise, atmospheric emissions…).

Moreover, if the implementation of the project leads to an increase of the water level downstream of the weir, crops and clove plantings could also be affected, depending on the extent of the ponded water.

The area has clove plantings and culture crops. The project could impinge on these surfaces, leading to a loss of resources for the concerned communities.

Furthermore, some tombs are spread near the site (within a radius of 1km of the expected infrastructures and alongside the track heading to the site). The works could potentially lead to the destruction of this type of heritage.

2.6.3 World Bank Safeguard Policies that might be applied

The World Bank Safeguard Policies that could be applicable for the SF 011 site are the following:

OP 4.01 – The Bank requires Environmental Assessment (EA) of projects proposed for Bank financing to help ensure that they are environmentally sound and sustainable, and thus to improve decision making. However, we can already estimate that the adverse impacts on human populations and environment-linked areas are limited. They are reduced, not irreversible and some measures can prevent, mitigate or minimize them. Moreover, these measures can improve the environmental performance.

OP 4.12 – Involuntary Resettlement: the hydropower project will require the use of a large space (implementation of the plant, creation of access roads to the site…), which sometimes are crop areas. Moreover, the ponded water upstream of the weir could impact some habitation huts or crop parcels. So the project will have to take into account the concerned people and communities, particularly regarding the restoration of the standards of living due to the loss of resources.

OP 4.04 – Natural Habitats: it is not applicable.

OP 4.11 – Cultural Heritage: some tombs and headstones can be seen near the site of the project.

The projected weir is classified as a small dam (<15m high); the usual generic safety measures for dams are appropriate and do not need the implementation of OP 4.37 – Safety of Dams (for large dams).

3 PROPOSED SCHEME LAYOUT

3.1 Technical assumptions

An assessment of the scheme potential in terms of installed capacity, energy generation (firm and average) and the associated capital investment costs (CAPEX) and productions costs (Levelized cost of energy) is presented in section 4. It is based on the scheme proposed in this section. Hence, at this stage of the study, the technical features of the hydropower scheme are designed for both firm and median discharges (respectively $Q_{95\%}$ and $Q_{50\%}$). The actual design flow will be determined during the detailed studies based on economical, financial and technical criterion as well as the future energy and power demand.

The proposed scheme layout is shown below and presented in A3 format in the Appendix of this report.

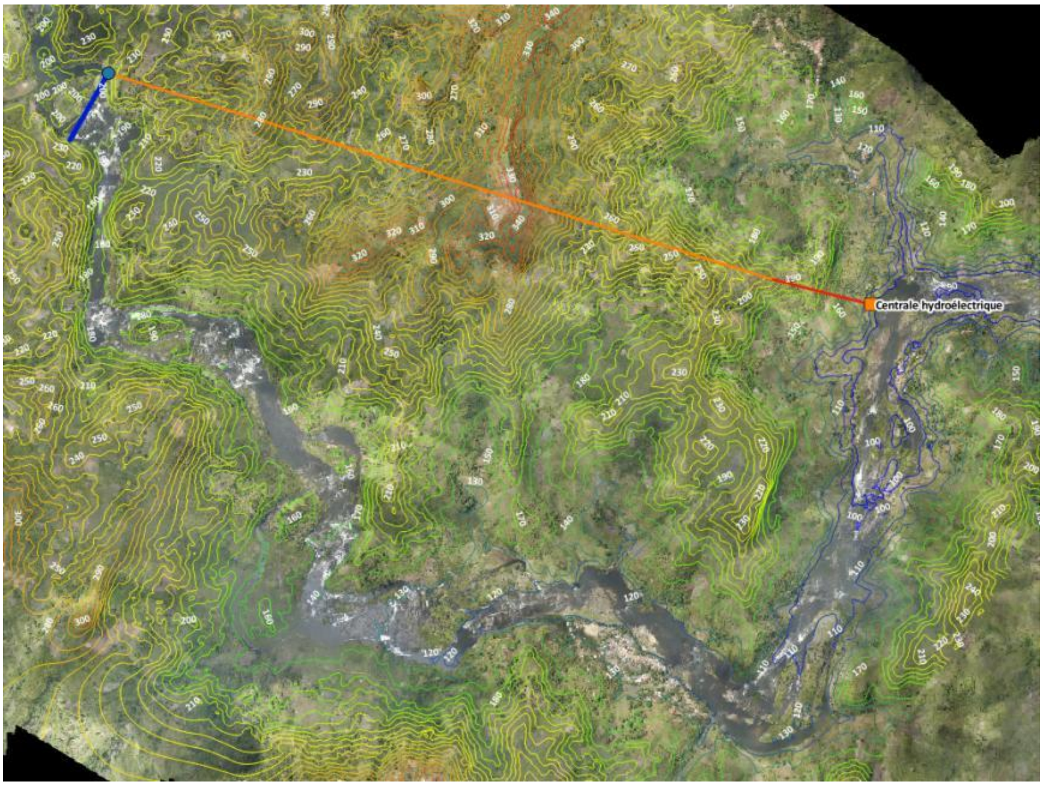


Figure 14. Proposed scheme layout

3.2 Weir and intake

The proposed weir is proposed to belocated in a place where the river widens and where small vegetalized islets are present. The weir would be wide (250m) but limited in height (4m). The intake is on the left bank.

3.3 Desander

Given the configuration of the scheme and the sediment issue, a desander will be necessary.

From a topographical point of view, the area just downstream of the intake seems favorable, but hydrology and geology conditions must confirm that choice.

Figure 15. View on the first rapids, at the proposed weir location

3.4 Waterways

A 30m long canal would carry the water to the entrance of a 2460m long tunnel. Terrain profile is shown on the figure below for the tunnel alignement.

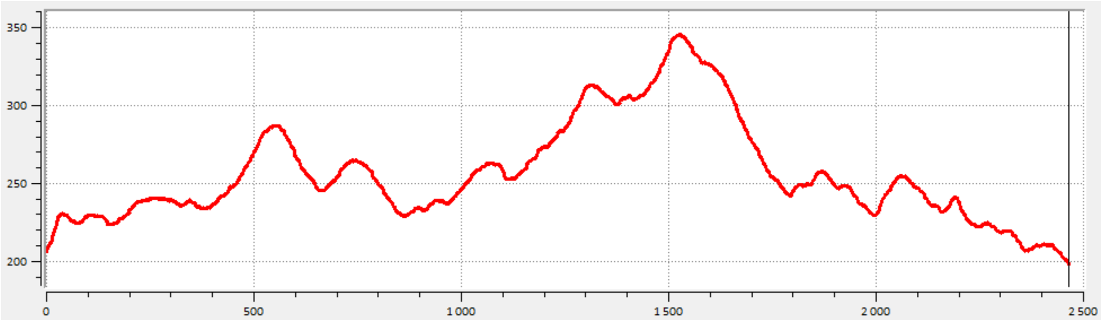


Figure 16. Terrain profile on the tunnel alignement

3.5 Penstock and powerhouse

The penstock will be 365m long: 2 pipes 1.40m diameter in case of design at firm flow, 3 pipes 1.80m diameter for median flow.

3.6 Electromechanical equipments

3.6.1 *Design flow taken at Q_{95}*

Theoretically, the project should be connected to Sonierana Ivnogo and surrounding coastal villages. Hence, the chosen turbine type must enable a maximization of the power output while enabling enough flexibility to absorb peaks and ensure production during low demand periods. Given the power potential of the site, it is recommended to install several similar units to optimize the plant efficiency and to enhance its availability and to follow the demand evolution as much as possible.

Head, discharge and foreseen output give the Francis turbine as and evidence. It offers a high performance level and a satisfactory flexibility.

Given observations formulated about water quality, a particular attention must be paid to the quality of materials used for the construction of the turbine. One should probably consider the need for an anti-abrasion coating.

Given the site characteristics, it is planned to install two identical units, each composed of:

- Butterfly safety valve with counterweight to ensure its closure in case of emergency of black out.
- A 6 940 kW vertical axis Francis turbine running at 600rpm.
- A 690V or 5.5 kV alternator, 6 520 kW/ 7 245 kVA.
- Control and monitoring system, including speed regulator and voltage regulator.
- Security system and electrical protection.
- Step-up transformer and electrical cabinet and switchgear.

- Emergency power unit.

A power plant PLC (Programmable Logic Controller) should also be foreseen to manage the two units.

Following issues should be studied as well in the next stages of the project :

- Sedimentation problem and the need for anti-abrasion coatings (e.g. Tungsten carbide).
- Technical and economic optimization of the penstock diameter.
- Technical and economic optimization of the number of units and of the design flow, according to the hydrology and the electrical demand.
- The need of a flywheel (for grid stability)
- The set up level and rotational speed of the turbine (Suction height and cavitation issues).
- Grid voltage.
- Preliminary turbine design.

Figure 17. Example of vertical-axis Francis sets

3.6.2 *Design flow taken at Q_{50}*

For a design flow taken at Q50, it is recommended to install three identical units (Francis turbines) in order to optimize the global efficiency and to increase the plant availability.

Other considerations exposed for a design flow at Q95 remain valid for a design flow taken at the median discharge (Q50).Turbines will have a unit nominal power of 12 020 kW and a rotation speed of 500 rpm. The alternator power will be 11 300 kV/ 12 550 kVA for a 5.5kV voltage.

A power plant PLC (Programmable Logic Controller) should also be foreseen to manage the three units.

3.7 Transmission lines

The produced power would be evacuated by a 30km long, 90kV to Sonierana Ivongo and the coastal villages south of it.

3.8 Key technical features

The main technical features are presented below for the firm and median flows.

		Firm flow	Median flow
Installed capacity	[kW]	12 480	33 900
Potential annual generation	[GWh/yr]	96.79	243.96
Design flow	[m³/s]	17.1	45.1
Gross head	[m]	95	
100yr return period flood	[m³/s]	3 546	
Weir length	[m]	250	
Weir height	[m]	4	
Desander		Large size	
Canal length	[m]	30	
Canal section (b x h)	[m]	4.8 x 3	10.05 x 3.75
Tunnel length	[m]	2 460	
Tunnel diameter	[m]	3.5	5.7
Penstock length	[m]	365	
Penstock diameter	[m]	1.4	1.8
Number of penstock(s)	[pce]	2	3
Number of T/G units	[pce]	2	3
Transmission line length	[km]	30	
Line voltage	[kV]	90	
Length of the access road to create	[km]	33	
Length of the access road to upgrade/rehabilitate	[km]	0	

4 ENERGY PRODUCTION AND COSTS

At this very early stage of study, and according to the hypotheses and options taken above, the project would have the following energy and economical performances as order of magnitude:

Gross head	**[m]**	95	
Design flow	**[m³/s]**	17.1 ($Q_{95\%}$)	45.1 ($Q_{50\%}$)
Installed capacity	**[kW]**	12 480	33 900
Potential annual generation	**[GWh/yr]**	96.79	243.96
CAPEX (excl. access and lines)	**[M$]**	66.53	151.89
LCOE (excl. access and lines)	**[$/kWh]**	0.082	0.075
Total CAPEX (incl. access and lines)	**[M$]**	91.39	176.75
Total LCOE (incl. access and lines)	**[$/kWh]**	0.113	0.087

5 APPENDICES

5.1 Socio-environmental datasheet

A – Site localisation

Site reference	:	SF 011
Villages / Fokontany	:	Ambinanifandrotra / Marolambo
Community / District-Region	:	Andapafito / Soanierana Ivongo - Analanjirofo

B - Description of the biophysical background

RELIEF	The SF 011 site is located in the Marimbona valley. The area is composed by a series of small hills that are rarely higher than 300m, except from the Antrafonomby Summit, which peaks at 485m. (3km as a crow flies, S-W of the site). The lowlands are provided by a dense hydrographic network that is generally narrow, but offering some farmable areas (rice). The Marimbona River is the main watercourse of the area. It begins near the plain of Marovoalavo. The Marimbona River flows from West to East and throw itself in the Indian Ocean near the Soanierana Ivongo. Several tributaries meet the main river near the weir and also downstream of the site. We can see that some localities are named after the tributaries : - Ambinanisarana village : estuary of the Sarana River ; - Ambinanifandroatra village : estuary of the Fandroatra River, etc. It should be noted that, between the intake site and the power plant site, two other rivers (right bank) meet the Marimbona : the Nampona River, that crosses the Marolambo village and the Bihotsahely River, further away downstream, near the power plant.
VÉGÉTATION	The primary vegetation is characterised by a low altitude wet forest (<800m high). Within a radius of 1km around the site, the primary vegetation turns into secondary and shrubby degraded vegetation, composed by savoka with or without woody elements. This is due to clearings and repetitive traces of fire (slash-and-burn). The vegetation alongside the river and the watercourses is characterised by the presence of *Typhonodorum, Raphia farinifera, Pandanus.* Moreover, clove plantings are really present in the area. The clove trees are mixed with the savoka in certain cases.  Landscapes near the power plant  S16°55'53.28" E49°25'52.70"

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

Landscape near the water intake

S16°55'0.66" E49°25'12.27"

General aspect of the vegetation: mainly dominated by secondary vegetation (bamboo and ravinala)

S16°55'21.22 E 49°25'01.63

OBSERVATIONS	The landscape is generally anthropized around the site. The majority of the hillsides are currently covered by clove trees, vanilla plants, coffee trees (around the housings) and banana trees. These are the main sources of income.
CRITICAL AREAS	The Marimbona River is the Southern limit of the Special Reserve of Ambatovaky, located 20km downstream of the SF011 site. It should be noted that this is the largest reserve of Madagascar and the largest low altitude forest after the National Park of Masoala. It spreads over 60 050 ha, and hosts some endemic species such as lemurs or birds such as the Madagascan serpent eagle (*Eutriorchis astur*), which is one of the rarest bird species of the world. It was called a Special Reserve in the end of the 50's (1958). It was delimited in 2010 and classified as Category 4 (Areas of management of the habitats/species) in the classification of the international union for the conservation of nature (IUCN).

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

B - Description of the socio-economic background

LOCALITY	**Rural community of Andapafito :** The rural community of Andapatifo, that spreads over more than 1 500 km², had about 23 000 inhabitants in 2009[1]. It is subdivided into 16 fokontany, which represent about 1 400 inhabitants/ fokontany. The community is only accessible by foot from the Soanierana Ivongo and/or by boat via the Marimbona River. Some villages can be found near this river. Education : the community has 45 schools (30 public primary schools (29 EPP[2] and 1 CEG[3]) ; 13 community schools and 2 private schools). Infrastructures : there is a lack of health infrastructures (only 2 CSB[4] : 1 CSB1 and 1 CSB2) and water supply infrastructures (no drinking water infrastructure so the population has to use the river water). ***Villages and hamlets :*** The main villages in the surroundings are alongside the Marimbona River. In the direct neighbourhood of the SF 011 site, some hamlets/ campsites can be seen. In particular, 3 villages have more than 100 huts. The closest one is Ambodinanto (~500m downstream of the power plant), Marolambo (~800m South of the intake), Ambianifandrotra (~1500m North of the intake). The Mangabe village is located about 2km N-E of the power plant. The seat county of the community of Andapafito is located about 5km as a crow flies, at the West of the intake. The villages are generally located alongside the watercourses, in particular Ambinanifandrotra, Ambodinanto, Mangabe alongside the Marimbona River. Some tombs were found during the investigations in the area.
ACTIVITIES	In order of importance, the local production is clove, rice, coffee and vanilla. Among the subsistence crops, the more frequent are manioc and corn. The villages are generally surrounded by culture fields and tree plantings. Clove can be natural of essential oil. Some local extraction units can be seen in the area. En general, the plantings of clove are really close to crops (dry crops, rice crops…). Tavy and fires are common in the area and are the main degradation factors of the local ecosystem.

[1] CREAM 2009, Monographie de la Région Analanjirofo (Monograph of the region of Analanjirofo)

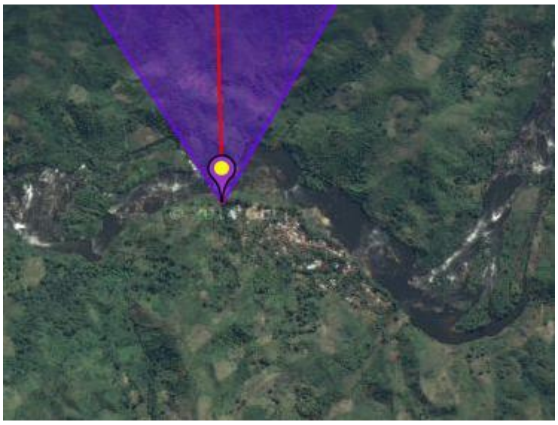
[2] EPP : Ecole Publique Primaire (public primary school)

[3] CEG : Collège d'Enseignement Général (college of general education)

[4] CSB : Centre Santé de Base (Basic Health centre)

Gobal overview of tanety S16°55'22.24 E49°25'03.92

Extraction of essential oil from clove branches and clove leaves.



S16°55'45.18 E49°26'11.79

Disposition of terrace rice crops

S16°55'58.75 E49°26'43.89

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C - World Bank operational policies that could be applicable:

OP 4.01 – Environmental Assessment ☒

OP 4.04 – Natural Habitats ☐

OP 4.11 – Cultural Heritage ☒

OP 4.12 – Involuntary Resettlements ☒

OP 4.37 – Safety of Dams ☐

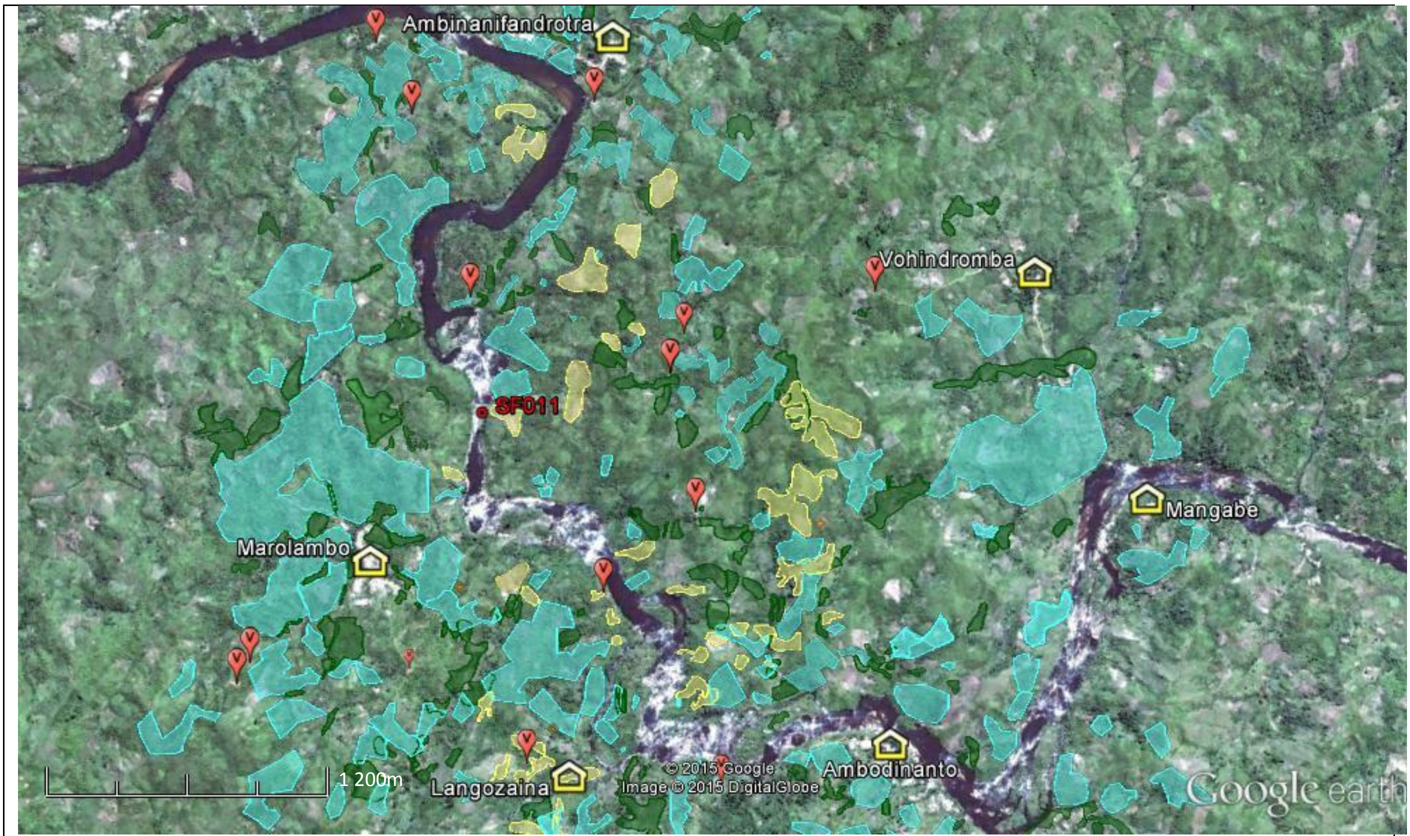
Land use around the site

Global overview (downstream to upstream)

River traffic of the Marimbona River

Type of seasonal campsites

Type of precarious irrigation, made with bamboo trunks



: plantation de girofliers

: parcelles de cultures

: mosaïques savoka/girofliers

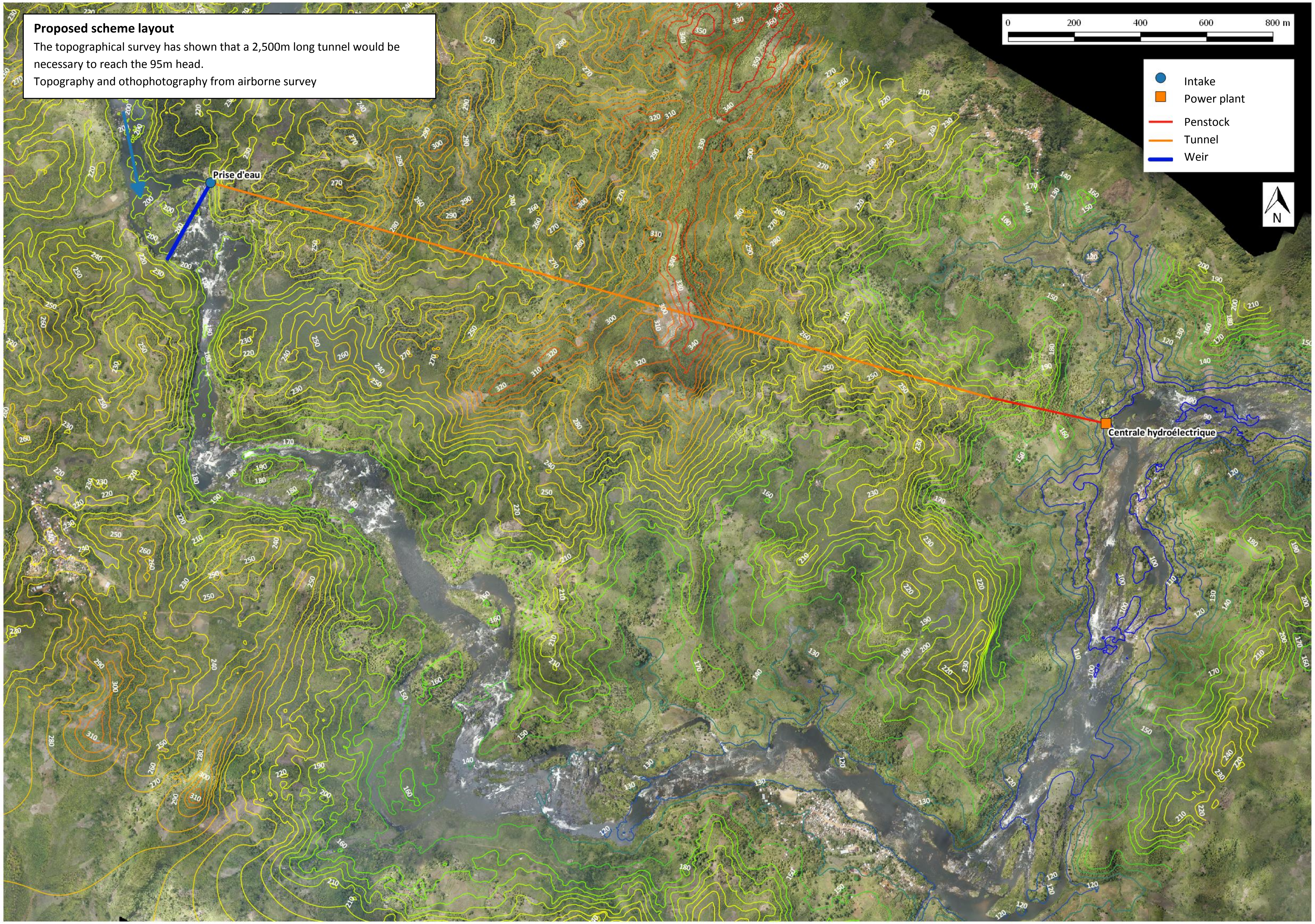
: défrichements récents

: villages

: hameaux/campement

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

5.2 Proposed scheme layout



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Madagascar: Small Hydropower Resource Atlas (1-20MW)
Site Investigation Report

SITE SF015

Maningory River | Atlas Code: SF015

Table of Content

1 SITE LOCATION

Geographical coordinates (WGS 84)	Longitude [°]	Latitude [°]
Intake	48.731	-17.406
Powerhouse	48.733	-17.405

1.1 Administrative data

Atlas code	SF015
Site name	SF015
River	Maningory
Major river basin	Maningory
Province	Toamasina
Region	Alaotra-Mangoro
District	Amparafaravola
Commune	Andrebakely
Village	Ambinaninandampy village is100m upstream of the site

1.2 Access

The projected site is accessed from the N44 that runs along Alaotra Lake. At Andromba city, there is an all weather condition track towards East that is drivable up to Ambatomafana. From there, the one must continue by foot on 7km to access to the projected site.

For the construction of a hydropower scheme, the all weather condition track will require upgrading from Andomba Bridge on about 10km in several sections. From Ambatomafana, access to the weir and powerhouse need to be created on about 18km (but in a relatively easy zone).

Figure 1. Site access

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

2 GENERAL SITE DESCRIPTION

2.1 Background

The site is characterized by a drop with appreciable slope in a meander that runs around a hill. This configuration enables the use of approximately 19m drop to produce hydropower by by-passing the 645m long meander through a 190m long tunnel in the hill. This site could feed cities and villages around Alaotra Lake, currently fed by a small private isolated grid belonging to BETC-Nanala. Moreover, the Maningory River benefits from the lake's natural flow regulation which positively impacts the projected infrastructures: 1°/ the lake stores water during rain events (that water would have been lost otherwise); 2°/ the lake allows flood peak reduction; 3°/ the lake acts as a huge sedimentation basin, what reduces solid transport in the Maningory River.

At present, there is neither hydro-agricultural nor hydropower scheme at the proposed site location. It shoud be noticed that there is a second interesting stretch for hydropower located 10km downstream of the projected site. Depending on the demand, the site could be extended by the use of the second stretch (cascade scheme)

Figure 2. Topographic map of the site

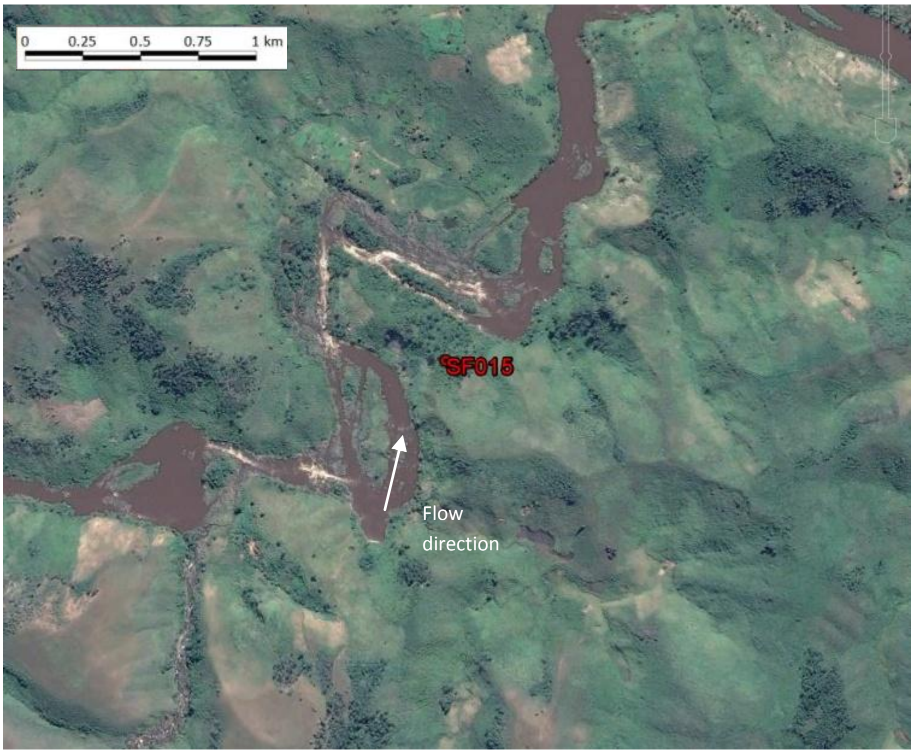

Figure 3. Satellite image (Google Earth)

Figure 4. Proposed site for the weir.

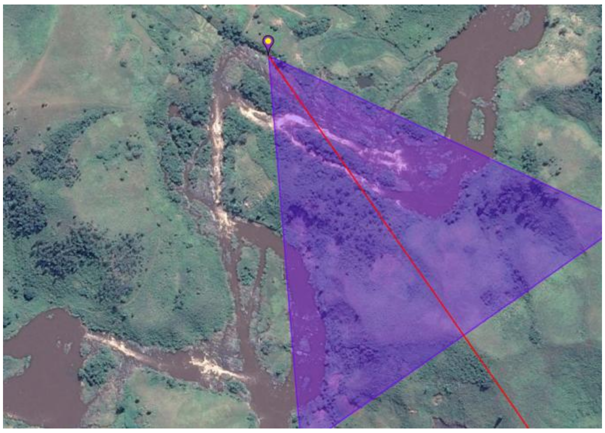

Figure 5. . View of the straight river stretch.

2.2 Topography

Figure 6. Aircraft and remote sensors container for airborne survey

The topographical survey was achieved through remote sensing. An aircraft was chartered and equipped with optical sensors.

The topographical survey has a point density of 5 /m² and a relative accuracy of 2%.

Outputs from airborne survey are (1) a high resolution orthophotography (0.2m to 0.4m resolution) and (2) a Digital Surface Model (DSM). The DSM includes the vegetal cover, but it gives an excellent global picture of the site topographical configuration. Results are illustrated in the figures below and the contour lines deducted from the DSM are presented on the detailed proposed scheme layout in section 0.

Figure 7. Orthophotography of the site

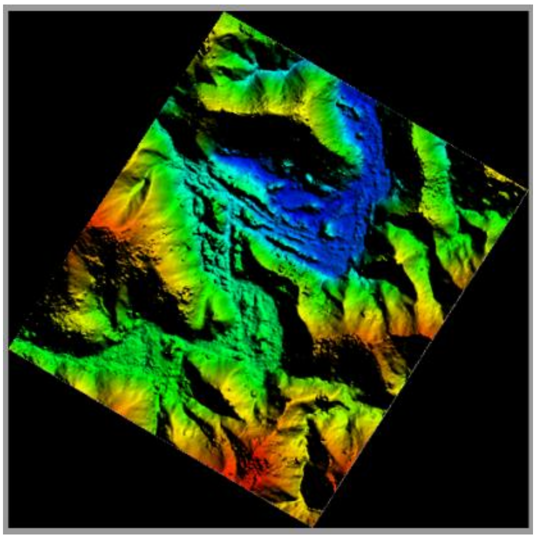

Figure 8. Digital Surface Model of the site

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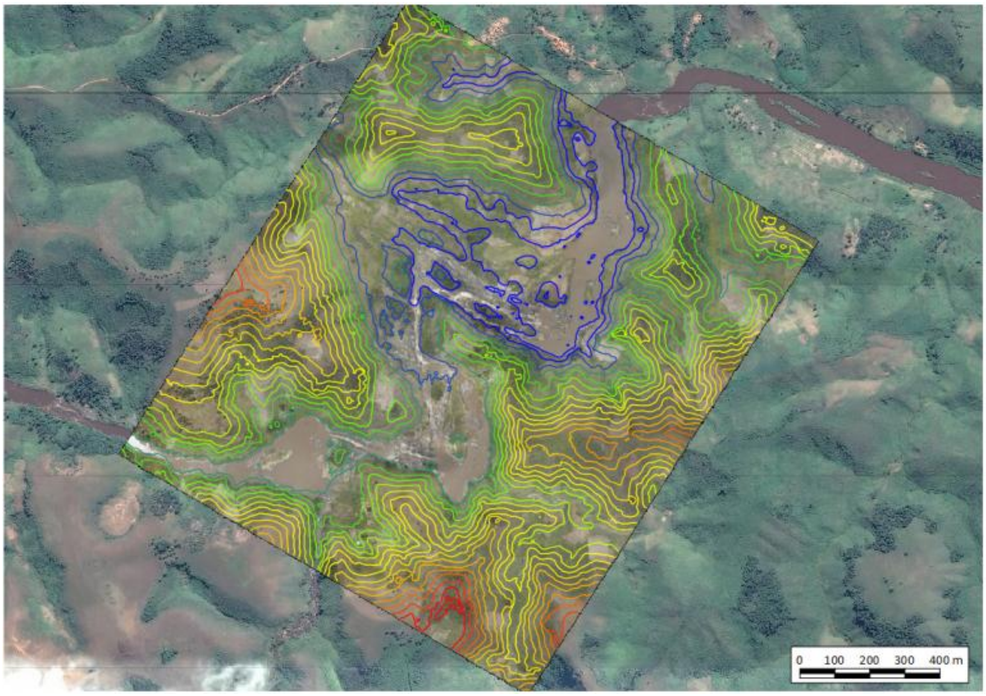


Figure 9. Contour lines derived from the DSM

2.3 Preliminary hydrological study

Accurate information on the hydrology of the Maningory River does not exist. However, monthly discharge data are available for a gauging station located at the outlet of Lake Alaotra, on the Maningory River (Andromba station). This station, installed and managed by ORSTOM, provided data from 1978 to 1988.

As a consequence, statistical characteristics of the river discharge at the site of interest have been estimated by extrapolation of available data at Andromba station. Given the limited temporal resolution of the available data, the results presented below are indicative only and are not intended to be used for design purposes without further detailed hydrological studies.

Key preliminary hydrological characteristics of the river at the site of interest are presented in the table below.

River	Maningory
Main river basin	Maningory
Area [km²]	8 474
Average elevation [m a.s.l]	915
Slope index [m/km]	0.9
Specific vertical drop [m]	83
Average annual rainfall [mm/yr]	1 189
Average interannual discharge [m³/s]	71.6
$Q_{95\%}$ - firm discharge [m³/s]	8.6
$Q_{50\%}$ - median discharge [m³/s]	46.9
$Q_{30\%}$ [m³/s]	82.7
10yr return period flood [m³/s]	363
100yr return period flood [m³/s]	860

2.4 Sediment transport

At the time of the site visit (june 2015), turbidity was good, measured at 40 NTU. However the presence of lateral silt and sand deposits demonstrates that sediment transport process occurs at some period of the year, likely during major flood events. Solid transport is however reduced by the sedimentation capacity of Lake Alaotra.

Adequate sediments and gravels trapping systems will be designed at the feasibility study stage based on an analysis of the sediment load at different river discharges.

2.5 Site geology

2.5.1 Geological context

The area is dominated by granitoid migmatites with big quartz and feldspar grains and rich biotite trails. Foliations are along the North-South alignement. The area is heavily marked by joints in two main directions : N30E and N70W. This configuration is profitable for the weathering of rock and splitting into boulders set in lateritic alteration, these are observed along the hills sides. During heavy rain, cyclonic or seismic events, these boulders may hurtle down the hills.

The dip is subhorizontal. Hence, decompression provoques a plane spalling (Figure 10). This section of the river presents several consecutive drops. Apparently massive rock outcrop around the drop during low flow season.

Figure 10. Geologic details

Note: at the time of the site visit, the geological team could not reach the supports locations. Indeed, the left bank support requires river crossing that was impossible while the way to the right bank support was blocked by another river, tributary of the main river. Hence, observations were conducted at a distance away.

2.5.2 Technical characteristics

Bed aspect at the projected weir location: the weir axis is located on massive bedrock found under a thin layer of sand and reworked boulders brought by the river flow during floods.

Left bank support aspect: the left bank support is the eastern side of Maromaniry hill. This one is fully of lateritic aspect, except at its basis where outcropping boulders are observed.

Nota : the lateritic constitution of this support should be confirmed in a further stage of the study.

Right bank support aspect: reworked boulders dominate the area at the slope basis. The hill side is also covered by boulders that might hurtle down the hill during heavy rain, cyclonic or seismic events.

Waterway: the tunnel trace crosses a hilly morphology area (with ups and downs). The tunnel trace should then be confirmed later.

Penstock: penstock will be set on a lateritic soils with incrusted rock boulders.

Powerhouse : the powerhouse foundations should not be a big issue as many massive in-place rocks are observed along the riverside. The only unknown is the depth at which this rock is found below the powerhouse.

2.5.3 Recommendations for further investigations

ELEMENT	UNCERTAINTY TO REMOVE	SURVEY TYPE
Bed at weir	- Position of the bedrock	- Removing of the sand and some reworked boulders along the weir axis until reaching a rock layer appropriate for supporting the weir.
Left support	- Nature of Maromaniry hill side	- More detailed observation should be conducted later to determine whether the hill is still under laterisation process or not (are the boulders just encastrated or are they in place).
Right support	- The weir viability could be endangered by the boulders located on the right bank hill side if those would hurtle down the hill during heavy rain, cyclonic of seismic event (as it already happened with the rocks observed at the bank foot)	- To be confirmed based on the final weir axis.
Waterway	- Nature, continuity and compactness of the lateritic mass to drill	- More detailed morphologic and geologic observations of the zone to drill. - Core drilling at some chosen points along the waterway to characterize the geotechnical properties of the laterite and to conduct percolation tests

ELEMENT	UNCERTAINTY TO REMOVE	SURVEY TYPE
Penstock	- Characterization of the supporting ground	- More detailed geological investigation must be conducted once the penstock axis is established (to check if rock slide might occur)
Powerhouse	- Characterization of the supporting ground (Massive rock? Boulder in place or not? Depth of laterite?)	- Auger drilling or seismic reflection geophysical survey

2.6 Aspects socio-environnementaux

The site detailed description sheet is provided in the Appendices.

2.6.1 Socio-environmental background

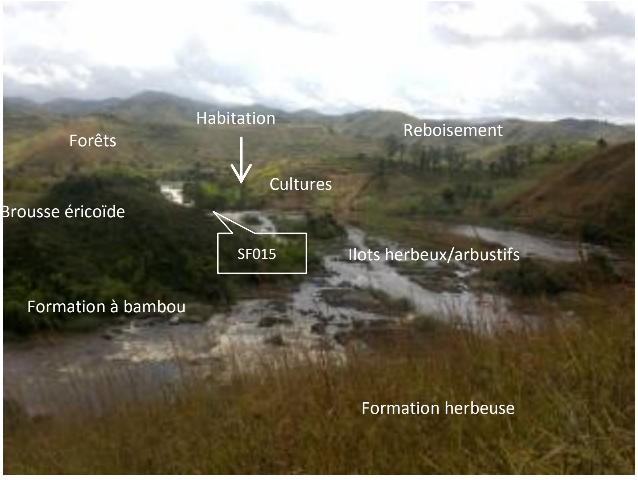
The site is located on the Maningory River, near the Ambinanindampy village. It is situated in the fokontany of Ampongabe, rural community of Andrebakely, Amparafaravola District, region of Alaotra Mangoro.

The area is characterised by an ecosystem which is degraded by clearings by fire and tavy. The main vegetation is composed by secondary forests (tree vegetation and herbaceous savannah).

The majority of the hillsides show traces of recent tavy, but also older ones (ericoid bush (*Helichrysum* sp.) and ferns (bamboos) or herbaceous vegetation (*Hyparrhenia*). Some Eucalyptus reforestation and natural shred forests (*Weinmannia*, *Tambourissa* can be seen on the middle and upper parts of the hillsides, in particular downstream of the expected weir (see SF015). The forest lowlands and the lower parts of the hillsides are turned into rice crops and cultivation crops.

Alongside the Maningory river, some leftovers of natural forests, more or less degraded, alternate with bamboos, Phragmites and cultivation crops, that are sometimes used as fallows. In particular, some dense natural forests and bamboos, sometimes associated with some bases of Eucalyptus can be found just downstream of the expected weir.

Upstream and downstream of the expected weir, the river is filled with islets. These are covered with shrubby savannah or are turned into temporary crops. However, some islets, just like the ones located downstream of the expected weir are still covered by a relatively dense riparian vegetation.



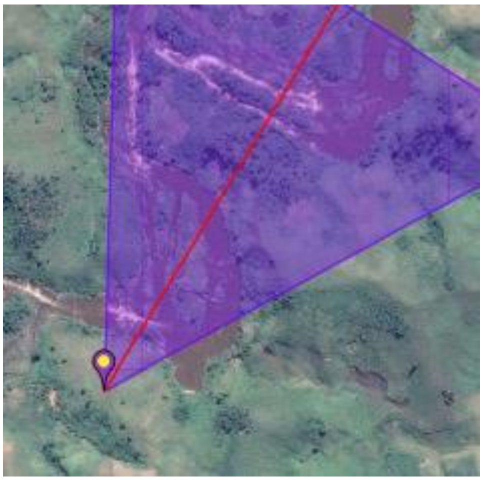


Image 11. Overview of the landscape near the expected weir

From the socio-economic perspective, the Ambinanindampy village is located about less than 500m upstream of the site. It has about 10 households, that mainly work in the agriculture sector. The housing is made of earth of vegetal materials, but the roofs are generally made of thatch. The villages in the neighbourhood are generally spread on the hillsides of the Maningory River. Other villages can be found within a radius of 2 or 3 km: Ankarongana, Marovanga, Ambodimanga and Menasaka. Moreover, some hamlets and seasonal campsites can be found alongside the watercourses, just like the housing on the right of the right river bank.

The main activity is agriculture. Tavy is common. Rice growing is generally associated with subsistence crops (manioc) and cash crops (plantations of banana trees and sugar cane). Culture crops can be found on the hillsides, the lowlands and the river banks.

Fishing is really common around the Maningory River. The main products are fish and eels. Fishermen use baskets and angling alongside the banks or using a pirogue.

The following image gives a global overview of the land use of the area.

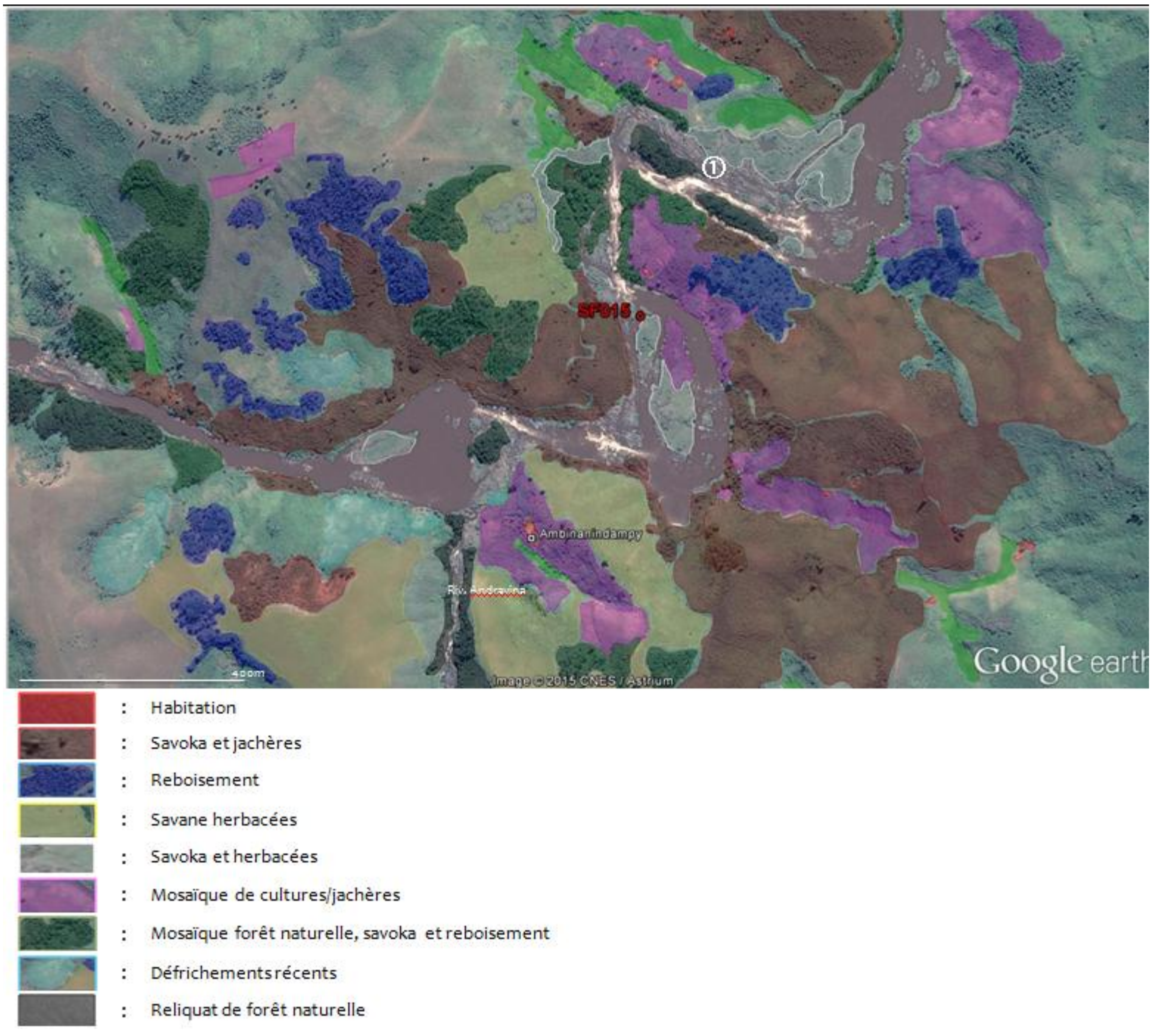


Image 12. Land use in the area of the SF 015 site

2.6.2 Socio-environmental constraints

The right bank of the expected weir is composed by some cultivation crops and we can see one housing on the lower part of the hillside. These parcels, and their inhabitants, can be affected by the project (noise, inconvenience…) and by the infrastructures (loss of cultivation crops). Moreover, the villages and hamlets located near the site (within a radius of 2 or 3km), such as the Ambinanindampy village, could be affected by the project, including noise and inconvenience during the works.

The implementation of the project could reduce the socio-economic value of the Maningory River, especially fish resources. In particular, the river is known for its eels migration (West coast). Selling eels (fresh or dried) is also one of the activities of the population.

The change of environment conditions downstream of the weir could affect the leftovers of existing riparian forests (loss of species), in particular species that are sensitive to the water availability.

2.6.3 World Bank Safeguard Policies that might be applied

The World Bank Safeguard Policies that could be applicable for the SF 015 site are the following:

OP 4.01 – The Bank requires Environmental Assessment (EA) of projects proposed for Bank financing to help ensure that they are environmentally sound and sustainable, and thus to improve decision making. However, we can already estimate that the adverse impacts on human populations and environment-linked areas are limited. They are reduced, not irreversible and some measures can prevent, mitigate or minimize them. Moreover, these measures can improve the environmental performance.

OP 4.12 – Involuntary Resettlement: the hydropower project will require the use of a large space (implementation of the plant, creation of access roads to the site…), which sometimes are crop areas. Moreover, the ponded water upstream of the weir could impact some habitation huts or crop parcels. So the project will have to take into account the concerned people and communities, particularly regarding the restoration of the standards of living due to the loss of resources.

OP 4.04 – Natural Habitats: the Maningory River is the habitat of fish species such as eels and crayfish. However, the habitats are not critical, and mitigation measures might be implemented during the planning studies and the building of the project. Further studies should evaluate the need for specific works ensuring free passage of fishes.

OP 4.11 – Cultural Heritage is not applicable because the site is not known for containing any particular cultural material resources.

The projected weir (4m high) is classified as a small dam (<15m high); the usual generic safety measures for dams are appropriate and do not need the implementation of OP 4.37 – Safety of Dams (for large dams).

3 PROPOSED SCHEME LAYOUT

3.1 Technical assumptions

The objective is to carry out a high level assessment of the scheme potential in terms of installed capacity, energy generation (firm and average) and the associated capital investment costs (CAPEX) and productions costs (Levelized cost of energy). Hence, at this stage of the study, the technical features of the hydropower scheme are designed in the following sections for both firm and median discharges (respectively $Q_{95\%}$ and $Q_{50\%}$). The actual design flow will be determined during the detailed studies based on economical, financial and technical criterion as well as the future energy and power demand.

The proposed scheme layout is shown in Figure 13 and presented in A3 format in Appendix of this report.

Figure 13. Proposed scheme layout for SF015 site (details in appendix 0)

The site could feed the minigrid currently under construction around Alaotra Lake who is fed by several power units (biomasse, existing hydropower plant and hydropower plant under construction).

3.2 Weir and intake

The weir would be constructed upstream of the meander, at the most downstream part of the islet. At that place, the weir would be about 175m long and 4m high.

Another variant that should be studied in the next stages, is to built the weir closer of the drop, in order to ease purges of the desander.

The intake would be located on the right river bank.

3.3 Desander

Given the potential sediment load in the river mentioned previously, adequate gravels trap and desander systems will be required. It will be located immediately downstream of the intake.

3.4 Waterways

Waterways consist of a 2.5m (assuming the design flow at $Q_{95\%}$) or 5.8m (assuming the design flow at $Q_{50\%}$) diameter and 190m long tunnel in the right bank

3.5 Penstock and powerhouse

A single 1.40m (assuming the design flow at $Q_{95\%}$) or three 1.80m (assuming the design flow at $Q_{50\%}$) diameter penstocks will be required to ensure that the head losses due to friction in the pipes will be below 5% of the available gross head. The penstock(s) will be 35m long. They will be set on a steep slope. As no alternative location is available, the powerhouse will also be constructed on the slope. Much excavations are expected and specific technical arrangement will have to be foreseen.

3.6 Electromechanical equipments

3.6.1 *Design flow taken at $Q_{95\%}$*

Theoretically, the project should be connected to the currently under construction grid around lake Aloatra . Although the plant will be installed in an isolated grid composed of several power generation sources, what will enhance adaptation to demand variation, the chosen turbine type must enable a maximization of the power output and enough flexibility to absorb peaks and ensure production during low demand periods. Given the power potential of the site, it is recommended to install several similar units to optimize the plant efficiency and to enhance its availability and to follow the demand evolution as much as possible.

Head, discharge and foreseen output allow the choice between a Francis turbine, which offers a high performance level and a satisfactory flexibility, and the double regulated Kaplan turbine which offers a high efficiency on a large discharge range. The final choice is set on a Francis turbine which is simpler and more robust. The suggested solution does not require the use of a gearbox, which is a sensitive and costly component, as well for operation as for maintenance.

Given observations formulated about water quality, a particular attention must be paid to the quality of materials used for the construction of the turbine. One should probably consider the need for an anti-abrasion coating.

Given the site characteristics, it is planned to install two identical units, each composed of:

- Butterfly safety valve with counterweight to ensure its closure in case of emergency of black out.
- A 690 kW horizontal axis Francis turbine running at 750rpm.
- A 400V alternator, 650 kW/ 725 kVA.
- Control and monitoring system, including speed regulator and voltage regulator.
- Security system and electrical protection.
- Step-up transformer and electrical cabinet and switchgear.
- Emergency power unit.

A power plant PLC (Programmable Logic Controller) should also be foreseen to manage the two units.

Figure 14 Example of a horizontal axis Francis turbine

Following issues should be studied as well in the next stages of the project :

- Sedimentation problem and the need for anti-abrasion coatings (e.g. Tungsten carbide).
- Technical and economic optimization of the penstock diameter.
- Technical and economic optimization of the number of units and of the design flow, according to the hydrology and the electrical demand.
- The need of a flywheel (for grid stability)
- The set up level and rotational speed of the turbine (Suction height and cavitation issues).
- Grid voltage.
- Preliminary turbine design.

3.6.2 *Design flow taken at $Q_{50\%}$*

For a design flow taken at Q_{50}, it is recommended to install six identical units (Francis turbines) in order to optimize the global efficiency and to increase the plant availability.

Other considerations exposed for a design flow at Q_{95} remain valid for a design flow taken at the median discharge (Q_{50}).Turbines will have a unit nominal power of 1 260 kW and a rotation speed of 600 rpm. The alternator power will be 1 185 kV/ 1 315 kVA for a 690 V voltage.

A power plant PLC (Programmable Logic Controller) should also be foreseen to manage the six units.

3.7 Transmission line

It is envisaged that the proposed hydropower scheme would be connected to the Aloatra Lake minigrid using a 30km long and 63kV line. The feasibility study should analyze whether a line with a lower tension(35kV) could suit.

3.8 Key technical features

The key features of the proposed hydropower scheme are summarized in the table below for both firm ($Q_{95\%}$) and median ($Q_{50\%}$) design flows.

		Firm discharge	Median discharge
Installed capacity	[kW]	1 300	7 110
Potential annual generation	[GWh/yr]	10.22	47.8
Design flow	[m³/s]	8.6	46.9
Gross head	[m]	19	
100yr return period flood	[m³/s]	860	
Weir length	[m]	175	
Weir height	[m]	4	
Desander		Déssableur de grande taille	
Tunnel length	[m]	190	
Tunnel diameter	[m]	2.50	5.80
Penstock length	[m]	35	
Penstock diameter	[m]	1.40	1.80
Number of penstock(s)	[-]	1	3
Number of T/G units	[-]	2	6
Transmission line length	[km]	30	
Line voltage	[kV]	63	
Length of the access road to create	[km]	18	
Length of the access road to upgrade/rehabilitate	[km]	10	

4 ENERGY GENERATION AND COSTS

Based on the assumptions of the economical and hydrological studies presented in the main report, the proposed hydropower scheme would feature the following values:

Gross head	**[m]**	19	
Design flow	**[m³/s]**	8.6 ($Q_{95\%}$)	46.9 ($Q_{50\%}$)
Installed capacity	**[kW]**	1 300	7 110
Potential annual generation	**[GWh/yr]**	10.22	47.8
CAPEX (excl. access and lines)	**[M$]**	6.45	20.12
LCOE (excl. access and lines)	**[$/kWh]**	0.076	0.051
Total CAPEX (incl. access and lines)	**[M$]**	19.78	39.12
Total LCOE (incl. access and lines)	**[$/kWh]**	0.229	0.098

The site could be equipped with turbines/alternator units progressively in order to spread investments and to follow the evolution of energy demand in the connected communes, until the maximal capacity is reached.

5 APPENDICES

5.1 Socio-environmental datasheet

A – Site localisation

Site reference	:	SF 015
Village / Fokontany	:	Ambinanindampy / Ambongabe
Community / District/Region	:	Amparafaravola / Andrebakely

B - Description of the biophysical background

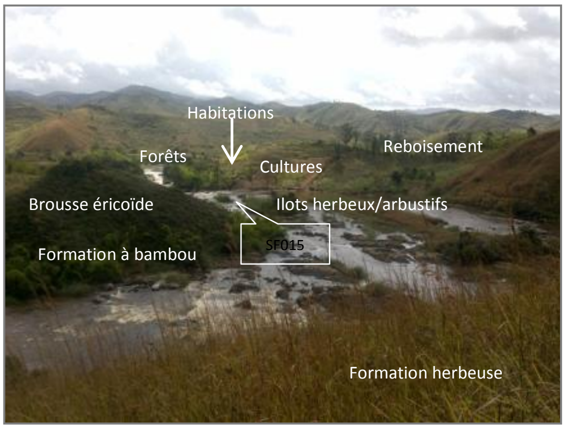
<table>
<tr><td>RELIEF</td><td>The SF 015 site is located at the West border of the big basin of the Alaotra Lake. The area is characterised by a precipitous relief that is crossed by watercourses. It spreads over an average high of 500m with peaks that can sometimes reach 900m, in particular Analamarina (South of the site).

The Maningory River is the main watercourse that flows near the site. It is the natural exit of the Alaotra Lake. After passing the edge of the Amdromba, it passes by the rocky edge of the Ambatomafana, where he heads West-East, turning itself into rapids near the Menasaka.

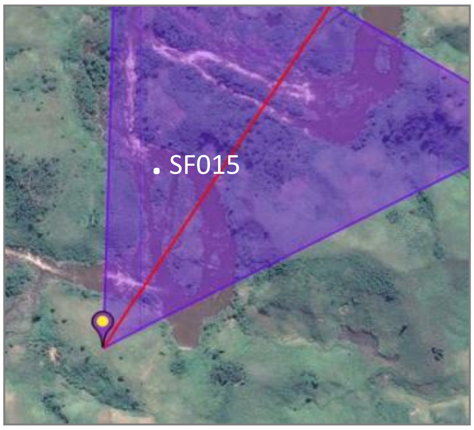
From the administrative perspective, the Maningory River represents the border between the two Districts : Ambatondrazaka (Community of Antanandava) and Ampararfaravola (Community of Andrebakely Antsinanana).</td></tr>
<tr><td>VEGETATION</td><td>The area is characterised by an ecosystem which is degraded by clearings by fire and tavy. The main vegetation is composed by secondary forests (tree vegetation and herbaceous savannah).

The majority of the hillsides have traces of recent tavy, but also older ones (ericoid bush (Helichrysum sp.) and ferns (bamboos) or herbaceous vegetation (Hyparrhenia). Some Eucalyptus reforestation and natural shred forests (Weinmannia, Tambourissa can be seen on the middle and upper parts of the hillsides, in particular downstream of the expected weir (see SF015). The forest lowlands and the lower parts of the hillsides are turned into rice crops and cultivation crops.

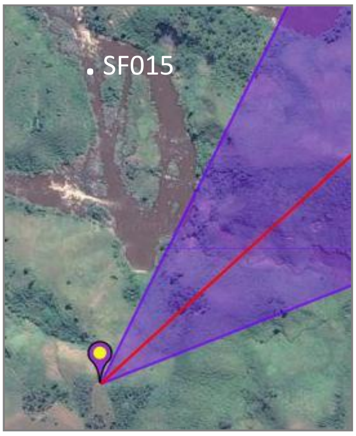
Alongside the Maningory river, some leftovers of natural forests, more or less degraded, alternate with bamboos, Phragmites and cultivation crops, that are sometimes used as fallows. In particular, some dense natural forests and bamboos, sometimes associated with some bases of Eucalyptus can be found just downstream of the expected weir.



Landscape near the expected site

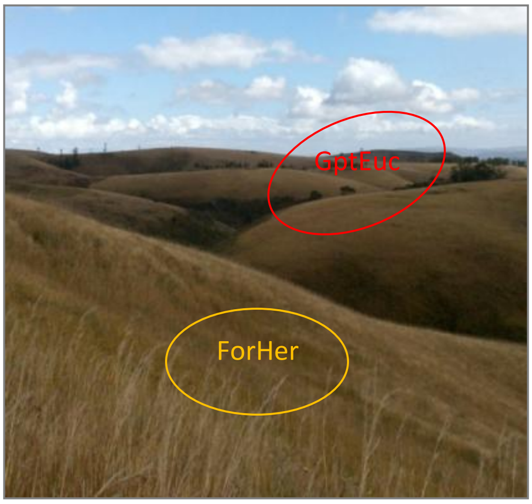


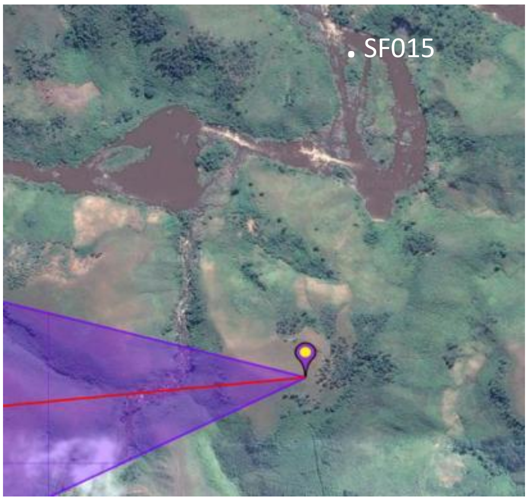
S17°24'31.11" E48°43'44.90"</td></tr>
</table>



Savoka on steep slope upstream of the expected weir

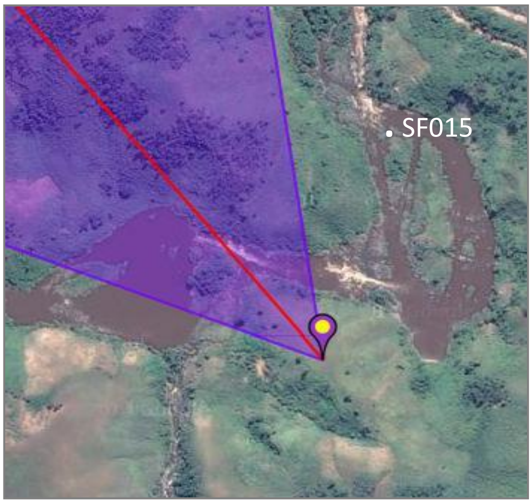
S17°24'37.80" E48°43'48.03"





Herbaceous plants (ForHer) et Eucalyptus groups

S17°24'42.50" E48°43'45.42"



Hillside (left bank) upstream of the expected weir

S17°24'31.12" E48°43'44.89"

<table>
<tr><td></td><td> 

Overview of the site close the the power plant   S17°24'14.51" E48°43'55.04"</td></tr>
<tr><td>OBSERVATIONS</td><td>In the surroundings of the site, the hillsides have steep slopes. However, these topographic units are the main cultivation areas, given that the lowlands are not developed. Despite the herbaceous cover of the hillsides, their stability is weak, in particular while talking about the bush fires and the steep slopes (upstream and downstream of the expected site).

Savannah with young bamboos

Sugar cane crops on hillside</td></tr>
<tr><td>CRITICAL AREA</td><td>The National Park of Zahamena is located about 8km South of the site and the new protected area of the Alaotra Lake is located about 14 km West of the site.

The closest area has no particular ecological sensitivity. However, some endemic species can be found (orchids) and some great diameter trees exist (DBH>15cm) inside the dense vegetation such as the ones that cover the islets downstream of the expected weir.</td></tr>
</table>

B - Description of the socio-economic background

LOCALITY

The SF 015 site is located near the Ambinanindampy village, in the fokontany of Ambongabe, Rural Community of Antanandava, Ambatondrazaka District, Region of Alaotra – Mangoro). You can access the site via a dirt road from the Ambodimanga village. The latter is the last village accessible by car from Ambatondrazaka

Rural community of Antanandava :

The rural community of Antanandava is the N-E limit of the Ambatondrazaka District / Amparafaravola District. It spreads over about 242 km² and had 10 377 inhabitants in 2013[1] , which represents about 1 400 inhabitants/ fokontany[2]. The community is subdivided in 7 fokontany. The site is located in the fokontany of Ambongabe.

Infrastructures:

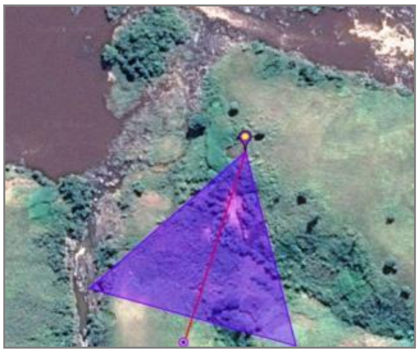
- 14 EPP in the fokontany's, which represents about 2 EPP/ fokontany;
- accessibility to health infrastructure for the whole community (one health centre) in the seat county of the community;
- water is available only via rivers and wells.

Localities and villages :

The villages near the site are generally spread on the hillsides of the Maningory River. The water intake and the ancillary works (gallery and plant) are situated next to the Ambinanindampy village. It has about 10 households that mainly practice agriculture. The habitat is made of earth of vegetal materials but the roofs are generally made of thatch.

Other villages are located within a radius of 2 or 3 km : Ankarongana, Marovanga, Ambodimanga and Menasaka. Moreover, some hamlets and seasonal campsites follow the watercourses and the cultivated lowlands.

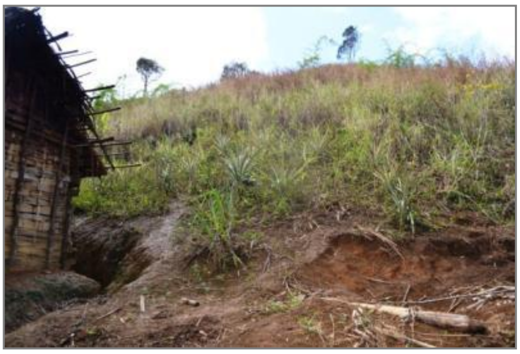
Ambinanindampy village



S17°24'29.81" E48°43'41.98"

[1] CREAM 2013, Monographie de la Région Alaotra Mangoro (Monograph of the region of Alaotra Mangoro)

[2] Densité : une quarantaine d'habitants au km² (Population growth : about 40 inhabitants/ km²)

	  *Seasonal campsite near the SF 015 site*
ACTIVITIES	The main local activity is rice growing. It is used in two topographic units : lowlands (vary horaka) and hillsides (tanety). The crops season is the same for both of them : from October to April. Rice growing is associated with subsistence crops and cash crops : manioc, sugar cane, banana and sometimes pineapple. The population of the area sometimes goes fishing during some parts of the year. The main products are fish (tilapia) and eels. Fishing is practiced during the low water season, from July to December. They use a pirogue and baskets or angling/fishing by hand. The products are dried/smoked in order to be commercialised to Ambatondrazaka or Antananarivo.  Lowlands rice growing, with banana trees  Tanety rice growing  Pineapple crops near the Ambinanindampy village  Local fish seller
OTHERS (IF ANY)	The inhabitants of the region belong to the ethnic group called Sihanaka. The site is located on mining plots (authorization to search for chrome, nickel and gold expired in 2008). Some mining plots (Crystal, haematoid quartz…) have an authorization for smallholder farmers (prospect, research and

	exploitation activities) are located less than 3km S-W of the site (authorization expires in 2018) and 4km N-W of the South (authorization expired in 2015).

C – World Bank Safety Policies that can be applicable :

OP 4.01 – Environmental Assessment ☒

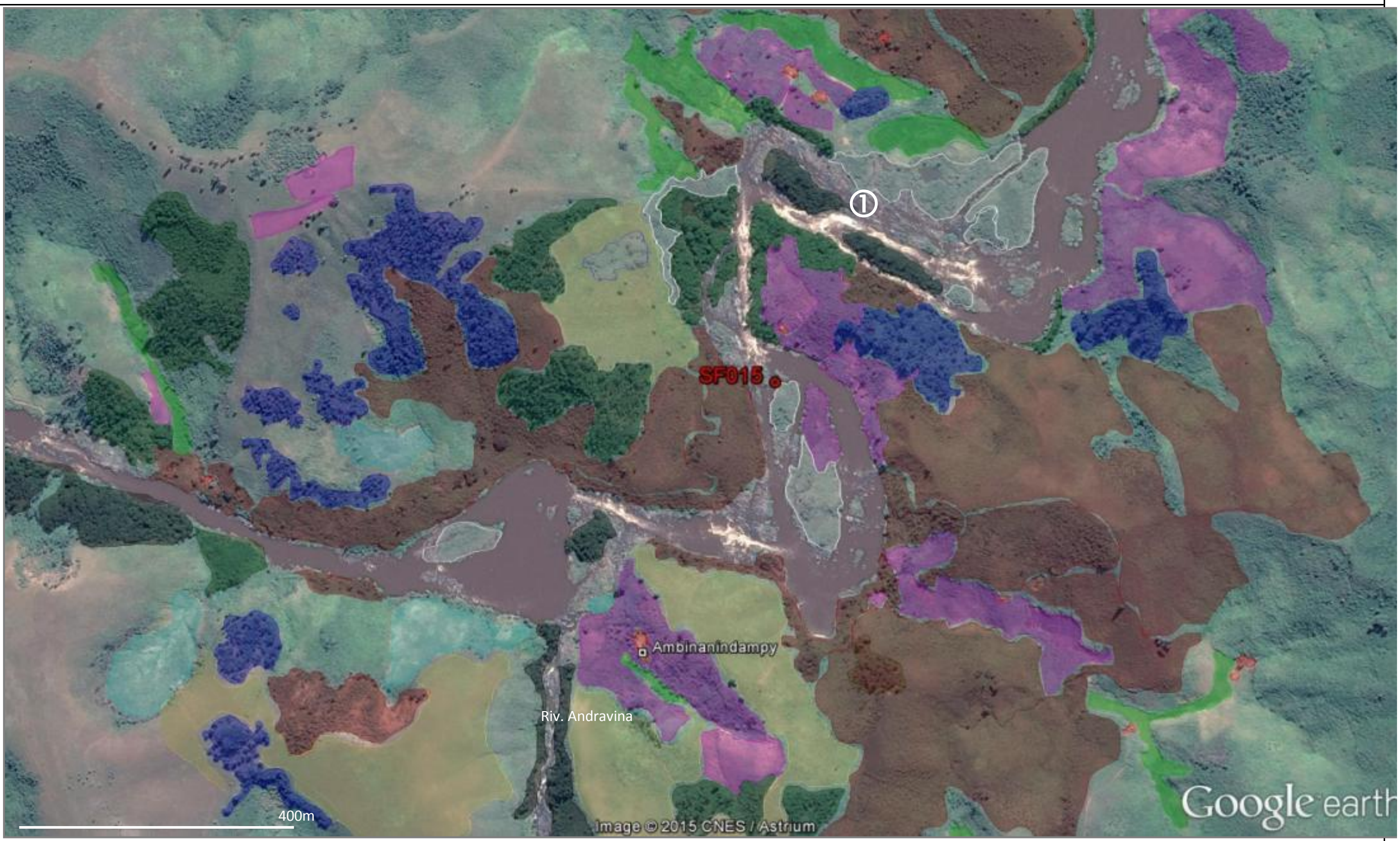
OP 4.04 – Natural Habitats ☒

OP 4.11 – Cultural Heritage ☐

OP 4.12 – Involuntary Resettlement ☒

OP 4.37 – Safety of Dams ☐

Land use around the site



: Housing

: Savoka and fallows

: Reforestation

: Herbaceous savannah

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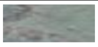
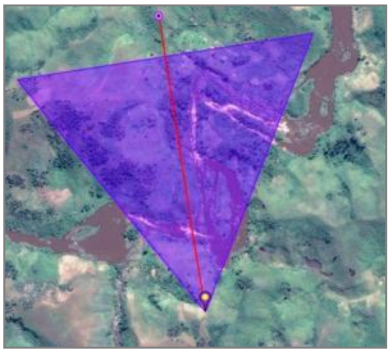
 : Savoka and herbaceous plants

 : Mosaic of crops / fallows

 : Mosaic of natural forests , savoka and reforestation

 : Recent forest clearings

 : Leftovers of natural forests

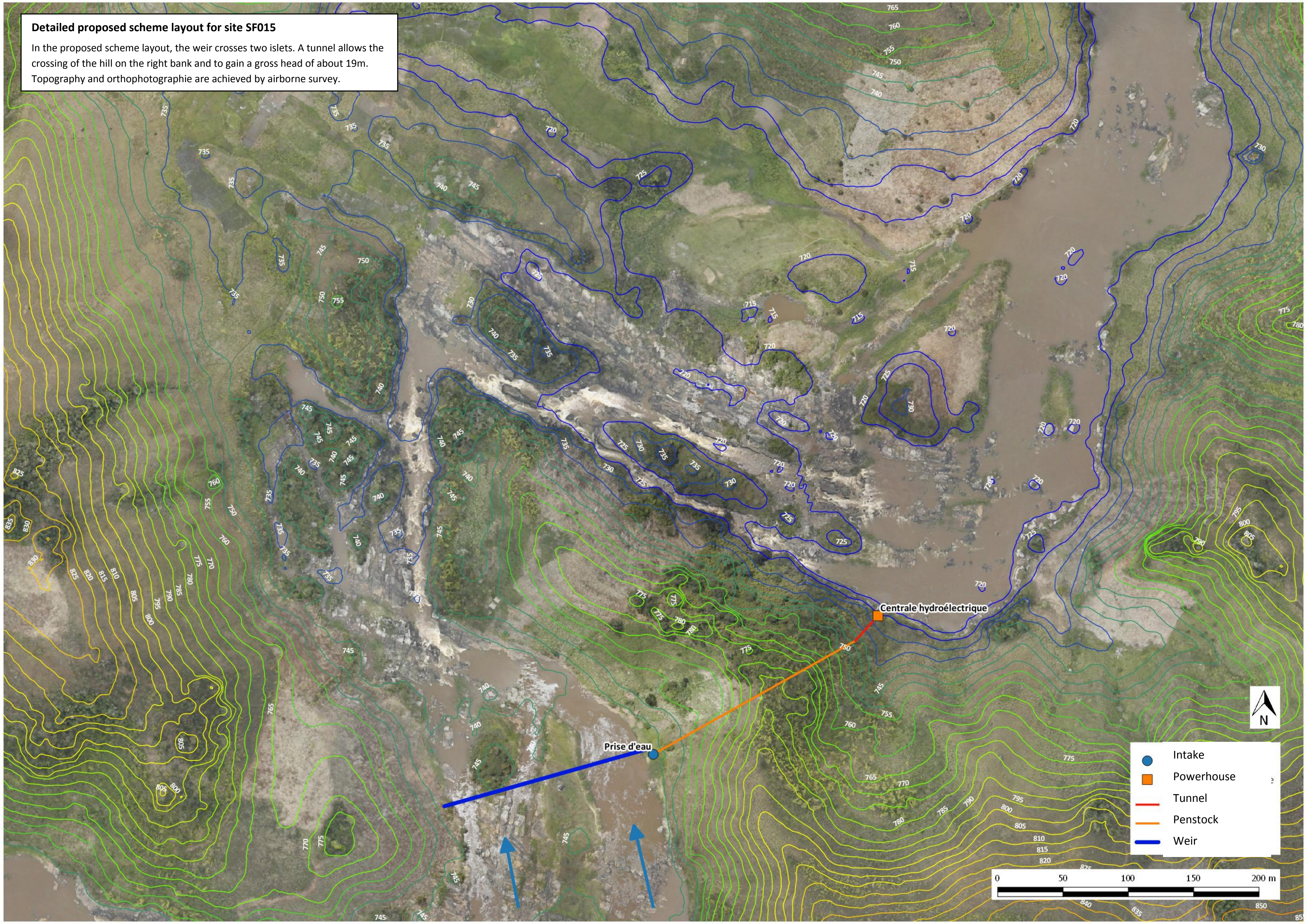


Panorama : view of the SF 015 site

Mosaic of crops near the meeting of the Maningory river and the Andravina River

housing in the Ambinanindampy village

5.2 Detailed proposed scheme layout



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Madagascar: Small Hydropower Resource Atlas (1-20MW)
Site Investigation Report

SF020 SITE

Sandratsiona River | Atlas Code: SF020

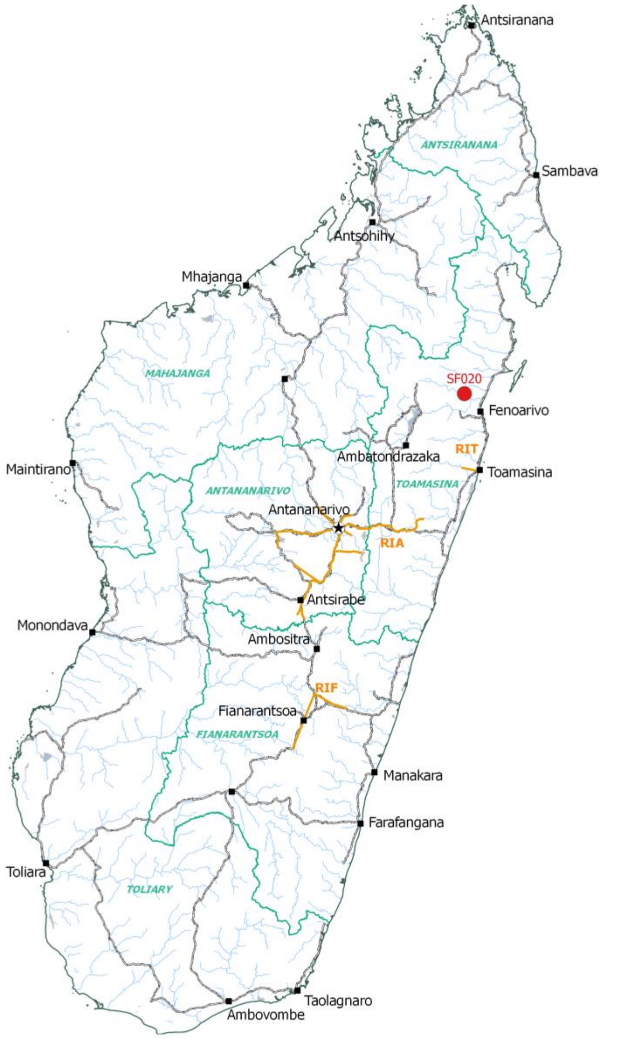

Table of content

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1 SITE LOCATION

Upstream option

Geographical coordinates (WGS 84)	Longitude [°]	Latitude [°]
Intake	49.193	-17.131
Powerhouse	49.195	-17.133

Downstream option

Geographical coordinates (WGS 84)	Longitude [°]	Latitude [°]
Intake	49.200	-17.144
Powerhouse	49.208	-17.146

1.1 Administrative data

Atlas code	SF020
Site name	SF020
River	Sandratsiona
Major river basin	Maningory
Province	Toamasina
Region	Analanjirofo
District	Fenoarivo Atsinanana
Commune	Vohipeno
Village	Ambatoharanana
Reference topographical map	Carte topographique n°U42 (échelle 1:50,000)

1.2 Access

It is possible to be accommodated in Vohipeno. This is currently necessary given the distance between the village and the site (about 15km).

To access Vohipeno, the easiest way is currently to take the road (in poor conditions) to Vohilengo. The road ends at the river before reaching the village. At this site it is possible to take a motorized boat going downstream to the confluence of the Sandratsiona river, and then upstream again on the latter to the road leading to Vohipeno. 3km separates the landing spot from Vhipeno, (by foot or elevated 4x4 only).

Figure 1. Dirt road between the landing spot and Vohipeno

As shown on Figure 2, it is also possible to reach Vohipeno by using the road going Northwards before reaching Vohilengo (elevated 4x4 only).

From Vohipeno, it is possible to rent a motorbike to get close to the site, but most of the distance is done by foot.

Access will be an issue for the project, given the 50km of dirt road to be rehabilitated to reach Vohipeno, including a solution to cross the river. Then 16km of new road to reach the site (18km for the upstream site).

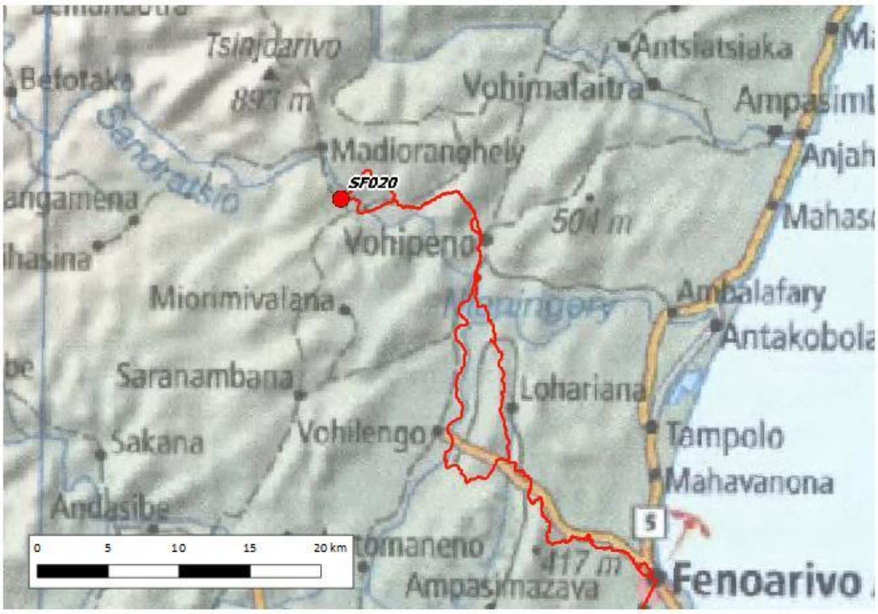


Figure 2. Site access (GPS tracks in red)

The site could feed the villages and towns between Toamasina and Soanierana Ivongo.

Figure 3. Villages andtowns around the site

2 GENERAL SITE DESCRIPTION

2.1 Background

The site context is presented on the figures below.

Figure 4. Geographical context of site SF020

Most of the waterfall is concentrated in a bend (80m available head). The first part of the bend is a steep slope which leads to a significant waterfall followed by another steep slope (Figure 5 to Figure 7).

2km upstream of this site, lies another site, with an available head of 30m (Figure 8).

The access roads and transmission lines will have a significant impact on the project financial parameters. Moreover, depending on the power needs to be covered, the following options might be considered:

Downstream site option (at the main waterfall): SF020-DS

Upstream site option (at the lower waterfall, 2km upstream) : SF020-US

Combined option. For this option, it is assumed that both sites will benefit from the same infrastructures in terms of access road and transmission lines. Although located as far as 120km from the Toamasina grid, connecting the plants to this grid might be considered.

Figure 5. Main waterfall of site SF020-DS

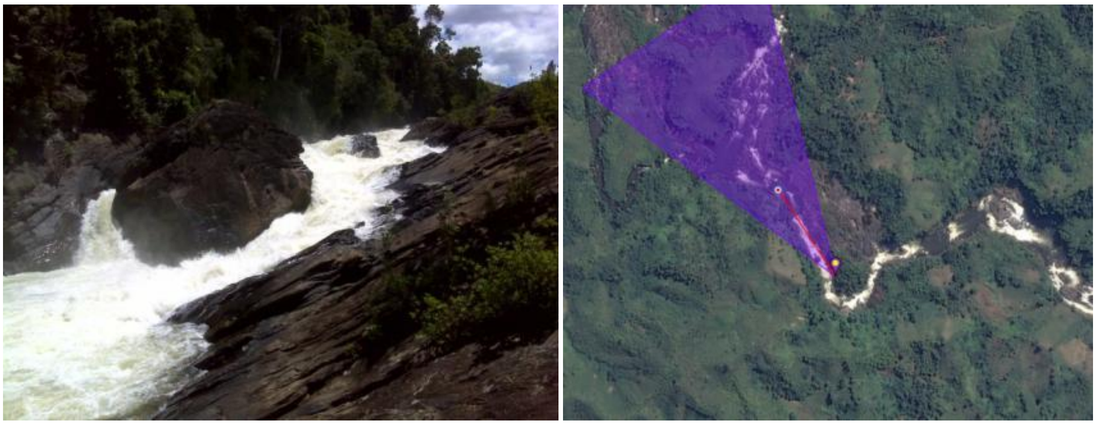


Figure 6. Upper side of the site – SF020 DS

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

Figure 7. Lower side of the site – SF020-DS

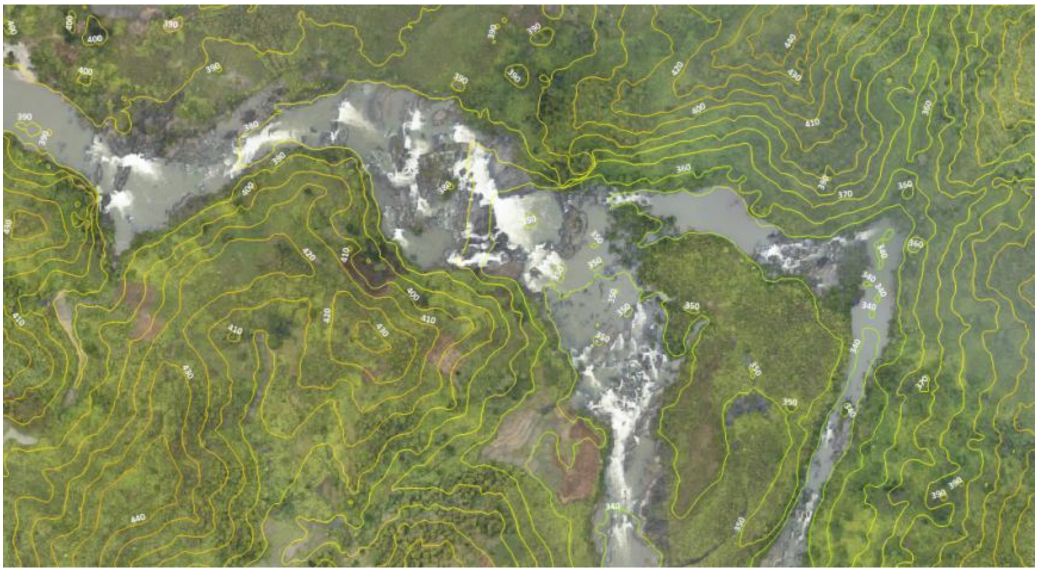


Figure 8 : Upstream site SF020-US

2.2 Sediment transport

Sediment transport is an issue in the river at the site location. Indeed, the basin has steep slopes but it is mostly uncovered by forest. As a matter of fact, most of the area is cultivated, with as consequences, heavy soil erosion during the rainy season. The following figure shows an active sand strip on several years of interval.

Figure 9. GoogleEarth satellite images of an active sandstrip downstream of the site (a) May 2000 (b) October 2009 (c) January 2014 and (d) May 2014

2.3 Topography

The topographical survey was achieved through remote sensing. An aircraft was chartered and equipped with optical sensors.

Figure 10. Aircraft and container of remote sensors for airborne survey

The topographical survey has a point density of 5 /m² and a relative accuracy of 2%.

Outputs from airborne survey are (1) a high resolution orthophotography (0.2m to 0.4m resolution) and (2) a Digital Surface Model (DSM). The DSM includes the vegetal cover, but it gives an excellent global picture of the site topographical configuration. Contour lines might be deduced from the DSM.

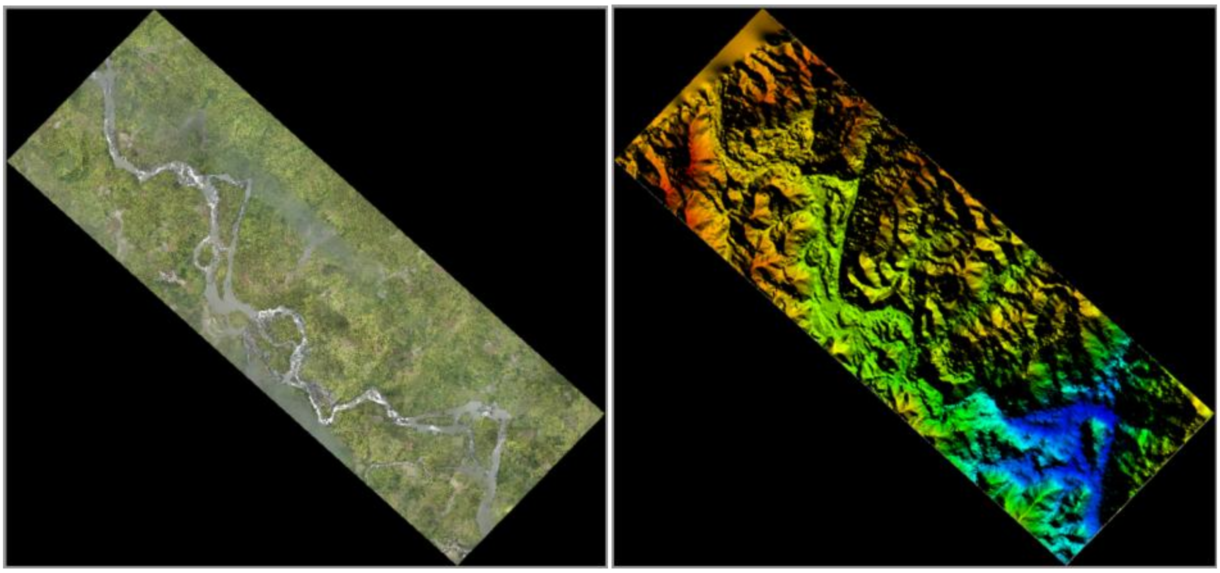


Figure 11. Digital Surface Model and orthophotographie from airborne survey

2.4 Preliminary hydrological study

Accurate information on the hydrology of the Sandratsiona River does not exist. As a consequence, statistical characteristics of the river discharge at the site of interest have been estimated using a regional methodology. This methodology is based on the available information at other hydrometric stations distributed in the country. Given the limited spatial and temporal resolution of the available data, the results of the regional study presented below are indicative only and are not intended to be used for design purposes without further detailed hydrological studies.

Key preliminary hydrological characteristics of the river at the site of interest are presented in the table below.

River	Sandratsiona
Main river basin	Maningory
Area [km²]	2183
Average elevation [m a.s.l]	915
Slope index [m/km]	2.3
Specific vertical drop [m]	107
Average annual rainfall [mm/yr]	1281
Average interannual discharge [m³/s]	65.5
$Q_{95\%}$ - firm discharge [m³/s]	17.9
$Q_{50\%}$ - median discharge [m³/s]	53.8
$Q_{30\%}$ [m³/s]	76.4
10yr return period flood [m³/s]	1363
100yr return period flood [m³/s]	3234

2.5 Site geology

Geological reconnaissance was only conducted on the downstream site. Hence, the next section is only about this sites. Considerations for the upstream site a formulated based on hypotheses that should be check in the next studies.

2.5.1 Geological context

The petrography of the area is characterized by augen textured migmatites, of heterogranular appearance, composed of quartz, biotite mica and feldspar (Figure 12). In situ, they are presented under the shape of foliated bed, plunging towards South-East (nearly following the river flow axis).

Figure 12 : Encountered magmatic rock

The rock crops out along the river and on the river bank, with largely open strata due to the water flow effects (Figure 13).

Figure 13 : Outcrops in the river

Joints being scarce, rock split up in big metric blocks in surface (Figure 14).

Figure 14 : Right bank support

Alteration effect is very superficial and weakly marked. It should be noted that the river is tumultuous with variable flows animated by drops of variable importance.

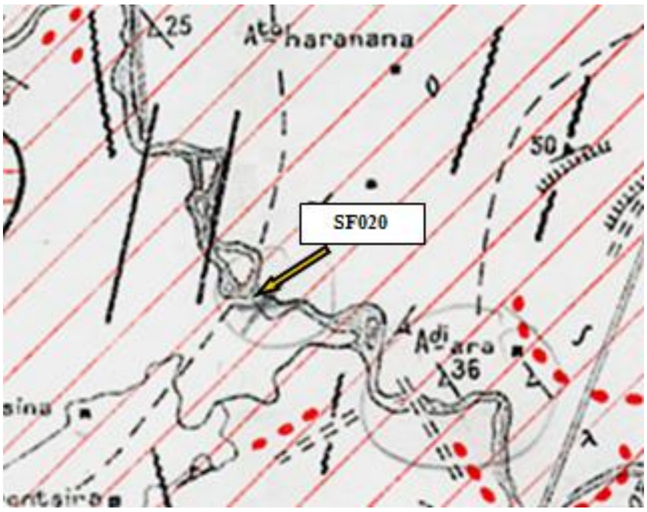


Figure 15 : Geological context

2.5.2 Technical characteristics

Bed aspect at the projected weir location: the weir would be founded on at rocky bed, characterized by layers plunging in the flow direction and superficially opened foliations.

Right bank support aspect: it is a high montainious area with difficult access (Figure 14). Along the river, the bedrock is topped with massive migmatite blocks with chaotic layout due to the large waterfall located upstream.

Left bank support aspect: it is made of sheer hills at the riverside. The rock structure crops out at its basis during low water period. It is composed of massive migmatite rock with apparent scaling along foliations (Figure 12). The whole formation plunges noticeably towards downstream.

Intake: for the intake, massive migmatite structure should be found under rock blocks. Drillings with percolation tests will be required to avoid potential leakages.

Waterway : the whole area to cross is composed of the same migmatites as described in the preceding section (Figure 15). Lateritique alteration in the area is poor and the riverbanks sometimes form rocky gorges. The tunnel will be set at such a level that enough compactness could be obtained; it means that the original migmatite foliations would be closed. However, the alignment should as much as possible follow the top-platform line. The tunnel should avoid crossing deep dells as they are characterized by open fractures due to runoff.

Penstock : it will follow the slope of a plateau hillside

Powerhouse : the powerhouse will be based on the bedrock, under a thin lateritic layer.

2.5.3 Recommendations for further investigations

ELEMENT	UNCERTAINTY TO REMOVE	SURVEY TYPE
Bed at weir	✓ Leakage due to counter current open foliations and potential joints.	✓ Identification of the potential joints oriented in the flow direction (this will require drying of the riverbed) ✓ Compressed air blowing, percolation tests and high pressure clogging should be foreseen in a second stage (this will require drying of the riverbed)
Right support	✓ No major issue for the weir anchoring (depending to final weir height). Leakage might occur along eventual open foliations.	✓ Detailed observation of the area to check if overhanging rock (in-situ or reworked) might harm infrastructures ✓ Drillings for percolation tests should be conducted
Left support	✓ Potential leakage towards downstream due to in-situ rock open foliations.	✓ Drillings to check the in-depth rock compactness (foliations opening limit) followed by percolation tests.
Intake and waterway	✓ In-depth foliations and open fractures	✓ Core drilling at some chosen points to check the in-depth rock compactness and to conduct percolation tests.

Penstock	✓ Hill slopes stability	✓ More detailed geological investigations to be defined in the next study stages, once the final penstock trace is defined based on the final tunnel exit opening
Powerhouse	✓ No particular issue	

2.6 Socio-environmental aspects

The site detailed description sheet is provided in the Appendices.

2.6.1 *Socio-environmental background*

The site is located on the Sandratsiona River. It is situated in the fokontony of Ambatoharanana, between the rural communities of Miorimivalana and Vohipeno, Fenoarivo Atsinanana District, Region of Analanjirofo.

The vegetation is mainly Savoka ravinala (*Ravenala madagascariensis)* and/or bamboo (*Nastus*) with or without woody elements, as well as some herbaceous bushy vegetation, covering the cleared soils.

Clove plantings are also present in the area. Some bases of clove trees have been seen in the savoka, in particular when they are located near the plantings.

However, some quite degraded shred forests can ben seen, in particular alongside the fall and sometimes reaching the crests. The following species are typical of the present forests : *Canarium madagascariensis, Uapaca sp., Acacia sp.* et *Phyllarthron* sp. Invasive species such as Takoaka (*Rubus molucana*), Taindelon-tsinoa (*Clidemia hirta*), Dingadingana (*Psiadia altissima*), Goavy (*Psidium*), bracken fern (*Pteridium aquilinum*) and Longoza (*Aframomum* sp.) can also be noticed inside/outside both shred forests and savoka. This shows the characteristic of the local ecosystem. The riparian vegetation is characterised by the domination of *Aframomum* sp, *Pteridium* sp., *Nastus* (bamboo), sometimes *Dypsis* spp. and *Typhonodorum lindleyanum*.

Image 16. Overview of the vegetation downstream of the weir

From the socio-economic perspective, some hamlets/campsites can be seen in the direct neighbourhood of the site. In particular, the Ambatoharanana village is located ~850m upstream of the power plant site, on the right bank of the River. Ambatoharanana is composed by two villages, separated by 2km and having more than 100 huts.

The main local activity is agriculture, in particular rice growing (lowlands and hillsides) and subsistence crops (manioc, sweet potato, sugar cane) which are generally terrace crops or bank crops.

Moreover, the local clove production also helps the local economy. Clove is sold as nail or essential oil. Furthermore, some artisanal extraction units can be seen in the area, built with local materials, and one or several handmade stills.

The following image gives a global overview of the land use in the area.

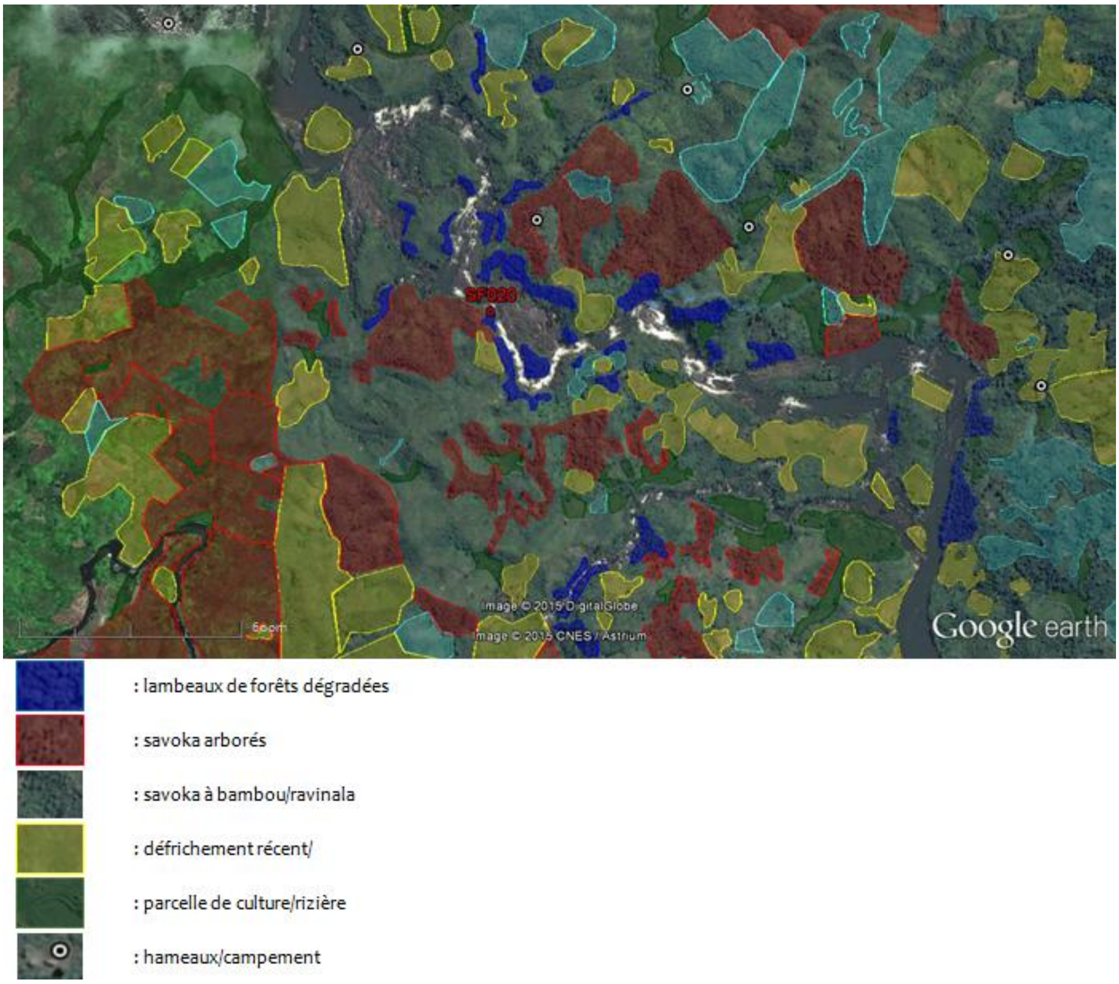


Image 17. Land use of the area of the SF 020 site

2.6.2 *Socio-environmental constraints*

The Ambatoharanana village is located about 850m downstream of the power plant. Moreover, some hamlets and campsite can be seen in the area, within a radius of 1km around the expected site. The implementation of the project will affect these villages and hamlets, especially regarding potential nuisances (noise, traffic, noise, atmospheric emissions…).

Moreover, if the implementation of the project leads to an increase of the water level upstream of the weir (~600m), crops and clove plantings could also be affected, depending on the magnitude of the provoked flood.

The implementation of the project's infrastructures could also impact the local natural resources, in particular the shred forests that are near the weir and including large diameter species. Furthermore, the project can impinge on the rural surfaces, leading to a loss of resources for the concerned communities.

2.6.3 World Bank Safeguard Policies that could be applicable:

The World Bank Safeguard Policies that could be applicable for the SF 020 site are the following:

OP 4.01 – The Bank requires Environmental Assessment (EA) of projects proposed for Bank financing to help ensure that they are environmentally sound and sustainable, and thus to improve decision making. However, we can already estimate that the adverse impacts on human populations and environment-linked areas are limited. They are reduced, not irreversible and some measures can prevent, mitigate or minimize them. Moreover, these measures can improve the environmental performance.

OP 4.12 – Involuntary Resettlement: the hydropower project will require the use of a large space (implementation of the plant, creation of access roads to the site…), which sometimes are crop areas. Moreover, the ponded water of the weir could impact some habitation huts or crop parcels. So the project will have to take into account the concerned people and communities, particularly regarding the restoration of the standards of living due to the loss of resources.

The projected weir is classified as a small dam (<15m high); the usual generic safety measures for dams are appropriate and do not need the implementation of OP 4.37 – Safety of Dams (for large dams).

3 PROPOSED SCHEME LAYOUT

As mentioned above, 2 sites lie close to each other, which leads to 3 possibilities : either one (exclusively) or combined.

An assessment of the scheme potential in terms of installed capacity, energy generation (firm and average) and the associated capital investment costs (CAPEX) and productions costs (Levelized cost of energy) is presented in section 4. It is based on the scheme proposed in this section. Hence, at this stage of the study, the technical features of the hydropower scheme are designed for both firm and median discharges (respectively $Q_{95\%}$ and $Q_{50\%}$). The actual design flow will be determined during the detailed studies based on economical, financial and technical criterion as well as the future energy and power demand.

The proposed scheme layout is shown below and presented in A3 format in the Appendix of this report.

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

3.1 Downstream option

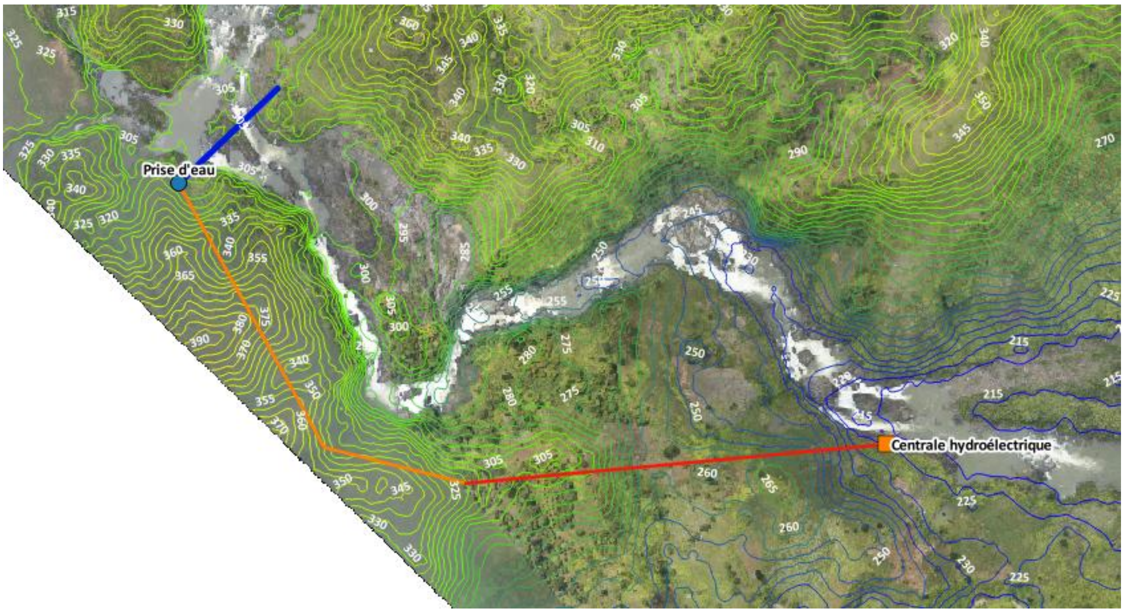


Figure 18. Porposed scheme layout for downstream site

3.1.1 Weir and intake

With the current knowledge of the site, the weir would be located upstream of the topographical constriction (main waterfall). It would be 140m long and 4m high. Intake would be on the right bank.

3.1.2 Desander

A desander is necessary as detailed above in the sediment issue.

3.1.3 Waterways

The left bank has steep slopes and is crossed by a thalweg. This is the reason why the right bank is chosen for the scheme's infrastructures. A 490m long tunnel will carry the water to the forebay. The diameter will be 3.6m (firm flow) or 6.2m (median flow).

Terrain profile above the tunnel is shown on the figure below.

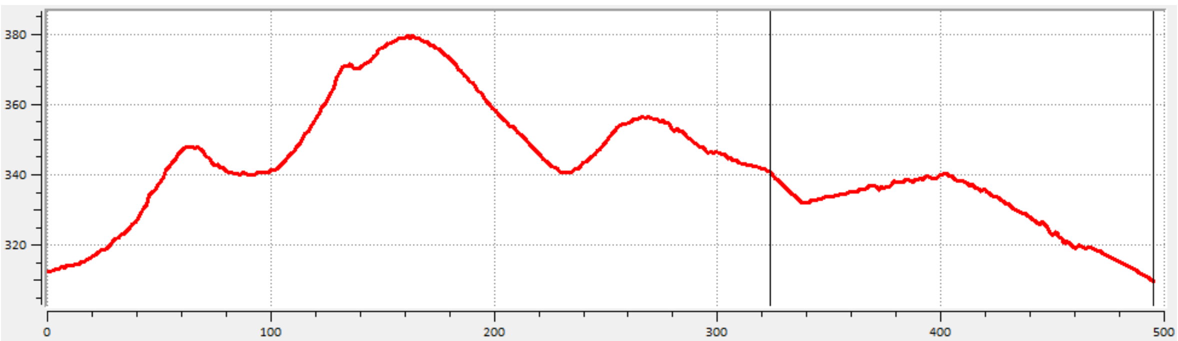


Figure 19. Terrain profile above the tunnel

3.1.4 Penstock and powerhouse

Penstocks will be 465m long. In case of a design at firm flow, 2 pipes with a diameter of 1.40m are necessary. In case of a design a median flow, 4 pipes with a diameter of 1.8m.

3.1.5 Electromechanical equipments

3.1.5.1 Design flow taken at Q_{95}

For a design flow at Q95, the selected turbine should enable a maximization of the power output while enabling enough flexibility to absorb peaks and ensure production during low demand periods. Given the power potential of the site, it is recommended to install several similar units to optimize the plant efficiency and to enhance its availability and to follow the demand evolution as much as possible. Moreover, this solution reduces transport and access issues.

Head, discharge and foreseen output give the Francis turbine as and evidence. It offers a high performance level and a satisfactory flexibility.

Given observations formulated about water quality, a particular attention must be paid to the quality of materials used for the construction of the turbine. One should probably consider the need for an anti-abrasion coating.

- Given the site characteristics, it is planned to install two identical units, each composed of:
- Butterfly safety valve with counterweight to ensure its closure in case of emergency of black out.
- A 6 050 kW vertical axis Francis turbine running at 600rpm.
- A 690V or 5.5 kV alternator, 5 690 kW/ 6 320 kVA.
- Control and monitoring system, including speed regulator and voltage regulator.
- Security system and electrical protection.
- Step-up transformer and electrical cabinet and switchgear.
- Emergency power unit.

A power plant PLC (Programmable Logic Controller) should also be foreseen to manage the two units.

Following issues should be studied as well in the next stages of the project :

- Sedimentation problem and the need for anti-abrasion coatings (e.g. Tungsten carbide).
- Technical and economic optimization of the penstock diameter.
- Technical and economic optimization of the number of units and of the design flow, according to the hydrology and the electrical demand.
- The need of a flywheel (for grid stability)
- The set up level and rotational speed of the turbine (Suction height and cavitation issues).
- Grid voltage.
- Preliminary turbine design.

Figure 20. Example of 2 vertical-axis Francis sets

3.1.5.2 Design flow taken at Q_{50}

For a design flow taken at Q50, it is recommended to install four identical units (Francis turbines) in order to optimize the global efficiency and to increase the plant availability.

Other considerations exposed for a design flow at Q95 remain valid for a design flow taken at the median discharge (Q50).Turbines will have a unit nominal power of 9 470kW and a rotation speed of 500 rpm. The alternator power will be 8 900 kV/ 9 890 kVA for a 5.5kV voltage.

A power plant PLC (Programmable Logic Controller) should also be foreseen to manage the four units.

3.1.6 Transmission lines

It is envisaged that the proposed hydropower scheme would feed the area including the coastal villages between the site and Sainte-Marie Island (included) by the mean of a 130 km long and 2*90kV line.

3.2 Upstream option

The proposed scheme layout is shown on the figure below.

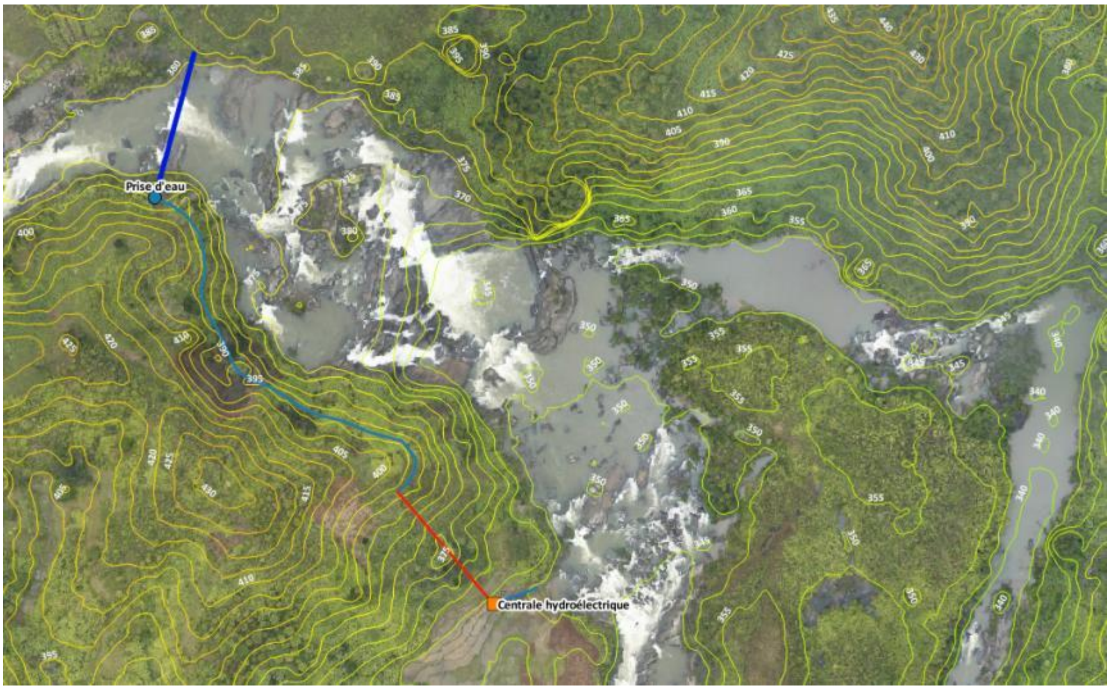


Figure 21. Proposed scheme layout for SF020 "upstream"

3.2.1 *Weir and intake*

A 85m long, 5m high weir would be necessary. The intake would be on the right bank.

3.2.2 *Desander*

Given the sediment issue, a desander is necessary.

3.2.3 *Waterways*

A 285m long canal will carry the water to the forebay.

3.2.4 *Penstock and powerhouse*

The penstock will be 90m long. For the firm flow 2 pipes (1.40m diameter) are necessary, for the median flow, 4 pipes (1.80m diameter).

3.2.5 *Electromechanical equipments*

3.2.5.1 *Design flow taken at Q_{95}*

For a design flow at Q95, the selected turbine should enable a maximization of the power output while enabling enough flexibility to absorb peaks and ensure production during low demand periods. Given the power potential of the site, it is recommended to install several similar units to optimize the plant efficiency and to enhance its availability and to follow the demand evolution as much as possible. Moreover, this solution reduces transport and access issues.

Head, discharge and foreseen output allow the choice between a Francis turbine, which offers a high performance level and a satisfactory flexibility, and the double regulated Kaplan turbine which offers a high efficiency on a large discharge range. The final choice is set on a Francis turbine which is simpler and more robust. The suggested solution does not require the use of a gearbox, which is a sensitive and costly component, as well for operation as for maintenance.

Given observations formulated about water quality, a particular attention must be paid to the quality of materials used for the construction of the turbine. One should probably consider the need for an anti-abrasion coating.

Given the site characteristics, it is planned to install two identical units, each composed of:

- Butterfly safety valve with counterweight to ensure its closure in case of emergency of black out.
- A 2 125 kW vertical axis Francis turbine running at 500rpm.
- A 690V alternator, 2 000 kW/ 2 220 kVA.
- Control and monitoring system, including speed regulator and voltage regulator.
- Security system and electrical protection.
- Step-up transformer and electrical cabinet and switchgear.
- Emergency power unit.

A power plant PLC (Programmable Logic Controller) should also be foreseen to manage the two units.

Following issues should be studied as well in the next stages of the project :

- Sedimentation problem and the need for anti-abrasion coatings (e.g. Tungsten carbide).
- Technical and economic optimization of the penstock diameter.
- Technical and economic optimization of the number of units and of the design flow, according to the hydrology and the electrical demand.
- The need of a flywheel (for grid stability)
- The set up level and rotational speed of the turbine (Suction height and cavitation issues).
- Grid voltage.
- Preliminary turbine design.

3.2.5.2 *Design flow taken at Q_{50}*

For a design flow taken at Q50, it is recommended to install four identical units (Francis turbines) in order to optimize the global efficiency and to increase the plant availability.

Other considerations exposed for a design flow at Q95 remain valid for a design flow taken at the median discharge (Q50).Turbines will have a unit nominal power of 3 265 kW and a rotation speed of 428.57 rpm. The alternator power will be 3 070 kV/ 3 410 kVA for a 690 V or 5.5kV voltage.

A power plant PLC (Programmable Logic Controller) should also be foreseen to manage the four units.

3.2.6 *Transmission lines*

The produced power would be evacuated by a 130km long, 90kV line to feed Sainte Marie and the villages along the way.

3.3 Combined sites and RIT connected option

This option requires the building of both sites detailed above.

For this option, a 130km long line is required to join the RIT.

3.4 Key technical features

The main features of the scheme are presented below for both the firm and the median flow and for the 3 cases (downstream option alone, upstream option alone, combined option). In case of the combined option, the technical features are the same of the 2 sites taken as single sites.

3.4.1 Downstream option

		Firm discharge	Median discharge
Installed capacity	[kW]	11 380	35 600
Potential annual generation	[GWh/yr]	88.55	251.94
Design flow	[m³/s]	17.9	53.8
Gross head	[m]	83	
100yr return period flood	[m³/s]	3 234	
Weir length	[m]	140	
Weir height	[m]	4	
Desander		Large size	
Tunnel length	[m]	490	
Tunnel diameter	[m]	3.6	6.2
Penstock length	[m]	465	
Penstock diameter	[m]	1.4	1.8
Number of penstock(s)	[pce]	2	4
Number of T/G units	[pce]	2	4
Transmission line length	[km]	130	
Line voltage	[kV]	138	
Length of the access road to create	[km]	16	
Length of the access road to upgrade/rehabilitate	[km]	50	

3.4.2 Upstream option

		Firm discharge	Median discharge
Installed capacity	[kW]	4 000	12 280
Potential annual generation	[GWh/yr]	31.25	87.22
Design flow	[m³/s]	17.9	53.8
Gross head	[m]	28	
100yr return period flood	[m³/s]	3 234	
Weir length	[m]	85	
Weir height	[m]	5	
Desander		Large size	
Canal length	[m]	285	
Canal section (b x h)	[m]	4.9 x 3.05	12 x 3.75
Tunnel length	[m]	90	
Tunnel diameter	[m]	1.4	1.8
Number of penstock(s)	[pce]	2	4
Number of T/G units	[pce]	2	4
Transmission line length	[km]	130	
Line voltage	[kV]	90	

Length of the access road to create	[km]	17
Length of the access road to upgrade/rehabilitate	[km]	50

3.4.3 Combined sites option

		Firm discharge	**Median discharge**
Installed capacity	[kW]	15 380	47 880
Potential annual generation	[GWh/yr]	119.8	339.16
Design flow	[m³/s]	17.9	53.8
Transmission line length	[km]	130	
Line voltage	[kV]	2*90	
Length of the access road to create	[km]	18	
Length of the access road to upgrade/rehabilitate	[km]	50	

4 ENERGY PRODUCTION AND COSTS

At this early stage of the study and with the technical assumptions detailed above, the energetical and economical performances of the projects would be of the following order of magnitude:

4.1 Downstream option

Gross head	**[m]**	83	
Design flow	**[m³/s]**	17.9 ($Q_{95\%}$)	53.8 ($Q_{50\%}$)
Installed capacity	**[kW]**	11 380	35 600
Potential annual generation	**[GWh/yr]**	88.55	251.94
CAPEX (excl. access and lines)	**[M$]**	39.38	114.29
LCOE (excl. access and lines)	**[$/kWh]**	0.054	0.055
Total CAPEX (incl. access and lines)	**[M$]**	118.83	193.75
Total LCOE (incl. access and lines)	**[$/kWh]**	0.160	0.092

4.2 Upstream option

Gross head	**[m]**	28	
Design flow	**[m³/s]**	17.9 ($Q_{95\%}$)	53.8 ($Q_{50\%}$)
Installed capacity	**[kW]**	4 000	12 280
Potential annual generation	**[GWh/yr]**	31.25	87.22
CAPEX (excl. access and lines)	**[M$]**	15.14	39.83
LCOE (excl. access and lines)	**[$/kWh]**	0.058	0.055
Total CAPEX (incl. access and lines)	**[M$]**	69.34	94.03
Total LCOE (incl. access and lines)	**[$/kWh]**	0.263	0.129

4.3 Combined sites option

Design flow	**[m³/s]**	17.9 ($Q_{95\%}$)	53.8 ($Q_{50\%}$)
Installed capacity	**[kW]**	15 380	47 880
Potential annual generation	**[GWh/yr]**	119.8	339.16
CAPEX (excl. access and lines)	**[M$]**	54.52	154.12

LCOE (excl. access and lines)	**[$/kWh]**	0.055	0.055
Total CAPEX (incl. access and lines)	**[M$]**	148.03	247.63
Total LCOE (incl. access and lines)	**[$/kWh]**	0.147	0.088

5 APPENDICES

5.1 Socio-environmental datasheet

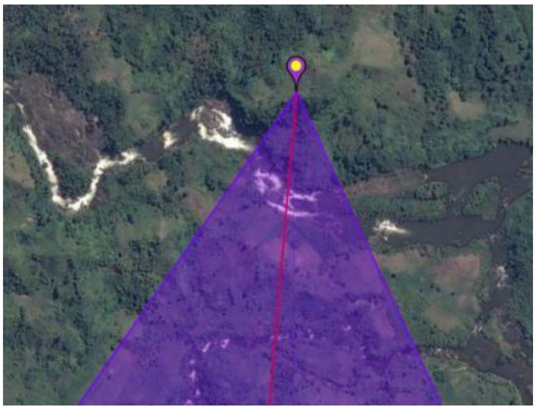
A – Site localisation

Site reference : SF020

Village / Fokontany : Ambodiara / Ambatoharanana

Community / District : Miorimivalana & Vohipeno / Fenoarivo Atsinanana

B - Description of the biophysical background

RELIEF	The site is located on a hill whose elevation is less than 300m high. The relief is quite precipitous. The main watercourse if the Sandratsiona River in the basin of the Maningory hillside. The river flows from South to East. Several watercourses also meet the river. The river banks and bed have a lot of rocky outcrops.  Rocky area  S17°8'39.78" E49°12'28.07"
VEGETATION	The vegetation is dominated by savoka (ravinala) and/or bamboo, with or without woody elements and some herbaceous or bushy vegetation. Some bases of clove trees can be found in the savoka, in particular when the latter are present near the plantings. However, some quite degraded shred forests can ben seen, with the following: *Canarium madagascariensis, Uapaca sp., Acacia sp.* and *Phyllarthron* sp. Invasive species such as Takoaka (*Rubus molucana*), Taindelon-tsinoa (*Clidemia hirta*), Dingadingana (*Psiadia altissima*), Goavy (*Psidium*), bracken fern (*Pteridium aquilinum*) and Longoza (*Aframomum* sp.) can also be noticed inside/outside both shred forests and savoka. This shows the characteristic of the local ecosystem. The riparian vegetation is characterised by the domination of *Aframomum* sp, *Pteridium* sp., *Nastus* (bamboo), sometimes *Dypsis* spp. and *Typhonodorum lindleyanum*.

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

Vegetation downstream of the weir

S17°8'43.70" E49°12'30.09"

Herbaceous/woody savannah, with isolated bases of clove trees near the route of the tunnel

S17°8’39.66 E49°12’28.07

Shred forests downstream of the expected weir site

S17°8’40.05 E49°12’25.38

OBSERVATIONS	The landscape is mainly composed by savoka. However, there are numerous crops with traces of forests clearings and slash-and-burn.
CRITICAL AREAS	There is no protected area in the surroundings of the site. The main vegetal protects the soils from erosion. However, water could be full of sand or alluvium from upstream erosion.

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

B - Description of the socio-economic background

<table>
<tr><td>LOCALITIY</td><td>The closest main villages are located downstream of the power plant: Ambatoharanana (~850m) and Ambodiara (~2km), respectively in the rural communities Miorimivalana and Vohipeno.

However, some hamlets and campsites are spread in the area. The site is only accessible by foot and a 50km dirt road should be built to reach the site.</td></tr>
<tr><td>ECONOMICAL ACTIVITIES</td><td>Rice crops can be seen alongside the river. The hillsides are cultivated with clove trees, vanilla plants and subsistence crops (essentially manioc).

Clove and vanilla are mainly exportation crops among the bases of the economy of the region. The extractions of essential oils are currently coming from the leaves and the branches of the clove trees. Clove plantings are more and more closed because of thefts.


Plantings of clove trees S17°9'10.03 E49°13'11.25


Extraction unit (clove essential oil) Unité d'extraction d'huiles essentielles de girofles S17°9'8.07 E49°13'19.11</td></tr>
</table>

C - World Bank Safety Policies that can be applicable :

OP 4.01 – Environmental assessment ☒

OP 4.04 – Natural habitats ☒
The river might be a natural habitat for indigenous water fauna.

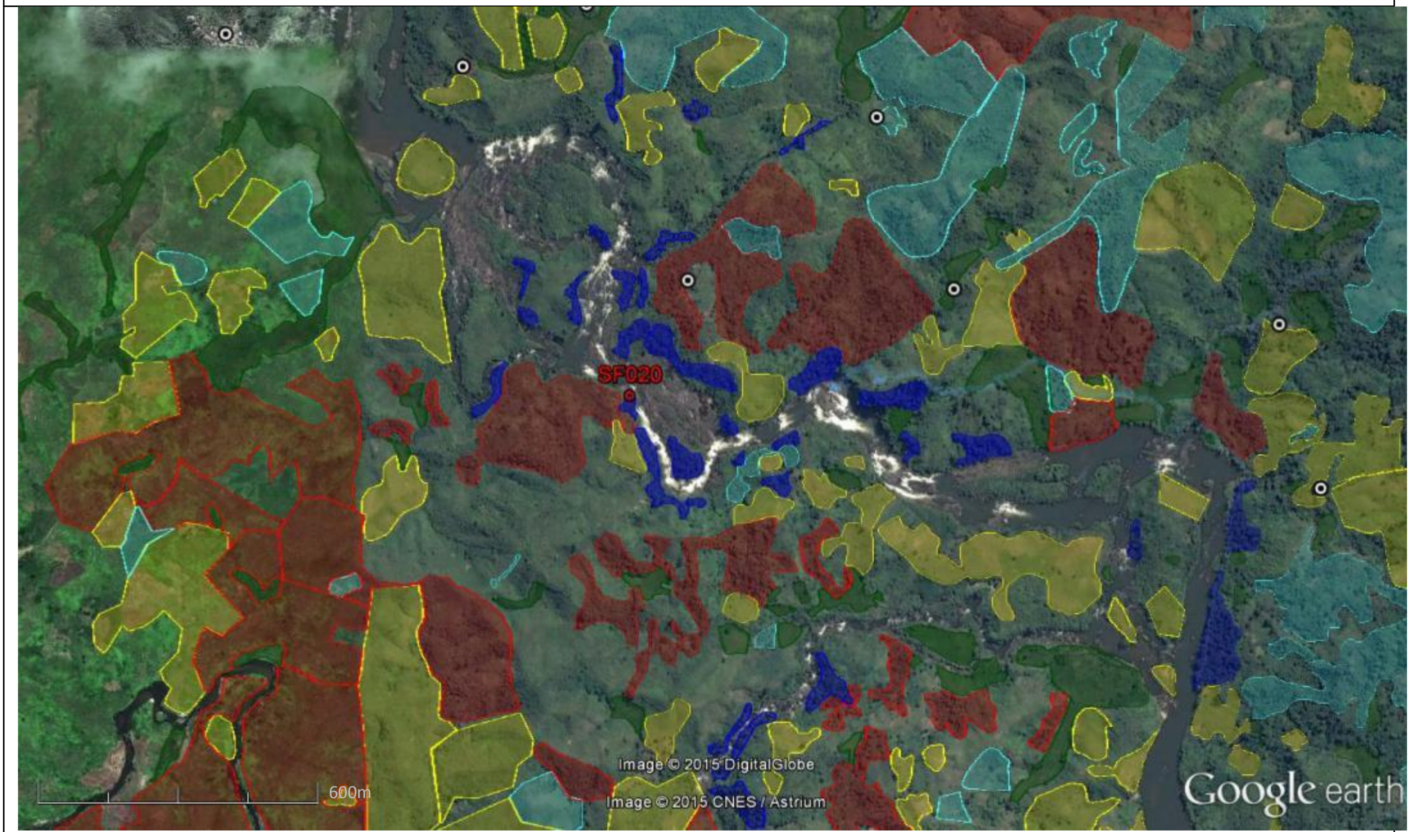
OP 4.11 – Cultural heritage ☐
There is no cultural site in the site vicinity.

OP 4.12 – Unvoluntary ressettlement ☒
The project, including modified water levels in the river might impact the cultivated parcels, especially those along the river.

OP 4.37 – Dams safety ☐
Being a small dam project (less than 15m high), only usual rules should be applied.

Land use around the site

Crops in the area



: Degraded shred forests

: woody savoka

: savoka bamboo/ravinala

: cultivated area/ricepcros

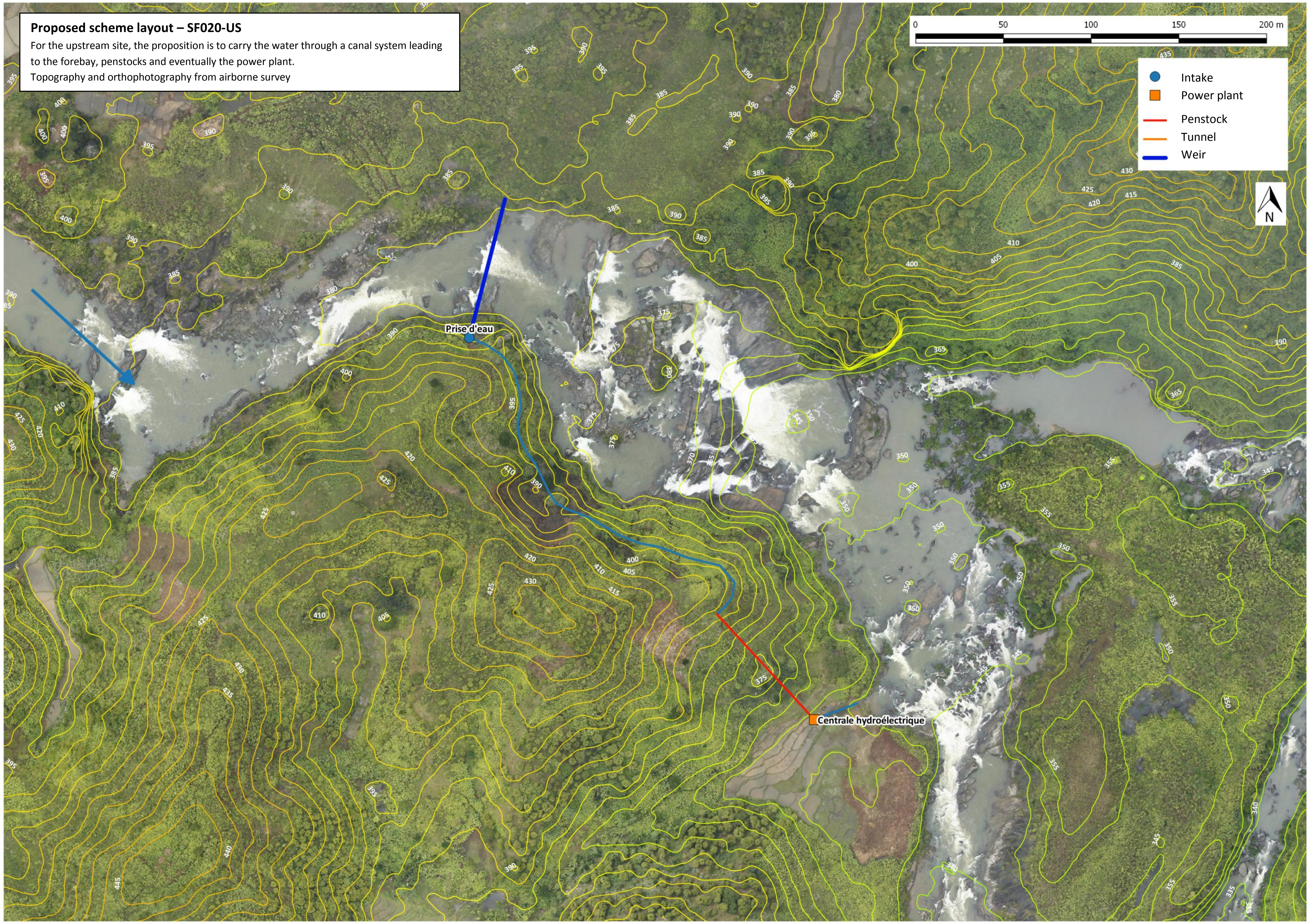
: hamlet/campsite

: recent clearing

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

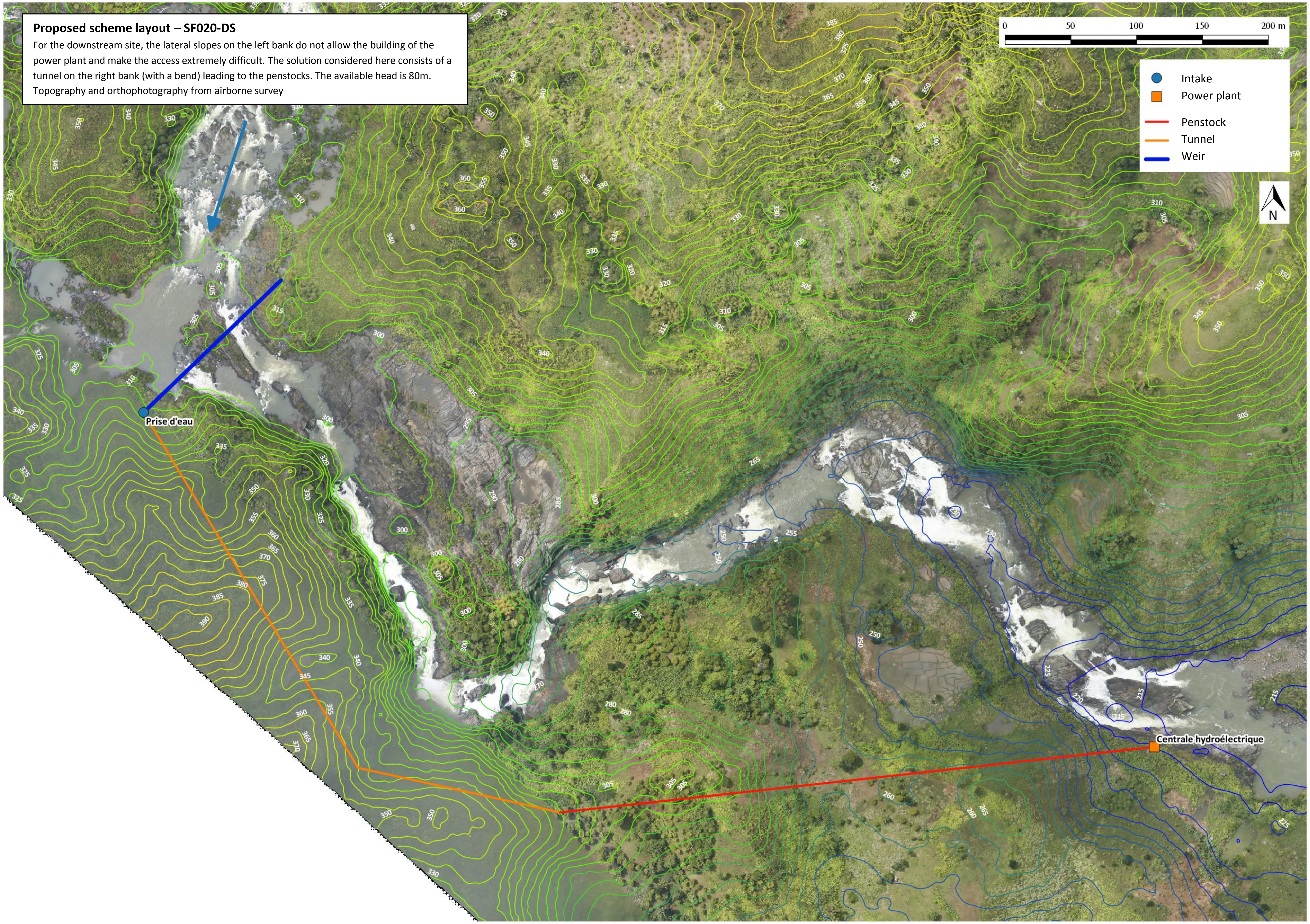
5.2 Proposed scheme layout

5.2.1 Upstream site (SF020-US)



In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

5.2.2 Downstream site (SF020-DS)



Madagascar: Small Hydropower Resource Atlas (1-20MW)
Site Investigation Report

SF038 SITE

Namorona River | Atlas Code: SF038

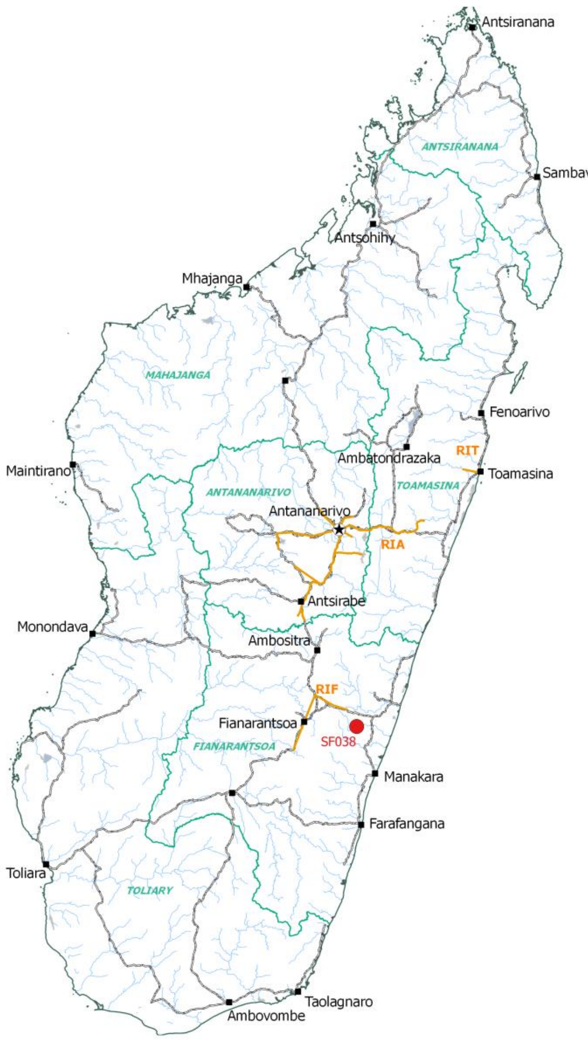


Table of content

1 SITE LOCATION

Geographical coordinates (WGS 84)	Longitude [°]	Latitude [°]
Intake	47.781	-21.522
Powerhouse	47.784	-21.522

1.1 Administrative data

Atlas code	SF038
Site name	SF038A
River	Namorona
Major river basin	Namorona
Province	Fianarantsoa
Region	Vatovavy Fitovinany
District	Ifanadiana
Commune	Androrangavola
Village	Androrangavola

1.2 Access

Access to the site is difficult because of the poor condition of the dirt road between the RN25 and Androrangavola (25km). Another 5km is necessary, currently by foot, on hilly conditions, including crossing a significant tributary of the Namorona.

Figure 1. Access to site SF038

A segment of the Fianarantsoa grid reaches Ifanadiana. Further investigations should study the possibility to connect the plant to the grid.

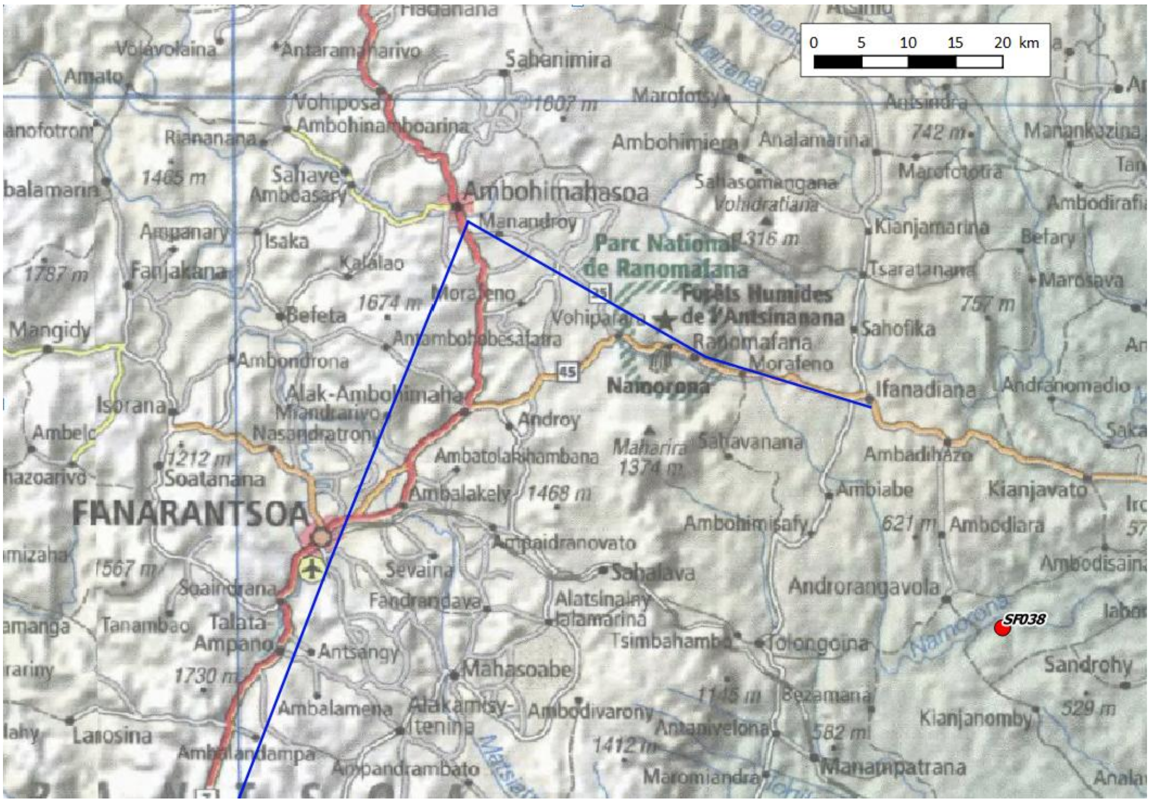


Figure 2. Proximity of the Fianarantsoa grid

2 GENERAL SITE DESCRIPTION

2.1 Background

The river takes a « S » shape when loosing elevation (when seen from the sky), which makes more complex the possibility of building hydropower infrastructures on this stretch. Different options are possible depending on the choice of the final stretch to be used.

There is currently no hydropower nor irrigation scheme at the site.

Figure 3. Site overview

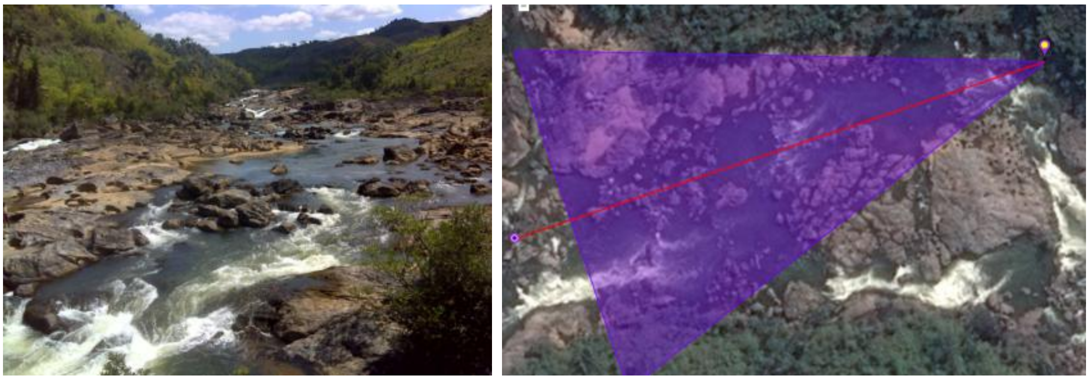


Figure 4. Detail of the site

2.2 Topography

Figure 5. Aircraft and container of remote sensors for airborne survey

The topographical survey was achieved through remote sensing. An aircraft was chartered and equipped with optical sensors.

The topographical survey has a point density of 5 /m² and a relative accuracy of 2%.

Outputs from airborne survey are (1) a high resolution orthophotography (0.2m to 0.4m resolution) and (2) a Digital Surface Model (DSM). The DSM includes the vegetal cover, but it gives an excellent global picture of the site topographical configuration. Contour lines might be deduced from the DSM.

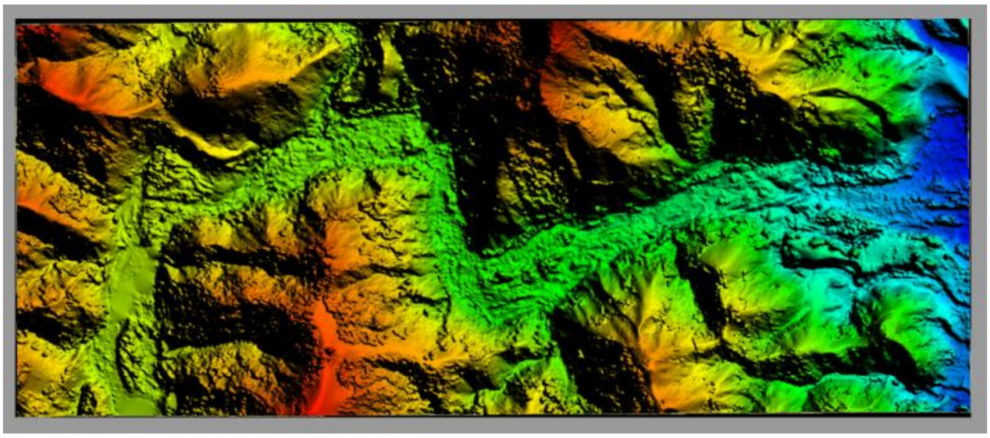


Figure 6. Digital Surface Model from airborne survey

Figure 7. Orthophotography from airborne survey

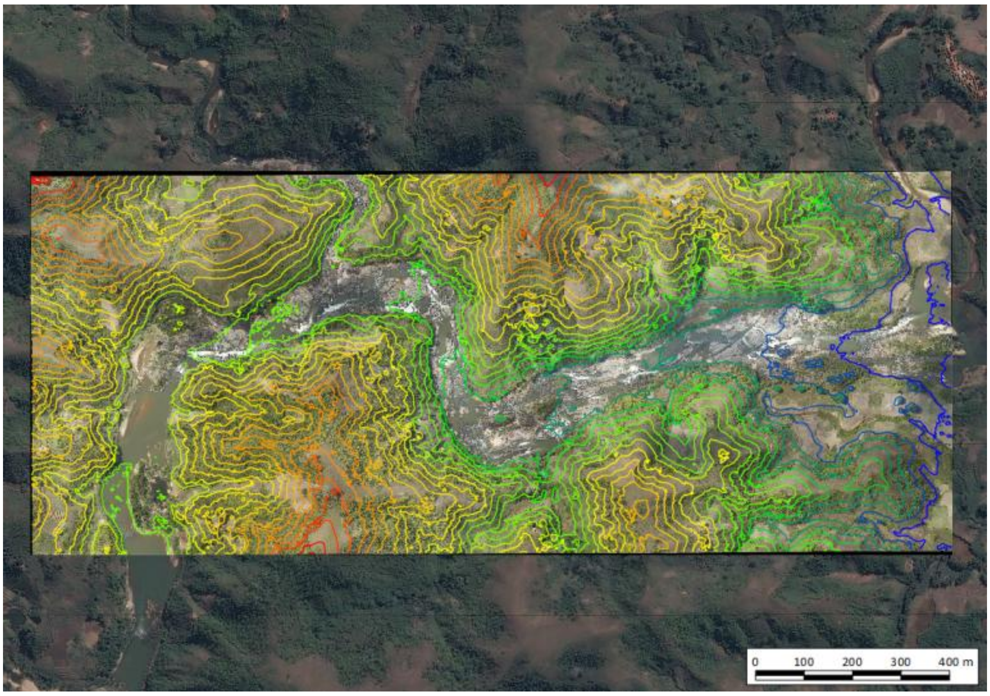


Figure 8. Contour lines deduced from the DSM

2.3 Preliminary hydrological study

Accurate information on the hydrology of the Namorona River does not exist. As a consequence, statistical characteristics of the river discharge at the site of interest have been estimated using a regional methodology. This methodology is based on the available information at other hydrometric stations distributed in the country. Given the limited spatial and temporal resolution of the available data, the results of the regional study presented below are indicative only and are not intended to be used for design purposes without further detailed hydrological studies.

Key preliminary hydrological characteristics of the river at the site of interest are presented in the table below.

River	Namorona
Main river basin	Namorona
Area [km²]	1301
Average elevation [m a.s.l]	895
Slope index [m/km]	2.0
Specific vertical drop [m]	73
Average annual rainfall [mm/yr]	1795
Average interannual discharge [m³/s]	54.2
$Q_{95\%}$ - firm discharge [m³/s]	16.9
$Q_{50\%}$ - median discharge [m³/s]	44.2
$Q_{30\%}$ [m³/s]	60.1
10yr return period flood [m³/s]	1066
100yr return period flood [m³/s]	1988

2.4 Sediment transport

As in most rivers where an important part of the watershed is not covered by forest and is cultivated and thus exposed, sediment transport is high during flood events as indicates presence of deposits on the riverbanks.

2.5 Site geology

2.5.1 Geological context

The area is dominated by a migmatitic granite composed of amphibole, quartz, feldspar and biotite. It is found under the shape of several layers of massive constitution plunging towards SE.

Under erosion and water current, the layers are shredded and disintegrated in boulders of various dimensions found on the river bed and banks and creating many islets within the Namorona River (Figure 9).

Figure 9. Islets in the Namorona River

Lateritic alteration is poor and sometimes very superficial. Is is often found under grus shape. Areas of alteration in boulders dominate in surface (boulders are noticeable on the slopes). Under erosion effect, they hurtle down in the rivers and, dragged by the current, they pile up in chaos and form islets.

Multiple fractures intersect along various directions, the most representative one being N120.82E.

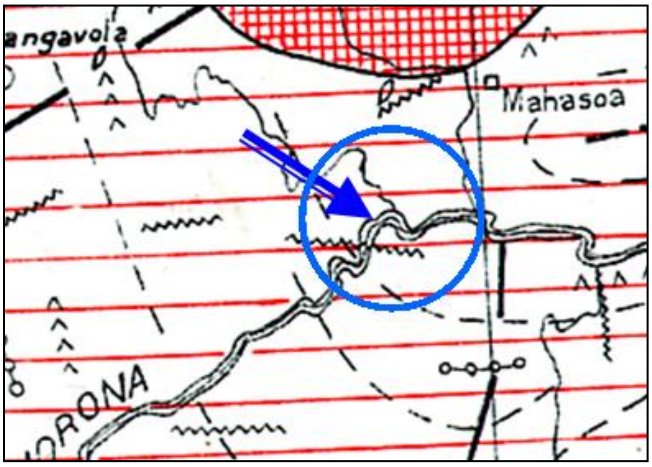


Figure 10. Contexte géologique

2.5.2 Technical characteristics

<u>Bed aspect at the projected weir location:</u> the projected weir axis crosses an islet made of sand and reworked granite-migmatitic rocks. It is encircled by the Namorona River which has a very sandy riverbed at that place. Big blocks are embedded in these sandy deposits.

Although an apparently massive bedrock, in surface the islet is composed of chaotic big rock blocks easy to clear (Figure 11).

Figure 11. Constitution of the rocky islets

Right bank support aspect: the right bank support will be founded on a steep hill slope ending with rock boulders piles. These boulders hide the massive structure of the hill which is observed from time to time at the hill basis with a folded, shredded and highly fractured aspect. The dip of the rock layers is parallel to the flow and plunges towards the right river bank (Figure 12).

Figure 12. Right riverbank at the projected weir location

Left bank support aspect: it is characterized by a steep hill slope with a heavy vegetal cover. The left bank support area is characterized by lateritic alteration ground included boulders that will have to be removed (Figure 9).

Intake: the intake and the tunnel opening are located in an area where many fractured rock boulders are found as well as in-situ massive rock (Figure 12).

Waterway: the tunnel opening is located in a boulders area and the tunnel alignment might be disrupted by a relatively deep depression line found after the intake. This issue could be mitigated if the intake is located a bit more downstream.

The rest of the tunnel will be realized in the same granitic formation as described above (Figure 10). Given the fractured aspect of rock along the river the global internal fracture state is to be determined.

Penstock and powerhouse: These areas were not accessible during the site visit. Based on the geological map, the penstock trace crosses the same geological formation as formerly described. Hazards of this area are related to poor lateritic alteration; found under granitic sand shape with in-situ boulders appearing along the hill sides.

2.5.3 Recommendations for further investigations

ELEMENT	UNCERTAINTY TO REMOVE	SURVEY TYPE
Bed at weir	✓ Existence of massive bedrock under the sand and rock blocks.	✓ Desanding ✓ Mechanical excavation or core drilling along the weir axis (on both river channels and on the islet)
Right support	✓ Continuity within the massive in-situ rock ✓ Important fractures and possible leakages towards downstream	✓ Check the support hill on the right river bank and its constitution (acquired data leave some uncertainties) ✓ Core drilling and percolation tests, compressed air blowing and sealing by the mean of injections
Left support	✓ Absence of massive rock under rock boulders chaos	✓ Mechanical excavation of the laterites and clearing of the rock boulders
Intake and waterway	✓ Level of the compact massive bedrock ✓ Leakage in the opened fractures	✓ Core drilling until reaching the massive bedrock structure ✓ Percolation test to estimate the importance of fractures and open foliations
Penstock	✓ Nature and quality of the downhill slope	✓ More detailed geological investigations to be defined in the next study stages, once the final penstock trace is defined based on the final tunnel exit opening
Powerhouse	✓ Characterization of the supporting ground (Massive rock? Boulder in place or not? Depth of laterite?)	✓ More detailed geological investigations ✓ Auger drilling or seismic reflection geophysical survey to define the bedrock level

2.5.4 Main risks

Too large distance between the two extremities of the weir (about one hundred meters) with the existence of an intermediate islet composed of chaotic boulders.

The two river channels surrounding the islets are heavily sanded up, hence heavy sedimentation is fear upstream of the weir during flood events.

2.6 Socio-environmental aspects

The site detailed description sheet is provided in the Appendices.

2.6.1 Socio-environmental background

The site is located on the Namorona River. It is situated in the fokontany of Androrangavola, rural community of Androrangavola, Ifanadiana District, Region of Vatovavy Fitovinany.

The main vegetation of the site is Savoka (secondary vegetation). We can see savoka (bamboo, ravinala) or Savoka (*Aphramomum angustifolium* and *Asplenium)*. The recent forest clearings, numerous in the area, revegetate by an herbaceous layer (*Helichrysum*, *Cynodon*).

On the Namorona banks, in particular near the weir site, we can see riparian and rupicolous forests, in the form of woody cluster (*Psiadia* and *Adina)*, and some bases of *Typhonodorum*.

Finally, we can also see some crops in the area : dry crops after forest clearings or terrace rice crops on the hillsides, that are developed alongside the watercourses and the narrow valleys.

Image 13. Vegetation upstream of the weir site

From the socio-economic perspective, the main villages in the area are Mahatsara and Antanantanana, located about 1,5km N-W of the site. However, about 40 hamlets and campsites are situated within a radius of 1km around the site. Most of them can be found ~30m and ~100m away from the route of the gallery, and ~200m upstream the weir.

The main activity in the area is agriculture: tavy crops and rain crops on the hillsides; lowlands crops (rice) ; watercourses crops (rice) and terrace crops.

The following image gives a global overview of the land use in the area.

Image 14. Land use of the area in the SF 038 site

2.6.2 Socio-environmental constraints

Several hamlets and campsites are situated in the direct neighbourhood of the site (within a radius of 1km around the site). The implementation of the project will affect these hamlets and campsites, especially regarding potential nuisances (noise, traffic, noise, atmospheric emissions…).

Moreover, if the implementation of the project leads to an increase of the water level upstream of the weir, crops and clove plantings could also be affected, depending on the extent of the ponded water.

2.6.3 World Bank Safeguard Policies that might be applied

The World Bank Safeguard Policies that could be applicable for the SF 038 site are the following:

OP 4.01 – The Bank requires Environmental Assessment (EA) of projects proposed for Bank financing to help ensure that they are environmentally sound and sustainable, and thus to improve decision making. However, we can already estimate that the adverse impacts on human populations and environment-linked areas are limited. They are reduced, not irreversible and some measures can prevent, mitigate or minimize them. Moreover, these measures can improve the environmental performance.

OP 4.12 – Involuntary Resettlement: the hydropower project will require the use of a large space (implementation of the plant, creation of access roads to the site…), which sometimes are crop areas. Moreover, the pond upstream of the weir could impact some habitation huts or crop parcels.

So the project will have to take into account the concerned people and communities, particularly regarding the restoration of the standards of living due to the loss of resources.

OP 4.11 – Cultural Heritage is not applicable; the site is not known to have special material cultural resources. Same applies for the OP 4.04 – Natural Habitats.

The projected weir is classified as a small dam (<15m high); the usual generic safety measures for dams are appropriate and do not need the implementation of OP 4.37 – Safety of Dams (for large dams).

3 PROPOSED SCHEME LAYOUT

3.1 Technical assumptions

Given the site complexity, different options are *a priori* possible, depending on the stretch to be intercepted.

Within this study, 2 options have been taken into account, as shown below. The main differences are the weir, head and the tunnel length. While option 1 tends to exploit the maximum of the available head, option 2 is focusing on a short, significant waterfall.

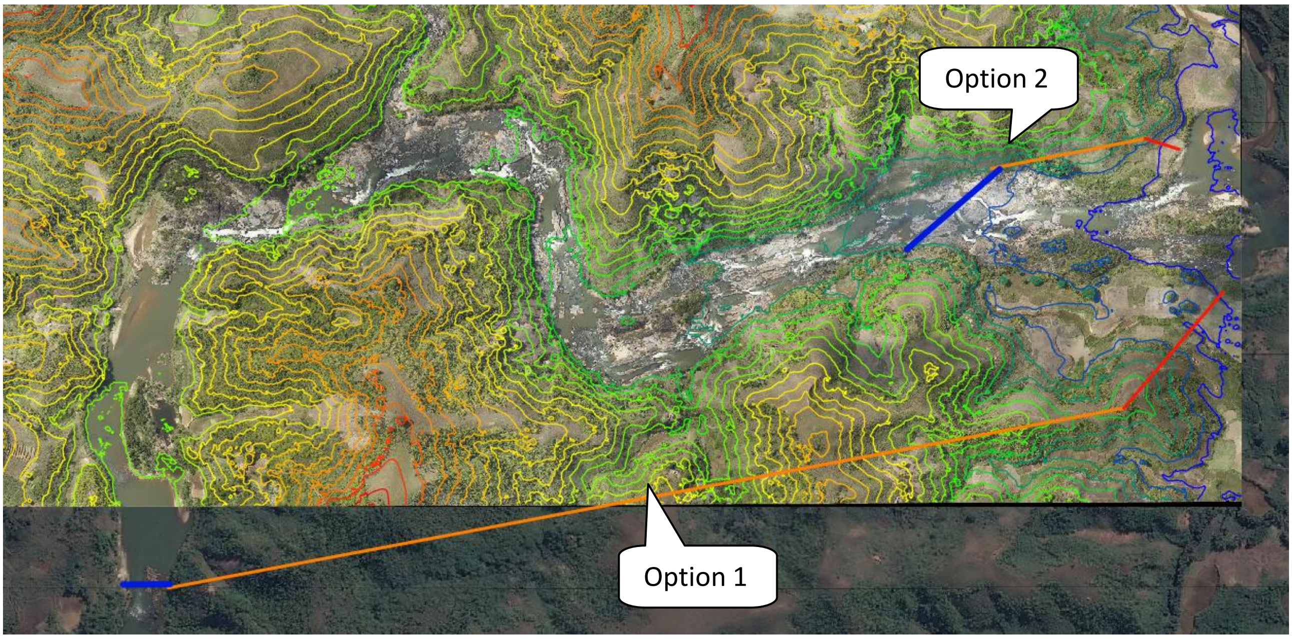


Figure 15. Options considered prior to this report

Results show that option 2 has the lowest costs in terms of LCOE (excluding access roads and transmission lines). This site has also the technically simplest and the lowest investment costs solution.

Those are the reasons why option 2 is the one considered below.

An assessment of the scheme potential in terms of installed capacity, energy generation (firm and average) and the associated capital investment costs (CAPEX) and productions costs (Levelized cost of energy) is presented in section 4. It is based on the scheme proposed in this section. Hence, at this stage of the study, the technical features of the hydropower scheme are designed for both firm and median discharges (respectively $Q_{95\%}$ and $Q_{50\%}$). The actual design flow will be determined during the detailed studies based on economical, financial and technical criterion as well as the future energy and power demand.

The scheme is presented in A3 format in Appendix 5.2 of this report.

3.2 Weir and intake

Different approach angles might be chosen for the weir, depending on the final technical choice (taking into account the geological directions of the rock, the project's flood height, etc.). A conservative value of 195m is considered here, corresponding to Figure 15. The weir's height would be 2m and the intake located on the left bank.

3.3 Desander

Given the sediment issue in the river, a desander is necessary.

3.4 Waterways

A 240m long tunnel will carry the water to the forebay. At this stage, it is considered to have a diameter of 3.5m (firm flow) or 5.6m (median flow). The tunnel option has been chosen as conservative option given the uncertainties on the canal option, but the possibility is not excluded. If feasible, this option would enhance significantly the economical performances of the project.

3.5 Penstock and powerhouse

Penstocks will be 60m long. Two pipes (1.4m diameter) are considered to carry the firm flow, 3 (1.8m diameter) to carry the median flow. Optimization of these values will be required in further studies.

3.6 Electromechanical equipments

3.6.1 Design flow taken at Q_{95}

For a design flow at Q95, the selected turbine should enable a maximization of the power output while enabling enough flexibility to absorb peaks and ensure production during low demand periods. Given the power potential of the site, it is recommended to install several similar units to optimize the plant efficiency and to enhance its availability and to follow the demand evolution as much as possible. Moreover, this solution reduces transport and access issues.

Head, discharge and foreseen output allow the choice between a Francis turbine, which offers a high performance level and a satisfactory flexibility, and the double regulated Kaplan turbine which offers a high efficiency on a large discharge range. The final choice is set on a Francis turbine which is simpler and more robust. The suggested solution does not require the use of a gearbox, which is a sensitive and costly component, as well for operation as for maintenance.

Given observations formulated about water quality, a particular attention must be paid to the quality of materials used for the construction of the turbine. One should probably consider the need for an anti-abrasion coating.

Given the site characteristics, it is planned to install two identical units, each composed of:

- Butterfly safety valve with counterweight to ensure its closure in case of emergency of black out.
- A 1 420 kW vertical axis Francis turbine running at 500rpm.
- A 690V alternator, 1 335 kW/ 1 315 kVA.
- Control and monitoring system, including speed regulator and voltage regulator.
- Security system and electrical protection.
- Step-up transformer and electrical cabinet and switchgear.
- Emergency power unit.

A power plant PLC (Programmable Logic Controller) should also be foreseen to manage the two units.

Following issues should be studied as well in the next stages of the project :

- Sedimentation problem and the need for antiabrasion coatings (e.g. Tungsten carbide).
- Technical and economic optimization of the penstock diameter.
- Technical and economic optimization of the number of units and of the design flow, according to the hydrology and the electrical demand.
- The need of a flywheel (for grid stability)
- The set up level and rotational speed of the turbine (Suction height and cavitation issues).
- Grid voltage.
- Preliminary turbine design.

Figure 16. Example of Francis vertical sets

3.6.2 Design flow taken at Q_{50}

For a design flow taken at Q50, it is recommended to install six identical units (Francis turbines) in order to optimize the global efficiency and to increase the plant availability.

Other considerations exposed for a design flow at Q95 remain valid for a design flow taken at the median discharge (Q50).Turbines will have a unit nominal power of 1 260 kW and a rotation speed of 600 rpm. The alternator power will be 1 185 kV/ 1 315 kVA for a 690 V voltage.

A power plant PLC (Programmable Logic Controller) should also be foreseen to manage the six units.

3.7 Transmission lines

Power production is assumed to be evacuated through a 63kV, 50km long line to the Fianarantsoa grid, connecting at Ifanadiana.

3.8 Key technical features

Key technical features are presented below for the firm and median flows.

		Firm flow	Median flow
Installed capacity	[kW]	2 670	7 110
Potential annual generation	[GWh/yr]	20.9	51.6
Design flow	[m³/s]	16.9	44.2
Gross head	[m]	20	
100yr return period flood	[m³/s]	1 988	
Weir length	[m]	195	
Weir height	[m]	2	
Desander		Medium size	
Tunnel length	[m]	240	
Tunnel diameter	[m]	3.5	5.6
Penstock length	[m]	60	
Penstock diameter	[m]	1.4	1.8
Number of penstock(s)	[pce]	2	3
Number of T/G units	[pce]	2	6
Transmission line length	[km]	50	
Line voltage	[kV]	63	
Length of the access road to create	[km]	5	
Length of the access road to upgrade/rehabilitate	[km]	25	

4 ENERGY GENERATIONS AND COSTS

Based on the assumptions of the economical and hydrological studies presented in the main report, the proposed hydropower scheme would feature the following values:

Gross head	**[m]**	20	
Design flow	**[m³/s]**	16.9 ($Q_{95\%}$)	44.2 ($Q_{50\%}$)
Installed capacity	**[kW]**	2 670	7 110
Potential annual generation	**[GWh/yr]**	20.9	51.63
CAPEX (excl. access and lines)	**[M$]**	10.07	20.74
LCOE (excl. access and lines)	**[$/kWh]**	0.058	0.049
Total CAPEX (incl. access and lines)	**[M$]**	28.21	38.88
Total LCOE (incl. access and lines)	**[$/kWh]**	0.160	0.090

5 APPENDICES

5.1 Socio-environmental datasheet

A – Site localisation

Site reference : SF 038

Village / Fokontany : Androrangavola

Community / District : Androrangavola / Ifanadiana

B - Description of the biophysical background

RELIEF	The relief in the area is precipitous with steep slopes and narrow lowlands. The Namora River is the main watercourse in the area. The river bed is really rocky, in particular near the expected weir site.  Rocky outcrop near the river
VEGETATION	The vegetation is mainly secondary vegetation, coming from the clearings of the area. It is mainly: - Savoka (bamboo, with a few bases of Ravinala) - Savoka (*Aphramomum angustifolium* and *Asplenium).* The recent clearings revegetate by an herbaceous layer (*Helichrysum, Cynodon*) Rupicolous and riparian forests can be seen alongside the river, in the form of woody cluster (*Psiadia* and *Adina),* and some bases of *Typhonodorum.* Some bases of banana trees are planted near the housings, while dry crops are present on the tavy hillsides. Rice crops are developed alongside the watercourse and in the narrow valleys. There are also some terrace rice crops on the hillsides.

<table>
<tr><td></td><td>

Overview of the site landscape — S21°31'31.45" E47°45'59.33"

Upstream of the expected weir site — S21°31'29.90" E47°46'5.13"
</td></tr>
<tr><td>OBSERVATIONS</td><td>
Hillsides with steep slopes, cultivated by tavy, that leads to the erosion and landslides. Moreover, they suffer from risks of materials washout upstream of the site and from sediment transport in the watercourses.

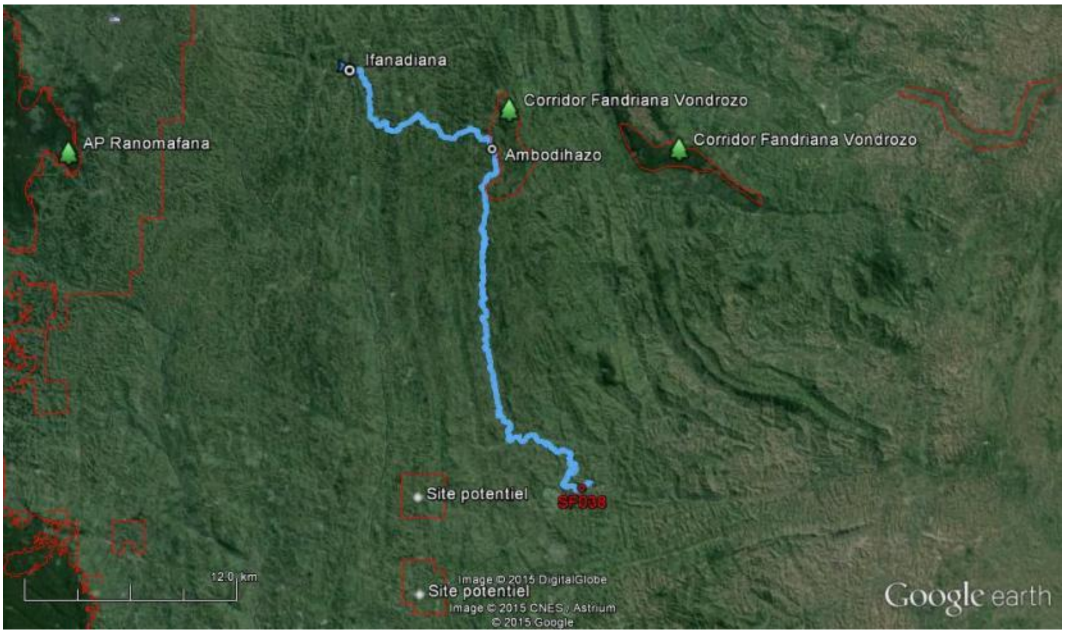

Landslide upstream of the weir — S21°31'29.92" E47°46'4.95"
</td></tr>
</table>

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

<table>
<tr><td></td><td> 
Silting of the river (upstream of the weir) S21°31'29.81" E47°46'8.00"</td></tr>
<tr><td>CRITICAL AREAS</td><td>The closest conservation site are located:

- ~8km West of the expected weir (potential protected area)

- ~10km South-West of the expected weir (potential protected area)

- ~20km North of the site (Protected Area: Fandriana Vondrozo corridor, managed by International Conservation

</td></tr>
</table>

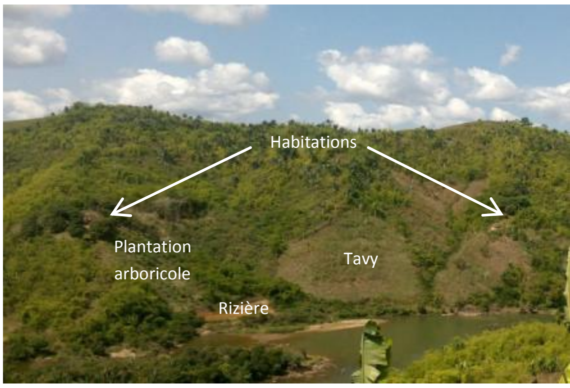
In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

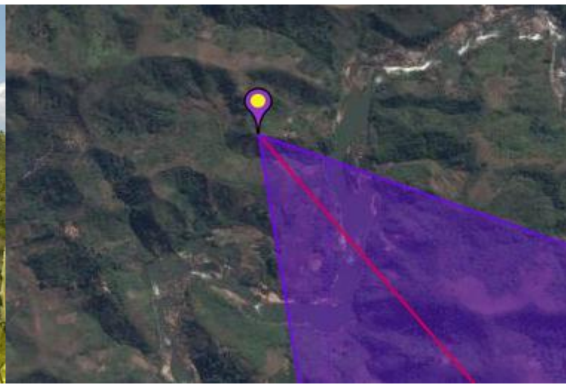
B - Description of the socio-economic background

<table>
<tr><td>LOCALITY</td><td>The site belongs to the Community of Androrangavola, Ifanadiana District. It is adjacent to Marotoko. The closest localities are Mahatsara and Antanantanana (~1km N-W of the expected weir site). Hamlets and campsites are spread alongside the watercourses and on the hillsides. You can access the site via the bifurcation situated near Ambodihazo (South), near Ifanadiana. A 40km track leads to Fenoarivo, then you have to walk for about 5km. The access follows the Western part of the Fandriana Vondrozo corridod – Protected Area, near Ambodihazo.</td></tr>
<tr><td>ACTIVITIES</td><td>Agriculture:

- Tavy crops and rain crops on hillsides
- Rice crops in the lowlands
- Rice crops alongside the watercourses
- Terrace crops


Type of housing (left hillside, upstream of the weir) S21°31'31.46" E47°45'59.33"





Typical activities S21°31'31.46" E47°45'59.32"</td></tr>
<tr><td>OTHERS</td><td>The main ethnic group is Tanala.

The site is located on mining plot that have an expired authorization for research (emerald, gold, beryl, corundum, crystal). However, the site is adjacent to another mining plot having an authorization to search for beryl and crystal (until 2046) (~500m West of the expected weir).</td></tr>
</table>

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

C – World Bank Safety Policies that could be applicable :

OP 4.01 – Environmental Assessment ☒

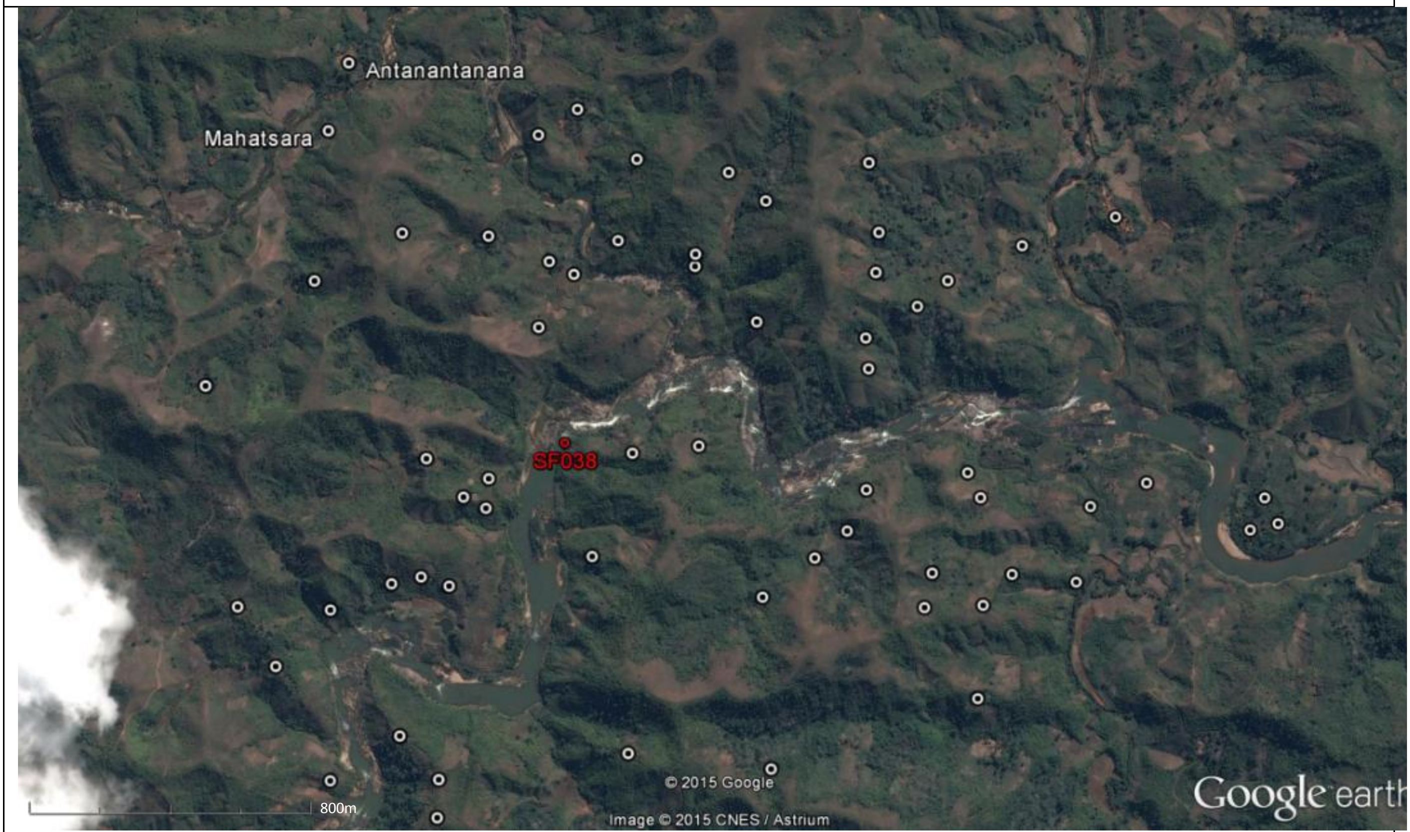
OP 4.04 – Natural Habitats ☐

OP 4.11 – Cultural Heritage ☐

OP 4.12 – Involuntary Ressettlement ☒

OP 4.37 – Safety of Dams ☐

Map of the hamlets



In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

Land use of the area of the site

: Housings/campsites

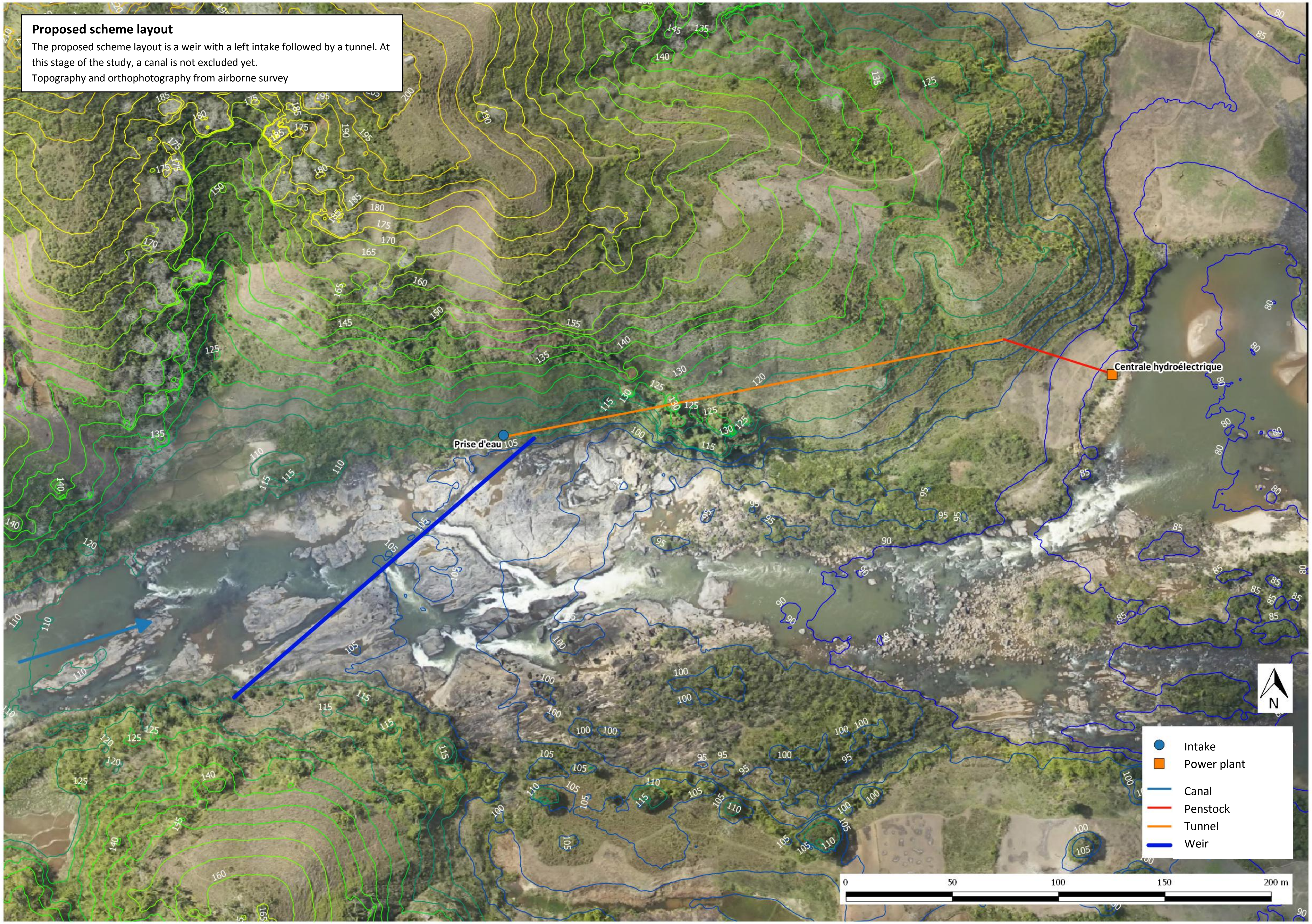
: Savoka (Ravinala and Bamboo)

: Ericoid bush / recent clearing

: Riparian forest

: Observed landslides

5.2 Proposed scheme layout



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Madagascar: Small Hydropower Resource Atlas (1-20MW)
Site Investigation Report

SF195 SITE

Namorona River | Atlas Code: SF195

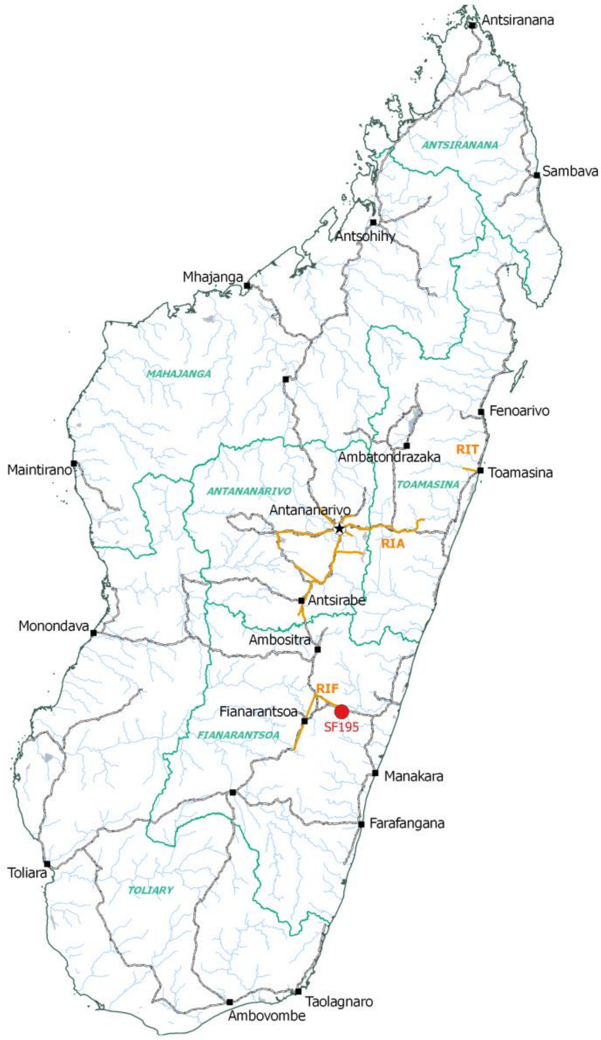


Table of Content

1 SITE LOCATION

Geographical coordinates (WGS 84)	Longitude [°]	Latitude [°]
Intake	47.567	-21.338
Powerhouse	47.571	-21.339

1.1 Administrative data

Atlas code	SF195
Site name	SF195
River	Namorona
Major river basin	Namorona
Province	Fianarantsoa
Region	Vatovavy Fitovinany
District	Ifanadiana
Commune	Kelilalina
Village	Fotsialanana (1km West from intake position)
Reference topographical map	Carte topographique n°P53 (échelle 1:50,000)

1.2 Access

At the time of visit, the site was reached by the road going southwards just before Ifanadiana. From the RN25, there are still 15km to go on a partly damaged dirt road, then another 8km to walk on a path.

During the next phases of the project's study, the option of building the access road directly from the RN25 should be considered.

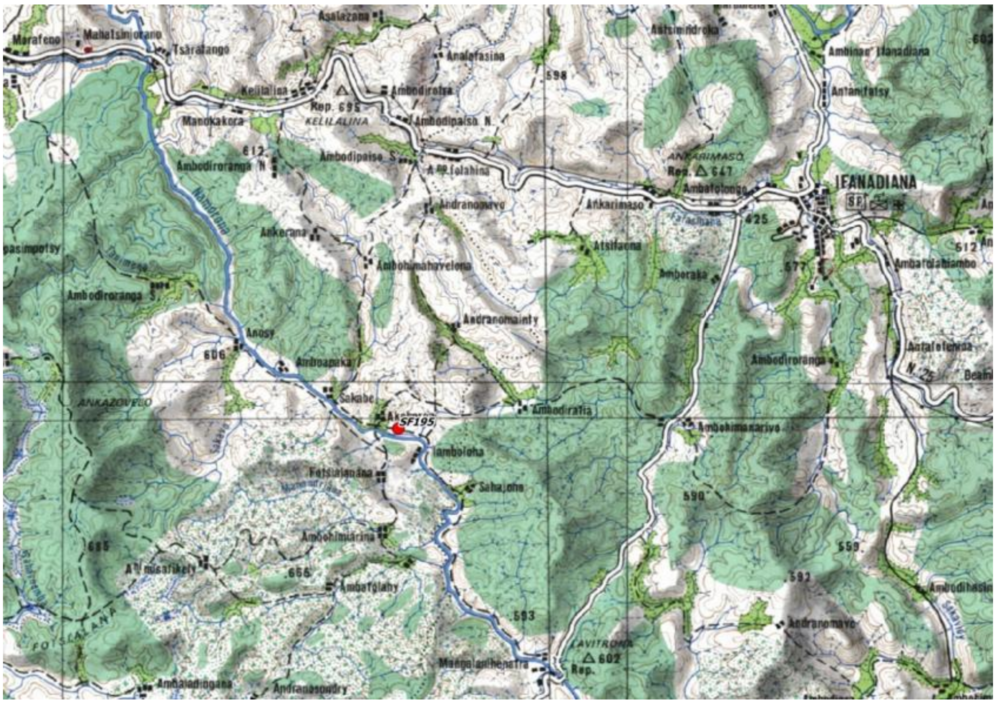


Figure 1. Access to the site.

The following picture shows the global position of the site relative to Fianarantsoa (and a schematic view of the corresponding grid).

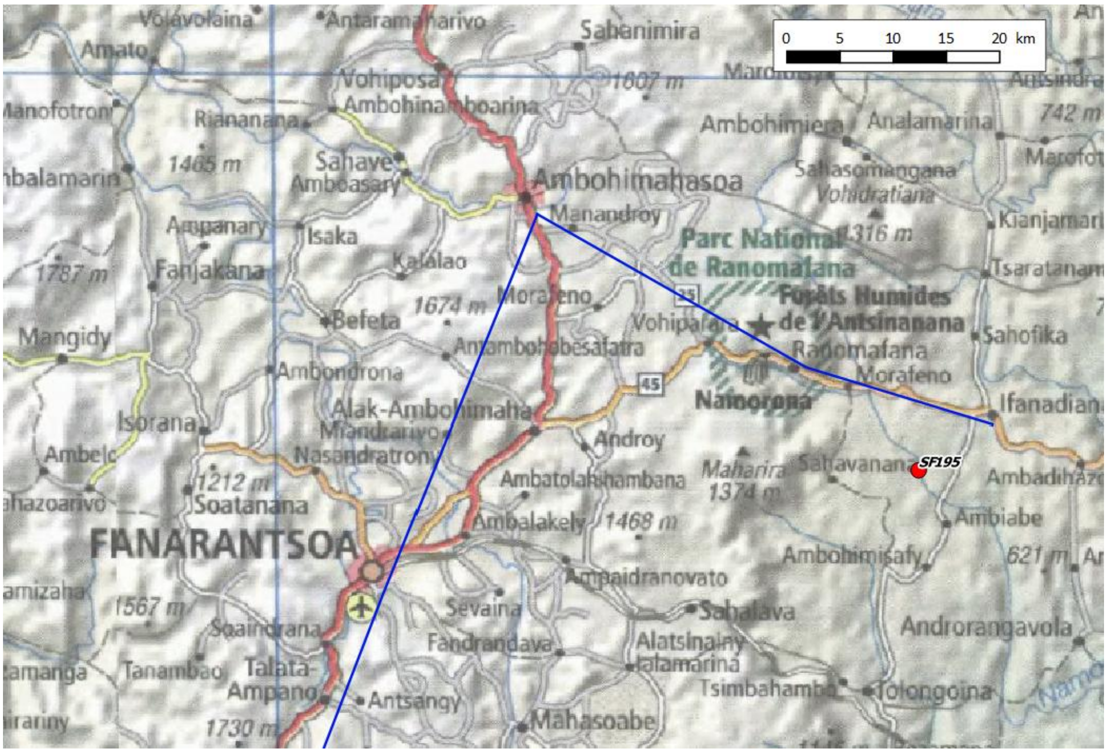


Figure 2. Position of site SF195 relative to Fianarantsoa and corresponding (schematic) grid.

2 GENERAL SITE DESCRIPTION

2.1 Background

Just upstream of the falls, the river flows on a flat stretch. The waterfalls is concentrated on a stretch between 2 hills.

Just downhill of this stretch, the river flows quietly on gentle slopes again.

Figure 3. Global view f the site (GoogleEarth)

Massive, rocky blocs lie in the river bed, sometimes covering it completely allowing the crossing of the river by foot.

Figure 4. Detail of the waterfall

It is possible to walk on both sides of the river at the site location. The left bank seems more suitable for the project's infrastructures because of (1) topography, (2) the river turning slightly left and (3) because it is on the side of the access road, thus making it easier for access purpose. Downstream of the main waterfalls follows another, small one but too far to be advantageously used in the project.

There is currently no hydropower nor irrigation scheme at the site location.

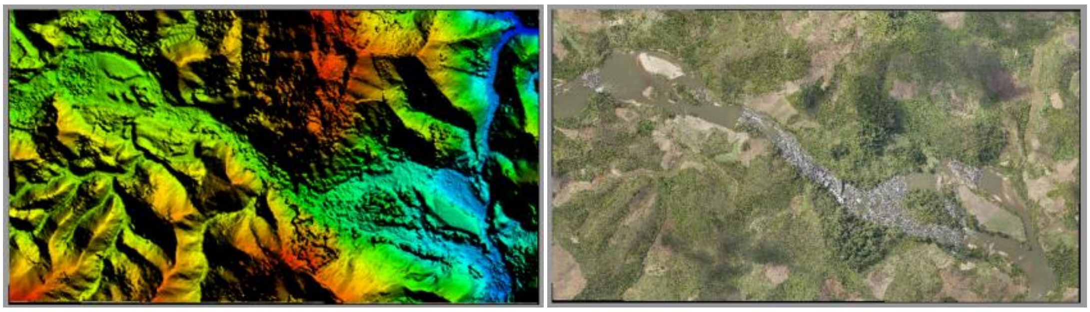
2.2 Topography

The topographical survey was achieved through remote sensing. An aircraft was chartered and equipped with optical sensors.

Figure 5. Aircraft and remote sensors container for airborne survey

The topographical survey has a point density of 5 /m² and a relative accuracy of 2%.

Outputs from airborne survey are (1) a high resolution orthophotography (0.2m to 0.4m resolution) and (2) a Digital Surface Model (DSM). The DSM includes the vegetal cover, but it gives an excellent global picture of the site topographical configuration. Contour lines might be deduced from the DSM.



In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

Figure 6. Orthophotography and Digital Surface Model from airborne survey

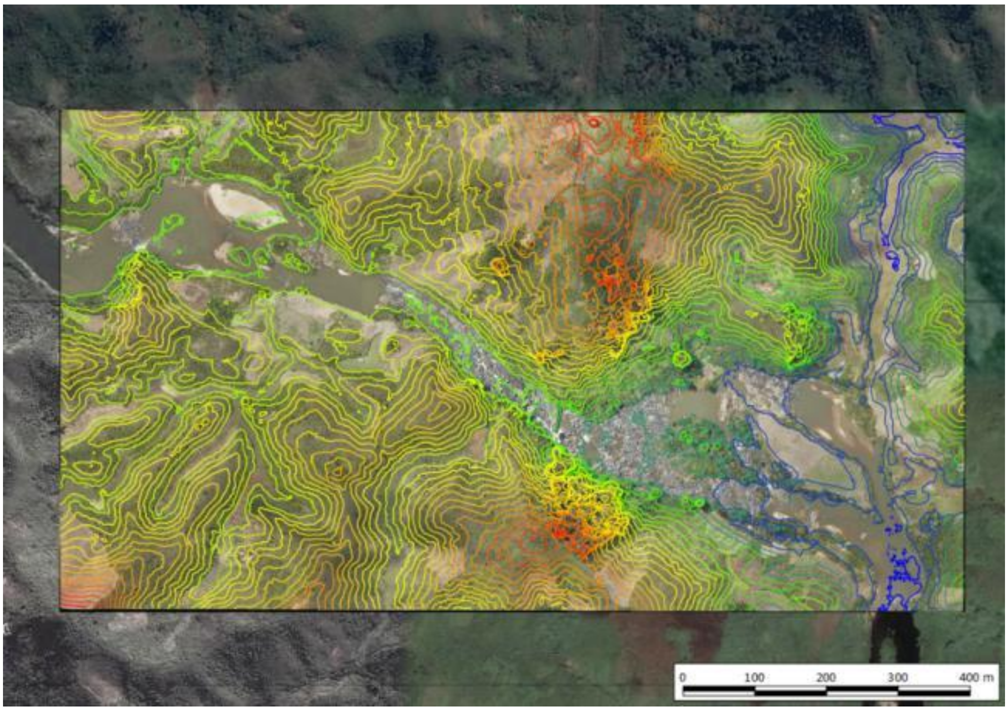


Figure 7. Coutour lines deduced from the DSM

2.3 Preliminary hydrological study

Accurate information on the hydrology of the Laroka River does not exist. As a consequence, statistical characteristics of the river discharge at the site of interest have been estimated using a regional methodology. This methodology is based on the available information at other hydrometric stations distributed in the country. Given the limited spatial and temporal resolution of the available data, the results of the regional study presented below are indicative only and are not intended to be used for design purposes without further detailed hydrological studies.

Key preliminary hydrological characteristics of the river at the site of interest are presented in the

River	Namorona
Main river basin	Namorona
Area [km²]	828
Average elevation [m a.s.l]	1 137
Slope index [m/km]	5.7
Specific vertical drop [m]	165
Average annual rainfall [mm/yr]	1 547
Average interannual discharge [m³/s]	28.8
$Q_{95\%}$ - firm discharge [m³/s]	7.8
$Q_{50\%}$ - median discharge [m³/s]	23
$Q_{30\%}$ [m³/s]	32.3
10yr return period flood [m³/s]	884
100yr return period flood [m³/s]	1 662

2.4 Sediment transport

At the time of visit, turbidity was very low (under 30NTU), yet apparently active sand strips show that sediment transport is an issue for the project.

Figure 8. Detail on a sand strip

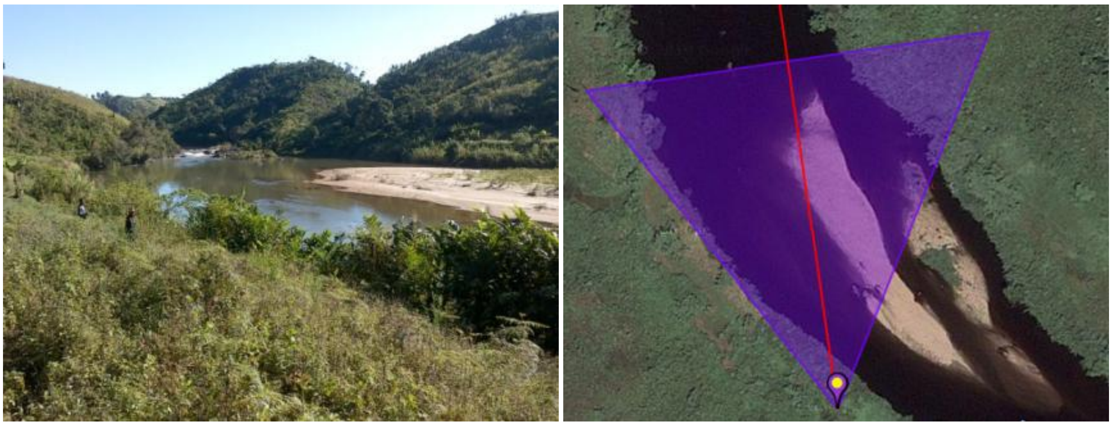


Figure 9. Active sands strip downstream of the site

2.5 Site geology

2.5.1 Geological context

The whole area petrography is characterized by heterogranular granitoid migmatite. Rarely, pink granite is found. The rocks have a foliated and are outcropping under the shape of stratiform beds, of metric thickness, plunging towards SW (that means towards the right bank of the study area - Figure 10).

Figure 10 : Outcrop on the riverbank

Two main joint directions are found : N250 60° W (same direction as the flow) et N320 70°E (intersecting the river). They are largely open and determine the size of rock boulders found a bit further.

Lateritic alteration is weak in the surroundings. It is very superficial and some massive rock layers are observed outcropping at the top of the mountains.

2.5.2 Technical characteristics

Bed aspect at the projected weir location: the weir will be founded on the bedrock. As layers plunge largely towards the right bank (in the continuation of those observed on the banks), foliations and interbed are laid parallel to the river flow direction at that place and nearly canalizing the flow.

Right bank support aspect: its basis is made of rock mass shredded into huge boulders laid anyhow along the riverbed (Figure 11). Given their dimensions, the water flow will be able to make them move towards downstream, even during floods.

Figure 11. Dismantled rock boulders, motionless even during floods

Left bank support aspect: the same applies for the left bank. At the mountainous area basis are found rock masses, dismantled into huge boulders without having been moved far from their original mass (Figure 12).

Figure 12. Dismantling of the rock blocks without displacement of them

Intake: the intake will be located on the left riverbank, within the in-situ rock masses that are deeply gashed by open fractures (Figure 10).

Waterway: with series of boulders and rock masses overhanging on the mountain sides, the geological aspect of the land does not allow and easy implementation of a canal solution for conveying water to the penstock (Figure 13). Drilling a tunnel is achievable as the mountain to cross is quite high and the tunnel alignment remains short. However, hazards such as open fractures due to interbeds and opened joints or foliations of spalling migmatites might be important.

Figure 13. Hill sides to cross to reach the penstock

A priori, the tunnel alignment is fully located in a rocky structure composed of granitoid migmatite, exception made of a section in the middle of the tunnel trace. This section would be composed of chaotic boulders made of grained rock and laid in surface. Geologicaly, it should be a granitic or andesitic inclusion (to be check during further investigations) of lenticular nature outcropping on about one hundred meter of length. The whole section is highly fractured and splits up in big boulders. The fractured aspect, noticed in surface could extend far in-depth within the formation. So, hardly controllable leakage are feared within this section and would imply masonry within a section of the tunnel.

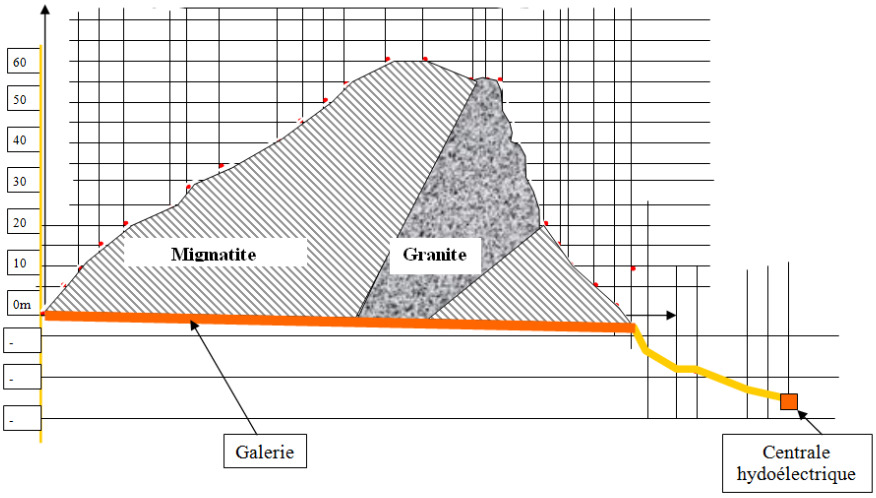


Figure 14. Indications of the presence of a highly jointed (fracture) granitic lens on about 10m (modified horizontal scale)

Penstock: the supporting land is hilly and big rock boulders are embedded in the hillside, especially at its basis.

Powerhouse: the area foreseen for the powerhouse is and extended land composed of lateritic deposits at a bank foot. Similar rock masses as those presented above are found along the riverside besides.

2.5.3 Recommandations for further investigations

ELEMENT	UNCERTAINTY TO REMOVE	SURVEY TYPE
Bed at weir	✓ Fear of leakage towards downstream given the layout of deeply opened foliations and interbeds.	✓ Drying of the riverbed, desanding and determining whether rock blocks are in-situ or reworked ✓ In-depth percolation tests along the open fractures
Right support	✓ Water tightness ✓ Stability	✓ Lateral mechanical excavation to determine the layout of rock blocks (in-situ or reworked) ✓ Taking into account cavities created by the hugge rock bouldersEssais de perméabilité
Left support	✓ Fear of leakage	✓ Percolation tests ✓ Compressed air blowing and injections within open fractures

Intake and waterway	✓ Water tightness	✓ Analytical analysis of the fractures (direction, opening, possible leakage, percolation tests) and compactness analysis by core drilling and seismic reflection geophysical survey ✓ Core drilling and percolation tests along the tunnel alignment
Penstock	✓ Nature and disposition of the land ✓ Hillsides stability	✓ More detailed geological investigations to be defined in the next study stages, once the final penstock trace is defined based on the final tunnel exit opening ✓ This observation will probably require large scale clearing
Powerhouse	✓ Existence of massive rock to serve as powerhouse foundation	✓ Auger drilling or seismic reflection geophysical survey

2.6 Socio-environmental aspects

The site detailed description sheet is provided in the Appendices.

2.6.1 Socio-environmental background

The site is located on the Namorona River. It is situated in the fokontany of Fotsialanana, rural community of Kelilalina, Ifanadiana District, Region of Vatovavy Fitovinany.

The vegetation is mainly secondary: savoka without woody elements: ravinala, bamboo, *Aframomum angustifolium*, *Asplenium* and harbeaceous plants such as *Lantana camara*, *Clidemia hirta*. Traces of forest clearings and slash-and-burn can be seen, on the hillsides, in particular on the right bank of the river. The cleared hillsides are cultivated (sugar cane, manioc…).

Nevertheless, some pieces degraded shred forests are present in the area. In particular, the pipes (gallery and penstock pipe) cross an important shred forest located on the left bank of the Namorona River. Shred forests in the area are characterized by species such as *Weinmania*, and *Harungana* in the edge of the forest.

On the Namorona banks, secondary vegetation is associated with riparian forests such as *Cyperus*.

Near the hamlets, some tree plantings (coffee, bananas…) can be found. They also sometimes meet at the edge of the rice crops in the valleys.

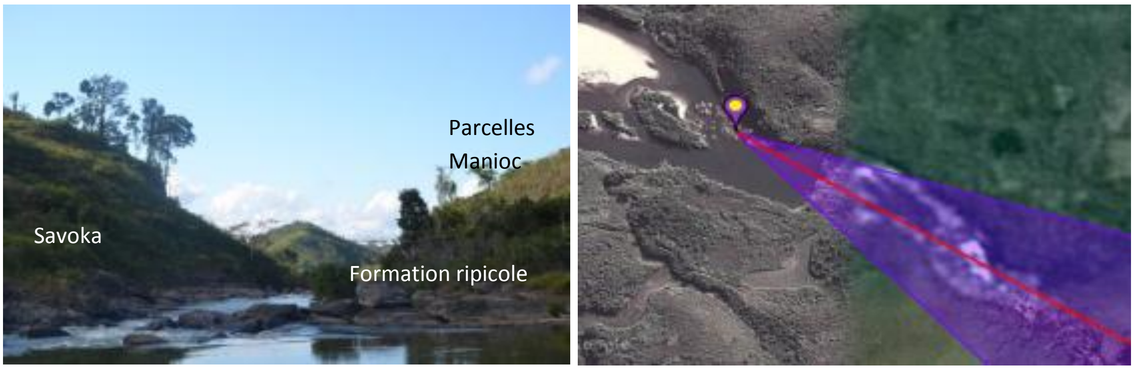


Image 15. Vegetation on the right of the weir

From the socio-economic perspective, about 15 hamlets can be found within a radius of 1km of the site. The closest hamlets of the site are Ankohoroho (about 100m from the route of the gallery) and one small campsite located about 70m away from the power plant, but on the right bank of the river. Most of the hamlets in the area have about 10 households.

Rice growing is associated with subsistence crops (corn, sweet potato, manioc) and is the main activity in the area. Generally, the land use is as follows: the upper part of the hillside is turned into subsistence crops (in particular dry crops such as manioc), the lower part of the hillside is turned into vegetable crops (bean, corn…), the lowlands are developed as rice crops, irrigated by the watercourses that cross them.

The vegetable crops are self-consumed. However, a part of the production is sold. Breeding, mainly poultry farm, is used by the majority of the households. Breeding of zebus is used for the rural activities.

Young people from the hamlets also go fishing (eels and crayfish). They sell their products in the markets of Ambiabe, Kelilalina or Ifanadiana.

The following image gives a global overview of the land use in the area.

Image 16. Land use of the soils in the SF 195 area

2.6.2 Socio-environmental constraints

Some villages and campsites can be found in the direct areas of the site (within a radius of 1km around the site). The implementation of the project will affect these villages and hamlets, especially regarding potential nuisances (noise, traffic, noise, atmospheric emissions…). In particular, a small campsite is located less than 70m away from the power plant site.

Moreover, if the implementation of the project leads to an increase of the water level upstream of the weir crops and clove plantings could also be affected, depending on the extent of the provoked ponded water.

Finally, the implementation of the weir could reduce the socio-economic value of the river, especially for fishing resources (eels and crayfish that go up the river).

2.6.3 World Bank Safeguard Policies that might be applied

The World Bank Safeguard Policies that could be applicable for the SF 195 site are the following:

OP 4.01 – The Bank requires Environmental Assessment (EA) of projects proposed for Bank financing to help ensure that they are environmentally sound and sustainable, and thus to improve decision making. However, we can already estimate that the adverse impacts on human populations and environment-linked areas are limited. They are reduced, not irreversible and some measures can prevent, mitigate or minimize them. Moreover, these measures can improve the environmental performance.

OP 4.12 – Involuntary Resettlement: the hydropower project will require the use of a large space (implementation of the plant, creation of access roads to the site…), which sometimes are crop areas. So the project will have to take into account the concerned people and communities, particularly regarding the restoration of the standards of living due to the loss of resources.

OP 4.04 – Natural Habitats: the Namorona River is the habitat of fish species such as eels and crayfish. However, those habitats are not critical, and mitigation measures could be set up during the planning studies and the implementation of the project. Further studies should evaluate the need for specific works ensuring free passage of fishes.

OP 4.11 – Cultural Heritage is not applicable because the site is not known for containing particular cultural material resources.

The projected weir (3m high) is classified as a small dam (<15m high); the usual generic safety measures for dams are appropriate and do not need the implementation of OP 4.37 – Safety of Dams (for large dams).

3 PROPOSED SCHEME LAYOUT

3.1 Technical assumptions

An assessment of the scheme potential in terms of installed capacity, energy generation (firm and average) and the associated capital investment costs (CAPEX) and productions costs (Levelized cost of energy) is presented in the following section. It is based on the scheme proposed in this section. Hence, at this stage of the study, the technical features of the hydropower scheme are designed for both firm and median discharges (respectively $Q_{95\%}$ and $Q_{50\%}$). The actual design flow will be determined during the detailed studies based on economical, financial and technical criterion as well as the future energy and power demand.

The proposed scheme layout is shown below and presented in A3 format in the Appendix of this report.

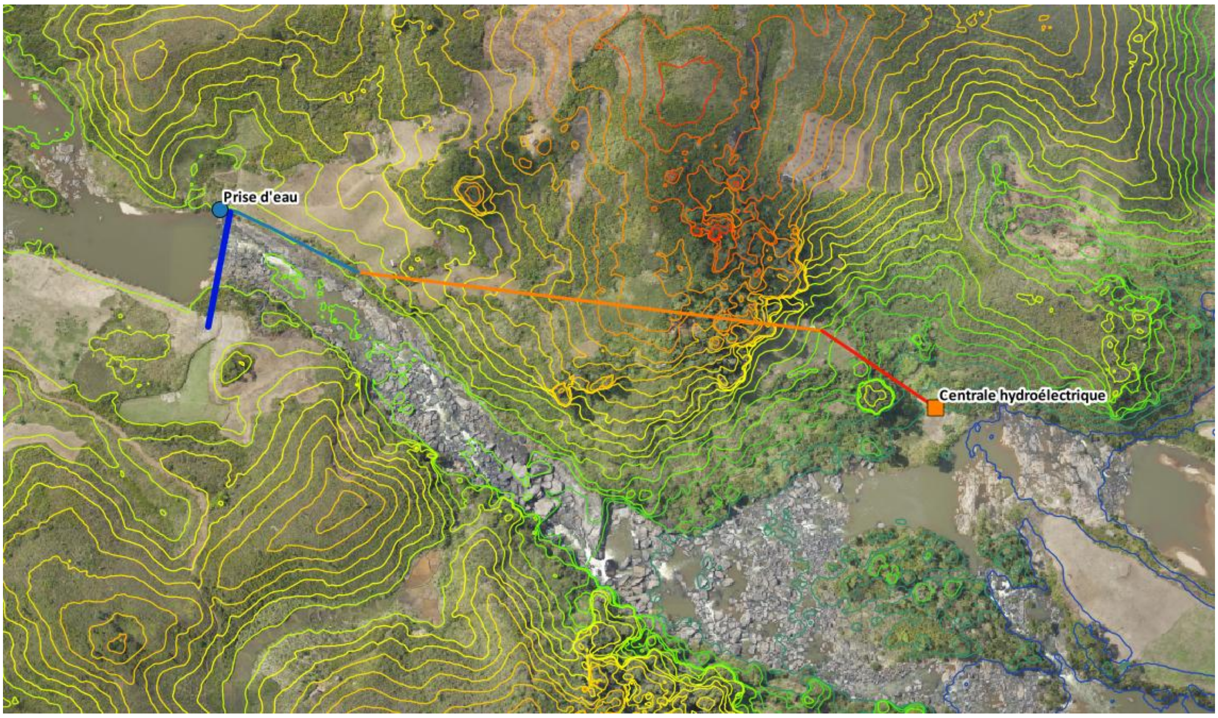


Figure 17. Proposed site layout

3.2 Weir and intake

The weir would be based on the rocky ground upstream of the falls. Its height would be low to avoid major disturbance of the river. The proximity of (a part of) the falls will help to get to a level that floods do not reach. The intake will be located on the left bank.

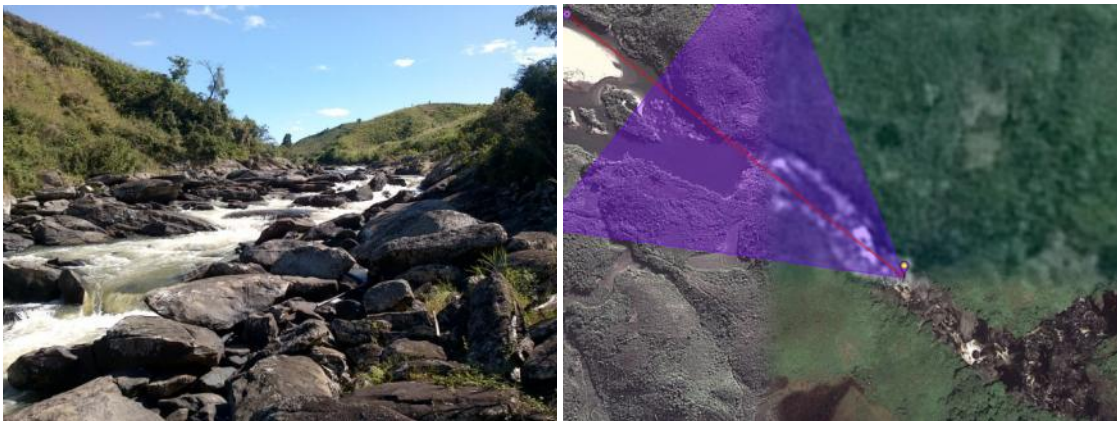


Figure 18. Vue de l'aval de l'emplacement du seuil.

3.3 Desander

Given the observations on sediment transport detailed above, it is expected to build a significant desander.

It will be located on the area following the intake, before the tunnel entrance.

3.4 Waterways

The intake will be followed by a 90m long canal (including desander), and a 300m long tunnel which allows to cross the hill avoiding the steep slopes on the left bank.

The canal will have a section of (width x height) 3.25 x 2.00m for the firm flow and 5.55 x 3.45m for the median flow.

A profile of terrain along the tunnel is presented on the figure below.

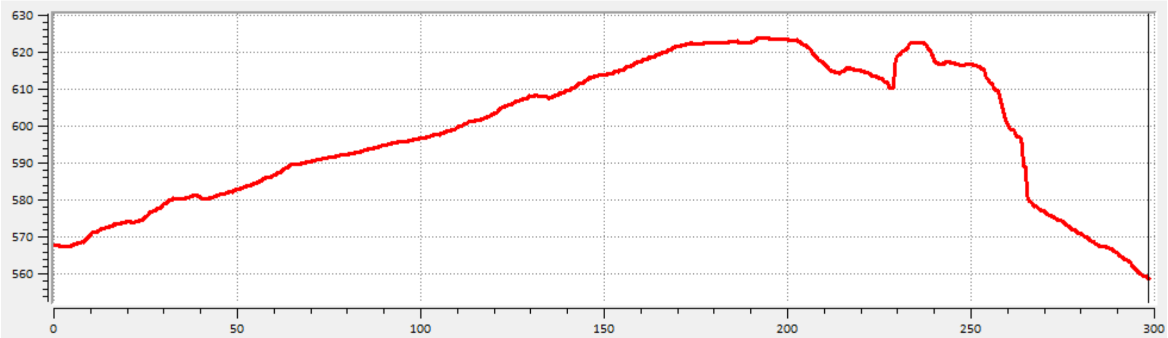


Figure 19. Terrain profile above the tunnel

3.5 Penstock and powerhouse

For the firm or median flows, the penstocks will have a diameter of respectively 1.4m or 1.6m for a length of 100m.

3.6 Electromechanical equipments

3.6.1 Design flow taken at Q_{95}

For a design flow at Q95, the selected turbine should enable a maximization of the power output while enabling enough flexibility to absorb peaks and ensure production during low demand periods. Given the power potential of the site, it is recommended to install several similar units to optimize the plant efficiency and to enhance its availability and to follow the demand evolution as much as possible. Moreover, this solution reduces transport and access issues.

Head, discharge and foreseen output allow the choice between a Francis turbine, which offers a high performance level and a satisfactory flexibility, and the double regulated Kaplan turbine which offers a high efficiency on a large discharge range. The final choice is set on a Francis turbine which is simpler and more robust. The suggested solution does not require the use of a gearbox, which is a sensitive and costly component, as well for operation as for maintenance.

Given observations formulated about water quality, a particular attention must be paid to the quality of materials used for the construction of the turbine. One should probably consider the need for an anti-abrasion coating.

Given the site characteristics, it is planned to install two identical units, each composed of:

- Butterfly safety valve with counterweight to ensure its closure in case of emergency of black out.
- A 875 kW horizontal axis Francis turbine running at 750rpm.
- A 400V or 690V alternator, 820 kW/ 910 kVA.
- Control and monitoring system, including speed regulator and voltage regulator.
- Security system and electrical protection.
- Step-up transformer and electrical cabinet and switchgear.
- Emergency power unit.
- A power plant PLC (Programmable Logic Controller) should also be foreseen to manage the two units.

Figure 20 Example of a horizontal axis Francis Turbine

Following issues should be studied as well in the next stages of the project :

- Sedimentation problem and the need for anti-abrasion coatings (e.g. Tungsten carbide).
- Technical and economic optimization of the penstock diameter.
- Technical and economic optimization of the number of units and of the design flow, according to the hydrology and the electrical demand.
- The need of a flywheel (for grid stability)
- The set up level and rotational speed of the turbine (Suction height and cavitation issues).
- Grid voltage.
- Preliminary turbine design.

3.6.2 *Design flow taken at Q_{50}*

For a design flow taken at Q50, it is recommended to install four identical units (Francis turbines) in order to optimize the global efficiency and to increase the plant availability.

Other considerations exposed for a design flow at Q95 remain valid for a design flow taken at the median discharge (Q50).Turbines will have a unit nominal power of 1 305 kW and a rotation speed of 600 rpm or 750 rpm. The alternator power will be 1 225 kV/ 1 365 kVA for a 690 V voltage. A vertical axis Francis turbine might suit as well.

A power plant PLC (Programmable Logic Controller) should also be foreseen to manage the four units.

3.7 Transmission lines

Power generated by the plant would be evacuated by a 10km long, 35kV line to the Fianarantsoa grid.

3.8 Key technical features

The scheme's key technical features are presented below for the firm and median flows' value.

		Firm discharge	Median discharge
Installed capacity	[kW]	1 640	4 900
Potential annual generation	[GWh/yr]	12.9	34.95
Design flow	[m³/s]	7.8	23
Gross head	[m]	27	
100yr return period flood	[m³/s]	1 662	
Weir length	[m]	80	
Weir height	[m]	3	
Desander		Large size	
Canal length	[m]	90	
Canal section (b x h)	[m]	3.25 x 2	5.55 x 3.45
Tunnel length	[m]	300	
Tunnel diameter	[m]	2.4	4.1
Penstock length	[m]	100	
Penstock diameter	[m]	1.4	1.6
Number of penstock(s)	[pce]	1	2
Number of T/G units	[pce]	2	4
Transmission line length	[km]	10	
Line voltage	[kV]	35	
Length of the access road to create	[km]	17	
Length of the access road to upgrade/rehabilitate	[km]	0	

4 ENERGY GENERATION AND COSTS

At this very early stage of study, and according to the hypotheses and options taken above, the project would have the following energitical and economical performances as order of magnitude:

Gross head	**[m]**	27	
Design flow	**[m³/s]**	7.8 ($Q_{95\%}$)	23 ($Q_{50\%}$)
Installed capacity	**[kW]**	1 640	4 900
Potential annual generation	**[GWh/yr]**	12.9	34.95
CAPEX (excl. access and lines)	**[M$]**	7.2	15.74

LCOE (excl. access and lines)	**[$/kWh]**	0.067	0.055
Total CAPEX (incl. access and lines)	**[M$]**	16.45	24.99
Total LCOE (incl. access and lines)	**[$/kWh]**	0.152	0.086

5 APPENDICES

5.1 Socio-environmental datasheet

A – Site localisation

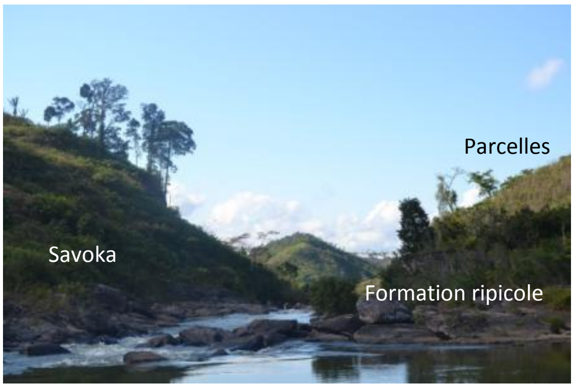
Site reference : SF195

Village / Fokontany : Fontsialanana

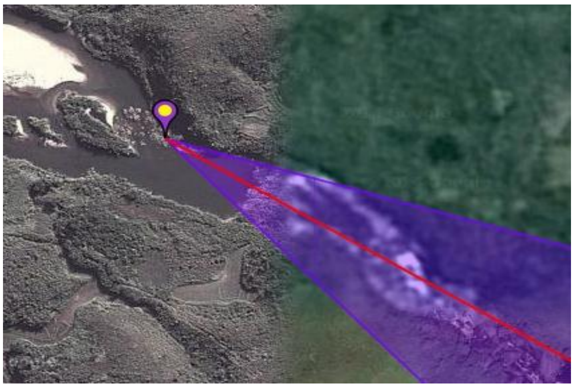
Community / District : Kelilalina / Ifanadiana

B - Description of the biophysical background

RELIEF	The expected infrastructures are located on the Namorona River. The relief is precipitous and has steep slopes.
VEGETATION	The area is mainly covered by savoka, coming from forest clearings and/or repetitive tavy. They are characterized by non woody species such as Ravinala, Bamboo, *Aframomum angustifolium*, *Asplenium and* herbaceous species such as *Lantana camara, Clidemia hirta*. On the river banks, the vegetation is mixed with riparian forests such as *Cyperus* and Phragmites. However, degraded shred forests can be found in the area. They are characterized by species such as *Weinmania*, and *Harungana* in the edge of the forest. Tree plantings (coffee, banana…) can be found near the hamlets and they sometimes are the limits of the rice crops in the valleys. The cleared hillsides are cultivated (sugar cane, manioc…).



Vegetation near the expected weir



S21°20'17.02" E47°34'0.65"

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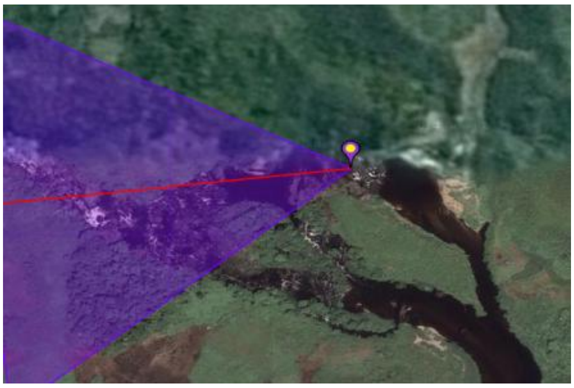
	  Vegetation near the power plant area S21°20'23.00"E47°34'22.08"
OBSERVATIONS	Some quite dense forest covers are located in rocky, hard to reach areas. On the other hand, the areas upstream of the site and alongside the watercourses are generally anthropized.
SENSITIVITIES	The SF195 site is located about 10km East of the Ranomafana Protected Area and less than 5km East than the potential Protected Area, proposed by REBIOMA. 15km East of the site is the New Protected Area called « Fandriana-Vondrozo forest corridor ». The International Conservation NGO is the sponsor. Tavy's are done by the local population and increase the sensibility of the area that can suffer from erosion and sedimentation of the watercourses at some points. Furthermore, the site is located on mining plots. Their research authorization expired. Some mining plots (research and exploitation), with authorization until 2017, allow smallholder farmers to look for crystal, corundum, emerald, beryl and tourmaline.

B - Description of the socio-economic background

LOCALITY	Fokontany Fotsialanana – Rural community of Kelilalina – Ifanadiana District (Région of Vatovavy Fitovinany). You can access the site from the seat county of the community of Kelilalina or from the Mangalahenatra village. **<u>Rural community of Kelilalina</u>** The rural community of Kelilalina is located between Ranomafana and Ifanadiana, about 10km from Ranomafana, Ifanadiana District. In 2009 the community had about 13 500 inhabitants in 13 fokontany, this represents about 1 000 inhabitants/fokontany. The seat county of the community can be reached all year round by the NR25. The community has 15 EPP[1], one CEG[2] and one new school. Health infrastructures : only one CSB[3] 2, but its proximity with Ranomafana and Ifanadiana helps the local population. The community also has sport infrastructures. The seat county of the community is linked to the JIRAMA electricity supply network. As a matter of fact, it is helped by the presence of the hydroelectric power plant of Andriamamovoka (Ranomafana). However, there is no drinking water supply network. ***Localities and villages*** Some villages and hamlets can be seen in the area (See Map of hamlets). The majority of the hamlets have less than 10 households belonging to the ethnic groups of Tanala or Betsileo. Woody plantings and/or vegetable crops surround the huts. Generally, the hamlets are located near the crops (rice crops in the lowlands, tavy crops…). They generally are temporary/seasonal crops. To cross the Namorona River, the population uses monoxyle pirogues or rafts. The hamlets are accessible by small paths from earth track or from the national road.  Typical campsite downstream of the site  Housing - Ankohoroa

[1] EPP : Ecole Primaire Publique (Public primary school)

[2] CEG : Collège d'Enseignement Général (College of General Education)

[3] CSB : Centre Santé de Base (Basic Health Centre)

Track leading to the site

Rice crop and breeding ground - Ankohoroa

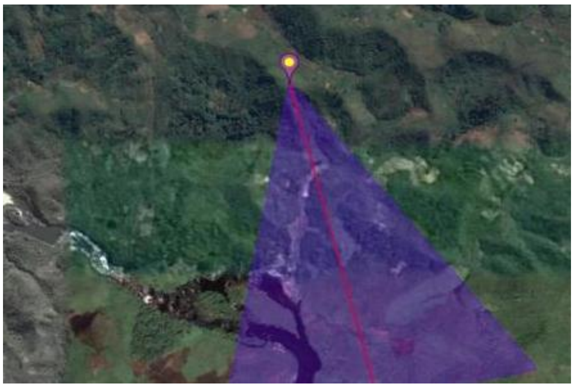
ACTIVITIES

Rice growing is associated with subsistence crops (corn, sweet potato, manioc) and is the main activity in the area. Generally, the land use is as follows: the upper part of the hillside is turned into subsistence crops (in particular dry crops such as manioc), the lower part of the hillside is turned into vegetable crops (bean, corn…), the lowlands are developed as rice crops, irrigated by the watercourses that cross them.

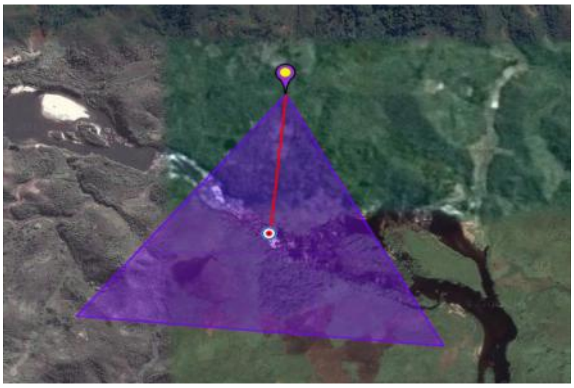
The vegetable crops are self-consumed. However, a part of the production is sold. Breeding, mainly poultry farm, is used by the majority of the households. Breeding of zebus is used for the rural activities.

Young people from the hamlets also go fishing (eels and crayfish). They sell their products in the markets of Ambiabe, Kelilalina or Ifanadiana.

Classification : rural landscape in the area : plantings (banana, sugar cane…) around the housings, rice crops alongside the valleys and the watercourses



21°20'3.01"S 47°34'26.07"E



In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

<table>
<tr><td></td><td>Slash-and-burn (tavy) : left bank on hillside, near the site S21°20'13.41" E47°34'12.69"</td></tr>
<tr><td>OTHERS</td><td>Gold diggers can be found alongside the Namorona River, upstream of the site (~2km).

Gold digging on the Namorona River

JIRAMA Ranomafana :

The closest electric network is located near Ranomafana.

It is provided by the hydroelectric plant of Namorona, which provides nearly every big town of the region of Haute Mastsiatra: Ambohimahasoa (North), Ambalavao, Betroka (South), Fianarantsoa and neighbourhood (Mahasoabe, Sahamabvy, etc.), Ifanadiana, Kelilalina and Ranomafana (East). The power plant was implemented 35 years ago and is composed by 2 5.6MW turbines. It works 24/7. However, given the more and more important needs of the Fianarantsoa city, with a peak of 10MW, the city has 4 other generators that are used during the rush hours and during the low-water period.</td></tr>
</table>

C – World Bank Safety Policies can could be applicable :

OP 4.01 – Environmental Assessment ☒

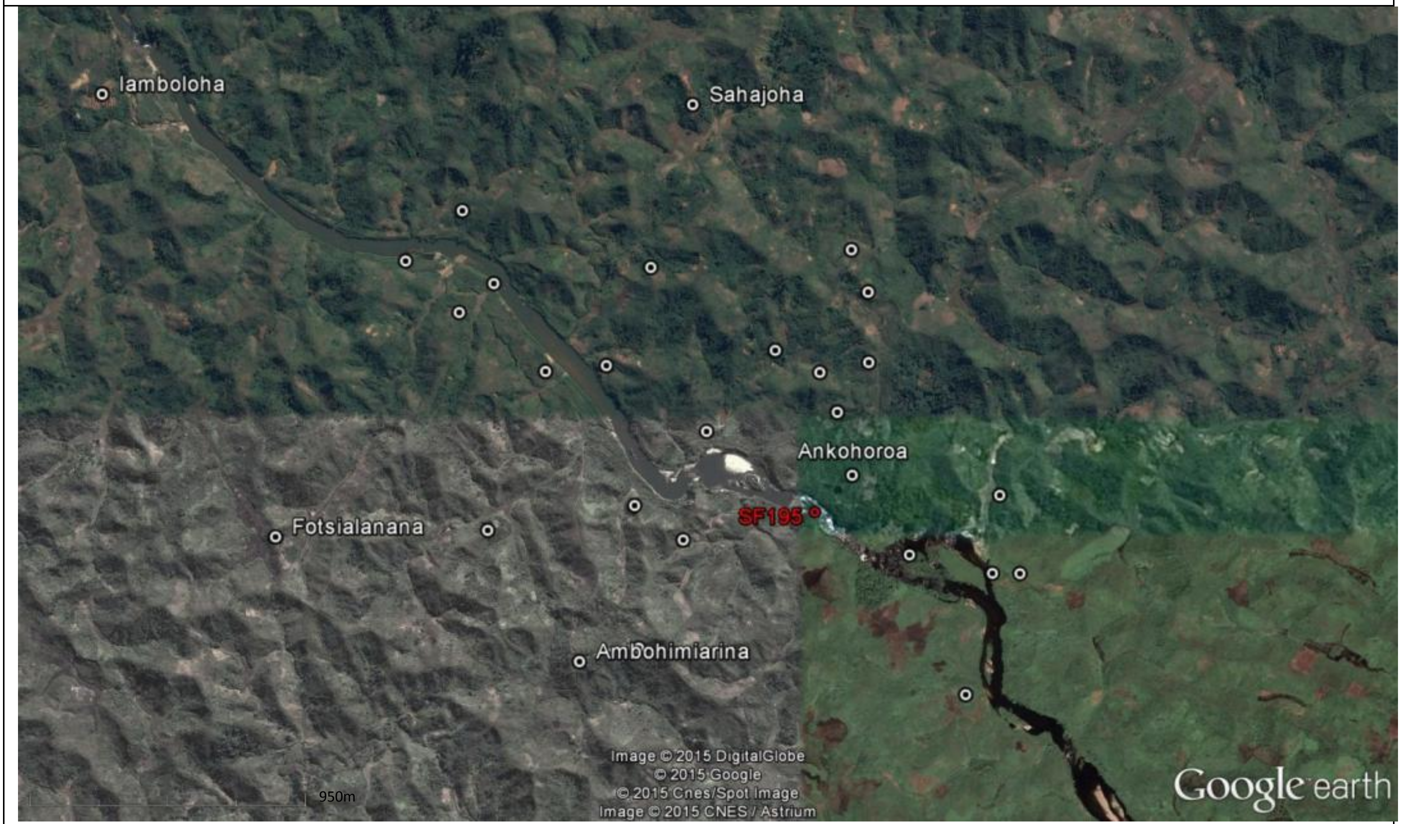
OP 4.04 – Natural Habitats☐

OP 4.11 – Cultural Heritage ☐

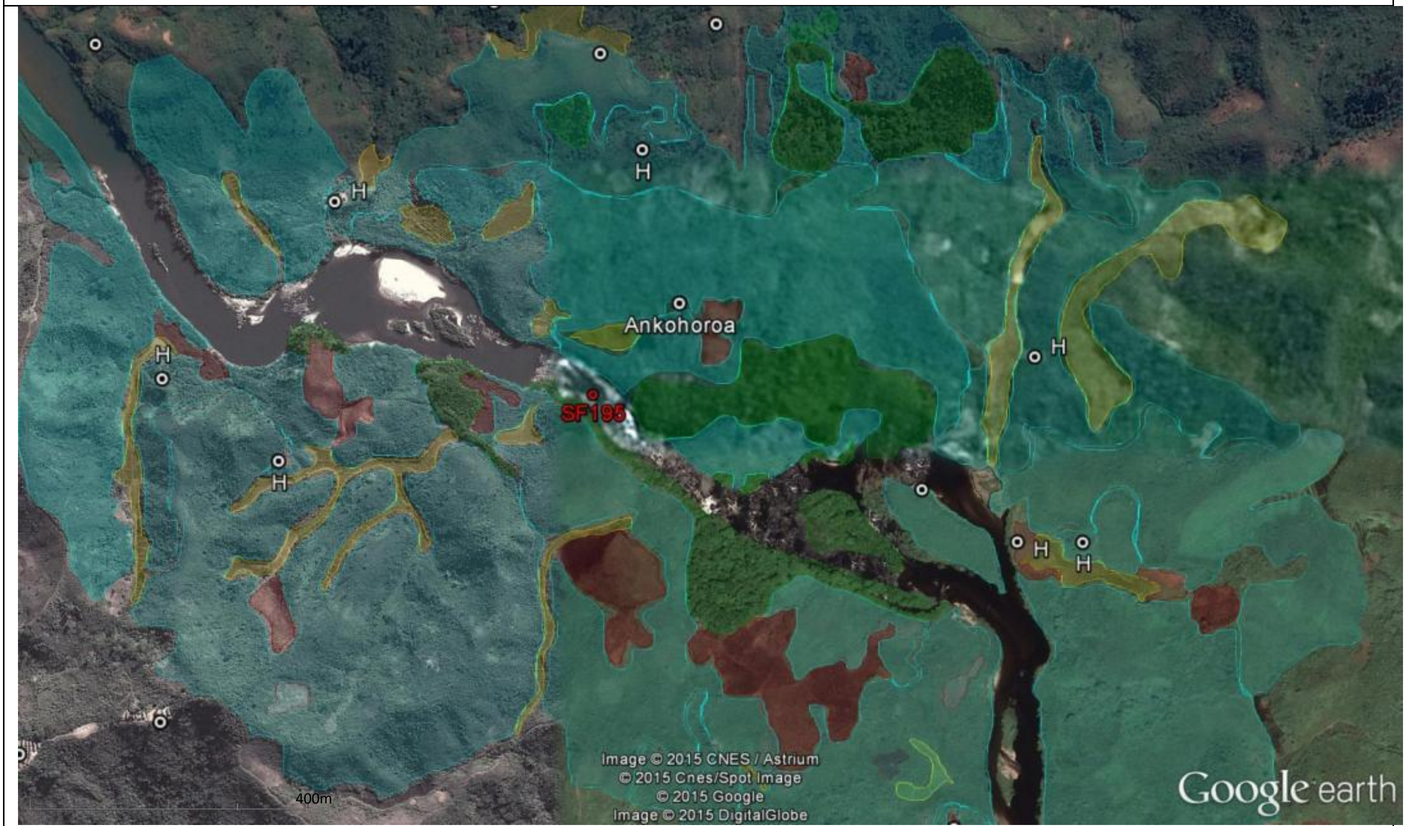
OP 4.12 – Involuntary Resettlement ☒

OP 4.37 – Safety of Dams ☐

Map of the hamlets



Land use around the site



: shred forests

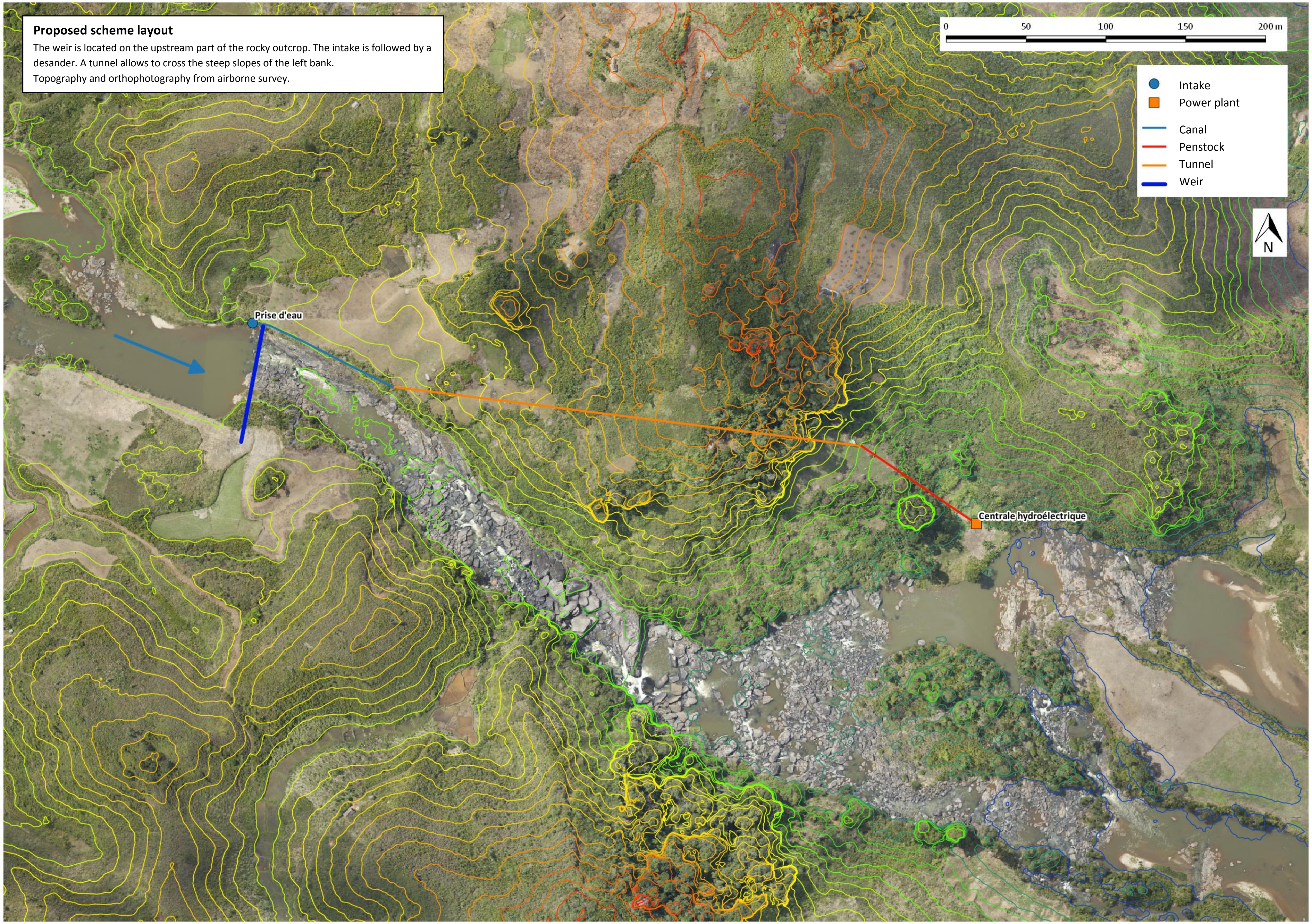
: savoka (secondary vegetation)

: rice crops

: forest clearings/slash-and-burn

: hamlets

5.2 Proposed scheme layout



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Madagascar: Small Hydropower Resource Atlas (1-20MW)
Site Investigation Report

SF196 SITE

Besana River | Atlas Code: SF196

Table of Content

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1 SITE LOCATION

Geographical coordinates (WGS 84)	Longitude [°]	Latitude [°]
Intake	47.916°	-21.032°
Powerhouse	47.922°	-21.037°

1.1 Administrative data

Atlas code	SF196
Site name	SF196
River	Besana
Major river basin	Mananjary
Province	Fianarantsoa
Region	Vatovavy Fitovinany
District	Mananjary
Commune	Ambodinonoka
Village	Ambodiara
Reference topographical map	Q52 Nord (scale 1:50,000)

1.2 Access

The site is accessed from the RN24 at Vohilava. Hence, an all-weather track follows the river to Ambodivandrika village. From there, there is another track of approximately 7km to Ambodiara village. Those two tracks and some section of the RN 24 (for a total length of 55km) require rehabilitation for the site development.

Access to the weir and intake site will need the creation of a 500m access track from Amodiara. Access to the powerhouse will require the rehabilitation of the track between the bridge on the Intsaka River and Ambohinanambo village (1.5km) as well as the creation of a 1.5km track from the bridge to the powerhouse.

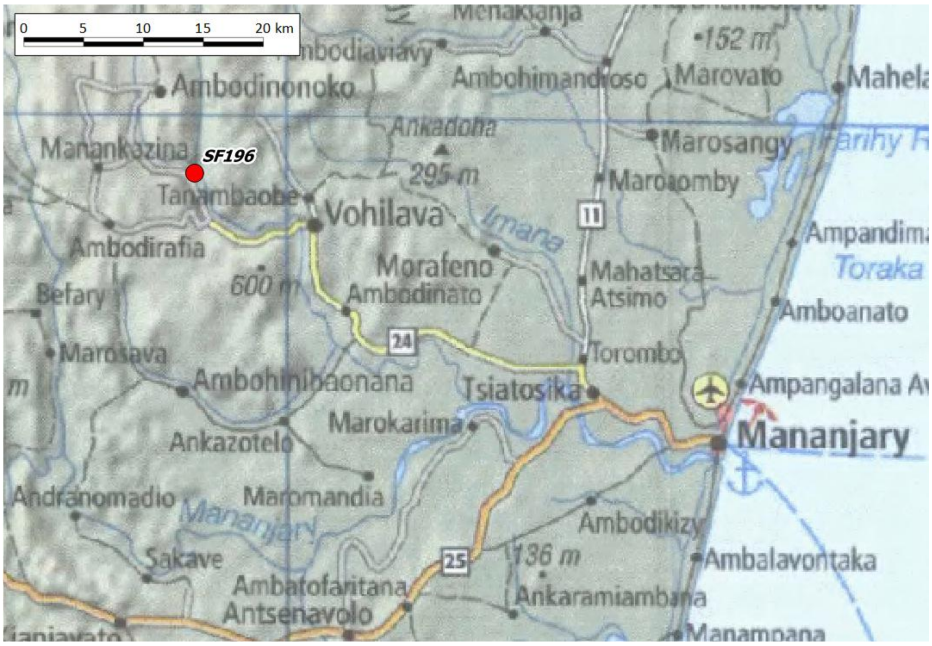

Figure 1. Site access

2 GENERAL SITE DESCRIPTION

2.1 Background

The site is characterized by a major drop of more than 150m of the Besana River in the south-East direction. The river trace 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 2 and Figure 3).

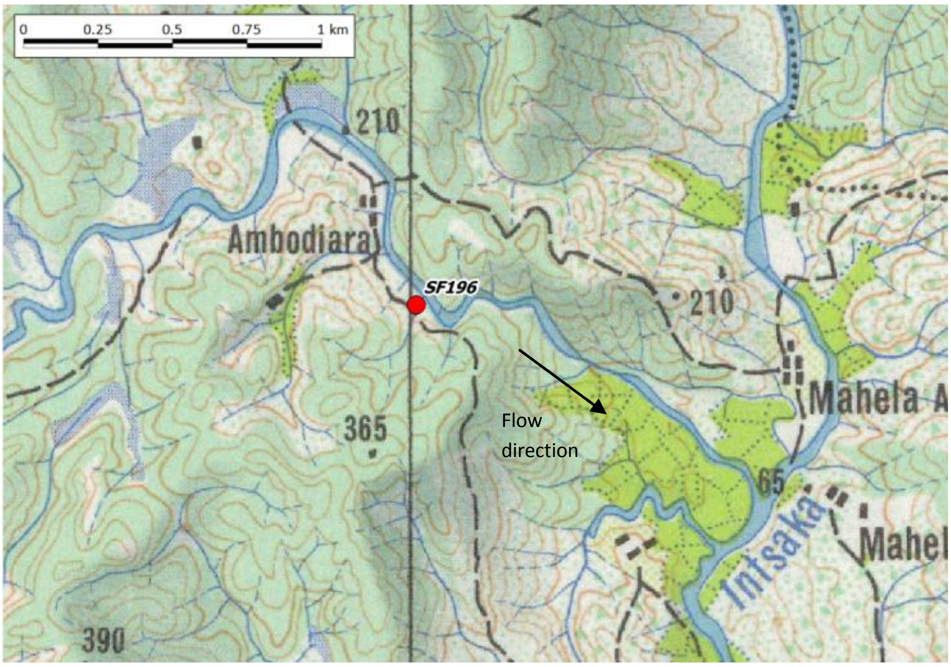

Figure 2. Topographic map (scale 1:50,000)

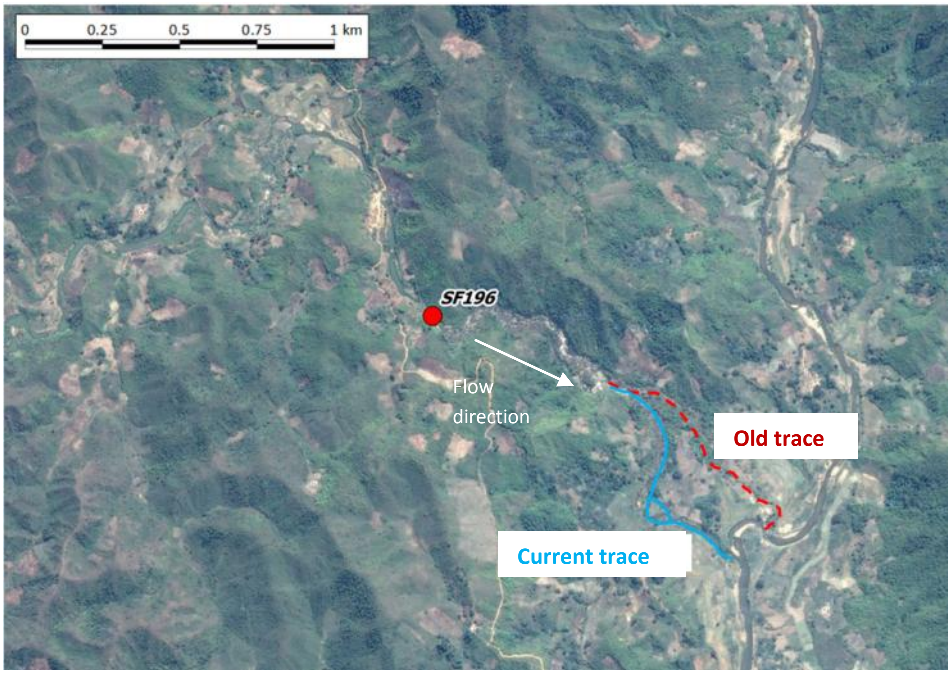

Figure 3. Satellite image of the site

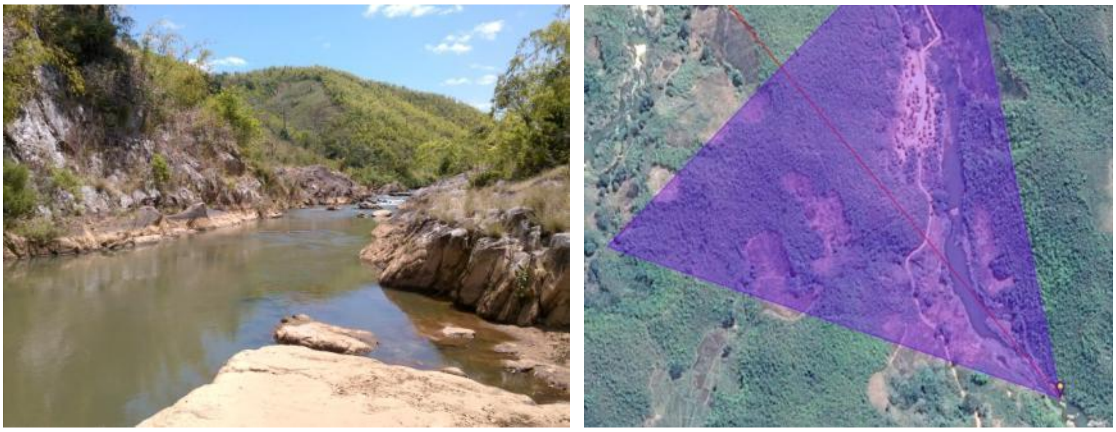

Figure 4. Suggested weir location.

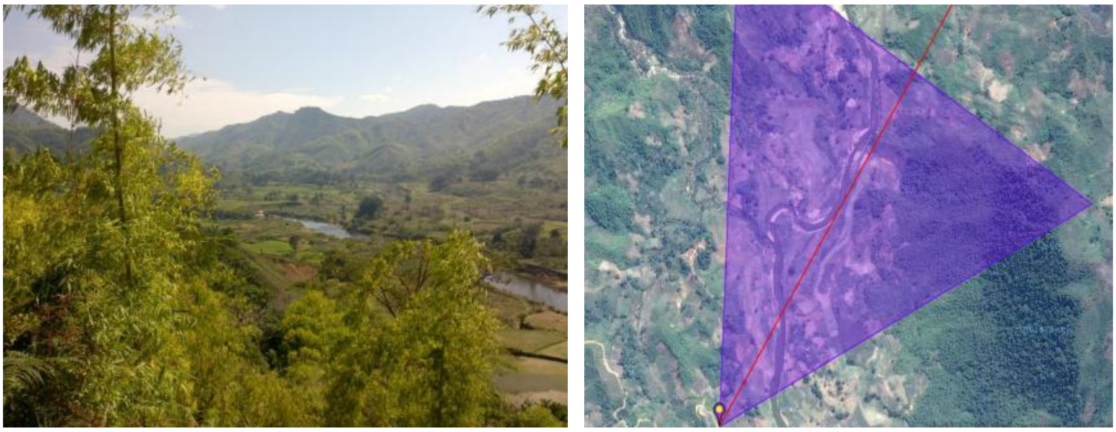

Figure 5. View towards downstream, characterized by a very flat topography.

2.2 Topography

The topographical survey was achieved through remote sensing. An aircraft was chartered and equipped with optical sensors.

Figure 6. Aircraft and remote sensors container for airborne survey

The topographical survey has a point density of 5 /m² and a relative accuracy of 2%.

Outputs from airborne survey are (1) a high resolution orthophotography (0.2m to 0.4m resolution) and (2) a Digital Surface Model (DSM). The DSM includes the vegetal cover, but it gives an excellent global picture of the site topographical configuration. Results are illustrated in the figures below and the contour lines deducted from the DSM are presented on the detailed proposed scheme layout in section 0.

Figure 7. Orthophotography of the site

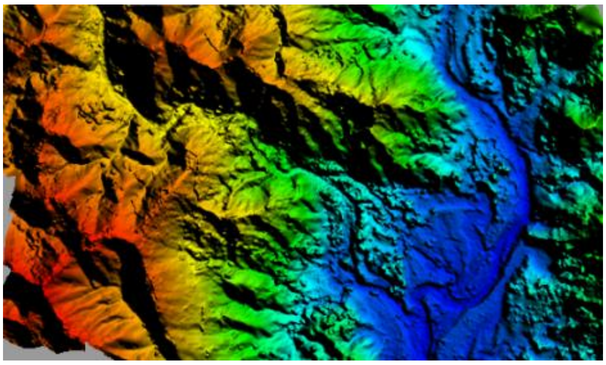

Figure 8. Digital Surface Model of the site

2.3 Preliminary hydrological study

Accurate information on the hydrology of the Besana River does not exist. As a consequence, statistical characteristics of the river discharge at the site of interest have been estimated using a regional methodology. This methodology is based on the available information at other hydrometric stations distributed in the country. Given the limited spatial and temporal resolution of the available data, the results of the regional study presented below are indicative only and are not intended to be used for design purposes without further detailed hydrological studies.

Key preliminary hydrological characteristics of the river at the site of interest are presented in the table below.

River	Besana
Main river basin	Mananjary
Area [km²]	125
Average elevation [m a.s.l]	366
Slope index [m/km]	5.2
Specific vertical drop [m]	58
Average annual rainfall [mm/yr]	2414
Average interannual discharge [m³/s]	6.3
$Q_{95\%}$ - firm discharge [m³/s]	1.4
$Q_{50\%}$ - median discharge [m³/s]	4.7
$Q_{30\%}$ [m³/s]	7.1
10yr return period flood [m³/s]	279
100yr return period flood [m³/s]	514

2.4 Sediment transport

At the time of the site visit (October 2014), turbidity was measured at 40 NTU, which is good. However the presence of lateral silt and sand deposits demonstrates that significant erosion and deposition processes occur at some period of the year, likely during major flood events.

Adequate sediments and gravels trapping systems will be designed at the feasibility study stage based on an analysis of the sediment load at different river discharges.

2.5 Site geology

2.5.1 Geological context

Figure 9. Domination of granite with lamellar quartzite intrusions.

All the area is dominated by heterogranular granite made of quartz, feldspar and biotite with lamellar quartzite intrusions (Figure 9). Visible rocky mass are highly fractured because of multiple cleavages, opened by decompression.

The Besana River is an affluent of the Saka River. Its flow is directed by an important regional fault, oriented N 70W. the presence of this faults locally increases local fracturing effects.

These facts favor rock alteration in boulders that are found in many places in superficial area and on the riversides. They are set in granitic sand and are sometimes rooted in laterite on the hills sides.

Total lateritic alteration remains low in the entire area (order of the meter). It is of grained texture with yellow to reddish color and is found below an important vegetal cover.

2.5.2 Technical characteristics

Figure 10. Bed aspect at the weir

Bed aspect at the projected weir location (Figure 10): along the projected weir axis, rock creates the riverbed. Faults planes are also observed ; they create some drops in elevation.

Left bank support aspect: the left bank is characterized by a steep hill slope with, at its basis, boulders dropped off by the flow during flood events. An in-place rock mass is also observed with an intense set of open cleavage that extends up to the riverside during low flow periods.

Figure 11. Right bank aspect.

Right bank support aspect (Figure 11): the hill on the right bank of the river is characterized by a highly fractured granitic structure.

Intake: Same aspect as the right bank. The rock structure has multiple cleavages and a tendency to form boulders.

Figure 12. Zone of the tunnel

Waterway: the tunnel will cross a hilly area (alternance of tops and depressions, see Figure 12) that culminates quite high (about 100m of elevation difference between the hill top and the river), what ensures enough cover for the tunnel.

However, one must fear the repercussions of the regional faults followed by the river which migh induce open fractures, even deep inside the hill.

Figure 13. Passage de la conduite forcée.

Penstock: the penstock will be located on a hilly slope presenting the same risks as previously defined. Rock boulders, or even rock masses, are found along the slope, enrooted in laterite surrounded by granitic sand.

Powerhouse: at the proposed powerhouse location, the land is clayey silt, with little sand fraction along the rice fields. No outcrops are seen but the existence of the rocky roof below the river close by (30 to 40m) suggests that the same structure should be found below the powerhouse foundations.

Tailrace canal: it is located on clayey silt, with little sand fraction

2.5.3 Recommendations for further investigations

ELEMENT	UNCERTAINTY TO REMOVE	SURVEY TYPE
Bed at weir	Existence of a fault along the river axis	✓ Conduct a study and geological observations in the dry to observe the fault followed by the river ✓ Percolation testing ✓ Core drilling of the rock and compression tests to define the level of alteration and the soil bearing capacity
Right support	Leakage through fractures	✓ Percolation tests in situ, grout injections for sealing.
Left support	difficulty caused by boulders spread out at the basis of the hill	✓ Mechanical excavation to get rid of boulders and to find the bedrock
Intake	Existence of multiple fractures within the rock mass of the bank	✓ Close analysis of the multiple fractures affecting the rock, grout injections for sealing

Waterway	State of internal fracturing of the rock structure under influence of the regional fault. Leakages within the tunnel.	✓ 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	Geological nature of the ground (structured laterite ? In-place boulders below laterite ? Fractured rock structure ?)	✓ More detailed geological reconnaissance to be defined in the next study stages, once the final penstock trace is defined
Powerhouse	Search of the bedrock for the powerhouse foundations	✓ Auger drilling or seismic reflection geophysical survey to determine the level of the bedrock

2.5.4 Major risks

The main regional fault followed by the river may create multiple fractures, with several opening state, within the granitic rock structure and even deep inside it. It such case, leakages will be hardly manageable unless the tunnel is designed with appropriate concrete cover.

2.6 Socio-environmental aspects

The site detailed description sheet is provided in the Appendices.

2.6.1 Socio-environmental context

The site is located on the Besana River. It is situated in the fokontany of Imahatsara, rural community of Ambodinonoka, Mananjary District, Region of Vatovavy Fitovinany.

The vegetation is mainly composed by savoka (*Ravenala madagascariensis)* and/or bamboo (*Nastus*) with/without woody plants, and by bushy vegetation and/or low vegetation covering the recently cleared soils. Savoka are secondary vegetation coming from the degradation of the environment due to forest clearings and repetitive fires.

Some shred forests (*Weinmania*, *Humbertia*…) which are relatively degraded can be seen, in particular near the falls. They are mixed with riparian forests and can sometimes be found on the crests. The riparian vegetation is characterised by the presence of *Pandanus*, *Typhonodorum*, *Raphia farinifera,* mixed with forest vegetation or savoka (bamboos, ferns).

Image 14. Overview of the vegetation near the weir

From the socio-economic perspective, the Imahatsara and Ambodinananambo villages are the closest localities of the site. They are respectively located less than 400m on the right bank, upstream of the weir, and ~200m South of the power plant. Other hamlets/ campsites are situated within a radius of 1km around the site: one particular hamlet is located less than 100m from the route of the expected penstock pipe, in particular along the track heading to the site.

The main local activity is the agriculture, in particular rice growing associated with subsistence crops (manioc, corn, sugar cane) and vegetable crops. Vast rice crops can be found in the lowlands and the terrace hillsides, such as the ones near the power plant. The river banks are also highlighted by the implementation of small crops (see downstream of the weir). Plantings (banana trees, coffee trees, pine trees) also surround the villages and hamlets of Imahatsara.

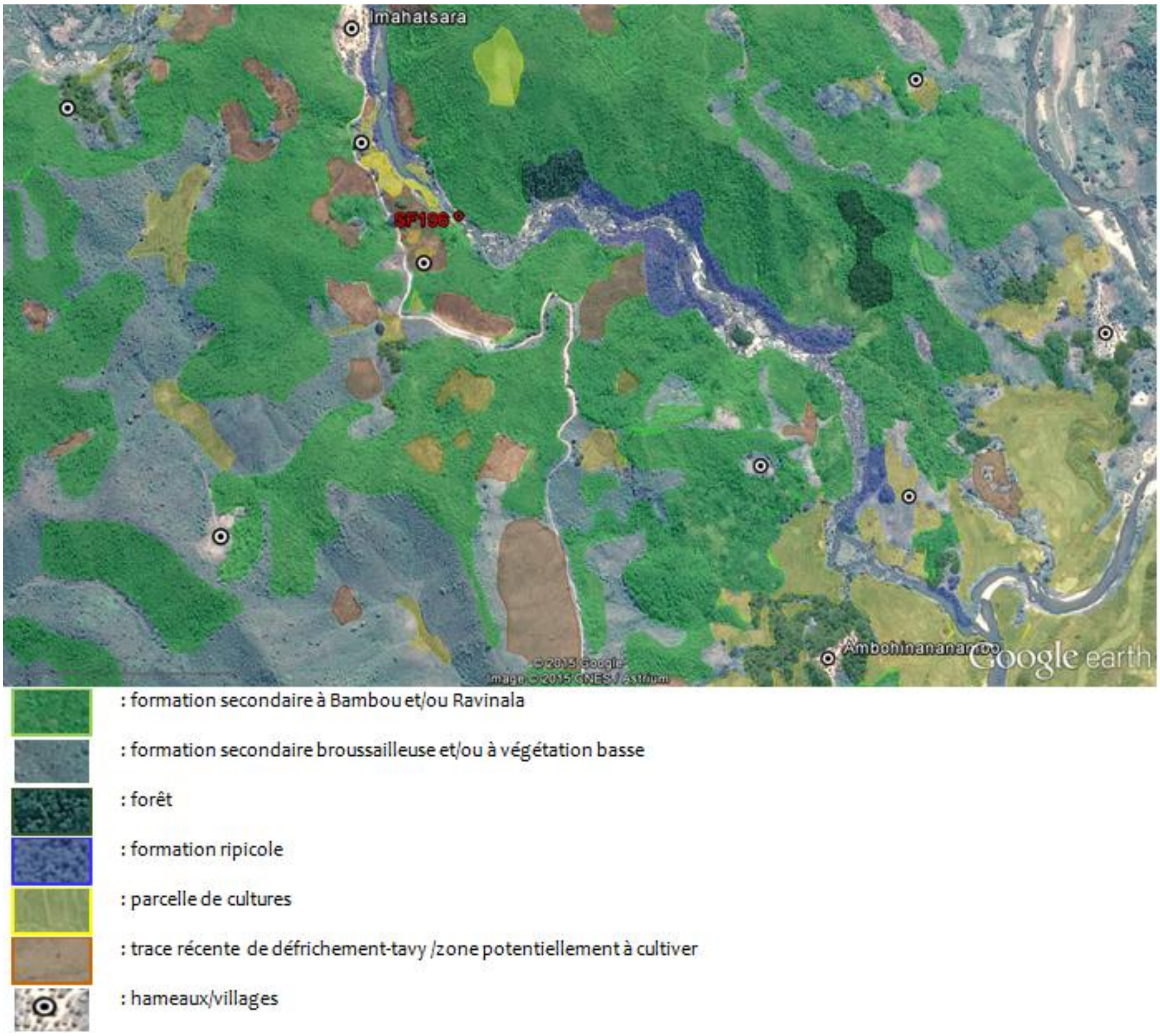

Image 15. Land use of the site

2.6.2 *Socio-environmental constraints*

The Imahatsara and Ambohinananambo villages, and other hamlets and campsites are located in the area (within a radius of 1km around the expected infrastructures). The implementation of the project will affect the villages and hamlets, , especially regarding potential nuisances (noise, traffic, noise, atmospheric emissions…).

Moreover, if the implementation of the project leads to an increase of the water level upstream of the weir, some crops, located upstream of the weir and the Imahatsara village, could be affected, depending on the extent of the water pond.

The project can impinge on rural areas, due to the implementation of the power plant, the weir and pipes, leading to a loss of resources for the concerned populations.

2.6.3 World Bank operational policies that might be applied

The World Bank Safeguard Policies that could be applicable for the SF196 site are the following:

OP 4.01 – The Bank requires Environmental Assessment (EA) of projects proposed for Bank financing to help ensure that they are environmentally sound and sustainable, and thus to improve decision making. However, we can already estimate that the adverse impacts on human populations and environment-linked areas are limited. They are reduced, not irreversible and some measures can prevent, mitigate or minimize them. Moreover, these measures can improve the environmental performance.

OP 4.12 – Involuntary Resettlement: the hydropower project will require the use of a large space (implementation of the plant, creation of access roads to the site…), which sometimes are crop areas. Moreover, ponded water upstream of the weir could impact some habitation huts or crop parcels. So the project will have to take into account the concerned people and communities, particularly regarding the restoration of the standards of living due to the loss of resources.

The projected weir (4m) is classified as a small dam (<15m high); the usual generic safety measures for dams are appropriate and do not need the implementation of OP 4.37 – Safety of Dams (for large dams).

3 PROPOSED SCHEME LAYOUT

3.1 Technical assumptions

The hydropower potential of the site makes it likely to feed the surrounding villages, up to the Mananjary isolated grid, currently fed by a thermal power plant. The objective is to carry out a high level assessment of the scheme potential in terms of installed capacity, energy generation (firm and average) and the associated capital investment costs (CAPEX) and productions costs (Levelized cost of energy). Hence, at this stage of the study, the technical features of the hydropower scheme are designed in the following sections for both firm and median discharges (respectively $Q_{95\%}$ and $Q_{50\%}$). The actual design flow will be determined during the detailed studies based on economical, financial and technical criterion as well as the future energy and power demand.

The proposed scheme layout is shown in Figure 16 and presented in A3 format in Appendix 0 of this report.

Given uncertainties concerning the geology and geotechnics of the site, especially about the presence of the regional fault along the river, further studies should analyze alternative scheme

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layout, especially a layout with a longer canal followed by a penstock. The location of the different infrastructures might then have to be reviewed.

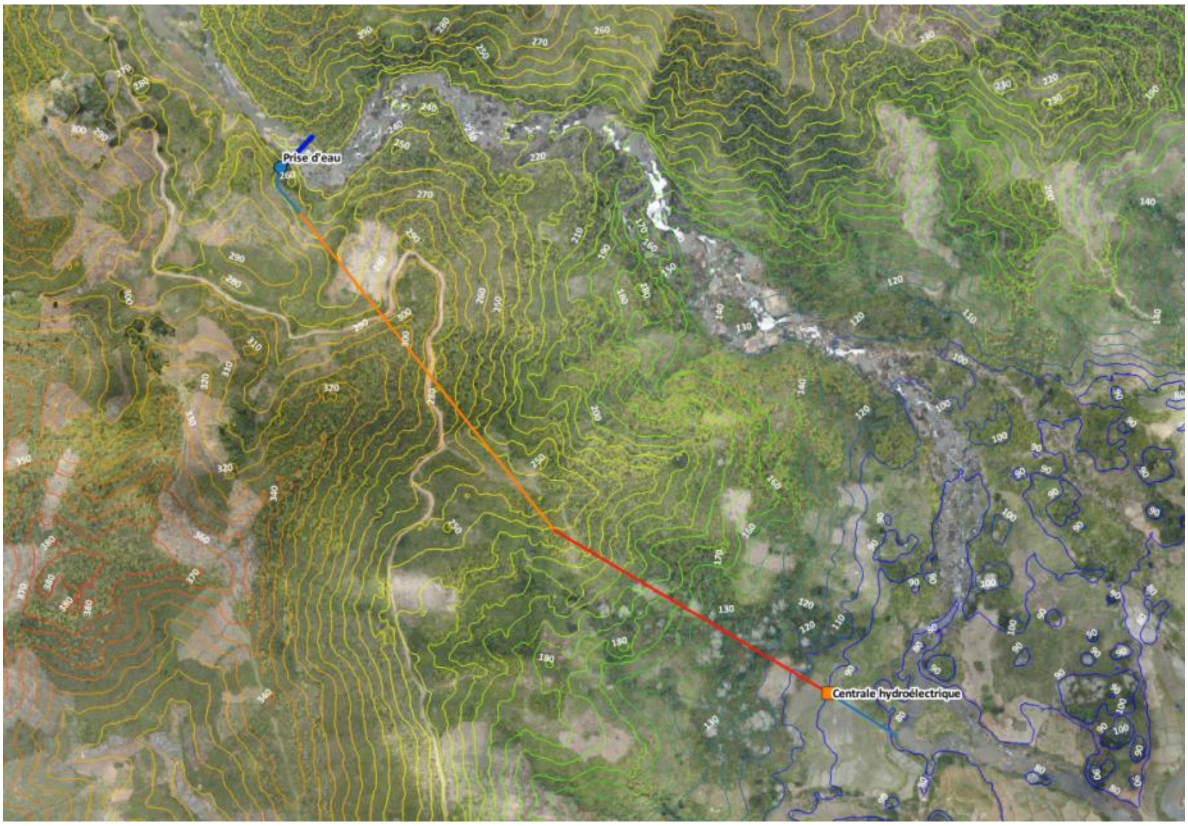


Figure 16. Proposed scheme layout for SF196 site

3.2 Weir and intake

The 50m long and 4m high weir would be founded on the rock in-place, upstream of the waterfall. The intake would be followed by a desander and a short canal arriving in the tunnel.

3.3 Desander

Given the potential sediment load in the river mentioned previously, adequate desander system will be required. It is suggested to implement it on the right river bank, close to the weir. The natural drop at the weir will enable an effective purge of the desander.

3.4 Waterways

Waterway consists of a 140m long canal (including desander) and of a 430m long tunnel. The canal section (b x h) would be 1.35m x 0.85m (assuming the design flow at $Q_{95\%}$) or 2.55m x 1.55m (assuming the design flow at $Q_{50\%}$). The tunnel diameter would be 2.00m whatever the design flow (2 m is the minimal dimension allowing an easy construction).

The elevation profile of the natural ground above the proposed tunnel alignment is illustrated in the figure below. The final tunnel alignment will be determined after the detailed geological and geotechnical surveys to ensure the presence of sufficient thickness of adequate rock around the tunnel. The tunnel will end in a surge chamber/shaft at the junction with the penstock leading to the powerhouse.

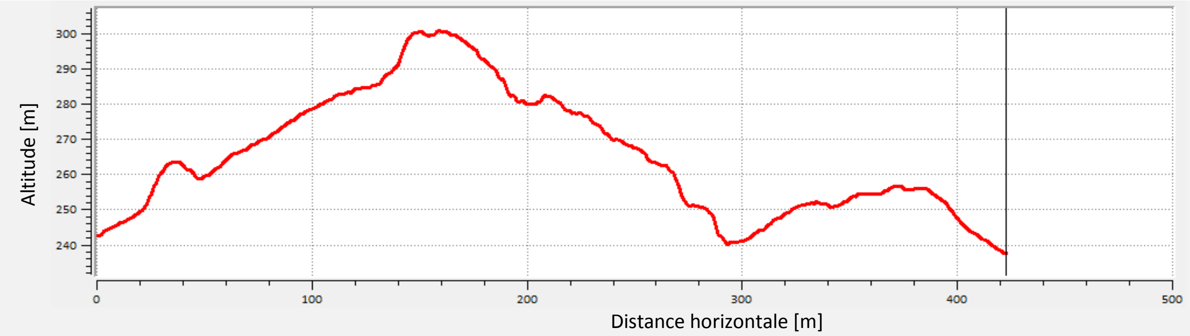


Figure 17. Elevation profile of the natural ground above the proposed tunnel alignment

3.5 Penstock and powerhouse

The penstock will have a total length about 370m and single 0.6 m (assuming the design flow at $Q_{95\%}$) or 1.2 m (assuming the design flow at $Q_{50\%}$) diameter penstocks will be required to ensure that the head losses due to friction in the pipes will be below 5% of the available gross head. The penstock diameter could be set to 0.8m for the firm discharge. This should be analyzed in the next stages of the study.

Given the instability of the Besana minor riverbed at its confluence with the Intsaka River, the powerhouse will be set at a sufficient level to remain out of the reach of floods and away from the unstable area. A 120 m long masonry tailrace canal will return turbined water in the Besana.

3.6 Electromechanical equipments

3.6.1 Design flow taken at $Q_{95\%}$

For a design flow at Q_{95}, there is no need to choose a turbine with a high flexibility regarding discharge variations. As the turbine will be installed in an isolated grid, flexibility is required to accommodate demand variation.

Head and discharge allow the choice between a Francis turbine, which offers a high performance level and a satisfactory flexibility, and a Pelton turbine which offers a satisfactory efficiency and a high flexibility.

Maintenance is easier on Pelton turbines than on Francis turbines. Therefore, Pelton turbines is preferred.

Given observations formulated about water quality, a particular attention must be paid to the quality of materials used for the construction of the turbine. One should probably consider the need for an anti-abrasion coating.

Given the site characteristics, it is planned to install two identical units, each composed of:

- Butterfly safety valve with counterweight to ensure its closure in case of emergency of black out.

- A 1 675 kW five injectors Pelton turbine running at 600rpm.
- A 690V alternator, 1 575 kW/ 1 750 kVA.
- Control and monitoring system, including speed regulator and voltage regulator.
- Security system and electrical protection.
- Step-up transformer and electrical cabinet and switchgear.
- Emergency power unit.

Figure 18 : Example of a 5-injectors Pelton turbine

Following issues should be studied as well in the next stages of the project :

- Sedimentation problem and the need for anti-abrasion coatings (e.g. Tungsten carbide).
- Technical and economic optimization of the penstock diameter.
- Technical and economic optimization of the number of units and of the design flow, according to the hydrology and the electrical demand.
- The need of a flywheel (for grid stability)
- The set up level and rotational speed of the turbine (Suction height and cavitation issues).
- Grid voltage.
- Preliminary turbine design.

3.6.2 Design flow taken at $Q_{50\%}$

For a design flow taken at Q_{50}, it is recommended to install three identical units (Pelton turbines) in order to optimize the global efficiency and to increase the plant availability.

Other considerations exposed for a design flow at Q_{95} remain valid for a design flow taken at the median discharge (Q_{50}).Turbines will have a unit nominal power of 2 000 kW and a rotation speed of 500 rpm or 600 rpm. The alternator power will be 1 880 kV/ 2 040 kVA for a 690 V voltage.

A power plant PLC (Programmable Logic Controller) should also be foreseen to manage the three units.

3.7 Transmission lines

It is envisaged that the proposed hydropower scheme would be connected to Manajary isolated grid using a 70 km long and 63kV line serving on its way Vohilava and Tsiatosika communes.

3.8 Key technical features

The key features of the proposed hydropower scheme are summarized in the table below for both firm ($Q_{95\%}$) and median ($Q_{50\%}$) design flows.

		Firm discharge	Median discharge
Installed capacity	[kW]	1 575	5 640
Potential annual generation	[GWh/yr]	12.15	40.34
Design flow	[m³/s]	1.4	4.7
Gross head	[m]	150	
100yr return period flood	[m³/s]	514	
Weir length	[m]	50	
Weir height	[m]	4	
Desander		Large size	
Tunnel length	[m]	140	
Tunnel diameter	[m]	1.35 x 0.85	2.55 x 1.55
Penstock length	[m]	430	
Penstock diameter	[m]	2	2
Number of penstock(s)	[-]	360	
Number of T/G units	[-]	0.6	1.2
Transmission line length	[km]	1	1
Line voltage	[kV]	1	3
Length of the access road to create	[km]	70	
Length of the access road to upgrade/rehabilitate	[km]	63	
Installed capacity	[kW]	2	
Potential annual generation	[GWh/yr]	55	

4 ENERGY GENERATION AND COSTS

Based on the assumptions of the economical and hydrological studies presented in the main report, the proposed hydropower scheme would feature the following values:

Gross head	**[m]**	150	
Design flow	**[m³/s]**	1.4 ($Q_{95\%}$)	4.7 ($Q_{50\%}$)
Installed capacity	**[kW]**	1 575	5 640
Potential annual generation	**[GWh/yr]**	12.15	40.34

CAPEX (excl. access and lines)	**[M$]**	7.86	16.91
LCOE (excl. access and lines)	**[$/kWh]**	0.078	0.051
Total CAPEX (incl. access and lines)	**[M$]**	33.42	42.47
Total LCOE (incl. access and lines)	**[$/kWh]**	0.326	0.126

5 APPENDICES

5.1 Socio-environmental datasheet

A – Site localisation

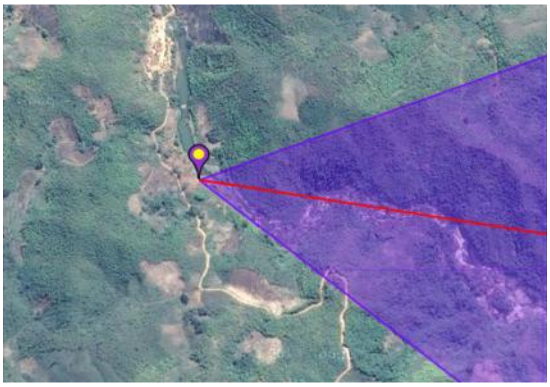
Site reference	:	SF 196
Village / Fokontany	:	Imahatsara
Community / District-Region	:	Ambodinonoka / Mananjary - Vatovavy Fitovinany

B - Description of the biophysical background

<table>
<tr><td>RELIEF</td><td>The SF 196 site is located in the S-E of Madagascar. It is situated between 2 hills: Vohijanahary (North, 454m high) and Bedamizana (South, 390m high).The relief of the area is relatively precipitous but the valleys are quite developed so lowland crops, such as rice growing, are possible.

The hydrographic network is dense, like in the majority in the regions of the oriental coast of Madagascar. The main river is the Besana River. It first flows from North to South, then from West to East before meeting the Intsaka. The latter is a tributary of the Mananjary River.</td></tr>
<tr><td>VEGETATION</td><td>The flora is formed by :

- Secondary vegetation (bamboos and ravinala), ericoid bush, low vegetation and grass meadows (ferns, Rubus, Lantana, Tridax, Psidium, Imperata…)
- Riparian forests (Raphia farinifera, Pandanus, Typhonodorum)
- Plantings : coffee trees, banana trees, pine trees, raffia, lychee
- Crops : rice, dry crops (manioc) and vegetable crops
- Shred forests with typical species such, Humbertia, Albizzia
Secondary vegetation, savoka (bamboo) have a very large surface in the area. They follow the primary vegetation after forest clearing and fires.

Cultivated bank and savoka (bamboo) on hillside, upstream of the weir
S21°1'53.36" E47°54'56.55"</td></tr>
</table>

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

	  Ericoid bush and savoka (bamboo) near the weir — S21°1'54.50" E47°54'58.97"   Rural landscape, downstream of the site — S21°2'30.08" E47°55'7.82"
OBSERVATIONS	Tavy is common for the local population and affects the landscape of the area: bare soils, secondary vegetation.
SENSITIVITIES	The Mananjary River, in which arrives the Besana via the Intsaka, is defined as a potential conservation site. The area downstream of the site has a relatively developed rural landscape. As a matter of fact, it has a huge lowland formed by crop cultures and trees plantings. The hillsides are composed by terrace crops.

B - Description of the socio-economic background

LOCALITY	**Rural community of Ambodinonoka :** The site belongs to the rural community of Ambodinonoka. It spreads on more than 350 km² and is subdivided in 8 fokontany. The population in 2009 was about 13 285[1] , this represents an average of more than 1 600 inhabitants/fokontany. Infrastructures: The community has 23 EPP[2] and 20 community schools. However, it has only one CSB[3] 1 and one CSB 2. The water supply comes from the watercourses. The housings are not provided in electricity yet.

[1] CREAM 2009, Monographie de la Région Analanjirofo (Monograph of the region of Analanjirofo)

[2] EPP : Ecole Primaire Publique (Primary public school)

<table>
<tr><td></td><td>Villages and localities :

The closest village is Imahatsara village. It is located less than 400m on the right bank downstream of the weir. Other villages can be found within a radius of 1km, in particular near the track that leads to the site. Some of these villages have more than 20 habitations.</td></tr>
<tr><td>ACTIVITIES</td><td>The local main activity is agriculture, thanks to the hydrographic network and to the presence of a vast rural lowland. The inhabitants can produce rice twice a year, sometimes 3 times if they also use the hillside crops. Rice growing is often associated with subsistence crop (manioc, corn) and also with vegetable crops. Moreover, the river banks are also used as vegetable crops and rice crops.

The hamlets are generally surrounded by plantings (banana trees, coffee trees, sugar cane,…).</td></tr>
<tr><td>OTHERS (IF ANY)</td><td>The population is composed by ethnic groups: Antambahoaka, Tanala and Antemoro.

Gold mining can be seen alongside the track that leads to the site and near the rivers. Locals use machines or hand-made tools (mostly used by local gold washers). In fact, the site is located on mining plots that have an authorisation to search for gold. The area is crossed by mining plots that belong to companies or individuals having an authorisation to search for gold and other minerals (crystal, emerald…).

Gold mining observed alongside the track that leads to the site</td></tr>
</table>

C – World Bank Safety Policies that are applicable:

OP 4.01 – Environmental Assessment ☒

OP 4.04 – Natural Habitats ☒

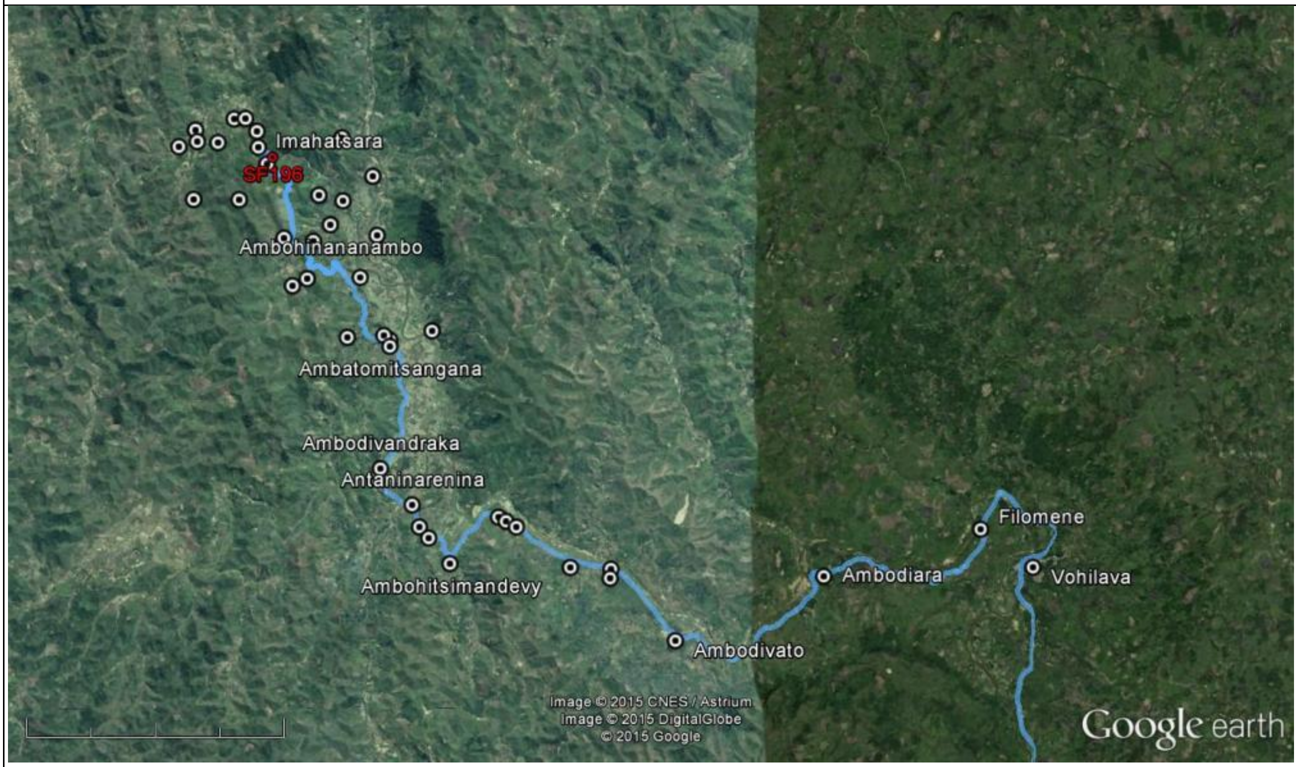
OP 4.11 – Cultural Heritage ☐

OP4.12 – Involuntary Resettlement ☒

PO 4.37 – Safety of Dams ☐

[3] CSB : Centre Santé de Base (Basic Health Centre)

Map of hamlets



Land use around the site

 : mixed with forest vegetation or savoka (bamboos, ferns)

In case of discrepancy between the French language original text and the English language translation, the French text shall prevail

: formation secondaire broussailleuse et/ou à végétation basse

: forêt

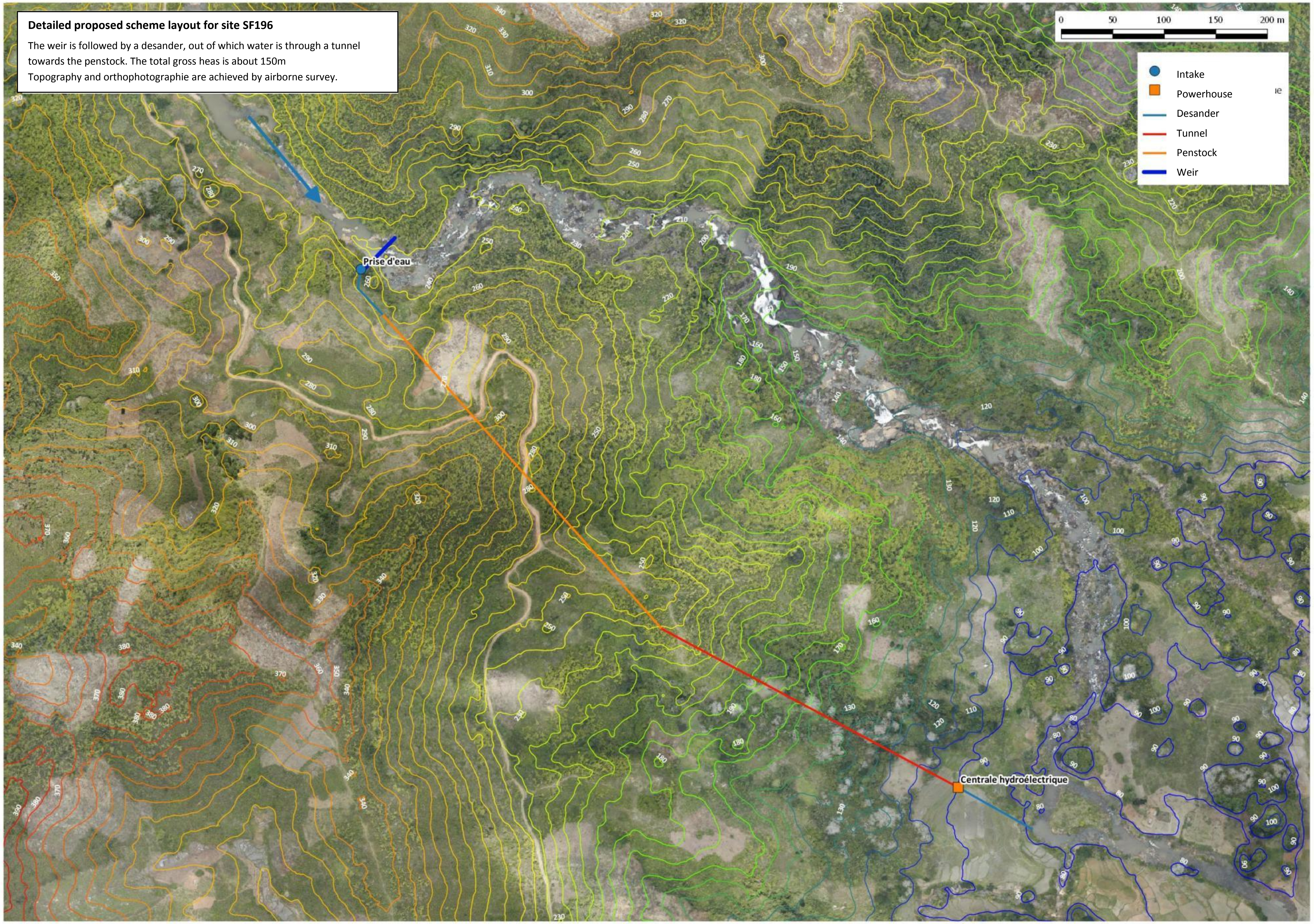
: formation ripicole

: parcelle de cultures

: trace récente de défrichement-tavy /zone potentiellement à cultiver

: hameaux/villages

5.2 Detailed proposed scheme layout



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