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Preliminary Report on Hin Nam No Hydrology and Geology Mission

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Contributions of the contractor, Terry Bolger and Gheorghe M.L. Ponta, do not necessarily represent the position of GIZ.

On behalf of the
German Federal Ministry for Economic Cooperation and Development (BMZ)

Objective: Conduct a field survey to evaluate the karst landscape and make hydrogeological measurements and observations on the karst springs, caves and main river systems of Hin Nam No National Protected Area (HNN NPA). The information and knowledge obtained from this project and its outputs (report and maps) can serve as a basis for management of the HNN karst in terms of conservation of its geological and hydrological resources, and identification of sites for further research. In addition, the results from this study may contribute to documenting the Outstanding Universal Values of the geological heritage of HNN NPA (World Heritage Criterion viii). The specific objectives of this mission are:

- To survey, measure and document the hydrologic and geologic characteristics of the karst springs, caves, and river systems of HNN NPA.
- To develop a basic hydrogeological map of HNN NPA, as a tool for the management of the karst and caves of HNN and the upstream catchment areas draining into the HNN NPA.
- To advise on the development of a basic hydro-meteorological monitoring and early warning system for HNN NPA.

Background:

The HNN NPA covers 94,000 ha of mainly limestone landscape in Boualapha District, Khammouane Province, in central Laos where the Central Indochina Limestone meets the Annamite Mountain Chain (Plate 1). It is bounded in the South and East by the Xe Bang Fai River and his tributaries, to the West by Nan Ngo and Nam Heu rivers, and in the Northeast with the Phong Nha-Ke Bang National Park, Vietnam. The German Government supported Hin Nam No Project, assists the HNN NPA authorities in developing and implementing a co-management system, where local communities share responsibilities and benefit from sustainable management of the biodiversity and geological resources in the NPA.

HNN NPA is a candidate for listing as a UNESCO natural World Heritage Site in the near future. Outstanding Universal Values (OUVs) are the justification of any inscription into the World Heritage list and the Xe Bang Fai (XBF) Cave is perhaps the world's largest river cave passage with the world's highest peak discharge from a cave (or karst spring), and therefore an OUV in itself (Mouret 1997, 2004, Mouret et al. 2010, Bunnell and Kambesis 2016, Pollack et al. 2015). As HNN NPA features a collaborative management system that follows an integrated conservation and development approach, it's essential to warrant the long-term integrity of the OUVs, namely the XBF Cave, and to understand the threats to the local communities living around Hin Nam No NPA through the high variation of the discharge in the XBF River, possibly aggravated through climate change. Key to the protection of XBF Cave and XBF River is the management of the catchment area, especially the area upstream of the cave.

The characteristic landscape style of Hin Nam No is that of a dissected plateau of karst massifs that are bordered by bare limestone walls or cliffs rising up to 500 m above intervening alluvial plains developed along Xe Bang Fai and Nam Ngo rivers (Bolger et al. 2017). The limestone massifs have been eroded into a classic fengcong karst of clustered cones, with pinnacles and deep fissures, making them virtually inaccessible. The sharp-edged and spectacular pinnacles up to 10 m high are signature features of the karst landscape, from which Hin Nam No derives its name i.e., spiky rocks in English (Bolger 2019).

Currently, little is known about the meteorology, hydrology or water quality of HNN and its water resources. Such information and knowledge are needed to support the World Heritage nomination and the sustainable management of the water resources for both conservation and human welfare and development. The information gained from such studies will contribute to developing a hydrogeological picture of HNN NPA.

Field Survey and Sampling Program

Field Survey Team

The field survey team was comprised of the international cave experts, Hin Nam No Project staff, and local village rangers. The international experts and GIZ-HNN staff were:

- Terry Bolger, karst and cave expert, liaison with HNN project (Australia/Laos)
- Gheorghe Ponta, karst geologist and hydrologist (USA/Romania)
- Thanousone Sikhod, Deputy Head of Hin Nam No NPA
- Mr. Jok, Hin Nam No Ranger
- Mr. Serth, GIZ-HNN Driver and Assistant

Field Survey Schedule

The field survey was conducted during the period 17-23 February 2020 as outlined below:

Date	Activity
17 February 2020	Thakhek to Ban Nongping, observations and sampling en route
18 February 2020	Observations and sampling at Xe Bang Fai Cave and Ban Chalou
19 February 2020	Observations and sampling at Ban Ka-I
20 February 2020	Observations and sampling at Ban Laboy
21 February 2020	Observations and sampling at Ban Pakphanang, Ban Thongxam
22 February 2020	Observations and sampling at Tham Bouam Bam (Ban Dou)
23 February 2020	Return from Hin Nam No (Langkhang) to Thakhek

Sampling Points and Samples

Water samples were collected from fourteen locations in and around HNN NPA as listed in Table 1 and shown on Plate 1. Geographic coordinates (UTM, WGS84) and elevation were recorded with a GPS (Garmin 62S) at each sampling point and presented in Table 1. The elevations of sampling points range between 141 and 323 m. The elevation of the Xe Bang Fai Cave at downstream entrance is 190 m and the elevation of the upstream entrance located 6.4 km away is only 14 m higher at 204 m.

Table 1

Sample Number	Sample Name	Type	Northing (Y Coordinates)	Easting (X Coordinates)	Elevation GMP	Discharge (Q) (estimated)	Date and Time	pH	Temperature (^{0}T)	Specific Conductance	Salinity	Total Alkalinity as $CaCO_3$	Carbon Dioxide	Total Hardness as $CaCO_3$
	Units				m (MSL[4/])	m^3/s			^{0}C	uS/cm	ppt	mg/l	mg/l	mg/l
1	Phacha stream near Laboy village	Spring	48 Q 1903233.51 mN	623427.53 mE	323	0.001	2/20/20 10:48	8.29	25.00	315.00	0.20	155	45.6	175
2	Xe Bang Fai River at Ban Laboy ford	River	48 Q 1902708.86 mN	622025.29 mE	310	5.00	2/21/20 13:50	8.48	23.20	226.50	0.10	102.0	37.6	117.0
3	Waterfall 1.6 km downstream of Ban Laboy ford	Spring	48 Q 1903306.41 mN	620871.10 mE	306	0.20	2/20/20 13:34	7.82	25.10	402.20	0.20	178.0	62.0	196.0
4	Xe Bang Fai River at Ka-I village	Spring	48 Q 1904588.83 mN	612096.11 mE	237	2.55	2/19/20 15:17	7.81	25.50	229.20	0.10	21.5	46.4	142.0
5	Nam Chala stream at Ka-I village	River	48 Q 1903950.14 mN	611965.77 mE	248	0.44	2/19/20 15:24	7.94	23.20	420.60	0.10	230.0	34.4	204.0
6	Xe Bang Fai River at Chalou village	Ponor	48 Q 1912111.69 mN	601213.69 mE	218	5.00	2/18/20 20:53	7.84	22.80	362.70	0.20	36.5	52.8	142.0
7	Xe Bang Fai River at 1.8 km into cave	Cave				5.00	2/18/20 14:42	7.52	22.50	289.70	0.10	27.0	54.8	160.0
8	Xe Bang Fai River at Cave Entrance	Spring	48Q 1920911.82 mN	589142.31 mE	171	5.00	2/18/20 15:00	7.78	22.90	323.20	0.00	25.5	58.6	153.0
9	Phanang River at Pakphanang village	River	48 Q 1923702.36 mN	577855.66 mE	159	5.00	2/21/16 9:48	7.73	26.10	354.80	0.20	178.0	61.8	194.0
10	Xe Bang Fai River at Pakphanang village	River	48 Q 1923966.24 mN	577741.74 mE	141	5.00	2/17/20 16:30	8.26	27.20	293.60	0.10	160.3	71.0	186.0
11	Nam Ngo River at Seanphan village	River	48 Q 1933529.49 mN	574071.13 mE	156	0.20	2/17/20 15:37	8.27	27.30	227.90	0.10	108.6	48.8	176.0
12	Hok Stream at Pak Tham Cave	Spring	48 Q 1942553.00 mN	589293.00 mE	183	0.22	2/21/20 14:32	7.78	25.70	276.50	0.10	139.0	40.0	142.0
13	Tham Bouam Bam Cave	Cave Spring	48 Q 1933986.68 mN	591936.68 mE	176	No flow	2/22/20 17:41	7.09	24.10	350.00	0.20	167.0	72.4	179.0
14	Nam Heu Stream at bridge	Rivier	48 Q 194016.17 mN	5778817.59 mE	164	0.29	2/21/20 11:15	8.22	28.10	296.00	0.10	138.0	45.2	152.0

Field Analyses and Methods

The fourteen water samples will be analyzed for anions, cations, and oxygen and hydrogen isotopes from caves streams and pools, springs and rivers. Selected water-quality parameters were monitored at each sampling point with an Hach HQ11d and YSI 63 instrument (pH, temperature, specific conductance, and salinity). Additionally, a Digital Titrator (Hach Model 16900) was used in the field to determine total hardness as alkalinity, total hardness as calcium, and carbon dioxide (Table 1).

Groundwater samples from each source were collected and pre-treated as shown below. Samples for cations were collected in 40 ml glass vials pre-treated with nitric acid. Samples for anions and stable isotopes were collected in 40 ml vials with no preservatives. All three water samples at each site were filtered to 0.2 microns attached to a 60 ml syringe, to remove sediments and microorganisms.

The visual estimated flow rates of the water samples range between 0.001 and 5 m^3/s. The observations were recorded in February 2020, in the late dry season, these values are characteristic for base flow. Water temperatures ranged between 22.5 ºC (in Xe Bang Fai Cave) and 28.10 ºC (Table 1), which correspond to the mean annual air temperature in the area.

Laboratory Analyses and Methods

Due to the Novel Coronavirus Disease 2019 (COVID-19), the lab was shut down (and is still closed) for over two months and no samples were analyzed so far. The laboratory results, and their interpretation, will be provided when they become available.

Hydrogeology - Occurrence and Availability of Water

A karst hydrogeological map describes the occurrence of water, the flow conditions and spatial distribution in soil and rocks with distinctive permeability and shows if a geologic unit will allow or not movement of groundwater. Additional information obtained during karst inventory regarding existing springs, seeps, caves, sinkholes, sinking streams, will help defining the recharge area of the aquifers.

Karst hydrogeological maps help to characterise and understand groundwater resources, economic development, engineering, management, and decision making on the water utilisation/exploitation and protection. They provide a planning tool for the government, provinces and private offices as a basis for establishing site-specific decisions.

The availability of ground water in the Hin Nam No National Protected Area varies widely largely due to the geologic complexity of the area. The water-bearing characteristics of the aquifers are discussed based on the physical features of the rocks or sediments in the area (porosity and permeability, granular or fractured), and the occurrence of springs and sinking streams. The hydrogeologic units on Plate 1 are represented according to the modified International Standard Legend for General and Special Hydrogeological Maps (Struckmeier, 1995). Because of a large range of karst features and the volume of information related to the ground/surface water in karst areas, data are presented on the map as a new subcategory, “Karst aquifers”, using a pink color to differentiate aquifers in karstic terrain, versus the

traditional range of green colors, used to represent the aquifers in fissured non-karstic rocks (Ponta, 2003, Ponta and Aharon 2014, Ponta 2019). Karst hydrogeologic map and symbols after Ponta 2019.

1. Aquifers in porous formations

Local aquifers hosted by alluvial deposits are located along the Nam Ngo and Xe Bang Fai Rivers and their tributaries. The thickness of these deposits is between 2 and 5 meters. Water is concentrated in open pore spaces between the grains, pebbles, and boulders. Some small (sometimes only temporary) springs and seeps were identified, and their flow depends on the amount of precipitation. Based on evidence of recent flows, the spring discharge increases substantially after heavy rains. The scale of the map did not permit to show these narrow/thin units on Plate 1.

2. Fissured aquifers (including karst aquifers)

2.1 Fissured aquifers

2.1.2 Local or discontinuous productive aquifers (shown in green on Plate 1)

A wide range of sandstones, conglomerates, and siltstones (from Lower Carboniferous to Lower Cretaceous) representing the “Local or Discontinuous productive aquifers” subcategory is present in the region. These units generally yield small quantities of water to springs that at the contact with the limestones sink underground.

Boualapha Formation (C_1 bp)

The Boualapha Formation of Lower Carboniferous age which covers extended areas in the Hin Nam No is characterized by terrigenous sediments with interbeds of chert, shale, and one to two thin coal seams with the total thickness of about 210-400 m. The Boualapha Formation lies unconformably on the Phon Keo Formation (D_{I-2} pk) (not present in the study area) and underlies conformably the Khammouan Formation (C-P_1km). The Boualapha Formation grade continuously upward to the thin-bedded cherty limestone of the overlying Khammouan Formation. The weathered marl bed of the transitional zone becomes chocolate cherty claystone, with fossils of Lower/Early Carboniferous age (Tran van Ban 2000).

Ban Lao Formation (J_{1-2} bl)

The Ban Lao Formation forms a narrow strip surrounding continuously the Jurassic-Cretaceous basin, in the Northwestern corner of the study area between Ban Nathin and Mu Gia Pass. The Ban Lao Formation is composed of two parts: the lower one including gray, dark-gray terrigenous sediments with interbeds of carbonate bearing marine fauna; the upper part including continental red beds. The Ban Lao Formation overlies unconformably the Carboniferous - Lower Permian limestone of the Khammouan Formation (Tran van Ban 2000).

Nam Phouan Formation (J_3 np)

The Nam Phouan Formation is distributed usually in a strip surrounding the Lower Cretaceous deposits, North/Northwest Boualapha (Khammouan province) areas and Northwestern corner of the study area, overlying the Ban Lao Formation. When this member covers directly the

Khammouan Limestone, the limestone gravel is abundant, and when covers the Boualapha or Ban Lao Formations the chert gravel prevails.

Nam Xot Formation (K_1 nx) Lower Cretaceous

The Nam Xot Formation is composed of red continental sediments (gravel, sandstones), locally forming high mountain ranges. The Nam Xot Formation lies conformably upon the Nam Phouan Formation of Late Jurassic age. In the study area several islands of this formation are present south of Xe Bang Fai River, overlaying the previous two formations described above. An additional island of Nam Xot Formation is in the Northwestern corner of the study area.

The water in the Boualapha Formation is concentrated/flows in small fractures and along bedding planes; small springs (~1 liter/second) are also present. Groundwater in the sedimentary deposits of the Ban Lao Formation (Lower-to-Middle Jurassic), Nam Phouan Formation (Upper Jurassic), and the Nam Xot Formation (Lower Cretaceous) occurs in open pore spaces between the grains, where they are present or along fractures, joints, and bedding planes. These deposits/rocks occasionally can supply moderate quantities (1 l/s) of water to springs.

2.2 Groundwater in karst aquifers

2.2.1. Highly productive karst aquifers (shown in pink on Plate 1)

Extensive and productive karst aquifers occur in the Khammouan Formation (C-P_1 km) of the upper Xe Bang Fai and Nam Ngo Rivers basins. The Khammouan Formation consisting of Carboniferous-Lower Permian age carbonate rocks exhibits little or no intercrystalline porosity. Groundwater flow occurs along solutionally enlarged fractures, cavities, joints, and along the bedding planes. This aquifer has a more extensive network of interconnected fractures than any other aquifer in the region. These interconnected fractures serve as conduits, leading the waters from the top of the mountains/karstic plateau down to the springs. At the contact between the non-calcareous units and carbonate bedrocks streams are sinking in the underground generating caves that occasionally exhibit large passages.

The Khammouan Formation is exposed largely in Mid Central Laos, forming a large area of karstic plateaus in this region, which stretches from north of Viengthong District to Khamkeut (Bolikhamxay Province), then from Hinboun District through to Boualapha (Khammouane province) (Tran van Ban 2000). In the study area it is present as elevated karst plateaus/islands above the surrounding Boualapha Formations. The limestones are part of the Annamite Mountains which are formed by a succession of synclines and anticlines-oriented NW-SE, fractured by a main group of faults parallel with the syncline/anticline axis and a secondary one (perpendicular on the first one) oriented NE-SW.

The hydrographic network is developed predominantly along the main fractures, running Southeast towards Northwest. At major intersection with the secondary faults, the limestone block is traversed/cut, separating the Hin Nam No karstic plateau along Nam Ngo and Nam Heu rivers in the vicinity of Mu Gia Pass and Ban Dou village in the Northwest and Ban Nam Chala/Ban Nongma villages, in the Southeast.

As shown on Plate 1, most of the stream caves and springs (perennial and temporary) known so far are in the central part of the study area, around the Xe Bang Fai Cave, and north of the

Xe Bang Fai River along the southwestern edge of the karst plateau, and in the area around Ban Dou village. The hydrologically inactive (fossil) caves (shown in black on Plate 1) are more spread out. The concentration of caves and springs mainly in the northern and central/western part of plateau is due the easier access in these areas. In the southern/eastern areas there are few access roads or trails, the area being still unexplored with regard to karst features.

Based on the topographic maps 1:50.000 scale, on Plate 1 are shown numerous sinkholes, a number of them more then 1 km across. Many of the larger depressions are poljes or kuans, and in the wet season are likely traversed by streams sinking underground and possibly flooded.

In the early dry season, the presence of four karst streams was noted and shown on the map as KS 1 through 4. One perennial waterfall was identified along the Xe Bang Fai River (Water sample 3, Plate 1) which apparently is coming from a cave/spring.

The lack of perennial large springs at the base of the cliffs surrounding the HNN karst plateau is remarkable. One explanation for this may be a high degree of secondary porosity (dissolved conduits) coupled with the very low primary porosity in the Khammouan Formation, providing very efficient drainage and resulting in springs and caves ceasing flow during the dry season.

Also, a portion of the HNN karst may be in the recharge area of some large springs in the neighboring Phong Nha Ke Bang karst area of Vietnam. Setting up a network of gauging stations and rain gauges will allow the calculation of a water budget. Those findings should confirm or not these assumptions and may provide an explanation for the presence of fewer large caves in HNN than in Phong Nha Ke Bang.

Implications for Management

The water quality management of allogenic streams draining into karst is the *key* issue for environmental management in any karst area, and is critically important for natural World Heritage properties (Williams, 2008). Allogenic streams are those derived from impervious rocks in catchment areas that lie beyond the boundary of the karst. Conditions upstream of the karst boundary can have a critical influence on the integrity of the karst ecosystem. River-borne pollution is a major threat to the animals living in and near rivers in the karst, with fragile cave-adapted species being particularly at risk.

The hydrogeological map of the Hin Nam No area (Plate 1) highlights the allogenic catchment areas critical to the environmental management and protection of HNN NPA. The headwaters of the Xe Bang Fai River are on mostly impervious rocks, but are protected as the Khoun Xe Nong Ma (KXNM) National Protected Area (on the southeast border of the map and continuing beyond). Between KXNM and HNN NPAs, there is a corridor of non-protected, agricultural land and settlements between Ban Nam Chala and Ban Nongma. Following the Xe Bang Fai River to the Northwest, there is allogenic catchment area of agricultural land and settlements along the left back (and small areas on the right bank) from Ban Ka-I to beyond Ban Chalou where the Xe Bang Fai River turns Northeast, into the HNN karst. These allogenic catchment areas are the key potential threats to water quality in HNN NPA. They should be included in the World Heritage buffer zone, with appropriate regulations and restrictions on land use and development to protect the quality of the water draining from these areas.

Recommendations for a hydro-met monitoring and early warning system

As HNN NPA features increased likelihood of flooding mainly by the XBF River, for the local communities and the safety of organizing tours in the cave, it became necessary to know when a flood event is approaching to give tourists and villagers enough time to evacuate or to take shelter. It is critical for these communities to have real-time warnings for when rising water levels are moving their way.

Based on rough numbers (estimated discharge and flow velocity) it was calculated that during the wet season peak, the Ban Nongping community would have about 3 hours to evacuate or prepare, if a flood warning system were in place at Ban Laboy. Flood pulses during the nominal dry season (such as the flood event in November 2019) would likely move somewhat slower, affording a bit more time to evacuate tourists and guides from the Xe Bang Fai Cave.

It is recommended that hydro-met stations be installed at four locations:

- Ban Laboy: monitoring and early warning of flood events
- Ban Chalou: monitoring and early warning for events initiated downstream of Ban Laboy
- Ban Nongping: monitoring and documenting peak discharge from the Xe Bang Fai Cave
- Ban Vangmaner: monitoring and documenting discharge from the Nam Ngo

OTT HydroMet/SUTRON, a German based company with offices all around the world, design flood warning packages. Each station consists of:

- 1 OTT Radar Level Sensor (RLS)
- 1 OTT Surface Velocity Radar (SVR) 100
- 1 Lufft WS 100 Radar Precipitation Sensor/Smart Disdrometer
- 1 SUTRON XLink 500 Data Transmitter
- 1 Solar panel.

Each station measures precipitation, water level, and water surface velocity. Given how intense incoming monsoons can be, it's important to know if a significant amount of water is approaching, how high it is, and how fast it is moving downstream. With the study area being located in a remote part of Laos with poor mobile phone coverage, an Iridium® satellite transmission is an option for Ban Laboy and Ban Chalou. Satellite or mobile phone telemetry would give updated data every 3 minutes if water levels exceed their threshold and are in alarm state. Two-way transmission capabilities also allow remote adjustment of warning thresholds as the needs of emergency managers are better understood. Each station has to be connected to the data management software HydroMet Cloud.

An indicative cost estimate for one station is provided separately. OTT HydroMet being a German company, it is likely that GIZ can get a better cost estimate/quotation by contacting them directly.

Recommendations for riverbank erosion near Xe Bang Fai Cave

The erosion of creek banks and stream edges is a result of Mother Nature's summer/wet season acts and is completely natural. As summer storms dump large amounts of rainfall, creeks and streams swell in size, and the forces of these large volumes of water are no match for saturated soils sitting on the edge of the waterways. The constant flowing water force and heavy rainfall against the exposed soil causes it to erode and fall into the waterways. Once a stream bank begins to erode and lose vegetation, such as trees and shrubs, the loss of soil can accelerate very quickly. When a stream or creek bank erodes, property is literally eaten away by the watercourse, leaving behind a void or pit when the water flows subside. This loss of land can create property and environmental damage.

The riverbank erosion problem near the Xe Bang Fai Cave can become costly if action is not taken as soon as possible. It could result in the loss of the main track to the cave. The most sustainable way to protect your riverbanks is by using living or dead tree stems, roots, or branches to cushion the bank from the force of the river. If you use live trees to cushion some of the force of river flows, you will gain the added benefit that, as the roots of these trees grow, they will increase the strength of the bank.

Based on visual observation performed in February 2020, a section of the track to the cave needs immediate attention and already cannot be fixed through revegetation. This area requires and engineering solution. Ideally, an embankment clad with rock and concrete could be constructed along this section. Alternatively, a steel walkway could to be designed by an engineering firm and installed by anchoring it to the side of the mountain/limestone bedrock.

Recommendations for further work

1. Further exploration and documentation of caves and springs in HNN NPA is warranted to improve the hydrogeological map and our understanding of the HNN karst system. In the remote southern and eastern areas of HNN NPA This could be initiated as part of ranger patrols, and gathering local knowledge from the villagers. Where sufficient information can be obtained, cave experts could be enlisted to explore, study and document significant features. Cave divers could further explore the known wet-season resurgence caves.
2. The analysis of historical hydro-meteorological data (from Boualapha, Kuanpho, Mahaxay) for flood frequency, intensity, and duration, and backwater effects from the Nam Theun 2 hydropower plant, would provide the basis for a risk analysis of potential hydrological threats to OUVs and local communities (lives and livelihoods), possible including climate change.
3. Baseline water quality information is required, so that in future years there is a reference point for assessing the effectiveness of river basin management. Both chemical/physical and biological indicators of water quality should be measured. The analysis of water samples from the current study will provide some information in terms of certain anions and cations in the water.

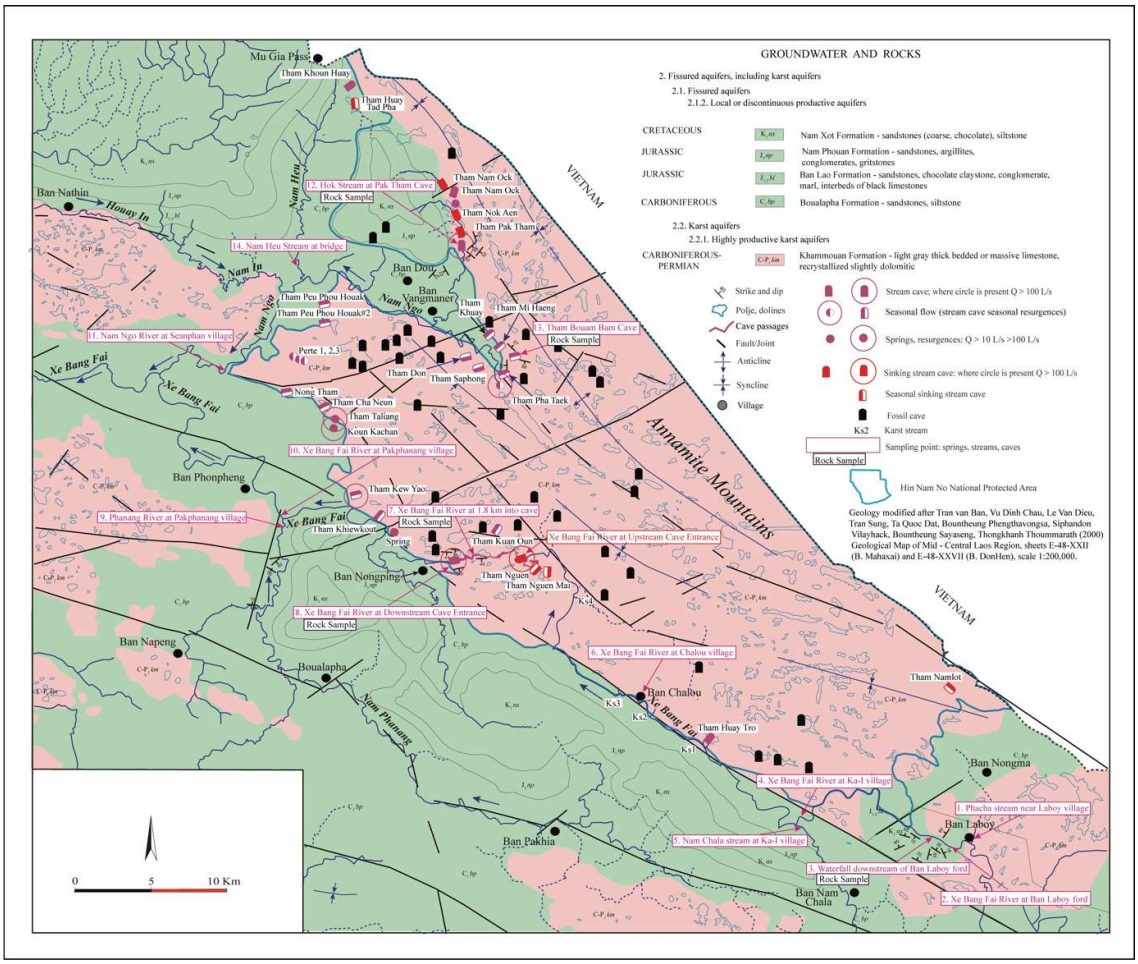

Plate 1. Hydrogeological Map of Hin Nam No National Protected Area (Geology modified after Tran van Ban, 2000). A high-resolution file is provided separately for printing at A2 or A3 size.

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