Characterization of the Ravine Tet Sous Alluvial Aquifer - Anse-à-Galets, Haiti

Inter-American Development Bank - Technical Report, Loan 1780/SF-HA - 09 August 2013

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SUMMARY

A study was commissioned by Direction Nationale de l'Eau Potable et de l'Assainissement (DINEPA) to evaluate the feasibility of using a small alluvial ravine aquifer near **Anse-à-Galets** to serve as the city's water supply. According to DINEPA, a demand of 14.8 l/s of water is needed to serve the projected future population of 29,719 people.

Anse-à-Galets is a coastal city located on the northeastern coast of the island of La Gonave, Republic of Haiti (Figure 1). The current water supply for the community is a narrow incised ravine called "Ravine Tet Sous" that is filled with alluvium (sands, gravels and silts) and impounded by carbonate bedrock. A French drain field was installed into this alluvium by the Wesleyan mission in the 1960s and is currently maintained by West Indies Self Help (WISH). The current intake location is shown on Figure 3.

Water is piped by gravity from this source, through a reservoir and into town where it serves private and public water supplies. System flow rates vary by season and are estimated between 4.2 - 6.0 l/s based on correspondence with WISH. According to WISH, the lowest flow since the system had been installed was around 3.0 l/s. This ravine alluvium has been traditionally believed to be the most feasible source of water to serve the city.

The goal of this investigation is to characterize the Ravine Tet Sous alluvial aquifer and determine whether it is a sustainable supply of water to serve the city of Anse-à-Galets. The aquifer was studied by a team that included geologists, hydrogeologists, and a geophysicist.

The investigation included the following field tasks that were performed during the week of 24 June 2013.

1. Survey of aquifer boundary by a professional geologist
2. Seismic refraction geophysical survey to define thickness of alluvium
3. Test pits with backhoe to characterize alluvium and water tables
4. Pumping test to estimate aquifer properties and develop aquifer flow analysis

Based on the study, the aquifer will not sustainably supply a demand of 14.8 l/s. Safe yield estimates of total flows from the ravine are 3.5 – 11.5 l/s, depending on season. During the time of the study, the total aquifer flow was estimated to be 7.2 l/s. The WISH system was capturing approximately 66% of the available flow with the remaining lost downstream. We believe this flow to be generally representative of an average dry season condition.

We believe that the Ravine Tet Sous alluvial aquifer should be considered as a part of the water supply solution to serve the city of Anse-à-Galets. The portion of the aquifer characterized is not susceptible to seawater intrusion due to its elevations above sea level. However, it alone is not capable of fully supplying the required water demand. The Ravine Tet Sous aquifer is very small, unconfined and extremely susceptible to contamination and drought. This observation further validates the need to secure additional water sources to serve the city.

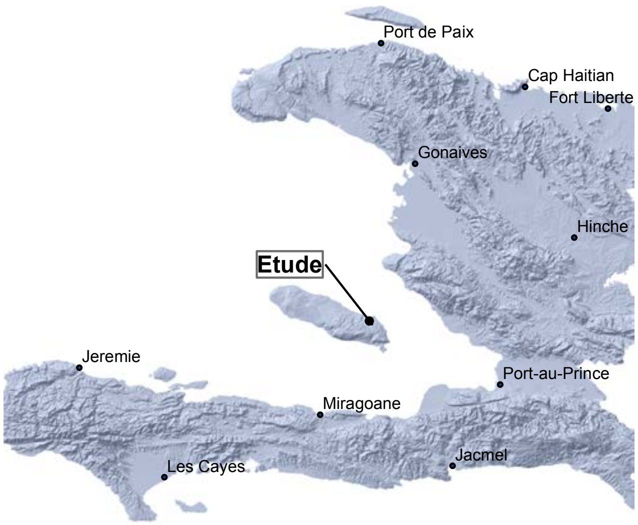


Figure 1. *Study Location in Haiti*

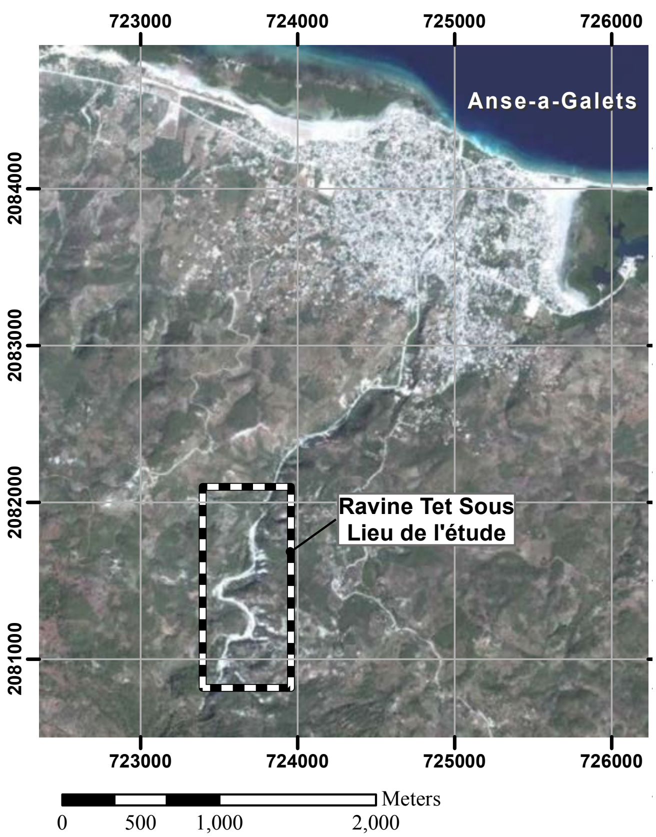


Figure 2. *Study Location Relative to Anse-a-Galets*

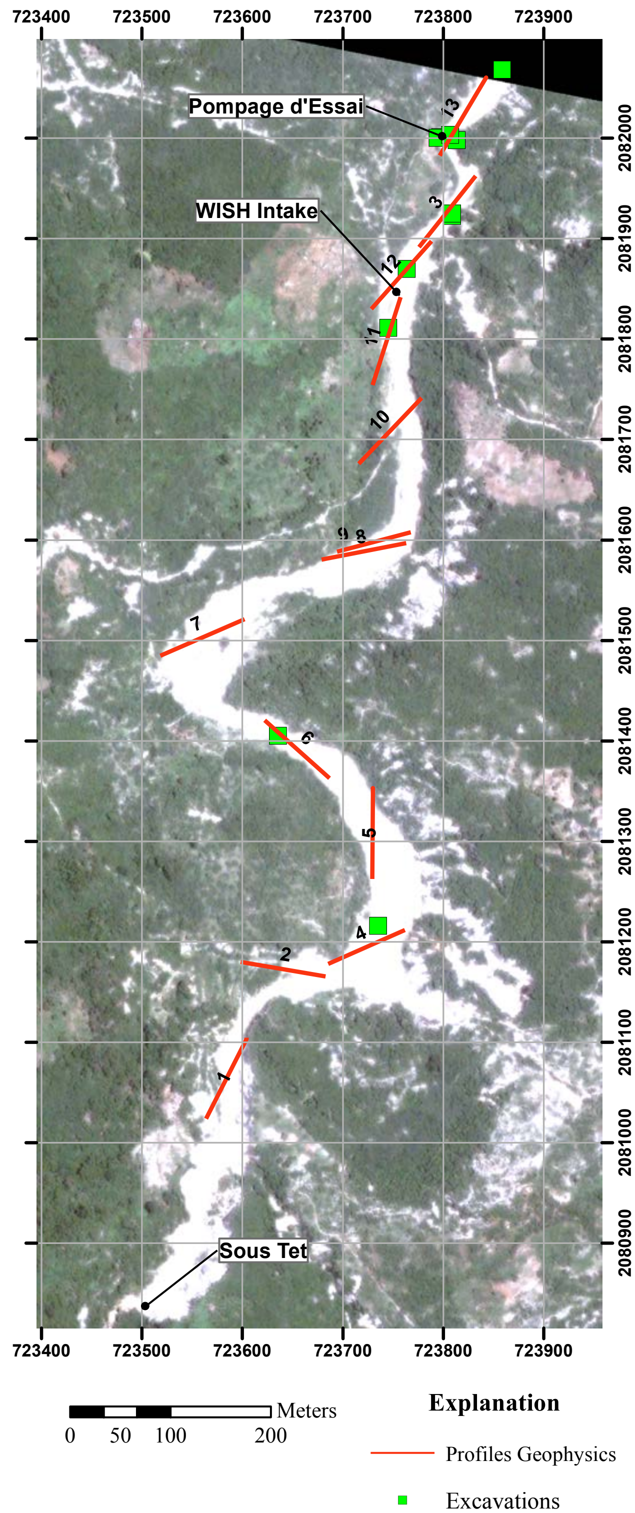


Figure 3. *Study Area Basemap*

Ravine Tet Sous Alluvial Aquifer

Figures 1, 2 and 3 illustrate the location of the Ravine Tet Sous aquifer and the study area. The spatial extent of alluvium in the ravine was delineated by a professional geologist using a Trimble GeoXH handheld GPS instrument.

The ravine is approximately 6.8 hectares in size and 1,400 meters in length. The average width is 65 meters, and varies between 12 and 96 meters wide. The gradient is relatively steep for an alluvial channel at 0.0514 m/m. It is an active and incised channel with steep vertical banks of carbonate limestone and chalk up to 30 meters high. These bedrock banks are the origin of the alluvium, as they are deposited into the channel due to mass-wasting processes. The channel and ravine system is dynamic and it is actively migrating, incising and depositing, mostly driven by large flood events.

The channel is mostly ephemeral, and is dry or has little surface water flow without precipitation events.

At the head of the ravine, a spring discharges from a massive karst limestone. At the time of this study, the spring was flowing at 5.7 l/s. Most of this water seeps into the alluvium and directly recharges the aquifer. Recharge to the aquifer is also provided by episodic rainfall and storm flow over the alluvium. Finally, there is the likelihood that one-to-several subsurface springs in the underlying bedrock also contribute to aquifer recharge.

Area	6.8 ha
Perimeter	3,290 m
Channel Length	1,400 m
Average Width	65 m
Maximum Width	96 m
Minimum Width	12 m
High Elevation	155 m
Low Elevation	83 m
Gradient of Channel	0.0514 m/m

Table 1. *Surface geometry of the Ravine Tet Sous Alluvial Aquifer*

Seismic Refraction Geophysical Survey and 3D Analysis of Aquifer

A 12-channel seismic refraction geophysical survey was completed using a Geometrics SmartSeis Seismograph supplied by Wheaton College in Illinois. A 9.1 kg sledgehammer was used as the source of energy for the survey. Thirteen seismic lines were performed, each 84 meters in length with 14-Hz geophones spaced at 7 meter intervals. The profile locations are shown on Figure 3. Photo 1 shows a typical setup. Sledgehammer shot points were performed at the end of each line and between each geophone in order to perform tomography modeling.

The geophysical survey was performed in order to estimate the depth to bedrock beneath the alluvium and estimate the thickness of the alluvium. The seismic data was modeled using tomography and displayed into elevation and depth cross sections (Figures 7 – 19).

Based on field observations and calibration, seismic velocities ranging from 1,750 – 2,000 m/s were determined to represent the bedrock below the alluvium. To be conservative, seismic velocities lower than 1,750 m/s are assumed to be unconsolidated materials that overlie the bedrock.

Based on the seismic tomography modeling, the average thickness of alluvium is 5.8 meters and the maximum thickness is 22 meters. The total estimated volume of the alluvium is 427,175 m^3 and the longitudinal slope of the bedrock profile is 0.0485m/m. Figures 4 and 5 illustrate the modeled bedrock elevations and the thickness of the alluvium as interpreted with the seismic refraction analysis and kriging analysis powered by ARCINFO.

Maximum Thickness	22 m
Average Thickness	5.8 m
Volume of Alluvium	427,175 m^3
Slope of Bedrock Profile (m/m)	0.0485 m/m
Volume of Saturated Alluvium	44,500 m^3
Volume of Groundwater	5,340 m^3

Table 2. *3D Analysis of Ravine Tet Sous Alluvium; saturation analysis is based on conditions at the time of the study.*

Three dimensional (3D) analysis of saturated alluvium was performed and suggests that at the time of the study, 44,500 m^3 of the alluvium was saturated or 10% of the total estimated volume of alluvium. Based on an assumption of 12% porosity, the total estimated volume of water in the aquifer is 5,340 m^3 or 1,411,000 gallons. The porosity was estimated based on inspection of the alluvium observed in the test pits.

Longitudinal Profile of Ravine Tet Sous Aquifer

A longitudinal profile was developed for the aquifer using survey and geophysical data collected for the study using ARCINFO. Figure 6 illustrates the alluvium surface, interpreted bedrock elevation and the interpreted thickness of alluvium along the profile.

The profile runs along the centerline of the ravine. The profile illustrates how steep the gradient of this ravine is and its associated hydraulic gradient. The aquifer maintains a steep hydraulic gradient due to the relatively low hydraulic conductivities.

Pumping Test and Analysis

A pumping test was performed at the location identified in Figure 3 and shown in the attached photo plate. The pump test was performed at this location due to the narrow confinement of the channel and the shallower depth to groundwater than was observed up- gradient of this spot. The location is a possible intake location for the water system and is approximately 100 meters downstream of the location identified during the site visit with DINEPA on 12 June 2013.

The aquifer test was conducted by excavating with a backhoe as far into the saturated zone as could be achieved without collapse of the sidewalls. A sump 2.5 meter in diameter was created at the bottom of the excavation in which the pump was installed. A 13 horsepower, 4-inch centrifugal pump with a capacity of 80 m^3/hour was used for the test. The total depth of the sump pit was 2.83 meters and bedrock was 0.1 meters deeper.

The suction hose of the pump was installed in the bottom of the sump and a measuring point was established along the wall of the excavation. The pump was started and timed measurements were taken both during pumping and recovery.

The test was intended to last 24 hours during which the drawdown and discharge would be regularly measured. The alluvium, however, was of a much lower hydraulic conductivity than was expected and the sump drew down within 40 seconds after initiation of pumping. A total of 0.9 m^3 of water was removed. The test was then converted to a slug test and the recovery was monitored until approximately 95% recovery, which was achieved after 60 minutes. See Appendix 1 for the GESFOR report of the test and the drawdown and recovery measurements.

Total Pump Rate	80 m^3/hr
Drawdown	0.52 m
Time of Recovery	60 min
Hydraulic Conductivity	0.0043 m/s

Table 3. *Pump Test Results*

Aqtesolv v 4.5 was used to analyze the results of the test in order to determine hydraulic conductivity of the aquifer. The hydraulic conductivity is estimated at 0.0043 m/s. It is important to note that this hydraulic conductivity is from one location and may not be representative of the entire aquifer system, however, our observations indicate that the aquifer properties are fairly uniform.

Test Pits

A series of seven test pits were dug using a Caterpillar 420E backhoe. The locations are shown on Figure 3. The purpose of the test pits was to characterize the nature of the alluvium, estimate depth to bedrock (if possible) and determine the water table (if possible).

We were also able to recognize the depth to the water table during the rainy season, as there was an abrupt horizon of oxidized strata at nearly each test pit location.

Table 4 summarizes the test pit results. Test pit locations are illustrated in Figure 3.

Test Pit #	Pit Depth (m)	Depth to Water (m)	Estimated Rain Season Depth to Water (m)
TP 1	2.3	1.67	1.22
TP1a	3.3	NA	NA
TP 2	3.3	2.77	1.52
TP 3	2.83	2.23	1.50
TP 4	2.44	1.86	1.22
TP 5	3.2	NA	3.0
TP 6	3.3	NA	NA

Table 4. *Test Pit Observations*

Based on the test pit excavations, the alluvium was very consistent and is characterized as gravel with appreciable amount of fine-grained sediment. The alluvium is well graded or poorly sorted consisting of boulders (> 300mm), cobbles (75-300mm) and fine to course sand (0.08-4.8mm). The pore space matrix is consistently a fine silt (<0.08mm). This fine silt matrix is a limiting factor in the permeability and porosity of the alluvium. The included photo plate shows a typical section of the alluvial materials.

Aquifer Flow Analysis and Safe Yield

An aquifer flow analysis was developed to represent the conditions in late June 2013. Based on trends of precipitation during the month of June and discussions with WISH, we believe the condition is representative of an average dry season period. Rainy season and drought condition scenarios were also estimated based on test pit observations of seasonal water tables.

Estimates for drought conditions are based on WISH system historical flows and an assumed 0.8 meter lower water table than observed in June 2013.

	June 2013	Rain Season	Est. Drought Conditions
WISH System Withdrawal (l/s)	5.1	6.6	3.0
Additional Flow (l/s)	2.6	4.9	0.5
Total Aquifer Flow (l/s)	7.7	11.5	3.5

Table 5. *Aquifer Flow or Safe Yield Estimates*

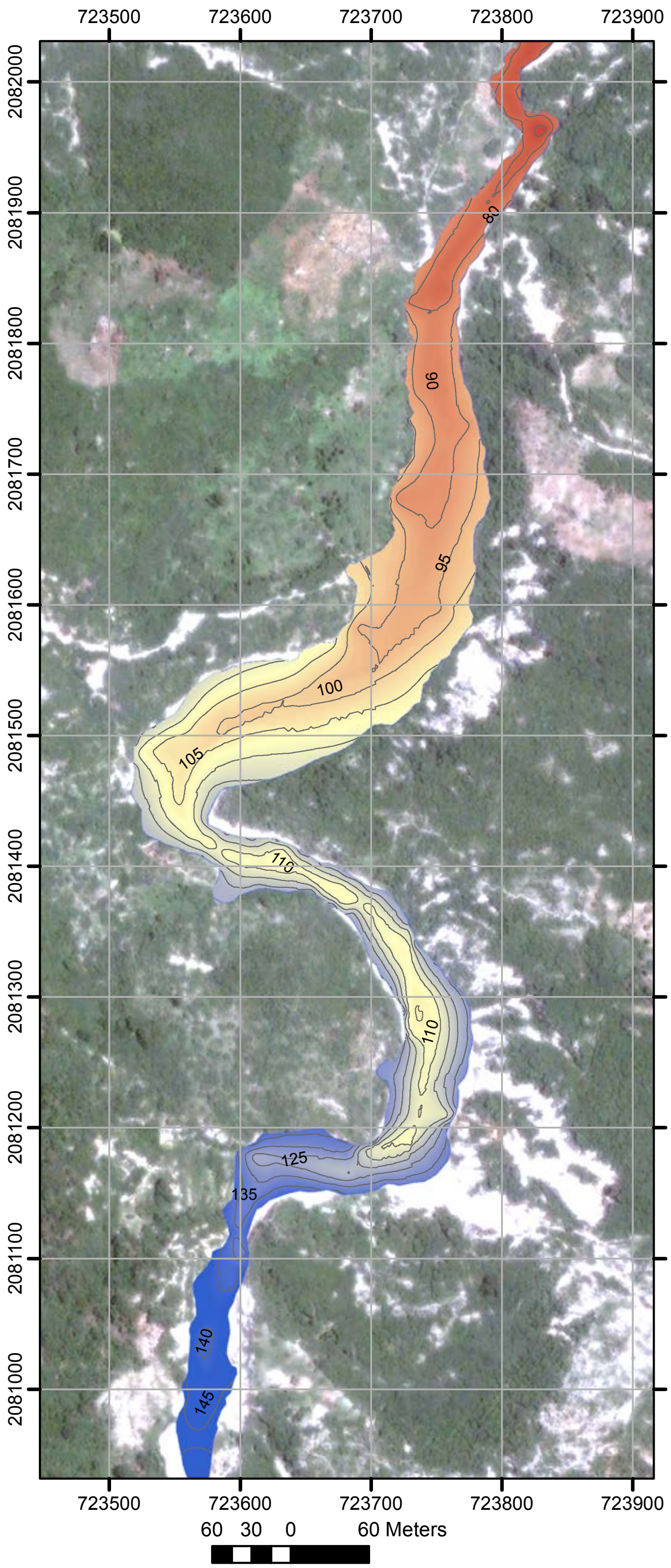


Figure 4. *Bedrock elevations, based on seismic geophysical data and 3D modeling. 5 meter elevation contours.*

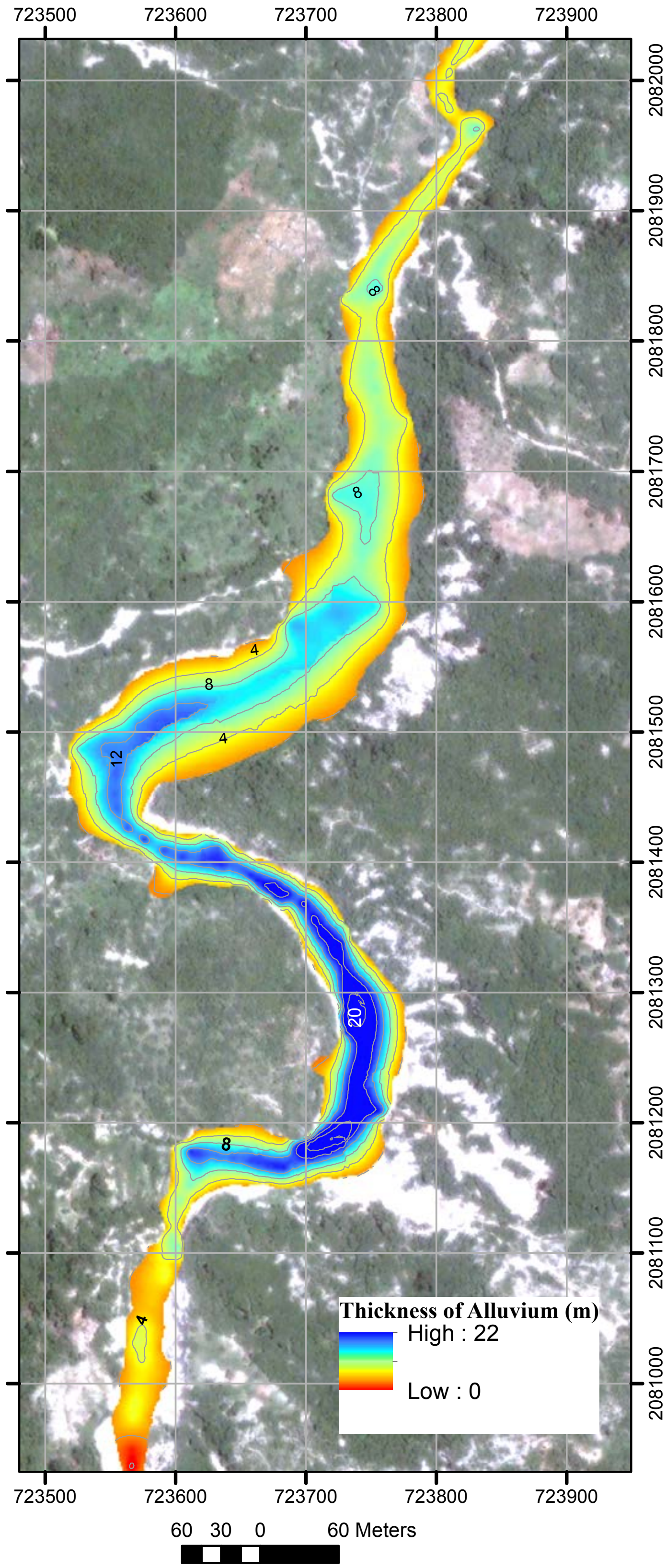


Figure 5. *Thickness of alluvium above bedrock, based on seismic geophysical data and 3D modeling. 4 meter depth contours.*

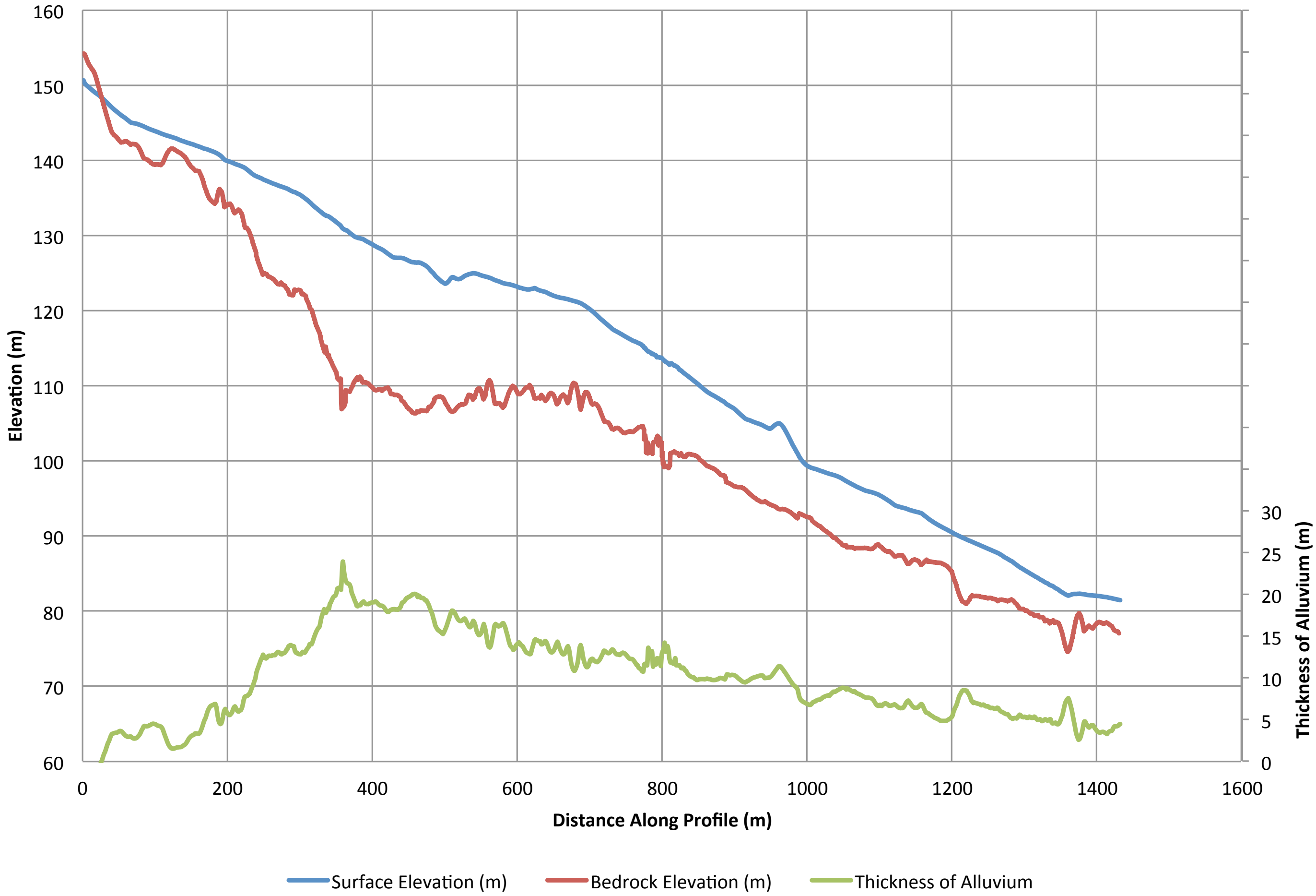


Figure 6. *Longitudinal Profile of Ravine Tet Sous Alluvial Aquifer; blue = surface of alluvium, red = bedrock, green = thickness of alluvium along profile*

The additional flow through the aquifer was calculated using Darcy's Law and applying the hydraulic conductivity from the pump test, the estimated hydraulic gradient of the aquifer and the cross section of alluvium that was surveyed at the location of the pump test.

Darcy's Law

$$Q = A * K(S)$$

Q = Discharge in m^3/s
A = Cross sectional area in m^2
K = Hydraulic conductivity in m/s
S = Hydraulic gradient of aquifer in m/m

Calculation for June 2013 aquifer flow conditions

$$Q = 14.4m^2 * 0.0043m/s * 0.045m/m$$
$$Q = 2.78x10^{-3}m^3/s$$
$$Q = 240m^3/jour$$
$$Q = 63,598gallons/jour$$

Conclusions

Based on the study, it does not appear feasible to use the Ravine Tet Sous alluvial aquifer as the sole source of water to serve the city of Anse-à-Galets. During the period of this study, the aquifer flow would only support approximately 50% of the required demand. During the dry season, it is possible that only 20-25% of the demand could be supplied by the aquifer. Additional studies can be considered to more accurately evaluate dry season and rainy season fluctuations in aquifer flow, however, we believe additional efforts should focus on securing additional sources of water.

The Ravine Tet Sous alluvial aquifer is an important and valuable resource and should be considered as a part of the water supply solution to serve the city of Anse-à-Galets. The aquifer alone is not capable of sustainably supplying the required water demands.

The Ravine Tet Sous aquifer is very small, unconfined and extremely susceptible to contamination and drought. This observation further validates the need to secure additional water sources to serve the city.

Recommendations

A three-part course of action is recommended that provides for more water to the community from current and new sources and that protects the existing resource.

Recommendation 1. Additional Water Source Exploration

It is recommended that additional water sources, apart from the Ravine Tet Sous alluvial aquifer, be investigated and, when located, an engineering feasibility analysis be performed for the construction of a pipeline for delivery of this water to the city.

The most likely additional resource is the La Palma aquifer located on the high plateau south of Anse-à-Galets, approximately 4 – 8 kilometers from the city along roads and trails. This limestone aquifer is a proven water supply for many communities and is also the source of water for Sous Tet at the head of the ravine aquifer. Wells in this aquifer are known to produce a range of yields since yields are dependent on drilling through cracks and fractures in the aquifer. Based on pump test data collected by V3 Companies from 2010 – 2013, wells in the aquifer have capacities that range from 0.51 to 7.0 m^3/h. However, greater yields are possible with geophysical studies that target cracks and fractures.

Evaluation of the potential La Palma aquifer requires hydrogeologic mapping, remote sensing analysis combined with a focused field program that includes geophysics to target locations most likely to result in higher capacity wells. Areas with significant subsurface fracturing and karst weathering are the most likely areas to produce a sufficient water supply.

Test drilling should be conducted of several of the most likely areas and evaluated for implementation of a higher capacity well system. A groundwater well pumping system may require one or more wells to achieve the desired water demands.

Recommendation 2. Infrastructure Improvements at Ravine Tet Sous Aquifer Intake

It is recommended that improvements be made to capture as much water as possible flowing within the Ravine Tet Sous alluvial aquifer. A subsurface dam is proposed that would capture most of the water flowing through the aquifer. Currently, the WISH system only captures a portion of the groundwater flow and the remaining is unused. This dam would intercept nearly all of the subsurface flow and back it up into the upstream alluvium creating a subsurface reservoir drained by a newly constructed French drain system.

The most cost-efficient location to build the dam would be in the area where bedrock is relatively close to the surface and where the valley is narrow. The location of the pump test, approximately 160 meters downstream of the WISH system, had bedrock within approximately 3 meters of the valley floor and it is confined between bedrock valley walls approximately 12 meters apart.

The dam would be keyed into the bedrock base and sidewalls and would rise approximately 0.5 meters above the current alluvium. The French drain would consist of multiple sloping perforated pipes placed at a depth of approximately 2 meters below the alluvium.

The ravine is a dynamic system subject to significant scour and deposition and experiences hydraulically extreme variations in discharges and velocities. As such, a subsurface dam should be constructed of reinforced concrete with downstream scour protection. The dam itself should allow emergency vehicle access but should prevent regular traffic up the valley.

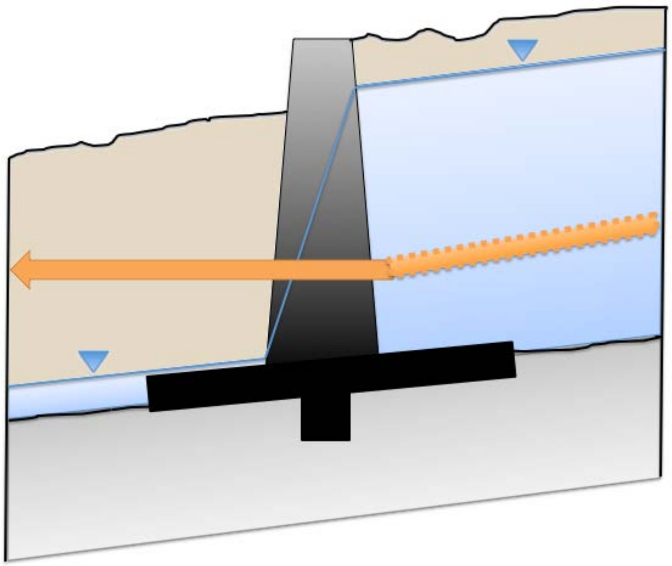


Illustration 1. *Schematic of Subsurface Dam*

Recommendation 3. Aquifer Protection Plan

An active aquifer protection plan should be developed for both the Ravine Tet Sous and La Palma aquifer sheds. The protection plan should provide for methods that both limit access to key infiltration areas and that encourage good handling methods for hazardous materials.

In the ravine Tet Sous, vehicle, animal and human traffic upstream of the proposed subsurface dam should be highly restricted to protect the water quality within the aquifer and in the runoff from the upstream ravine.

Finally, throughout the aquifer shed, appropriate sanitation methods should be encouraged through education and incentives.

Photo 1 & 2. *Seismic Survey and Test Excavation*

Photo 3. *Anse-à-Galets Pump Test Configuration*

Photo 4. *Representative Alluvium Composition*

Photo 5. *Backhoe Trench*

ANSE-À-GALET RAVINE TET SOUS PHOTO PLATE

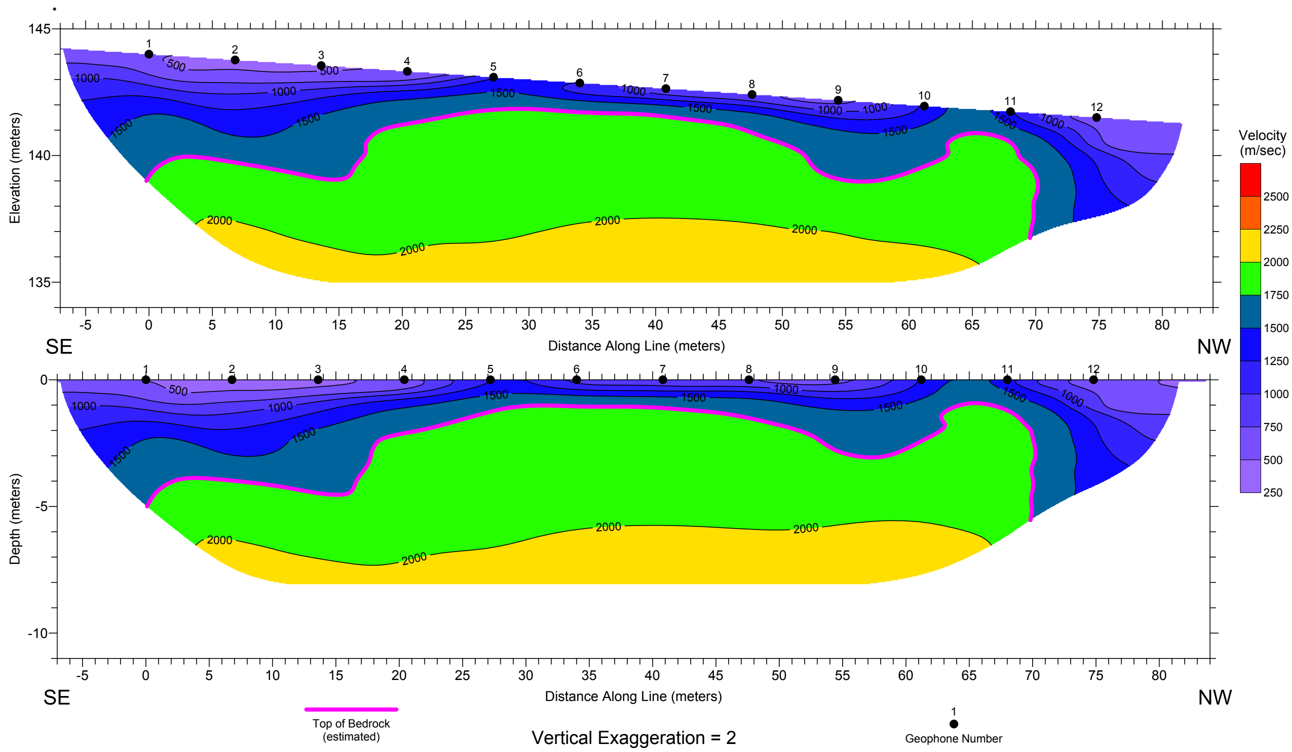


Figure 7. *Line 1 – Seismic Tomography Profile, elevation and depth sections*

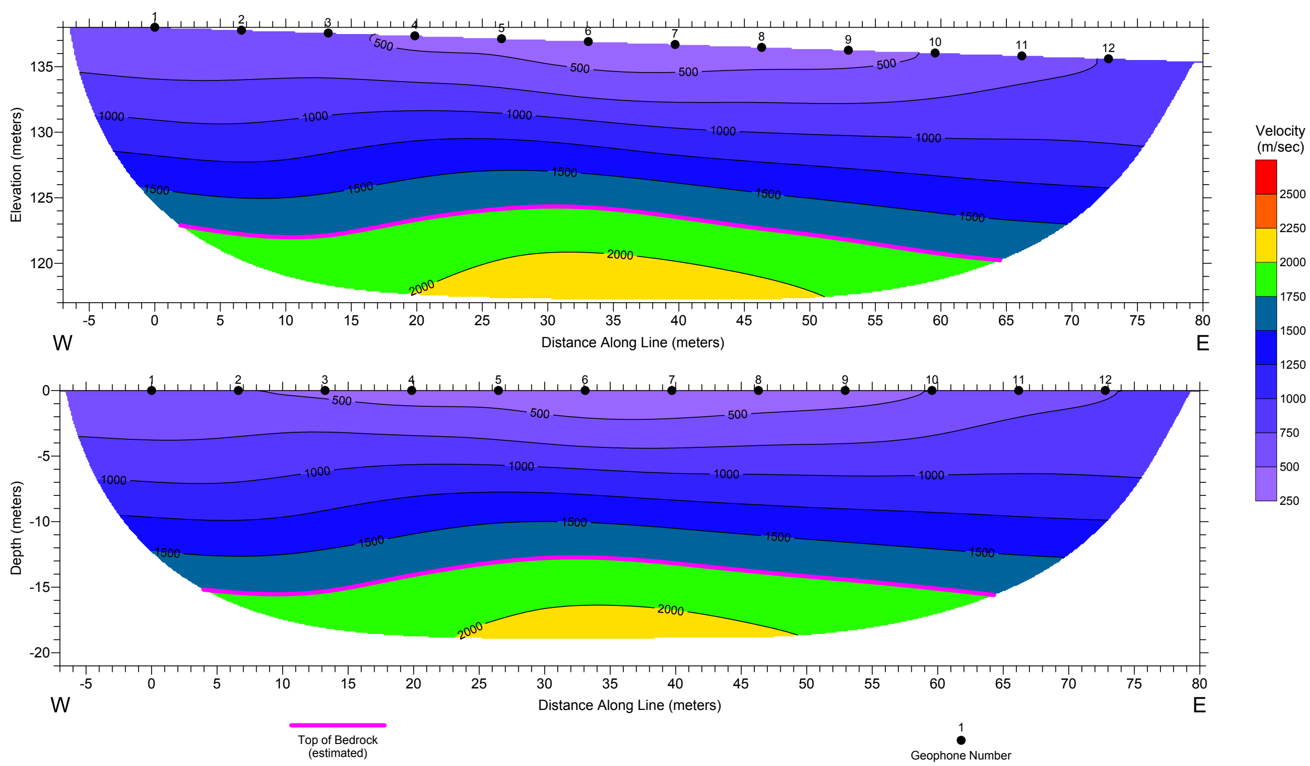


Figure 8. *Line 2 – Seismic Tomography Profile, elevation and depth sections*

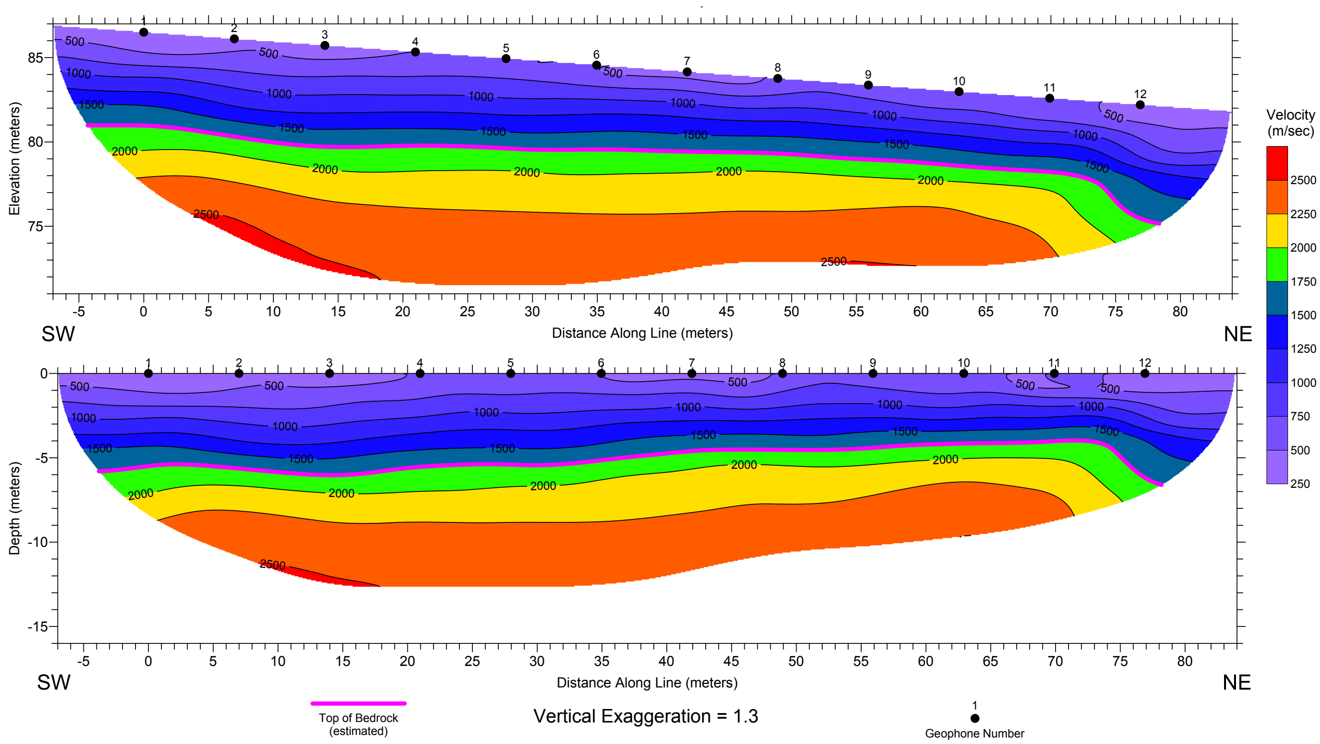


Figure 9. Line 3 – Seismic Tomography Profile, elevation and depth sections

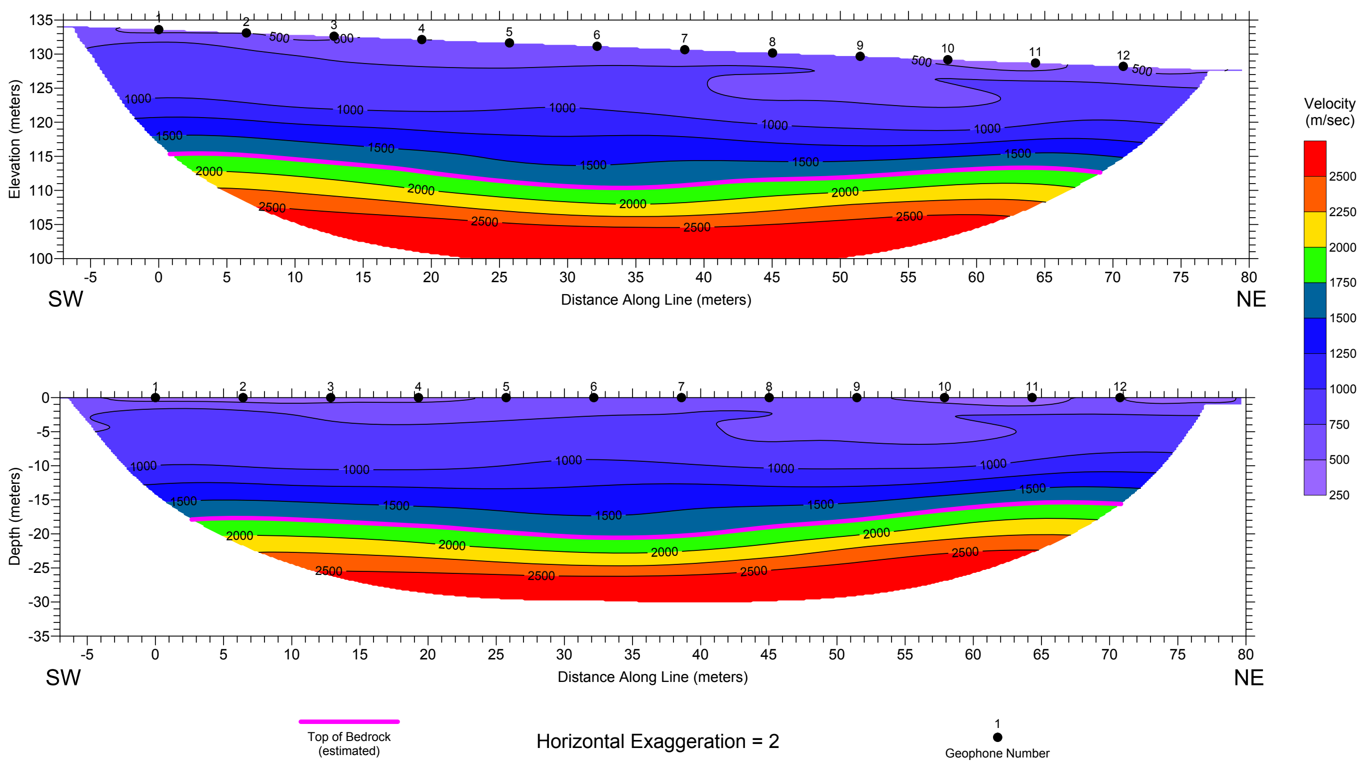


Figure 10. Line 4 – Seismic Tomography Profile, elevation and depth sections

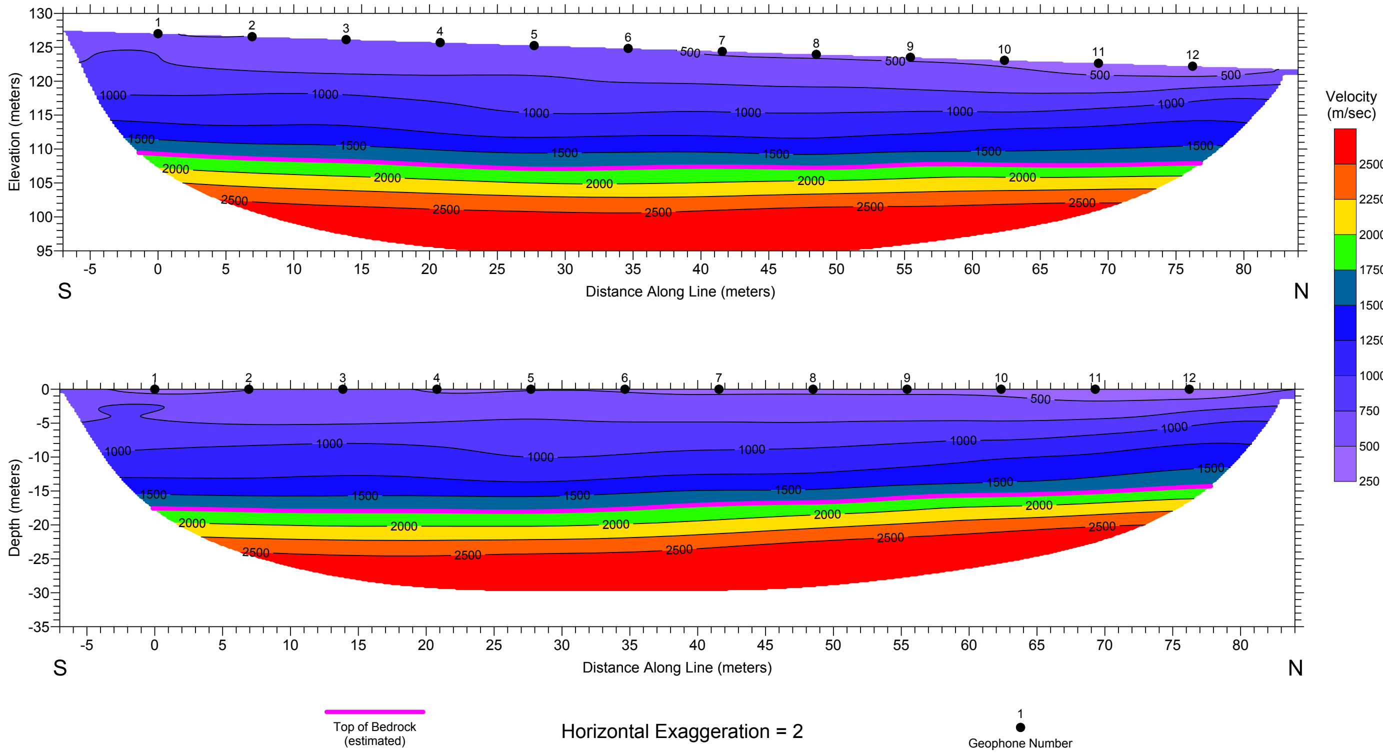


Figure 11. *Line 5 – Seismic Tomography Profile, elevation and depth sections*

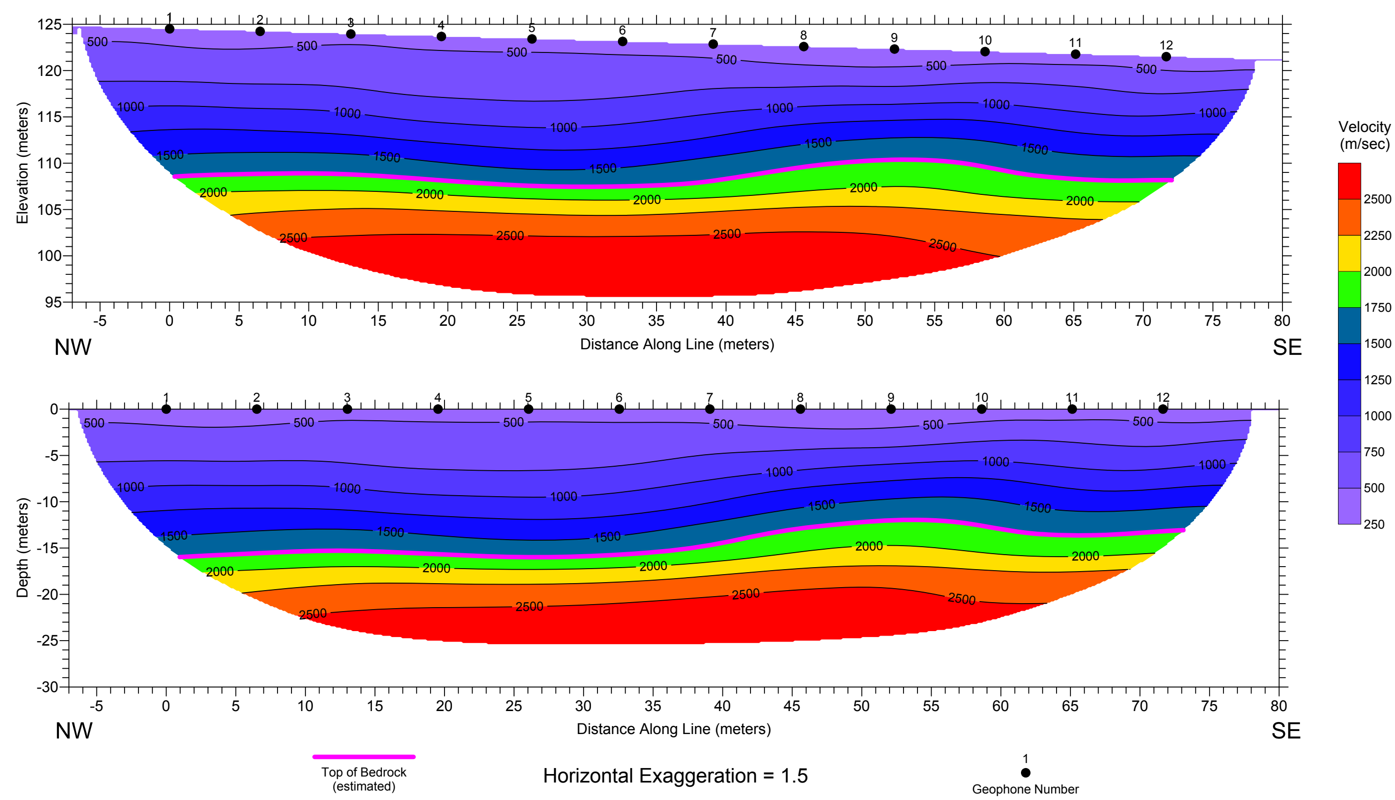


Figure 12. *Line 6 – Seismic Tomography Profile, elevation and depth sections*

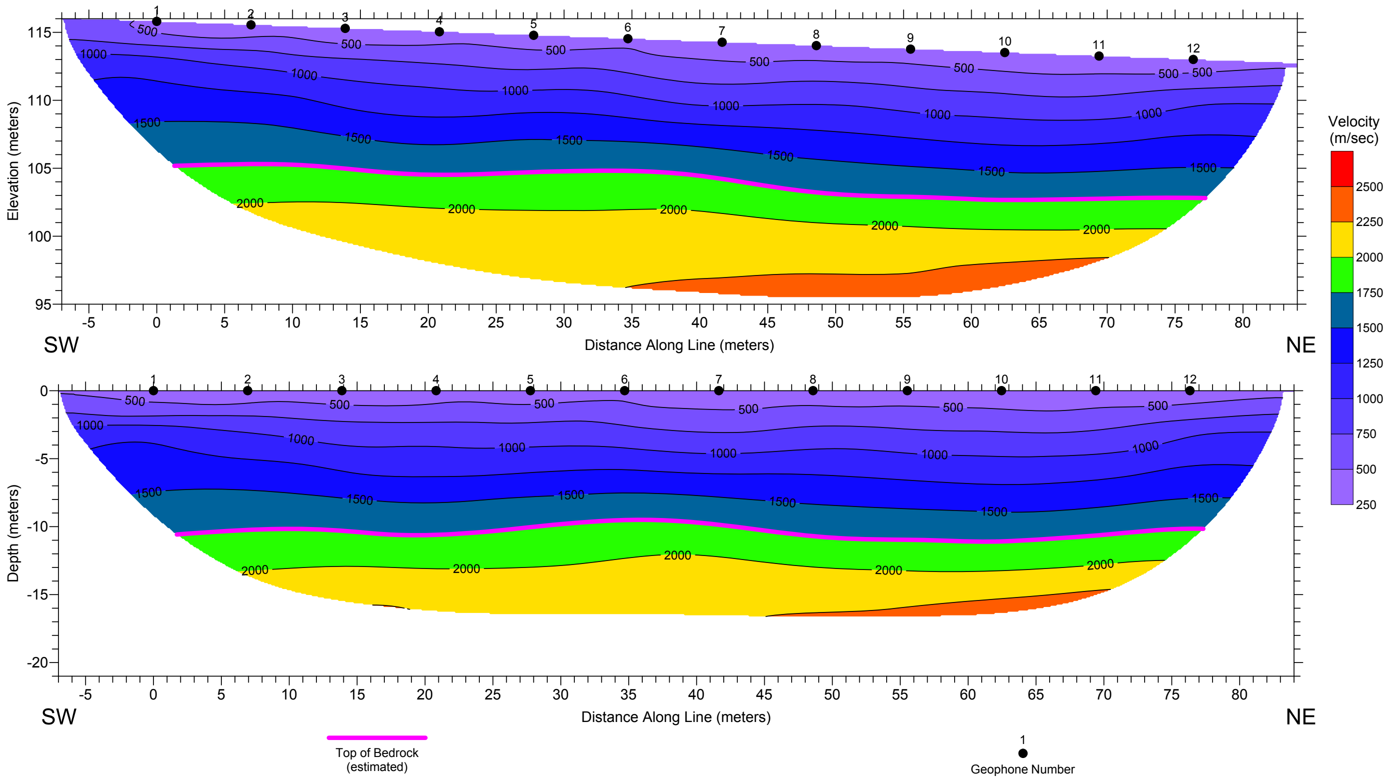


Figure 13. *Line 7 – Seismic Tomography Profile, elevation and depth sections*

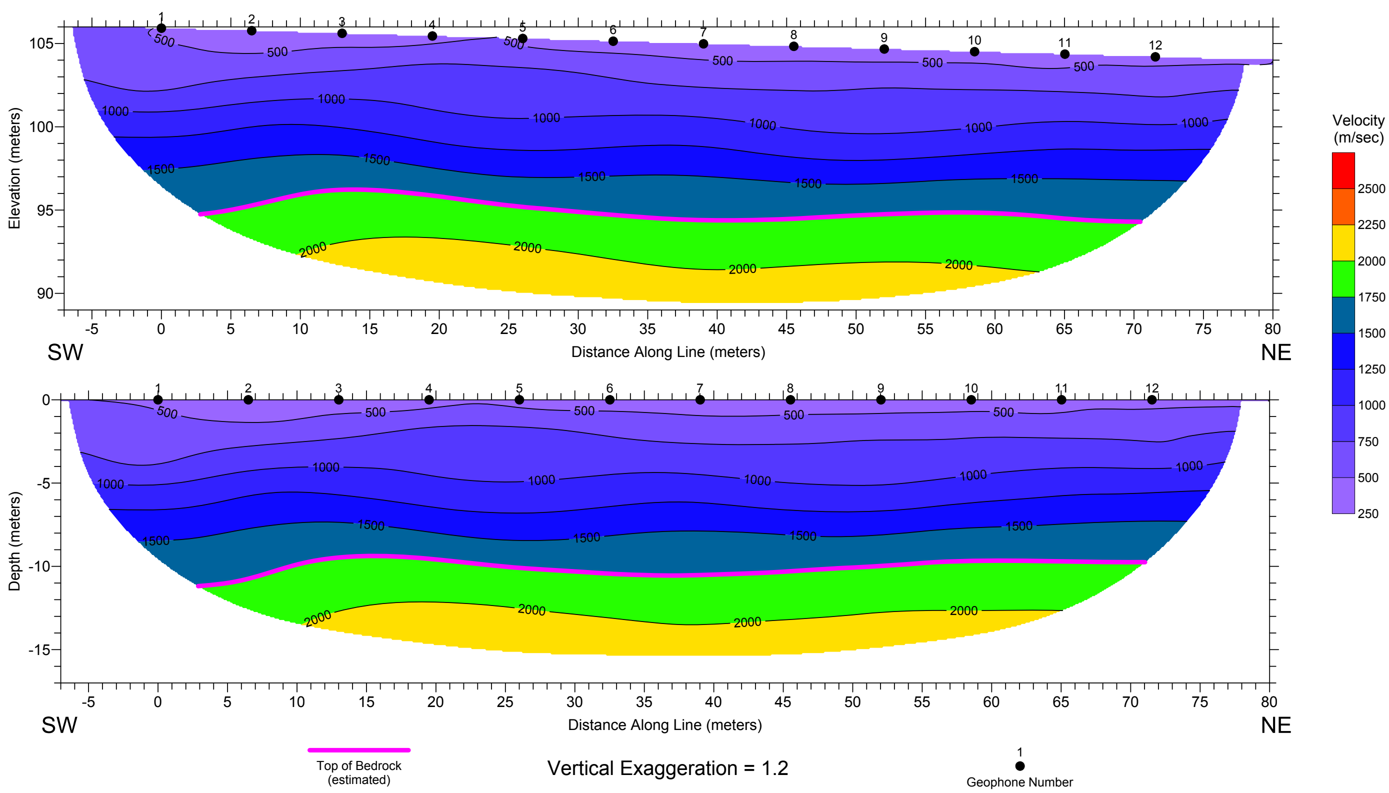


Figure 14. *Line 8 – Seismic Tomography Profile, elevation and depth sections*

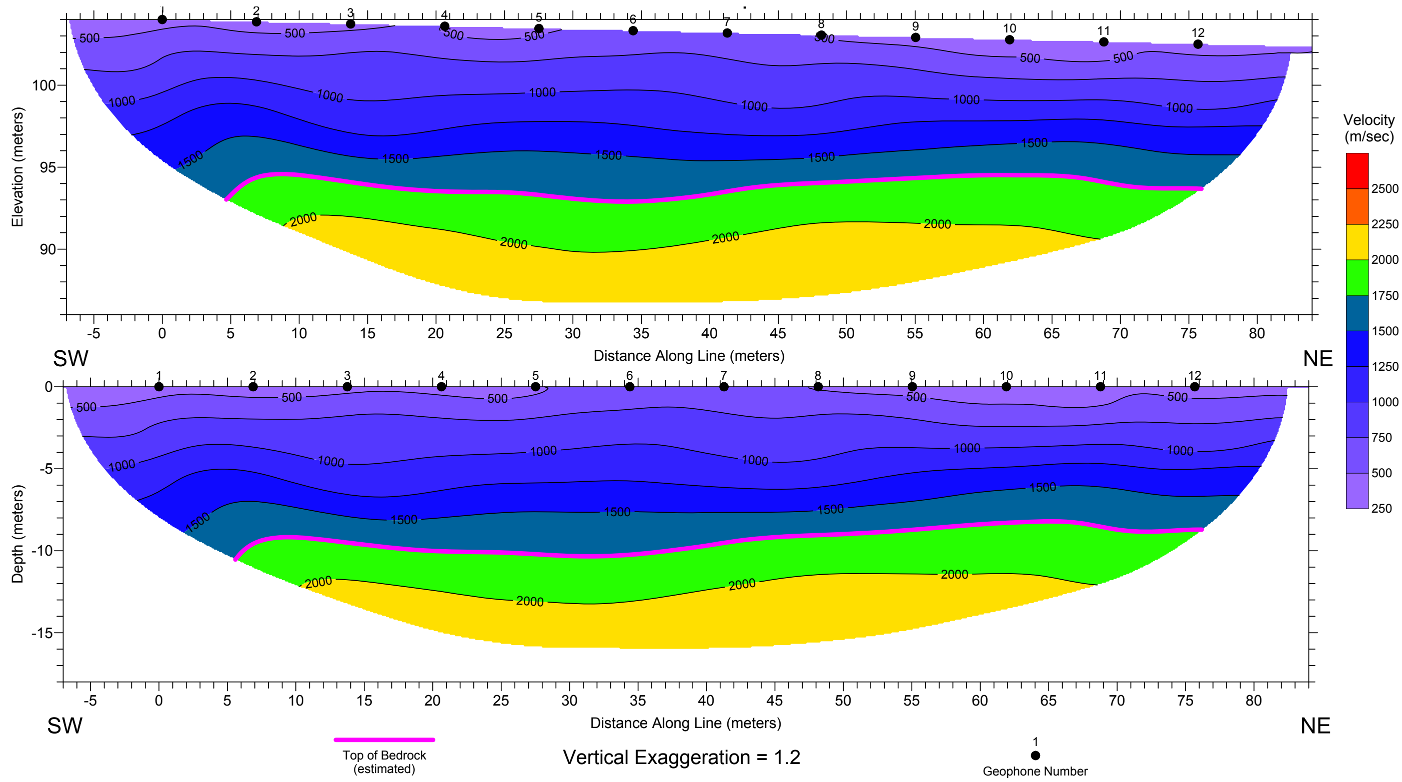


***Figure 15.** Line 9 – Seismic Tomography Profile, elevation and depth sections*

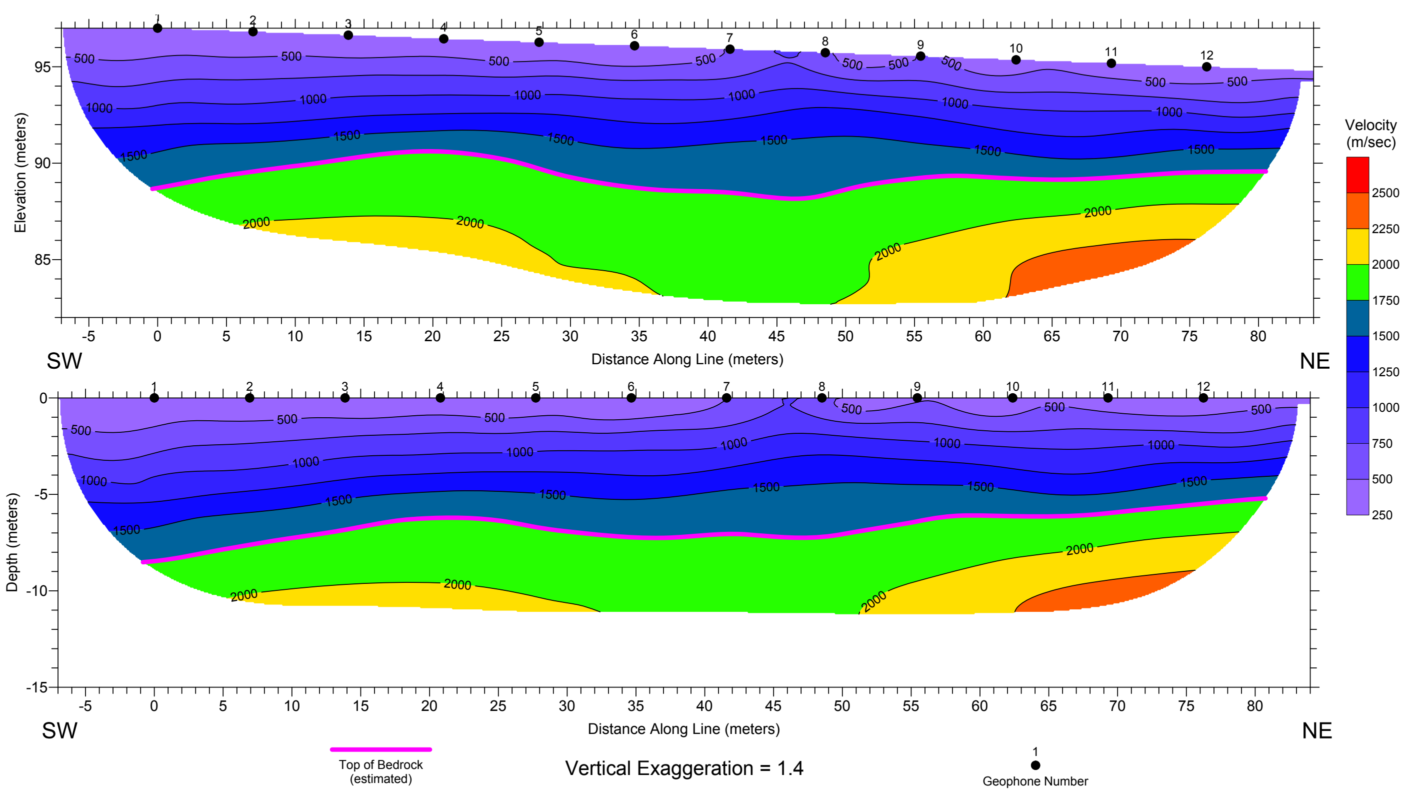


***Figure 16.** Line 10 – Seismic Tomography Profile, elevation and depth sections*

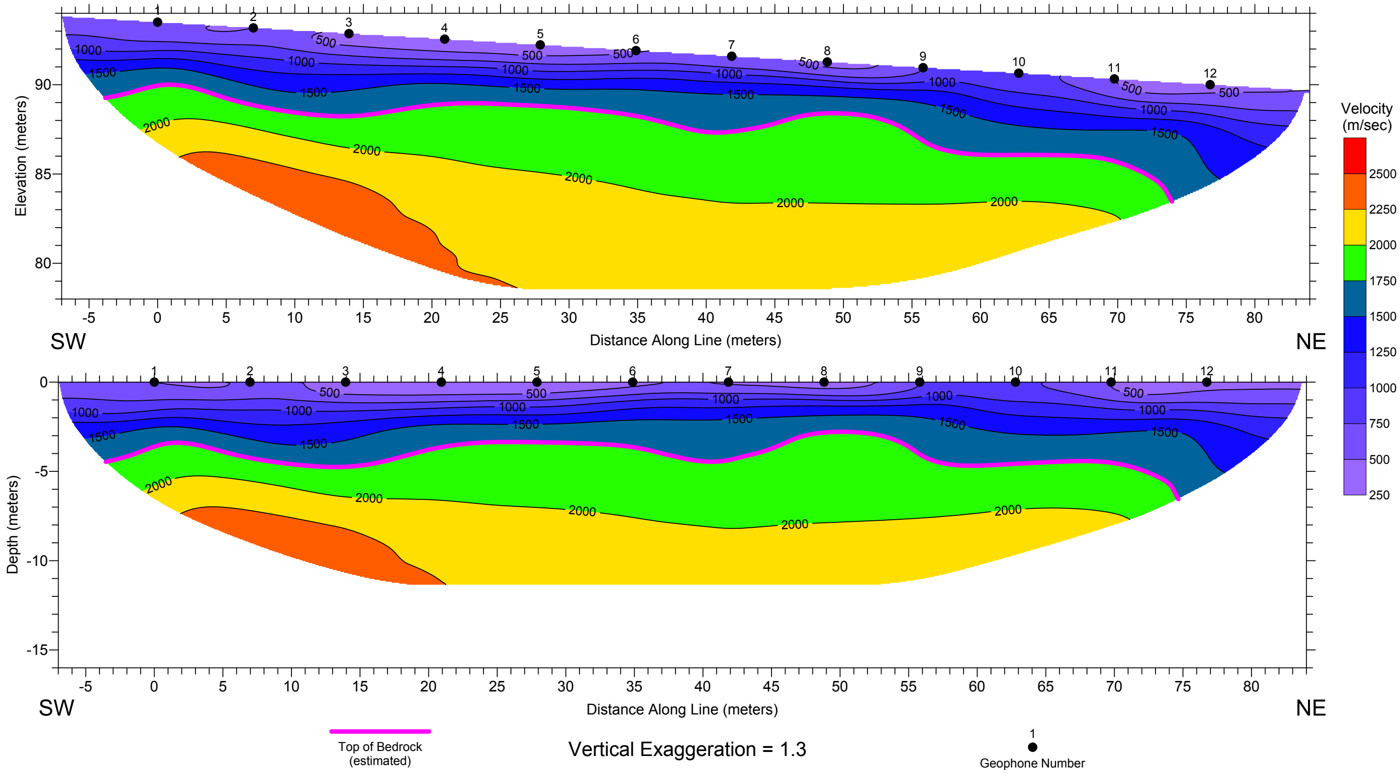


Figure 17. *Line 11 – Seismic Tomography Profile, elevation and depth sections*

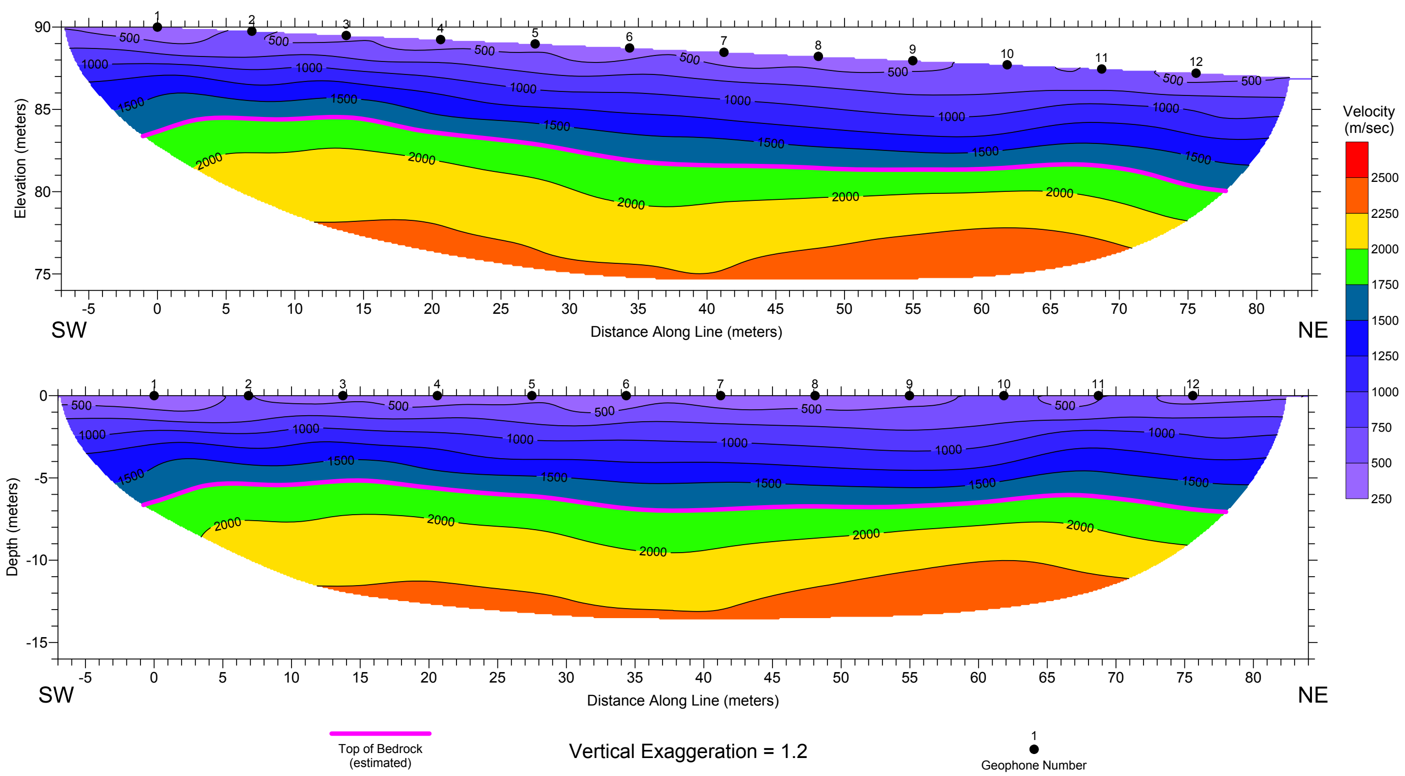


Figure 18. *Line 12 – Seismic Tomography Profile, elevation and depth sections*

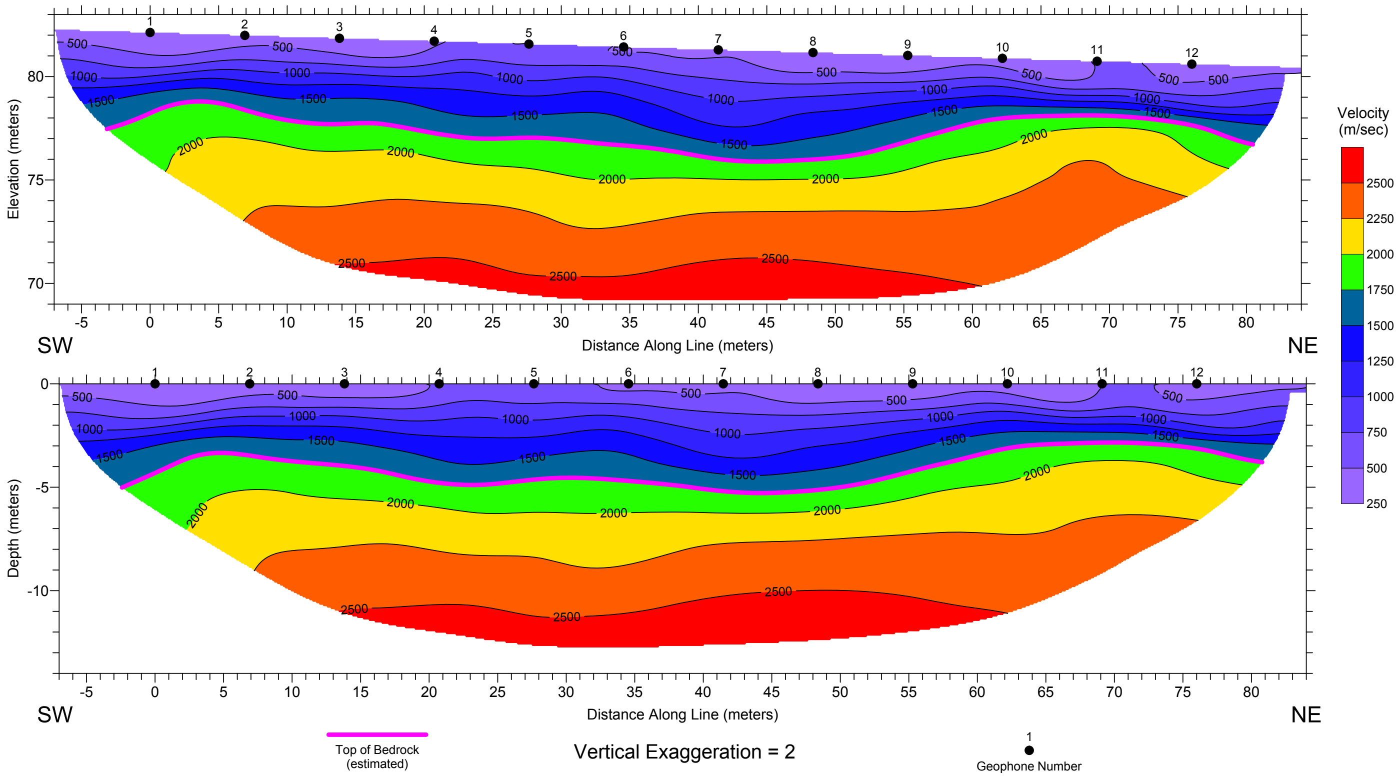


Figure 19. *Line 13 – Seismic Tomography Profile, elevation and depth sections*

DOSSIER TECHNIQUE

POMPAGE D'ESSAI

Entreprise:	**V3 COMPANIES LTD**
Client:	**DINEPA**
Maître d'oeuvre:	**V3 COMPANIES/HAITI OUTREACH**
Exploitant:	**COMMUNE DE ANSE-A-GALETS, HAITI**

Code National BSS :

N° Déclaration ** :

Police de l'eau * :

* Numéro de déclaration au titre de la police de l'eau

** N° d'enregistrement de déclaration préalable

Lieu de l'ouvrage : Ravine Tet Sous

Coordonnées : **Longitude** 072°52'35,06"W **Latitude** 018°49'3,81"N ***Altitude :*** 100.00 m

Nombre de forages : 1

Date début de l'ouvrage : 26/06/2013

Date fin de l'ouvrage : 26/06/2013

Machine : CAT 420E

Resp. M. Ouvrage : JAMES K. ADAMSON

Resp. M. Oeuvre : STUART DYKSTRA

Resp. Chantier :

Date début pompage : 26/06/2013

Date fin de pompage : 26/06/2013

Nombre de nappes identifiées : 1

Niveau statique non perturbé : 2.35 m

Débit Maxi. d'essai : 80.00 m3/h

Rabattement correspondant : 0.52 m

Notes :

Coordonnées = (m) pour mètres m = mètres m3/h = mètres cube par heure

TRONCONS de L'OUVRAGE

POMPAGE D'ESSAI

Client:	**DINEPA**
Maître d'oeuvre:	**V3 COMPANIES/HAITI OUTREACH**
Lieu de l'ouvrage :	**Ravine Tet Sous**

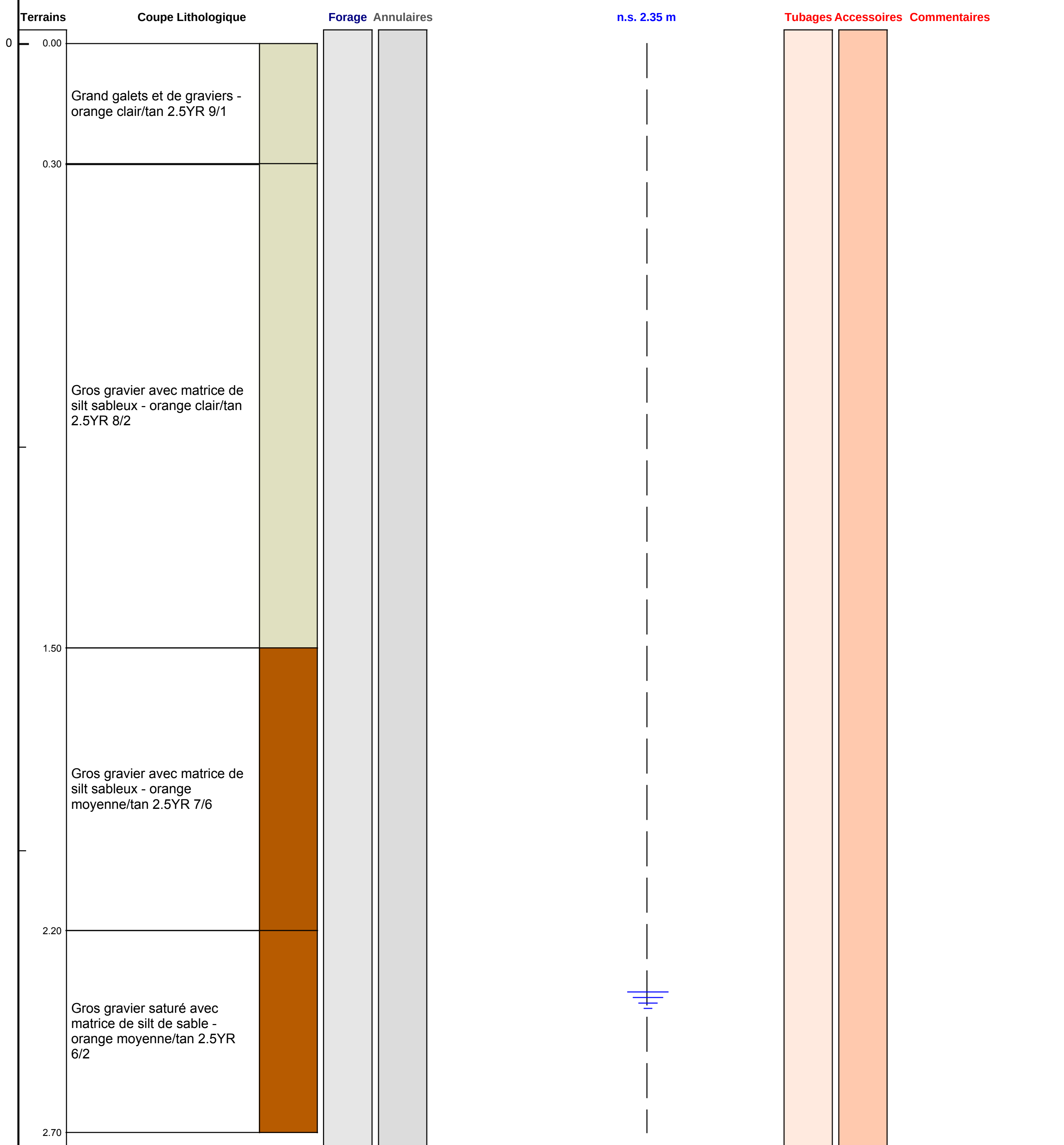
LITHOLOGIE

De	à	Libellé
0.00	0.30	Grand galets et de graviers - orange clair/tan 2.5YR 9/1
0.30	1.50	Gros gravier avec matrice de silt sableux - orange clair/tan 2.5YR 8/2
1.50	2.20	Gros gravier avec matrice de silt sableux - orange moyenne/tan 2.5YR 7/6
2.20	2.70	Gros gravier saturé avec matrice de silt de sable - orange moyenne/tan 2.5YR 6/2

Epais.=Epaisseur (mm) Ecra.=Résist. à l'ecrasement (bar) Slot (mm) Granul.=Granulométrie Min/Max (mm)

	POMPAGE D'ESSAI	**Travaux réalisés :** **1\2** du : 26/06/2013 au : 26/06/2013
Client :	**DINEPA**	**Coordonnées de l'ouvrage :**
Maitre d'oeuvre :	**V3 COMPANIES/HAITI OUTREACH**	Géographique Longitude (X): 072°52'35,06"W Latitude (Y): 018°49'3,81"N Altitude sol (Z): +100.000 m
Localisation de l'ouvrage :	**Ravine Tet Sous**	

Echelle : 1/14 — Profondeurs en m au-dessous du repère zéro sol (signe + au-dessus) — Nombre de forages : 1



Le ....../....../............ à ....

CERTIFIE CONFORME A L'OUVRAGE EXECUTE

Tampon et signature du chef d'entreprise

POMPAGE D’ESSAI

Excavation D’Essai

Client:	**DINEPA**
Maître d’oeuvre:	**V3 COMPANIES/HAITI OUTREACH**
Lieu de l’ouvrage :	**Ravine Tet Sous**

Profondeur utile du forage:	2.74	m	Niveau repère/sol:	0.00	m
Diamètre de la chambre de pompage:	0	mm	Niveau statique/sol:	2.35	m
Type de la pompe: MPOWER 4" Centrifugal 13Hp			Puissance de la pompe:	0	Kw
Diamètre nominal:	2.5 m		Diamètre hors tout de la pompe:	0	mm
Débit maxi de la pompe:	80.00	m3/h	Hauteur de refoulement maxi:	0	mm
Installée à (profondeur):	2.74	m	Longueur de refoulement:	13	m

Observations :

Date et heure de début de pompage le **26/06/2013** à **14:55**

Type de sonde : Sonde de Niveau

Date	Heure	Temps	Débit	Sonde	Niveau/sol	Rabatt.	Observation
26/06/2013	14:56	0h01		2.87	2.87	0.52	
	14:57	0h02		2.82	2.82	0.47	
	14:58	0h03		2.77	2.77	0.42	
	15:00	0h05		2.65	2.65	0.30	
	15:05	0h10		2.58	2.58	0.23	
	15:10	0h15		2.54	2.54	0.19	
	15:15	0h20		2.52	2.52	0.17	
	15:25	0h30		2.46	2.46	0.11	
	15:35	0h40		2.41	2.41	0.06	
	15:45	0h50		2.39	2.39	0.04	
	15:55	1h00		2.37	2.37	0.02	

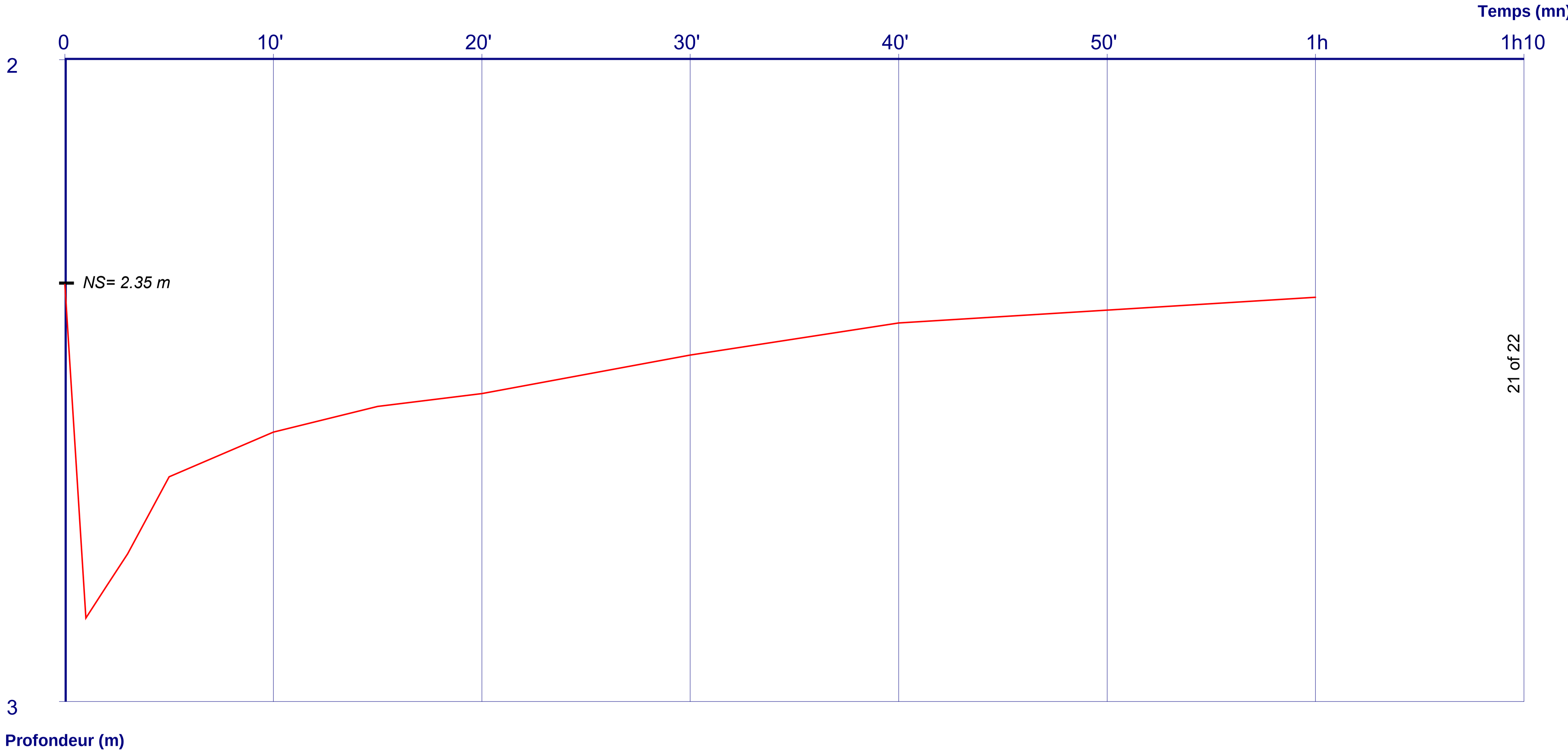
V3 COMPANIES LTD

COURBE DE POMPAGE

POMPAGE D'ESSAI

Date début: 26/06/2013
Heure début: 14:55

Excavation D'Essai



Débits:

	POMPAGE D'ESSAI	Travaux réalisés : du : 26/06/2013 au : 26/06/2013
Client :	**DINEPA**	**Coordonnées de l'ouvrage :** Géographique
Maitre d'oeuvre :	**V3 COMPANIES/HAITI OUTREACH**	X: 072°52'35,06"W
Localisation de l'ouvrage :	**Ravine Tet Sous**	Y: 018°49'3,81"N
		Z altitude sol: +100.000 m