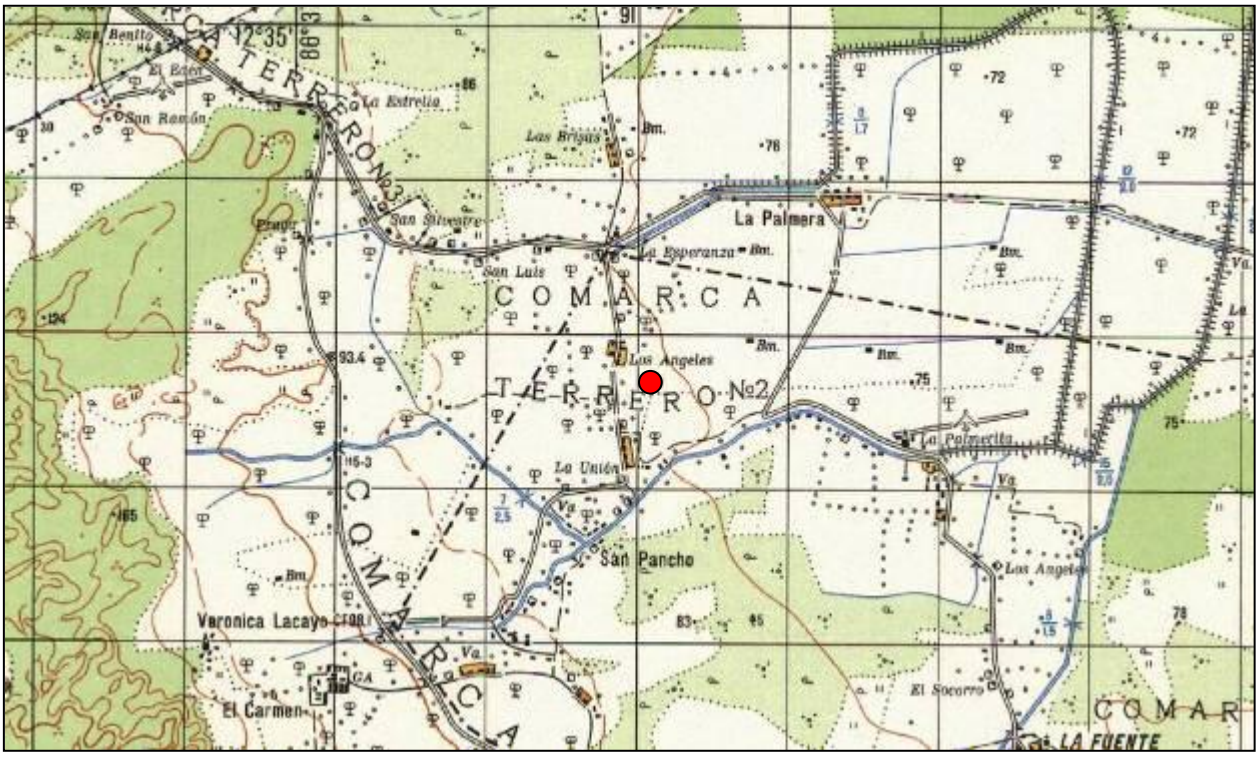
HYDROGEOLOGICAL ANALYSIS

Proposal

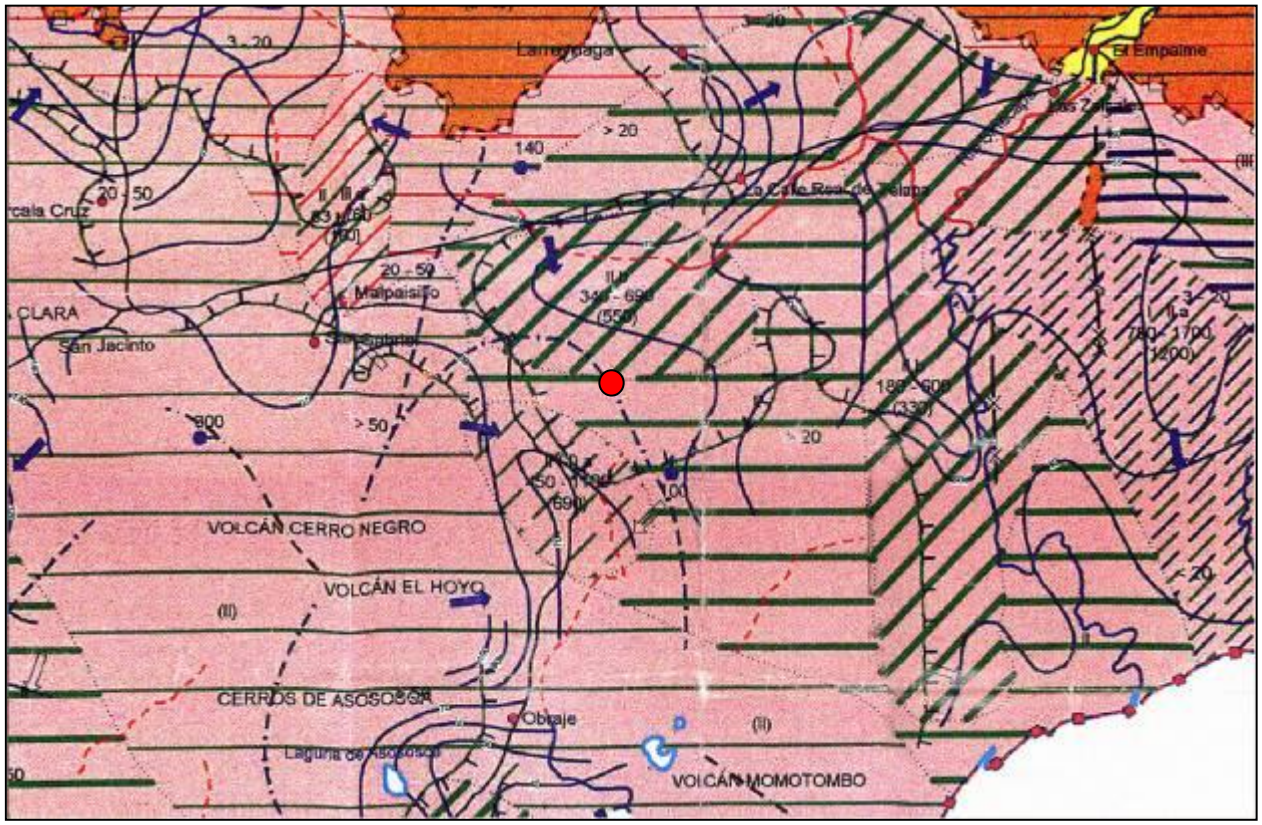
The proposal is for a water supply for a community of 153 households at *La Palmerita* from a borehole to be drilled near the western edge of the property at grid reference (5)431 (13)887 as shown on the map below. The maximum required yield according to the engineering design is approximately 3 l/s. The borehole would be drilled at a 6 inch diameter to a depth of approximately 30 metres.



Hydrogeological setting

The proposed borehole site is located in a relatively flat area of alluvial deposits to the east of the Maribios chain of volcanoes at an altitude of approximately 80 m.a.s.l. The area has no perennial streams but is drained by numerous ephemeral streams and man-made channels. These perched streams drain the area during the wet season to a watercourse known as El Madroño which flows into El Caimito, a tributary of the Rio Sinecapa which flows into the north end of the Lago de Managua. La Palmerita is thus a part of the Rio San Juan surface water catchment.

The area of interest is covered by the maps and report *Estudios Hidrogeológicos e Hidroquímicos de la Región del Pacífico de Nicaragua* (Krasny & Hecht, 1998, published by INETER). The proposed borehole site is shown on the Managua sheet of the hydrogeological map published as part of this study below:



The principal aquifer is comprised of unconsolidated and semi-consolidated Quaternary alluvium including some re-worked pyroclastic sediments, conglomerates, pumice and ash. This aquifer generally has high porosity and permeability. Groundwater contours on the above map indicate that the groundwater level is between 70 and 80 m.a.s.l. and that it is between 3 and 20 metres below ground level. Groundwater flow is generally towards the east where it discharges in the influent lower reaches of the Rio Sinecapa, but as the site lies close to an inferred groundwater divide which separates this groundwater catchment from another which drains south towards El Obraje on the west side of Volcán Momotombo, it is possibly that local patterns of groundwater flow may be different.

The transmissivity of the aquifer is classed as high (100 – 1000 m^2/day) with low variability. The site lies close to two zones for which statistical analyses of transmissivity data have been undertaken: the zone 'Al E de Malpaisillo' to the north has an average T of 550 m^2/day (n=8) while the zone 'El Carmen – La Fuente y el área más al norte' has an average T of 690 m^2/day (n=7). Data obtained from IPEMSA for three irrigation wells drilled in 1973 at La Palmera just to the north of the site show that yields of 1200 g.p.m., 1100 g.p.m. and 1100 g.p.m. were achieved with drawdowns of 52 ft, 74 ft and 44 ft respectively. Using 'Logan's rule' the estimated transmissivities for these three wells were calculated as 500 m^2/day, 290 m^2/day and

550 m^2/day respectively. These various sources of data therefore consistently indicate that the transmissivity is high, probably around 500 m^2/day.

Existing groundwater abstractions

In addition to the three irrigation wells in the neighbouring property mentioned above, there are three large diameter irrigation wells at La Palmerita itself, drilled around 30 years ago by Riegos de Nicaragua, two 6 inch irrigation wells drilled in November 2002 by Mercy Ships Nicaragua and at least six hand-dug wells. No details are available for the large irrigation wells, but the two wells drilled by Mercy Ships Nicaragua were to depths of 70 and 120 ft respectively. The rest water levels were 23 and 22 ft b.g.l. and the yields of these wells were interpreted by the driller to be >100 g.p.m. and around 200 g.p.m. respectively.

The old irrigation wells were fitted with rotary pumps but the wells are no longer in use. One of the wells drilled in 2002 has a windpump but the other is not currently in use. The hand dug wells have either rope pumps or buckets. None of the current abstractions result in any detectable drawdown.

Estimated yield

It is clear from the transmissivity values calculated above and the data from nearby wells that the proposed abstraction could be achieved many times over. Using Logan's rule, the predicted drawdown for the proposed abstraction rate of 3 l/s (assuming T = 500 m^2/day) would be 0.63 m. A well 30 m deep would be capable of yielding around 85 l/s (assuming rest water level = 7 m, pump depth = 25 m, T = 500 m^2/day). Given the results of these calculations and the relative homogeneity of the aquifer, there are no foreseeable reasons why the proposed abstraction rate would not be achieved.

Water Quality

Prediction of the quality of water from the proposed abstraction has been made from both published sources and from original investigations. These investigations were carried out in response to concerns previously raised about drinking water quality at La Palmerita including faecal contamination, arsenic and pesticides, and the results are presented below.

According to the hydrochemical map published as part of *Estudios Hidrogeológicos e Hidroquímicos de la Región del Pacífico de Nicaragua*, the proposed borehole site lies within an area where groundwater is typically HCO_3 – Ca – Na or HCO_3 – Na – Ca in composition. It lies between the 500 mg/l and 1000 mg/l contours for Total Dissolved Solids and in an area where Boron is found at 'acceptable' concentrations of 0.5 – 1.0 mg/l. The Sodium Absorption Ratio is low, which means that irrigation is possible. pH measurements in the field have been between 6.9 and 7.4 with TDS values measured at 570 – 730 mg/l. All these parameters are within

acceptable limits as defined by INAA (Normas Técnicas para el Diseño de Abastecimiento y Potabilización del Agua, NTON 09003-99).

Bacteriological Quality

Microbiological analysis of water samples from the rehabilitated hand-dug well at La Palmerita was undertaken on four occasions from July 2002 until September 2003 using the Oxfam-DelAgua field testing kit (based on membrane filtration and cultivation of colonies of thermotolerant coliforms). *Escherichia coli* were found at 570/100 ml on 27th July 2002 before rehabilitation work was undertaken. This work included covering the well, protecting the well surround with improved drainage, installing a sealed rope pump and 'shock' disinfection. On 23rd October 2002, two months after this work was undertaken, *E. coli* were found at 16/100 ml sample in the same well. On 21st January 2003, the count was 34/100 ml, but by 16th September 2003, levels had risen back to 350/100 ml after the protected rope pump was changed back to an uncovered design when the community encountered problems with the sealed pump.

Analysis on 16th September 2003 of water abstracted by the windpump installed on an irrigation borehole, showed very high levels of faecal contamination with 1100 *E. coli* per 100 ml. This borehole was in use at the time and the windpump was frequently in need of repairs, thus introducing a potential form of contamination. By contrast, the other 6 inch irrigation well drilled in 2002 was unused and sealed and this showed 1 *E. coli*/100 ml. Contamination of the hand dug well and the borehole with the windpump was considered to be directly related to activities associated with the operation and maintenance of the wells and pumps and not, therefore, an indication of faecal contamination of the aquifer.

Faecal contamination, as evidenced by the presence of *Escherichia coli*, may be caused by direct contamination of wells through handling of pumps and buckets, or it may come from sources of groundwater contamination such as latrines or open field defecation. The evidence of the analysis undertaken at La Palmerita suggests that contamination is most likely to have come from direct sources. However, the relatively shallow depth to water at La Palmerita does mean that the aquifer should be regarded as reasonably vulnerable and precautions should be taken to ensure that the proposed abstractions meets the INAA standard of 0 E. coli/100 ml. It is recommended that the borehole be sited to the west of the housing development as this is most likely to be up-gradient of proposed latrines. It is also recommended that a protected area around the borehole be established and protected with barbed wire. Finally, it is recommended that a means of chlorination be included in the design for the system. At pH 7.3, groundwater at La Palmerita falls well within limits for effective chlorination.

Arsenic

Two 50 ml water samples from the rehabilitated hand-dug well at La Palmerita were analysed for Arsenic on 16th July 2002 using the Hach EZ Arsenic Test Kit. Both samples gave positive results, but both were less than 0.01 mg/l. Two further samples were analysed on 27th July 2002, one from a hand-dug well just south of La Palmerita and the other from a capped spring source at

La Fuente. The well near La Palmerita gave a result in the range 0.010-0.025 mg/l but the spring source at La Fuente did not show any sign of arsenic at all. It should be noted, however, that the reliability of field test kits at low concentrations has been questioned.

The maximum permissible limit for arsenic published by INAA and the current provisional WHO guideline are 0.01 mg/l. WHO's norms for arsenic concentrations go back to 1958 when 0.20 mg/l was established as an allowable concentration. In 1963 the standard was re-evaluated and reduced to 0.05 mg/l. In 1984, this was maintained as WHO's 'Guideline Value' and many countries have kept this as the national standard or as an interim target. According to the last edition of the WHO Guidelines for Drinking Water Quality (1993):

- Inorganic arsenic is a documented human carcinogen
- Based on health criteria, the guideline value for arsenic in drinking water would be less than 0.01mg/l
- Because the guideline value is restricted by measurement limitations, and 0.01 mg/1 is the realistic limit to measurement, this is termed a provisional guideline value

On the basis of the WHO guidelines, adverse health effects due to arsenic in the drinking water at La Palmerita cannot be ruled out. However, the field tests have shown that arsenic is not present at the higher concentrations found in some parts of Nicaragua or other parts of the world where symptoms of hyperkeratosis associated with chronic arsenic poisoning are common. On the basis of this investigation, there is no evidence that arsenic is a particular problem.

Pesticides

In response to concerns about potentially harmful contaminants in drinking water at La Palmerita, Mercy Ships Nicaragua commissioned the Centro para la Investigación en Recursos Acuáticos de Nicaragua (CIRA) in April 2002 to analyse samples for concentrations of organic compounds. Water samples from the rehabilitated hand-dug well and a disused irrigation well were analysed and a number of organochloride and organophosphate pesticides were found to be present. The full results of these analyses are attached to this report, but interpretations of the concentrations of those compounds detected are given here in the light of national and international standards.

<u>Hexachlorocyclohexane (γ-BHC (Lindane) and β-BHC)</u>
β-BHC was found in the irrigation well at 3.91 ng/l and γ-BHC was found in the hand dug well at 0.32 ng/l. The WHO guidelines indicate that concentrations of Lindane in drinking water should not exceed 2 µg/l (i.e. approximately 500 times greater than the concentrations in the samples from La Palmerita) and this limit is also adopted as a national standard by INAA. In general, HCH isomers are broken down quickly in water and γ-HCH does not remain for much longer than 30 days. γ-HCH is not generally found in drinking water. Thus, even if the analyses significantly underestimated the presence of this substance, it is unlikely to be a major concern. (ATSDR (1999) *Toxicological Profile for Alpha-, Beta-, Gamma- and Delta-Hexachlorocyclohexane;* WHO (1996) *Guidelines for Drinking-Water Quality, Second Edition, Volume 2 - Health Criteria and Other Supporting Information*)

Endosulfan (α-endosulfan and β-endosulfan)
Endosulfan was detected in both the hand dug well and the irrigation well at concentrations of 1.82 and 1.70 ng/l respectively for α-endosulfan and 4.34 ng/l in the hand dug well for β-endosulfan. No WHO guideline value exists for this substance, but the EPA ambient water quality criteria for protection of human health is given as 110 µg/l (i.e. 25 000 times greater than the concentrations in the samples from La Palmerita) although some individual US states have drinking water guideline limits slightly lower than this. Endosulfan is a manufactured pesticide used to control insects on food crops such as grains, tea, fruits, and vegetables and on nonfood crops such as tobacco and cotton. It does not dissolve easily in water. Most endosulfan in surface water is attached to soil particles floating in the water or attached to soil at the bottom. The small amounts of endosulfan that dissolve in water break down over time, from 1 day to several months depending on the conditions in the water. Because it does not dissolve easily in water, only very small amounts of endosulfan are found in groundwater. Thus, even if the analyses significantly underestimated the presence of this substance, it is unlikely to be a major concern. (ATSDR (2000) *Toxicological Profile for Endosulfan*)

Dieldrin
Dieldrin was detected in both the hand dug well and the irrigation well at concentrations of 1.62 and 4.11 ng/l respectively. The WHO guidelines indicate that concentrations of Dieldrin in drinking water should not exceed 0.03 µg/l (i.e. approximately 7 times greater than the concentrations in the samples from La Palmerita) and this has been adopted as the national standard by INAA. From the 1950s until 1970, Dieldrin were used extensively in the US as insecticides on crops such as corn and cotton. The US Department of Agriculture cancelled all uses in 1970. Dieldrin breaks down very slowly in soil or water and sticks to soil, staying unchanged for many years. It does not dissolve very well and is therefore not found in water at high concentrations. Thus, even if the analyses significantly underestimated the presence of this substance, it is unlikely to be a major concern in groundwater. (ATSDR (2000) *Draft Toxicological Profile for Aldrin/Dieldrin*; WHO (1996) *Guidelines for Drinking-Water Quality, Second Edition, Volume 2 - Health Criteria and Other Supporting Information*)

Endrin
Endrin was detected in both the hand dug well and the irrigation well at concentrations of 2.33 and 4.88 ng/l respectively. No WHO guideline value exists for this substance, but the EPA Maximum Contaminant Level Goal (MCLG) is given as 2 µg/l (i.e. 400 times greater than the concentrations in the samples from La Palmerita). Endrin is a solid, white, almost odorless substance that was used as a pesticide to control insects, rodents, and birds. Endrin does not dissolve very well in water and has been found in groundwater and surface water, but only at very low levels. It is more likely to cling to the bottom sediments of rivers, lakes, and other bodies of water. This substance should therefore not be regarded as a major problem in drinking water, even if the analyses at La Palmerita have underestimated concentrations. (ATSDR (1996) *Toxicological Profile for Endrin*)

DDT (DDT, DDE, DDD)
DDT was detected in both the hand dug well and the irrigation well at concentrations of 2.27 and 3.92 ng/l respectively; DDE and DDD were also detected in both sources at concentrations of

1.23 ng/l (hand dug well) and 2.41 ng/l (irrigation well) and 8.89 ng/l (hand dug well) and 9.27 ng/l (irrigation well) respectively. The WHO guideline value for DDT in drinking-water is 2 µg/l (i.e. approximately 200 times greater than the concentrations in the samples from La Palmerita) and this has been adopted as the national standard by INAA. Both DDE and DDD are breakdown products of DDT. DDT, DDE, and DDD last in the soil for a very long time. Eventually, most DDT breaks down into DDE and DDD, generally by the action of microorganisms but these compounds also last in soil for long periods. They stick strongly to the soil, and therefore generally remain in the surface layers, although soil particles with attached DDT, DDE, or DDD may get washed into rivers and lakes. Concentrations in groundwater are generally very low. The WHO guideline value exceeds the water solubility of DDT of 1 µg/l. However, since DDT may be adsorbed on to the small amount of particulate matter present in drinking water, the guideline value of 2 µg/l could potentially be reached under certain circumstances, but it is most unlikely that DDT or its derivatives would ever be a significant problem in groundwater. (ATSDR (2000) *Draft Toxicological Profile for DDT, DDE and DDD*; WHO (1996) *Guidelines for Drinking-Water Quality, Second Edition, Volume 2 - Health Criteria and Other Supporting Information*)

Toxaphene

Toxaphene was detected in both the hand dug well and the irrigation well at concentrations of 73.26 and 105.34 ng/l respectively. No WHO guideline value exists for this substance, but the EPA Interim Primary Drinking Water Standard is given as 5 µg/l (i.e. approximately 50 times greater than the concentrations in the samples from La Palmerita) although the MCLG is zero and some individual US states have drinking water guideline limits as low as 0.24 ng/l. Toxaphene was one of the most heavily used insecticides in the United States until 1982. It was used primarily in the southern United States to control insect pests on cotton and other crops. Toxaphene does not dissolve well in water, so it is more likely to be found in air, soil, or the sediment at the bottom of lakes and streams. If it is found in surface water or groundwater, it is usually at very low levels. Once toxaphene is in the environment, it can last for years because it breaks down very slowly. However, as it is so insoluble, it is unlikely to be a major problem, even in concentrations significantly higher than those reported. (ATSDR (1996) *Toxicological Profile for Toxaphene*)

Ethyl Parathion

Ethyl Parathion was detected in both the hand dug well and the irrigation well at concentrations of 38.96 and 53.38 ng/l respectively. No WHO guideline value exists for this substance. However, the EPA quote a Drinking Water Level of Comparison (DWLOC) of 2 µg/l for acute conditions and 0.3 µg/l for chronic conditions (i.e. approximately 5 times greater than the concentrations in the samples from La Palmerita). Parathion is an organophosphorus insecticide currently registered in the US for use on alfalfa, barley, corn, cotton, canola, sorghum, soybean, sunflower, and wheat. (EPA Human Effects Division (1999) Memorandum: *Ethyl Parathion: Revised Human Health Risk Assessment*)

DEF

No published references or acceptable limits were found for DEF (SSS Tributylphosphorotrithioate) which was found in the irrigation well at a concentration of 19.8

ng/l, although the 1985 European Drinking Water Standard of 100 ng/l for all organophosphorous insecticides would apply to this substance.

No pesticides other than those discussed above were above detection limits. It can therefore be concluded that although contamination from pesticides has been found at La Palmerita, there are no specific causes for concern with respect to drinking water quality.

Impact on existing abstractions

Since the predicted drawdown of the proposed abstraction is less than 1 metre, and in view of previous abstractions in the area of up to 75 l/s, negative impacts on existing abstractions are most unlikely.

Environmental impact

As stated above, in the context of historical abstractions of groundwater at La Palmerita, the impact of the proposed abstraction on groundwater levels would be negligible. Since it is intended for domestic use, a significant proportion of the water used would be returned to ground, thereby minimising the consumptive use of water. Any net loss would probably be at the expense of baseflow to both the lower reaches of the Rio Sinecapa to the east and El Obraje to the south, both of which are more than 10 km away. There are no environmental features in the area supported by groundwater and thus the environmental impact of the proposal is negligible.

Conclusions

The proposed abstraction of groundwater at up to 3 l/s for water supply at La Palmerita is both technically feasible and likely to be neutral in terms of impact. A sufficient yield of good quality drinking water is virtually guaranteed from the proposed source, so long as simple measures are taken to protect the groundwater source from contamination.

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