Advances in Project Site Investigation: Using Google Earth

By James L. Gordon

The use of the Internet tool Google Earth to view structures can aid in site investigation for proposed hydro projects.

In February 1965, I was part of a group climbing over the eastern slopes of the Cordillera Real just north of La Paz, Bolivia, at an altitude of over 4,300 meters.[1] We were going to look at the sites for three proposed storage dams for hydroelectric power plants in the Zongo River Valley.

Today, there are ten hydro developments with about 170 MW, operating in a cascade along the river to provide power to La Paz. The series of plants starts at the Zongo Dam at Elevation 4,756 meters, contains 3.255 million cubic meters of live storage, and is adjacent to the Huayna-Potosi Hostel. A contour-following canal can be observed on the eastern slope of Huayna-Potosi, where runoff from a glacier is collected and transported into the icy Zongo Reservoir. In this area, the climate is sub-arctic, with no vegetation.

The hydro powerhouses — with the exception of Tiquimani and the high-head Santa Rosa unit — are built in a cascade and have a total operating head of 5,826 meters. The powerhouses in cascade with capacities and net heads are:

- Zongo, 10 MW, 378 meters;
- Botijlaca, 6.6 MW, 383 meters;
- Cuticucho, 20 MW, 703 meters;
- Sainani, 9.9 MW, 291 meters;
- Chururaqui, 26 MW, 375 meters;
- Harca, 27.2 MW, 345 meters;
- Cahua 28.8 MW, 245 meters; and
- Huaji, 28 MW, 245 meters.

In addition to these powerhouses in cascade, there is 9-MW Tiquimani at 500 meters and 10.3-MW Santa Rosa with two units, each at a different head (one 3.6-MW unit at 198 meters and a second 6.7-MW unit at 792 meters).

The developments terminate 3,800 meters lower down the valley in the tropical rain forest of the Amazon watershed. The Zongo is a tributary of the Beni, which, in turn, is a tributary of the Amazon.

The Tiquimani development was built in two stages. The first stage, in 1967-69, involved construction of three storage dams on streams in the watershed just west of the Zongo River and a long diversion canal-tunnel system through the height-of-land to the Viscachani River, a tributary of the Zongo. The second stage, in 1995-97, involved construction of another tunnel and the Tiquimani power plant. The powerhouse discharges water into the Zongo River, directly upstream of the intake to the Botijlaca power plant.

In the 1960s, when we first began investigating the sites, our only reference was high-level aerial photographs, since there were no maps of the area. Until recently, even the drainage areas were unknown. So imagine my surprise to find that the development can now be seen using the Internet tool Google Earth (http://earth.google.com)!

With this Internet tool, it is possible to obtain most dimensions for a proposed project while sitting in your office. Approximate dam elevations, crest lengths, tunnel lengths, and canal routes following contours easily can be developed without ever setting foot on the proposed site — a vast change from 45 years ago! Distances between points defined by latitude and longitude can be obtained using the Vincenty formula.[3]

Of course, I am not suggesting that a site inspection is unnecessary — it is still essential to ascertain foundation conditions and sources of materials. But the work is now quicker and simpler than in 1965.

To illustrate how to use this tool as an aid in site investigation, I describe, in the following sections, the Tiquimani development. Using the Google Earth references given in the box on page XXX, you can take a virtual tour of the development I am describing. The local Google resolution is sufficiently high so that the small canals can be clearly seen; the surrounding scenery is spectacular and best viewed at an angle.

Physical challenges of the Zongo River Valley

The area is quite unique, and posed many problems for the developers. The Tiquimani storage development was all built at an altitude in excess of 4,000 meters, with a minimum of construction equipment. The access road into the

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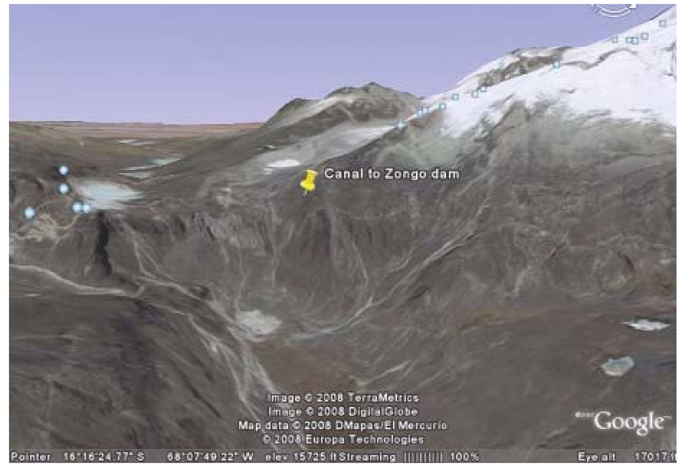
In 1965, to investigate the site of a proposed hydro development near the 6,100-meter-high Huayna-Potosi in Bolivia, engineers had to ascend the mountain.



Today, the same view of the site can be found on the Internet with the click of a mouse.

valley from the Zongo summit dam has 14 switch-backs down to the Zongo valley, some so tight that the heavy transport truck used to bring in the generating equipment could not turn around, and thus had to back down much of the road. Also, the long truck has to back out onto specially constructed concrete cantilevers hanging out over the precipitous mountainside at several of the bends. Needless to say, the drivers insisted on cutting off the cab, so that they could jump off if necessary!

Construction in the valley started at Zongo Dam in 1907, and the first 1,100-horsepower (hp), single-jet, horizontal-axis, impulse turbine was commissioned in 1909. Additional power plants were added at a rate matching the load increase in La Paz, and the last units at Huaji on the lower reach of the Zongo River, with the tailrace at Elevation 950 meters were completed 90 years later.[2]

Site investigation

With so many developments in cascade, upstream storage for this project was very valuable. However, with the steep mountains, this storage would be difficult and expensive to develop. It was only with the availability of high-level aerial photographs around 1958 that Bolivia Light and Power engineers were able to identify possible storage sites in the adjacent Tiquimani Valley where water could be collected and then diverted into the Zongo River. Stream gages were installed at three possible dam sites and monitored by utility technicians for a few years. Aneroid barometers were used to outline possible diversion routes following contours, for canals and tunnels through the heights of land. By 1965, it was evident that the storages could be economically developed. So our engineering team organized a trip to the site.

Our ascent to the site began in the early morning. On the way, we paused to admire the view of Huayna-Potosi, a 6,100-meter-high mountain in the Cordillera Real. The same view can be seen using Google Earth. (The box on page XXX provides the Google Earth latitude-longitude references to the features of the Tiquimani development; the reference to the view of the mountain is given in Description 1.)

We climbed over the pass to Lake Taypicota (to view the lake on Google Earth, use the reference given in Description 3 in the box on page XXX). Next, we climbed to Lake Hatilata (see Google Earth references in Description 4), and then back to camp on the shore of Lake Taypicota. The next day we walked out, roughly on the canal-tunnel route, arriving that evening at the Botijlaca village (to view on Google Earth, use the references given in Description 5).

Taking a virtual tour of the site

In this section of the article, I describe the technical aspects of the various features of the development. Use the latitude/longitude references provided in the box on page XXX to view these features on Google Earth.

The Taypicota and Hatilata dams at the two lakes are masonry, with a crest width of about 0.5 meter and a downstream slope of ½ in 1. With masonry construction, there is an impervious upstream concrete face formed with a rich mix of gravel, sand, and cement. The remainder of the dam is masonry and quite pervious, so that there is no uplift, otherwise the dam would fail on overturning. The dams are both 15 meters high, with crest lengths of 91 meters and are designed to contain the full summer glacier runoff, for release in the winter dry season. The crests also act as weir spillways. All materials for the dams were hauled in by llamas, with loads limited to about 22 kilograms. Over 40,000 sacks of cement, each split in two, were transported, 80 percent by llamas, and the remainder by mules. A short switch-back road was constructed to shorten the climb over the mountain pass. (To view the road on Google Earth, use the references given in Description 5.) The heaviest components were the three 0.9-meter-square steel low-level gates, each weighing 295 kilograms.

▶ Google Earth Guide to the Zongo River Valley in Bolivia

The information below is Google Earth latitude-longitude references to the various features of the Tiquimani development. Using these references, you can actually see the project's dams, tunnel entrances and exits, canals, forebay, penstock, and the 9-MW Tiquimani power plant.

All references are at latitude of 16 degrees south and 68 degrees west. For brevity, references are to minutes and seconds only, with elevations in feet. Enlarge, tilt, and rotate to obtain the best view.

	Description	*Latitude (south)*	*Longitude (west)*	*Elevation (in feet)*
1.	View of Zongo Valley[1]	15-38.76	06-56.85	14,402
2.	Mountain pass	14-17.51	06-18.25	15,948
3.	Taypicota Lake Dam	14-07.00	04-45.00	14,941
4.	Hatilata Lake Dam	14-35.00	04-34.31	15,365
5.	Botijlaca village	12-29.20	07-29.00	13,162
6.	Canal to tunnel	14-05.31	04-57.29	14,865
7.	Lake Cotachaco Dam	14-09.92	04-58.08	14,947
8.	Tunnel spoil slide	13-45.35	04-57.95	14,783
9.	Tunnel spoil exit	13-18.84	04-46.01	14,821
10.	Tunnel exit to canal	13-13.06	04-50.19	14,950
11.	Lago Chico	12-48.37	05-29.36	14,808
12.	Lago Guaraguarani	12-55.46	05-28.15	15,027
13.	Chico Tunnel outlet	12-37.15	06-02.50	14,799
14.	Tiquimani Forebay	12-45.28	06-56.89	14,735
15.	Tiquimani Powerhouse	12-25.88	07-25.73	13,161
16.	Cascada artificial Zongo	03-24.80	01-00.63	4,784

Note:
[1]Turn the scene to looking southwest, enlarge to eye level at 17,000 feet, and go to full tilt.

They were strapped to stretchers and hand-carried by four men.

Water discharged from Hatilata Lake flows down to Taipicota Lake. From Taypicota, it flows through a low outlet gate into a 90-meter-long canal (Description 6), to a tunnel entrance hidden below the adjacent cloud. There is a small saddle dam (Description 7) on Lake Cotachaco which drains into Lake Taypicota. The 1,677-meter-long tunnel is the smallest which can be constructed, about 1.8 meters wide by about 2 meters high. It follows the contour, just a few meters into the mountainside, so that short exit adits could be built for ventilation and used to dispose of the tunnel muck, without hauling it long distances. Tunnel spoil from the adits can be seen on Google Earth at Descriptions 8 and 9. All tunneling equipment (such as compressors) had to be disassembled into small components, carried into the site by men, and then re-assembled. Llamas refused to carry fuel, so mules were used instead.

The 2,300-meter-long canal section starts at the tunnel exit (see Description 9) and ends in Lake Chico (Description 11). The canal follows the contour, is only 2 meters wide, and cuts into the steep mountainside, with a 0.5 to 0.8-meter-high masonry wall to contain the flow. In places, the mountainside is almost vertical, requiring a "C" cut for the canal. After the canal was commissioned, a few short sections of the canal wall had to be increased in height, where turbulent flow at bends overtopped the wall. There is a small dam at the outlet of Lake Chico.

Another two dams were built at Lake Guaraguarani (see Description 12), just upstream of Lake Chico. They are both 7 meters high, with a crest length of 46 meters. Total volume in the dams is about 7,700 cubic meters of masonry and about 1,300 cubic meters of concrete. Concrete use was limited to the upstream face and the areas around gates. All cement was mixed by hand, with sand and gravel being transported in wheelbarrows for distances of up to 1.5 kilometers. Over 250,000 stones were cut and dressed for the masonry work. Total storage in the three reservoirs at Hatilata, Taipicota, and Guaraguarani is just over 5 million cubic meters. While the reservoirs may not be very large, they are very valuable, since the stored water flows through turbines at nine powerhouses. In total, these powerhouses produce about 400,000 megawatt-hours of electricity.

The water flows out of the west end of Lake Chico into a 920-meter-long tunnel to an outlet on the mountainside into the Viscachani Valley (see Description 13). Until 1996, the water flowed down the Viscachani Valley into the Zongo Valley. Unfortunately, the Google resolution in this area is low, hence the tunnel exit is not visible. The canal-tunnel design flow is only about 1 cubic meter per second and is kept reasonably constant.

In 1996, a 1,700-meter-long diversion tunnel was constructed to intercept the Chico-Viscachani tunnel. It exits at the forebay (see Description 14) above the Zongo River where a masonry dam retains pondage, sufficient for a few hours of peak flow. The 1-meter-diameter, 1,200-meter-long penstock transports 2.24 cubic meters per second of water to the Tiquimani power plant (clearly visible in see Description 15). The access road from the power plant up to the forebay has 25 switch-backs, many located to access the concrete anchor blocks on the penstock. The east half of the forebay dam comprises an overflow weir. In the Google Earth image showing downstream of the weir, collecting walls are visible. These walls direct the overflow into a stream, which flows down to the Viscachani River.

The final Google Earth reference, Description 16, is for the forebay overflow weir for the Cahua power plant. With ten plants in cascade, it is difficult to control flows to match load demand, so occasionally there is a small overflow at a forebay. Click on the reference to open a photo of the weir. Google is continuously improving image resolution, so, in a few years, these downstream developments should be clearer. ▲

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Notes

[1]Gordon, J. L. "The Harca Hydro Development," *Transactions Engineering and Operating Division Canadian Electrical Association,* 9: Part 2, paper #70-H-105, 1970.

[2]"Zongo valley generation and power system expansion" brochure, Monenco-Agra, November 12, 1996.

[3]www.movable-type.co.uk/scripts/latlongvincenty.html.