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Identifying and Allocating Geodetic Systems to historical oil gas wells by using high-resolution satellite imagery

Gabriel O. Alvarez[a]

[a] *YPF, Buenos Aires, Argentina; gabriel.alvarez@ypf.com*

Abstract: Hydrocarbon exploration in Argentina started long before the IGM created a single, high-precision geodetic reference network for the whole country. Several geodetic surveys were conducted in every producing basin, which have ever since then supported well placement. Currently, every basin has a huge amount of information referenced to the so-called "local" geodetic systems, such as Chos Malal – Quiñi Huao in the Neuquén Basin, and Pampa del Castillo in the San Jorge Basin, which differ to a greater or lesser extent from the national Campo Inchauspe datum established by the IGM in 1969 as the official geodetic network. However, technology development over the last few years and the expansion of satellite positioning systems such as GPS resulted in a new world geodetic order. Argentina rapidly joined this new geodetic order through the implementation of a new national geodetic system by the IGM: POSGAR network, which replaced the old national Campo Inchauspe system. However, this only helped to worsen the data georeferencing issue for oil companies, as a third reference system was added to each basin. Now every basin has a local system, the national system until 1997 (Campo Inchauspe), and finally the newly created POSGAR network national satellite system, which is geocentric unlike the former two planimetric datums. The purpose of this paper is to identify and allocate geodetic systems of coordinates to historical wells, whose geodetic system is missing or has been erroneously allocated, by using currently available technological resources such as geographic information systems and high-resolution satellite imagery.

Keywords: Geodetic Systems, Map Reference, Posgar, Satellite imagery, Campo Inchauspe, Chos Malal, Pampa del Castillo

1. Introduction

Hydrocarbon exploration in Argentina started long before the IGM created a single, high-precision geodetic reference network for the whole country.

For that reason, several geodetic surveys were conducted in every producing basin, which have ever since then supported land surveys, well placement, seismic programs, etc.

Currently, every basin has a huge amount of information referenced to the so-called "local" geodetic systems, such as Aguaray in the Northwestern Basin, 25 de Mayo in the Cuyo Basin, Chos Malal – Quiñi Huao in the Neuquén Basin, Pampa del Castillo in the San Jorge Basin, and Tapi Aike in the Austral Basin, which differ to a greater or lesser extent from the national Campo Inchauspe datum established by the IGM in 1969 as the official geodetic network.

However, technology development over the last few years and the expansion of satellite positioning systems such as GPS resulted in a new world geodetic order.

Argentina rapidly joined this new geodetic order through the implementation of a new national geodetic system by the IGM, i.e. the so-called POSGAR network, which replaced the old national Campo Inchauspe system. However, this only helped to worsen the data georeferencing issue for oil companies, as a third reference system was added to each basin. Now every basin has a local system, the national system in force until 1997 (Campo Inchauspe), and finally the newly created POSGAR network national satellite system, which is geocentric unlike the former two planimetric datums.

This variety and complexity of reference systems leads to significant inconsistencies and impairs data quality and metric precision.

The objective of this paper is to show a reliable and specific project to standardize all data measured in the local geodetic systems into a single, high-precision system in line with official organizations' standards and linked to a global framework through the South American Geodetic Network SIRGAS for improved consistency, precision, and eventual data quality.

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Fig. 1. Old reference frames

2. Methodoly

The methodology consisted of the steps described below.

2.1 Densify of Posgar

YPF, through Energicon and Geodatos, densified the above-referred network in the Neuquén and San Jorge ba- sins, from the 127 POSGAR points established by the IGM, which are evenly distributed all over the country. In the Neuquén Basin, efforts focused on the Chos Malal local system (densified and renamed by YPF as Quiñi-Huao da- tum), the previous national geodetic datum, i.e. Campo Inchauspe 69, and the new national system, i.e. POSGAR 94 spanning the provinces of Neuquén and Mendoza.

Sixty-two (62) vectors with 47 vortexes were measured, of which 39 were existing monuments from the IGM's Leveling Network and POSGAR 94 System Networks, Campo Inchauspe 69, and Chos Malal. And 8 monuments were built for the Network geometry to have easily accessible points.

The work was designed to provide a planimetric frame in the 3 above-referred systems, an altimetric frame for the zone, system conversion parameters, and geoid-ellipsoid separation.

Three Ashtech dual-frequency receivers with P-code suppression were used to take measurements as they yield L2 with full wavelength. To recognize and locate existing monuments, a Garmin, GPS12 navigator-type receiver was used. Simultaneous observation time for vectors less than 40 km was always longer than 1 hour, while for vec- tors in excess of 40 km, it was at least an hour and a half.

The precision of these GPS observations is 2 cm +/-2 ppm in planimetric terms and 2 cm +/-3 ppm in altimetric terms.

Measurements in the San Jorge Basin were taken in the local system of the area, i.e. Pampa del Castillo, the na- tional Campo Inchauspe 69 datum, and the POSGAR 94 system, spanning the provinces of Chubut and Santa Cruz. Here, thirty-one (31) vectors with 22 vortexes were measured, of which 20 were existing monuments with 2 being monumented to complete the network geometry.

Overall, work on the 2 basins showed the same level of precision of GPS measurements, and the same reading time, and used the same equipment and software.

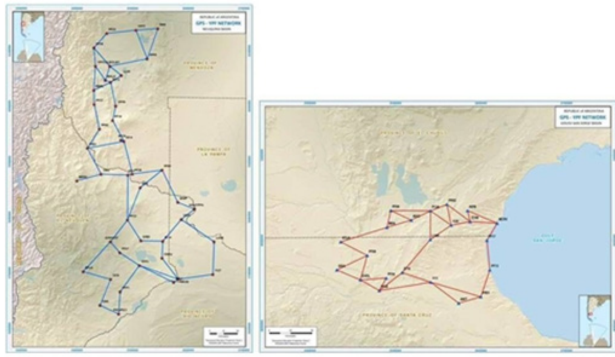

Fig. 2. Posgar Network densification in the Neuquina and Golfo San Jorge basins

2.2 Geocentric and planimetric shift calculation

The transformation of a system into another is performed from its plane Gauss Kruger coordinates or from its Cartesian geocentric coordinates. For this reason, transformation parameters were collected and calculated for both types of coordinates. Transformation parameters were grouped as shown below.

- Plane Gauss Kruger coordinate parameters. These values were appropriately determined by the IGM for transformation from Campo Inchauspe into Pampa del Castillo datums: Δx = +126 meters Δy = -128 meters.

  And these other values were calculated for transformation from Campo Inchauspe into Chos Malal (Quiñi- Huao): Δx = +52.5 meters Δy = +158.5 meters
- Cartesian geocentric coordinate parameters. In 1991, the Defense Mapping Agency (DMA) published multi- ple regression formulae for transformation from Campo Inchauspe 69 into WGS 84 with +/- 2 m standard shift. The following three average translation of origin parameters for transformation from Campo Inchauspe into WGS 84 were also published: Δx = -148 meters Δy = +136 meters Δz = +90 meters with an uncertainty of 5 meters.
- In the Golfo San Jorge Basin
- Plane coordinate parameters. The geodetic coordinates compensated in the three systems were taken to determine these parameters, they were converted to plane coordinates, and the tables titled Constants Between Plane Coordinate Systems and Constants Between Cartesian

Coordinate Systems were drafted. The resulting average values and their shifts are shown below.

From Campo Inchauspe into Posgar: Δx = -203.34 m +/- 0.25 m Δy = -88.12 m +/- 0.18 m From Pampa del Castillo into Posgar: Δx = -78.85 m +/- 0.46 m Δy = -215.61 m +/- 0.75 m

From Pampa del Castillo into Campo Inchauspe: Δx = +124.48 m +/- 0.50 m Δy = -127.49 m +/- 0.82 m

- Cartesian geocentric coordinate parameters. The geodetic coordinates compensated in the three systems were taken to determine these parameters, they were converted to Cartesian coordinates, and the tables titled Con- stants Between Plane Coordinate Systems and Constants Between Cartesian Coordinate Systems were draft- ed. The resulting average values and their shifts are shown below.

From Campo Inchauspe into Posgar:

Δx = -146.73 m +/- 0.26 m Δy = +136.55 m +/- 0.49 m Δz = +87.85 m +/- 0,39 m

From Pampa del Castillo into Posgar:

Δx = -233.43 m +/- 0.91 m Δy = +6.65 m +/- 0.21 m Δz = +173.64 m +/- 0.80 m

From Pampa del Castillo into Campo Inchauspe:

Δx = -86.70 m +/- 1.00 m Δy = -129.90 m +/- 0.33 m Δz = +85.80 m +/- 1.17 m

- In the Neuquen Basin

  The transformation was performed among all three systems for the basin and a general average was obtained.

- Plane coordinate parameters. The geodetic coordinates compensated in the three systems were taken to determine these parameters, they were converted to plane coordinates, and the tables titled Constants Between Plane Coordinate Systems and Constants Between Cartesian Coordinate Systems were drafted. The resulting average values and their shifts are shown below.

From Campo Inchauspe into Posgar: Δx = -205,77 m +/- 0,55 m Δy = -90,82 m +/- 0,54 m

From Chos Malal (Quiñi-Huao) into Posgar: Δx = -156,45 m +/- 0,89 m Δy = -73,84 m +/- 1,45 m

From Chos Malal (Quiñi-Huao) into Campo Inchauspe: Δx = +49,33 m +/- 1,14 m Δy = +164,65 m +/- 1,84 m

- Cartesian geocentric coordinate parameters. The geodetic coordinates compensated in the three systems were taken to determine these parameters, they were converted to Cartesian coordinates, and the tables titled Constants Between Plane Coordinate Systems and Constants Between Cartesian Coordinate Systems were draft- ed. The resulting average values and their shifts are shown below.

From Campo Inchauspe into Posgar:

Δx = -148,73 m +/- 0,32 m Δy = +133,91 m +/- 1,84 m Δz = +87,00 m +/- 1,06 m

From Chos Malal (Quiñi-Huao) into Posgar:

Δx = +15,75 m +/- 1,88 m Δy = +164,93 m +/- 1,98 m Δz = +126,18 m +/- 1,29 m

From Chos Malal (Quiñi-Huao) into Campo Inchauspe:

Δx = +164,47 m +/- 1,75 m Δy = +31,02 m +/- 2,11 m Δz = +39,17 m +/- 0,46 m

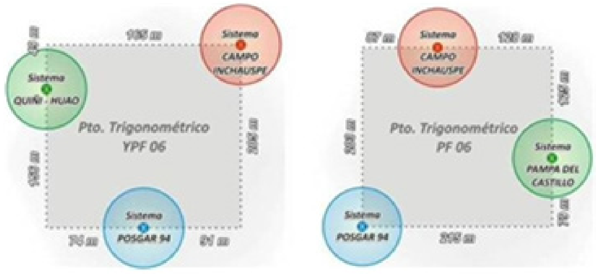

Fig. 3. Planimetric shifts among networks

2.3 High-resolution satellite image acquisition and orthorectification

Images have stereoscopic pairs that enabled the generation of DEMs (Digital Elevation Models) with a resolution not lower than 5 meters.

The supporting points from YPF networks were used for planimetric adjustment by taking the coordinates referenced to the local system for each basin (neither Campo Inchauspe nor Posgar) and Gauss Kruger projection, Zone

2. This is critical to obtaining reliable results for well locations. Since the datum for the original satellite image and all its byproducts is the local one but no geodetic datum has been allocated to them, ArcGIS is unable to perform an on the fly projection, which would alter well locations in YPF GIS database. In turn, the reference system must not have been allocated in the base because the coordinates of each well are referenced to different datums, and these datums are the ones to be determined.

The altimetric adjustment was based on the DEMs and supporting points.

The nearest neighbor method was used for resampling purposes because it preserves original pixel values. In or- der to achieve the desired outcome, it is critical that georeferenced and orthorectified images have the same radiometric and spectral features as the original ones.

2.4 Satellite image processing

The sequence of subprocesses required to achieve the final result, i.e. is a vector point layer representing well- heads clipped from the satellite image, is described.

2.4.1 *Band combination*

The combination of Standard Composite False Color (4-3-2) is used for screen display purposes because it readily discriminates vegetation, which appears in shades of red. In addition, a standard shift highlighting effect is applied with n = 3 in order to discriminate small image details, such as wellheads on the derrick floor. Digital classification uses all image bands in order to better discriminate existing coverages.

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2.4.2 *Supervised classification*

Two classes of sample areas are determined to represent the Patagonian steppe and wellheads for the system to recognize them from their spectral signatures in all other image pixels. The result of the classification is a theme image with the two above-referred classes that are assigned colors and designations for easy recognition.

2.4.3 *Post-classification*

- Recodification: Recodification consists of clumping several derrick floor classes into a single one and sever- al steppe classes into another single class. Thus, the resulting theme image will have only those two classes.
- Cleaning of the recoded image using masking techniques: A 5 meter-buffer is created on either side of the line layers representing available pipelines and roads. The buffer acts as a masking process to clean spectral noise which is not derrick floors.
- Removal of poorly classified sectors: Some small areas other than derrick floors, which were not removed by masking techniques, were clumped on the basis of neighborhood 4 to convert related sectors in the theme image with two classes into multiple objects that retain the original value of their respective pixel, which renders a raster image. Objects smaller than 0.5 hectares are then filtered on the surface. Thus, the classification is cleaned and only large objects, i.e. derrick floors, are left.

2.4.4 *Vectorization*

The vector polygon layer for derrick floors is automatically created from the final theme image.

2.4.5 *Derrick floor clipping from the image*

Those parts of the satellite image containing derrick floors are clipped using the vector polygon layer with derrick floors and the rest is discarded.

2.4.6 *Unsupervised classification*

Using the satellite image containing derrick floors, an unsupervised classification process is conducted in order to identify wellheads on each derrick floor. Classes for each wellhead are defined for recodification aimed at simplifying the resulting image into only two classes: wellhead and the rest.

To achieve this, a polygon layer representing the wellhead is created from its theme image. The polygon layer is then converted into a point layer representing wellheads. This is the end product corresponding to well locations clipped from the satellite image, which is critical for comparison with vector wells from the GIS base, calculate shifts, determine the types of errors, and identify the geodetic systems for YPF' wells.

2.5 Getting results

The layers and features shown below must be necessarily compared to ensure reliable results:

1) Satellite imagery and all their byproducts must have plane Gauss Kruger coordinates, Zone 2, referenced to the local system for the basin but with no allocated system.
2) Vector layer of wells from YPF GIS base with plane Gauss Kruger coordinates, Zone 2, with no allocated geodetic system.

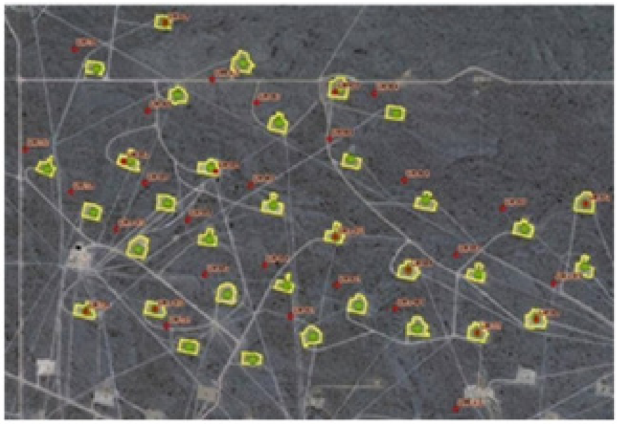

Fig. 4. Shifts between satellite image wells and database wells

YPF GIS database well offsets vs offsets derived from the satellite image, as background, is shown in Fig. 4.

Green dots are image-derived wellheads. Red dots (from YPF GIS database) show location errors resulting from several factors. Wells for both layers have their respective coordinates. Using ArcGIS analysis tools base wells (along with all necessary attributes for the user, including well name) are associated with satellite image wells, which are properly located but have no attributes available. The result is only one table containing the attributes shown below.

- WELL_NAME
- X_ORI (original x-coordinate)
- Y_ORI (original y-coordinate)
- REFSIS_ORI (original reference system)

Coordinate fields in their right positions (as they have been derived from the satellite image referenced to the local datum) are related to the table of wells in the GIS database. In the example shown, Pampa del Castillo is the da- tum because they are located in the Golfo San Jorge basin.

- X_IMAG_PdC
- Y_IMAG_PdC Next, fields are defined:
- Delta X (difference between X_ORI – X_PdC)
- Delta Y (difference between Y_ORI – Y_Pdc)

Based on the above-referred differences, the geodetic system of the original coordinates from the Well Base is determined and then the type of error relating to the original coordinates is also determined and input into the field:

- ERR_TYPE

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After identifying the actual geodetic systems of the original well coordinates, they were allocated in another field:

- REFSIS_FIN

Finally, the coordinate fields in the official reference frame, i. e. Posgar 2007: X_Pos Y_Pos, are added. And the coordinate fields in the Campo Inchauspe system: X_CAI Y_CAI

In the latter two cases, datum transformations are performed, as necessary, in order to have a fully validated YPF GIS well database (in terms of position and table quality) referenced to the three systems of the basin.

The last step involves drafting the Excel spreadsheet with all above-referred fields using ArcMap and creating a final layer of wells in the official reference frame, but containing also the original coordinates with properly identified and allocated geodetic system.

WELL_NAME	WELL_S_NAME	YEAR	X_ORI	Y_ORI	REFSIS_ORI	X_IMAG_PdC	Y_IMAG_PdC	DeltaX	DeltaY	ERR_TYPE	REFSIS_END
YPF.SC.LM.a-572	LM.a-572	2001	2467920,74	4891515,88		2468046,90	4891391,45	126,16	-124,43	GEODETIC (SYSTEMATIC)	CAMPO INCHAUSPE
YPF.SC.LM.a-665	LM.a-665	2003	2469297,84	4891123,06		2469425,76	4890998,60	127,92	-124,46	GEODETIC (SYSTEMATIC)	CAMPO INCHAUSPE
YPF.SC.LM-706	LM-706	2007	2467712,42	4892410,28		2467840,32	4892285,37	127,90	-124,91	GEODETIC (SYSTEMATIC)	CAMPO INCHAUSPE
YPF.SC.LM-717	LM-717	2007	2467468,37	4891912,63		2467596,58	4891788,67	128,21	-123,96	GEODETIC (SYSTEMATIC)	CAMPO INCHAUSPE
YPF.SC.LM-727	LM-727	2008	2468168,88	4891034,27		2468296,39	4890909,73	127,51	-124,54	GEODETIC (SYSTEMATIC)	CAMPO INCHAUSPE
YPF.SC.LM-729	LM-729	2008	2467696,41	4891700,64	POSGAR	2467825,19	4891575,11	128,78	-125,53	GEODETIC (SYSTEMATIC)	CAMPO INCHAUSPE
YPF.SC.LM.a-570	LM.a-570	2000	2470037,03	4891224,47		2470252,19	4891304,33	215,16	79,86	GEODETIC (SYSTEMATIC)	POSGAR
YPF.SC.LM-565	LM-565	2001	2468026,63	4892077,48		2468241,00	4892157,05	214,37	79,57	GEODETIC (SYSTEMATIC)	POSGAR
YPF.SC.LME.x-7	LME.x-7	2000	2468347,90	4892232,92		2468563,43	4892312,43	215,53	79,51	GEODETIC (SYSTEMATIC)	POSGAR
YPF.SC.LME.x-2	LME.x-2	1988	2469614,96	4890601,33	CAMPO INCHAUSPE	2468613,49	4890845,12	-1001,47	243,79	BLUNDER	
YPF.SC.LM.a-571	LM.a-571	2001	2469020,92	4891452,13		2469020,88	4891452,25	-0,04	0,12	NO	PAMPA DEL CASTILLO
YPF.SC.LM.a-573	LM.a-573	2001	2468131,03	4891093,72	PAMPA DEL CASTILLO	2468131,00	4891093,72	-0,03	0,00	NO	PAMPA DEL CASTILLO
YPF.SC.LM-552	LM-552	2001	2470257,24	4891616,24		2470257,24	4891616,24	0,00	0,00	NO	PAMPA DEL CASTILLO
YPF.SC.LM.x-3	LM.x-3	1948	2469020,31	4892170,35		2469042,48	4892184,89	22,17	14,54	PRECISION (RANDOM)	PAMPA DEL CASTILLO
YPF.SC.LM-x-2	LM.x-2	1942	2468430,16	4891776,84	PAMPA DEL CASTILLO	2468403,83	4891795,41	-26,33	18,57	PRECISION (RANDOM)	PAMPA DEL CASTILLO

Table 1. . Determination of geodetic system and type of error found

3. Analysis of results

Historical wells are all wells drilled until August 31, 2009 because pursuant to new in-house regulations issued by YPF use of the Posgar 2007 Network for every topographic data surveying, generation and acquisition operation for hydrocarbon exploration and exploitation became mandatory as from September 1, 2009.

As a result of the many years elapsed since drilling the earliest wells, the amount of historical wells accounts for 92 % of total wells in YPF GIS database. The total number of wells in both basins (Neuquen and Golfo San Jorge) as of December 31, 2015, i.e. 33,068, is shown in the table; 30,622 of these are historical wells. To date, the percentage progress in identifying and allocating geodetic systems is just 49.6 %.

TOTAL WELLS TO 2015 DEC 31	33068				
HISTORICAL TO 2009 AUG 31	30622		ADVANCE %		
RELIEVED WELLS	15187	EVALUATED	49,6		
		%o/15187	EVALUATED WELLS		
WITH ERRORS	11215	74			
WITHOUT ERRORS	3972	26			
ERROR TYPES		%o/11215			
BLUNDER	580	5			%o/9579
GEODETIC SYSTEM	9579	86	NOT ALLOCATED	8797	92
			WRONG ALLOCATED	782	8
MEASUREMENT PRECISION	1056	9			

Table 2. Table of errors

Historical wells were first divided into:

- Wells without errors
- Wells with errors

In turn, wells “with errors” were divided into 3 classes:

- Gross Errors. Gross errors exhibit significant shifts, so they are easy to be visually identified. The causes of these errors are many and include both human and instrumental. This type of error requires in situ setting out and al- so involves a geodetic error because in most cases the datum had not been specified and, where available, it was not possible to check its correctness because the main error exceeded verification parameters. Fortunately, gross errors account for less than 5 % of total wells with errors.
- Geodetic System Errors. According to the Theory of Measurement Errors, this typification applies to Systematic Errors because behavior sense is always the same regardless of the geodetic system. Since these errors occur as a result of permanent causes, they always have the same sign and module, which makes correction easier. No field visit is required as they can be corrected at the office by applying the parameters involved in calculated shifts among geodetic systems. Geodetic System Errors account for 86% of wells with errors.
- Measurement Precision Errors. Measurement Precision Errors are Accidental Errors and show very small offsets from actual well locations; however, they are characterized by a random behavior with both positive and negative signs. This type of error becomes apparent when comparing measurements made in the past with current measurements for the same points of the local geodetic systems. Offsets never exceed 25 meters (diagonally) and, in our case, they always occurred within the derrick floor. As is the case with wells with gross errors, wells with measurement precision errors also involve a geodetic error. As in the former case, regardless of the fact that the respective geodetic systems had been allocated, this could not be confirmed because of their random behavior and small location offsets.

Errors of this type account for 9 % of total wells with errors and occurred mainly in the first four decades of the 20th century.

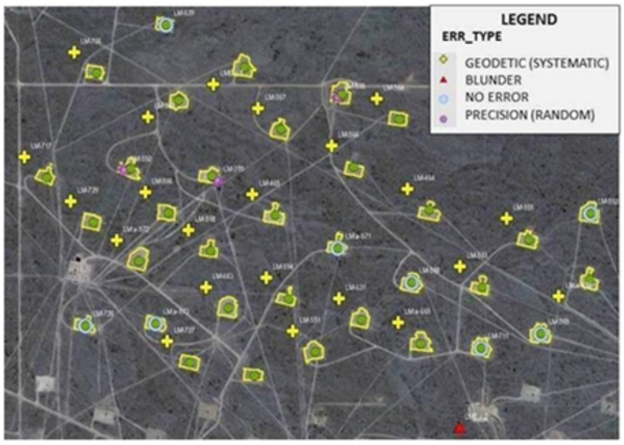

Fig. 5. Clasification of well shift type of error

4. Conclusions

Use of this methodology is an integral part of what is known as “repairing a historical error” for data quality management.

For oil companies, wells are strategic information in the hydrocarbon business. Therefore, it is important to validate the quality of all their components.

Well quality components validated by this methodology are as shown below.

- position accuracy, which is the difference between the coordinates in the vector base and the actual ground coordinates as seen in the satellite image.
- table accuracy, which is the lack of consistency between the attributes shown in the table and the actual attributes. For wells, the geodetic system shown in the table may be erroneous or missing.

Data quality management involves a set of successive and interconnected processes which, when implemented, represent a turning point from which the solution to the problem is installed. In this case, the solution was based on two relevant facts:

- A theoretical fact: in-house regulations pursuant to which use of Posgar 2007 network has become mandatory.
- A practical fact: the implementation of the methodology described herein. As from installation of the solution, management involves two processes:
- A continuous data quality process for the future. In this case, all wells drilled pursuant to current regulations would be validated for position and table accuracy.
- A historical error repairing process whose complexity is directly proportional to the volume of historical data and which also requires a continuous and careful process to achieve the final goal.

The methodology described is being applied only to historical wells but may be extended to other strategic business assets such as historical seismic lines and surface facilities (pipelines, batteries, plants, etc.).

5. Acknowledgements

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