# Trend of Standards for Hydrographic Survey

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*Abstract-* Reservoir storage capacity impacts hydroelectric power generation and flood control operation. Storage capacities are affected by sedimentation build up over time, typically below the minimum pool elevation. Reservoir sedimentation surveys are performed to monitor periodic build up of sediment in the reservoir, which allow computation of reductions in reservoir capacities. This paper traces methods and trends in hydrographic survey using sound echo single beam and GPS positioning. The accuracy and calibration methods are issued for both geographic and depth considerations. Scattered data collection was treated for a reservoir computer reconstruction using MATLAB based software.

*Keywords:* Hydrographic survey, GPS, sonar, reservoir volume reconstruction

## 1 Introduction

Reservoir sedimentation surveys require a combination of hydrographic and topographic methods. Hydrographic surveys are performed to determine the underwater topography. Topographic and photographic methods are performed to map the areas above the pool in which the hydrographic surveys were performed. The surveys are merged into a digital terrain database from which quantity take offs are made for reservoir capacities. Hydrographic surveys are usually performed with small boats, using standard automated hydrographic data collection systems [1], [2], [3], [4].

The most efficient geographic positioning methods are: meter-level, code phase DGPS, or private provider networks. Positional accuracy is not critical for reservoir sedimentation surveys, the 5 meter RMS level is recommended in most cases. This is easily achievable with current DGPS methods. Depth measurement accuracy is critical in reservoir sedimentation surveys and it is usually performed using single beam sonar. The master gage reference used is usually located near the outlet works or dam. The elevation of the gage should be checked by connection to existing benchmarks. For long reservoirs, a slope gradient may exist; requiring additional gages be set in the upper reaches [5], [6], [7].

The topographic relief and size of the reservoir will dictate the coverage density requirements. Single beam survey lines are typically run bank-to-bank perpendicular to the axis of the reservoir. Since the objective is to compute the volume of an irregularly shaped impoundment basin, there is no rigid requirement for a specific cross-section alignment or spacing. Typically lines are spaced between 10 m and 100 m, with a not-to-exceed spacing specified. If the topography in the reservoir is fairly uniform, then line spacing may be increased. Specifying too tight a line spacing on a large reservoir is uneconomical. The accuracy requirements of the reservoir capacity computation must be fully considered in selecting line spacing. Since volumes are typically computed by contour intersect methods, the accuracy of the reservoir storage volume is a primary a function of the computed areas for each elevation stage. Thus the digital terrain model (DTM) must have sufficient density to delineate accurate contours from which areas are computed. Depth accuracy must be absolutely free of any systematic biases. Thus, accurate gage readings, bar checks, and velocity calibrations are critical to preclude against systematic errors in reservoir surveys. Random errors in the depth measurements are not significant as long as there is no bias error.

In order to compute the full capacity rating for a reservoir, topographic mapping must be obtained up to the normal pool or spillway crest elevation. A variety of automated techniques are used to compute the storage area-capacities. The areas and accumulated storage volumes are tabulated and plotted on a standard area-capacity curve.

## 2 Data acquisition system

The most common survey conducted within the USACE is a channel cross-section survey, using a single-beam acoustic echo sounder to measure depth, a differential GPS to provide accurate position, and a PC-based data acquisition system to time-tag and record the depth and position data. Multiple transducer sweep systems or multibeam swath systems may also be used. Prior to beginning this type of survey, the data acquisition system needs to be configured to reflect the particular survey vessel and the types of sensors being used and also the area being surveyed.

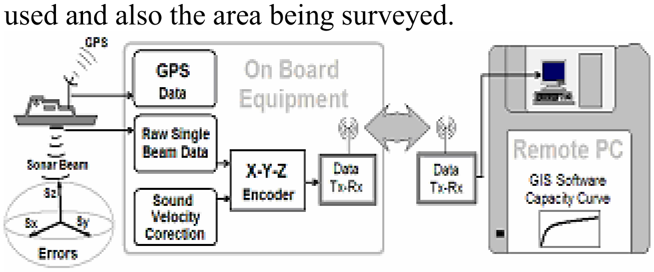


Fig. 1. Embarqued and on shore equipment. The three-dimensional uncertainty affects the measured depth.

Data management relates to transporting, processing, presentation, and archival/retrieval of survey data. In modern hydrographic surveying vast amounts of quality data can be generated very quickly. Moving data physically or by some digital communications system is critical for the hydrographic surveyor. With modern data collection systems, collecting gigabytes of data per day is increasingly common [1], [2].

## 3 New Survey Trends

Given the variety of automated hydrographic surveying systems in use, it is not presently feasible or practical to specify a particular data format for recording field data. For the project was used a simple text format organized in columns for XYZ raw data: X-longitude, Y-latitude and Z for depth. This opened standard is translated by software from ASCII X-Y-Z-descriptor files to a MATLAB program oriented for reservoir area-capacity curves and volume reconstruction.

The International Hydrographic Organization (IHO) traces its origin to the establishment of the International Hydrographic Bureau (IHB) in 1921 which was formed to consider adopting similar methods and procedures in hydrographic data acquisition and nautical chart publication. In September 1970, the Member States formally adopted the IHO name and narrowed the meaning of the IHB to refer only to the organization’s headquarters in Monaco [8]. The stated objectives of the IHO include, among others, the coordination of the activities of national hydrographic offices and the adoption of reliable and efficient methods of conducting hydrographic surveys. To accomplish these objectives several committees and working groups have been periodically established to draft standards.

The S-44 Working Group proposed a classification scheme for hydrographic surveys based on an area's importance for the safety of surface navigation. The variation in accuracy standards for each survey "order" reflects this variable importance and effectively replaces the scale-based positioning and data density standards of previous editions of the Standards.

Special Order hydrographic surveys cover areas where ships may need to navigate with minimum under keel clearance and where the bottom characteristics are potentially hazardous to vessels such as boulders or rock outcroppings. This Order survey requires higher accuracies than those previously specified and for that reason has been particularly controversial. Special Order surveys are only applicable to those areas specifically designated by the Member State’s agency responsible for the survey quality. Inherent in the requirements are closely spaced survey lines with side-scan sonar, multi-transducer arrays or multibeam echo sounder arrays to obtain "100% bottom search".

Order 1 surveys are intended for harbors and general intercostals and inland navigation channels including those approaching harbors where vessel drafts have a greater clearance above the seafloor or where the bottom characteristics are less hazardous (e.g. silt or sand) than for Special Order survey areas. The standards for this order are very similar to the general standard of previous editions of S-44.

Order 2 surveys are applicable for those areas with depths less than 200 meters which are not covered by the criteria for Special Order or Order 1.

Specifications for Order 3 surveys are applicable in water depths greater than 200 meters.

## 5 Positioning Standards for Soundings

The Third Edition of the S-44 IHO Standards specified that soundings should be determined, relative to shore control, such that there is a 95% probability that the true position lies within a circle of radius 1.5mm, at the scale of the survey, of the determined position. Therefore, for a 1:10,000-scale survey, soundings were to be located within 15 meters of their true position with a confidence of 95% probability. In addition to all of the equipment and measurement errors associated with positioning systems, random errors associated with plotting soundings, either manually or by plotter, had to be included.

The horizontal position accuracy standard specified in Table-1 is a two-dimensional circular (radial) accuracy measure. A circular accuracy is an approximate estimate in that it approximates a 2-D error ellipse, as shown in Figure 1. Positional accuracy standard is specified relative to this 95% confidence level. This means that on average 19 of 20 observed positions will fall within the required standard.

The new Fourth Edition of the Standards specifies varying horizontal accuracy, in meters at the 95% confidence level, for the four survey orders. One new aspect of the positioning standard is the inclusion of a depth-dependent factor which takes into account the added uncertainty of the positions of soundings from multibeam sonar systems as depth increases:

2 meters for Special Order
5 meters + 5% of depth for Order 1
20 meters + 5% of depth for Order 2
150 meters +5% of depth for Order 3

Because the term accuracy is used in these specifications, it is incumbent on the data acquisition unit to minimize all systematic errors and use appropriate equipment and techniques with sufficiently small random errors.

## 6 Depth Accuracy Standards

The total error in measuring depths, according to the Third Edition of the IHO Standards, should not exceed, with a probability of 90%, 0.3 meters for depths less than 30 meters or 1% of depths greater than 30 meters. This did not include the errors associated with the measurement of tides, determination of a sounding datum and the transfer of the sounding datum from an appropriate tide gage to the survey area. The combination of such tide-related errors was not to exceed the error allowed for depth measurement.

A brief review of measurement errors is needed to understand the meaning of the 95% confidence levels specified for position and depth accuracies in the new Standards. Accuracy relates to the closeness of measurements to their true or actual value. Accuracy, therefore, includes both precision, pointing the random errors, and any systematic biases that may be present in the system. In practice, random errors of hydrographic measurements are assumed to be normally distributed.

The area under the "bell-shaped" curve between +/- 2σ from the mean is 95.4% of the total area under the curve. In the strictest definition, the usage of standard deviation, or probability percentage, in describing the quality of data refers to precision or the repeatability of a measurement.

Geospatial depth observations containing both random errors and systematic biases, a consistent accuracy measurement is required. These biases and random errors can be combined to obtain the Mean Square Error (MSE) or Root Mean Square (RMS) error of a depth observation. The equation for computing one-dimensional MSE or RMS error is (Mikhail, 1976).

$$(RMSerror) = \sqrt{(Randomerror)^2 + (Systematierror)^2} \quad (1)$$

The *RMSerror* estimator is used for comparing relative accuracies of estimates that differ substantially in bias and precision. RMS depth errors are computed at the 95% confidence level in accordance with FGDC geospatial positioning reporting standards

The Working Group decided during the drafting of the Fourth Edition of the Standards to adopt three major changes regarding depth accuracy in addition to the introduction of the four survey orders:

- the probability or confidence level should be increased from 90% to 95% which is a more widely used value for survey measurements;
- depth accuracy standards should allow for fixed errors as well as depth dependent errors and these should vary according to survey order;

- errors due to tidal measurements, datum determination and sounding datum transfer should be included.

The below listed values "*a*" and "*b*" should be introduced into the following equation to calculate the error limits for depth accuracy:

$$\Delta d = \pm\sqrt{a^2 + (bd)^2} \quad (2)$$

In the above expressions *a* is the depth independent error, i.e. the sum of all constant errors, *b* is the factor of depth dependent error and *d* is the depth:

| | | |
|---|---|---|
| Special Order | $a = 0.25$ m | $b = 0.0075$ |
| Order 1 | $a = 0.5$ m | $b = 0.013$ |
| Order 2 | $a = 1.0$ m | $b = 0.023$ |
| Order 3 | $a = 1.0$ m | $b = 0.023$ |

## 7 Data Density Standards and Feature Detection

Previous editions of the Standards included recommended sounding line spacing and sounding interval based on the scale of the survey. It was anticipated that these "data density" standards would provide a reasonable probability that features potentially hazardous to navigation would be detected.

The Working Group initially considered the use of geostatistics to determine the best estimate of the depth of the reservoir floor, called a bathymetric model, and an error estimation of that modeled surface using bottom roughness and the proximity of the soundings to one another. The acceptability of the survey data could be judged by comparing the resulting error model to values based on the above equation for depth accuracy where the values for *a* and *b* is as follows:

| | |
|---|---|
| Special Order | Not applicable since 100% bottom search is compulsory |
| Order 1 | $a = 1.0$ m $b = 0.026$ |
| Order 2 | $a = 2.0$ meters, $b = 0.05$ |
| Order 3 | $a = 5.0$ meters, $b = 0.05$ |

The error model could be used to identify areas of high probability of the occurrence of shoals due to geological processes. Obviously, it could not provide any statistical model for the occurrence of man made features. This latter characteristic plus the lack of widespread familiarity and use of geostatistics rendered it unsuitable as the primary international standard. However, it was retained as an option in a later section of the new Standards. Eventually a combination of maximum line spacing, sonar system detection capability and the concept of 100% bottom search were adopted. While the Third Edition of the Standards prescribed line spacing that was dependent on the scale of the survey, the new Standards are generally dependent on the average water depth (Order 1 - 3 times average depth or 25 meters, whichever is greater; Order 2 - 3 to 4 times average water depth or 200 meters, whichever is greater; and Order 3 - 4 times water depth).

## 8 Quality Control, and Quality Assurance

The standards in Table 1 represent the resultant elevation (or depth) accuracies of the data set collected on a survey. Various Quality Control (QC) procedures and Quality Assurance (QA) performance tests are performed to meet and confirm these accuracy requirements. The distinction between QC and QA is important.

Quality control procedures are prescribed for survey instrumentation and data collection techniques in order to minimize systematic and random errors in individual data points. Table 1 only specifies general speed of sound and position QC tests. Related QC tests include: bar checks, velocity casts, patch tests, instrument alignment tests, vessel velocity limitations, multibeam beam-width restrictions, and overlapping coverage.

Recommended QC procedures are contained in this manual and in equipment manufacturer's operating manuals. These recommended QC procedures are based on past experience and practices by Corps districts and should not be waived without thorough justification and analysis. Performing all recommended QC procedures does not necessarily ensure that the resultant elevation data will meet the accuracy standards in Table 1, as measured by a QA performance test.

Quality assurance tests are performed to verify the survey data meets the required accuracy standard. An ideal QA procedure compares observed X-Y-Z coordinate dataset values with coordinate values obtained from an independent source of higher accuracy for the same identical points. Obtaining independent, higher-accuracy test points is either impractical or impossible for most hydrographic survey data collection systems. Thus, acceptable hydrographic QA performance tests typically compare two nearly independent sets of elevation data collected over the same area. The resultant statistical comparison between the two data sets is evaluated against the required elevation accuracy in Table 1. If a QA test indicates data does not meet the accuracy standard, then additional or more stringent QC procedures and calibrations may be required. QA performance tests are not always feasible or practical for all survey methods or the results may not be definitive due to few independent depth comparison. QA tests are essential for acoustic multibeam surveys and typically compare more accurate vertical beam elevations and positions against those obtained from the outer portions of the array.

Table 1 Minimum Performance Standards for Hydrographic Surveys

| RESULTANT ELEVATION/DEPTH ACCURACY (95%) | | | | |
|---|---|---|---|---|
| System | Depth ($d$) | Bottom Material Classification | | Other recommended Standards |
| | Depth (d) | Hard | Soft | |
| Mechanical (manual) | $d$<5m | ± 0.08m | ± 0.08m | ± 0.16m |
| Acoustic | $d$<5m | ± 0.16m | ± 0.16m | ± 0.32m |
| Acoustic | 5>$d$<13m | ± 0.32m | ± 0.32m | ± 0.64m |
| Acoustic | $d$>13m | ± 0.32m | ± 0.64m | ± 0.64m |
| HORIZONTAL POSITIONING | | | | |
| SYSTEM ACCURACY (95%) | | 2 m | 2 m | 5 m |
| MINIMUM SURVEY COVERAGE DENSITY | | 100% | NTE 60 m | NTE 150m |
| QUALITY CONTROL & ASSURANCE CRITERIA | | | | |
| Sound velocity QC calibration | | > 2/day | 2/day | 1/day |
| Geographical position control | | 1/day | 1/project | 1/project |
| Maximum systematic errors | | +/- 0.033m | +/-0.066m | +/- 0.16m |

The accuracy performance criteria in Table 1 distinguish between two general classes of support surveys, those performed in support of navigation and dredging projects and those supporting general engineering studies. In general, accuracy requirements are more demanding for navigation projects where ship clearance and contract dredging payment issues are especially critical. Surveys for general hydraulic engineering studies, reconnaissance, planning, etc., usually do not require the same levels of accuracy. This distinction is not entirely rigid -- specific horizontal and vertical accuracy requirements should always be assessed and defined for each project.

## 9 Data Processing and Results

Most hydrographic data acquisition and processing software, and office CADD packages, now provide terrain modeling modules to allow input, modeling, editing, and analysis of 3-D models [9]. A user has direct interface necessary to build a non-uniform space point files (XYZ file) that can be used to create triangulated models and/or gridded models.

Triangulated models can be created by two methods, Triangulated Irregular Network (TIN) and Topological Triangle Network (TTN). A TIN file is a surface model created from an XYZ file. It is defined by a set of 3-D triangular facets, which are defined by lines drawn between the points that define the surface.

A surface model created from an XYZ file was used in a MATLAB based grid reconstruction from scattered data. This type of reconstruction, with a matrix split algorithm adjusts the large matrix to several low dimension matrixes with a certain level of overlap. In figure 2 are presented the raw data acquired on an accumulation lake for a hydroelectric plant in district Buzau of Romania. The long shape of the lake and the high level of sedimentation have restricted the access of the sonar boat to an improper data acquisition. The difference between the actual acquired data and the ideal collection is illustrated in Figure 3.

An issue of data gathering using sonar and GPS is data stream is very populated but it is a lack of data between rows. Due to errors and careless navigation the straight lines are not fallowed and the data set may be considered scattered.

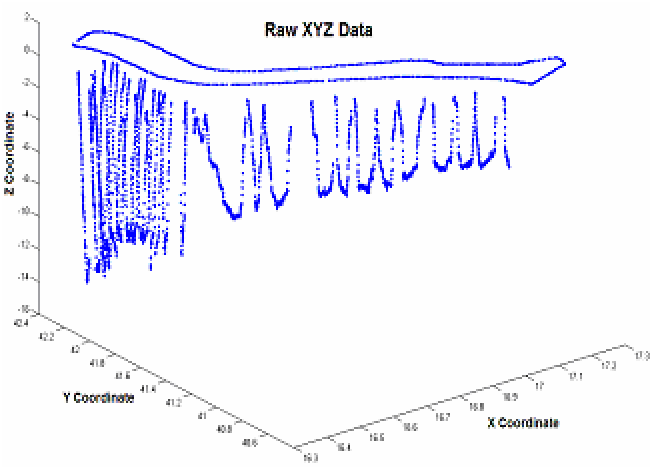


Fig. 2. Raw XYZ data collection on a hydrographic survey in district Buzau of Romania.

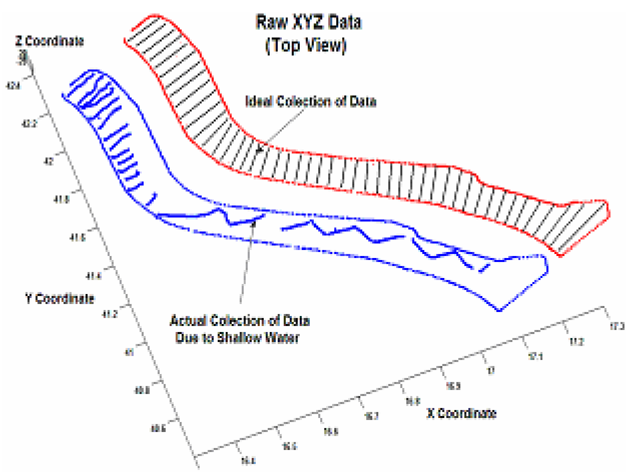


Fig.3 Differences in the actual data acquisition (bottom) and the ideal data collection (top).

For further processing for accumulation volume reconstruction and capacity and area curves calculation, one has considered a grid reshape of data to be valuable. For this reason a MATLAB based algorithm for grid fit and interpolation was used. The large number of date makes the lake print matrix huge, but scattered. The algorithm (proposed by John R. D'Errico) uses a matrix division to keep the dimensions under control. The inherent dense data for the sonar moving direction were also decimated. In Figure 4, raw XYZ data was decimated by a factor of 10 making possible to the algorithm to use one grid matrix. Figure 5 presents the same situation in top view. For a 4 factor of decimation the algorithm splited the matrix in 4 sections with overlap, as in Figure 6. The same situation, but in top view (Figure 7) reveals a gap at the matrix joints due the lack of data.

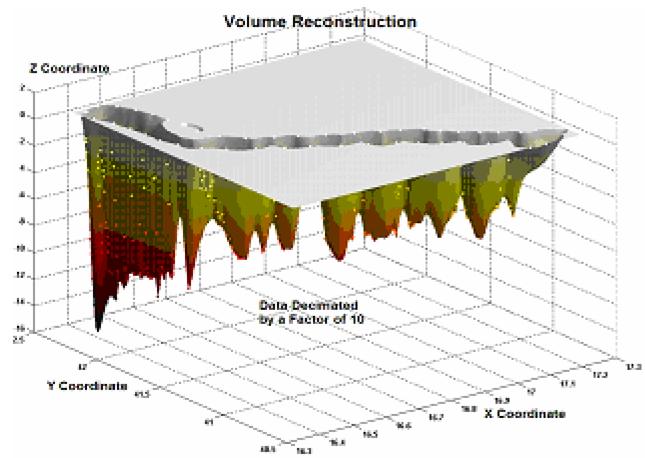


Fig. 4. Grid reconstruction of the lake decimating raw XYZ data by a factor of 10.

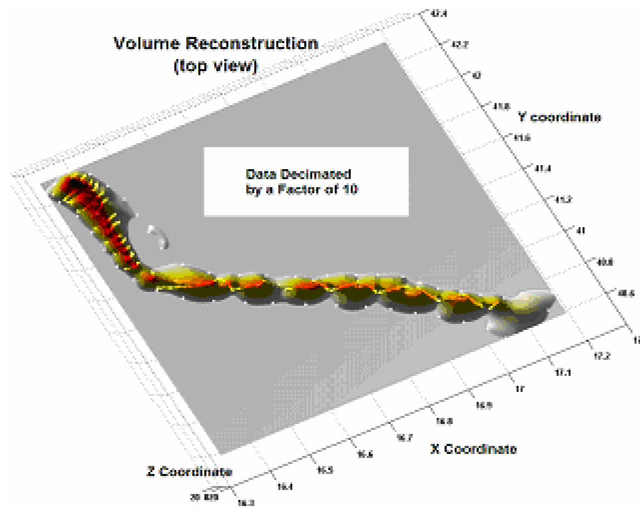


Fig. 5. Top view of grid reconstruction of the lake decimating raw XYZ data by a factor of 10.

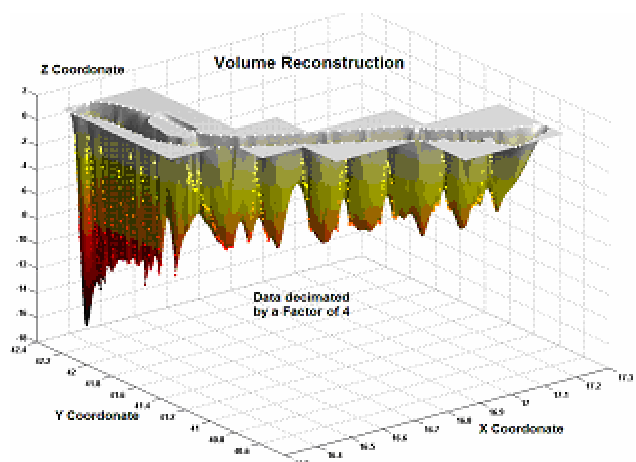


Fig. 6. Grid reconstruction using factor 4 decimation of data and 4 matrix split.

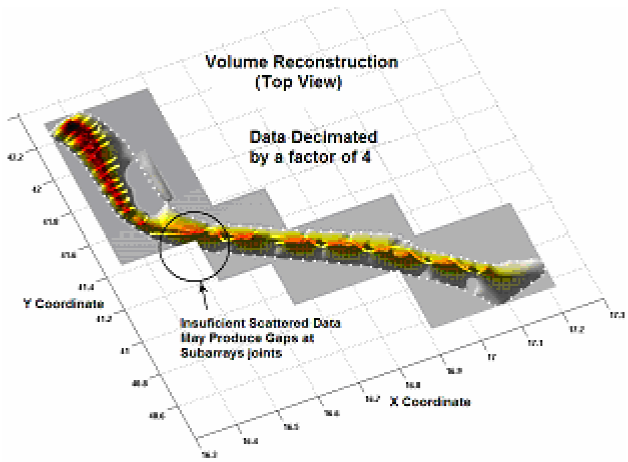


Fig. 7. Top view of Figure 6 reveling a gap in reconstruction due the lack of nearby data.

## 10 Conclusions

Measurements around the hydrographic survey for reservoirs are found to be especially sensitive to systematic errors.

The effort for a new trend in accuracy and control for bathymetric survey took effect of this Fourth Edition of the Standards on NOAA, where hydrographic surveys has not yet been fully determined. Given that, most surveys will fall into the Order 1 category, particular care will be necessary to meet the horizontal accuracy requirements. It is also likely that renewed attention will be given to quantifying the errors associated with tidal height measurements, datum determination and related errors.

Appling knowledge to a pour scattered collection of data for a reservoir in Buzau, district of Romania, a numeric reconstruction technique based on MATLAB was proven good with respect to a right amount and quality of gathered data.

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