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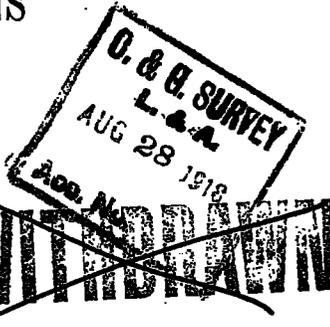
E. LESTER JONES, SUPERINTENDENT

HYPSONOMETRY

USE OF MEAN SEA LEVEL AS THE DATUM FOR ELEVATIONS

BY

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SUPERINTENDENT



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USE OF MEAN SEA LEVEL AS THE DATUM FOR ELEVATIONS.

By E. LESTER JONES, *Superintendent.*

The term "engineering" is usually considered to be synonymous with the word "efficiency," but in at least one branch of engineering it is only partly true. This is in leveling.

There is scarcely any surveying or civil engineering which does not require that differences in elevation be determined by spirit leveling, and in nearly all cases the absolute elevation of the bench marks above some plane of reference or datum is determined. Efficiency in operation and in the results frequently depends upon the datum selected.

What is a satisfactory datum? This is a very important question and one to which much thought is directed by engineers. If one is grading streets or extending a sewerage or water system in a city, it is evident that the official city datum should be used in the leveling operations; but if a city is to adopt a surface for its datum, what should it be? Evidently it should adopt that datum which is most generally used by State engineering departments, by the railroads which enter it, and by other engineering organizations.

Then the State itself must consider what datum it should adopt, and its decision should be based upon the previous decision of other States adjoining it.

Finally, what datum should the Nation adopt? It is evident that it would be impracticable for the Nation, especially one of 3,000,000 square miles of area, as is the case in the United States, to adopt the surface through some one bench mark as its datum in its early engineering work, for this would require that an elaborate system of levels should precede all its surveying and engineering operations.

Only slight consideration leads one to conclude that the ideal datum for a nation is one which may be established at many places. The only one of this kind is mean sea level.

Mean sea level is that surface which would be assumed by the surface of the water of the ocean if it were not disturbed by the attraction of the sun and moon and the force of the wind.

Mean sea level may be established within a very small fraction of a foot by continuous tidal observations for at least a year. It has been found from precise-leveling observations that mean sea level, as established at different points on the open coasts, is at all such points in the same equipotential surface; that is, if there were no resistance of the water and wind to the movement of an object floating on the ocean the object could be moved from one point on the coast to another without performing any work—there would be no lifting necessary.

While this statement may not be absolutely true, yet it is so nearly the case that for all engineering and surveying purposes it may be accepted as rigidly true.

If we have a surface at hand which makes an ideal datum for the elevations of the country, should it be adopted? Efficiency demands that it should be.

Mean sea level is now used exclusively as the datum for all surveys on land by the Coast and Geodetic Survey and by the United States Geological Survey. It is only occasionally used by the Engineering Corps of the Army and not always by the Reclamation Service.

Usually the General Land Office does no leveling in connection with its surveys of the public lands. There is no other Federal organization which covers large areas in its surveying work.

We can scarcely say, in consideration of the evidence, that mean sea level has been universally adopted by the Federal Government as the datum for all of its elevations.

In December, 1916, the Coast and Geodetic Survey sent the following letter, or one similar to it, to the chief engineers of most of the large cities of the country, to the State engineer of each State, and to the chief engineer of each of about 150 railroads in the United States:

As you know, one of the important operations of the United States Coast and Geodetic Survey is the extension over the country of a network of precise leveling which will give elevations of great accuracy, based upon mean sea level.

We believe that this precise leveling is essential in the surveying and engineering work done in this country by various public and private agencies. The network will enable engineers to use the sea-level datum on new projects and to reduce to this datum existing elevations referred to arbitrary datums. We believe that this country should eventually have but one datum, in order that all engineering and surveying work may be easily coordinated. We believe also that the presence of various datums leads to much confusion and waste.

In order that we may get into closer touch with the needs of the engineering profession, I should be glad if you will let me know to what extent your State is basing the elevations of its road and other surveys and engineering works upon mean sea level; also whether the use of various arbitrary datums by counties, cities, and private organizations within your State is a serious matter in the industrial development of your State.

Replies were received from many of these engineers.

The engineers of five of the cities, namely, Fort Worth and El Paso, Tex., Poughkeepsie, N. Y., Birmingham, Ala., and Terre Haute, Ind., reported that mean sea level had been adopted as the official datum for all elevations used by those cities. It was known that Cincinnati had adopted mean sea level as its official datum some years ago.

The engineers of most of the cities reported that arbitrary datums had been in use for many years. Many of them stated that it was generally realized that mean sea level should be used as the official datum, but that the expense incident to changing the many ordinances, profiles, plates, etc., made its adoption of doubtful expediency. There are given later extracts from some of the city engineers' replies. (See pp. 6 to 8.)

Responses were received from most of the State engineers, some of them signing as State highway engineer, others as director of the State Geological Survey, engineering commissioner, etc. In all cases except one, the State engineer informed the Bureau that mean sea level was used as the datum for the State work wherever bench marks were available whose elevations were based on this datum. They strongly advocated the rapid extension of the precise-leveling system of the country in order that no extensive engineering and surveying should have to be based upon assumed elevations or arbitrary datums.

Extracts from the letters of some of the State engineers are given on pages 9 to 12. They show very clearly and strongly the desirability of having a single datum for the country.

The chief engineers of many of the railroads replied to the inquiries of the Survey and, in nearly all cases, they stated that mean sea level was used, or was in process of adoption, by their roads. The general expression of opinion was that the precise-leveling net of the country should be completed or greatly extended in order that the accurate elevations might be at hand as the base for what might be termed the "detailed leveling."

Instances were cited where a road had apparently been on sea-level datum, but considerable error had been disclosed after the precise leveling had been extended to its lines. Such instances as these show that mean sea-level elevations in areas far from the coasts, if not based upon precise levels, may be in error to such an extent that for practical purposes they may be considered as being based upon arbitrary datums.

Extracts from letters of some of the chief engineers of railroads are given on pages 13 to 18.

The city engineer of Terre Haute, Ind., stated that sea-level datum was in use in his city and that he found the use of the United

States Government bench marks of great benefit to him. He thought that the Government should have bench marks in all cities of at least 25,000 population and that it would be of great benefit if the Government established bench marks in even smaller cities.

The city engineer of Fort Worth, Tex., wrote this Office in part as follows:

The elevations of our bench marks throughout Fort Worth have been changed to conform to the datum established by the Coast and Geodetic Survey. We have extended these bench marks to cover the entire town. I consider the extension of your level nets of the greatest importance to the country. Having some definite datum to work from has been a great convenience and benefit to us.

The city engineer of Detroit, Mich., stated that in his city the official datum is an arbitrary one, but that the relation between the city datum and mean sea level had been established. He added:

I can see no objection to the city adopting the Government datum as established here. Of course there are a great many records throughout the city, both public and private, that would be affected, but I think it would be wise to make the change.

The chief engineer of the Topographical Survey Commission of the City of Baltimore wrote this office, in part, as follows:

The city of Baltimore in 1893 established a series of precise-level bench marks which have been used since that time in connection with all engineering work carried on by the municipality. This survey has for its datum the mean low tide at Baltimore.

The Pennsylvania Railroad, as well as other organizations, used still a different datum, so one can see that, although the city's precise-level work has been carried out to a degree of precision equal to that adopted by your survey and is satisfactory for all city work, it would have been much better if the datum adopted for Baltimore had been that of mean sea level. This, I am sure, would have been done if at the time this survey was started a Government bench mark had been available. This would, to a certain extent, have done away with certain confusions which now exist.

We believe that the plan for the United States Government to establish bench marks throughout the country, based on mean sea-level datum, would encourage the use of that datum by all who wish to carry on any extensive system of leveling, and would prove a great convenience and eliminate many errors and much confusion.

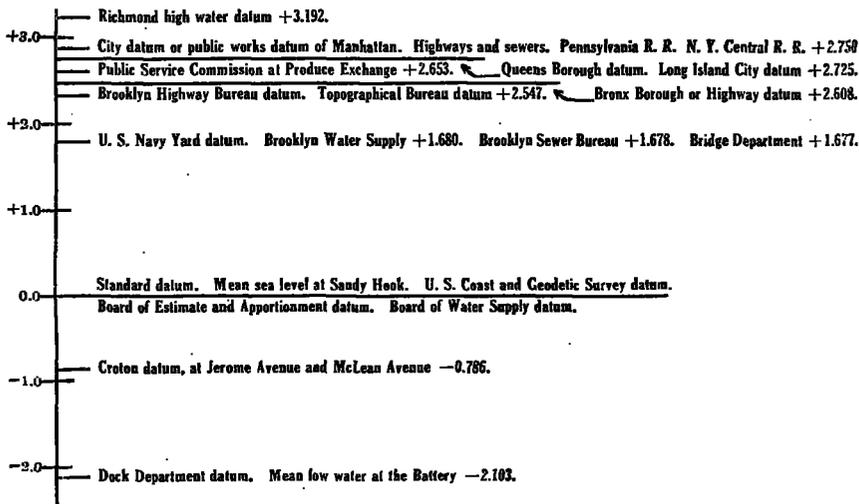
The city engineer of Duluth, Minn., wrote that Duluth had adopted mean level of Lake Superior as its datum. He stated:

The only objection to making the change to sea-level datum would be the altering of our records, but other than that it would be a good move to adopt sea-level datum.

There is shown below the information given on a card issued by the municipal engineers of the city of New York. It was prepared by the special committee on datum planes. It gives a comparison of the various datum planes in use in the city of New York.

THE MUNICIPAL ENGINEERS OF THE CITY OF NEW YORK.

COMPARISON OF DATUM PLANES.



For history of above datum planes see Proceedings of Municipal Engineers for 1915.—
Prepared by the Special Committee on Datum Planes November, 1916.

It is evident that in the city of New York there must be much confusion resulting from the use of so many datums, and it is possible that the confusion in the elevations and the datums may involve the city in much extra expense on engineering work, due to errors which must inevitably be made in interpreting the leveling data.

Conditions in the city of Cincinnati in regard to elevations were so unsatisfactory that, in August, 1913, the council of that city adopted by ordinance mean sea level as the official datum for all city surveying and engineering operations. Before the adoption of this datum each of the various sections of Cincinnati which had been an independent town had its own datum for levels, and there was no official connection of the various systems of elevations.

The city engineer of Birmingham informed the Coast and Geodetic Survey that mean sea level had been adopted as the official datum for that city. He said that Birmingham was made up of 13 municipalities, which were consolidated into one city government. At the time of the consolidation each of these municipalities had its own datum, and, owing to the fact that the city is about 14 miles long and 5 or 6 miles wide, it would have been a considerable expense to the city after the consolidation to undertake to harmonize all of these datum planes.

The engineer of the department of improvements and parks of the city and county of Denver replied that the city datum for Denver

was not referred to the sea in any way. He closed his letter with the statement:

There is, so far, no sentiment in favor of changing the old datum to that of sea level. Personally, I am in favor of doing whatever is necessary to bring about a change to the end that the official datum of every city in the country will refer to the sea.

The city engineer of Memphis wrote, in part, as follows:

I regret to advise that years ago an arbitrary datum was adopted here and that all of our city work is based on this datum. It has no relation and no meaning whatsoever. However, our records at the present time comprise probably 10,000 profiles and over 500,000 individual elevations, which would involve us in an enormous expense, with very serious chances of error, if we should try to change them. Personally, I should like to see them changed, but I see no chance of getting an appropriation for the work, and if I did have it the job would be a staggering one.

The experience of the city of Memphis is what may be expected in any city that may adopt a datum not based on sea level. It is a warning to cities which have not yet adopted official datums that mean sea level should be the one selected.

A letter was received from the assistant engineer of streets of Trenton, N. J., which read in part as follows:

So far as our experience has taught us there can be no question as to the desirability of a universal datum plane, and I think there can be no doubt in the minds of engineers engaged in municipal work that mean sea level is the only logical datum plane to adopt.

In your advocacy of an extension of such bench marks you deserve the support and cooperation of every engineer in the country.

That it is necessary to have precise leveling extended into areas where such control is not now available is clearly indicated by the data furnished by the city engineer of Salt Lake City. The only elevations available in Utah previous to about 15 years ago were from leveling by railroads, and that leveling was done for the immediate control of railroad construction rather than to carry absolute values with great accuracy. His letter contained the following:

Below please find list of the different sea-level datum lines used in Salt Lake City. The city's datum being the lowest, I am calling it zero:

	Feet.
Salt Lake City corporation.....	0.00
United States Weather Bureau.....	23.28
Oregon Short Line Railroad.....	} 26.95
United States Coast and Geodetic Survey.....	} 26.95
Denver & Rio Grande Railroad.....	28.42

Frederick Law Olmstead, an authority on city planning, spoke of the need of a single datum in his report of the Pittsburg Civic Commission, which is entitled, "Pittsburg main thoroughfares and the downtown district," which appeared in December, 1910. In Part III, under the heading "Surveys and a city plan," he spoke of the need for surveys. One of the objects which he thought should

be secured is an accurate framework of reference points, including (1) the gradual systematic setting of street monuments throughout the city to serve as reference points for the definite determination of street locations and for all public and private local surveys; (2) the accurate determination of the locations and elevations of these and other monuments and bench marks in reference to a single general system of coordinates and in reference to the United States Government bench marks; and (3) as a means of accomplishing these ends an accurate geodetic triangulation of the district, supplemented by the necessary precise traverse work and precise leveling all fully checked and compensated for errors.

It will be seen from the preceding quotations and statements that city engineers in general are in favor of mean sea level as the datum for their elevations, but many of them hesitate at present to advocate a change from the arbitrary datums on account of the expense involved. It is reasonably certain, however, that each city will eventually have to make a change, in order that the confusion incident to the presence of many datums in the city and in the contiguous territory may be eliminated.

As previously stated, the chief engineer of each of the States of the Union was requested by the Coast and Geodetic Survey to inform this Office as to whether mean sea level was the datum used on official work in the State and whether the use of arbitrary datums by the various political and private organizations in the State retarded its development.

In nearly all cases the State engineers answered that they are using mean sea-level datum on engineering work wherever it is practicable to do so, and in most cases they expressed a desire that precise leveling, with elevations based on mean sea level, should be extended over the country as rapidly as possible, in order that mean sea level may be available to public and private engineers and surveyors. There are given below extracts from some of the letters received:

The State engineer of Oklahoma wrote, in part:

Replying to your letter, will say that this department is using sea-level datum on all of its work. The same datum is used in almost all of the cities of the State. I do not believe that any particular trouble is occasioned by the use of private or assumed datum planes, owing to the fact that we are so well fixed with the elevations all through the State that elevations may be reduced to sea level when the same may be needed.

The State reclamation engineer of Texas said that his department constantly makes use of the bench marks established by the Government and that all of his work is based upon mean sea level.

The State engineer of Wyoming said that he was heartily in accord with the views of this Office relative to a standard datum for all elevations connected with surveying work throughout the United

States. The surveys made under his supervision are, whenever possible, based on elevations referred to mean sea level. In his opinion the standardization of all elevations and placing them on the same datum would be of great value to the engineering profession throughout the country.

A letter received from the road engineer of the Iowa State Highway Commission read as follows:

Replying to your letter of December 14, we would say that in highway work the county engineers are using the sea-level datum for all surveys wherever bench marks referred to such datum are available. We are unable to say just what percentage of the counties have such bench marks available.

It would be a very great convenience to us if all of the surveys were referred to sea-level datum, as in a few years we will possibly want to prepare a topographical map of the State, and if all the surveys were referred to one datum it would be unnecessary to reduce these various surveys to a common base.

We are unable to state to which extent cities and towns are using the sea-level datum, but we think it is not very general except, possibly, in the cities and towns along the Mississippi or Missouri Rivers.

The State engineer of New Mexico expressed the hope that some organization would take hold of the matter of the adoption of a single datum and try to persuade all engineers in his State to adopt mean sea-level datum in order to avoid confusion which is occasioned by the use of a number of datums. He closed his letter as follows:

This day (Dec. 27, 1916) there is being held at El Paso a tentative-plan meeting, calling all the engineers in New Mexico, Arizona, and Texas to organize a southwestern engineering society, and I feel that an organization of this kind, as soon as it is established and in working order, can do a great deal of good along this line of work. I will take it upon myself, after the organization of the society, to bring this particular subject before it.

The chief engineer of Pennsylvania wrote that all the district engineers used mean sea level as the datum for their elevations and that his reports indicated that the majority of the city engineers also used mean sea level, but that the cities of York, Philadelphia, and Pittsburgh were using arbitrary datums. He expressed the opinion that there is no question but that in time it would be a great help if all leveling could be based on one datum.

The State engineer of South Dakota wrote that in all of the irrigation, drainage, road, and other surveys that had been conducted under him mean sea level had been used as a datum for elevations.

The engineer of the State of Kansas, in replying to the letter from the Survey, stated that—

In so far as I have any information in the matter the various engineering projects of the State are based on various arbitrary datums. This condition necessarily causes much trouble in many instances. The most recent example I now have in mind is in connection with our investigation of flood conditions here in Kansas. Some of the most important data in this connection are those in the possession of the railroads, and in order to make them available it

would probably be necessary to make many adjustments in the various datums employed. Had all elevations been based on mean sea level, this trouble would, of course, have been avoided.

The State engineer of Oregon wrote that in connection with the State's irrigation and highway work his department endeavored, wherever possible, to base its surveys on mean sea-level datum. He stated also that he found the bench marks of the United States Coast and Geodetic Survey and the United States Geological Survey of great benefit, as all surveys based upon them are on the same datum, and when connected form a uniform network over the State.

This is a very important point brought out by the State engineer of Oregon, for it is where new surveys must be connected with other surveys that great confusion arises unless all are based upon the single datum for elevations. If there were to be only one survey in a restricted area, and that survey would never have to be joined to any others, it would be a matter of indifference as to whether one datum or another were used for elevations.

The State engineer of Minnesota stated that he had not been able to use mean sea level throughout the State, but that as a general thing an arbitrary datum had been adopted in each county; and, in fact, in each of several counties more than one arbitrary datum had been adopted. The reason for this condition was the lack of bench marks in his State. He closed his letter with this statement:

We agree with you that it would be very valuable to the State if a system of levels could be established, and believe that such will need to be done in the near future in order to correlate the drainage, highway, and other engineering work in the State.

The State highway engineer of Alabama, in a letter to this Office, stated that wherever possible his department based the elevations of their road work upon mean sea level. He expressed the wish that a sufficient amount of leveling might be done in his State to enable all of the road work to be based upon mean sea level for elevations.

The deputy State engineer of New York informed this Office that the engineering department of that State has, since 1898, used mean sea level in all of its work. Previous to that time, elevations were upon a different datum for each of the three divisions of the New York State canals, those divisions having their headquarters at Albany, Syracuse, and Rochester. He said that several hundred engineers, who had been employed by his department, but were no longer connected with it on account of the completion of the barge canal, are now employed by municipalities and large corporations, or are in private practice. As they are familiar with the sea-level datum they are gradually changing the datums in different localities to that one. They are having considerable influence toward securing the general adoption of mean sea-level datum.

The assistant superintendent of the Department of Public Works of the State of Ohio expressed the hope that mean sea level would be adopted throughout the entire country as the datum for elevations. His letter read, in part, as follows:

This department has spent some time and considerable money in standardizing our levels over the public works of the State and we are now using United States datum (sea-level datum).

The writer had occasion to be called in consultation on certain proposed improvements and the county engineer used a datum of his own selection. The city engineer selected a different datum, while the writer used in his calculations the United States datum. The result, as you can very readily see, was confusion which made necessary an extra amount of work to bring the various arbitrary datums to the same standard.

The chairman of the Public Utilities Commission of Maine stated in his reply that—

We are thoroughly in accord with your ideas as to the confusion resulting from the use of arbitrary datums on projects requiring the determination of elevations and this commission has endeavored, in so far as it has been able to do so, to extend the use of mean sea-level datum on State, municipal, and private engineering works in Maine.

He closed his letter with the request for the elevations of bench marks established on a line of precise levels extended across the State of Maine by a party of the United States Coast and Geodetic Survey in 1916. He believed that such data as may be available could be advantageously tabulated and published in the volume of the annual report of the Public Utilities Commission relating to topography, geology, and water resources.

It might be well if the various States were to assist the Federal Bureaus in placing the leveling and other engineering data before the engineers of the States. This could be done very well by having the necessary data appear in the annual reports of the State engineers and of public utility commissions.

The various railroads of the country are vitally interested in the adoption of mean sea level as the sole datum for elevations in the country, for each of a number of railroads traverses the territory of several States and of innumerable cities and towns. There is necessarily a great deal of confusion in elevations between the railroads and the various municipalities and political units through which the roads pass if each unit has its own datum.

The Interstate Commerce Commission directed the various railroads of the country to show on their profiles the equations necessary to reduce elevations to sea-level datum or to have the profiles based upon mean sea level. This was for the valuation work undertaken by the commission. The result of this requirement has been that many railroads changed from arbitrary datums to the mean sea-level datum, although probably most of the roads of the country had previously adopted mean sea level as their datum. It may be inter-

esting to note that the Board of Railway Commissioners of Canada has directed the railroads of the Dominion to submit all information in connection with elevations and profiles on mean sea-level datum.

It will be of interest and value to learn the opinion of a number of the chief engineers of the various railroads of the country with regard to mean sea-level datum. To a letter sent out to them by the United States Coast and Geodetic Survey a number of replies were received. The Survey's letter requested information as to whether or not mean sea level was used by the railroads; if not, what datum was used; and if arbitrary datums were used in the territory traversed by the roads, whether they were a handicap to the development of the territory.

There are given below the substance of some of the letters and actual quotations from others.

The assistant chief engineer of the Minneapolis, St. Paul & Sault Ste. Marie Railway Co. stated that his road was using sea-level datum on its entire system, except on the Chicago division, but that, as fast as possible, that division was being reduced to mean sea-level datum. He said in part:

The use of various arbitrary datums by States, cities, counties, and private organizations along our line has not been a very serious matter, except that it requires more labor and particular care to convert their datums to the one which we use. There is always a possibility of error in this conversion of datums that would be eliminated by standardizing sea-level datum.

The chief engineer of the Duluth & Iron Range Railroad Co. said:

Many other organizations in our vicinity use either an assumed datum or a datum which is supposed to correspond to the mean low water of Lake Superior. The discrepancy between the various datums is often confusing, and I have known cases where the confusion resulted in mistakes in construction which were expensive.

The chief engineer of the Chicago Great Western Railroad stated that his road used sea-level datum for all of its elevations in connection with maps and profiles. He added:

We consider the use of arbitrary datums by States, cities, and counties as causing considerable inconvenience. Quite frequently it is necessary to compare [our] levels with local work, and where elevations are not on sea-level datum it results in confusion and more or less misunderstanding.

The chief engineer of the Philadelphia & Reading Railway Co. wrote in part:

Our system for some years back has used mean tide at Sandy Hook for its datum, and we believe that it is the only reasonable one for such purposes. In the city of Philadelphia, where an arbitrary datum is used, we have to make our plans conform to the Philadelphia city datum, in so far as such plans affect city improvements.

It is distinctly a serious matter to have different localities using different datums, and we shall be glad to see any movement toward the abolishment of any datums which are not based on mean sea level.

The chief engineer of the Chicago & North Western Railway said :

I thoroughly agree with you that this precise leveling is essential in the surveying and engineering work done in this country by various public and private agencies.

We endeavor to base our elevations upon mean sea level wherever possible, but find that the use of various datums by cities, counties, and States results in considerable confusion and arguments. I am of the opinion that if we had but one datum all of our work would be more easily coordinated and would result in less confusion and waste than at present.

The chief engineer of the Chicago, Rock Island & Pacific Railway expressed the opinion that the establishment of arbitrary datums by States, cities, counties, and private organizations should be discouraged as much as possible, as they cause a great deal of confusion.

The chief engineer of maintenance of way and structures, lines east, of the Southern Railway system said, in part :

I am glad to advise that for some years past on this railway we have had all our surveys tied into sea-level datum. We have found that the presence of various datums leads to much confusion and waste.

The chief engineer of the Western Maryland Railway Co. said :

We have had and still encounter trouble in avoiding errors due to the different datums used by adjacent railroads, various cities, counties, and private organizations. We are heartily in favor of the establishment of an authoritative datum for use and adoption by all.

The engineer of the Chicago, Peoria & St. Louis Railway Co. wrote that—

We are endeavoring to reduce the various arbitrary datums used in the construction of this line to sea-level datum. We do find that considerable inconvenience is occasioned by the use of arbitrary datums. Inasmuch as we are brought in touch with various drainage projects along the line we feel that some common datum should be used.

The chief engineer of the Missouri Pacific Railway wrote as follows :

It is very desirable, though not absolutely essential, to use one datum plane for all engineering elevations, as with conditions as at present existing there is a great deal of confusion and time lost in looking up proper equations to change from one datum plane to another.

In getting rough approximations of the discharge of streams it is necessary to know the approximate slope, and to get this it is necessary to know the elevations of crossings of the river at different points on its course. Where elevations of these crossings are referred to different datums it is frequently impossible to get more than a very rough approximation of the difference of elevations, which results in a corresponding approximation of the discharge. This also very frequently happens in connection with drainage work.

The use of various arbitrary datums by States, counties, cities, and private organizations is becoming more and more a serious problem, for the reason that it requires considerable research or investigation to determine whether the elevations used are referred to sea level or other datum planes and then to ascertain the correct equations.

I do not know of any one thing which the Coast Survey has undertaken which will be of greater benefit to the engineering profession of the country at large, in so far as all engineering operations are concerned—and by this one can almost say all industrial development of the country—than to promote and secure the adoption of mean sea level as the datum for all elevations.

The chief engineer of the Illinois Central Railroad Co. informed this Office that his road uses mean sea level as the datum for its elevations. He concluded by saying:

The various datum planes used by cities and surveyors along the lines of this company cause, in many cases, confusion and inconvenience in connection with the working up of plans and the correlating of them to local surveys. It would be of great benefit if, as you suggest, a single datum plane were in use all over the United States, and presumably this will be in effect some day, but the time will be greatly advanced through the establishment by the United States Coast and Geodetic Survey of bench marks throughout the country.

The chief engineer of the Kansas City Southern Railway Co. said he believed that if a universal sea-level datum could be adopted by all State, county, and city organizations it would be of great benefit, not only to the railroads but to other industrial as well as private organizations. He heartily indorses any movement that would bring about this plan.

The chief engineer of the Lehigh Valley Railroad Co. said in part:

I agree with you that it would be a very great benefit if the country should eventually have but one datum, in order that all engineering and surveying work may be easily coordinated. This would save considerable annoyance and many errors.

The chief engineer of the Hocking Valley Railway Co. said that all of the elevations of his road are referred to sea-level datum but that, as far as he knew, none of the towns or cities on his line used that datum. He said that the idea that all levels should be referred to sea-level datum is an excellent one and that it would facilitate matters if the whole country would adopt this datum for all of its leveling.

The chief engineer of the Delaware, Lackawanna & Western Railroad Co. said:

There is no question in our work but that the variation in the data is confusing, and it certainly would be not only to the railroad company's interest but to the interest of the municipalities, boroughs, etc., along the line to have a uniform datum.

The chief engineer of the Michigan Central Railroad Co. is using mean sea level on that road as the datum for all elevations. He adds:

I believe that the use by States and counties and by private organizations of datums different from the sea level one is a great disadvantage, especially where the railroads are requested to do work in connection with them, such as building sidetracks, etc. When the elevations of floors and other portions of a building are given on an arbitrary datum and the railroad work is done on the

sea-level datum, there is always very great chance of error in relating one datum to the other.

The chief engineer of the Chicago & Alton Railroad Co. stated that it is unfortunate that the municipalities have not, like the railroads, adopted the mean sea level. As an illustration he stated that almost every day situations occur in Chicago where elevations are referred to city datum; that is, the average elevation of Lake Michigan. This produces confusion, as it is necessary to consider the relation of the arbitrary datums with reference to mean sea level, which is almost universally used as the datum by railroads, geological surveys, etc. He added:

Any departure from the Government datum produces confusion and oftentimes embarrassing situations. I have had such experience in the city of Cleveland and in the city of Pittsburgh, where for many years no datum plane of any sort existed that was reliable and properly referenced.

The chief engineer of the Pennsylvania Railroad Co. informed the Survey that all construction on his road was based upon elevations on the sea-level datum, with the exception of some few cases where his work joined with that of cities, when it was necessary to have plans based upon the datums adopted by the municipalities. He expressed himself as being heartily in favor of reducing all elevations in the country to the mean sea-level datum.

The chief engineer of the Boston & Albany Railroad wrote in part as follows:

We have found Government precise leveling of the greatest service to us in connection with our heavy reconstruction on the Boston & Albany Railroad. We are running altogether on the Government datum, and I quite agree with you that the whole country should adopt it if at all possible.

The various datums at present in use in cities and towns cause much confusion and waste of time in equating between them. For instance, in our work in the city of Boston, with which the city work comes in contact, we have to run everything on sea-level datum and also on the city of Boston datum, and similar conditions obtain in Worcester and Springfield.

I have been endeavoring, as far as possible, to get the various town and city engineers along our road to adopt the sea-level datum, and several of them are now using it.

The chief engineer of the Los Angeles & Salt Lake Railroad Co. wrote that—

A book can be written setting forth the value of precise levels and the disadvantages of assumed levels. Therefore, I think it only necessary to say that we use your levels wherever we find them, and our regret is that your work is not now further advanced. We are in hearty sympathy with your work and hope that you will be able to continue it in a broad way.

The chief engineer of the St. Louis-San Francisco Railway Co. informed the Survey that all the profiles of his road that are now

being prepared, or that have been prepared for some time past, are based on sea-level datum, and that he considers it a serious proposition to have various arbitrary datums by States, counties, cities, etc. He said that serious difficulties were encountered by his road as a result of various datums in connection with drainage matters, grade separation, and development work.

The chief engineer of the Wisconsin & Northern Railroad Co. said, in part:

As a general proposition there can be no question as to the great desirability of having all surveys and benches referred to sea-level datum, and in other surveys upon which I have been engaged in this territory for interurban lines, and, to a minor extent, water-power development, I have gone to some pains to establish such datum. While from my own experience I can say but little as to the bearing of this question upon industrial development, I can say without hesitation that the matter is an important one and will become increasingly so as the country becomes more highly developed. I would add from observation that from the tremendous expansion now beginning in permanent road construction, the providing of such base lines of precise leveling as you mention at the earliest practicable date would be of the greatest importance and benefit.

The chief engineer of the Oregon Short Line Railroad Co. announced that his road is using mean sea-level datum for all of its elevations. He said that he found the results of the United States Coast and Geodetic Survey leveling invaluable for his use in connection with location and maintenance work. He expressed the belief that, if engineers generally could realize the saving in time and lessening in confusion which would result from the use of the mean sea-level datum, they would eliminate the various independent datums and adopt the standard sea-level datum.

The chief engineer of the Northern Pacific Railway Co. replied that there is a great deal of confusion at present caused by the various datums used for level work by different railroad companies, cities, and private organizations. He also said that the Northern Pacific is using sea-level datum, but that there is confusion caused by the fact that sea-level datum, as used by other organizations, had different elevations. He expressed the opinion that engineering work would be greatly facilitated if it could be based on the same datum for all the States.

This is another instance where elevations, supposedly based on mean sea level, are in error because of the lack of precise leveling elevations before the detailed leveling was run. This is an argument for the extension of the precise level net into the areas which now do not have this fundamental control.

The chief engineer of the Toledo & Ohio Central Railway Co. approved of any movement to establish reliable bench marks, referred to sea level, over the territory of the United States as, in his opinion, it would be of great value to the engineering profession and to all industries which have engineers in their service. He added:

In days gone by a great many surveys were made on our road and referred to any arbitrary datum that the man in charge might choose, with the result that we find it difficult and inconvenient many times to utilize properly the results obtained from these old surveys. All the work we are now doing is referred to sea-level datum.

The quotations contained herein from letters received from many of the most prominent engineers of the country prove conclusively, it is believed, that it would be far better for the country in its industrial and engineering developments if there were used only one datum and if that datum were mean sea level. It is realized by the members of the Coast and Geodetic Survey that much of the confusion in datums which now exists is due to the fact that the precise level net of the United States was not extended in the past as rapidly as it should have been. It, of course, was impossible, or rather impracticable, to extend a precise level net into areas through which railroads had not been run, for the expense would have been prohibitive. It may be that the Survey did not fully realize the necessity for having all engineering and surveying work on the same datum, but in recent years it has been fully alive to the necessity of having a single datum for the entire country, and it is consequently extending its precise leveling net as rapidly as funds available will permit.

To show how active the Survey has been in its precise leveling in recent years, it may be stated that in December, 1907, there were in the United States 24,000 miles of precise leveling which had been run by the United States Coast and Geodetic Survey, the Corps of Engineers, United States Army, the United States Geological Survey, the United States Lake Survey, the Pennsylvania and the Baltimore & Ohio Railroads, together with the Mississippi and Missouri River Commissions. The amount of precise leveling in the country in December, 1916, was 35,500 miles. It may be interesting to note that during the calendar year 1916 about 2,500 miles of precise leveling were added to the net by the Coast and Geodetic Survey.

That the amount of precise leveling in the United States is entirely inadequate is shown in the following table which gives the amount of leveling in many of the countries of the world. This table also shows the amount of such leveling for each 100 square miles of area. We should double the amount of leveling in this country within the next few years.

PRECISE LEVELING IN A NUMBER OF COUNTRIES.

Country.	Area.	Miles of precise leveling.	Miles of precise leveling per 100 square miles of area.
	<i>Square miles.</i>		
United States.....	3,370,000	35,500	1.2
Alaska.....	591,000	20	.0
British Isles.....	121,000	12,804	10.6
Austria-Hungary.....	241,000	13,129	5.4
France.....	207,000	7,284	3.5
Germany.....	309,000	30,051	10.0
Italy.....	111,000	4,093	4.2
Japan.....	176,000	9,129	5.2
India.....	1,707,000	17,301	1.0

While it is of value to the Nation for various organizations and individuals to adopt and use mean sea-level datum for their elevations, the country will benefit still more if each organization doing extensive leveling will publish in pamphlet form the elevations and descriptions of the bench marks they may establish in order that other organizations and individuals may properly coordinate their levels. Engineers are urged also to use substantial bench marks in order that future work may be benefited by their preservation. In this connection it may be interesting to quote from a letter which was sent to the Engineering Record by F. D. Yeaton, of Oak Harbor, Ill. This letter appeared in the issue of May 20, 1916, and is entitled: "Surveys and bench marks—more permanence needed." It reads as follows:

SIR: I would like to suggest a more general use of sea-level datum and reference ties to public land lines for all surveys, the lack of which will generally be found to be weak points in many surveys. The too frequent practice of using assumed bench marks, such as spikes in trees, or tops of curbs, should be discontinued wherever practicable. Reference points, such as stakes and marks opposite center of structures, are often used instead of township and section lines. It is only a question of a few years before assumed bench marks and reference points will be destroyed, and the surveys will be practically valueless for future use.

Recently I desired records of high-water marks along a certain strip of land to use in establishing a high-water plane. Several dozen surveys, which had been made for permanent bridge work and which contained high-water records, were obtained from the files. As is often the case, the surveys had been made from assumed bench marks. The connecting links were missing and the surveys were valueless for my purpose.

One finds many maps, profiles, and topographical surveys on file in engineering offices bearing practically no direct relation to each other. Engineers have had occasion in valuation work, and in lawsuits involving surveys, to handle maps and profiles the value of which would have been intrinsic if only some relation between the maps and the profiles could have been established. The engineering departments of both small and large corporations are more or less at fault in the matter of allowing surveys to be made and filed which are of practically no future value.

The Federal Government has established sea-level bench marks and permanent land lines in many parts of the country, and their use should become more general in surveys of all kinds. The more general use of sea-level datum and land-line ties for surveys will aid greatly in reducing the duplication of field surveys, and will tend toward inaugurating a more permanent and economical policy of making and filing surveys.

In the October 13, 1916, copy of *Science* there is a short article entitled "Expedite the map." It announced that a committee to expedite the completion of the topographic map of the United States had been formed, on the invitation of the well-known geographer and geologist, Prof. W. M. Davis, of Harvard University. Prof. Davis, the writer of the article in *Science*, made the statement:

Every industry, art, and science which demands a knowledge of the lay of the land is benefited by good maps of the area in which work is carried on. The general location of railways and highways, the planning of water supplies, irrigation, and drainage projects, the prosecution of geological, soil, and forest surveys, the development of water powers, and the installation of electric transmission lines, the promotion of large-scale realty transactions such as are common in the less settled parts of the country, are all aided immensely if good topographic maps of their areas are available, and they are correspondingly embarrassed if such maps are wanting. Practical men who have had experience in mapped and in unmapped areas can testify to the ease and the difficulty of work in the two cases.

This is admirably stated and is convincing in showing the necessity for accurate topographic maps in the country. Engineers will realize that such maps can not be accurate and can not be of the greatest value unless each map or section of a map has its elevations and contours referred to a common datum.

CONCLUSION.

The Survey, whose obligation it is to extend the precise leveling net over the country for the use of Federal, State, city, and other engineering, surveying, and mapping work, feels that the expressions of opinion of the leading engineers of the country point to only one conclusion. This is that the Federal Government should provide the fundamental elevations in sufficient number that the various Federal engineering and surveying organizations and the smaller political units such as States, counties, and cities, as well as private organizations and individuals, may have available fundamental elevations upon which to start leveling, precise or otherwise, for detailed operations.

The amount of precise leveling which should be done by the Federal Government can not be foretold. It must depend upon the needs of the various organizations and individuals using the results. After a certain development of the precise level net which appears now to be absolutely necessary, the rapidity with which further extensions are

made should depend upon the development of the country. But such further extensions should precede rather than follow such development as is proved by the unfortunate condition of affairs in much of our engineering and surveying work, due to lack of precise elevations in the past, when such work was inaugurated.

With the increased demands for accurate topographic maps of the country, the wonderful extension of our good-roads movement, the extension of the railroads, and the development of river, irrigation, and drainage projects, the precise leveling of the country should be carried in the near future into many of the large areas now having little or no accurate leveling. The further conclusion may be drawn that it will be best for the efficiency of the country as a whole that all new leveling, by the various organizations and individuals engaged upon engineering and surveying work, be placed upon mean sea-level datum, wherever this is practicable, and also that as far as possible existing leveling referred to arbitrary datums should be changed to sea-level datum.

It is hoped that as a step toward the industrial preparedness of our Nation the engineering press, the National, State, and city engineering societies and associations, and engineering organizations and individuals of the country will take an active part in furthering the use of mean sea level as the datum for elevations.

