A Colorado River Sediment Inventory

Compiled by John Weisheit

The table below is a compilation of scientific data from reports written by hydrologists. For the US Geological Survey (USGS) Eugene LaRue documented the sediment loads of the Colorado River in early *Water Supply Papers*. A very comprehensive study on sediment in Lake Mead reservoir was conducted by the USGS in 1948-49 and published in 1960 as *Professional Paper #295*. This paper set the standard for the study of sedimentation in large reservoirs that has yet to be repeated. Subsequent studies, but limited in scope, have been accomplished such as the *1986 Lake Powell Survey* by the Bureau of Reclamation, and an excellent report was written by Edmund D. Andrews of the USGS, *Sediment Transport in the Colorado River Basin,* which was published in 1991 by the National Academy of Sciences. Unfortunately, the collection of data for sediment was discontinued by the USGS in 1989.

The chart below is basically accurate in all columns and rows. Two points of climate history must be considered when reviewing this data: 1) sediment loads vary considerably due to changes in climate regimes; 2) since the construction of Hoover Dam, additional reservoirs have been added to the plumbing system, which are collecting sediment independently throughout the entire basin. Incidentally, all river sections between dams have had their sediment loads reduced.

The government scientists who studied the sedimentation of Lake Mead in 1948 were actually alarmed at the rapid accumulation of sediment in that reservoir. To mitigate the problem, and to their chagrin, they recommended the building of upper basin dams. Though this provided more longevity for Lake Mead, it essentially spread the sediment problem to more than one place and effectively increased future mitigation costs substanitally. This demonstrates the mismanagement of water resources in the Colorado River basin, which can be summarized best as stealing the future to gain the present.

What the studies show is that sediment transport in the Colorado River itself has been greatly reduced since 1942 and by as much as 400%. This does not necessarily mean that natural erosion on the Colorado Plateau is at rest. More likely, sediment is being stored in the arroyos of the basin and waiting for threshold events to transport their loads into the Colorado River, and subsequently into mainsteam reservoirs such as Mead and Powell.

For example, a flood with a peak discharge of 140,000 cfs roared through San Juan Canyon below Mexican Hat, Utah in October 1911. It is just a matter of time before similar flood events mobilize many decades worth of sediment from arroyos and send huge plugs of sediment into Lake Powell.

A sediment management plan must be conducted in the very near future by the Bureau of Reclamation. This study must not only evaluate the sediment of all the mainstem reservoirs of the Colorado River and its tributaries, but it must also evaluate the storage of sediment in all the ephemeral arroyos, especially where soft Mesozoic rocks dominate the landscape such as the basins of the San Juan and Little Colorado rivers. It must also determine the effects that sediment will have on dam safety, power generation, water storage, recreation, and the management of endangered species.

How Much Sediment Are We Talking About?

According to E. D. Andrews' very reasonable estimate, which was published in 1990, there are 44,400,000 tons of sediment arriving into Lake Powell reservoir on a yearly basis under the current climate regime. A truck pulling a street legal load has a carrying capacity of 22 tons. In one year, it would require 2.018 million truck loads to remove the annual sediment load of Lake Powell. That is 5,529 truck loads per day; 230 loads per hour; 4 loads per minute.

This scenario demonstrates very well the costs and impacts involved in solving the sediment problem of reservoirs. It also destroys the myth that federal dams are cost-effective and that hydropower is a renewable resource.

Author and year	Location	Years of analysis	Total annual average in tons	Total annual average in acre feet
E.C. LaRue 1916	Yuma, AZ	1892-1912 (inclusive)	162,500,000	
E. C. LaRue 1925	Yuma, AZ	1909-1922	196,673,400	
W.O.Smith 1960	Hoover Dam	1935-48	143,000,000	
E. D. Andrews 1990	Grand Canyon @ Bright Angel	1925-1940	195,000,000	
E. D. Andrews 1990	Grand Canyon @ Bright Angel	1941-1957	86,000,000	
E. D. Andrews 1990	Grand Canyon @ Bright Angel	1963-1990	11,000,000	
E. D. Andrews 1990	Lee's Ferry	1941-1957	66,100,000	
BuRec 1962	Glen Canyon Dam	?		85,400
W. Condit; 1978	Glen Canyon Dam	1963-1977		27,000
R. Ferrari 1988	Glen Canyon Dam	1963-1986		36,946
E. D. Andrews 1990	Glen Canyon Dam	1963-1986	44,400,000	

THE SEDIMENT PROBLEM IN RESERVOIRS

by Thomas L. Maddock, Jr
U.S. Bureau of Reclamation

A chapter from: Comprehensive Survey of Sedimentation in Lake Mead, 1948-1949, USGS Professional Paper 295; W. O. Smith, C. P. Vetter, G. B. Cummings, et. al.

The accumulation of sediment in reservoirs has long been recognized as one of the principal problems involved in the Western United States in providing for regulation of rivers by storage. Even the rivers in humid regions carry some sediment, and in several reservoirs in the eastern half of the country the accumulation of sediment is a significant engineering problem. More than 50 years ago F. H. Newell of the Geological Survey, later to become the first Director of the Reclamation Service [now called Bureau of Reclamation] wrote: "Thus, the upper ends of all reservoirs are rapidly filled with silt and it becomes an important question to the projectors of storage works as to how many years will elapse before the value of the reservoir is practically destroyed and whether its use can be restored in part by subsequent removal of some of this material."

To answer part of the question posed by Newell, the Geological Survey undertook, from 1904 to about 1910, what today would be called a miscellaneous sediment sampling program on many streams in the West, particularly those whose load of sediment was obviously great. For a long time records collected during this period formed the basis for estimates of the sediment load of western streams, and such estimates in turn provided the basis for decisions as to the amount of reservoir capacity to allocate to sediment storage and for estimates of the useful life of proposed reservoirs.

The greatest interest centered in the rate of sediment movement in the Rio Grande and Colorado River basins, perhaps the two streams most heavily laden with sediment in the country. Reports by Stabler (1911), Follett (1913), and Fortier and Blaney (1928) are the best known studies of sediment load in these two streams. The early estimates of sediment movement appear to be surprisingly good and reflect the ability and good judgment of those engaged in the early development of the water resources of the West.

In the light of more recent data, the estimates of average sediment load were generally somewhat high, and the predictions of reservoir life thus appear to be conservative. In 1899, the sediment load of the Gila River at San Carlos, Ariz., was estimated to average 8,440 acre-feet per year, but the observed rate of deposition in San Carlos Reservoir on the Gila River in the period 1928-47 was 3,200 acre-feet per year. In 1913, the average annual sediment load of the Rio Grande at Elephant Butte Reservoir, N. Mex., was estimated to be 19,700 acre-feet; the observed rate of accumulation in Elephant Butte Reservoir in 1915-47 was 14,400 acre-feet per year. Prior to the construction of Hoover Dam the sediment load of the Colorado River was estimated to be 137,000 acre-feet per year, but the 1948-49 survey has shown the average annual rate of accumulation to have been about 102,000 acre-feet. In nearly all cases present estimates promise a greater length of life for major western reservoirs than those made prior to 1930.

This encouraging news does not allay the problem of sedimentation in reservoirs, but merely puts off the day of reckoning. Commonly sedimentation is a minor problem during the first years of operation of a reservoir, but as the water-storage facility is used by succeeding generations the problem becomes of progressively greater significance and concern. Sooner or later the water users ask the questions: How long will the reservoir continue to be of use to

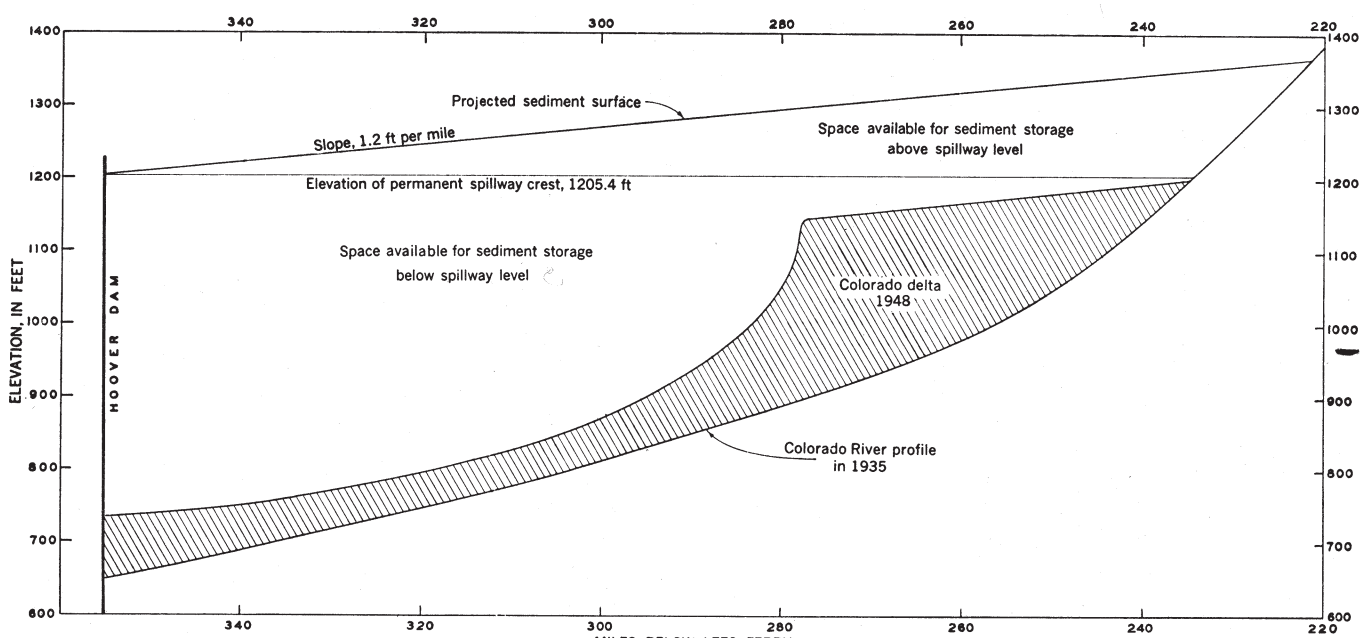

FIGURE 57.—Diagrammatic representation of the surface of the sediment that would be accumulated in Lake Mead when the lake is filled to permanent spillway level.

them; what can be done to increase that economic life; will there be diminution or deterioration of their water supplies (and, if so, when and how much); and what alternatives are available for meeting their continuing requirements?

These questions cannot be answered merely from an analysis of records of the rate of movement of sediment into reservoirs, even if those records were complete and accurate, which they are not. Also, detailed information is essential as to the mechanics of transportation and deposition of sediments in reservoirs, which is obtained by comprehensive surveys such as the one undertaken in Lake Mead during 1948-49. In part, the answers would depend upon an understanding of the dynamics of sedimentation, including erosion and transportation in the tributary watershed, as well as deposition in the reservoir.

It is difficult to predict the useful life of a reservoir even if the rate of sediment movement into the reservoir is known. This difficulty comes about partly because the rate of sediment movement in streams is measured by weight, and the weight of the sediment must be converted into space occupied. The conversion factor as found by reservoir surveys is not constant because the sediment becomes more compact as it dries and as deposits deepen. The space occupied by a given weight of sediment, therefore, will vary with the type of reservoir operation and the age of the reservoir. This is one of the reasons why successive volumetric surveys of a reservoir tend to show decreasing rates of sediment accumulation.

> *"Thus, the upper ends of all reservoirs are rapidly filled with silt and it becomes an important question to the projectors of storage works as to how many years will elapse before the value of the reservoir is practically destroyed and whether its use can be restored in part by subsequent removal of some of this material."*
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> Frederick Newell, first commissioner of Reclamation.

In the United States there is no experience to guide any estimate of how rapidly a large reservoir will fill to the last stages of its life. It is known that, as the capacity of a reservoir diminishes, more of the sediment load passes through without being deposited. It is known also that, as deposition in a reservoir proceeds, a considerable quantity of sediment is deposited upstream from the flow line of the reservoir. Here again experience is not yet a sufficient guide to a determination of the amount of sediment that will be deposited in such locations. Critical problems can result from upstream deposition, and some have been observed. However, what happens above a reservoir seems to be dependent on many factors, such as reservoir operating levels, the amount of the sediment load, the amount of water carried by the stream, and the potential for vegetal growth.

If the problem of determining the life of a reservoir is not a simple one, the value of preventing sediment accumulation in a reservoir is not easily determined either. The difficulty is complicated by the fact that reservoir storage may have different values from place to place, or from time to time. Streamflow generally must be regulated to be useful, and the degree of regulation desired is a measure of the reservoir storage required. Filling a reservoir with sediment does not destroy the value created by the falling water in power production and may even increase power production by holding a given amount of water at a higher elevation, although if regulatory space is lost the firm power production may be decreased. Loss of reservoir capacity is not of tremendous importance when ample supplies of water are available, nor is it of importance in the dry years when storage space will not be filled. But maintenance of reservoir storage is of tremendous importance in the transition from wet to dry years, and most western irrigation projects now under way contemplate holding over the surplus flows of wet years to make up the expected deficiency in dry years. Thus, irrigated acreage is directly related to reservoir capacity and must be decreased as the reservoir capacity is reduced.

If, then, irrigated acreage is dependent on reservoir capacity, what should be the criteria for project life? This is a question that has never been answered satisfactorily. With few exceptions, large reservoirs so far constructed in the West have economic lives well in excess of 100 years. The economic value of a reservoir during its useful life should be based, not only on the strictly economic benefits that are obtained from its construction as measured by comparison with costs, but on the intangible returns that come from a sustained irrigation economy in an area with little or no other development.

> *"You hear that it is filling with sediment, and it's just not true," he said. "It was built with a 100-year sediment pool, and it isn't collecting as fast as we thought it would."*
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> John Keys III, current commissioner of Reclamation. See *Deseret News*, June 18, 2002.

The possibility of prolonging the life of a reservoir hinges upon our success in developing economical techniques for either moving some of the sediment out of the reservoir or reducing the rate of sediment contribution to the reservoir. From our present state of knowledge it is apparent that by far the greater part of the incoming sediment load must be trapped in a reservoir in the early stages of its life, and that the movement of sediment out of the reservoir will be uneconomical, because of cost of removal as compared with cost of storage or because of undesirable use of water. Because the early studies made it perfectly clear that the sediment load of streams would eventually reduce or deplete reservoir capacity and render reservoirs of limited or no value, there has been considerable interest in means of evacuating sediment from reservoirs. Many proposals for methods of sediment removal were made, from sluicing to dredging. None of the methods proposed has ever been put to practical use in the West.

Operation of Elephant Butte Reservoir on the Rio Grande, Lake Mead on the Colorado River, and Conchas Reservoir on the South Canadian River brought the phenomenon of density currents to the fore. It was clearly evident that some flows, heavily laden with sediment upon entering a reservoir, plunge beneath the surface water owing to their greater density and travel long distances downlake practically intact. Density currents are responsible for the deposition of sediments of low weight per unit volume that occupy a relatively large amount of space in

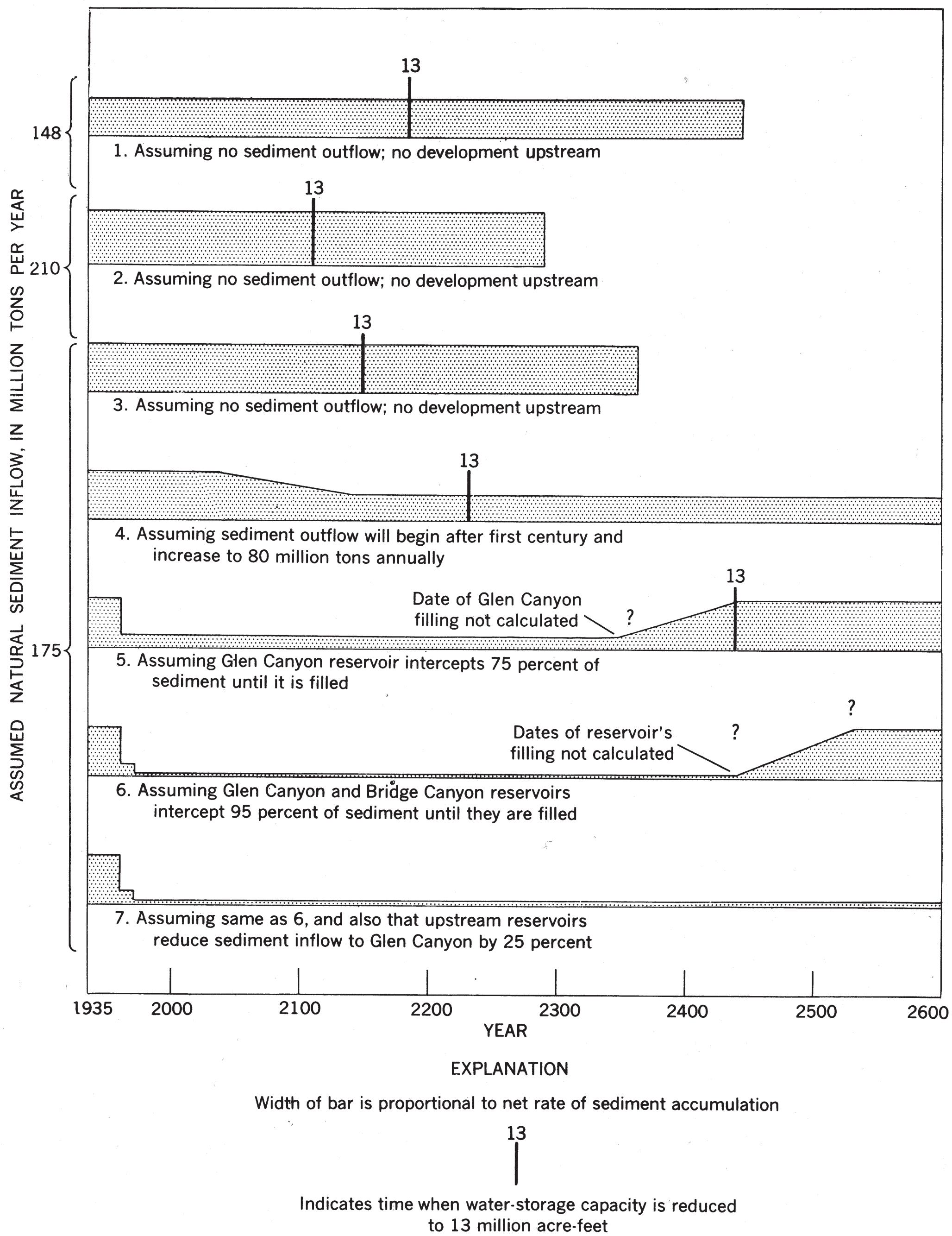

FIGURE 64.—Actuarial projections for Lake Mead, showing estimated dates when it will be completely filled with sediment.

Editor's comment: Survey scientists (circa 1950) determined when Lake Mead becomes half-filled with sediment (13 million acre-feet), it will no longer serve as a beneficial water storage facility. What is important to realize is that a reservoir's life span should not be measured in the terms of complete filling, but in terms of economic efficiency. Today, the public relations office of the Bureau of Reclamation projects the life span of their reservoirs in terms of complete filling, which is an admission of mismanagement and a statement that is unresponsive to science.

the lowest parts of a reservoir, and they have engendered a considerable amount of interest and discussion concerning design of reservoir outlets expressly for evacuation of density currents. The fact that reservoir outlets are not yet so designed is due largely to two factors: (1) The movement of density currents is not yet fully predictable; and (2) the amount of water that must be released from the reservoir for such a purpose must be large. Studies of sediment movement and deposition in Lake Mead will aid in further understanding the density current problem and so help to solve the problem of moving the greatest amount of sediment through the reservoir with the least use of water.

Prolonging reservoir life by reducing sediment inflow is dependent on the potentiality for reducing erosion and sediment movement in streams through watershed control. It is unfortunate that knowledge is so limited regarding the effect of watershed management in terms of reduction of sediment movement in streams. It is known that relatively small areas within western drainage basins contribute disproportionately large quantities of sediment to streams. Within these areas the factors of geology, soils, topography, vegetation, and climate are as critical, from the standpoint of sediment production, as anywhere in the United States. Many of these areas are practically uninhabited and have little present economic value, but they are of considerable local importance; because they are largely within the public domain or Indian reservations, their administration poses many problems for the agency responsible for their use.

It should be stated frankly that not enough is known about the erosion problem to evaluate fully a management program. For example, how well do present rates of sediment movement represent the rates to be expected over a long period of years? Is the long-term rate more or less than the present rate? What stage of gully development provides the greatest amount of sediment load to streams; and in what stage of gully development are we at the present time? To what extent can vegetation be increased in areas of low rainfall; and to what extent will such increases reduce rates of runoff and erosion? These and many other questions cannot be answered at the present time. They will be unanswered for a long time in the future, unless impetus is added to the rate at which investigations are undertaken.

The effect of sediment accumulation in reservoirs upon the quantity and quality of the available water supplies is not apparent at first glance. It should be pointed out that all reservoirs exact a certain water cost for their storage facilities, by reason of evaporation from their water surfaces. As water evaporates, there is some increase in concentration of dissolved solids in the water remaining in the reservoir. In areas where the average evaporation exceeds the average precipitation, therefore, the water in the stream is diminished in quantity and deteriorated in quality by reservoir storage.

"Construction of new reservoirs and dams—even if sites were available—does not provide a satisfactory solution to the problem. With the construction of a new, alternate reservoir for storage, the water losses must inevitably increase, because the evaporation from the new water-surf ace area is added to the evapotranspiration from the abandoned, sediment-filled reservoir."

Thomas L. Maddock, Jr., U.S. Bureau of Reclamation (1949)

Evaporation losses in the West are high, varying from location to location but probably averaging about 50 inches per year. Thus for every acre of exposed water surface in a reservoir, enough water is lost to irrigate as much as two acres of land. The total area of water surface in western reservoirs is measured in thousands of acres, and the magnitude of the price paid for water stored, in terms of water loss, can be readily visualized.

Sediment accumulation in most reservoirs tends to increase the area of exposed water surface per unit of water stored. Thus reservoir sedimentation increases losses from evaporation. But of far greater importance is the fact that most sediment deposits are fertile enough to encourage growth of types of vegetation that consume large amounts of water. It is now considered that the loss of water from reservoir areas having heavy sediment deposits is practically constant from year to year, and that this is due to combined transpiration and evaporation demands and is not dependent upon the area of exposed water surface alone.

Water losses through transpiration can be reduced by providing drainage of the sediment deposits and a channel to carry the streamflow, but these also hasten the movement of sediment into the reservoir area and thus increase the rate of depletion of storage capacity. The whole problem of transpiration and evaporation losses from reservoir areas and from channel deposits upstream from reservoirs is so important that it is the subject of intensive study at the present time. The work now being done toward control of phreatophytic growth in the Southwest shows considerable promise, and water losses from this source may ultimately be shown to be controllable. Increased use of groundwater storage may reduce the amount of surface storage required, thus resulting in a lower loss of water through evaporation. Doubtless it is the fond hope of all water users dependent upon reservoir storage that, as the existing reservoirs become useless by sediment accumulation, new reservoirs can be formed to replace them. It is true that there are numerous damsites and reservoir sites not yet occupied, but their number is diminishing, and some have been rendered unsuitable by reason of development of more favorable sites. A case in point is the Boulder Canyon site, once studied and then passed over in favor of the Black Canyon site for Hoover Dam, and now untenable because it is within the area of sediment accumulation in Lake Mead.

Construction of new reservoirs and dams, even if sites were available, does not provide a satisfactory solution to the problem. With the construction of a new, alternate reservoir for storage, the water losses must inevitably increase, because the evaporation from the new water surface area is added to the evapotranspiration from the abandoned, sediment-filled reservoir.

Future progress will be dependent on further study of the phenomena of reservoir sedimentation. The Lake Mead survey is a survey of but one of the many reservoirs in the West. Other reservoirs have been surveyed and the amount of data available for analysis is growing year by year. Investigations as complete as those at Lake Mead are expensive and can be undertaken only at infrequent intervals, but these serve the special purpose of increasing our understanding of the problems of reservoir storage.

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"A 1988 government study found that it would take more than 700 years for sediment to fill the reservoir," said Barry Wirth, a public relations officer for the Bureau of Reclamation. "We know that that reservoir is going to be there for many hundreds of years to come," he said.

The Associated Press on August 10, 2003

Editor's comment: Mr. Wirth's statement is a complete deception to the American people and assumes that Glen Canyon Dam is a useful facility even after losing its ability to store water and produce power efficiently, and to provide safe flood control and incidental recreation opportunities. After 40 years of operation it has already been demonstrated that sediment has impacted white water recreation and that sediment loads will soon impact dam and power operations as the sediment pool fills, which was estimated to occur in 100 years and confirmed most recently by Commissioner Keys in the Deseret News *on June 18, 2002.*