plant operation. We will be seeking ways to get more power from present fuels, to improve and simplify fuel-processing techniques, and to develop methods whereby radioactive wastes will be less of an economic burden.

Reactor safety will continue to be one of our most important areas of study, testing, and evaluation.

All of this will continue to require a relatively expensive program, but while it is true that development costs are high and that fossil fuels will meet our nation's power needs for many years to come, other factors, such as the needs of our national defense, the need to conserve our natural resources, and—also of major importance—the need for man to continue to explore the new frontiers of science and technology, will require the continued development of nuclear power. In addition, we will be developing a new and healthy industry which gradually will assume a more important role in our economy. As industry assumes more responsibility for nuclear power development, we will be able to turn to other areas of this new science—areas which require resources that only the government can supply.

Protection of Rainbow Bridge National Monument

An exchange of views on the effects of Glen Canyon dam shows that complex problems remain to be solved.

Comment by Halliday

The problem of protecting Rainbow Bridge National Monument from the waters of Glen Canyon reservoir is complex. Although there has been a 5-year period during which detailed studies could have been made—studies on which rational decisions might be based—available data on the subject are scanty, incomplete, and contradictory.

Many factors must be considered before acceptance of the drastic and irreversible step of abolishing, or abandoning by default, national-monument-type protection for Rainbow Bridge, as recently proposed by A. M. Woodbury in *Science* (*1*), and as proposed on other occasions by other supporters and by officials of the Bureau of Reclamation. Since the effects of this proposal would be irreversible, available data must be analyzed in detail, and certain alternative proposals which were ignored or summarily dismissed by Woodbury must be given due consideration. At the present time, such a "default decision," based on governmental inaction rather than on rational considerations, is imminent. As discussed below, the impending filling of Glen Canyon reservoir now threatens Rainbow Bridge National Monument (*2*, *3*) despite its supposed legal protection (*4*). The filling of the reservoir would also provide a precedent for the construction of Echo Park dam in Dinosaur National Monument, a recently revived project, and for construction of other dams which have been proposed in locations which would adversely affect Yellowstone National Park, Grand Canyon National Monument, Glacier National Park, and other units of the National Park System. In evaluating Woodbury's article on Rainbow Bridge it should be remembered that in 1954, when the Bureau of Reclamation was struggling for approval of the Upper Colorado Storage Project Act, Woodbury similarly advocated construction of Echo Park dam in Dinosaur National Monument, in two articles in *Science* (*5*, *6*), and dismissed as of little importance "whether we are setting a precedent of invading a national monument, *and various other minor matters*" (italics mine) (*5*).

Many discrepancies on both vital and trivial matters in reports and public statements of the Bureau of Reclamation make it difficult to conduct a precise analysis of this matter. In one official report, for example, the distance from Rainbow Bridge to the Colorado River is variously given as 6 miles and 4½ miles (*7*). In 1957 it was stated that the surface of the reservoir would be at 3700 feet 7 percent of the time (*8*). In 1959 and 1960 (*1*, *7*), the figure was given as 13 percent. An official 1954 "Fact Sheet" of the Department of the Interior not only used an incorrect name for the national monument but erroneously stated that it was threatened by the San Juan River arm of the reservoir, and that the monument could be protected by a mere "dike" (*9*). These and similar errors and inconsistencies which have come to light during study of this problem contrast remarkably with the professional reputation of the Bureau of Reclamation. However, it does appear, upon careful study of available data, that enough information is available to permit considered action—and to indicate that it is needed in the immediate future.

Basic Geographic Factors

Rainbow Bridge National Monument (Fig. 1) is located in the slick-rock country of south-central Utah, about five miles north of the Arizona-Utah state line, in the magnificent Glen Canyon area. The monument encompasses 160 acres on the north fork (Bridge Canyon) of a tributary canyon (Aztec Canyon) of the Colorado River's Glen Canyon section. Bridge Canyon is spanned by Rainbow Bridge.

Because of the length and difficulty of the trails from the nearest road ends, most of the 2000-odd annual visitors to Rainbow Bridge National Monument (*10*) now use the river route. In linear distance, the monument is about 2¼ miles from the Colorado River, but the gentle trail up Aztec Canyon and Bridge Canyon is about 4¾ miles long, as determined by Bureau of Reclamation surveys. Rainbow Bridge itself spans an inner gorge of Bridge Canyon, which will be completely filled at high water of the reservoir if no barrier dam is erected.

Woodbury was in error in statements about the maximum height of the reservoir and hence about the proximity of the reservoir to the base of

Rainbow Bridge. The maximum height of the reservoir will be at 3715 feet (*7*, *11*) rather than at 3700 feet, as stated (*1*). The 3700-foot level, rather than the maximum, is to be the "normal surface elevation" of the reservoir. It has been stated that part of the additional capacity will be used very rarely (*8*). However, in the spring of 1941, Roosevelt Dam, another large Bureau of Reclamation dam in Arizona, operated at more than its stated maximum storage capacity for several weeks. Conditions requiring a similar occurrence must be anticipated in Glen Canyon and in all of its tributaries.

With the level at 3715 feet, the reservoir would temporarily rise to within 6 feet of one buttress of Rainbow Bridge, which is at 3721 feet (*7*, *8*), rather than to within "40 to 50 feet," as claimed by Woodbury. The inner channel beneath the great arch would be filled with water, silt, and debris 55 feet deep (Fig. 2).

As now planned, the reservoir will begin to fill in January 1962 (*2*), and water will be allowed to rise to the dead storage level (elevation, 3490 feet) "at the earliest practical time" (*2*). This level will be 125 feet above the elevation of the only satisfactory site for a restraining dam to keep the reservoir from encroaching on the national monument. Such a dam would require at least one year to build, and perhaps much more. For the reservoir to rise to the 3490-foot level would require about 6½ million acre-feet of water. The average annual flow of the Colorado River is almost twice this amount, and the annual flow at times has exceeded 24 million acre-feet per year (*12*). Most of this flow results from the seasonal runoff in late spring, so that even if the flow of the Colorado River is below average, default on construction of this dam would constitute an irrevocable "decision" by the summer of 1962.

Upstream from Rainbow Bridge the canyon floor gradually ascends to reach the 3715-foot level a short distance above the national monument. The downstream boundary is just above the minimum level planned for the reservoir during its first 50 years of operation. As a result, the elevation of the zone of fluctuation of the reservoir corresponds closely with the elevation of the canyon bottom within the monument. Since it is within the zone of fluctuation of similar reservoirs that severe damage has occurred, this is a key factor in analysis of the problem.

History of Pertinent Legislation

A knowledge of certain legislative actions pertinent to this area is essential to an understanding of the present problem. In 1956 the Colorado Storage Project Act became law (*4*). As a part of this act, the construction of a 700-foot dam in Glen Canyon, just south of the Utah-Arizona border, was authorized, provided that "as a part of the Glen Canyon unit, the Secretary of the Interior shall take adequate protective measures to preclude the impairment of the Rainbow Bridge National Monument." It was further stated that "it is the intention of Congress that no dam nor reservoir constructed under the authorization of this act shall be within any national park or monument."

These provisions were introduced into this bill as a result of an agreement between proponents of the Upper Colorado Storage Project and representatives of conservation organizations (*13*). The provisions were included when it became apparent that the mobilization of public opinion by the conservation organizations for the purpose of protecting Echo Park in Dinosaur National Monument, Rainbow Bridge National Monument, and other units of the National Park System had been successful (*13*). Had a vote been taken on the original proposal, which did not provide this protection, the bill would have been defeated (*14*), on the grounds that passage would have resulted in damage to these areas and would have established a precedent for invasion of other national parks and monuments.

At that time, a spokesman for the Bureau of Reclamation stated: "We can build the necessary works [below Rainbow Bridge] to protect that bridge in the manner suitable to the National Park Service and others that are interested, within the amounts of money that we have estimated in our overall estimate for the Glen Canyon Dam and Reservoir, and we have no question about the economic, engineering or

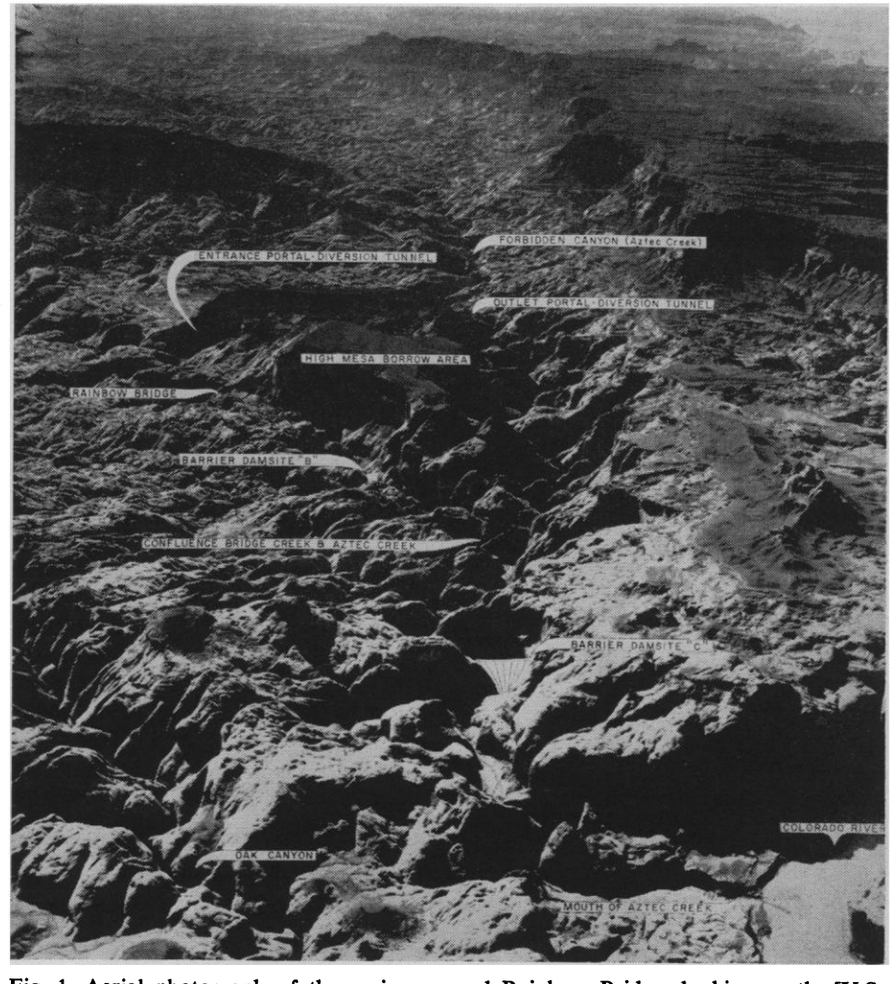

Fig. 1. Aerial photograph of the region around Rainbow Bridge, looking south. [U.S. Bureau of Reclamation]

practical feasibility of taking care of that monument" (*15*).

The plan to build protective works seems to have been rescinded. Reclamation spokesmen have repeatedly emphasized, in recent statements, the difficulty of constructing such works, and have claimed that they are unnecessary (*16*).

Possible Courses of Action

There appear to be various possible courses of action in regard to the threatened inundation of Rainbow Bridge National Monument. Only three of these (1, 5, and 9, below) were considered by Woodbury in the recent article in *Science* (*1*).

1) Allow the reservoir to invade the national monument.

2) Abandon the Glen Canyon dam project.

3) Allow the reservoir to invade the national monument to determine how much damage it would do, before taking steps for protection.

4) Enlarge Rainbow Bridge National Monument to such an extent that it could not be protected from damage from the reservoir and hence would require abandonment of the Glen Canyon dam project under present law.

5) Abolish Rainbow Bridge National Monument.

6) Reduce the height of Glen Canyon dam.

7) Reduce the depth of dead storage space in the reservoir.

8) Delay construction of Glen Canyon dam.

9) Construct the proposed dam and also a barrier dam at "site *B*."

10) Construct the proposed barrier dam at "site *C*."

Some of these plans can be bypassed with only a few words of explanation. The proposal to allow temporary inundation within the monument to determine the resulting damage seems to have been abandoned by its originators. It is contrary to the National Parks Act of 1916 (*17*), to the Colorado Storage Project Act (*4*), and to basic principles of the National Park System and of leading conservation organizations; it would require a very difficult legislative campaign at some indefinite future date; and, finally, it is eliminated by the finding that, because of the peculiar design of Glen Canyon dam, once the reservoir was about one-fourth full, the water level could not again be lowered sufficiently to allow the site for the proposed protective project to reemerge. The idea of enlarging Rainbow Bridge National Monument to force abandonment of the Glen Canyon dam project, while ingenious, is too far-fetched and smacks too much of trickery to be considered seriously. However, enlargement of the monument when it has been fully protected, in such a way that there will be no interference between the monument and the reservoir, as discussed below, is both practical and desirable. Abolition of Rainbow Bridge National Monument would solve the problem from the standpoint of reclamation enthusiasts, but it is doubtful that the American people would knowingly allow such a fate to befall this uniquely magnificent, world-famous monument. On the other hand, if through a "default decision" the monument is invaded by the reservoir, abolition of the monument probably will be necessary for various legal and administrative reasons. The proposals for reducing the height of Glen Canyon dam, for delaying its completion, and for redesigning the dam to permit a lower water level for the reservoir are better comprehended when discussed with other proposals, as they are below.

Invasion of the National Monument

Much has been said and written in support of the idea that flooding and aggradation in Rainbow Bridge National Monument would "enhance" rather than impair it (*1*, *16*). [Only one of the individuals who hold this view (*1*) has conceded that "for probably 50 or 100 years" the zone of fluctuation might be of less than prime scenic quality.] Analysis of information obtained from the existing, similar reservoir of Lake Mead, together with personal investigations of these areas and study of applicable legal and related data, has led me to a conclusion opposite to that of Woodbury in his recent, undocumented article in *Science* (*1*).

In addition to the fact that artificial flooding and aggradation of this sort would be contrary to law and to the principles of the National Park System (*17*), there is considerable evidence that flooding and aggradation of sediments, sand, and silt in and near Rainbow Bridge National Monument would be highly detrimental to that monument and the adjoining area and that the proximity of the reservoir would seriously threaten the stability of Rainbow Bridge itself.

In filling the inner gorge of Bridge Canyon to a depth of 55 feet beneath Rainbow Bridge, and to a much greater depth a short distance downstream, the reservoir would saturate the upper part of the Kayenta formation on which the Navajo sandstone of the bridge rests (*11*). This upper part of the Kayenta formation is "less resistant to erosion than the lower part" (*18*) and hence a matter of concern in the zone of fluctuation. The last official statement of the National Park Service on this subject expressed great concern about this matter, and the Park Service requested a reduction in the height of Glen Canyon dam for that reason (*19*). This reduction was not achieved, probably because of the statement of the Bureau of Reclamation quoted above (*15*) and because of subsequent reports by some Interior Department geologists which are in conflict with National Park Service reports. It has been stated that the Kayenta formation beneath Rainbow Bridge is saturated under present conditions and that consequently flooding and aggradation would retard rather than hasten collapse of Rainbow Bridge (*7*). This is partially implied in the oft-quoted final section of a U.S. Geological Survey report (*11*), but not in the body of that report, which, instead, mentions the presence of *local* saturation and perched water tables in the canyon walls beneath the bridge, with the water table at or just below the present level of the creek. This was also my conclusion when I made a short field study in 1953.

These conflicting conclusions are cause for serious concern for the safety of Rainbow Bridge if flooding of Bridge Canyon is permitted. Bureau of Reclamation studies indicate that standing water would be present beneath Rainbow Bridge 77 percent of the time in the absence of a restraining dam (*7*). Any possible error in efforts to resolve these conflicting opinions must be in the direction of greater safety of the bridge. If those who fear that the bridge will collapse are mistaken and yet prevail, the error will be of little significance. If those who hold the reverse view prevail, and are mistaken, and the reservoir causes the collapse of Rainbow Bridge, the error will be grave beyond words.

A very important additional factor, not mentioned in any published state-

ment on this problem, is the possible occurrence of pseudokarst in the Rainbow Bridge area. Its occurrence a few miles to the north in a region of similar stratigraphy has been known to staff members of the U.S. Geological Survey for several years (*20*), but until mid-1960 the Bureau of Reclamation apparently was not aware of its presence. Until the cause of this nearby phenomenon and the occurrence or nonoccurrence of pseudokarst in the Rainbow Bridge area have been determined, pseudokarst must be considered at least a potential danger to Rainbow Bridge and the reservoir must be kept as far away from the bridge as possible (*21*). Here again, the wrong decision could lead to disaster.

As mentioned above, about 95 percent of the zone of fluctuation of the arm of the reservoir that extends through the monument would be within the monument boundaries (*7*, *11*). This zone is the site of heaviest aggradation within such reservoirs. From the examples of similar tributary canyons of Lake Mead, where very large accumulations of silt, sand, quicksand, and drifted debris have developed, the conditions that would result from sediments in Rainbow Bridge National Monument can be deduced. It is of some significance that one senatorial proponent of the Colorado Storage Project has an intimate knowledge of the Rainbow Bridge area. He states regretfully (*22*): "Of far more concern to me than the dangers to [Rainbow] Bridge from water is the fact that after one or two seasons of floods, Forbidden Canyon [the combined term for Aztec and Bridge Canyons] will be actually just that. I can predict this with accuracy because the side canyons entering Lake Mead below Separation Canyon are now [1954] clogged with silt. This likewise will happen to all of the side canyons of Glen Canyon."

Many persons who are familiar with the Glen Canyon area concur in the belief that a sewer-like swamp of quicksand, silt, and impenetrable vegetation may block access to Rainbow Bridge from the reservoir if no protective structure is provided. They cite the example of side canyons of the Colorado River in which the profiles of the creeks now bear approximately the same grade relationship to the Colorado River that Bridge Creek will bear to the reservoir. Chamber-of-commerce type statements about anticipated wonders of the reservoir as a whole, although given wide credence, seem overstated. For example, a recent study (*23*) indicates that serious fishery problems may attend the creation of the reservoir. Many persons, perhaps including Woodbury, have been misinformed about the long-term recreational values of Lake Mead, and hence of the Glen Canyon reservoir. Figures on visitors to the Lake Mead Recreation Area, which are largely based on the number of cars that cross Hoover (Boulder) Dam en route to Las Vegas, are misleading. Besides blockage of many sections of the lake by aggradation, which caused abandonment of the plans for extensive development at Pierce's Ferry, a serious problem of spontaneous bacterial accumulation in lake sediments has forced closure of many areas to the public. The U.S. Geological Survey has compared these contaminated sediments unfavorably with raw sewage (*24*). Bacterial counts exceeded 1 million bacteria per gram at all depths, with a minimum of 10 million bacteria per gram near the surface. A similar sewer-like result must be anticipated in the Glen Canyon reservoir, including its Aztec–Bridge Canyon arm.

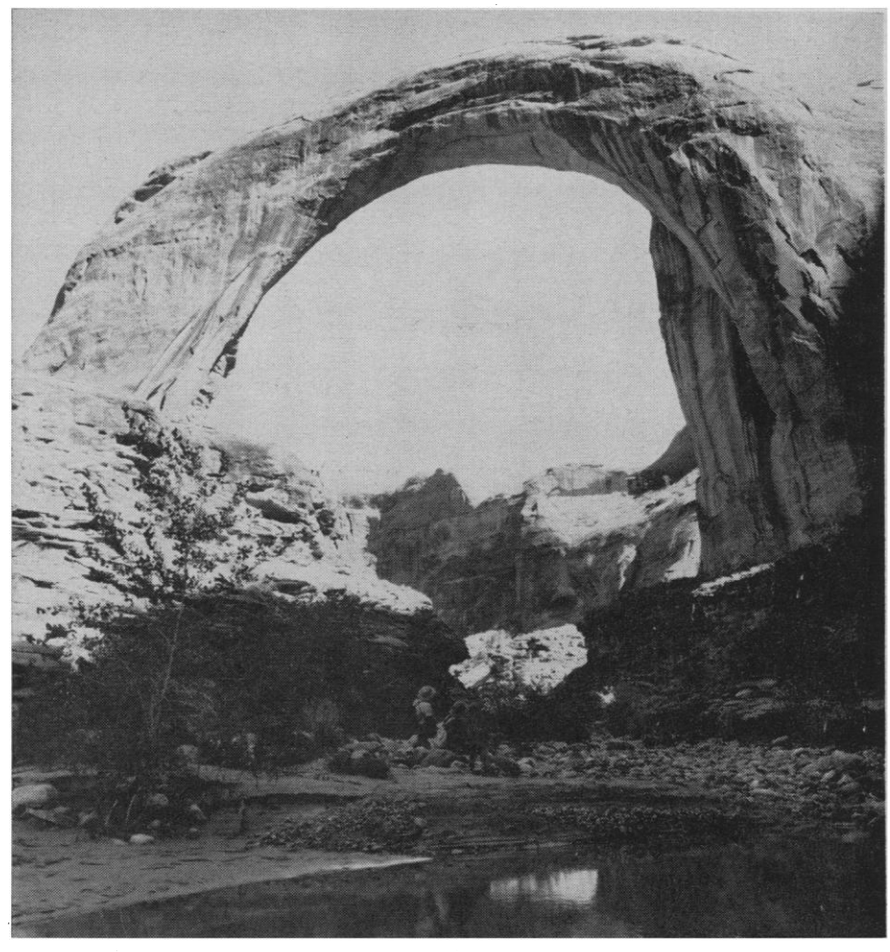

Fig. 2. View of Rainbow Bridge from an ephemeral pool in Bridge Canyon. Silts, gravels, and cobbles primarily deposited and transported by flash floods are shown. At present, high-velocity flow prevents massive aggradation of these deposits. In the absence of a downstream barrier dam the reservoir will fill this inner gorge completely and will rise to a point only 6 feet below the buttress at right. [Walter S. Chamberlin]

Figures 3 and 4, showing the zone of fluctuation of Lake Mead, indicate a part of what can be expected for much of the Glen Canyon reservoir within a very few years. Woodbury's recent condemnation of conservationists for "joining a crusade" (*1*) to prevent this fate for Rainbow Bridge National Monument seems unjustified.

It therefore appears that future proximity of the Glen Canyon reservoir may seriously threaten the stability of Rainbow Bridge. Pertinent data are incomplete and contradictory. On the other hand, evidence that the proposed flooding and aggradation within the monument would drastically impair it is overwhelming, and such flooding would and should be illegal.

Abandonment of Glen Canyon Dam

The opposite course to abandoning Rainbow Bridge National Monument would be to abandon construction of the partially built Glen Canyon dam. Although many conservation factors suggest that this would be the ideal solution from some standpoints, drawbacks to such a proposal appear insuperable at this time. Too many millions of dollars have been spent on the beginnings of this extremely costly dam to permit its abandonment except for the most compelling reasons. It appears that another alternative will permit both establishment of the reservoir and full protection of the monument. Therefore, unless for some reason the protective project discussed below cannot be built, compelling reasons for abandoning construction of the dam cannot be said to exist.

Barrier-Dam Proposals

If water and sediments resulting from the construction of Glen Canyon reservoir are not to be permitted within Rainbow Bridge National Monument, either a barrier dam must be constructed downstream from the monument or the height of Glen Canyon dam must be lowered drastically. As discussed below, the latter alternative does not seem practical. Four sites for a barrier dam between Rainbow Bridge and the Colorado River have been proposed. One of these sites, at the Narrows of Bridge Canyon, a few feet upstream from its confluence with Aztec Canyon, is impractical for engineering reasons (*7*). Another, site *A* in Bridge Canyon, would have all the disadvantages of site *B*, a short distance farther downstream, and a dam at site *A* would have even less capacity to withstand flash floods than one at site *B*. Site *A* is no longer under consideration. Woodbury discussed in detail (*1*) the project which includes a restraining dam at site *B*, but I will give some additional information. Woodbury dismissed the proposal concerning site *C*, in Aztec Canyon, three miles downstream from the monument, as if this plan were not worthy of consideration. Actually, it is site *C* which has been acclaimed by leading conservation spokesmen, not site *B*. It is difficult to understand an error of such magnitude in a supposedly authoritative article.

The Site B Project

The plan for a protective project involving a restraining dam at site *B*, 3200 feet downstream from Rainbow Bridge National Monument, would also require a diversion tunnel and barrier upstream from the monument, to divert water, sediments, and flood debris from upper Bridge Canyon to upper Aztec Canyon because of the very limited storage space on the upstream side of such a restraining dam. As a result of this analysis, it appears that Woodbury is correct in opposing this project (*1*), although some of his objections were overstated. Use of the "High Mesa Borrow Area," for example, would not necessarily be an integral part of such a project; the diversion tunnel could be drilled from Aztec to Bridge Canyon rather than in the opposite direction, and many of the construction scars would be submerged. But other factors, including inadequate upstream reservoir space, uncertainty of siltation rate, headward aggradation into the national monument (*11*), and the threat from possible pseudokarst, discussed above, make site *B* unsuitable for a restraining dam, even though this is the plan favored by the Bureau of Reclamation if any protective project must be built.

Reservoir storage upstream from site *B*, for example, is sufficient to handle local runoff from only one 5-hour flash flood per 30 days (*7*). Most individuals who are familiar with the erratic timing of rainstorms in this "slickrock country" would consider this completely inadequate in view of the absence of data to the contrary.

Another example of unacceptable planning for this site is the calculation of the rate of sedimentation behind the restraining dam, which supposedly indicates that sediment storage space will be adequate until the year A.D. 2140 (*1*). The statistics in Table 1 are from the pertinent Bureau of Reclamation report (*7*, pp. 6–10). In the report these figures are not tabulated but appear in the text. When they are arranged as in Table 1 it is apparent, from the fact that columns 2 and 3 are identical, that they are not valid. Moreover, it is not known how the size of the drainage areas was determined to the second decimal point. Presumably this was done by acceptable methods. It appears, however, that studies of the sedimentation rate sufficiently detailed to justify this use of three significant figures were not made. It is obvious, when thus tabulated, that the sedimentation rate was stated to be 1.000 acre-foot per square mile per year for each of the five areas. This gives an erroneous and unjustified appearance of great accuracy. Even if there is an unpublished but acceptable basis for estimating a sedimentation rate of 1 (not 1.000) acre-foot per year per square mile for one of these areas, it would not necessarily be pertinent to the other areas. Their topography, vegetation, bedrock, and mantle are far from uniform. Instead of the claimed 80 years (*1*) required to fill the sediment storage space behind site *B*, it probably would be more nearly correct to say that the range of possibilities is from 8 to 800 years.

Table 1. Figures cited by the Bureau of Reclamation for the rate of sediment deposition in various parts of the Rainbow Bridge area.

Drainage area	Area (mi^2)	Sedimentation rate (acre-ft/yr)
Part of Bridge Canyon	6.54	6.54
Part of Bridge Canyon	0.84	0.84
Part of Bridge Canyon	7.62	7.62
Part of Bridge Canyon	1.05	1.05
Aztec and Bridge canyons	56.4	56.4

Some conservation leaders initially were impressed by the site *B* proposal before it was analyzed in detail. Now, however, conclusions similar to the above seem to be widespread, and as a result, the proposal for a restraining dam at site *C* is being supported instead.

Site C and Proposed Modification of Glen Canyon Dam

The situation that would prevail if a barrier dam were constructed at site *C*, three miles downstream from the monument, would differ markedly from the situation if one were built at site *B*. Because of the intervening distance, risk of collapse of Rainbow Bridge from blasting nearby, from undermining in the Kayenta formation, or from pseudokarst would be reduced to a minimum. At first it was feared that a diversion tunnel and barrier upstream from the monument might also be necessary, as they would be in the case of site *B*. However, a subsequent proposal to modify this plan, so that backwater at the base of the restraining dam

would be kept from rising to a level which would extend into Bridge Canyon, would obviate this. Such a plan would assure high-velocity flow of flash-flood waters past the narrows of Bridge Canyon, which otherwise would be an important barrier, causing rapid deposition of sediments in lower Bridge Canyon. This modification requires a larger pumping system than had been originally planned, and possibly intermittent dredging at the base of the site *C* dam, but no serious alterations in design or planning.

A dam at site *C* would not impair the beauty of the environs of Rainbow Bridge National Monument and would fully protect the monument itself. Access roads to the dam site could and should be built through the mouth of Aztec Canyon, and hence would be hidden by the rising waters of the reservoir. No scarring would be necessary away from the margins of the dam. Construction of an easy three-mile trail to Rainbow Bridge, above the level of the backwater, would involve no serious problems. Because Aztec Canyon has no important tributaries below site *C*, little silt would accumulate to block this arm of the reservoir, and access would be unimpeded. Otherwise, much silt would accumulate in lower Aztec Canyon whether or not a dam was constructed at site *B*. By obtaining material for the restraining dam from sources outside Aztec Canyon, ugly scarring of any adjacent area could be avoided.

A dam at site *C* would provide much greater protection in the event of flash-floods than one at site *B* (*7*). Moreover, it would permit eventual enlargement of Rainbow Bridge National Monument to include the portion of Bridge Canyon now downstream from the monument—an area which would thus be preserved in all its unspoiled magnificence.

It is not surprising that many conservation organizations have endorsed the site *C* project. On 18 January 1960 the executive director of the Sierra

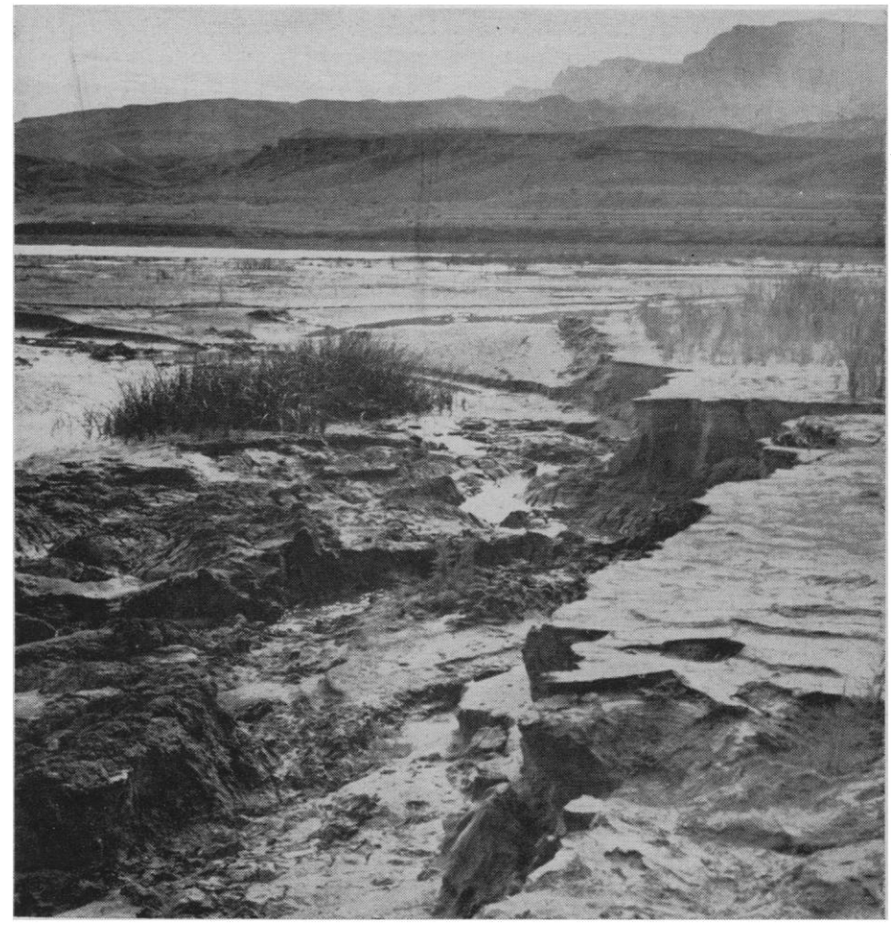

Fig. 3 (top). The zone of fluctuation of Lake Mead at a low reservoir level, showing aggradation. Such aggradation, it is claimed, would enhance Rainbow Bridge National Monument. [Sierra Club] Fig. 4 (bottom). The zone of fluctuation of Lake Mead at an intermediate reservoir level, showing aggradation of the kind anticipated for Rainbow Bridge National Monument if no protective project is constructed. [Harold C. Bradley]

Club (perhaps America's leading conservation organization) informed the Secretary of the Interior that site *C* was "far and away the best, and is a brilliant blend of engineering and scenic-resource planning" (*25*). This view seems entirely justified. There are, of course, problems associated with site *C*. Some are real. Others, upon analysis, appear artificial. As mentioned above, the backwater and silt accumulation upstream from the restraining dam should not be permitted to rise above 3450 feet, the elevation just below the Narrows, and thus a larger pumping system would be required than had been originally proposed. Transportation of equipment and materials to the site by barge would not be feasible since this would require postponement of construction until filling of the reservoir was under way. Unless provision were made for dropping the minimum level of the reservoir far below the present intake elevation, postponement of construction of this protective dam until barges could be used would not be safe, in view of the danger of sudden rises in the reservoir level, which are to be expected because of the sudden variations in flow of the Colorado River (*12*). The question of possible engineering difficulties at site *C* has been submitted to a consulting engineer, who has submitted the following report (here abridged) (*26*).

"A dam built at Aztec Canyon Damsite *C* would, if a pool is maintained above the dam, have water standing on both sides, and the base of the dam would be 140 feet below the dead water storage elevation of Glen Canyon Reservoir. There are engineering problems involved but they are not critical. If a masonry dam were built, there is a precedent in the Parker Dam built by the Bureau of Reclamation. The differential elevation of the water downstream and Havasu Reservoir is about 80 feet. If an earth-filled dam were built, the main difference would be that rip-rap would have to be provided on both sides. If a rock-filled dam, the rock-fill itself would provide the rip-rap. The material below the water on the low side would need to be designed for its net weight instead of its gross weight. The problem is one of cost rather than critical engineering considerations."

Contrary to Woodbury's statement (*1*), such a dam would not "require a fantastic investment." In 1955 the Bureau of Reclamation estimated that the cost would be $2 million to $4 million for any type of protective project (*15*). Two years later, the Upper Colorado River Commission estimated the cost at $3 million (*27*). Recently, the Bureau of Reclamation has increased its estimates to $15 million to $25 million for site *B*, and $25 million to $35 million for site *C* (*7*). Even these new figures are small in comparison with even the initial cost of Glen Canyon dam—$400-odd million exclusive of interest (*15*).

It is true that the site *C* dam would be an unnatural work, as Woodbury pointed out, but if Glen Canyon dam is completed, unnatural works of some kind inevitably will be present in the Rainbow Bridge area. The only unsettled matter is the question of what unnatural works will be permitted, and where they will be. Woodbury, in articles in 1954 and 1960, failed to recognize the major principle at stake: If there are to be destructive effects in the general area of a landmark that is important enough to require protection by law and solemn agreement, not only must the objectionable features be minimized but they must be outside rather than inside the boundaries of the area given that protection.

It therefore appears that a restraining dam at site *C* would provide a satisfactory and practical means of protecting Rainbow Bridge National Monument at reasonable cost, and with minimum risk to the stability of the great arch. However, this is not the only way to provide both a Glen Canyon reservoir and an inviolate Rainbow Bridge National Monument. The height of Glen Canyon dam might be lowered to about 3450 feet; this would permit high-velocity flow throughout Bridge Canyon and obviate the need for any protective project. This would, however, greatly reduce the power output and the cost of the dam, and the reclamation lobby, which has enormous political strength, would oppose it as bitterly as it would oppose abandonment of the dam project. Nevertheless, it would solve the problem of protecting the monument.

While it would appear reasonable to hold off the threats to the monument, to law, and to the integrity of Congress by merely halting temporarily the construction of Glen Canyon dam until the issue is resolved, this and similar proposals for a temporary halt have been effectively resisted by the monolithic reclamation lobby, even though it is probable that the site *C* dam site will be flooded by the reservoir before construction of a barrier dam can be begun (*11*). In 1960, under the influence of this lobby, Congress not only removed an appropriation for a protective project from the Public Works Appropriation Bill but included a provision which forbade the diversion of any other appropriation to the protection of Rainbow Bridge National Monument (*28*), despite the terms of the Colorado Storage Project Act and of the 1955 agreement. The chief objection to such a halt in construction is that it would delay the initial power output of the dam—a matter of great importance to reclamationists.

As a kind of compromise, certain hopeful conservation leaders urged that the reservoir be operated at a low level, below the elevation of site *C*, until the problem is resolved. This proposal is fiercely opposed by those who object to the delay in initial power production that would result, and, furthermore, it ignores the fact that, because of the curious design of Glen Canyon dam, the lowest intake of the dam and thus the minimum level of the reservoir are about 25 feet higher than the site *C* dam site. The same objection, and also that of headward aggradation into the national monument (*11*), applies to a similar proposal to hold the reservoir at an elevation of about 3590 feet. Because of this, the Sierra Club recently proposed modifying the design of the dam to include a lower intake, and hence a lower minimum level for the reservoir. This would provide a satisfactory temporary solution to the problem, even if a somewhat risky one because of the inherent human element. However, this suggestion has met with less than enthusiastic response from reclamationists.

Conclusions

From analysis of the available data it now appears that the Bureau of Reclamation either overstated its ability to protect Rainbow Bridge National Monument in 1954 (*7*) and 1955 (*15*), thereby obtaining Congressional approval of the Glen Canyon Project, or else is now exaggerating the difficulties (*29*). Law, specific agreement, and the conscience of the American people require that Rainbow Bridge National Monument be protected fully or that Glen Canyon dam be abandoned or greatly reduced in height. Contrary to the conclusion

recently expressed by Woodbury (*1*), flooding and aggradation in Rainbow Bridge National Monument would severely impair the monument and might threaten the stability of Rainbow Bridge.

Abandonment of the Glen Canyon dam project represents one extreme in this matter. Abandonment of Rainbow Bridge National Monument, or grudging provision for incomplete protection, is the other. As long as there is a satisfactory alternative, neither of these extremes is acceptable. It is evident that construction of a barrier dam at site *C* before construction is carried further at the Glen Canyon dam site represents a middle ground which should be acceptable to all but the extremists on both sides. Modification of the design of Glen Canyon dam to permit a lower minimum level of the reservoir might be worth while if infallible safeguards are set up, and if good faith is maintained better than it was in the case of the 1955 agreement. Obdurate reclamation leaders should beware lest the "default decision" they have sought endangers the entire Upper Colorado Storage Project. The American people do not like being double-crossed.

The new Secretary of the Interior faces a hard and immediate decision. He must choose between (i) constructing the restraining dam at site *C* essentially as outlined in this analysis; (ii) lowering the elevation of the top of Glen Canyon dam to 3450 feet; (iii) abandoning construction of Glen Canyon dam; (iv) lowering the minimum elevation of the reservoir, through redesign of Glen Canyon dam, to about 3300 feet, keeping it at that level until a dam is built at site *C*; or (v) violating law, solemn agreement, and basic conservation principles. Of these alternatives, only the site *C* plan, with or without lowering of the intakes of Glen Canyon dam, seems reasonable, and even this plan must be initiated speedily to avoid a disastrous outcome of this unfortunate and unnecessary situation.

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Reply by Woodbury

As Halliday has indicated in the preceding article, the protection of Rainbow Bridge National Monument presents a very complex problem. He complains that inadequate information has been accumulated in the past 5-year period to provide a sound basis for rational decisions, but he fails to note that 5 years ago I proposed (*1*) that Congress "authorize the development of the river basin, determine the policy of water use, provide funds for operation and refer minor items of dispute to some fact-finding scientific body for final adjudication as Sears (*2*) suggested. . . . If the Sears approach were accepted and the controversial matters were referred to scientific boards for investigation, then a positive approach for getting the unbiased facts for Congressional consideration and decision would be the main problem for scientists. The Congress would still have to set the policies and make the decisions, but it would have data carefully prepared by people trained in the art of fact finding."

Since the conservation leaders did not support my plea for factual studies, plans matured to "protect" Rainbow Bridge in accordance with the Act of Congress of 11 April 1956 (*3*), without any move being made to have the disputed problem studied by a fact-finding body of respected scientists. When I saw the plans developed by the Bureau of Reclamation and the National Park Service for protection of the bridge, I became convinced that they would do so much violence to the magnificent scenery in the adjacent area that the result would not be in keeping with the conservationist objective. This drove me to provide the factual information given in my article in *Science* (*4*).

Instead of accepting this as a contribution toward clarifying the complex problem, an anonymous editor (*5*) and Halliday (*6*) both attacked my article as partisan propaganda designed to confuse the issue. Halliday, in particular, quoted some statements of mine out of context and assigned distorted meaning to them. I refuse to be pushed into the role that has been assigned me by Halliday and the anonymous editor.

In none of my publications (*1*, *4*, *7*) have I recommended the construction of Echo Park reservoir. Instead of deciding in advance, as many other conservationists had done, that no reservoir should be built at that site, I called for a fact-finding study of the site, under the Sears proposal to supply Congress with a basis for rational, unprejudiced determination of the issue.

During my career I have been associated at different times with the U.S. Forest Service, the National Park Service, the U.S. Army, and the state of Utah and indirectly, through the University of Utah, with the Bureau of Reclamation. I am thus personally acquainted with many of the conserva-

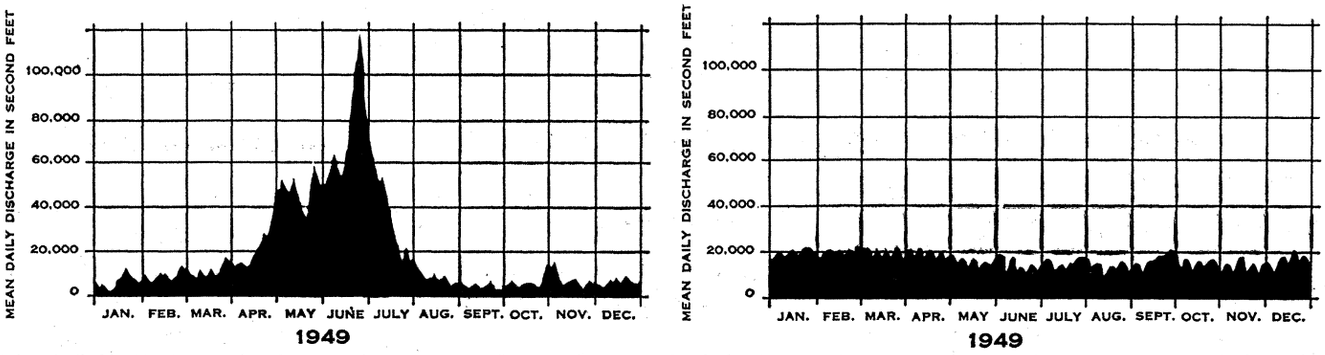

Fig. 1 (left). Hydrograph of unregulated stream flow at lower end of the Upper Colorado River Basin (at Lee Ferry) before the building of Glen Canyon dam. Fig. 2 (right). Hydrograph of regulated water flow in the Lower Colorado River Basin below Hoover Dam. [Upper Colorado River Commission]

tion problems of these and other agencies dealing with conservation of natural resources. With this background I can understand the need for conservation of forests, ranges, wildlife refuges, water supplies, natural areas, wildernesses, recreational areas, and other important resources as well as national parks and monuments.

For this reason I cannot take the extreme view advocated by many conservation leaders that establishment of an additional precedent of "invasion" of the National Park System must be avoided at all costs. It is my opinion that precedent-setting, important as it is, must be weighed against other values.

In my general article (*4*) I selected for emphasis those aspects of the problem that would give factual data regarding the plan proposed by the two government agencies concerned. In that plan I found no indication that site *C* was under serious consideration. I stated (*4*), "Two sites for such a dam have been studied, one in Bridge Canyon at site *B* . . . and another, much larger site, where construction would be much more expensive, in Forbidden Canyon below the mouth of Bridge Canyon (site *C* . . .). Site *B* has been selected by the Bureau of Reclamation and the National Park Service as most suitable. . . . Although construction of a barrier dam at alternate site *C* has been considered, it was excluded from the present proposal [of the two agencies]. From Fig. 8 it can be seen that this would be a much larger and more expensive dam than one at site *B*. It would require much larger pumping operations and would involve other complicating problems which need not be discussed here." Halliday's article now demands further discussion of these complicating problems.

Background

Many years ago, seven Colorado River Basin states made a compact to conserve the water of the river by impounding high waters, regulating stream flow, and dividing the water between the upper and lower parts of the basin. Congress made the decision to implement that agreement and provided for development of the lower basin first. Development of a suitable plan for the upper basin, comprising the heart of the great rough country of the American Southwest, presented more difficulties. It took a quarter century of intensive study of that colorful land of deep winding canyons, intricately dissected plateaus, and upthrust mountains to work out a practicable program to present to Congress.

The problem of devising a fitting program for water conservation was complicated by the potential value of the magnificent region for park, recreational, and other purposes. Many parts of the area might well be included in the national park, monument, and recreation system. Moreover, there are valuable mineral deposits (for example, uranium) in this rough country that provide further complications.

It was a decade before the Upper Basin Program, completed about 1946, was given partial approval by Congress. The delay was prolonged by the heel-dragging resistance of many conservationist groups, using political pressure to kill the Echo Park reservoir proposal and force inclusion of the amendment to the Glen Canyon reservoir proposal for the protection of Rainbow Bridge. At the same time, these groups failed to mobilize political support for preservation of other scenic areas of that colorful region, some of which are of even greater value, for National Park Service purposes, than Echo Park.

If scientists trained in specialized fields were authorized to make a fact-finding study of this remarkably varied and beautiful region, I believe they could provide, within the next 5 years, accurate data from which Congress could classify these lands according to their suitability for national parks, monuments, recreation areas, national forests, livestock ranges, wilderness areas, reservoirs, power sites, wildlife preserves, state parks, or other purposes, perhaps even including irrigation.

I envision a greatly expanded role for the National Park Service under such a classification program. Such areas as the triangle between the Green and Colorado rivers, Robber's Roost, San Raphael Swell, Goblin Valley, Cathedral Valley, the Circle Cliffs, Escalante River Canyon, Kaiparowits Plateau, the north foot of Navajo Mountain, the triangle between Colorado and San Juan rivers, the Needles, the Land of Standing Rocks, and other interesting areas might well be considered for inclusion in the park and monument system. Such a solution would give the government agencies involved a stable basis of action and help resolve many of the present conflicts.

The Upper Basin program provided for a dam in the main stem of the Colorado River in Glen Canyon, to store high water and regulate its flow out of the Upper Basin, much as the Hoover (Boulder) Dam had done for the Lower Basin, as illustrated in Figs. 1 and 2. As I understand it, the Bureau of Reclamation engineers designed the dam in Glen Canyon with a view to achieving maximum efficiency in the creation of a storage lake from which a regulated stream would run through the power plants to the Lower Basin.

This design calls for spilling water

at the 3700-foot contour level, considered by the Bureau to be the maximum operating level, above which no water can be stored. I am informed by the Bureau office in Salt Lake City that there is an 11-foot safety zone above this level, capable of containing the maximum probable flood, which greatly exceeds the largest flood of historical record. It is standard procedure to provide such safety zones in all dams. According to the most accurate forecasts obtainable with present techniques, there is little chance that any uncontrolled flood water would ever flow over the spillway after the initial testing had been completed. Flood waters above Glen Canyon will be stored, and streams will be regulated, by the Flaming Gorge Dam on Green River, the Curecanti dams on Gunnison River, the Navajo Dam on San Juan River, and other dams to be constructed. No overflow emergency is anticipated in Glen Canyon. No such uncontrolled overflow has occurred at the Hoover Dam in the Lower Basin, even though there have been no regulating reservoirs above it.

As an ecologist, I have a good working knowledge of the geology of this rough country of the Colorado Basin, having been associated with Herbert E. Gregory during my work as a naturalist in Zion Canyon and having been selected by him to lead a tour of members of the International Geological Congress through the region of Zion Canyon, the north rim of Grand Canyon, Bryce Canyon, and Cedar Breaks in 1933 (*8*). It was my conclusion, from my intimate knowledge of the geology and physiography of the Rainbow Bridge setting, that water from Lake Powell could not endanger the mammoth bridge.

Since Halliday has questioned my conclusion and has brought up hypothetical dangers of pseudokarst, water soaking, and enhanced erosion, I have consulted the eminent geologist Armand J. Eardly of the University of Utah, who has authorized me to quote him as saying that he sees no danger to the bridge from reservoir water standing under it. Figure 3 is a detailed view of the inner gorge from upstream, showing where the high-water mark would be, under the bridge, when the lake was at the 3700-foot maximum operating level. At a level of 3711 feet, water would still be confined to this inner gorge and would not approach the bases of the arch resting on the broad platform above.

There are many natural bridges, arches, and caves in the colorful Navajo sandstone cliffs of this region. The long life of these structures attests to the adequacy of the sandstone for supporting Rainbow Bridge for so long a time that the present discussions will be lost in antiquity before the majestic arch crumbles.

Alternatives

The real problem at issue is whether to (i) prevent the water of Lake Powell from backing up into the monument in accordance with the requirements of the existing law, or (ii) change the law to remove the requirements. Under (i) there are two further alternatives: to install the protective structures or to lower the level of Lake Powell. As for the first of these alternatives, it has been shown adequately (*4*) that installation of a barrier dam below the monu-

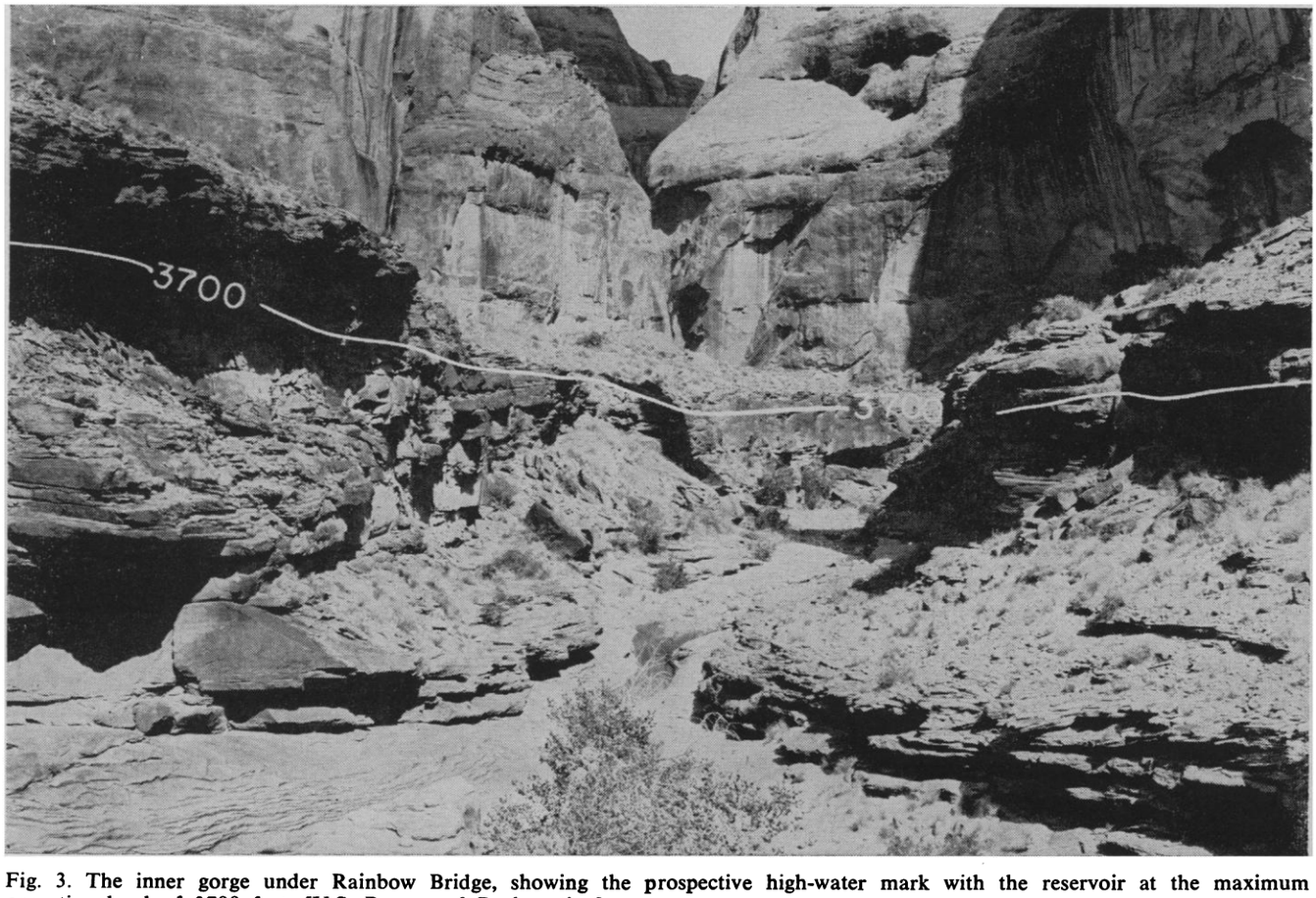

Fig. 3. The inner gorge under Rainbow Bridge, showing the prospective high-water mark with the reservoir at the maximum operating level of 3700 feet. [U.S. Bureau of Reclamation]

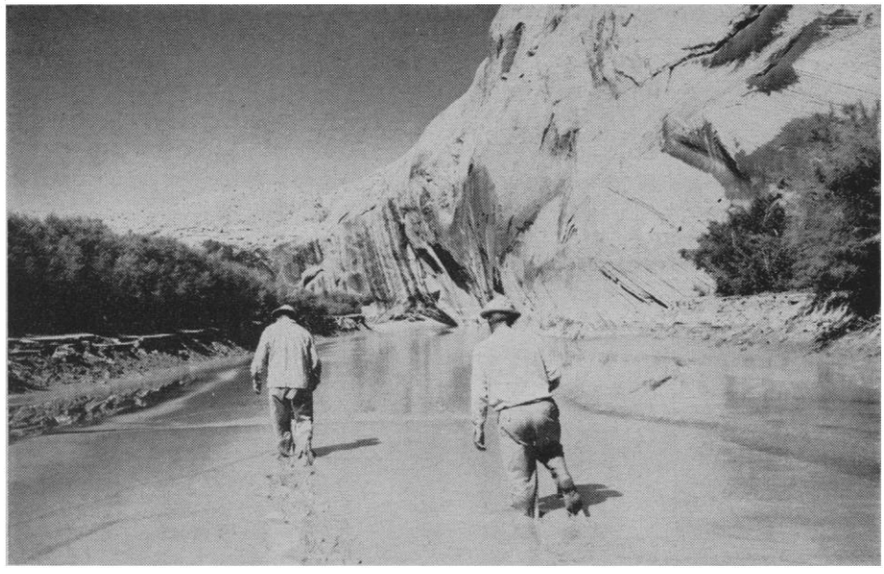

Fig. 4 (top). Soft, slushy mud left in the mouth of Bullfrog Creek after a flood in September 1957 [Stanley Rasmussen, U.S. Bureau of Reclamation] Fig. 5 (bottom). A small stream trickling through willows in an "inner gorge" in the mouth of Kane Creek. [Delbert Lindsay]

ment (site *B*) and a diversion dam and tunnel above it to divert water from Bridge Canyon would produce unacceptable marring of surrounding landscapes. A dam at site *C*, in Forbidden Canyon, would have the following disadvantages. (i) It would produce even more marring of the landscapes than a dam at site *B* because it would require about five times as much material, and the material would have to come from the high mesa adjacent to the monument, as shown in my earlier article (*4*, pp. 520, 523). Of the other scars at the dam site, those near the bottom would be permanently covered with water, those at the top would be permanently exposed, and those between would be periodically covered and uncovered by the fluctuating water level. (ii) Much more water and sediment would collect at site *C* than at site *B*, and larger pumping operations would be required. (iii) A dam at site *C* would constitute a barrier to navigation in the lake; visitors to the bridge would have to dock their boats on one side, climb over the dam, and obtain different transportation on the other side. (iv) Installation and maintenance of a dam at site *C* would require heavy financial investment. (v) The dam would provide only temporary protection for the monument because the unwanted lake above the dam would eventually fill with sediment and back up into the monument in a delayed "invasion" from man-made works. And (vi), it would be impossible to build the dam at the present time without disrupting the development of the Glen Canyon project. Halliday's "easy three-mile trail" from site *C* to the bridge is much less feasible to construct than he indicates. The alternatives would be to cut the trail in the face of the cliffs above the water level or to construct a very difficult trail along the top of the deeply eroded ridge beside the canyon.

As for the second alternative, lowering the level of Lake Powell from a maximum operating level of 3700 feet to a level of approximately 3600 feet would have the following disadvantages. (i) It would reduce the storage capacity of the lake from approximately 28 million to less than 15

million acre-feet of water—a loss of nearly half the storage capacity and of much more than half the usable storage space above the minimum dead-level contour of 3490 feet. The water that thus could not be stored at this reservoir site would have to be stored in some other reservoir in the Upper Basin where evaporation would be greater than from Lake Powell, unless it could be stored in Echo Park, use of which as a reservoir is not authorized. (ii) Lowering the water level would result in a tremendous reduction in the amount of electric power that could be produced at Glen Canyon. (iii) Drastic revisions of the design of the Glen Canyon dam and power plants would be required. (iv) Dam construction would be interrupted. And (v), the construction contracts would have to be revised.

As for changing the law to remove the existing requirements, if Congress should take a new look at past commitments and decide that the cost of protecting Rainbow Bridge would be unjustifiably high, it could certainly change its policy and correct past mistakes. If it decides to revise the law for this purpose, then development of the Glen Canyon project could proceed on schedule to provide storage of high water and regulation of stream flow.

In that event, the sliver of water from Lake Powell would back up under the bridge and rise and fall in accordance with the fluctuations of the lake. Both high water and erratic floods from Navajo Mountain would deposit sediment and debris at the end of the sliver of water at whatever level it happened to occupy at the time. Since much of the sediment in Bridge Canyon would be sand, the deposit at the mouth of the stream would probably be much less "gooey" than that shown in Fig. 4. When finally filled and overgrown with vegetation, the inner gorge would probably look something like the partly filled gorge shown in Fig. 5. Both of these pictures are views from Glen Canyon.

Discussion

The essential question of debate here is one of precedent. If invasion of the monument is authorized, the whole question will be automatically settled and nothing further need be done about it. The price paid, if this is the decision taken, will be the sliver of water under the bridge, filling of the bottom of the gorge with sediment, and eventual covering of the sediment with vegetation. There is nothing that I can discern in the geology and physiography of this deeply eroded region, where geology is an open book, to substantiate Halliday's far-fetched contention that water standing in the inner gorge would constitute a significant threat to the foundations of Rainbow Bridge. During the period when the gorge was filling with sediment, there would be a lot of messy deposits of debris and sediment in Bridge Canyon. During this interim period, measures could be taken to give visitors access to the bridge through Bridge Canyon. The administrative costs of such measures would be about equal to costs of similar procedures at a lake above a barrier dam.

The price to be paid if invasion of the monument is not authorized would be the cost of installing and maintaining protective works and the marring of surrounding landscapes or interference with the Glen Canyon project. Refusal to give such authorization because a precedent is at stake would hardly seem justified in view of the fantastic sum that such a refusal would cost society.

There is another consideration, one not discussed by Halliday. Any reservoir above any barrier dam that might be placed in Bridge or Aztec Canyon would eventually fill with sediment and back up into the monument. This means, then, that any protective barrier dam could only serve as a temporary expedient and could not permanently prevent the invasion of the monument by debris and sediments. Such installations would only delay the invasion.

Furthermore, Bridge and Aztec canyons are both part of the magnificent areas surrounding the bridge, and messy deposits of silt and debris above a barrier dam in either of these canyons would be just as devastating as silt and debris inside the monument. The final argument, then, simmers down to a question of whether the gorge under the bridge should be filled first or last, now or later. To fill it now would cost practically nothing. The alternative plan would require a fantastically large investment, and would not permanently achieve its objective; eventually the gorge would be filled.

This is a case that calls for soul-searching on the part of conservationists. To make a decision first and then hunt for evidence to support that position is not the method of science. Taking an adamant stand that ignores opposing evidence will not inspire the degree of confidence that is to be derived from open-minded evaluation of all evidence. If conservationists would take this objective attitude and expend their energy in studying the problems of this last frontier of the rough country of the Southwest, they could build much more strength into the National Park Service and the conservationist movement than they do by dissipating their efforts and arguing from unrealistic assumptions. Can it be that some conservationists are operating in such a deep groove of dogma that they cannot see the plain facts staring them in the face?

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