Sediment Transport in the Bill Williams River and Turbidity in Lake Havasu During and Following Two High Releases from Alamo Dam, Arizona, in 2005 and 2006

Scientific Investigations Report 2009-5195

U.S. Department of the Interior
U.S. Geological Survey

FRONT COVER: Looking southwest over Lake Havasu. The mouth of the Bill Williams River is in the foreground. The Central Arizona Project inlets are at the upper left, and Parker Dam is at the upper middle. Photo taken by Andrew Pernick, U.S. Bureau of Reclamation, March 3, 2009.

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Prepared in cooperation with the Bureau of Reclamation, Central Arizona Project,
and the Fish and Wildlife Service

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KEN SALAZAR, Secretary

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Contents

Appendixes

Figures

Conversion Factors and Datum

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
	Discharge	
cubic feet per second (ft^3/s)	0.0278	cubic meters per second (m^3/s)

Vertical coordinate information is referenced to the insert datum name (and abbreviation) here for instance, “National Vertical Geodetic Datum of 1929 (NGVD 29).”

Horizontal coordinate information is referenced to the insert datum name (and abbreviation) here for instance, “North American Datum of 1927 (NAD 27).”

Sediment Transport in the Bill Williams River and Turbidity in Lake Havasu During and Following Two High Releases from Alamo Dam, Arizona, in 2005 and 2006

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Abstract

Discharges higher than are typically released from Alamo Dam in west-central Arizona were planned and released in 2005, 2006, 2007, and 2008 to study the effects of these releases on the Bill Williams River and Lake Havasu, into which the river debouches. Sediment concentrations and water discharges were measured in the Bill Williams River, and turbidity, temperature, and dissolved oxygen were measured in Lake Havasu during and after experimental releases in 2005 and 2006 from Alamo Dam. Data from such releases will support ongoing ecological studies, improve environmentally sensitive management of the river corridor, and support the development of a predictive relationship between the operation of Alamo Dam and downstream flows and their impact on Lake Havasu and the Colorado River.

Elevated discharges in the Bill Williams River mobilize more sediment than during more typical dam operation and can generate a turbidity plume in Lake Havasu. The intakes for the Central Arizona Project, which transfers Colorado River water to central and southern Arizona, are near the mouth of the Bill Williams River. Measurement of the turbidity and the development of the plume over time consequently were important components of the study. In this report, the measurements of suspended sediment concentration and discharges in the Bill Williams River and of turbidity in Lake Havasu are presented along with calculations of silt and sand loads in the Bill Williams River.

Sediment concentrations were varied and likely dependent on a variable supply. Sediment loads were calculated at the mouth of the river and near Planet, about 10 km upstream from the mouth for the 2005 release, and they indicate that a net increase in transport of silt and a net decrease in the transport of sand occurred in the reach between the two sites.

Introduction

Planned high-discharge releases from dams have become a valuable management tool for riparian corridors downstream from dams (see, for example, Webb and others, 1999). High discharges were planned and released from Alamo Dam in 2005, 2006, 2007, and 2008 to study the effects of these releases on the Bill Williams River downstream. Sediment concentrations and water discharges that were measured in the Bill Williams River and turbidity that was measured in Lake Havasu during and after experimental releases in 2005 and 2006 from Alamo Dam (fig. 1) are the subject of this report. Temperature, specific conductance, dissolved oxygen, and pH were also measured in Lake Havasu in 2006 but are not discussed here. Data from such releases will support ongoing ecosystem studies, improve environmentally sensitive management of the river corridor, and support the development of a predictive relationship between the operation of Alamo Dam and downstream flows (Hautzinger, 2001).

Elevated discharges in the Bill Williams River mobilize more sediment than is transported during more typical dam operation. As a result, more sediment is delivered to Lake Havasu and a turbidity plume can form at the mouth of the Bill Williams River and spread into the lake. The intakes for the Central Arizona Project (CAP), which transfers Colorado River water to central and southern Arizona, are in Lake Havasu near the mouth of the Bill Williams River. The CAP shuts down operation at turbidity levels in Lake Havasu between 25 and 50 nephalometric turbidity units (NTU) because of problems associated with possible damage to the pumping plant's impellers, the effect of turbidity on water treatment plants, and reduction in infiltration rates at recharge projects (Brian Henning, Water Systems Supervisor, Central Arizona Project, oral commun., 2009). Measuring the intensity of the turbidity and the development of the plume over time were consequently important components of the study.

Purpose and Scope

This report presents discharge and sediment data collected in the Bill Williams River and turbidity and related measurements made in Lake Havasu during and following high-discharge releases from Alamo Dam in 2005 and 2006. Cumulative silt and sand volumes were computed for two locations in 2005 and for one location in 2006. The cumulative

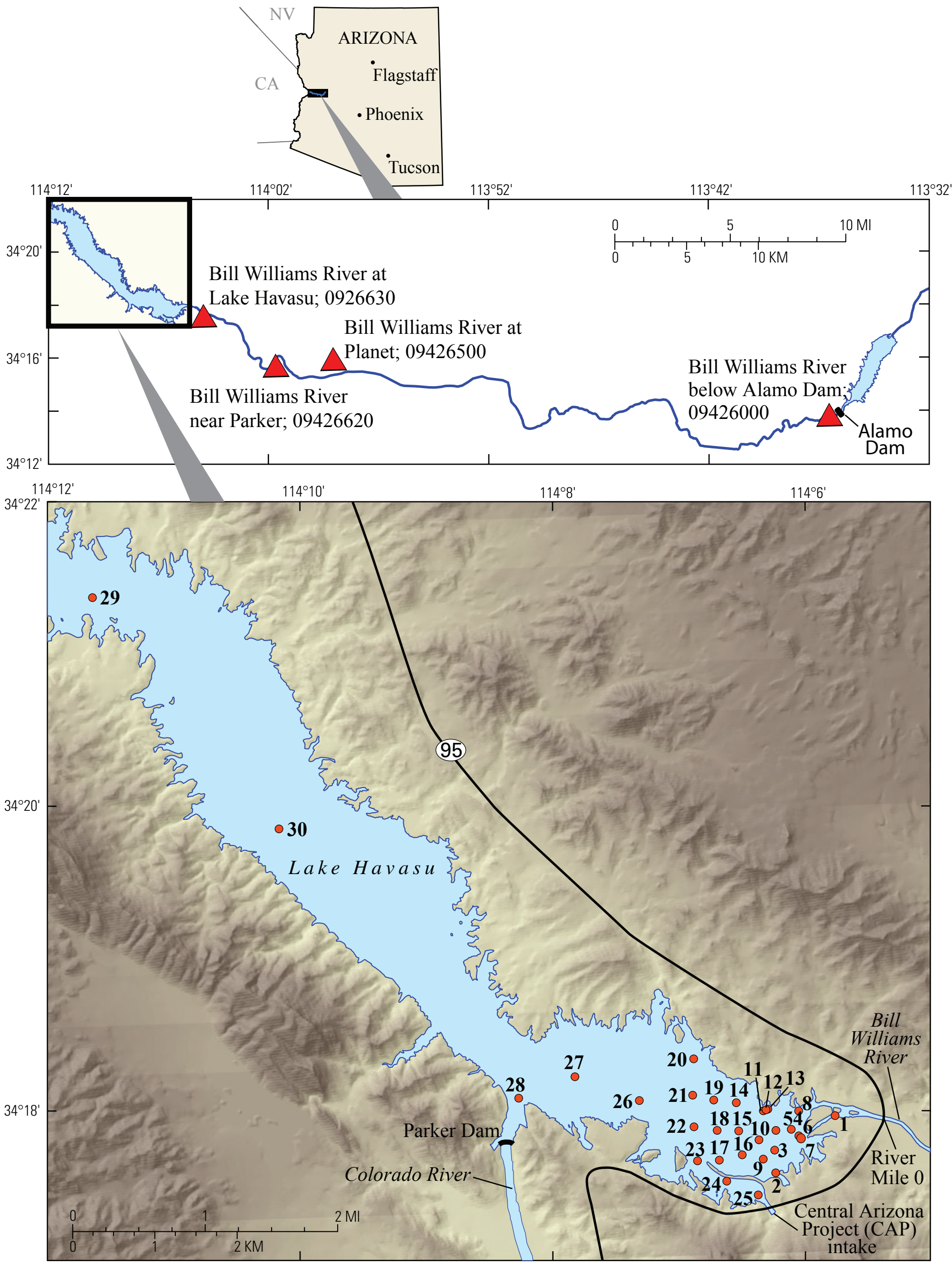


Figure 1. Maps showing measurement locations on the Bill Williams River and in Lake Havasu.

sediment volumes quantify the total sediment load during the high flows at a point above the mouth during the 2005 event and at the river mouth during both the 2005 and 2006 events.

Description of Study Area

The study area consists of the Bill Williams River between Alamo Dam and the mouth and Lake Havasu between the mouth of the river and Parker Dam (fig. 1). The Army Corps of Engineers operates Alamo Dam and describes it as a “multiple-purpose facility providing the following benefits: flood control, water supply and conservation, recreation, and fish and wildlife enhancement” (http://www.spl.usace.army.mil/resreg/htdocs/almo_2.html). The gates of the dam were first closed in 1968. Since then, discharge in the Bill Williams River has been largely controlled by dam operation, except for contributions from tributaries downstream from the dam (Wilson and Owen-Joyce, 2002), and the peak discharges have declined markedly since 1968 (fig. 2). The Bill Williams River

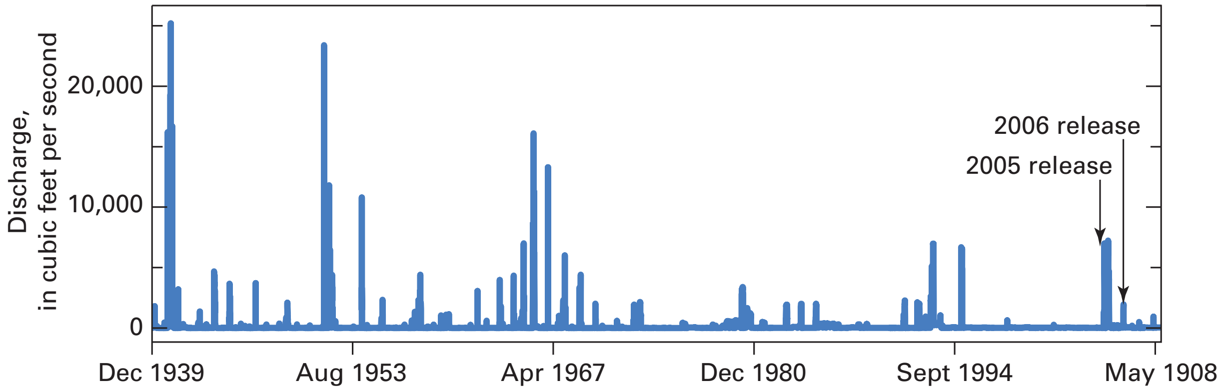


Figure 2. Daily average discharge record at the Bill Williams below Alamo Dam gage for the period of record.

National Wildlife Refuge is located in the reach upstream from the mouth. Operation of Alamo Dam also affects Alamo Lake State Park and Wilderness Area and the downstream river, which passes through Planet Ranch (owned by the City of Scottsdale, Arizona), Bureau of Land Management Wilderness, and two private land holdings.

The Bill Williams River occupies an alluvial bed and alternates between narrow gorges and wider alluvial reaches (House and others, 1999). The channel is braided at low flows, with a bed composed of sand and gravel (House and others, 1999). The river aquifer is well connected to surface water (Hautzinger, 2001), and the 39 miles between Alamo Dam and the mouth contain multiple sequences of reaches that gain and lose discharge through exchange with the river aquifer.

A significant fraction of the water released from Alamo Dam can infiltrate the channel bed. The fraction of the water released from Alamo Dam that passes gages located 26 mi. (Bill Williams River at Planet; 09426500) and 31 mi. (Bill Williams River near Parker; 09426620) below Alamo Dam is variable at base flows (discharges less than about 100 ft^3/s; Shafroth and Beauchamp, 2006). At higher average annual discharges, the average annual discharge consistently declines about 10 percent between the dam and the lower gage sites (fig. 3). Other factors, such as evapotranspiration and tributary inputs, can also affect differences in water volume between the two gages.

Leading up to the experimental releases, significantly more rain fell in water year (October 1 to September 30) 2005 (fig. 4) than in water year 2006 (fig. 5); water from 2005 storms was intentionally stored to support the 2006 experimental release. Tributaries to the Bill Williams River were running before and during the 2005 release but were dry before and during the 2006 release. The rainfall in 2005 also required high releases before and after the scheduled experimental release (fig. 6); in 2006, releases prior to the experimental release were much lower (fig. 7).

Locations along the Bill Williams River are designated by river mile upstream from the Highway 95 bridge near the river mouth. The distance along the river below the dam is also given in the context of flow processes.

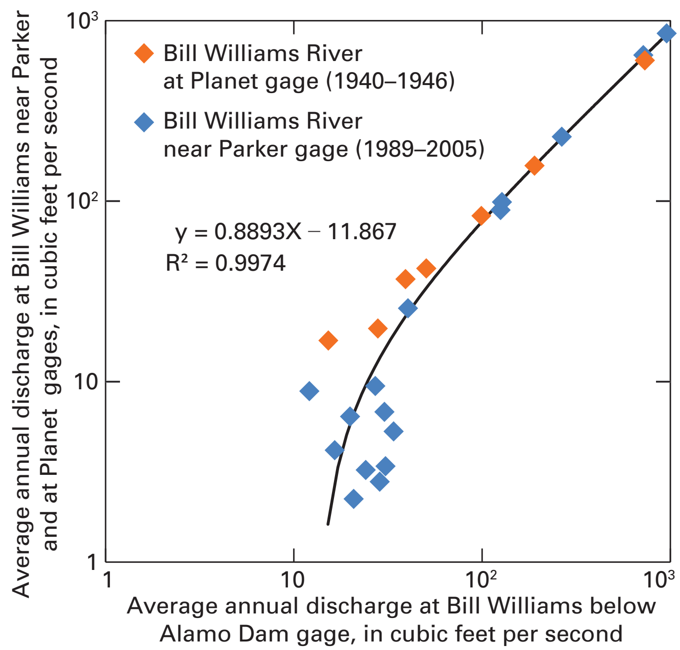


Figure 3. Average annual discharge at the Bill Williams below Alamo and Bill Williams at Planet and near Parker gages.

Streamflow Gaging Station Discharge Records and Measurements

There are currently two active streamflow gaging stations on the Bill Williams River (fig. 1): Bill Williams River below Alamo Dam (gage number 09426000) and Bill Williams River near Parker (09426620). Before the Bill Williams below Alamo Dam gage, which came into operation in 1968, a gage located 1.7 mi upstream from the current site monitored Bill Williams River streamflow. This gage was known as the Williams River near Alamo gage from October 1939 through September 1943 and as the Bill Williams River near

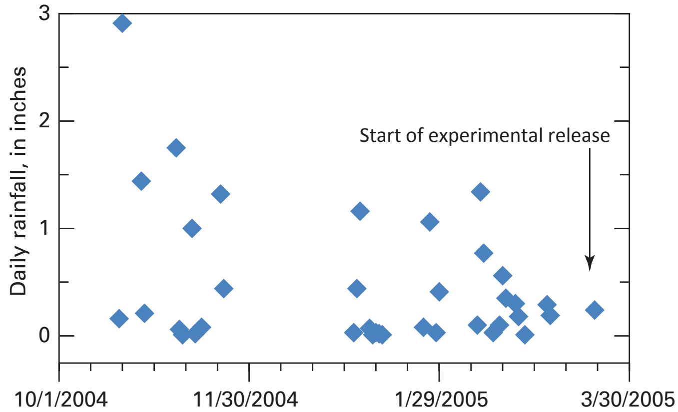


Figure 4. Daily rainfall at the Alamo Dam rainfall gaging station (CoopID 020100) before and during the 2005 release.

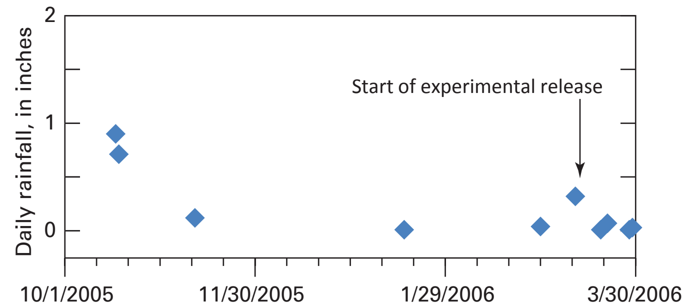


Figure 5. Daily rainfall at the Alamo Dam rainfall gaging station (CoopID 020100) before and during the 2006 release.

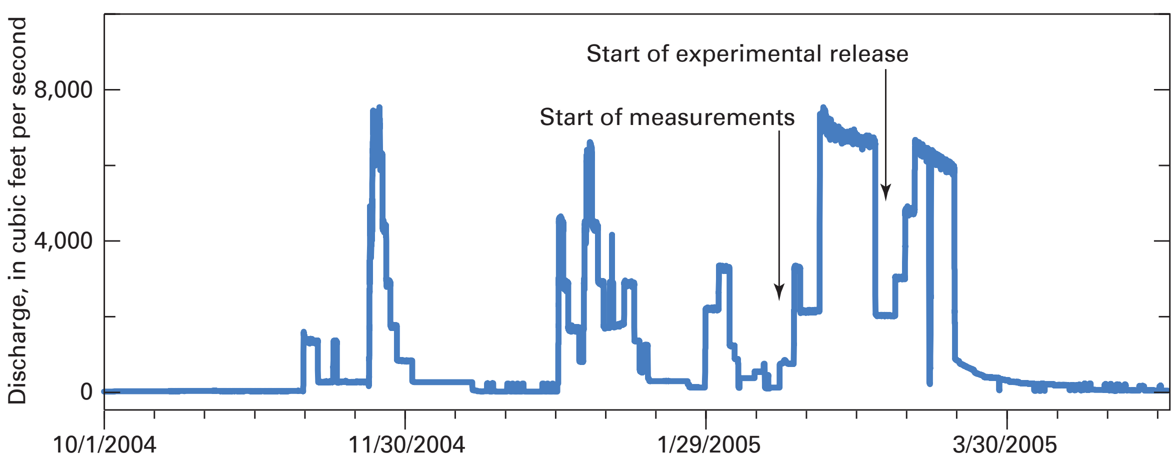


Figure 6. Discharge record at the Bill Williams below Alamo Dam gage from the start of the 2005 water year to the end of the 2005 experimental release.

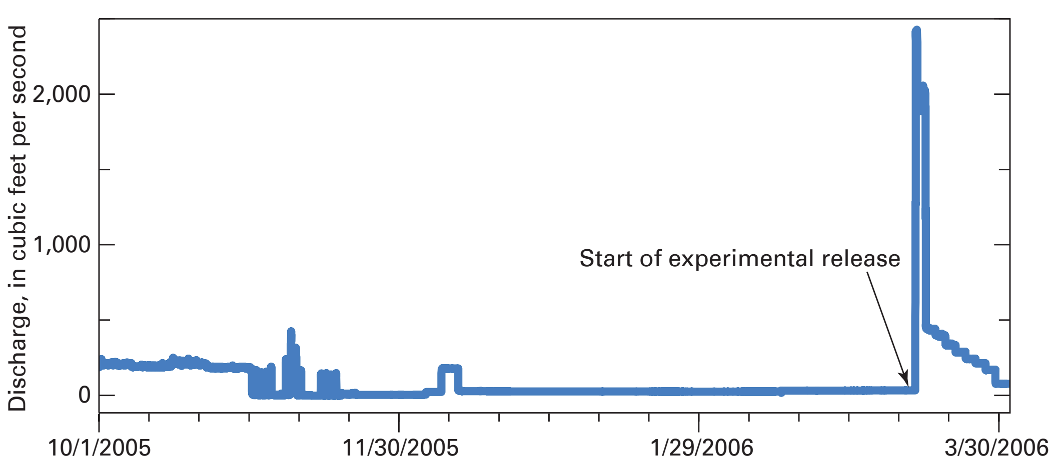


Figure 7. Discharge record at the Bill Williams below Alamo Dam gage from the start of the 2006 water year to the end of the 2006 experimental release.

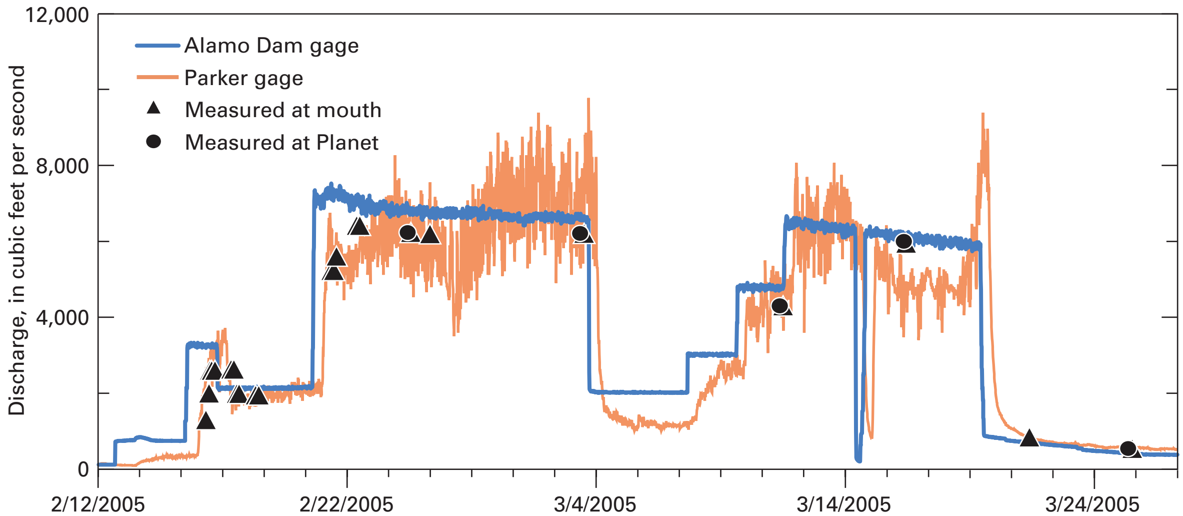


Figure 8. Hydrographs before and during the 2005 experimental

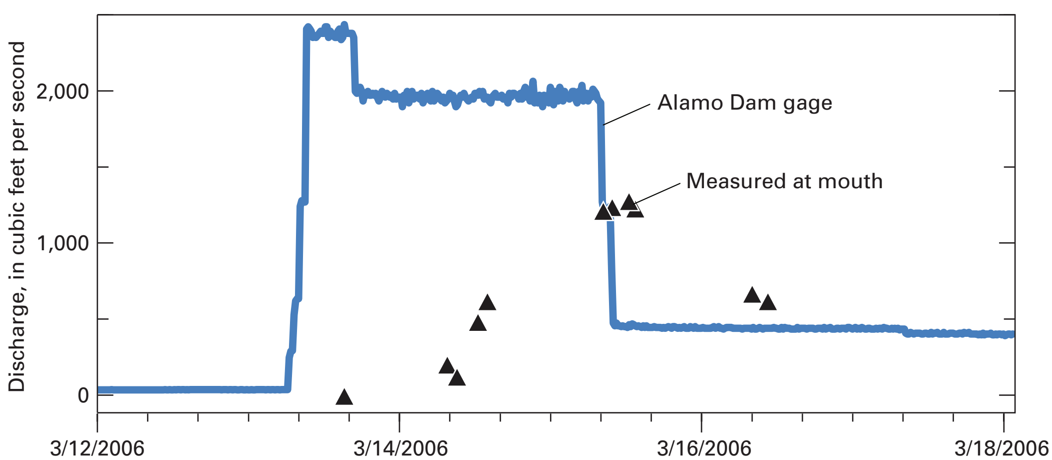


Figure 9. Hydrographs during the 2006 experimental

Alamo gage from October 1943 to September 1967. The two gages with three names near the current location of Alamo Dam have the same site identification number (09426000), and the data from these gages is stored as a continuous record in the U.S. Geological Survey (USGS) National Water Information System database. For brevity, the gages near Alamo and Alamo Dam will be referred to as the Alamo gage and the Bill Williams River near Parker streamflow gaging station will be referred to as the Parker gage. The locations of two additional sites are used to indicate measurement locations (fig. 1): Bill Williams River at Planet (09426500), which was active between 1928 and 1946, and Bill Williams River at Lake Havasu (09426630), which is located near the mouth of the Bill Williams River and was designated as a gaging site for the 2005 discharge measurements and sediment sampling. Also for brevity, these two locations will be referred to as the Planet and Bill Williams mouth sites.

The current Alamo gage is 0.6 mi below Alamo Dam (river mile 36, 36 miles upstream from the Highway 95 bridge), the Planet site is about 26 mi below Alamo Dam (river mile 10), and the Parker gage is about 31 mi below Alamo Dam (river mile 5). The Alamo gage has a cableway, enabling measurement of discharge and sediment across the channel at any discharge. At the other locations, measurements across the channel must be made by wading or from a boat, but neither could be safely accomplished during the highest discharges. Measurements were made at the Alamo and Planet sites and at the Bill Williams mouth during the 2005 release (fig. 8) and only at the mouth during the 2006 release (fig. 9). The discharge records and related gage information for the Alamo, Planet, and Parker streamflow gaging stations are available at http://waterdata.usgs.gov/az/nwis/nwis.

The Parker gage is an active streamflow gaging site but is inaccessible during high flows. High-flow measurements were made instead at the Planet site during 2005, but they were limited to wading measurements at discharges less than about 500 ft^3/s. The discharges at Parker were estimated from the Alamo discharge record and the Parker stage records. The Parker and Alamo gages were operating normally during the 2005 release, and 15-minute stage data are available for both sites. Discharges were measured at the Alamo gage during the high flows in 2005 and 2006. Those measurements were used to develop shifts to the rating curve to account for channel changes. Because direct discharge measurements were not possible during the experimental flows at the Parker gage, discharge measurements made at the mouth, incorporating the estimated traveltime between the two locations, were used to develop shifts for the Parker gage rating curve. The rating curve and associated shifts were applied to the stage record from the Parker gage to provide a continuous record of discharge at this site. For the 2006 release, 15-minute discharge data are available only from the Alamo gage.

Releases from Alamo Dam

In February 2005, measurements were made during a high-flow release from Alamo Dam designed to control lake level. This release reached a peak of 7,300 ft^3/s and declined to 6,600 ft^3/s over 11 days (fig. 8). A planned experimental release began on March 19 and reached a peak of about 6,700 ft^3/s that declined to 5,800 ft^3/s over about 8 days. The 2005 sediment and turbidity measurements presented in this report were made before, during, and after the planned experimental releases. Before the high releases in February and March 2005, peaks of about 7,000 ft^3/s in November 2004, 4,600 ft^3/s in December 2004, and 6,500 ft^3/s in January 2005 were recorded at the Alamo gage (fig. 6). The peak discharges in 2005 were in the range of moderate floods on the Bill Williams River that would support the riparian corridor (Shafroth and Beauchamp, 2006).

The 2006 experimental release began on March 13 and rose from a steady discharge of about 36 ft^3/s to a peak of about 2,400 ft^3/s over a period of about 3 hours (fig. 9). About 11 hours after the initial rise, the discharge declined and was held at about 1,900 to 2,000 ft^3/s for 38 hours. The discharge then was lowered to about 450 ft^3/s over 3.5 hours,

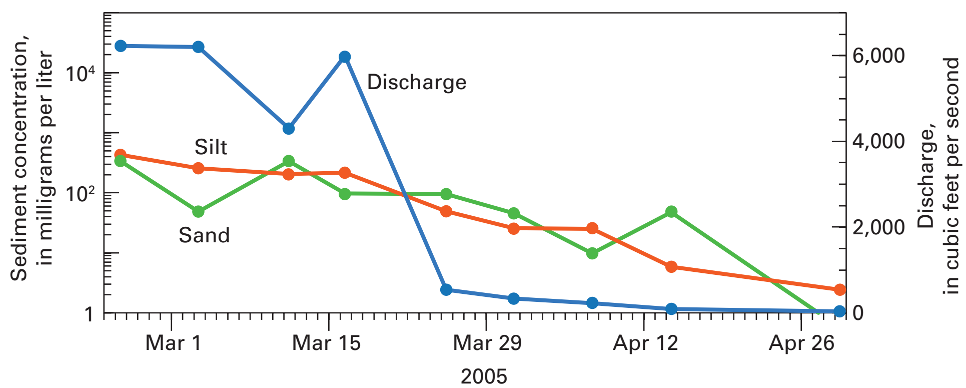


Figure 10. Sand and silt concentrations and discharge measured near Planet during the 2005 release.

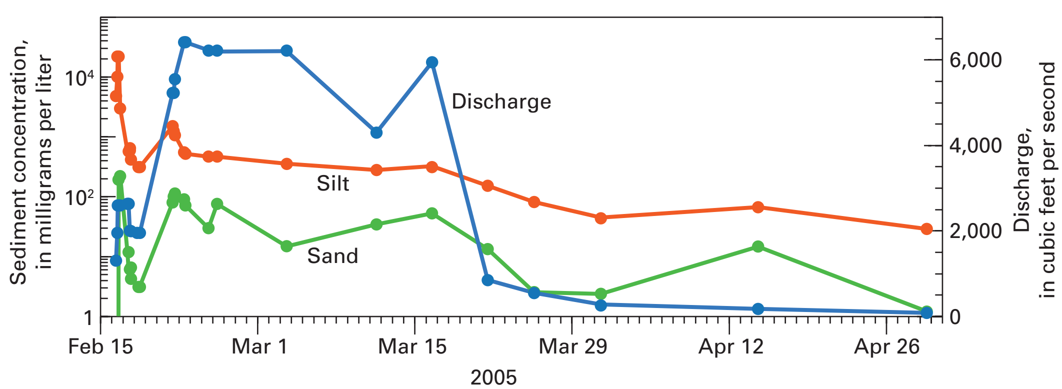


Figure 11. Sand and silt concentrations and discharge measured near the mouth of the Bill Williams River during the 2005 release.

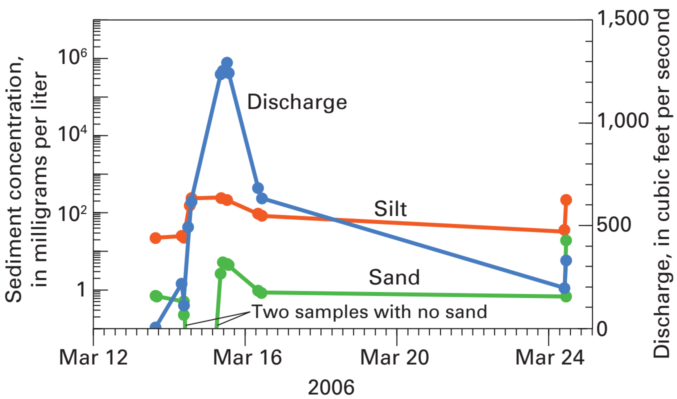


Figure 12. Sand and silt concentrations and discharge measured near the mouth of the Bill Williams River during the 2006 release.

then gradually declined to 36 ft³/s over the next 2 weeks. The 2006 sediment and turbidity measurements presented in this report were collected before, during, and after the experimental release in March 2006. Before the March 2006 release, a peak discharge of about 400 ft³/s in November 2005 was recorded at the Alamo gage. The peak discharges in 2006 after the November 2005 peak were less than about 200 ft³/s (fig. 7). The peak discharge of around 2,000 ft³/s in 2006 is near the middle of the magnitude of small floods on the Bill Williams River that would support the riparian corridor (Shafroth and Beauchamp, 2006).

Suspended Sediment Sampling in the Bill Williams River

Suspended sediment samples were collected at the Alamo, Planet, and Bill Williams mouth sites (appendix 1; figs. 10 and 11) during the 2005 release. The samples at the mouth were collected from a boat and integrated vertically and across the channel using standard methods as described by Edwards and Glysson (1998). Point samples were collected at the Planet site by wading. As described in the previous section, discharges above 500 ft³/s were too swift to safely wade or operate a boat. When the discharge was greater than 500 ft³/s, the suspended sediment was sampled with a point sampler about five to ten feet from the bank and four feet below the surface. The samples at the Alamo gage were collected from a cableway and integrated vertically and across the channel using standard methods as described by Edwards and Glysson (1998).

During the 2006 release, sediment samples on the Bill Williams River were collected only at the mouth site (appendix 1; fig. 12) to estimate the sediment volume delivered to Lake Havasu. These samples were collected from a boat and integrated across the channel, as in 2005.

The sediment samples were analyzed by the USGS sediment laboratory at the Cascades Volcano Observatory in Vancouver, Washington. The analysis determined the sediment concentration and the percent finer and coarser than 0.63 mm. Suspended sediment data and discharge measurements are in appendix 1.

Sediment Volumes Transported by the Bill Williams River During and Following the Experimental Releases

A significant factor in the geomorphological development of the Bill Williams riparian corridor and in the turbidity observed in Lake Havasu during high releases from Alamo Dam is the cumulative sediment load carried by the river. Estimates of the silt and sand loads could be made at the Planet site and at the mouth during the 2005 release and at the mouth during the 2006 release. Accuracy of these estimates of sediment load depends on the coverage of the measurements as well as on the accuracy of discharge and sediment measurements.

Because of logistical and resource limitations, continuous measurements were not possible. Consequently, there are gaps in the records during which changes in discharge and sediment load occurred. An approximation of the sediment load can be made by developing a discharge-sediment-transport rating curve and applying it to a discharge record to determine sediment transport. During the 2005 release, the continuous stage record at the Parker gage provided a discharge record that can be used at both the Planet site and near the mouth with appropriate offsets for traveltime (fig. 8). Because the Parker gage is only 5 mi. above the mouth, differences in peak discharges between the two sites are assumed to be small.

Power functions were fitted to the silt and sand concentrations (fig. 13) to develop sediment concentration-discharge relations at the Planet site during the 2005 release. Those relations were then used with the estimate of continuous discharge to compute the sediment mass transport over time (fig. 14). The cumulative mass was computed with

$$m_s = \sum_{i=n}^{i=2}(q_s^i + q_s^{i-1})(t^i - t^{i-1})/2 \qquad (1)$$

where *ms* is the cumulative sediment mass, *qs* is the silt or sand transport rate in mass/time, *t* is time, *i* is the index of sediment transport at time *t*, and *n* is the number of values used in the calculation.

A similar procedure was used to compute the cumulative silt and sand transport at the mouth site in 2005. The measurements at the mouth early in the 2005 release, however, indicate that an initial surge of sediment was transported as the flow rose (figs. 11 and 15), which generated substantially higher sediment concentrations than occurred later during the event. A similar surge may have occurred during the early part of the first sustained peak that preceded the planned experimental release (fig. 8) at the Planet site, but samples at that location

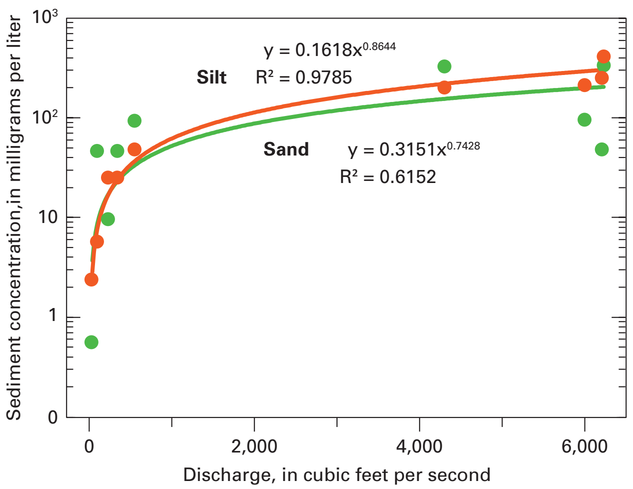


Figure 13. Concentrations of silt and sand sampled near Planet on the Bill Williams River in 2005 with fitted lines.

were not collected until after the flow had peaked. Measurements of discharge and sediment concentration at the mouth were frequent enough to define the sediment transport during the rise of the first sustained peak. Because of this and the higher concentrations during that part of the flow, the cumulative sediment transport is computed directly from the measurements of sediment concentration and discharge at the mouth for the early part of the flow, up to February 16 at 14:00. For the same reasons, the sediment concentrations sampled up to February 16 at 14:00 are not included in the formulation of the sediment transport-discharge relation that was used to compute the silt and sand mass transport following that date and time (fig. 16). Equation 1 was used to compute the cumulative masses of sand and silt transported (fig. 17).

During the 2006 experimental release, measurements were made during the initial rise, during the peak, and during the following low flow with gaps between those measurements (fig. 12). Unlike the data in 2005, these discharge measurements show a significant drop in peak discharge at the mouth, indicating that the hydrograph at the mouth cannot be reasonably approximated by translating the hydrograph of the dam release downstream. In the absence of sufficient information to reconstruct the hydrograph at the mouth in 2006, estimates of sediment transport rates between measurements were not attempted and the cumulative sediment volumes are presented as straightforward summations of available data using equation 1 (fig. 18).

Turbidity Measurements in Lake Havasu

During the 2005 measurements, McVan (http://www.mcvan.com/) and HACH 2100HP (http://www.hach.com/) turbidity instruments were used to measure turbidity at selected depths in Lake Havasu between the mouth of the Bill Williams River and Parker Dam and at two additional uplake locations (fig. 1). Both instruments were calibrated before each environmental measurement with turbidity standards of 0, 100, 500, and 1,000 NTUs. All calibrations were within 0 to 0.002 percent of the standard.

During 2006, a Sea-Bird Electronics (http://www.seabird.com/) SBE25 was used to make profile measurements. The sensors for pressure, water temperature, specific conductance, dissolved oxygen, and turbidity were calibrated annually by the manufacturer. Calibration coefficients were updated in the Sea-Bird software following calibration. All measurements from the SBE25 are included in the appendix, but only turbidity is discussed in this report.

The Sea-Bird SBE25 was programmed to scan the sensors at 2 Hz. The data were logged as raw voltages from the sensors in hexadecimal format. At this sampling interval and

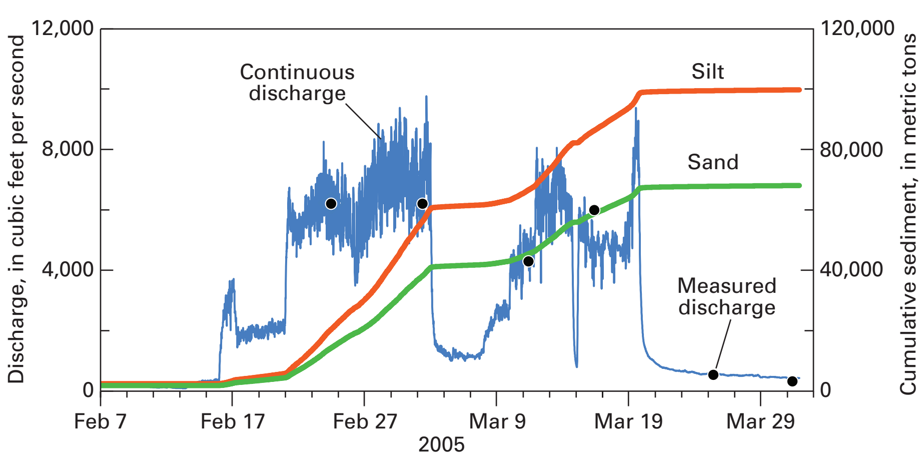


Figure 14. Discharge and cumulative sediment volumes during the 2005 release at the Planet streamflow gaging station.

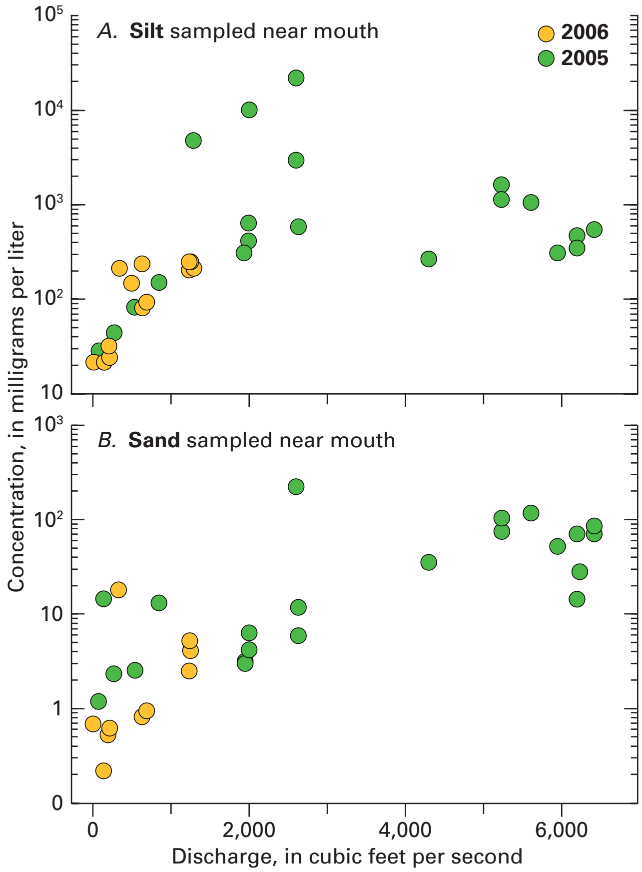


Figure 15. Silt (*A*) and sand (*B*) concentrations at the mouth of the Bill Williams River during the 2005 and 2006 experimental releases.

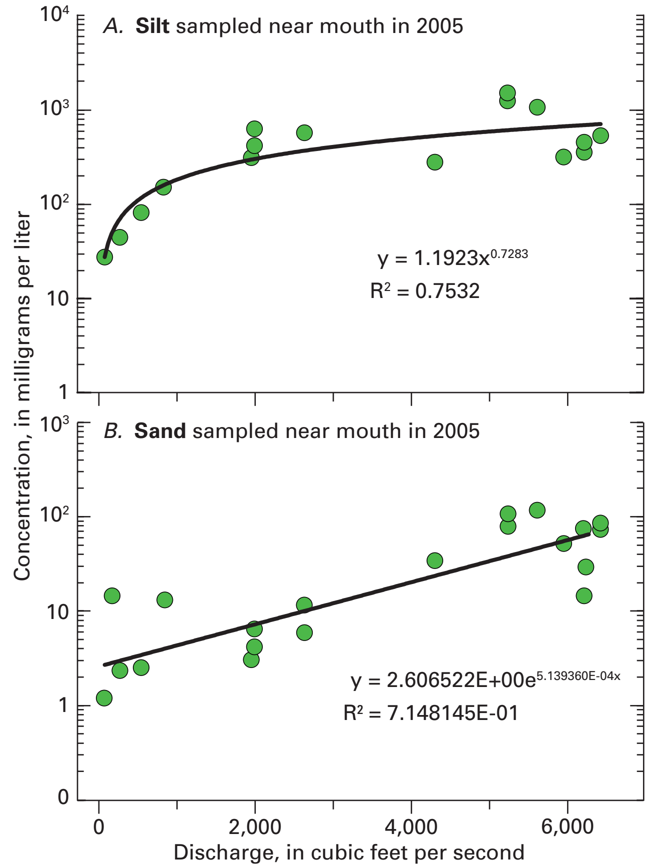


Figure 16. Silt (*A*) and sand (*B*) concentrations used to formulate discharge-sediment concentration rating curves use in the 2005 cumulative volume calculation release at the mouth of the Bill Williams River.

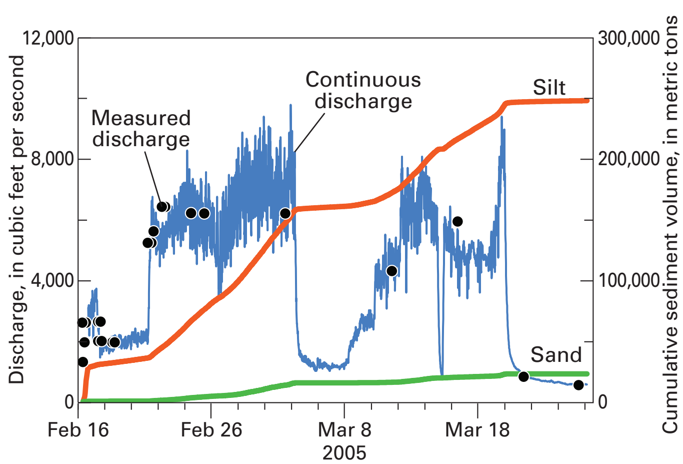


Figure 17. Discharge and cumulative sediment volumes during the 2005 release at the mouth of the Bill Williams River.

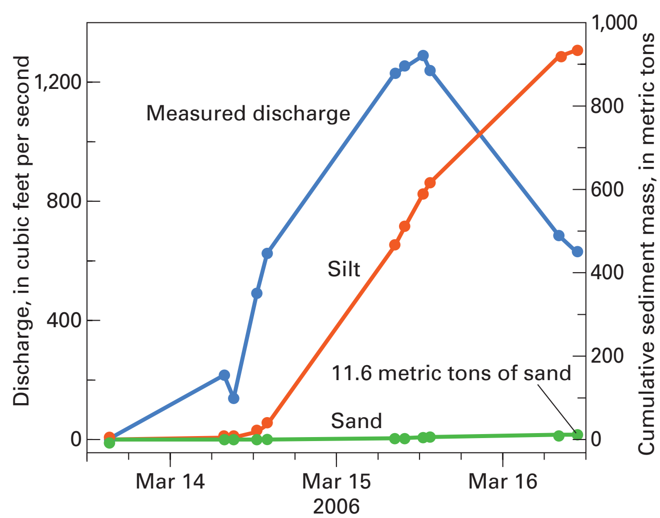


Figure 18. Discharge and cumulative sediment volumes during the 2006 release at the mouth of the Bill Williams River.

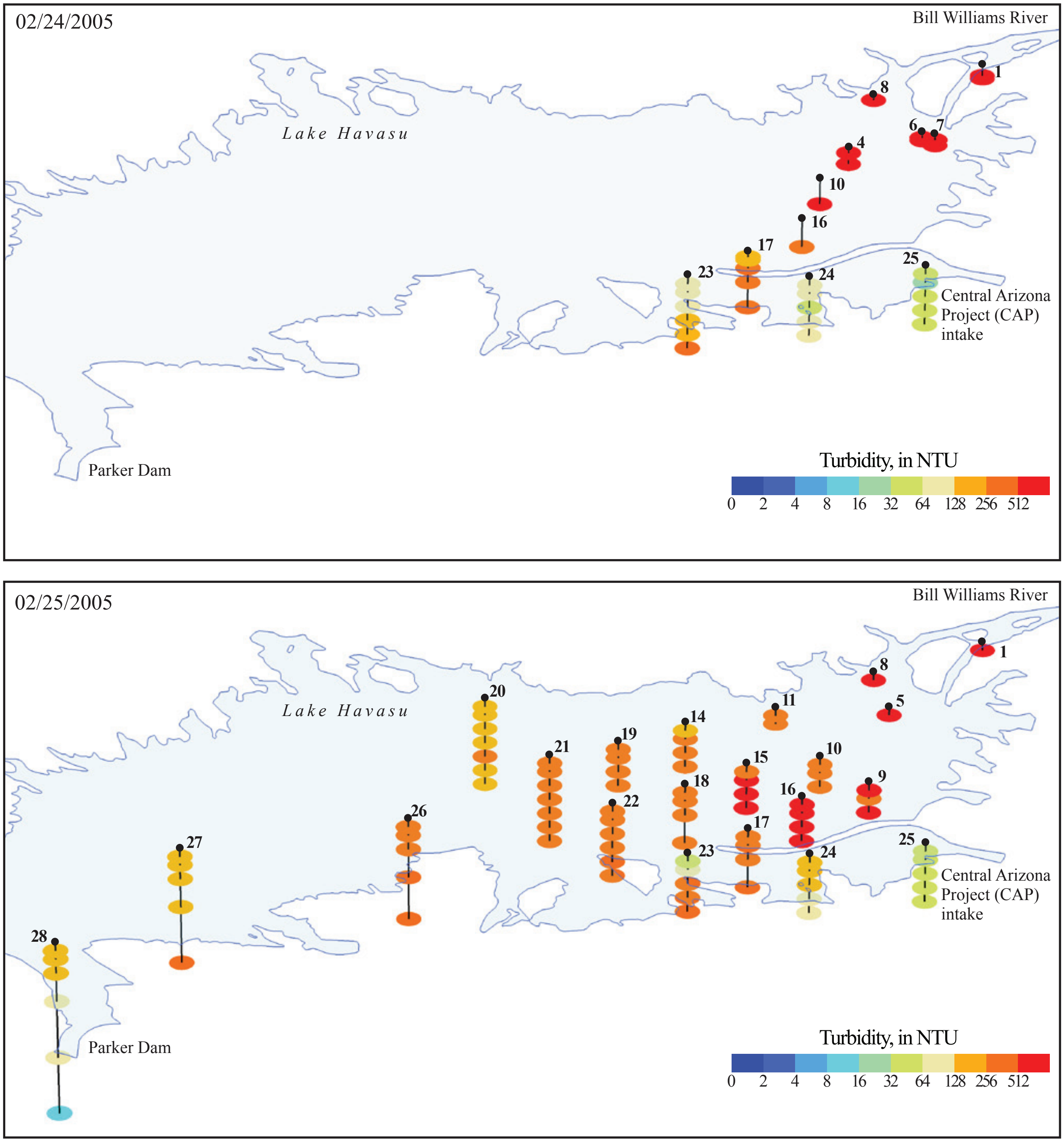


Figure 19. Turbidity point measurements in Lake Havasu during the planned release from Alamo Dam during February through April, 2005. Black dots show the location of each measurement site.

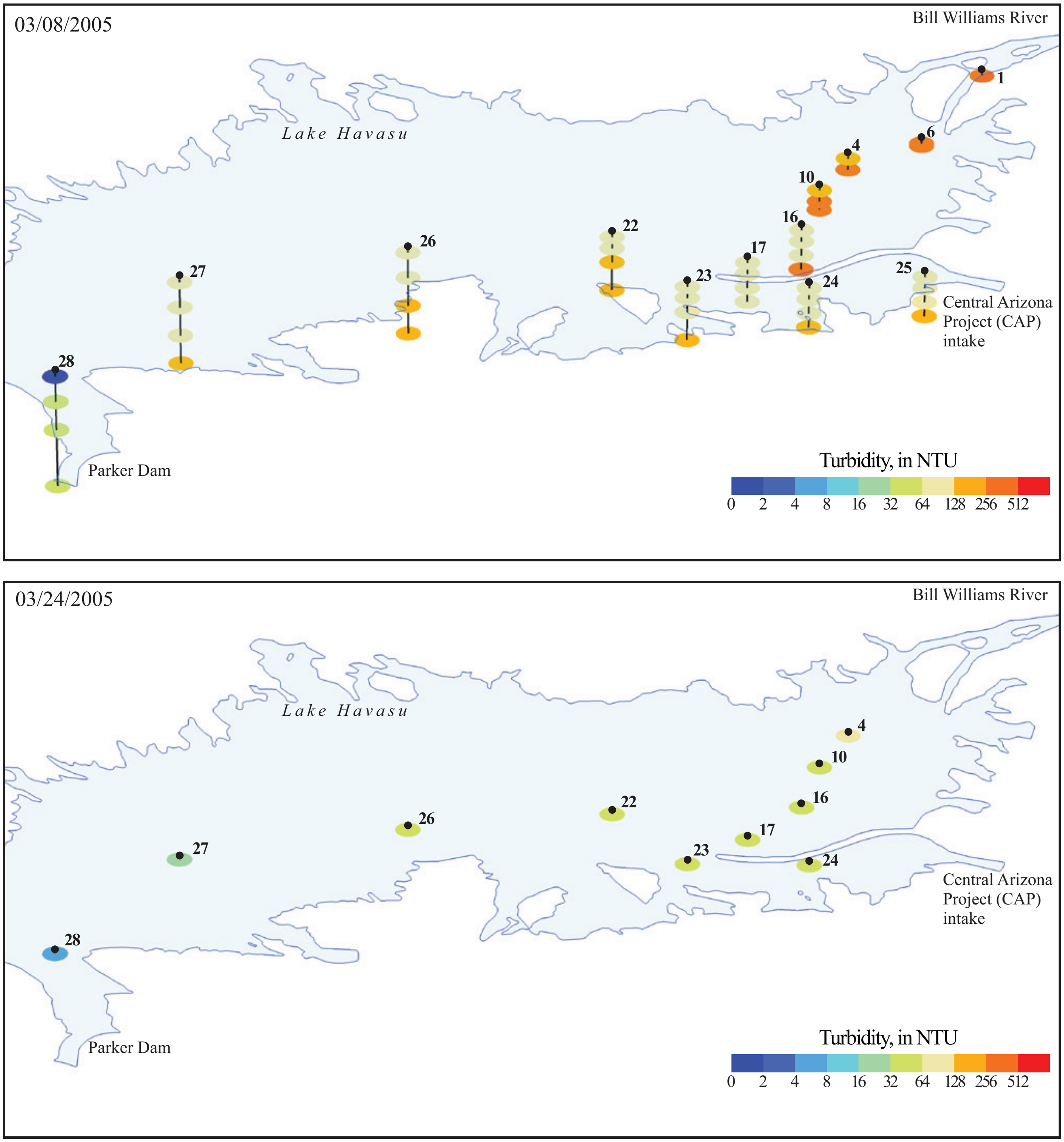


Figure 19. Turbidity point measurements in Lake Havasu during the planned release from Alamo Dam during February through April, 2005. Black dots show the location of each measurement site—Continued.

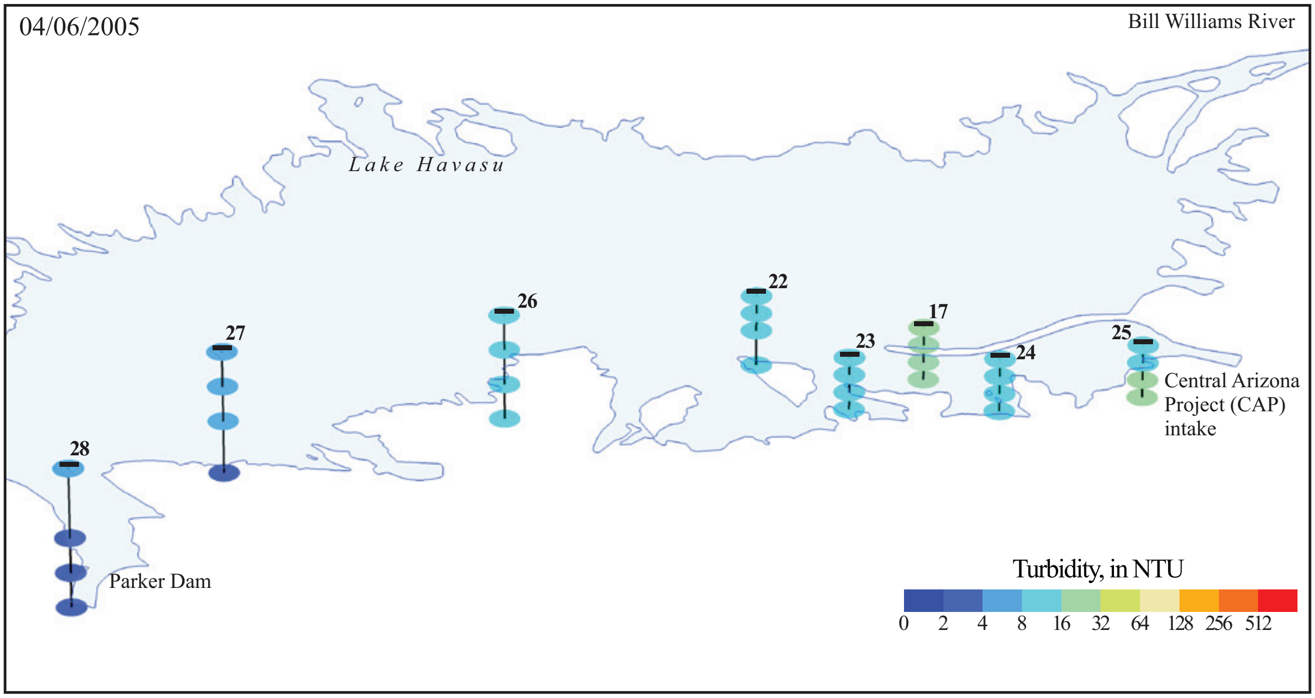


Figure 19. Turbidity point measurements in Lake Havasu during the planned release from Alamo Dam during February through April, 2005. Black dots show the location of each measurement site—Continued.

with a descent rate of about 1 m/s, the profiler scanned each sensor two times per meter. Start time of the downcast and other information pertinent to the measurement site were entered into the Sea-Bird software for site identification purposes. Profile graphs of the data presented in this report are based on derived, converted, and bin-averaged values from the raw hexadecimal data files. Raw data are available, but the Sea-Bird processing software is needed for data conversion.

A 20-cm-diameter Secchi disk was used to measure the transparency of water as a way of inferring turbidity. Secchi-disk measurements were made from the shaded side of the boat while profile measurements and water samples were being collected. The disk was lowered through the water column until it was no longer visible, and the depth of the disk was recorded. This process was repeated three times, and the average value recorded. Secchi-disk transparency depends on several factors, including the observer's eyesight, the contrast between the disk and the surrounding water, the reflectance of the disk, and the disk's diameter (Cole, 1975). The surface condition of the lake also can affect the readings.

The study area extended westward from the mouth of the Bill Williams River toward the forebay of Parker Dam. Thirty sites were sampled on the lake and four sites were sampled on the river (fig 1). A numbering system consisting of 30 sampling points was designed for the area of study in Lake Havasu. Sampling points were selected to provide adequate coverage from the Bill Williams delta west toward the Central Arizona Project intake structures. Several sites were located closer to Parker Dam, and two sites were located, respectively, northwest of and uplake of Parker Dam (fig. 1). The sites were georeferenced using a handheld Brunton global positioning system. Depth-profile measurements of turbidity, specific conductance, water temperature, dissolved oxygen, and pH were made at the sampling points. The complete Lake Havasu data sets are in appendix 2 (available only online at http://pubs.usgs.gov/sir/2009/5195/appendixes).

Measurements of turbidity profiles in 2005 started near the time of the peak discharge in the Bill Williams River. Turbidity profiles were measured on 5 days over a 6-week period and show the spread and dissipation of the turbidity plume (fig. 19). The profiles of turbidity in 2006 started before the peak discharge in the Bill Williams River and show the spread and dissipation of the turbidity plume, with measurements made on 10 days over about 5 weeks (fig. 20).

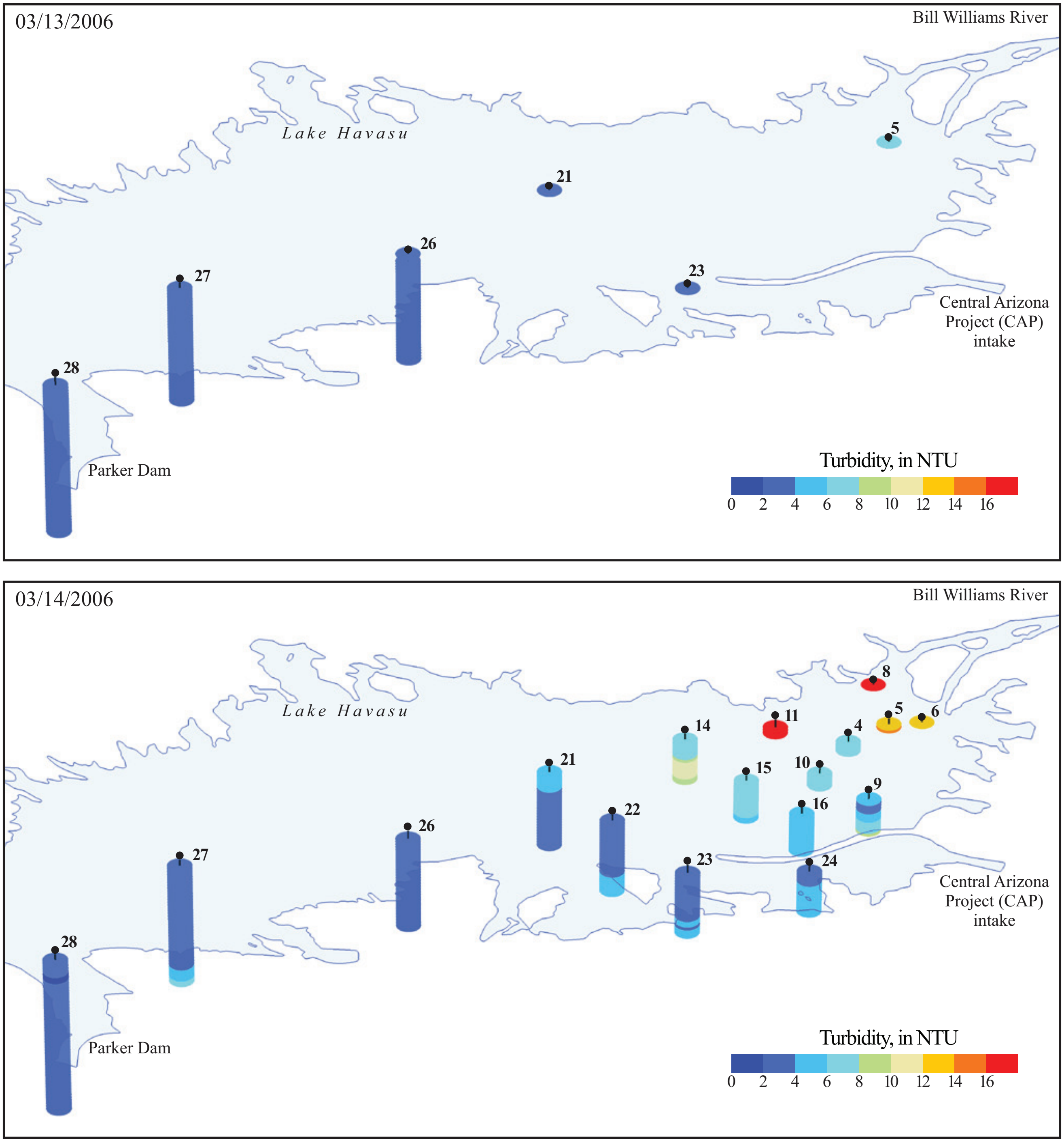
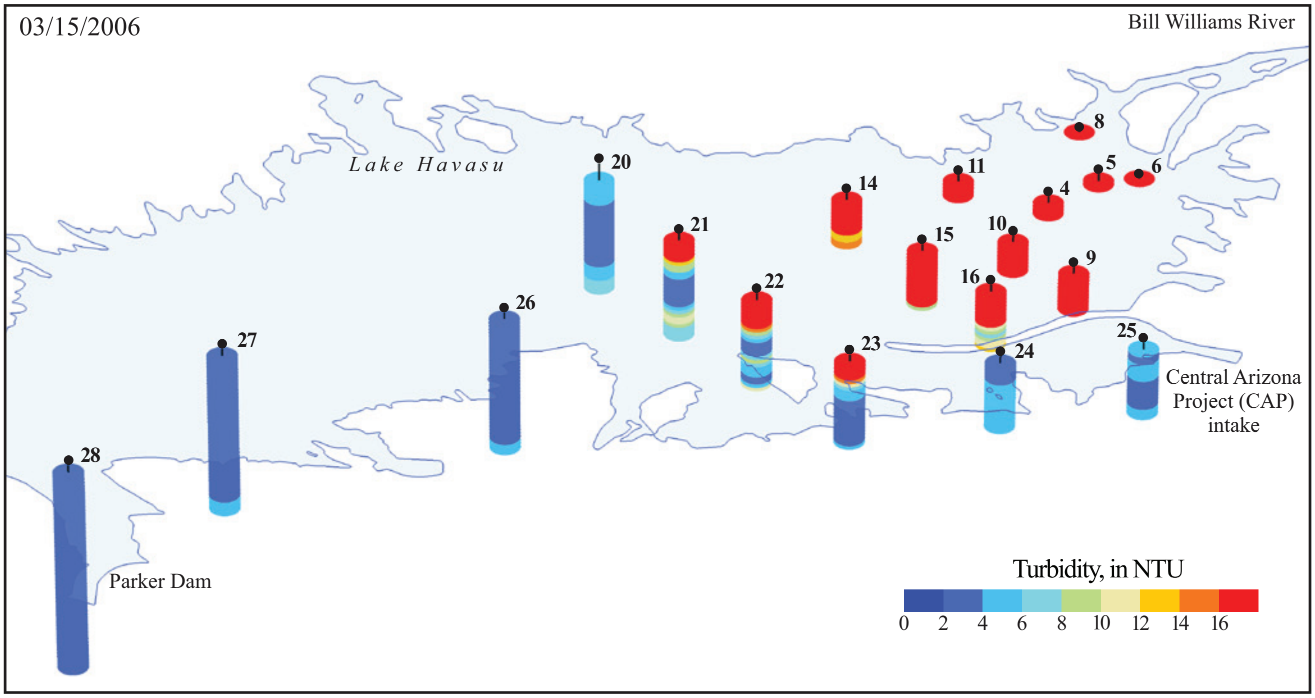


Figure 20. Turbidity continuous measurements in Lake Havasu during the planned release from Alamo Dam in March and April, 2006. Black dots show the location of each measurement site.



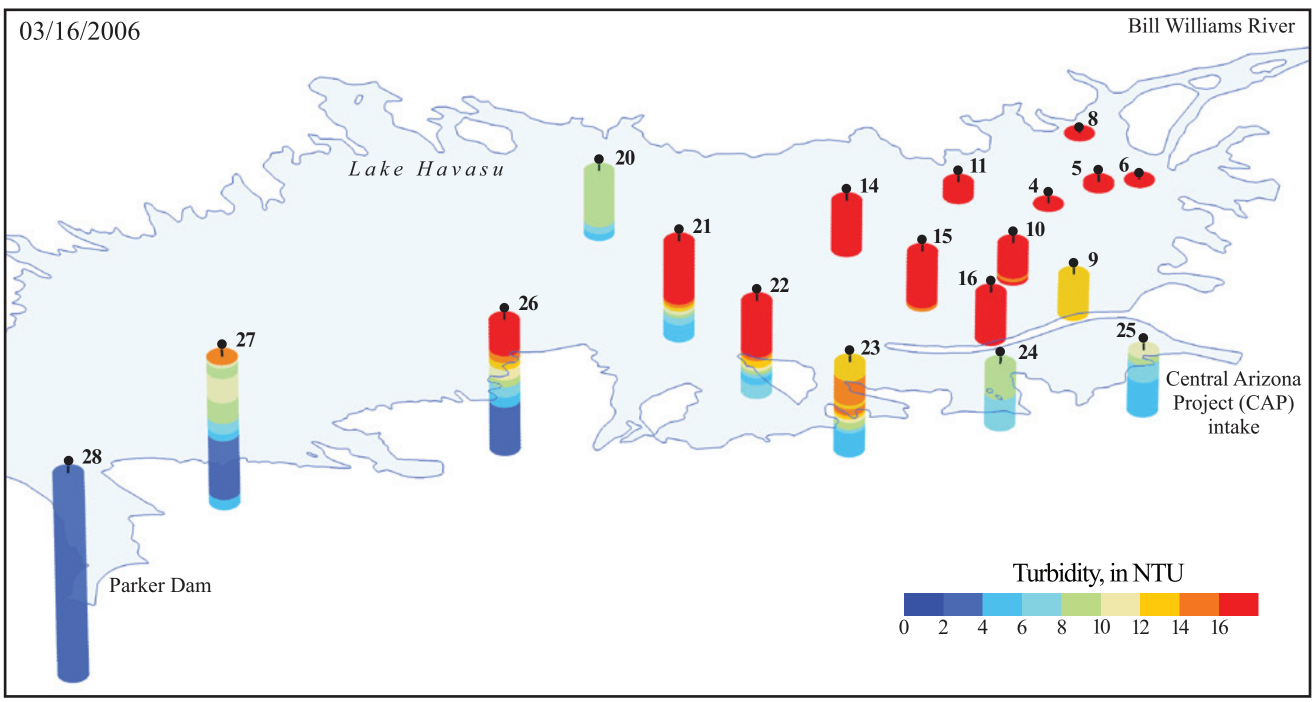


Figure 20. Turbidity continuous measurements in Lake Havasu during the planned release from Alamo Dam in March and April, 2006. Black dots show the location of each measurement site—Continued.

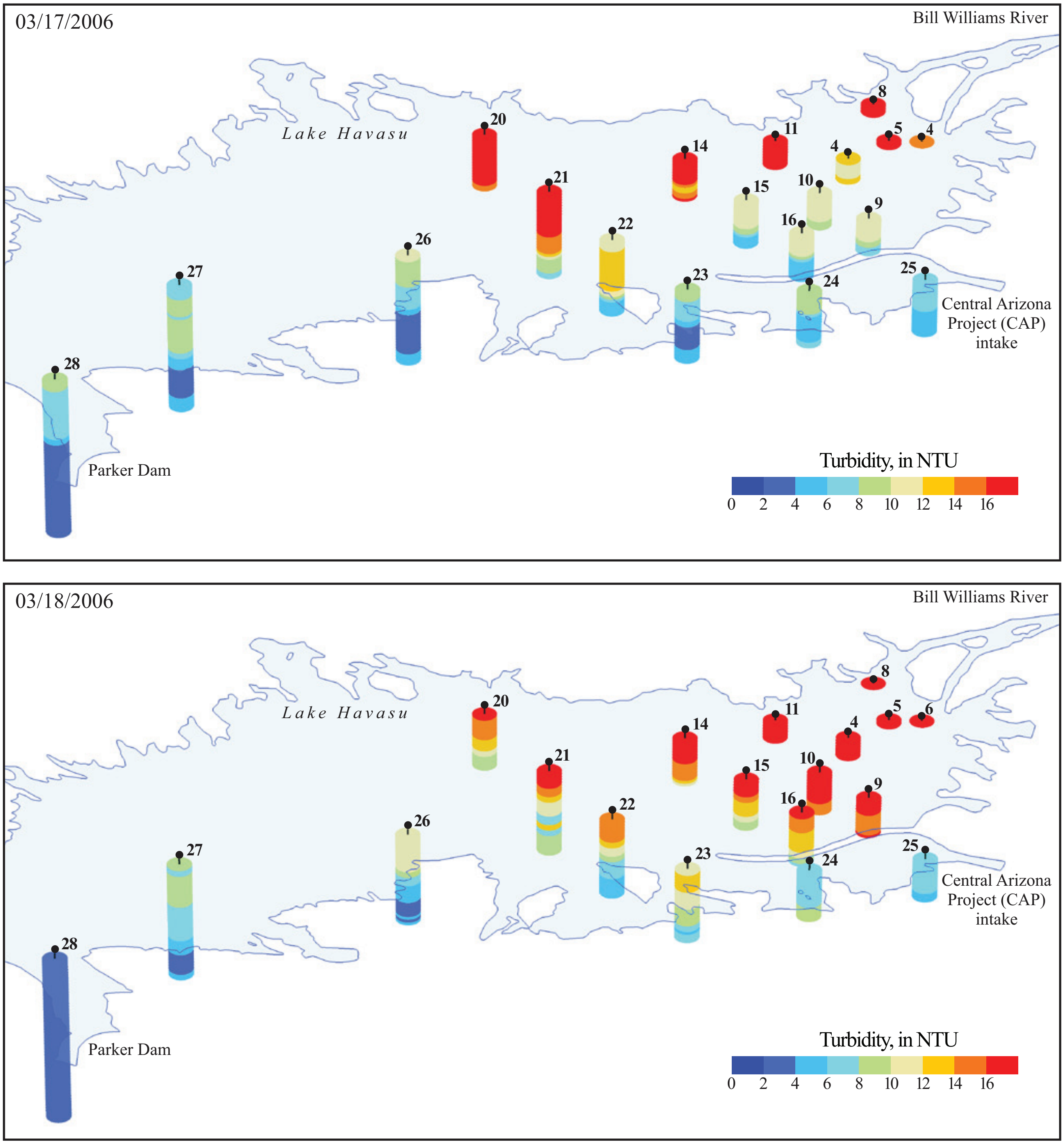


Figure 20. Turbidity continuous measurements in Lake Havasu during the planned release from Alamo Dam in March and April, 2006. Black dots show the location of each measurement site—Continued.

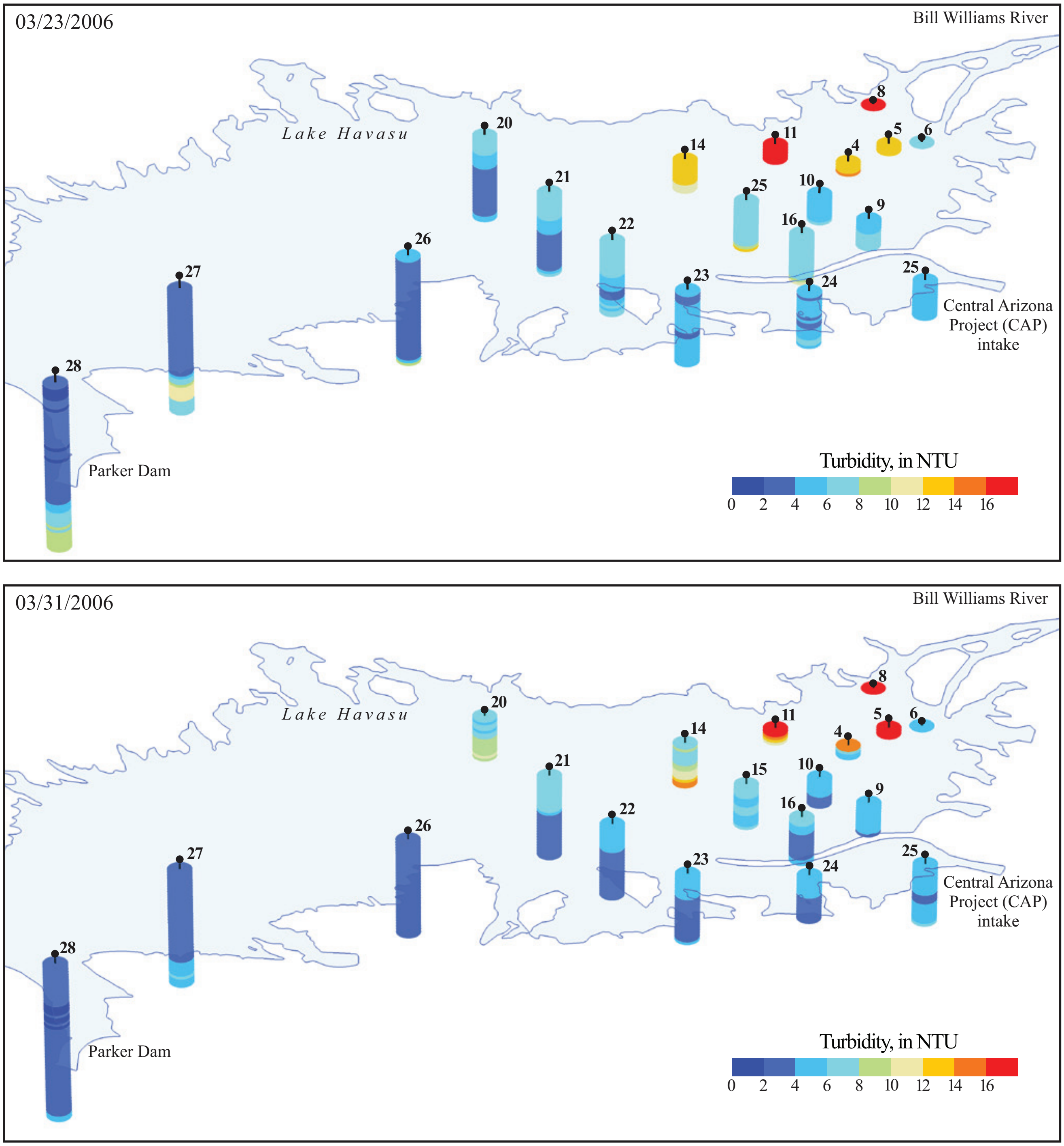


Figure 20. Turbidity continuous measurements in Lake Havasu during the planned release from Alamo Dam in March and April, 2006. Black dots show the location of each measurement site—Continued.

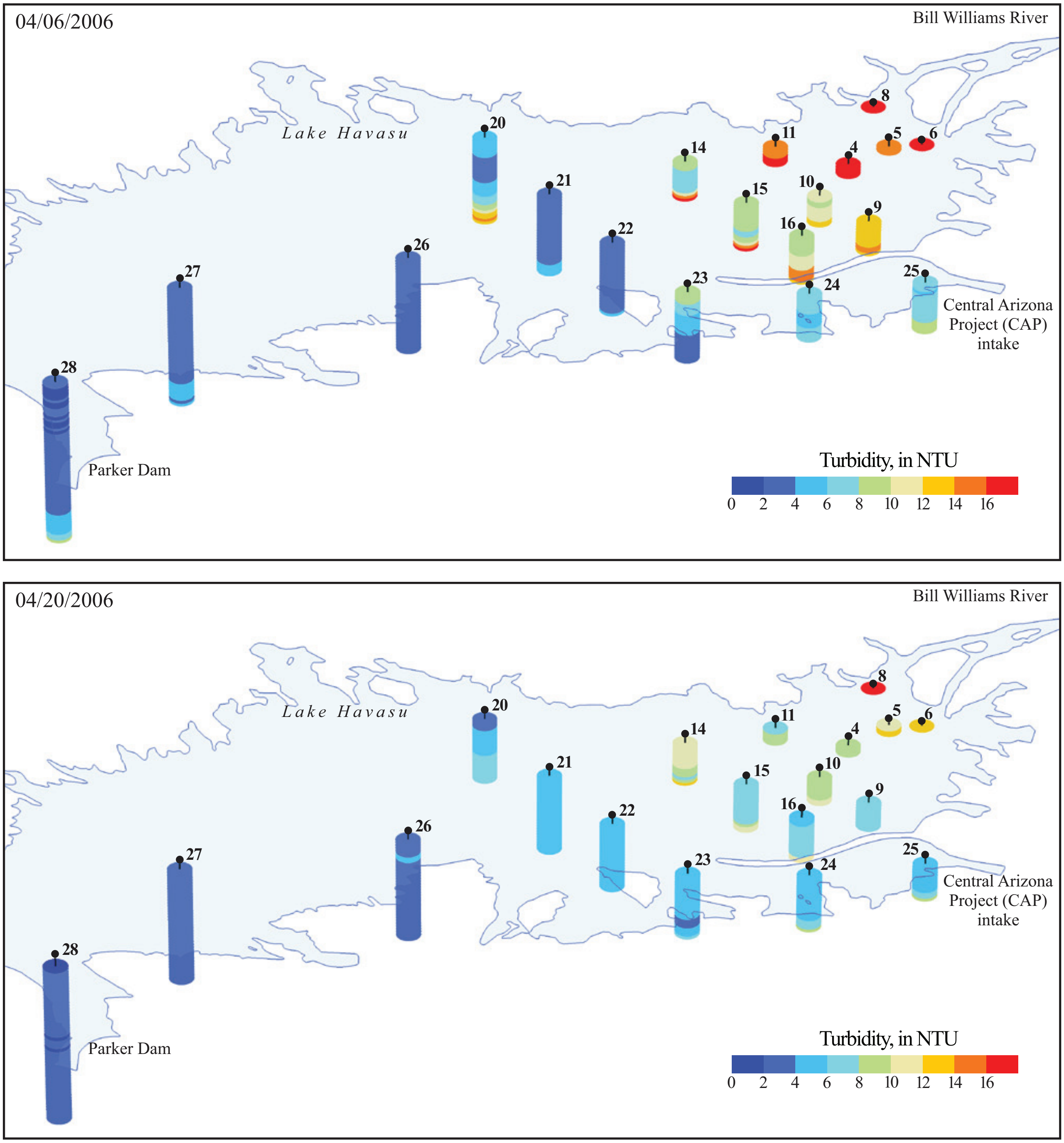


Figure 20. Turbidity continuous measurements in Lake Havasu during the planned release from Alamo Dam in March and April, 2006. Black dots show the location of each measurement site—Continued.

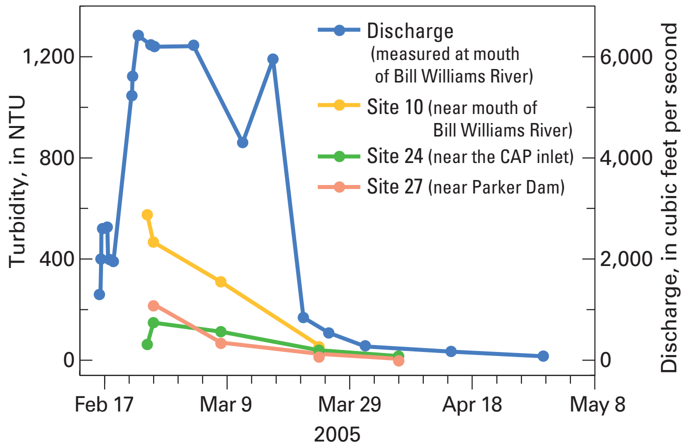


Figure 21. Vertically-averaged measured turbidity in Lake Havasu at three locations and measured discharge at the mouth of the Bill Williams River during the 2005 planned release from Alamo Dam.

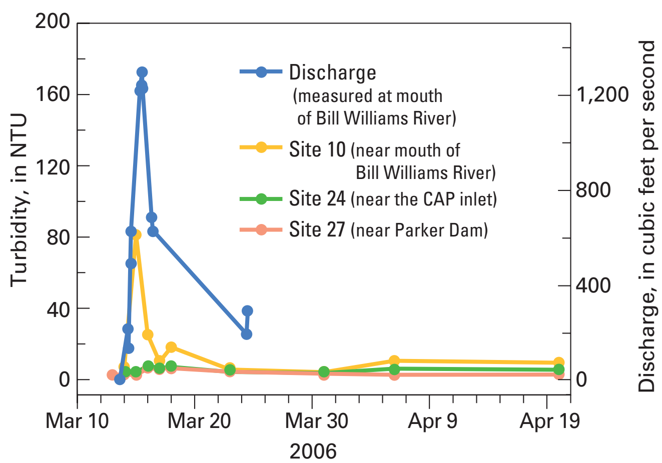


Figure 22. Vertically-averaged measured turbidity in Lake Havasu at three locations and measured discharge at the mouth of the Bill Williams River during the 2006 planned release from Alamo Dam.

Discussion

During the 2005 release, silt loads calculated from measurements indicate more silt was transported at the mouth of the Bill Williams River than at the Planet site, indicating that silt was entrained in the lower part of the river. About 2.5 times more silt, about 150,000 metric tons, was transported past the mouth than was transported at the Parker site. This is consistent with the domination of sand and gravel on the bed in the upper reaches and the favorable sites for storage of silt in the lower gradient, vegetation-rich part of the river downstream. The reverse pattern occurred with the sand: about three times more sand, about 45,000 metric tons, was transported past the Planet site than past the mouth, indicating sand deposition occurred between the two sites. The sediment load at Planet may be underestimated because no measurements were made during the early part of the high release. A surge in sediment transport similar to that which occurred near the mouth may have occurred at Planet, but this cannot be confirmed or accounted for.

Sediment rating curves were constructed to estimate the volume transported at the measurements sites. The sediment concentrations as functions of discharge, however, show considerable scatter, especially at the mouth (figs. 15 and 16). Some of this scatter may be a result of sampling variability, but changes over time in the sediment supply, particularly during the initial rise in discharge, may be a significant contributor and have been observed elsewhere in rivers dependant on tributary inputs for sediment supply (for example, Topping and others, 1999). Variations in sediment supply can be especially pronounced in channels downstream from dams, where tributaries are the sole source of fresh sediment. During the 2005 release, the silt and sand concentrations spiked with the first rise in discharge, then declined. This spiking is consistent with a limited or variable supply of such sediment.

Development of a predictive capability for sediment transport and discharge along the Bill Williams River as a function of dam releases is complicated by two characteristics: the sediment discharge is variable and appears to be supply dependant, and the water discharge along the channel can be reduced by infiltration into the river aquifer. The variability in the sediment transport was demonstrated by the high concentrations measured during the rise of the 2005 release at the mouth. Silt concentrations were nearly two orders of magnitudes higher, at around 2,000 ft^3/s, during the rise than after the peak discharge. This variability in sediment supply makes problematic the tracking of net sediment deposition or erosion over reaches of the Bill Williams River with sediment rating curves applied to continuous hydrographs.

The turbidity in Lake Havasu followed the concentration patterns in the Bill Williams River (figs. 19–22). In 2005, the maximum vertically averaged measured turbidity at site 10, about 500 m from the mouth of the Bill Williams River, was 575 NTU. The turbidity at this location declined from the peak, even though the releases continued for about three weeks (fig. 21). The change in turbidity over time near the CAP intake (site 24) and Parker Dam (site 27) followed similar patterns, but the maximum measured vertically averaged turbidities at these two sites were lower than near the mouth at 184 (higher than CAP standards for Lake Havasu turbidity) and 222 NTU, respectively (fig. 21).

In 2006, the discharge peak at the mouth of the Bill Williams River was only about a fourth of the peak discharge in 2005, and the duration was much shorter (figs. 8 and 9). The turbidity in 2006 reached a peak of 80 NTU at site 10 near the mouth and declined to less than 10 NTU in about 14 days. Near Parker Dam (site 27) and the CAP intake (site 24), the highest vertically averaged turbidity measurements did not exceed 10 NTU (fig. 22), which is below CAP standards for turbidity in Lake Havasu.

In large part, this study was implemented to take advantage of the high flows in 2005 to better characterize the sediment dynamics of the Bill Williams River. The acquisition of field data in 2005, which was conceived, arranged, and implemented in the midst of flood conditions, provided an excellent opportunity to learn more about how to design a systematic approach to collection of high-flow sediment data. The field experience in 2005 and 2006 demonstrated the difficulty in obtaining accurate discharge and sediment data in the Bill Williams River because of its complex morphology and dense vegetation. The collection of discharge and sediment data, especially between the two gage locations, may be enhanced by ongoing technological improvements and increased resources. The establishment of several stations where high discharges could be measured along the river corridor of the Bill Williams River is a high priority of the U.S. Fish and Wildlife Service.

Improved discharge and sediment data collection would address priority management needs, as expressed by the member agencies of the Bill Williams River Corridor Steering Committee (http://billwilliamsriver.org). The current state of knowledge of the river's sediment dynamics is very limited, with little ability to predict flow-sediment relations. An important management need exists to better characterize turbidity plumes in Lake Havasu and their relation to Alamo Dam releases (for example, looking at predicting plume intensity and the duration and rates of plume expansion and contraction over a range of flows). The 2005–2006 data collected in this investigation help to address key management concerns, namely an improved understanding of flow and sediment dynamics, and will provide guidance for managing river flows to meet human and ecological concerns. The development of accurate numerical models to predict flow-sediment relationships would be highly beneficial, as they would contribute to resolving both of these management concerns.

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References Cited

Cole, G.A., 1975, Textbook of limnology: Department of Zoology, Arizona State University, C.V. Mosby Company, 283 p.

Edwards, T.K., and Glysson, G.D., 1998, Field methods for measurement of fluvial sediment; Book 3, Applications of Hydraulics: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chapter C2, 80 p.

Hautzinger, A., 2001, Surface water and groundwater measurements along the Bill Williams River, AZ associated with the mini-flush release from Alamo Dam, June 11 - to - 15, 2001: U.S. Fish and Wildlife Service, Technical Brief, 10 p.

House, P.K., Wood, M.L., and Pearthree, P.A., 1999, Hydrologic and geomorphic characteristics of the Bill Williams River, Arizona: Arizona Geological Survey Open-File Report 99-4, 37 p.

Shafroth, P.B., and Beauchamp, V.B., 2006, Defining ecosystem flow requirements for the Bill Williams River, Arizona: U.S. Geological Survey Open-File Report 2006-1314, 135 p. [http://www.fort.usgs.gov/products/publications/21745/21745.pdf; last accessed August 24, 2009].

Topping, D.J., Rubin, D.M., Nelson, J.M., Kinzel, P.J., and Bennet, J.P, 1999, Linkage between grain-size evolution and sediment depletion, during Colorado River floods, in Webb, R.H., Schmidt, J.C., Marzolf, G.R., and Valdez, R.A., (eds.), The controlled flood in Grand Canyon: Washington, D.C., American Geophysical Union, Geophysical Monograph 110.

Webb, R.H., Schmidt, J.C., Marzolf, G.R., and Valdez, R.A., (eds.), 1999, The controlled flood in Grand Canyon: Washington, D.C., American Geophysical Union, Geophysical Monograph 110.

Wilson, R.P., and Owen-Joyce, S.J., 2002, Hydrologic conditions in the Bill Williams River National Wildlife Refuge and Planet Valley, Arizona, 2000: U.S. Geological Survey Water-Resources Investigations Report 02-4214, 16 p.

Appendix 1. Suspended Sediment Concentrations and Discharge Measurements on the Bill Wiliams River

Station 9426630; Bill Williams River at Lake Havasu, AZ

Date	Time	Suspended sediment, sieve diameter percent <.063mm, mg/L	Suspended sediment concentration, mg/L	Measured discharge, cfs	Notes
2/16/05	0830	100	4,790	1,300	estimated from surface velocity
2/16/05	1130	100	10,100	2,000	estimated from surface velocity
2/16/05	1215	100	22,000	2,600	estimated from surface velocity
2/16/05	1400	99	22,400	2,600	
2/16/05	1715	93	3,200	2,600	
2/17/05	0845	98	582	2,630	
2/17/05	1145	99	594	2,630	
2/17/05	1415	99	650	1,990	
2/17/05	1630	99	420	1,990	
2/18/05	0845	99	319	1,950	
2/18/05	1130	99	314	1,950	
2/21/05	0930	95	1,590	5,230	
2/21/05	1200	92	1,350	5,230	
2/21/05	1430	90	1,180	5,610	
2/22/05	1000	86	639	6,420	
2/22/05	1300	88	591	6,420	
02/24/05	1430	94	493	6,233	
02/25/05	0845	86	539	6,200	
03/03/05	1330	96	369	6,210	
03/11/05	1330	89	313	4,300	
03/16/05	1215	86	374	5,950	
03/21/05	1115	92	165	843	
03/25/05	1430	97	84	540	
03/31/05	1310	95	47	268	
04/14/05	1330	82	81	168	
04/29/05	1400	96	30	75	

Station 9426500; Bill Williams River at Planet, AZ					
Date	**Time**	**Suspended sedi-ment, sieve diameter percent <.063mm, mg/L**	**Suspended sediment concentration, mg/L**	**Measured discharge, cfs**	**Notes**
02/24/05	1115	56	761	6,233	point samples collected 5–10 ft from bank at depth of 4 ft
03/03/05	0930	84	304	6,210	point samples collected 5–10 ft from bank at depth of 4 ft
03/11/05	1015	38	537	4,300	point samples collected 5–10 ft from bank at depth of 4 ft
03/16/05	1000	69	313	6,000	point samples collected 5–10 ft from bank at depth of 4 ft
03/25/05	1030	34	144	540	point samples collected 5–10 ft from bank at depth of 4 ft
03/31/05	1020	36	71	324	sediment and discharge measured across channel
04/07/05	1000	72	35	225	sediment and discharge measured across channel
04/14/05	1045	11	53	85	sediment and discharge measured across channel
04/29/05	1015	81	3	28	sediment and discharge measured across channel

Station 9426000; Bill Williams River below Alamo Dam, AZ					
Date	**Time**	**Suspended sediment, sieve diameter percent <.063mm. mg/L**	**Suspended sediment concentration, mg/L**	**Measured discharge, cfs**	**Notes**
3/3/05	1035	0	91	6840	samples collected and discharge measured across channel from cableway

Station 9426630; Bill Williams River at Lake Havasu, AZ				
Date	Time	Suspended sediment, sieve diameter percent <.063mm, mg/L	Suspended sediment concentration, mg/L	Measured discharge, cfs
03/13/06	1515	97	23	3
03/14/06	745	98	25	216
03/14/06	910	99	22	138
03/14/06	1230	100	149	491
03/14/06	1400	100	239	625
03/15/06	825	99	253	1,230
03/15/06	950	98	256	1,250
03/15/06	1230	98	218	1,290
03/15/06	1330	98	210	1,240
03/16/06	805	99	95	685
03/16/06	1035	99	84	631
03/24/06	1000	98	33	194
03/24/06	1105	92	233	329

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