Description of Map Units to Accompany Maps Showing the Distribution of Fine-Grained Deposits Before and After the March 1996 Experimental Flood in the Point Hansbrough Reach of the Colorado River, Grand Canyon National Park, Arizona

by

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The controlled release of high discharges from Glen Canyon Dam in March and April 1996 caused scour and fill of eddy sand bars and channel-margin deposits throughout the 425-km Colorado River corridor between the dam and Lake Mead. Resulting changes in the topography of sand bars caused changes in campsite size and in the distribution of riparian vegetation. Topographic changes in sand bars were measured by several research teams using daily bathymetric measurements, before-and-after-flood topographic measurements, oblique photography, and aerial photography. Analysis of aerial photography provides an opportunity to evaluate the representativeness of detailed measurements made at a few sites.

The accompanying maps describe the distribution of fine-grained sand deposits in the Point Hansbrough study reach, which has been designated as GIS Site 3 by the Glen Canyon Environmental Studies program. Maps showing the distribution of fine-grained sediments in 1935, 1973, 1984, 1990, and 1992 were developed by Leschin and Schmidt (1995) and analyzed by Schmidt and Leschin (1995). Similar techniques were used to develop the maps that accompany this report. Pre-flood air photos were taken at a river discharge of 226 m^3/s on March 24, 1996; post-flood photos were taken at a discharge of 385 m^3/s on April 4, 1996.

Map unit descriptions used in the development of the pre-flood and post-flood maps are included as appendix A. Plates 1 and 2 show the distribution of fine-grained deposits before and after the flood. Plate 3 shows the distribution of eddy complexes, as defined by Schmidt and Leschin (1995) and as redefined using previously published data and the data of this report. An eddy complex is the largest contiguous area of fine sediment deposited as eddy, separation, or reattachment bars in any year of available photography. In some cases, separation and reattachment bars are included as a single eddy complex even though they are not contiguous if other data show that they form within the same persistent eddy.

Areas of net erosion and deposition (Plate 4) were determined by comparison of the pre-flood map (Plate 1) with the post-flood map (Plate 2) using a GIS system. Each map unit has an associated pseudo-topographic level based upon the flow level of the river at the time of deposition of that deposit. A numeric value was assigned in the GIS system to each pseudo-topographic; higher values were assigned to higher-elevation deposits and lower values to lower-elevation deposits. If an area's numeric value changed from a lower value in the pre-flood map to a higher value in the post-flood map then aggradation was recognized as having taken place. If the change was in the opposite direction, degradation was recognized as having occurred. For example; an area in the pre-flood map designated **ff-cm**, is assigned a value of 4. If, in the post-flood map, that area is designated **ef-cm**, it is assigned a value of 5. Since the change is to a greater value aggradation is recognized.

The post-flood aerial photos were taken at a higher discharge than the pre-flood photos. Consequently, a simple comparison between the two maps biases the resulting change map to show more erosion than actually occurred. In order to reduce this bias, the numeric values assigned to the post-flood deposits were modified to account for higher discharges. **Sub**, **wet**, and **wet (perched)** units were all given a numeric value one unit higher than they would have in the case of a simple analysis (Fig. 1). For example, post-flood **wet**, which would have been assigned a numeric value of 3, was assigned a value of 4; the same as the pre-flood **ff** level. The lack of water clarity at the time of the post-flood photos meant that areas designated **river** on the post-flood maps were actually areas of **no data**. To prevent erroneous designation of an area as erosional, areas that were labelled **ff(sub)** on the pre-flood maps and **river** on the post-flood maps were designated as **no change** rather than **erosion**.

Preliminary analysis of the maps shows a consistent pattern of nearshore aggradation combined with offshore degradation within eddy complexes. This agrees with our scour-chain data. Those data show that the nearshore area near the reattachment point was a depositional environment. They also indicate that at some distance offshore from the reattachment point, the environment quickly changed to erosional. The abruptness of the change is also evident in the shapes of post-flood emergent sand bars which are not typically larger than they were before the experimental flood, but they are typically higher. This is true for channel-margin deposits as well as eddy deposits. Another change which is common to the larger eddy complexes is the creation, reworking, and/or deepening of the return current channel.

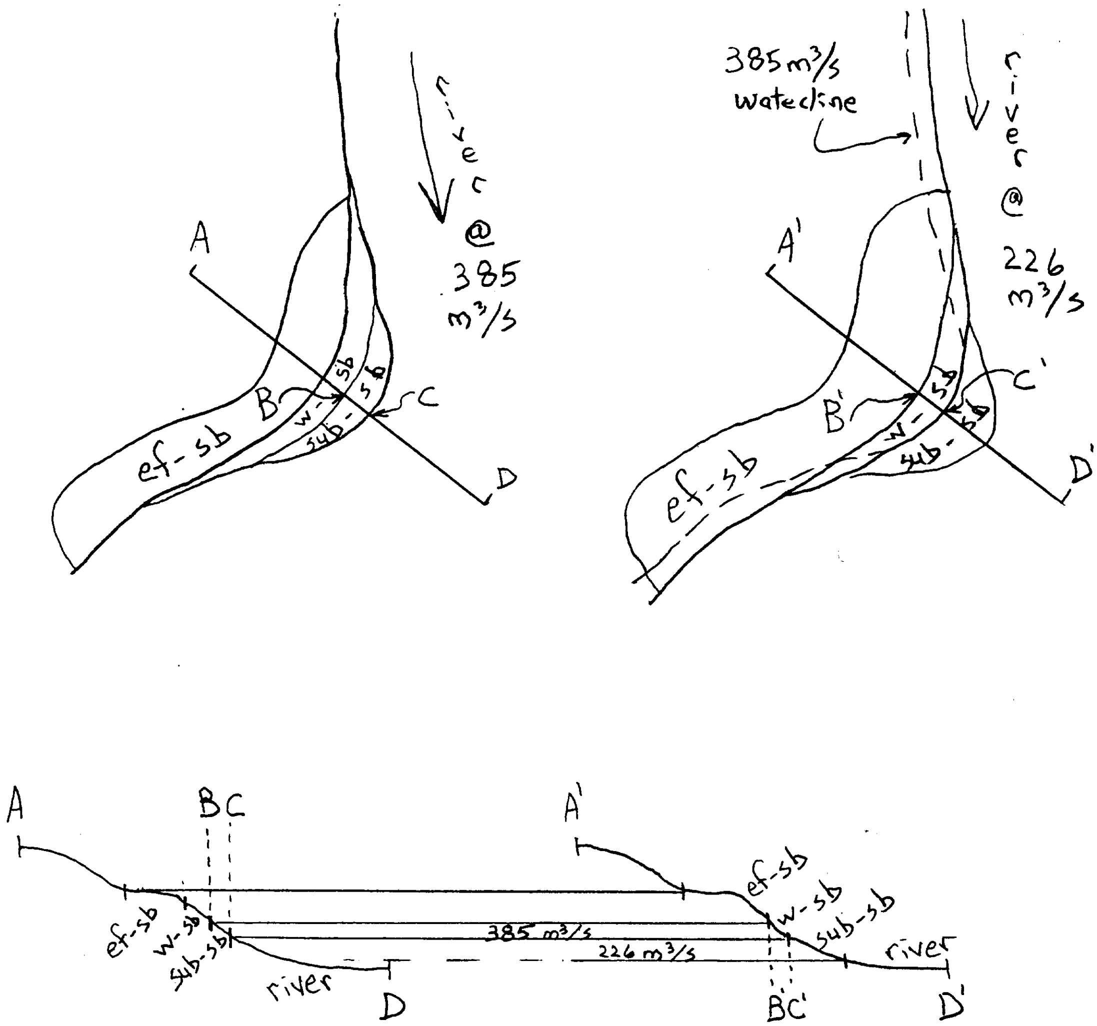

Figure 1. Diagrams showing a hypothetical post-flood deposit at two discharges and how level designations change accordingly.

The areal distribution of post-flood fine-grained deposits is not greatly different than the pre-flood distribution. This is especially true for the larger eddy complexes. The outlines of the larger eddy complexes was rarely extended as a result of adding the 1996 flood data into the eddy complexes. Small eddy complexes showed a different pattern. While the presence or absence of fine-grained deposits in the larger eddy complexes was a good indicator of the presence or absence of fine-grained deposits in that same eddy complex after the flood, the antecedent conditions within an eddy complex of smaller size apparently played little part in determining the presence or absence of flood deposits left behind after the flood recession.

REFERENCES CITED

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Schmidt, John C. and M.F. Leschin, (1995), Geomorphology of Post-Glen Canyon Dam Fine-Grained Alluvial Deposits of the Colorado River in the Point Hansbrough and Litttle Colorado River Confluence Study Reaches in Grand Canyon National Park, Arizona; report to U.S. Bureau of Reclamation, Glen Canyon Environmental Studies, Flagstaff, AZ.

APPENDIX A

DESCRIPTION OF MAP UNITS

ALLUVIUM

ALLUVIAL DEPOSITS OF THE COLORADO RIVER

Topographic levels of channel-side bar and bank deposits formed during and after 1983 and before the 1996 experimental flood

ff(sub) **Fluctuating-flow level(submerged) (1993-1984)**--Coarse- to fine-grained sand, underwater, and visible on aerial photos. Extent of deposits is partially dependent on the quality of each aerial photo, the angle of the sun in the photo, the distribution of shadows in each photo, the electomagnetic wavelength used for photography, and the depth and clarity of the river at the time of photography. There is poor resolution of submerged deposits for some reaches in the 1984 photos because of the high turbidity in the river at that time and in the 1990 photos due to the color infrared wavelengths used. The orthophoto base maps used a different set of photos and so show submerged deposits much better. There is excellent delineation of the submerged deposits in the 1992 and 1993 photos.

ff(w) **Fluctuating-flow level(wet) (1993-1984)**--Coarse- to fine-grained sand with some silt and clay. These deposits appear darker on aerial photos than adjacent or nearby subaerial deposits of similar type. This level typically occurs adjacent to the river or to a **ff(sub)** deposit at elevations within 1 m of the water surface at the time of photography.

ff **Fluctuating-flow level (1993-1984)(formed at discharges less than 890 m^3/s)**--Silty, very-fine- to fine-grained sand with widely ranging colors of light gray, brown, and reddish brown. Exposed thicknesses may exceed 1 m. On aerial photography these deposits appear as clean or sparsely vegetated. They are low-elevation deposits with only a single small scarp between them and the river or are smoothly sloping into **ff(w)**- or **ff(sub)**- deposits or directly into the river. In photos from 1992 and 1993 there may be young vegetation covering the area farthest from the shoreline. The precipitous lowering of the river level just two days prior to the 1984 photography resulted in diagnostic rills appearing on the riverward side of many **ff** deposits. Well-defined bedforms are visible on some **ff**-level deposits especially in 1984 photos.

lc **Little Colorado River flood of winter 1993 level (1993)(formed at a discharge of 990 m^3/s)**--Fresh alluvial sand located downstream of the confluence with the Little Colorado River and, when viewed stereoscopically, appear at a level higher than **ff**. A high-water mark and/or one or two cutbanks are typically present between these deposits and the river. In the 1993 photos these deposits have no new vegetation growing on them but may extend into previously vegetated areas, particularly if that area was previously covered by an **hf** deposit.

hf **High-flow level of 1984-1986(1986-1984)(formed at discharges between 890 and 1400 m^3/s)**--Medium- to very-fine grained sand, with some silty layers, silt and clay drapes over bar surfaces and in return channels. Saltcedar knocked over in the 1983 flood is commonly sprouting new sapling growth. Modern debris such as plastic bottles, lighters, and processed lumber is present in the deposits. Identification on aerial photos is typically dependent upon the appearance of the deposit in the 1984 photos. In that set of photos a number of features are useful for identifying **hf** deposits. **Hf** deposits are darker than and generally have Munsell gray scale values half a unit less than adjacent **ff** deposits. This is true whether the deposits are both in shadow or both in sunlight. The color difference between **hf** and **fs** deposits is more variable. **Hf** deposits, viewed stereoscopically, appear at higher elevations than **ff** deposits and at lower ones than **fs** deposits. Commonly, there are 2 cutbanks between the **hf** deposit and the river. One of these is developed in the **hf** deposit and other is in the adjacent **ff** deposit. Less commonly there is a cutbank between the **hf** deposit and an adjacent **fs** deposit. A high-water mark defined by features such as color differences, texural differences, or possibly a drift line is often visible between the **hf** deposit and an adjacent **fs** deposit. Typically, a high-water mark is visible between an **hf** deposit and an adjacent **ff** deposit. Dune bedforms are sometimes present and are distinct from the sharper and generally smaller bedforms often evident on the **ff** deposits. All bedforms are assumed to have been developed while the bars were submerged and active. Vegetation covering **hf** deposits is dominated by trees and/or large bushes. This vegetation often has a water-swept appearance. Aerial photos from 1990, 1992, and 1993 rarely show any of these features. Some small **hf** deposits are identifiable on the basis of longitudinal correlation.

fs **Flood level of summer 1983 (June-July)(formed at discharges between 1400 and 2700 m^3/s)**--Medium- to very-fine-grained sand, very well-sorted to well-sorted, distinctive very light gray with some salt-and-pepper coloring. Internal structures include ripples, climbing ripples, cross-laminations, and planar bedding. Plastic bottles, processed lumber, and other modern-era debris are found buried in this level. Photo identification is best done using 1984 photos. Any smooth, planar sand deposit in that set of photos that fails to meet the criteria for a lower level, is mapped as **fs**. Cutbanks developed in **fs** deposits are rarely as sharp as those found in **hf** or **ff** deposits. Color as a guide to distinguish **fs** deposits is not reliable. Mature trees are the dominant vegetation present on **fs** deposits. Some grasses or young bushes may sparsely cover an **fs** deposit in 1984. There is often a driftwood line on the shoreward side of an **fs** deposit.

Topographic levels of channel-side bar and bank deposits formed during the 1996 experimental flood

sub — **sub**--Coarse- to fine-grained sand, underwater, and visible on aerial photos. Extent of deposits is partially dependent on the quality of each aerial photo, the angle of the sun in the photo, the distribution of shadows in each photo, and the clarity of the river at the time of photography.

wet — **wet**--Coarse- to fine-grained sand with some silt and clay. These deposits appear darker on aerial photos than adjacent or nearby subaerial deposits of similar type. This level typically occurs adjacent to the river or to a **sub** deposit at elevations within 1 m of the water surface at the time of photography.

wp — **wet perched**--Silty fine-grained sand that appears wet in photos but is located too far from the river to reasonably expect it to still be wet or in a position known to be more than a vertical meter from the water surface at the time of photography.

ef — **experimental flood**--Coarse- to fine-grained sand appearing clean and fresh in aerial photos taken immediately after the flood recession. Deposit forms are generally sharp and well-defined. Deposits are typically lighter colored than the nearby older fine-grained deposits. In some vegetated areas and in some low-velocity areas deposits may appear wet or darker due to higher silt content.

Depositional facies of channel-side bar and bank deposits

Bars formed in recirculating currents

eb — **Undifferentiated eddy bar**--Fine-grained sediment downstream from debris fans, talus cones, bedrock promontories, and very sharp meander bends.

sb — **Separation bar**--Very-fine-grained sediments on the downstream side of debris fans and adjacent to eddies. Subaqueous bedforms visible on the aerial photos have slipfaces facing upstream. The highest part of these bars is typically at the upstream end of the deposit.

rb — **Reattachment bar**--Fine-grained sediment within a channel expansion, with a return-current channel along the shoreward side of the deposit. Subaqueous bedforms are often present and well-defined on this facies at levels below **ff**. The topographic high for a deposit of this facies is typically at the downstream end of the deposit.

Riverbank deposits

cm — **Channel margin**--Fine-grained sediment in long, narrow bands parallel to the river with occasional levee topography; also fine-grained deposits of unknown origin.

Topographic level of gravel deposits

ff(sub) **Fluctuating-flow level (submerged)**--Gravel visible on aerial photos and underwater. River surface wave patterns characteristic of shallow water may, on the 1984 and 1990 photos, substitute for the clear visibility criteria if these deposits occur in an area that has submerged gravel in 1992 and 1993.

ff(w) **Fluctuating-flow level (wet)**--Gravel, wet at the time of photography, as indicated by a darker color. There may be pockets and pools of water visible within the unit's outline.

ff **Fluctuating-flow level**--Gravel deposits are mapped as this level based upon the relative position and level of adjacent fine-grained deposits and upon longitudinal profiles developed from 1990 geomorphic mapping and topography.

hf **High flow level of 1984 to 1986**--Gravel deposits are mapped as this level based upon the relative position and level of adjacent fine-grained deposits and upon longitudinal profiles developed from 1990 geomorphic mapping and topography.

Depositional facies of gravel deposits

gv **Gravel**--Unconsolidated clasts, cobble to boulder-size, occasionally with a coarse-sand matrix, sub-rounded to rounded clasts of local Proterozoic and Paleozoic formations. Gravel bars occur as mid-channel and channel-side deposits.

COLLUVIUM

df **Debris flow**--Gravel, cobble to boulder size with scattered boulders larger than 1-2 m consisting mainly of Paleozoic limestone and sandstone, clasts angular to subangular; clast-supported texture; matrix is moderate-reddish orange (10R 6/6) coarse silt to very-fine sand. Forms conspicuous cones of debris flow and rock-slide origins.

tal **Talus**--Gravel, pebble to boulder size; angular, flat and platy; forms cones at base of bedrock.

EOLIAN DEPOSITS

es **Eolian sand**--Fine-grained sand deposits, often with dune-like features, commonly found on **ht** deposits and large, high-relief gravel bars. Reworking of a deposit between times of photography is considered good evidence of eolian sand if the deposit is topographically higher than any level the river reached during those same intervening years.

BEDROCK

br **Bedrock**--Undifferentiated Precambrian and Paleozoic sedimentary and igneous rocks.

EXPLANATION

Unit descriptions have the inundation level listed first followed by a hyphen and then the deposit facies. For example; **ff-cm** is the designation for a channel-margin deposit inundated by the river at fluctuating flow levels. **Fs-gv** is the designation given to a gravel deposit that was underwater during the flood of 1983. Multiple level or facies designations indicate uncertainty. For example; a unit labelled **hf-cm/gv** is an area of gravel with some alluvial sand that was inundated during the high flow years of 1984-1986. A unit labelled **fs/hf-eb** indicates uncertainty in the formative discharge. The deposit could have been formed by either the **fs** level flood or an **hf** level flood or by a combination of the two.