GILA RIVER SEDIMENT PROGRAM – BED MATERIAL ANALYSIS

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Abstract The 20-mile stretch of the Gila River within Maricopa County, Arizona is impacted by rapid urban growth. These impacts include encroachment on the river, sand and gravel mining and proliferation of salt cedar. This area is the subject of several hydrologic, hydraulic and sediment studies and includes the Flood Control District of Maricopa County (FCDMC), Army Corps of Engineers, local agencies, developers and sand and gravel operators.

As part of these projects bed material samples were collected. The average size of the samples collected from these projects ranged from less than 0.07 mm to 20mm. Concerns were raised by the FCDMC regarding the range of sizes from each of the projects. These samples were being used to determine the following:

- Regulation of sand and gravel mining on the river.
- Encroachment into the river by developers.
- Constriction of the river by bridges.

The FCDMC developed a project to characterize the bed material size of the Gila River. As part of this project the following was completed:

- 32 test pits up to 10 feet deep were dug in the river using a backhoe and 59 bed material samples were obtained along the 20-mile reach.
- Size gradation analyses of the samples were performed.
- Dr. Pierre Julien and Dr. Paul Mielke of Colorado State University developed a statistical analysis procedure called Multi-Response Permutation Procedure (MRPP) to classify the bed material.
- The procedure was used to evaluate bed material samples that were collected by others.

The study has the following conclusions:

- The sampling identified three material types in that reach of the Gila River; Type A is deposited wash load in the overbanks, Type B is a predominantly sand bed material, and Type C is a predominantly gravely bed material.
- Soil in the overbanks is typically composed of very fine sand, silt and clay. The source of that material is upland watershed wash load which is deposited during over bank flooding. This material is classified as Type A using MRPP.
- A composite mix of two or more of those types is not strongly indicated. Occasionally, two of those sediment types occur at the same location at different depths. Where that stratification occurs and Type A material is present, the Type A soil is the upper most material.
- Sampling to depths of up to 10 feet did not necessarily provide additional information as to the bed material size gradation.
- In nearly 75 percent of the pits the material was essentially of uniform grain size throughout the depth.
- The source and distribution within the river bed of the two distinct bed materials is not known.

- Surface deposits of gravel and cobbles occur throughout the Gila River study area. Those gravel deposits do not represent the bed material of the river. Rather those deposits are the result of selective transport of finer bed material leaving a veneer of coarser gravel and cobble.
- The occurrence of Type B and Type C bed material cannot be predicted based on the presently available data. For sediment transport modeling and estimate of scour depths, the use of the finer bed material size gradation, Type B, may be justified to obtain maximum scour depths.

The paper will present the environmental and regulatory constraints to sediment sampling in desert southwest rivers, the development and use of the statistical program to classify bed material samples, the spatial analyses of the bed material in that reach of river, and the unique occurrence of what appear to be two distinct bed material size gradations in the river and the possible cause of that occurrence.

INTRODUCTION

The purpose of this project is to characterize bed material size gradation of the Gila River between 115th Avenue and State Route 85 (SR85), for the Flood Control District of Maricopa County (District). The major elements of the project include:

- selecting, identifying and inspecting bed material sampling sites in the project study area,
- obtaining bed material samples and documenting the sample sites,
- performing size gradation analyses of samples,
- developing a statistical analysis procedure (MRPP) to classify bed material samples (performed by Dr. Pierre Julien and Dr. Paul Mielke),
- performing statistical analyses of the size gradation data.
- using the statistical analysis procedure to evaluate bed material samples that were collected by others,
- analyzing the data to identify spatial trends, if any, and
- to the extent practical, characterize the bed material of the Gila River in the study area.

Location The study limits extend approximately 20 miles upstream from SR85 to Avondale Boulevard (115th Avenue) (see Figure 1). There are five bridges within the study area; Bullard Avenue, Estrella Avenue, Cotton Lane, Tuthill and SR85. Two major washes enter the river within the study area, Agua Fria River and Waterman Wash. The Salt River and Gila River confluence is just upstream of 115th Avenue.

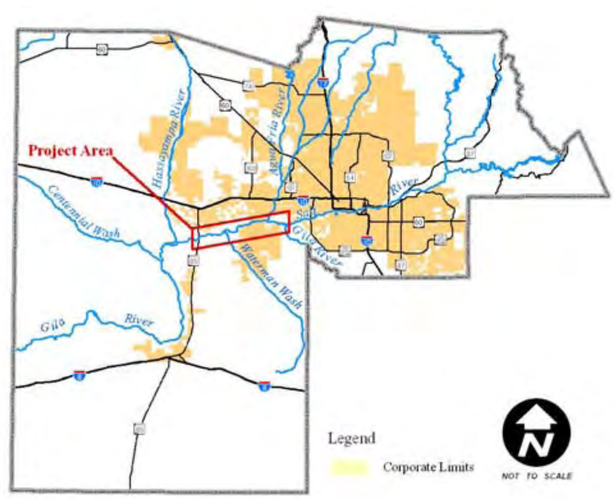

Figure 1 Vicinity Map.

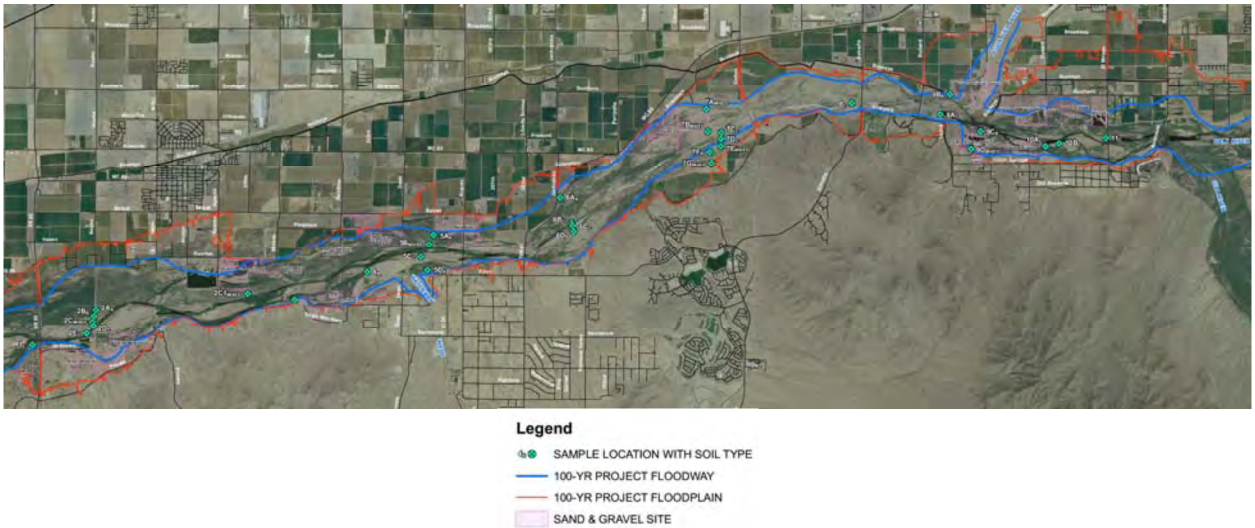

Figure 2 Location of Test Pit Sites.

OTHER SAMPLING EVENTS

The Gila River within the project area is the subject of several recent large scale hydrologic, hydraulic and sediment studies. The studies include Salt – Gila River Floodplain Delineation Study, Hydraulic Design of Tres Rios North Levee, El Rio Watercourse Master Plan and Cotton Lane Bridge. Also several sand and gravel operators have collected bed material samples in the Gila River. Data from these sources were incorporated into the project. A summary of previous sampling event and samples collected as part of this project are summarized in Table 1. The sample locations are shown on Figure 2.

Table 1 Summary of Gila River Bed Material Size Gradation Data.

Source of Samples **(1)**	**No. of Samples** **(2)**
1. For this District project by Stantec:	
Used by Julien and Mielke to develop MRPP	29
Used by Julien and Mielke to test MRPP	18
Used by Stantec to classify samples	12
	59
2. For the El Rio WMP by Stantec (Stantec, 2005)	12
3. For Burlingame by Construction Inspection & Testing Co.	8
4. For the Gila River at Airport Road crossing by Terracon	13
5. For the Cotton Lane Bridge CLOMR by River Research & Design (R2D, 2008)	4
6. For Cotton Lane Bridge by Richer-Atkinson-McBee & Associates for Michael Baker Jr., Inc. (RAM, 2005)	7
7. For Tres Rios North Levee by WEST Consultants, Inc. (WEST, 2004)	7
	110

DATA COLLECTION

During March and May 2009, 32 test pits were excavated in the Gila River to depths ranging from 2 to 10 feet below ground surface (bgs) using a backhoe. The test pits were located to obtain bed material along the length and width of the river. They were also located such that a backhoe could access the site. The maximum depth for the excavation was set to 10 feet bgs for safety reasons. Excavations were stopped when groundwater was encountered or for safety reasons. The test pits were backfilled with the material excavated from the pits. In some excavations the groundwater was as shallow as 2 feet bgs. At least one grab sample (approximately 1 cubic foot) from the backhoe bucket was collected in each test pit. Additional samples were collected at changes in soil type or at the bottom of the test pit. For instance, in Test Pit 8 one sample was collected at 1 foot bgs and at the bottom of the pit at 8 feet bgs. The excavation was stopped at 8 ft bgs for safety reasons. The soil encountered in the test pits were examined, visually classified, photographed and logged. Fifty-nine samples at various depths were collected for laboratory analysis. Figure 3 shows the results of the sieve analysis.

For the purpose of hydraulic analyses of sediment, 0.062 mm is used as the demarcation between silt and very fine sand. For these mechanical sieve analyses, the ASTM sieve #200 is used as the upper size limit of silt. The composition of fine material, silt and clay, is not important when characterizing bed material. In this study, 0.075 mm is used to define fine sediment material.

In areas where the surface material consisted of coarse gravel and cobbles, pebble counts were conducted. The pebble count data were collected by first laying a tape across the channel. A sampling interval was selected so that 50 to 75 measurements were taken at the section with a sampling interval larger than the visual estimate of the D_{50}. The intermediate axis of each sediment grain under the sampling interval was measured. For sediment grains too small to be measured, a sand grain sizing folder was used to estimate the sediment size. Measurements of the sediment grains were converted to a percent smaller size fraction. Figure 4 shows the results of the pebble count analyses.

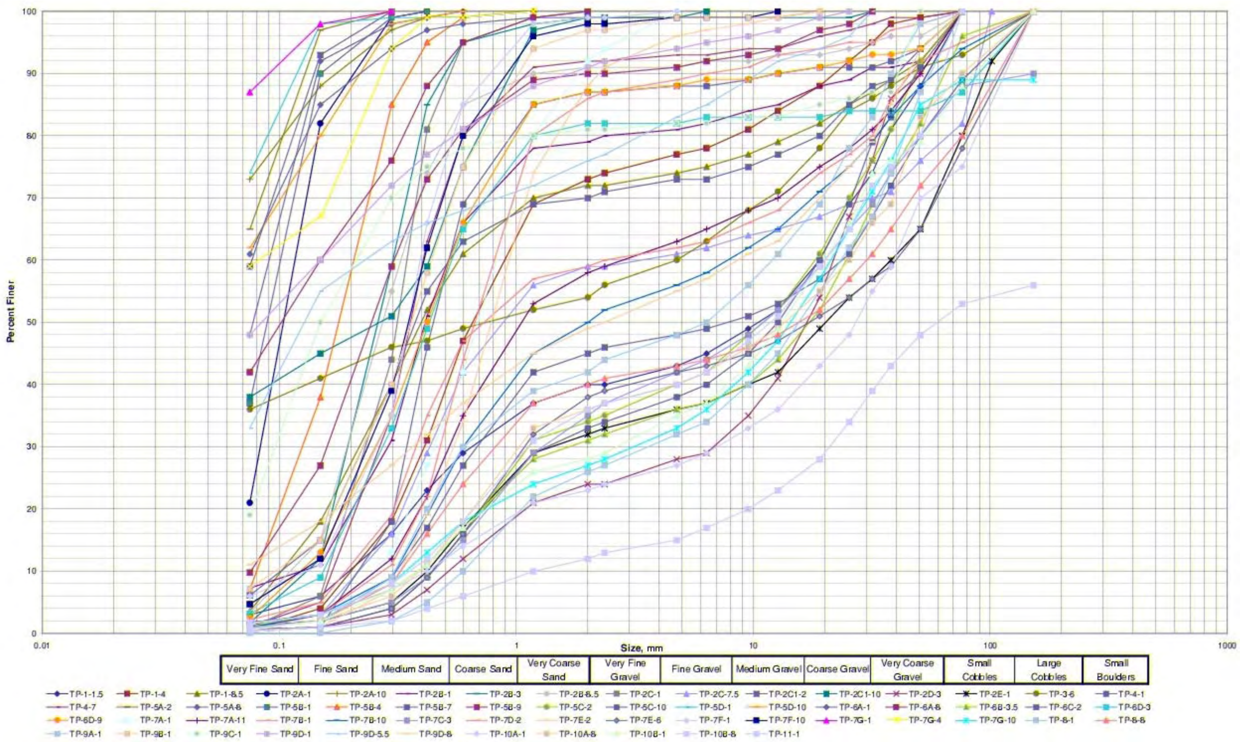

Figure 3 Size gradation of samples from the Gila River Sediment Program Test Pits – All data.

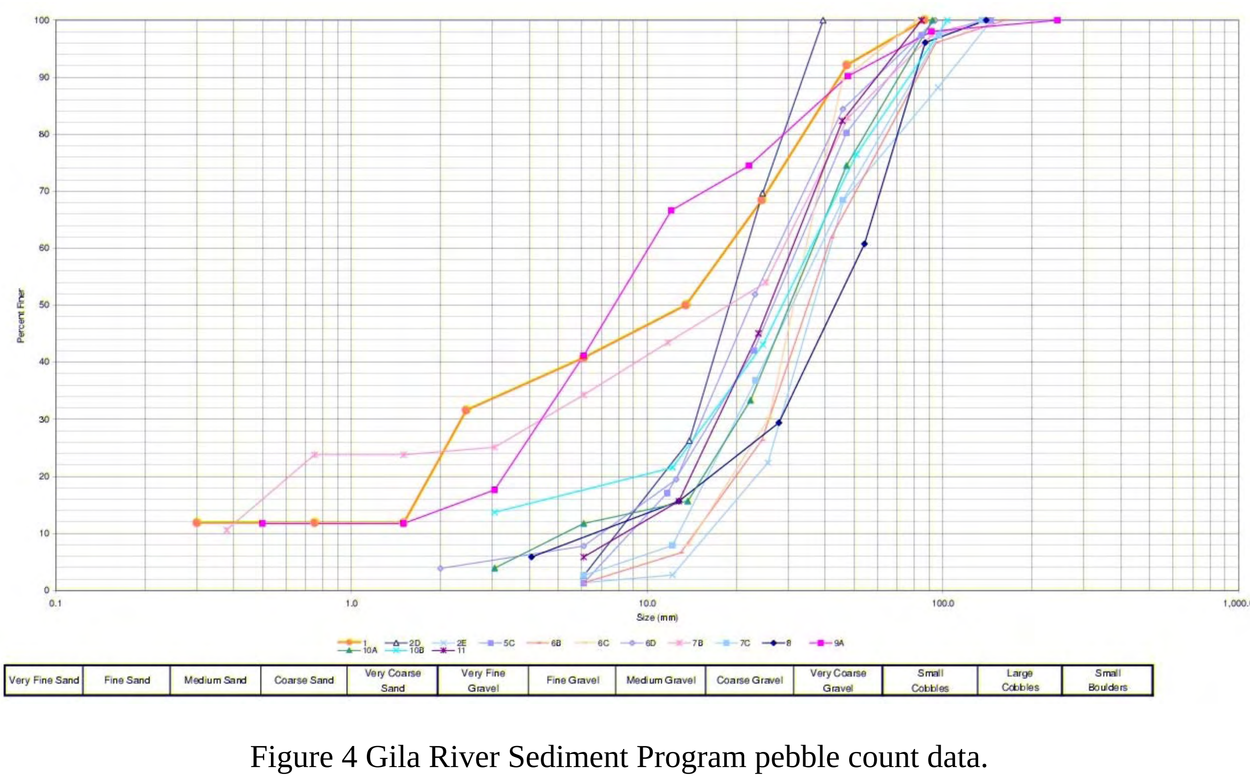

Figure 4 Gila River Sediment Program pebble count data.

ANALYSES AND RESULTS

Stantec was assisted in the statistical analysis of the data by Dr. Pierre Julien, Dr. Paul Mielke, and Dr. Anne Paris of Colorado State University. Using some of the data, they wrote a Fortran program, Multi-Response Permutation Procedure (MRPP), that can be used to classify bed material size gradation samples into one of three types. That program was subsequently used to classify the currently available bed material size gradation data, summarized in Table 1, into those types.

The analysis was conducted in the following steps:

1. Size gradation data and statistics from the 47 samples obtained during March 18-27, 2009 were sent to Julien and Mielke. They selected data from 29 of those samples to develop a statistical test program, MRPP. They used the data from the remaining 18 samples to test the MRPP program. The results of the statistical testing and the MRPP program are presented later.
2. The size gradation data obtained during May 4-5, 2009 were subjected to testing using the MRPP program.
3. The other size gradation data (items number 2 through 7 in Table 1) were subjected to testing using the MRPP program.
4. The results of steps 1 through 3 provided a classification of the bed material samples identified in Table 1 into three types: Type A, Type B and Type C. That classification is described later. Using those results, Stantec performed an inspection of the spatial distribution of those bed material types in the study reach of the Gila River.

Upon visual inspection of the initial set of 47 size gradation graphs (see Figure 3 for all 59 graphs), the following was noted;

1. There is a wide range of size gradation variability from fine particle sizes (less than 0.075 mm) to large cobbles (greater than 128 mm).
2. There are samples where more than 50 percent is silt and clay (finer than 0.075 mm).
3. There are samples where more than 50 percent is gravel and cobble (larger than 2.0 mm).
4. There are samples that are predominantly sand (between 0.075 mm and 2.0 mm).

From the data set of 47 samples that were sent to Julien and Mielke, and noting the above observations, 29 samples were selected that represent three distinct groups of size gradation: Group A, Group B and Group C. It is noted that the term “Group” is used with A, B or C to distinguish the 29 samples that were used to develop the statistical program, MRPP, while “Type” is used with A, B or C to classify any sample as to its size gradation character. Using the statistics from that data set, Mielke wrote the Fortran code for MRPP. Group A is predominantly silt and clay, Group B is predominantly sand, and Group C is predominantly gravel. Upon completion of the MRPP code, Julien and Mielke tested the program using the remaining 18 samples. Of the 59 samples from this project, the size gradations graphs of the 12 samples that are Type A are shown in Figure 5, the 21 samples that are Type B are shown in Figure 6, and the 26 samples that are Type C are shown in Figure 7. MRPP was also used to classify the 51 bed material samples from sources 2 through 7 of Table 1.

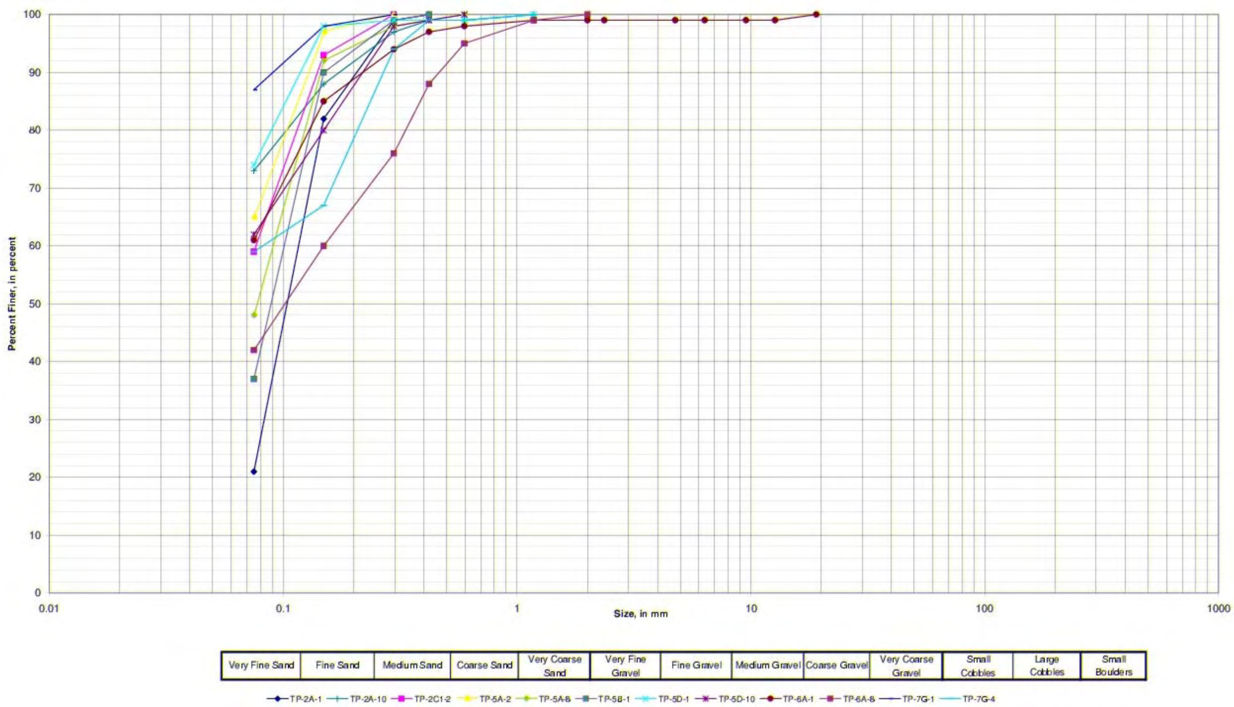

Figure 5 Size gradation of samples from the Gila River Sediment Program test pits – Type A.

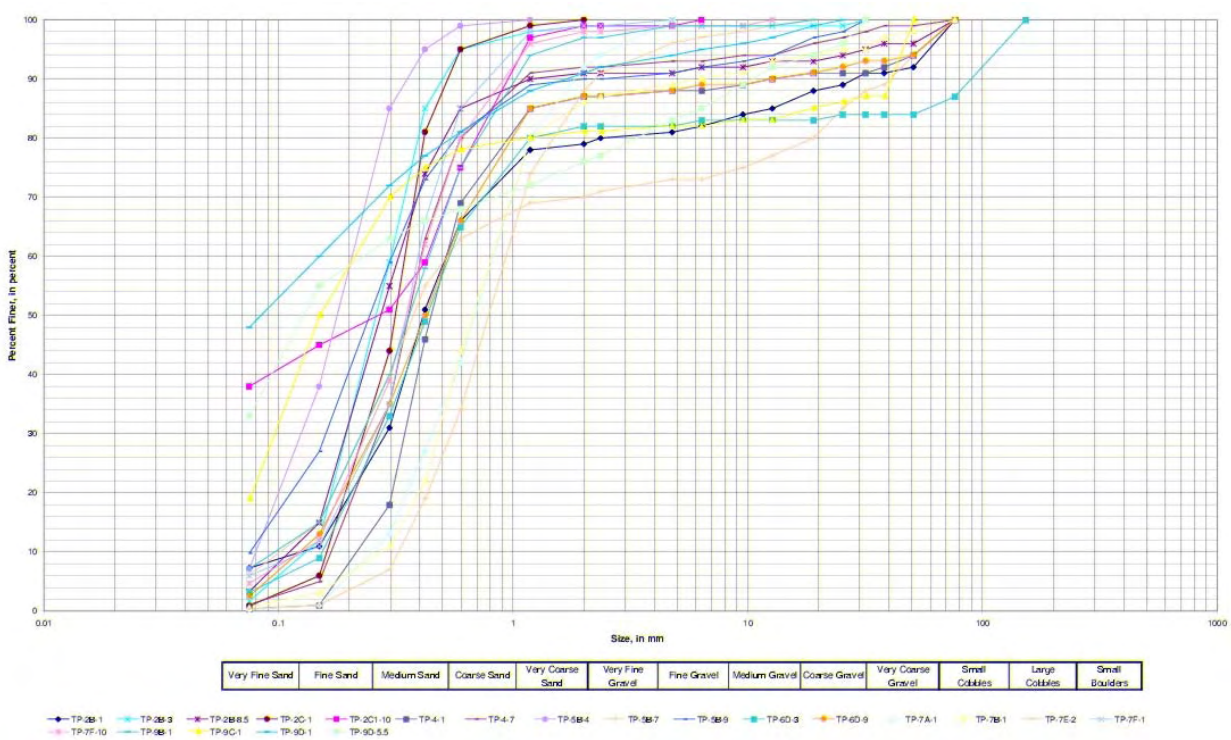

Figure 6 Size gradation of samples from the Gila River Sediment Program test pits – Type B.

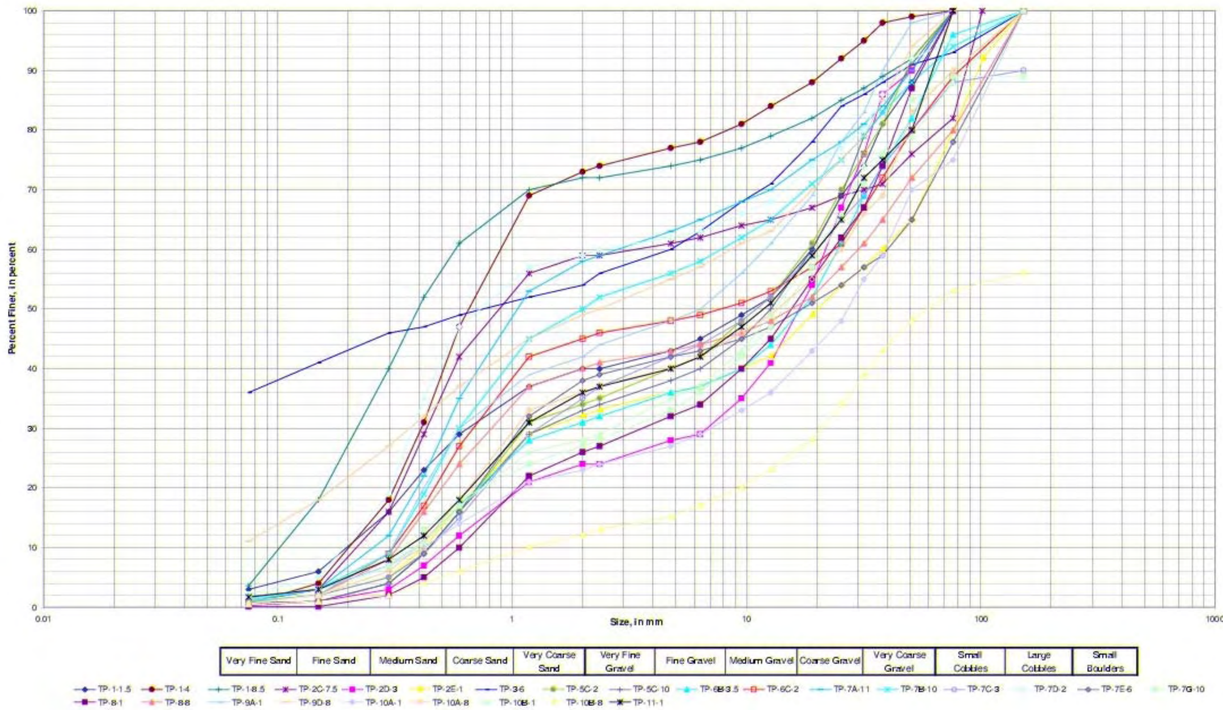

Figure 7 Size gradation of samples from the Gila River Sediment Program test pits – Type C.

The spatial occurrence of those three soil types was investigated. To investigate the occurrence of soil type with depth, the 59 samples from the current project were used. In Figure 8, the depth of sample from each test pit is plotted along with its class Type A, B or C. Figure 8 shows the excavated depth of each pit and the depth to groundwater, if encountered in the pit. Figure 8 also indicates whether the soil in the pit was uniformly Type A, B or C, or if it was a mix of soil types.

To investigate aerial spatial distribution, the type of each sample is located on an aerial photograph of the study area in Figure 9. In that plate, the sample number and Type A, B or C is shown for the 110 samples. To facilitate the interpretation of that data, Figure 9 shows the soil type of each sample plotted on the aerial photograph with a color code to distinguish the soil type. The following is noted concerning the data depicted on Figure 9:

1. The study area from the confluence of the Salt River with the Gila River downstream to Tuthill Bridge has a greater density of sampling than the study area from Tuthill Bridge downstream to SR85.
2. Based on the sampling that is currently available, bed material Type C is the dominant bed material from the confluence of the Salt and Gila Rivers to Tuthill Bridge. However, the lack of comparable sampling frequency downstream of Tuthill Bridge may not adequately represent the occurrence of Type C in that reach.
3. Type B bed material occurs with about the same frequency throughout the study area.
4. Type B and C bed material generally occur in less densely vegetated sections of the river and in near-term active braids of the river.
5. Type A soil generally occurs in densely vegetated overbank areas of the floodplain.

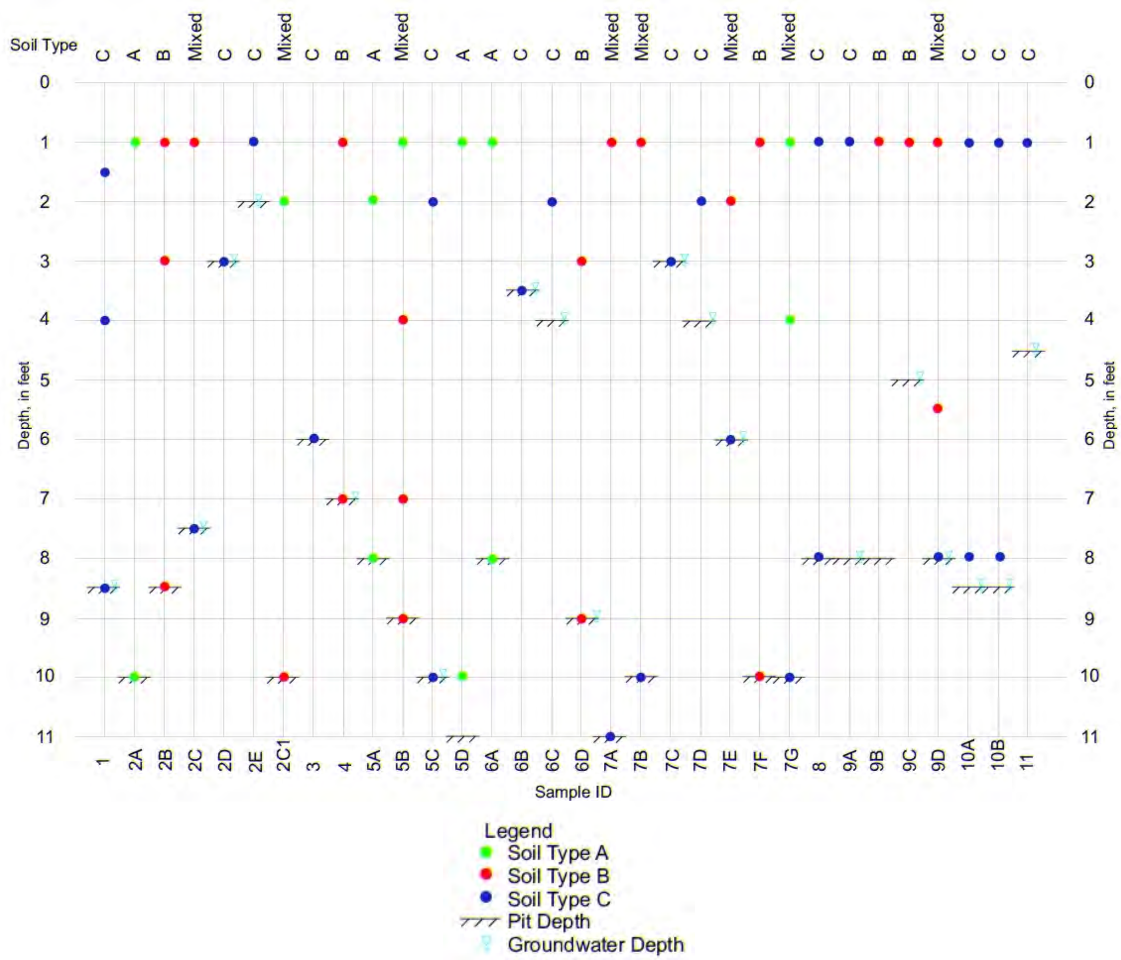

Figure 8 Comparison of soil type in each pit and depth of sample.

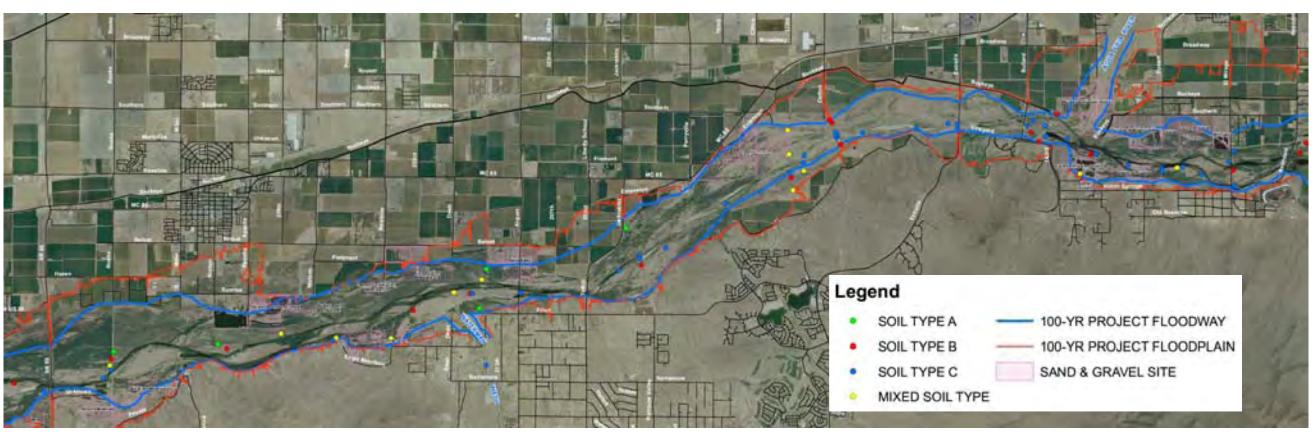

Figure 9 Spatial distribution of samples by soil type.

The number of times Type A, B or C material occurs relative to depth of sample is shown in Figure 10. From that analysis, it is noted that more than 50 percent of all samples were obtained at a depth of 3 feet or less. It is noted that this statistic is biased due to operational factors in that a sample is almost always (30 of 32 pits) extracted from the top 3 feet of the pit, but deeper samples are not necessarily obtained, or are distributed between 3 and 11 feet.

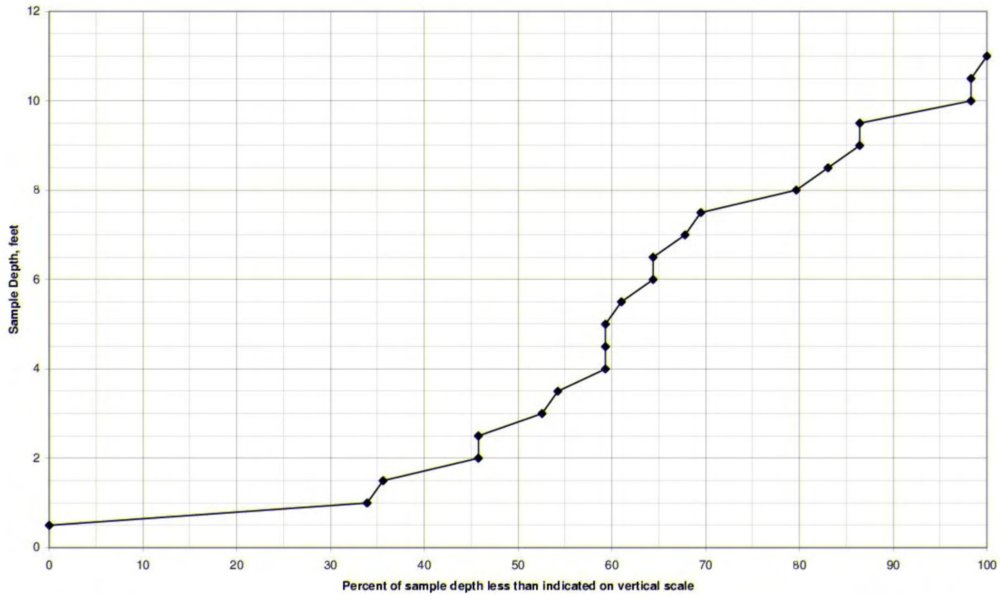

Figure 10 Frequency of Sample with Depth.

A similar frequency graph was prepared using the data for material Types A, B and C and those results are presented in Figure 11. In Figure 11, it is noted that the frequency of encountering either Type B or C material is about the same regardless of depth.

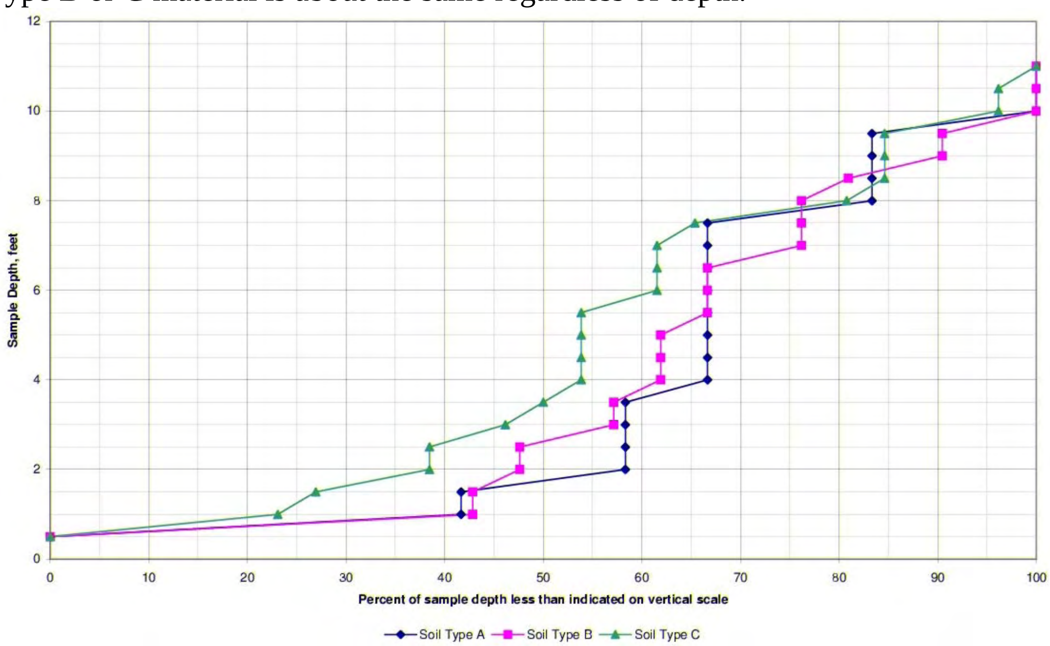

Figure 11 Frequency of sample with depth for Soil Types A, B and C.

An analysis was performed of the uniformity of material in the pits. Uniformity is a measure of consistency of material type in a test pit. A pit of high uniformity contains all one material type.

The results are presented in Table 3 and illustrate that about 75 percent of the pits contained only one material type and that 25 percent of the pits contain two material types. None of the pits contained three material types.

Table 3 Analysis of Uniformity of Bed Material in the Test Pits (all pits).

Soil Type	Test Pits	No. in Group	% of Total
"A"	2A, 5A, 5D, 6A	4	13%
"B"	2B, 4, 6D, 7F, 9B, 9C	6	19%
"C"	1, 2D, 2E, 3, 5C, 6B, 6C, 7C, 7D, 8, 9A, 10A, 10B, 11	14	44%
"A" & "B"	2C1, 5B	2	6%
"B" & "C"	2C, 7A, 7B, 7E, 9D	5	16%
"A" & "C"	7G	1	3%

Although 11 of the 32 pits had only one sample that does not bias the results. If the pit, regardless of the depth, would have indicated nonuniformity of material, additional samples would have been obtained. Therefore, a pit with only one sample contained uniform bed material of one type.

CONCLUSIONS

1. Soil in the Gila River overbanks is typically composed of very fine sand, silt and clay sized particles. The source of that material is fine, suspended load during overbank flooding that settles on the floodplain due to low velocity (energy) flows as a result of high flow resistance from dense vegetation. That material is classified as Type A in this study. It represents "wash load" that enters the river during upland watershed runoff. The source of that sediment is predominantly watershed soil erosion and some amount of river bank erosion. That material is not bed material and it does not represent the active channel bed material size gradation. That material is susceptible to reintrainment as suspended load during floods if the vegetation is removed or as a result of lateral migration of braids in the Gila River. That material, once entrained in the flow, will remain in suspension until the velocity (energy) is low enough to allow settling of the suspended particles.
2. The bed material of the Gila River in the study area is represented by two general size distributions. Type B is composed mostly of fine to coarse sand. Type C is composed of mostly very coarse sand, gravel and some small cobbles.
3. Type B, sandy, bed material is less frequent than Type C throughout the study area, although current data tends to indicate a greater frequency of it occurring downstream of Tuthill Bridge compared with upstream of that bridge.
4. Type C, gravely, bed material is the dominant bed material between the confluence of the Salt River with the Gila River downstream to Tuthill Bridge. This conclusion may be biased by the greater frequency of sediment sampling in that reach of river.
5. Generally, the sediment in the Gila River floodplain can be classified with confidence as Type A, B or C. A composite mix of two or more of those types is not strongly indicated. Occasionally, two of those sediment types occur at the same location at different depths. Where that stratification occurs and Type A material is present, the Type A soil is the upper most material.

6. Sampling to depths of up to 10 feet did not necessarily provide additional information as to the bed material size gradation. In nearly 75 percent of the pits the material was essentially of uniform grain size throughout the depth, although this conclusion is biased due to the frequency of pits at 3 feet deep, or less.

7. The source and distribution within the river bed of the two distinct bed materials is not known. Two postulates are offered; either the two bed materials are derived from different upland sources, or it is the result of selective transport of finer grain sizes during floods and subsequent deposition of that material during flood recession. In the first case, it is possible that the finer grain size material (Type B) is introduced from the Gila River, while the coarser material (Type C) is delivered from the Salt River system. Alternatively, it is possible that segregation of Type B material from parent Type C material could be the result of winnowing of finer bed material during floods. However, that process would be expected to produce more of a graded mix of Type B and Type C material. The size gradation graphs of Figures 6 and 7 do not strongly suggest that process. Regardless of the source of Type B and Type C bed material, those materials clearly comprise the vast majority of the bed material of the Gila River in the study area. Those materials are interbedded deposits. There is a greater occurrence of Type C material upstream near the confluence of the Salt and Gila Rivers. The materials are randomly segregated downstream of the Agua Fria River confluence.

8. Surface deposits of gravel and cobbles occur throughout the Gila River study area. The size gradation of those deposits was determined by pebble count. The results are shown in Figure 4. Those gravel deposits do not represent the bed material of the river. Rather those deposits are the result of selective transport of finer bed material leaving a veneer of coarser gravel and cobble. Due to the extreme range of discharges in the Gila River, those surficial deposits zones are transitory and will be subject to mobilization during episodic floods. That thin veneer of gravel deposit does not constitute a stable armouring of the bed of the river or provide any reasonable degree of protection against bed scour or bank erosion.

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