FINAL

Two-Dimensional Modeling and Analysis of Spawning Bed Mobilization, Lower American River

Prepared for

U.S. Army Corps of Engineers
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1. INTRODUCTION

1.1 General

The Lower American River (LAR) is a 23-mile length of the American River that flows from Folsom Dam to the Sacramento River. Modifications to the existing outlets at Folsom Dam, that would allow releases to match inflows during the early portion of the storm hydrograph, have been proposed by the U.S. Army Corps of Engineers (USACE). Under existing operational conditions, releases are kept to the capacity of the outlets (32,000 cfs) until the pool elevation reaches the spillway. At that point the flow releases are increased. The proposed outlets would be able to release flows up to the objective release of 115,000 cfs. Proposed modifications would increase the frequency of flows above 32,000 cfs in the Lower American River. The duration of the peak flows, however, would be shorter under proposed conditions than the duration of the 32,000 cfs releases under existing conditions. In their Coordination Act Report (CAR) addressing these proposed modifications (Schoenberg 2000), the U.S. Fish and Wildlife Service (USFWS) cautioned that the change in flow conditions may adversely impact fisheries habitat through the mobilization and subsequent loss of spawning gravels and the destruction of redds. In response to the CAR, the USACE initiated this project, which was conducted to analyze the potential for spawning bed materials to mobilize at various flow conditions on the Lower American River.

1.2 Purpose and Scope of Project

The primary purpose of this project was to develop a two-dimensional model of the upper 10 miles of the Lower American River, extending the existing model to Nimbus Dam. The model was then used to analyze a range of flow conditions and the potential for those flows to mobilize existing spawning bed materials. The project scope consisted of the following main tasks:

- *Data Collection and Field Review* – This task included assembling data from various sources and conducting a field visit to collect additional bed material samples and identify areas that could complicate model development.

- *Develop and Calibrate Hydraulic Model* – This task called for the development of a two-dimensional hydraulic model from RM 12 to 22 (upper model) that would connect with and extend an existing model covering the lower 12 miles (lower model). Work under this task also included calibration of the upper model to the 1997 flood event, which is the same calibration event used for the lower model.

- *Hydraulic Model Runs* – The calibrated model was used in this task to run simulations for a range of flow conditions.

- *Analysis of Spawning Bed Mobilization* – This task consisted of using the results from the hydraulic model runs to analyze the potential for mobilization of bed materials under each of the modeled flow conditions.

1.3 Acknowledgements

This project was conducted for the USACE, Sacramento District under a contract with CH2M-Hill, Sacramento. Ms. Patricia Roberson was the project lead for the USACE. Tom Smith was the project manager for Ayres Associates. Matt Franck provided coordination and contract management for CH2M-Hill.

Several individuals and agencies supported this project by providing data and information. Kris Vyverberg of the California Department of Fish and Game (CDFG) provided spawning habitat data for the Lower American River, including bed material sample data, redd surveys, and aerial maps delineating habitat areas. MBK Engineers, as a consultant to the Sacramento Area Flood Control Agency (SAFCA), provided high water mark data from the 1997 flood event, including surveyed elevations, maps, and descriptions of surveyed points that were used in the calibration of the hydraulic model. The USACE provided topographic mapping data used to construct the model as well as stage and flow hydrograph data for the 1997 flood event used to determine boundary conditions.

1.4 Report Format

This report focuses on the background, purpose, and findings of this project. It provides only a general discussion of the methodology and assumptions used in the hydraulic modeling and spawning bed mobilization analysis. A detailed description of the technical aspects of the project is provided in Section 2 for the interested reader. The **Appendix** includes particle size distribution curves for spawning bed samples taken within the project reach. The results of the hydraulic modeling are presented in the Plates in the **Attachment**.

2. BACKGROUND

2.1 Characteristics of the Lower American River

The Lower American River flows for a distance of approximately 23 miles from Nimbus Dam to its confluence with the Sacramento River in the city of Sacramento as shown in **Figure 1**. Flood control levees are located on the north (right) bank of the river up to approximately RM 14. On the south (left) bank levees are located up to approximately RM 12. The 23 miles of the Lower American River can be divided into three distinct reaches that differ in hydraulic, geomorphic, geometric, and sediment properties.

The lower 5-mile reach from the confluence to Paradise Beach (RM 5) is influenced by daily tidal fluctuations as well as backwater conditions from the Sacramento River. The levee on the right bank is set back from the channel creating significant conveyance for passing flood flows. The channel is deep and the channel bed is covered with a layer of fine, sandy sediment. The channel slope is mild and velocities in this reach tend to remain slow. There are several locations in this reach where the left bank is stabilized with revetment.

At RM 5, the levees begin to encroach on the channel and by the upstream end of the riffle along Paradise Beach (RM 6), the levees are close to the channel margins creating only minimal floodplain. This reach continues to approximately RM 12 where the presence and influence of the levees tend to diminish. While the channel slope is still fairly mild in this reach, velocities are generally faster than in the lower reach due to the lack of overbank conveyance. The riffle along Paradise Beach also tends to drown-out any influence from the Sacramento River or tidal fluctuations extending into this reach. Bed materials in this reach are predominantly gravel and cobble. There are point bars as well as mid-channel bars creating split flow conditions. Revetment is present at locations on both banks in this reach.

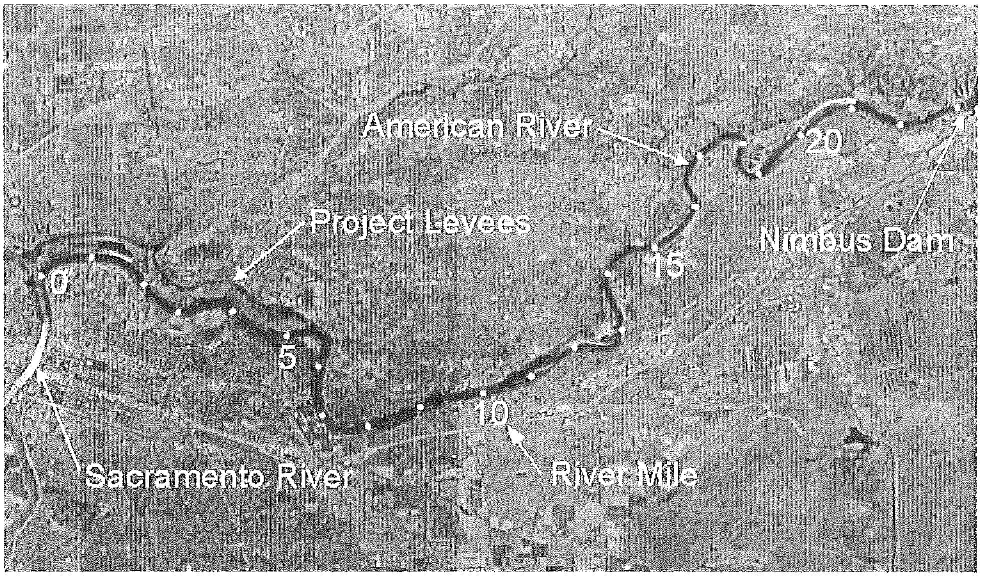

Figure 1. Location map of the Lower American River.

The next reach begins at the upper extent of the left bank levees, near RM 12. Upstream of the levees, particularly at Goethe park, there is a noticeable change in the gradient or slope of the river channel. High bluffs are present on either side of the channel at many locations. Large point bars and mid-channel bars are present in this reach and the bed is composed of gravel and cobble. Velocities tend to be higher in this reach than in the lower reaches for any given flow condition.

Figure 2 shows the distribution of spawning habitat in the Lower American River. Fish spawn predominately in the upper 10 miles of the river, with most habitat sites being located in the upper 5 miles (Schoenberg 2000). A few spawning sites were mapped as far downstream as RM 6, just downstream of the H Street bridge.

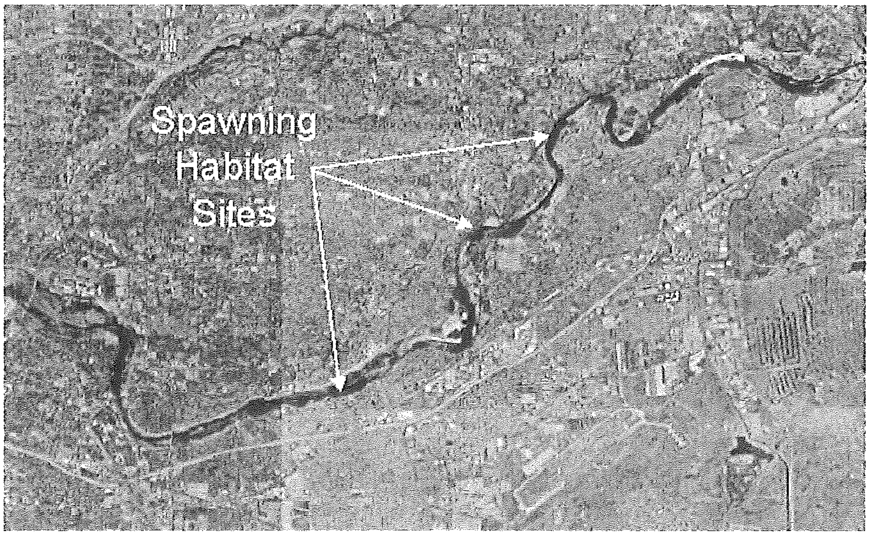

Figure 2. Spawning habitat sites on the Lower American River.

2.2 Previous Investigations

Several investigations have been conducted of the Lower American River to define spawning areas, quantify gravel and cobble sizes being used in spawning, and to determine hydraulic and sediment transport characteristics of the system. Extensive redd and spawning habitat data has been collected by the CDFG in recent years (Snider and Vyverberg 1996; Vyverberg et al. 1997). This includes detailed counts of spawning redds using aerial images and sediment sampling to determine particle size distribution of the gravel and cobble present in spawning areas.

A Geomorphic, Sediment Engineering, and Channel Stability Analysis (Ayres 1997) was conducted by the USACE in the early 1990s and represents the most recent study of sediment transport and channel stability issues in the lower river. In this analysis, one-dimensional sediment transport modeling was conducted to determine the flows necessary to mobilize the bed materials and the resulting vertical changes along the Lower American River in response to such flows. This study concluded that the bed of the channel is generally immobile at discharges less than or equal to approximately 50,000 cfs. One-dimensional modeling is based on limited topographic data defined by isolated cross sections and yields only average hydraulic values. The two-dimensional modeling described in this report provides a more detailed look at hydraulic conditions.

In recent years, two-dimensional modeling has been conducted for portions of the Lower American River to support bank protection design efforts for the USACE and floodway management practices for SAFCA. This is discussed in the following section.

3. HYDRAULIC MODELING

3.1 General

Extensive two-dimensional modeling of the lower 12 miles of the Lower American River has been conducted in recent years by SAFCA. The model has been used as a planning and management tool for addressing issues related to the American River, such as floodway capacity, vegetation management, protection and enhancement of environmental and recreational resources, and erosion prevention. The model of the lower 12 miles was initially constructed to represent conditions during the 1997 flood season. It was calibrated to the peak flow that occurred during January 1 and 2 of that year. Subsequent calibration was made to high water marks surveyed during 1999 for a bank-full flow condition of approximately 22,900 cfs resulting in slight modifications to roughness coefficients used in the model. Two-dimensional modeling provides a valuable tool for visualizing the spatial distribution of hydraulic properties throughout the entire river. The model has since been used for several purposes, including:

- Incorporating bank protection and mitigation measures constructed at Sites 1-5 in the last few years in order to model "existing conditions"
- Modeling the impacts of the proposed extension to the E.A. Fairbairn Water Treatment Plant intake structure
- Simulating flow conditions related to proposed overbank modifications in the Howe to Watt reach of the river

3.2 Model Development

For this project, the existing two-dimensional model was extended to RM 22 in the vicinity of Nimbus Dam. Due to the computational time required to run the model, the upper model was developed to run separately from the lower model. The upper model overlaps the lower model by approximately 2 miles as shown in **Figure 3.**

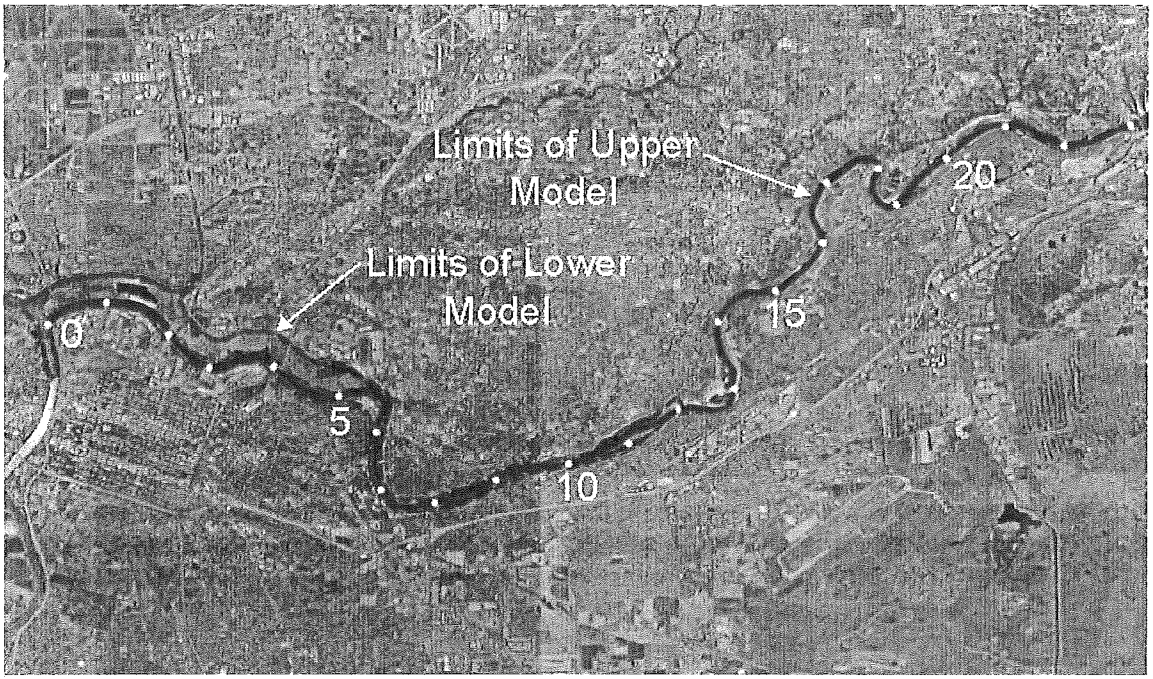

Figure 3. Plan view of the Lower American River showing the limits of the upper and lower models.

Like the lower model, the upper model was based on 1997 topographic conditions. The topography was developed from extensive hydrographic and photogrammetric mapping conducted by the USACE. The delineation between various land "roughness" types (i.e. vegetation, soil, cobble, etc.) was determined from 1997 aerial photographs. Bridges and other structures were incorporated into the model based on as-built plans where available and also from the mapping data.

3.3 Model Calibration

The upper model was calibrated against surveyed high water marks from the 1997 flood. During the peak of the flood on January 1 and 2, high water marks were staked along the Lower American River from its confluence with the Sacramento River to Nimbus Dam. These same high water marks were previously used to calibrate the lower model. Only five high water marks were available within the limits of the upper model.

The boundary conditions used for calibrating the model were the same as those used in the lower model. The water surface elevation at the downstream end of the upper model was obtained by first running the lower model for the same flow.

Slight refinements were made to the model and its input parameters as part of the calibration process. The calibration results are presented in **Table 1**, which compares the predicted water surface elevations from the model against the surveyed high water marks from the 1997 flood. The results compare well against the high water marks with the largest difference occurring in the region near Goethe Park. The exact location of this high water mark was difficult to determine in the model and the slope of the water surface profile in this region is fairly steep. As a result, the location of the reading has a fairly significant impact on the water surface elevation reported by the model. The points at the upstream and downstream extents of the model are within a couple of tenths of the surveyed values.

Table 1. Comparison of the Predicted Water Surface Elevations From the Model Against the Surveyed High Water Marks for the Calibration Flood Event.

RM	Location	Surveyed HWM Elevation (ft, NGVD)	Calibration Water Surface Elevation (ft, NGVD)	Difference (ft)
10.884	Downstream of Mayhew Drain	49.7	49.8	+0.1
13.465	Goethe Park	53.7	53.1	-0.6
20.123	Sunrise Blvd. (downstream)	88.0*	86.7	-
20.203	Sunrise Blvd. (upstream)	87.9	87.8	-0.1
22.657	Upstream end of model	98.0	97.8	-0.2

*This HWM is questionable since it is reported as higher than the HWM upstream of the bridge.

3.4 Modeling Project Flow Conditions

Using the calibrated model, simulations were made for river flows of:

- 115,000 cfs
- 80,000 cfs
- 50,000 cfs
- 30,000 cfs

The objective release from Folsom reservoir is currently 115,000 cfs. The flow from the Geomorphic, Sediment Engineering, and Channel Stability Analysis (Ayres 1997) that was determined to generally start movement of the bed materials is 50,000 cfs. A bank-full flow condition is approximately 30,000 cfs. The 80,000 cfs run was included to bridge the large gap between 50,000 and 115,000 cfs.

As mentioned previously, the modeling procedure involved two steps: running the lower model first, then obtaining boundary conditions from the lower model to run the upper model. The following boundary conditions were required as input to the lower model:

- Flow in the Lower American River
- Flow contributing from the Natomas East Main Drainage Canal (NEMDC)
- Flow in the Sacramento River
- Stage on the Sacramento River at I-Street

For any given flow condition on the Lower American River, any number of conditions may be present on the Sacramento River. This is because these two rivers drain completely different watersheds. Conditions on tributaries upstream and diversions into flood bypass channels have a large impact on flows in the Sacramento in the vicinity of the Lower American River confluence. As a result, it is difficult to determine "typical" boundary conditions for a given flow condition on the Lower American River. For this modeling effort, the boundary conditions for the project flows were taken from hydrographs of the 1997 flood. During that event, flows on the Lower American River started and finished below the 30,000 cfs mark, peaking at 116,500 cfs.

3.5 Modeling Results

The two-dimensional model computes hydraulic values such as depth of flow, water surface elevation, and velocity. The results can be viewed spatially in the form of contour plots. A set of velocity contour plots for all 23 miles of the Lower American River for each flow condition is provided in the Plates in the Attachment. These plots provide an "aerial atlas" of velocity conditions within the system. Additional results are presented in the Plates as described below.

4. MOBILIZATION OF SPAWNING BED MATERIAL

4.1 Sediment Transport Concepts

A number of forces act on a given particle resting on the channel bed as illustrated in **Figure 4**. Some of those forces resist motion and include the weight of the particle and external forces caused by contact with adjacent particles. Hydrodynamic forces work to induce motion and include forces of lift, buoyancy, and drag. The best way to determine the magnitude of these hydrodynamic forces and their ability to mobilize particles is through analysis of shear stress.

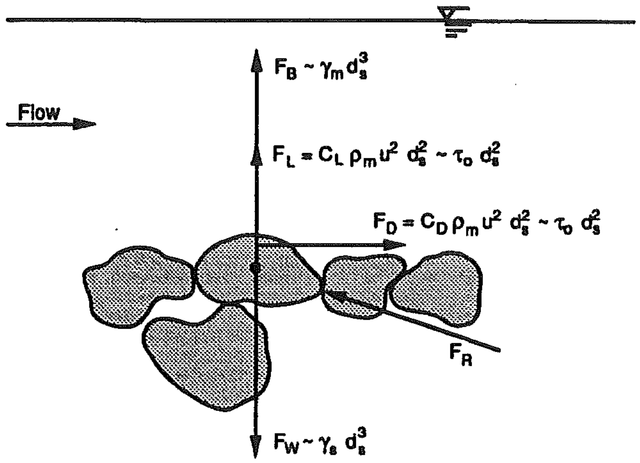

Figure 4. Diagram of forces acting on a particle resting on the channel bed.

Stress is simply the measurement of a force or forces acting over some surface area. One way to visualize shear stress is to take a piece of tape, stick one end of it to the back of your hand, then pull on the tape with your other hand. There is a shear stress developed between the tape and your hand. This is similar to the stress induced at the interface between the channel bed and moving water in the channel. The hydrodynamic forces of the flowing water column create stress that pulls and plucks particles off the bed and puts them into motion when conditions reach the threshold.

The concept of "incipient motion" refers to the condition where these forces are of sufficient magnitude that, if increased even slightly, the particle will move. A relationship has been established between particle size and the critical shear stress acting on that particle at the condition of incipient motion. From this relationship an "incipient grain size" can be computed, or in other words, the grain size that will begin to move for the given shear stress conditions.

4.2 Analysis of Spawning Bed Mobilization

To analyze the potential for spawning gravel to mobilize in the Lower American River, the incipient grain size was computed as described above based upon the shear stress conditions at each flow. Shear stress conditions were first calculated using the velocity and depth results from the model as well as input parameters defining channel roughness. The shear stress results were then used to calculate incipient grain size.

Incipient grain size is measured by the median diameter (D_{50}) of a bed sample. By comparing the D_{50} of a field sample for a known spawning area with the incipient grain size at that same location, it can be determined whether or not the spawning materials would be expected to move for a modeled flow condition.

4.3 Results

Comparison of the incipient grain size results against bed material samples tends to confirm the findings of the Geomorphic, Sediment Engineering, and Channel Stability Analysis (Ayres 1997) which concluded that the bed was relatively immobile for flows below 50,000 cfs. **Table 2** shows the mobility conditions for each of the available bed samples for the range of flows modeled. For each bed sample, the approximate location and median grain size (D_{50}) is given as well as an indication as to whether or not the material would be mobilized for each of the flows. A map showing the location of each sample as well as grain size distribution curves are provided in the Appendix.

Some of the bed material samples shown in Table 2 are not in movement for any of the flows. This is either because the sample is located in a section of the river where conditions are insufficient to move the material for any flow or because the material is large. A few of the samples are large enough (#74, 42, 26) that they only move during the objective release of 115,000 cfs. The rest of the samples in motion during 115,000 cfs are also in motion during 80,000 cfs and most of those continue to be in motion during flows of 50,000 cfs. Only one sample (#39) would be in motion during the lowest modeled flow of 30,000 cfs.

Contour plots of incipient grain size are included in the Plates in the Attachment for all 23 miles of the Lower American River for each of the modeled flow conditions. The locations of spawning bed material samples are also shown on these plots. For each sample, the measured D_{50} is presented for comparison with the calculated incipient grain size. Contours are shown for each 10 mm range in incipient grain size. Within a given contour, any bed material sample having a D_{50} smaller than or equal to the contour is expected to be mobilized. Based upon this premise, each sample has also been color-coded to show whether or not it is mobilized for the flow being modeled. If the marker for a given pebble count sample is green, it indicates that the median particle size for that sample would be in motion for that flow condition. If the marker is red, it means that the median particle size for that sample would not be in motion.

Table 2. Mobilization Results for Bed Material Samples for each of the Modeled Flow Conditions.

Bed Material Sample Data				Mobilization Results			
Sample ID	Sample Source	Sample Location*	Sample D50 (mm)	115,000 cfs	80,000 cfs	50,000 cfs	30,000 cfs
H1	•	RM 6	58				
G1	•	RM 9	28				
G2	•	RM 9	55				
F1	•	RM 12	58				
E1	•	RM 13	50				
#74	••	RM 16	70	X			
#72	••	RM 16	48				
D1	•	RM 18	115				
#42	••	RM 19	50	X			
C1	•	RM 20	32	X	X	X	
C2	•	RM 20	33	X	X		
#39	••	RM 20	26	X	X	X	X
#37	••	RM 20	34	X	X		
#30	••	RM 20	54				
#29	••	RM 20	38	X	X	X	
#27	••	RM 20	43	X	X		
#26	••	RM 20	44	X			
B1	•	RM 20	19	X	X	X	
#17	••	RM 21	75				
#16	••	RM 21	37	X	X		
#11	••	RM 22	34	X	X		
#10	••	RM 22	37				
#5	••	RM 22	32	X	X	X	
#7	••	RM 22	42	X	X	X	
A1	•	RM 22	125				
#3	••	RM 22	80				
#2	••	RM 22	140				
#1	••	RM 22	49				

• – Sample taken by Ayres Associates personnel during November 2000
•• – Sample from "Lower American River Chinook Salmon Spawning Habitat Evaluation October 1994" CDFG (Vyverberg et al. 1997)
* – Sample location reported to the nearest River Mile
X – Sample is in motion based upon the incipient motion calculations

Presenting the model results in this manor allows for a generic, system-wide look at mobilization conditions on the river. If a new bed sample is taken, the D_{50} and location of that sample can simply be plotted on the Plates to view its corresponding incipient grain size contour and to determine whether it will mobilize or not.

5. DISCUSSION

The two-dimensional model provides valuable data concerning the hydraulic conditions in the Lower American River for a range of flows. The ability to visualize and manipulate the results makes it a powerful tool for investigating issues relating to the mobilization of spawning habitat. The velocity and incipient grain size Plates as presented in the Attachment can be used to:

- Determine the velocity conditions in the river
- Determine the size of bed material that is expected to be in motion for the modeled flow scenarios
- Determine if a known sample size is in motion for certain flows by comparing its median diameter to the incipient grain size contour plot at the sample location
- Determine areas where mobilization potential is great or minimal
- Qualitatively determine areas where conditions taper down such that particles in motion will likely redeposit

From the results, the following observations are made:

- Modeling results indicate that the spawning bed materials are moving for flows of 50,000 cfs or greater. There appears to be minimal movement for flows as low as 30,000 cfs, although some movement may occur for flows between 30,000 and 50,000 cfs.
- From an overall perspective, shear stress conditions tend to be greater in the upper reaches of the Lower American River, upstream of Goethe Park. The ability of the river to mobilize and carry gravel diminishes downstream although there are isolated sections in the lower reaches where shear stresses remain high.
- Results suggest that spawning bed materials in the upper reaches are being activated if not physically moved by flows on a regular basis.

The following cautions are given in using and applying the results of this modeling effort as presented in the Plates:

- While the model is well suited as a tool for determining the likelihood of certain material sizes to mobilize under certain flow conditions, it cannot be used to determine where those materials will be transported or any associated adjustments in channel planform or elevation. The results presented in this report are based on an incipient motion analysis, not detailed sediment transport modeling.
- The results reflect steady state conditions for each of the flows modeled. The duration over which a flow condition occurs will impact the extent of mobilization and sediment transport that would occur during that flow.
- The results provide detailed hydraulic information for quantifying conditions in the river channel for the range of flows modeled. The model refinement is not such that it can be used to micro-analyze conditions around an individual spawning redd or bed material sample location.
- The model is based upon 1997 topography and does not account for changes in topography that have occurred since the date of the mapping, except for the inclusion of bank protection sites 1-5 that were constructed by the USACE.

6. REFERENCES

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1. INTRODUCTION

1.1 General

This Section provides background and discussion of technical issues related to the hydraulic modeling and incipient motion analysis. The scope of work for this project included the following key components:

- Data collection and field review
- Hydraulic modeling (including model construction and calibration, and simulation of project flow conditions)
- Analysis of spawning bed mobilization

A discussion of the technical issues, including assumptions and methodology, is provided below for each of these components.

2. DATA COLLECTION AND FIELD REVIEW

2.1 Data Sources

Existing data were provided by several sources, which were used in all aspects of the project. Kris Vyverberg, with the California Department of Fish and Game (CDFG), provided detailed information concerning the location of spawning use areas and redds, as well as abundant sample data for the river bed material. The Sacramento Area Flood Control Agency (SAFCA), through their consultant, MBK Engineers, provided maps and survey data for the high water marks that were staked during the 1997 flood event. The U.S. Army Corps of Engineers (USACE) provided hydrograph data for multiple gages for the 1997 flood event from the UNET model being developed for the Comprehensive Study.

2.2 Pebble Counts

Pebble count data were collected at various locations along the lower American River during a field visit conducted November 9, 2000. Samples were taken from bar surfaces at various locations between RM 6 and RM 23. The samples were taken to get an idea of the size of material currently present in spawning use areas along the river and to compare with samples taken in previous years. The pebble count method was used because it provides a quick, simple, inexpensive technique for quantifying the size distribution of the materials. In theory, the pebble count method for sampling particles should give similar size distribution information as a bulk sample, although the pebble count generally does not account for fine sediment that may be present.

At each sample location, 100 particles were selected randomly and the dimension of the intermediate axis was recorded. The particles were selected by placing one foot directly in front of the other, reaching down to the tip of the boot with eyes closed, and grabbing the first particle that the index finger touched. This was done along a line for about 30 paces, after which another sample line was walked three or four feet away from the previous, and progressing in the opposite direction. Size distribution curves are presented for each of the pebble count samples in the **Appendix**, including a map showing the approximate location of each sample. The location of each sample can be determined with more precision from the plates provided in the **Attachment**.

In 1994, extensive sampling was conducted by the CDFG at several spawning habitat sites (Vyverberg et al. 1997). Both pebble count and bulk samples were collected. The pebble count results and sampling locations from CDFG are also included in the Appendix for comparison. In general, there does not appear to be much variation in the size distribution of the bed material between 1994 and 2000 samples collected at similar locations.

3. HYDRAULIC MODELING

3.1 Modeling Procedure

The two-dimensional model developed for this project extends the previous model from River Mile (RM) 12 to between RM 22 and 23, just downstream of Nimbus Dam and Hazel Blvd., in the proximity of the fish hatchery. Due to the size of the existing model and the time required to run simulations, it was decided to create a separate model of the upper 10 miles rather than simply extend the existing model. Approximately 2 miles of overlap was included in the upper model so that boundary conditions for modeling could be obtained from results of the lower model. **Figure 1** shows the finite element mesh for the existing model (lower model) extending from RM 0 to 12 and for the new model (upper model) which extends up to approximately RM 22.6.

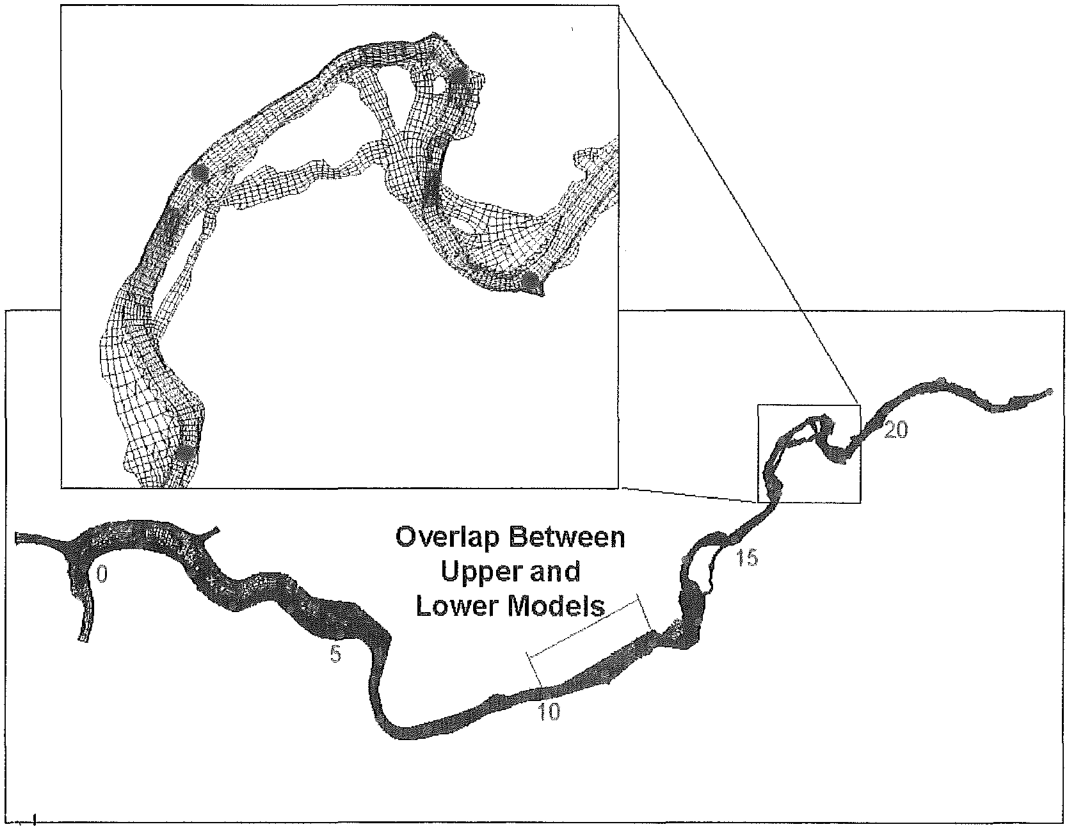

Figure 1. Plan view of the finite element mesh showing the delineation between the upper and lower models.

Most observed redd locations and spawning areas occur within the limits of the upper model. Some locations of interest, however, are also located in the lower model. As a result, both models were used in this project. For each flow condition, simulations were first made using the lower model to provide boundary conditions for running the upper model.

The lower model extends beyond the confluence of the Lower American River with the Sacramento River, and includes short reaches of the Sacramento, upstream and downstream. The downstream limit on the Sacramento River is the I-Street Bridge. A gage, located at this bridge, was used to determine boundary conditions at this location of the model. The upstream limit on the Sacramento is approximately halfway between the confluence with the Lower American River and the Sacramento Weir.

3.2 Model Development

Like the lower model, the model of the upper 10 miles was based on 1997 topographic conditions. The topography was developed from extensive hydrographic and photogrammetric mapping conducted by the USACE. The vertical limits for defining elevations along the model were determined from preliminary results of HEC-RAS modeling at the 115,000 cfs flow condition.

In a few locations during the 1997 survey, the flow depths were inadequate to obtain accurate bathymetric conditions using the survey boat. In these areas, typically riffles, channel bed elevations were estimated to provide more accurate data.

The difference between channel and overbank roughness types (vegetation, soil, cobble, etc.) is delineated in the model by assigning unique material types to each of the elements in the finite element mesh. The material types were assigned based on aerial photography from the 1997 mapping effort conducted by the USACE. For each material type, a Manning's roughness coefficient (*n value*) was assigned to represent roughness types. These values were assigned primarily based on the previous modeling efforts of the lower 12 miles of the river, with minor adjustments being made during calibration. Material types and Manning's n values used in the model are described in the discussion concerning model calibration.

Bridges and other structures were incorporated into the model based on as-built plans where available and also from mapping data.

3.3 Finite Element Mesh

Geometric definition of the project reach is given in the form of a finite element network of triangular and quadrilateral elements (Figure 1). The corner nodes of each element represent points in space (X,Y,Z) defining the topography of the project reach. These nodes were laid out along cross sections using the topographic mapping and aerial photography as a reference for element size and orientation. Nodes were also added at spot locations to define breaklines, structures, or other significant changes in topography. Elevation values were then assigned to the nodes using a digital terrain model of the river reach.

The effect of bridge piers and other structures in the main channel on hydraulic conditions and flow patterns are typically greater than those located in the overbank areas. To provide more accurate data, the geometry of the piers located in the main channel was incorporated into the mesh. At each pier, a "hole" was left in the mesh acting as an obstruction to flow. This required tight refinement of the mesh in the area of the bridge crossing. Because this type of refinement can increase the computational time required for the model, a different approach was taken for piers located in the overbank. Roughness values were simply increased in the areas around the overbank piers to simulate their effect on flow.

3.4 Model Calibration

3.4.1 Surveyed High Water Mark Data

The upper model was calibrated against surveyed high water marks from the 1997 flood. During the peak of the flood (January 1 and 2), high water marks were staked along the Lower American River from its confluence with the Sacramento River to Nimbus Dam. These same high water marks were used to calibrate the lower model. As shown in **Table 1**, only five surveyed high water marks are available for the reaches contained in the upper model. One of them, just downstream of Mayhew Drain, is located in the portion of the model that is overlapping with the previous model.

Table 1. High Water Marks (HWM) Surveyed During the 1997 Flood Event used in Calibration of the Upper Model.

RM	Location	Date Staked	Time Staked	Bank	Surveyed HWM Elevation (ft, NGVD)
10.884	Downstream of Mayhew Drain	1/2/97	1600	Left	49.73
13.465	Goethe Park	1/2/97	1520	Left	53.73
20.123	Sunrise Blvd. (downstream)	1/2/97	1400	Left	88.04
20.203	Sunrise Blvd. (upstream)	1/2/97	1400	Left	87.91
22.657	Upstream end of model	1/2/97	1255	Left	97.99

High water marks were staked by MBK Engineers and surveyed by Psomas and Associates.

3.4.2 Boundary Conditions

Boundary conditions used for calibration of the upper model were the same as those used in the calibration of the lower model. The peak flow during the January 1997 flood was 116,650 cfs, occurring early morning January 2 as recorded at the Fair Oaks gage. Sustained, high flows near 105,000 to 110,000 cfs persisted following the peak until the afternoon of January 3, after which there is a noticeable drop in the hydrograph. The discharge used in the calibration is 108,000 cfs. The water surface elevation at the downstream extent of the model (near RM 10) was taken from the previously calibrated lower model at that location.

3.4.3 Refinements Made During Calibration

During the calibration process, some minor adjustments were made to the Manning's n values that were used to represent roughness characteristics in the model. These adjustments were made based on a comparison of the predicted water surface elevations and the surveyed high water marks. Adjustments focused on the channel bed and bridge crossings.

Channel Manning's n Value

During initial calibration runs, the model appeared to be underestimating the overall water surface profile in comparison to the surveyed high water marks. Initially, a Manning's n value of 0.025, which was the final calibrated value used in the lower model, was used to represent the river bed in the upper model. The underestimation led to further investigation concerning the appropriate assumption concerning the roughness effects of the channel. In the early 1990s, the USACE funded a Geomorphic, Sediment Engineering, and Channel Stability Analysis of the Lower American River (Ayres 1997). During this investigation, sediment samples were taken of the bed materials along the lower 22 miles of the river. The results from these samples, shown in **Table 2** indicate that the size of the bed material tends to increase upstream along the system. The table also shows estimates of corresponding Manning's n values for these sample sizes using the Strickler relation, which is given by:

$$n = 0.04\ D_{50}^{1/6} \tag{1}$$

where D_{50} represents the median particle size of a sample in feet

Table 2. Bed Material Sample Sizes from Ayres Associates 1997 and the Corresponding Manning's n Value Given by the Strickler Relation.

Location of Sample	D_{50} (mm)	Manning's n (from Strickler)
RM 0 – 7.9	33	0.027
RM 7.9 – 13.6	43	0.029
RM 13.6 – 20.1	88	0.033
RM 20.1 – 22.7	96	0.033

Bed material information is also available from samples collected for this modeling effort as well as samples collected by CDFG in 1994 (Vyverberg et al. 1997). These samples were taken along bar surfaces and exposed bed areas. The range of values in D_{50} from the sampled data and the corresponding estimates of Manning's n via the Strickler relation are presented in **Table 3**.

Table 3. Bed Material Sizes From CDFG and Samples Taken for this Project and the Corresponding Manning's n Value Given by the Strickler Relation.

Sample	D_{50} (mm)	Manning's n (from Strickler)
DFG Samples	25 – 130	0.026 – 0.034
Ayres Samples	20 – 140	0.025 – 0.035

The data presented in Tables 2 and 3 indicate that values between 0.025 and 0.035 would be reasonable for modeling the channel roughness of the upper 10 miles of the Lower American River. While a value of 0.025 provided the best results for calibrating the model of the lower 12 miles, the Manning's n value for the bed was increased to 0.030 for the upper model starting at RM 12. This resulted in a closer match between the predicted water surface elevations and the high water marks.

While surface roughness of the channel perimeter and vegetation are primary indicators for estimating the Manning's n value, the physical characteristics of the reach also tend to influence the roughness characteristics. Below Nimbus Dam, the Lower American River can be divided into three reaches with distinctly different geomorphic, geometric, and hydraulic properties. The channel of the Lower American River in the lower 5 miles is relatively flat and conditions are heavily influenced by backwater from the Sacramento

River. The levees are also set back substantially on the north side of the river (right floodplain) and as a result, a large conveyance area exists for passing high flows. The flow is deep in this reach and velocities are generally lower than the upper reaches of the river. Conditions change along the riffle at Paradise Beach, just downstream of RM 6. In the reach between RM 5 and RM 12, the levees encroach on the channel margins on both the right and left banks, leaving only small amounts of floodplain. Velocities are higher than the lower reach for comparable conditions but flows remain fairly deep and the channel slope remains fairly mild. At RM 12, the left levee disappears and a different reach begins which continues all the way up to the dam. Upstream of the levees, particularly at Goethe Park, there is a noticeable change in the gradient or slope of the channel. Velocities in this upper reach are higher than in the lower two reaches and high bluffs are present on either side of the channel at many locations.

Noticeable differences in this upper reach justify a slight increase in the assumption of Manning's n value for the channel, particularly changes in channel irregularity, alignment, and flow conditions. The geometry of the channel cross section is more irregular within this upper reach than in the lower two reaches. The alignment of the channel is also more irregular (see Figure 1). In the lowest reach (RM 0 to 5), the alignment goes through several, mild bends yet maintains a general east-to-west flow alignment. Backwater influence from the Sacramento tends to diminish the influence of these bends on hydraulic conditions. The middle reach (RM 5 to 12) is characterized by two fairly straight reaches connected by one, sharp bend in the vicinity of the Sacramento State University campus (RM 7.5). In the upper reach, the channel alignment has sharper bends and is subject to more frequent changes in flow direction. Finally, flow depths tend to be shallower in the upper reach for the same flows which increases the influence of channel bed and bank roughness on flow conditions.

Standard practice supports the use of a single Manning's n value to describe the roughness of the entire channel, even though the actual material size varies to some degree spatially along the system and also along a single cross section. In standard practice, however, detailed sediment sampling is not usually available to justify varying the definition of roughness spatially, except when there is an obvious change in conditions. Also, bed material size varies from year to year at a given location depending on flows while the overall roughness conditions for a reach may stay the same. In other words, the material is moving around but the size and nature of the material is not changing much over time.

Manning's n Value at Bridge Crossings

Manning's n values were also adjusted at some of the bridges included in the model. This was necessary because the model tends to underestimate the degree of losses that occur through a bridge, particularly at bridges with multiple piers or substantially large piers in the channel.

As noted, the footprint of the pier was incorporated into the model, leaving a "hole" in the finite element mesh. While this hole represents an obstruction to flow in the model, the model does not account for friction losses due to the drag forces acting on the pier itself. While this friction loss cannot be fully accounted for in the model, some account can be made by incorporating the drag components of the pier into the channel roughness.

Some bridges have relatively few piers obstructing flow or those piers are small compared to the overall conveyance of the channel. For these bridges, a small blanket of elements surrounding each pier was identified and given a higher Manning's n value. The pedestrian bridge upstream of Sunrise Blvd. and the foot bridge over Goethe Park were treated this way.

Other bridges, such as Sunrise Blvd. and the foot bridge downstream of Sunrise, have multiple piers and/or the presence of those piers create a substantial obstruction to flow. For these bridges, a blanket of elements approximating the footprint of the bridge structure was identified and the Manning's n value was incrementally increased to account for the form losses due to the piers. The incremental increase in Manning's n value is determined by estimating the drag force due to the piers, which is given by:

$$F_d = 0.5\rho C_d A V^2 \qquad (2)$$

where:

C_d = Coefficient of drag
A = Area of obstruction = (width of piers)(# of piers)(avg. depth of flow at pier)
V = Velocity

This drag force can be translated into an incremental increase in shear stress at the channel bed through:

$$\tau = \frac{F_d}{A_{plan}} \qquad (3)$$

where:

A_{plan} = Area of the bridge footprint in plan view

The equation for average bed shear stress is given by:

$$\tau = \frac{\rho g n^2 V^2}{1.486^2 y^{1/3}} \qquad (4)$$

Substituting (2) into (3), and then (3) into (4), then solving for Manning's n value, yields the following equation:

$$n = \sqrt{\frac{0.034 A y^{1/3}}{A_{plan}}} \qquad (5)$$

This equation provides an estimate of the incremental increase required in the Manning's n to compensate for the drag forces acting on the piers. Based on this procedure, Manning's n values were increased by 0.025 for Sunrise Blvd. and 0.12 for the foot bridge downstream of Sunrise Blvd. The incremental increase for the foot bridge accounts for the obstruction of the piers as well as the road deck since it is submerged by higher flows.

The material types used in the model and their associated, calibrated Manning's n values are presented in **Table 4**.

Table 4. Material Types and Corresponding Manning's n Values used in the Model.

Description	Material Number	Calibrated Manning's n Values
Short grass	1	0.033
Long grass	2	0.040
Scrub	3	0.055
Sparse trees	4	0.085
Trees	5	0.110
Dense trees	6	0.130
Dirt / gravel	7	0.025
Pavement	8	0.022
Cobble	9	0.035
Riprap	10	0.045
Bed material, lower reach	11	0.025
Bed material, upper reaches	12	0.030
Bed elements, foot bridge downstream of Sunrise Blvd.	13	0.150
Bed elements, Sunrise Blvd. bridge	14	0.060
Flow entrance zone, upstream end of model	15	0.100
Bed elements at piers of pedestrian bridge, upstream of Sunrise Blvd.	16	0.100
Bed elements at piers, Sunrise Blvd. bridge	18	0.100

3.4.4 Results

Table 5 presents the calibration results by comparing the predicted water surface elevations against the surveyed high water marks from the 1997 flood. The results show close agreement between the model and the surveyed values. Readings near the downstream extent of the model (RM 10.9, downstream of Mayhew Drain) and near the upstream extent of the model (RM 20.2, upstream face of Sunrise Blvd.) are within 0.1 ft. of the high water marks. The values at Goethe Park differ by just over 0.5 ft. This difference, while not large, is likely due to a combination of two factors. First, the exact location of the surveyed high water mark was difficult to determine based upon the available information. Second, the water surface profile along Goethe Park is steep, changing by more than 3 feet between RM 14 and the foot bridge. As a result, the location of the reading will have a fairly significant impact on the water surface value given by the model. The surveyed high water mark at the downstream face of Sunrise Blvd. is questionable since the elevation reported is greater than the value for the upstream face.

The reading at the upstream end of the model (R 22.657) was taken at the most upstream extent where the model can be assumed to provide accurate results. The actual HWM falls in a short section of the upstream limit of the model where boundary condition effects make the results non-applicable. The reported value is about 400 ft downstream of the actual HWM. From the results of the model downstream of the reading, the slope of the water surface is approximately 0.0006. If this slope is assumed to continue upstream, the model would read approximately 98.02, which matches even more closely with the surveyed HWM elevation.

Table 5. Comparison of the Predicted Water Surface Elevations From the Model with the Surveyed High Water Marks for the Calibration Event.

RM	Location	Surveyed HWM Elevation (ft, NGVD)	Calibration Water Surface Elevation (ft, NGVD)	Difference (ft)
10.884	Downstream of Mayhew Drain	49.7	49.8	+0.1
13.465	Goethe Park	53.7	53.1	-0.6
20.123	Sunrise Blvd. (downstream)	88.0*	86.7	-
20.203	Sunrise Blvd. (upstream)	87.9	87.8	-0.1
22.657	Upstream end of model	98.0	97.8	-0.2

*This HWM is questionable since it is reported as higher than the HWM upstream of the bridge.

3.5 Modeled Flows and Boundary Conditions

According to the scope of work, the calibrated model was to be used to simulate four flow conditions: 115,000, 80,000, 50,000, and 30,000 cfs. The objective release from Folsom reservoir is currently 115,000 cfs. The flow from the Geomorphic, Sediment Engineering, and Channel Stability Analysis (Ayres 1997) that was determined to generally start movement of the bed materials is 50,000 cfs. A bank-full flow condition is approximately 30,000 cfs. The 80,000 cfs run was included to bridge the large gap between 50,000 and 115,000 cfs.

As described above, the modeling procedure involved two steps: running the lower model first, then obtaining boundary conditions to run the upper model. The following boundary conditions were required as input into the lower model:

- Flow in the Lower American River
- Flow contributing to the Lower American River from the Natomas East Main Drainage Canal (NEMDC)
- Flow in the Sacramento River
- Stage on the Sacramento River at I-Street

For any given flow condition on the Lower American River, a number of conditions may be present on the Sacramento River. This is because these two rivers drain completely different watersheds. Conditions on tributaries upstream and diversions into flood bypass channels have a large impact on flows in the Sacramento in the vicinity of the Lower American River confluence. As a result, it is difficult to determine "typical" boundary conditions for a given flow condition on the Lower American River.

Higher flows on the Lower American River are typically associated with a large storm event. In the 1997 flood, flows on the Lower American River were at or below 10,000 cfs in late December, 1996, peaked at 116,650 cfs on January 2, 1997, and dropped back down below 20,000 cfs by January 10. Rather than developing generic boundary conditions for the given Lower American River flow conditions, the boundary conditions were simply taken from the 1997 hydrograph, an event that hit the entire range of flows to be modeled.

Figure 2 shows the flow hydrographs for the Lower American River, Sacramento River, and the NEMDC during the month of January 1997. Using the hydrograph for the Lower

American River at the Fair Oaks gage, the flow conditions of 30,000, 50,000, 80,000 and 115,000 cfs were located on both the rising and receding limbs. On each of these limbs, flows hovered around 30,000 cfs for a period of hours. The flows of 50,000 and 80,000 cfs only occurred for short periods of time as the releases from Folsom increased and decreased to pass the flood waters. The peak flow for the flood event of 1997 was 116,650 cfs, with flows hovering around 110,000 cfs for just over 24 hours. For the same time periods that these flows were located on the Fair Oaks hydrograph, the corresponding conditions were obtained from the flow and stage hydrographs at I-Street on the Sacramento River and from the flow hydrograph on the NEMDC. **Table 6** shows these values. When the flow of interest was of short duration, single values corresponding most closely to the flow of interest were reported. When conditions hovered around the flow of interest, a range of values were reported.

Table 6. Flow Conditions From the 1997 Flood Event Used to Develop Boundary Conditions for the Two-Dimensional Model.

Rising Limb of Hydrograph				Falling Limb of Hydrograph			
Fair Oaks Flow (cfs)	I Street Stage (ft)	I Street Flow (cfs)	NEMDC Flow (cfs)	Fair Oaks Flow (cfs)	I Street Stage (ft)	I Street Flow (cfs)	NEMDC Flow (cfs)
30,900 – 31,050	24.35 – 26.34	83,460 – 91,360	9,245 – 9,859	32,000 – 31,000	24.72 – 24.32	84,908 – 83,300	9,010 – 8,850
51,775	26.06	90,240	10,507	54,794 – 45,076	26.73 – 26.52	92,920 – 92,080	9,416 – 9,305
79,298	25.9	89,600	11,061	83,857 – 79,500	29.84 – 29.91	105,640 – 105,360	10,549 – 10,562
114,000 – 116,650	27.6 – 27.9	96,240 – 97,400	11,325 – 11,342	116,650 – 114,590	27.9 – 28.2	97,400 – 98,600	11,342 – 11,368

From the data in Table 6, boundary conditions were determined for each of the flows as shown in **Table 7**. Typically, the values on the receding limb of the hydrograph were used since conditions on the Sacramento River were higher at this point. For the 115,000 cfs flow condition, the maximum values reported during the 1997 flood were used for the boundary conditions on the Sacramento River and the NEMDC. Even though these peaks did not occur simultaneously with the 115,000 cfs flow on the Lower American River, they did occur within a short time-frame of each other and when combined, represent the most conservative case in terms of flood stages on the Lower American River.

Table 7. Boundary Conditions Used to Model the Project Flows.

Flow Scenario	Flow on LAR (cfs)	NEMDC Flow (cfs)	I Street Flow (cfs)	I Street Stage (ft)
30,000 cfs	30,000	9,000	84,000	24.5
50,000 cfs	50,000	9,500	92,000	26.5
80,000 cfs	80,000	10,500	105,500	29.0
115,000 cfs	115,000	11,400	107,500	30.4

3.6 Hydraulic Modeling Results

The results of the hydraulic model are presented in detail in the Plates in the Attachment.

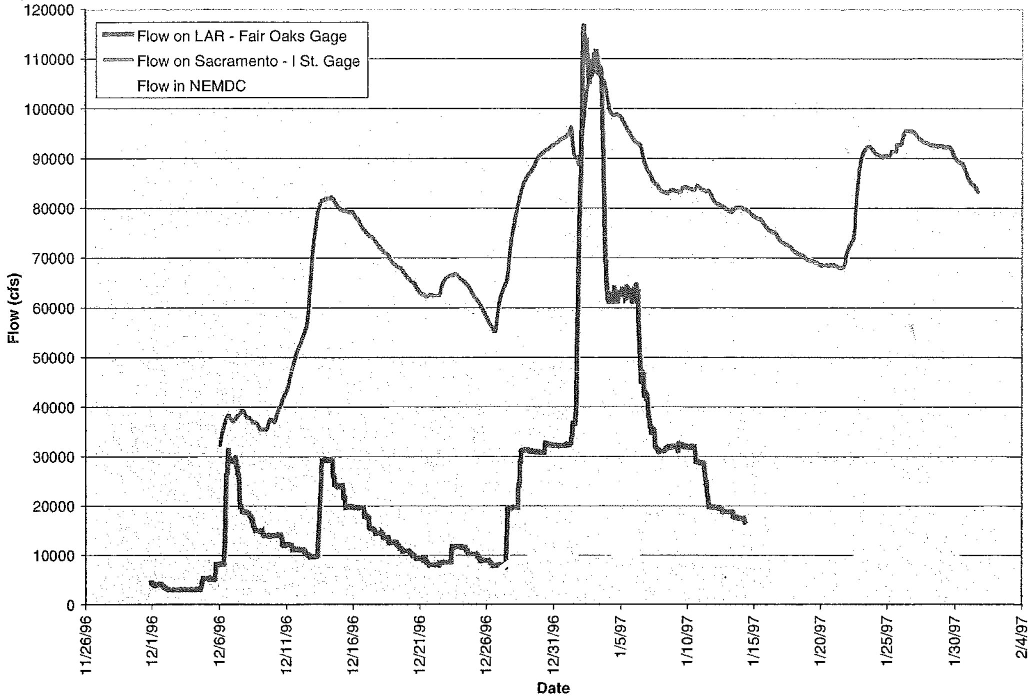

Figure 2. Flow hydrographs for the Lower American River, Sacramento River, and the Natomas East Main Drainage Canal during the 1997 flood event.

4. ANALYSIS OF SPAWNING BED MOBILIZATION

4.1 Introduction

As defined by the scope of work, the purpose of this task was to use the hydraulic model results to analyze "the potential for mobilization of bed materials at the spawning locations." The results of the two-dimensional model are well-suited for this type of investigation. Analyzing the potential for the bed materials to mobilize is different from analyzing the question of where those particles travel once they mobilize. The two-dimensional model is not well-suited to analyze this second question without significant modification to the model and quantification of physical properties and processes. Therefore, this analysis of spawning bed mobilization should be used to examine the river's ability to initiate movement of certain material sizes for the flows that were modeled and not as an indication of sediment transport processes.

4.2 Hydraulic Model Output

For each node in the finite element mesh, the two-dimensional model computes hydraulic values such as velocity, depth of flow, and water surface elevation. These results can then be contoured to provide spatial definition of conditions. Using the model results, other hydraulic values or properties, such as shear stress, can be computed. As described in the next section, shear stress is the main parameter used for quantifying the ability of the river to mobilize the bed materials. Using the model results, shear stress values were computed using the following procedure.

Shear stress is given by the following equation:

$$\tau = \gamma RS \tag{6}$$

where:

γ = Specific weight of water
R = Hydraulic radius
S = Energy slope

Manning's equation is given by:

$$V = \frac{1.486}{n} R^{2/3} S^{1/2} \tag{7}$$

Solving Manning's equation for slope and then inserting it into equation (6) produces:

$$\tau = \frac{\gamma V^2 n^2}{1.486^2 d^{1/3}} \tag{8}$$

This form of the equation makes it possible to solve for shear stress at every node in the hydraulic model using the depth and velocity results as well as the roughness characteristics (Manning's n) of the channel and floodplain surfaces defined in the model input.

The equation is quite sensitive to the assumption of channel roughness as defined by the Manning's n value. Theoretically, there are numerous ways of estimating Manning's n for gravel and cobble bed rivers. In cases of shallow depth (low relative-submergence of the bed materials) it has even been shown that Manning's n should be varied based upon depth of flow. As described in the discussion on model calibration, estimates of the Manning's n value were made based on bed material samples using the empirical equation developed by Strickler. From the available sample data, which were taken by different investigators over the last 10 years, values ranging from 0.025 to 0.035 were computed for the channel bed. Calibration of the model confirmed the assumption that 0.030 provides a reasonable estimate of the roughness of the entire channel bed. Since the velocity and depth values used in the shear stress equation are based on hydraulic model results computed with a Manning's n value of 0.030, it was decided that the same value needed to be used to compute shear stress for consistency. Likewise, shear stress results in the lower model were computed using a Manning's n value of 0.025 since this value was used to represent the channel roughness of the lower reaches.

Since the Manning's n value used to compute shear stresses was the same as that used to define the channel roughness in the model, the shear stress and incipient grain size results are accurate within the channel limits. In overbank areas the computed shear stress values may be slightly less than the actual conditions to be expected since the Manning's n values are typically higher than the channel in overbank areas.

4.3 Incipient Motion of Bed Material

A number of forces act on a particle resting on the channel bed. **Figure 3** illustrates these forces for a simplified condition where the slope of the channel is flat. The resisting forces include the weight of the particle and external forces caused by contact between it and adjacent particles. The hydrodynamic forces acting on the particle include lift force, buoyant force, and drag force.

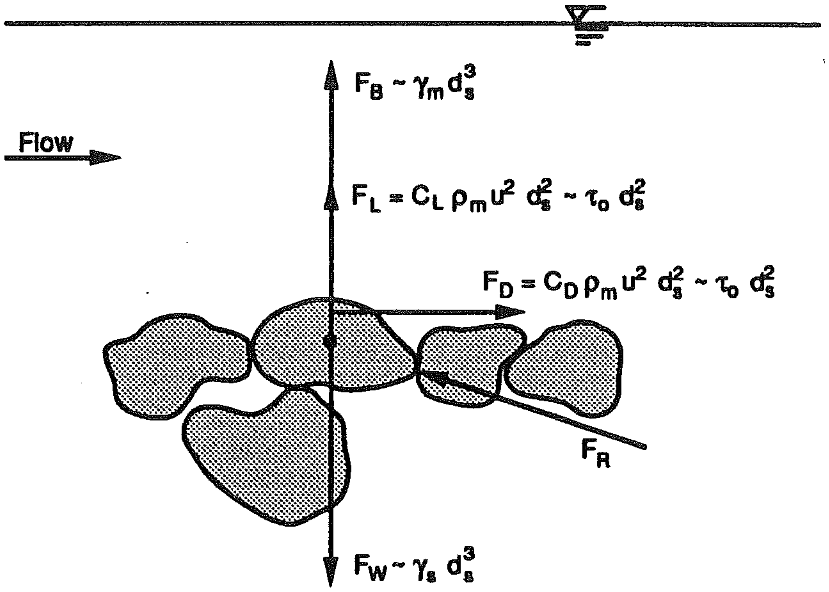

Figure 3. Diagram of forces acting on a particle under steady uniform flow (from Julien 1995).

The ratio of those forces that tend to cause motion of the particle to those forces that tend to resist motion is called the Shields parameter, and is given by:

$$\tau_{*c} = \frac{\tau_o}{(\gamma_s - \gamma)D_c} \tag{9}$$

where:

τ_{*c} = Dimensionless shear stress (Shields parameter)
τ_o = Bed shear stress
γ_s = Specific weight of the particle
γ = Specific weight of water
D_c = Median grain size of the bed material (D_{50})

The concept of "incipient motion" refers to the condition where the hydrodynamic forces acting on a particle are of sufficient magnitude that, if increased even slightly, the particle will move. The Shields relation given above can be used to analyze incipient conditions. If the shear stress acting on the particle is considered to be the critical shear stress ($\tau_o = \tau_c$), or the shear stress at which the particle will begin to move, the equation yields an "incipient particle size" as given by:

$$D_{50} = \frac{\tau_c}{(\gamma_s - \gamma)\tau_{*c}} \tag{10}$$

Several laboratory experiments have been conducted to determine the dimensionless shear stress parameter (τ_{*c}) for incipient conditions with the results typically presented by the modified Shields diagram. The diagram can be formulated to present the relationship of the dimensionless shear stress parameter to a dimensionless particle diameter as shown in **Figure 4** (Julien 1995; Hoffmans and Verheij 1997).

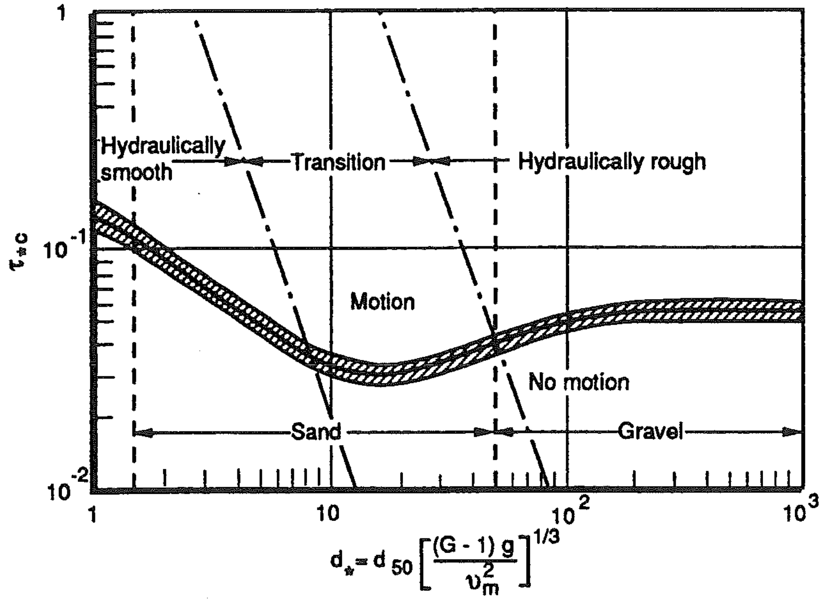

Figure 4. Modified Shields diagram relating dimensionless shear stress to dimensionless particle diameter (from Julien 1995).

As discussed previously, the D_{50} size from the pebble count samples ranges from 20 mm (~ 0.8 inches) to 140 mm (~ 5.5 inches), which result in values for d_* above 500. Hoffmans and Verheij (1997) report using a value of 0.055 for τ_{*c} when d_* values are greater than 150. This is consistent with Julien (1995) who reports that τ_{*c} can be approximated by $0.06\tan\phi$ for values of d_* greater than 50, where ϕ is the angle of repose of the bed material. For the particle sizes mentioned above, the angle of repose ranges from 39 to 42°, which yield values for τ_{*c} of 0.049 to 0.055. For this analysis, the dimensionless shear stress value used in Shields equation to determine incipient grain size was assumed to be 0.055.

4.4 Spawning Bed Mobilization

For analyzing the potential for the spawning bed materials to move, the incipient particle size was computed for each of the flow conditions. This was accomplished by first computing shear stress from the velocity and depth results from the model. Then, assuming the existing shear stress conditions from the model to be critical, the incipient particle size was computed from Equation 10. As described in the main report, the results indicate that many of the bed material samples would be in motion for the modeled flows of 50,000, 80,000, and 115,000 cfs. Below 50,000 cfs, the ability of the river to mobilize the bed diminishes. Only one of the bed material samples would be in motion during a flow of 30,000 cfs according to the modeling results. Mobilization may continue to occur to some degree for flows below 50,000 cfs.

Contour plots showing incipient particle size are presented in the Plates in the Attachment for all flow conditions. For any given particle size contour, the plots show the area where materials having a median diameter equal to or less than that contour will be in motion. The location, ID number, and median size of the CDFG pebble counts and those taken for this project are also included on these plots. If the marker for a given pebble count sample is green, it indicates that the median particle size for that sample would be in motion for that flow condition. If the marker is red, it means that the median particle size for that sample would not be in motion.

5. DISCUSSION

Because of its ability to manipulate, analyze and display hydraulic results, the two-dimensional model is a valuable tool for investigating the potential for mobilization of the spawning bed material. There is much information contained in the results of the model as well as numerous ways to display the results. Due to the number of sheets required to show results for all 23 miles of the river for all four modeled flows, only velocity and incipient grain size plots are provided. These plots provide the most valuable data for analyzing the ability of the river to mobilize certain particle sizes. These plots, presented in the Attachment, can be used to:

- Determine velocity conditions in the river for the modeled flow scenarios
- Determine the size of bed material that is expected to be in motion for the modeled flow scenarios
- Determine if a known sample size is in motion for certain flows by comparing its median diameter to the incipient grain size contour plot at the sample location
- Determine areas where mobilization potential is great or minimal
- Qualitatively determine areas where conditions taper down such that particles in motion will likely redeposit (assessing potential gravel recruitment areas)

Other information and data types available from the model not presented in the Attachment include:

- Depth, water surface elevation, and shear stress contour plots
- Velocity vectors depicting surface flow patterns such as eddies, backwater areas, etc.
- Water surface profiles along the system
- Cross section plots for bed elevation, velocity, shear stress, incipient grain size, etc.

Now that the two dimensional model has been constructed for the entire Lower American River below Nimbus Dam, there are many potential applications for its use, including:

- Modeling other flow conditions
- Determining impact on water surface elevation and flood conveyance of actions taken within the floodplain (clearing or establishing vegetation, bank protection projects, removal of levees, etc.)
- Delineating existing aquatic habitat by investigating the spatial relationships between velocity and depth for various flow conditions
- Analyzing bank erosion potential using velocity and shear stress data for various flow conditions
- Designing bank protection and/or biotechnical features based on the hydraulic results of the model

The following limitations should be kept in mind when using and analyzing the results of the model.

- The model is based upon 1997 topography and does not account for changes in topography that have occurred since the date of the mapping, except for the inclusion of bank protection sites 1-5 that were constructed in recent years.
- The results cannot be used to determine where bed particles will be deposited in the event that they mobilize. The results presented in this report are based on an incipient motion analysis, not detailed sediment transport modeling.
- The results provide detailed hydraulic information for quantifying conditions in the river channel for the range of flows modeled. The model refinement is not such that it can be used to micro-analyze conditions around an individual spawning redd or bed material sample location.

6. REFERENCES

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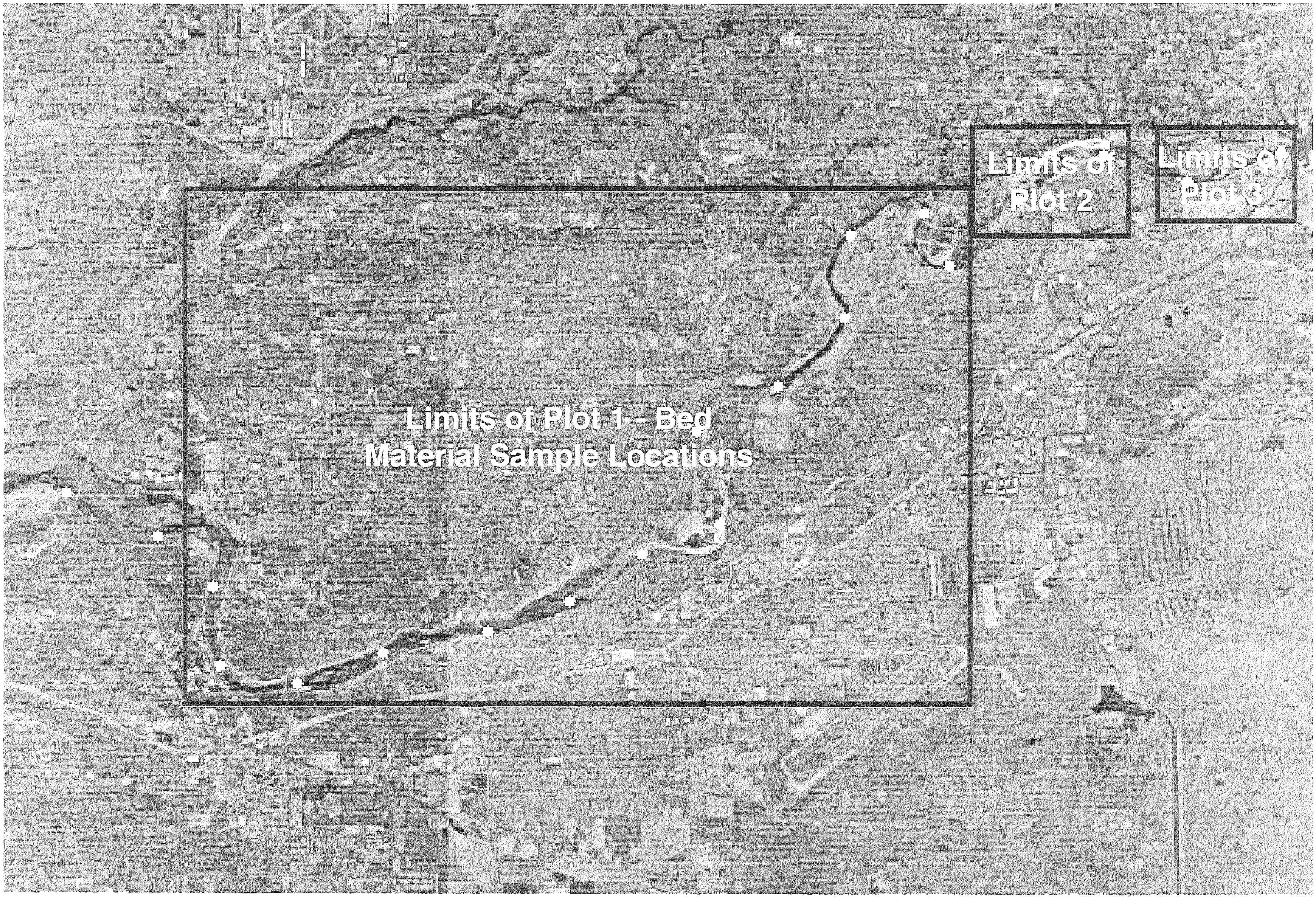
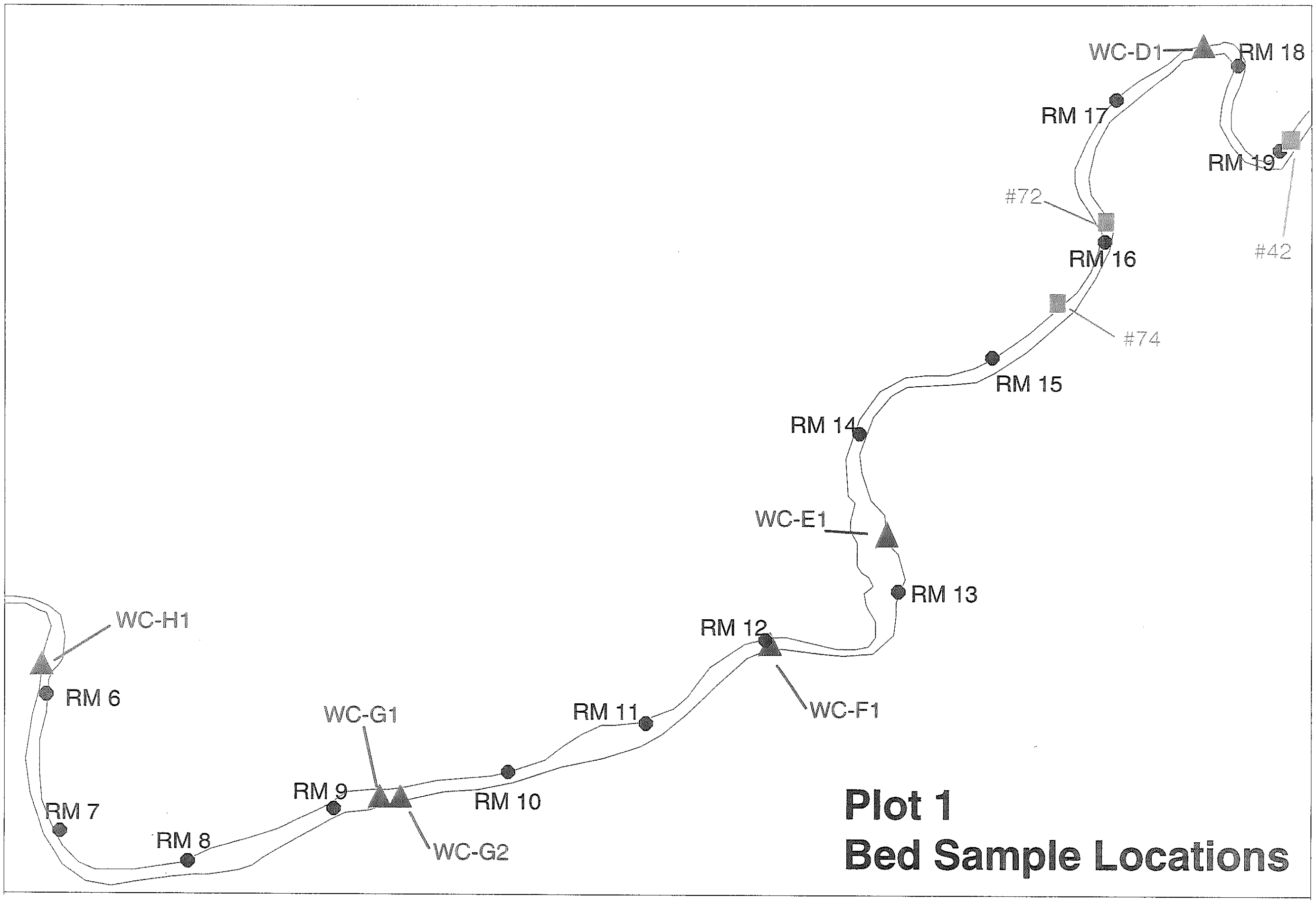
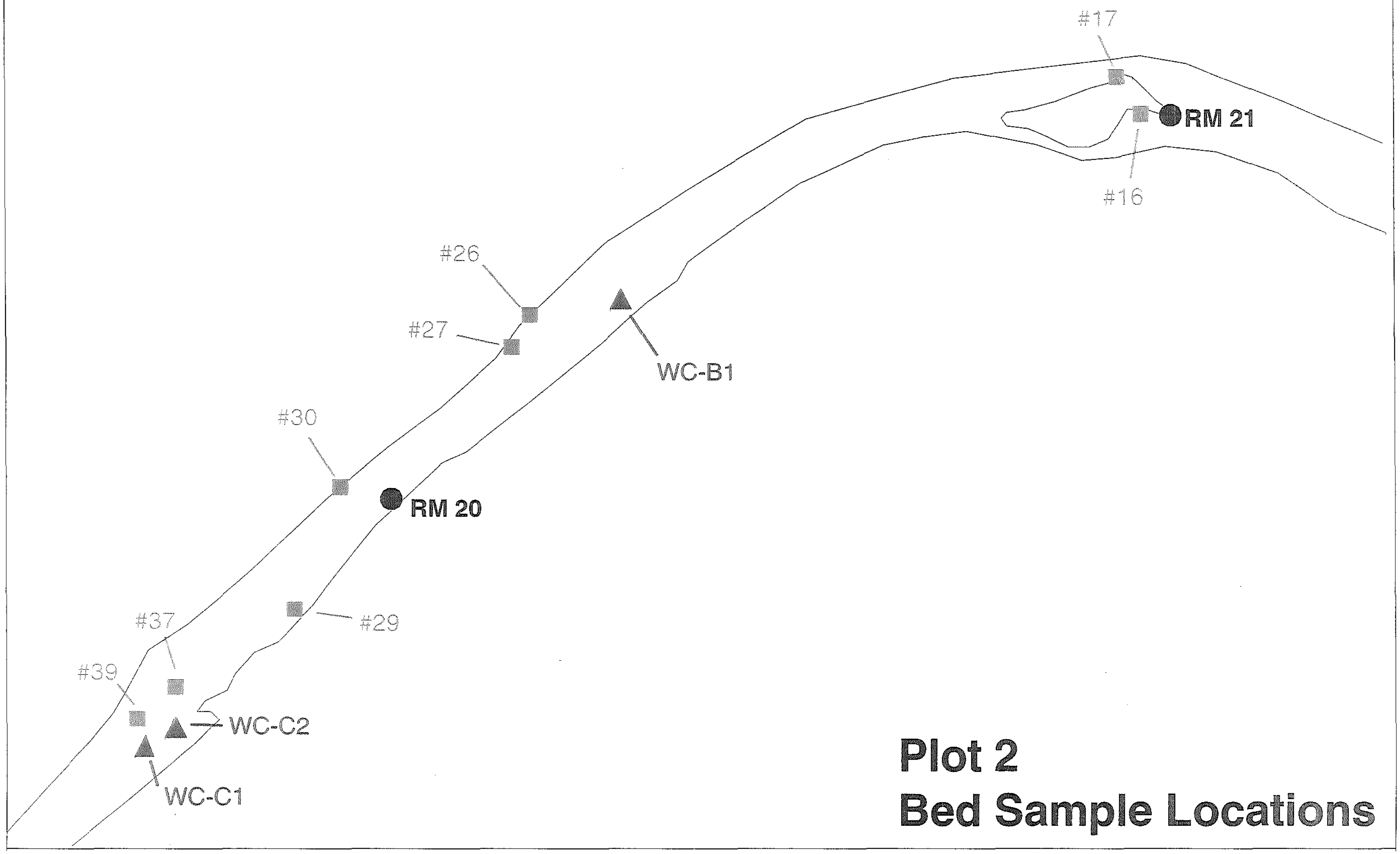
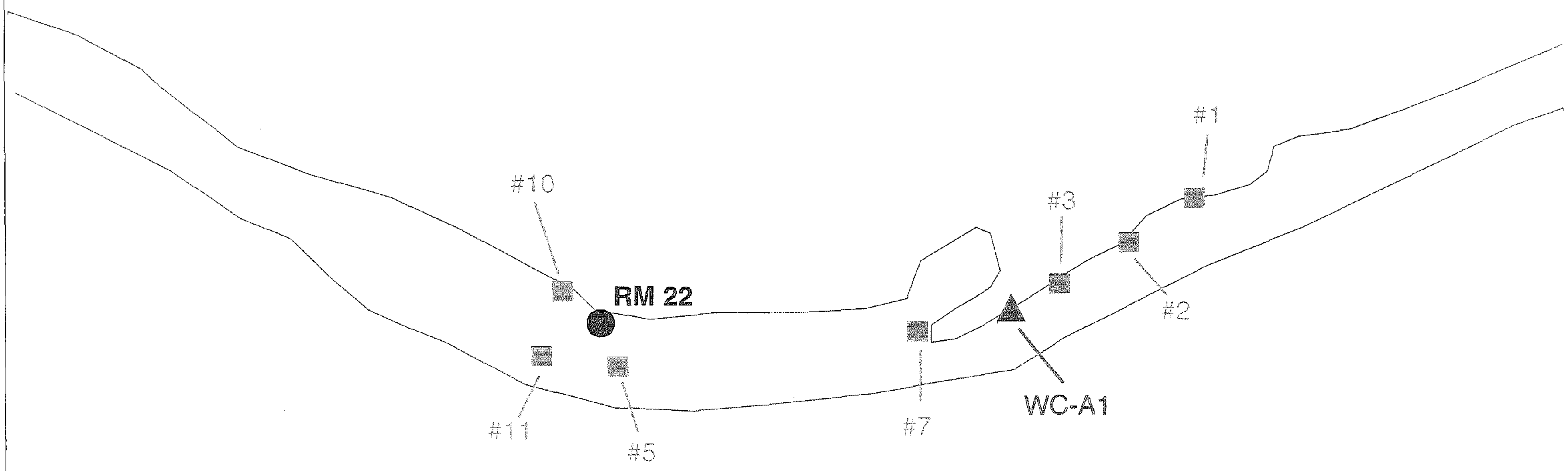

Limits of Plot 1 -- Bed
Material Sample Locations
Limits of
Plot 2
Limits of
Plot 3



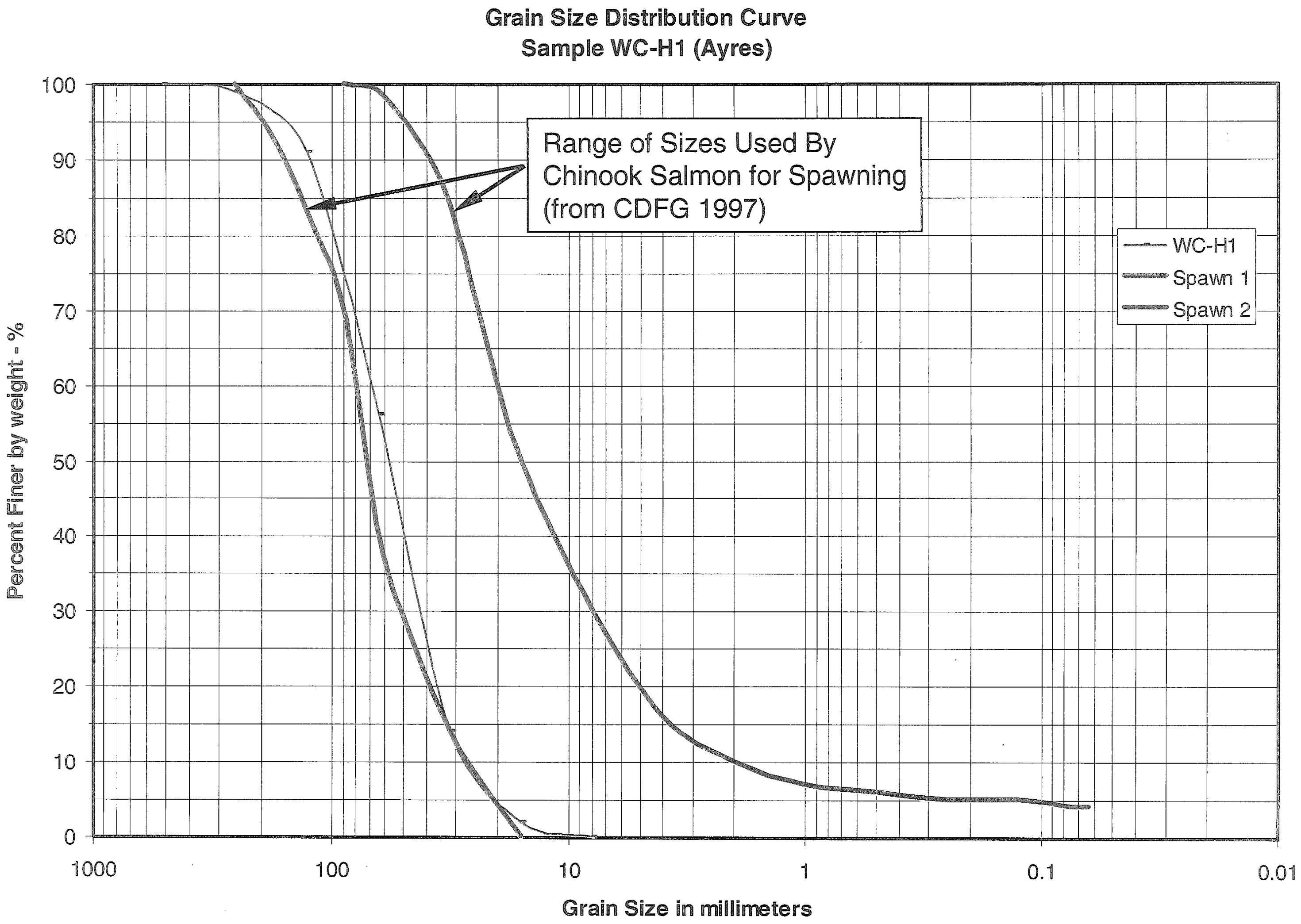
Plot 1
Bed Sample Locations

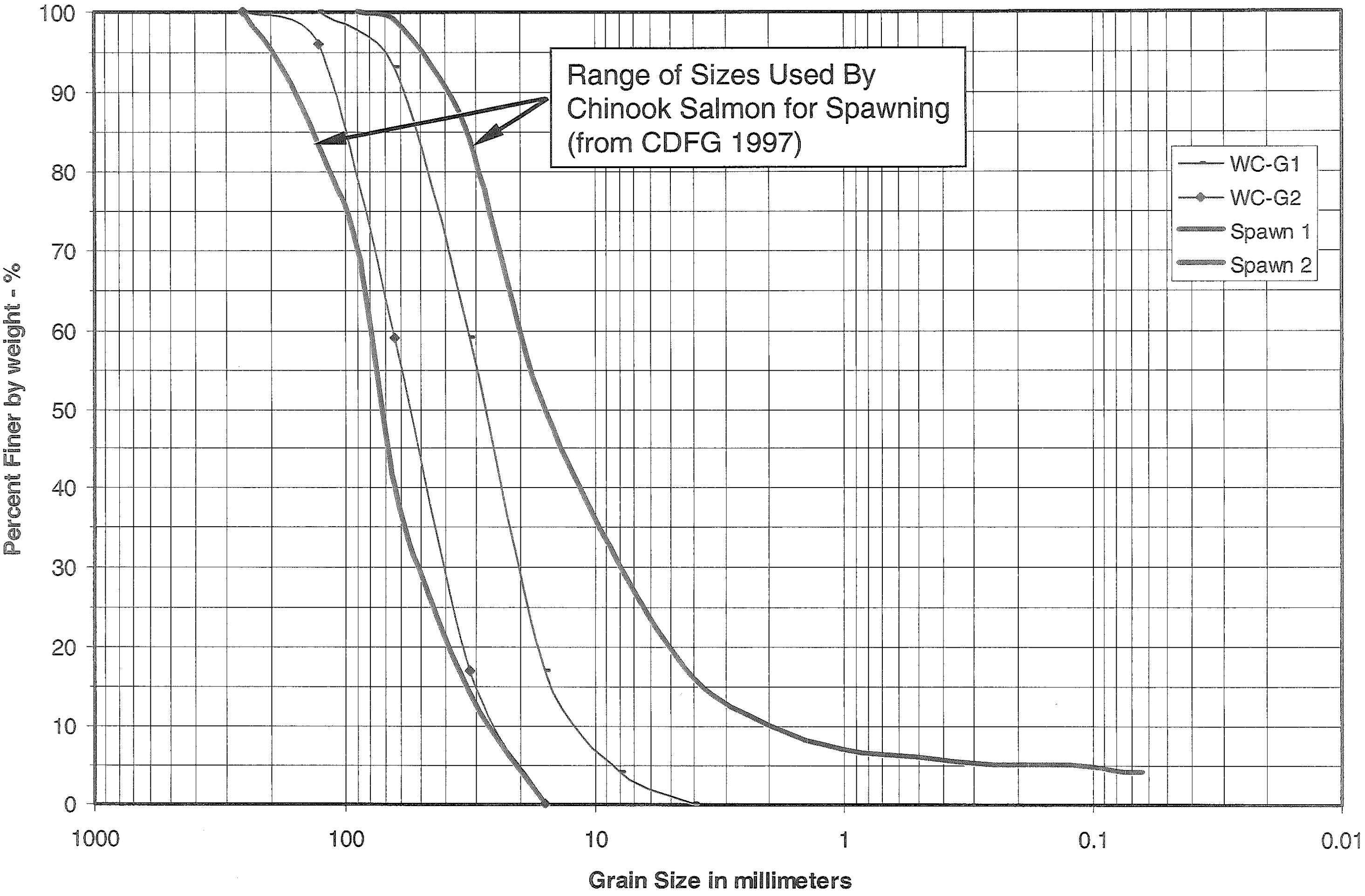


Plot 2
Bed Sample Locations



Plot 3
Bed Sample Locations

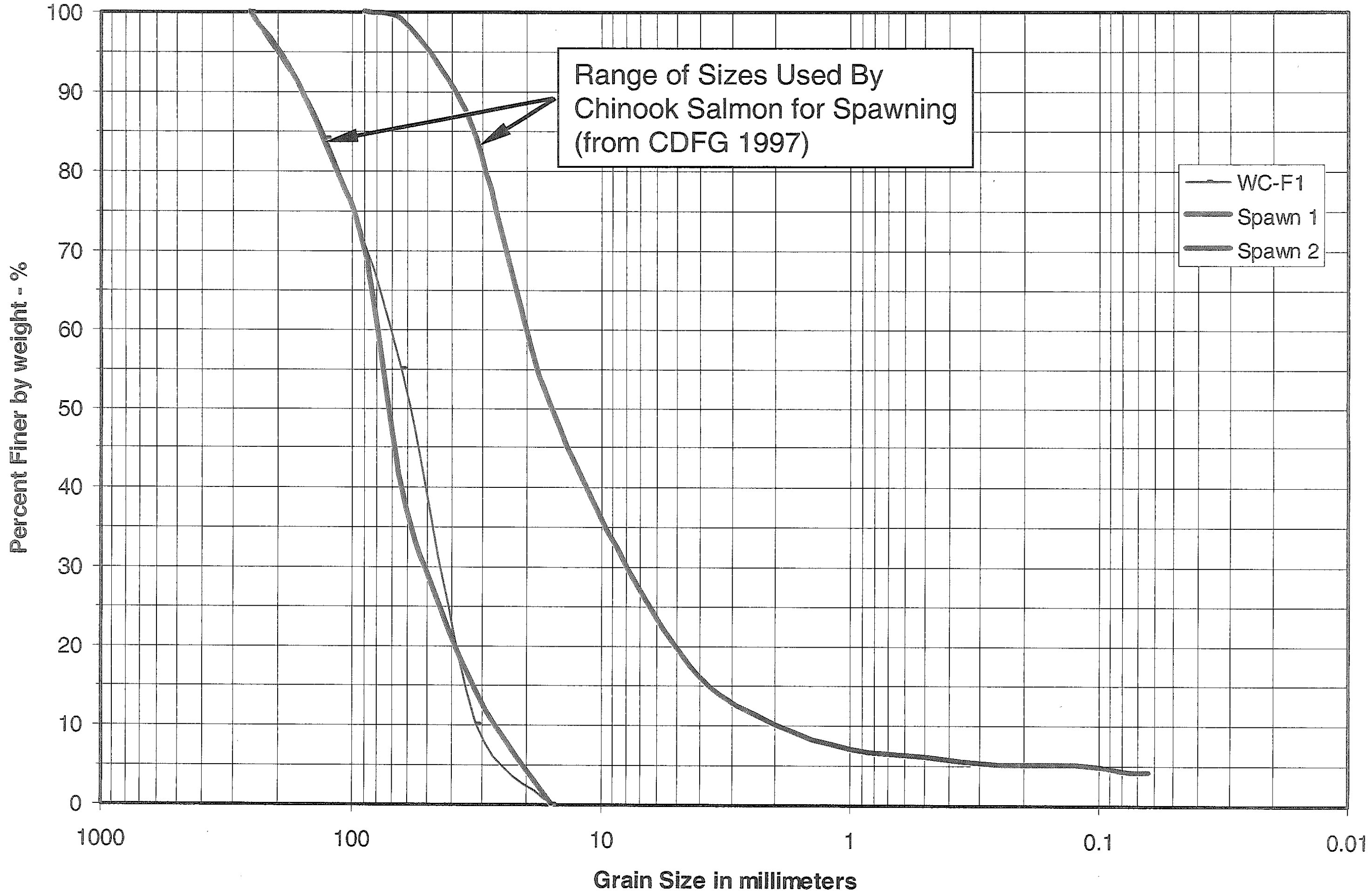

Grain Size Distribution Curve
Sample WC-H1 (Ayres)
Range of Sizes Used By Chinook Salmon for Spawning (from CDFG 1997)
WC-H1
Spawn 1
Spawn 2
Percent Finer by weight - %
100
90
80
70
60
50
40
30
20
10
0
1000
100
10
1
0.1
0.01
Grain Size in millimeters

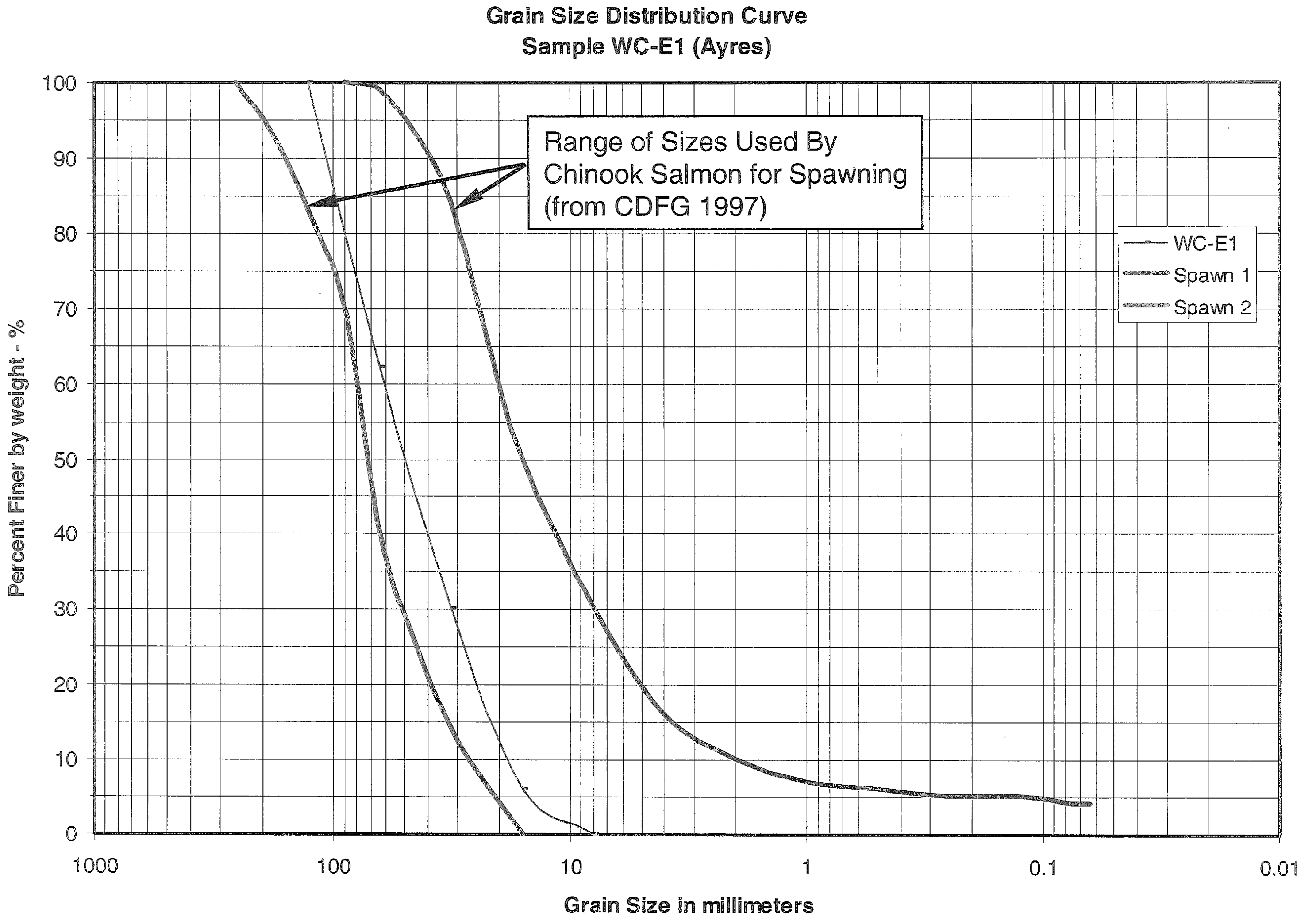


Grain Size Distribution Curve
Samples WC-G1 and WC-G2 (Ayres)

Range of Sizes Used By Chinook Salmon for Spawning (from CDFG 1997)

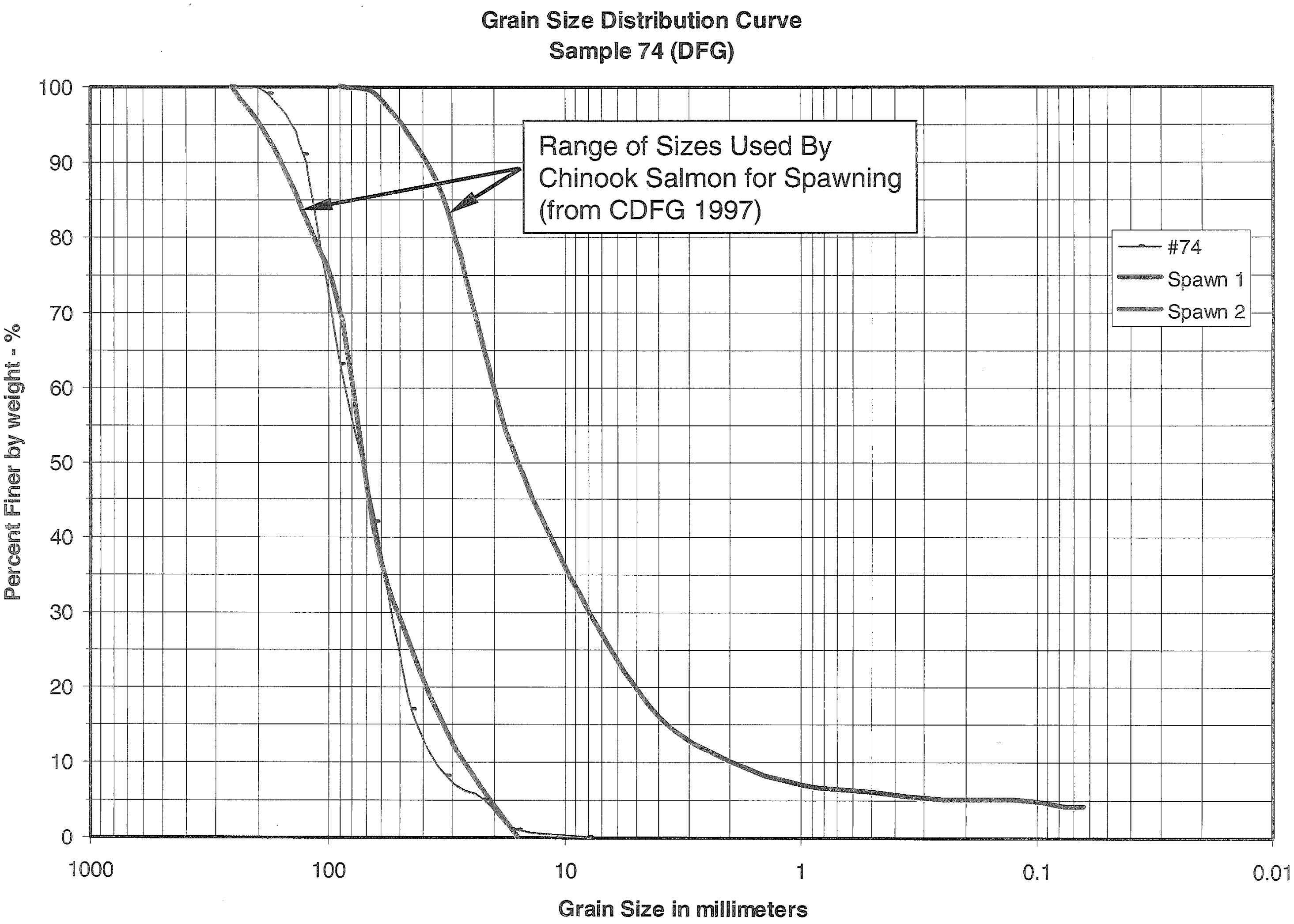
Grain Size Distribution Curve
Sample WC-F1 (Ayres)





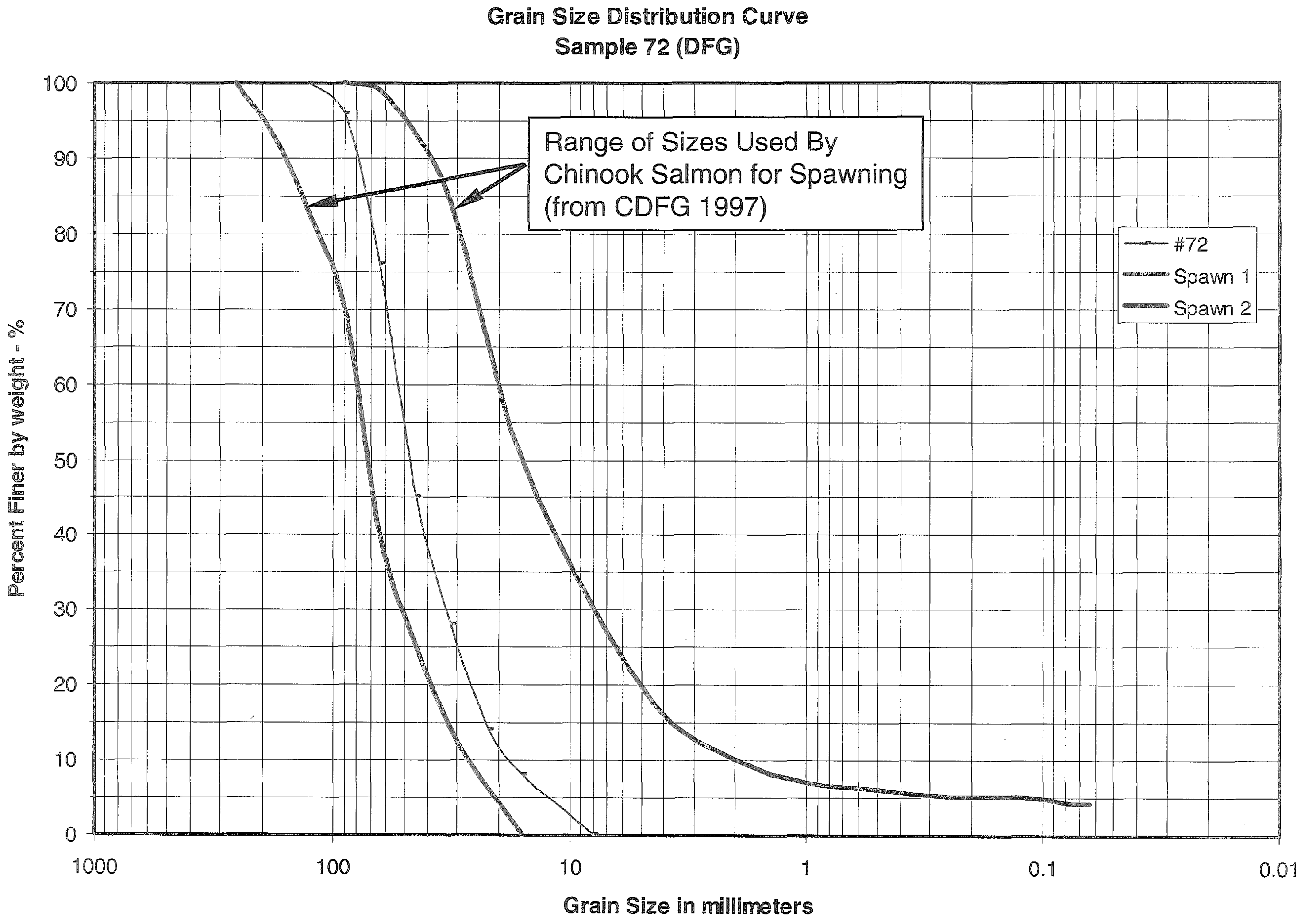
Grain Size Distribution Curve
Sample WC-E1 (Ayres)

Range of Sizes Used By Chinook Salmon for Spawning (from CDFG 1997)

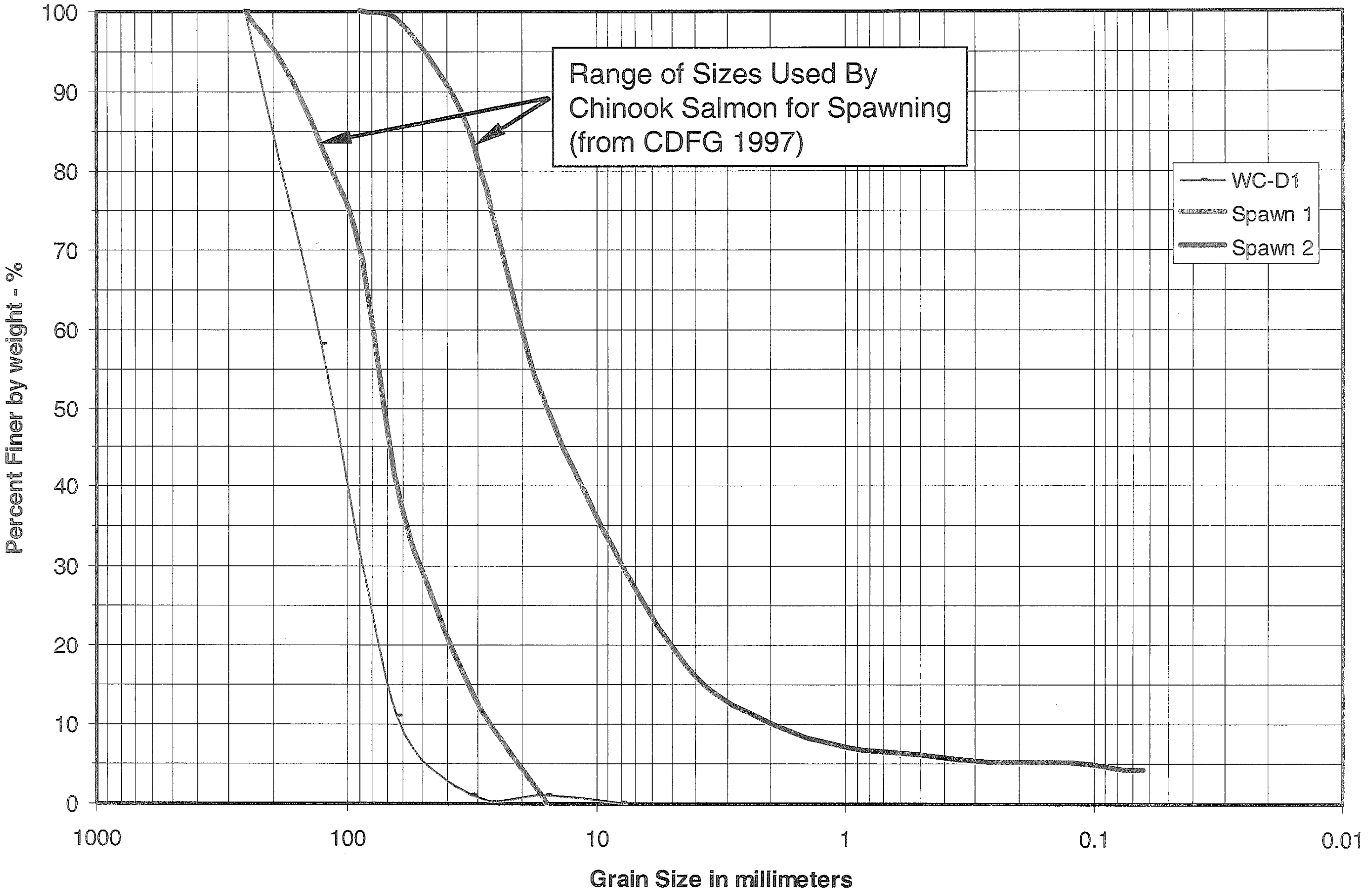


Grain Size Distribution Curve
Sample 74 (DFG)

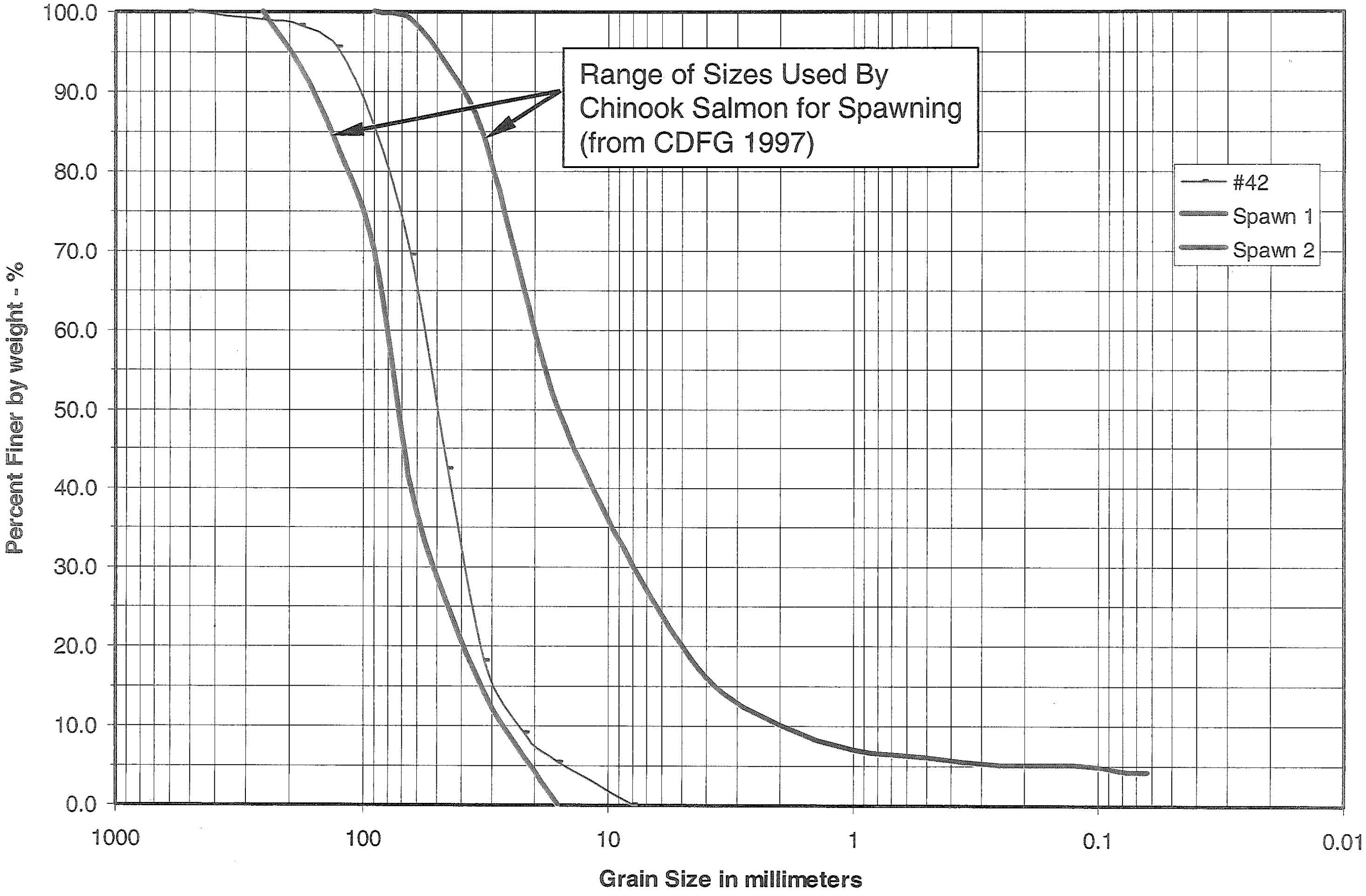
Range of Sizes Used By Chinook Salmon for Spawning (from CDFG 1997)


Grain Size Distribution Curve
Sample 72 (DFG)
Range of Sizes Used By Chinook Salmon for Spawning (from CDFG 1997)
#72
Spawn 1
Spawn 2
Percent Finer by weight - %
100
90
80
70
60
50
40
30
20
10
0
1000
100
10
1
0.1
0.01
Grain Size in millimeters

Grain Size Distribution Curve
Sample WC-D1 (Ayres)

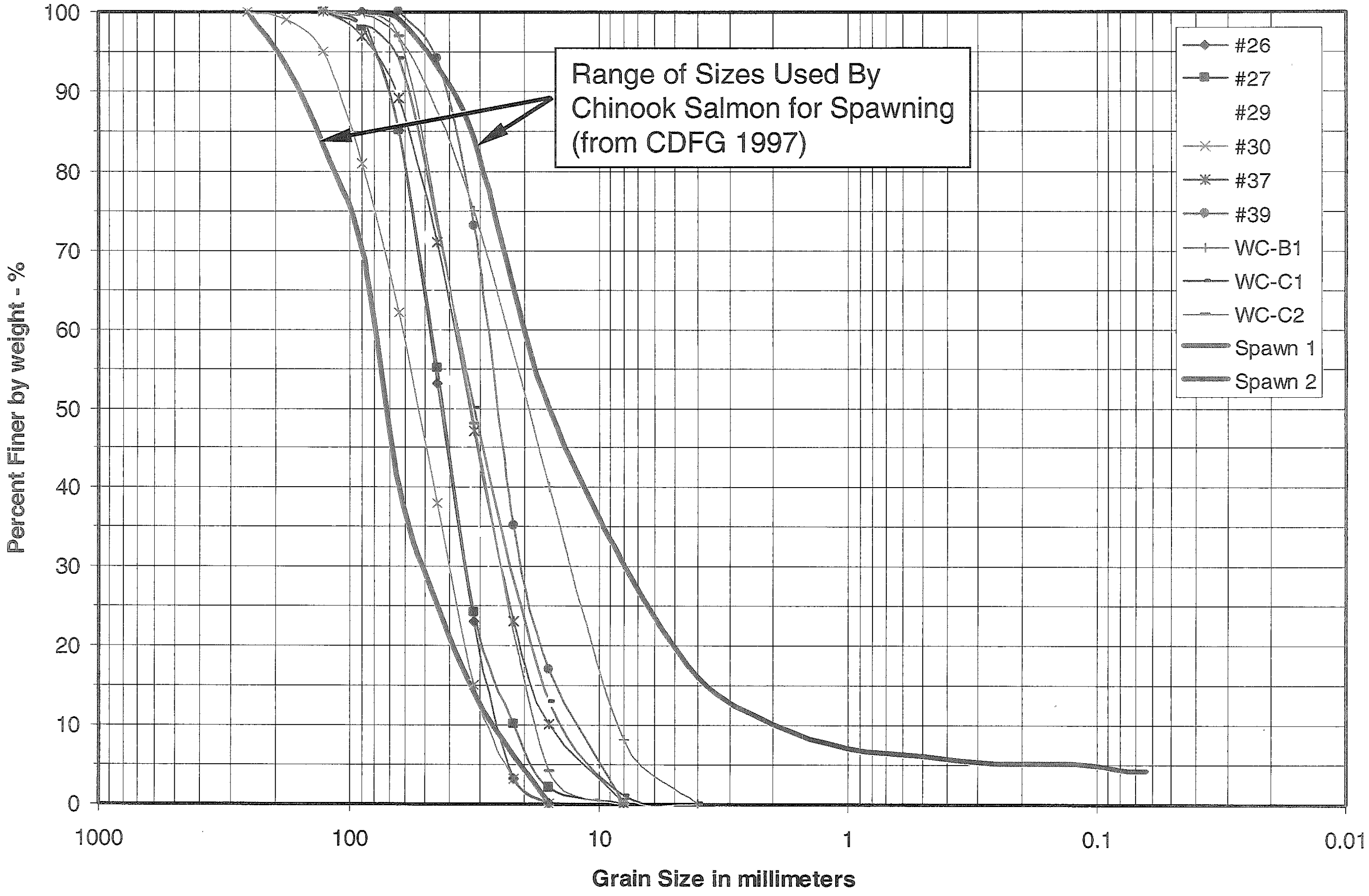

Range of Sizes Used By Chinook Salmon for Spawning (from CDFG 1997)

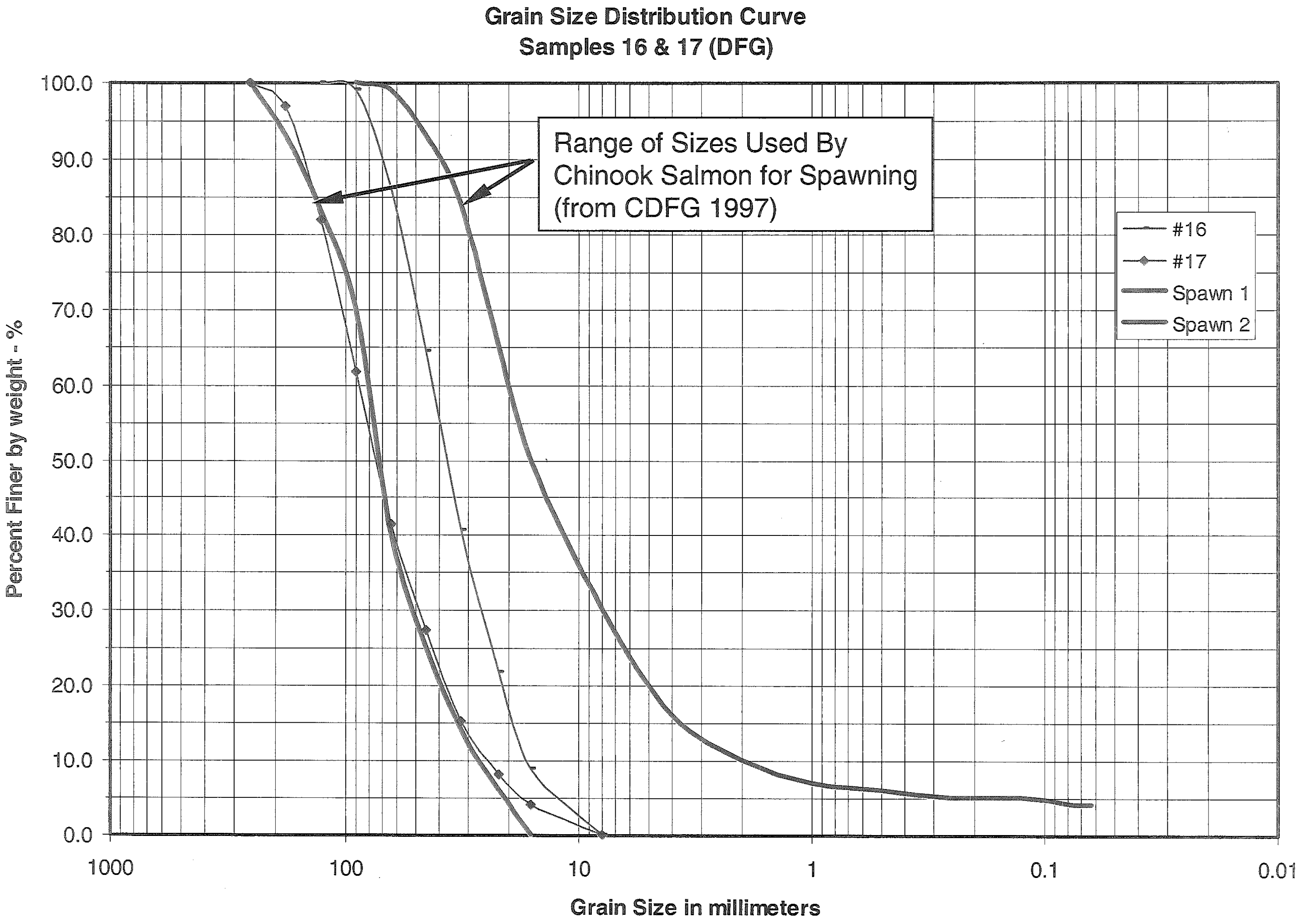
Grain Size Distribution Curve
Sample 42 (DFG)



Range of Sizes Used By Chinook Salmon for Spawning (from CDFG 1997)

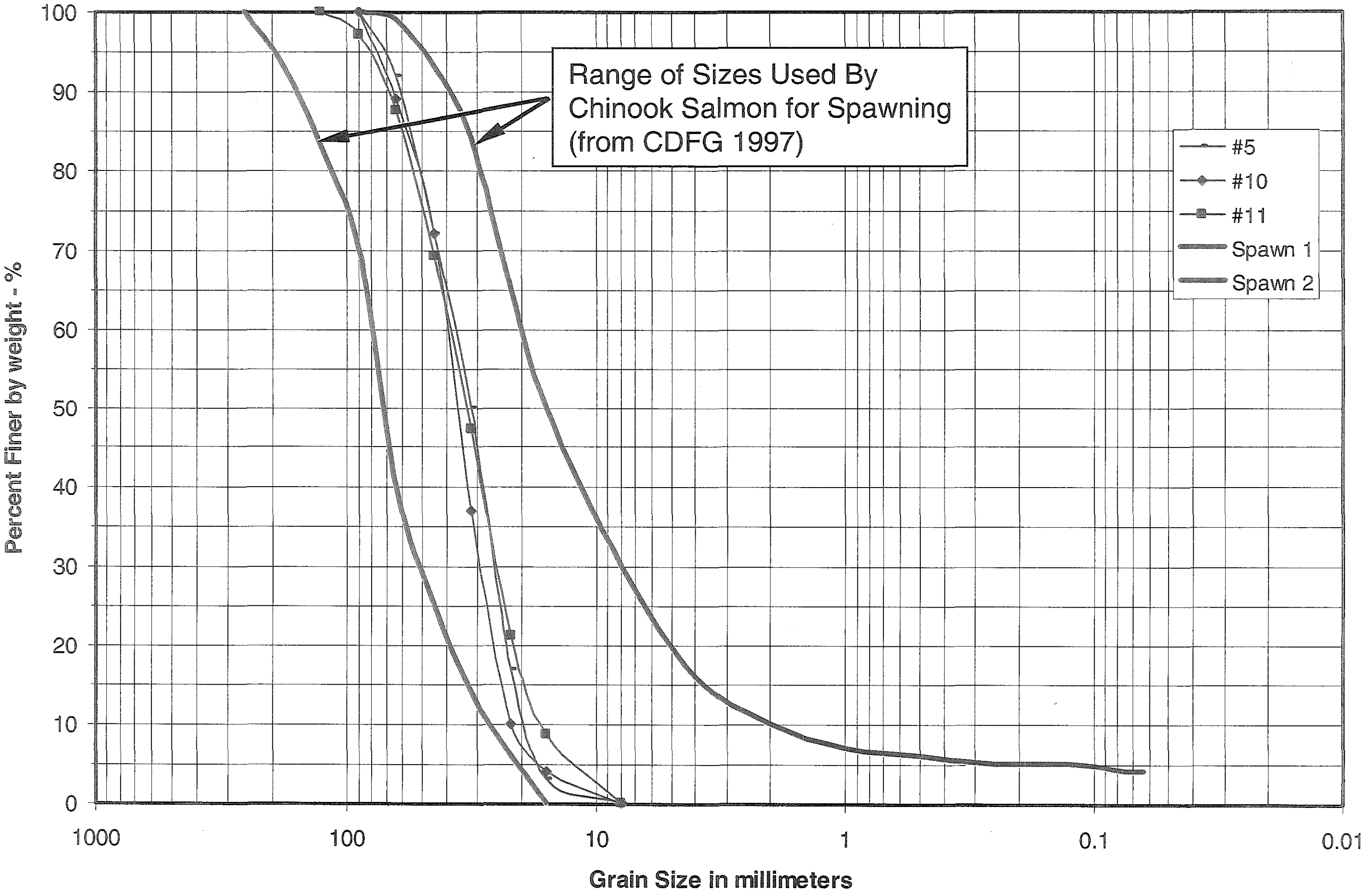
Grain Size Distribution Curve
Samples 26, 27, 29, 30, 37, 39 (DFG) & WC-B1, WC-C1, WC-C2 (Ayres)





Grain Size Distribution Curve
Samples 16 & 17 (DFG)

Grain Size Distribution Curve
Samples 5, 10, & 11 (DFG)



Grain Size Distribution Curve
Samples 1, 2, 3, 7 (DFG) & WC-A1 (Ayres)