INTERIM REPORT--YEAR 1

Sediment Retention in Stream Corridors of the lower Trinity River Basin, Texas

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SUMMARY

This study seeks to document the effects of the Lake Livingston dam on downstream sediment regimes, in particular the delivery of sediment to the lower Trinity River and the Trinity Bay estuary.

The study addresses the following problems:

1) What are the geomorphological and sedimentological impacts of Lake Livingston on the Trinity river system downstream of the dam?

2) How has this affected the transport of sediments into the upper Trinity River Delta?

3)If there has been a significant reduction in sediment delivery, are there any economically feasible available sources of sediment to increase the total sediment load to the delta?

Preliminary results suggest that there has been no detectable reduction in sediment delivery to the lowermost reaches of the Trinity River, and to Trinity Bay. Flow regimes downstream of Livingston Dam have not been greatly modified, and there is no flow-related decline in sediment transport capacity. There is also no shortage of available sediment in the lower Trinity. Sand is abundant, and there is no evidence of depletion of sandy bars since the dam was constructed. Floodplain accretion is occurring, also indicating that the river is not sediment supply-limited. There is evidence of channel incision associated with reduced sediment loads immediately downstream of the lake, and as far downstream as Romayor, and evidence of reduced post-dam sediment yields at Romayor. However, there is no evidence of a post-dam reduction in sediment yield further downstream at Liberty. Sediment yield data also show that sediment storage in the lower Trinity valley--which is independent of, and occurred both before and after impoundment of Lake Livingston--is a more important control over sediment transport to the estuary than sediment trapping in Lake Livingston.

Upland sediment production within the lower Trinity Basin is adequate to supply the river's transport capacity, but the relative importance of upland erosion, tributary

erosion, and erosion of the Trinity channel itself needs further investigation. Preliminary results do suggest that much of the sand in the lower Trinity is reworked fluvial and alluvial sediment, as opposed to material recently eroded from uplands.

Channels in the lower Trinity are geomorphically active, even downstream of the zone of post-dam channel incision. Bank erosion and channel shifting due to meander migration are common, and most of the point bars are active and mobile. However, field, map, and aerial photography evidence suggest that the lower Trinity was a highly active channel long before Livingston Dam. Therefore, the nature and extent of post-dam channel change is under further investigation.

Finally, while there has been no dam-related reduction in flows in the Trinity, water withdrawals downstream of Liberty may reduce discharge in the tidally-influenced portion of the river by 10 percent or more. The potential effects of this flow reduction on sediment delivery are still under investigation.

BACKGROUND

Dams typically have significant geomorphic effects downstream, but these impacts vary substantially with size, hydrologic regime, environmental setting, history and channel morphology of the stream in question, as well as with the nature and operation of the impoundment (Williams and Wolman, 1984; Friedman and Osterkamp, 1998; Brandt 2000; Phillips, 2001; Graf 2001). Most previous studies were conducted relatively near the dam site and most examine visible changes such as channel patterns, and indirectly, sediment movement. While in some cases dams dramatically reduce sediment transport well downstream, in other cases there is no apparent impact on sediment regimes except in the reach immediately downstream of the dam. Phillips (1992; 1995) has documented this pattern in large rivers of the North Carolina coastal plain, and more recently on a small East Texas stream (Phillips 2001; Phillips and Marion 2001). The main conclusion is that one needs to study impounded rivers individually, and no general conclusion can be compiled from the literature.

White and Calnan (1991) and Solis, Longley, and Malstaff (1994) have documented the sediment station history at the Trinity River gage at Romayor, downstream of Lake Livingston. This evidence suggests the dam has significantly reduced downstream sediment inputs and points to a need for a direct investigation.

The coastal zone near the mouth of the Trinity is experiencing erosion along barrier beaches and subsidence and wetland loss in its estuaries. Along Galveston Island 57 percent of the shoreline has experienced erosion rates averaging 0.6 m/yr or more in recent years, while on Bolivar Peninsula the figure is 86 percent. In the Galveston Bay estuarine system, which includes the Trinity Bay and Trinity River delta, shoreline retreat of 1.5 to >3 m yr is common in recent years, and conversion of marshes to open water at a rate of 47 ha/yr has been documented for the Trinity Delta (Morton and Paine 1990; White and Calnan 1991; Morton 1993; GLO 2001). The erosion and land loss has, in many cases, accelerated within the past 50 years. White and others (2002) note that the Trinity River Delta was prograding through most of the 20th century, with a transition to degradation beginning between 1956 and 1974. Beach erosion in Texas shows an apparent increase beginning in the 1960s (Davis 1997; Morton 1977, Morton and Paine 1990). The increase in erosion and land loss roughly coincides with the impoundment of the Trinity and other Texas rivers and suggests the possibility that, in addition to the other factors that influence coastal geomorphology, human modifications of both coastal systems and the fluvial systems draining to them may be contributing to erosion and land loss.

Study objectives

The following objectives were outlined in the original scope of work:

1) Characterize the historic discharge and sediment data at two stations on the Trinity River which started recording data in 1938, the Crockett station, (1968) and Long King Creek, (1968-1979).

2) Assess changes in channel and floodplain morphology, alluvial sedimentation, and sediment delivery at the river mouth following completion of the dam.

3) Evaluate the sediment inputs from upland erosion, tributaries, and bank erosion downstream of Lake Livingston.

4) Characterize the channel and floodplain sediment above and below the lake and dam site.

5) Identify the difference in sediment transport to the upper delta before and after the dam placement.

6) Determine the sediment sources that could replenish the stream sediment supply that are near the river channel or in the lake.

These objectives will form the outline for reporting of results in this report.

FLOW AND SEDIMENT YIELDS

The relevant study plan objective from the scope of work is to "characterize the historic discharge and sediment data at two stations on the Trinity River which started recording data in 1938, the Crockett station, (1968) and Long King Creek, (1968-1979)." This objective has been modified somewhat to focus on changes from Crockett to Romayor (upstream to downstream of Lake Livingston) and from Romayor to Liberty. Since the gage at Liberty has a datum about 0.6 m below sea level, this represents the approximate head of ponding and backwater effects from the Trinity estuary. Also, there is a pronounced increase in floodplain width and decrease in floodplain elevation downstream of Romayor, suggesting the possibility of increased sediment storage opportunities in the Romayor-Liberty reach as compared to upstream.

Reductions in sediment loads downstream of several Texas impoundments has been documented (Solis et al. 1994). A change in sediment regimes toward lower sediment loads was found for the Trinity, Nueces, and Lavaca Rivers. However, the Lavaca river is not impounded, measurements on the Nueces are from a station immediately downstream of a dam, and the six other stations examined show no clear evidence of a change in sediment delivery. The Trinity is examined more closely below.

Discharge

Annual maximum streamflows for three large east Texas rivers were examined by Phillips (2001) for evidence of changes in peak flow following dam construction. The Neches River shows clear evidence of decreased peak flows following impoundment of the Sam Rayburn reservoir in 1965, but the Sabine and Trinity Rivers show no evidence of a reduction in annual discharge afer the construction of the Toledo Bend (1967) and Lake Livingston (1967) impoundments, respectively (Phillips 2001). Note that while Sam Rayburn lake has a primary flood control function, Toledo Bend and

Livingston reservoirs are not designed or operated for flood control. The Trinity is a 46,100 km^2 drainage basin, with the headwaters in north Texas, west of Fort Worth, which drains to the Trinity Bay, part of the Galveston Bay system (Figure 1). Most of the drainage area (95 percent) lies upstream of Livingston Dam. Lake Livingston has a conservation pool capacity of more than 2.2 billion m^3. Its primary purpose is water supply for Houston.

As a water supply reservoir, releases from Lake Livingston do not illustrate the pulsed pattern of a hydropower reservoir such as Toledo Bend, and over the long term flow regimes are similar to the pre-dam regime (though over the short term dam operation may significantly influence flow in the lower Trinity). The lake has limited storage capacity above its conservation pool and is essentially a flow-through reservoir. There is no evidence of a post-dam decline in mean discharges at downstream stations, or in peak discharges (Phillips 2001). Flow duration curves show that, if anything, Lake Livingston has increased flow in the lower Trinity.

Fig. 1. Trinity River basin. Numbers are U.S. Geological Survey gaging stations.

While there are no effects on the highest peaks, exceedence frequencies for flows smaller than about 40,000 ft^e sec^{-1} have increased. Thus there has been no flow-related decline in sediment transport capacity downstream of the dam (Figure 2). At Liberty, TX near the head of tidal influence there is also no evidence of flow reduction (Fig. 3). Water withdrawals downstream of Liberty for the city of Houston and for rice farm irrigation are significant, though the largest withdrawal (Coastal Water Authority, supplying Houston) amounts to only about 10 percent of the flow at Liberty. There are no major withdrawals between Lake

Livingston and Liberty.

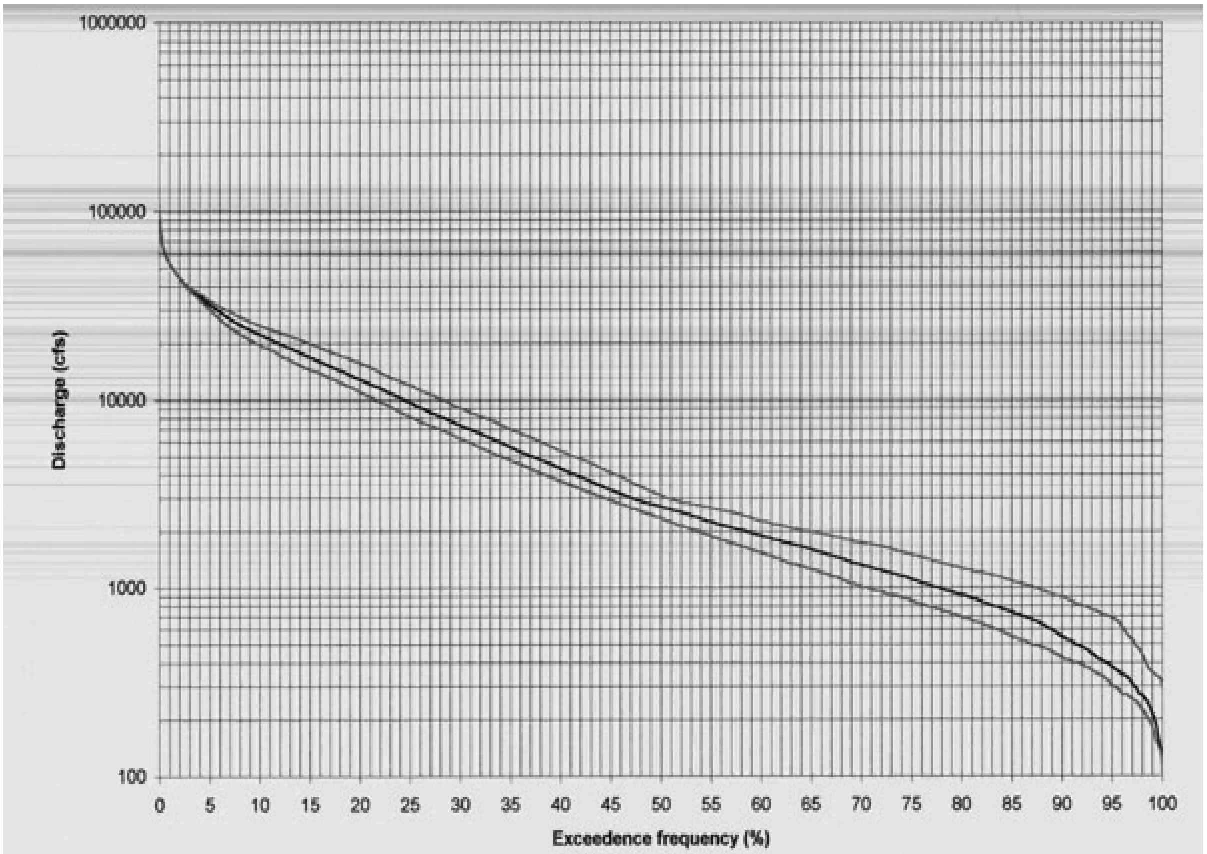


Fig. 2. Flow duration curves for the Trinity River at Romayor (courtesy of M.C. Slattery, Texas Christian University). The top curve is for post-dam conditions, the bottom for pre-dam flows, and the middle curve is the aggregate of all data.

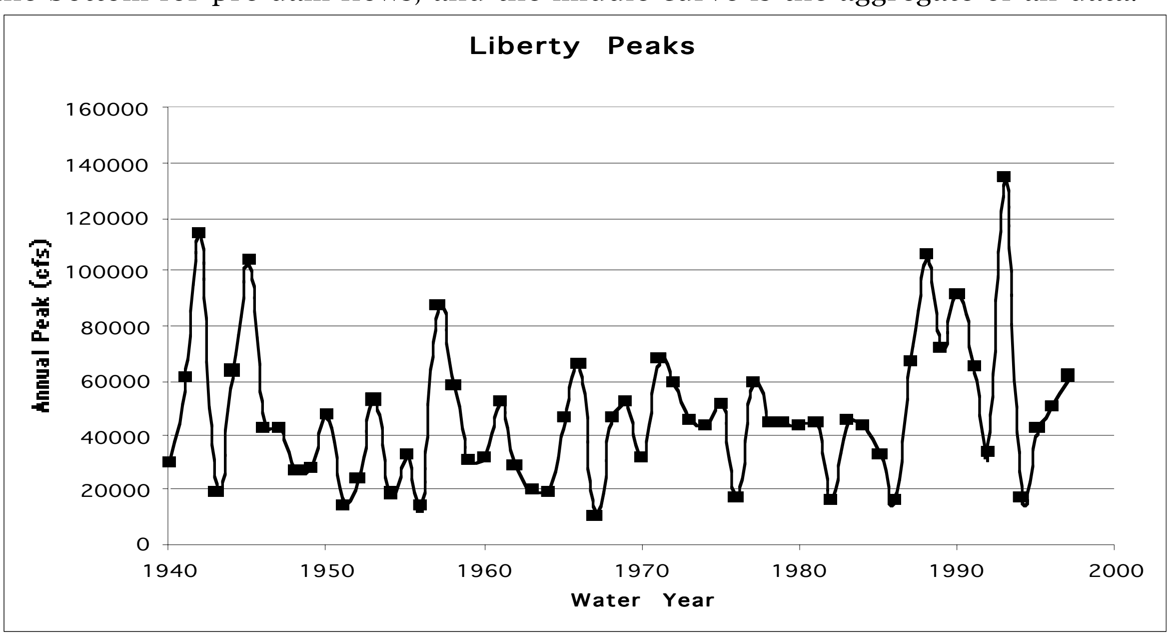


Figure 3. Annual peak flows at the Liberty gaging station.

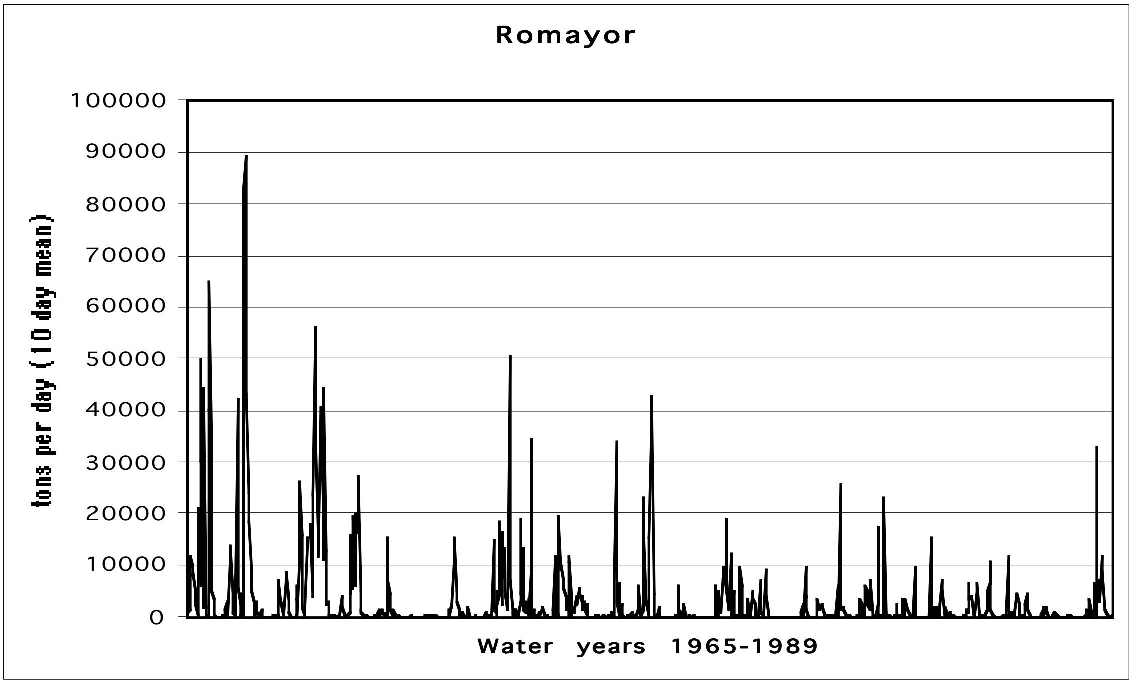
The capacity:inflow ratio for Lake Livingston is 0.316, based on the conservation pool capacity, and an extrapolation of mean annual flow per unit drainage area for the Crockett gaging station on the Trinity River upstream of the lake.

Sediment Transport

The Texas Water Development Board (TWDB) collected daily suspended sediment samples at three stations on the Trinity River (Liberty, Romayor, and Crockett, upstream of Lake Livingston) over the 1964-1989 period, allowing an assessment of sediment transport pre- and post-dam. The samples were taken with the "Texas Sampler," which yields results lower than, but systematically related to, yields based on depth-integrated sampling using standard U.S. Geological Survey methods (Andrews 1989; Welborn 1967). Values at the Romayor station were compared to same-day samples collected by the USGS, indicating that a multiplier of 2.37 should be used to convert TWDB values to equivalent depth-integrated values. As we are concerned here with relative sediment loads pre- and post-dam, the original TWDB values are used.

Data from the Romayor station shows a clear decline in sediment transport following completion of Livingston Dam (Fig. 4). Sediment loads at Liberty, however, show no evidence of a change in sediment regime (Fig. 4). The very low sediment yields and concentrations at Liberty compared with those at Romayor suggest that there is extensive alluvial storage between Romayor and Liberty, and that little sediment reaches the lower river at Liberty, with or without Lake Livingston.

Comparing sediment loads for Romayor and Crockett for all post-dam years (Fig. 5) it can be seen that in general there are lower yields at the downstream station, presumed to be due primarily to sediment trapping in Lake Livingston. These effects are sometimes apparently more than compensated for by other sediment sources, and in most cases any deficit is less than 20,000 tons. By contrast, subtracting sediment loads at Romayor from those at Liberty (10-day means) shows that there is always a loss of sediment, and that these losses are often greater than the Crockett-to-Romayor deficits. This shows that sediment storage in the lower Trinity is greater than storage in Lake Livingston, and suggests that alluvial storage in the lower river is a bottleneck for sediment delivery to the coast, independently of the effects of upstream impoundment.



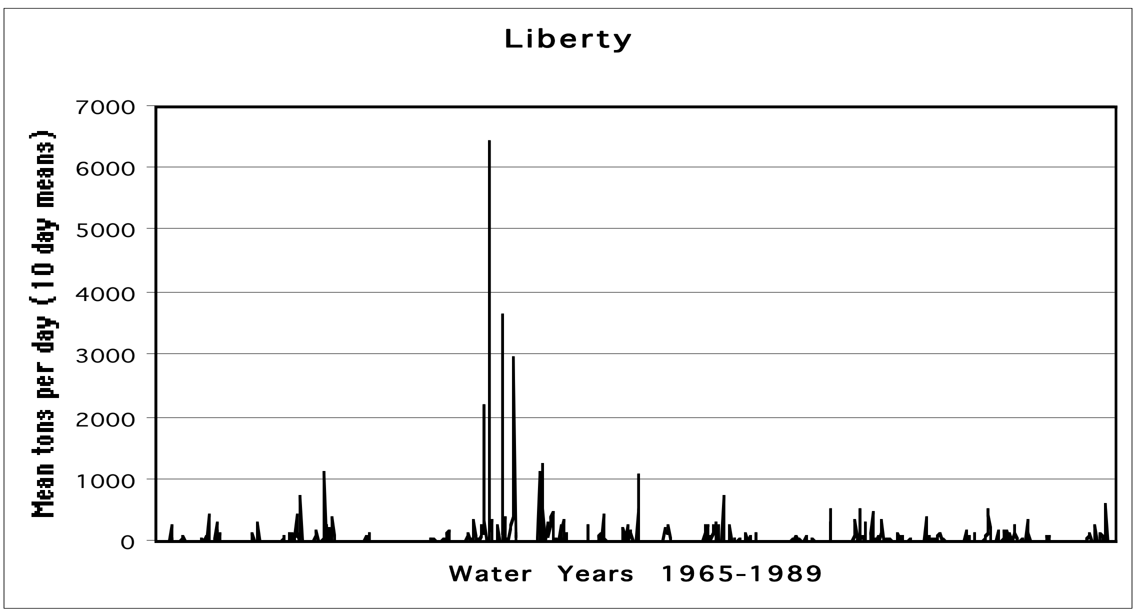
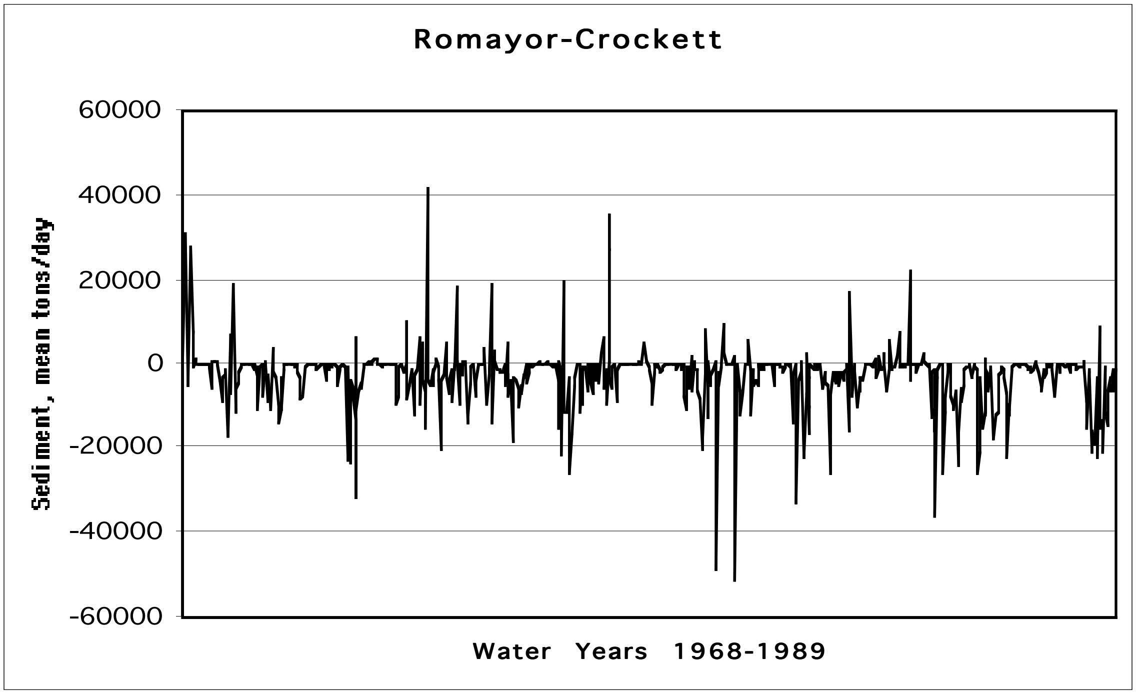


Figure4. Sediment loads for lowerTrinity River gaging stations at Romayor and Liberty. Values are means for 10-day periods. Note difference in scale of y-axis.



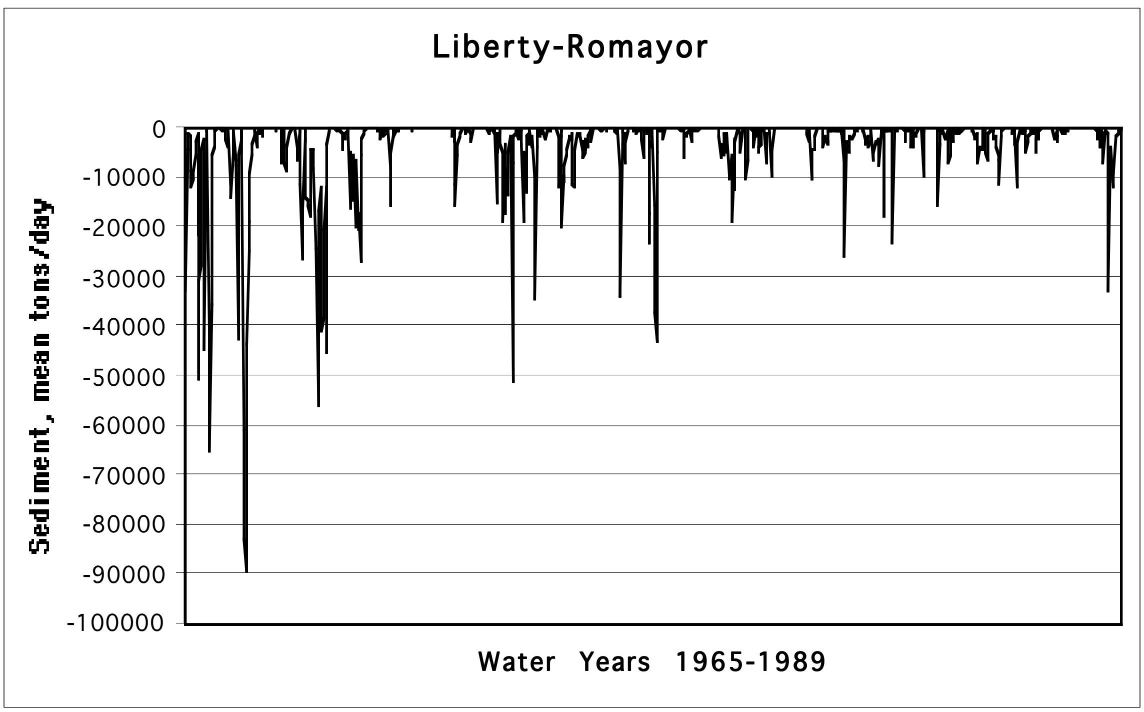


Figure 5. Comparison of sediment loads (daily means for 10-day periods) from Crockett to Romayor and Romayor to Liberty; obtained by subtracting Crockett from Romayor and Romayor from Liberty values, respectively.

It is not known whether the Trinity is characterized by long-term stability of sediment yields. The Colorado River, Texas, has apparently experienced a major decline in sediment yields, based on a comparison of dated Quaternary deltaic accumulations offshore and contemporary and historical sediment yields (Blum and Price 1994). Estimates of long-term sediment budgets and yields for coastal plain rivers such as the Trinity are difficult because of the migration of depocenters up and downstream as sea level varies. There are fluvial and deltaic deposits associated with the Trinity River well offshore of the current coastline, and evidence that sea level rise may have influenced aggradation up to 130 km upstream of the highstand shoreline (Thomas and Anderson 1994). Thus the "mouth" of the river may have varied in location by as much as 200 km in the upstream-downstream direction, considerably complicating efforts to define an accumulation basin. Even now, it is 60 km from the point, near Liberty, where the channel bed is below sea level to the mouth of the Trinity at Trinity Bay.

The alluvial morphology and stratigraphy of the lower Trinity (and the nearby and similar Sabine River), and the deposits and paleochannels now submerged in Trinity and Galveston Bays and the Gulf of Mexico unquestionably preserve evidence of climate, sea level, and upstream sediment delivery changes (Anderson and Rodriguez 2000; Anderson et al. 1992; Blum et al. 1995; Phillips 2003; Phillips and Musselman 2003; Rodriguez and Anderson 2000; Rodriguez et al. 2001; Thomas and Anderson 1994). If these are interpreted as representing variations in alluvial storage and remobilization, is it possible that alluvial buffering in the Trinity is sufficient to minimize long-term variation in export to the bay?

Estimates of sediment delivery to streams are available, based on reservoir surveys conducted by the Texas Water Development Board. The surveys document changes in reservoir capacity, which are assumed to be due to sedimentation. Dividing the capacity change by the number of years between surveys gives a volume of sediment accumulation per year. This is further adjusted for drainage areas to produce a virtual rate in m^e km^{-2} yr^{-1}. Bulk density of newly-deposited lake sediments in Texas range from 0.5 to 0.9 t m^{-3}, and those of older, more compacted lake sediments are typically 1.1 to 1.3 (Welborn 1967; Williams 1991). Thus, assuming a density of 1 tm^{-3} is a conservative estimate, and follows the practice of Smith et al. (2001). Data were averaged for 21 lakes in east and central Texas, in the same land resource areas as those encompassing the Trinity drainage basin.

The TWDB sediment data was used to compute an average daily sediment load, which was then mutltiplied by the 2.378 correction factor. This was used to compute sediment yield in tonnes per square kilometer of drainage area per year. A similar correction factor was used by Solis et al. (1994). Data were used from the Trinity River stations at Liberty, Romayor, and Crockett. Liberty is the downstream-most station where sediment data are available. The Crockett station is upstream of Lake Livingston and not influenced by the impoundment. Data were also examined for Long King Creek, a Trinity River tributary that enters downstream of Lake Livingston.

The sediment yields (Table 1) clearly show the importance of alluvial sediment storage in the contemporary Trinity River. The lake surveys and Long King Creek data suggest about 275 to 400 t km^{-2} yr^{-1} of sediment are being delivered to channels, no more than a third of which is transported into the lower Trinity. The sediment yields for Long King Creek, the surveyed lakes, and at the Crockett, Romayor, and Liberty stations illustrate the increasing sediment storage and declining channel delivery ratio with total stream length and basin area. While sediment loads at Romayor are apparently reduced by Lake

Livingston, there is no evidence of a dam-related change in sediment yields at Liberty.

Table 1. Sediment delivery and yields in the lower Trinity River Basin. Sediment data from the Texas Water Development Board, adjusted as decribed in the text.

Location or data source	Drainage area (km^2)	Yield ($t\ km^{-2}\ yr^{-1}$)
Lake surveys	8,196 (mean)	276
Long King Creek	365	425
Trinity @ Crockett	36,029	129
Trinity @ Romayor	44,512	69
Trinity @ Liberty	45,242	1.4

A short distance downstream of Romayor, the Trinity floodplain becomes wider, lower, and characterized by a greater number and size of oxbows and other depressions. The effects on alluvial storage are obvious in the difference in yield between Romayor and Liberty--in fact, alluvial storage in the lower Trinity appears to exceed sediment storage in Lake Livingston.

The Trinity valley from Livingston dam to the head of Trinity Bay is 174 km long. The average width of the floodplain is about 5 km. Channel surveys at 12 locations on the lower Trinity in 2002 indicate a typical bank height of about 7 m. Taking the latter as an effective thickness of potential activation of alluvium (a reasonable assumption, as the Trinity is near bedrock at many locations below Lake Livingston) yields a total volume of potentially remobilizable alluvial storage of $6.0858 \times 10^9\ m^3$. At a typical bulk density of 1.4 $t\ m^{-3}$, there are 8.52×10^9 tonnes available. This represents 138,758 years worth of sediment yields at Liberty. While these calculations are admittedly rough, since they only consider alluvial storage in the lowermost reaches of the river, they are sufficient to make the point that the reaction time of the floodplain sediment storage is substantially longer than the timescales of climate and sea level oscillations.

This is generally consistent with studies of the Quaternary evolution of central and east Texas rivers (Blum and Price 1998; Blum et al. 1994) and of southeast Texas estuary and delta complexes (Anderson and Rodgriguez 2000; Rodriguez et al. 2001). These studies show episodes of cut and fill, and of inland-offshore migration of depositional loci, but no evidence of anything approaching complete evacuation of stored alluvium.

GEOMORPHIC CHANGES

One objective in the scope of work is to assess changes in channel and floodplain morphology, alluvial sedimentation, and sediment delivery at the river mouth following completion of the dam.

Erosion, Accretion, and Channel Change

Field observations were made at 18 locations between Livingston Dam and the river mouth. The sites were assessed for evidence of geologically recent and contemporary geomorphic change based on morphology, vegetation indicators, sedimentological and pedological characteristics, effects of fluvial processes on cultural features, and comparison of field observations with digital orthophotoquads based on aerial photographs taken in 1994.

The results, in terms of the types of changes observed, are summarized in Table 2. More complete details will be provided in the final report. Note that the information in Table 2 is all positive evidence--that is, there was clear evidence that a particular process has occurred, but the absence of such evidence does not necessarily indicate that a process is not occurring. That is, bank erosion or floodplain accretion (for instance) could be occurring at a site, but if there is no clear field evidence the change is not listed in Table 2.

Accretion Rates

Floodplain surface sedimentation rates were measured at three sites using dendrogeomorphic methods. This is based on the principle that upon germination, tree root crowns and basal flares are approximately flush with the ground surface. Substantial amounts of sedimentation may bury these features. By measuring the distance from the surface to the root crown the depth of burial may be estimated. Ring count determination of tree ages (using an increment borer to extract cores) allow the time frame of accretion to be determined, and a minimum mean rate to be estimated. The rate is a minimum in that it assumes sedimentation began immediately after tree establishment. In some cases buried tree bases send out adventitious roots; these may allow some additional discrimination of sedimentation rates and timing.

Measurements were made at the Goodrich, Moss Hill, and Liberty sites. Additionally, field assessments of vegetation burial (but without measurements) were made at the Mouth of Menard Creek, Romayor, and Port of Liberty 2 sites.

As shown in Table 3, significant accretion is occurring at all sites in recent years. Typical accretion rates of 18 to 40 mm yr^{-1} are consistent with vertical accretion rates in alluvial floodplains elsewhere in the U.S. Atlantic and Gulf coastal plains, which range from <1 to 61 mm yr^{-1} over periods of 1 to 25 years (Phillips 2001: table 3). Obvious burial of vegetation indicating recent sedimentation was also noted at the mouth of Menard Creek, Romayor, and Port of Liberty 2 sites (see fig. 6,7).

Table 2. Recent geomorphic changes at selected locations, based on field observations.

Site	Evidence of geomorphic change/activity
Camilla (FM 3278 just downstream of dam)	Channel incision, lateral channel migration
Camilla Twin Harbors	Bank erosion
Cedar Valley	Cutbank erosion, point bar migration, channel incision
Goodrich (US 59 crossing)	Channel incision, incision at mouth of Long King Creek, floodplain accretion, bank erosion
Mouth of Menard Creek	
Romayor railroad bridge	Channel incision; bank erosion
Romayor (SH 787 crossing)	Channel incision; bank erosion; sand bar mobility, floodplain accretion
Sam Houston Lake Estates	Cutbank erosion; point bar accretion; slope failures on bank
Cypress Lakes (sandbar beach)	Cutbank erosion, point bar growth and migration, lateral channel migration
Moss Hill (SH 105 crossing)	Floodplain accretion, bank erosion, cut bank erosion, point bar migration
Dayton Lakes	Cut bank erosion; point bar growth and migration; slope failures on bank
Kenefick	Lateral channel migration and meander cutoff; cutbank erosion; point bar migration; floodplain accretion
Liberty (US 90 crossing)	Floodplain accretion; bank erosion; point bar growth and mobility; lateral channel migration
Port of Liberty 1 (upstream end of Old River)	Bank erosion; slope failures on bank; lateral channel migration
Port of Liberty 2 (downstream end of Old River)	Floodplain accretion; lateral channel migration; slope failures on bank
Moss Bluff	Bank erosion
Wallisville	Engineered site; no obvious fluvial changes observed
Trinity River mouth/Trinity Delta`	Engineered and coastal-dominated site; no obvious fluvial changes observed

Table 3. Accretion rates based on dendrogeomorphology. Rates are in mm yr^{-1}.

Site	N of trees	measure-ments	age range (years)	mean accretion rate	min accretion rate	max accretion rate
Goodrich	7	10	1 - 27	18.5	0	41.0
Moss Hill	5	6	1 - 16	45.4, 18.5 (1)	3.6	180, 41.2 (1)
Liberty	2	3	2 - 21	39.9	28.1	56.7

(1) First number includes 180 mm of deposition in one year as measured by adventitious root. The second number excludes this measurement.

Figure 6. Tree on floodplain at Port of Liberty 2 site, with base buried by recent deposition. Note branches close to ground surface.

Figure 7. Typical appearance of floodplain surface just downstream of Liberty, lower Trinity River. Note the buried bases and “utility pole” appearance of lower tree trunks, indicating recent sedimentation.

SEDIMENT INPUTS

The scope of work objective is to “evaluate the sediment inputs from upland erosion, tributaries, and bank erosion downstream of Lake Livingston.” TWDB data indicate a mean annual sediment yield at Long King Creek at Livingston of 155,125 t yr^{-1}. This accounts for only about five percent of the mean annual yield of 3,071,028 t yr^{-1} at Romayor, but is 2.45 times the annual yield at Liberty (63,339 t yr^{-1}).

There are 1447 km^2 of drainage area between Livingston Dam and Liberty. Sediment production at 425 t km^{-2} yr^{-1} (based on Long King Creek) would would yield 614,965 tons per year, or about 10 times the annual yield at Liberty. At a mean rate of 276 t km^{-2} yr^{-1} (based on lake data), this drainage are would produce an amount (399,372 t) more than six times the annual yield at Liberty. Given the reduction in sediment loads and apparent alluvial storage downstream of Romayor, it is clear that sediment production within the lower basin is sufficient to maintain sediment loads in the lower river. This suggests that even if Lake Livingston was a perfect sediment trap, and independently of erosional adjustments in the river channel downstream of the dam, upland erosion in the lower Trinity basin exceeds the long-term transport capacity of the lower Trinity.

Long King Creek at the gaging station accounts for about half of the drainage area between Livingston Dam and Romayor. Doubling this contribution would account for only about 10 percent of the yield at Romayor. This suggests that a large proportion of the sediment at Romayor must be derived from sources other than tributary inputs and upland erosion from drainage areas not controlled by Livingston Dam. The only two possibilities are that sediment is derived from channel erosion or sediment that is passed through Lake Livingston.

Channel erosion, including lateral erosion, vertical incision, and remobilization of alluvium stored in the channel or floodplain, is a significant source (see Geomorphic Changes section). The sediment load of water passing through Livingston Dam is unknown, though the low capacity-inflow ratio of the lake indicates that it may be a "leaky" sediment trap.

SEDIMENT CHARACTERIZATION

Scope of work objectiv e (4) is to characterize the channel and floodplain sediment above and below the lake and dam site.

Grab samples of sediments were collected in the field from channel, channel bar (generally point bar), floodplain, and bank environments. A number of samples were also collected from potential upland source areas. These included erosion surfaces, rills, and gullies, and eroding ditches and minor tributaries. The sand fraction of samples was examined under a binocular microscope primarily for two properties--the degree of rounding or angularity, and the presence and abundance of iron oxide coatings.

Grains were classified as angular, subangular, subrounded, or rounded based on standard sedimentological categories. For each sample both the range of angularity and the dominant or modal angularity class was recorded. Iron-oxide stains or coatings on sand grain were recorded as none, few (<10 percent of grains coated), rare (10-25%), common (25-50%), or many (>50%) based on the proportion of sand grains which had oxide coatings. Residual upland soils in east Texas have dominantly angular and subangular grains, and iron oxide coatings are ubiquitous. The logic of the approach is that once such grains are delivered to the fluvial environment then angularity will decrease and rounding will increase; and iron oxide coatings will decrease as a function of transport distance and time in the channel environment. This occurs primarily due to grain abrasion, but removal of Fe coatings in solution by reduction in the aqueous environment is also possible.

Similar methods were used by Phillips (2003) in the Sabine River, and the principle of increasing in rounding as a function of the time or distance of transport is well established (Knighton 1998: 136-140; Mills 1979). Stanley et al., (2000) showed that iron-staining of sand grains could be used to distinguish between in situ Pleistocene deltaic sediments from reworked Holocene material. This suggests that the length or intensity of reworking results in the loss of iron stainings and coatings. Eriksson et al. (2000) used intact iron oxide coatings of sand grains in colluvial and alluvial deposits as an indicator transport has occurred over relatively short distances.

Results are reported in Appendix A and summarized below.

Fe coatings

The examination of iron oxide coatings is summarized below.

1. No channel, sandbar, or floodplain samples have *many* coatings. This compares to 48 percent of upland source samples, 20 percent in tributariess, and 25 percent in bank samples.

2. 59 percent of channel, 67 percent of sandbar, and 50 percent of floodplain samples have rare or no oxide coatings. This compares to 16 percent of source samples. Fewer than half of the river bank and tributary samples lack oxides, but there are a significant number of samples in this category.

3. The channel, bar, and floodplain samples in the "common" coating category were disproportionately associated with finer material.

4. The two bank samples in the "rare" category seem to be clearly alluvium. The two in the "many" category occur in a well-defined soil. The other four (in the "common" class) are a mixture of alluvial and upland.

5. The five source samples where some fluvial transport has obviously occurred fall into the "common" or "rare" (2) categories. But three "rare" and eight "common" source samples are not obviously recently fluvially transported.

The results indicate that Fe coatings are inversely associated with bedload, abrasive transport, which apparently removes the coatings. The absence or rarity of coatings in well-drained upland soils may indicate a geologically recent fluvial origin or local fluvial or aeolian transport. However, they may also be exposed E horizons or soils that do not acquire Fe coatings. The presence of numerous Fe coatings in fluvial sediments indicates recent delivery from uplands, but the absence of coatings does not necessarily imply long storage, reworking, or a lack of upland sediment delivery.

In general, results suggest a significant and perhaps dominant role for bank erosion and alluvial remobilization, and a relatively long residence time for alluvium. However, the erosion of older alluvium from terrace uplands cannot be ruled out.

Angularity and Rounding

Assessment of angularity and rounding can be summarized as follows:

1. Dominantly angular sand grains are found only in the uplands, but are the most common type of particle in only two of 31 samples.

2. Angular grains make up a significant portion of 48 percent of upland samples, but make a significant portion of 62 percent of bank and floodplain samples, and 35 percent of channel samples.

3. Dominantly rounded sand grains are found in only two samples--one channel, and one bank sample that derives from alluvial terrace deposits of the Deweyville formation.

4. Rounded grains make up a significant portion of 41 percent of channel, 58 percent of sandbar, 60 percent of tributary, and 50 percent of bank and floodplain samples. This compares to 39 percent of source samples with a significant component of rounded sand grains.

5. Channel, sandbar, and tributary samples are dominantly subrounded--in 65, 67, and 70 percent, respectively of the samples the modal shape was subrounded.

6. Upland, bank, and floodplain samples are dominantly subangular--in 48, 75, and 75 percent, respectively of the samples the modal shape was subangular (upland = 15 subangular, 14 subrounded, two angular).

7. Rounding is irreversible. A grain can only follow the path angular - subangular - subrounded - rounded; it cannot become more angular.

Results indicate that grain rounding is associated with bedload, abrasive transport. However, rounding observed in any setting may be ancient or recent. Rounding in upland grains indicates a fluvial source, but this is possibly ancient deposits. The presence of numerous angular and subangular grains in fluvial sediments indicates recent delivery from uplands, but the absence of angularity does not necessarily imply long storage, reworking, or a lack of upland sediment delivery.

Results are generally consistent with those of the Fe oxide coatings, and indicate a mixture of reworked alluvium and recently-eroded upland material. The irreversibility of rounding makes it difficult to distinguish geologically recent versus ancient fluvial transport.

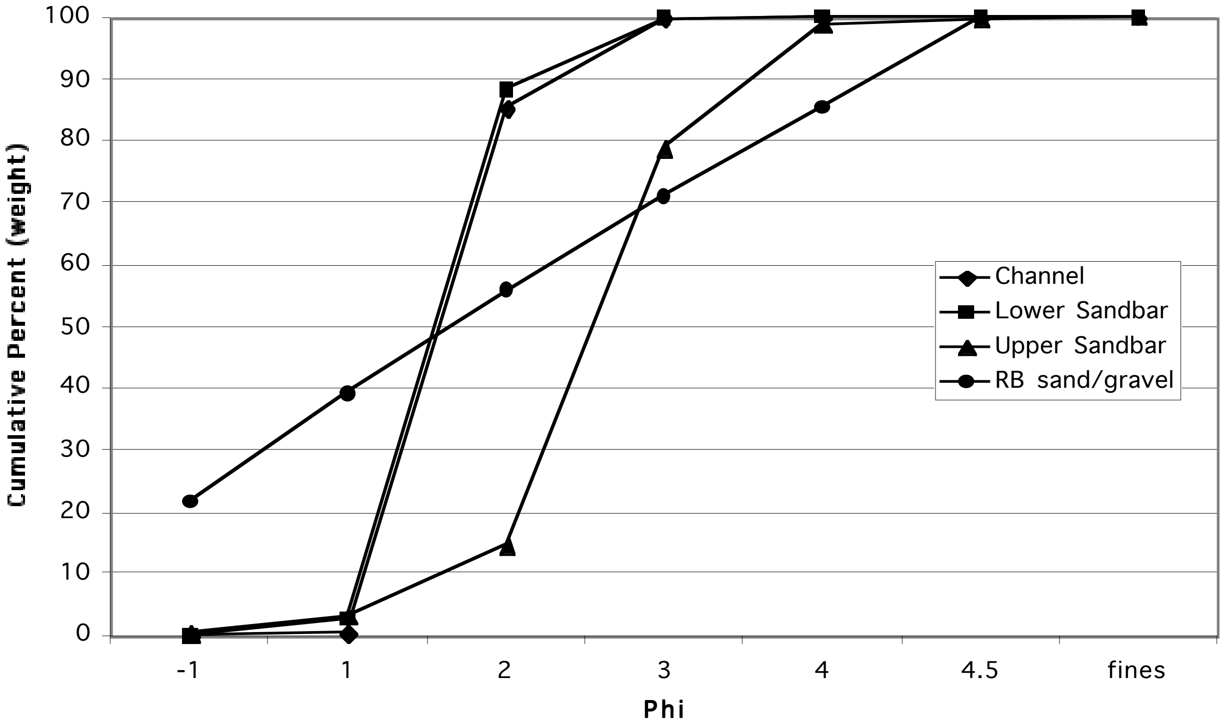
Grain Size Distributions

Grain size distributions focussing on the sand fraction were examined for sediments collected from channels and bars at four sites (Romayor, Cypress Lakes Beach, Moss Hill, and Liberty. Samples were air-dried, disaggregated, and sieved using at ATM sonic sifter. Sieve sizes represented -1, 1, 2, 3, 4, 4.5 phi units, corresponding with the gravel, and the very coarse, coarse, medium, fine, and very fine sand fractions. Grain size distribution curves are shown in Figure 8.

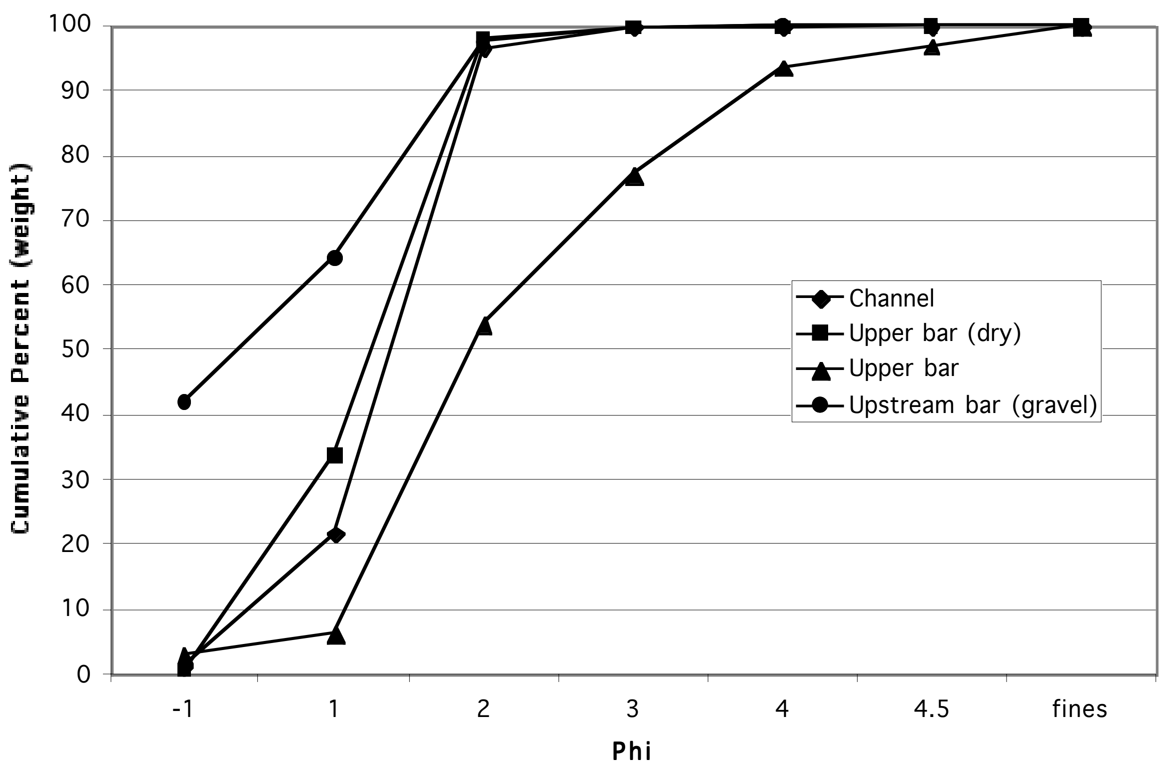
Further analysis of grain size distributions, including the inclusion of additional samples, will be conducted in the second year of the project.

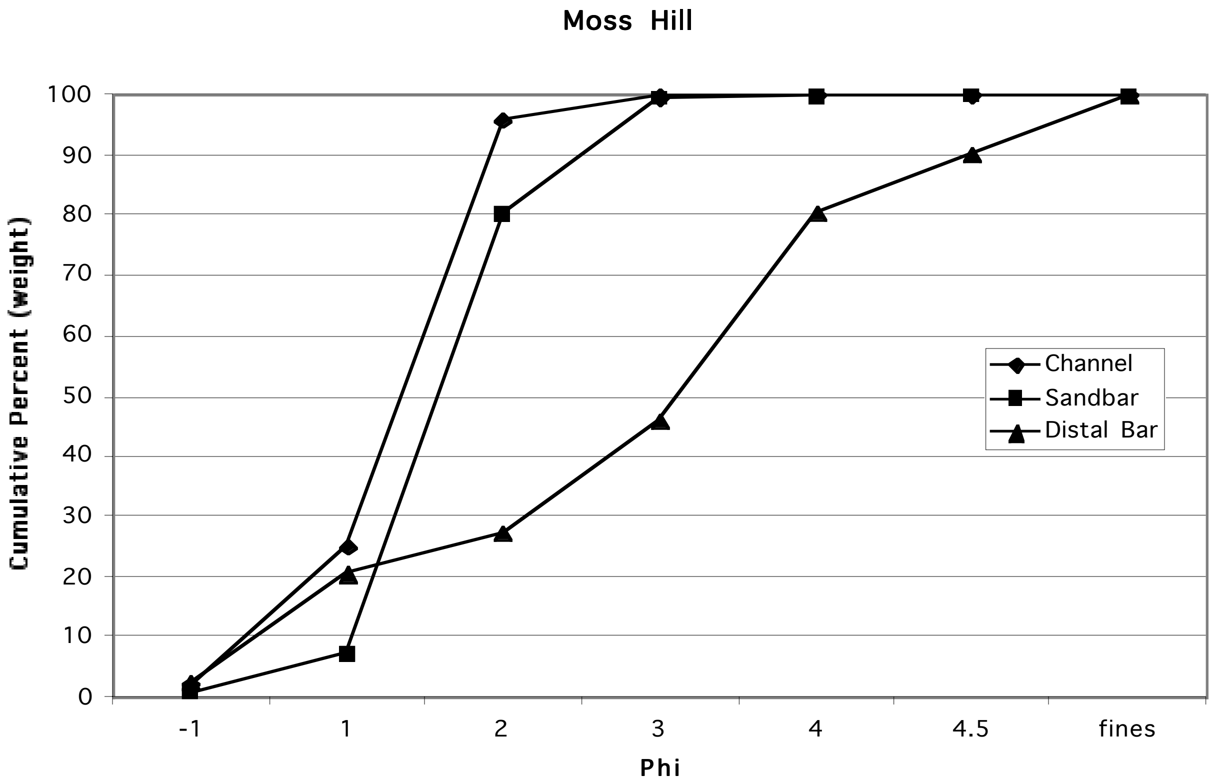
Figure 8 (following pages). Grain size distribution curves.

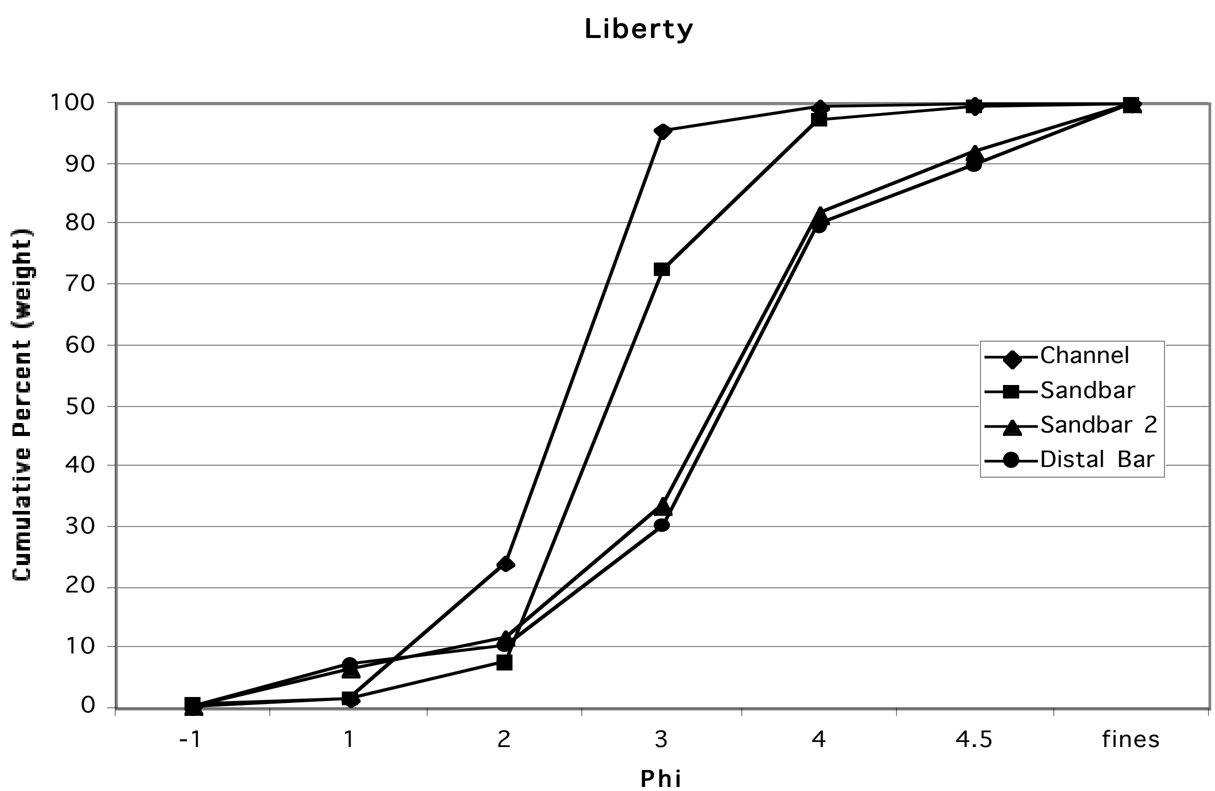
Romayor



Cypress Lakes Beach




Moss Hill
Cumulative Percent (weight)
100
90
80
70
60
50
40
30
20
10
0
-1
1
2
3
4
4.5
fines
Phi
Channel
Sandbar
Distal Bar


Liberty
Cumulative Percent (weight)
100
90
80
70
60
50
40
30
20
10
0
-1
1
2
3
4
4.5
fines
Phi
Channel
Sandbar
Sandbar 2
Distal Bar

SEDIMENT TRANSPORT TO UPPER DELTA

Objective (5) is to "identify the difference in sediment transport to the upper delta before and after the dam placement." As indicated in the sections above, there is no evidence of a reduction in sediment supply to the upper delta after dam placement. Sediment transport in the lower Trinity, as in any river, is highly variable day-to-day and year-to-year. However, there is no evidence of any long-term upward or downward trends, or of any significant shifts in sediment regime in the past 40 years.

POTENTIAL SEDIMENT REPLENISHMENT SOURCES

Study objective (6) is to determine the sediment sources that could replenish the stream sediment supply that are near the river channel or in the lake. This objective appears to have limited relevance, given the lack of evidence of any dam-related reduction in sediment supplies to the estuary. More importantly, there is abundant mobile sand in the Trinity channel. Many alluvial and terrace soils of the lower Trinity have high sand contents. However, this objective will not be pursued further, given results obtained thus far.

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APPENDIX A

IRON OXIDE (Fe) COATINGS AND ANGULARITY OF SEDIMENT SAMPLES

Sample	Fe coatings	Angularity range	Modal
Tributaries			
Upper Long King	common	rounded to subangular	subrounded
Long King at 942	common	subrounded to subangular	subangular
Long King at 190	rare	rounded to subangular	subrounded
Long King at 1988	rare	subrounded to subangular	subrounded
Long King delta 1	common/rare	rounded to angular	subrounded
Long King delta 1	rare	rounded to subangular	subangular
Long Tom	rare	rounded to subangular	subrounded
Bennett Creek	common	rounded to subangular	subrounded
Menard Cr. mouth	many	subrounded to angular	subangular
Big Creek	many	subrounded to subangular	subrounded
Upland sediment sources			
PCU1	many	subrounded to subangular	subrounded
PCU2	common	rounded to angular	subrounded
PCU3	common	rounded to subangular	subrounded
PCU4	common	subrounded to angular	subangular
PCU5	many	subangular to angular	angular
PCU6	common	subrounded to subangular	subangular
PCU7	many	rounded to angular	subangular
PCU8	common	rounded to angular	subangular
PCU9	rare	rounded to subangular	subrounded
PCU10	many	subrounded to subangular	subrounded
PCU11	common	subrounded to angular	subangular
PCU12	common	subrounded to subangular	subrounded
PCU13	many	subrounded to angular	subangular
PCU14	many	rounded to subangular	subrounded
PCU15	many	subrounded to angular	subangular
LMP upland	rare	rounded to angular	subrounded
LMP gully wall	many	subrounded to angular	subangular
LMP gully subsurf.	common	subrounded to subangular	subangular
LMP gully floor	rare	rounded to subangular	subrounded
BT1	many	subrounded to angular	subangular
BT2	many	subrounded to subangular	subangular
BT3	many	subrounded to angular	angular
BT4	common	rounded to subangular	subrounded
BT5	many	subrounded to subangular	subangular
BT6	rare	rounded to subangular	subrounded
SHNF1	common	subrounded to angular	subangular
SHNF2	many	rounded to subangular	subrounded
SHNF3	many	subrounded to angular	subangular
SHNF4	many	rounded to subangular	subrounded
SHNF5	rare	subrounded to angular	subangular
SHNF6	common	subrounded to subangular	subrounded

Channel

3278 channel clay	common	subangular to angular	subangular
3278	common	rounded to subrounded	rounded
Goodrich 1	rare	subrounded to subangular	subrounded
Goodrich 2	common	subrounded to subangular	subangular
Romayor upstream	rare	subrounded to subangular	subrounded
Romayor	none	rounded to subangular	subrounded
SHLE	rare	subrounded to angular	subangular
Cypress Lakes	common	rounded to subangular	subrounded
Moss Hill 1	rare	subrounded to angular	subrounded
Moss Hill 2	common/rare	rounded to subangular	subrounded
Dayton Lakes	rare	subrounded to angular	subangular
Kenefick 1	common	rounded to subangular	subrounded
Kenefick 2	rare	rounded to subangular	subrounded
Kenefick margin	rare	subrounded to angular	subrounded
Liberty 1	rare	subrounded to subangular	subrounded
Liberty 2	rare	rounded to subrounded	subrounded
Port of Liberty	common	subrounded to angular	subangular

Banks

3278 lower bank	rare	rounded to angular	subangular
3278 bank scarp	common	rounded to subangular	subrounded
3278 Deweyville	common	rounded to subrounde	rounded
Romayor 1	many	rounded to subangular	subangular
Romayor 1 44-111	many	subrounded to angular	subangular
SHLE cutbank	common	subrounded to angular	subangular
Dayton Lakes	common	subrounded to angular	subangular
Kenefick cutbank	rare	subrounded to angular	subangular

Floodplain

3278 fresh deposits	rare	rounded to subangular	subrounded
Goodrich tree 1	rare	subrounded to subangular	subangular
Goodrich tree 5	rare	subrounded to angular	subangular
Menard Cr. mouth	common	subrounded to angular	subangular
Moss Hill	common	subrounded to angular	subangular
Moss Hill Tree 3	common	rounded to angular	subangular
Moss Hill Tree 5	common	rounded to angular	subangular
Liberty 1	rare	rounded to subrounded	subrounded

Sandbars

Romayor lower	none	rounded to subangular	subrounded
Romayor upper	rare	subrounded to subangular	subangular
Romayor 3	rare	rounded to subangular	subrounded
Cypress Lakes 1	rare	rounded to subangular	subrounded
Cypress Lakes 2	rare	rounded to subangular	subrounded
Cypress Lakes 3	rare	rounded to subangular	subrounded
Moss Hill 1	rare	subrounded to subangular	subrounded
Moss HIll 2	common	rounded to subangular	subrounded
Moss Hill distal	rare	subrounded to subangular	subangular
Liberty-mud drape	common	subrounded to subangular	subangular
Liberty distal mud	common	subrounded to subangular	subangular
LPT2 delta	common	rounded to angular	subrounded