FIELD INVESTIGATION REPORT

LOCATING AND DESIGNING STRUCTURES TO IMPROVE STREAM GAUGING ACCURACY IN THE RIO GRANDE RIVER BASIN

This Report is Submitted to the
International Boundary and Water Commission
United States Section
El Paso, Texas

by the

Field Investigation Team
Colorado State University Research Foundation
Fort Collins, Colorado

June 1960

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To: Commissioner L. H. Hewitt
International Boundary and
Water Commission
United States and Mexico
United States Section
P. O. Box 1859
El Paso, Texas

Transmitted herewith are four (4) copies of the report covering the Field Investigation, as called for in Contract IBM6542. This report emphasizes the four top priority stations, including recommendations--Langtry, Pecos, Amistad and Del Rio. Other sites along the river were also visited and discussed with your staff on the spot; these other sites are not emphasized in this report except insofar as they provided background information.

As stated in this report, it is recommended that design and construction of a structure for the Del Rio site have top priority. If you wish to implement the option in our present contract, we will be happy to serve you.

On behalf of the Colorado State University and its staff we have enjoyed working for the Commission and look forward to a continued association.

Sincerely yours,

A. R. Chamberlain, Acting Dean
College of Engineering
Chief, Engineering Research
President, Colorado State University
Research Foundation

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES --Continued.

FIELD INVESTIGATION REPORT

LOCATING AND DESIGNING STRUCTURES TO IMPROVE STREAM GAUGING ACCURACY IN THE RIO GRANDE RIVER BASIN EL PASO, TEXAS, TO LAREDO, TEXAS.

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Period of Investigation - May 20-22, 1960

INTRODUCTION

AUTHORIZATION

The field investigation of the Rio Grande River Basin reported herein was conducted under contract between the International Boundary and Water Commission, El Paso, Texas, and Colorado State University Research Foundation, Fort Collins, Colorado, (Contract IBM 6542). This report is a culmination of the investigation.

STATEMENT OF THE PROBLEM

The need for improving the accuracy of records of stream flow at stations in the Rio Grande arises principally from the responsibilities assigned to the two Sections of the Commission in accounting for the national ownership of waters of the Rio Grande from Fort Quitman to the Gulf of Mexico alloted to the United States and Mexico under the 1944 Water Treaty between the two countries. The principal basic data for such accounting comprise records of the flow at gaging stations on the main river and on principal tributaries in each country.

Accurate water accounting, however, has not been possible, due primarily to inherent inaccuracies, in stream discharge data based upon usual stream gauging practices. One of the major problems in making river stage records has been that during alternate periods of low and high water stages the river channel has shifted in alignment because of the natural meandering of the river, leaving the water stage recorder out of contact with the main channel and adversely affecting flow conditions at the measuring section such that accurate current meter measurements cannot be made.

Scour and deposition of the bed at or near the gauging stations have also caused frequent variations in the stage-discharge relationships, leading to difficulties in maintaining accurate records of discharge. Unless the channel bed is controlled, almost continuous current meter measurements of stream discharge would have to be made to detect the shifts in the rating curve for each gauging station.

These difficulties have led the United States Section of the International Boundary and Water Commission to conclude that in order to establish more reliable stream flow records artificial controls in the river channel would be necessary. It is hoped, furthermore, that these controls will effectively reduce the number of current meter discharge measurements presently being made to establish reliable rating curves, thereby effecting considerable savings in the cost of the total stream gauging function.

The objective of the field investigation was to make basic recommendations for the location and hydraulic design of control structures so that accurate measurements of discharge could be made and the stage-discharge relationship stabilized in a range from 100 to 10,000 c.f.s. with a minimum of interference from aggradation and deposition of material near the structure. The recommended structure must of course be capable of remaining in place at all stages of the river.

DESCRIPTION OF GAUGING STATIONS

PART I - PRIORITY STATIONS

Rio Grande River at Langtry

The proposed gauging station is to be located downstream from Losier Creek, and about 10 miles upstream from the town of Langtry. A sketch of the river reach is shown in Fig. 1.

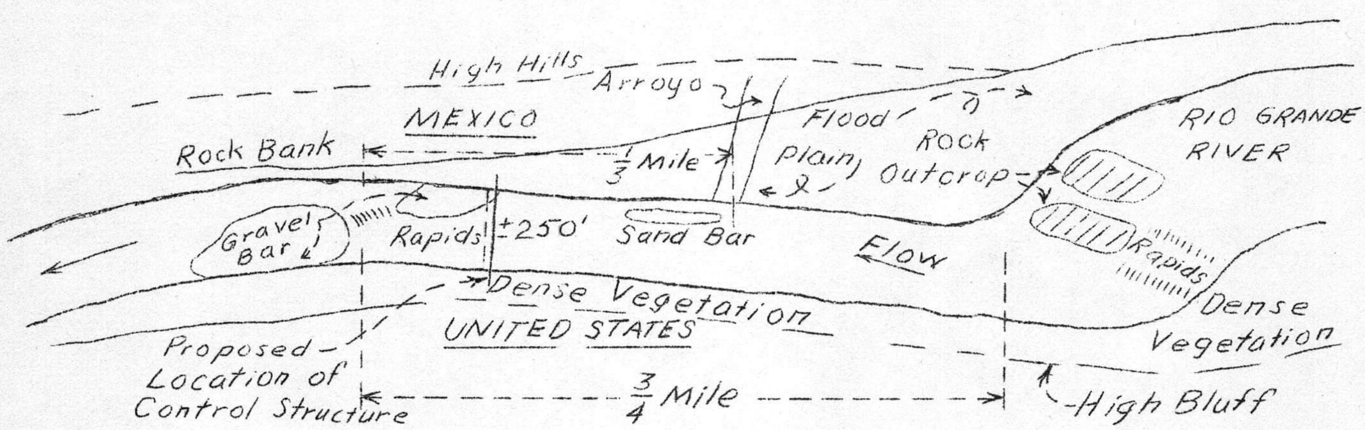


Fig. 1 Sketch of Langtry Site (Not to Scale).

A view of the lower rapids section and river bend is shown in Fig. 2, as seen from the United States side of the river. The river flow is from right to left. Near the bend, center of the photograph, there is a longitudinal deposit of gravel which forms a control section. The velocity of flow upstream from this gravel bar was very small at the estimated discharge of about 600-700 c.f.s. The gravel bar, and rapids, evident in Fig. 2 is shown also in Fig. 3.

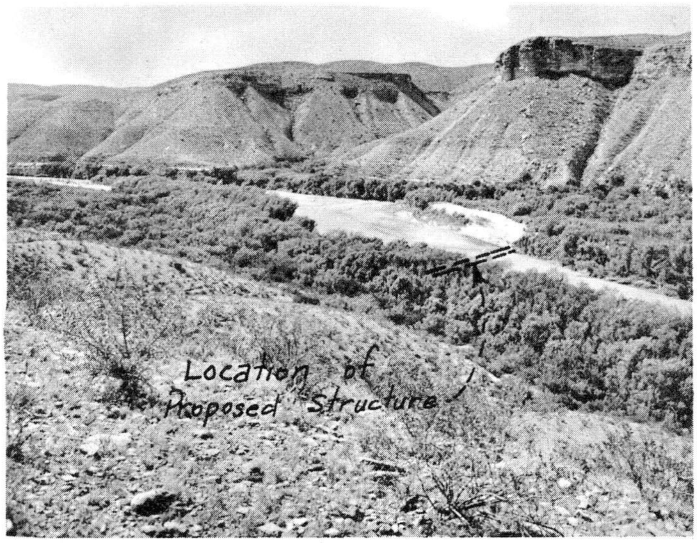


Fig. 2 (Left) Proposed Langtry Gauging Station Site. Photograph taken from United States side. Note gravel bar and rapids in center of picture. Flow is from right to left.

Fig. 3 (Right) View of gravel bar, lower rapids and upstream river reach. Fall in water surface at the rapids is about 3 ft. Average fall in river is approximately 5 ft per mile.

Along the Mexico side of the river near the bend, there is an outcropping of rock, shown in Fig. 4. Along the United States side opposite this point, the gravel deposit extends higher and is overlain by a layer of fine sand which supports dense vegetation. See Fig. 5. The size of gravel and cobbles on the river bed can be seen in Fig. 6. The shapes and sizes vary from fine sand to cobbles 7 - 10 inches in diameter.

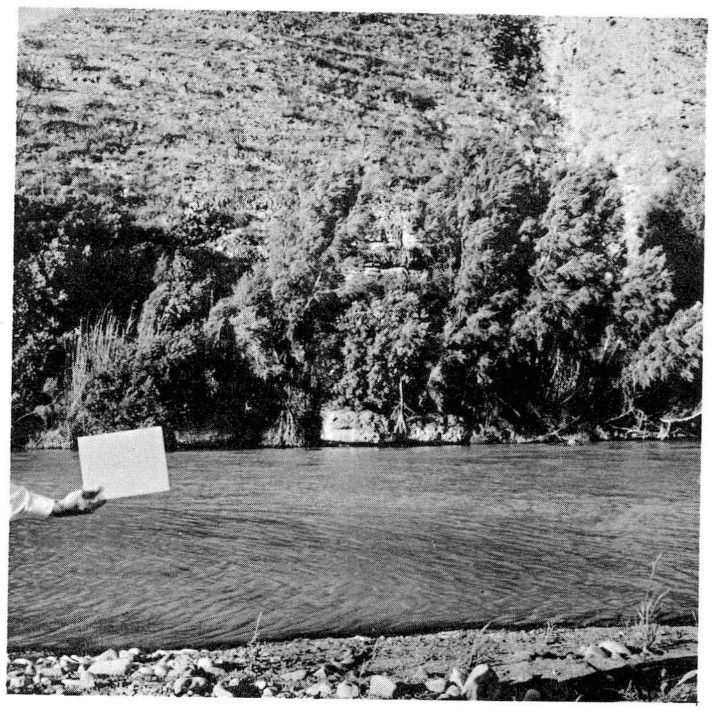
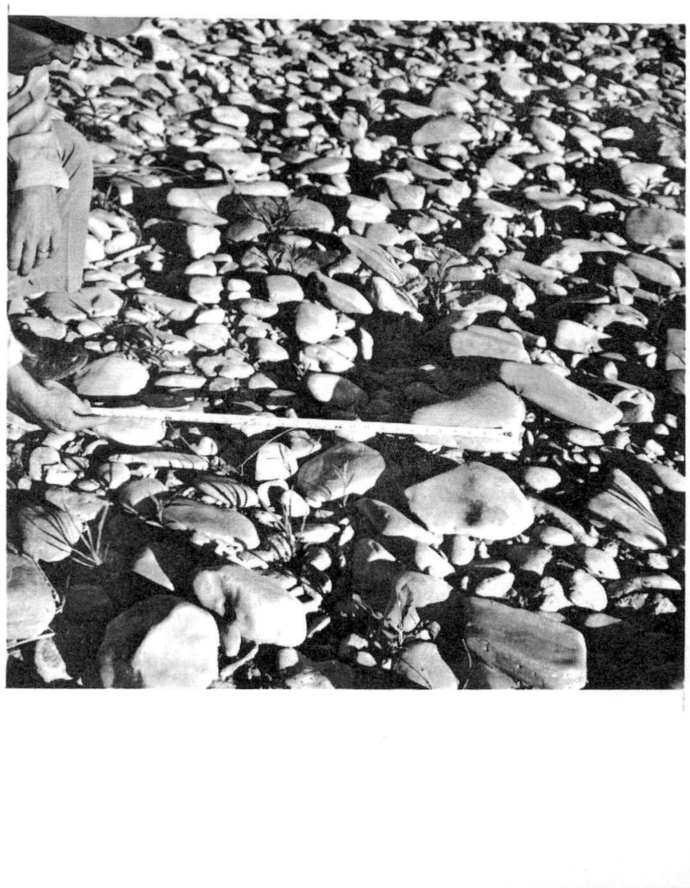


Fig. 4. Note outcrop of rock along Mexico side, downstream from the lower rapids, at the bend.

Fig. 5 (Left) View of United States bank opposite rock out-crop near gravel bar and lower rapids of Langtry site. Note gravel material extending up side slope and dense vegetation on sand overlying the gravel.

Fig. 6 (Right) Typical bed material at lower rapids section at the proposed Langtry gauging station. Material is well worn and varies in size and shape.



Upstream from the lower rapids, the river is straight on a reach of about 3/4 mile. Midway in this reach there is an arroyo on the Mexico side which contributes some amount of sediment to the river. At the time of field inspection, the flow of 600 to 700 c.f.s. in the Rio Grande carried very little sediment.

The characteristic slope of the river is approximately 5 feet per mile.

A view of the upper rapids section and a close-up photograph of the rapids is shown in Figs. 7 and 8 respectively.

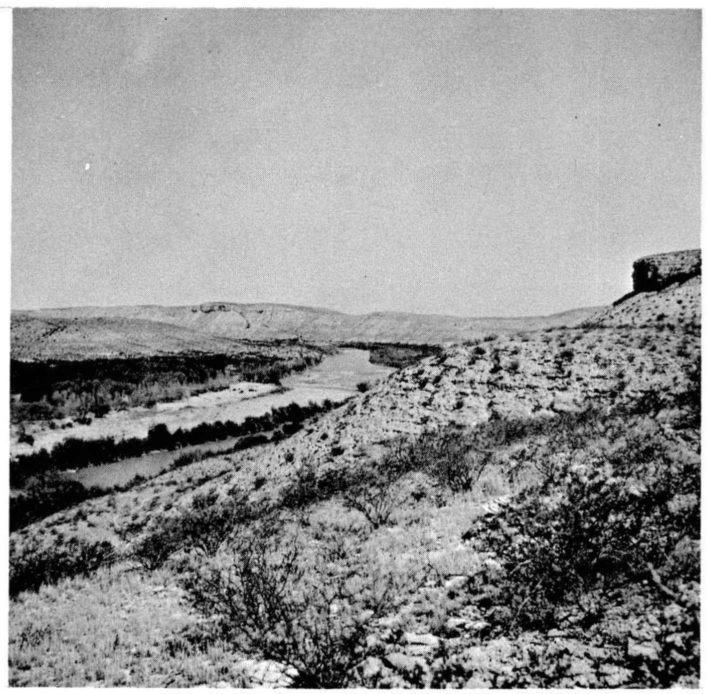
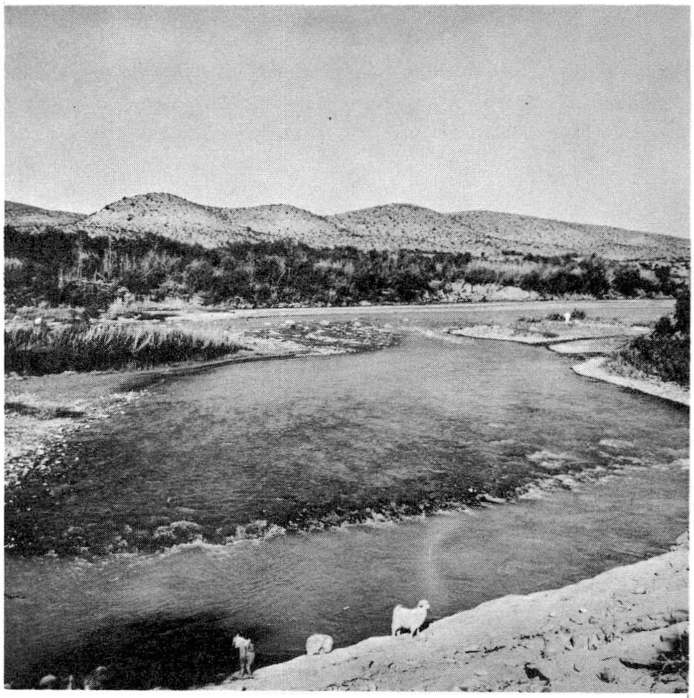


Fig. 7 View of the upper rapids section at Langtry site. The river is straight for about 3/4 mile from the rapids.

Fig. 8 Close-up view of upper rapids. The control is effected by a rock ledge overlain by cobbles and gravel.



Upstream from the upper rapids the river is straight for approximately 3/4 mile. There are frequent outcrops of rock along the Mexico and United States banks at the edge of the flood plain. A moving sand bar of fine material parallels the rock outcrop on the Mexico side.

Pecos River at Shumlá

The proposed Pecos River gauging station is located near Shumla and north of U. S. Highway 90. A sketch of the river reach is shown in Fig. 9.

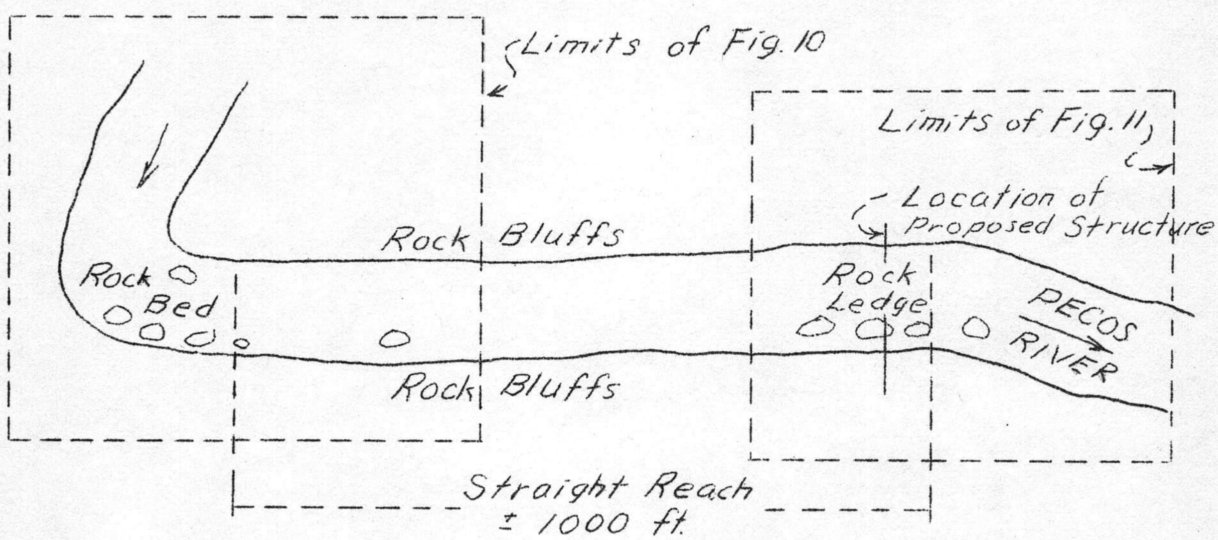


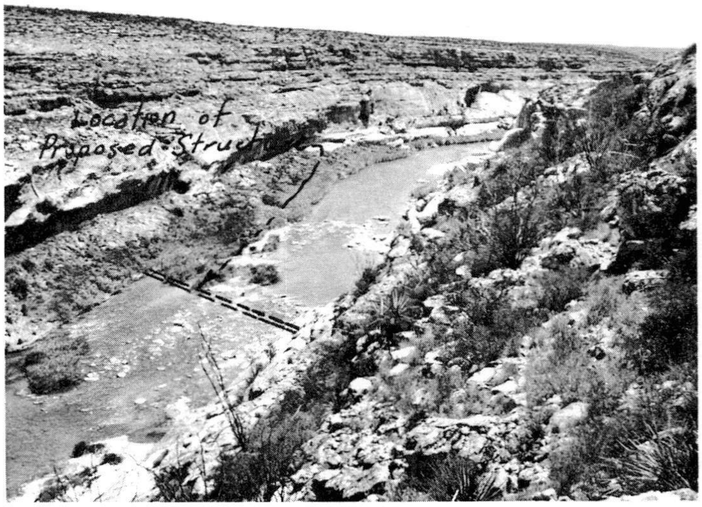
Fig. 9 Sketch of Pecos River Reach at Shumla (Not to Scale).

The proposed gauging site is near the downstream end of the straight river reach. Figs. 10 and 11, approximate limits of which are indicated on Fig. 9, show the upstream and downstream views of the river canyon. The channel is about 150 feet wide and the canyon walls are about 200 feet deep from the level of the surrounding plains.

The river bed is composed of very large boulders and rock ledges. The rock bluffs on both banks prevent meandering, and rock ledges in the river bed retards erosion.

Fig. 10 (left) Upstream view near the proposed Pecos gauging station site. Note large boulders in the stream. High rock bluffs blank each side of the river. River channel is approximately 150 feet wide.

Fig. 11 (right) Downstream view of Pecos site. Rock ledges overlain by cobbles and boulders prevents river bed erosion. In 1954 a flood in this channel was estimated to be approximately 100 feet deep.



Rio Grande River Below Amistad Dam Site

The Amistad gauging station is located a short distance downstream from the confluence of the Rio Grande and Devils Rivers, approximately 10 miles upstream from Del Rio. A sketch and photograph of the Rio Grande River reach are shown in Figs. 12 - 15. The limits of the photographs are outlined on the sketch.

The reach of river from the existing cableway to a point approximately one third mile downstream was carefully inspected. At the upper end of the island (see sketch and Fig. 15) rapids existed. The discharge at the time of inspection was about 1200 c.f.s. and the depth of flow in the vicinity of the island was about 3 feet. Upstream from the island, the depth increased gradually to about 6 feet near the cableway. The channel bottom is shaped in a "gentle V" with the deepest portion of the channel near the center.

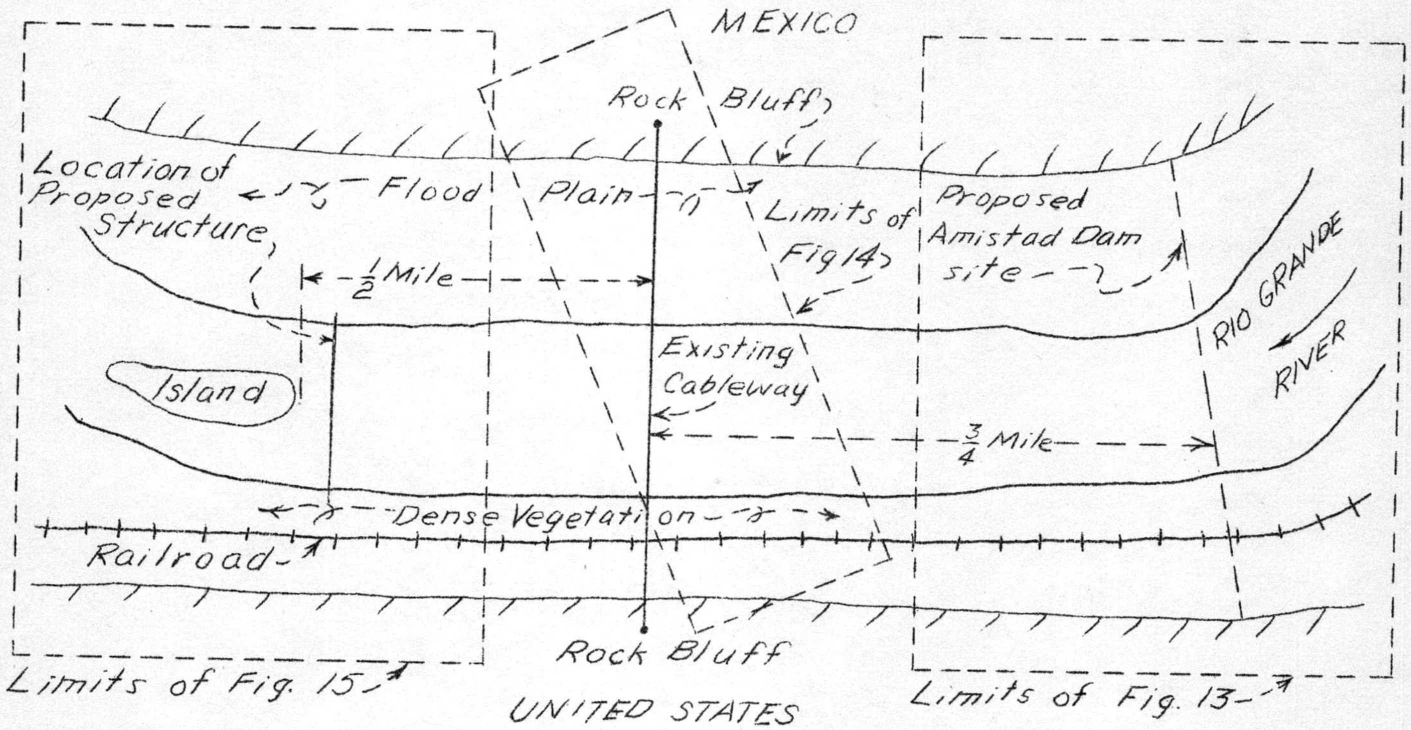
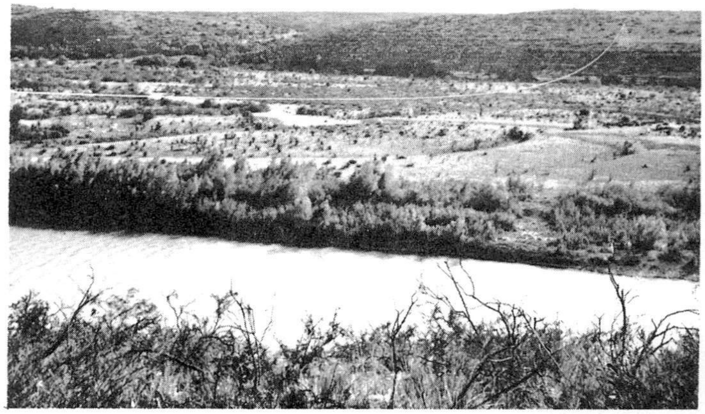


Fig. 12 Sketch of River Reach Below Amistad Dam Site (Not to Scale).

The size of bed material ranged from cobbles 6 to 10 inches in diameter to gravel, which was lodged between the cobbles. The river channel was about 300 feet wide with a wide flood plain on the Mexico side of the river. On the United States bank there is a high rock bluff, at the base of which an elevated railroad bed has been constructed by the Southern Pacific Railway.

Fig. 13 (left) View near the proposed Amistad Dam near bend in river. Mexico is to the left. See limits of photo in sketch of Fig. 12.

Fig. 14 Cableway of existing gauging station. United States bank is in foreground. Note gravel dunes on flood plain.



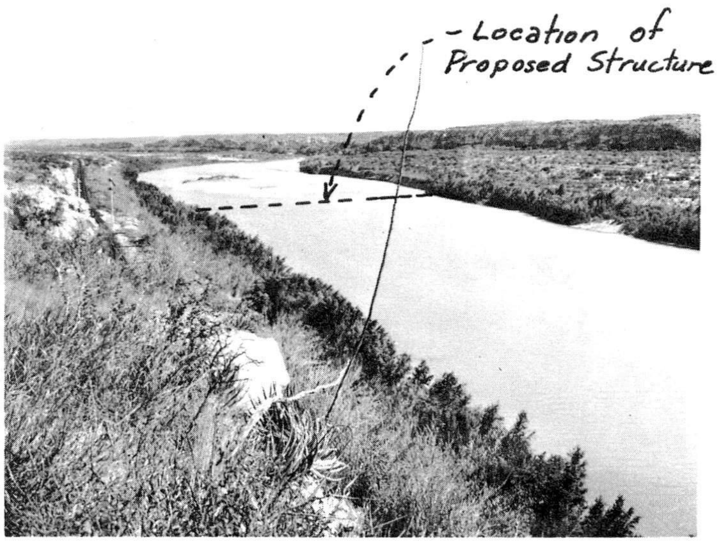


Fig. 15 (left) Downstream view of reach below proposed Aimstad Dam. Note island near bank of river. Rapids presently exist on both sides of the island. Upstream of the island the river is straight to dam site.

Rio Grande River at Del Rio

The Del Rio gauging station is located near the town of Del Rio, Texas, upstream from the International bridge. A sketch of the river reach is shown in Fig. 16.

Approximately one mile upstream of the International bridge there begins an outcrop of limestone on the river bed. This outcrop extends into the channel for about three-fourths the total width, and extends downstream approximately one-half mile. The level of the limestone bed is only slightly higher than the water surface for a discharge of about 1200 c.f.s.

Immediately upstream of the limestone outcrop, gravel pits which formerly existed, were inundated by high water and ultimately changed the river course.

There are rapids at the beginning of the limestone section with a drop in water surface of about 3 feet. Thereafter, the channel widens gradually for about 250 feet to 400 feet. The depth of flow is about

3 to 4 feet deep through the rapids section and remains at about the same depth through the reach. The river bank on the United States side is composed of sandy soil which is gradually eroding.

Downstream from the first rapids there are smaller rapids with a drop in water surface of approximately 1 foot. Some 250 feet downstream from the lower rapids section is the old gauging station. This station was abandoned because of silt deposition, making it difficult to keep the water intake lines clear. Currently the bank has extended about 50 feet out from the gauge house with about 12 to 15 feet of fine sediment deposited over the limestone bed. Throughout the reach inspected, bed material consisted of cobbles and gravel with fine sediment toward the Mexico bank. The slope of the river in this reach is about 6 feet per mile.

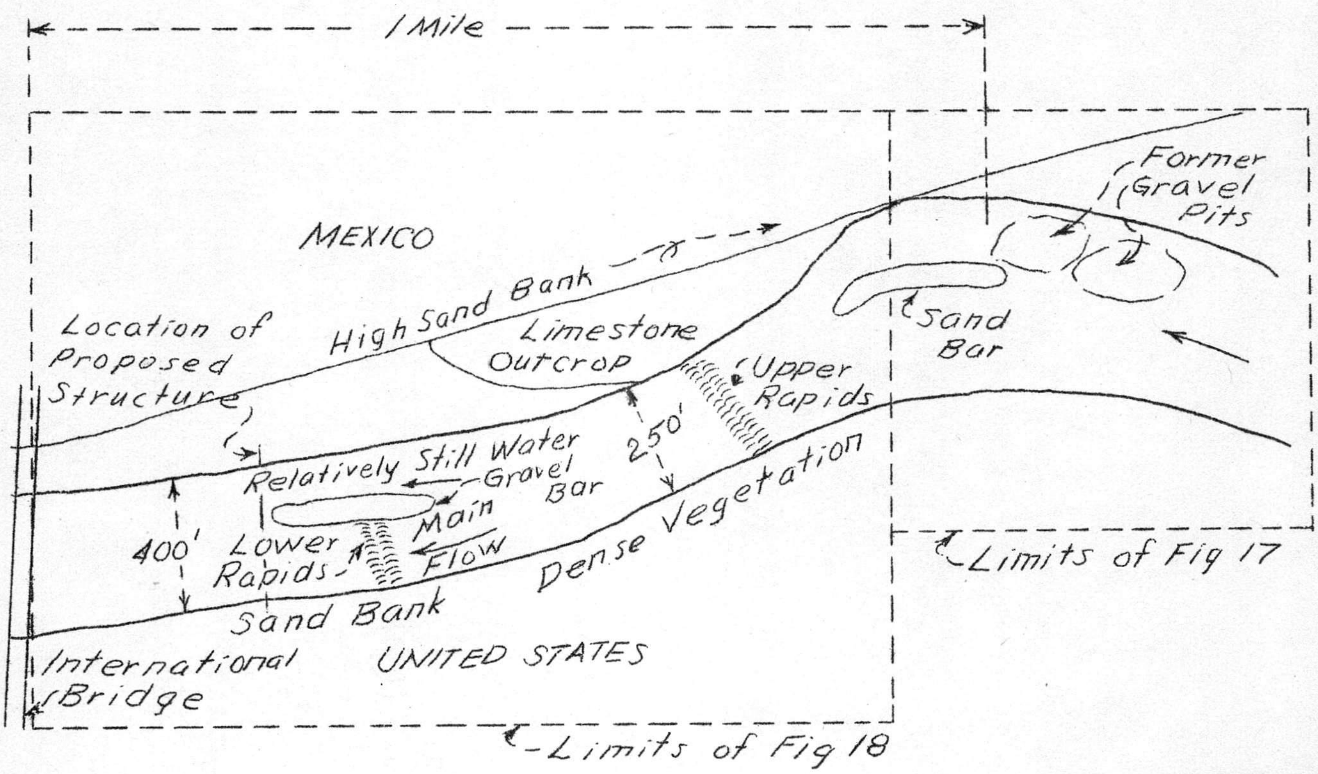


Fig. 16 Sketch of Del Rio Gauging Station Site (Not to Scale).

Fig. 17 (left) Del Rio gauging station. Upstream view of river. Gravel pits which exist along Mexico side were inundated by high water and river course was changed.

Fig. 18 (right) Downstream view of proposed Del Rio station. There is an outcrop of limestone, right foreground which extends about one-half mile downstream. Upper rapids are to the left, on United States bank.

PART II - OTHER GAUGING STATIONS

Rio Grande at Lower Presidio

The Lower Presidio gauging station is located near Fort Leaton, downstream from Alamito Creek as shown in the sketch below.

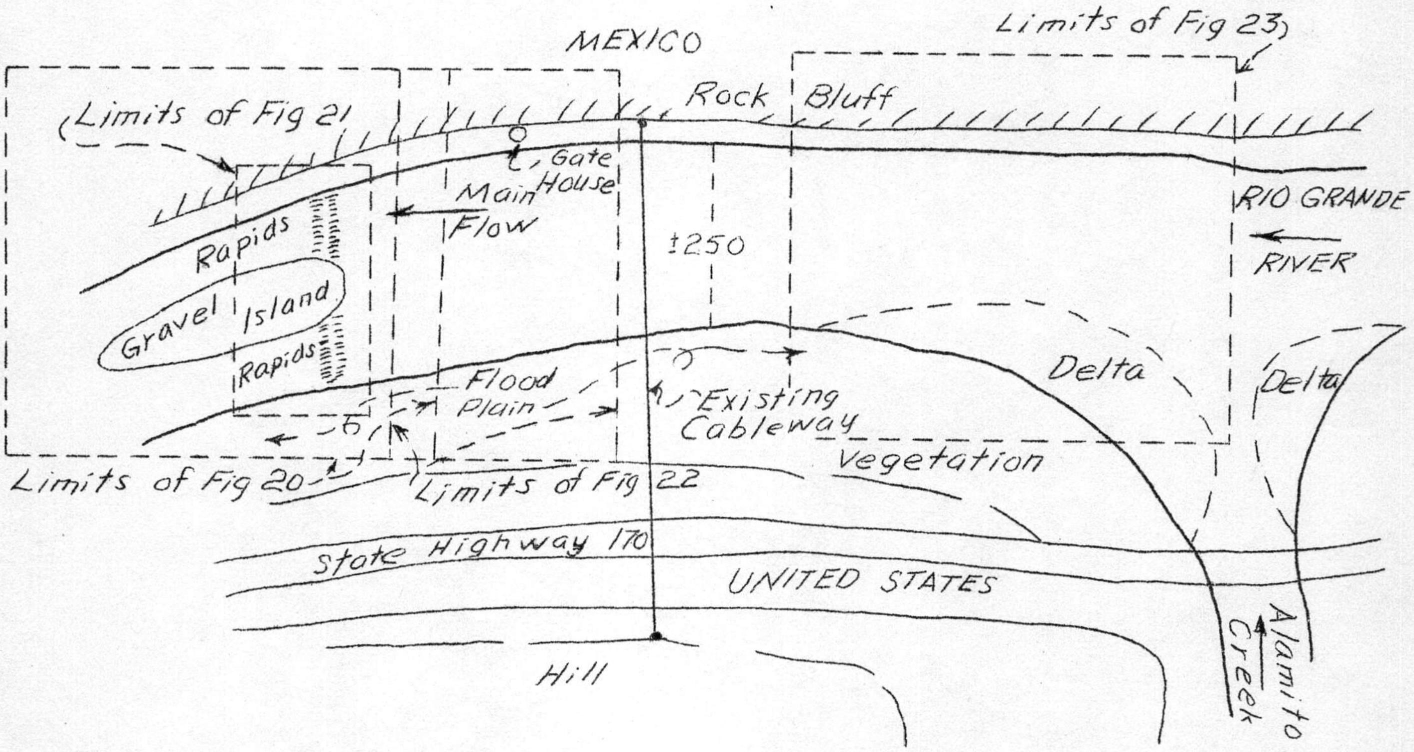


Fig. 19 Sketch of Lower Presidio Gauging Station (Not to Scale).

There is a high cableway extending from the rock bluffs on the Mexico side to a sandy bluff on the United States side. Downstream from the cableway there exists a gravel island around which the river is currently flowing. The main flow of the river is on the Mexico side of the island. The island and rapids are shown in Figs. 20 and 21.

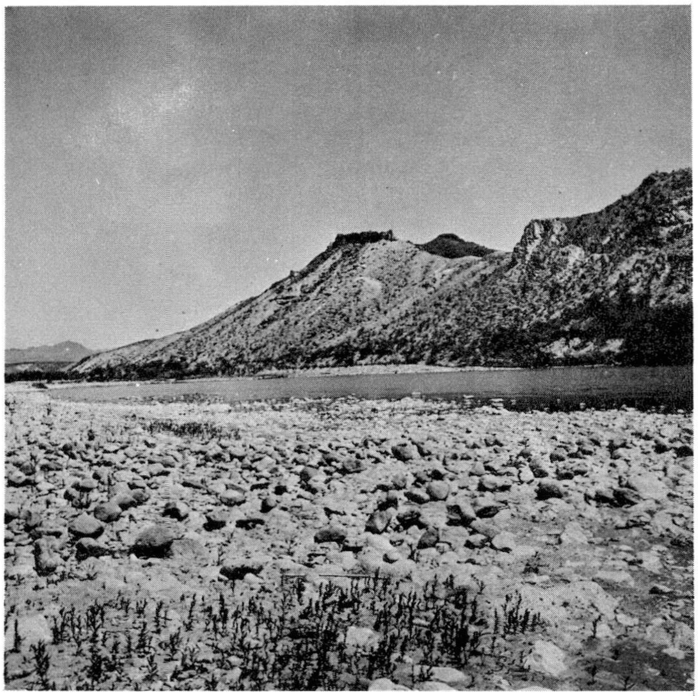


Fig. 20 (left) Lower Presidio Gauging Station. Island in channel controls flow. Main flow is on Mexico (right) Bank. Some flow through U. S. side also. Rapids have developed on both sides of the island. See Fig. 21.

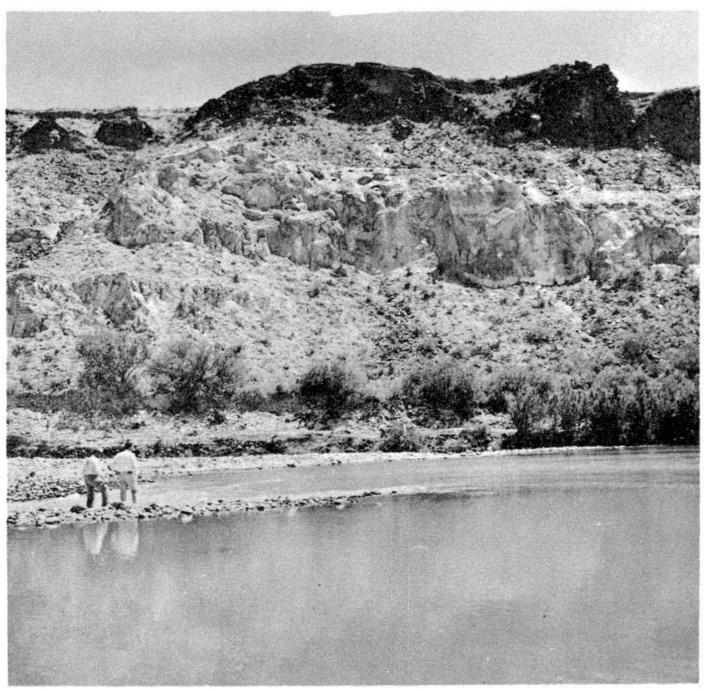


Fig. 21 (right) Rapids at Island, Lower Presidio Gauging Station

There is considerable deposition of fine sand on the U. S. bank on the flood plain, Fig. 23. The sediment is supplied by Alamito Creek which flows into the Rio Grande River a short distance upstream.

Fig. 22 (left) Gauging Station located on Mexico bank. High Rock Bluffs in background. The bed material in the foreground is characteristic through the reach. See Fig. 24 for indication of size.

The bed material in this reach consists of slightly water-worn cobbles ranging in size from 1 foot in diameter to gravel and fine sand. Size and gradation of material is indicated in Fig. 24.

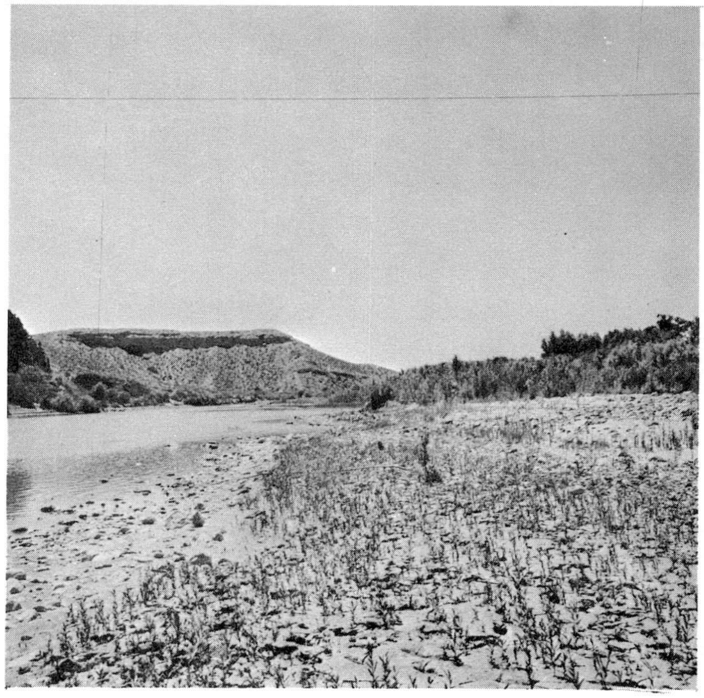


Fig. 23. (right) Upstream view of Lower Presidio Gauging Station site. U. S. Bank to right. Vegetation covers sand deposition on flood plain. Note cableway overhead.

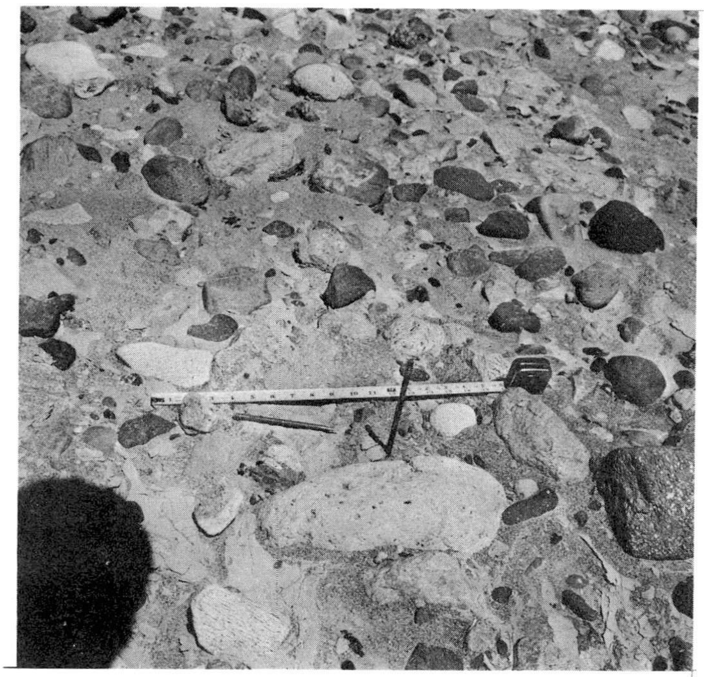


Fig. 24 (left) Characteristic bed material in Rio Grande River. Size is indicated by scale in photo.

The depth of flow upstream of the gravel island is about 3 feet for a discharge of 300 cfs.

Rio Grande River at San Antonio Crossing

The gauging station at San Antonio Crossing is located approximately 45 miles downstream from Eagle Pass, Texas. The sketch of Fig. 25 shows the present gauging station.

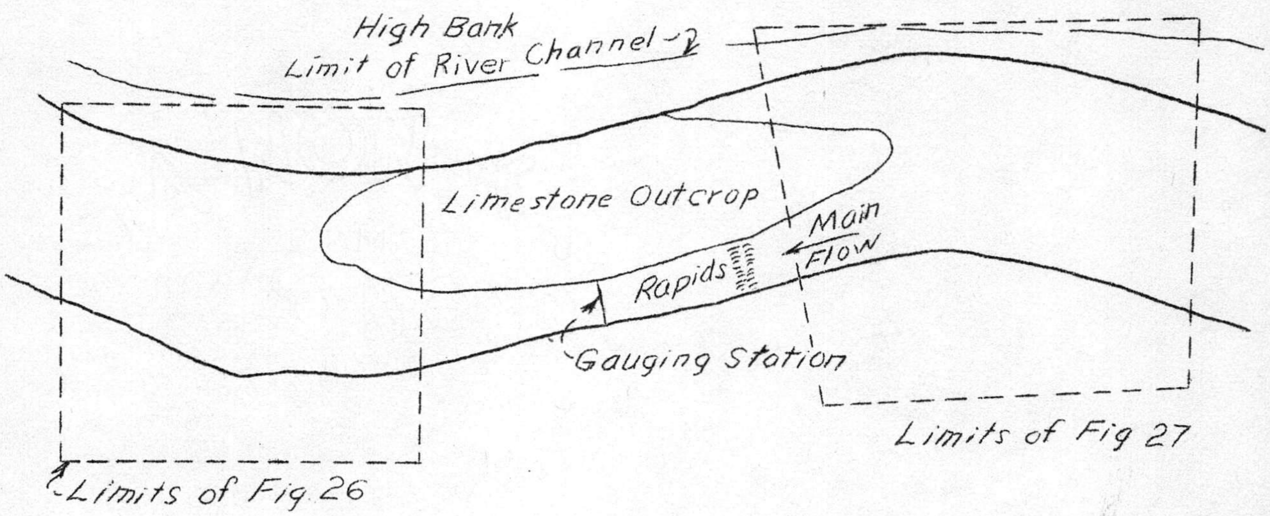


Fig. 25 Sketch of San Antonio Crossing Gauging Station Site
(Not to Scale)

There is a large outcrop of limestone extending between 6 inches and 2 feet above the water surfaces at the time of inspection. (Discharge 1000 c.f.s.) The beginning of the outcrop is shown in Fig. 27.

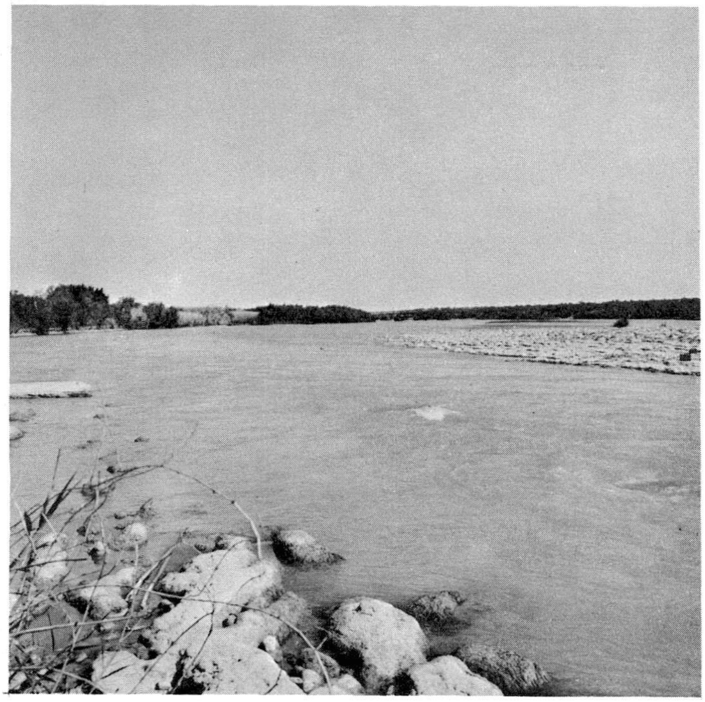


Fig. 26 (Left) Downstream view at San Antonio Crossing. Limestone outcrop at right extends to Mexico bank. Main channel and gauging section in foreground.

Fig. 27 (Right) Rapids section upstream of gauging section. Limestone outcrop begins, left of picture, and extends to the Mexico bank and downstream approximately 1000 ft.

The limestone is extensively channeled, which conveys a considerable amount of flow. The channel at the gauging section is about 50 feet wide and 9 feet deep at its deepest point. The velocity for a discharge of 1000 c.f.s. was estimated to be about 5 feet per second.

The slope of the river at this point is nearly 5 feet per mile. Upstream of the limestone outcrop. The river forms a wide gently flowing pool. Sediment transport did not appear to be of significance at the low discharge observed.

EXISTING STRUCTURES IN THE RIO GRANDE RIVER

There are several overflow structures existing in the Rio Grande River which are used for diversion of irrigation water. Descriptions of three of the structures inspected are included in this report.

The two rock-fill structures, shown in Figs. 28 and 29, are located downstream from the mouth of Alamito Creek near Redford.

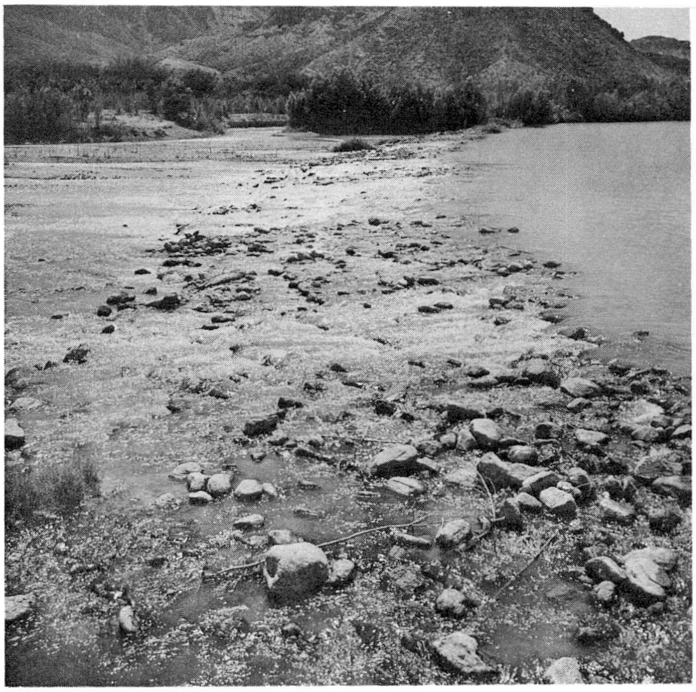


Fig. 28 Rock fill across Rio Grande used for diversion of irrigation water on U. S. side. Fill is 3 feet high. Largest rock in fill is about 1 foot in diameter.

The structure of Fig. 28 is about 3 feet high and is placed at a skew ~~sheer~~ of about 45 degrees with respect to the alignment of the river. It has withstood many floods during the last 35-40 years with little damage to the fill or river banks. Some replacement rock has been required from time to time to rebuild the crest to the desired elevation. There appeared to be no serious sedimentation of the upstream reach of the river and there remained considerable ponding depth relative to the total height of the fill.

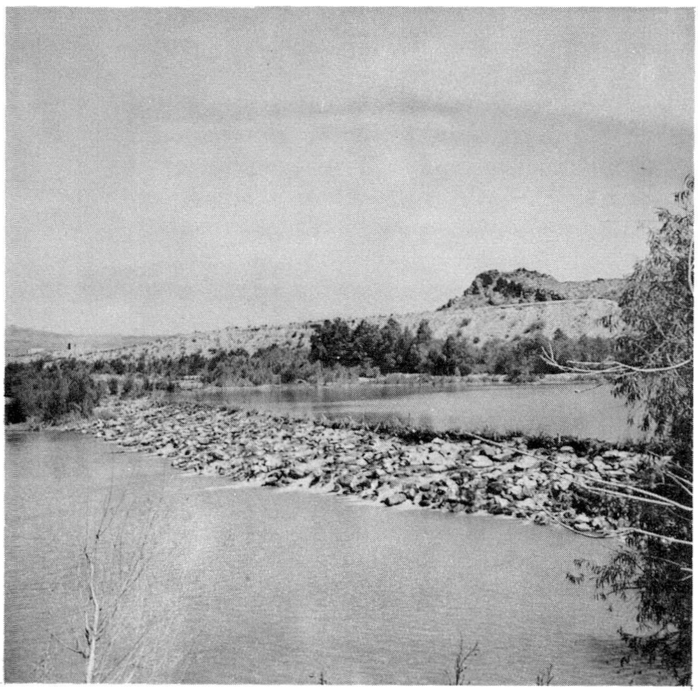


Fig. 29 (Left) Rock fill across Rio Grande. Mexican Diversion, background. Fill is approximately 15 feet high, normal to the river alignment.

The rock fill shown in Fig. 29 is normal to the alignment of the river. It is about 15 feet high with an auxiliary bush extension to raise the water level about 1 foot. The largest single rock on the fill which was observed on the surface of the dam was about 2 feet in diameter.

This structure has also withstood several floods with little damage to the fill or abutments. Some rock has been periodically removed by high flows from the crest of the dam necessitating minor maintenance. Some scour was in evidence at the base of the fill, particularly along the United State bank. The extent of scour, however, did not appear to be extensive enough to endanger the rock fill. It was reported that sediment deposition was also minor upstream of this diversion structure, but no actual investigation was made during this site visitation.

Maverick Dam was the last control structure inspected. It is a masonry-rock structure with a concrete cap, and was constructed in 1948 by the Maverick Irrigation District. A photograph of the structure is shown in Fig. 30. The length is approximately 400 feet. The height is 9 feet above a blue shale foundation. The top width of the structure is 15 feet and side slopes are 2:1. There is an auxiliary masonry wall, about 1 foot high on the upstream side at the top of the dam.

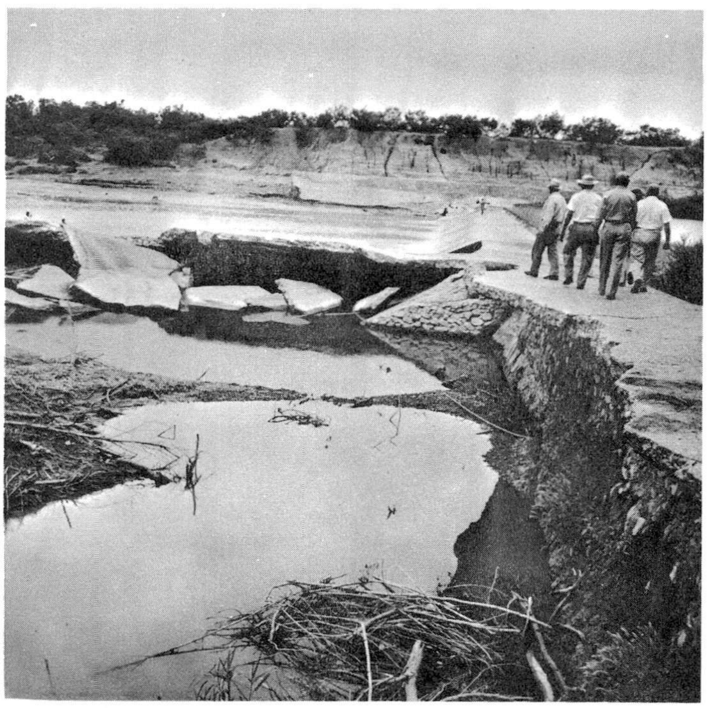


Fig. 30 (left) Maverick Dam. River Bank in background is Mexico. The structure is a concrete masonry structure with a concrete cap.

Soon after completion in 1948, the structure was subjected to a flood which caused abutment failure on the United States Bank. The damage was subsequently repaired by extending the dam an additional 50 feet in length. A concrete cap was placed over the concrete masonry and extended over the sand bank. In 1952 the structure was again subjected to a major flood which caused the damage seen in Fig. 30. This was not repaired but no further damage was noted by the major floods of 1954 and 1958.

The pool immediately upstream of the dam was inspected. With only a trickle of water over the top, it was found that water depths of about 3 to 4 feet existed towards the United States bank and 5 to 6 feet near the Mexico bank of the river.

SUMMARY OF FIELD OBSERVATIONS AND CONCLUSIONS

Flow in the Rio Grande River varies considerably, from as much as a million cubic feet per second to only sub-surface flow in places. The bed material in the river channel consisted generally of cobbles and gravel while the flood plains showed extensive deposition of fine sand. In some cases gravel bars overlaid portions of the sand deposits. In general, the channel of the Rio Grande, between Presidio and Del Rio, is about three to four hundred feet wide and shows shifting characteristics due to deposition and scour of gravel and sand. Observations indicated that the gravel and cobble depositions were made only during periods of extreme high water, and flows of a few thousand second feet probably did not contain sufficient energy to cause serious bed movement. Very little sediment appeared to be moving during the period of this field trip -- in general, it appears that sediment may not be as serious a problem as has been contemplated, this however, remains to be proved.

There is another important similarity in river condition at most of the gauging sites inspected. Natural controls have formed at the downstream sections of each gauging station site, usually in the form of what appears to be huge sand or gravel waves left by a major flood. These deposits seem to control the depth of river flow for some distance upstream. There are other controls effected by outcropping rock ledges, but at each control there is sufficient instability to cause serious shifts in the rating curve after every significant flood.

From the observations, summarized here and described in detail in the previous section, it is concluded that artificial controls in the river are necessary to (1) stabilize the river channel at stream gauging stations and (2) stabilize the stage discharge relationship for the gauging station. Recommendations for the type and locations of the structures are given in the following sections.

RECOMMENDATIONS FOR TYPE OF CONTROL STRUCTURES

A sketch of the basic structure recommended for use at the gauging stations is shown in Fig. 31. The top width B, of the structure is recommended to be not less than 14 feet. This width will, in effect, make the structure a broadcrested weir. It will permit current meter measurements to be made on the crest and may allow vehicular traffic at low discharges. The height of the structure H, should be of the order of 3 feet above bed level. This height will be dependent, however, on the amount of submergence which will occur at discharges near 10,000 c.f.s. It is also dependent upon the slope at the top and length of the structure; location of the structure relative to natural controls; and height of river banks upstream of the proposed location of the structure, or more concisely, the greatest value of D permissible. The side slopes of the structure described by α and β will depend upon the sediment carrying capacity of the stream, the tendency of the stream to deposit transported material upstream of the control structure, whether the structure should be permeable or non-permeable, and the amount of the downstream scour that is to be expected. The length of the structure should be from bank to bank of the stream, placed as normal to the channel alignment as possible, and therefore will vary for each location.

There are some variations to the basic structure that may be necessary to insure its proper function. A particular structural feature which might be required is that the top of the structure should be formed not as one gently sloping V but as several V notches. Each notch may be at the

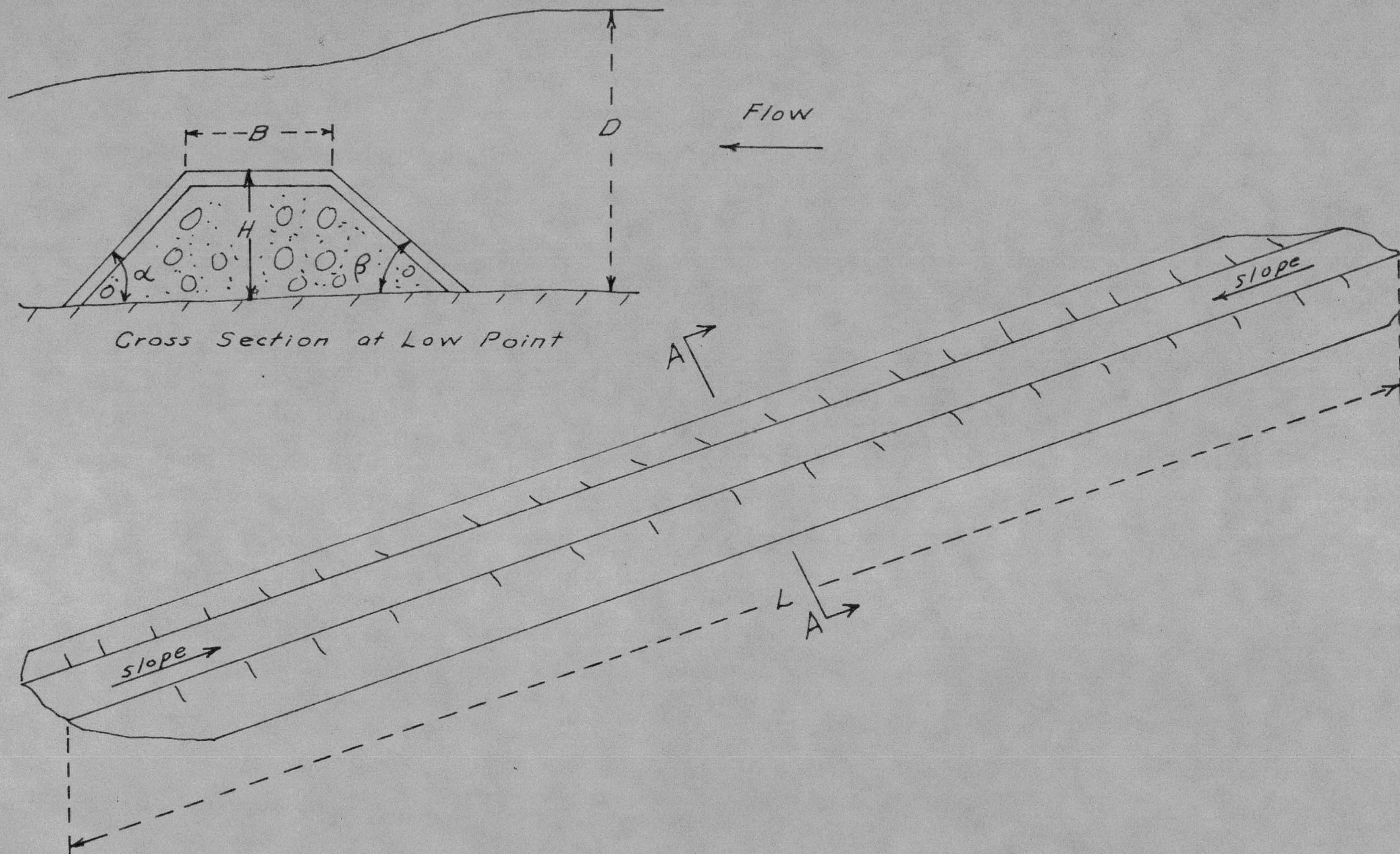


Fig. 31 Recommended Basic Structure

same, or different elevation. It might be necessary or desirable to construct short wing walls upstream of the structure as shown in Fig. 32, to prevent both shifting of the channel and extensive lateral flow of water across the top.

The dimensions of the structure are generalized because many of the hydraulic factors which govern them are unknown or cannot be calculated with sufficient accuracy to establish reliable dimensions. Therefore, it is recommended that a model study be conducted for the purpose of obtaining data on which to base the design of the control structure. Specific problems to be investigated in the model study and recommended procedures are stated in some detail on pages 38 and 39. It is further suggested that a specific gauging station site be modelled to develop a control structure for that site. Because of the similarities of gauging stations already discussed, the data from the specific model will provide valuable information for the design of other controls. Should specific models of other sites become desirable, however, the initial model should be designed so that this can be accomplished with a minimum of change and cost.

The Del Rio site is recommended for initial modelling. Because of the accessibility of the basic information, the general topographical features, and the long period of observation and records, this site should be chosen among the priority stations for initial emphasis.

In reviewing the recommendations and conclusions;

1. It is practical to design and construct control structures to assist in obtaining accurate discharge measurements;

2. That a model study is necessary to provide adequate data for designing the recommended control structure.

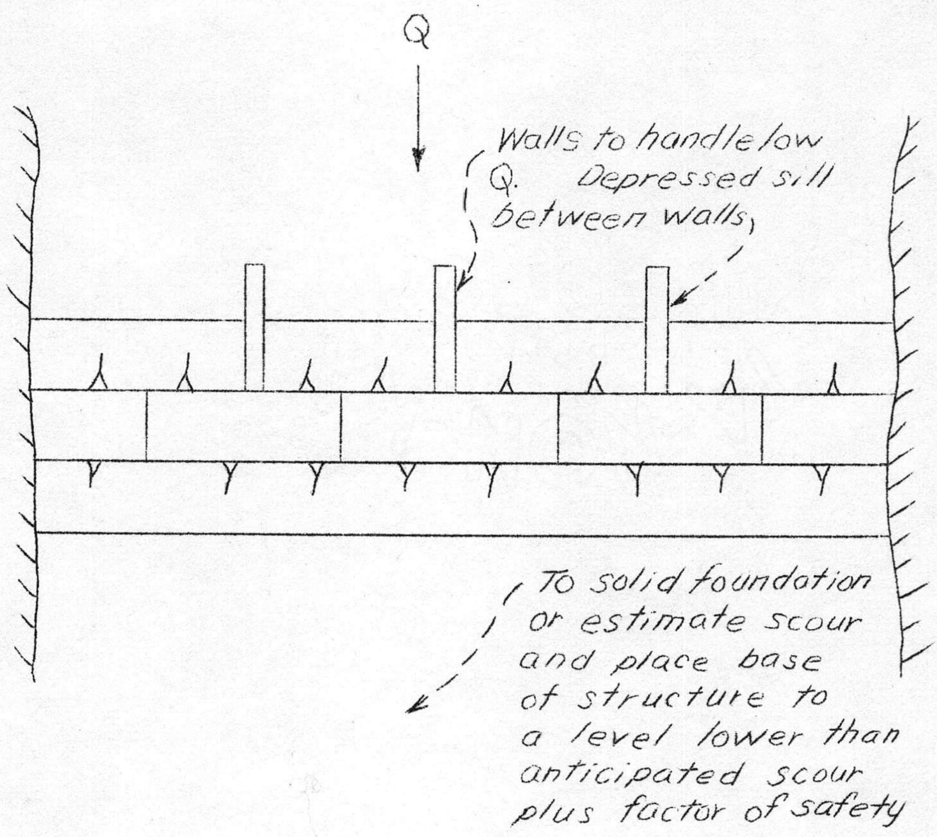


Fig. 32 Variation of the Basic Structure

RECOMMENDATIONS FOR LOCATION OF CONTROL STRUCTURES

PART I - PRIORITY STATIONS

Rio Grande River at Langtry

The recommended location of a control structure for the Langtry gauging station is about 150 to 200 feet upstream from the lower rapids near recent sand deposition on the Mexico bank. See Figs. 1 and 2. This recommended location is based upon the type of structure discussed in the previous section. The channel is well developed at the recommended site and there is an appreciable length of straight approach section. The banks are about 15 feet above the present river bed and well protected by undergrowth. The total channel width is about 250 feet. This location should be far enough upstream to avoid the effects of alluvial deposition, and also to take advantage of the grade change at the rapids through the gravel bar.

Pecos River at Shumla

The control structure should be located close to the downstream bend in the river, near the rock ledge presently effecting control in the river. See Figs. 9 and 11. The structure should extend from bank to bank and be firmly founded on the rock base. This location for the control structure should provide ample length of straight approach. It might be desirable to remove large boulders in the stream immediately upstream of the structure to develop the best flow conditions possible. Sediment, except possibly huge boulders moved during major floods, should not cause any difficulty at this gauging station.

Rio Grande River at Amistad Dam Site

Recommendation for location of the control structure at this site is slightly upstream of the gravel island near the bend in the river. See Figs. 12 and 15. The reasons for this location are similar to those given for the Langtry site. The required structure at this site will be larger than that at Langtry, but should be designed so that the backwater for a discharge of 10,000 c.f.s. does not overtop the present banks.

Rio Grande at Del Rio

The control structure should be located at or near, what is described in this report as the lower rapids. See Fig. 16. The main river flow should continue to be along the United States bank, at least for flows under 1000 c.f.s. Some amount of channel excavation may be necessary to clear the apparently shifting sand bar currently deposited at this site immediately upstream of the point recommended for the structure. This site is recommended because of the river alignment and, also because the channel has more stable banks. A location further upstream might well be bypassed by rechannelization during a flood.

PART II - OTHER GAUGING STATIONS

Rio Grande at Lower Presidio

The location of the control structure at Lower Presidio gauging station is recommended at about 75-100 feet upstream of the gravel bar (island). This gauging station, more than any other discussed in this report, will experience sedimentation difficulties because of Alamito Creek joining the Rio Grande from the United States side, a short distance upstream. The abutment on the Mexico side is rock; the flow is concentrated along this bank. Some channel stabilization will be necessary at the United States abutment.

Rio Grande River at San Antonio Crossing

It is recommended that a low structure, probably only a sill, be located near the present gauging station to define channel shape in the area of low flow concentration in the 50-foot channel. It might be wise to consider some low concrete cut-offs on the limestone outcrops to cut off some of the unmeasured flow. Because of the excessive length it would be costly to construct a braod-crested flow measuring section from bank to bank on the limestone bed. If the long structure should be considered, it would be desirable to give some thought to short wing walls to be constructed at periodic intervals normal to the structure. Thus, preventing lateral flow of water at the structure.

RECOMMENDATIONS FOR MODEL STUDY

The model study should be undertaken in two phases. These phases include, respectively, a two- and three-dimensional model study.

The first phase, a two-dimensional model study, should be made of the structure to investigate the following factors:

1. The general shape of the cross section to minimize aggradation and degradation of sediment (α , β , H - Fig. 31).
2. The size of movable bed material to be used in the model.
3. The gradation of the material to be used in the model.
4. The effects of deposition both upstream and downstream of the structure on the hydraulic performance of the structure as a flow measurement section.
5. Scour at the toe of the structure.
6. The desirability of making the structure permeable, impermeable, or semi-permeable.
7. An approximate rating curve at the structure, or some distance upstream from the structure.
8. A study of some of the problems to be expected in a distorted three-dimensional model.

The second phase, assisted by the information determined from the two-dimensional model, will consist of a three-dimensional model to study:

1. The transverse profile of the structure, whether it should be a V-notch, multiple V-notch, straight, or stepped.
2. Confirmation of the cross-section for the structure (α , β , H).
3. The effects of a concentration of flow at the abutments of the

structure; whether scour or deposition will occur.

4. The amount and location of bank protection necessary to safeguard the structure.

5. A qualitative study of the effects of upstream and downstream degradation or aggradation of sediment on flow measurement.

6. Downstream scour and the protection necessary on the bed at the toe of the structure.

7. The desirability of a semi-permeable structure for stability and control of sediment deposition.

8. The transverse flow effects at low discharges across the top of the structure.

9. How to control transverse flow satisfactorily.

10. The behavior of the system when it is submerged at high discharges.

11. Whether guide walls normal to and extending upstream of the structure are necessary.

12. A qualitative rating curve for the structure and a suitable location for a water stage recorder.

It is expected that the model would be a fixed boundary-type with sediment introduced or recirculated in the flow. The scale of the model will depend on the length of the river reach to be modelled. It is anticipated that the model will be distorted to provide sufficient depth to reduce viscous and surface tension effects.

Basic prototype information desirable for the model study are:

1. Topography of the river reach to be modelled.

2. Several cross-sections of the river channel.

3. Pertinent stream bed features, such as sand bars and rock outcrops.

4. Water surface profiles along each bank for two or three discharges, if possible.

5. Qualitative (Quantitative if possible) information on the water surface pattern, or discharge distribution.

6. More specific location of rapids and drop in water surface locally at the rapids.

7. Bed roughness where the bed is alluvial.

The model study of a specific structure and development of basic dimensions for the gauging station at Del Rio will provide a fundamental basis for design of control structures at other sites. Should it be anticipated before completion of the Del Rio model, however, that detailed studies may be required specifically for other sites shortly after completion of the Del Rio model, the model set-up of the Del Rio station should be designed so that by minor modification in topography, the same model could be used to develop the final details of the designs of control structures for the other priority stations.