Appendix F – Geotechnical Engineering

Lower Guadalupe Feasibility Study
(Guadalupe and Blanco Rivers), TX
Integrated Draft Feasibility Report and Environmental Impact Assessment

December 2018

US Army Corps of Engineers®
Fort Worth District

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LOWER GUADALUPE RIVER

Geotechnical Issues and Opportunities in Tentative Plan Selection

Introduction

The Lower Guadalupe River watershed covers over 488 square miles in five south Texas counties, viz. Blanco, Comal, Guadalupe, Hayes and Kendall. Known for its recreational facilities near the cities of San Marcos, New Braunfels and Seguin, the river is also known to flood the populated areas of these cities. The only and major flood control dam in this region is the Canyon Dam near San Antonio in Comal County. San Marcos River with its tributaries of Blanco River, Comal River, Peach Creek, Sandies Creek and Coleto Creek discharge in to Guadalupe River and all of these tributaries are located downstream of Canyon Dam. A study conducted by the Federal Emergency Management Agency (FEMA) in 2016 identified many of the cities and surrounding farming communities are at risk of flooding. Under the Capital Authorities Program, US Army Corps of Engineers (USACE), Southwest District (SWF) was authorized to conduct a feasibility study of designing and implementing flood damage control measures. This Appendix deals with the geotechnical aspects of the proposed alternatives, which include various alternatives from construction of a dam on Blanco River to construction of bypass channels to divert the flood waters around the city of San Marcos. However, the bypass channel was discarded on the economics of and acquisition costs.

NO ACTION ALTERNATIVE

The communities affected by the occasionally heavy flooding (cities of San Marcos, New Braunfels and Seguin) have dealt with repair, renovation and substantial loss of tourist revenue due to flooding. These cities have dealt with releases of waters from Canyon Dam under normal overflows and appear to have some control over emergency action plans. However, uncommon rainfall and flooding that has impacted southern Texas in the last five years is beyond the control and resources of these cities, though they are among the fastest growing neighborhoods in Texas. Hydrological models could only be constructed for realistic increases in flood flows caused by measurable factors such as population growth, reduction or increase in impervious areas and potential economic impacts. The current feasibility study therefore is aimed at providing a structural alternative (by the construction of a new detention reservoir for temporary storage and controlled release) downstream of Canyon Dam. Taking no action would leave the cities along the Lower Guadalupe River subject to occasional inundation, both seasonal and excessive flooding that has become more frequent. As these are growing communities, the economic losses and loss of life is likely to increase with a No Action alternative.

STRUCTURAL ALTERNATIVES

As mentioned above, construction of a bypass canal was considered economically unviable. In that context other structural alternatives were considered, with the construction of building new holding reservoirs at potential alternative locations as discussed below.

Structural alternatives considered included building a new dam on Blanco River; Hays Dam (Hays County) or Bear Creek (Comal County). Based on a Hydraulic and Hydrographic (H&H) analysis of stream flows, dam cross-sections were developed and are discussed in other Appendices to this report on Civil Engineering and H&H Analysis. As all these sites lie within the five county area described above, the regional geological conditions could be generalized for this reach of the Lower Guadalupe River. However, the geotechnical conditions at each of the selected alternative sites would differ and could not be generalized. Further, though there are a number of reports on the Guadalupe River and the Edwards Aquifer, site specific information of the sites considered in the tentative plan selection does not exist. Thus, the site specific soil and subsurface conditions that would impact the selection of the site bear comparable and similar risks in all the sites considered. None of the three alternatives considered poses a geotechnical risk that could not be mitigated.

Project Area

The Guadalupe River study area covers the river from Blanco County to Victoria County as shown in the graphic below. However, this study covers only the green shaded area.

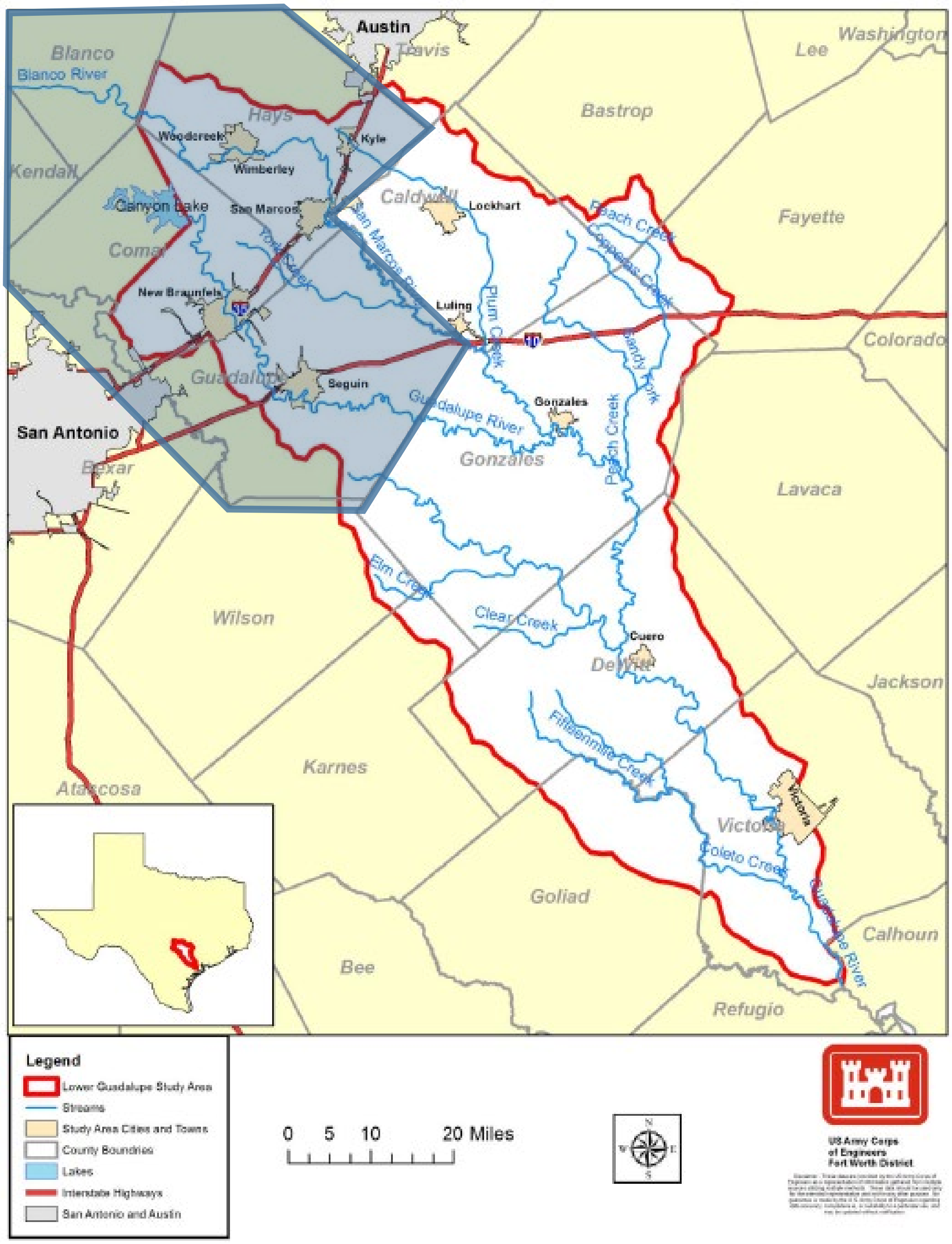

Figure 1: Guadalupe River Basin (white) with the current study area shown (green)

As noted above, this study is confined to the five-county area and the cities impacted by the Blanco River, Bear Creek, San Marcos River and their primary tributaries within this five county area. The population centers impacted include the cities of San Marcos, New Braunfels, Seguin, Wimberley and

Kyle. The tentative site selection would be downstream of Canyon Dam on the Guadalupe River. The watershed covering this study area impacts the Edwards Aquifer and hence the site selection would have to comply with the best management practices of Edwards Aquifer recharge area. This is covered in Texas Commission on Environmental Quality publication RG-348 July 2005 Edition. TCEQ also has published guidelines for geologic assessments on the Edwards Aquifer Recharge/Transition Zones in Publication TCEQ 0585 in October 2004. The geology of the study area therefore is primarily associated with the contributing zone and recharge areas of the Edwards Aquifer. Surficial geological and geomorphological features are discussed in the following section. The tentative site selection for the flood damage reduction measures of the study area will require additional site-specific geotechnical information, which will have to be acquired for the selected site, as all potential sites being considered have similar geological constraints.

Geological Background

The Edwards Aquifer is an artesian aquifer and the primary water source for the Central Texas area that covers a large area extending from the Rio Grande River to the City of San Antonio. The Edwards Aquifer is a karst formation that was exposed in the Paleozoic era that and that was lifted during the Mesozoic era by tectonic activity. Due to the sea level changes that occurred during this period the aquifer was confined by sediments that act as an aquiclude. Tectonic activity towards the end of Cretaceous era created granitic mountains west of San Antonio. The current surficial deposits of the Buda and Eagle Ford limestone formations are Tertiary and Quaternary periods of the Cenozoic era. This was also the period when the thickness of the sediments caused a series of faults to be formed between the Edwards Aquifer and the Gulf of Mexico.

The Edwards Limestone is about 300 to 700 feet thick and it outcrops as a narrow band about 50 miles north of San Antonio (near Hondo) and tilts towards the south and east to about 3,500 feet below sea level, about 40 miles south of San Antonio. Smaller outcrops can also be seen near New Braunfels and San Marcos area, which are popular recreational springs. Surficial deposits of the study area are described as the Balcones Escarpment and is a heavily faulted zone. The following graphic taken from the Edwards Aquifer website shows the current conditions as interpreted from the geologic conditions of the aquifer.

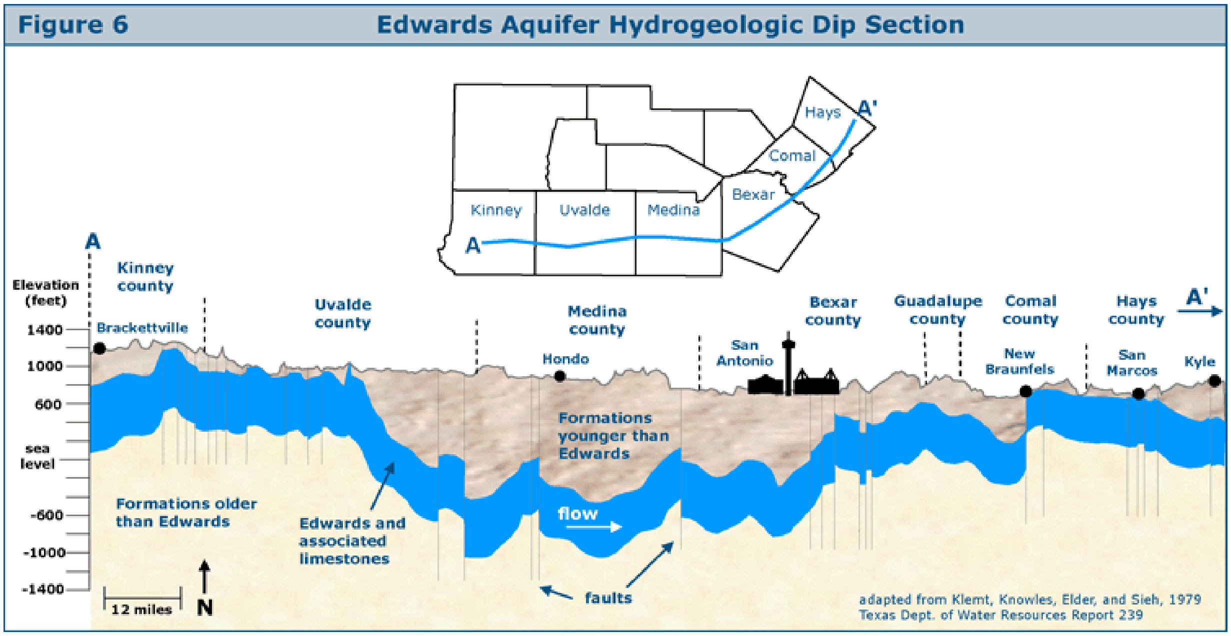

Figure 2: Geologic cross-section of the Edwards Aquifer
(Taken from http://www.edwardsaquifer.net/geology.html)

Artesian conditions no longer exist in Edwards Aquifer due to excessive pumping, especially in Bexar and Comal Counties. Even the natural springs of San Marcos Springs and Comal Springs are dry except in the wet season. The controlling factor in the tentative site selection are therefore the numerous fault zones, which impact the Edwards Aquifer as shown above in the graphic in Figure 2.

The geological sequence near San Marcos area can be briefly stated as follows. The Balcones fault zone consists of numerous fault zones, cross faults, grabens, horsts, step faults, en echelon faults and similar features. The rocks of the Lower Cretaceous unit consist of limestones, dolomites and marls. The rocks exposed in the eastern zone of the Upper Cretaceous era are non-resistant chalk and calcareous clay units. This difference in resistance to erosion results in escarpments, generally addressed as Balcones Escarpment. East of the scarp the soil cover is thick and forms prime agricultural soil and west of the scarp the soils are thin and rocky and are primarily ranches and agricultural land (Grimshaw and Woodruff, 1976).

The principal rock stratigraphic units in the Hays County is detailed in the following page, which describes the various formations and the soil/rock types.

Table 1. Summary of the lithologic and hydrologic properties of the hydrogeologic subdivisions of the Edwards aquifer outcrop, Hays County, Texas

[Hydrogeologic subdivisions modified from Maclay and Small (1976); groups, formations, and members modified from Rose (1972); lithology modified from Dunham (1962); and porosity type modified from Choquette and Pray (1970). CU, confining unit; AQ, aquifer]

Hydrogeologic subdivision			Group, formation, or member			Hydro-logic function	Thickness (feet)	Lithology	Field identification	Cavern development	Porosity/ permeability type
Upper Cretaceous	Upper confining units		Navarro and Taylor Groups, undivided			CU	600	Clay; chalky limestone	Gray-brown clay; marly limestone	None	Low porosity/ low permeability
Upper Cretaceous	Upper confining units		Austin Group			CU; rarely AQ	130 – 150	White to gray limestone	White, chalky limestone; *Gryphaea aucella*	None	Low porosity/ low permeability; rare water production from fractures
Upper Cretaceous	Upper confining units		Eagle Ford Group			CU	30 – 50	Brown, flaggy, sandy shale and argillaceous limestone	Thin flagstones; petroliferous	None	Primary porosity lost/ low permeability
Upper Cretaceous	Upper confining units		Buda Limestone			CU	40 – 50	Buff, light gray, dense mudstone	Porcelaneous limestone	Minor surface karst	Low porosity/ low permeability
Upper Cretaceous	Upper confining units		Del Rio Clay			CU	40 – 50	Blue-green to yellow-brown clay	Fossiliferous; *Ilymatogyra arietina*	None	None; primary upper confining unit
Lower Cretaceous	I	Edwards aquifer	Georgetown Formation			CU	10 – 40	Gray to light tan marly limestone	Marker fossil: *Waconella wacoensis*	None	Low porosity/ low permeability
Lower Cretaceous	II	Edwards aquifer	Edwards Group	Person Formation	Cyclic and marine members, undivided	AQ	80 – 100	Mudstone to packstone; *miliolid* grainstone; chert	Boxwork vugs; light tan, massive; some *Toucasia* and *Caprinid*	Many caves; might be associated with earlier karst development	Laterally extensive; both fabric and not fabric/one of the more porous and permeable of the subdivisions
Lower Cretaceous	III	Edwards aquifer	Edwards Group	Person Formation	Leached and collapsed members, undivided	AQ	80 – 100	Crystalline limestone; mudstone to grainstone; chert; collapsed breccia	Bioturbated iron-stained beds separated by massive limestone beds; *Montastrea* (?) sp.	Extensive lateral development; large rooms	Majority not fabric/ probably the most permeable of the subdivisions
Lower Cretaceous	IV	Edwards aquifer	Edwards Group	Person Formation	Regional dense member	CU	20 – 24	Dense, argillaceous mudstone	Wispy iron-oxide stains	None; only vertical fracture enlargement	Not fabric/ low permeability; vertical barrier
Lower Cretaceous	V	Edwards aquifer	Edwards Group	Kainer Formation	Grainstone member	AQ	50 – 60	*Miliolid* grainstone; mudstone to wackestone; chert	White crossbedded grainstone; *Toucasia* and *Turritella*	Few caves	Not fabric/ recrystallization reduces permeability
Lower Cretaceous	VI	Edwards aquifer	Edwards Group	Kainer Formation	Kirschberg evaporite member	AQ	50 – 60	Crystalline limestone; chalky mudstone; chert	Boxwork voids, with neospar and travertine frame	Probably extensive cave development	Majority fabric/one of the more porous and permeable of the subdivisions
Lower Cretaceous	VII	Edwards aquifer	Edwards Group	Kainer Formation	Dolomitic member	AQ	110 – 130	Mudstone to grainstone; crystalline limestone; chert	Massively bedded light gray, *Toucasia* abundant	Caves related to structure or bedding planes	Mostly not fabric; some bedding-plane fabric/ locally permeable
Lower Cretaceous	VIII	Edwards aquifer	Edwards Group	Kainer Formation	Basal nodular member	Karst AQ; not karst CU	50 – 60	Shaly, nodular limestone; mudstone and *miliolid* grainstone	Massive, nodular and mottled, *Exogyra texana*	Few caves	Fabric/low permeability
Lower Cretaceous	Lower confining unit		Upper member of the Glen Rose Limestone			CU; evaporite beds AQ	350 – 500	Yellowish tan, thinly bedded limestone and marl	Stair-step topography; alternating limestone and marl	Some surface cave development	Some water production at evaporite beds/ relatively impermeable

Figure 3: Geologic Stratigraphy of Hays County
(Taken from Hanson and Small, 1995)

Proposed Alternatives for Control Structures

Analysis conducted by the Hydrology & Hydraulics Section of the Water Resources Branch and preliminary civil designs completed by the Civil Section of the Design Branch (of the Fort Worth District) have identified three potential alternative locations for flood control structures. These are briefly discussed below.

Blanco River:

The proposed dam sites on Blanco River could be accessed from Chimney Valley Road (County Road 407), an asphalt paved road extends through the center of the proposed dam site (denoted as Dam Site 2 in the civil and H&H Appendices) and crosses the Blanco River near the proposed dam site. San Marcos is the major city and the County seat of Blanco County and the siting of this dam would directly impact the city of San Marcos. Because of the historical flooding events that have impacted San Marcos published records show only the impact of the flooding (including human and economic impact) were available, but no additional geotechnical information was available.

Hays County:

The proposed Hays County dam is located near the Hays/Comal/Blanco County Line. The Dam site extends across the Blanco River in tree covered ranch land with some open pasture. This dam would cross an unpaved dirt road which extends through the river at an unpaved low water crossing. One of the ranch roads at the far northwest end of the flood zone has an existing concrete low water crossing extending across the river. This area is a privately owned ranch, and no further geotechnical information is available. Though the site selection might be feasible on basis of technical criteria, the involvement of three Counties and private ownership renders this site more challenging.

Bear Creek:

The proposed location of the Bear Creek dam is about 1.5 miles east of Farm to Market road 2722 and Bear Creek Trail. FM 2722 is a two lane asphalt road and Bear Creek Trail is an asphalt surfaced trail. Bear Creek is one the tributaries of the Guadalupe River, Oso Arroyo Road is an unpaved gravel road which runs through the inundation footprint for approximately 1.2 miles, continuing through the dam footprint. There are 3 lower water crossings along Oso Arroyo road. The site is not accessible from public roadways. No additional geotechnical details were available on this site. The proposed Bear

Creek dam would lie completely in Comal County and the primary impact would be felt by the City of New Braunfels and Seguin, which are downstream of Canyon Dam.

Geotechnical Impact on the Proposed Site Selection

Three options were studied for the Blanco 2 site, and as determined from H&H analysis, the maximum dam heights of 60, 65 and 73 feet were evaluated. Based on these dam heights provided, the lengths of dam were estimated at 1972, 2139, and 2457 feet respectively for the three impoundment heights. The following image is taken from the Civil Engineering Appendix.

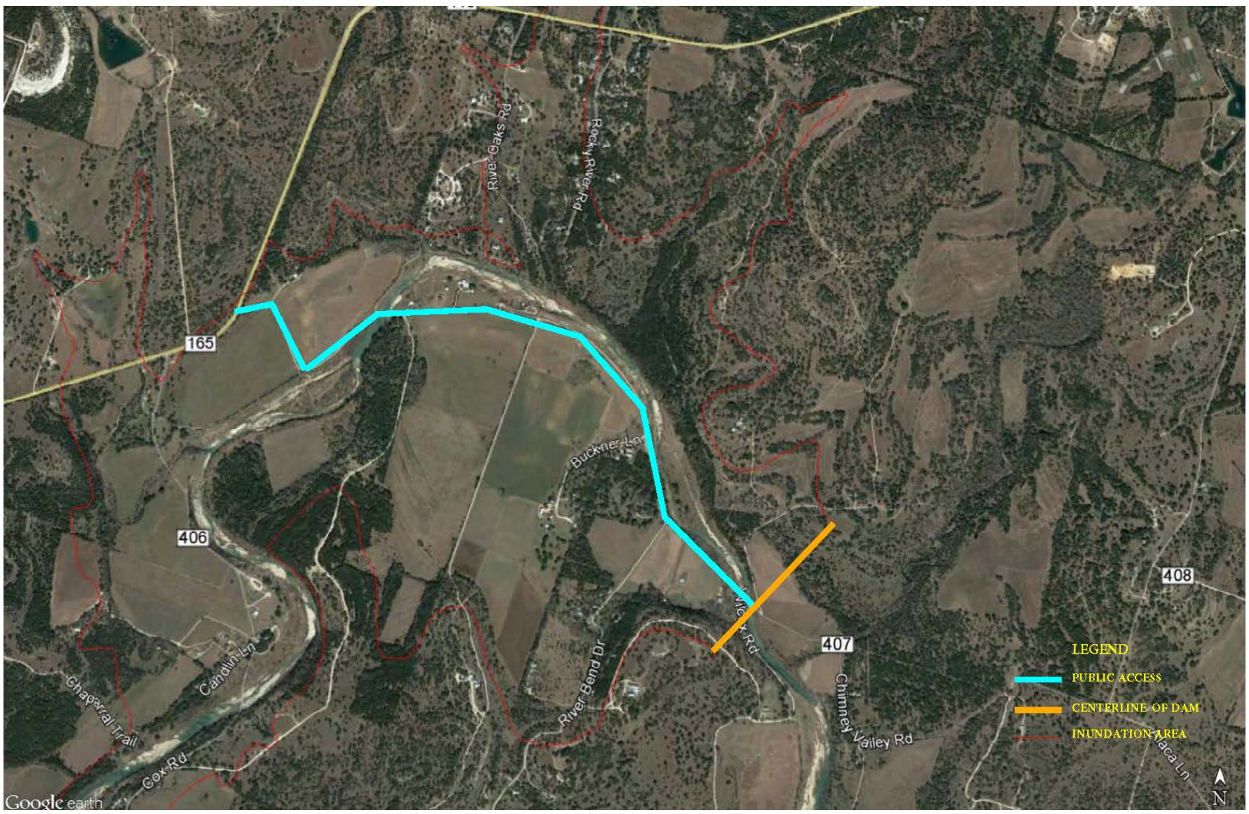

Figure 4: Proposed Blanco 2 Dam site location

<u>Hays Dam Site 2 Hays County, Texas</u>

The dam is proposed to be located near the Hays/Comal/Blanco County Line. The Dam site extends across the Blanco River in tree covered ranch land with some open pasture. The dam crosses an unpaved dirt road. The unpaved road extends through the river at an unpaved low water crossing. One of the ranch roads at the far northwest end of the flood zone has an existing concrete low water crossing extending across the river. As determined by the H&H analysis, the Hays Dam site will have a maximum height of 110 feet and is estimated to be approximately 4090 feet long. This site would require coordination with two counties and private owners. In addition, if there are utilities within the proposed dam site or the inundation zone, they may have to be relocated, abandoned or replaced. The location of the Hays/Blanco site is shown in the graphic below.

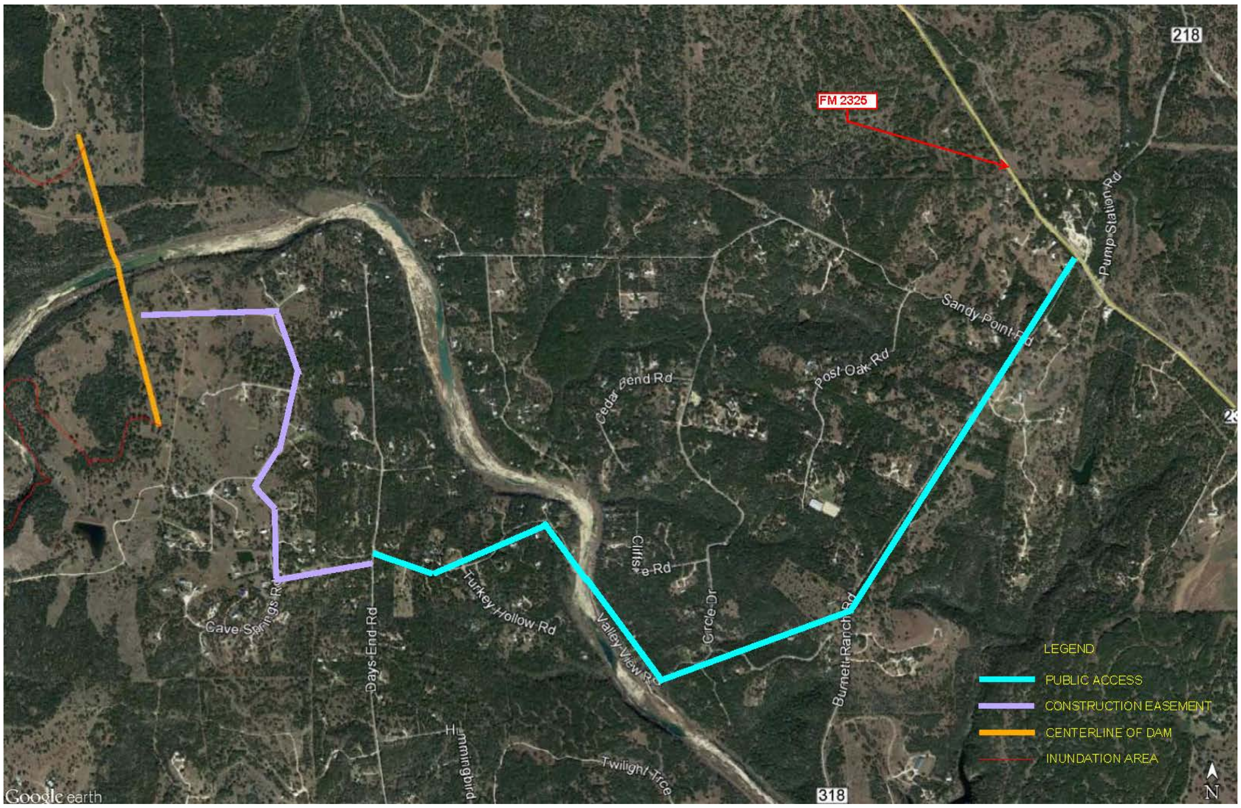

Figure 5: Proposed Hays/Blanco Dam site location

<u>Bear Creek, Comal County, Texas</u>

The Bear Creek dam is proposed at location about 1.5 miles east of Farm to Market Road 2722 a 2-lane asphalt road and Bear Creek Trail an asphalt road. Bear Creek Trail extends from FM 2722 southeast through tree covered canyons for approximately 1.76 miles then southwest for approximately .67 miles to FM 2722. The proposed dam extends across Bear Creek in tree covered canyon lands. There is also another unpaved road called Oso Arroyo Road in the inundation area, which would cross the dam footprint, has three low level crossings. The Bear Creek Dam Site is estimated to have a maximum height of 75 feet, and the dam is approximately 680 feet long. The height of the dam will be 70 feet at the spillway. These estimates are based on H&H analysis. The following graphic taken from the Civil Design Appendix shows the proposed Bear Creek dam location.

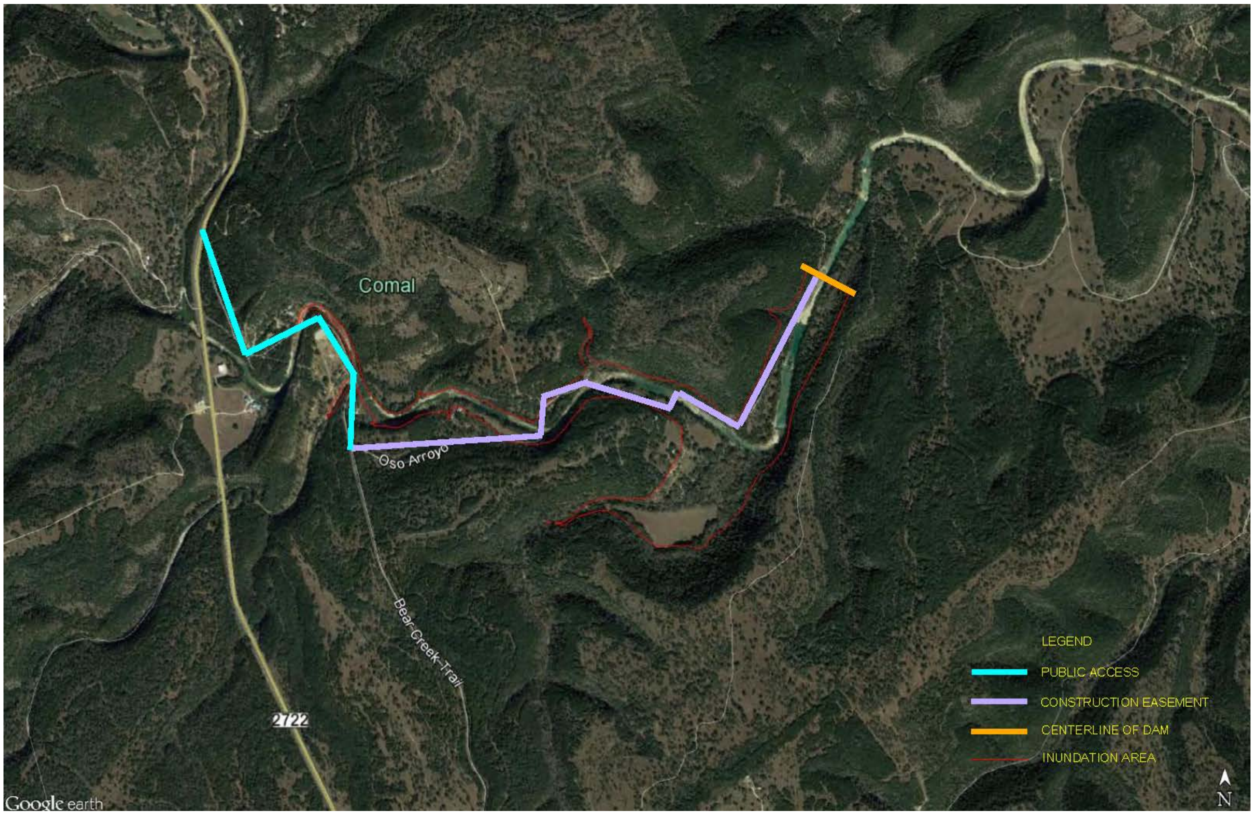

Figure 6: Proposed Bear Creek Dam site location

Geotechnical Considerations

As far as the foundations of flood control structures are concerned, the upper two strata mentioned in the Figure 3 above, Navarro and Taylor Group and the Austin Group are the most influential. While the clay and limestone are reported to be of low permeability, the limestone is likely to have contiguous cavities which will yield a much higher permeability. This is a characteristic of the Balcones scarp which is a karst terrane. This imposes potentially two critical design challenges – foundation support and seepage through the foundation.

Foundation Support:

Irrespective of the alternative selected, the proposed dam alignment would range from a low of 680 feet to 4,900 feet. Soil and rock conditions would differ significantly within such distances and the foundation material may not be uniform. This implies that either some reworking of the materials at site would be required or additional fill would have to be brought in from outside sources. Some of the preliminary research conducted by the project team suggest that good structural fill would be available within a 30-mile radius of the selected site. Given the geomorphology of the limestone formations, it is anticipated that cavities and even some caverns may be encountered during the foundation excavations. Surficial soils may also present high plasticity clayey soils which might require treatment to reduce the plasticity. Thus the preparation of the foundations for the dams is expected to require additional site preparation, such as soil stabilization and grouting.

Seepage issues:

Seepage through the dam would be designed to be minimized by the use of a relatively impervious core and a shell to provided slope stability. In addition, filters would be incorporated in the design of the dam section to reduce seepage pressures. Piezometers and relief wells may also be required to monitor the seepage. However, the underlying limestone formation presents a unique challenge in that the contiguous cavities would act as channels for seepage under the foundation. This has been a major cause of failure in dams in karst, even when some precaution was taken to form a grout curtain during construction. In most of these cases of failures that have been studied, the conclusion was that the grouting should have been done deeper than initially estimated. Thus forming a grout curtain in the limestone and providing a cut-off trench under the foundation are likely to be critical issues in the control of seepage.

Dam Configuration:

Based on initial studies and the geological data, tentative configurations for the dams were developed. The dams will be constructed of compacted earth fill core and a roller compacted concrete (RCC) shell. The outer shell will have a 6 foot thick RCC layer. The inner core will be compacted earth fill consisting of relatively impervious clayey soils. The dam will have a top crest width of 30 feet. The upstream and downstream side slopes will be at 2:1 or 3:1 depending upon the height of the dam. A trapezoidal outlet will be constructed having a 20 foot flat bottom width at the existing channel alignment, with 1:1 side slopes extending to the crest of the dam. Based on these parameters, the Civil Section of the Design Branch developed dam cross-sections which are shown in the Civil Drawings CF100, CF101, and CF102 (Appendix K). A concrete stilling basin will be provided to dissipate the energy of the water at the outlet of each of the three dams. The stilling basin will have a width of 80 feet or more, depending upon the anticipated flow rate and flow velocity. Based on these design parameters, Civil Design Section has estimated quantities of earthwork for each of the dam sites in the tentative site selection process, which is included in the Civil Design Appendix. The volume of earthwork, Roller-compacted concrete (RCC) stilling basin and the access roads will require additional geotechnical investigations and irrespective of the site chosen, the complexities are anticipated to be similar, with quantifiable risks that could be mitigated.

Construction Issues:

The source of materials have not been identified but given the natural resources of the general area, it is anticipated that the materials required for the construction of the dams would be available within a 30-mile radius. A number of concrete batching plants operate in the same radius and with a number of qualified and experienced contractors available in the San Antonio area, construction risks could be well mitigated. The following table summarizes the anticipated quantities based on the calculations provided by the H&H and Civil Design sections of the Fort Worth District.

Parameter	Blanco Option1	Blanco Option2	Blanco Option 3	Hays	Bear Creek	Remarks
Length	1972 feet	2139 feet	2457 feet	4,090 feet	680 feet	
Top elevation	1232 feet NGVD	1237 feet NGVD	1245 feet NGVD	1092 feet NGVD	850 feet NGVD	
Maximum height above streambed	60 feet	65 feet	70 feet	110 feet	75 feet	
Earthwork for the core	207,000 CY	253,000 CY	351,000 CY	367,000 CY	143,000 CY	
RCC cover	65,000 CY	75,000 CY	84,000 CY	120,000 CY	32,000 CY	
Stilling basin	2,100 CY	2,100 CY	2,100 CY	2,100 CY	10,500 CY	
Access Road removal	Under 4 miles	Under 4 miles	Under 4 miles	Under 1.5 miles	Under 2.0 miles	

All the dam sites are accessible through paved or unpaved roads, which would require to be restored after construction as the movement of construction traffic would obviously result in the deterioration of these roads.

Concluding Remarks

While the selection of the site for the proposed flood control structure is primarily controlled by the hydraulic, hydrological and civil engineering design constraints, the sites under consideration present a common geotechnical challenge of siting the structure in karst. Associated with karst terrane is the consideration of preparing an adequate foundation with potentially varying surficial and subsurface deposits and the control of seepage under the dams. Under-seepage through the limestone below the foundation strata has been a primary risk factor in many cases of dam failures in karst, but this risk can be mitigated by forming a properly designed and effective grout curtain.

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