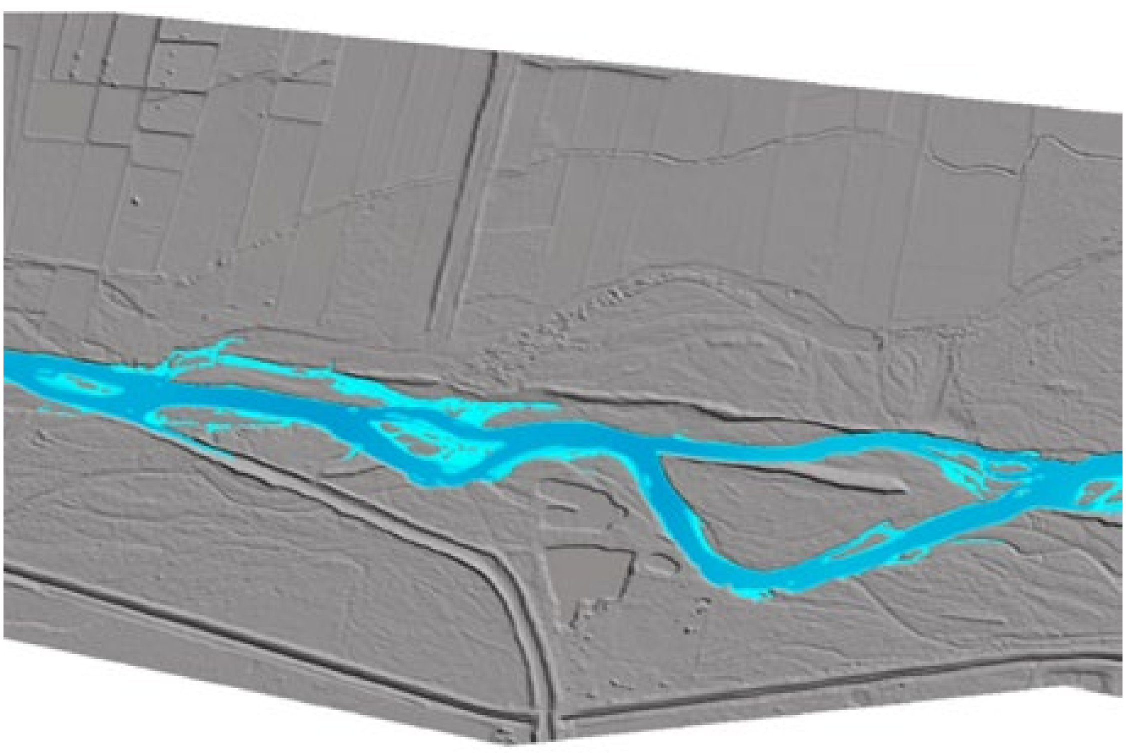
BUREAU OF RECLAMATION

Technical Report No. ENV-2025-010

Middle Rio Grande 2D Overbanking and Levee Impact Assessment

Middle Rio Grande Project, New Mexico
Upper Colorado Basin Region



U.S. Department of the Interior

December 2024

Mission Statements

The U.S. Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; honors its trust responsibilities or special commitments to American Indians, Alaska Natives, Native Hawaiians, and affiliated Island Communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Disclaimer – The results presented within this report will not reflect the exact areas that would be inundated. The 2D model incorporates the Middle Rio Grande's geometry in early 2022, but may differ from actual conditions due to numerous variations in hydrology, infrastructure, uncertainty in overbank roughness values, and facility operations.

Cover Image – Representation of 2D hydraulic model results roughly 1 mile below Cochiti Dam (Bureau of Reclamation)

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Prepared by:

Bureau of Reclamation
Technical Service Center
Denver, Colorado

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RYAN BERNARDINO-MCCLOUD Digitally signed by RYAN BERNARDINO-MCCLOUD Date: 2024.12.19 14:00:00 -07'00'

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Peer Review Certification

This technical report has been reviewed and is believed to be in accordance with the service agreement and standards of the profession.

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Acronyms and Abbreviations

1D	one-dimensional
2D	two-dimensional
AAO	Albuquerque Area Office
Agg/Deg	aggradation/degradation
approx.	approximately
DEM	digital elevation model
ft	foot or feet
ft^3/s	cubic feet per second
HEC-RAS	Hydrologic Engineering Center's River Analysis Software
LFCC	Low Flow Conveyance Channel
Reclamation	Bureau of Reclamation
RM	river miles
USACE	United States Army Corps of Engineers
U.S.	United States
WSE	water surface elevation

Symbols

=	equal to
%	percent

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Overview

The Bureau of Reclamation (Reclamation) and other partner agencies have monitored the Middle Rio Grande since the 1930s, focusing on the area from Cochiti Dam to Elephant Butte Reservoir (figure 1). This report details the first reach-scale two-dimensional (2D) hydraulic model of the Middle Rio Grande using the topography and channel depths from the 2022 aggradation/degradation (Agg/Deg) geometry report (Bernardino-McCloud 2024). The model represents the existing channel and floodplain geometry as of March 2022 but does not include bridges and gates at diversion dams. The analysis focuses on estimating the river's channel capacity, the flowrate that inundates the toes of the levees, and the overall levee capacity. The area considered for this study extends from Cochiti Dam to Rangeline EB-63 (figure 1).

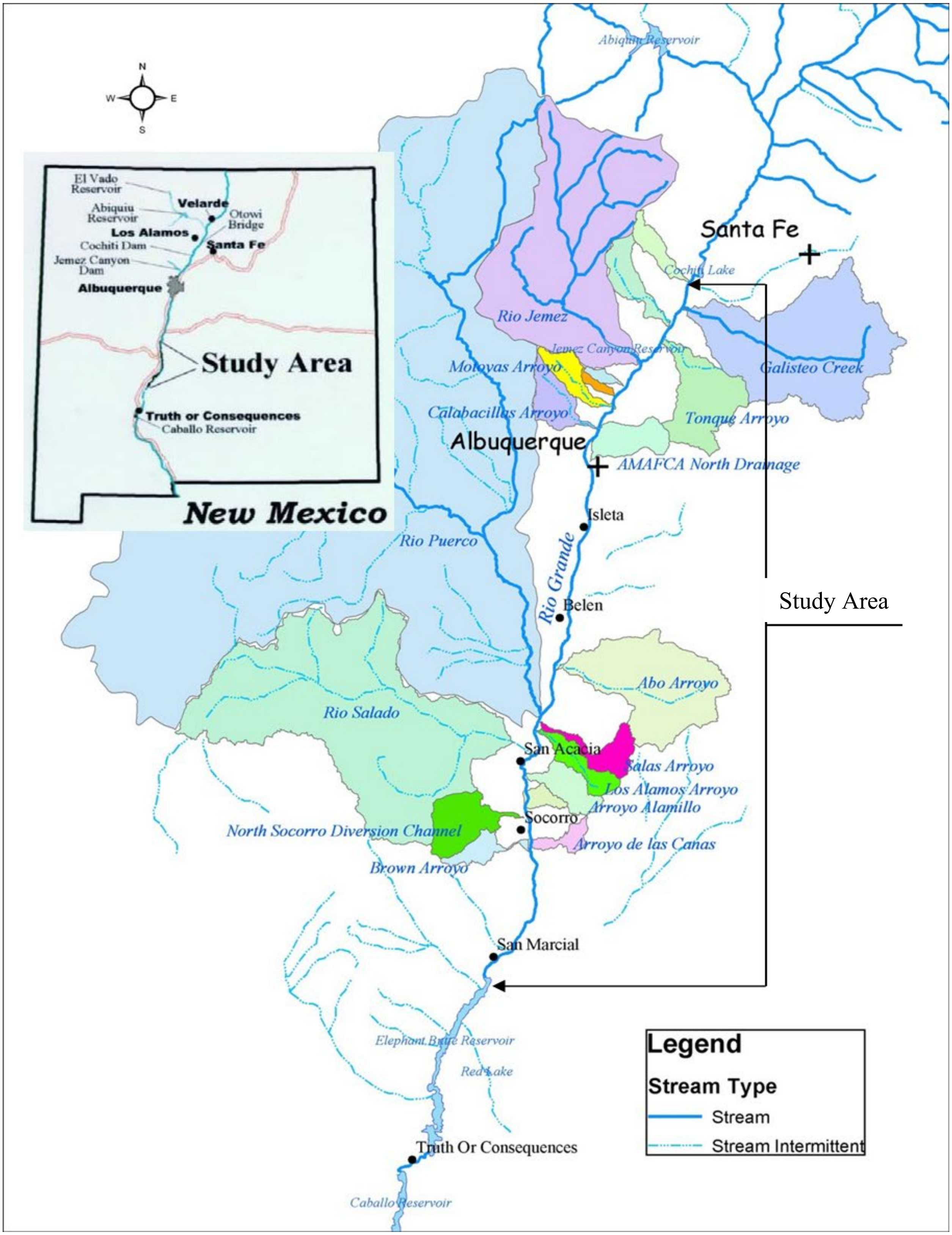


Figure 1.—An overview of the study area extent and contributing watersheds (Varyu 2013).

Hydraulic Model

The inundated area was simulated using the U.S. Army Corps of Engineers' (USACE) Hydrologic Engineering Center's River Analysis Software (HEC-RAS) version 6.5.1 2D unsteady flow module. Model simulations used the diffusion-wave approximation to improve runtimes at a large spatial scale. Other computation options such as the full momentum equation would be appropriate for studies interested in detailed hydraulics. The full 200-mile study area is divided into four sub-reaches for model efficiency. The model begins at Cochiti Dam and ends just below Agg/Deg line EB-63, and the divisors of modeling reaches are Angostura Diversion Dam, Isleta Diversion Dam, and San Acacia Diversion dam. Table 1 lists the characteristics of each model reach below.

Table 1.—Characteristics of the four sub-reaches used to model the Middle Rio Grande

Start Point	End Point	Length (river miles)	Area of Overbank (square miles)
Cochiti Dam	Angostura Diversion Dam	23	38
Angostura Diversion Dam	Isleta Diversion Dam	40	18
Isleta Diversion Dam	San Acacia Diversion Dam	57	29.4
San Acacia Diversion Dam	Agg/ Deg line EB-63	90	113

Modeled Flows

A variety of staff from the Albuquerque Area Office (AAO) were consulted when selecting the flowrates to model. The flows selected range from 1,000 cubic feet per second (ft^3/s) to 10,000 ft^3/s. Flows between 2,000 ft^3/s and 5,000 ft^3/s have the smallest interval because overbanking for most reaches begins in this range. The modeled flow scenarios are presented in table 2 below. The HEC-RAS is limited to 99 combinations of geometry and flow files per project, which allowed for 25 different flowrates to be tested per sub-reach.

Table 2.—A list of selected flows that will be modeled in each reach

Flow Scenario Number	Flow (ft^3/s)
1	1,000
2	1,500
3	2,000
4	2,200
5	2,400
6	2,600
7	2,800
8	3,000
9	3,200
10	3,400
11	3,600
12	3,800
13	4,000
14	4,200
15	4,400
16	4,600
17	4,800
18	5,000
19	5,500
20	6,000
21	6,500
22	7,000
23	8,000
24	9,000
25	10,000

Data Sources

Lidar Terrain

The AAO provided the terrain layer that is the basis of the elevations for all islands, overbank areas, and water surfaces. Woolpert Inc. was contracted to fly the project area to collect aerial imagery and lidar data (Woolpert Inc. 2022). Woolpert Inc. processed the lidar and prepared the terrain layer to represent a hydro-flattened bare earth raster surface with a resolution of 1 foot (ft) by 1 foot (Woolpert Inc. 2022). No field data collection was performed by Reclamation staff as part of this effort (Woolpert collected ground-truthing data as needed). The spatial reference system for the 2022 lidar and terrain layer used in the modeling study is described below:

- North American Datum of 1983 (NAD83) State Plane Coordinate System, New Mexico Central
- North American Vertical Datum of 1988 (NAVD88); Geoid 18

Channel Bathymetry

A mean channel bed elevation was estimated at each Agg/Deg line to represent the bathymetry of the river as part of the decadal aggradation and degradation analysis. These elevations were calculated by an iterative one-dimensional (1D) hydraulics model and were calibrated to recorded low flow conditions during the collection of lidar data (Bernardino-McCloud 2024). The 1D cross section channel elevations serve as the basis for a linearly interpolated 2D channel surface. The Agg/Deg lines were imported into a RAS geometry as 1D cross sections that contained only the estimated bed elevation values. The 1D cross sections were interpolated into a terrain covering both the channel and overbank. Then, the hydro-flattened portion of the terrain surface layer was erased from the ground surface.

Channel Feature Outlines

The following shapefiles were used to create the model and process the results:

- Channel center polyline
- Agg/Deg polylines
- Bankline polylines
- Levee crest polylines
- Levee toe polylines
- Wetted area polygon

The channel centerline and wetted area polygons were provided by Woolpert as part of the lidar deliverable, and the Agg/Deg lines were provided by AAO. Bankline polylines were previously created while estimating the location of bank points in the 1D model (Bernardino-McCloud 2024). As a result, these banklines are coarse resolution and were optimized for accuracy at the intersection point of each Agg/Deg line.

Levee crest and levee toe polylines were manually digitized using aerial imagery and a hill shade digital elevation model (DEM). The DEM was the terrain surface downsampled to a 3x3 ft resolution to mimic the surface layer used for hydraulic modeling. The USACE National Levee Database polylines were used as an initial set of lines for some levees. The relevant

National Levee Database polylines were included or adjusted depending on their alignment with the DEM. Other levees were deemed levees only by the appearance of the features in the DEM and aerial imagery. These features are not necessarily confirmed to be levees claimed by any other entity. Some features were included as levees due to their typical levee-like form but have intermittent breaks that may keep them from functioning as a typical levee (figure 2). These lines were included in analysis to understand when water contacts these features. The levee toe polylines were outlined following the completion of the initial levee crest layer. Levee toe polylines were also outlined with reference to a slope raster calculated from the DEM to assist in determining where the sloped levee sides begin.

For this study, levees are defined as man-made features of higher ground intended to limit the extent of high flow inundation. They may be engineered, spoil material, or constructed features adjacent to the river meant to control overbanking flow. The goal of identifying levees for this study is to characterize the interaction of varying river flows and when the levees are contacted or overtopped. Identifying these interactions may provide insight into locations where levees should be reinforced, raised, set back, or where other maintenance is needed in the floodplain.

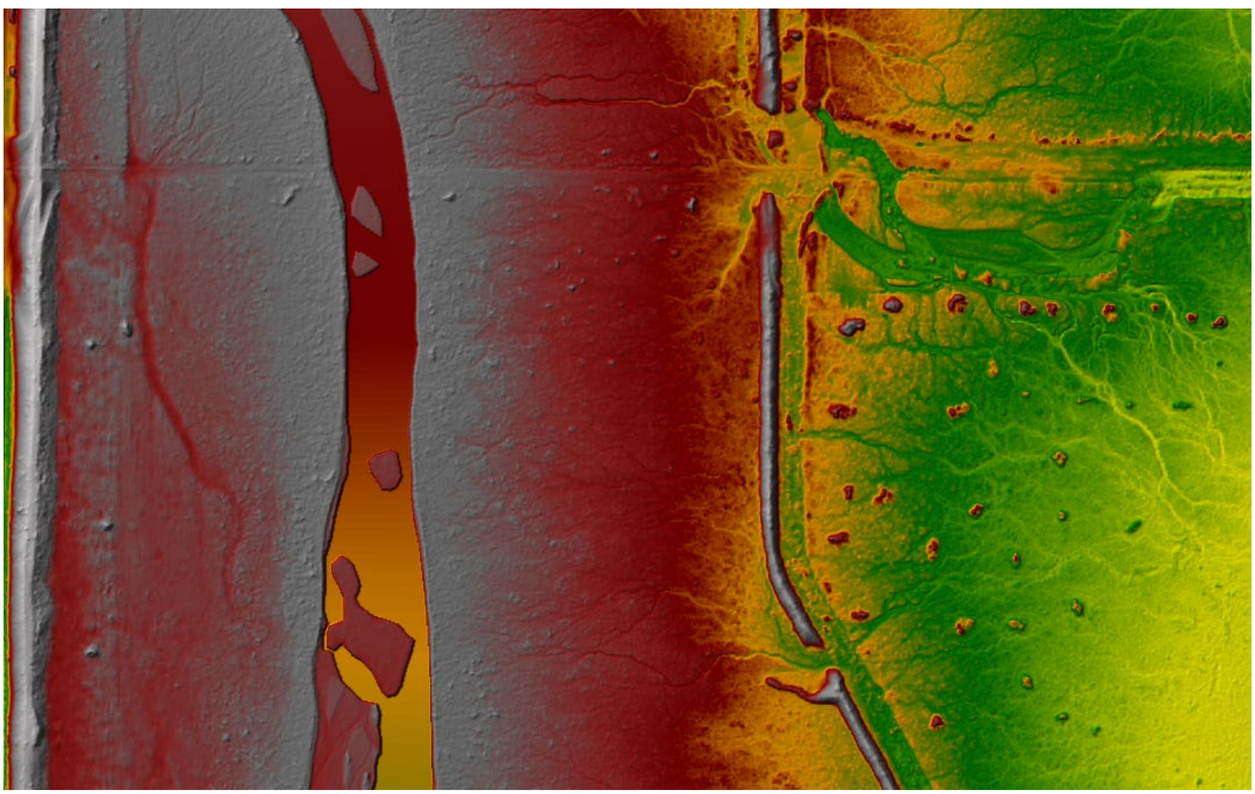


Figure 2.—An example of features found in the lidar near Agg/Deg 1514 that resembles a levee and contains gaps that will allow water to flow past.

Digital Elevation Model

The final surface used in the model combined the above water lidar terrain with the estimated channel bathymetry. The terrain raster was resampled to a 3x3 ft resolution to reduce processing times while still retaining influential hydraulic features. The bathymetry surface and the ground surface were merged into a single raster.

Computational Mesh

The computational mesh for each model domain was created using HEC-RAS's Ras Mapper mesh generation tool. A baseline cell size was selected for each sub reach to represent floodplain area in the models (table 3). Breaklines and refinement regions were added to allow HEC-RAS to capture important topography in hydraulic calculations.

The levee crest polylines were imported into the geometry as breaklines, and the wetted channel polygon was used to create a refinement region for the channel. The levee breaklines' primary purpose was to align the 2D mesh with the highest elevations. This ensures the water does not pass through the levee before overtopping the crest. The wetted channel refinement region was also used to align the 2D mesh with the bank edges and create smaller cells within the channel. The region was particularly important for portions of the channel that were incised so that flow did not leave the channel until overtopping the bank. Many portions of the channel also have a width that required smaller cell sizes to achieve at least 3–4 cells spanning the channel width.

Table 3.—A summary of mesh parameters for the four model sub-domains

Model Domain	Default Cell Size (ft)			Average Cell Size (ft^2)	Number of Cells	Average Face Length (ft)
	Floodplain	Channel Edge	Inside Channel			
Cochiti Dam to Angostura Diversion Dam	100	30	50	4,571	70,458	68
Angostura Diversion Dam to Isleta Diversion Dam	100	30	50	4,258	124,904	65
Isleta Diversion Dam to San Acacia Diversion Dam	100	30	50	4,929	148,081	70
San Acacia Diversion Dam to EB-63	125	30	75	5,242	317,993	72

Final breaklines in the model adjusted the original levee crest polyline and added other breaklines to represent features that were expected to have significant hydraulic effects. The refinement region began as the wetted channel polygon and was extended outward 15 ft to capture the channel banks rather than the edge of low flow conditions. In the model domain starting at San Acacia Diversion Dam, the refinement region was traced manually in many locations due to the highly incised channel requiring more iterations to contain flow appropriately.

Roughness Coefficient

The Manning's n values for the model were first assigned from the National Land Cover Database. The channel polygon was overlayed onto the land cover layer to enforce a more accurate area of channel roughness. The channel upstream and downstream of Isleta Diversion Dam was assigned Manning's n values of .025 and .020 respectively. Each land cover category was assigned one of three roughness zones: .04, .06, and .08 (table 4), to reflect the expected roughness values of the project area. Areas beyond the wetted floodplain may have different roughness values than assumed in the table (i.e., Developed High Intensity = .08), but do not affect results and were assigned to one of the three roughness zones for simplicity. Floodplain areas subject to inundation typically have Manning's values of 0.06 or 0.08, with 0.06 occupying the largest area.

Table 4.—Translation from National Land Cover Database categories to Manning's N Roughness for the project area

Land Cover Category	N Value
No data	0.04
Shrub-scrub	0.06
Grassland-herbaceous	0.08
Woody wetlands	0.06
Developed, open space	0.04
Developed, medium intensity	0.08
Emergent herbaceous wetlands	0.06
Developed, low intensity	0.04
Cultivated crops	0.04
Developed, high intensity	0.08
Open water	0.06
Barren land rock-sand-clay	0.08
Evergreen forest	0.08
Pasture-hay	0.08
Deciduous forest	0.08
Channel (upstream of San Acacia)	0.025
Channel (downstream from San Acacia)	0.02

Time Step and Duration

The time step and duration for each model domain was expected to be highly dependent on reach and flow due to wide variations in the size of the channel and floodplain. The variable time step available in HEC-RAS was utilized for each run, so that the model would run the highest time step possible while maintaining values of the Courant number that provide numerical stability. The most common initial and stable time step was 3.125 seconds. A unique HEC-RAS plan was created for each flowrate. The initial flows in each geometry of 1,000 ft^3/s transitioned the model from dry to wet, which requires the lowest Courant number. A maximum value of 1 was selected for all 1,000 ft^3/s flows, which is consistent with the HEC-RAS user manual's recommendation for initial wetting plans. The manual also states that in models with slowly increasing velocity and depth, the Courant number can be set as high as 5.0. The reaches modeled are not steep, have gradually increasing inflows between plans, and are using the diffusion wave equation, so a maximum courant number of 4.0 was selected for all other flows. To ensure there were not errors within the model, the volume accounting error percentage was monitored and never was above 0.5 percent (%). All plans besides the initial 1,000 ft^3/s flowrates were initialized with a restart file from the previous flow. The duration of each model run is dependent on how long it takes the new flowrate to become steady at the downstream boundary. Any difference in volume entering and exiting the model is due to cells within the model filling in extremely slowly and are considered to have a small effect on the steady state inundation profile. This was verified by viewing the flow rate through the most downstream Agg/Deg line and verifying that it appeared steady and no more than 5% different than the inflow value (figure 3).

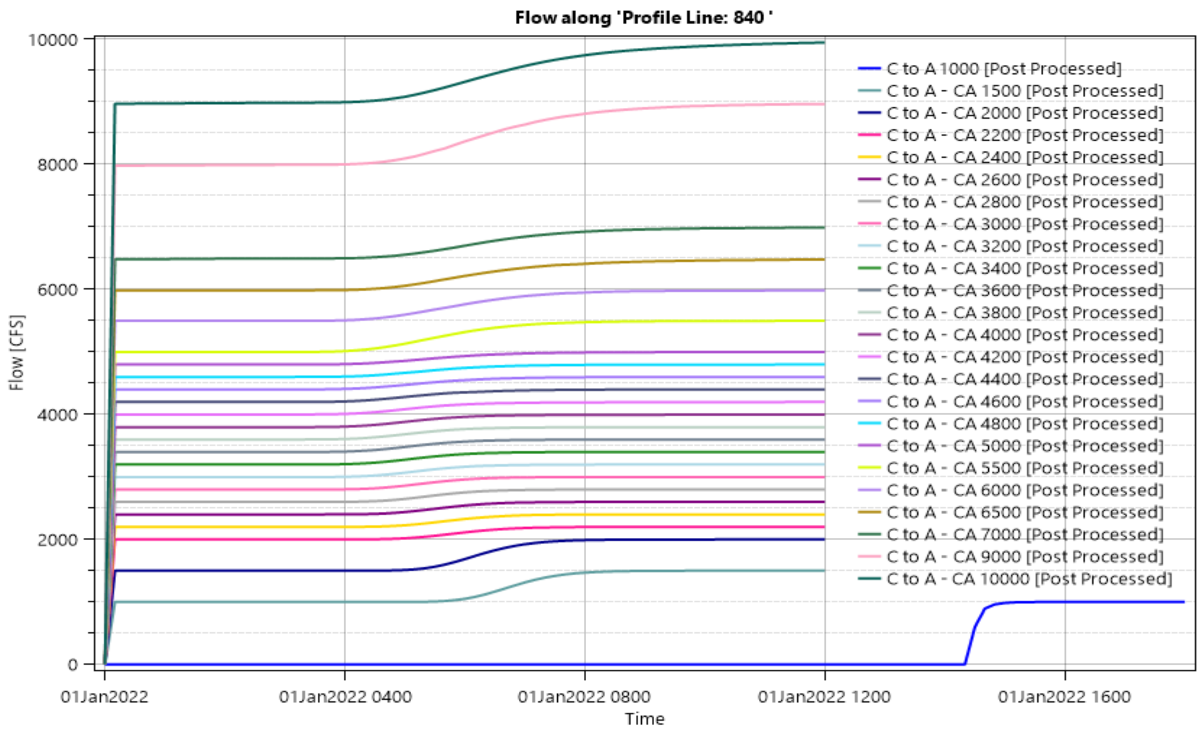


Figure 3.—A summary graph output from HEC-RAS that displays the flow passing through the end of Cochiti Dam to Angostura Diversion Dam Model Domain

A table of each flow and sub-reach's duration is below (table 5). The shortest duration is 12 hours for flows 1,500–10,000 ft^3/s for the Cochiti to Angostura Diversion Dam model domain. The longest duration is 96 hours for flows 5,000 ft^3/s and larger for the San Acacia Diversion Dam to EB-63 model domain The time it takes the flow to equalize is dependent on the length of the reach and the volume of overbanking flows being filled. Multiple iterations of the model were run to determine the shortest duration that could be modeled for each flow.

Table 5.—Summary of all plan durations

Reach	Flow Scenario (ft^3/s)	Duration (Hours)
Cochiti Dam to Angostura Diversion Dam	1,000	18
	1,500–10,000	12
Angostura Diversion Dam to Isleta Diversion Dam	1,000	43
	1,500–10,000	24
Isleta Diversion Dam to San Acacia Diversion Dam	1,000–3,000	24
	3,200–10,000	36
San Acacia Diversion Dam to EB-63	1,000	48
	1,500–5,000	72
	5,500–10,000	96

Boundary Conditions

The boundaries of each model domain are based on the major diversion dams along the Middle Rio Grande Cochiti Dam, Angostura Diversion Dam, Isleta Diversion Dam, and San Acacia Diversion Dam. The upper boundary for each model domain was set at the immediate downstream side of each dam, and the lower boundary for the model domain was set at a section of river far enough downstream to avoid boundary condition impacts on model results. Results were clipped to delete overlapping areas affected by reach boundaries. Both boundaries require local slopes to be input into HEC-RAS, which were determined by using the measuring tool along the channel center near the boundary to find the average slope. The downstream boundary of each geometry is a normal depth condition. The end of each model was placed purposefully below dams or wide channels so that there are minimal errors from unaccounted backwater effects.

The upstream boundary conditions were set as inflow hydrographs to place flow into the model. The initial flow of 1,000 ft^3/s for each sub-reach began at 0 and linearly increased to 1,000 ft^3/s over the first hour of the simulation. All other flow files began and ended with their respective inflow amounts. Although the HEC-RAS filetype and model are considered unsteady, the inflows after 1,000 ft^3/s can be considered conceptually steady.

Results and Analysis

Geomorphic Reaches

The model results are split into subreaches for summarization and visualization. Geomorphic regions have already been established and have been used as a reference in previous Agg/Deg reports (Varyu 2013). The main scope of this study is to understand the hydraulics of the major reaches’ channel and overbank geometry, so summarizing results by geomorphic reaches will show meaningful trends. The only alteration to the previous delineation of geomorphic reaches is that from river mile (RM) 60 to the end of the model domain, there are two reaches split by the confluence located between RM 55 and 54. The name of each geomorphic reach and the associated Agg/Deg lines are in table 6 below.

Table 6.—Summary table of geomorphic reaches used for analysis

Reach Name	Starting Agg/Deg[1]	Agg/Deg Count
Cochiti Dam to Angostura Diversion Dam	17	218
Angostura Diversion Dam to Isleta Diversion Dam	237	415
Isleta Diversion Dam to Rio Puerco Confluence	657	435
Rio Puerco Confluence to San Acacia Diversion Dam	1099	108
San Acacia Diversion Dam to Arroyo de las Cañas	1207	189
Arroyo de las Cañas to San Antonio	1397	78
San Antonio to RM78	1476	108
RM78 to RM60	1585	198
RM60 to LFCC West Outfall	1796	34
LFCC West Outfall to EB-63	EB-33	63

[1]The channel in the last geomorphic reach doesn't align with established Agg/Deg lines and the upstream boundary is set to the EB-33 rangeline. Counts in third column may include rangelines as needed.

All categories of analysis are summarized by geomorphic reach, but some figures are also plotted longitudinally. The results of this study are intended to be interpreted at the geomorphic reach-scale and processing and visualizing results at the Agg/Deg scale may inform understanding of broad trends within the reaches. The Agg/Deg lines were converted to polygons to further analyze results by calculating inundated areas between Agg/Deg lines. The lines were extended to the edge of the surface domain and any intersecting lines were manually straightened to avoid overlapping polygons.

Model Output

The results exported from HEC-RAS are water surface elevation (WSE) rasters for each model-subdomain and each flow scenario. The ArcGIS® Pro was used for all analysis and result processing. All raster results were clipped to their respective boundaries and then merged by flow scenario. This resulted in 25 raster files representing WSEs for each flow rate modeled over the entire Middle Rio Grande. These 25 rasters were then converted into polygons to represent the inundation extent.

Analysis Results

Overbanking Analysis

The purpose of this analysis is to understand the channel flow capacity of each reach. This is summarized by calculating the total inundated area within each reach and plotting it relative to the flow scenario (appendix A). Slope breaks in the plot are good indications of when new areas start to become inundated. Typically, a small slope break occurs at relatively low flows that represents the inundation of point bars, backwater areas, or secondary channels. Another small slope break may be present at a slightly higher flow if the reach is long and there are other backwater areas, islands, or side channels that become active at higher flows. A more prominent slope break represents the start of significant overbank inundation, and the flow value at this slope break can be interpreted as the channel capacity. The estimated channel area included in the figures in appendix A is based on the area of channel polygon previously discussed in the 'Data Source' section of this report and can also be used as a guide to when flow starts to spill out of the channel.

There is also a longitudinal figure of each reach that displays the ratio of inundated area to the channel area within each Agg/Deg polygon for each flow (appendix A). Spikes in this graph may indicate that a particular portion of the reach has a relatively low channel capacity and more risk of flooding. Care must be taken in interpreting these longitudinal plots of capacity, because it is not uncommon (especially downstream of San Acacia) for water to get out of bank and then start to fill low-lying areas lateral to and upstream of where the water gets out of bank. In that case, high values of the inundation ratio will be present at cross sections upstream of where water gets out of bank even though there is not active overbanking at that cross section. Figure 4 and figure 5 below are examples plots for the Arroyo de las Cañas to San Antonio reach and the plots for other reaches are found in appendix A.

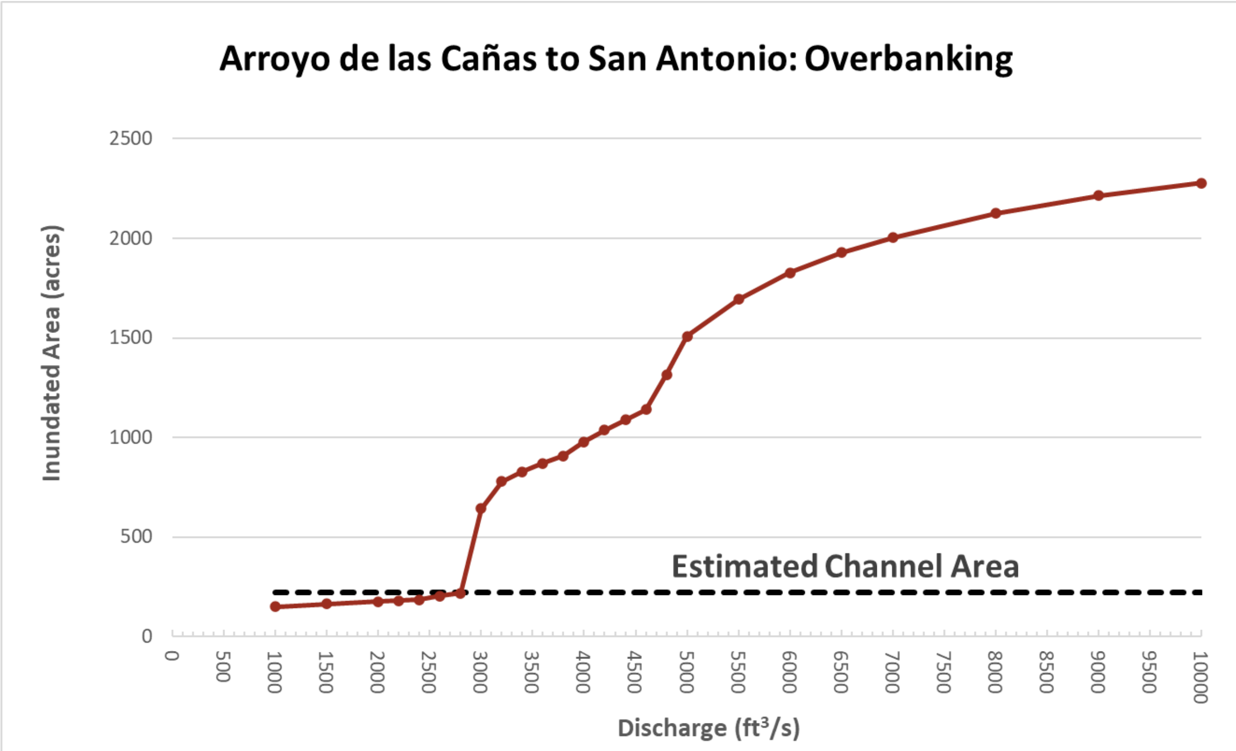


Figure 4.—Inundated area for the Arroyo de las Canas to San Antonio geomorphic reach for flows ranging from 1,000 ft^3/s–10,000 ft^3/s.

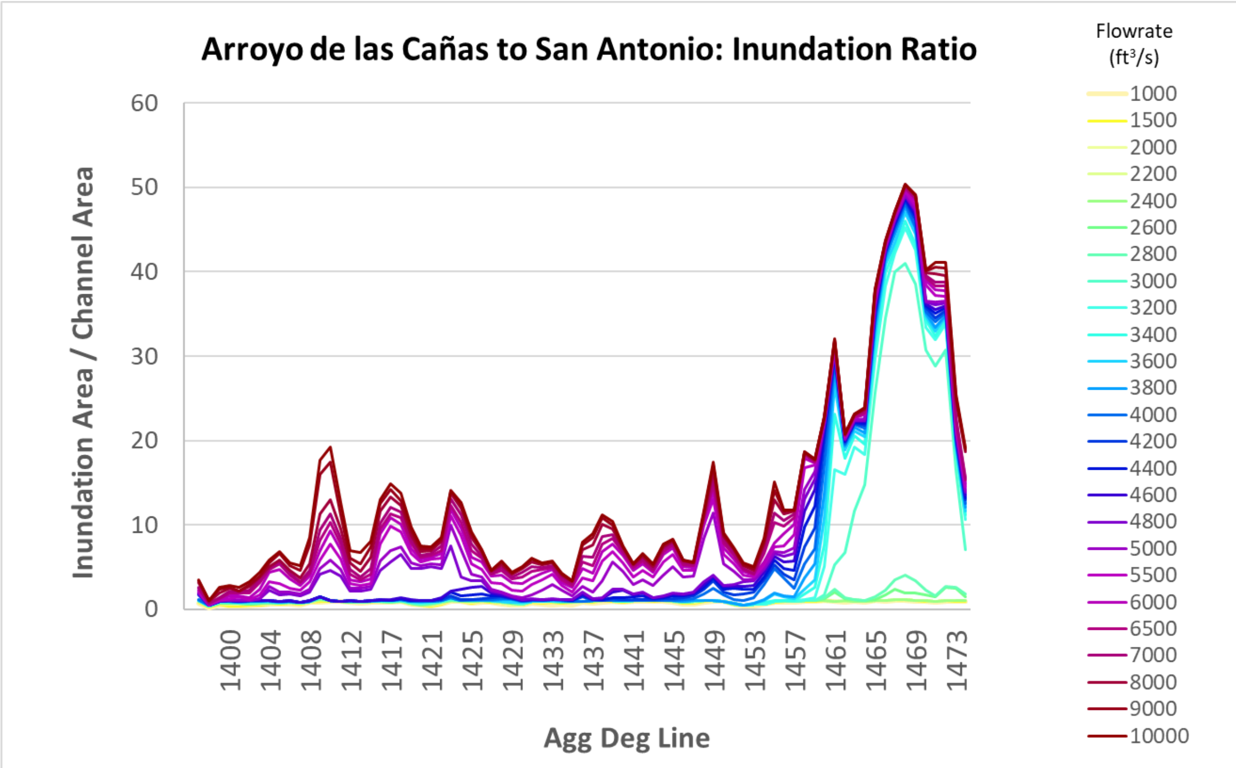


Figure 5.—Ratio of inundated area and estimated channel area for flows ranging from 1,000 ft^3/s–10,000 ft^3/s.

For the Cochiti Dam to Angostura Diversion Dam geomorphic reach, the area of inundation ranges from 392 acres to 1,374 acres from 1,000 ft^3/s to 10,000 ft^3/s. The increase in inundation area is roughly linear until 4200 ft^3/s, where a slope break is present in the plot of inundated area vs. discharge (appendix A). There is a second slope break that occurs between 5,500 and 6,000 ft^3/s. The channel capacity is approximately (approx.) 5,500 ft^3/s, which is just before the slope break evident at 6,000 ft^3/s. The inundation ratio fluctuates between 0 and 5 for most of the reach, with two small spikes of 6 and 8 around Agg/Deg lines 127 and 148, respectively, which are both locations of high flow side channels. There is a very large spike ranging from Agg/Deg lines 166 to 180, with an inundation ratio reaching a peak of 22. This area is a wide floodplain upstream of the relatively narrow valley at Tonque Arroyo and high flows are choked, increasing backwater effects upstream. Channel capacity is estimated at 5,000 ft^3/s.

For the Angostura Diversion Dam to Isleta Diversion Dam geomorphic reach, the area of inundation ranges from 1,090 acres to 4,808 acres for the range of simulated flows. The increase in inundation area is roughly linear until 5,000 ft^3/s, and then linear again above 5,000 ft^3/s but with a steeper slope. The channel capacity is approx. 5,000 ft^3/s, above which there is inundation of the bosque, generally downstream of the I-40 bridge. The peak inundation ratio fluctuates between 0 and 6 for most of the reach, with 3 small spikes falling between 6 and 8 near Agg/Deg lines 250, 426, and 616. The confluence of the Jemez River is near Agg/Deg 250 and higher flows can begin to access the delta confluence, increasing the inundated area with increasing discharge. The high inundation ratios in the Agg/Deg range of approx. 400 to 460 is urban Albuquerque with many bridges whose abutments cause backwater at flows above 5,000 ft^3/s. The spike near Agg/Deg 616 is upstream of the I-25 bridge, so similar backwater issues present here at higher flows. There are also two larger ratio spikes of 9 and 10 around Agg/Deg line 395 and 641, respectively. Agg/Deg 395 is upstream of the AMAFCA North channel and the inundation at higher flows is nearly levee to levee here, along with a very localized narrow width, leading to a high inundation ratio. The same is true for Agg/Deg 641; the river is relatively narrow, and coupled with levee-to-levee inundation, generates a high inundation ratio.

For the Isleta Diversion Dam to Rio Puerco geomorphic reach, the inundation area ranges from 784 acres to 6,820 acres across the range of simulated flows. Backwater and secondary channels begin to become inundated downstream of Agg/Deg 1016 by 3,000 ft^3/s and there is a small change in slope at this flowrate in the inundation plot in Appendix A. Upstream of Agg/Deg 1016, side channels and backwater areas become inundated at 4,000 ft^3/s and another small slope break is noticeable at this flow rate. Significant floodplain inundation occurs at 6,500 ft^3/s, but general floodplain inundation begins at 5,000 ft^3/s and this value is determined to be the channel capacity for this reach. The inundation ratio fluctuates between 0 and 13 for most of the reach, with 3 spikes of 21, 19, and 15 at Agg/Deg lines 670, 828, and 939 respectively. Agg/Deg lines 670 and 828 are narrow sections of river that lead to a spike in inundation ratio; inundation is essentially levee to levee for these locations. There is a slightly wider section between levees at Agg/Deg 939 leading to the high inundation ratio here.

For the Rio Puerco to San Acacia Diversion Dam geomorphic reach, the area of inundation ranges from 172 acres to 1,250 acres. There is a slope break at the approx. channel area of 293 acres which corresponds to 3,200 ft^3/s. A much more noticeable slope break exists at 4,800 ft^3/s, The lower slope break (3,200 ft^3/s) represents backwatering into low lying areas; it is not flow getting out of bank and traveling down valley but rather flow going overbank and filling areas upstream of the overbanking. This is true for the section of reach with the highest ratio of inundation area to channel area; Agg/Deg approx. 1138–1148. The left floodplain is wider here than in the section just upstream or downstream, and this floodplain is accessible to a range of flows. The channel capacity is estimated to be 4,600 ft^3/s for this reach.

For the San Acacia Diversion Dam to Arroyo de las Cañas geomorphic reach, the area of inundation ranges from 384 acres to 1,791 acres for the range of simulated flows. The plot of inundation area vs. flow has a well-defined slope break at 4,000 ft^3/s between two very linear sections. The inundation ratio is generally higher (more inundation at lower flows) downstream of about Agg/Deg 1348 even though the inundation is minimal at 4,000 ft^3/s upstream of Agg/Deg 1348. The upstream portion of thus reach, from San Acacia to about Agg/Deg 1254, contains 10,000 ft^3/s in channel. For the overall reach, the channel capacity is estimated to be 4,000 ft^3/s.

For the Arroyo de las Cañas to San Antonio geomorphic reach, the area of inundation ranges from 149 acres to 2,294 acres. There is a major increase in inundation area occurring at 3,000 ft^3/s. The estimated channel area is well represented by the inundation area at 2,800 ft^3/s. Another steep increase in inundation occurs between 4,600 and 4,800 ft^3/s. The increase that occurs at 3,000 ft^3/s is largely due to overbanking just upstream of the Highway 380 bridge. The inundation increase at 4,800 ft^3/s is due to overbanking into the east floodplain just downstream of the Arroyo de las Cañas. These two pronounced slope breaks overshadow a smaller slope break at 4,000 ft^3/s, which is the flow at which more consistent inundation begins to occur for the overall reach. The estimated channel capacity for this reach is 3,800 ft^3/s.

For the San Antonio to RM 78 geomorphic reach, the area of inundation ranges from 200 acres to 3,966 acres for the range of flowrates simulated. Water is predicted to access the low-lying eastern floodplain at flows as low as 2,000 ft^3/s at Agg/Deg 1550. The backwatered inundation area increases at 2,200 ft^3/s as this backwater area increases in the upstream direction. The plot of inundation area vs. flow for this reach is atypical in that the slope of the curve tends to decrease with increasing flow above 3,000 ft^3/s, after a relatively linear section between 2,000 and 3,000 ft^3/s. Most of this reach has high ratios of inundation area to channel area. The lowest values for this ratio occur around Agg/Deg 1561, near the downstream end of the recently completed channel realignment project in the Bosque del Apache National Wildlife Refuge. The channel capacity is estimated to be 2,000 ft^3/s for this reach.

For the RM 78 to RM 60 geomorphic reach, the area of inundation ranges from 210 acres to 3,951 acres for the range of flowrates simulated. The curve of inundation area vs. flowrate is quite flat up to 4,600 ft^3/s although there is a jump at 2,800 ft^3/s. This reach is perched, and a lot of the low-lying floodplain on both sides of the river are inundated at relatively low flow because of water entering the reach already in the floodplain from the upstream reach. The channel contains flows up to 2,600 ft^3/s, but at 2,800 ft^3/s there is overbank flow coming into the reach that stays in the floodplain until it returns to the channel at RM 74 (Agg/Deg 1638). Downstream of RM 74, the channel contains flowrates up to 5,500 ft^3/s. At 6,000 ft^3/s, both sides of the valley are inundated down to Agg/Deg 1672, and the southeastern floodplain continues to be inundated down to Agg/Deg 1693. The inundation ratio plot exemplifies that the 10,000 ft^3/s flow is contained within the channel downstream of the San Marcial Railroad Bridge (Agg/Deg 1703) until a small amount of flooplain inundation starting at Agg/Deg 1787, just upstream of the reach boundary at Agg/Deg 1797. For the overall reach, the channel capacity is estimated to be 5,500 ft^3/s based on the estimated channel capacity downstream of RM 74. The observed inundation areas occurring at lower flow rates are related to flow coming into the reach from the upstream reach already in the floodplain and is not reflective of the channel capacity of this reach.

For the RM 60 to Low Flow Conveyance Channel (LFCC) West geomorphic reach, the area of inundation ranges from 69 acres to 558 acres. The inundation area vs. flowrate curve is linear up to 2,200 ft^3/s, where a slope break is evident. At 2,400 ft^3/s, there are some low-lying areas to the east of the river downstream of Agg/Deg 1854 that become inundated. The eastern floodplain at the downstream end where the LFCC west comes into the Rio Grande also becomes more noticeably inundated at this flow rate. Except for the eastern floodplain at the LFCC Confluence, the channel in this reach contains 6,500 ft^3/s. At 7,000 ft^3/s, the east floodplain at the downstream end of the reach (below Agg/Deg 1859) becomes inundated, which causes the increase in the inundated area vs. flow plot for this reach. For the overall reach, the channel capacity is estimated to be 6,500 ft^3/s.

For the LFCC West Confluence to EB-63 geomorphic reach, the area of inundation ranges from 255 acres to 3,798 acres. The western floodplain upstream of EB-35.5 is inundated at 2,400 ft^3/s, along with the eastern floodplain between EB-47 and EB-49. There is inundation of the west floodplain between EB-45 and EB-49 at 4,200 ft^3/s which is responsible for the increase in inundation area at this flowrate. The estimated channel area is consistent in area with the inundation area associated with 2,400 ft^3/s. The overall channel capacity is estimated at 2,400 ft^3/s for this reach.

Figure 6 summarizes the overbank discharges for the geomorphic reaches for the Middle Rio Grande between Cochiti Dam and Elephant Butte Reservoir. Figure 7 represents the ratio of inundated area to channel area for each geomorphologic reach, for flowrates in 1,000 ft^3/s increments.

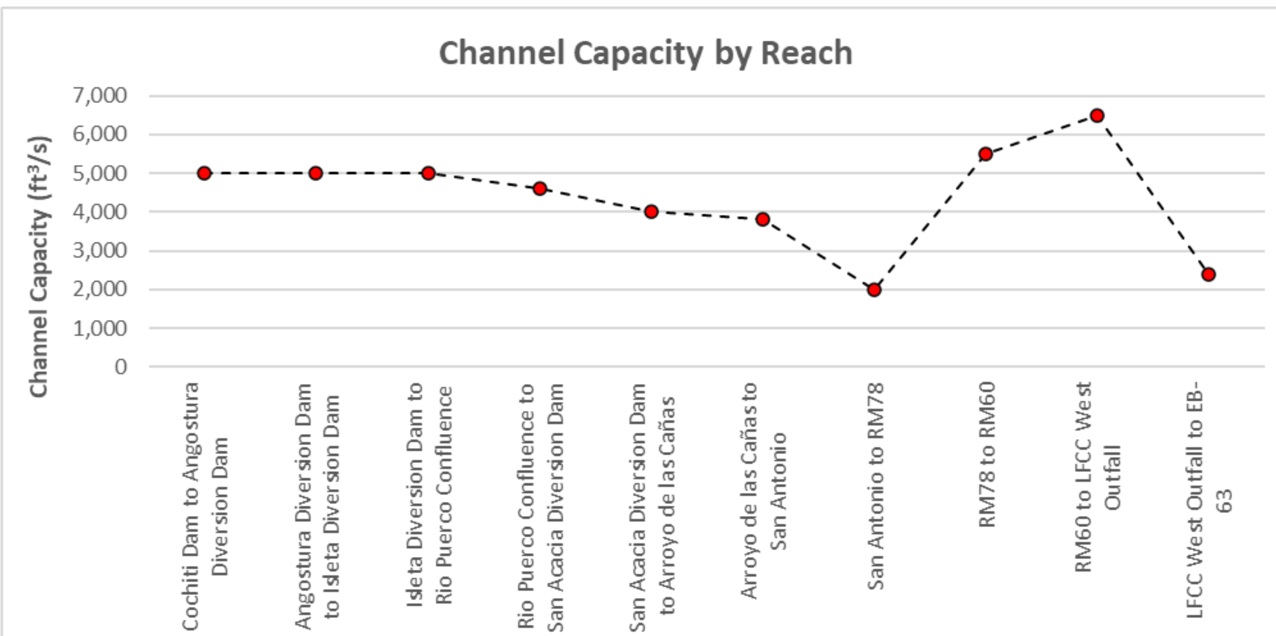


Figure 6.—The flow rate at which overbanking occurs for each geomorphic reach of the Middle Rio Grande.

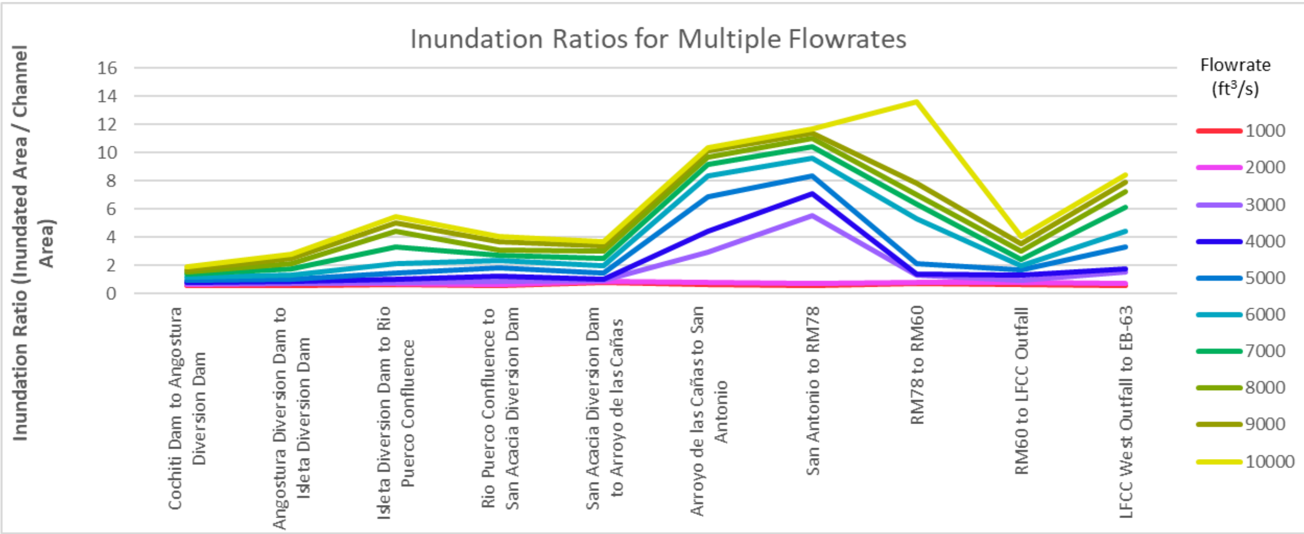


Figure 7.—The total inundation ratio of each geomorphic reach, for flowrates in increments of 1,000 ft^3/s.

Levee Toe Inundation Analysis

The purpose of this analysis is to understand at what flows the toes of levees will begin to be inundated. This is summarized by calculating the total length of levee toes that are wet for each given flow (appendix B). The total length of levees is also plotted, along with a secondary axis of percentage of this total levee length. A sharp increase in this graph would indicate a flow threshold that will begin inundating areas that contain levees. Figure 8 below is an example plot for Isleta Diversion Dam to Rio Puerco and the plots for other reaches are found in appendix B.

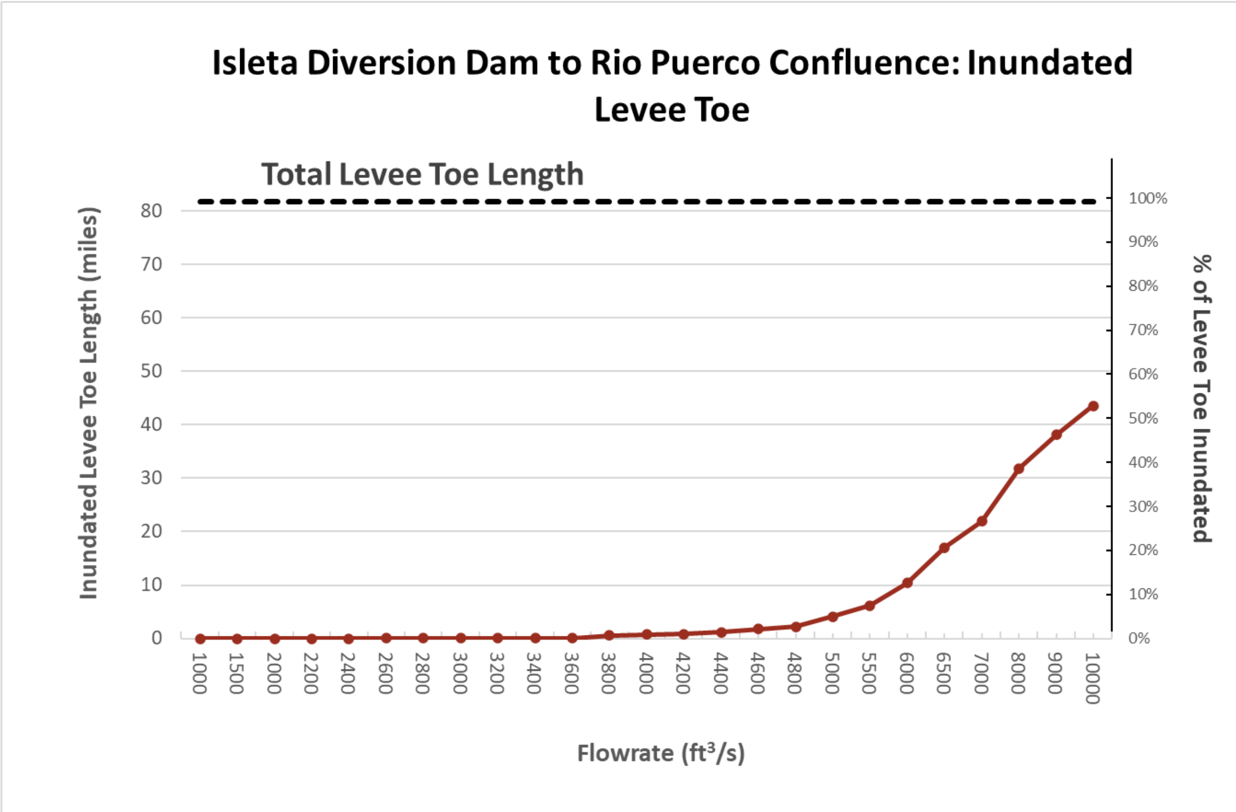


Figure 8.—Length of inundated levee toes in feet and percentage of total levee toes of the Isleta Diversion Dam to Rio Puerco Confluence geomorphic reach for flows ranging from 1,000 ft^3/s–10,000 ft^3/s.

For the Cochiti Dam to Angostura Diversion Dam geomorphic reach, there are 26.4 miles of levees. The first inundation occurs at 5,500 ft^3/s and increases very slowly up to the maximum simulated discharge of 10,000 ft^3/s. The maximum length of levee toe inundation is .5 miles, or 2% of the total levee length.

For the Angostura Diversion Dam to Isleta Diversion Dam geomorphic reach, there are 63.6 miles of levees. The first levee toe inundation occurs at 1,000 ft^3/s and increases very slowly until it reaches 2% inundation at 5,500 ft^3/s. The length of wetted toe increases exponentially up to 8,000 ft^3/s (15% of the levee length inundated) and then a steeper, linear rate of inundated toe length is apparent up to the maximum simulated discharge, with a maximum of 20.6 miles, or 32% of the total levee length inundated.

For the Isleta Diversion Dam to Rio Puerco Confluence geomorphic reach, there are 81.7 miles of levees. The first levee toe inundation occurs at 1,500 ft^3/s at a levee alongside the channel but is below 1% of the total length up to 3,400 ft^3/s, where there is a slow exponential growth until 10,000 ft^3/s. Less than 15% of the levee toe length is inundated at 5,500 ft^3/s, and the maximum length of levee toe inundation is 48.1 miles, or 59% of the total levee length.

For the Rio Puerco Confluence to San Acacia Diversion Dam geomorphic reach, there are 15.6 miles of levees. The first levee toe inundation occurs at 1,500 ft^3/s but stays below 1% up to the simulated flow rate of 3,200 ft^3/s. Less than 10% of the toe is inundated at 5,000 ft^3/s, and a large increase from 21% to 31% occurs between 8,000 ft^3/s and 9,000 ft^3/s. The maximum length of levee toe inundation is 4.8 miles, or 34% of the total levee length.

For the San Acacia Diversion Dam to Arroyo de las Cañas geomorphic reach, there are 20.3 miles of levees. The first levee toe inundation occurs at 4,600 ft^3/s and stays below .1% of the total levee length until 6,000 ft^3/s, where it quickly increases to 0.7 miles, or 3.6%. It then follows a roughly linear growth to 1.3 miles at 8,000 ft^3/s. It then has a faster growth to the maximum length of 2.6 miles, or 12% of the total levee length.

For the Arroyo de las Cañas to San Antonio geomorphic reach, there are 7.3 miles of levees. The first levee toe inundation occurs at 2,400 ft^3/s and grows with a logarithmic pattern until reaching 1.5 miles at 4,600 ft^3/s. It then has a fast exponential increase to 3.1 miles at 6,500 ft^3/s, followed by a slower exponential growth towards 10,000 ft^3/s. The maximum length of levee toe inundation is 5.8 miles, or 80% of the total levee length.

For the San Antonio to RM 78 geomorphic reach, there are 13.9 miles of levees. The first levee toe inundation occurs at 2,200 ft^3/s and has a sharp linear growth to 9.7 miles of inundated toe at 3,000 ft^3/s. The increase in length then becomes much slower, and linearly continues to increase to the maximum length of levee toe inundation of 12.7 miles, or 91% of the total levee length.

For the RM 78 to RM 60 geomorphic reach, there are 20.9 miles of levees. The first levee toe inundation occurs at 2,800 ft^3/s and has an inundated length of 3.3 miles, or 16% of the total levee length. The increase at higher flows is gradual, eventually reaching 4.3 miles of inundated toe at 5,500 ft^3/s. The inundated length then increases to 5.7 miles at 6,000 ft^3/s, and grows slowly towards 6.7 miles at 9,000 ft^3/s. It jumps rapidly again to the maximum length of levee toe inundation of 9.6 miles, or 46% of the total levee length.

For the RM 60 to LFCC Confluence geomorphic reach, there are 1.8 miles of levees. The first levee toe inundation occurred at 3,200 ft^3/s and has a gradual linear growth except for a slower increase from 5,500 ft^3/s to 8,000 ft^3/s. The maximum length of 0.19 miles, or 8% of the total levee length occurs at 10,000 ft^3/s.

For the LFCC Confluence to EB-63 geomorphic reach, there are no levees.

Figure 9 plots the first flowrate to inundate at least 10% of the total levee length within each geomorphologic reach. The first and last reach are never inundated by 10% and are therefore left blank. Figure 10 plots the overall percent of levee toe that is inundated for each geomorphologic reach at the highest flowrate of 10,000 ft^3/s.

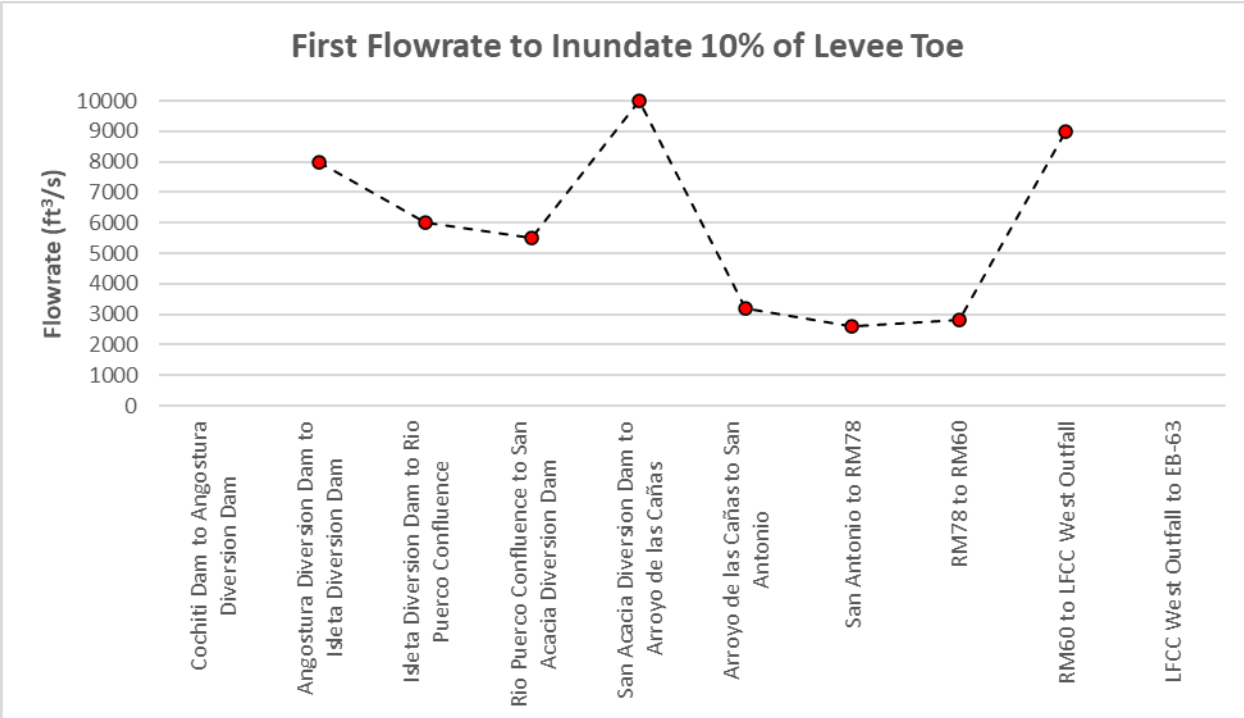


Figure 9.—The flowrate that first inundates at least 10% of the levee toe for each geomorphic reach within the Middle Rio Grande.

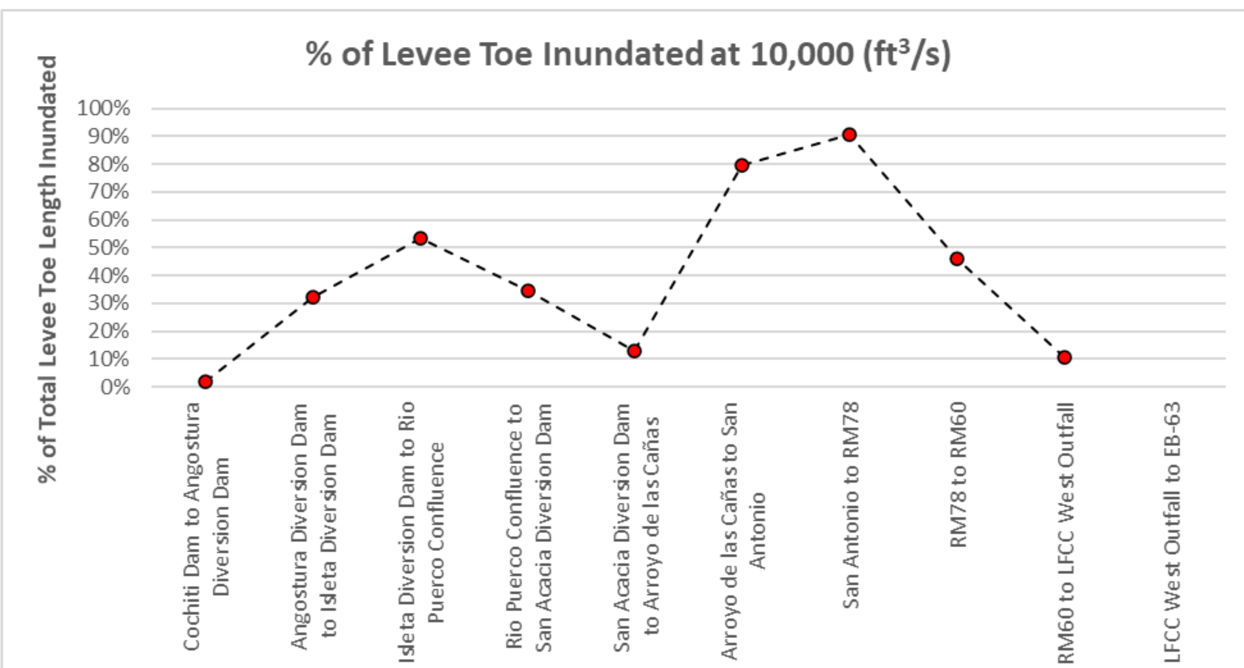


Figure 10.—The percent of the total levee toe length that is inundated at 10,000 ft^3/s for each geomorphic reach within the Middle Rio Grande.

Levee Freeboard Analysis

The purpose of this analysis is to understand the capacity of the levees for each reach. This is displayed by plotting the elevation of levee crests at each Agg/Deg line, as well as the WSE of the water over the levee toe. If the toe of the levee is not inundated, it will not be included in the figure. If levees exist on both sides of the river the one with the lower elevation will be the one represented. If no levee exists, there will be no data displayed for that Agg/Deg location. There is also a figure that plots the amount of freeboard at each Agg/Deg line for any levee with an inundated toe. These graphs may provide insight on the general elevations of levees within a reach and highlight areas of concern for low freeboard at higher flows. Any locations with 3 feet or less of freeboard will be discussed, as well as instances of 0.5 ft of freeboard or less that may indicate a higher risk of overtopping. Figure 11 and figure 12 below are examples for the Arroyo de las Cañas to San Antonio geomorphic reach and the plots for other reaches are found in appendix C.

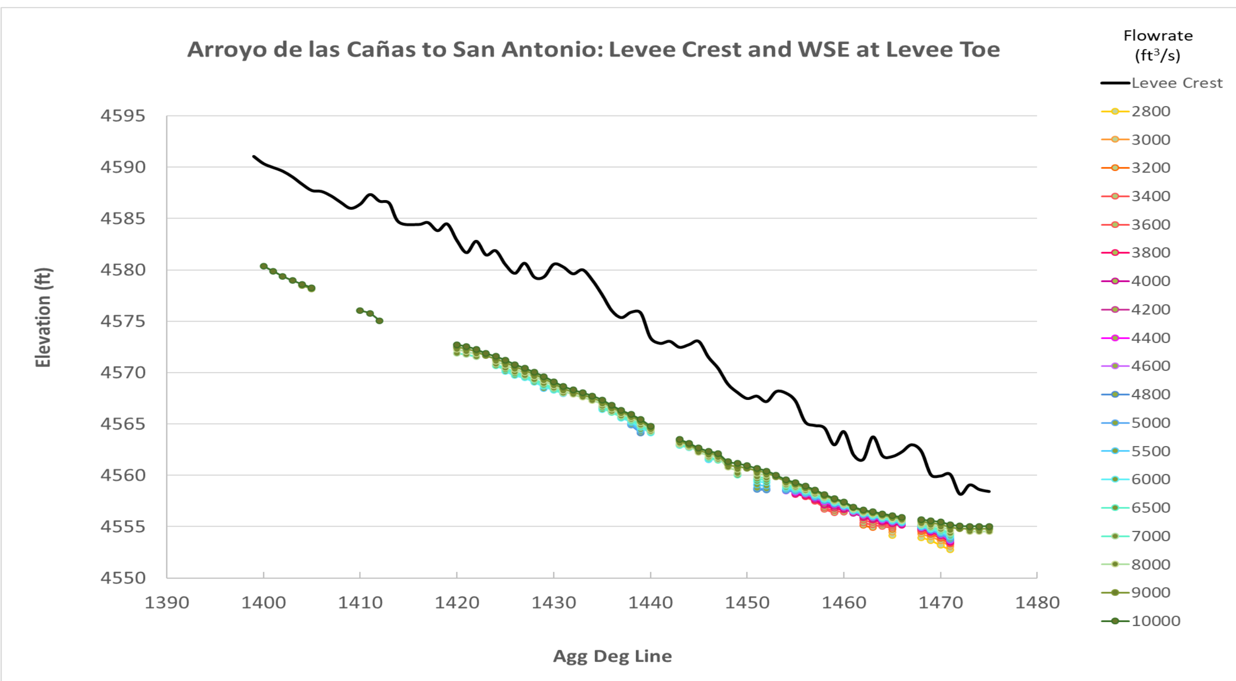


Figure 11.—Elevations of levee crests and water surface elevation at levee toes for Arroyo de las Cañas to San Antonio geomorphic reach for flows ranging from 1,000 ft^3/s–10,000 ft^3/s.

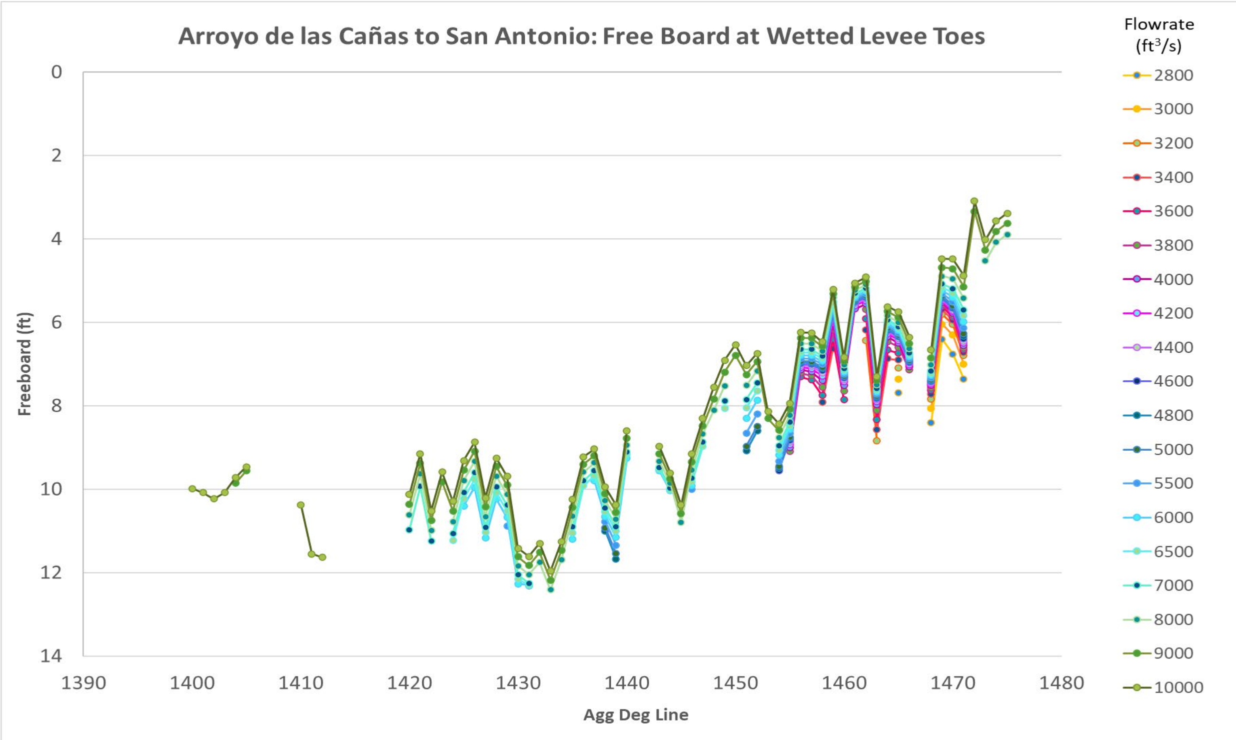


Figure 12.—Freeboard at inundated levee toes of Arroyo de las Cañas to San Antonio geomorphic reach for flows ranging from 1,000 ft^3/s–10,000 ft^3/s.

The Cochiti Dam to Angostura Diversion Dam reach shows a freeboard of less than 3 ft at the simulated flow rate of 10,000 ft^3/s for a single location. It occurs at Agg/Deg line 170, on river left near a secondary channel. A freeboard of less than 0.5 ft does not occur at any flowrate. There is a break in the levee within 100 feet of Agg/Deg line 170 that will keep flow from rising near the top of the levee height.

The Angostura Diversion Dam to Isleta Diversion Dam reach shows a freeboard of less than 3 ft at the simulated flow rate of 4,800 ft^3/s for a single location. At the maximum flowrate of 10,000 ft^3/s, there are 18 locations. These locations are mostly between Agg/Deg lines 636 and 651. The inundation begins due to the backwater effect of flow behind the road intersecting Agg/Deg line 638. The levee areas near the river left secondary channel are inundated next, and eventually the entire floodplain area between both levees is inundated which allows the flow to accumulate and rise in elevation. A freeboard of less than 0.5 ft does not occur at any flowrate.

The Isleta Diversion Dam to Rio Puerco Confluence reach shows a freeboard of less than 3 ft at the simulated flow rate of 4,600 ft^3/s for a single location. At the maximum flowrate of 10,000 ft^3/s, there are 81 locations. These locations are mostly between Agg/Deg lines 669 and 794, as well as between lines 959 and 989. These regions are bounded by levees on both sides, leading to increased elevations as flow accumulates. A freeboard of less than 0.5 ft occurs once at 9,000 ft^3/s and in 4 locations at 10,000 ft^3/s, located between Agg/Deg lines 677 and 682 where the floodplain width begins to constrict.

The Rio Puerco Confluence to San Acacia Diversion Dam reach shows a freeboard of less than 3 ft at the simulated flow rate of 5500 ft^3/s for 4 locations. At the maximum flowrate of 10,000 ft^3/s, there are 23 locations. These 23 locations fall between Agg/Deg line 1150 and 1177. This region is more constricted relative to its immediate upstream and downstream area. It is bounded by a high terrace on river right and a levee on river left, leading to an accumulation of flow. A freeboard of less than 0.5 ft does not occur at any flowrate.

The San Acacia Diversion Dam to Arroyo de las Cañas reach has a minimum freeboard of 6.4 ft at Agg/Deg line 1360. Therefore, there are no areas within this reach that have a freeboard below 3 ft or 0.5 ft.

The Arroyo de las Cañas to San Antonio reach has a minimum freeboard of 3.1 ft at Agg/Deg line 1472. Therefore, there are no areas within this reach that have a freeboard below 3 ft or 0.5 ft.

The San Antonio to RM 78 reach shows a freeboard of less than 3 ft at the simulated flow rate of 2,400 ft^3/s for 5 locations. At the maximum flowrate of 10,000 ft^3/s, there are 10 locations. A freeboard of less than 0.5 ft occurs at 5 locations for 2,400 ft^3/s and in 5 locations at 2,600 ft^3/s. These freeboards are reported as negative values, indicating the flow is above the height of the levee. These specific locations occur at the river left side levee near Agg/Deg line 1510. This area was the example given previously in the report where several gaps exist in the levee feature, causing the freeboard to indicate overtopping.

The RM 78 to RM 60 reach shows a freeboard of less than 3ft at the simulated flow rate of 8,000 ft^3/s for a single location at Agg/Deg line 1591. A freeboard of less than 0.5 ft did not occur at any flowrate. At some locations, the flow within the channel reached an elevation near the levee's crest elevation while the elevation of flow in the floodplain is much lower. One example of this is Agg/Deg line 1670, shown in figure 13.

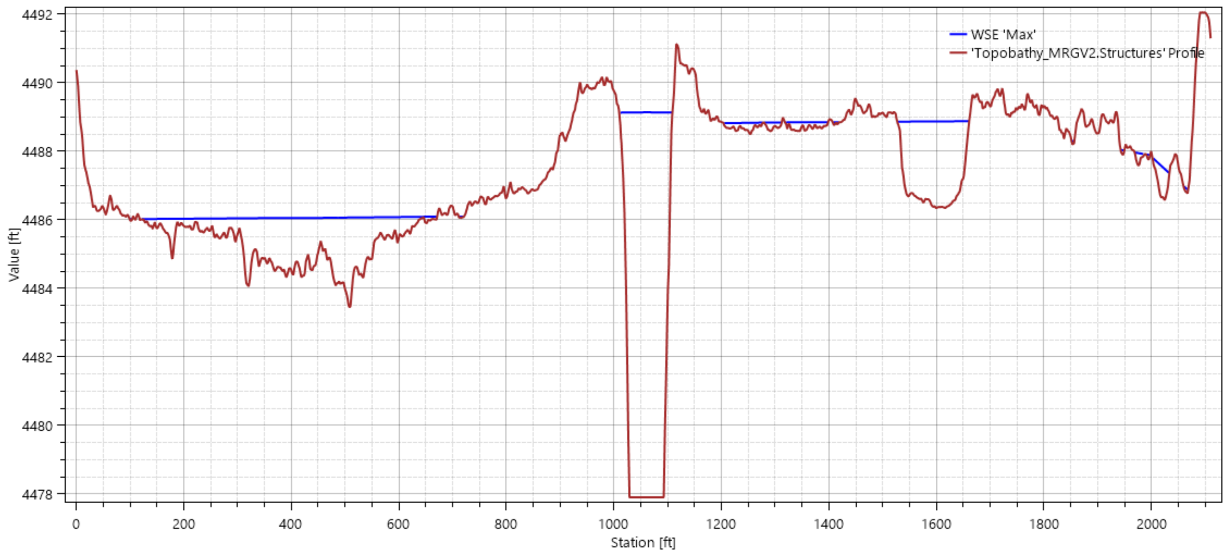


Figure 13.—The modeled water surface (blue line) of Agg/Deg line 1670 at 8,000 ft^3/s of flow, demonstrating over 3 ft of difference of the water surface elevation within the channel versus the floodplain.

The RM 60 to LFCC Confluence reach has a single instance of a wetted levee toe, which has a minimum freeboard of 9.1 ft at Agg/Deg line 1796. Therefore, there are no areas within this reach that have a freeboard below 3 ft or 0.5 ft.

For the LFCC Confluence to EB-63 geomorphic reach, there are no levees.

Figure 14 plots the first flowrate to create an occurrence of less than 3 ft of freeboard at an intersection of levee and Agg/Deg line, for each geomorphologic reach. Multiple reaches did not have any instances of freeboard below 3 ft and are left blank on the plot.

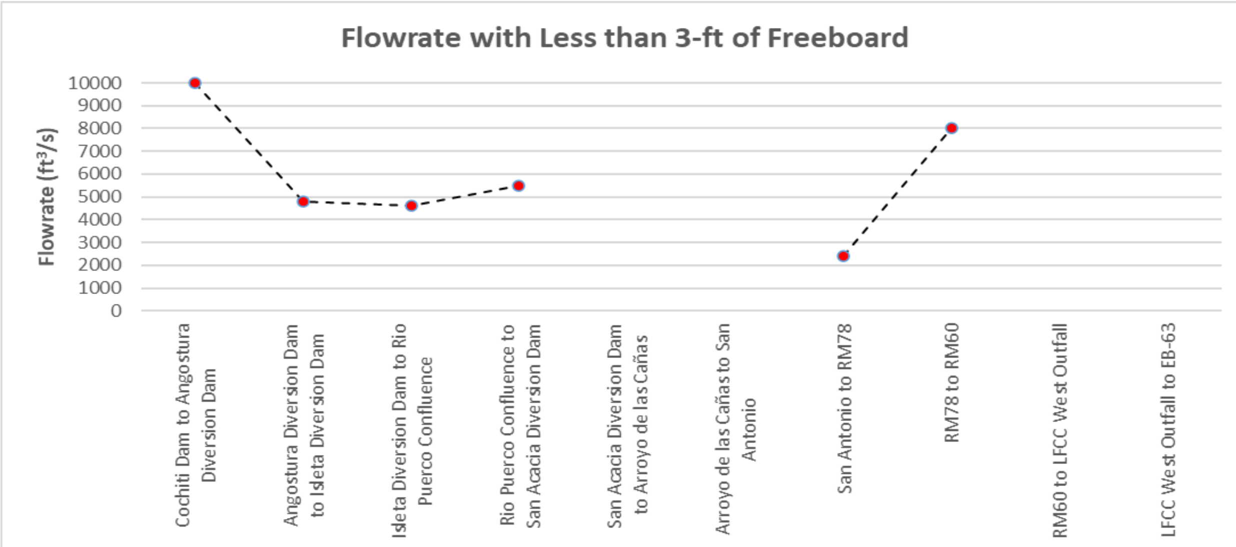


Figure 14.—The minimum flowrate to create less than 3 ft of levee freeboard at any intersection of Agg/Deg lines and Levees within each geomorphic reach for the Middle Rio Grande.

Summary

Four 2D hydrodynamic models were created to analyze overbanking flow and levee impacts for the 2022 Middle Rio Grande terrain. The surface was created from 2022 lidar with channel modifications based on 1D underwater mean-depth prism beds (Bernardino-McCloud 2024). The analysis determined the following characteristics by geomorphic reach: channel capacity, flow rate when levee toes become wetted by overbank flows, and flow rates when levees are at risk of overtopping and/or when freeboard requirements are violated.

Detailed graphs of each geomorphic reach can be found in the appendices. A summary of some useful metrics is presented in table 7 below.

Table 7.—Summary overbanking and levee metrics for each geomorphic reach in the study area

Reach Name	Channel Capacity (ft^3/s)	Levee Toe Wetting: First Flowrate to Wet 10% of Levee Toes (ft^3/s)	Levee Toe Wetting: Percent of Levee Toe Inundated at 10,000 ft^3/s	Top of Levee Assessment: Flowrate when 3-ft Freeboard is Violated (ft^3/s)	Top of Levee Assessment: Flowrate when 0.5-ft Freeboard is Violated (ft^3/s)
Cochiti Dam to Angostura Diversion Dam	5,000	Does not Occur	2%	10,000	Does not Occur
Angostura Diversion Dam to Isleta Diversion Dam	5,000	8,000	32%	4,800	Does not Occur
Isleta Diversion Dam to Rio Puerco Confluence	5,000	6,000	53%	4,600	9,000
Rio Puerco Confluence to San Acacia Diversion Dam	4,600	5,500	34%	5,500	Does not Occur
San Acacia Diversion Dam to Arroyo de las Cañas	4,000	10,000	13%	Does not Occur	Does not Occur
Arroyo de las Cañas to San Antonio	3,800	3,200	80%	Does not Occur	Does not Occur
San Antonio to RM 78	2,000	2,600	91%	2,400	2,400
RM 78 to RM 60	5,500	2,800	46%	8,000	Does not Occur
RM 60 to LFCC West Outfall	6,500	9,000	10%	Does not Occur	Does not Occur
LFCC West Outfall to EB-63	2,400	N/A (no levees)		N/A (no levees)	

References

U.S. Army Corps of Engineers (USACE). 2024. HEC-RAS User's Manual, version 6.5.1. Hydrologic Engineering Center, Davis, California.

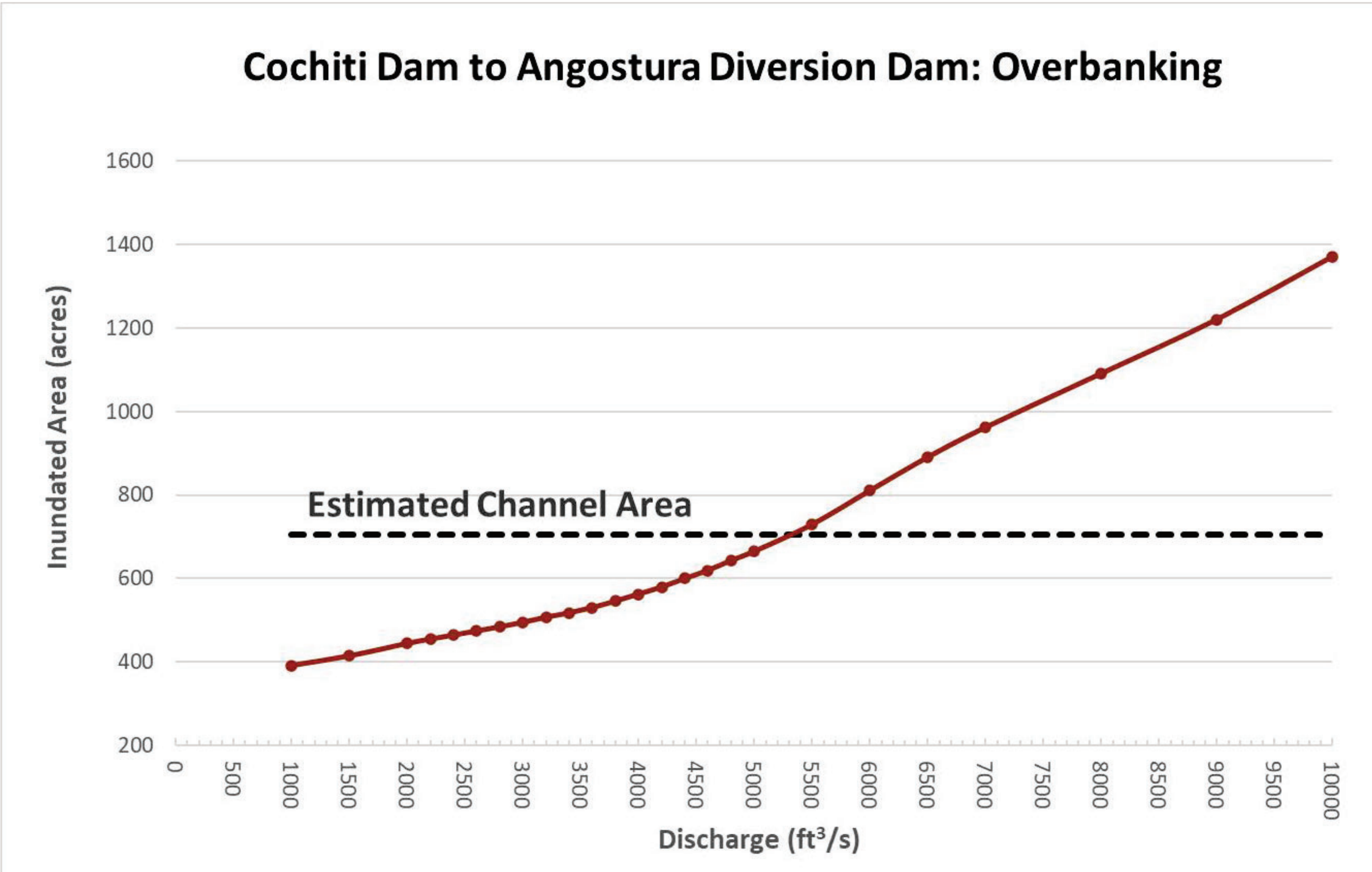
Bernardino–McCloud, R. 2024. 2022 Geometry Generation and Validation. Technical Report, Bureau of Reclamation, Technical Service Center, Denver, Colorado.

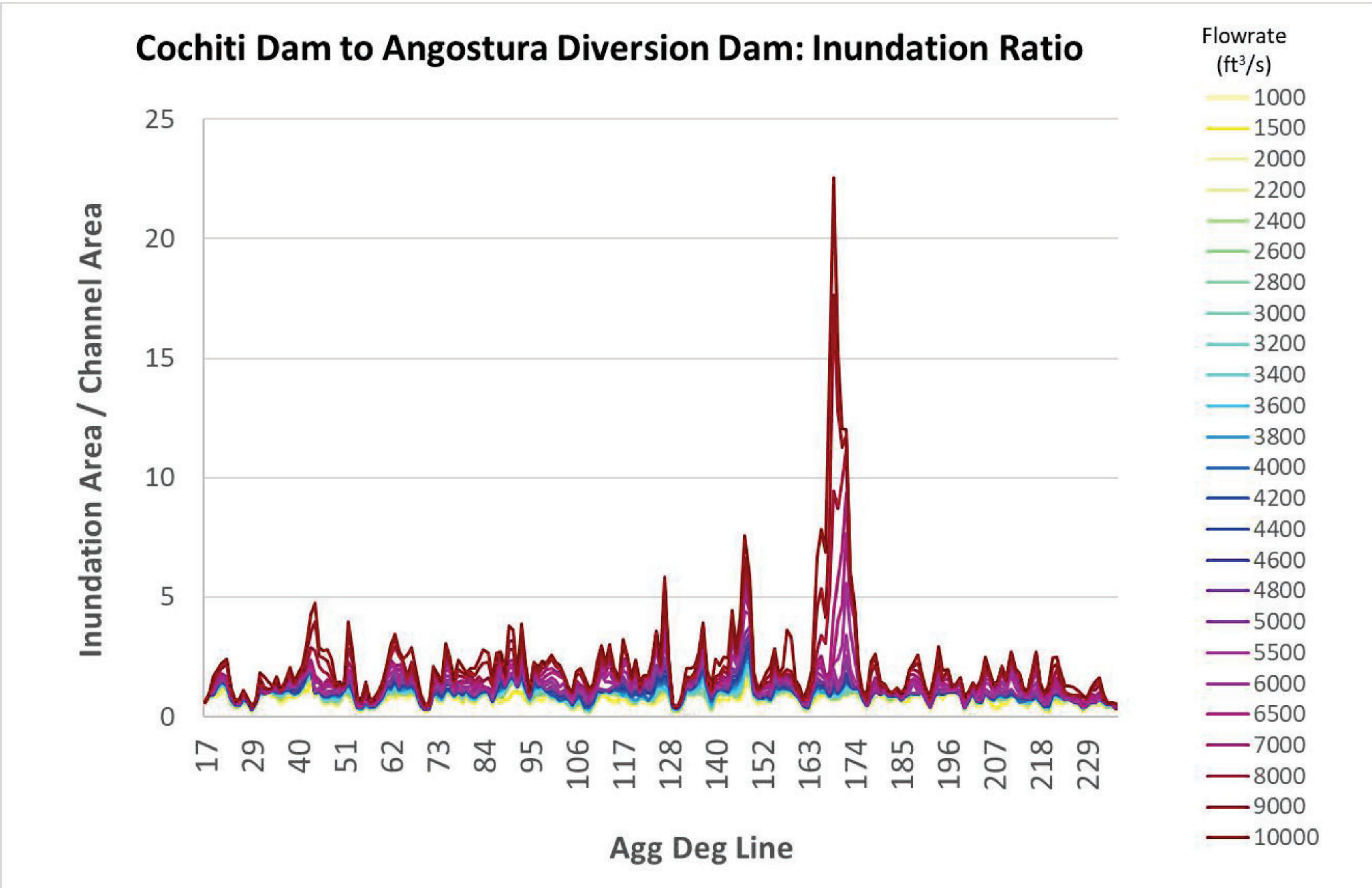
Varyu, D. 2013. Aggradation/Degradation Volume Calculations: 2012–2022, Technical Report No. SRH- 2013-22. Bureau of Reclamation, Technical Service Center, Denver, Colorado.

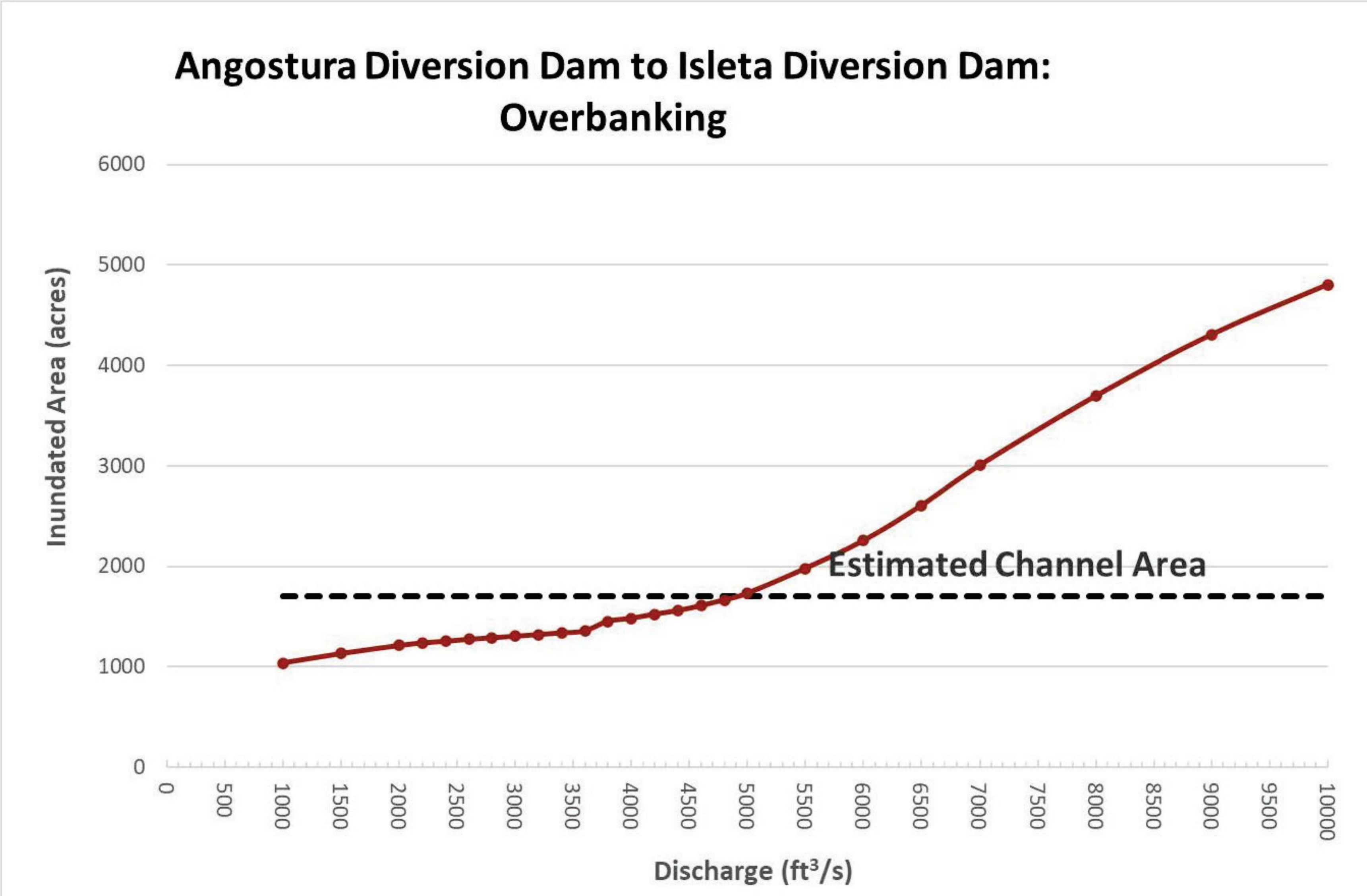
Woolpert Inc. 2022. Lidar Mapping Report Middle Rio Grande Project 2022. Middle Rio Grande Project, New Mexico, Woolpert Task Order No. 140R4021F0026.

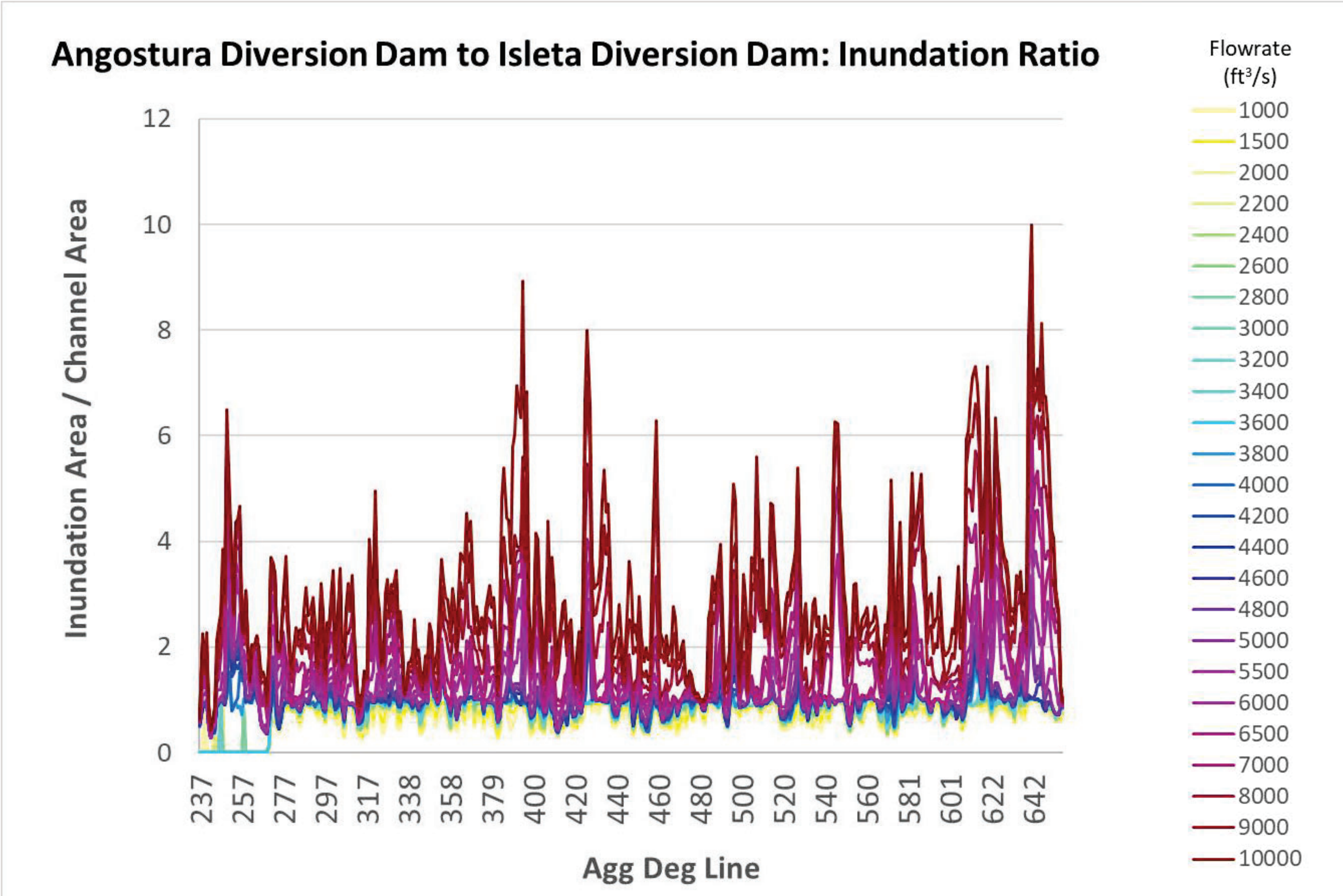
Appendix A

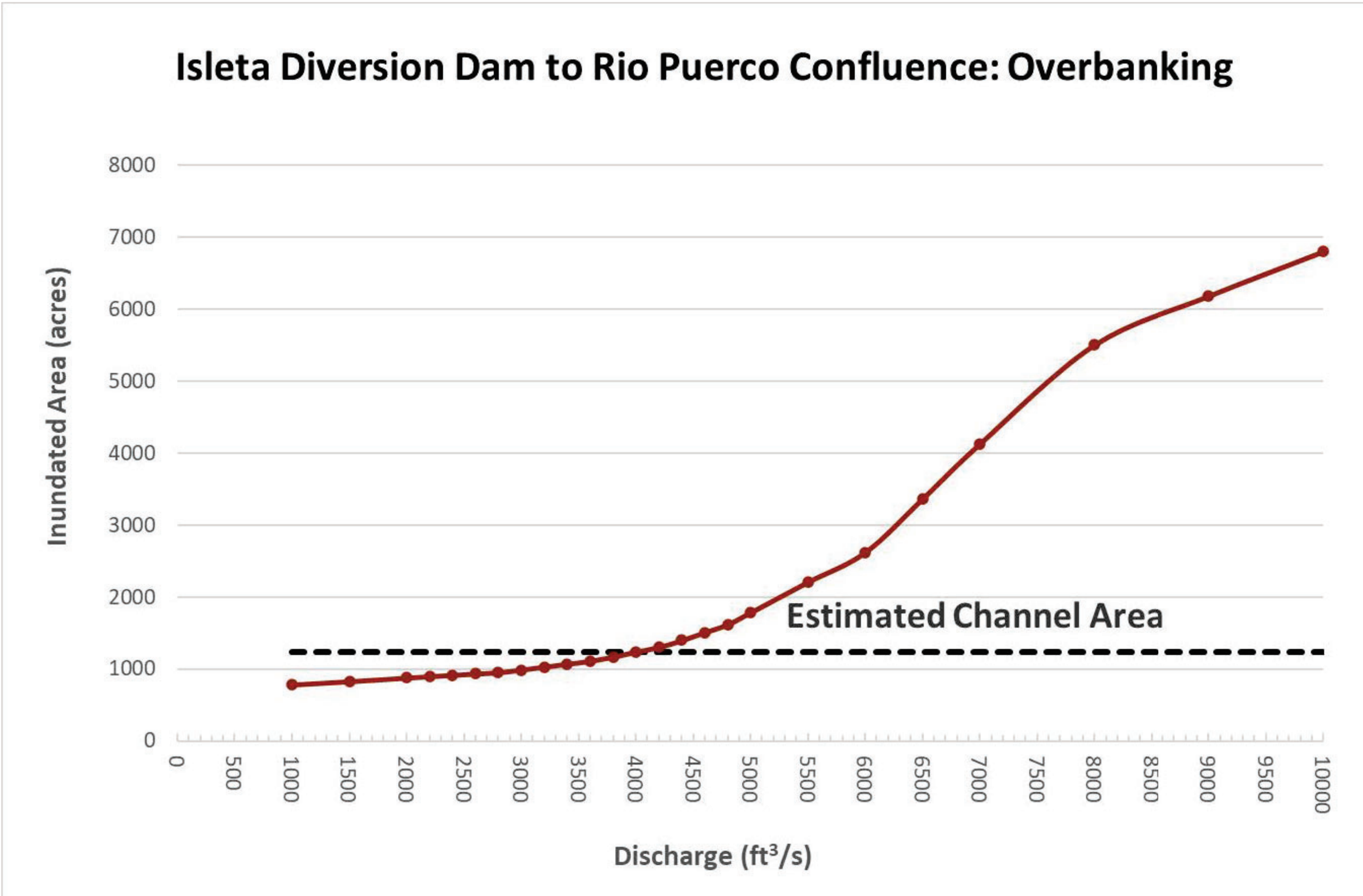
Overbanking Figures

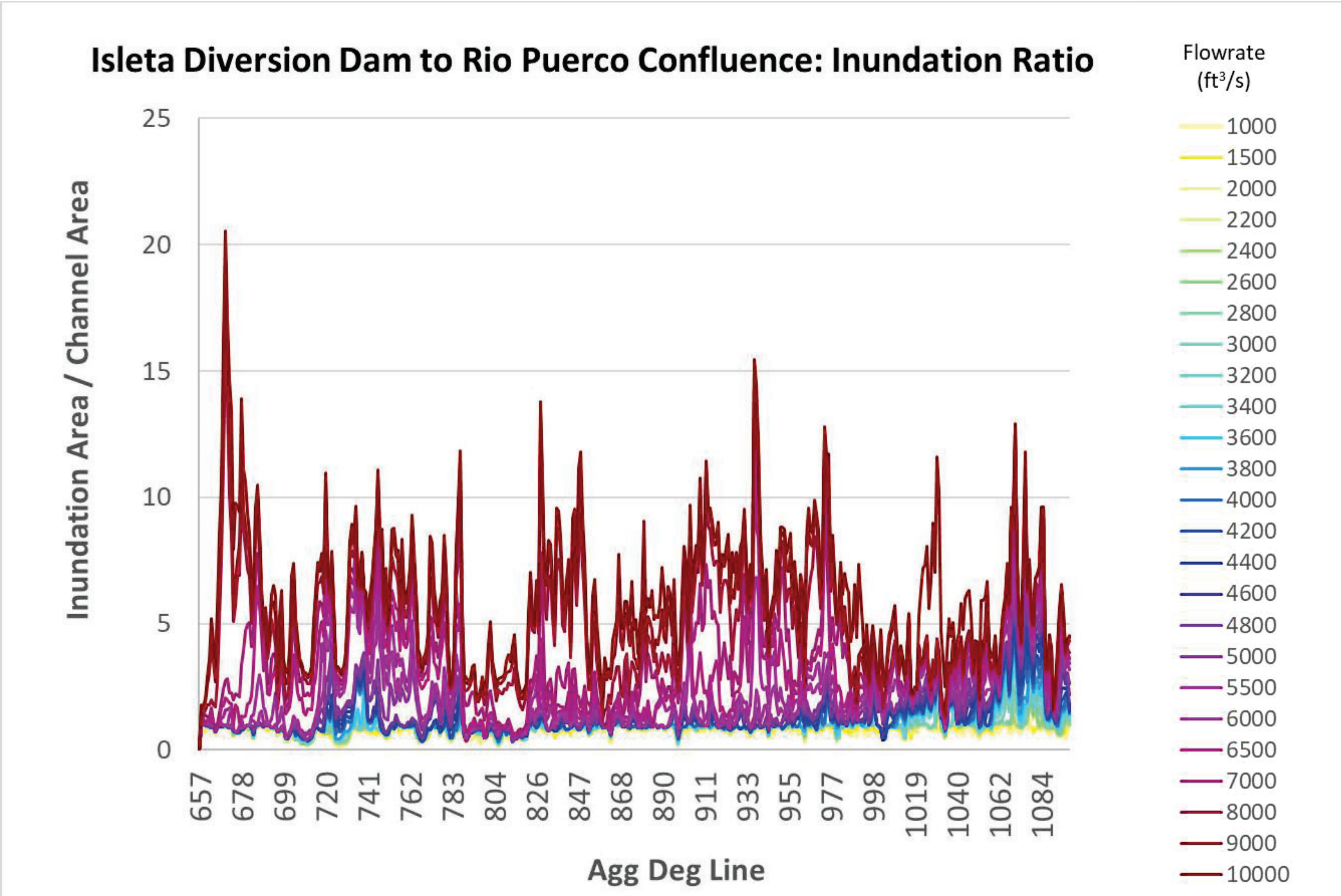

Cochiti Dam to Angostura Diversion Dam: Overbanking
Inundated Area (acres)
1600
1400
1200
1000
800
600
400
200
Estimated Channel Area
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000
9500
10000
Discharge (ft³/s)


Cochiti Dam to Angostura Diversion Dam: Inundation Ratio
Inundation Area / Channel Area
25
20
15
10
5
0
17
29
40
51
62
73
84
95
106
117
128
140
152
163
174
185
196
207
218
229
Agg Deg Line
Flowrate (ft³/s)
1000
1500
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000

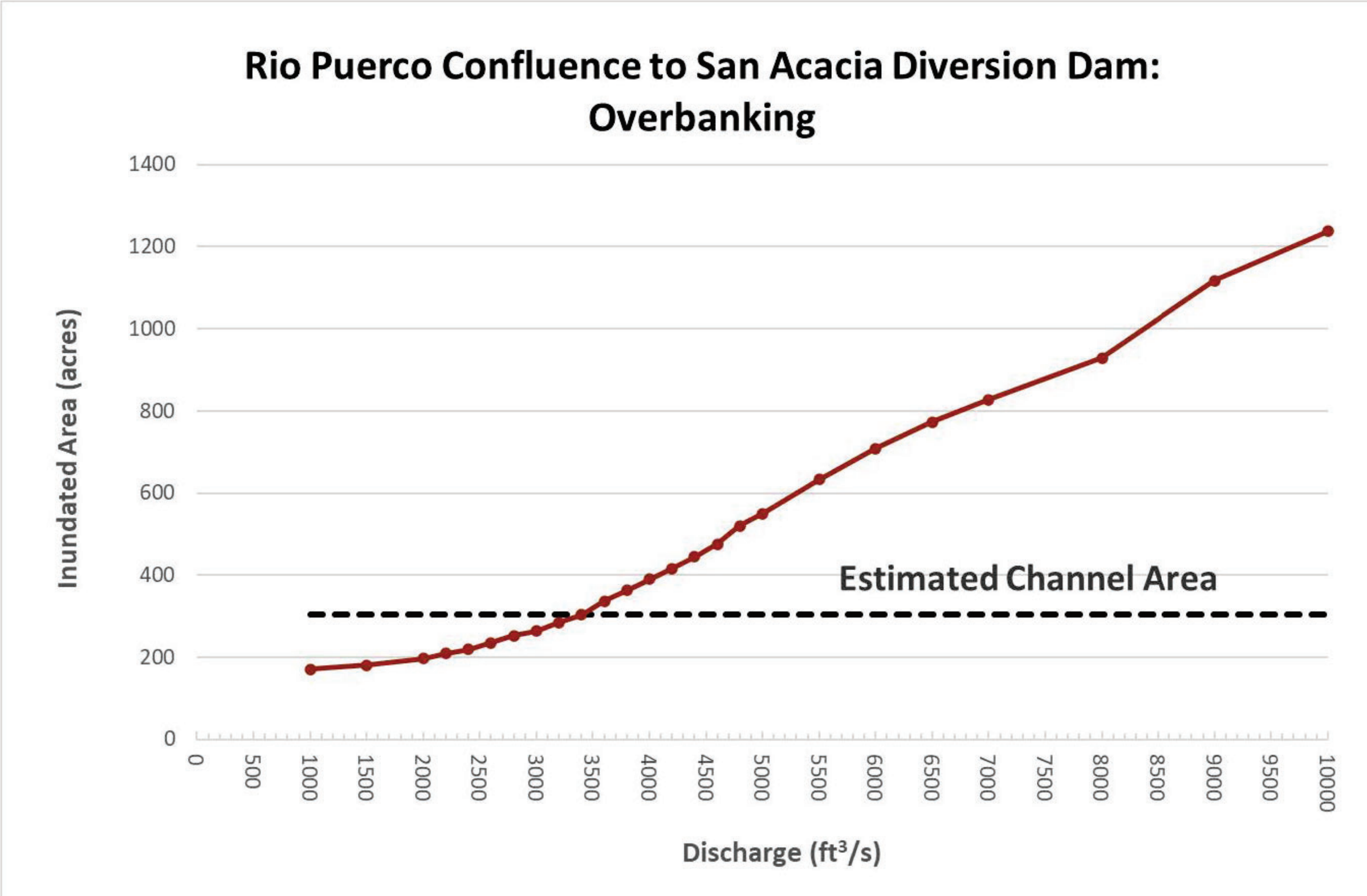

Angostura Diversion Dam to Isleta Diversion Dam:
Overbanking
Inundated Area (acres)
6000
5000
4000
3000
2000
1000
0
Estimated Channel Area
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000
9500
10000
Discharge (ft³/s)


Angostura Diversion Dam to Isleta Diversion Dam: Inundation Ratio
Inundation Area / Channel Area
Agg Deg Line
0
2
4
6
8
10
12
237
257
277
297
317
338
358
379
400
420
440
460
480
500
520
540
560
581
601
622
642
Flowrate (ft³/s)
1000
1500
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000

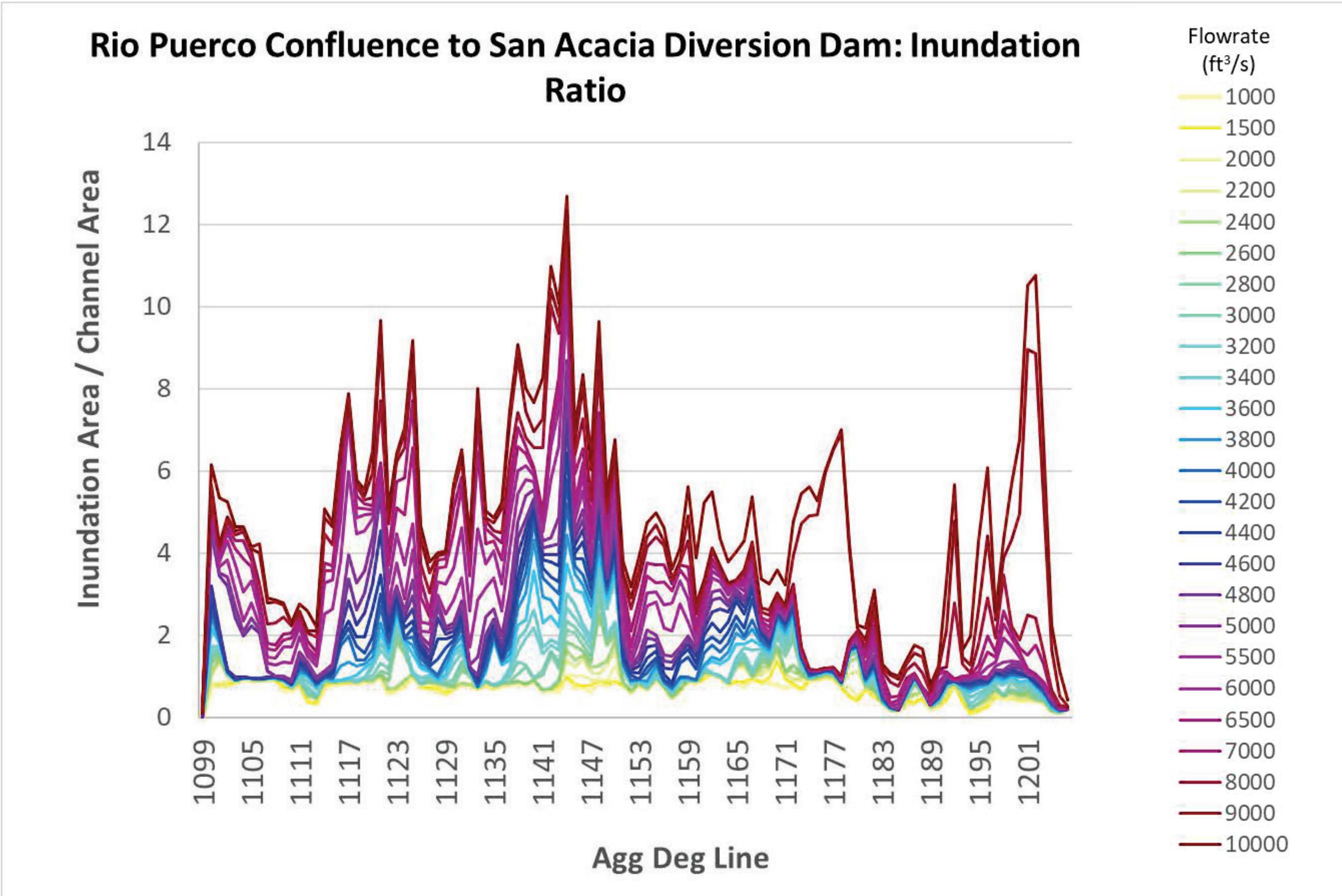

Isleta Diversion Dam to Rio Puerco Confluence: Overbanking
Inundated Area (acres)
8000
7000
6000
5000
4000
3000
2000
1000
0
Estimated Channel Area
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000
9500
10000
Discharge (ft³/s)

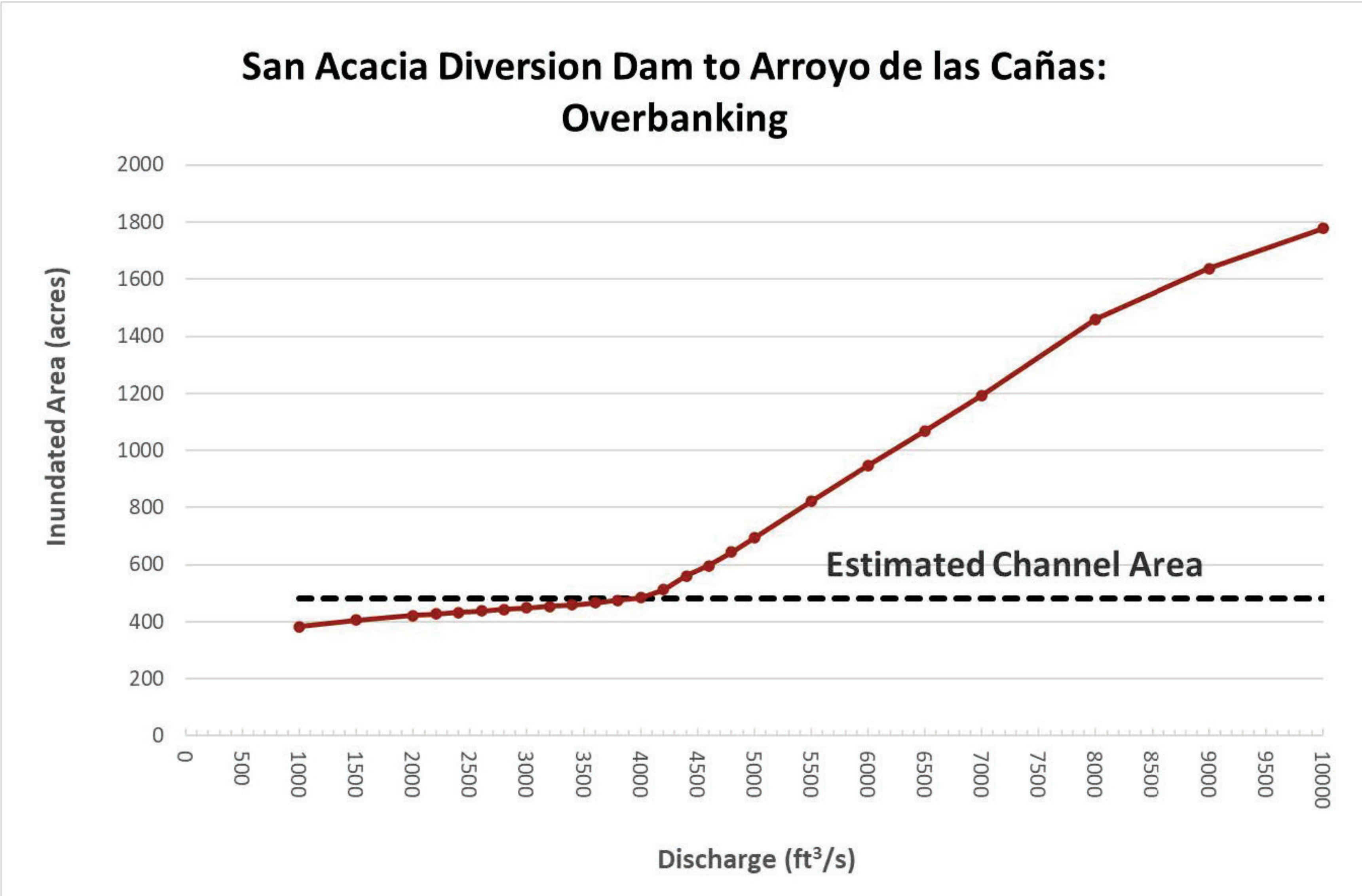


Isleta Diversion Dam to Rio Puerco Confluence: Inundation Ratio
Inundation Area / Channel Area
25
20
15
10
5
0
657
678
699
720
741
762
783
804
826
847
868
890
911
933
955
977
998
1019
1040
1062
1084
Agg Deg Line
Flowrate (ft³/s)
1000
1500
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000

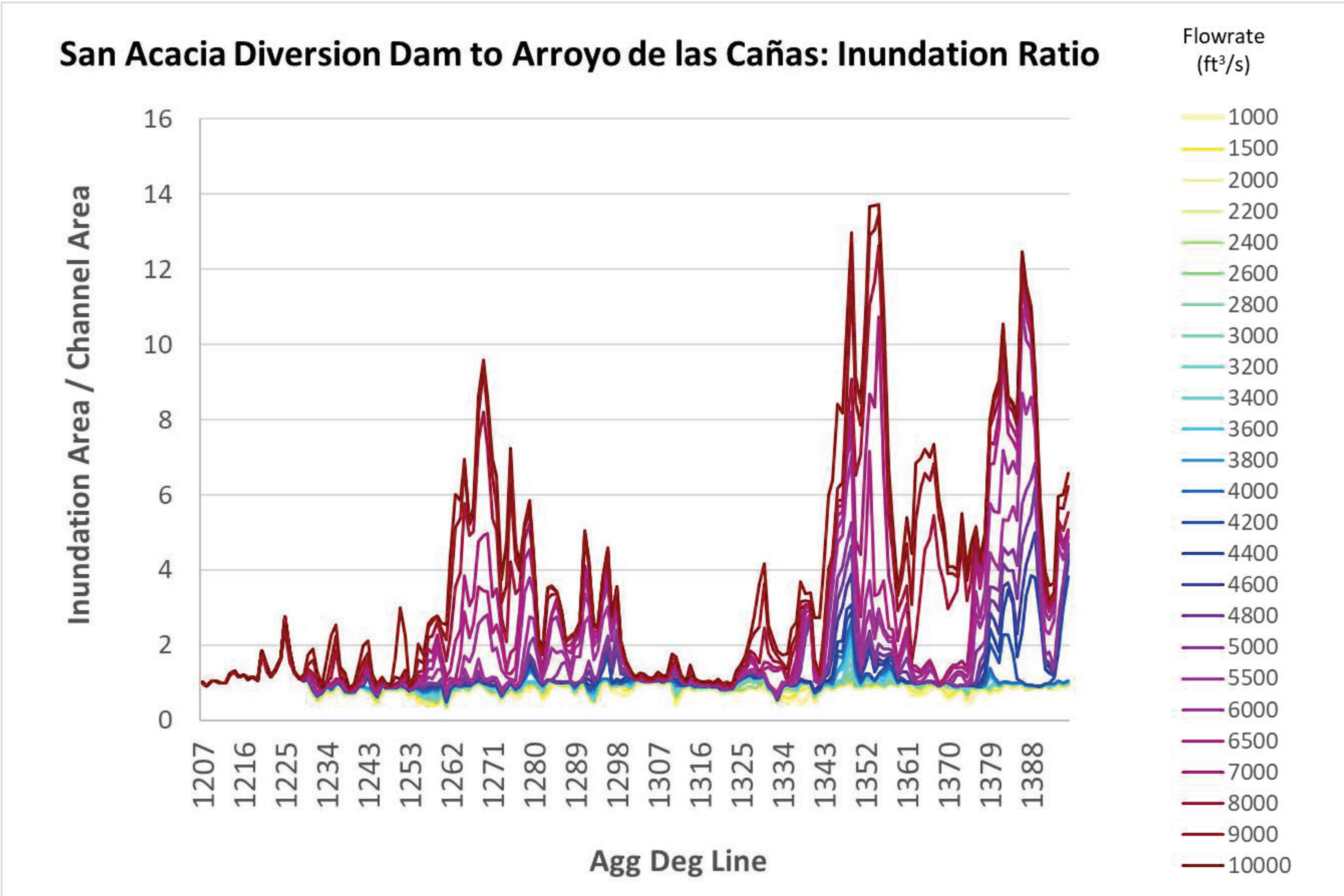


Rio Puerco Confluence to San Acacia Diversion Dam:
Overbanking
Inundated Area (acres)
1400
1200
1000
800
600
400
200
0
Estimated Channel Area
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000
9500
10000
Discharge (ft³/s)

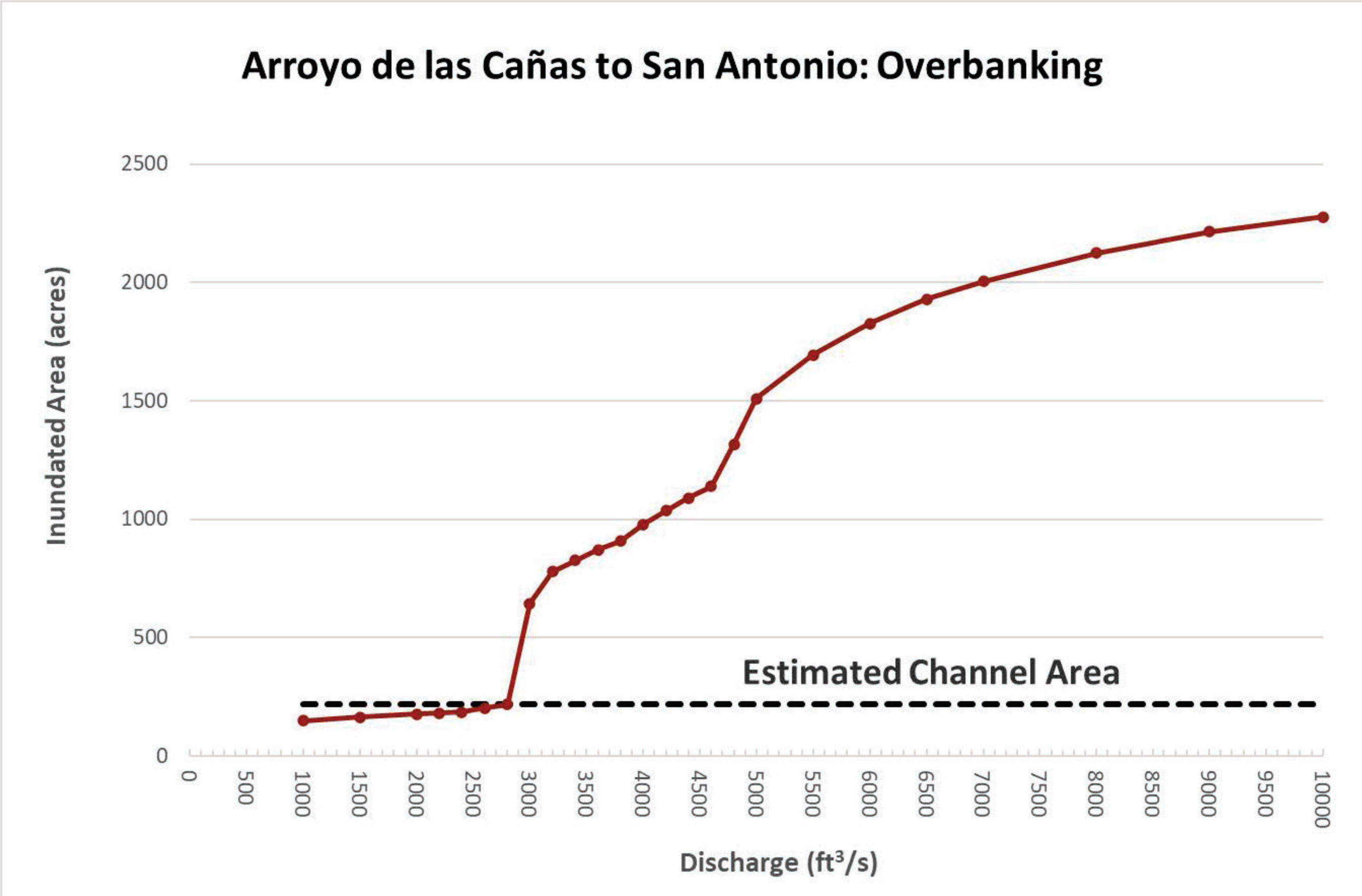

Rio Puerco Confluence to San Acacia Diversion Dam: Inundation Ratio
Inundation Area / Channel Area
0
2
4
6
8
10
12
14
1099
1105
1111
1117
1123
1129
1135
1141
1147
1153
1159
1165
1171
1177
1183
1189
1195
1201
Agg Deg Line
Flowrate (ft³/s)
1000
1500
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000



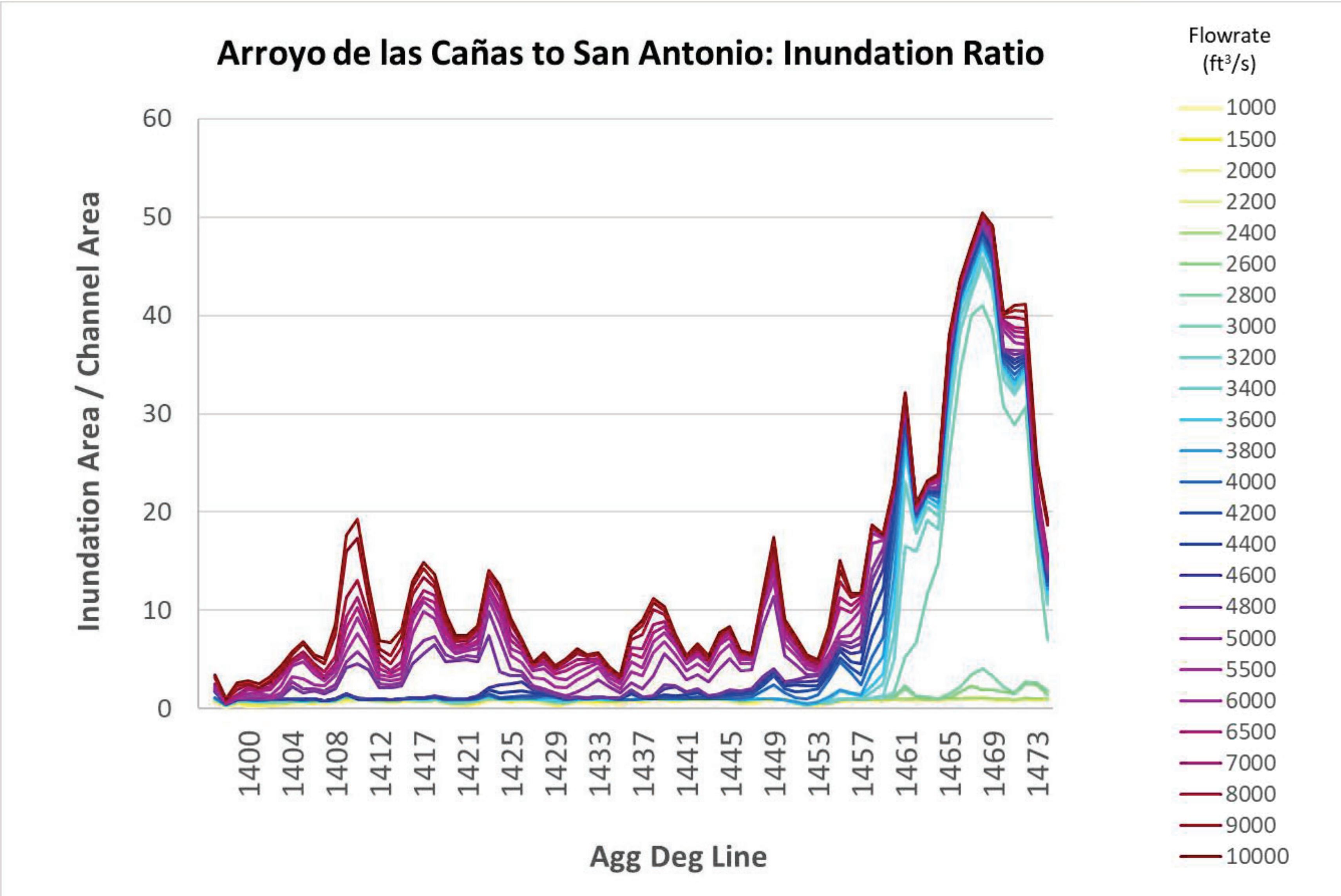
San Acacia Diversion Dam to Arroyo de las Cañas: Overbanking
Inundated Area (acres)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Estimated Channel Area
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000
9500
10000
Discharge (ft³/s)



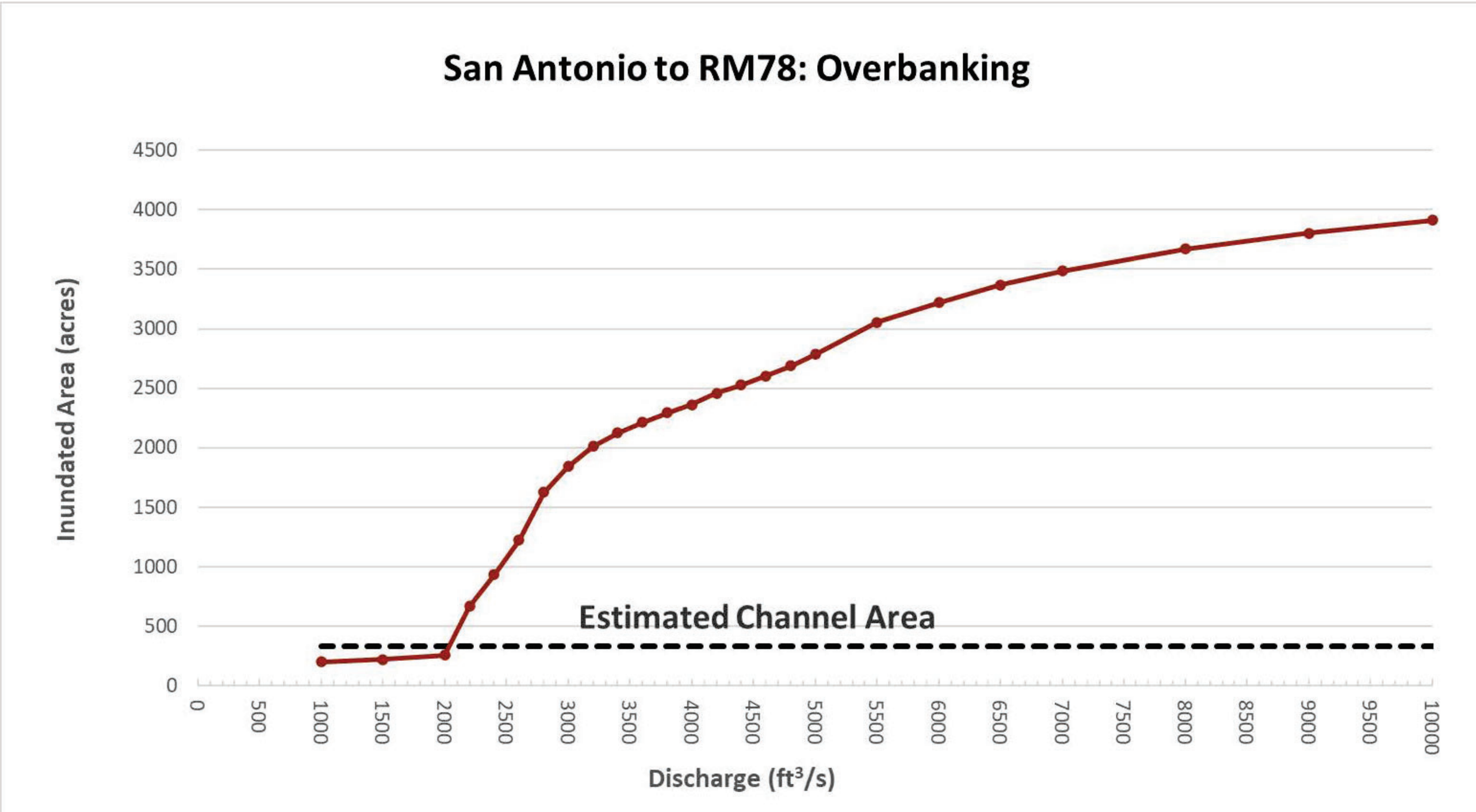
San Acacia Diversion Dam to Arroyo de las Cañas: Inundation Ratio
Flowrate (ft³/s)
1000
1500
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000
Inundation Area / Channel Area
0
2
4
6
8
10
12
14
16
Agg Deg Line
1207
1216
1225
1234
1243
1253
1262
1271
1280
1289
1298
1307
1316
1325
1334
1343
1352
1361
1370
1379
1388

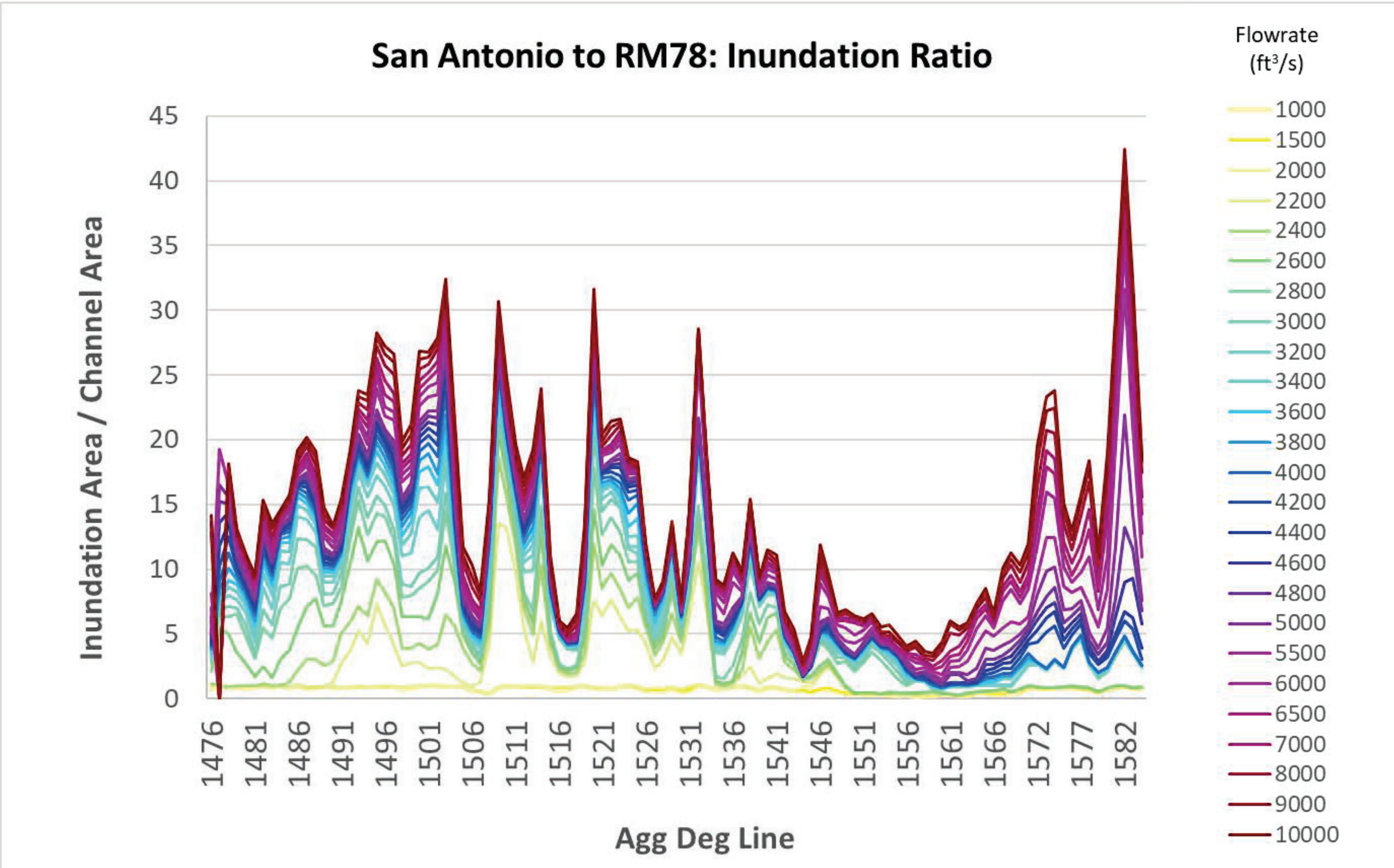


Arroyo de las Cañas to San Antonio: Overbanking
2500
2000
1500
1000
500
0
Inundated Area (acres)
Estimated Channel Area
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000
9500
10000
Discharge (ft³/s)

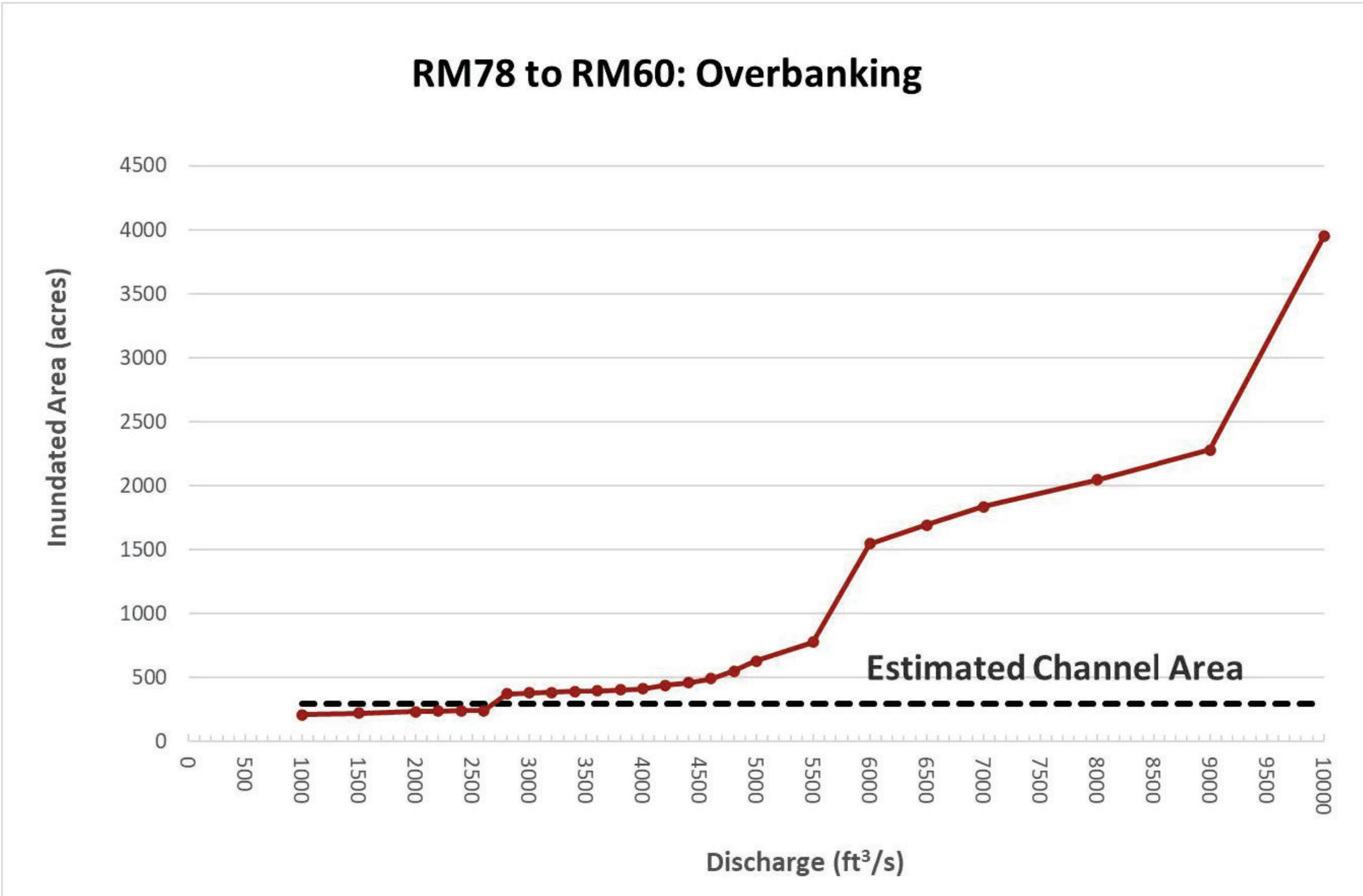


Arroyo de las Cañas to San Antonio: Inundation Ratio
Inundation Area / Channel Area
60
50
40
30
20
10
0
1400
1404
1408
1412
1417
1421
1425
1429
1433
1437
1441
1445
1449
1453
1457
1461
1465
1469
1473
Agg Deg Line
Flowrate (ft³/s)
1000
1500
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000

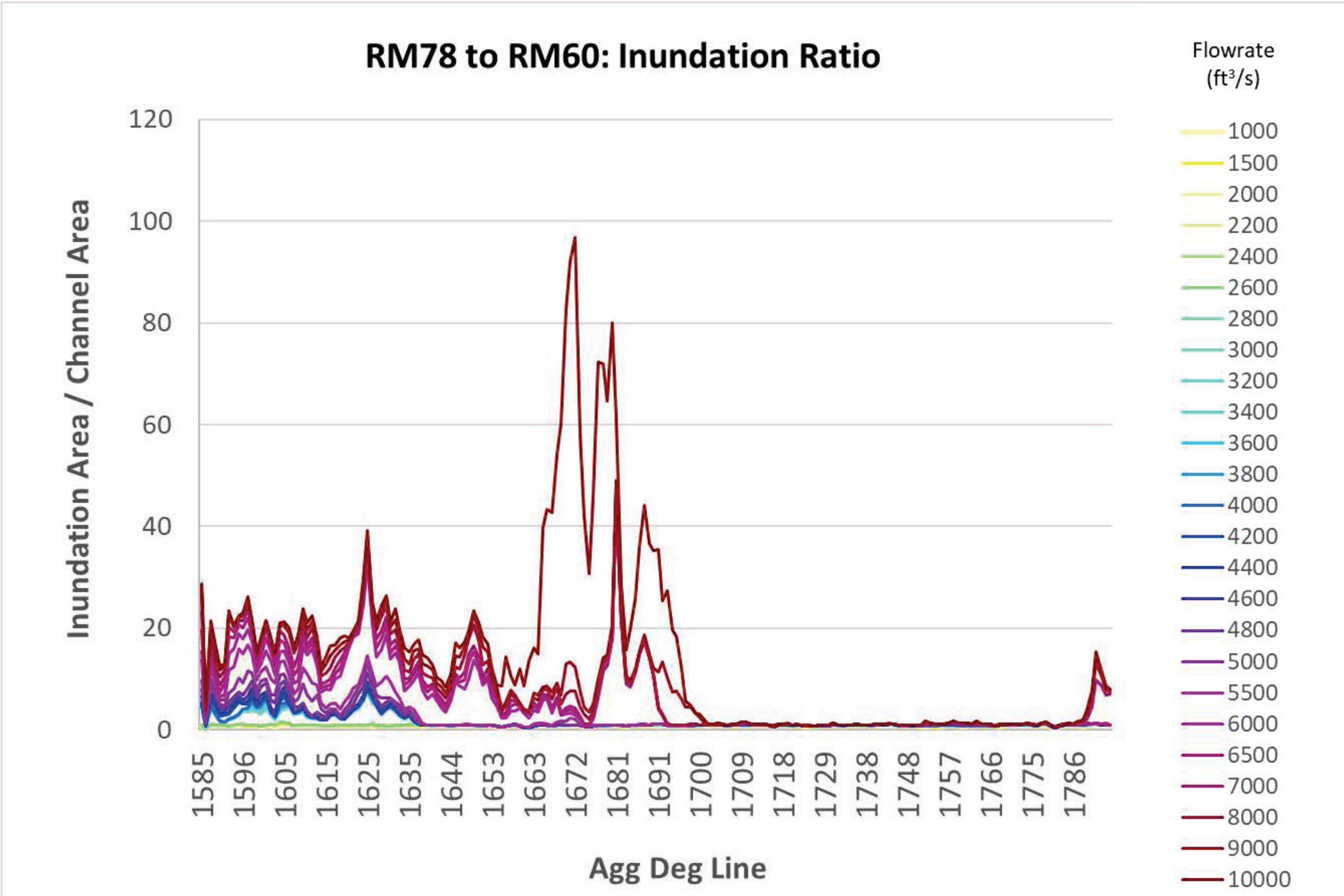

San Antonio to RM78: Overbanking
Inundated Area (acres)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Estimated Channel Area
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000
9500
10000
Discharge (ft³/s)



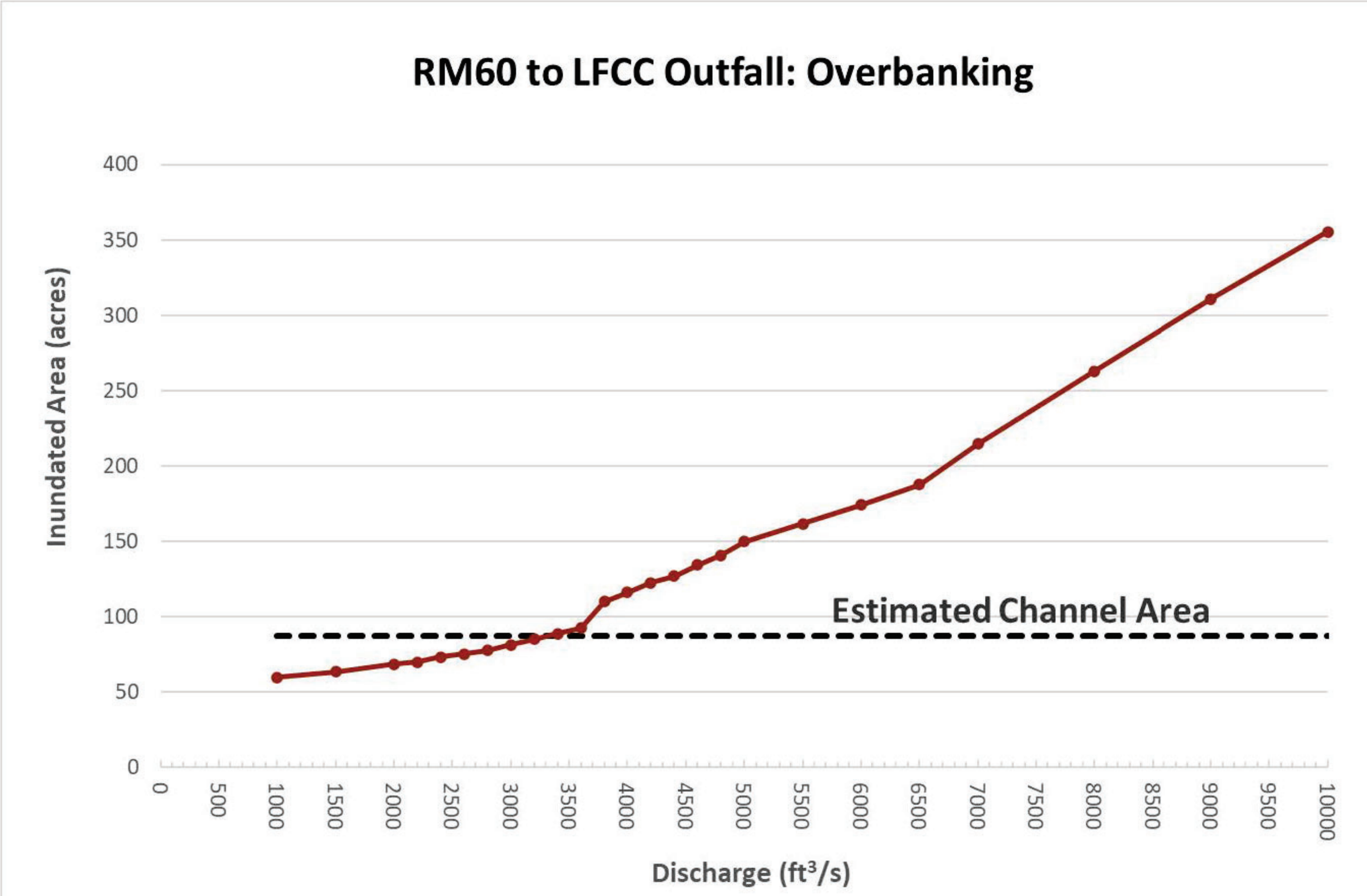
San Antonio to RM78: Inundation Ratio
Flowrate (ft³/s)
Inundation Area / Channel Area
Agg Deg Line
45
40
35
30
25
20
15
10
5
0
1476
1481
1486
1491
1496
1501
1506
1511
1516
1521
1526
1531
1536
1541
1546
1551
1556
1561
1566
1572
1577
1582
1000
1500
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000



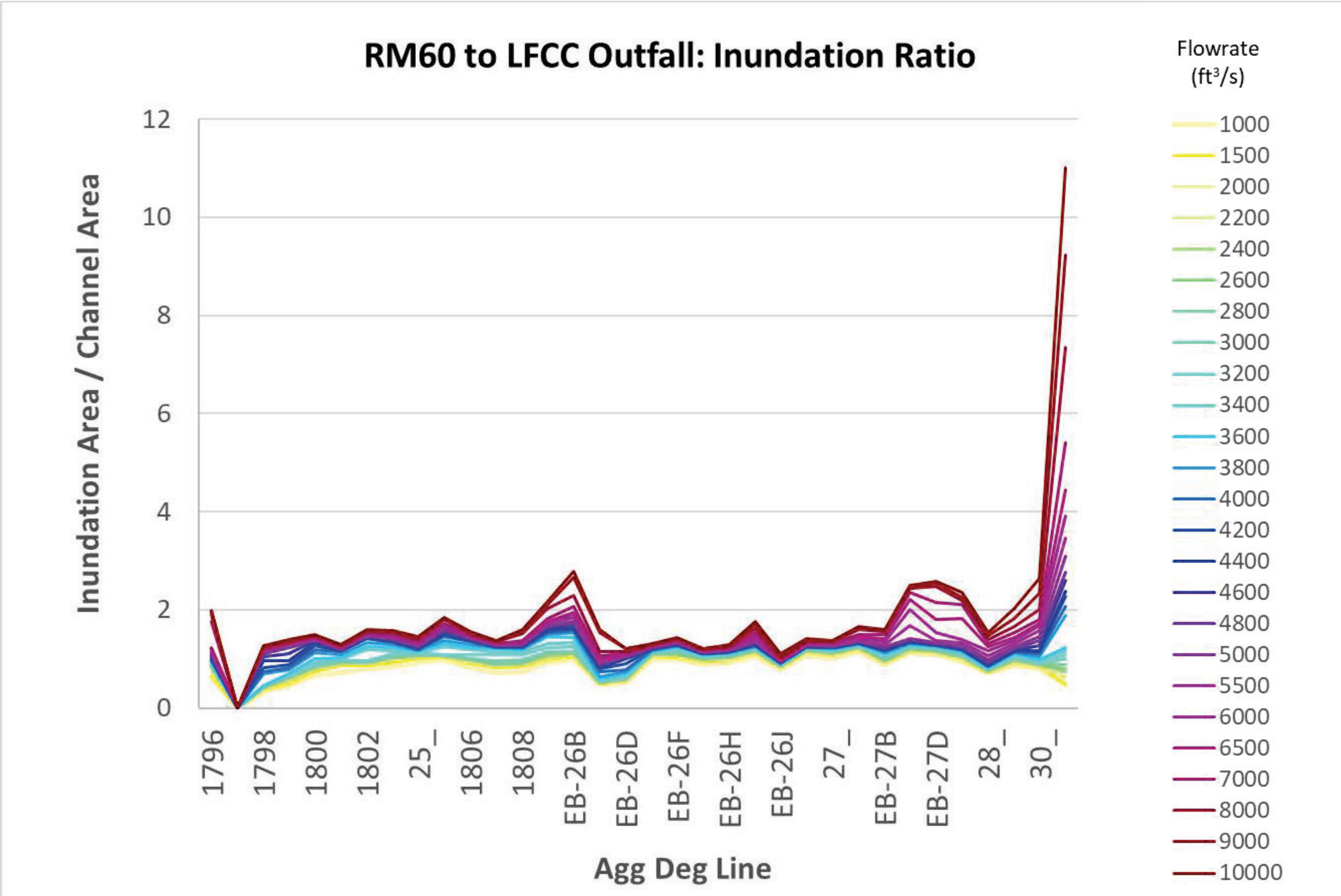
RM78 to RM60: Overbanking
Inundated Area (acres)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Estimated Channel Area
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000
9500
10000
Discharge (ft³/s)

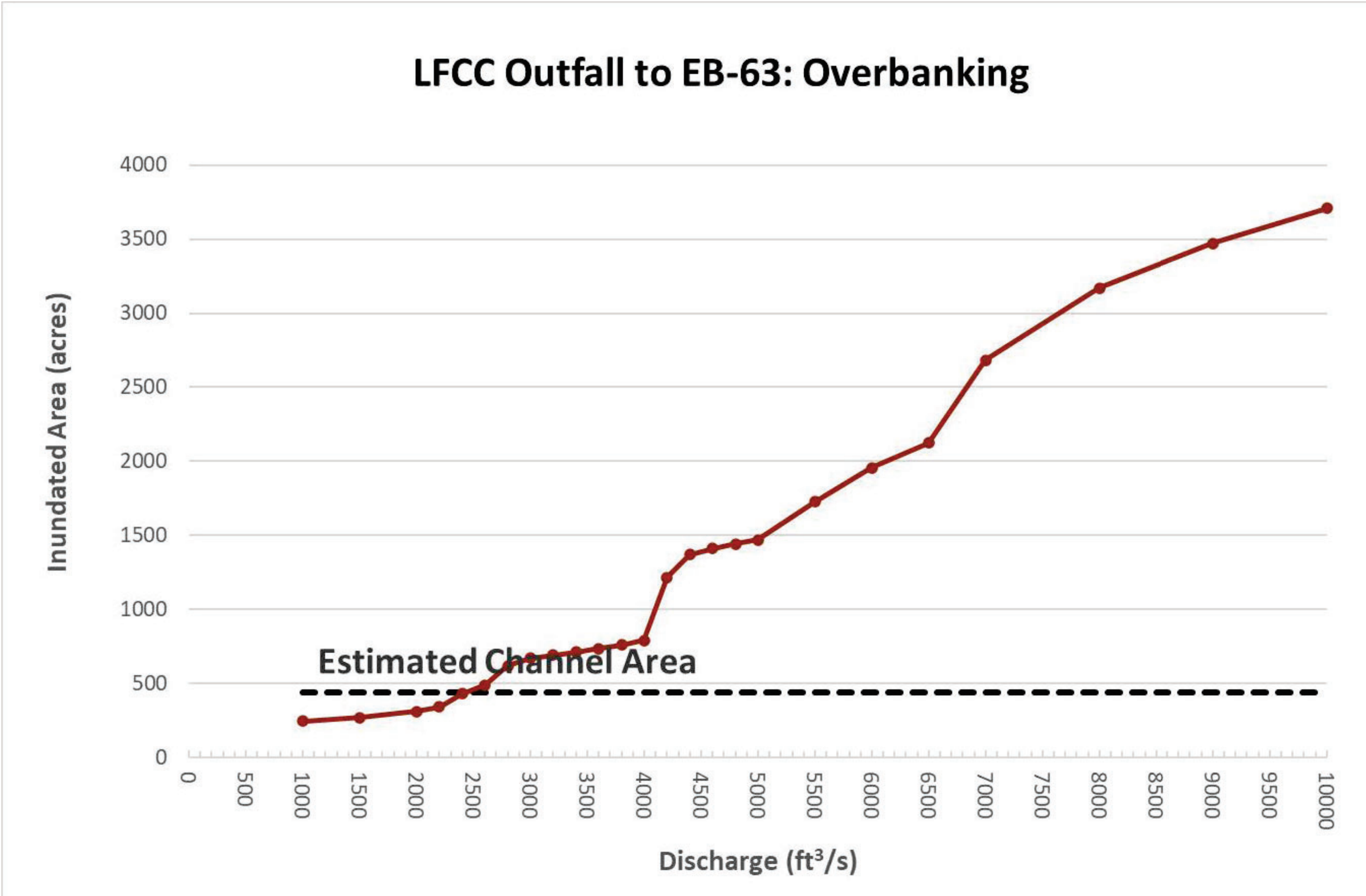


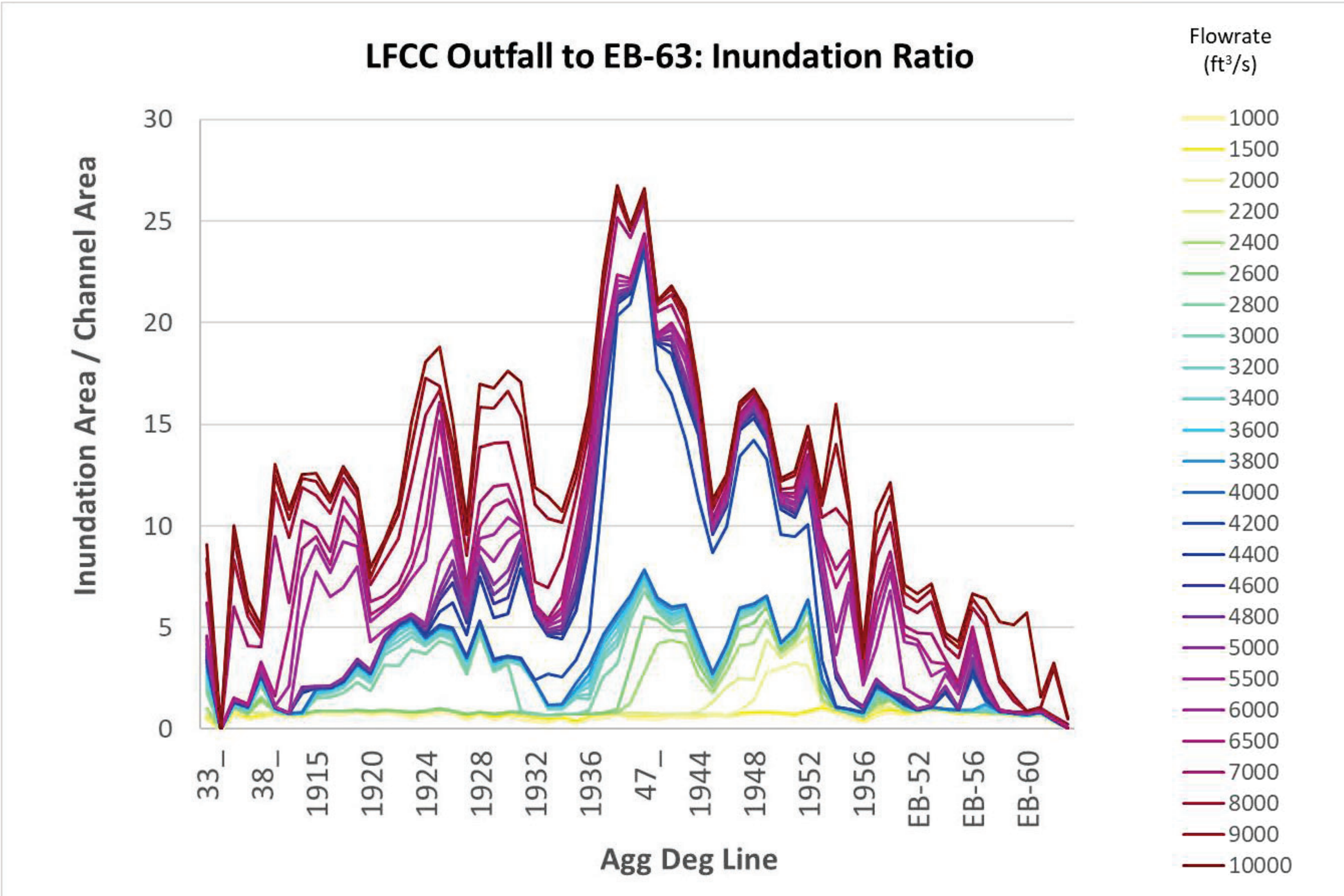
RM78 to RM60: Inundation Ratio
Inundation Area / Channel Area
120
100
80
60
40
20
0
1585
1596
1605
1615
1625
1635
1644
1653
1663
1672
1681
1691
1700
1709
1718
1729
1738
1748
1757
1766
1775
1786
Agg Deg Line
Flowrate (ft³/s)
1000
1500
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000



RM60 to LFCC Outfall: Overbanking
Inundated Area (acres)
400
350
300
250
200
150
100
50
0
Estimated Channel Area
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000
9500
10000
Discharge (ft³/s)

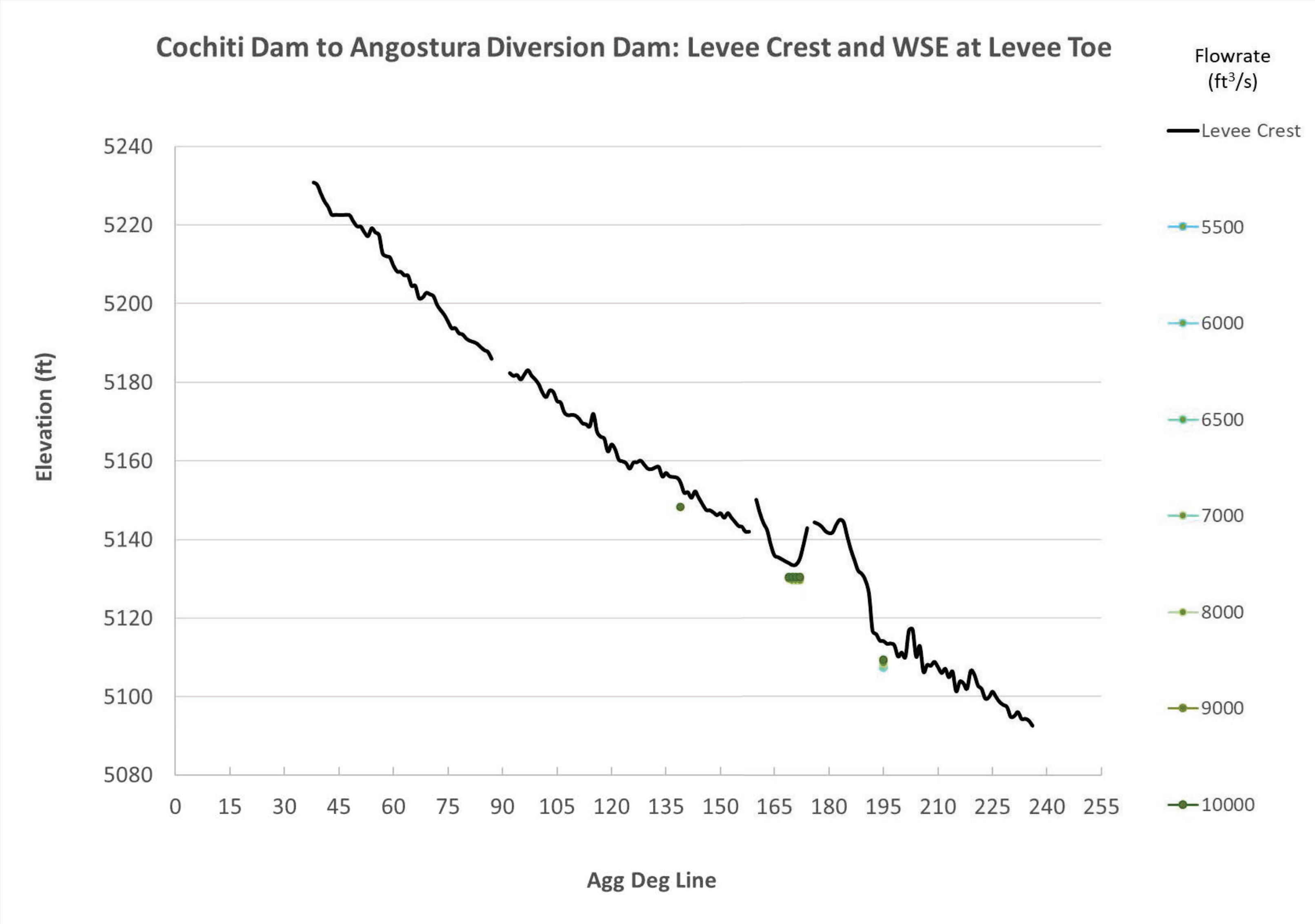

RM60 to LFCC Outfall: Inundation Ratio
Inundation Area / Channel Area
0
2
4
6
8
10
12
1796
1798
1800
1802
25_
1806
1808
EB-26B
EB-26D
EB-26F
EB-26H
EB-26J
27_
EB-27B
EB-27D
28_
30_
Agg Deg Line
Flowrate (ft³/s)
1000
1500
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000


LFCC Outfall to EB-63: Overbanking
Inundated Area (acres)
4000
3500
3000
2500
2000
1500
1000
500
0
Estimated Channel Area
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
8500
9000
9500
10000
Discharge (ft³/s)

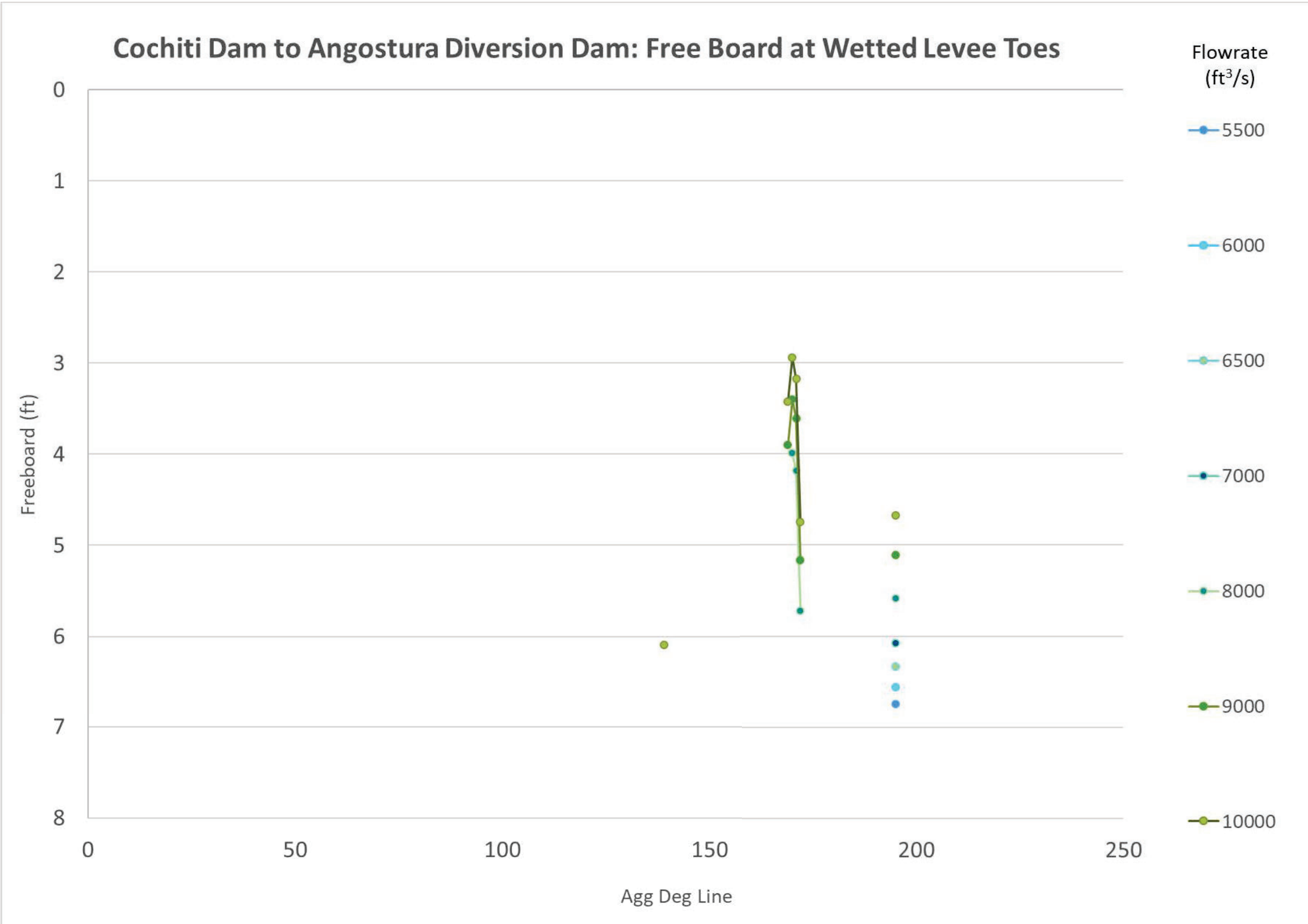

LFCC Outfall to EB-63: Inundation Ratio
Flowrate (ft³/s)
1000
1500
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000
Inundation Area / Channel Area
0
5
10
15
20
25
30
33_
38_
1915
1920
1924
1928
1932
1936
47_
1944
1948
1952
1956
EB-52
EB-56
EB-60
Agg Deg Line

Appendix B

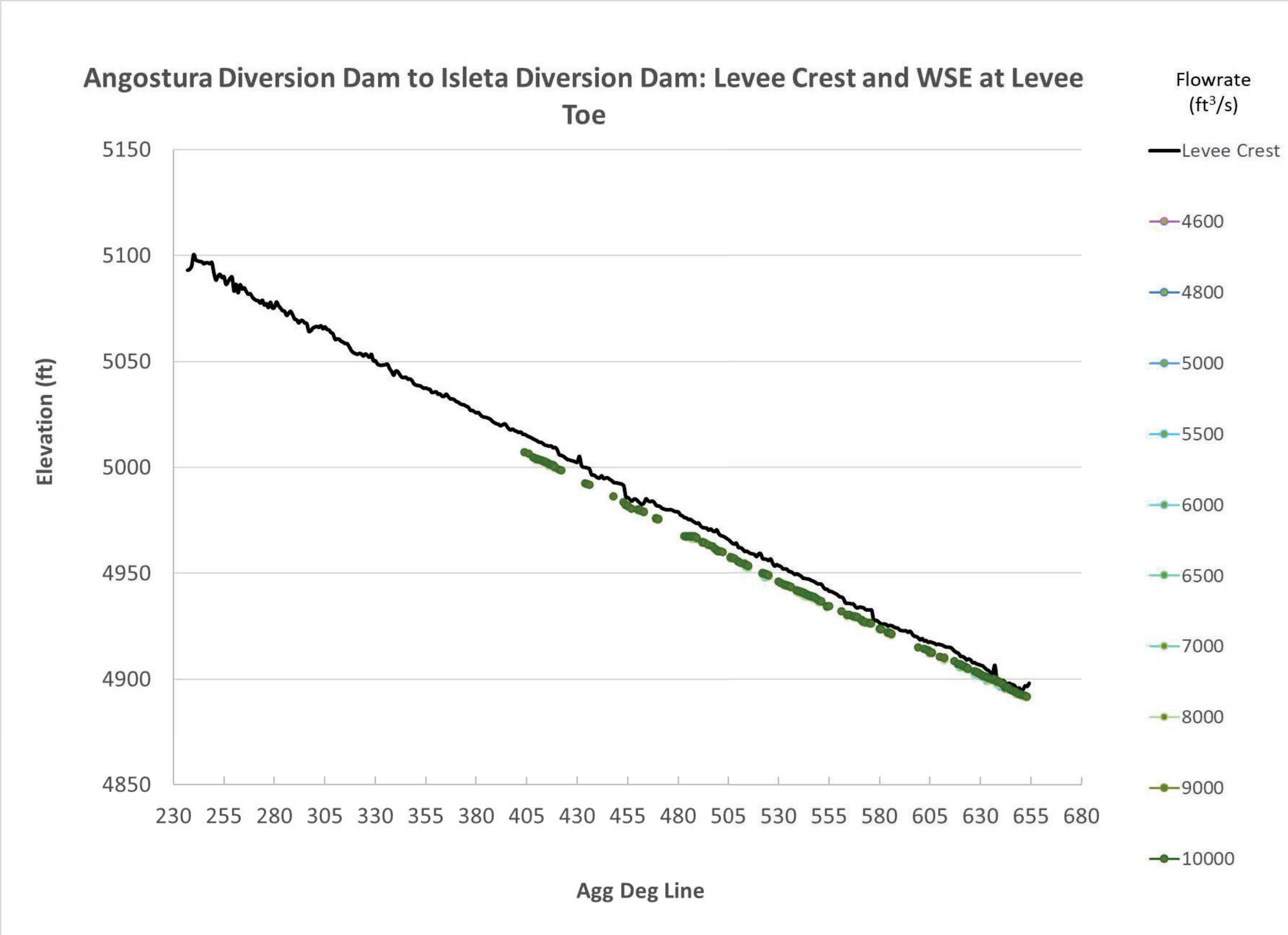
Freeboard Figures

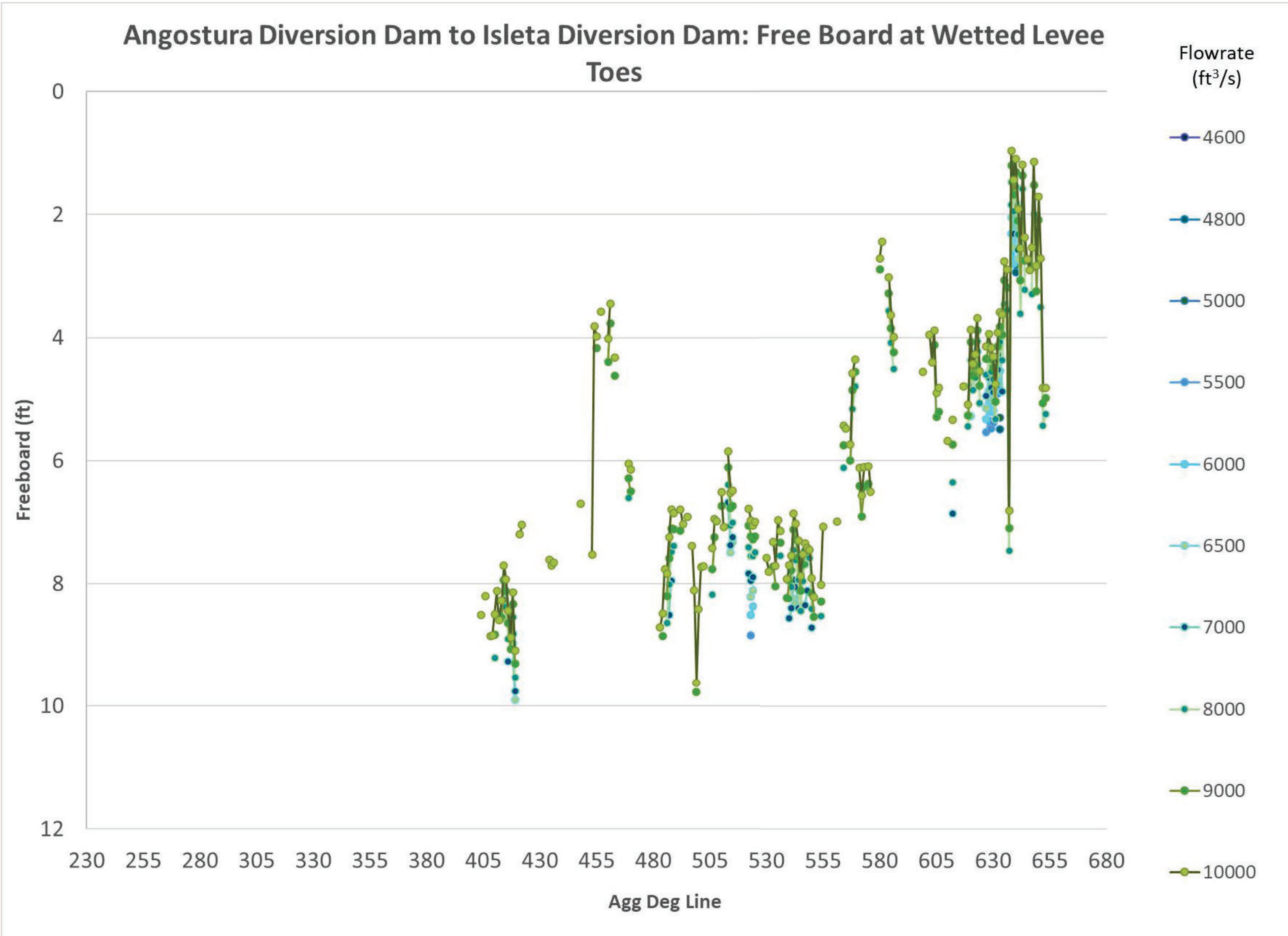


Cochiti Dam to Angostura Diversion Dam: Levee Crest and WSE at Levee Toe
Flowrate (ft³/s)
Levee Crest
5500
6000
6500
7000
8000
9000
10000
Elevation (ft)
5240
5220
5200
5180
5160
5140
5120
5100
5080
0
15
30
45
60
75
90
105
120
135
150
165
180
195
210
225
240
255
Agg Deg Line

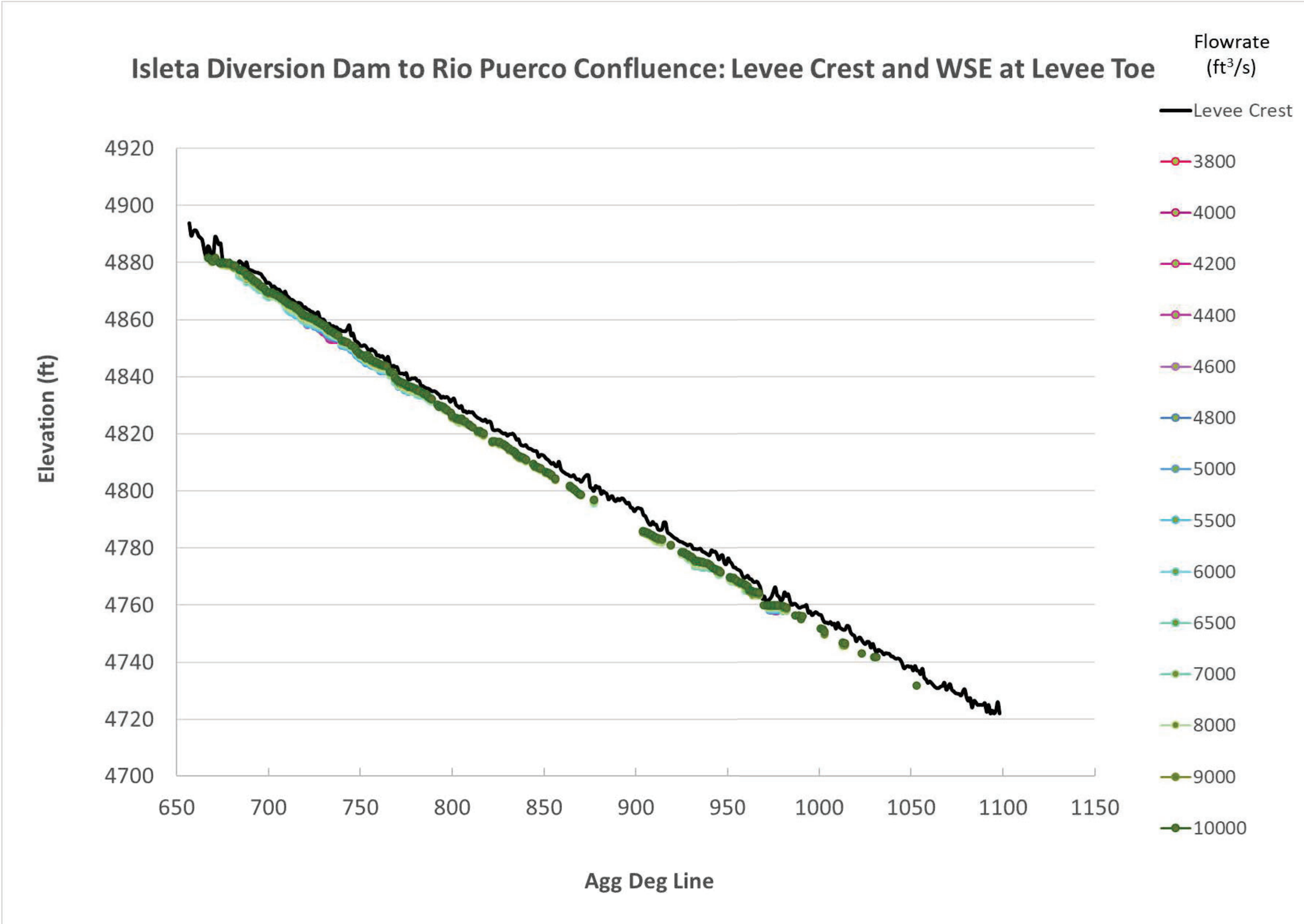


Cochiti Dam to Angostura Diversion Dam: Free Board at Wetted Levee Toes
Freeboard (ft)
0
1
2
3
4
5
6
7
8
0
50
100
150
200
250
Agg Deg Line
Flowrate (ft³/s)
5500
6000
6500
7000
8000
9000
10000

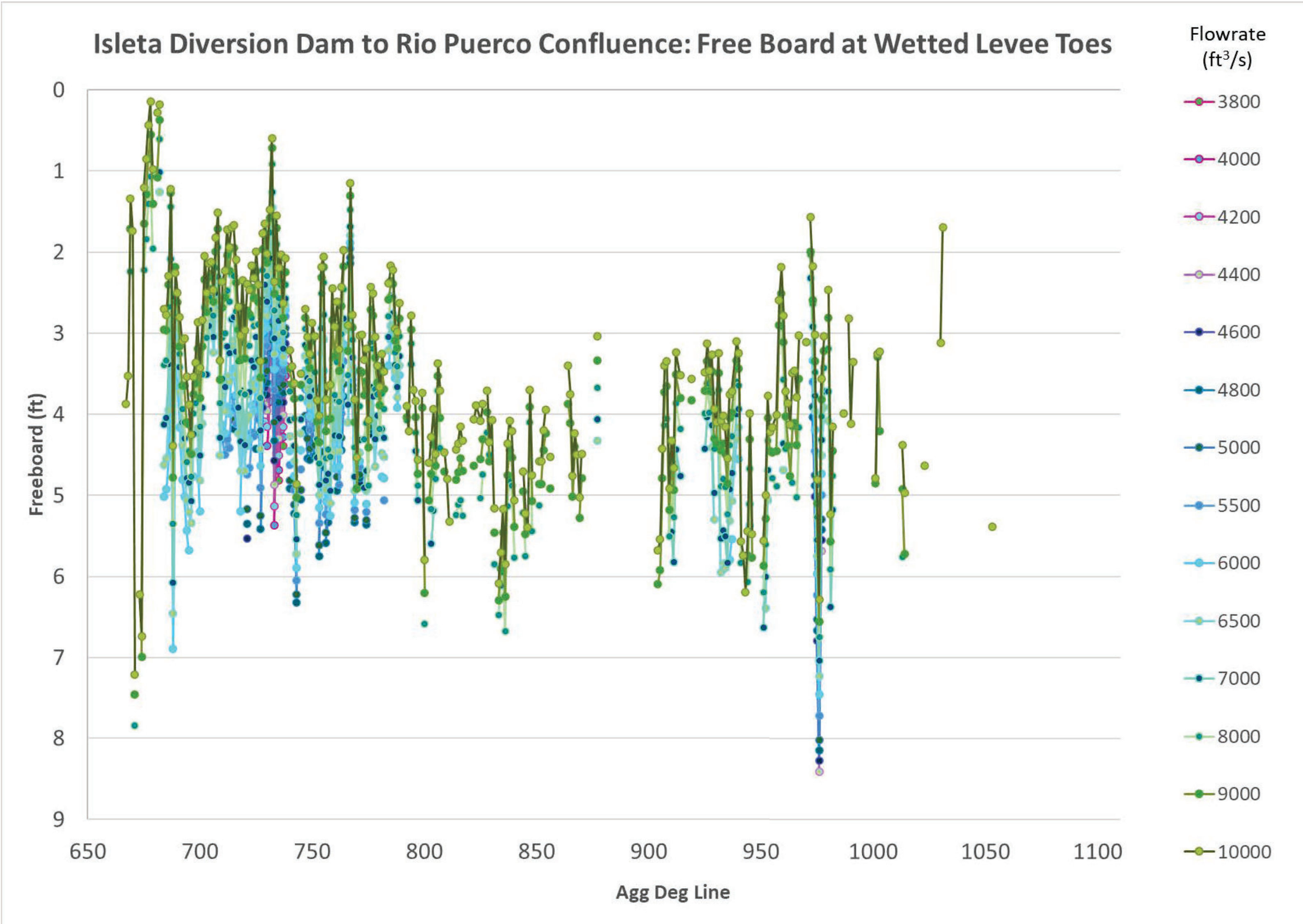

Angostura Diversion Dam to Isleta Diversion Dam: Levee Crest and WSE at Levee Toe
Elevation (ft)
5150
5100
5050
5000
4950
4900
4850
230 255 280 305 330 355 380 405 430 455 480 505 530 555 580 605 630 655 680
Agg Deg Line
Flowrate (ft³/s)
Levee Crest
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000



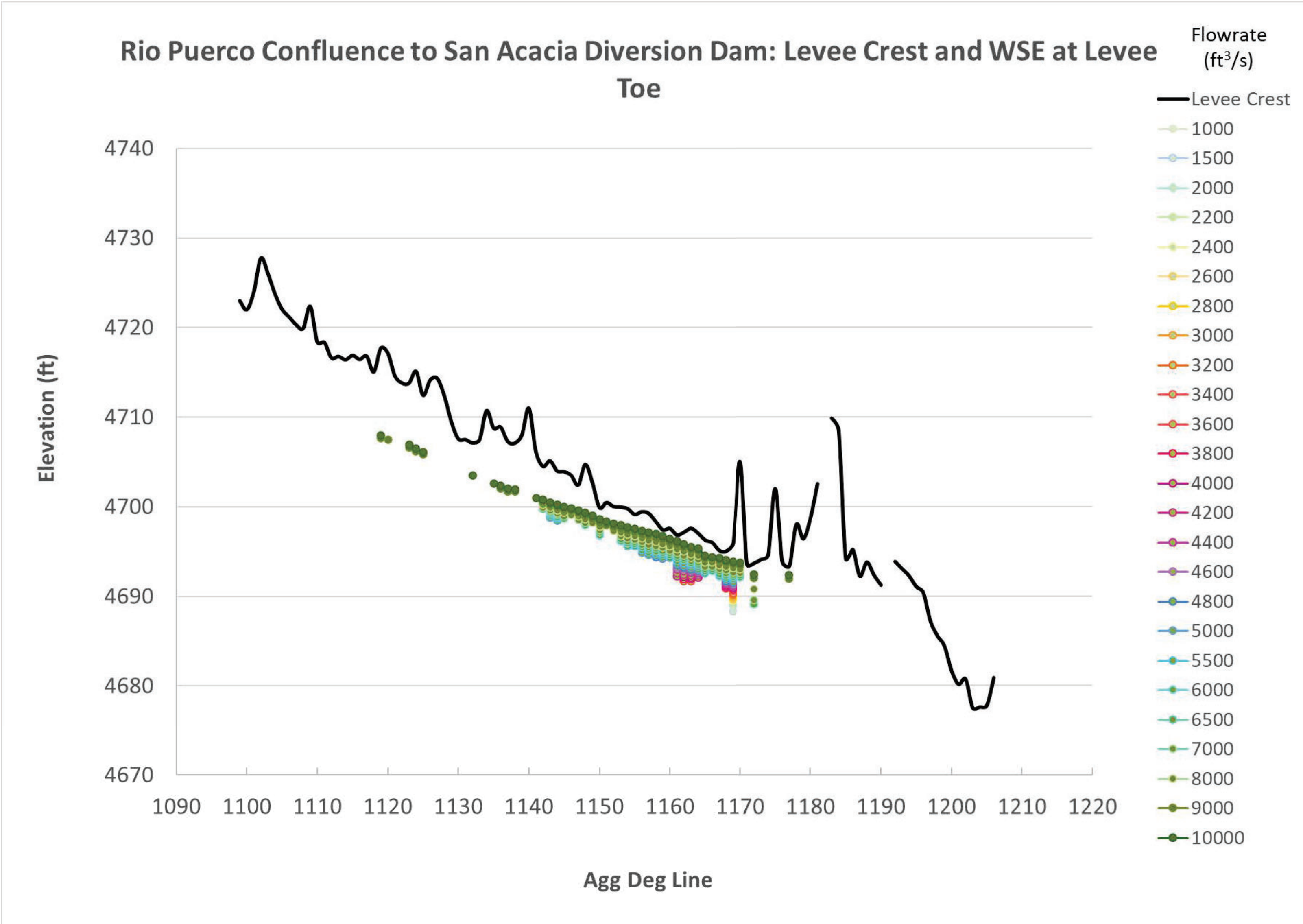
Angostura Diversion Dam to Isleta Diversion Dam: Free Board at Wetted Levee Toes
Freeboard (ft)
0
2
4
6
8
10
12
230
255
280
305
330
355
380
405
430
455
480
505
530
555
580
605
630
655
680
Agg Deg Line
Flowrate (ft³/s)
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000



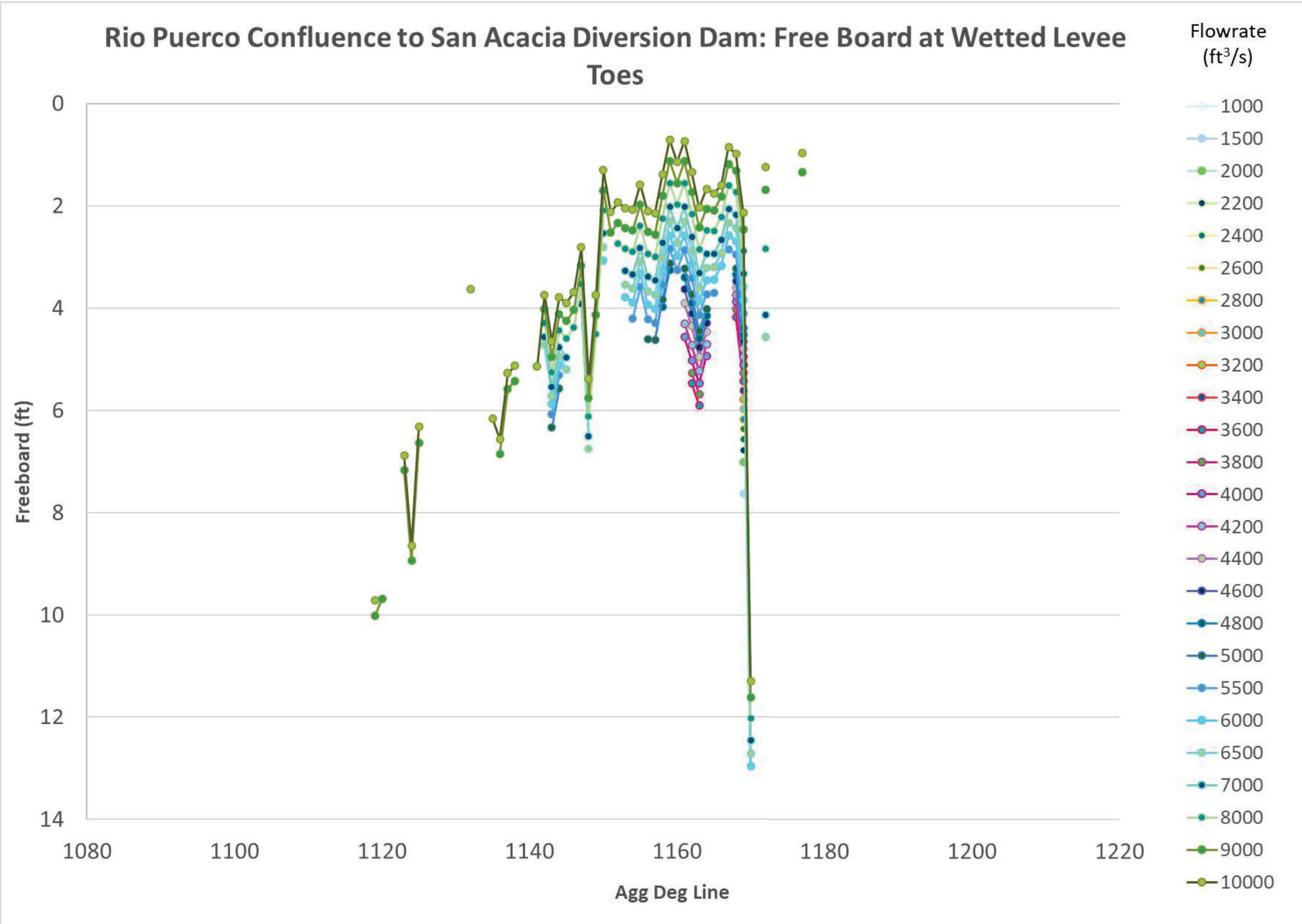
Isleta Diversion Dam to Rio Puerco Confluence: Levee Crest and WSE at Levee Toe
Flowrate (ft³/s)
Levee Crest
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000
Elevation (ft)
4920
4900
4880
4860
4840
4820
4800
4780
4760
4740
4720
4700
650
700
750
800
850
900
950
1000
1050
1100
1150
Agg Deg Line



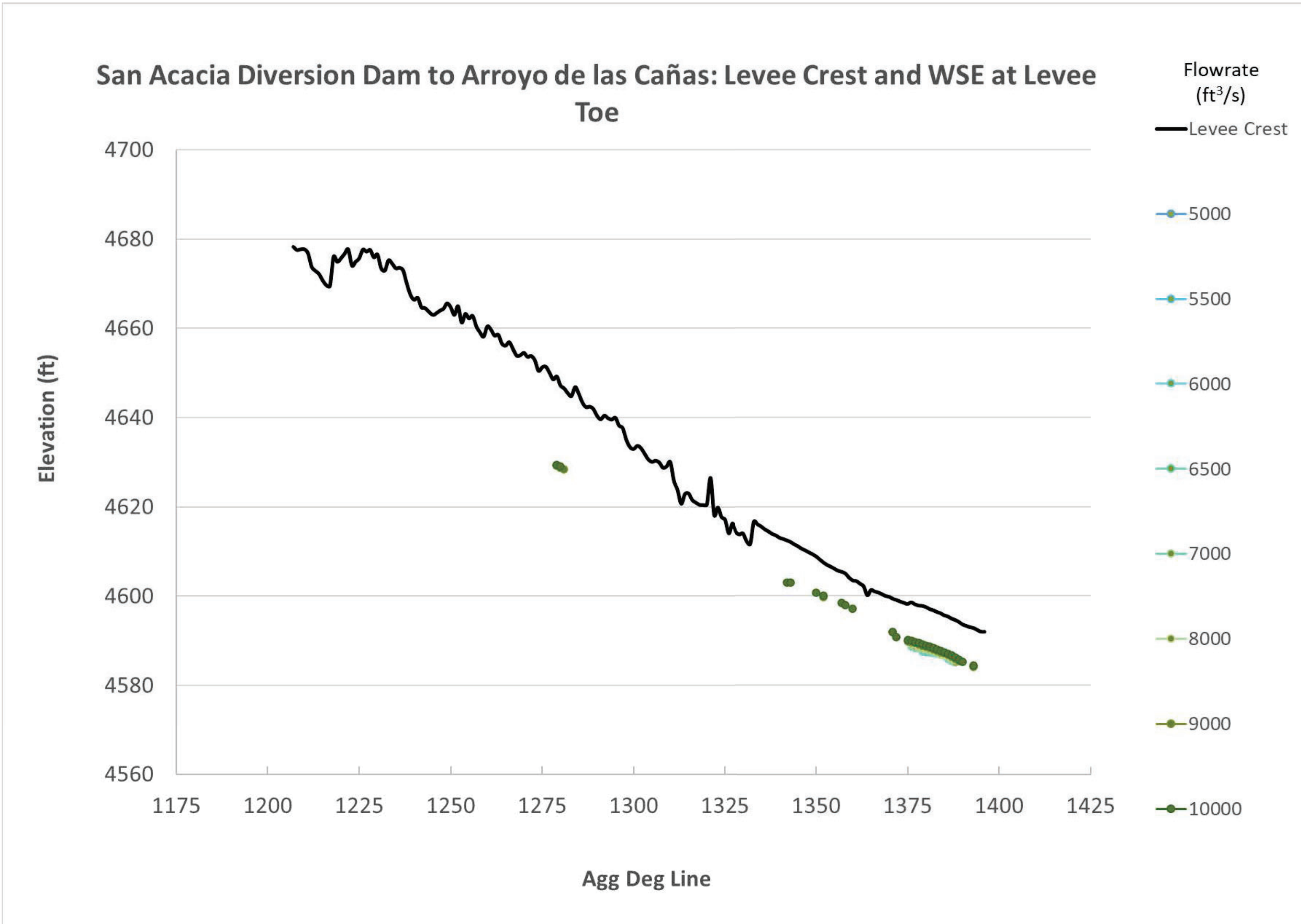
Isleta Diversion Dam to Rio Puerco Confluence: Free Board at Wetted Levee Toes
Flowrate (ft³/s)
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000
Freeboard (ft)
0
1
2
3
4
5
6
7
8
9
650
700
750
800
850
900
950
1000
1050
1100
Agg Deg Line

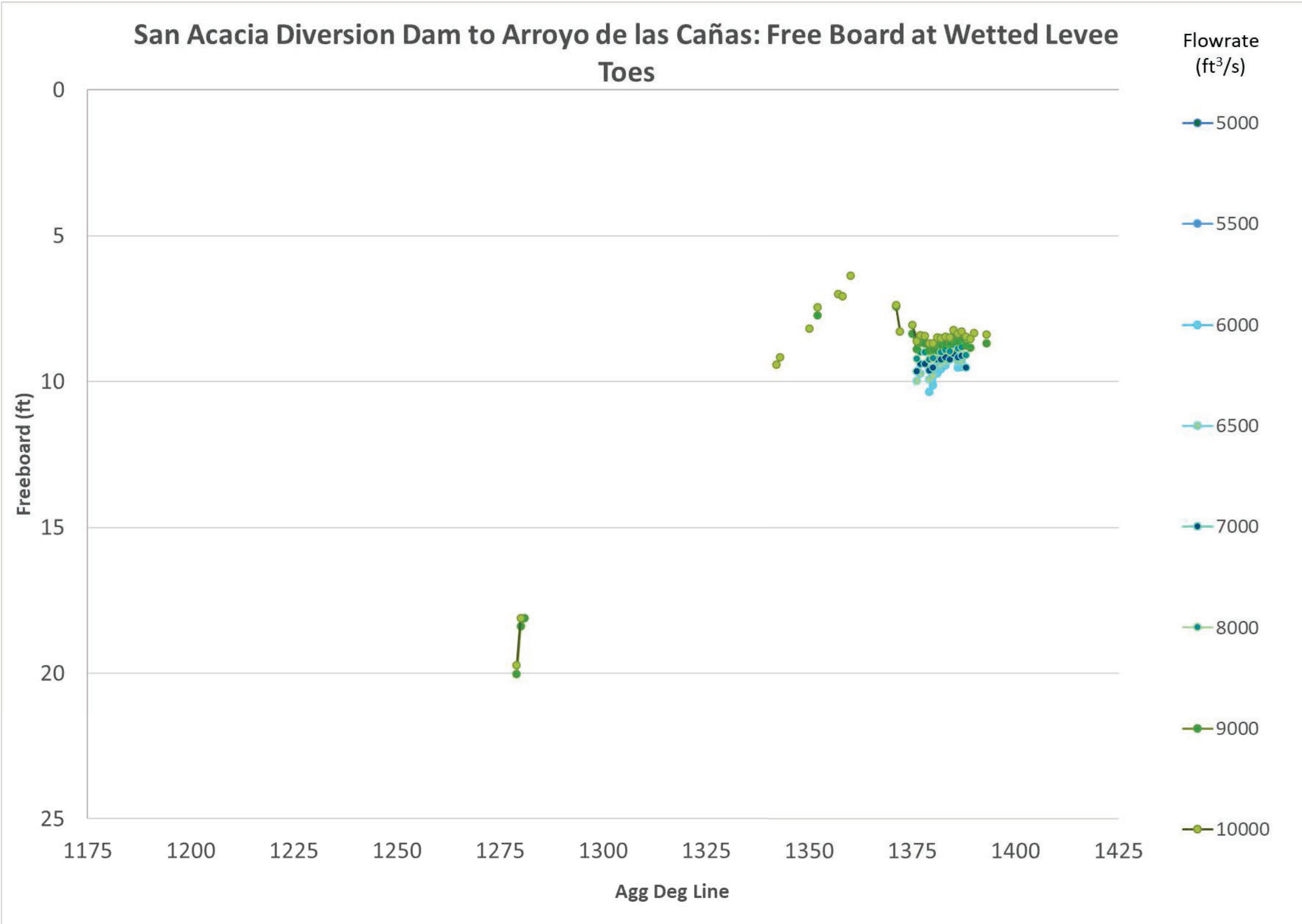


Rio Puerco Confluence to San Acacia Diversion Dam: Levee Crest and WSE at Levee Toe
Flowrate (ft³/s)
Levee Crest
1000
1500
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000
Elevation (ft)
4740
4730
4720
4710
4700
4690
4680
4670
1090
1100
1110
1120
1130
1140
1150
1160
1170
1180
1190
1200
1210
1220
Agg Deg Line

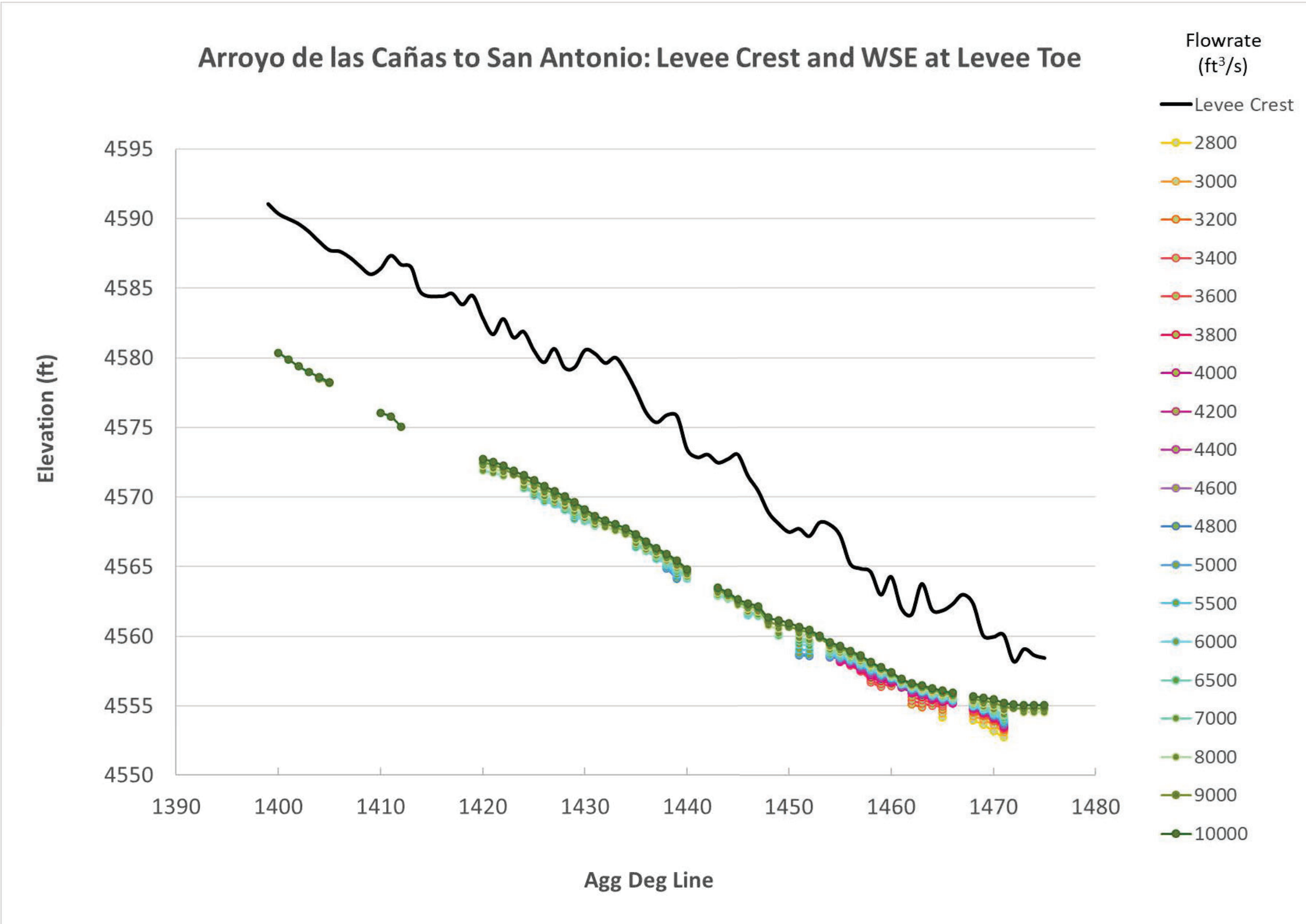


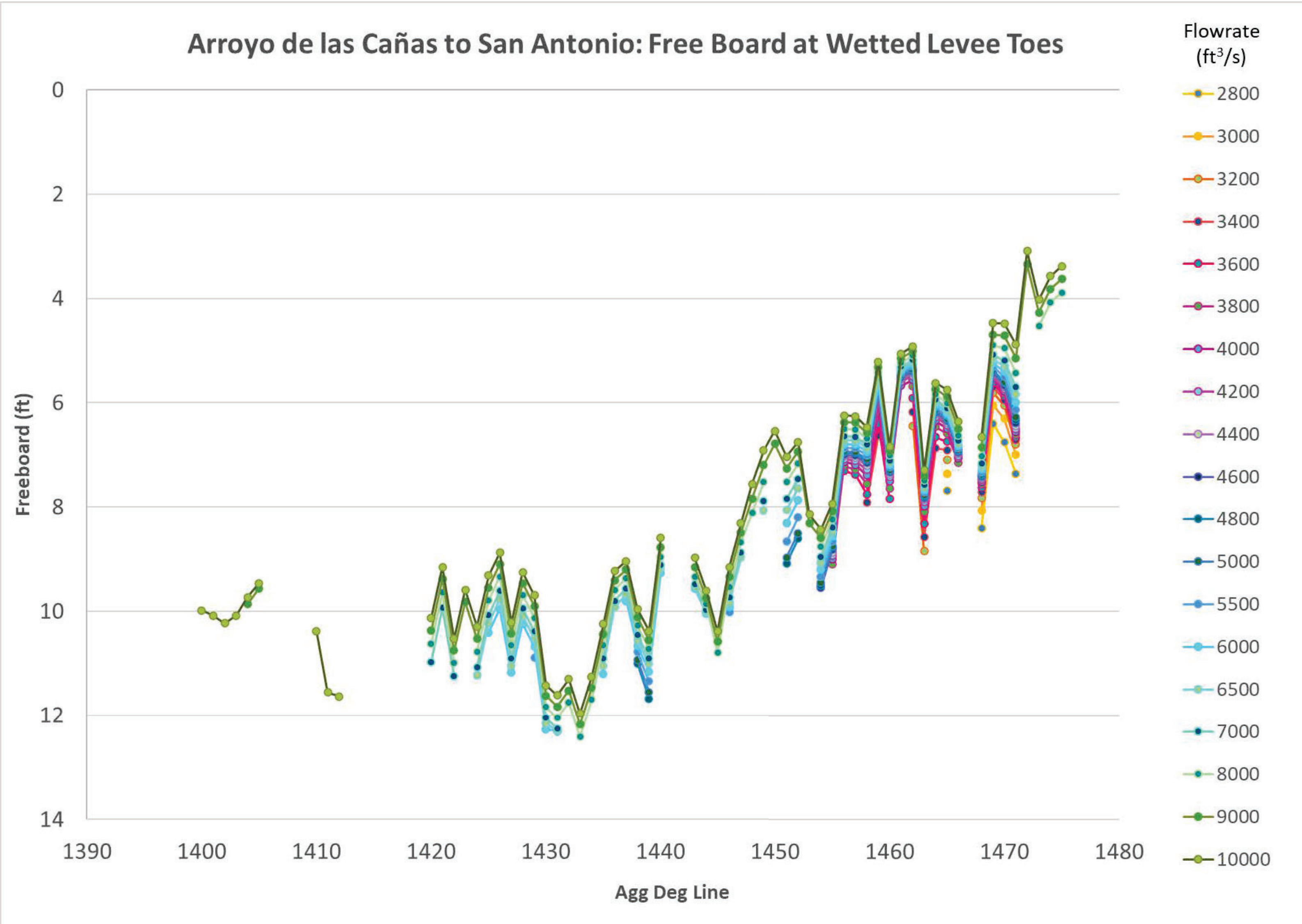
Rio Puerco Confluence to San Acacia Diversion Dam: Free Board at Wetted Levee Toes
Freeboard (ft)
0
2
4
6
8
10
12
14
1080
1100
1120
1140
1160
1180
1200
1220
Agg Deg Line
Flowrate (ft³/s)
1000
1500
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000

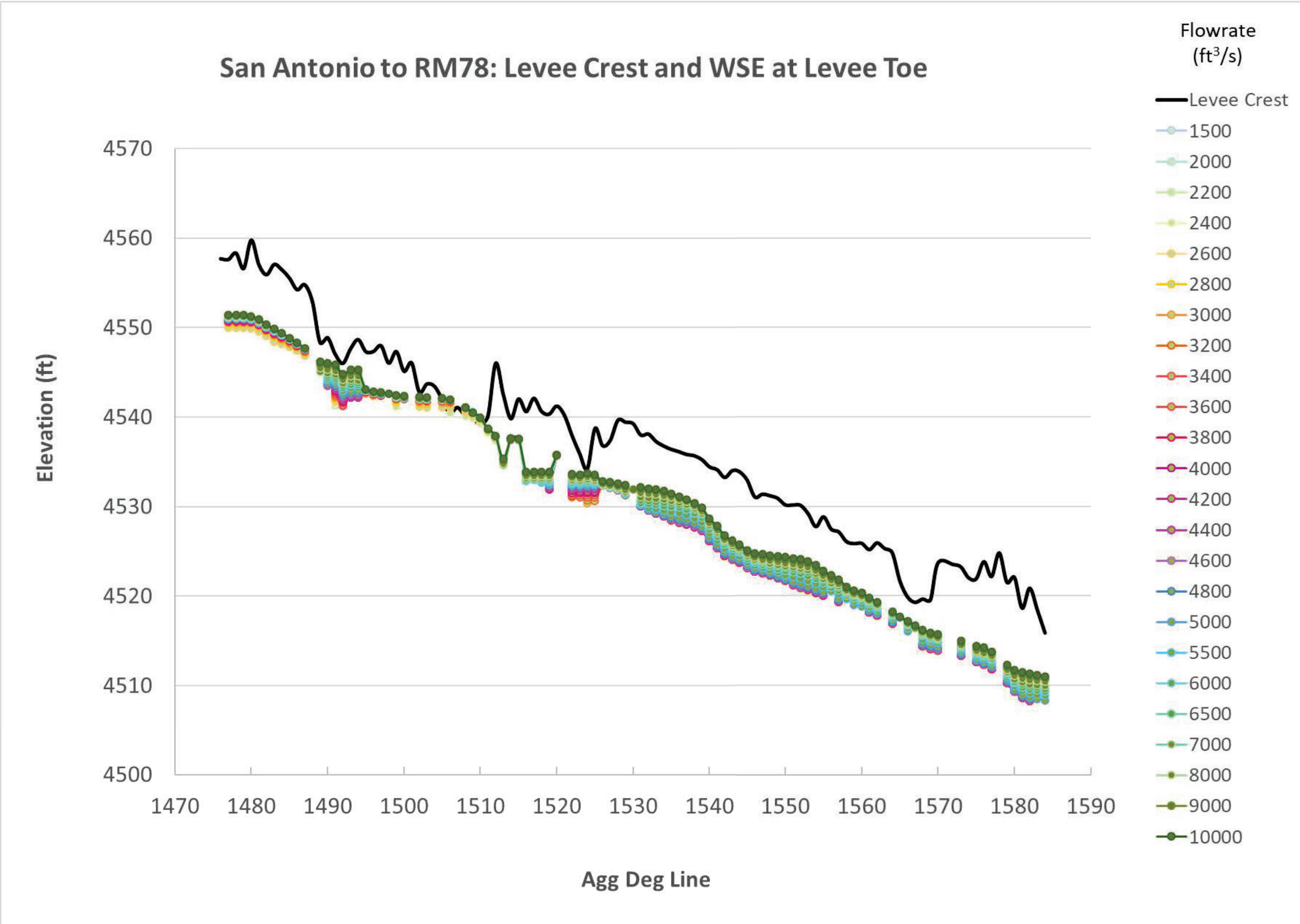

San Acacia Diversion Dam to Arroyo de las Cañas: Levee Crest and WSE at Levee Toe
Elevation (ft)
4700
4680
4660
4640
4620
4600
4580
4560
1175
1200
1225
1250
1275
1300
1325
1350
1375
1400
1425
Agg Deg Line
Flowrate (ft3/s)
Levee Crest
5000
5500
6000
6500
7000
8000
9000
10000



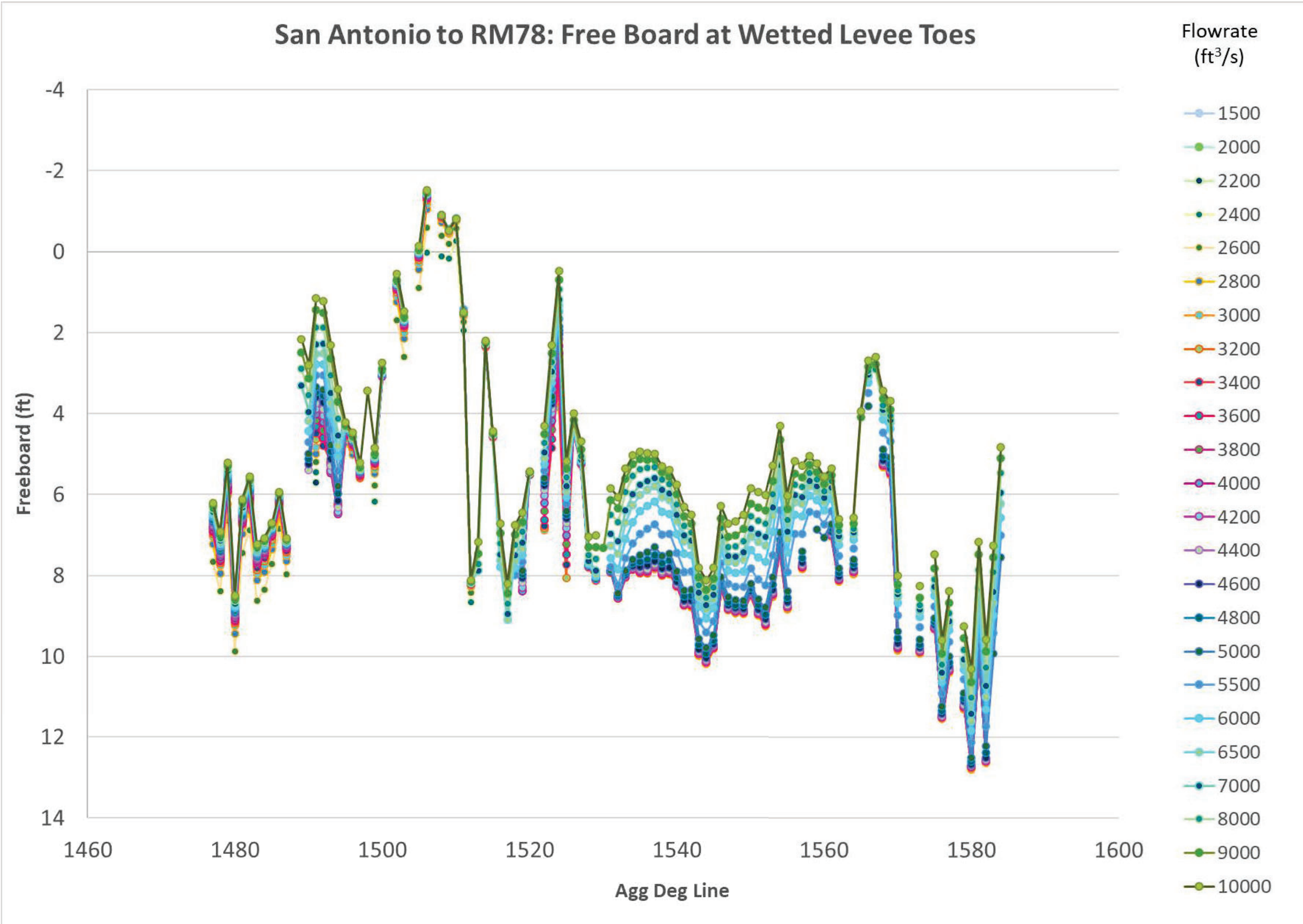
San Acacia Diversion Dam to Arroyo de las Cañas: Free Board at Wetted Levee Toes
Freeboard (ft)
0
5
10
15
20
25
1175
1200
1225
1250
1275
1300
1325
1350
1375
1400
1425
Agg Deg Line
Flowrate (ft3/s)
5000
5500
6000
6500
7000
8000
9000
10000


Arroyo de las Cañas to San Antonio: Levee Crest and WSE at Levee Toe
Elevation (ft)
4595
4590
4585
4580
4575
4570
4565
4560
4555
4550
1390
1400
1410
1420
1430
1440
1450
1460
1470
1480
Agg Deg Line
Flowrate (ft³/s)
Levee Crest
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000


Arroyo de las Cañas to San Antonio: Free Board at Wetted Levee Toes
Freeboard (ft)
0
2
4
6
8
10
12
14
1390
1400
1410
1420
1430
1440
1450
1460
1470
1480
Agg Deg Line
Flowrate (ft3/s)
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000



San Antonio to RM78: Levee Crest and WSE at Levee Toe
Elevation (ft)
4570
4560
4550
4540
4530
4520
4510
4500
1470
1480
1490
1500
1510
1520
1530
1540
1550
1560
1570
1580
1590
Agg Deg Line
Flowrate (ft³/s)
Levee Crest
1500
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000


San Antonio to RM78: Free Board at Wetted Levee Toes
Freeboard (ft)
-4
-2
0
2
4
6
8
10
12
14
1460
1480
1500
1520
1540
1560
1580
1600
Agg Deg Line
Flowrate (ft³/s)
1500
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
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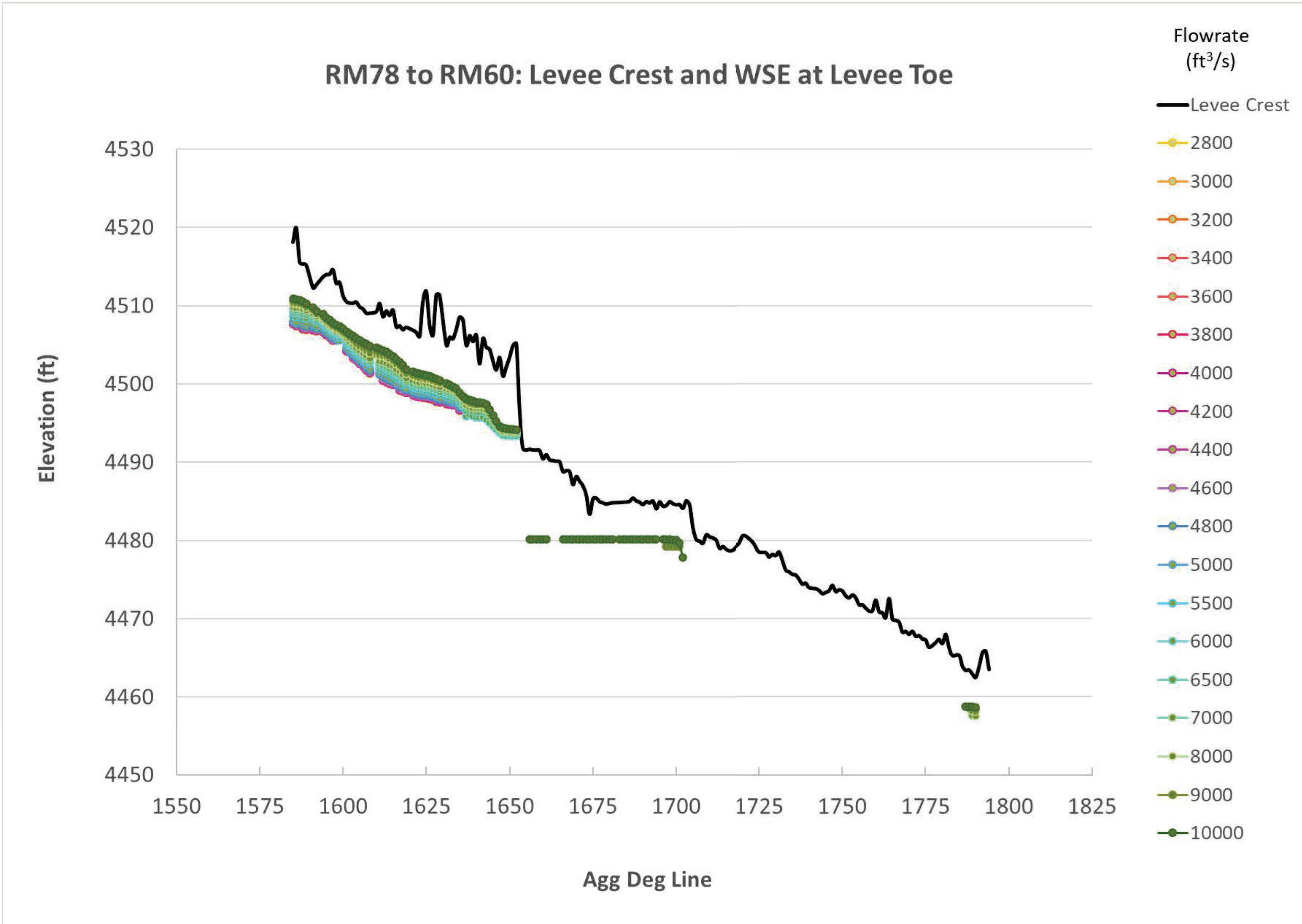
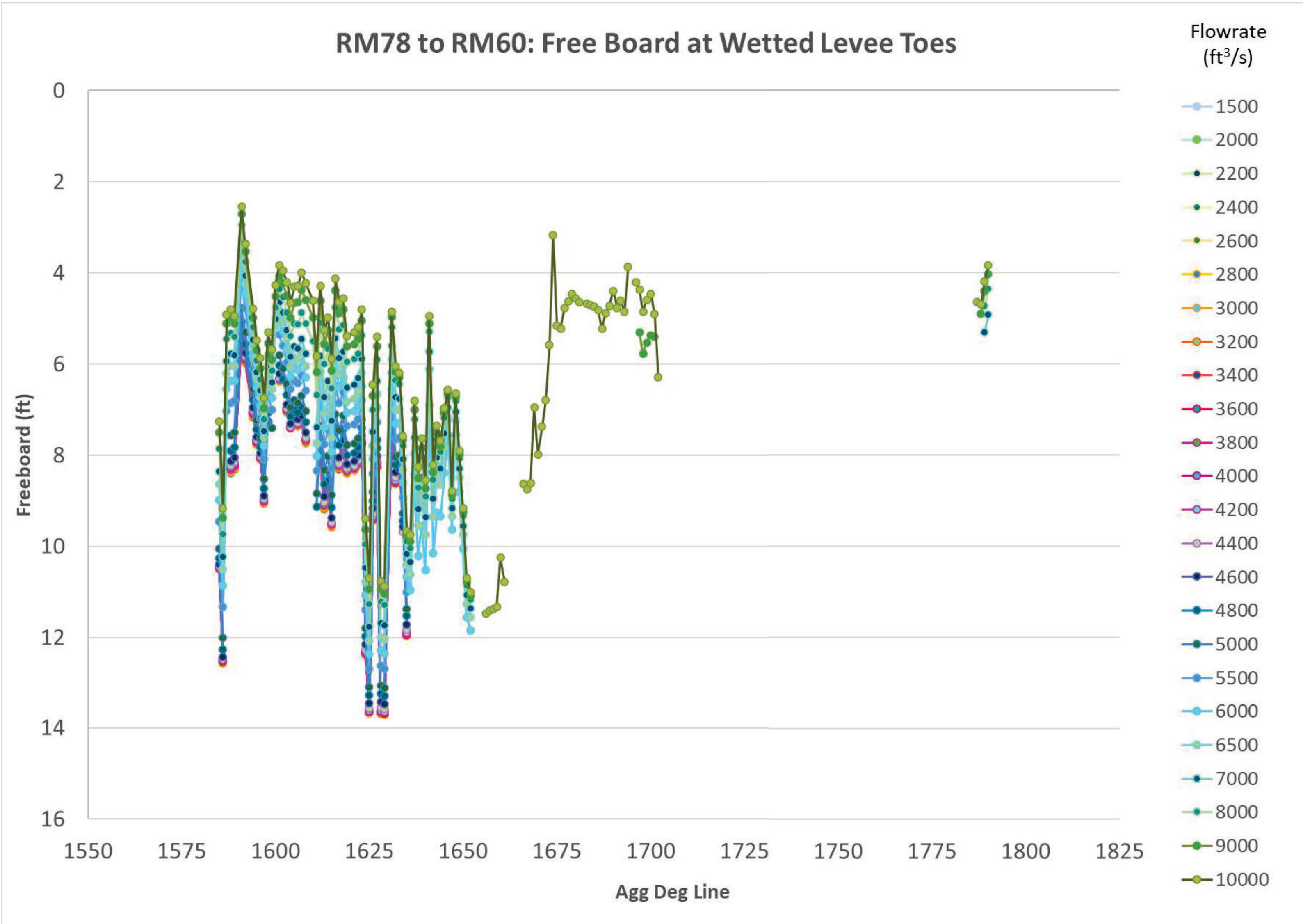
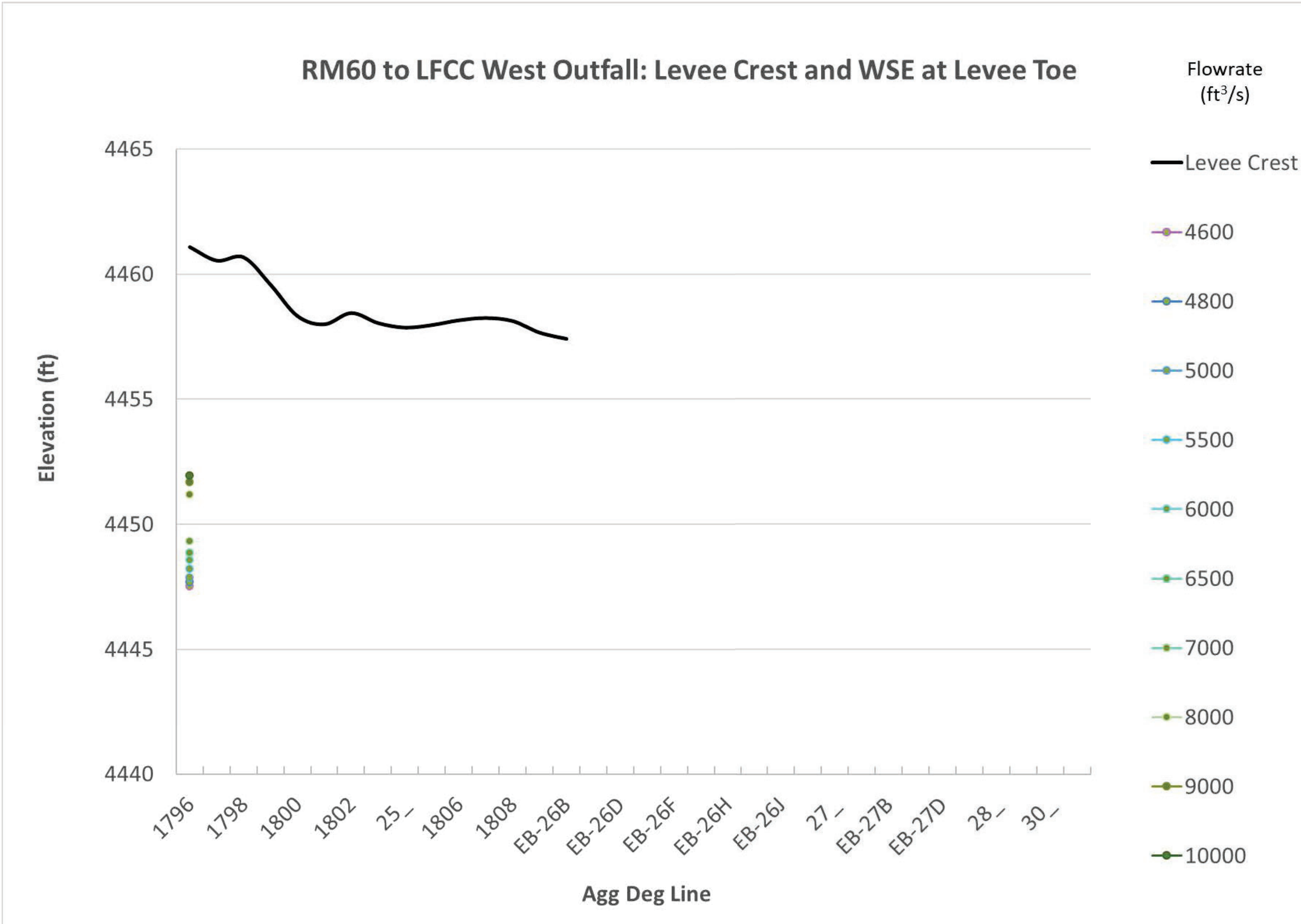
7000
8000
9000
10000

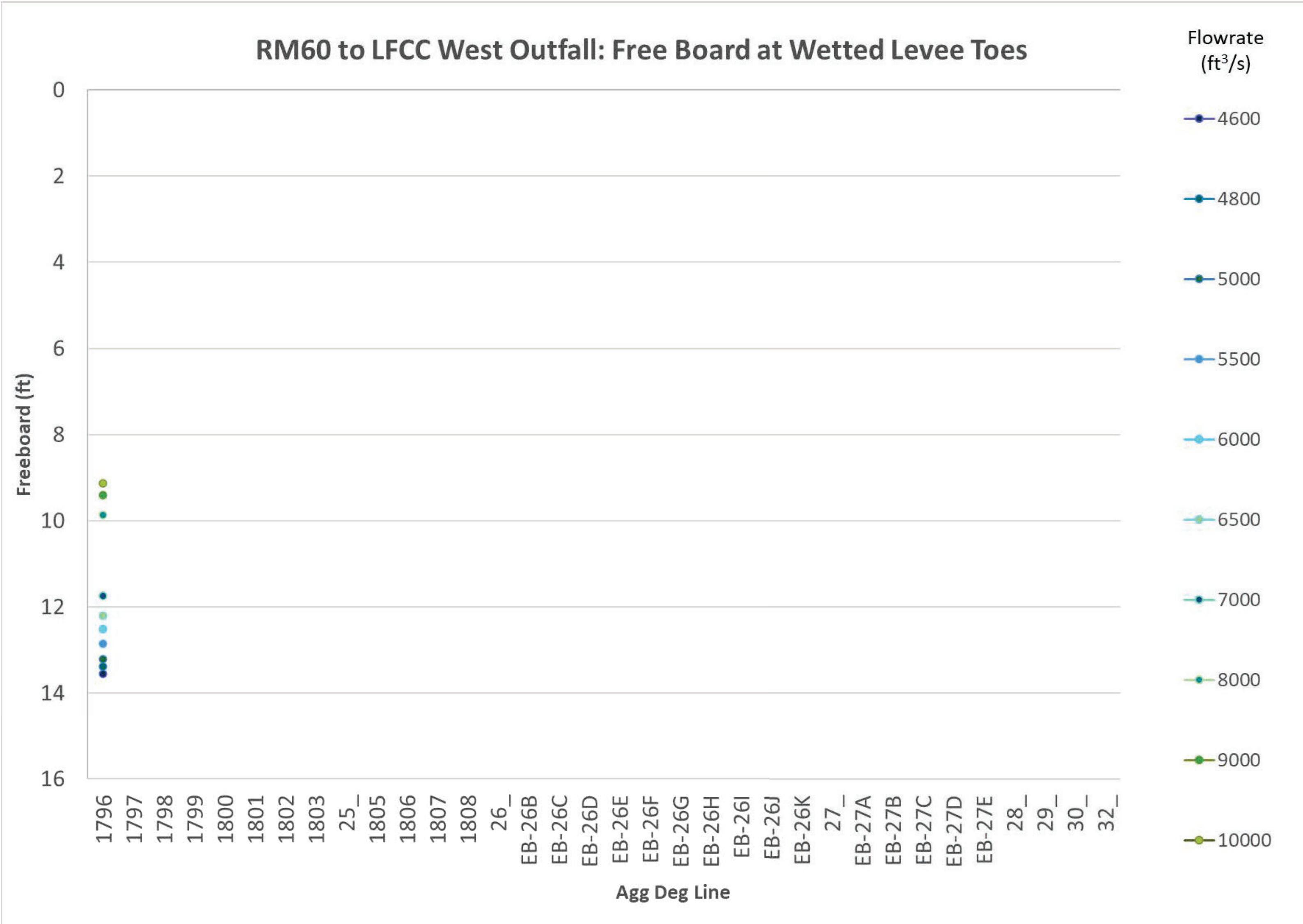

RM78 to RM60: Levee Crest and WSE at Levee Toe
Elevation (ft)
4530
4520
4510
4500
4490
4480
4470
4460
4450
1550
1575
1600
1625
1650
1675
1700
1725
1750
1775
1800
1825
Agg Deg Line
Flowrate (ft³/s)
Levee Crest
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000



RM78 to RM60: Free Board at Wetted Levee Toes
Freeboard (ft)
0
2
4
6
8
10
12
14
16
1550
1575
1600
1625
1650
1675
1700
1725
1750
1775
1800
1825
Agg Deg Line
Flowrate
(ft3/s)
1500
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000



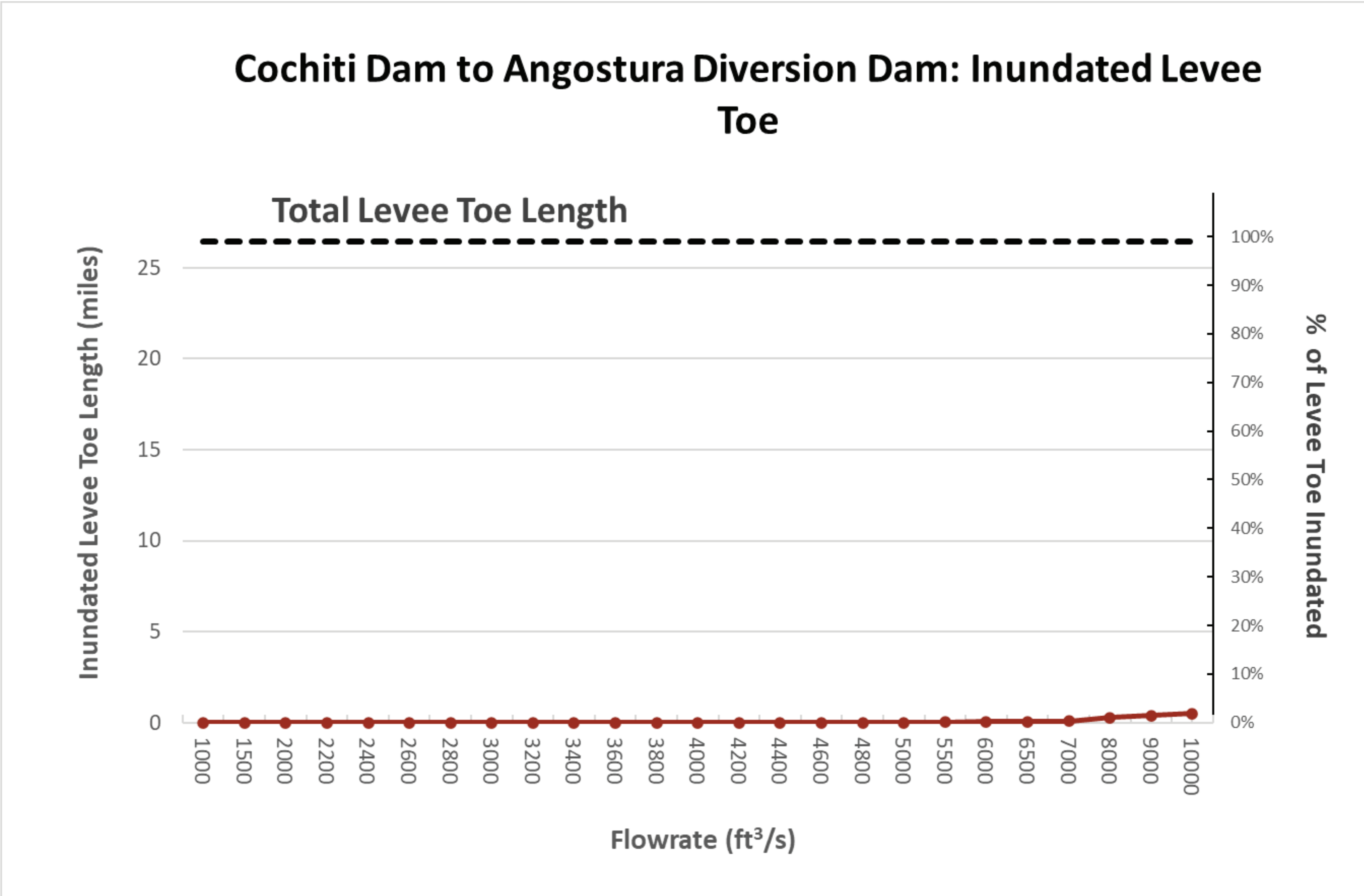
RM60 to LFCC West Outfall: Levee Crest and WSE at Levee Toe
Flowrate
(ft³/s)
Levee Crest
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000
4465
4460
4455
4450
4445
4440
Elevation (ft)
1796
1798
1800
1802
25_
1806
1808
EB-26B
EB-26D
EB-26F
EB-26H
EB-26J
27_
EB-27B
EB-27D
28_
30_
Agg Deg Line



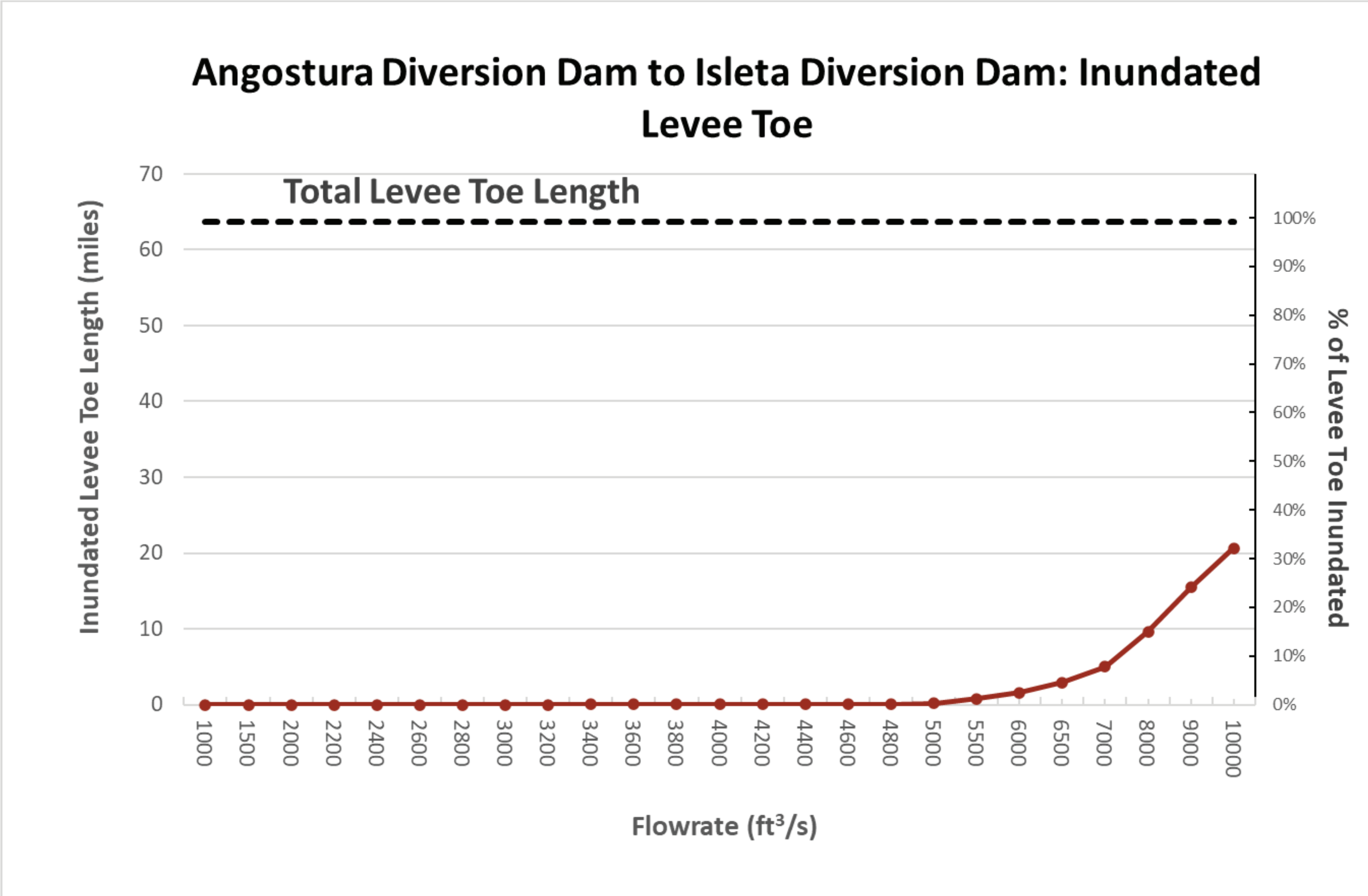
RM60 to LFCC West Outfall: Free Board at Wetted Levee Toes
Flowrate (ft³/s)
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000
Freeboard (ft)
0
2
4
6
8
10
12
14
16
1796
1797
1798
1799
1800
1801
1802
1803
25_
1805
1806
1807
1808
26_
EB-26B
EB-26C
EB-26D
EB-26E
EB-26F
EB-26G
EB-26H
EB-26I
EB-26J
EB-26K
27_
EB-27A
EB-27B
EB-27C
EB-27D
EB-27E
28_
29_
30_
32_
Agg Deg Line

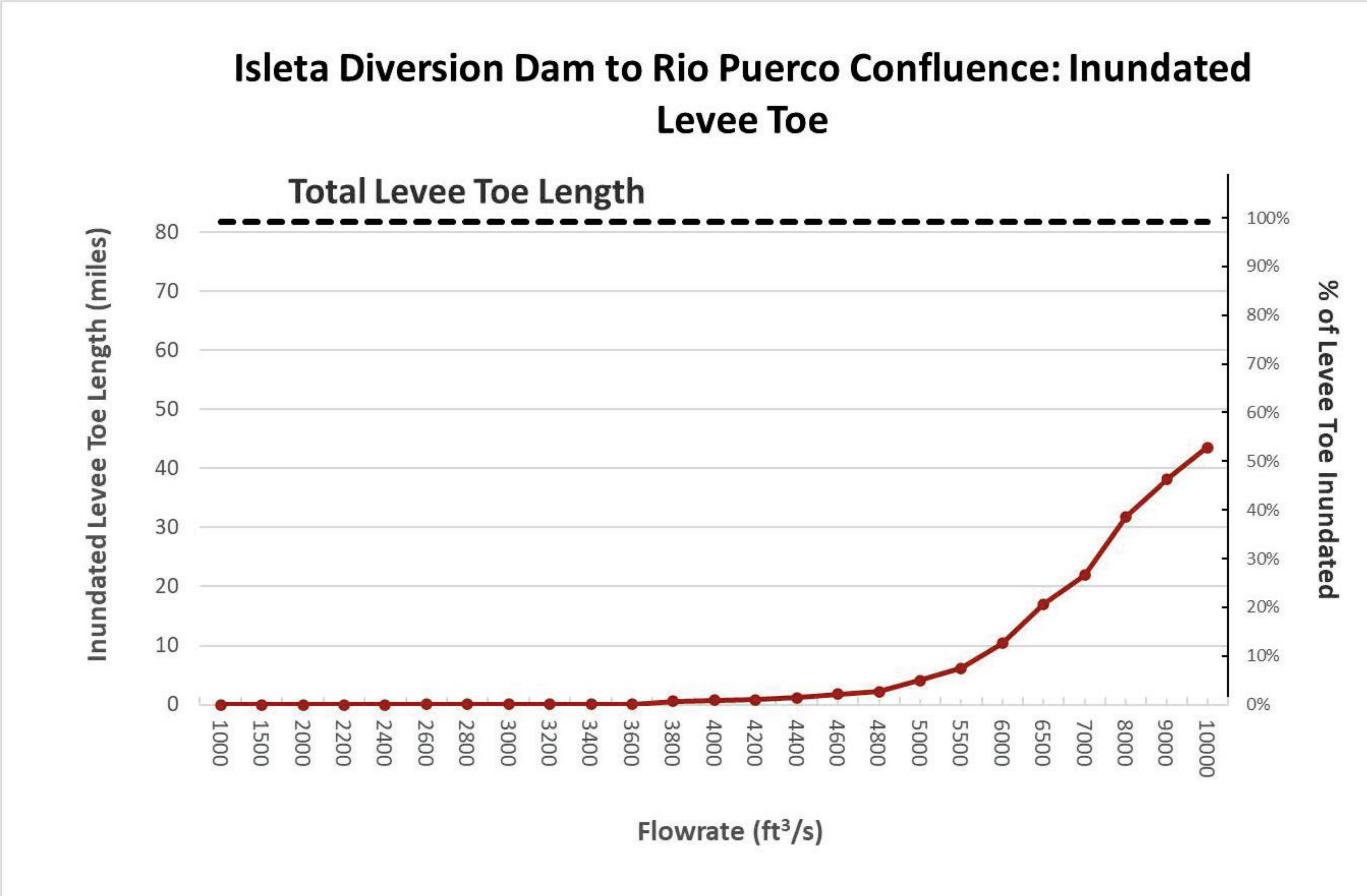
Appendix C

Inundated Levee Toe Figures

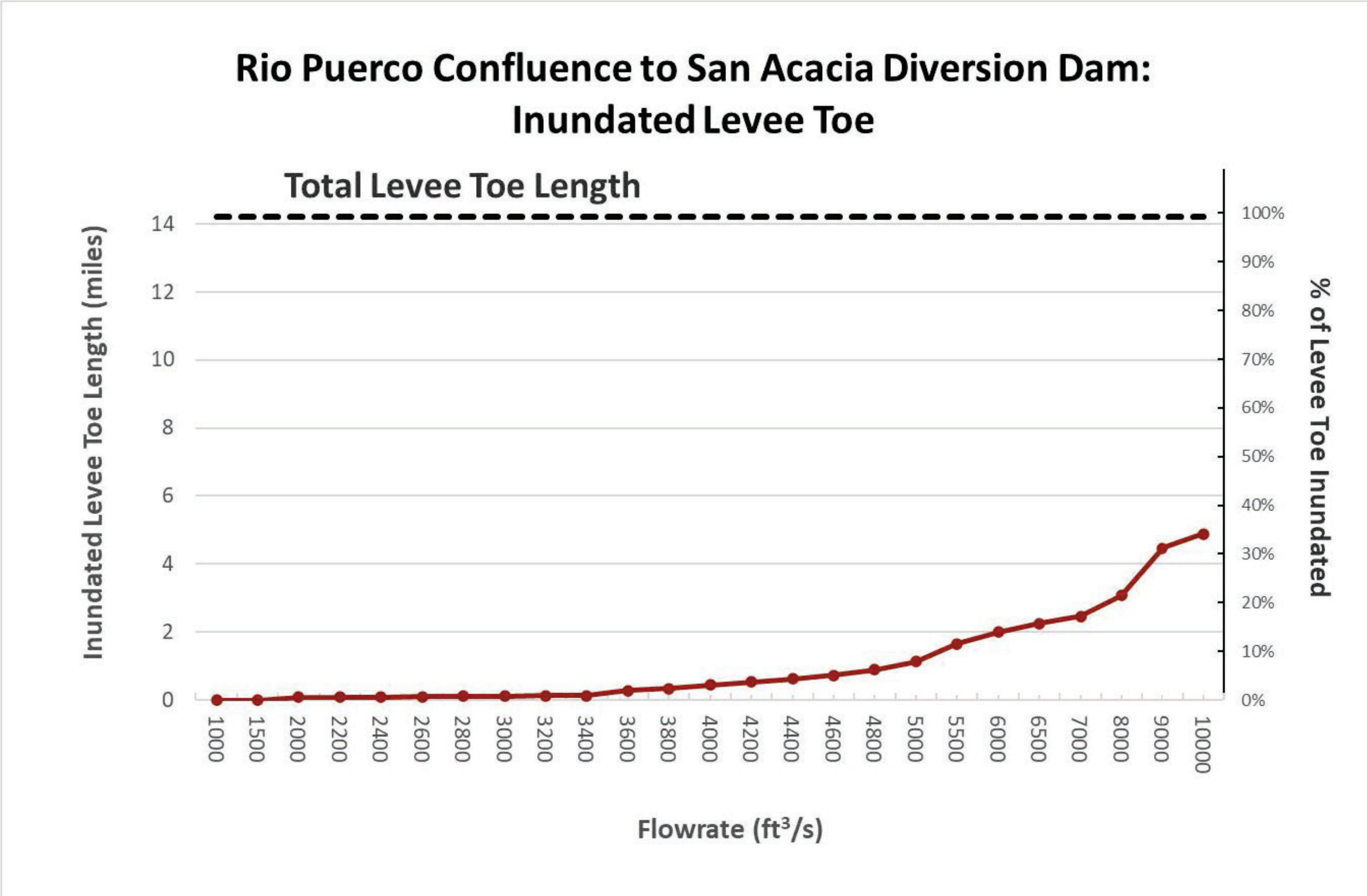


Cochiti Dam to Angostura Diversion Dam: Inundated Levee Toe
Total Levee Toe Length
Inundated Levee Toe Length (miles)
0
5
10
15
20
25
% of Levee Toe Inundated
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
1000
1500
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000
Flowrate (ft³/s)

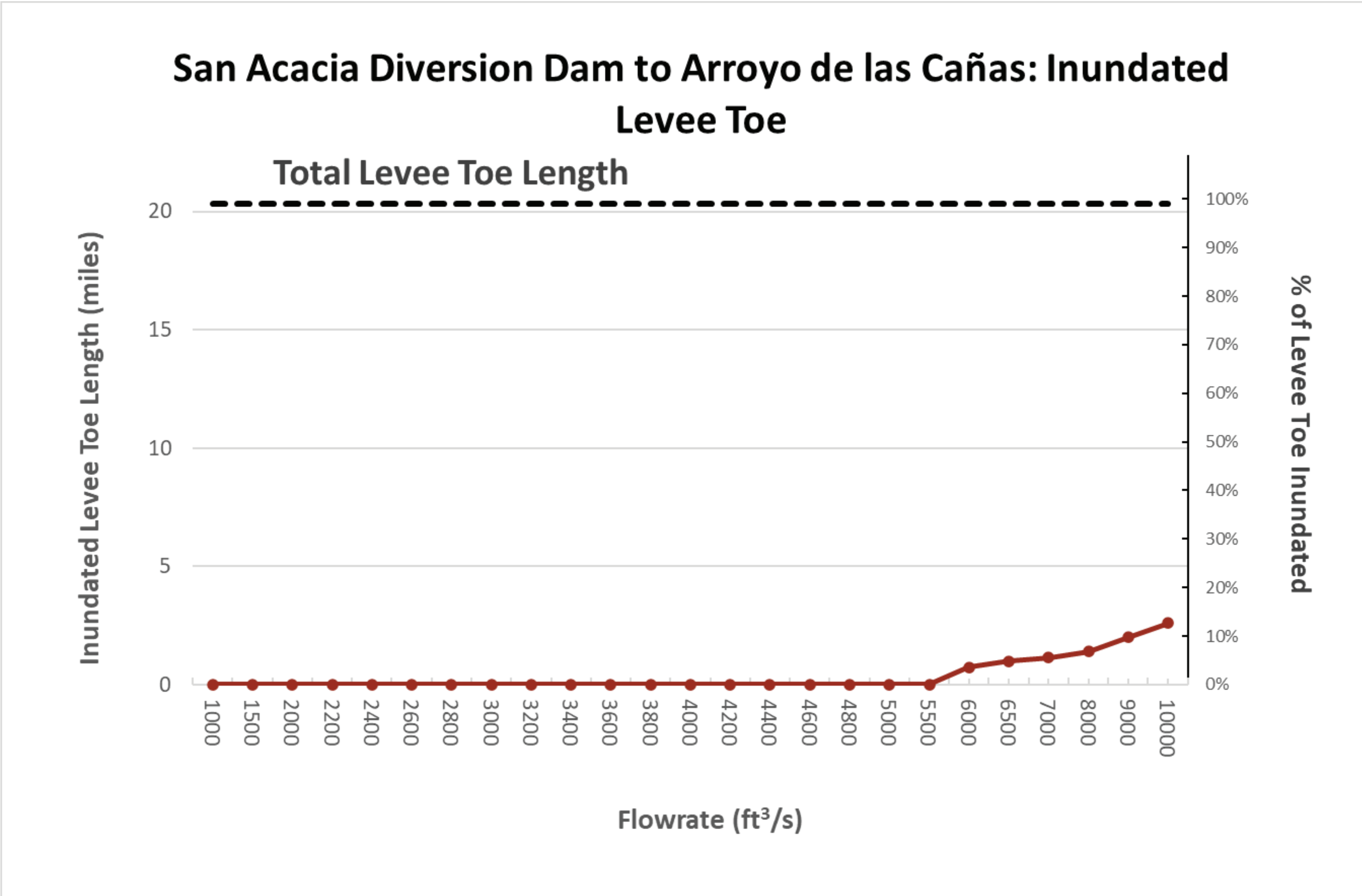

Angostura Diversion Dam to Isleta Diversion Dam: Inundated Levee Toe
Total Levee Toe Length
Inundated Levee Toe Length (miles)
% of Levee Toe Inundated
Flowrate (ft³/s)
70
60
50
40
30
20
10
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1000
1500
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000

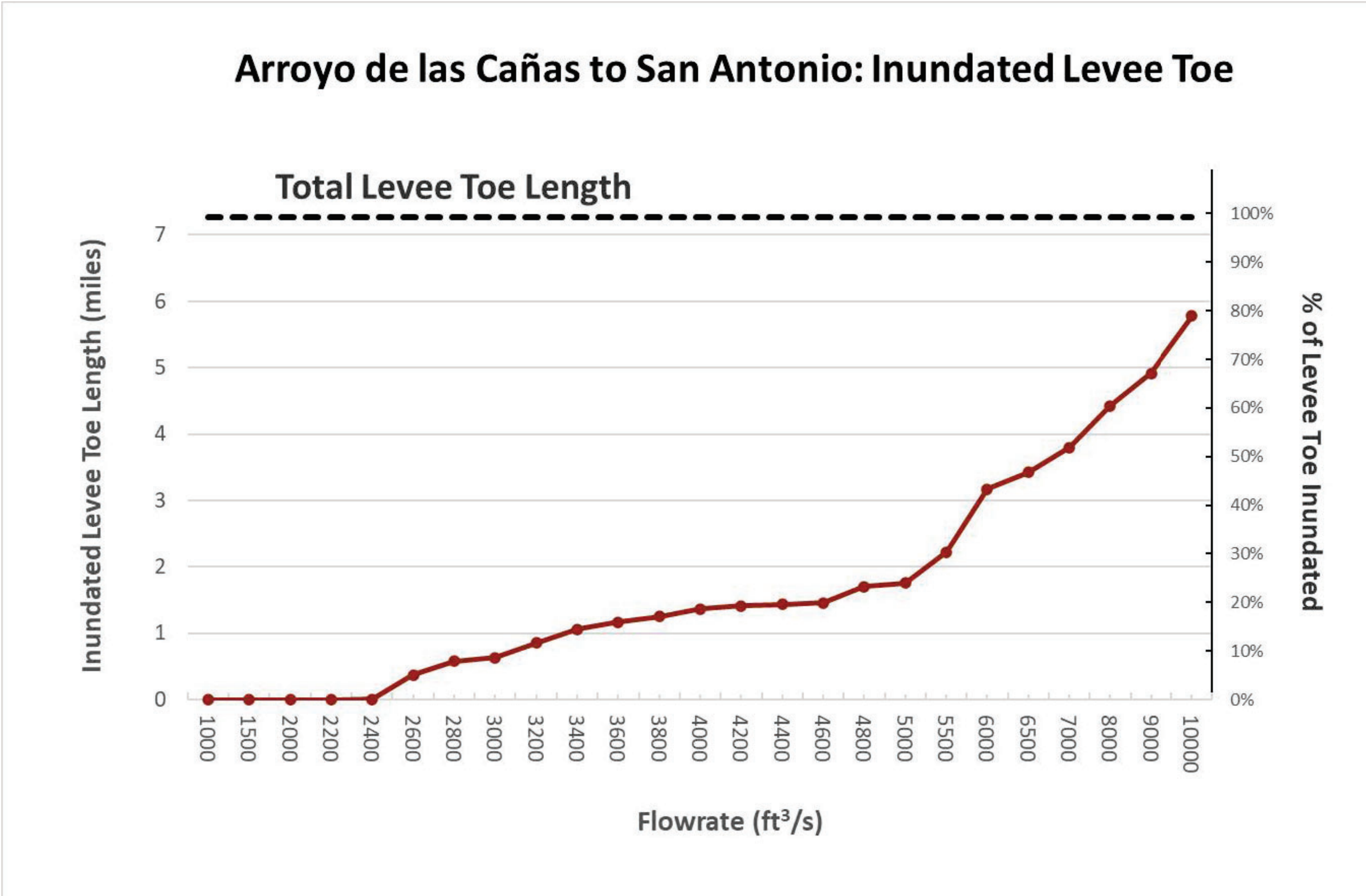


Isleta Diversion Dam to Rio Puerco Confluence: Inundated Levee Toe
Total Levee Toe Length
Inundated Levee Toe Length (miles)
% of Levee Toe Inundated
Flowrate (ft³/s)
0
10
20
30
40
50
60
70
80
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
1000
1500
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000

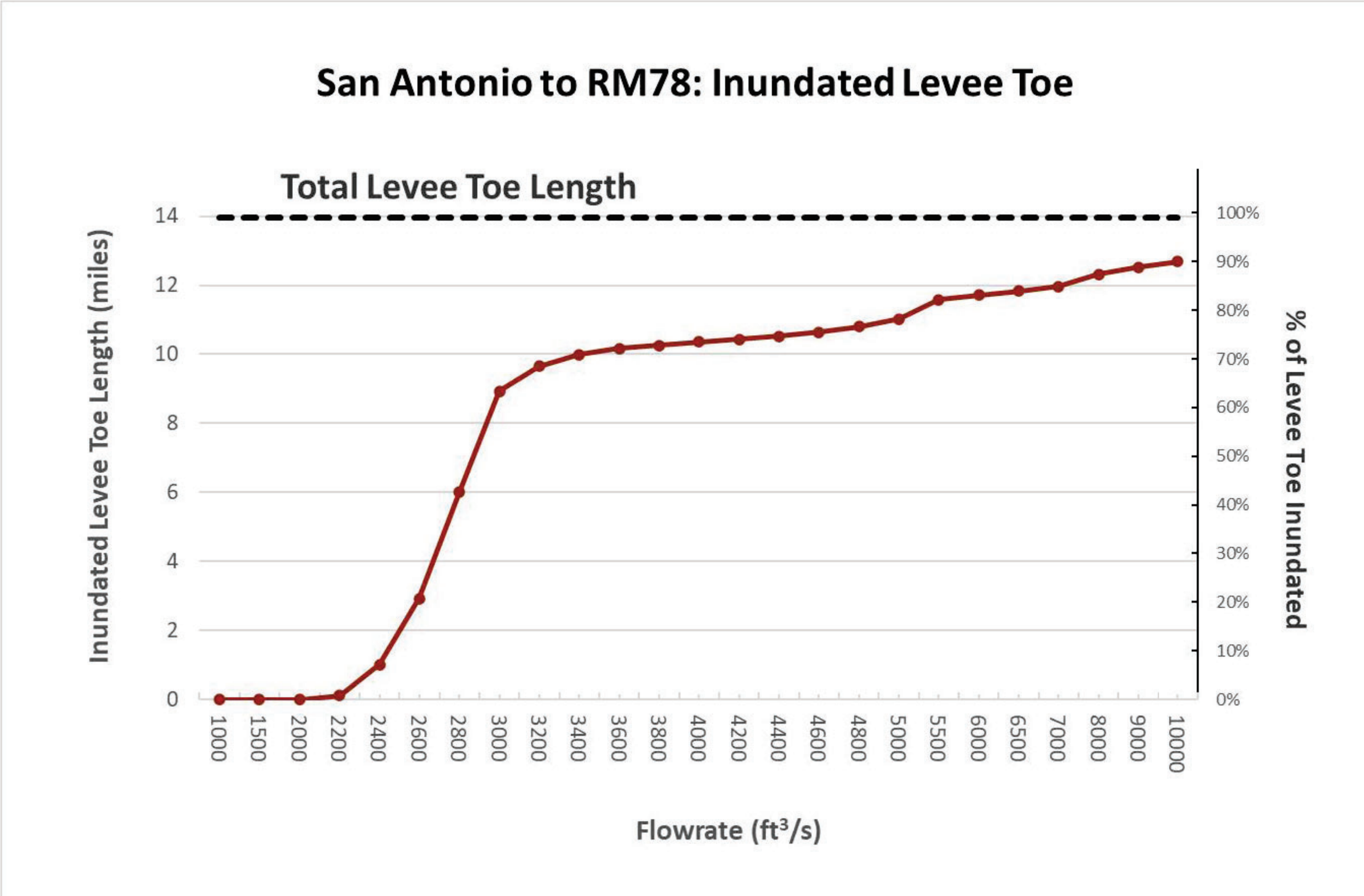


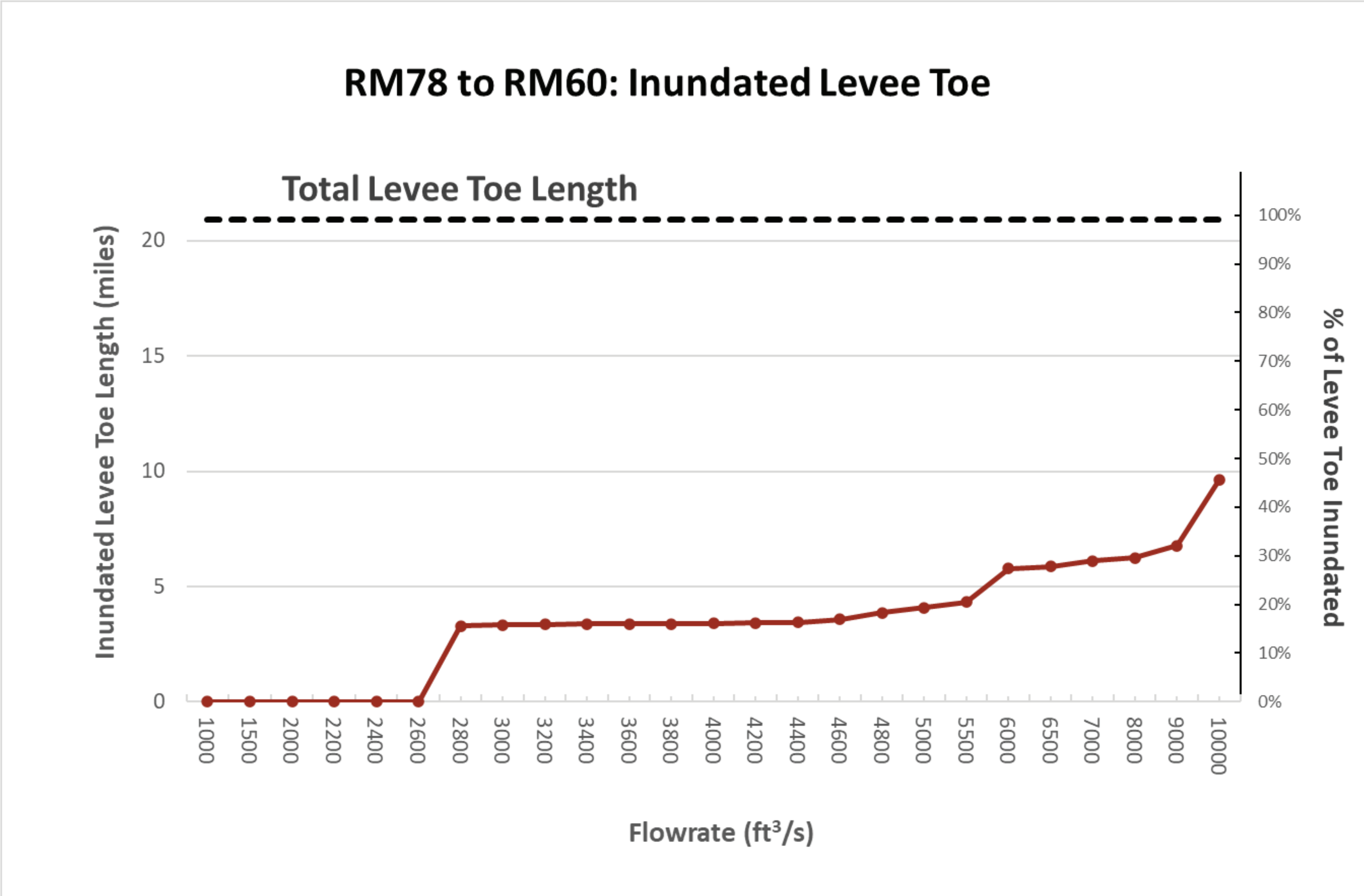
Rio Puerco Confluence to San Acacia Diversion Dam: Inundated Levee Toe
Total Levee Toe Length
Inundated Levee Toe Length (miles)
% of Levee Toe Inundated
0
2
4
6
8
10
12
14
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
1000
1500
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000
Flowrate (ft³/s)


San Acacia Diversion Dam to Arroyo de las Cañas: Inundated Levee Toe
Total Levee Toe Length
Inundated Levee Toe Length (miles)
20
15
10
5
0
% of Levee Toe Inundated
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1000
1500
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000
Flowrate (ft³/s)

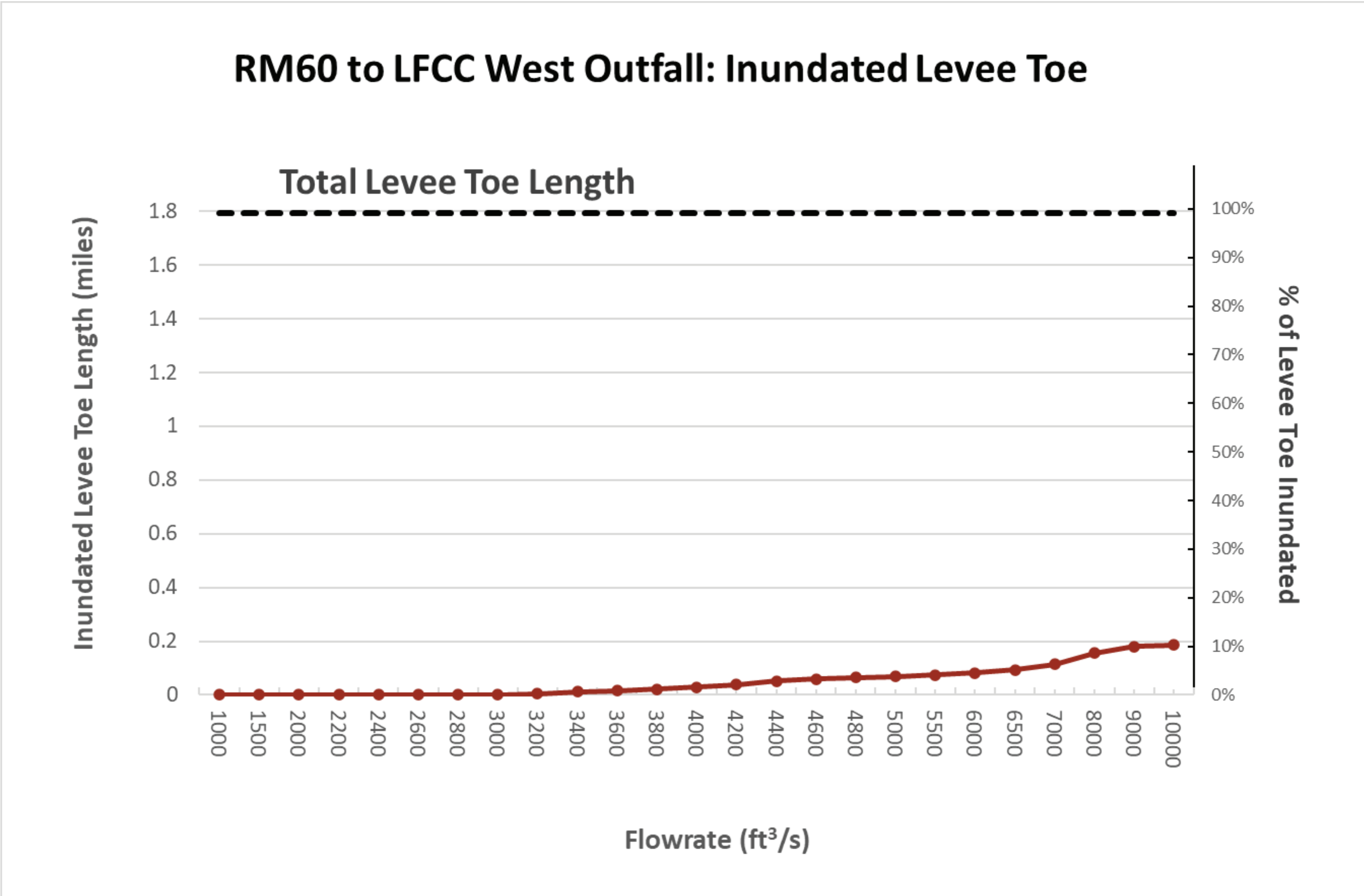


Arroyo de las Cañas to San Antonio: Inundated Levee Toe
Total Levee Toe Length
Inundated Levee Toe Length (miles)
% of Levee Toe Inundated
0
1
2
3
4
5
6
7
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
1000
1500
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000
Flowrate (ft³/s)


San Antonio to RM78: Inundated Levee Toe
Total Levee Toe Length
Inundated Levee Toe Length (miles)
% of Levee Toe Inundated
0
2
4
6
8
10
12
14
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
1000
1500
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000
Flowrate (ft³/s)



RM78 to RM60: Inundated Levee Toe
Total Levee Toe Length
Inundated Levee Toe Length (miles)
0
5
10
15
20
% of Levee Toe Inundated
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
1000
1500
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000
Flowrate (ft³/s)



RM60 to LFCC West Outfall: Inundated Levee Toe
Total Levee Toe Length
Inundated Levee Toe Length (miles)
% of Levee Toe Inundated
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1000
1500
2000
2200
2400
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
4600
4800
5000
5500
6000
6500
7000
8000
9000
10000
Flowrate (ft³/s)