MS4 STORMWATER QUALITY STUDY

FOR

NORTH DIVERSION CHANNEL WATERSHED

MAY 25, 2016

Prepared in Cooperation with:

AMAFCA

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I. SUMMARY

A municipal separate storm sewer system (MS4) Permit for the Middle Rio Grande Watershed (NPDES Permit No. NMR04A000) was issued by EPA Region 6 in December 2014. Notice of Intents were accepted by EPA for all of the MS4s by late February 2016. MS4 Permit compliance has led the Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA) to research and analyze multiple water quality components related to Albuquerque's existing stormwater system. AMAFCA and Bohannan Huston, Inc. (BHI) looked at three elements: (1) tabulation of the MS4 Permit post-construction storm event discharge volumes relative to average rainfall amounts when compared to retention requirements for the rest of the United States; (2) Analysis of the MS4 Permit post-construction storm event discharge volumes specific to two sub-watersheds in the North Diversion Channel (NDC) watershed in northeast Albuquerque; and (3) Analysis of stormwater discharge events from the North Diversion Channel into the Rio Grande to determine system volume and peak discharge reductions as well as impacts on turbidity in the Rio Grande. The research, analysis, and conclusions for these three elements are summarized in this document.

One component of the MS4 Permit addresses post-construction stormwater management in new development and redevelopment. Post-construction stormwater standards were researched for other states to provide an understanding and comparison of the numerical precipitation depths used for calculating post-construction stormwater quality volumes. Stormwater quality volumes are typically determined using a percentage of the MS4 area's precipitation. The MRG MS4 Permit bases the stormwater quality volume on the 90th percentile storm, but the 90th percentile storm is not necessarily the basis for other states' stormwater quality volumes. Table 3, page 7, shows that the MS4 post-construction standard imposed on New Mexico has the highest percentage in the country of stormwater quality volume compared to annual rainfall for both new development (7 percent) and redevelopment (5.4 percent). This research also found that for EPA Region 6 states (Arkansas, Louisiana, Oklahoma, New Mexico, and Texas), only New Mexico has a numerical post-construction stormwater management storm event discharge volume defined as a regulatory requirement in the MS4 Permit. Typically, other states throughout the U.S. define the post-construction stormwater management storm event discharge volume in stormwater drainage manuals, best management practice manuals, and in some cases, ordinances.

For the second element of this report, a high-level hydrologic analysis was conducted for the North Pino and South Pino Arroyo watersheds in the North Diversion Channel (NDC) watershed in northeast Albuquerque. The analysis calculated the runoff volume for the EPA defined 90th percentile storm event at the watershed level. The HEC-HMS model results were compared to the potential stormwater quality volumes calculated by applying the 0.615-inch 90th percentile storm to the entire existing watersheds' impervious area. The results demonstrate that the existing watersheds already largely achieve compliance with the MS4 Permit requirements to retain the 90th percentile storm event discharge volume. The analysis also demonstrates that the impacts of future development and re-development will have minimal effect on the urban hydrology, and in particular, the water quality volume over these watersheds.

In anticipation of the new MS4 Permit, and related to the third element of this report, AMAFCA constructed a structural Best Management Practice (BMP) in 2014 at the NDC outfall to the Rio Grande to reduce the stormwater quality volume and pollutant load that discharge to the river during a given storm. To monitor this BMP, AMAFCA installed a flow gage at the NDC outfall. The peak discharge and runoff volume recorded at the USGS Alameda gage, located in the NDC approximately 0.5 mile upstream of the NDC outfall, was compared to the discharge and volume at the NDC outfall to the Rio Grande recorded at the NDC outlet equipment crossing. The results show that the NDC structural BMP reduced the peak runoff by 45 percent and the volume of runoff by 55 percent - see Tables 1 and 2 below. Each individual storm was graphed and compared to turbidity measurements in the Rio Grande, and those graphs are included in Section I.C.

Table 1 – Monthly Comparison of Peak Flow Amounts

Date: 2015	NDC at Alameda Gage Monthly Summation of Peak Flows (cfs)	Discharge to Rio Grande Monthly Summation of Peak Flows (cfs)	Percent Reduction (%)
June	3,560	2,121	40%
July	8,428	3,737	56%
September	4,000	3,046	24%
October	2,510	1,095	56%
November	953	605	37%
December	540	351	35%
Totals	19,991	10,955	45%

Table 2 – Monthly Comparison of Total Volume Amounts

Date: 2015	NDC at Alameda Gage Monthly Summation of Total Volumes (ac-ft)	Volume to Rio Grande Monthly Summation of Total Volumes (ac-ft)	Percent Reduction (%)
June	434	171	61%
July	1,731	598	65%
September	879	390	56%
October	703	289	59%
November	497	380	24%
December	429	256	40%
Totals	4,673	2,085	55%

This report provides an analysis of the three components listed above related to understating Albuquerque's existing stormwater system in relationship to the MS4 Permit water quality requirements. The first element demonstrates that the MS4 post-construction standard imposed on New Mexico has the highest percentage in the country of stormwater quality volume compared to annual rainfall. In addition, placing this requirement in the MS4 Permit with a rigid numerical value takes away New Mexico's local decision making choices and authority; something other states and MS4s have been granted. AMAFCA, the City of Albuquerque, and mulptiple consulting hydrologists conclude that the analysis of Albuquerque's historical precipitation events show that the actual precipitation depth that occurs 90 percent of the time is 0.44 inches. The post-construction numerical standard should be left to the MS4s to determine and stipulate and not be a numerical requirement in the MS4 Permit.

The second element encompassed the hydrologic analysis of two large sub-watersheds in Albuquerque's NDC watershed and indicates that Albuquerque's existing development and stormwater system already largely achieve compliance with the MS4 Permit requirements to retain the MS4 Permit defined 90th percentile storm event discharge volume. This is the result of both the nature of residential development in New Mexico (i.e. the backyard effect) and the existing stormwater infrastructure of unlined arroyos, stormwater detention ponds, and water quality structures. Compliance with the MS4 Permit should account for Albuquerque's existing system which is already fundamentally achieving compliance with MS4 Permit requirements.

The third element focused on the terminal end of the NDC, which has been extensively reconfigured to provide detention of low volume runoff, diversion of low flows to the Alameda Drain, and passive water treatment facilities to capture floatables, debris, and sediment. The Alameda Drain, as part of this outfall system, provides additional benefits by attenuating peak flows and providing natural treatment of low volume stormwater flows before discharing to the river. Analysis of monitoring data shows that there is no detectable impact of NDC stormwater discharges on the quality of the Rio Grande as measured by turbidity. This element again demonstrates that Albuquerque's existing system is fundamentally achieving compliance with the MS4 Permit requirements.

A. COMPARISON OF POST-CONSTRUCTION STORMWATER MANAGEMENT PERMIT STANDARDS IN THE UNITED STATES

Prior studies conducted by the City of Albuquerque (Derivation of the 90th Percentile Precipitation for Albuquerque, Easterling Consultants, LLC, June 2013) had determined the 90th percentile storm event consists of 0.44 in. rainfall, which differs from the MS4 Permit value of 0.615 in. determined by EPA. The difference between the locally determined value and the higher federally stipulated value is the arbitrary exclusion of rainfall events below 0.10 in. in the watershed. The rainfall analysis by EPA was done without an understanding of the local weather patterns and has created a need to examine and explain the post-construction stormwater management requirements to the community.

One component of the MS4 Permit involves post-construction stormwater management in new development and redevelopment (Part I.5.b). The Permit requires that an ordinance or policy "incorporate a stormwater quality design standard that manages on-site the 90th percentile storm event discharge volume associated with new development sites and the 80th percentile storm event discharge volume associated with redevelopment sites…" EPA, in the MS4 Permit, provides reference to and requires use of an EPA Technical Report entitled "*Estimating Predevelopment Hydrology in the Middle Rio Grande Watershed, New Mexico,*" EPA Publication Number 832-R-14-007. This report provides a numerical value of 0.615 in. for the 90th percentile storm event discharge volume. The report does not specifically list an 80th percentile storm event discharge volume, though it provides a figure to extrapolate a value. Discussions and e-mails with EPA Region 6 Permitting have identified a value of 0.48 in. for the 80th percentile storm event.

Post-construction stormwater standards were researched for other states. Research began with the EPA Office of Water and Wastewater Management, Water Permits Division, "*Summary of State Stormwater Standards,*" June 30, 2011. Several additional references were used and are listed in Section III. It was difficult to determine Post-construction stormwater numerical standards because, typically, numerical values are not specified in

MS4 Permits but given to MS4's to determine and define. Often, the post-construction stormwater management requirements are non-regulatory (regarding the MS4 Permit) and defined in MS4 specific stormwater management and design manuals.

For this study, eighteen (18) states were researched around the United States to provide a comparison of the precipitation depths used for calculating post-construction stormwater quality volume. These states were selected to provide coverage of the United States with a focus on the states in EPA Region 6 and the southwest. Table 3, page 7, summarizes these findings and compares the precipitation depths for calculating post-construction stormwater quality volume to the state's average annual rainfall. This information is also shown in Figure 1, page 8, Comparison of Post-Construction Stormwater Quality Design Standards. Additional information related to Table 3 is provided in Appendix A.

This research also showed that for EPA Region 6 states (Arkansas, Louisiana, Oklahoma, New Mexico, and Texas), only New Mexico has a numerical post-construction stormwater management storm event discharge volume defined in the MS4 Permit. Research into the larger MS4s in the other EPA Region 6 states determined 0.5 in. water quality volume for Harris County, Texas (Houston area) and 0.5 in. in Norman, Oklahoma but did not find any specific numeric post-construction stormwater management values for the other states.

Table 3 and Figure 1 show that the New Mexico MS4 post-construction regulatory requirement is 7 percent of the average annual rainfall (0.615 in. / 8.9 in.) for new development compared to typically 2 to 4 percent in other states. As an example, if Georgia was held to a comparable numerical requirement as New Mexico, their 1.2 in. for calculating water quality volume would increase to (48.6 in. x 0.07) 3.4 in. and inland New York's 1 in. would increase to (39.28 in. x 0.07) 2.7 in.

The MS4 post-construction regulatory requirement for New Mexico is an unrealistic expectation compared to the rest of the Unites States. It is inequitable in terms of the relative stormwater management storm event discharge volume, requiring 7 percent of the average annual rainfall (0.615 in. / 8.9 in.) for new development compared to typically 2 to 4 percent in other states. The City of Albuquerque's locally determined 90th percentile storm event of 0.44 in. is 4.9 percent of the average annual rainfall (0.44 in. / 8.9 in.), which is still high but is more in line with other state's requirements. In addition, placing this requirement in the MS4 permit with a rigid numerical value takes away New Mexico's local decision making choices and authority; something other states and MS4s have been granted.

New Mexico MS4s were not provided an adequate opportunity to provide peer review or comments on the EPA Technical Report "*Estimating Predevelopment Hydrology in the Middle Rio Grande Watershed, New Mexico,*" which defines the regulatory numerical precipitation requirement. Finally, setting a post-construction stormwater management design standard should account for and optimize environmental, economic and social/political considerations. The EPA Technical Report "*Estimating Predevelopment Hydrology in the Middle Rio Grande Watershed, New Mexico,*" presents a methodology for estimating the predevelopment hydrology and ties the predevelopment hydrology to a post-construction stormwater management design standard, but it does nothing to address local environmental, economic and social/political considerations.

Table 3 – Comparison of MS4 Post-Construction Stormwater Quality Design Standards in the United States

EPA Region	State	Rainfall (in./yr.)	Precipitation Depth to use for Water Quality Volume (New Development) (inches)	Precipitation Depth to use for Water Quality Volume (Re-Development) (inches)	Percentage (New Development) - WQ Volume / Rainfall	Percentage (Re-Development) - WQ Volume / Rainfall
6	New Mexico	8.91	0.615	0.48	7%	5.4%
9	Arizona	7.11	0.5	0.5	7%	7%
9	Nevada	7.87	0.37	0.37	4.7%	4.7%
8	Montana	11.37	0.5	0.5	4.4%	4.4%
7	Kansas	28.61	1.2	1.2	4.2%	4.2%
8	Utah	15.31	0.6	--	3.9%	--
5	Minnesota	26.36	1	1	3.8%	3.8%
2	New York - costal	39.28	1.5	1.5	3.8%	3.8%
10	Gresham, Oregon	37.4	1.37	--	3.7%	--
4	North Carolina - costal	42.46	1.5	1.5	3.5%	3.5%
8	Colorado	15.31	0.5	0.5	3.3%	3.3%
10	Eugene, Oregon	46.6	1.4	--	3.0%	--
2	New York - inland	39.28	1	1	2.5%	2.5%
4	Georgia	48.61	1.2	1.2	2.5%	2.5%
4	North Carolina-non-costal	42.46	1	1	2.4%	2.4%
3	Maryland	41.84	1	0.9	2.3%	2.1%
10	Portland, Oregon	36	0.83	--	2.3%	--
5	Ohio	37.77	0.75	--	2.0%	Varies
6	Norman, Oklahoma	38.87	0.5	--	1.3%	--
6	Harris Co. (Houston), TX	49.77	0.5	--	1.0%	--
6	Arkansas	49.2	None	None	--	--
6	Louisiana	59.74	None	None	--	--

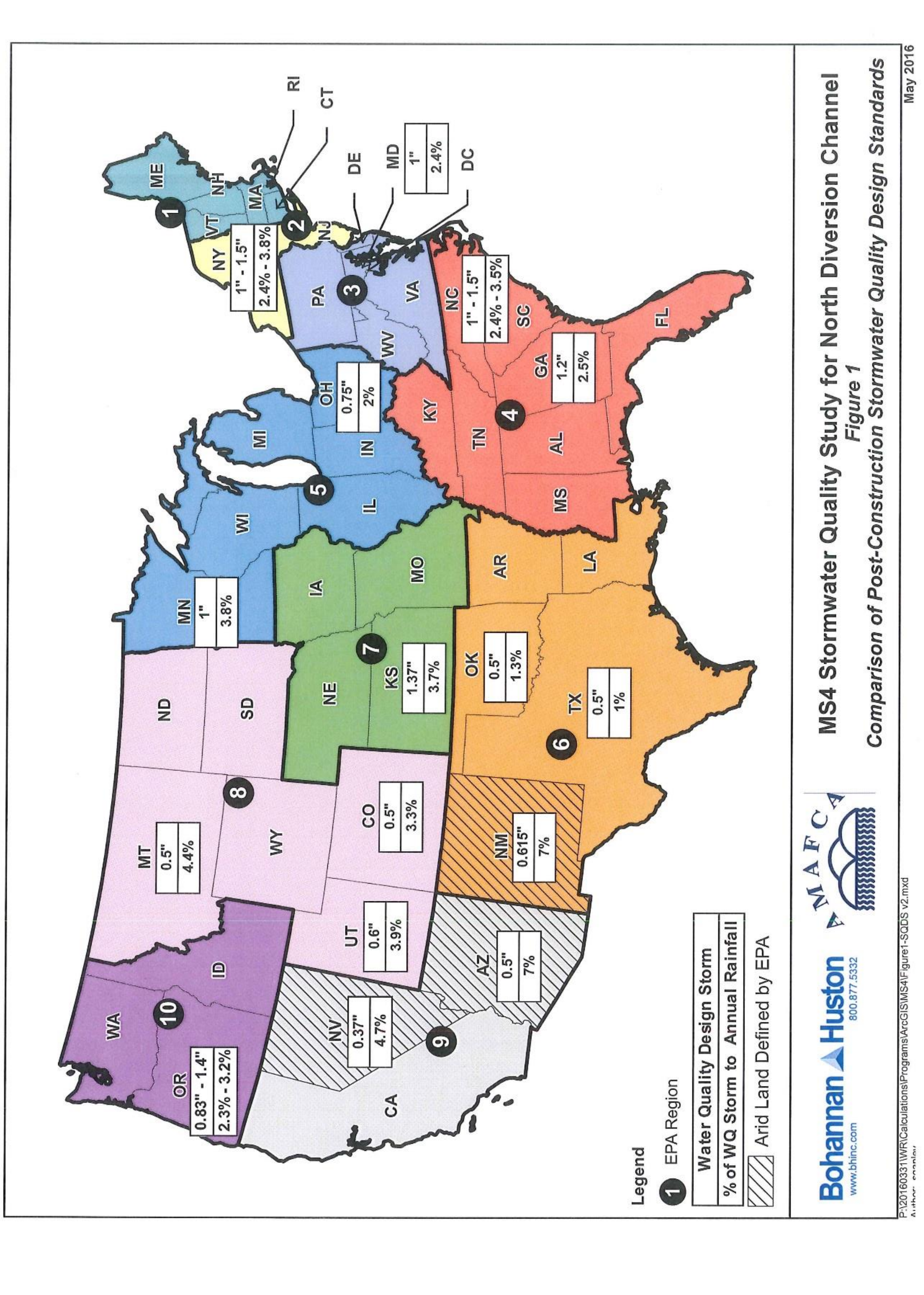

Figure 1 – Comparison of Post-Construction Stormwater Quality Design Standards

B. NORTH DIVERSION CHANNEL WATERSHED ANALYSIS OF POST-CONSTRUCTION DISCHARGE VOLUMES

The North Diversion Channel is a large concrete lined channel that collects stormwater from 11 watersheds in northeastern Albuquerque, transports it north and discharges it to the Rio Grande near the Bernalillo County-Sandoval County boundary. A high-level hydrologic analysis is currently being conducted within the North Pino and South Pino Arroyo watersheds in northeast Albuquerque, New Mexico, to determine how watershed based BMPs can be used to comply with the MS4 Permit. This initial study analyzed two of eleven watersheds that discharge stormwater into the NDC. Figure 2, page 11, shows the North and South Pino watershed basins. The basins were chosen to represent both fully developed and undeveloped conditions.

The hydrologic analysis for the two watersheds was completed using the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS Version 4.1), based on the methodology presented in AMAFCA's draft *White Paper – Migrating from AHYMO '97 to HEC-HMS (and US EPA SWMM)*, Easterling Consultants LLC, September 29, 2014 (AMAFCA White Paper). The intent of this hydrologic analysis is to provide the necessary foundation for similar studies of other NDC watersheds and to establish a hydrologic modeling framework for comparing existing stormwater runoff rates to those occurring under pre-development conditions. A future AMAFCA project will be to calibrate the models using future stormwater flow and rainfall gage data to better represent actual watershed conditions and determine loading potential for other watersheds in the AMAFCA service area.

The North Pino watershed covers a land area of approximately 1,830 acres (2.9 sq. mi.). Existing flood control facilities in the North Pino watershed include a series of ponds connected to the Quintessence Storm Drain system and AMAFCA's North Pino Water Quality Pond at the arroyo's outfall to the NDC. Covering an area of 6,646 acres (10.4 sq. mi.) the South Pino watershed flows west from the crest of the Sandia Mountains to its outfall at the NDC. The South Pino watershed contains the Pino Dam with 63 percent of its area (approx. 6.5 sq. mi.) located east of the Dam with significant area that is City Open Space or National Forest Land. Land use within each of these watersheds is shown in Figures 3 – North Pino Land Use, page 12, and Figure 4 – South Pino Land Use, page 13.

In addition to the stormwater management facilities present in the watersheds served by AMAFCA, it is vitally important to recognize the very different nature of residential development in Albuquerque and other communities in New Mexico. As is readily apparent to visitors to these communities or can be seen in high resolution aerial photography such as is available on Google Earth, nearly all residential development in central New Mexico consists of yards that are fenced in by concrete cinder block walls. With few exceptions, these fences are completely impervious to surface water flow so that nearly every backyard serves as a small detention basin, a phenomenon referred to locally as the “backyard effect.” Thus, although residential development is commonly assumed to result in increased urban runoff, in Albuquerque and other New Mexico communities this does not necessarily occur. One of the objectives of the hydrologic modeling study described below was to quantify this effect.

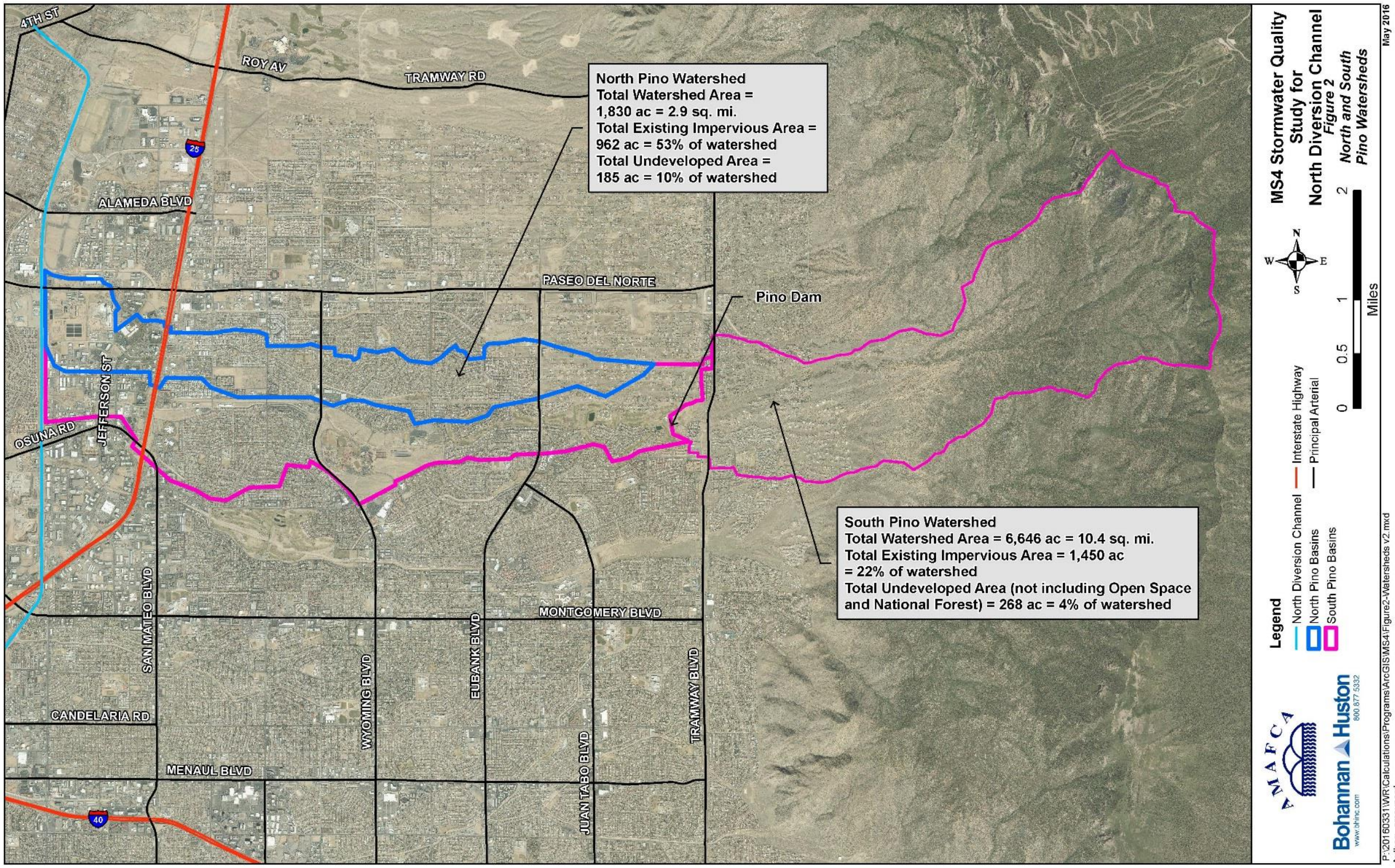

Figure 2 – North and South Pino Watersheds

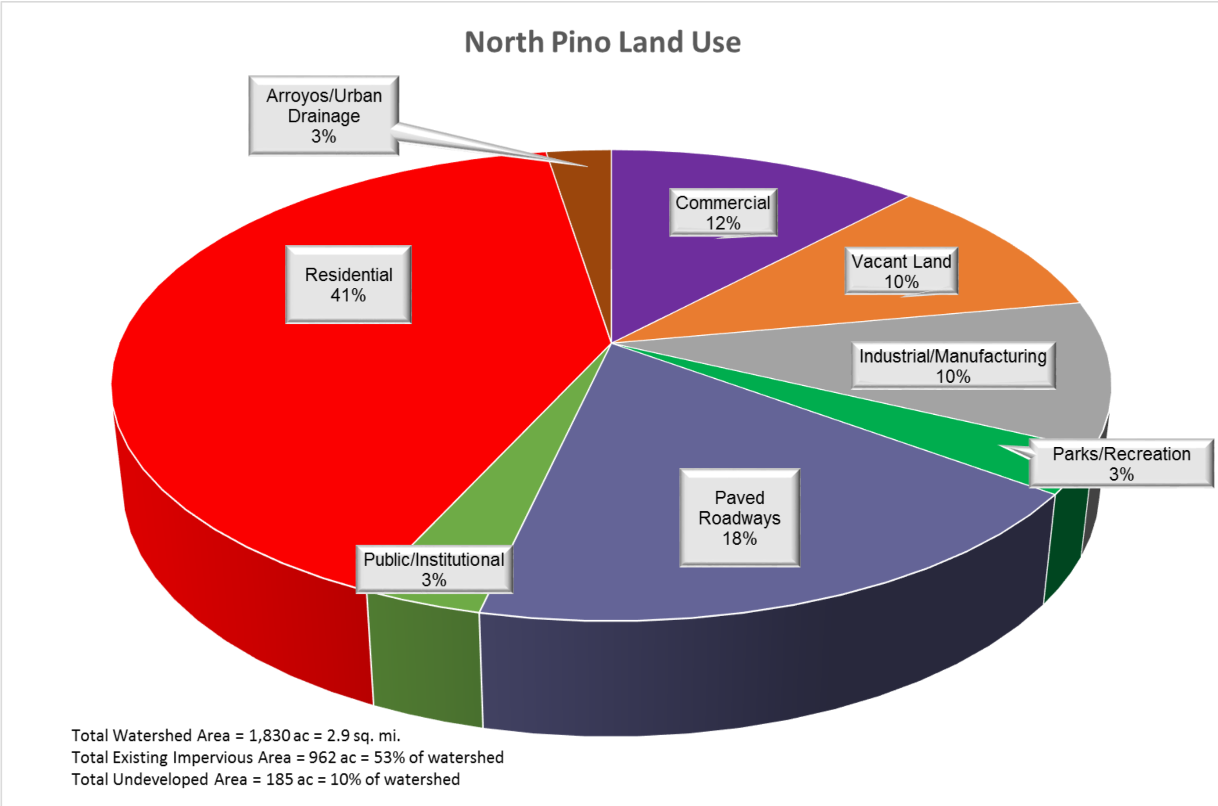

Figure 3 – North Pino Land Use

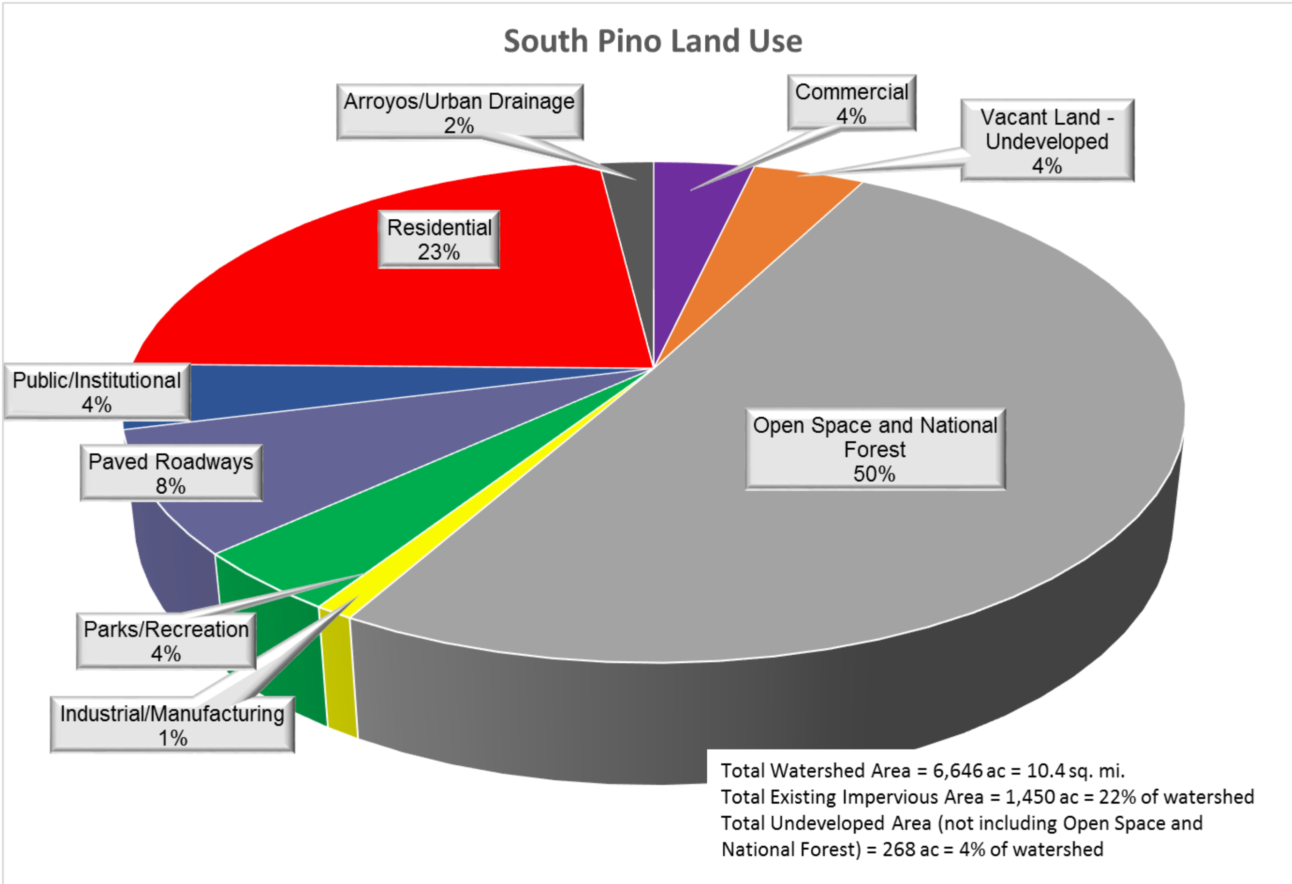

Figure 4 – South Pino Land Use

For this MS4 stormwater study, the 90th percentile storm event associated with the MS4 Permit Post-Construction required design standard for new development (0.615-inch, 24-hour storm) as defined in the EPA Technical Report entitled "*Estimating Predevelopment Hydrology in the Middle Rio Grande Watershed, New Mexico,*" was modeled as a storm in HEC-HMS for these two watersheds to determine the existing and future runoff volume for the EPA defined 90th percentile storm event in these two watersheds. The models were run for two scenarios: (1) existing conditions with existing dam (South Pino) and major stormwater quality ponds as identified on the AMAFCA maintenance/facility map and (2) existing conditions with existing dam (South Pino) and major stormwater quality ponds as well as modeling the backyard effect as a reduction to impervious area.

Hydrologic models were developed to simulate and account for the typical residential development scheme in Albuquerque where residential lots have backyards surrounded by impervious walls where portions of drainage infiltrate within these backyard areas. Runoff from most backyards will not occur in the 90th percentile storm event and other small rainfall events. To account for the backyard effect, the directly connected impervious area was reduced in the hydrologic models. The amount of reduction was determined by looking at typical low, medium, and high density residential developments in the watersheds to determine a typical impervious area per lot that drains to the backyard. The backyard reduction, applied to each sub-basin, reduces the directly connected impervious area by 3 to 7 percent for the North Pino sub basins and by 0 to 7 percent for the South Pino sub basins. Additional calculations related to this are provided in Appendix B.

The HEC-HMS model results for the two development scenarios were compared with the runoff volume calculated by applying the 0.615 in. 90th percentile storm to the entire existing watershed impervious area to calculate a potential runoff volume for each watershed. This is the potential volume of runoff that EPA's 90th percentile storm event would produce over the watershed's impervious area, not accounting for any watershed infiltration, evaporation, or system reductions. One way to envision this is the total summation of potential runoff from the existing developed sites in each watershed if they had to retain EPA's 90th percentile storm event. The two hydrologic analysis scenarios and the potential volume of runoff from EPA's 90th percentile storm event are shown in Figure 5 – North Pino – EPA 90th Percentile Storm Event – Existing Conditions – Runoff Volume Comparisons, page 16, and Figure 6 - South Pino – EPA 90th Percentile Storm Event – Existing Conditions – Runoff Volume Comparisons, page 17.

When modeling the EPA 90th percentile storm event, accounting for the backyard effect, runoff volume is reduced by 17 percent over the South Pino watershed. For the North Pino Watershed, the backyard ponding reduces the runoff volume approximately 9 percent.

Figures 5 and 6 demonstrate that, on a watershed level, accounting for watershed level losses (surface depressions, interception by vegetation, infiltration and evaporation) and system reductions, the runoff volume for the 90th percentile storm event is lower than the volume of runoff that EPA's 90th percentile storm event would produce over the watershed's impervious area (49 ac-ft runoff for the North Pino and 74 ac-ft runoff for the South Pino). On a small development site, which is how the MS4 post-construction stormwater design standard is applied, the post-construction stormwater design criteria required by the MS4 Permit does not account for watershed and system wide reductions. The existing watershed available stormwater quality volume is the difference between the potential volume of runoff that EPA's 90th percentile storm event would produce over the watershed's existing impervious area and the runoff volume computed by the hydrologic model – this runoff volume reduction is occurring in the existing systems of these watersheds when analyzed on a larger, watershed level verses a project or site level.

Albuquerque's existing flood control and stormwater quality systems function to reduce the stormwater runoff peak flows reaching the Rio Grande. These stormwater systems include the operation of a large network of regional water quality and flood control facilities by AMAFCA, the City of Albuquerque (COA), and Bernalillo County. In addition, Albuquerque's historical residential development scheme (i.e. the backyard effect) functions as small on-site detention facilities throughout the watershed. Also, stormwater conveyance toward the NDC in this area of Albuquerque is through a series of constructed channels and natural arroyos (typically these conveyances are part of AMAFCA's backbone infrastructure) with an emphasis not only on flood control but also on water quality. Examples of the channel water quality components include disconnected impervious areas (ex. sections of arroyo are unlined, natural earthen sections), water quality structures in detention ponds, and widely dispersed use of water quality manholes (i.e. small passive treatment structures to remove floatables and sediment before storm drains discharge to AMAFCA channels).

Essential to the regional BMPs is the NDC itself and its outfall, which functions as a facility to treat nearly half of the stormwater originating from Albuquerque's entire watershed. The NDC and its tributary channels function as an integrated system that collects stormwater throughout the 11 watersheds, attenuates its flow and provides treatment to remove floatables, trash, and sediment from stormwater before discharging it to the Rio Grande. The NDC provides Albuquerque with an effective system, where other cities may have numerous discharge points directly into a river, the NDC provides flood control, water quality protection, and a single controlled outlet to the river.

The NDC outlet was recently re-designed by AMAFCA as a Stormwater Quality Facility, and recent analysis has shown that the outfall reduces the volume of stormwater released into the Rio Grande at the NDC outfall by 55 percent and the peak runoff by 45 percent for small storms (refer to Section I.C). This is accomplished by directing approximately 50 cfs from the NDC into the Alameda Riverside Drain, an earthen channel that conveys drain flows and stormwater approximately 22 miles to the south before it discharges to the Rio Grande. This configuration for conveying the NDC runoff to the Rio Grande takes advantage of existing regional infrastructure and provides stormwater quality improvement by reducing the peak runoff, reducing the runoff volume, prolonging UV contact time for enhanced disinfection, providing natural treatment of contaminated stormwater by physical and biological filtration by aquatic vegetation along the length of the drain.

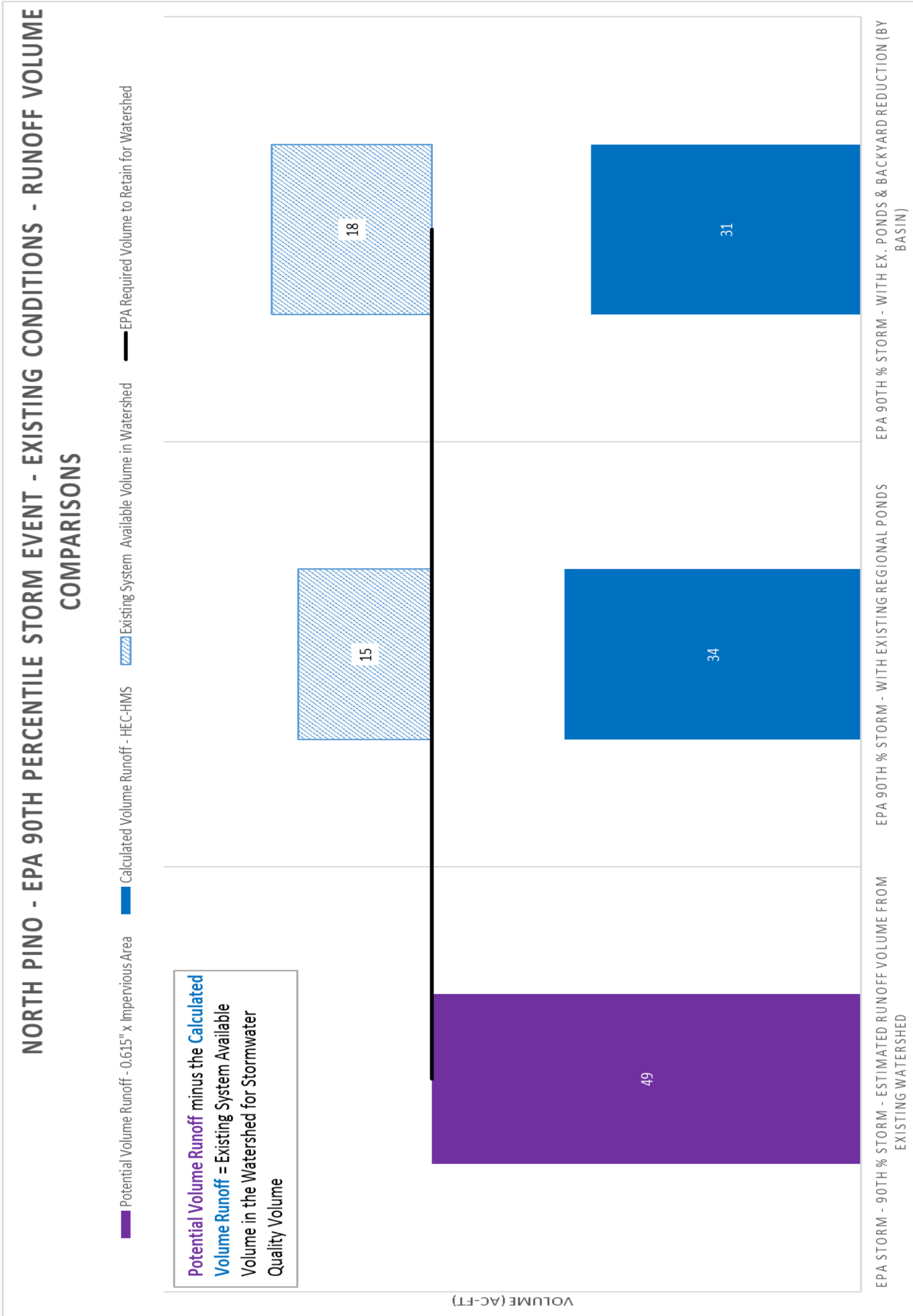

Figure 5 – North Pino – EPA 90th Percentile Storm Event – Existing Conditions – Runoff Volume Comparisons

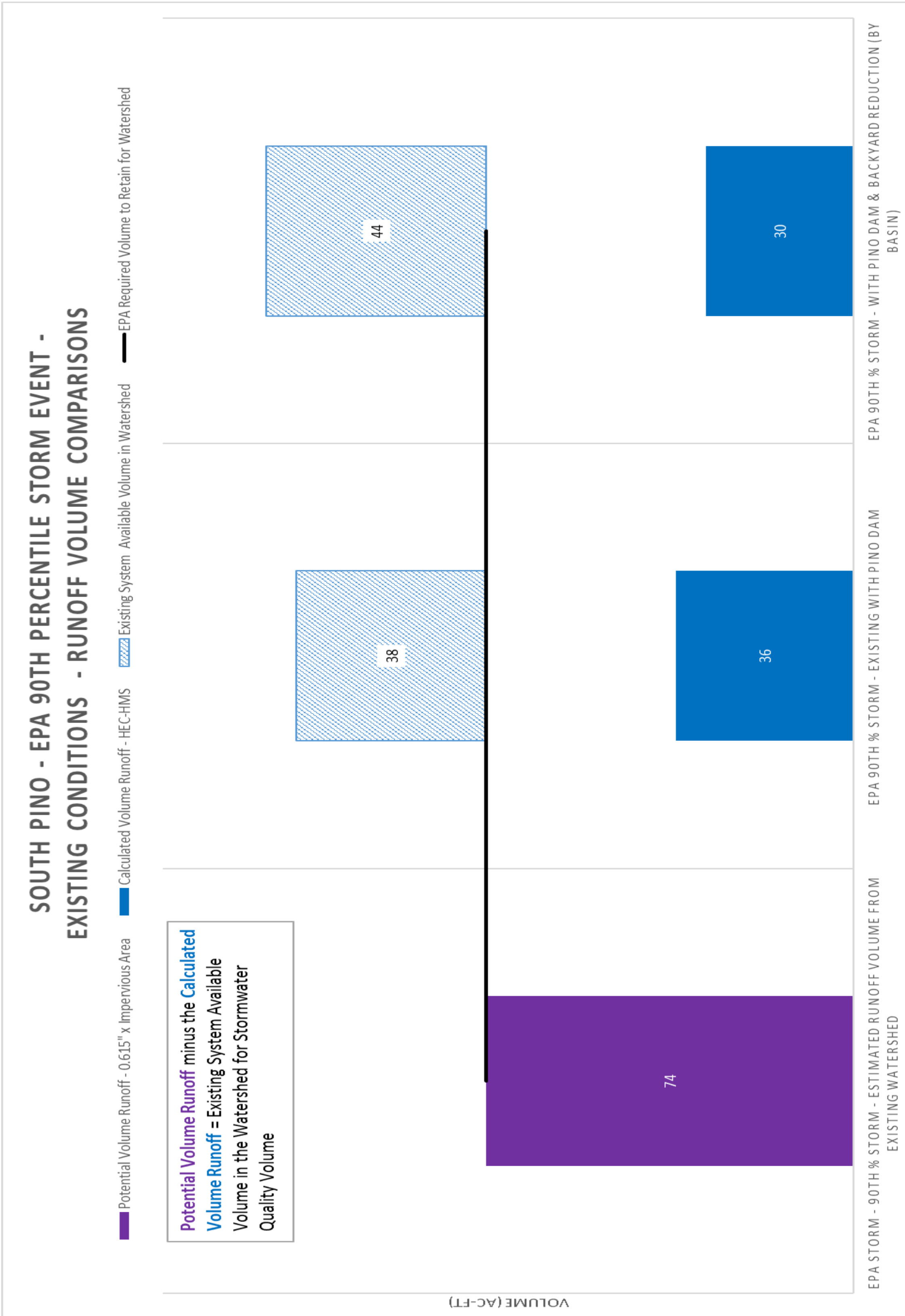

Figure 6 – South Pino – EPA 90th Percentile Storm Event – Existing Conditions – Runoff Volume Comparisons

The North and South Pino watersheds were analyzed to determine what areas in the watershed could be developed (new development) or potentially redevelop. It was assumed that half of all undeveloped land (not including City Open Space or National Forest) will develop as new development and as an estimate, this same acreage was used as potential redevelopment areas throughout the watershed. The new and redevelopment is assumed to occur at the same average percent impervious as the existing sub basins in each watershed. Table 4 below summarizes the undeveloped areas and assumptions for new and redevelopment for each watershed.

Table 4 – Undeveloped Areas and Assumptions for New and Redevelopment

Watershed / Development Assumption	Area (acres)	Ave. Percent Impervious
North Pino Watershed - Undeveloped	185	47%
New Development	92.5	47%
Redevelopment	92.5	47%
South Pino Watershed – Undeveloped (Not Open Space or National Forest)	268	38%
New Development	134	38%
Redevelopment	134	38%

The runoff volume from these areas within each watershed that could develop or redevelop was calculated using the method for calculating the volume of runoff required in the MS4 Permit. The runoff volume (ac-ft) was calculated using 0.615 in. of precipitation for the new development (90th percentile storm event) and 0.48 in. (80th percentile storm event) for the redevelopment multiplied by the area (acres, see Table 2) multiplied by the average percent impervious (see Table 4). These required capture volumes, which are between 1 and 3 ac-ft, as shown in Figure 7 – North Pino – EPA 90th Percentile Storm Event – Future Conditions – Runoff Volume Comparisons, page 20, and Figure 8 - South Pino – EPA 90th Percentile Storm Event – Future Conditions – Runoff Volume Comparisons, page 21.

The post construction stormwater management of the on-site design storm event discharge volumes that is required in the MS4 Permit is already accomplished within the North and South Pino respective watersheds when viewing the design storm event discharge volumes over each watershed. Referring to the MS4 Permit Post-Construction stormwater quality design standards, on a watershed level, verses a project level/site development level analysis, shows that Albuquerque's overall existing stormwater conveyance system meets the intent and goals of the MS4 Permit. The existing watershed stormwater conveyance systems incorporate residential backyard ponding, large dams that reduce runoff volume and capture sediment, smaller water quality ponds throughout the system (on individual sites as well as on arroyos), and disconnected impervious areas (ex. sections of arroyo are unlined, natural earthen sections) that retard peak flows and facilitate infiltration. The post-construction runoff volume for sites in these two watersheds that could potentially develop or redevelop (future 3.9 to 4.6 ac-ft stormwater quality volume) is readily handled in the existing watershed stormwater system. In addition, in the NDC watershed, the ephemeral arroyos do not connect directly with the Rio Grande but rather are collected and conveyed in the NDC, which has outlet stormwater quality facilities to reduce the volume and peak discharge to the Rio Grande (refer to Section I.C).

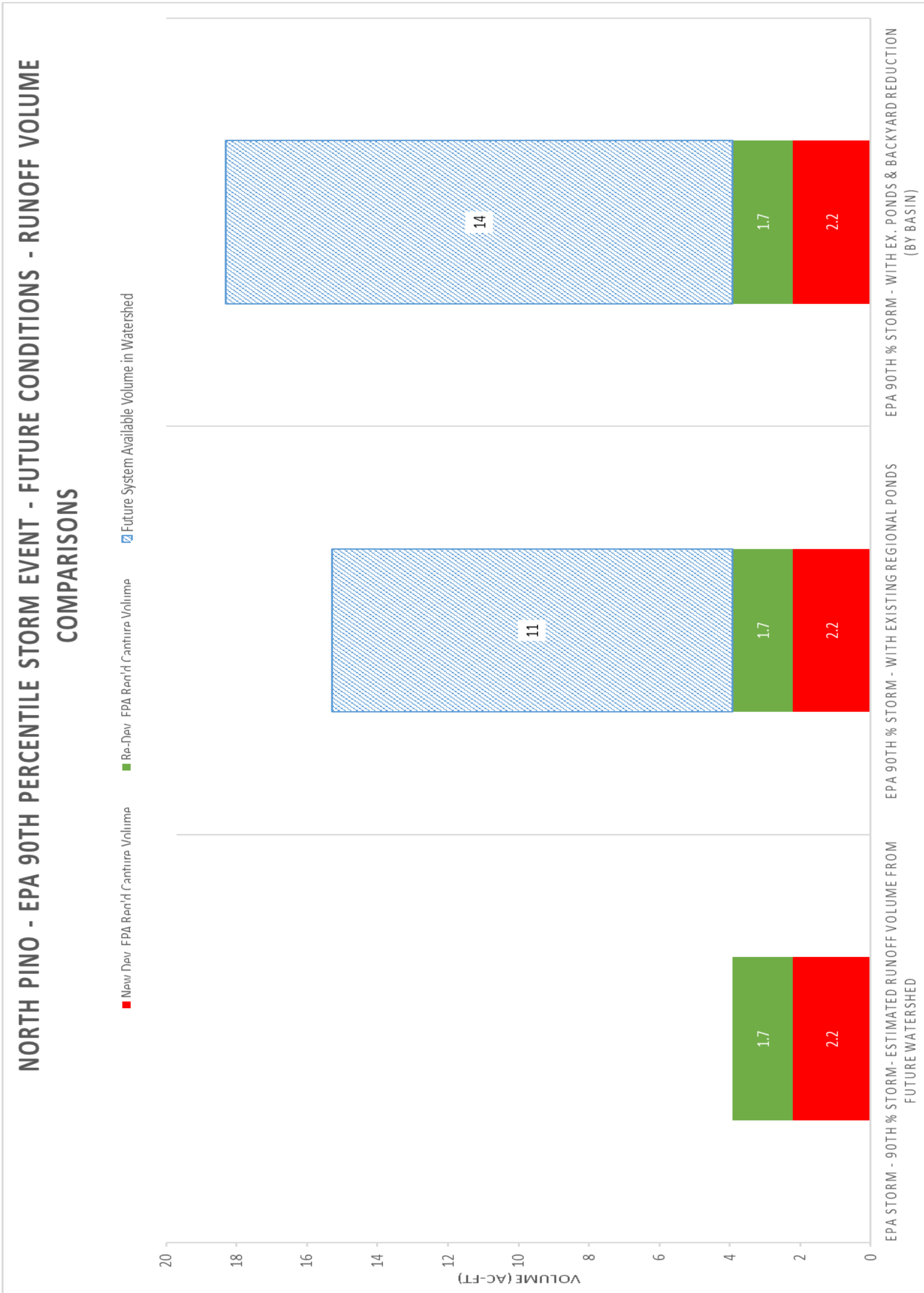

Figure 7 – North Pino – EPA 90th Percentile Storm Event – Future Conditions – Runoff Volume Comparisons

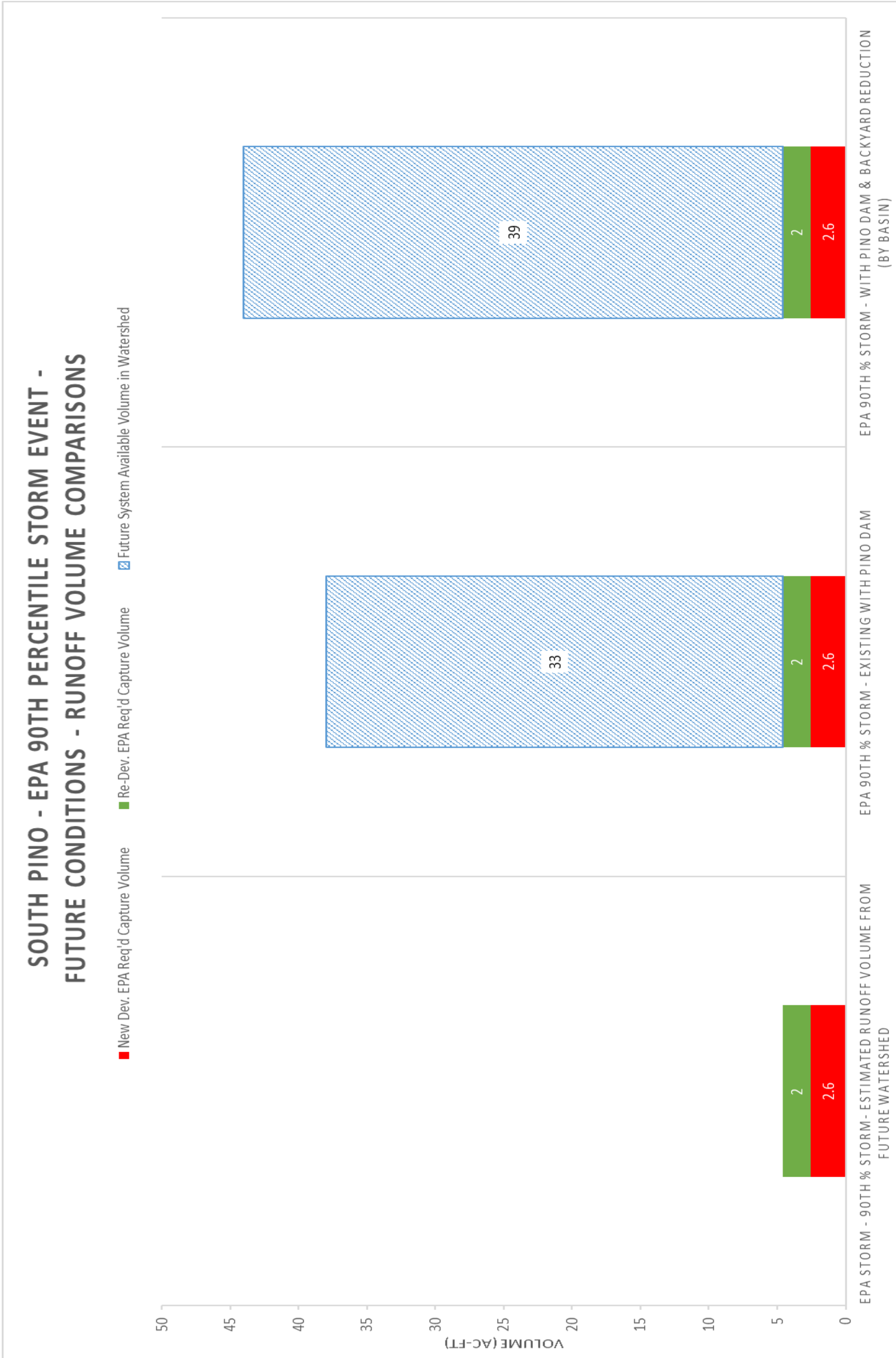

Figure 8 – South Pino – EPA 90th Percentile Storm Event – Future Conditions – Runoff Volume Comparisons

C. NORTH DIVERSION CHANNEL STORMWATER DISCHARGES – REDUCTIONS TO PEAK FLOWS AND VOLUMES AND IMPACT ON TURBIDITY IN RIO GRANDE

In an average year the North Diversion Channel (NDC) discharges approximately 5,000 acre-feet of runoff to the Rio Grande. The NDC collects runoff from approximately 95 square miles in the northeast and southeast heights of Albuquerque. AMAFCA re-designed the NDC outlet to function as a Stormwater Quality Facility that has been able to reduce the volume of stormwater released directly into the Rio Grande by 55 percent for small storms. This is accomplished by directing approximately 50 cfs from the NDC into the Alameda Riverside Drain, an earthen channel that conveys drain flows and stormwater approximately 22 miles to the south before it is discharged to the Rio Grande. This configuration for conveying the NDC runoff to the Rio Grande takes advantage of existing regional infrastructure and provides stormwater quality improvement by reducing the peak runoff, reducing the runoff volume, allowing infiltration through the long, earthen Alameda Riverside Drain, and providing natural treatment of contaminated stormwater by physical and biological filtration by aquatic vegetation along the length of the drain.

The NDC Outlet area has essentially four parts: 1) the “bathtub”; 2) the stilling basin; 3) the equipment crossing; and 4) a pipe that hydraulically connects the “bathtub” and stilling basin to the Alameda Drain. The “bathtub” is a sump area that is approximately 1,200 ft long and about half of it is a concrete rectangular channel, and the other half transitions to an earthen trapezoidal section. The stilling basin is an earthen trapezoidal channel that varies from 110 ft wide to 400 ft at the equipment crossing. The stilling basin has side slopes that are 17 ft high and riprap-lined. The equipment crossing is a concrete paved berm at the downstream end of the stilling basin that is 20 ft wide and 2 ft high built to allow maintenance equipment to cross the channel. It functions as a low head dam to detain water in the stilling basin. Low flows in the NDC are diverted to the Alameda Drain through a 36-inch pipe that conveys approximately 50 cfs when the stilling basin is full. The “bathtub” and stilling basin can hold about 72 acre-ft of stormwater. In addition to the improvements, AMAFCA set up a datalogger to track the amount of stormwater that spills over the equipment crossing to the Rio Grande. Refer to Figure 9 for a location map.

AMAFCA is using a product called the “Levelogger Edge” to measure the depth of flow over the equipment crossing which permits measurement of discharges to the river. The Levelogger is a non-vented datalogger that measures groundwater and surface water levels that are displayed as temperature compensated pressure readings and are barometrically compensated with the aid of a Barologger. AMAFCA received the M30 Levelogger and installed it at the equipment crossing on June 26, 2015. The Levelogger is located 2.30 ft below the top of the equipment crossing. AMAFCA had a rating curve developed for the equipment crossing to allow the flow rate over the equipment crossing to be calculated using the Levelogger data.

In the Rio Grande, AMAFCA, through a contract with USGS, operates several water quality sondes. These sondes measure turbidity, dissolved oxygen, temperature, electrical conductivity, and pH. Turbidity at three sondes (refer to Figure 10, page 25, for sonde locations) – US 550, Sandia Pueblo, and Central – were analyzed for each of the storm events from July – December 2015 that overtopped the NDC equipment crossing. Table 8 provides a summary of the turbidity data and Figures 11-13 show the turbidity in the Rio Grande from June through December 2015. The plots in Figures 11 through 13 show that the turbidity readings fluctuate over a large range. As the river bed shifts, which is very common, the sonde can become partially or completely buried, or clogged, and the instrument readings for all parameters then become unusable.

The NDC outlet datalogger at the equipment crossing has recorded every runoff event from the NDC to the Rio Grande that has occurred beginning on June 27, 2015, through December 15, 2015. The peak discharge and runoff volume recorded at the USGS Alameda gage are compared to the discharge and volume recorded at the NDC outlet equipment crossing in Tables 6 and 7, page 26. The results show that the NDC outlet reduced the peak runoff by 45 percent and the volume of runoff by 55 percent. Each individual storm was graphed and compared to turbidity measurements in the Rio Grande. The results of comparing the turbidity to the NDC equipment crossing flow rates show that the turbidity downstream of the NDC outlet did not increase (refer to Figures 11-47). The downstream turbidity of the river was not influenced by the stormwater discharged from the NDC.

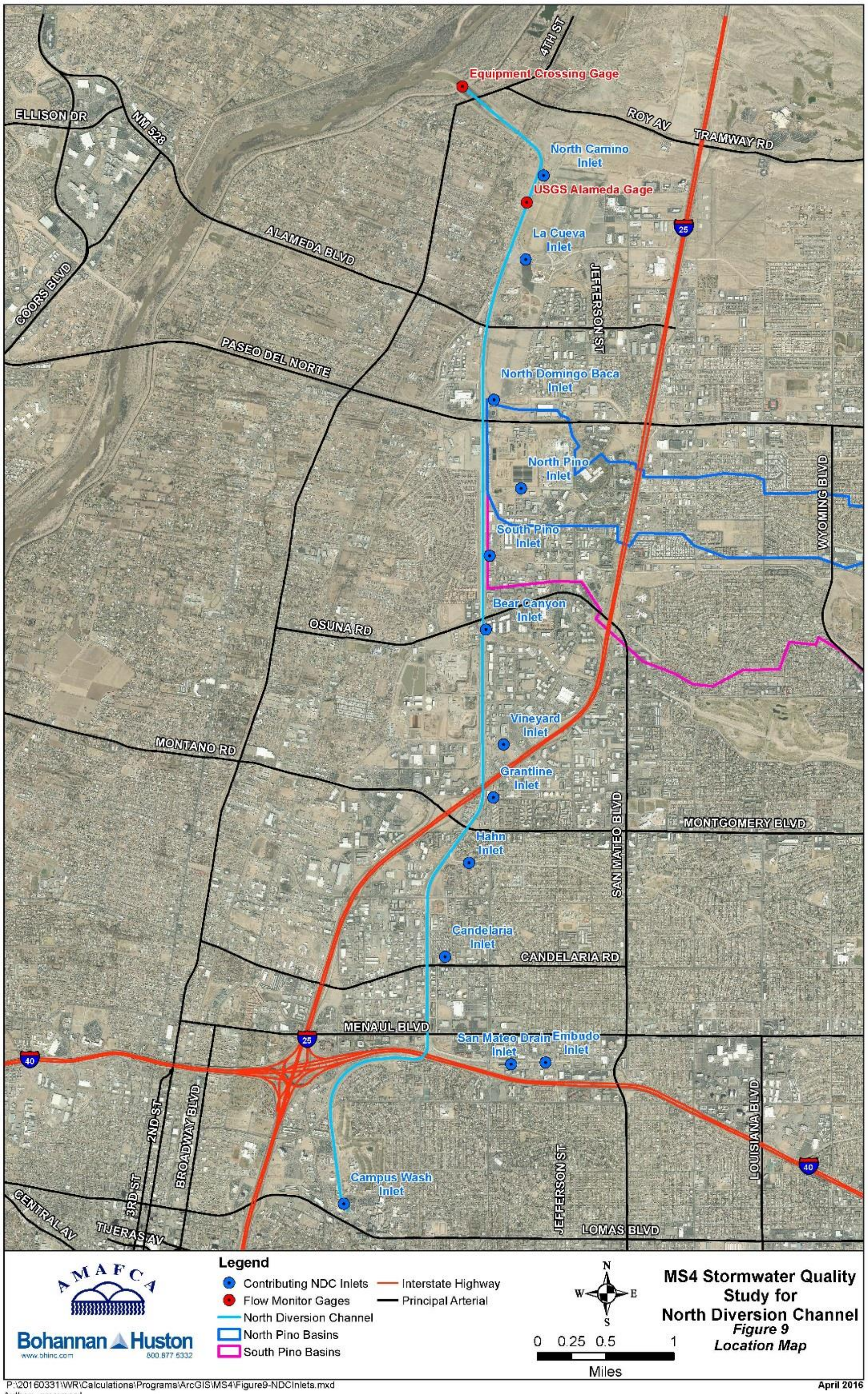

Figure 9 – Location Map

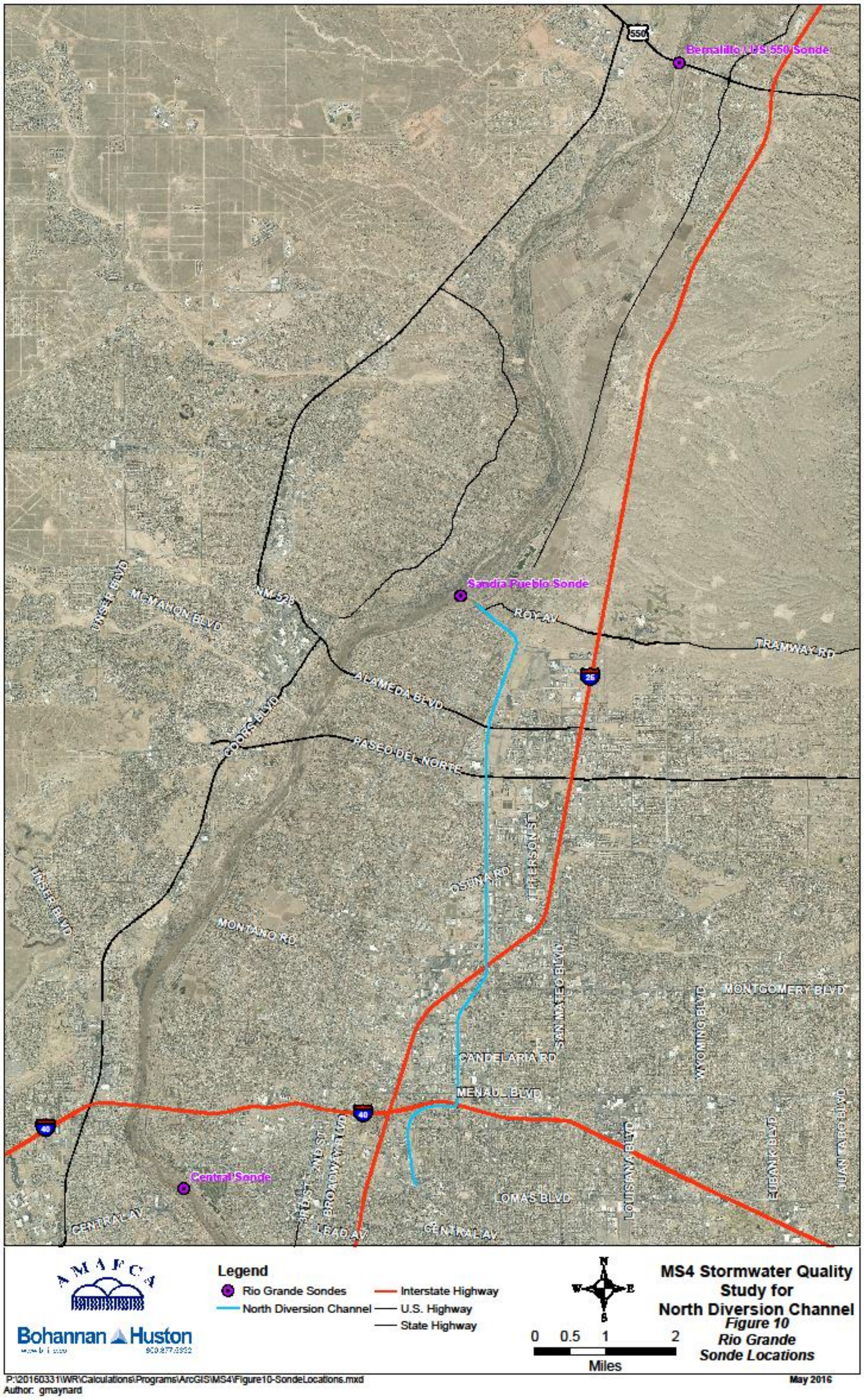

Figure 10 – Rio Grande Sonde Locations

Table 5 – Rainfall for Storm Events that Resulted in NDC Flow into the Rio Grande

Rainfall Amounts by Location *(inches)*		
	Albuquerque Sunport *(Source: Weather Underground)*	**NDC Watershed** *(Source: CoCoRaHS)*
6/27/2015	0.2	1-2
7/6/2015	0.69	0.95-1.4
7/7/2015	1.82	0.3-0.5
7/21/2015	Trace	0.1-0.3
7/29/2015	0.25	0.9-1.14
9/22/2015	1.05	0.6-1.19
10/21/2015	0.58	0.9-1.09
10/30/2015	0.13	0.2-0.37
11/4/2015	0.14	0.15-0.31
11/15/2015	0.28	0.45-0.71
11/16/2015	0.16	0.5-0.75
12/12/2015	0.64	1.1-1.2
12/13/2015	0.23	1.1-1.18

Table 6 – Monthly Comparison of Peak Flow Amounts

Date: 2015	NDC at Alameda Gage Monthly Summation of Peak Flows (cfs)	Discharge to Rio Grande Monthly Summation of Peak Flows (cfs)	Percent Reduction (%)
June	3,560	2,121	40%
July	8,428	3,737	56%
September	4,000	3,046	24%
October	2,510	1,095	56%
November	953	605	37%
December	540	351	35%
Totals	19,991	10,955	45%

Table 7 – Monthly Comparison of Total Volume Amounts

Date: 2015	NDC at Alameda Gage Monthly Summation of Total Volumes (ac-ft)	Discharge to Rio Grande Monthly Summation of Total Volumes (ac-ft)	Percent Reduction (%)
June	434	171	61%
July	1,731	598	65%
September	879	390	56%
October	703	289	59%
November	497	380	24%
December	429	256	40%
Totals	4,673	2,085	55%

Table 8 – Summary of Turbidity Results in Rio Grande (July 2015 – Dec. 2015)

Turbidity (NTU) in Rio Grande							
		Bernalillo		Sandia Pueblo		Central	
No.	Date	Storm Event Ave.	Monthly Ave.	Storm Event Ave.	Monthly Ave.	Storm Event Ave.	Monthly Ave.
1	6/27/2015	875	236	369	1,868	1	124
2	7/6/2015	No Data	719	108	131	No Data	589
3	7/7/2015	No Data	719	86	131	No Data	589
4	7/21/2015	140	719	40	131	233	589
5	7/29/2015	96	719	37	131	339	589
6	9/22/2015	653	131	262	189	374	574
7	10/21/2015	330	171	277	50	2,720	2,523
8	10/30/2015	No Data	171	No Data	50	251	2,523
9	11/4/2015	76	391	68	693	172	1,150
10	11/15/2015	113	391	540	693	1,590	1,150
11	11/16/2015	150	391	560	693	901	1,150
12	12/12/2015	No Data	429	25	1,103	742	1,017
13	12/13/2015	No Data	429	29	1,103	88	1,017

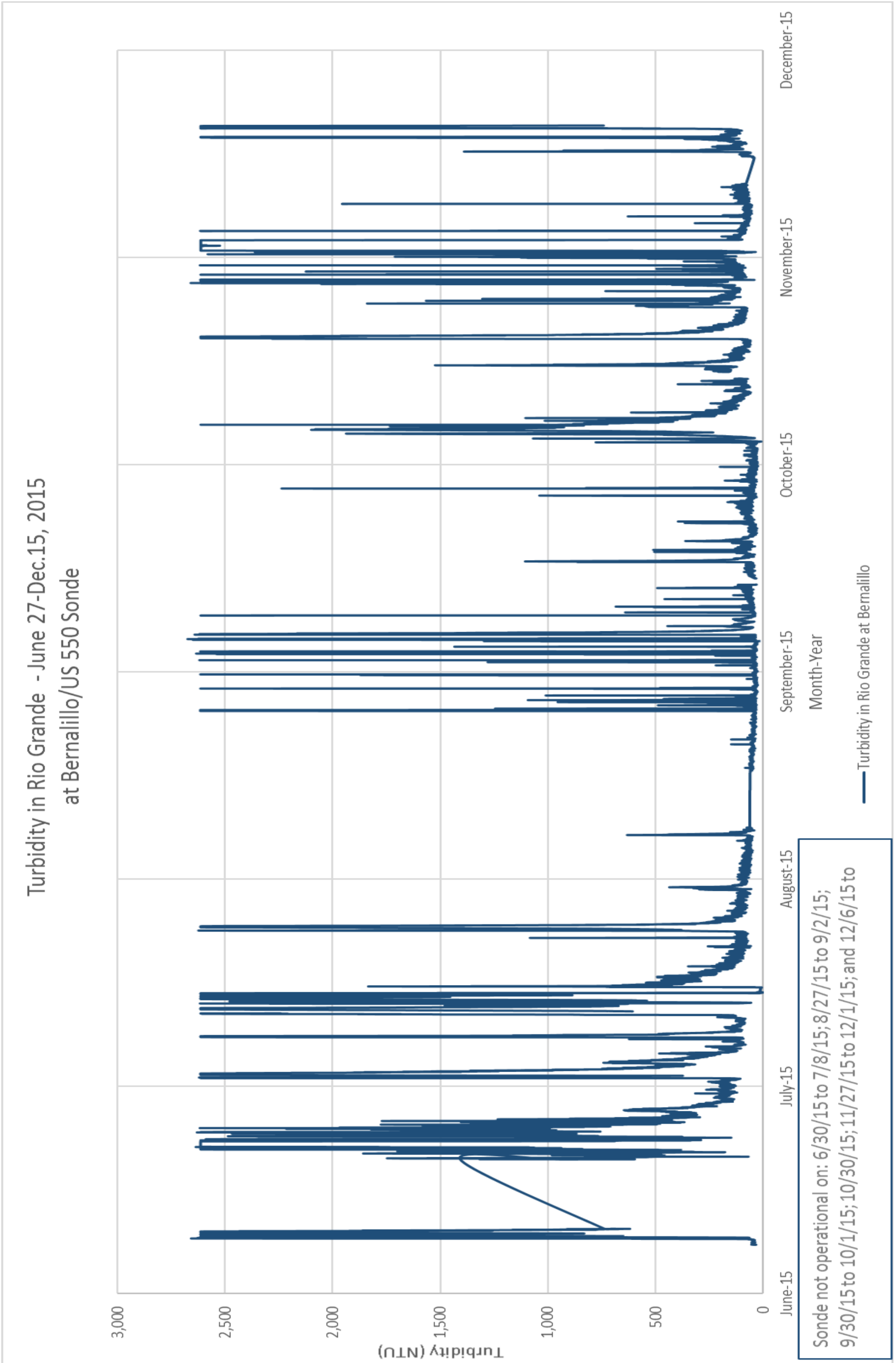

Figure 11 – Turbidity in Rio Grande at Bernalillo/US 550 Sonde

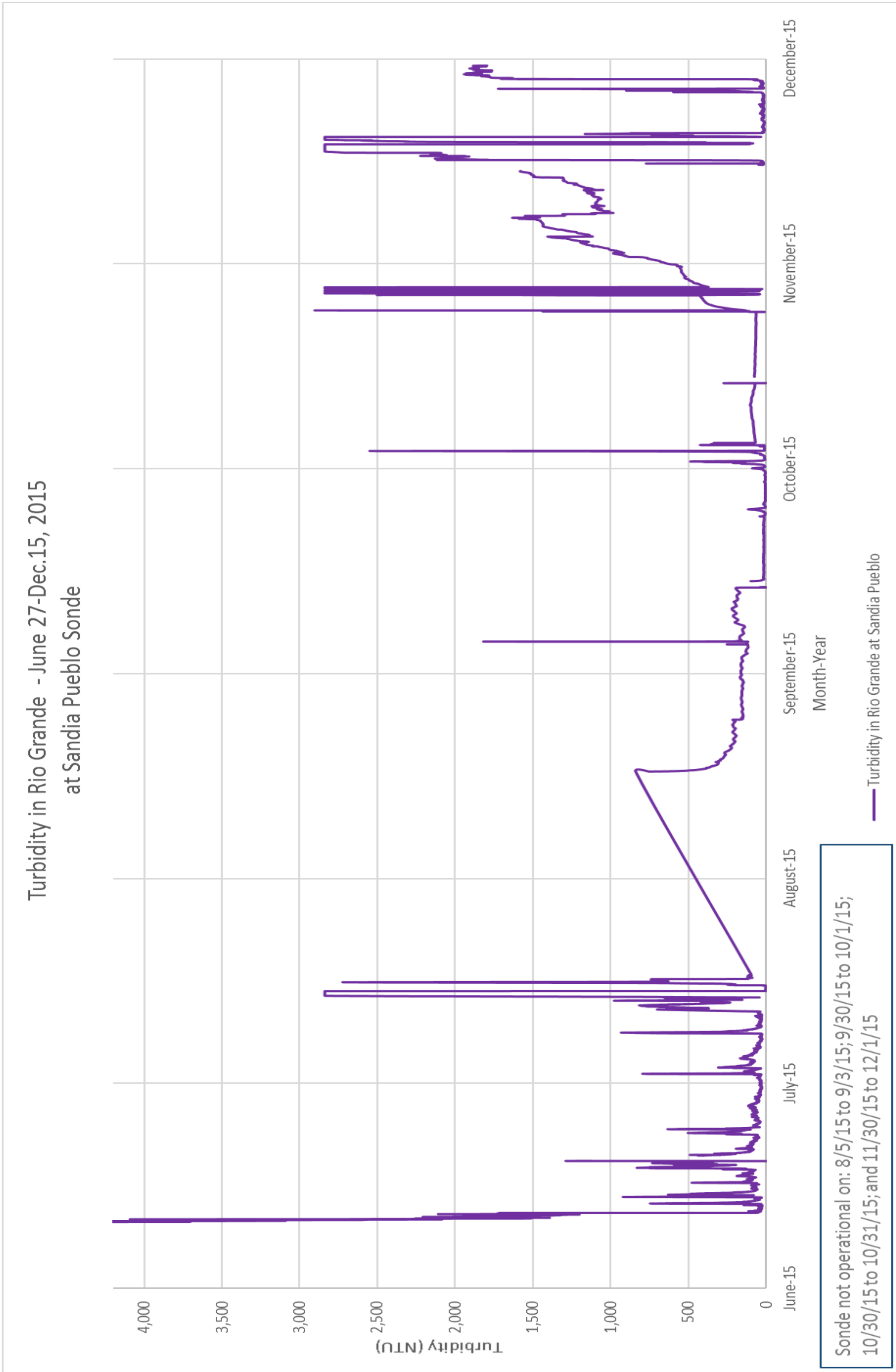

Figure 12 – Turbidity in Rio Grande at Sandia Pueblo Sonde

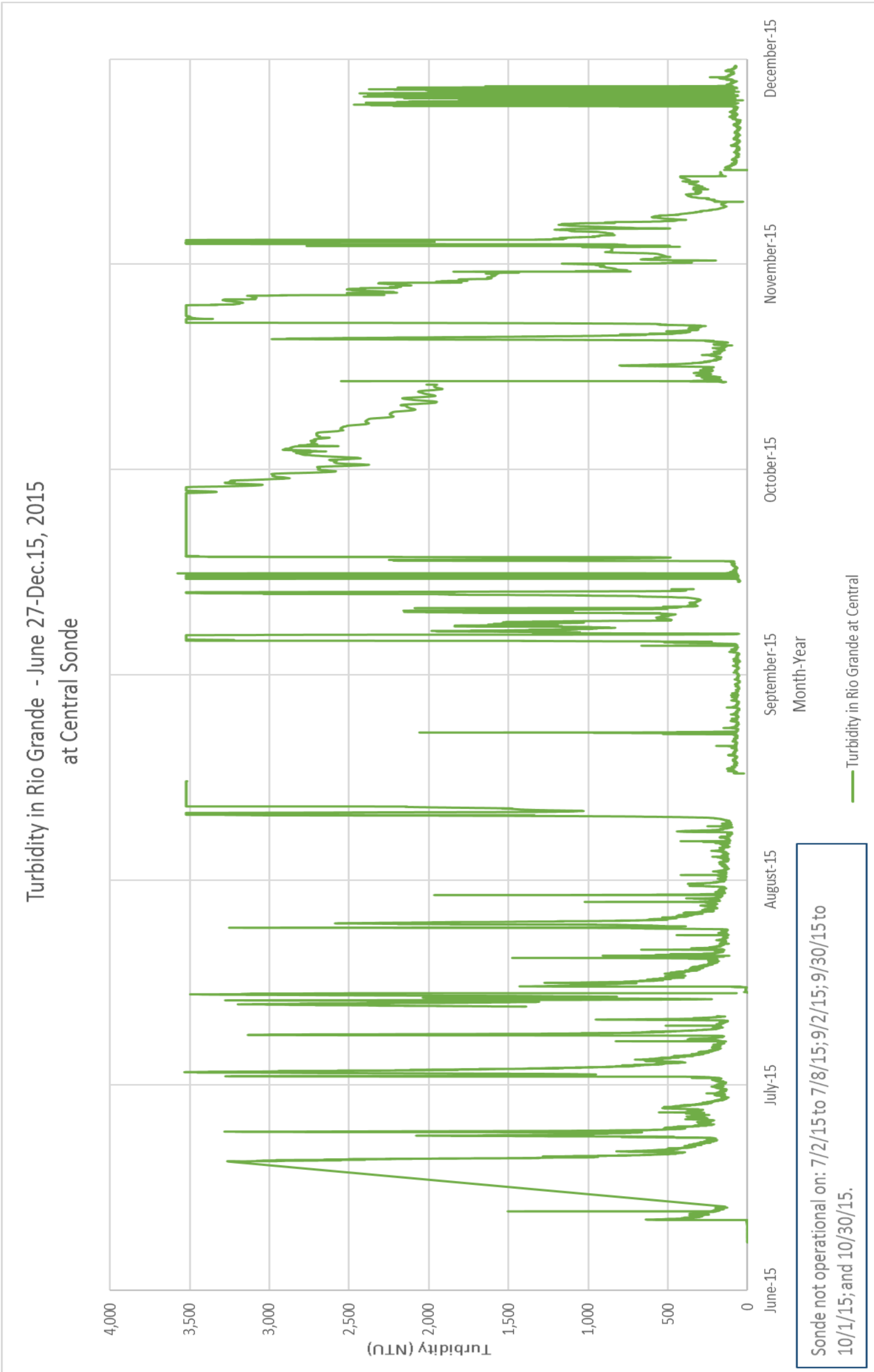

Figure 13 – Turbidity in Rio Grande at Central Sonde

1. JUNE DATA

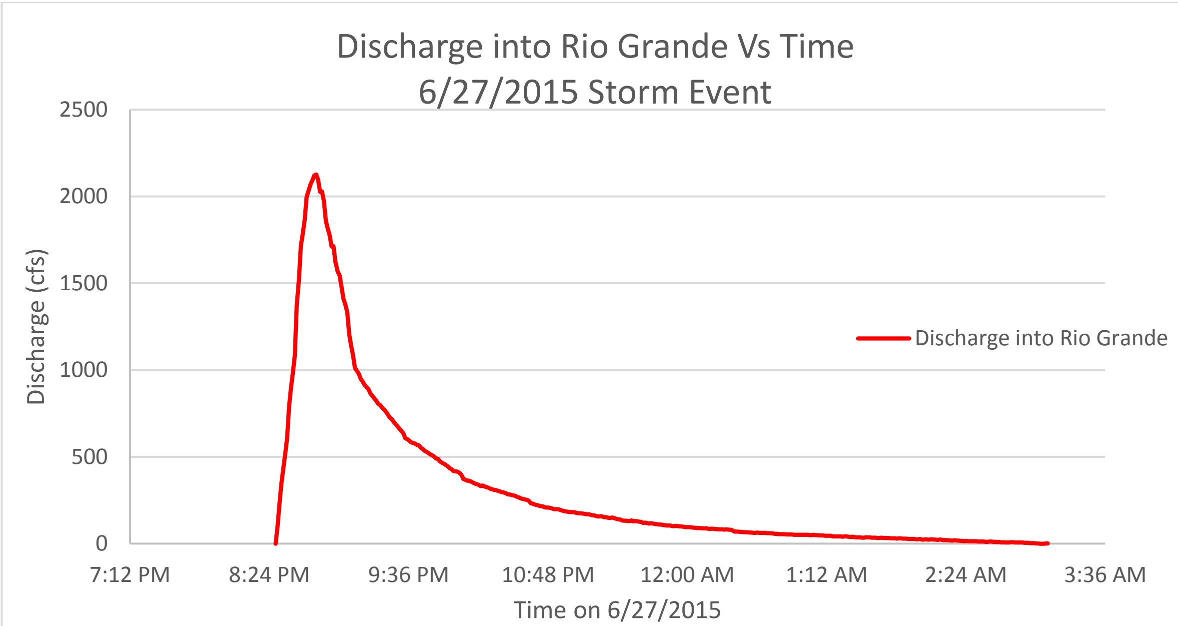

Figure 14 – Discharge into Rio Grande for June 27, 2015, Storm Event; Peak = 2,121 cfs

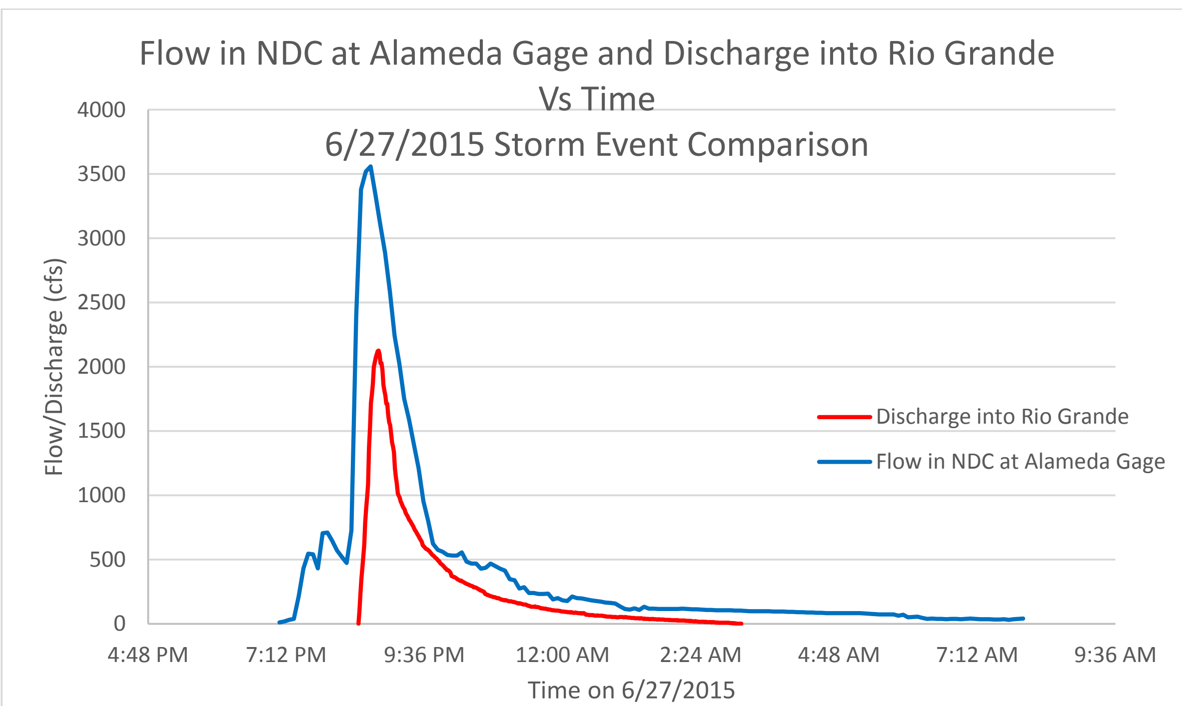

Figure 15 – Flow in NDC at Alameda Gage and Discharge into Rio Grande Vs Time for June 27, 2015, Storm Event

Total Volume in NDC at Alameda Gage

18,916,200 cubic ft.

141,493,176 gallons

434.23 ac-ft

Total Volume Discharged over Equipment Crossing from Storm

7,454,522.16 cubic ft.

55,759,825.73 gallons

171.12 ac-ft

Date	Flow Peak in NDC at Alameda Gage (cfs)	Discharge into Rio Grande Peak (cfs)	Percent Reduction (%)
6/27/2015	3,560	2,121	40%

Date	Volume in NDC at Alameda Gage (ac-ft)	Volume into Rio Grande (ac-ft)	Percent Reduction (%)
6/27/2015	434	171	61%

Rainfall Amounts by Location *(inches)*		
	Albuquerque Sunport *(Source: Weather Underground)*	**NDC Watershed** *(Source: CoCoRaHS)*
6/27/2015	0.2	1-2

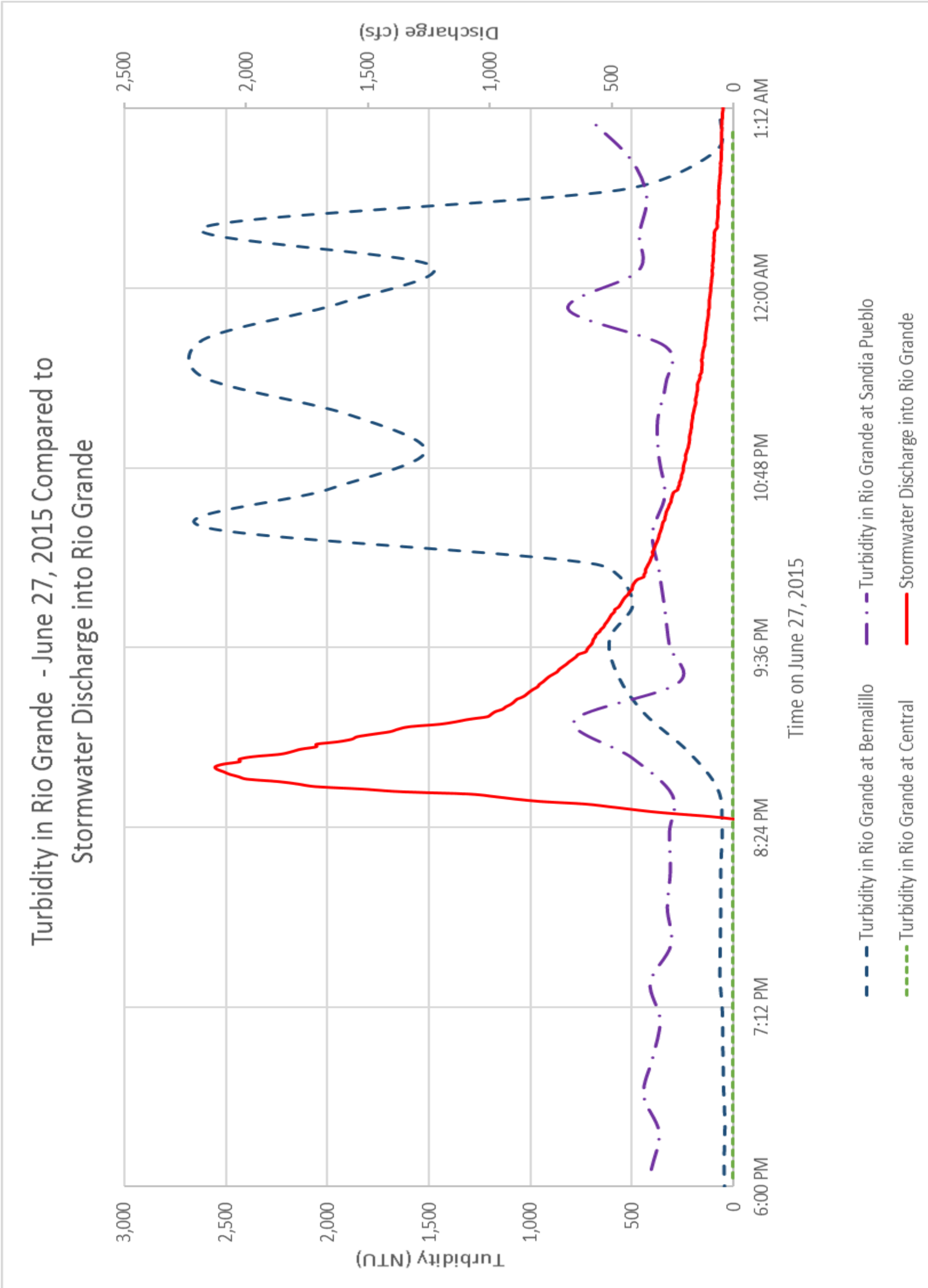

Figure 16 – Turbidity in Rio Grande – June 27, 2015

2. JULY DATA

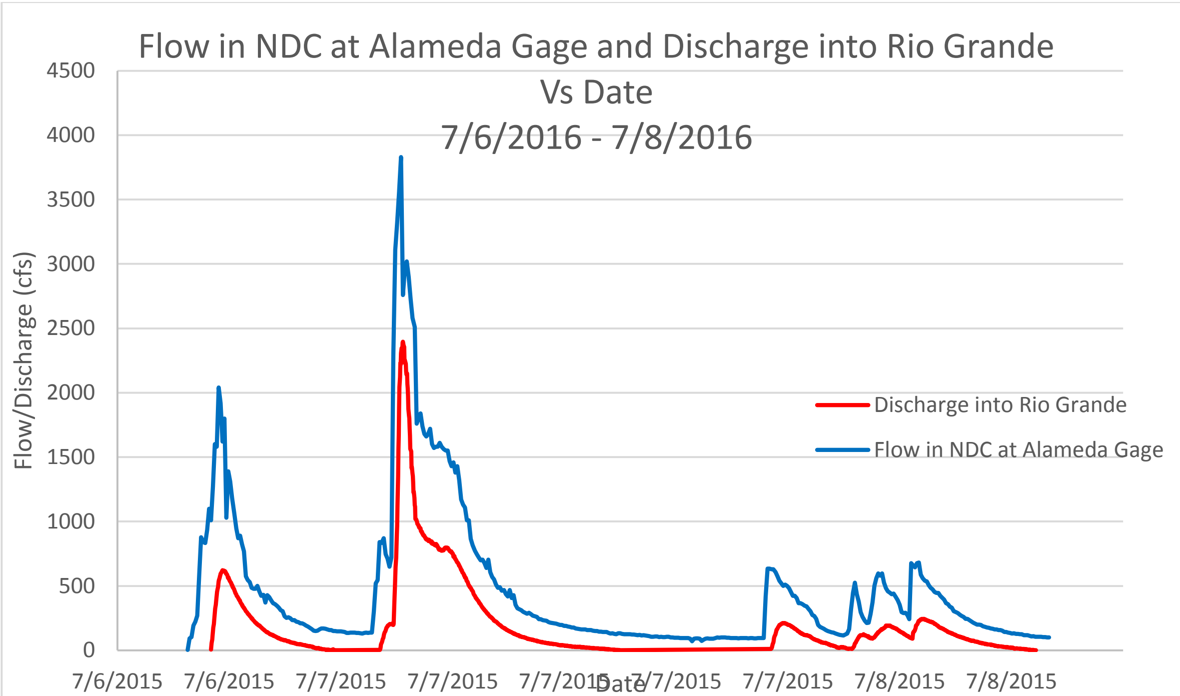

Figure 17 – Flow in NDC at Alameda Gage and Discharge into Rio Grande Vs Time for Early July Storms

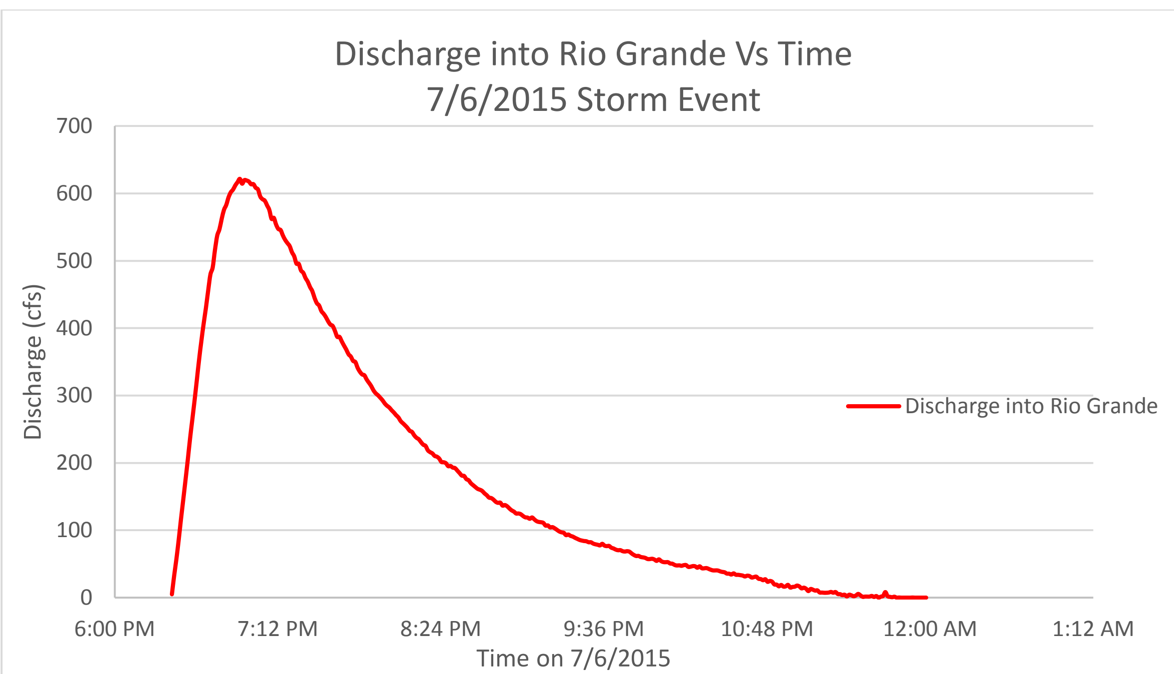

Figure 18 – Discharge into Rio Grande for July 6, 2015, Storm Event; Peak = 622 cfs

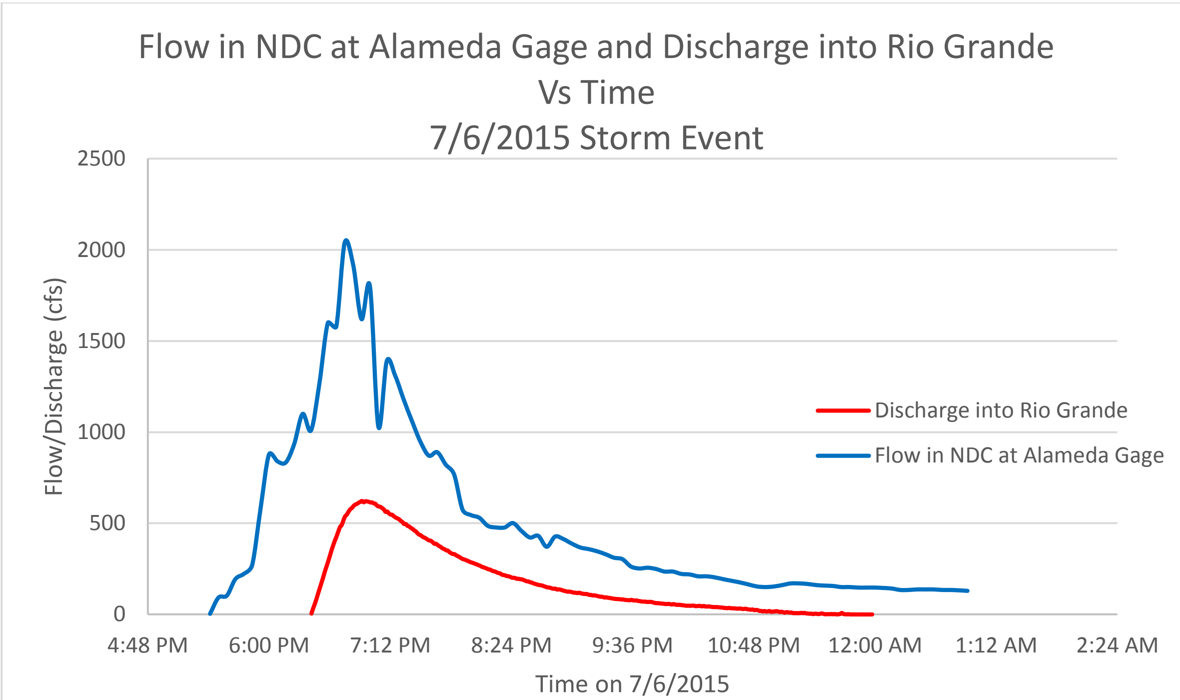

Figure 19 – Flow in NDC at Alameda Gage and Discharge into Rio Grande for July 6, 2015, Storm Event

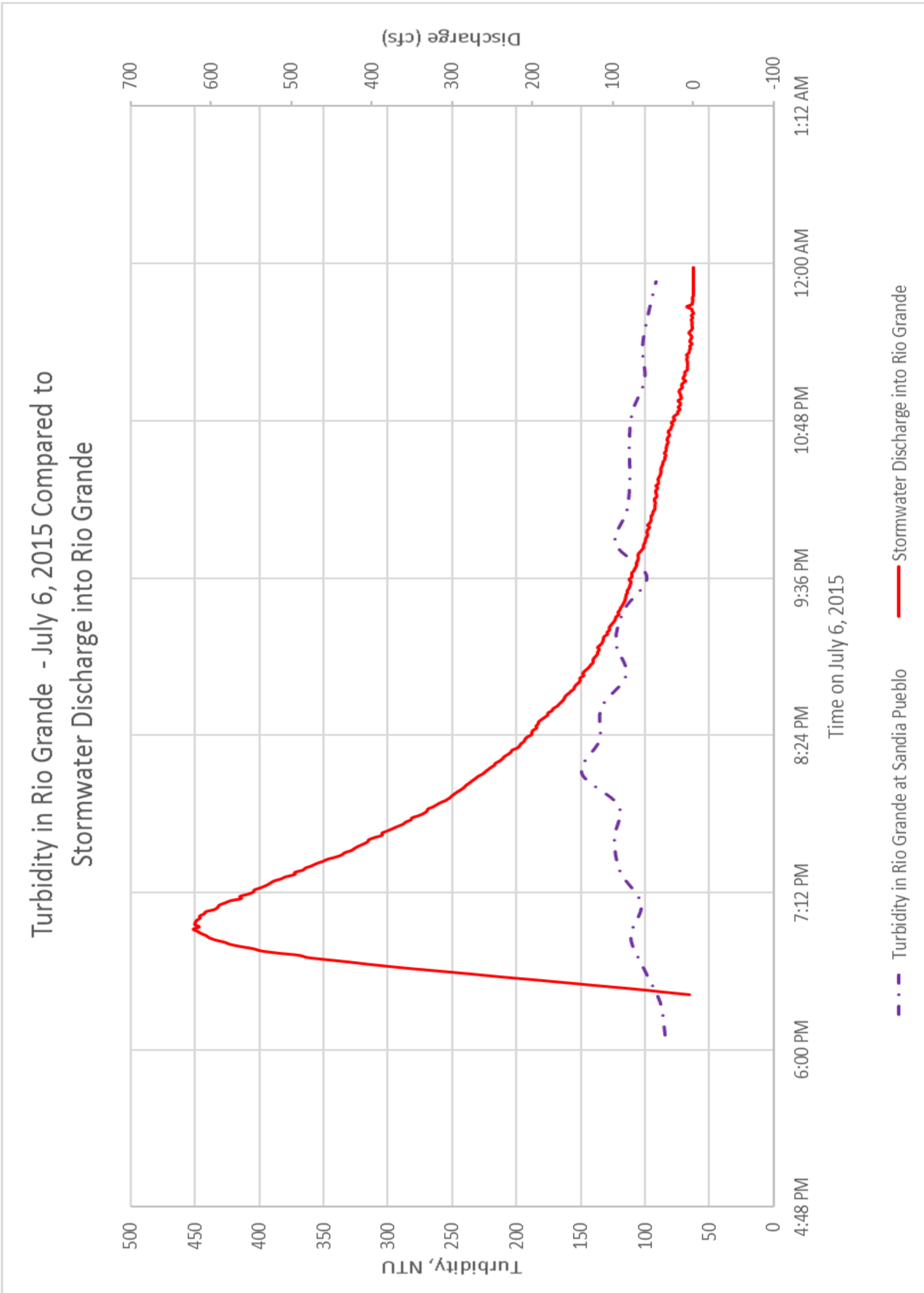

Figure 20 – Turbidity in Rio Grande – July 6, 2015

Total Volume in NDC at Alameda Gage	**Total Volume Discharged into Rio Grande**
13,432,770 cubic ft.	3,616,788.33 cubic ft.
100,477,119.60 gallons	27,053,576.72 gallons
308.35 ac-ft	83.02 ac-ft

Date	Flow Peak in NDC at Alameda Gage (cfs)	Discharge into Rio Grande Peak (cfs)	Percent Reduction (%)
7/6/2015	2,040	622	70%

Date	Volume in NDC at Alameda Gage (ac-ft)	Volume into Rio Grande (ac-ft)	Percent Reduction (%)
7/6/2015	308	83	73%

Rainfall Amounts by Location *(inches)*		
	Albuquerque Sunport *(Source: Weather Underground)*	**NDC Watershed** *(Source: CoCoRaHS)*
7/6/2015	0.69	0.95-1.4

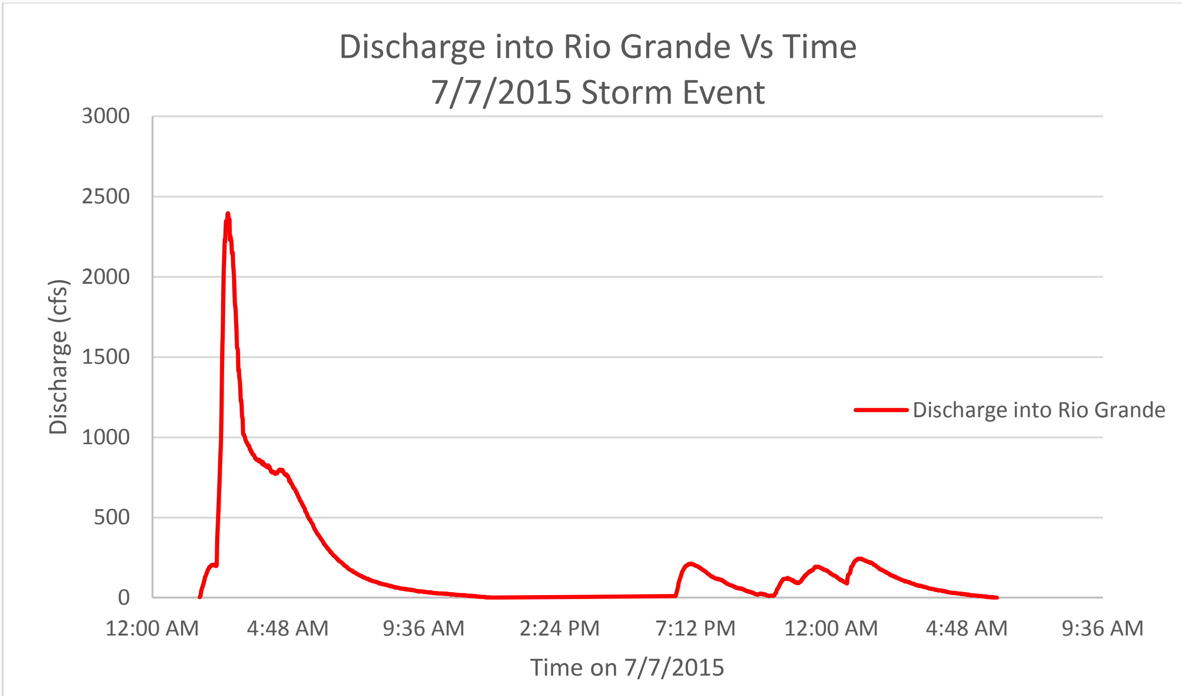

Figure 21 – Discharge into Rio Grande for July 7, 2015, Storm Event; Peak = 2,396 cfs

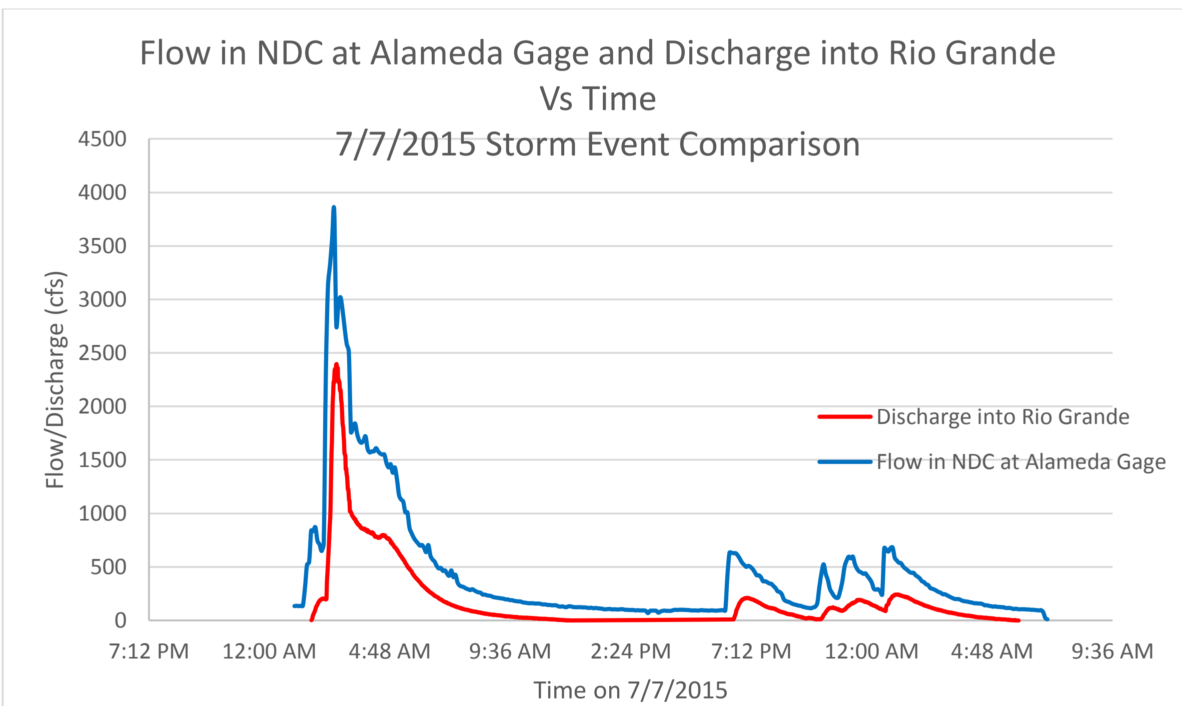

Figure 22 – Flow in NDC at Alameda Gage and Discharge into Rio Grande Vs Time for July 7, 2015, Storm Event

Total Volume in NDC at Alameda Gage	**Total Volume Discharged into Rio Grande**
48,909,300 cubic ft.	19,080,611.01 cubic ft.
365,841,564 gallons	142,722,970.33 gallons
1,122.73 ac-ft	438 ac-ft

Date	Flow Peak in NDC at Alameda Gage (cfs)	Discharge into Rio Grande Peak (cfs)	Percent Reduction (%)
7/7/2015	3,830	2,396	37%

Date	Volume in NDC at Alameda Gage (ac-ft)	Volume into Rio Grande (ac-ft)	Percent Reduction (%)
7/7/2015	1,126	438	61%

Rainfall Amounts by Location *(inches)*		
	Albuquerque Sunport *(Source: Weather Underground)*	**NDC Watershed** *(Source: CoCoRaHS)*
7/7/2015	1.82	0.3-0.5

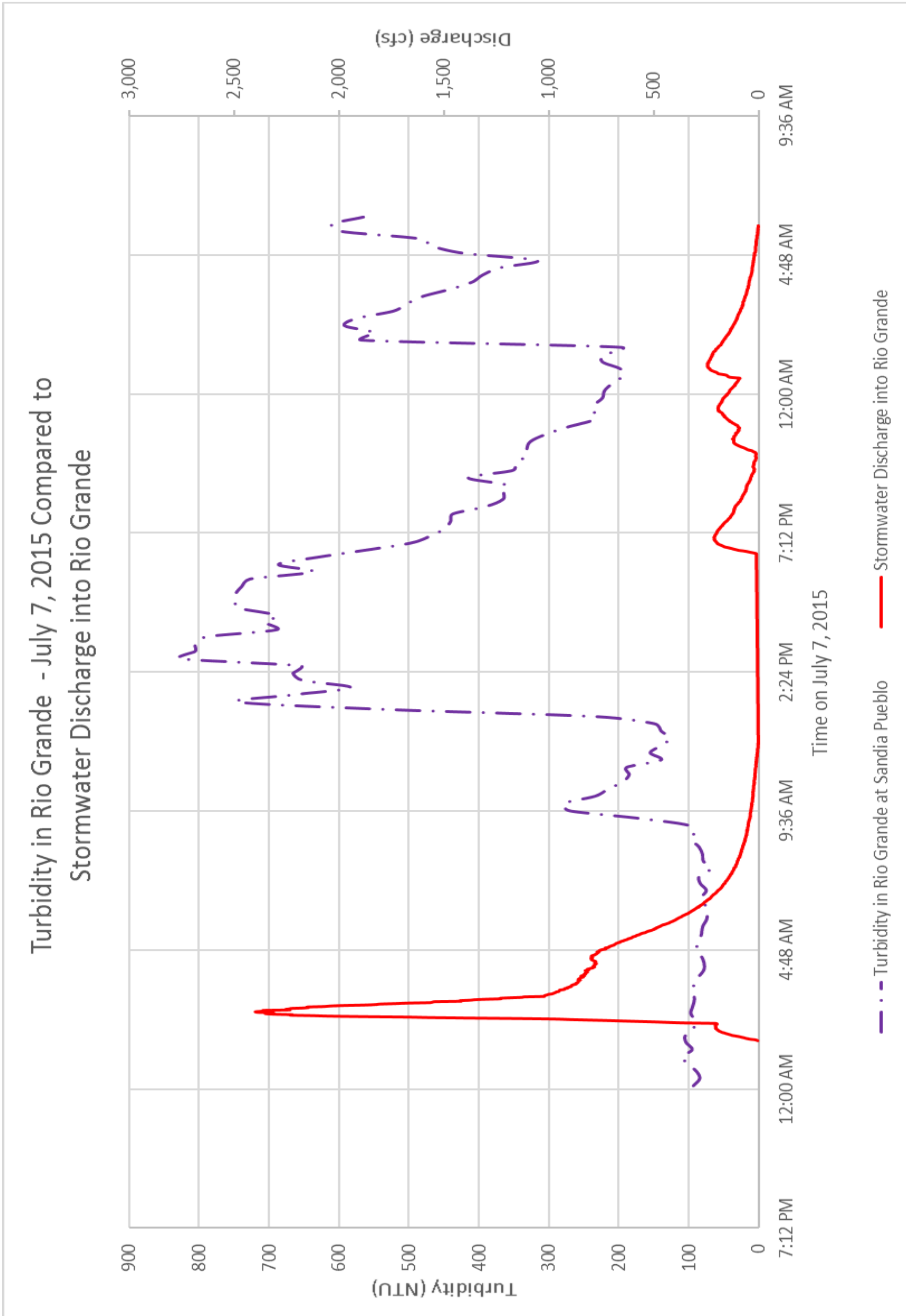

Figure 23 – Turbidity in Rio Grande – July 7, 2015

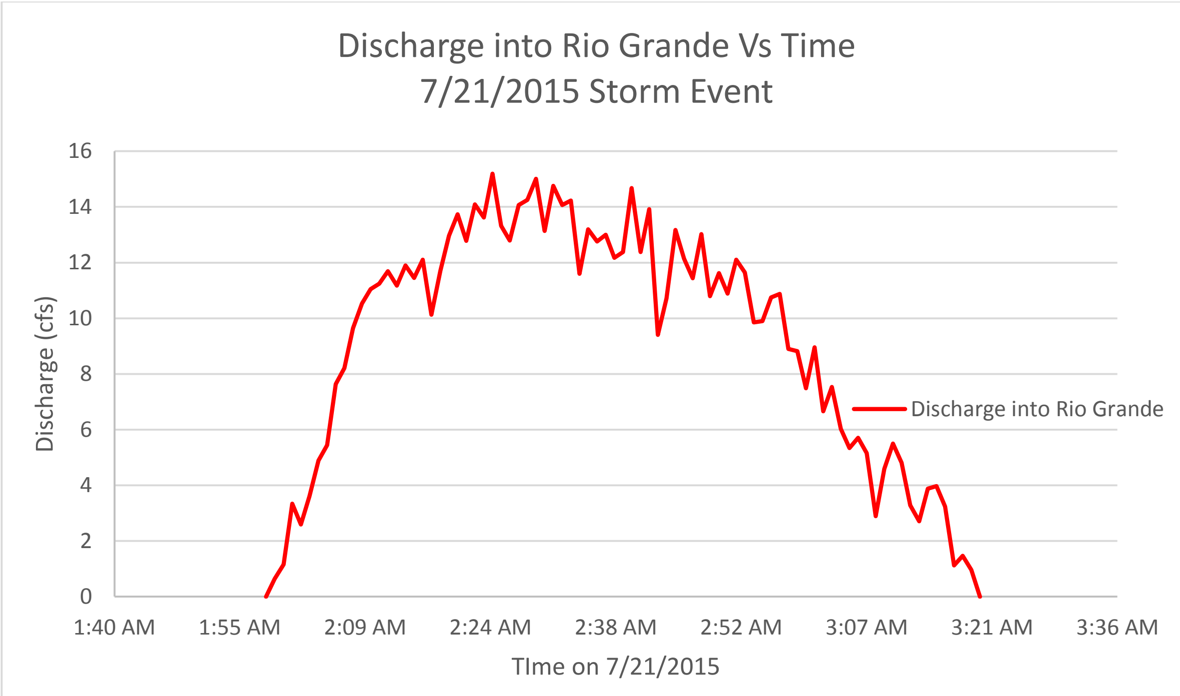

Figure 24 – Discharge into Rio Grande for July 21, 2015, Storm Event; Peak = 15 cfs

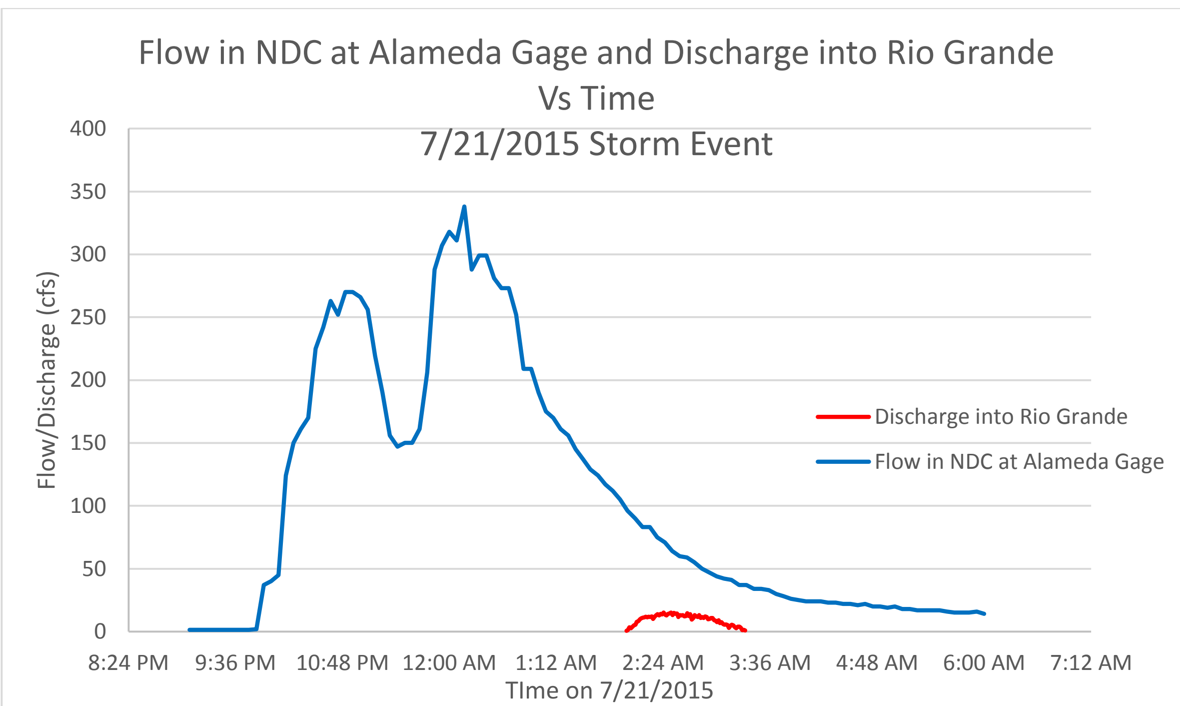

Figure 25 – Flow in NDC at Alameda Gage and Discharge into Rio Grande Vs Time for July 21, 2015, Storm Event

Total Volume in NDC at Alameda Gage	**Total Volume Discharged into Rio Grande**
3,466,050 cubic ft.	45,692.97 cubic ft.
25,926,054 gallons	341,783.38 gallons
79.56 ac-ft	1.05 ac-ft

Date	Flow Peak in NDC at Alameda Gage (cfs)	Discharge into Rio Grande Peak (cfs)	Percent Reduction (%)
7/21/2015	338	15	96%

Date	Volume in NDC at Alameda Gage (ac-ft)	Volume into Rio Grande (ac-ft)	Percent Reduction (%)
7/21/2015	80	1.05	99%

Rainfall Amounts by Location *(inches)*		
	Albuquerque Sunport *(Source: Weather Underground)*	**NDC Watershed** *(Source: CoCoRaHS)*
7/21/2015	Trace	0.1-0.3

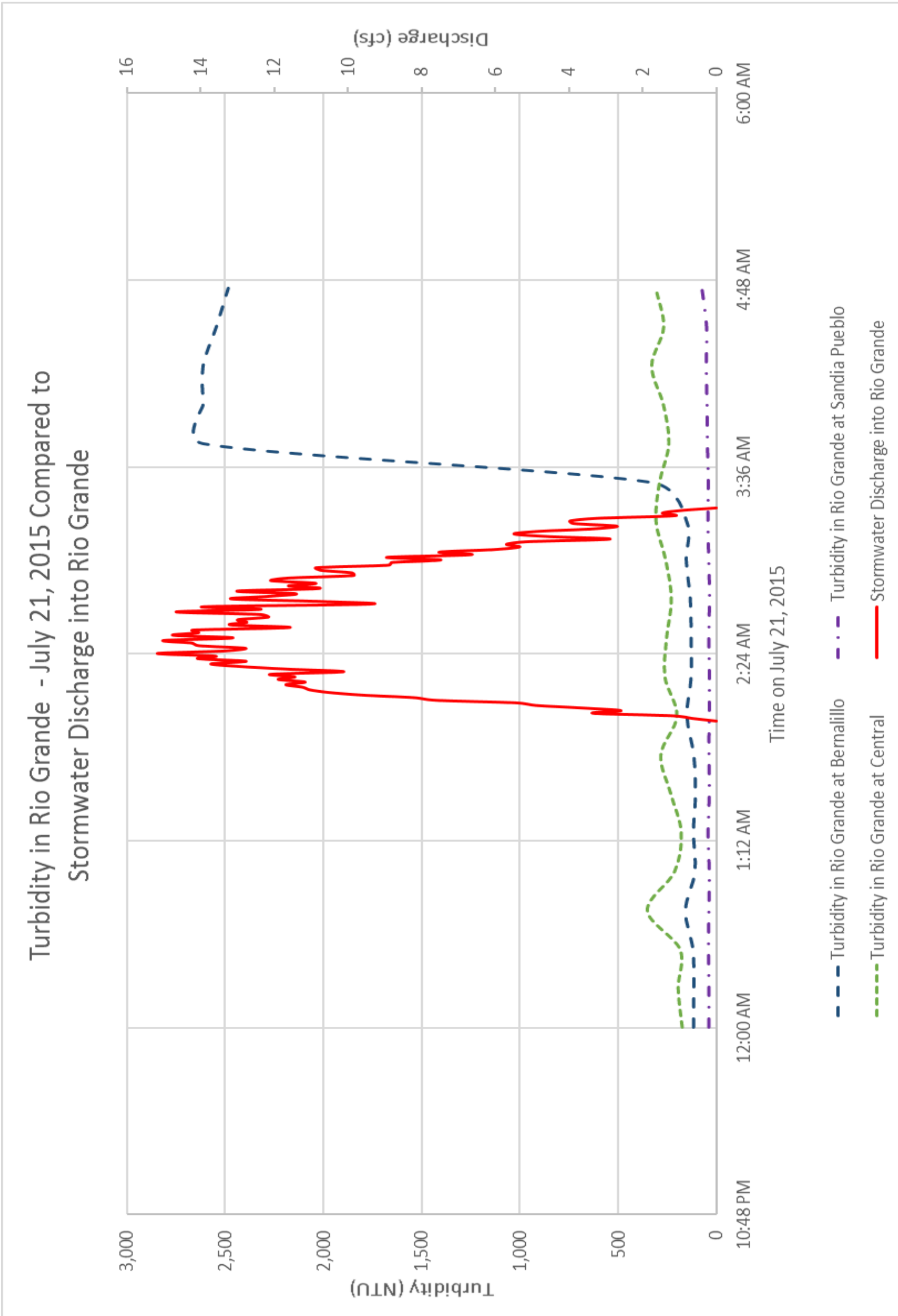

Figure 26 – Turbidity in Rio Grande – July 21, 2015

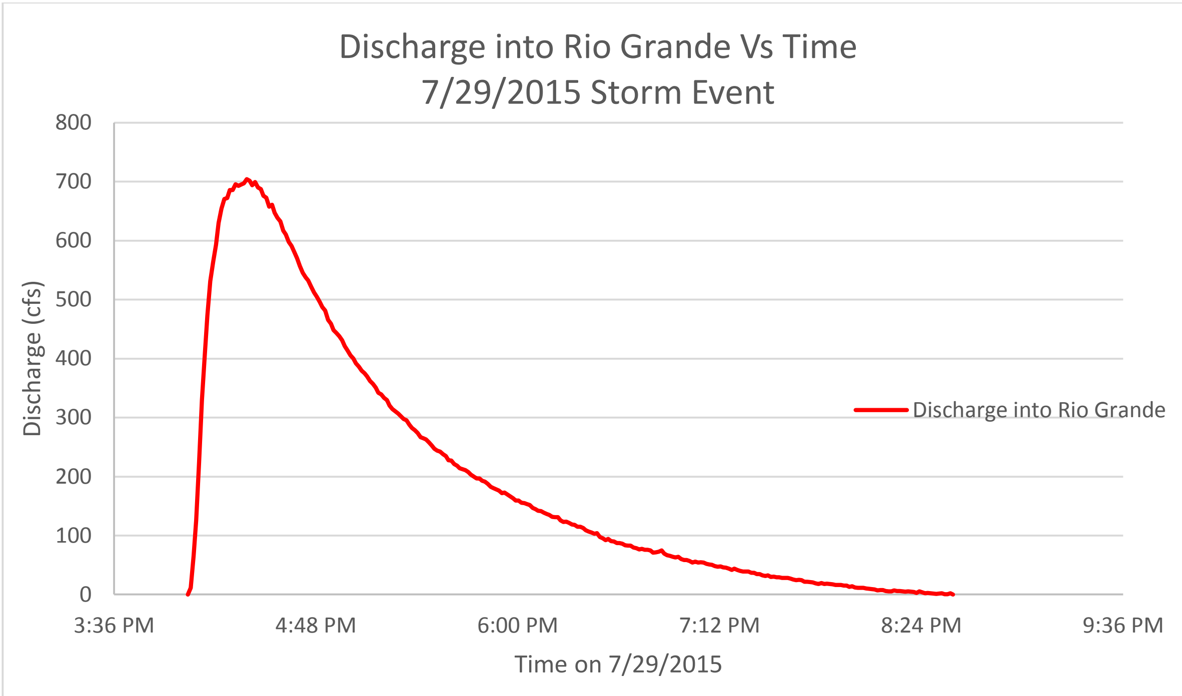

Figure 27 – Discharge into Rio Grande for July 29, 2015, Storm Event; Peak = 704 cfs

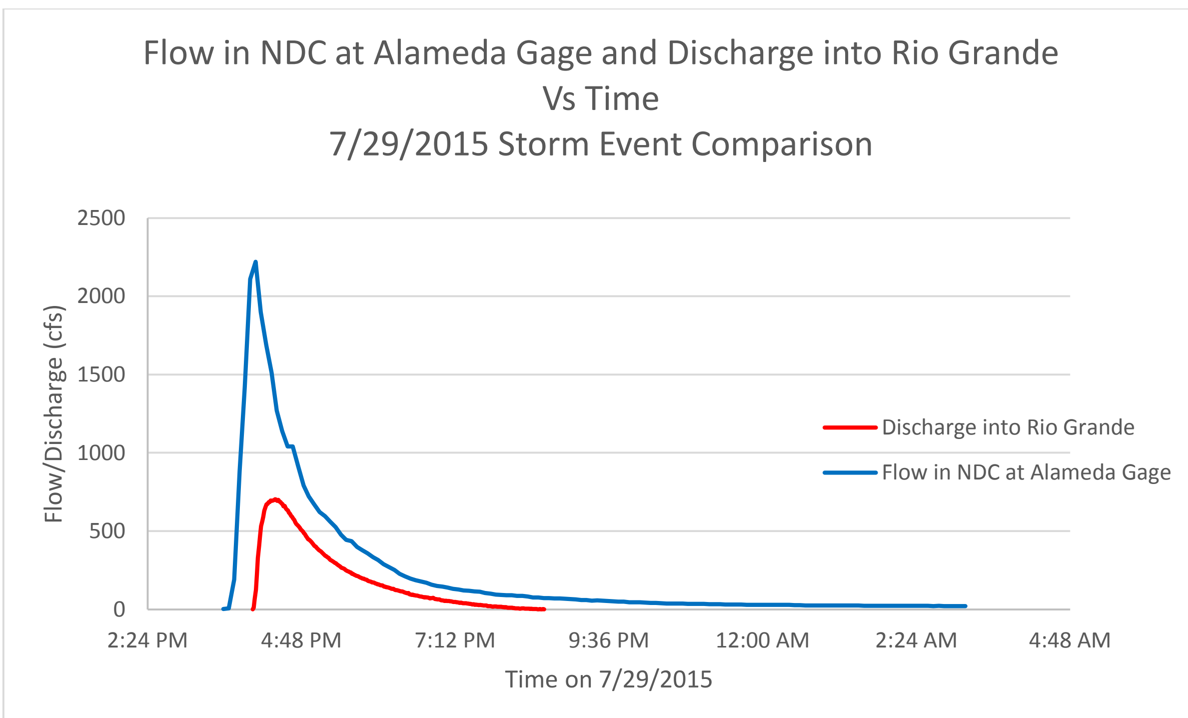

Figure 28 – Flow in NDC at Alameda Gage and Discharge into Rio Grande Vs Time for July 29, 2015, Storm Event

Total Volume in NDC at Alameda Gage	**Total Volume Discharged into Rio Grande**
9,627,180 cubic ft.	3,312,549.38 cubic ft.
72,011,306.40 gallons	24,777,869.34 gallons
220.99 ac-ft	76.04 ac-ft

Date	Flow Peak in NDC at Alameda Gage (cfs)	Discharge into Rio Grande Peak (cfs)	Percent Reduction (%)
7/29/2015	2,220	704	68%

Date	Volume in NDC at Alameda Gage (ac-ft)	Volume into Rio Grande (ac-ft)	Percent Reduction (%)
7/29/2015	221	76	66%

Rainfall Amounts by Location *(inches)*		
	Albuquerque Sunport *(Source: Weather Underground)*	**NDC Watershed** *(Source: CoCoRaHS)*
7/29/2015	0.25	0.9-1.14

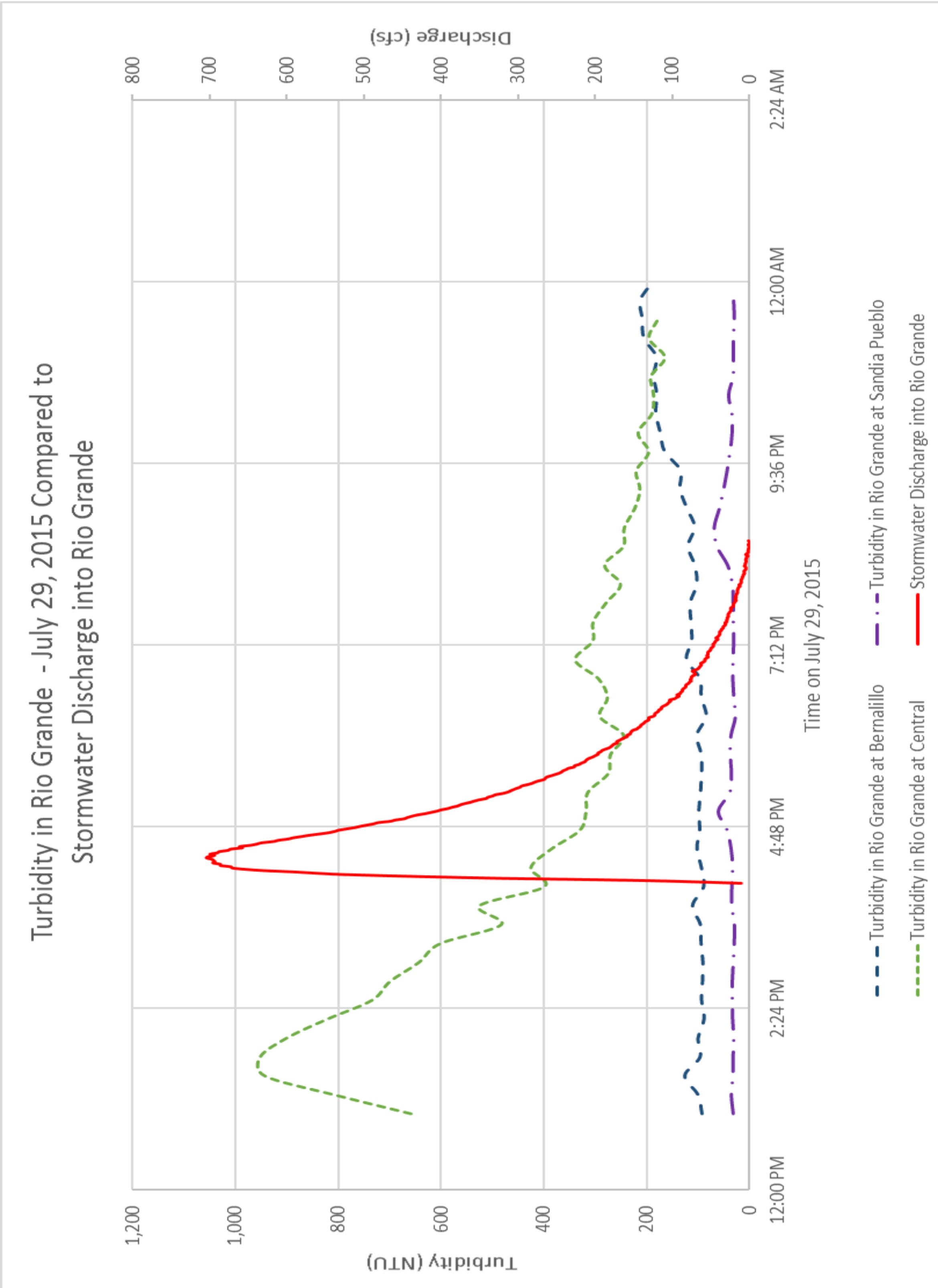

Figure 29 – Turbidity in Rio Grande – July 29, 2015

3. SEPTEMBER DATA

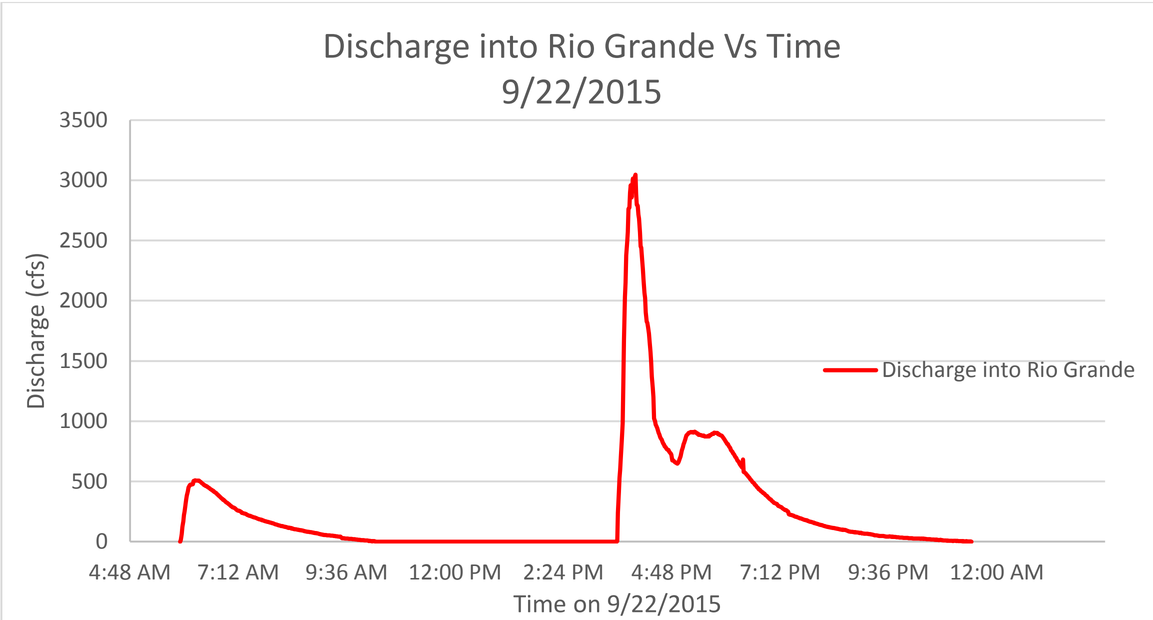

Figure 30 – Discharge into Rio Grande for September 22, 2015, Storm Event; Peak = 3,046 cfs

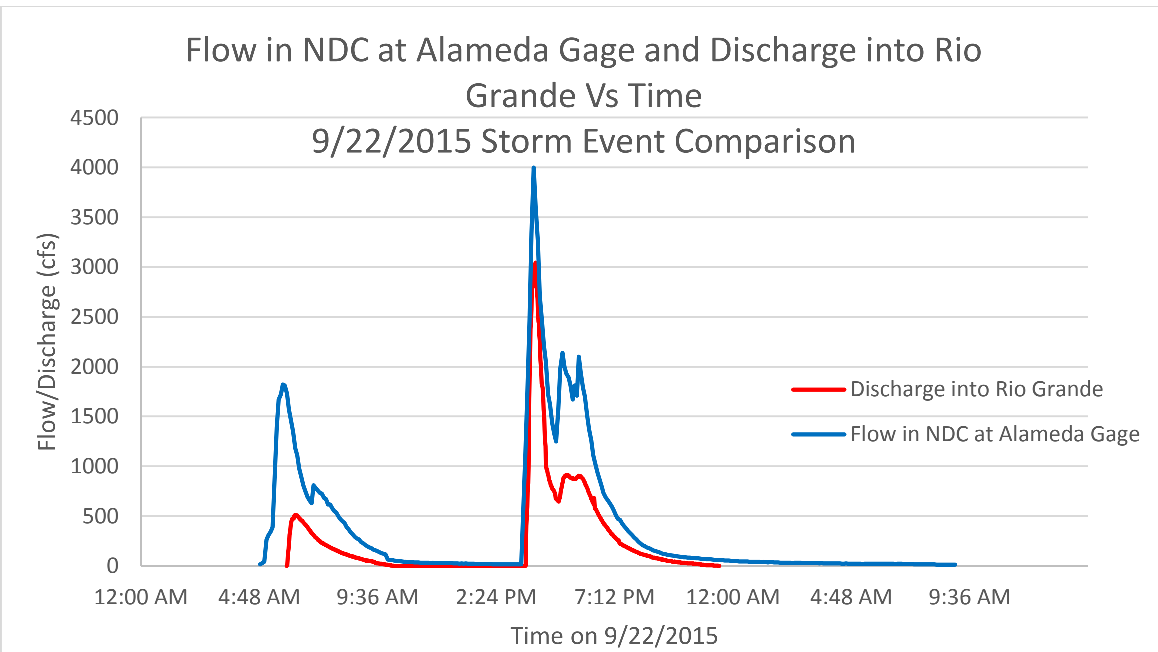

Figure 31 – Flow in NDC at Alameda Gage and Discharge into Rio Grande Vs Time for September 22, 2015, Storm Event

Total Volume in NDC at Alameda Gage	Total Volume Discharged into Rio Grande
38,303,100 cubic ft.	17,001,831.19 cubic ft.
286,507,188 gallons	127,173,697.28 gallons
879.26 ac-ft	390.28 ac-ft

Date	Flow Peak in NDC at Alameda Gage (cfs)	Discharge into Rio Grande Peak (cfs)	Percent Reduction (%)
9/22/2015	4,000	3,046	24%

Date	Volume in NDC at Alameda Gage (ac-ft)	Volume into Rio Grande (ac-ft)	Percent Reduction (%)
9/22/2015	879	390	56%

Rainfall Amounts by Location *(inches)*		
	Albuquerque Sunport *(Source: Weather Underground)*	NDC Watershed *(Source: CoCoRaHS)*
9/22/2015	1.05	0.6-1.19

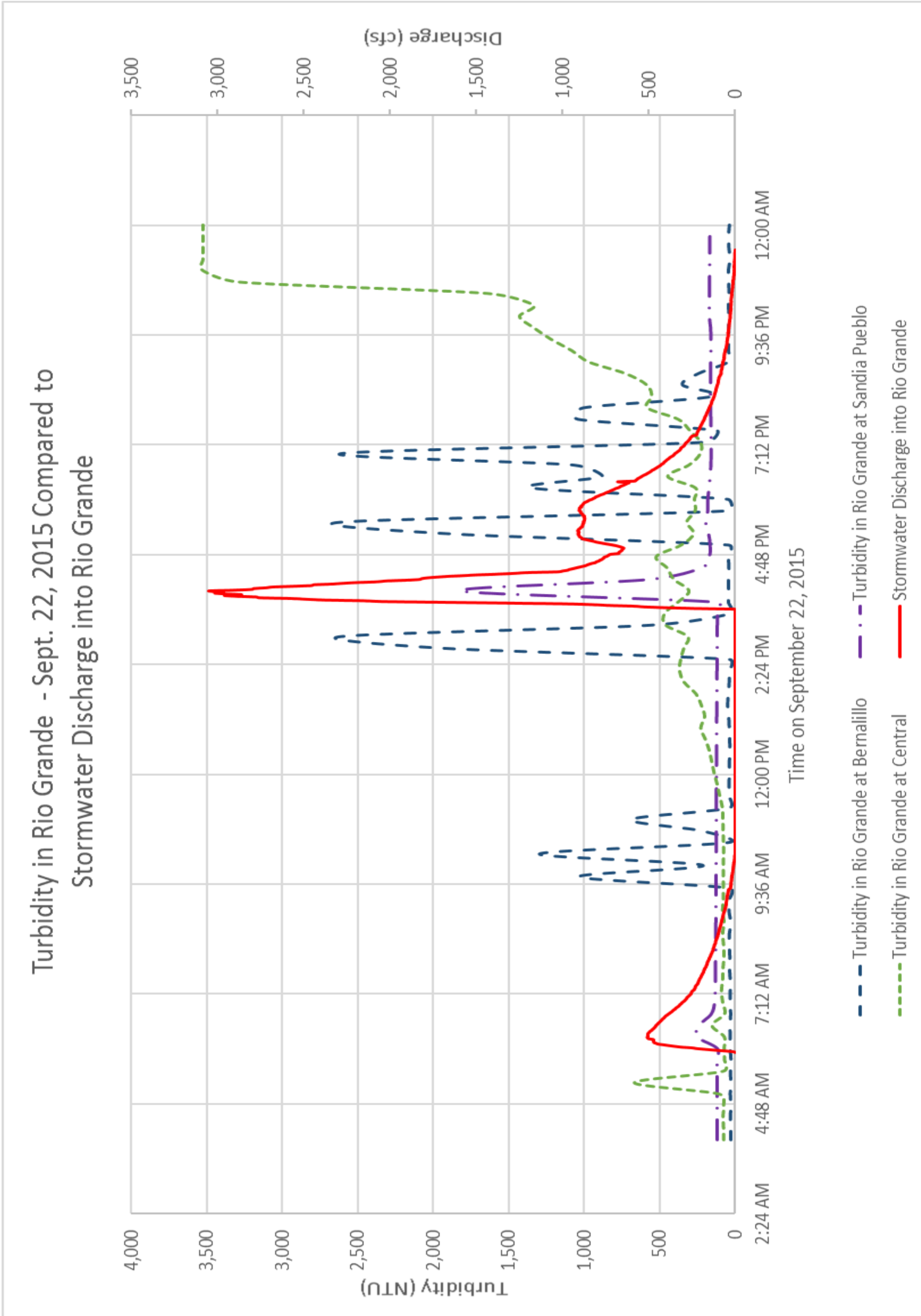

Figure 32 – Turbidity in Rio Grande – September 22, 2015

4. OCTOBER DATA

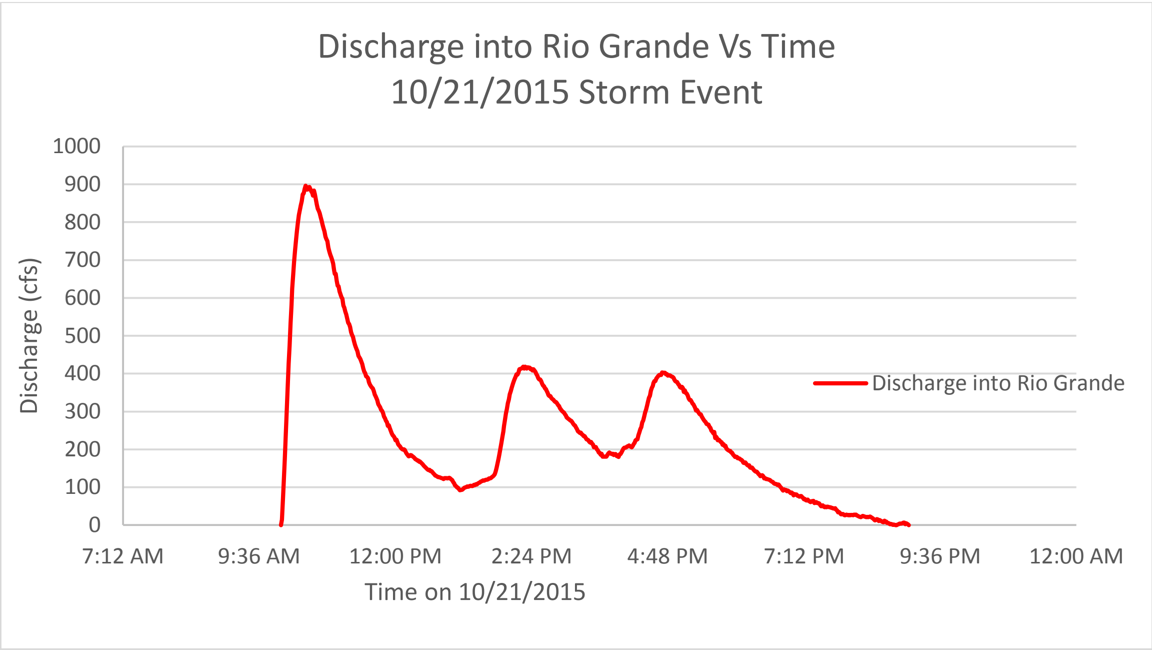

Figure 33 – Discharge into Rio Grande for October 21, 2015, Storm Event; Peak = 893 cfs

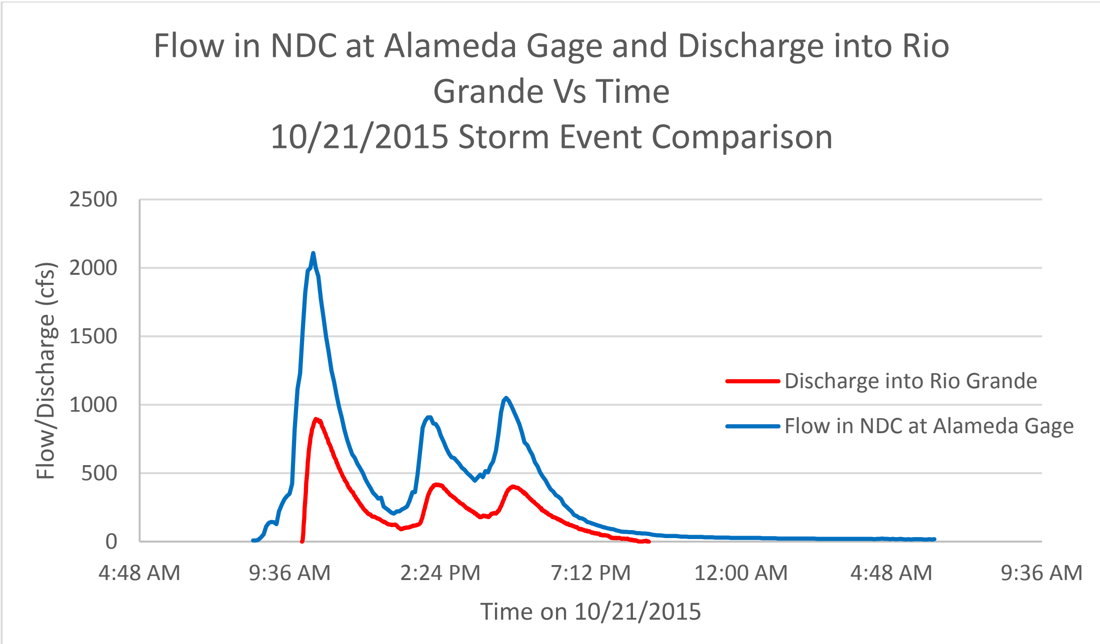

Figure 34 – Flow in NDC at Alameda Gage and Discharge into Rio Grande Vs Time for October 21, 2015, Storm Event

Total Volume in NDC at Alameda Gage	**Total Volume Discharged into Rio Grande**
25,635,060 cubic ft.	9,998,542.12 cubic ft.
191,750,248.8 gallons	74,789,095.05 gallons
588.46 ac-ft	229.52 ac-ft

Date	Flow Peak in NDC at Alameda Gage (cfs)	Discharge into Rio Grande Peak (cfs)	Percent Reduction (%)
10/21/2015	2,110	893	58%

Date	Volume in NDC at Alameda Gage (ac-ft)	Volume into Rio Grande (ac-ft)	Percent Reduction (%)
10/21/2015	588	230	61%

Rainfall Amounts by Location *(inches)*		
	Albuquerque Sunport *(Source: Weather Underground)*	**NDC Watershed** *(Source: CoCoRaHS)*
10/21/2015	0.58	0.9-1.09

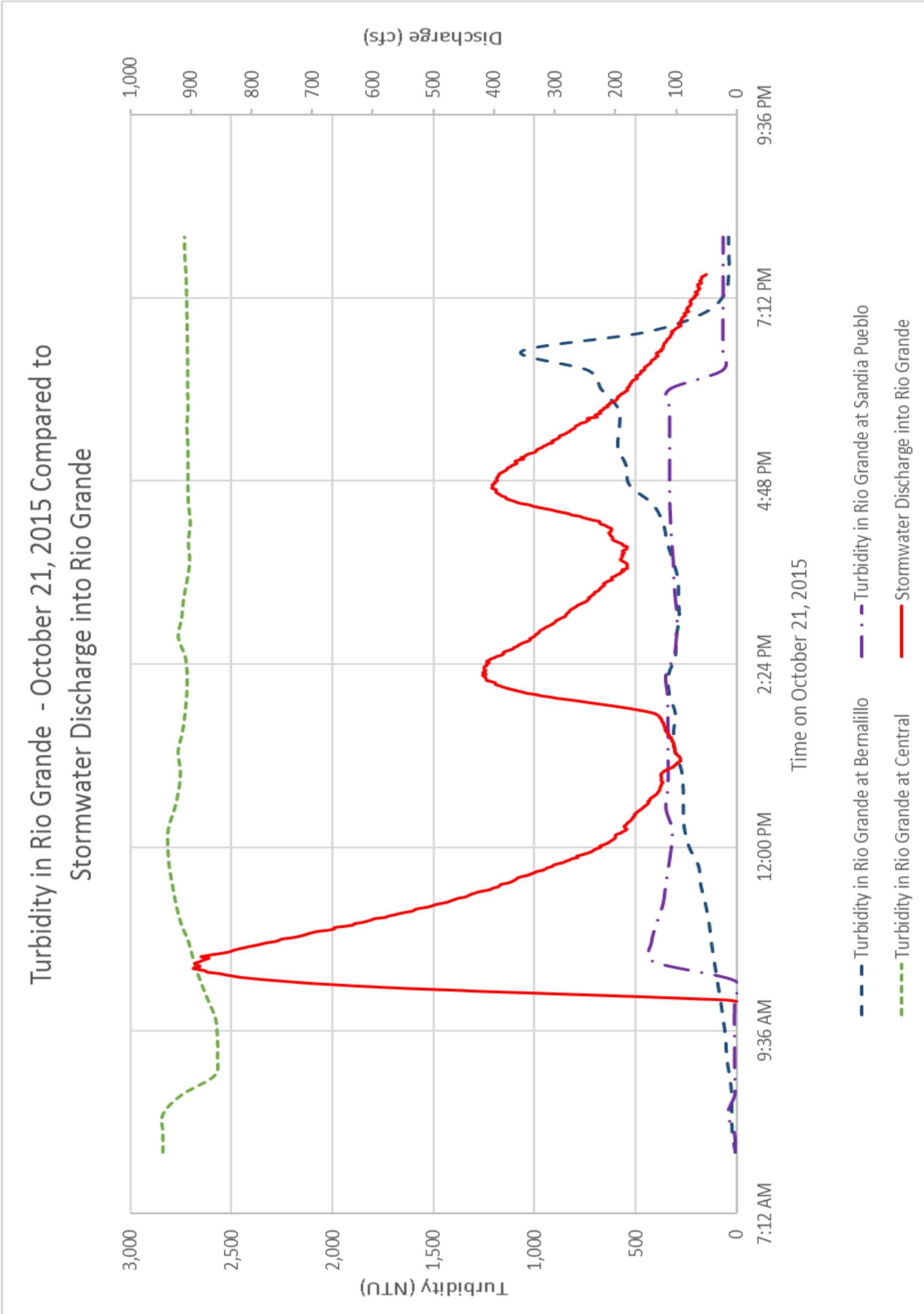

Figure 35 – Turbidity in Rio Grande – October 21, 2015

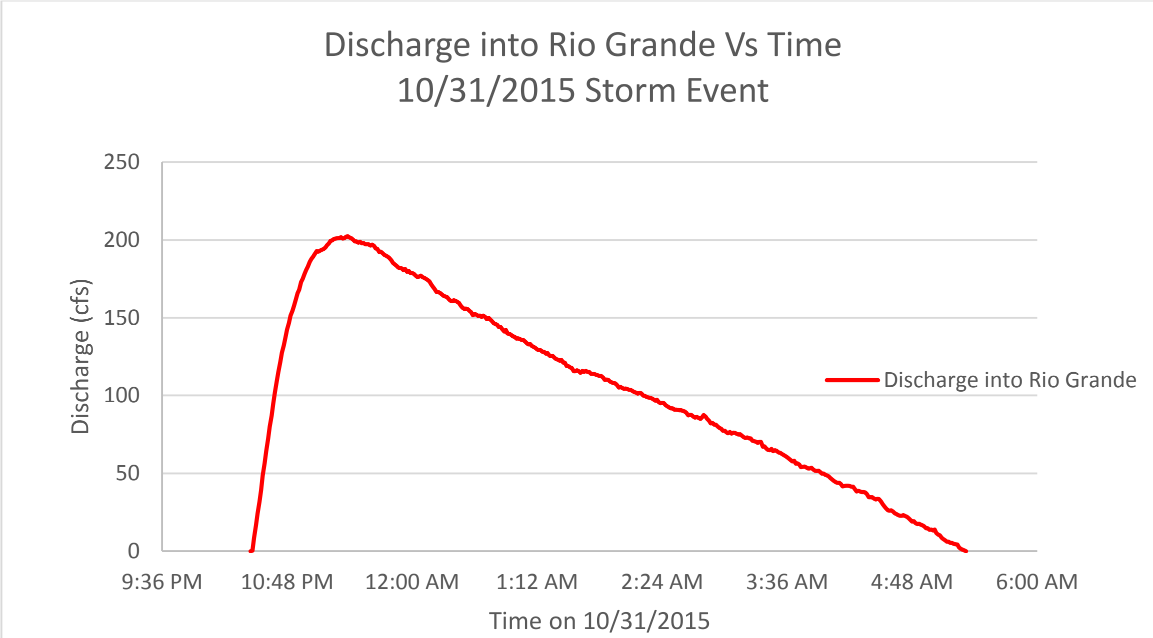

Figure 36 – Discharge into Rio Grande for October 31, 2015, Storm Event; Peak = 202 cfs

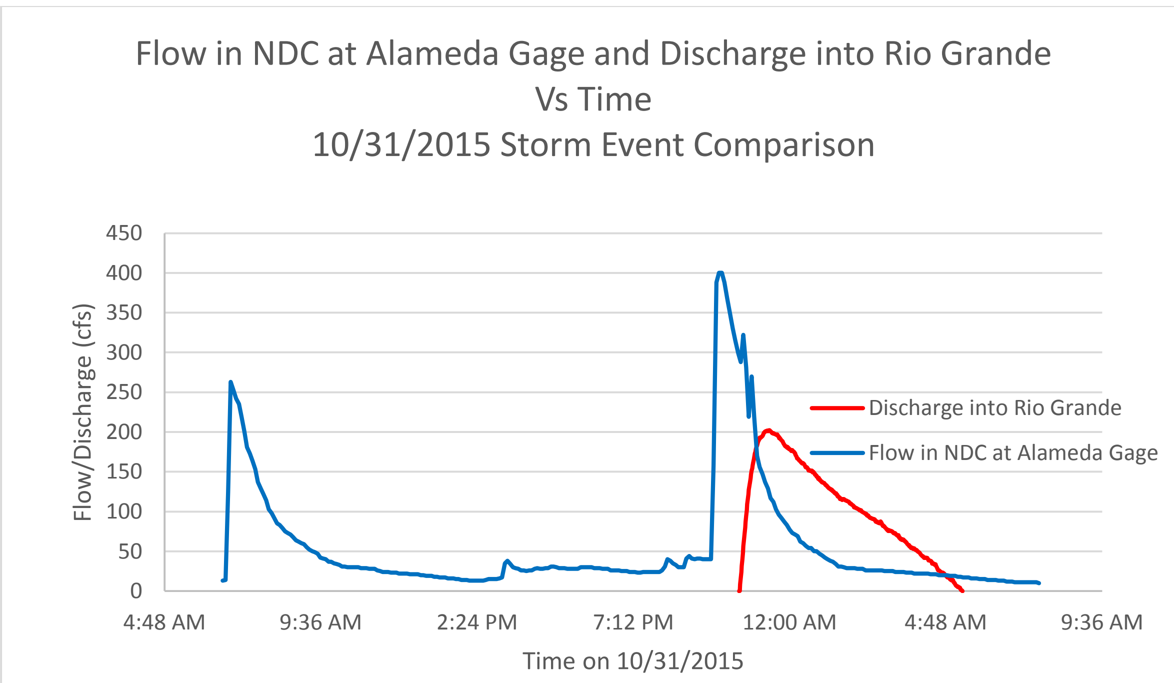

Figure 37 – Flow in NDC at Alameda Gage and Discharge into Rio Grande Vs Time for October 31, 2015, Storm Event

Total Volume in NDC at Alameda Gage

5,030,700 cubic ft.

37,629,636 gallons

115.48 ac-ft

Total Volume Discharged into Rio Grande

2,583,910.16 cubic ft.

19,327,648.02 gallons

59.31 ac-ft

Date	Flow Peak in NDC at Alameda Gage (cfs)	Discharge into Rio Grande Peak (cfs)	Percent Reduction (%)
10/31/2015	400	202	49%

Date	Volume in NDC at Alameda Gage (ac-ft)	Volume into Rio Grande (ac-ft)	Percent Reduction (%)
10/31/2015	115	59	49%

Rainfall Amounts by Location *(inches)*		
	Albuquerque Sunport *(Source: Weather Underground)*	**NDC Watershed** *(Source: CoCoRaHS)*
10/31/2015	0.13	0.2-0.37

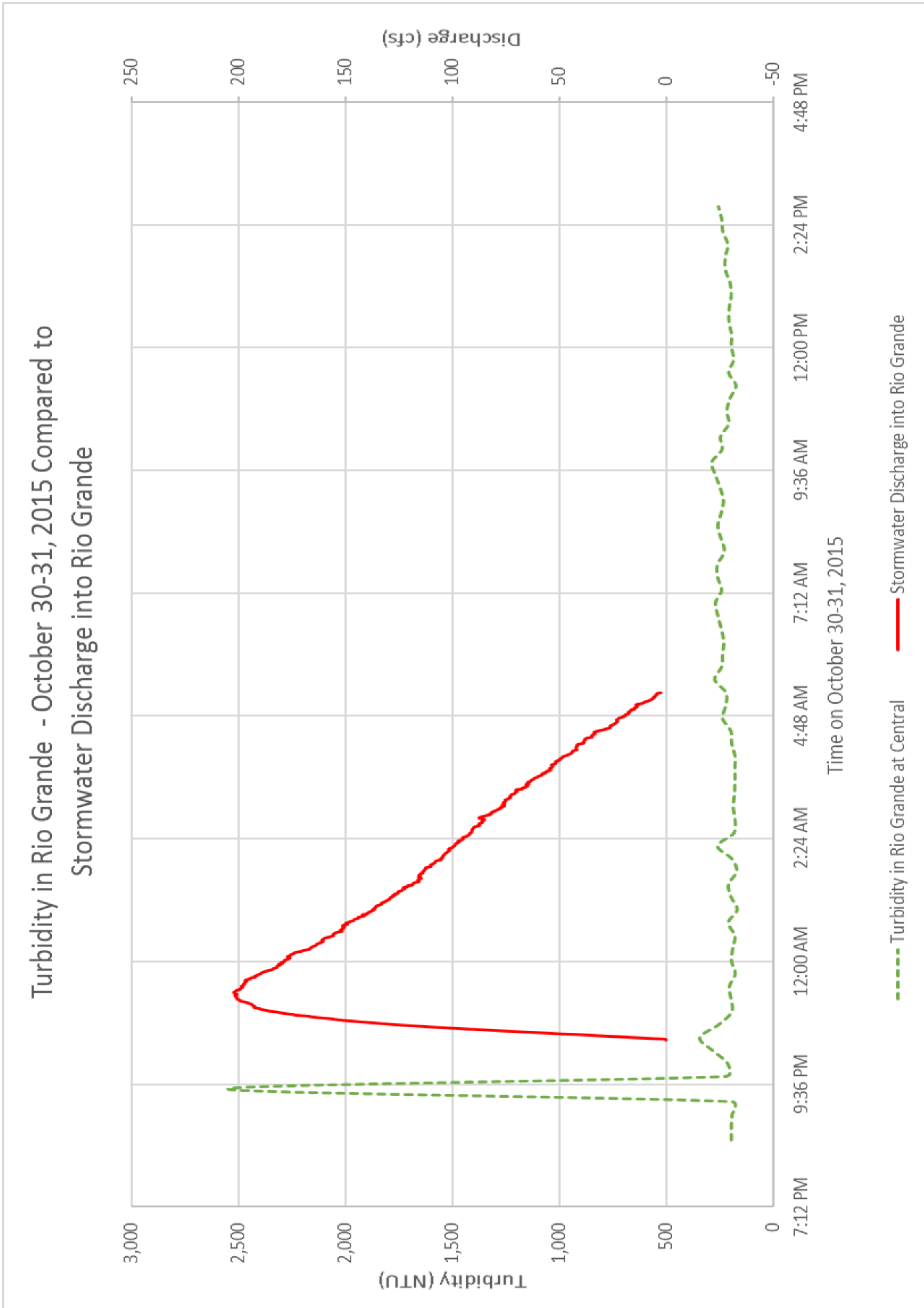

Figure 38 – Turbidity in Rio Grande - October 30-31, 2015

5. NOVEMBER DATA

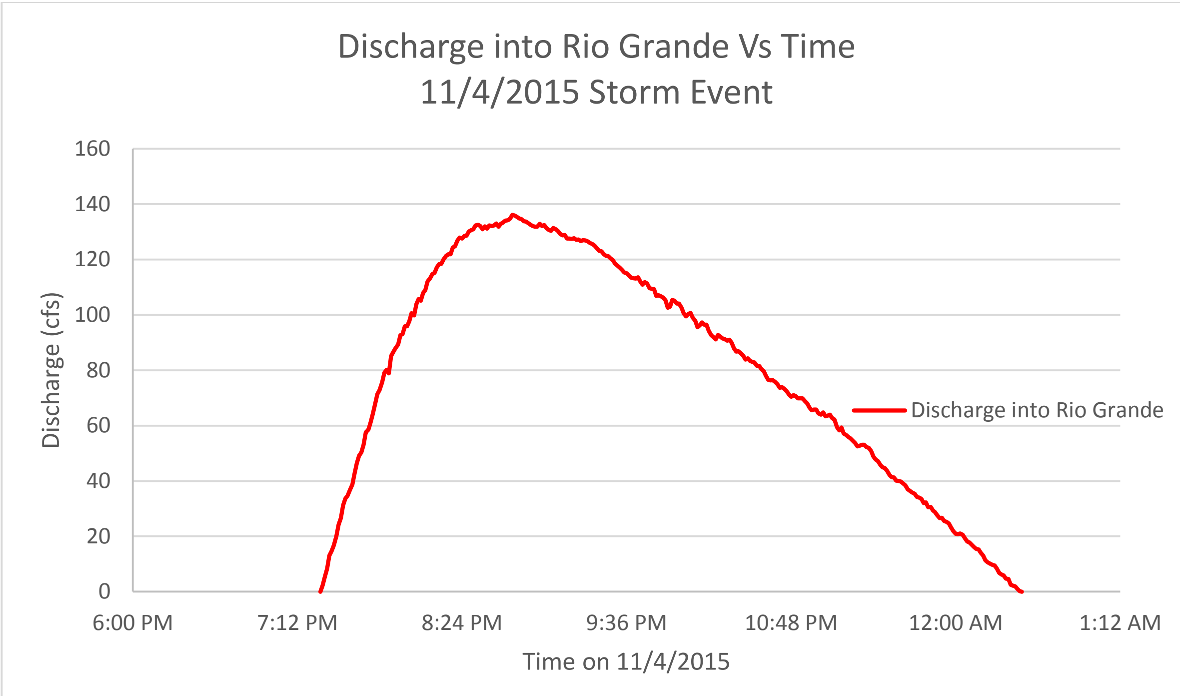

Figure 39 – Discharge into Rio Grande on November 4, 2015 Storm Event; Peak = 136 cfs

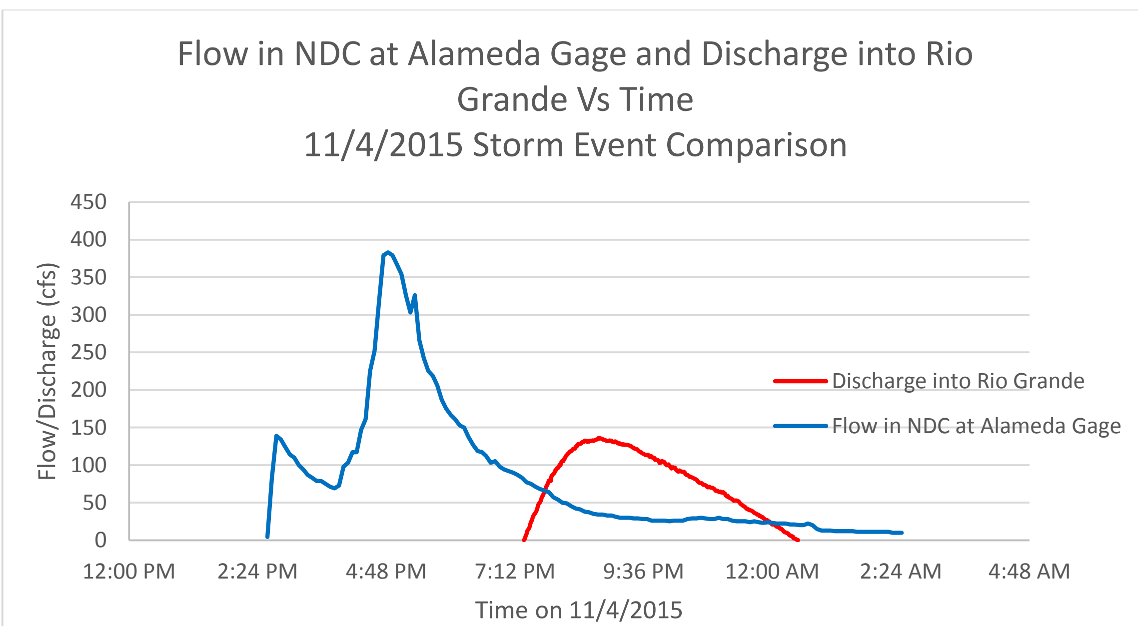

Figure 40 – Flow in NDC at Alameda Gage and Discharge into Rio Grande Vs Time for November 4, 2015, Storm Event

Total Volume in NDC at Alameda Gage	Total Volume Discharged into Rio Grande
3,535,890 cubic ft.	1,473,723.57 cubic ft.
26,448,457.20 gallons	11,023,452.27 gallons
81.17 ac-ft	33.83 ac-ft

Date	Flow Peak in NDC at Alameda Gage (cfs)	Discharge into Rio Grande Peak (cfs)	Percent Reduction (%)
11/4/2015	383	136	64%

Date	Volume in NDC at Alameda Gage (ac-ft)	Volume into Rio Grande (ac-ft)	Percent Reduction (%)
11/4/2015	81	34	58%

Rainfall Amounts by Location *(inches)*		
	Albuquerque Sunport *(Source: Weather Underground)*	**NDC Watershed** *(Source: CoCoRaHS)*
11/4/2015	0.14	0.15-0.31

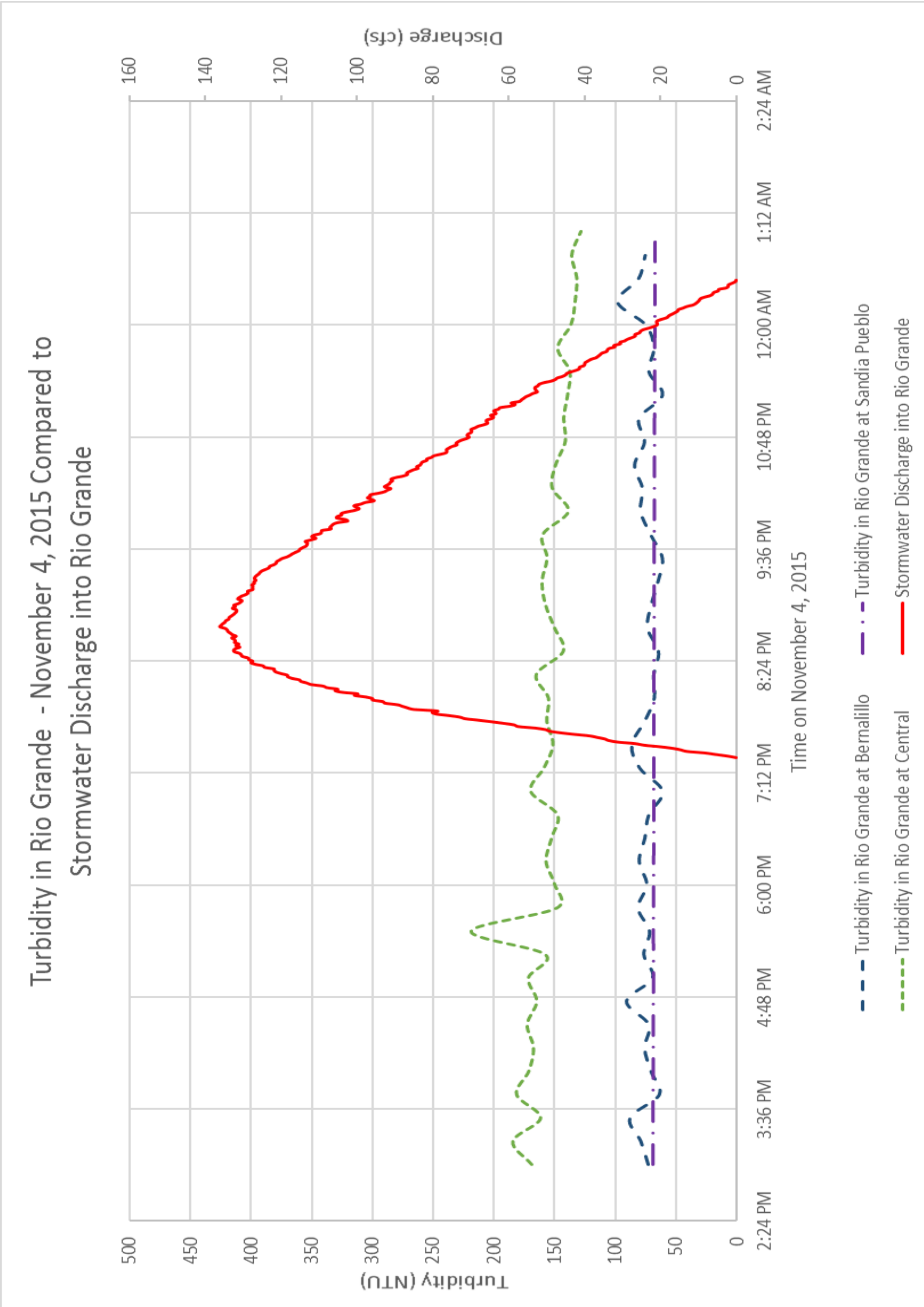

Figure 41 – Turbidity in Rio Grande- November 4, 2015

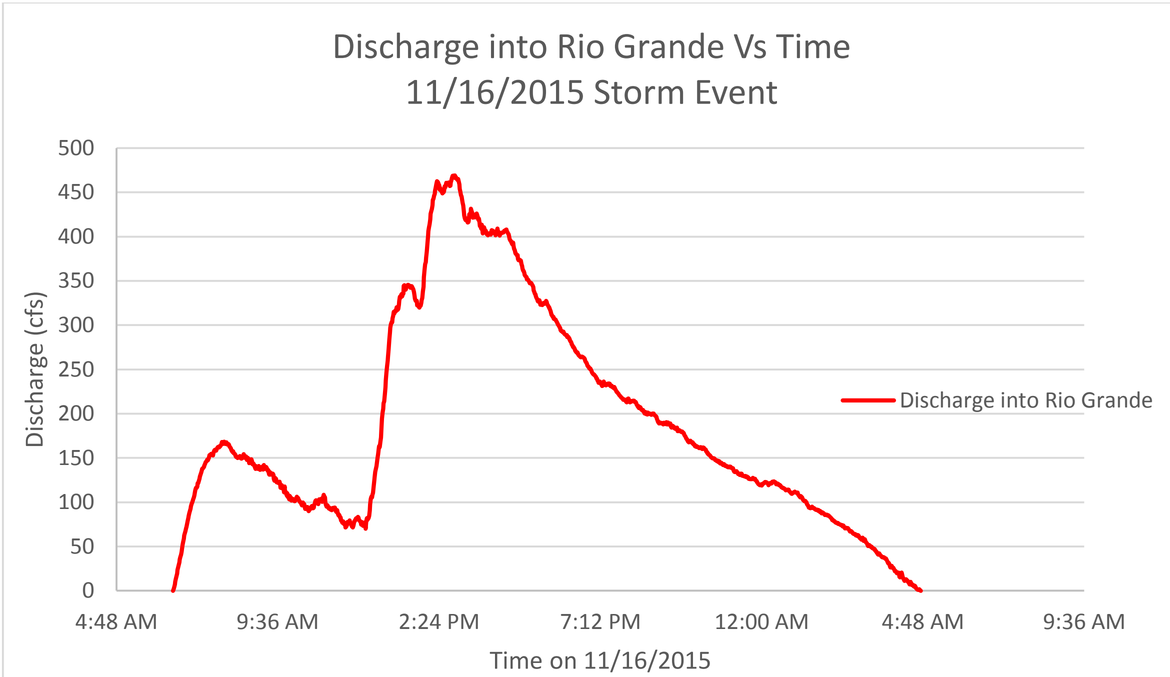

Figure 42 – Discharge into Rio Grande for November 16, 2015 Storm Event; Peak = 469 cfs

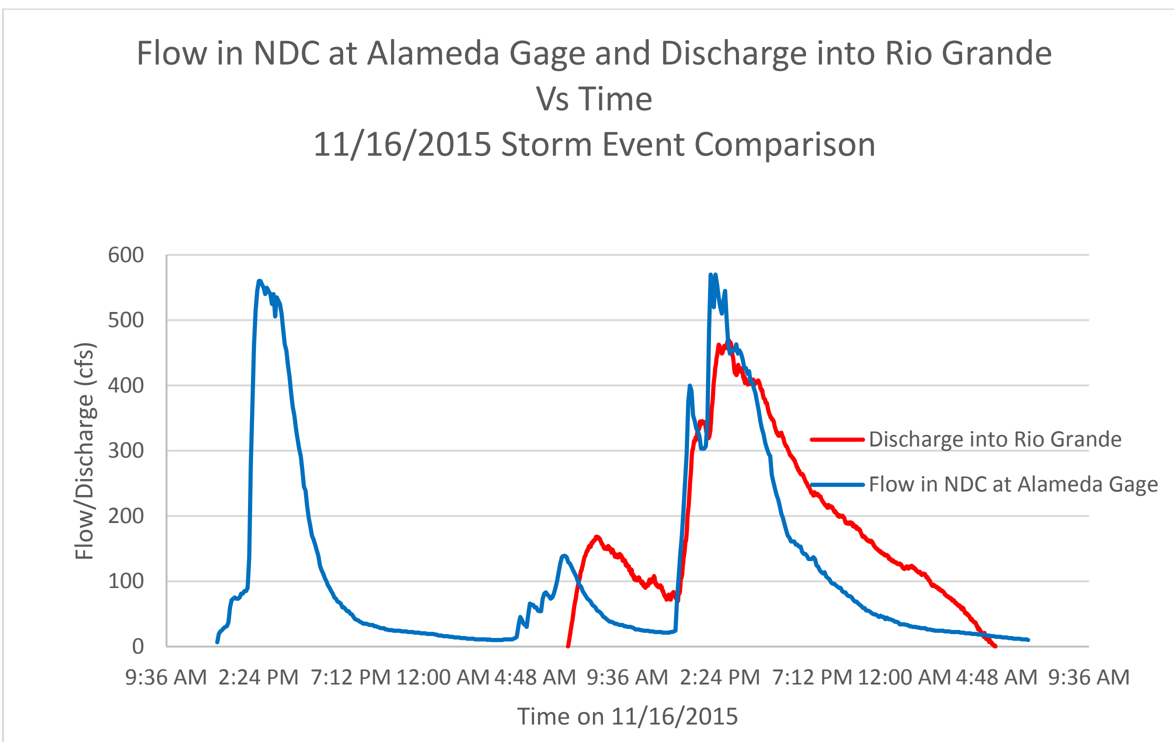

Figure 43 – Flow in NDC at Alameda Gage and Discharge into Rio Grande Vs Time for November 16, 2015, Storm Event

Total Volume in NDC at Alameda Gage	**Total Volume Discharged into Rio Grande**
18,154,410 cubic ft.	15,090,107.60 cubic ft.
135,794,986.80 gallons	112,874,004.82 gallons
416.74 ac-ft	346.40 ac-ft

Date	Flow Peak in NDC at Alameda Gage (cfs)	Discharge into Rio Grande Peak (cfs)	Percent Reduction (%)
11/16/2015	570	469	18%

Date	Volume in NDC at Alameda Gage (ac-ft)	Volume into Rio Grande (ac-ft)	Percent Reduction (%)
11/16/2015	417	346	17%

Rainfall Amounts by Location *(inches)*		
	Albuquerque Sunport *(Source: Weather Underground)*	**NDC Watershed** *(Source: CoCoRaHS)*
11/15/2015	0.28	0.45-0.71
11/16/2015	0.16	0.5-0.75

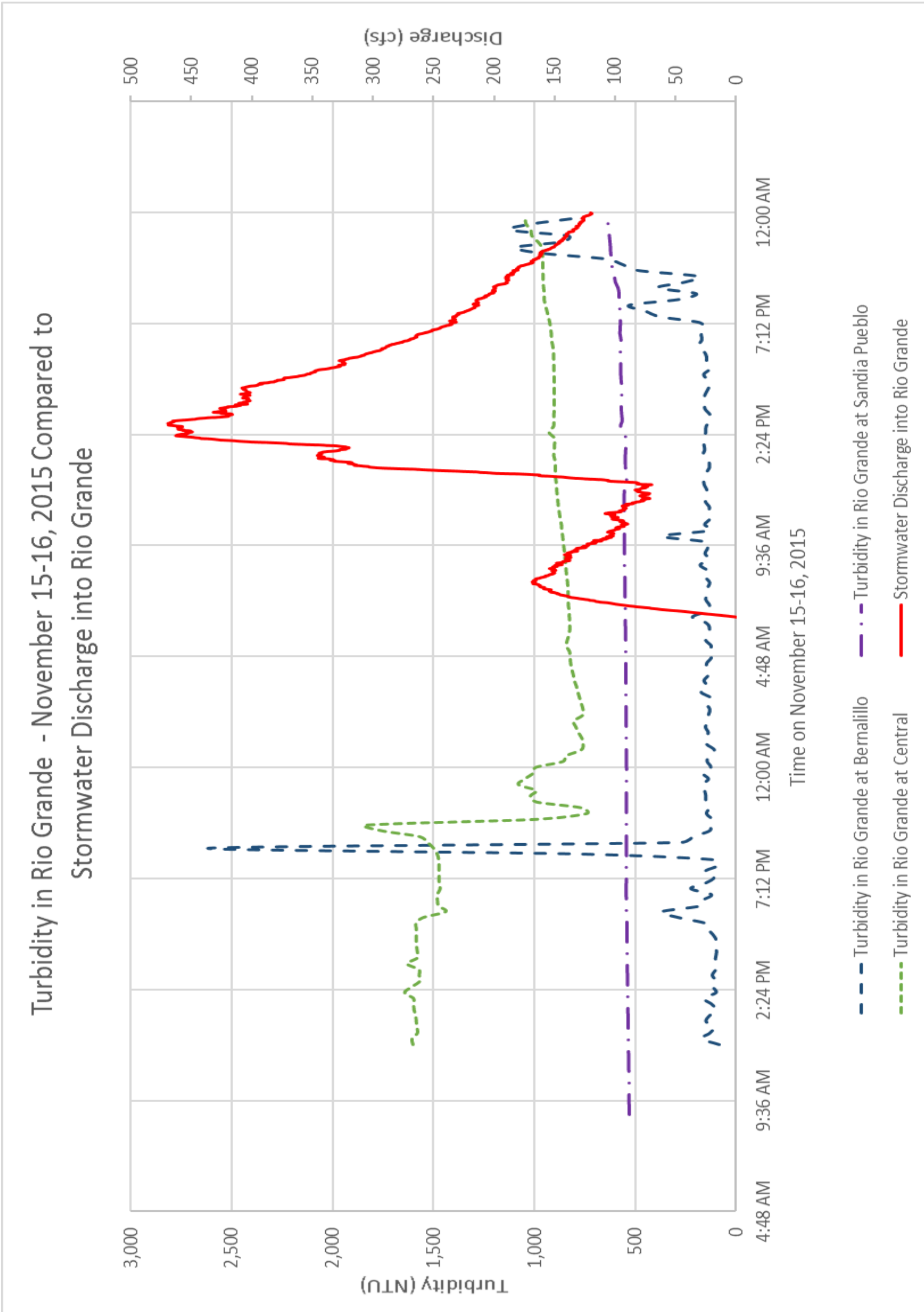

Figure 44 – Turbidity in Rio Grande – November 15-16, 2015

6. DECEMBER DATA

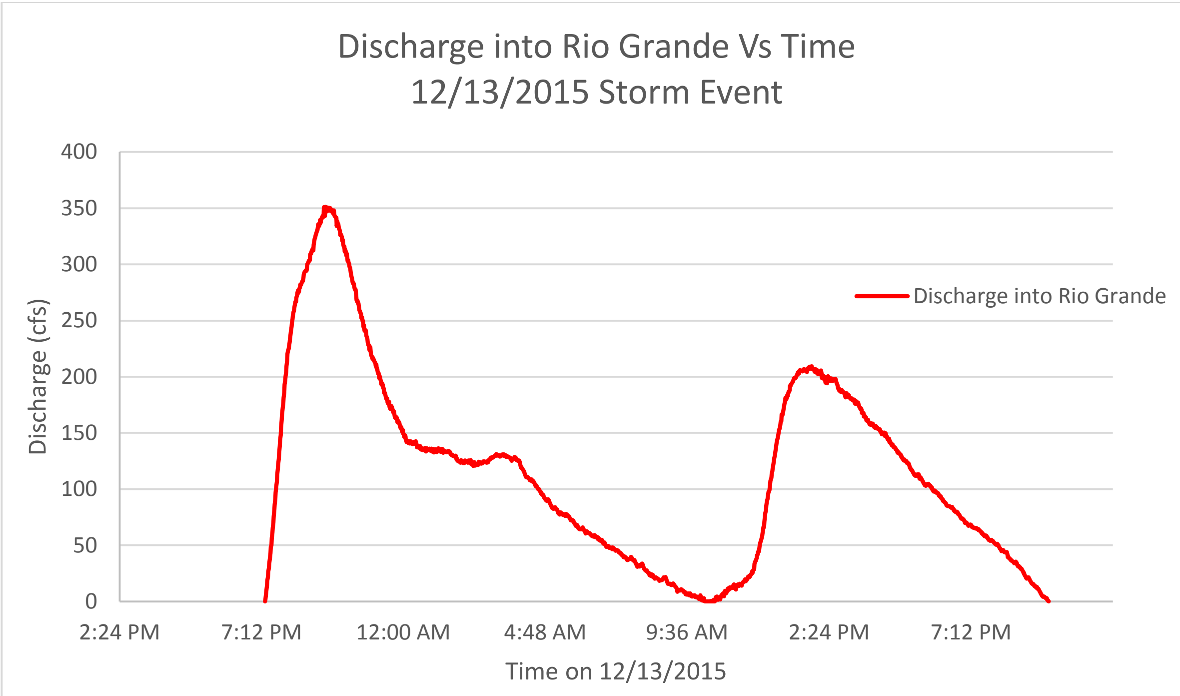

Figure 45 – Discharge into Rio Grande for December 13, 2015 Storm Event; Peak = 351 cfs

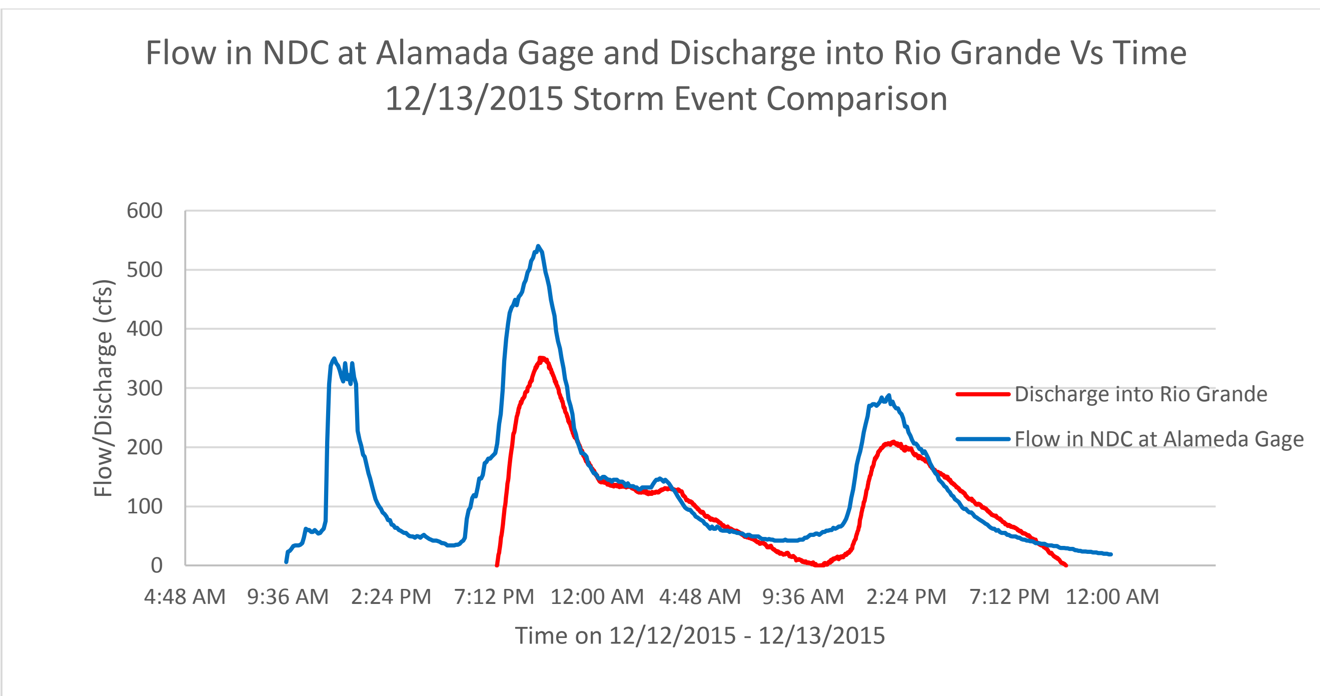

Figure 46 – Flow in NDC at Alameda Gage and Discharge into Rio Grande Vs Time for December 13, 2015, Storm Event

Total Volume in NDC at Alameda Gage

18,687,840 cubic ft.

139,785,043.20 gallons

428.98 ac-ft

Total Volume Discharged into Rio Grande

11,149,923.61 cubic ft.

83,401,428.58 gallons

255.95 ac-ft

Date	Flow Peak in NDC at Alameda Gage (cfs)	Discharge into Rio Grande Peak (cfs)	Percent Reduction (%)
12/13/2015	540	351	35%

Date	Volume in NDC at Alameda Gage (ac-ft)	Volume into Rio Grande (ac-ft)	Percent Reduction (%)
12/13/2015	429	256	40%

Rainfall Amounts by Location *(inches)*		
	Albuquerque Sunport *(Source: Weather Underground)*	**NDC Watershed** *(Source: CoCoRaHS)*
12/12/2015	0.64	1.1-1.2
12/13/2015	0.23	1.1-1.18

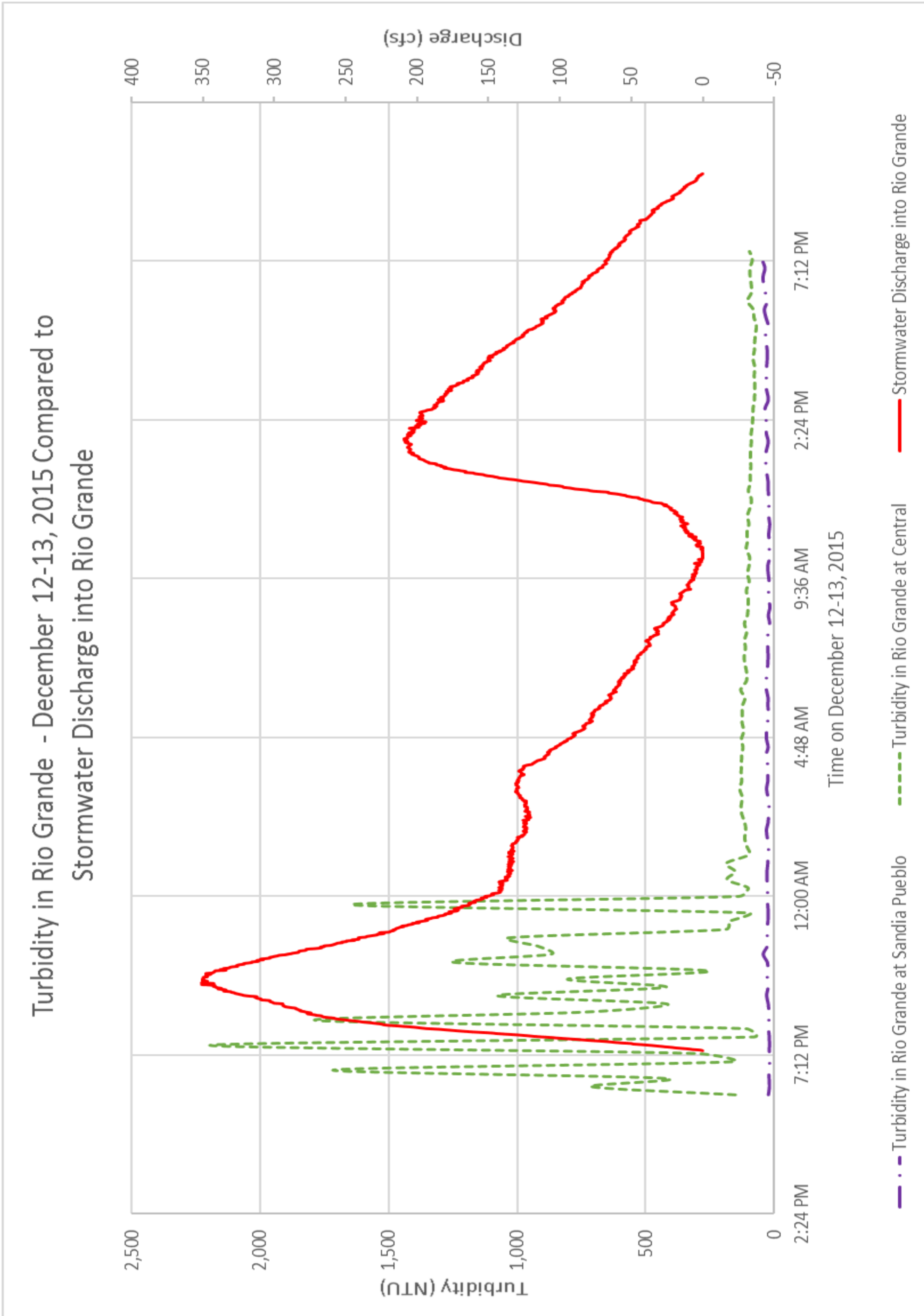

Figure 47 – Turbidity in Rio Grande - December 12-13, 2015

II. CONCLUSION

This report provides an analysis of three components related to understating Albuquerque's existing stormwater system in relationship to the MS4 Permit water quality requirements. The three elements considered include: (1) the MS4 Permit post-construction storm event required discharge volumes relative to average rainfall amounts and compared to retention requirements for the rest of the United States; (2) Analysis of the MS4 Permit post-construction storm event required discharge volumes specific to two sub-watersheds in the North NDC watershed in northeast Albuquerque; and (3) Analysis of stormwater discharge events from the NDC into the Rio Grande to determine system volume and peak discharge reductions, as well as impacts on turbidity in the Rio Grande.

The first element shows that the MS4 post-construction standard imposed on New Mexico has the highest percentage in the country of stormwater quality volume compared to annual rainfall for both new development (7 percent) and redevelopment (5.4 percent). In addition, placing this requirement in the MS4 Permit with a rigid numerical value takes away New Mexico's local decision making choices and authority, something other states and MS4s have been granted. AMAFCA, the City of Albuquerque, and mulptiple consulting hydrologists conclude that the analysis of Albuquerque's historical precipitation events shows that the actual precipitation depth that occurs 90 percent of the time is 0.44 inches. This numerical standard should be left to the MS4s to determine and stipulate and not be a numerical requirement in the MS4 Permit.

The second element encompassed the extensive hydrologic analysis of two large sub-watersheds in Albuquerque's NDC watershed and shows that Albuquerque's existing development and stormwater system already largely achieve compliance with the MS4 Permit requirements to retain the MS4 Permit defined 90th percentile storm event discharge volume. This is the result of both the nature of the residential development in New Mexico (i.e. the backyard effect) and the existing stormwater infrastructure of unlined arroyos, stormwater detention ponds, and water quality structures. The analysis shows that the impacts of future development and redevelopment within these watersheds will have little effect on urban hydrology and, in particular, the water quality volume over the watersheds. Compliance with the MS4 Permit should account for Albuquerque's existing system which is fundamentally achieving compliance with MS4 Permit requirements.

The third element focused on the terminal end of the NDC. The NDC outlet has been extensively reconfigured to provide detention of low volume runoff, diversion of low flows to the Alameda Drain, and passive water treatment facilities to capture floatables, debris, and sediment. These improvements include facilities for better measurement of stormwater quality and more accurate measurement of discharges to the river. Further, the Drain provides additional benefits by attenuating peak flows and providing natural treatment of low volume stormwater flows before discharging to the river. Analysis of monitoring data show there is no detectable impact of NDC stormwater discharges on the quality of the Rio Grande, as measured by turbidity. This element again demonstrates that Albuquerque's existing system is fundamentally achieving compliance with MS4 Permit requirements.

III. REFERENCES

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Kosco, J., K. Alvi, and M. Faizullabhoy. 2014. *Estimating Predevelopment Hydrology in the Middle Rio Grande Watershed, New Mexico*. U.S. EPA Office of Wastewater Management. EPA 832-R-14-007.

Portland Oregon, 2008. *Stormwater Management Manual, Appendix E, Stormwater Pollution Reduction Storm Development Methodology*.

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APPENDIX A – COMPARISON OF POST-CONSTRUCTION STORMWATER MANAGEMENT PERMIT STANDARDS IN THE US

NDC Water Quality Calculations, Research and Analysis

Primary Reference:
"Summary of State Stormwater Standards", June 30, 2011, EPA, Office of WaterOffice of Wastewater ManagementWater Permits Division
Most states do not have a numerical value in their permit (not regulatory), however, many states have Stormwater Management Manuals, which are non-regulatory, offer options, andmay be adopted by the MS4s

Number	EPA Region	State	Rainfall (in./yr.)	Precipitation Depth to use for Water Quality Volume (New Development) (inches)	Precipitation Depth to use for Water Quality Volume (Re- Development) (inches)	Percentage (New Development) - WQ Volume / Rainfall	Percentage (Re- Development) - WQ Volume / Rainfall	WQ Volume Notes
1	9	Arizona[1]	7.11	0.5	0.5	7%	7%	State - no numerical requirements, #s listed are from Pima Co. Stormwater Detention Retention Manual. AZ allows dry wells, Groundwater infiltration.
2	9	Nevada[2]	7.87	0.37	0.37	4.7%	4.7%	Las Vegas - Clark Co - HCDDM Manual
3	6	New Mexico	8.91	0.615	0.48	7%	5.4%	From Permit NMR04A000
4	8	Montana	11.37	0.5	0.5	4.4%	4.4%	From Permit MTR040000, 0.5" listed in Permit related to Low Impact Development.
5	8	Colorado[3]	15.31	0.5	0.5	3.3%	3.3%	No numerical stds. in Permit; value from Urban Drainage & Flood Control District (UDFCD), Vol. 3
6	8	Utah[4]	15.31	0.6	--	3.9%	--	No numerical stds. in MS4 Permits for SLC or DOT / Does have 90th storm event on new Small MS4 Permit
7	5	Minnesota[5]	26.36	1	1	3.8%	3.8%	From MN PCA (Poll. Control Agency) Manual
8	7	Kansas[6]	28.61	1.2	1.2	4.2%	4.2%	BMP Manual - Kansas City Metropolitan Area and the MARC planning region
9	6	Oklahoma[7]	30.89					
9a	6	Norman, OK	38.87	0.5	--	1.3%	--	Norman, OK - Storm Water Master Plan
10	6	Texas[8]	34.7					
10a	6	Harris Co. (Houston), TX	49.77	0.5	--	1.0%	--	Harris Co. Regulations for Stormwater Quality Management
11	10	Oregon[9]	37.39					Varies for MS4s - on approach and on volume
11a	10	Portland, Oregon	36	0.83	--	2.3%	--	Figure 3 - http://www.portlandoregon.gov/bes/article/202909
11b	10	Eugene, Oregon	46.6	1.4	--	3.0%	--	Figure 3 - http://www.portlandoregon.gov/bes/article/202909
11c	10	Gresham, Oregon	37.4	1.37	--	3.7%	--	Figure 3 - http://www.portlandoregon.gov/bes/article/202909
12	5	Ohio[10]	37.77	0.75	--	2.0%	Varies	From Permit OHC000003
13a	2	New York[11] - inland	39.28	1	1	2.5%	2.5%	New York State Stormwater Management Design Manual
13b	2	New York[11] - costal	39.28	1.5	1.5	3.8%	3.8%	New York State Stormwater Management Design Manual
14a	3	Maryland - Eastern Zone	41.84	1	0.9	2.3%	2.1%	From Stormwater Design Manual
14b	3	Maryland - Western Zone	41.84	1	0.9	2.3%	2.1%	From Stormwater Design Manual
15a	4	North Carolina-non-costal[12]	42.46	1	1	2.4%	2.4%	From Session Law 2006-246
15b	4	North Carolina - costal[12]	42.46	1.5	1.5	3.5%	3.5%	From Session Law 2006-246
16	4	Georgia	48.61	1.2	1.2	2.5%	2.5%	From Permit GAG610000
17	6	Arkansas[13]	49.2	None	None			Reviewed Permits and Annual Reports
18	6	Louisiana[14]	59.74	None	None			Reviewed Permit and Regulations

Median values	39

Notes:

1. **Arizona** - This MS4 standard is applicable for the City of Phoenix; City of Phoenix Stormwater Management Plan 2013 Update, https://www.phoenix.gov/waterservicessite/Documents/102562.pdf, Page 8-2.
Tucson has Stormwater Retention Detention Manual; Pima County as Design Standards for SW Detention and Retention - defines "Balanced" and "Critical" basins, retention/detection to reduces post-dev. Peaks to pre-dev. Peaks (2-, 10-, and 100-yr events). Also apply the first flush - 0.5" retention for impervious areas/disturbed areas. AZ allows dry wells, allows retention.
0.48" is the 85% rainfall for Pima Co. (see Appendix A of their Manual) - used 105 years of rainfall, did not exclude storms below 0.1", 80th percentile = 0.37", 90th = 0.61"
2. **Nevada** - Stormwater Quality Management Committee (SQMC) is made up of Clark County, City of Las Vegas, City of Henderson, City of North Las Vegas, and the Regional Flood Control District.
website - http://www.lvstormwater.com/
BMP Manual (2009) does not give Volume. Hydrologic Criteria and Drainage Design Manual has a WQ volume section (section 1207) - used 0.37"
Las Vegas Valley is the driest large MS4 community in the nation, with a mean annual rainfall of about 4.2".Rainfall is infrequent, with an average of 15 days with measurable rainfall per year, and 11 days witha minimum of 0.10 inches of rainfall needed to produce significant runoff.
Up to 0.20 inches of rainfall may be necessary to produce substantial runoff in undeveloped desert areas upstream ofurban development.

0.37" determined from Figure 1206 - Urban Runoff Quality Management - WEF Manual of Practice No. 23,ASCEM Annual and Report on EngineeringPractice No. 87 June 1998, Page 176
3. **Colorado** - no numerical values found for State or City/County of Denver. Permits/requirements more general "develop/implement strategies which include BMPs…minimize pollutants".
Boulder - has had on-site detention requirements since 1970's - uses UDFCD, Vol. 3 - 0.5" (0.6" - 80th per. Storm with 0.1" depression storage for imperv. Areas).
4. **Utah** - has 90th percentile event in Permit (like NM) but no numerical value added to most recent (March 1, 2016) Small MS4 Permit; Jan. 2015 SLC MS4 permit - does not have 90th % requirement
5. **Minnesota** - MN PCA - several options allowed to comply - one is 1", one is calc. the 95% storm, match pre-dev. runoff conditions
6. **Kansas** - No statewide requirement for on-site retention or volume control. Many areas had adopted 85th to 90th percentile rain events to compute WQv.
Kansas City - has developed BMP Manual, Has minimum BMPs required, uses a Value Rating calc for site BMPs, Water Quality Storm = 1.37", WQv=1.37*(0.05+0.009I) where I is % impervious
7. **Oklahoma** - No numerical standards located. Develop program that will minimize water quality impacts, and attempt to maintain pre-development runoff conditions (Oklahoma MS4 General Permit, p. 15)
Reviewed Oklahoma City & Norman, OK documents - did not find any stormwater quality treatment storm of volumes.
Norman, OK - Storm Water Master Plan - sets "capture and treatment volume" to 0.5". In some cases, increases this to 0.7".
8. **Texas** - No numerical standards in the Small MS4 General Permit, larger cities (ex. - Houston) - have required Stormwater Quality Management Plans for all new and re-development over 5 ac.
These plans address structural and non-structural controls, maintenance, and inspections. Have guidance manual for developing these plans and appropriate BMPs.
Also (Austin), impervious cover limits, critical water quality zones (keeping transition zones by waterways, keeping 100-year floodplains), set backs, etc.
Harris Co. Regulation - states water quality treatment volume=0.5" runoff from drainage area. Rainfall for Houston from NOAA for 30-year period (1981-2010).
Edwards Aquifer (portions of Medina, Bexar, Comal,Kinney, Uvalde, Hays, Travis and Williamson Counties) Rules - volumes/sizes based on TSS removal; sediment basins require storage of 2-yr, 24-hour storm (3.2 to 3.8").
9. **Oregon** - Portland has two method to calculate WQv - they are based on the 10-year storm (3.4") - requires infiltration facilities to max. extent feasible
Treatment of 90% of ave. annual runoff vol = 0.83" rainfall over 24 hr.
MS4s in Oregon vary on their WQvs. Summary - http://www.portlandoregon.gov/bes/article/202909
10. **Ohio** - MS4 permit requires a re-developed water quality volume reduction of 20% or a 20% reduction from the initial condition runoff volume. For new -development - 0.75".
0.75" is Guidance/Ordinance (not in Permit) - Reference: http://epa.ohio.gov/Portals/41/storm_workshop/dorsey.pdf
11. **New York** - MS4 manual (GP-0-10-002) requires a new development retention of between 0.8 and 1.2 " with any water quality volume not retained being treated. This is the same for re-developed conditions with the nuance that if this treatment level is not possible than the retained water volume can be equivalent to either 25% of the initial condition or 25% of the water quality volume.
New York State stormwater management design manual - http://www.dec.ny.gov/docs/water_pdf/swdm2015chptr04.pdf - has 1" to 1.5" for 90th percentile storm
12. **North Carolina** - MS4 permit requires a new development/re-development rainfall volume of 1" to be retained within non-coastal areas. This value changes to 1.5" in coastal areas.
13. **Arkansas** - Permit (ARR040000, 2014) states goal of 80% removal of TSS from flows which exceed pre development levels; no mention of water quality volume. Has ordinance requirement but not tied to storm event or volume.

14. **Louisiana** - from Permit (p. 197) "minimize water quality impacts and attempt to maintain pre-developed runoff conditions". Has ordinance requirement but not tied to storm event or volume.

Easterling Consultants LLC

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June 10, 2013

Mr. Kevin Daggett, PE
Storm Drainage Section Manager
Engineering Division
Department of Municipal Development
City of Albuquerque
PO Box 1293
Albuquerque, NM 87103

Re: Derivation of the 90th Percentile Precipitation for Albuquerque

Dear Kevin:

As part of Easterling Consultant LLC's task assignment relating to "Revising COA Drainage Ordinance and DPM Updates" to conform to US EPA's issuance of a new MS4 Permit for the City of Albuquerque, the National Weather Service precipitation records for Albuquerque were collected for the period 1891-2010 (119 years) and tabulated in the attached table and graph. From this analysis, it is our opinion that the most reliable estimate of any precipitation event equaling or exceeding the 90th percentile precipitation is 0.44 inches.

In the course of our analyses, we noted that the selection of the period of record can have a significant impact on the results. As a result, it is our opinion that using the longest available record will produce the results most representative of local climate conditions and precipitation patterns.

If you have any questions, please do not hesitate to contact me.

Sincerely,

Charles M. Easterling, P.E.
President

Attachment

cc: Kathy Verhage, P.E.
Melissa Lozoya, P.E.

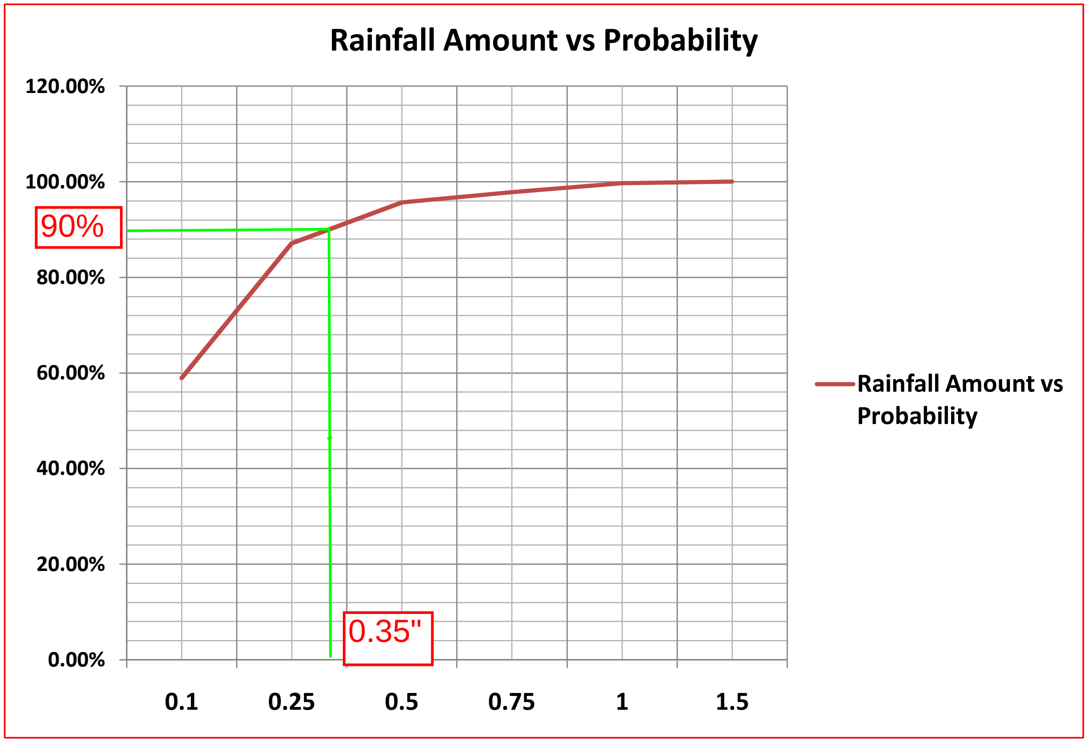
Albuquerque Precipitation Statistics 1891-1970

Number of Events per Period

Period	Yrs of Record	Precipitation Range						
		0.1"	0.25"	0.5"	0.75"	1"	1.5"	
1891-1910	20	414	192	67	29	16	3	
1911-1930	20	504	233	70	19	11	4	
1931-1940	10	0	225	0	0	7	0	
1951-1970	20	443	0	62	0	10	0	
Totals	70	1361	650	199	48	44	7	
Percentages		58.94%	28.15%	8.62%	2.08%	1.91%	0.30%	2309
Accumulated		58.94%	87.09%	95.71%	97.79%	99.70%	100.00%	

Events per Year		19.4	9.29	2.84	0.686	0.629	0.100
Rainfall Volume		0.1	0.25	0.5	0.75	1	1.5

Events/yr	Precip Amount
19.4	0.1
9.29	0.25
2.84	0.5
0.69	0.75
0.63	1
0.10	1.5

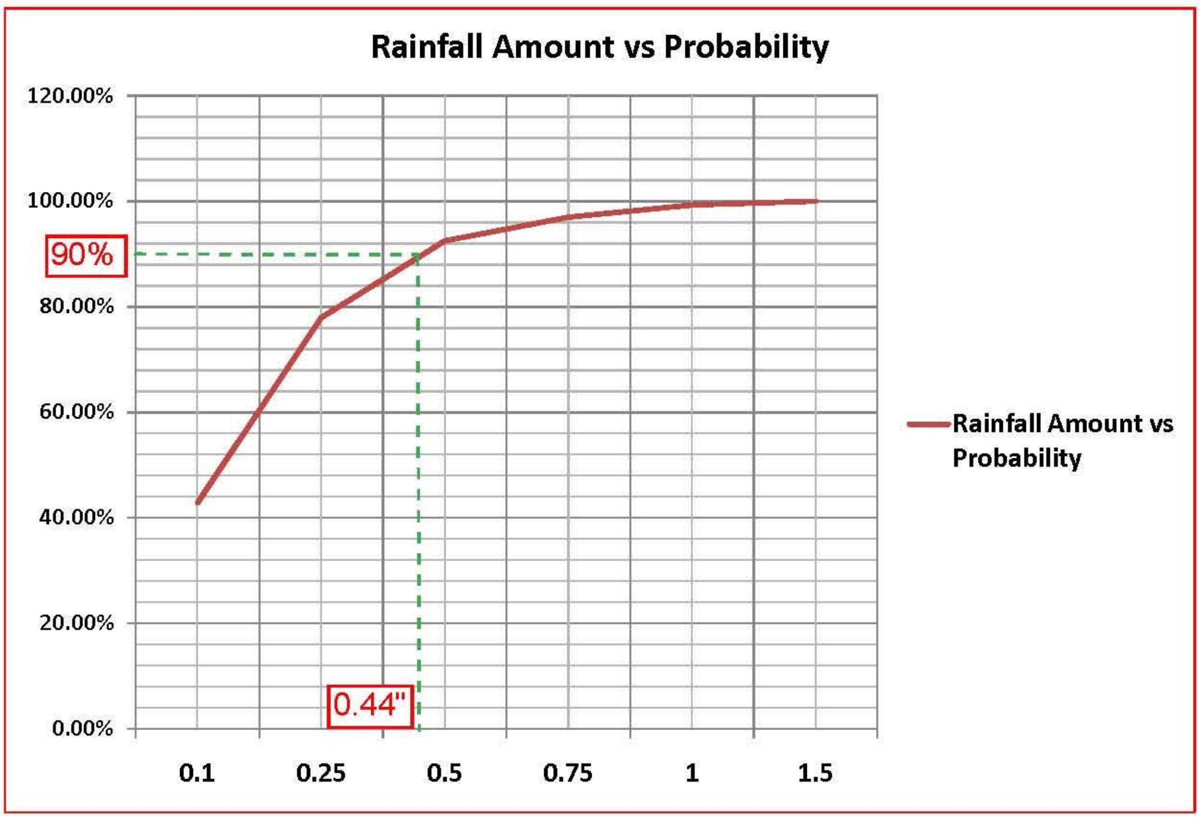


Albuquerque Precipitation Statistics 1891-2010

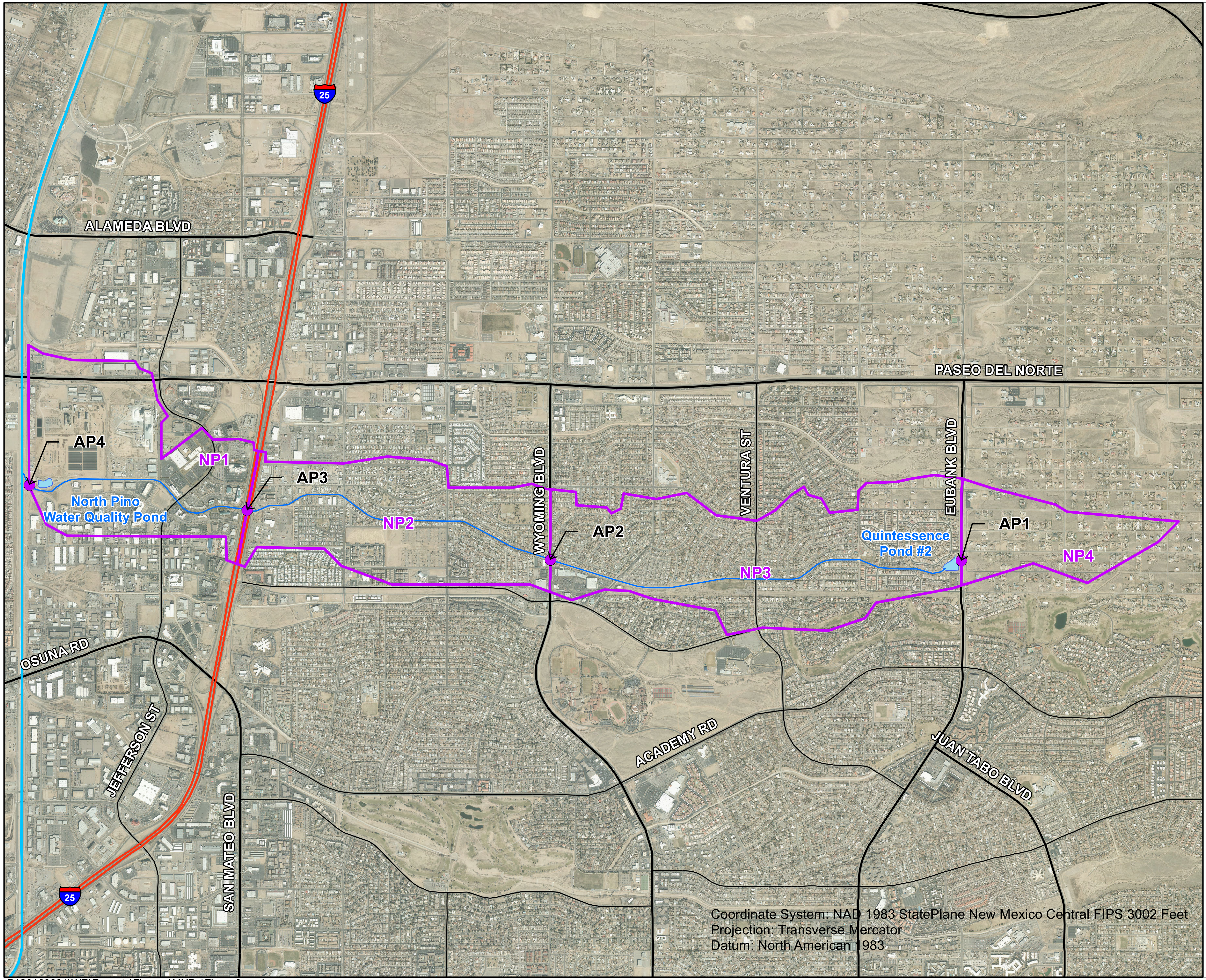
Number of Events per Period

Period	Yrs of Record	Precipitation Range					
		0.1"	0.25"	0.5"	0.75"	1"	1.5"
1891-1910	20	414	192	67	29	16	3
1911-1930	20	504	233	70	19	11	4
1931-1940	10	0	225	0	0	7	0
1951-1970	20	443	0	62	0	10	0
1970-2010	40	79	532	291	102	34	18
Totals	**110**	**1440**	**1182**	**490**	**150**	**78**	**25**
Percentages		42.79%	35.13%	14.56%	4.46%	2.32%	0.74%
Accumulated		42.79%	77.92%	92.48%	96.94%	99.26%	100.00%

Events per Year		13.1	10.75	4.45	1.364	0.709	0.227
Rainfall Volume		0.1	0.25	0.5	0.75	1	1.5



APPENDIX B – HYDROLOGIC ANALYSIS INFORMATION AND CALCULATIONS



Legend

- North Pino Analysis Points
- North Diversion Channel
- AMAFCA Drainage
- AMAFCA Ponds
- North Pino Basins
- Interstate Highway
- Principal Arterial
- Minor Arterial

NDC Watershed Hydrologic Analysis Study North and South Pino Watersheds

Figure 6

North Pino Watershed Basin Map

N W E S

0 2,500 5,000 Feet

1 in = 2,500 ft

AMAFCA

Bohannan Huston
www.bhinc.com 800.877.5332

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Author: gmaynard

April 2016

MS4 Stormwater Quality Study for North Diversion Channel Watershed
Appendix B

New Development & Re-Development - NORTH PINO - Area = 1,830 ac		
Area that is undeveloped in Basin/Watershed	Undeveloped Area (ac)	Average % Impervious for overall basin
NP-1	45	69
NP-2	46	56
NP-3	29	47
NP-4	65	24
Total in N. Pino Watershed	185	47
		Average % Impervious for undeveloped. Area

- Information from 20160331_NPinoLandUseBreakdown.xlsx - sum of vacant (disturbed and undisturbed) land, % impervious for basin calc. in that spreadsheet 20160331_NPinoLandUseBreakdown.xlsx
- kept same impervious area that was used for entire watershed - to calculate "potential" runoff volume
- Per Patrick's direction (3/3/16) - assume 1/2 of undeveloped land will develop as new development at same % impervious as existing watershed (used average).
- Per Nelly, EPA, 80th percentile storm is used for redevelopment = 0.48" - this value is not in Tetra Tech's report - only 95th, 90th, and 85th are reported.
- Per Patrick's direction (3/3/16) - assume 1/2 of undeveloped land will be redevelopment at same % impervious as existing watershed (used average).

North & South Pino - Backyard Analysis - Percent Impervious
Backyard Effect
Pino Watershed Analysis (BHI Proj. #20160331)
Design Engineer: Cameron Herrington and S. Ganley

Low Density Residential - includes single-family lots from 1/3 acre to 1+ acres in size					
	Lot Area (ac)	Area Draining to Backyard (ac)	Impervious Area Draining to Backyard (ac)	% of lot draining to Backyard	% impervious (Just to Backyard)
10810 San Rafael Ave. NE	1.00	1.00	0.24	100%	24%
10809 Coronado Ave. NE	0.93	0.93	0.49	100%	53%
11305 Santa Monica Rd. NE	0.89	0.89	0.22	100%	25%
Average	**0.94**	**0.94**	**0.32**	**100%**	**34%**
Medium Density Residential - includes single-family lots 1/4 acre or less					
	Lot Area (ac)	Area Draining to Backyard (ac)	Impervious Area Draining to Backyard (ac)	% of lot draining to Backyard	% impervious (Just to Backyard)
6839 Jade Park Ave. NE	0.16	0.08	0.04	50%	25%
7508 Burke St. NE	0.19	0.10	0.04	53%	21%
Average	**0.17**	**0.09**	**0.04**	**52%**	**23%**
High Density Residential - includes multi-family & multi-family dense land-use categories					
	Lot Area (ac)	Area Draining to Backyard (ac)	Impervious Area Draining to Backyard (ac)	% of lot draining to Backyard	% impervious (Just to Backyard)
9912 Irbid Rd. NE	0.13	0.04	0.03	29%	21%
9709 Larnaca Rd. NE	0.13	0.06	0.04	48%	27%
9116 Flushing Meadows Dr. NE	0.11	0.04	0.03	38%	24%
Average	**0.12**	**0.05**	**0.03**	**38%**	**24%**

Example - Med. Density Residential

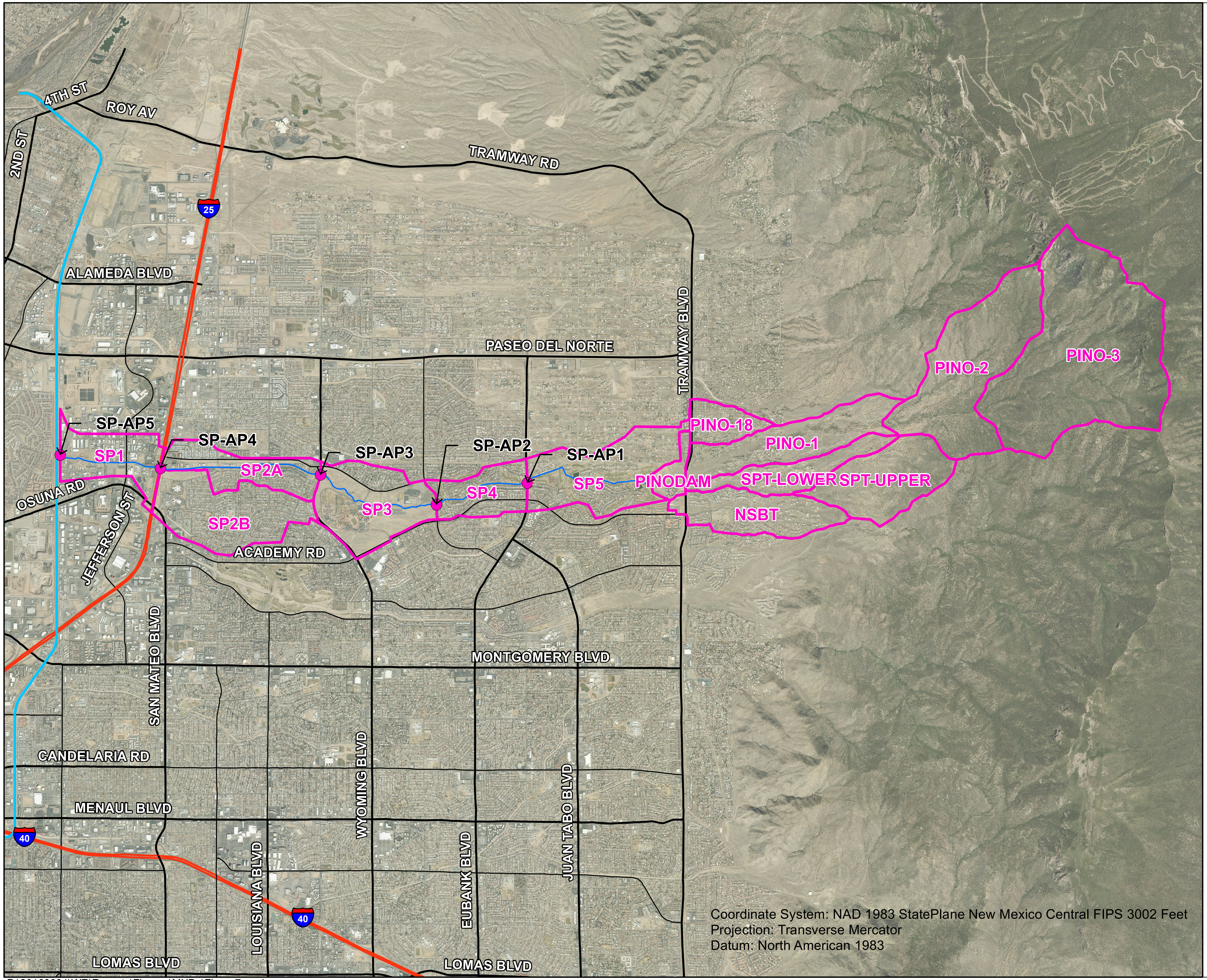
Example - Low Density Residential

MS4 Stormwater Quality Study for North Diversion Channel Watershed
Appendix B

NDC Watershed Analysis - North Pino 1 Watershed
Land Use Comparison
Project #: 20160331
Design Engineer: Cameron Herrington
Date: 2/16/2016

Land Use Category	Land Area (ft^2)	Land Area (ac)	% Coverage	% Impervious	Imperv. Area (ac)	Imperv. Area w/ Backyard (ac)	Reduction Percent
Commercial	6,847,691	157	33%	85%	134	127	5%
Vacant Land - Disturbed	1,946,551	45	9%	0%	0	0	
Vacant Land - Undisturbed	12,161	0	0%	0%	0	0	
Arroyos - Naturally lined	490,184	11	2%	0%	0	0	
Arroyos - Concrete lined	122,933	3	1%	90%	3	3	
Arroyos - Concrete lined w/natural buf	232,186	5	1%	40%	2	2	
Industrial/Manufacturing	7,568,391	174	37%	72%	125	119	5%
Parks/Recreation	0	0	0%	15%	0	0	
Paved Roadways	2,784,922	64	13%	90%	58	58	
Public/Institutional	646,692	15	3%	50%	7	7	5%
Low Density Residential	0	0	0%	35%	0	0	34%
Medium Density Residential	0	0	0%	45%	0	0	23%
High Density Residential	0	0	0%	66%	0	0	24%
	Total:	474			328	315	
					Imperv. %	Reduced Imperv. %	Delta
					69%	66%	3%

Notes:
1. High Density Residential includes multi-family and multi-family dense land-use categories.
2. Medium Density Residential includes single-family lots 1/4 acre or less in size.
3. Low Density Residential includes single-family lots from 1/3 acre to 1+ acres in size.
4. For Impervious Area with Backyard - looking at % impervious that pond/flows through backyards to determine a % impervious reduction
For commercial and public/institutional - assumed a 5% decrease in imperviousness (ponds, swales, etc)
For low density residential - 34% decrease in per. Imperviousness; medium density residential - 23% decrease in % imperviousness;
high density - 24% decrease in % imperviousness.



Legend

- South Pino Analysis Points
- North Diversion Channel
- AMAFCA Drainage
- South Pino Basins
- Interstate Highway
- Principal Arterial
- Minor Arterial

NDC Watershed Hydrologic Analysis Study North and South Pino Watersheds

Figure 7
South Pino Watershed Basin Map

N W E S

0 5,000 10,000 Feet

1 in = 5,000 ft

AMAFCA

Bohannan Huston
www.bhinc.com 800.877.5332

P:\20160331\WR\Reports\Figures\MXDs\Figure7.mxd
Author: gmaynard

April 2016

New Development & Re-Development - SOUTH PINO - Area = 6,646 ac		
Area that is undeveloped in Basin/Watershed	Undeveloped Area (ac)	Average % Impervious
SP1	8	72%
SP2A	12	62%
SP2B	16	53%
SP3	61	36%
SP4	4	41%
SP5	61	31%
PINODAM	2	35%
PINO-18	4	42%
PINO-1 (without pasture- open space land)	11	33%
SPT-LOWER (without pasture- open space land)	34	29%
NSBT	55	38%
Open space in PINO-1, SPT-LOWER, SPT-UPPER, PINO-2 & PINO-3	3,359	0%
Total Undeveloped Area - not open space	268	
Total in S. Pino Watershed	3,627	38%

Weighted % imperv average does not count STP-UPPER, PINO-2 or PINO-3

- Information from 20160331_SPinoLandUseBreakdown.xlsx - sum of vacant (disturbed and undisturbed) land & vacant land pasture and vacant land pinon juniper
- kept same impervious area that was used for entire watershed - to calculate "potential" runoff volume
- Per Patrick's direction (3/3/16) - assume 1/2 of undeveloped land will develop as new development at same % impervious as existing watershed (used average).
- Per Nelly, EPA, 80th percentile storm is used for redevelopment = 0.48" - this value is not in Tetra Tech's report - only 95th, 90th, and 85th are reported.
- Per Patrick's direction (3/3/16) - assume 1/2 of undeveloped land will be redevelopment at same % impervious as existing watershed (used average).

APPENDIX C – INFORMATION ABOUT EQUIPMENT USED TO MEASURE DISCHARGE INTO RIO GRANDE

There were two different pieces of equipment that were used in collecting data for this report; Solinst Levelogger and In-Situ Multi-Parameter TROLL 9500.

AMAFCA is using the Solinst Levelogger (Figure A) to measure the depth of flow over the equipment crossing which permits measurement of discharges to the river. The Levelogger is a non-vented datalogger that measures groundwater and surface water levels that are displayed as temperature compensated pressure readings and are barometrically compensated with the aid of a Barologger. AMAFCA received the M30 Levelogger and installed it at the equipment crossing on June 26, 2015. AMAFCA had a rating curve developed for the equipment crossing to allow the flow rate over the equipment crossing to be calculated using the Levelogger data. The Equipment Crossing rating curve and general overview are located in this appendix.

The In-Situ Multi-Parameter TROLL 9500 (Figure B) is a water quality sonde used to measure turbidity, dissolved oxygen, temperature, electrical conductivity, and pH. The turbidity data was analyzed for this report at three sites. The details of turbidity maintenance and general overview of the product are located in this appendix.

Figure A: Solinst Levelogger

Figure B: In-Situ Troll 9500

10 MONITORING WATER QUALITY: OVERVIEW

WHY MONITOR WATER QUALITY?

At a time of increasing demands on the finite natural resources of our planet, public organizations and private individuals alike have become acutely aware of the responsibility to maintain the quality of the earth's air and water supplies.

Recent rapid advances in knowledge and technology have made it possible to deliver accurate, timely, and reliable data on processes we cannot necessarily examine visually. New-generation sensors for in-situ measurement of surface waters and groundwater can be an efficient alternative to time- and labor-intensive programs of field sampling and transportation to a laboratory for analysis, or can supplement such programs. If it is possible to collect, interpret, and respond in a timely fashion to accurate information about water supplies and water quality, we can design better systems for protection of those supplies.

Monitoring water-quality parameters can reveal much about the presence and movement of natural and unnatural components of water—the presence of harmful bacteria, potential pollution sources, depletion of nutrient requirements for aquatic life, salt-water intrusion into fresh water bodies, changes in water level or temperature that can alert observers to the onset of an "event" that can adversely affect the quality of the resource.

Monitoring water quality in surface and groundwater resources may be required by Federal, state, or local regulations. Digital records of monitoring can document compliance with guidelines and standards mandated by regulatory bodies.

Profiling and logging water-quality data can provide timely information on continually changing conditions—profiling to provide instantaneous real-time feedback, logging to track trends and demonstrate compliance.

THE SENSORS

The Multi-Parameter TROLL 9500 takes advantage of new technologies to monitor water-quality parameters in-situ with high accuracy. Each sensor has been manufactured to our rigid specifications and is designed to operate with the entire suite of sensors and with the MP TROLL 9500 electronics. These "smart" sensors retain serial number identification and calibration information, and are detected and identified by the instrument. A sensor may be calibrated in any MP TROLL 9500 and moved to another port that accepts the sensor type, or used in another MP TROLL 9500, without recalibration. The most accurate results will be obtained when a sensor is calibrated and operated in the same MP TROLL 9500.

The water quality sensors available for the Multi-Parameter TROLL 9500 may be classed in two general types:

BASIC SENSOR SET

- pH
- Combination pH/ORP (Oxidation-Reduction Potential)
- Dissolved Oxygen, polarographic (DO)
- Conductivity (and Specific Conductance, Salinity, Total Dissolved Solids, Resistivity)

The pH sensor is a Single ISEs (ion-selective electrode). The Combination pH/ORP sensor is a Multiple ISE.

The Basic sensors can be factory-calibrated and pre-installed in the MP TROLL 9500. They are ready for use right out of the box with a brief Quick Cal. However, for best results, if your software supports it, we recommend that you perform a traditional two-point calibration for pH and DO, and a specific range calibration for conductivity as described in sections 11-13 below. The accuracy that can be achieved from the instrument is proportional to the time and care you put into calibration.

EXTENDED SENSOR SET

The Extended Sensor set includes:

- Ammonium
- Chloride
- Nitrate
- Turbidity (factory-installed)
- RDO® Optical Dissolved Oxygen

INSTALLING SENSORS

The diagram below represents a head-on view of the “sensor block” in the front end of the MP TROLL 9500. There are four sensor ports, plus permanently installed pressure and/or turbidity and temperature sensors. Pressure and turbidity sensors are optional—if your instrument does not include one or both of these sensors, there will be a permanently installed plug in the port.

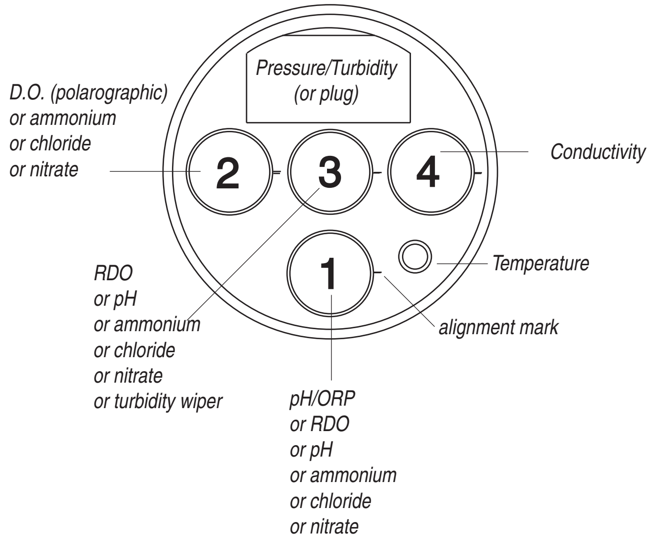
Do not try to remove the pressure or turbidity sensor or permanently installed plug.

Although the sensor design permits any sensor to install into any sensor port without damage to either the sensor or the instrument, for proper functioning please insure that sensors are installed in their intended ports, as shown in the diagram.

To install sensors:

1. Remove the restrictor or Cal Cup from the front end of the MP TROLL 9500. This allows access to the sensor block shown below.

End view of sensor block



Will a sensor work if installed in the wrong port?

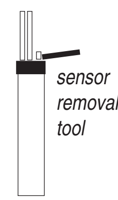
Physically, a sensor may be plugged into any port. However, a sensor that is detected in the wrong port for its type will generate an error message in the software. The message will let you know which port or ports the incorrectly installed sensor should be moved to.

In this case, remove the offending sensor and install it in the correct port. Then “refresh” the device view in the software to update the display.

2. Remove the cap or storage bottle from the sensor. Retain the cap or bottle for future storage and protection of the sensor. If the connector end is covered with a cap, remove it also.

TIP: *To ensure optimum membrane response for new ion-selective electrodes (pH, ORP, nitrate, ammonium, chloride), soak the sensor in calibration solution for at least 15 minutes and up to several days before calibration.*

3. Remove any moisture or dirt from the area around the port where you will install the sensor, then use the sensor removal tool to remove the plug from the port. Retain the plug for use with fewer than 4 removable sensors installed.

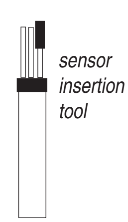


TIP: *If you are installing a sensor in port 3 (the central port), install it first. This will make it easier to install sensors in other ports.*

4. Remove any moisture or debris from the connector in the bottom of the port with a clean swab or tissue.
5. Check lubrication of the sensor o-rings.

The sensor o-rings require generous lubrication before installation. New sensors will be lubricated at the factory. If the o-rings appear dry, apply a silicone lubricant before installation.

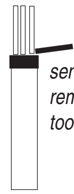
6. Align the mark on the sensor with the alignment mark on the correct port (see diagram), or visually align the sensor connector pins with the port connector pins.
7. Press the sensor firmly into the port until it is securely seated. When properly inserted a small gap (width of the sensor removal tool) remains between the instrument body and the widest part of the sensor, for ease of removal.



REMOVING SENSORS

Sensors may be removed for inspection, cleaning, routine maintenance, and storage. Because the smart sensors retain calibration information, they may be removed and re-installed—even in another MP TROLL 9500— as often as necessary.

Remove a sensor by positioning the yoke of the sensor removal tool at the point where the sensor enters the sensor block. Firmly pry the sensor upward until it pops out.



sensor removal tool

Sensor O-Rings

Two Viton® o-rings on each sensor provide a watertight seal against water leakage into the instrument body. We recommend that you inspect these o-rings each time you remove or install a sensor. Check carefully for cracks, tears, splitting, shredding, and other damage. If the o-rings are in good condition, apply silicone lubricant before installing the sensor again. Remove excess lubricant with a tissue, and take care to keep grease away from the area around the connector at the bottom of the sensor. Should lubricant get into this area, it can be removed with a clean cotton swab.

If the o-rings become damaged to the extent that no longer provide an effective seal, they should be replaced. Sensor o-rings and lubricant are available from In-Situ Inc. or your distributor.

CALIBRATION OVERVIEW

The MP TROLL 9500 and its control software provide several options for calibration of the water-quality sensors. Select the method that suits the time you have at your disposal and the degree of accuracy you want to achieve when measuring water-quality parameters.

Satisfactory results may be achieved using the Quick Cal procedure. Some sensors can even return nominal results straight out of the box using the factory-supplied default calibration coefficients. However, for best results we recommend a full traditional calibration procedure before the first field use, and periodic checks and recalibrations as necessary thereafter.

The following available options are briefly described in the next two pages:

- Traditional Calibration
- Quick Calibration
- Out-of-Box
- Factory Defaults

TRADITIONAL CALIBRATION

A full traditional calibration, guided by software wizards, can achieve the highest level of accuracy. Some sensors require a single-point calibration, others present a choice of single- or multi-point, requiring more than one calibration standard. A single-point calibration gives good results in the range of values represented by the selected calibration solution. When a wide range of values are expected, a multi-point calibration is recommended.

With the sensor installed in the MP TROLL 9000 and immersed in calibration solution, the sensor is powered at regular intervals and its response is monitored. The difference (deviation) between the minimum and maximum response over a predetermined time period is tracked by the software. When the peaks of the response fall within predetermined limits for the time period, the sensor response is considered sufficiently stable to provide a valid calibration point. The length of time and allowable deviation are specific to each sensor type, and furthermore are specific to the determination of nominal stability or complete stability. The time period of interest is shorter for nominal stability than for complete stability, allowing for a shortening of the calibration soak time while still returning a valid calibration point.

- Available for: All water-quality parameters.
- Requirements: MP TROLL 9500, sensors (installed), Cal Cup, and one or more calibration solutions for each parameter to be calibrated. Suitable calibration solutions are supplied in In-Situ's individual calibration kits.
- Where to find the method in this manual: Sections 11-19.

Q: ***What is the difference between NOMINAL and STABLE?***

A: *To meet the criteria for a valid calibration point, the change (deviation) in sensor response is monitored over time. The software is looking for the calibration solution temperature and the sensor readings to settle over a specific time period. The criteria for STABLE are designed to meet the published specifications. The NOMINAL criteria are designed to shorten the calibration time when an approximate calibration is acceptable. When the deviation falls within the limits of the "loosened" specifications, NOMINAL is displayed in the Status area, and the Accept button becomes available to store the current calibration point.*

Accepting a NOMINAL value may save considerable time. In some cases, especially if the sensors have been soaking in the solution for several minutes prior to calibration, the accuracy achieved by accepting a nominal value may be very similar to that obtained by waiting for complete stability.

QUICK CALIBRATION

A "Quick Cal" calibrates the Basic sensors simultaneously to achieve adequate performance with minimal labor using a single "universal" calibration solution.

- Available for: pH, ORP, polarographic Dissolved Oxygen, and Conductivity.
- Requirements: MP TROLL 9500, sensors (installed), Cal Cup, and Quick Cal solution.
- Where to find the method in this manual: Section 3, Getting Started.

OUT OF THE BOX

Some sensors may be installed and used right out of the box using factory-supplied default calibration coefficients.

- Available for: pH, ORP, and Conductivity.
- Requirements: MP TROLL 9500, sensors (installed).
- Where to find the method in this manual: No method required, plug-and-play.

DEFAULT COEFFICIENTS

This option resets the sensor's factory defaults and is best when the sensor is new.

- Available for: pH, ORP, and Turbidity.
- Where to find the method in this manual: See pH calibration in Section 11, ORP calibration in Section 14, Turbidity calibration in Section 18.

The cell constant for a conductivity sensor may be entered "by hand," without performing a complete calibration, if desired. See the procedure in Section 12 below.

TIP: *When using Pocket-Situ to perform calibrations, do not let the PDA time out during the procedure. To locate this setting in most PDAs, display the Start menu, select Settings, System tab, Power.*

PREPARING TO CALIBRATE

CALIBRATION KITS

Kits of calibration solutions for various parameters and ranges are available from In-Situ Inc. Our calibration solutions are certified to N.I.S.T. standards, packaged in quarts, each providing sufficient fluid for at least 6 calibrations. Kits include deionized water if that substance is recommended for rinsing a particular sensor during calibration.

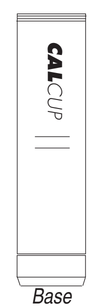
The Quick Cal kit provides a convenient "universal" calibration solution, designed to calibrate multiple parameters simultaneously.

THE CALIBRATION CUP

The clear acrylic Cal Cup shipped with your MP TROLL 9500 is used to hold solution during sensor calibration. When fitted with a small moist sponge, it also provides a convenient way to protect and hydrate the sensors of the MP TROLL 9500 between uses.

The base of the Cal Cup is removable so that the stirrer may be attached for calibrations where continuous agitation of the solution is recommended. A small hole in the threads of the base near the o-ring permits venting during 100% dissolved oxygen calibration with the Cal Cup and probe inverted.

The Cal Cup's fill lines indicate the recommended amount of solution for most calibrations, and ensures the temperature sensor is immersed.



- With a full complement of sensors installed, use the lower line as a guide.
- With only 1 or 2 removable sensors installed, fill to the upper line.

The temperature sensor should always be immersed in at least one-half inch of fluid.

When attaching the Cal Cup to the front end of the MP TROLL 9500, align carefully and thread the Cal Cup onto the body until seated against the o-ring, then back off slightly to avoid overtightening.

When attaching the Cal Cup to the instrument body, be careful not to overtighten.

EFFECT OF TEMPERATURE ON CALIBRATION

The most successful calibrations reproduce field conditions as nearly as possible, especially temperature. It is best to calibrate at the expected field temperature.

RINSING

As a general guideline, we recommend you rinse the Cal Cup, the front end of the MP TROLL 9500, and the installed sensors prior to beginning calibration. This will remove trace contaminants or solutions used in previous calibrations, and prepare the instrument for a clean calibration.

A good way to do this is to fill the Cal Cup with water, attach to the instrument, and shake vigorously. This may need to be done a couple of times.

Rinse first in tap water, followed by a rinse with distilled or deionized water.

Shake or wipe with a clean lint-free tissue to dry. It is not necessary to dry thoroughly.

Some calibration procedures also recommend a rinse in the selected calibration solution. In this case, drying is not necessary.

STIRRING

When to Stir?

The stirrer accessory should be used during a calibration procedure if it will also be used during field use—for example, if the instrument will be in stagnant or very slowly moving water. The more closely calibration conditions reflect field conditions, the more successful the calibration. This is especially important when calibrating the ISE sensors (ammonium, chloride, and nitrate).

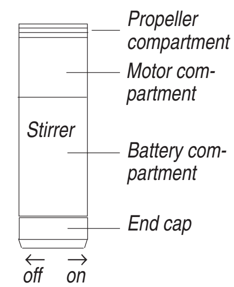
ISE sensors in close proximity to each other can sometimes create interferences. Constant stirring can enhance the performance of the ISE sensors.

Attaching the Stirrer for Calibration

To use the battery-powered stirrer for calibration, attach it to the MP TROLL 9500 and Cal Cup as follows. See illustration C on the following page.

1. Remove the restrictor (nose cone attached) from the MP TROLL 9500 and set it aside.
2. Remove the black end cap from the Cal Cup.
3. Screw the top of the stirrer (propeller end) to the bottom of the Cal Cup (the end from which you just removed the end cap).
4. Fill Cal Cup to fill line with solution.
5. Attach Cal Cup/stirrer assembly to front end of MP TROLL 9500.

Starting the Stirrer



The stirrer is powered by two alkaline D-cells (installed). To start the motor, tighten the end cap.

The magnetic stir bar in the propeller compartment will start to spin. The stir bar is protected by a guard plate that may be removed for cleaning if necessary.

TIP: *Should the stir bar not start spinning, try giving it a gentle nudge by sliding a narrow tool such as a screwdriver or key between the protective bars of the guard plate.*

To turn the stirrer off, back off the end cap until the stir bar stops spinning.

CALIBRATION PROCEDURES

Refer to the following sections for specific calibration procedures and guidelines:

Quick Cal	Section 3
pH	Section 11
Conductivity	Section 12
Dissolved Oxygen (polarographic)	Section 13, first half
Dissolved Oxygen (optical)	Section 13, second half
ORP	Section 14
Ammonium	Section 15
Chloride	Section 16
Nitrate	Section 17
Turbidity	Section 18

AFTER CALIBRATION

When you finish calibrating with any method, the following happens:

- The newly calculated calibration coefficients are written to the “smart sensor” memory.
- You have the option of viewing the calibration report. The report may be viewed immediately after calibration, or at any time. See Calibration History, below.
- The sensors are ready to take measurements.

MP TROLL 9500

A. with restrictor and nose cone

B. with Cal Cup in place of restrictor and nose cone

C. with Cal Cup and stirrer, for stirring calibrations

D. with Restrictor and stirrer, for monitoring water quality in stagnant water

SENSOR STORAGE

It is best to calibrate just before field use. However, should you need to store calibrated sensors, there are a couple of options:

- If the instrument will be used in a day or so, leave the sensors installed. Remove the Cal Cup and rinse it and the sensors. Moisten a sponge and place it in the bottom, or add a little water (deionized, distilled, or tap) to the Cal Cup—just enough to create a moist environment. Return the probe to the Cal Cup for transport to the field site.

  TIP: *Deionized water is preferred over tap water, but it is not essential; especially if the local tap water is of good quality.*

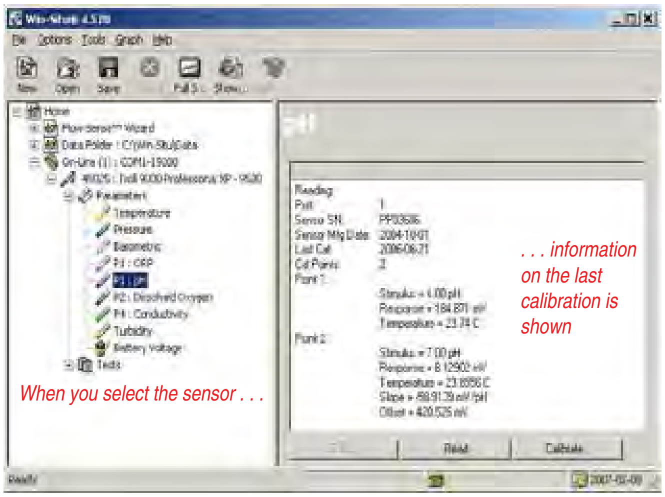
  To seal the Cal Cup against leakage, seat it lightly against the o-ring on the instrument body. It is best not to over-tighten.

- For longer storage, remove the sensors from the MP TROLL 9500. Store the conductivity sensor dry. Store the DO, pH, and pH/ORP sensors in their storage bottles (located in the sensor kits): DO in clean water, pH and pH/ORP in the solution they were shipped in, or with a moist sponge in the sensor storage bottle to avoid depleting the reference solution.

CALIBRATION HISTORY

Each time a sensor is calibrated, the information is written to the sensor, where it is stored until the next calibration. Details on the most recent calibration are displayed by the software when a parameter is selected in the Navigation tree.

The software also creates a calibration report in html format each time a sensor is calibrated. A separate report is created for every calibration of every parameter—even for a calibration that was cancelled. You have the option to view the report immediately after calibration. Reports are stored for later retrieval and reference in a folder named “Calibration Reports” in the folder where Win-Situ 4 or Pocket-Situ 4 is installed. Reports include a detailed record of date and time, parameter, calibration type, number of calibration points, stimulus and response, and calculated coefficients. An index in html format is also created and updated each time a calibration is performed.



pH calibration information for a combination pH/ORP sensor in port 1

The calibration reports are accessible from the Tools Menu and the Show Calibration Report button on the toolbar. They may also be accessed like other files through Windows Explorer (desktop PC) or File Explorer (PDA); they are not displayed in the Data Folder. They may be viewed or printed to provide a complete calibration history.

***TIP:** Here's how to find the calibration report indexes:*

Desktop or laptop PC—Calibration Reports subfolder in the folder where Win-Situ 4 is installed

PDA—Calibration Reports subfolder in the folder where Pocket-Situ 4 is installed

Example of a calibration report index

Folders:

Folder
SN32072
SN45025

Click a folder to see its listings

Click a tile to open it

SN32072

Files:

File Name
SN32072 2006-04-17 171530 TURB.html
SN32072 2006-06-18 102309 DO.html
SN32072 2006-08-14 134200 QuickCal.html
SN32072 2006-11-25 121530 PH.html
SN32072 2007-01-11 154322 Cond.html

MP TROLL 9500 serial number — *Cal Date* — *Cal Time (hhmmss)* — *Parameter*

HOW OFTEN TO CALIBRATE

No sensor will remain in calibration forever. The calibration frequency is almost completely determined by the chemical properties of the fluid being monitored, and the accuracy you wish to achieve from the instrument. For example, when used in relatively clean water, in a normal pH range, at a relatively stable temperature, some sensors could remain in calibration for a couple of weeks or longer. On the other hand, in surface water with a high nutrient content and wide temperature fluctuations, the sensors may need to be cleaned and recalibrated every few days. Your own measurement results are the best guide to the need to recalibrate.

When a sensor or instrument is new, we recommend checking the readings often (say, once a day) to get an idea of the stability of the sensor.

Changes in flow also affect readings. Constant flow will increase the accuracy. This can be achieved with the stirring accessory.

The table below may be used as a very general guideline to how long sensors may be expected to remain in calibration under optimum conditions:

pH, ORP	1-2 months
Conductivity	2-3 months
D.O. (polarographic)	2-4 weeks
D.O. (optical, RDO)	up to a year if foil is not damaged
ISEs	1 day

***TIP:** For additional information on calibration schedules, see the Technical Note on Instrument Calibration in the Downloads section at www.in-situ.com.*

HOW TO CHECK IF A SENSOR IS STILL IN CALIBRATION

Immerse the sensor in a calibration standard of known value and at the same temperature as the original calibration. Compare the sensor reading to the solution value. Some drift is to be expected, but generally the readings should fall within the sensor's accuracy specification. If readings fall outside the accuracy specification by an amount that is not acceptable for your current application, recalibration is recommended. You will quickly learn by experience how often you need to recalibrate a given sensor based on usage.

***TIP:** Quick Cal solution may be used for a quick check of pH, ORP, and conductivity. Refer to the values printed on the label.*

WHEN TO REPLACE A SENSOR

After a certain amount of use even a complete recalibration will not be able to accurately calculate calibration coefficients. The slope will gradually become lower and lower. At this point the sensor should be replaced. Specific slope guidelines for individual sensors are given in the individual parameter sections below.

USING A STIRRER

In-Situ's stirrer accessory provides continuous sample circulation or agitation, which can improve the performance of water-quality sensors in a number of applications.

Dissolved oxygen (DO) measurements drop in very stagnant water due to depletion of oxygen next to the membrane. A slight perturbation to the system will cause the DO measurements to return to normal. Stirring is recommended if the instrument is anchored to a fixed structure in stagnant conditions—for example, attached to a pier in a calm lake that has no underwater currents. If the wind is blowing and waves are slightly moving the cable, then stirring is probably not necessary.

ISE sensors in close proximity to each other can sometimes create interferences. Constant stirring can enhance the performance of the ISE sensors.

Sample agitation can also help to improve sensor response time when water-quality conditions are subject to change (e.g., in a moving contaminant plume) and can speed up temperature stabilization.

Attaching the Stirrer for Field Use

The stirrer accessory is easily installed on the MP TROLL 9000. See illustration D earlier in this section.

1. Remove the nose cone from the MP TROLL 9500. Leave the restrictor attached to the instrument.
2. Screw the top of the stirrer (propeller end) to the stainless steel restrictor in place of the nose cone.
3. Start the stirrer; see Starting the Stirrer earlier in this section.

The instrument is ready for use in stagnant water.

Q: ***How can I find the serial number of a water quality sensor—pH for example?***

A: *The software can display the sensor serial number. Do this:*

1 Select pH in the Navigation tree

2 Look at the information displayed The serial number is displayed in the Information pane on the right side of the screen (or at the bottom on a PDA)

REFERENCES

Eaton, A.D., L.S. Clesceri, E.W. Rice, and A.E. Greenberg, eds., *Standard Methods for the Examination of Water and Wastewater,* 21st edition, Washington, D.C.: American Public Health Association, American Water Works Association, and Water Environment Federation, 2005.

A Fish Farmer's Guide to Understanding Water Quality. LaDon Swann, Dept. of Animal Sciences, Illinois-Indiana Sea Grant Program, Purdue University. On the web at AquaNIC (Aquaculture Network Information Center), aquanic.org.

Rundle, Chris C., A Beginners Guide to Ion-Selective Electrode Measurements. Nico2000 Ltd., London, UK. On the web at www.nico2000.net

Water on the Web (WOW). University of Minnesota project initially funded by the National Science Foundation. On the web at wow.nrri.umn.edu

Water Quality Sensor Pressure Ratings

Sensor	Pressure Rating PSI	Usable Depth Meters	Usable Depth Feet
pH	300	210	692
pH/ORP	300	210	692
Conductivity	350	246	807
D.O. polarographic*	350	246	807
Turbidity	350	246	807
Wiper	350	246	807
Chloride	100	70	231
Ammonium	20	14	46
Nitrate	20	14	46
RDO	*exceeds rating of the TROLL 9500*		

** Submersion and retrieval at up to 4 feet per second.*

18 TURBIDITY

WHAT IS TURBIDITY?

Turbidity is an indirect measure of the clarity or transparency of water, and thus an important indicator of its condition and productivity. Created by suspended matter and microscopic organisms, turbidity causes light to be scattered and absorbed rather than transmitted directly through water. Turbidity is the physical characteristic of the solution that causes light scattering. Turbidity is the opposite of clarity.

The APHA reference work *Standard Methods* (Eaton and others, 2005) defines turbidity as "an expression of the optical property that causes light to be scattered and absorbed rather than transmitted with no change in direction or flux level through the sample."

Turbidity is not . . .

- a direct measure of clarity.
- a measure of color.
- a measure of suspended solids; it is a measure of their light-scattering abilities.

The In-Situ Turbidity sensor* is in conformance with the ISO 7027 turbidity standard which specifies 90° scattered light.

WHY MEASURE TURBIDITY?

Turbidity measurements

- can provide a reasonable estimate of the *total suspended solids* or sediments (TSS) concentration in water.
- can tell us something about the health of a natural water body. Clear water lets light penetrate more deeply into a lake or stream than does murky water. This light allows photosynthesis to occur and oxygen to be produced.

Typical turbidity values

EPA drinking water	0.3 - 0.5 NTU
Treated water	0 - 1 NTU
Fresh water, >21.5" visibility	< 10 NTU
Fresh water, 2.5" visibility	240 NTU
Short-term stress to aquatic life	> 10 NTU
Unsafe level for most aquatic life	> 100 NTU

- can be a useful indicator of runoff into surface water systems.
- in flow-cell or in-line applications, when pumping water at very low rates, can provide a good indication of true formation water.

Higher turbidity levels make it more costly to treat surface water for use as drinking water. Controlling turbidity may be an effective way to protect against pathogens in drinking water.

Aesthetic considerations also play a role in our desire to quantify turbidity: Most people would rather look at, drink, or swim in clear water than in water that appears cloudy, and closely associate appearance with the health of the body of water.

HOW IS TURBIDITY MEASURED?

Historical methods for measuring turbidity relied on subjective estimates that depended largely on the eye of the beholder.

In the Jackson Candle method, for example, a candle flame is observed through the length of a glass tube into which a fluid sample is poured until the rays of transmitted and scattered light appear equal and the flame essentially disappears. Among several drawbacks to this method, the reproducibility of standards formulated from natural sediments was difficult to control.

The Secchi disk method used in limnological studies involves submerging a weighted, black-and-white painted metal plate until the pattern can no longer be detected. The plate is then pulled up until it is visible again. The average of the two depths provides an estimate of water clarity or transparency.

Modern turbidimeters measure the loss in intensity of a light beam as it passes through a solution containing suspended and dissolved particles that are large enough to scatter the light. The method is based upon a comparison of the intensity of light scattered by the sample with the intensity of light scattered by a standard reference suspension. The *nephelometer* is a particular type of turbidimeter that measures the intensity of light scattered at right angles (90°) to the incident light. This lessens the difficulty of differentiating small changes against a large background. Standards for turbidity-measurement instruments specify the light source, angle, wavelength, beam width, and sample suspensions, among other factors. Many of today's commonly accepted procedures (e.g., Standard Methods, EPA, and ISO) apply to laboratory bench-top instruments.

THE TURBIDITY SENSOR

The optional turbidity sensor of the Multi-Parameter TROLL 9500 is permanently-installed and factory-calibrated. It may be a turbidity sensor alone or a pressure/turbidity sensor combination. If your MP TROLL 9500 was ordered without a turbidity sensor or a pressure sensor, there will be a permanently installed plug in the pressure/turbidity sensor slot. A turbidity sensor or combination pressure/turbidity sensor can be added at the factory.

The In-Situ turbidity sensor is comprised of a matched solid-state detector-emitter pair positioned at right angles. The light source is an infrared LED, optimized for operation at 870 nanometers (nm). The optical windows of the detector (photodiode) and emitter (LED) are scratch-resistant sapphire. ISO 7027 has set a detection angle of 90° and the light wavelength at 860 nm. The sensor uses active modulation for ambient light rejection.

The In-Situ sensor is an electronic nephelometer which compares the intensity of light scattered by the environmental fluid with intensity of light scattered by a standard reference suspension. The higher the intensity of scattered light, as measured in NTU's, the higher the turbidity. This measurement generally provides a very good correlation with the concentration of particles in the water that affect clarity. However, measurements of scattered light cannot be directly related to a gravimetric equivalent, such as suspended sediment load, unless a working curve for the specific sample is created.

THE TURBIDITY WIPER

The optional wiper accessory helps to keep the turbidity sensor optics free of bubbles and fouling.

The wiper installs in port 3 of the MP TROLL 9500 like other removeable sensors. A positional brace aligns it with respect to the turbidity sensor and keeps it stable in moving waters.

The wiper pad is adhesive-free, low-abrasion cotton material. The pad is easily replaced when it becomes too soiled to clean the sensor optics effectively.

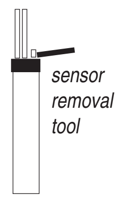
Use of the wiper will significantly impact battery life. Lithium batteries are recommended.

WIPER INSTALLATION

The MP TROLL 9500 may be shipped with the optional wiper already installed in port 3, as shown on the drawing below. If installation is necessary, unpack and install the wiper in port 3 as follows.

*The turbidity wiper will function properly only when installed in **port 3**.*

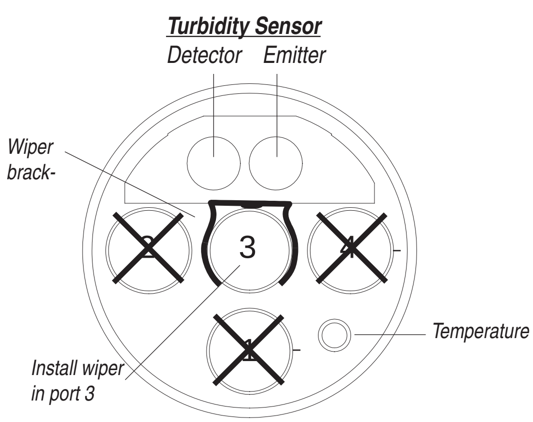
1. Remove the restrictor from the front end of the MP TROLL 9500. This allows access to the sensor block depicted in the drawing below.
2. Use the sensor removal tool to remove the sensor or plug from port 3. Retain the plug for future use. For best access to port 3, you may need to remove sensors or plugs from other ports as well.



3. Check lubrication of the o-rings on the connector end of the wiper.

TIP: *The wiper o-rings require generous lubrication before installation. New wipers will be lubricated at the factory. If the o-rings appear dry, apply apply a silicone lubricant before installation.*

4. Visually align the connector on the wiper with the connector at the bottom of port 3.
5. Press firmly until you feel the wiper dock with the port connector. When properly inserted a small gap (width of the sensor removal tool) remains between the wiper body and the instrument body.
6. Press the wiper into the bracket attached to the turbidity sensor.
7. After installing a new wiper, we recommend you access wiper control in the software while you can clearly see the wiper movement. Connect in software, select the wiper, and click **Wipe** to ensure the wiper passes over the turbidity sensor optics properly.



What does the wiper do, and when is wiping necessary?

The wiper helps keep the optical windows of the turbidity sensor clear of bubbles and debris during measurements. When the sensor is off, the wiper is parked in its "home" position over sensor port 4. When a turbidity measurement is called for—a manual reading, a scheduled reading during a test, while calibrating or profiling—the wiper makes a full 360 degree sweep to clean the optics.

Wiping is not needed when the instrument is hand-held for short periods (Profiling). Gently swishing the MP TROLL in the water should serve to dispel air bubbles.

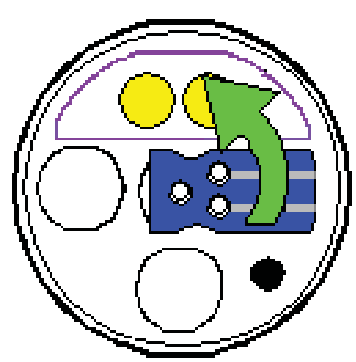
WIPER MOVEMENT

When the turbidity sensor is off—not taking a measurement—the wiper head is "parked" over port 4. When a turbidity measurement is requested, the wiper head passes over the optics, sweeping them clean, and returns to its parking place. One "wipe" consists of a 360° counter-clockwise sweep (viewed from the sensor end), as shown in the drawing below. Wiping occurs automatically before turbidity readings—manual reads, profiling, calibration, and tests—that are more than 15 seconds apart. If readings are less than 15 seconds apart, the wiper will wipe once, before the first reading.

A single wipe may be initiated in the software when the instrument is idle to clear the turbidity optics of bubbles or debris. The wiper's movements are entirely software-controlled.

TIP: *15 seconds are alotted for a wipe cycle. This time is generous to allow for slower wiper movement at very low temperatures.*

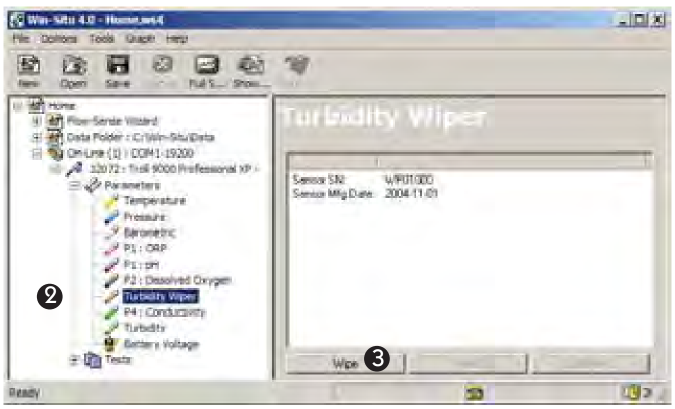
If readings—test, calibration, profiling—are more than 15 seconds apart, the turbidity sensor will be wiped automatically before each reading. If readings are less than 15 seconds apart, the wiper will wipe the windows just once, before the first reading.



MANUAL WIPE

To wipe the turbidity sensor optics manually:

1. With the wiper installed in port 3, connect the MP TROLL 9500 to a PC and establish a connection in Win-Situ 4 or Pocket-Situ 4.
2. Select the Wiper in the Navigation tree.



3. Click **Wipe**. The wiper will pass once over the turbidity sensor optics and return to its home position.

WIPER GUIDELINES AND PRECAUTIONS

- If a wiper is installed during a Quick Cal of the Basic sensors (see Section 3, Getting Started), steps should be taken to insure the wiper pad material does not absorb the Quick Cal solution. There are two ways to do this.
  - Remove the wiper head before doing the Quick Cal. Refer to Wiper Maintenance guidelines later in this section for instructions on removing the wiper head.
  - Alternatively, soak the front end of the instrument in plain water before calibrating to allow the wiping pad to absorb sufficient water to prevent its absorbing any Quick Cal solution.
- **Do not attempt to move the wiper head by hand.** Wiper movement is software-controlled.
- The wiper pressure may be adjusted if necessary so that the pad is effectively cleaning the sapphire windows of the turbidity sensor during movement. Refer to Wiper Maintenance guidelines later in this section.
- The wiper pad or head may be replaced as needed. Refer to Wiper Maintenance guidelines later in this section.
- When an RDO optical dissolved oxygen sensor is installed, check to see that the RDO adapter cable is out of the way of wiper movement.

CALIBRATION

FACTORY CALIBRATION

The turbidity sensor has been factory-calibrated to achieve a sensor accuracy of ± 5% or 2 NTU (whichever is greater). The sensor is calibrated over its full range, 0 to 2000 NTU, using polymer standards. The resulting calibration coefficients are written to the sensor memory, where they are stored permanently. They may be overlaid by performing a field calibration as described below, or may be recalled from the sensor memory at any time.

The MP TROLL 9500's turbidity sensor is ready to measure turbidity without any user intervention. It is advisable to take a turbidity reading first in your own calibration solution(s) as a check to ensure the accuracy is within your operational standards and requirements. If this result is satisfactory, a field calibration is not required.

FIELD CALIBRATION

Field calibration (or "user calibration") is an overlay function that is applied after the factory calibration math is done. The factory calibration applies across the entire range of NTU, and can be altered in the field with a 1 to 4 point calibration procedure as described below to compensate for effects of sensor fouling and other factors. You may wish to perform a field calibration with standards other than polymer (i.e., Formazin).

For best results, calibrate as close to field temperature as possible.

CALIBRATION SOLUTIONS

A nephelometer such as the In-Situ turbidity sensor should be calibrated using standard reference suspensions having reproducible light-scattering properties. The sensor has been factory-calibrated with polymer suspensions, and the resulting calibration coefficients take into account the light-scattering properties of the suspensions and the sensor optics.

> **Q:** ***Why do I need to calibrate the turbidity sensor if it has been calibrated in the factory?***
>
> **A:** *A new turbidity sensor is ready to measure turbidity with reference to suspended polymer standards. If you prefer to reference turbidity measurements to Formazin rather than polymer, a field calibration with Formazin should be performed.*
>
> *After cleaning the sensor, readings should be checked with standards and a field calibration performed if necessary.*

Polymer-based standards are submicron, non-surface charged, solid spheres in matrixes of ultrapure water in homogeneous suspension; this homogeneity allows linear dilutions. EPA approved the polymer suspensions in 1984 as a calibration standard for turbidimeters. Polymer suspensions are very stable, can withstand temperature extremes, and have excellent lot-to-lot precision. A range of polymer suspensions are available individually from In-Situ Inc. for calibrating any expected turbidity range. They can be diluted with turbidity-free water to achieve other NTU values (but see the cautions below).

Avoid vigorous mixing or agitation, which will create air bubbles and lower the accuracy of the standards. It is advantageous to calibrate a nephelometric turbidimeter with a standard that most closely matches the size of the particulates you will be measuring.

Calibrating with Other Solutions

Formazin: If you wish to recalibrate with Formazin, keep these points in mind.

- Requires very careful handling.
- Must be shaken gently and allowed to settle for at least 5 minutes before use.
- Should not be diluted.

Diluting Polymer Suspensions: If you dilute polymer suspensions, keep these points in mind:

- Do not dilute more than 10:1. Use good laboratory techniques.
- Store carefully. PVC bottles are recommended.
- Diluting polymer suspensions takes them out of the category of “primary standards”, they become “secondary standards.”
- If not handled carefully, the dilutions can become unstable; the suspension of particles may be lost.

RECOMMENDED CALIBRATION FREQUENCY

Your own experience is the best guide to how often the turbidity sensor will benefit from recalibration. The need for recalibration depends on the condition of the optical windows, which in turn depends on the environment. In a biologically active environment, cleaning and calibration will be required more often. Periodic checks in calibration solutions of known turbidity can be beneficial in indicating how well the sensor is holding its calibration.

A field calibration is recommended

- if you wish to reference turbidity measurements to a standard other than polymer.
- after cleaning the sensor windows of contamination.
- when readings appear to drift, or show unexpectedly high or low results.

* if algal or other growth on the front end of the MP TROLL 9500 changes the reflective properties of the device.

TURBIDITY CALIBRATION PROCEDURE

You will need:

- MP TROLL 9500 with turbidity sensor (wiper optional), plugs in any unused sensor ports.
- The restrictor, nose cone, and removable sensors (if any) that will be installed when turbidity is measured.
- A laboratory beaker large enough to hold the instrument and calibration solution.
- One or more calibration standards for the region in which you wish to calibrate. Several ranges from Very Low to Full are suggested in the Calibration Wizard.

> ***TIP:*** *A 1-point to 4-point field calibration may be carried out in any range. When performing a multi-point calibration, begin with 0 NTU solution. For best measurement precision the highest NTU value should exceed the readings you expect in the field.*

1. Rinse the front end of the MP TROLL 9500 with clean water. Shake well to remove the rinse water; dry external surfaces (not the optical windows) with a clean tissue.
2. Pour the selected calibration standard into the beaker and insert the MP TROLL 9500 into the solution.

   The windows of the turbidity sensor should be immersed at least ¼” (a quarter of an inch) deep in the solution. If no wiper is present, gently agitate the instrument to dispel any air bubbles.

3. Connect the MP TROLL 9500 to a PC and establish a connection in Win-Situ 4 or Pocket-Situ 4. Win-Situ screens are illustrated here. The Pocket-Situ interface is similar, with the Navigation tree at the top of the screen and the Information pane below it.

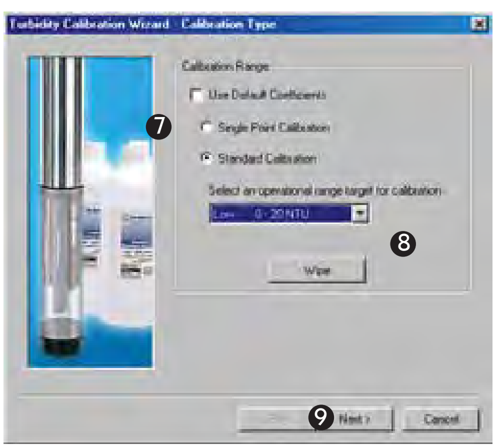
4. Select the MP TROLL 9500 in the Navigation tree.

   The installed sensors will be displayed—including the turbidity wiper, if installed in port P3.

5. Click to select Turbidity in the Parameters list. The sensor serial number (S/N) and recent calibration information is displayed.

6. Select **Calibrate**.

   The Turbidity Calibration Wizard starts. A screen like the one below is displayed.



7. Select the type of calibration you wish to do:

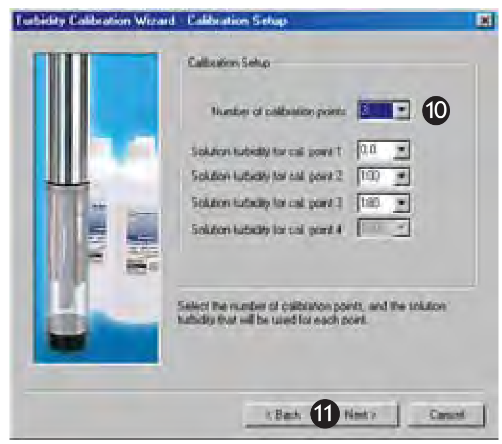
   - Use Default Coefficients resets the factory defaults. If you select this option, click **Next** and proceed to step 17.
   - Single-Point Calibration. Click **Next** and go to step 12.
   - Standard Calibration (default).

8. If you selected a Standard Calibration, select an operational range target. The ranges are suggestions only; a 1- to 4-point calibration may be performed in any range, using any standards

   Note: If the software detects a turbidity wiper accessory, pressing the **Wipe** button will result in one complete wipe cycle of the turbidity sensor optics.

9. Select **Next** to continue.

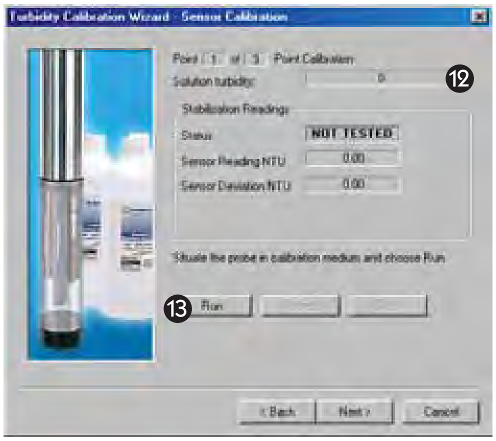
10. In the next screen, select the number of calibration points for this calibration, and the turbidity value (in NTU) of the calibration solution for each point. One to four points (solutions) may be selected for any operational range target selected in the previous screen.



   When performing a multi-point calibration, cal point 1 must be taken in a standard with a value of 0 NTU. Use clear water for this. Purchased distilled or deionized water will generally measure less than 0.5 NTU. Filtered water will have a lower NTU value.

11. Select **Next** to continue.

A screen similar to the one shown below is displayed.



12. If you are performing performing a single-point calibration, enter the value of the calibration standard (NTU). For a multi-point calibration, the value of the first solution will be displayed.

13. When the sensor is situated in the calibration medium, select **Run** to begin the stabilization.

    The display will continuously update as readings are taken and compared against the stabilization criteria.

- Status indicators:

  NOT TESTED is displayed until you begin the calibration by selecting Run.

  UNSTABLE indicates the sensor response does not meet the criteria for a valid calibration point.

  NOMINAL indicates the sensor deviation meets early stabilization criteria.

  The **Accept** button becomes available when nominal stability is achieved. You may accept the early value, or wait for complete stability. If you accept the early value, the calibration point will be designated “USER SET” in the calibration report. (For more on calibration reports, see “Calibration History” in Section 10.)

  STABLE is displayed when the readings have stabilized sufficiently to take a valid calibration point. The calibration proceeds automatically to the next screen.

- Sensor Reading: The current sensor response in NTU
- Sensor Deviation: Change in sensor response between the last two readings.
- Temperature

14. If doing a one-point calibration, go to step 17.

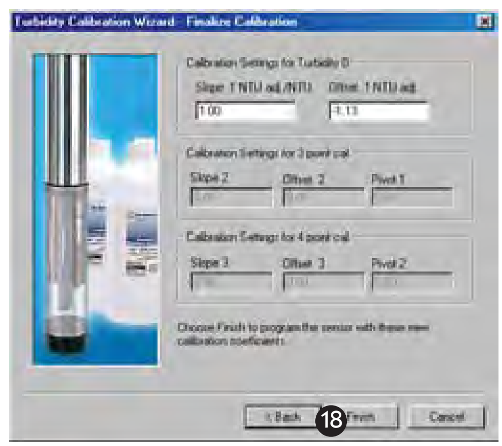
    For a multi-point calibration, the Wizard returns to the screen shown at step 13 and waits for you to situate the probe in the next calibration solution and click Run.

15. Discard the first solution, rinse the beaker and the front end of the instrument thoroughly, wipe off excess water, refill the beaker with the second solution, and insert the MP TROLL 9500 as before.

16. Select **Run** to begin the stabilization for the second calibration point. Status indicators and controls are the same as for the first calibration point (step 13).

    Again wait for stabilization, dump, rinse, dry, refill, Run, as many times as necessary to collect a stable calibration point in each solution.

17. The final screen shows the sensor slope and offset calculated during the calibration process (or the default settings if you selected that option at step 7). A slope and offset will be shown for each calibration point.



“Pivot” designates the point at which the slope characteristics change with a multi-point calibration. The correct slope for the turbidity values being monitored will automatically be applied.

18. Select **Finish** to program the sensor with the newly calculated calibration coefficients.

    TIP: *You can look at the calibration report right after calibrating, or at any time. See “Calibration History” in Section 10 for details.*

RESETTING DEFAULT COEFFICIENTS

The sensor's calibration may be reset back to factory defaults at any time. As long as there is no contamination on the optical windows, this will restore the factory accuracy (± 5% or 2 NTU).

1. Establish a connection to the instrument in Win-Situ 4 or Pocket-Situ 4.
2. Select Turbidity in the Parameters list and click **Calibrate**.
3. In the first screen, select Use Default Coefficients, then **Next**.
4. In the final screen, click **Finish** to restore the sensor's factory calibration coefficients.

SENSOR SLOPE AND OFFSET

The offset is factory-set at 0 NTU. The zero offset may be recalculated for any appropriate value by performing a single-point calibration using a calibration standard of the desired NTU value. The sensor response is very linear up to 200 NTU.

UNITS AND CALCULATED MEASUREMENTS

Two units are available for readings from the turbidity channel:

- NTUs—Nephelometric Turbidity Units. Select NTU when the sensor has been calibrated with polymer suspensions.
- FNUs—Formazin Turbidity Units. Select FNU when the sensor has been calibrated with Formazin.

USAGE RECOMMENDATIONS AND CAUTIONS

The operational pressure rating of the turbidit y sensor is 150 psi. Do not submerge it deeper than 346 ft (105 m).

Avoid use of the stirrer accessory (recommended for monitoring dissolved oxygen in stagnant water) when measuring turbidity.

When used without a wiper, dirty sensor optics can be compensated for to some extent by changing the offset.

Optical absorbancy ("color") will lessen the turbidity signal.

Turbidity readings are temperature-commpensated.

The optics need 5 seconds warm-up time to take the first reading later. Subsequent readings can be returned instantaneously.

COMMON INTERFERENCES

Light scattering depends upon the size, shape, refractive index, and other characteristics of the particles and the wavelength of the light. Optically black particles, such as those of activated carbon, may absorb light and effectively decrease turbidity measurements. Nephelometers are relatively unaffected by small changes in design parameters and therefore are specified as the standard instrument for measurement of low turbidities. Nonstandard turbidimeters, such as forward-scattering devices, are more sensitive than nephelometers to the presence of larger particles and are useful for process monitoring. Reported turbidities are heavily dependent on the particulate matter contained in the suspensions that are used to prepare instrument calibration curves.

Due to current technological limitations, field turbidity measurement is "a snapshot of averages," Field measurements can be an excellent indicator of in-situ turbidity; final determination for reporting purposes should be conducted in a laboratory.

PROFILING TURBIDITY

The turbidity sensor's 5-second warmup will result in a slight delay before the first Profiler reading for all parameters. Subsequent readings can be taken within the Profiler's 2-second cycling.

If a turbidity wiper accessory is installed, it performs an initial wipe of the sensor optics—this takes about 15 seconds—then displays the first turbidity reading. If the profiling rate is longer than 15 seconds, this 15 second wipe will happen before each reading. To avoid this delay, set the profiling rate to less than 15 seconds. See Customizing the Profiler in Section 5 for details.

LOGGING TURBIDITY DATA

The wiper is activated automatically before turbidity readings during tests, so long as the readings are 15 seconds or more apart. To prolong battery life when running a wiper, we recommend the use of external power or two internal lithium D-cells installed in the MP TROLL 9500.

SENSOR CARE

INSPECTION/MAINTENANCE/CLEANING

The optical windows of the sensor are made of scratch-resistant sapphire. The optical components are not user-serviceable. Serious mechanical and temperature shock are about the only things that can damage the LED. If you feel the instrument has suffered such damage, contact In-Situ Technical Support.

However, the windows may need frequent cleaning, especially if used in a biologically active environment. A wiper accessory can help to prevent the accumulation of foreign material.

Cleaning may be necessary if the optical windows of the sensor become visibly contaminated by the gradual accumulation of foreign material. Because the sensor is not removable, we recommend gentle swabbing of the windows with a circular motion using plain water. Solvents are not recommended, although an ammonia solution (e.g., grocery-store ammonia) may be used with good effect to remove particularly stubborn materials.

A calibration check should be performed after cleaning, using calibration standards.

WIPER MAINTENANCE

The cotton wiper pad will require replacement periodically to maintain its effectiveness in cleaning the turbidity sensor optics. The entire head may be replaced, or just the pad. In either case, the wiper head will need to be removed. A hex wrench is supplied for this purpose. You do not need to remove the entire wiper; leave the wiper body installed in port 3.

Replacement pads and wiper heads are available from In-Situ Inc. or your distributor.

To remove the wiper head, use the supplied hex wrench to loosen the set screw

Removing the Wiper Head

With the wiper parked over port 4, loosen the set screw on the wiper head until you can grasp the wiper head and gently pull it out.

Replacing the Wiper Pad

1. Remove the wiper head as above. Remove and discard the used pad.
2. Insert a new pad into the slots with the smooth side facing out, and pull to eliminate slack. Excess material may be trimmed close to the wiper head.
3. Position the head on the motor shaft with the pad facing down toward the sensors. The button at the top of the shaft should be flush with the wiper head surface. Tighten the set screw against the flat of the motor shaft. ***Be very careful not to move the wiper head in a lateral direction by hand after tightening.***
4. If convenient, connect in software, select the wiper, and click **Wipe** to ensure the wiper passes over the turbidity sensor optics properly.

Adjusting Wiper Pressure

If necessary, loosen the set screw on the wiper head and gently pull the head up or press down lightly to ensure the pad just brushes the optical windows when it passes over the turbidity sensor. Then re-tighten the set screw. ***Be very careful not to move the wiper head in a lateral direction by hand when engaged with the motor shaft.***

TIP: *The wiper head is at the best height when it just brushes the optical windows of the turbidity sensor—too high and it will not clean effectively; too low and it may not be able to spin.*

If it is necessary to remove the entire wiper assembly, be sure to use the sensor removal tool and grasp the body of the wiper. Do not attempt to pull the wiper out by the head.

Wiper Replacement Parts	Catalog No.
Replacement wiper head	0044520
Wiper pad replacement kit	0044530

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CALCULATION COVER SHEET

PROJECT:	JOB NO.	CALC NO.	SHEET
NDC Outfall GCS Modifications	14580.003.001.0070	1	1 of 11

SUBJECT:	DISCIPLINE (Civil, Mech. Process, Elect.):
Equipment Crossing Rating Curve/Table	Civil Engineering

PREPARED BY:	DATE:
David "Sonny" Cooper, PE / Richard Waters, CFM	September 9, 2015

CALCULATION STATUS	ISSUED FOR REVIEW	FINAL	CONFIRMED	SUPERSEDED	VOIDED
	☒	☐	☐	☐	☐

COMPUTER PROGRAMS USED:	☒ Yes ☐ No	DESCRIPTION/ VERSION: AutoCAD Civil 3D 2015; HEC-RAS Version 4.1.0

REFERENCE SPECIFICATIONS:	REFERENCE DRAWINGS:

SOURCES OF DATA:

Existing Conditions Land Survey by Wilson and Company. Performed July 2013. Datum: NAD 83 (NM State Plane Central Zone-Scaled to Ground); Vertical Datum: NAVD 88. Grid to Ground Factor: 1.000324001

As-built Land Survey by Cartesian, Performed June 2015. Datum: NAD 83 (NM State Plane Central Zone-Scaled to Ground); Vertical Datum: NAVD 88.

Bernalillo County LiDAR Data, 1999

HEC-RAS River Analysis System, Hydraulic Reference Manual, Version 4.1, prepared by the U.S. Army Corps of Engineers (USACE) Hydraulic Engineering Center, January 2010.

RECORD OF REVISIONS

NO.	REASON FOR REVISION	TOTAL NO. OF SHEETS	LAST SHEET NO.	BY	CHECKED	APPROVED/ ACCEPTED	DATE
0	Issued for Review	11	11	RW/SC	DP	SC	9/9/2015

1 Objective

The objective of the model is to calculate the hydraulic characteristics of flows over the new North Diversion Channel (NDC) Equipment Crossing, with the purpose of developing a rating curve and table.

2 Design Conditions

- Location: Albuquerque
- Latitude/Longitude: 32.646762 / -106.156465
- Elevation: 5000’ ASL
- Datum: NAD ’83, NAVD 88
- Landuse: Stormwater Conveyance

3 Method of Calculation

- Obtain detailed survey data for the project area.
- Generate the Digital Elevation Model (DEM) for the project area using AutoCAD Civil 3D
- Cross-sections were created (also referred to as a “cut”) using AutoCAD Civil 3D. Cross sections were cut every 200 feet of stream length and at irregularly spaced intervals to capture analysis points throughout the project area.
- Import cross-sectional data into HEC-RAS and create model of the project reach.
- Input flow data ranging from 50 cubic feet per second (cfs) to 10,000 cfs.
- Run HEC-RAS and collect the computational data.
- Use the computational data to create a rating curve and table for depth vs. flow.

4 Data and Assumptions

- Design Flows: Range of flows from 50 cfs to 10,000 cfs
    - 50 cfs – 300 cfs in 50 cfs increments
    - 300 cfs – 1000 cfs in 100 cfs increments
    - 1000 cfs-10,000 cfs in 500 cfs increments

- Manning’s Coefficients from Table 5-6 in Open-Channel Hydraulics (Ven Te Chow, 1959)
    - Concrete: n = 0.015 (B-2.c.2: *Lined channel, concrete, float finish*)
    - Embayment: n = 0.022 (C.a.2: *Excavated channel, earth, after weathering*)
    - Stilling Basin-Earthen Bottom: n = 0.030 (C.b.4: *Excavated channel, earth bottom and rubble sides*)
    - Stilling Basin-Riprap Bottom: n = 0.033 (B-2.e.3: *Lined channel, gravel bottom with rubble sides*)
    - Overbanks – not Bosque: n = 0.035 (D-2.a.2: *Floodplain, pasture, high grass*)
    - Overbanks – Bosque: n = 0.060 (D-2.c.3: *Floodplain, light brush and trees in summer*)

5 Calculations & Analysis

5.1 Obtain Detailed Survey Data for the Project Area

Weston received an existing Wilson and Company ground survey from AMAFCA at the start of the project. This was augmented with an as-built survey performed by Cartesian Surveys and Bohannan Huston. The topographic data for the Rio Grande and the Bosque were taken from the Bernalillo County 1999 LiDAR. The composition of this data was used to create the DEM using AutoCAD Civil 3D.

The more recent Bernalillo County 2011 LiDAR appeared to have data inconsistencies along the southern levee near the project. A site visit was performed to confirm the approximate height of the levee with respect to the surrounding topography, and it did appear that the 2011 LiDAR may be incorrect near the NDC. Since Weston and AMAFCA were confident that the levees have not changed in several years, the older LiDAR data was used to complete the hydraulic model.

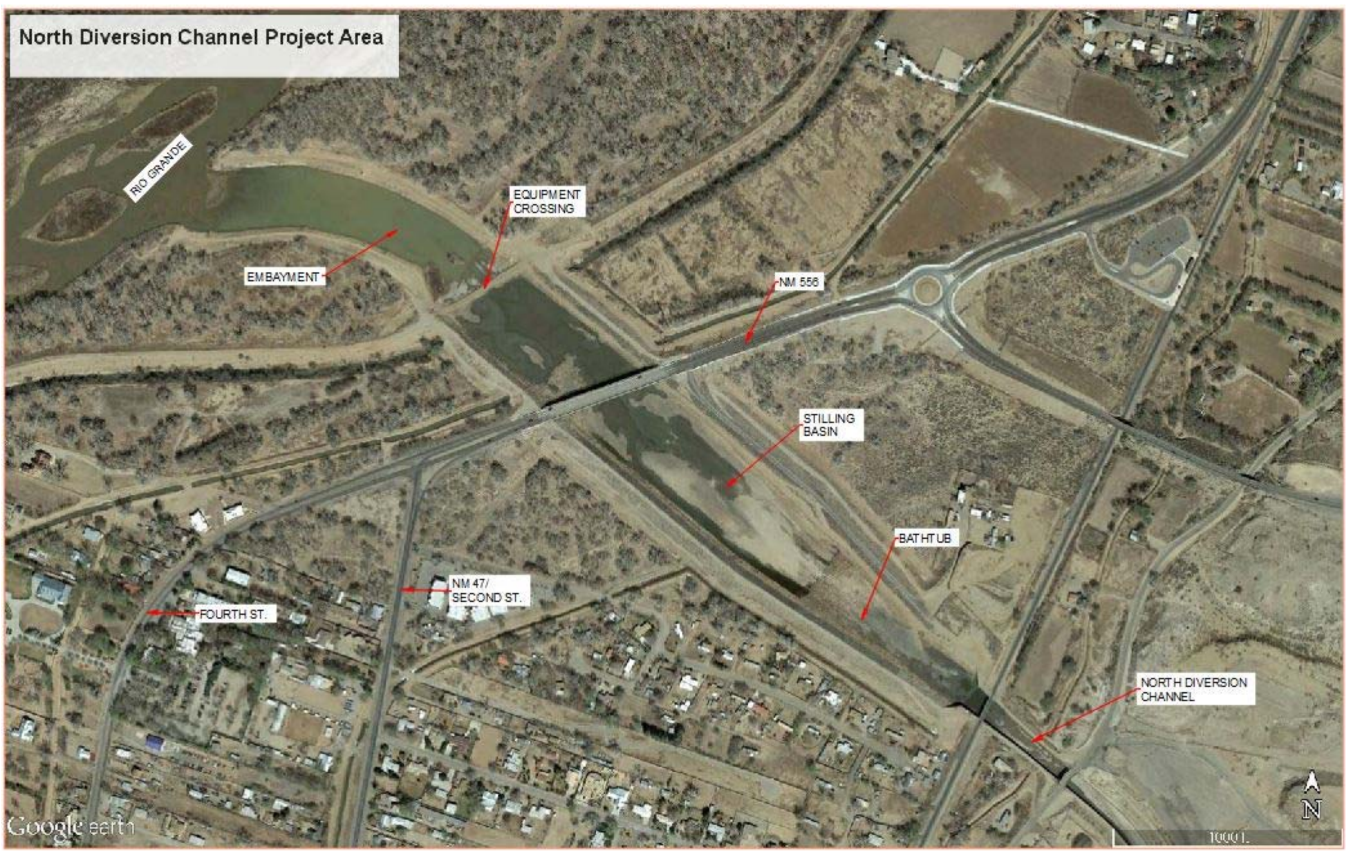

Figure 1: Project Area

5.2 Cut Channel Cross-Sections

A total of 33 cross-sections were cut from the DEM. Three cross-sections (also referred to as River Stations [RS]), 5150, 5100, and 5000 were cut on the upstream end to model the incoming NDC, and to establish the upper boundary conditions. RS 4842 to 4277 model the Bathtub; RS 4200 to 2051 model the Stilling Basin; RS 2051, 2027, 1997 and 1905 model the Equipment Crossing; RS 1905 to 984 model the Embayment, the Bosque, the riverside levees, and the Rio Grande. See Figure 2 for the cross sections and the limits of the DEM. See Figure 3 for the cross-sections in HEC-RAS, and their respective RS designations.

Figure 2: AutoCAD Civil 3D Cross-sections Cut through the Project Area

5.3 Import Cross-Sectional Data into HEC-RAS and Build Geometric Models

Once the cross-sectional data was created for the project reach, it was exported into a georeferenced geometry file which was then imported into HEC-RAS 4.1.0 to build the geometric channel model. Once in the model, the geometric data was filtered for extraneous points, the overbank stations were placed at the edges of the channel, and all cross-sections were assigned Manning's roughness values (see Section 4). See Figure 3 for the cross-sections in HEC-RAS, and their respective RS designations. See Figure 4 for an example cross-section in HEC-RAS.

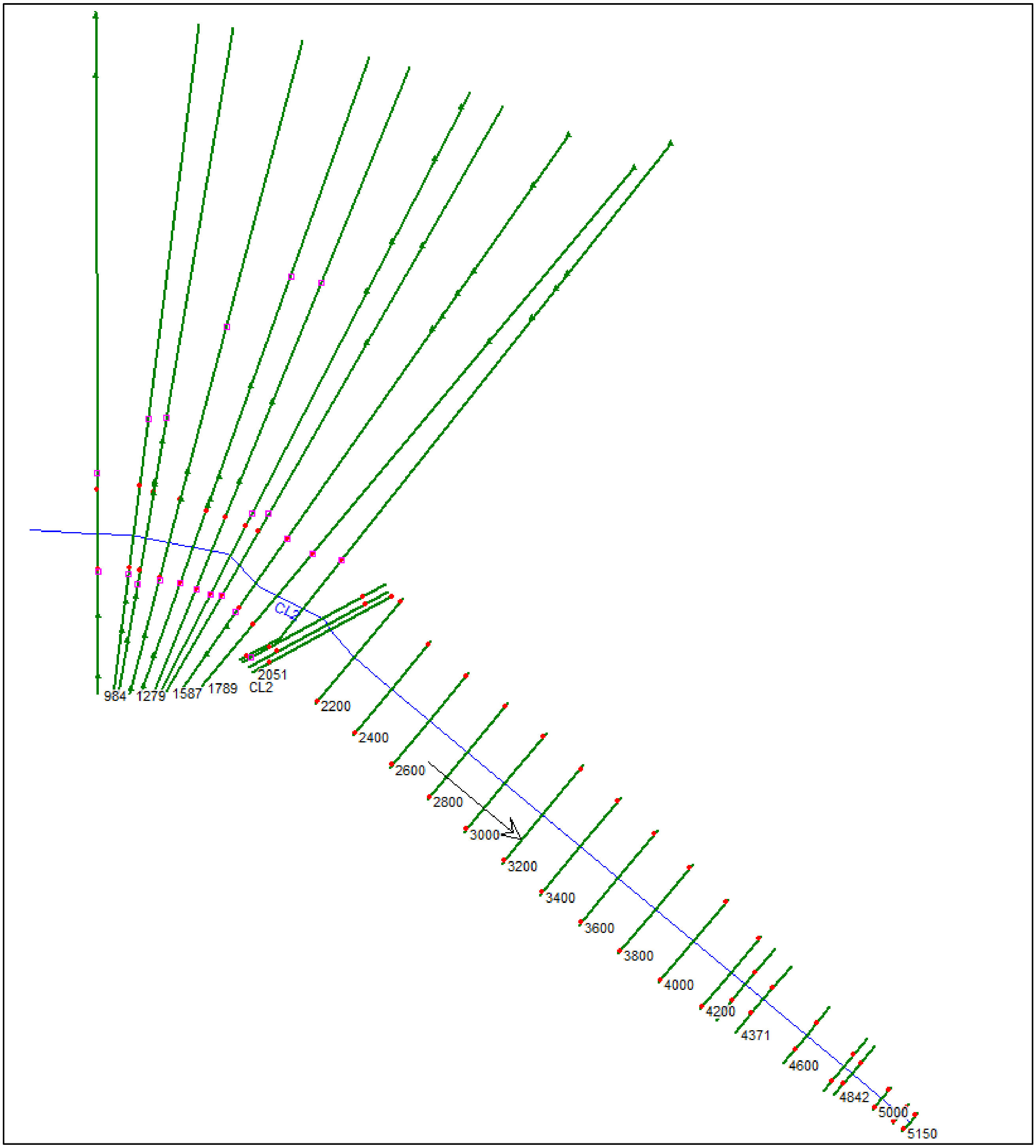

Figure 3: Bathtub Cross-Sectional Data in HEC-RAS with Corresponding RS Designations

While performing the HEC-RAS computations, it was noticed that the water surface elevations for high flows on cross-sections downstream of the Equipment Crossing would exceed the elevations of known ground surface points (i.e. the water surface did not “hit” the ground). When a water surface reaches the edge of the cross-sectional data, HEC-RAS assumes a vertical “wall” at the edge of the cross-section.

The cross-sections downstream of the Equipment Crossing were cut a minimum of 2,000 feet to the north to provide as much surface data as possible; however, the water surface profile at high flows still reaches the end of the cross-sectional data. Therefore, it was assumed that further cross-sectional data was not required, and that at high flows, the Bosque would be flooded with one to two feet of water on both sides of the Embayment.

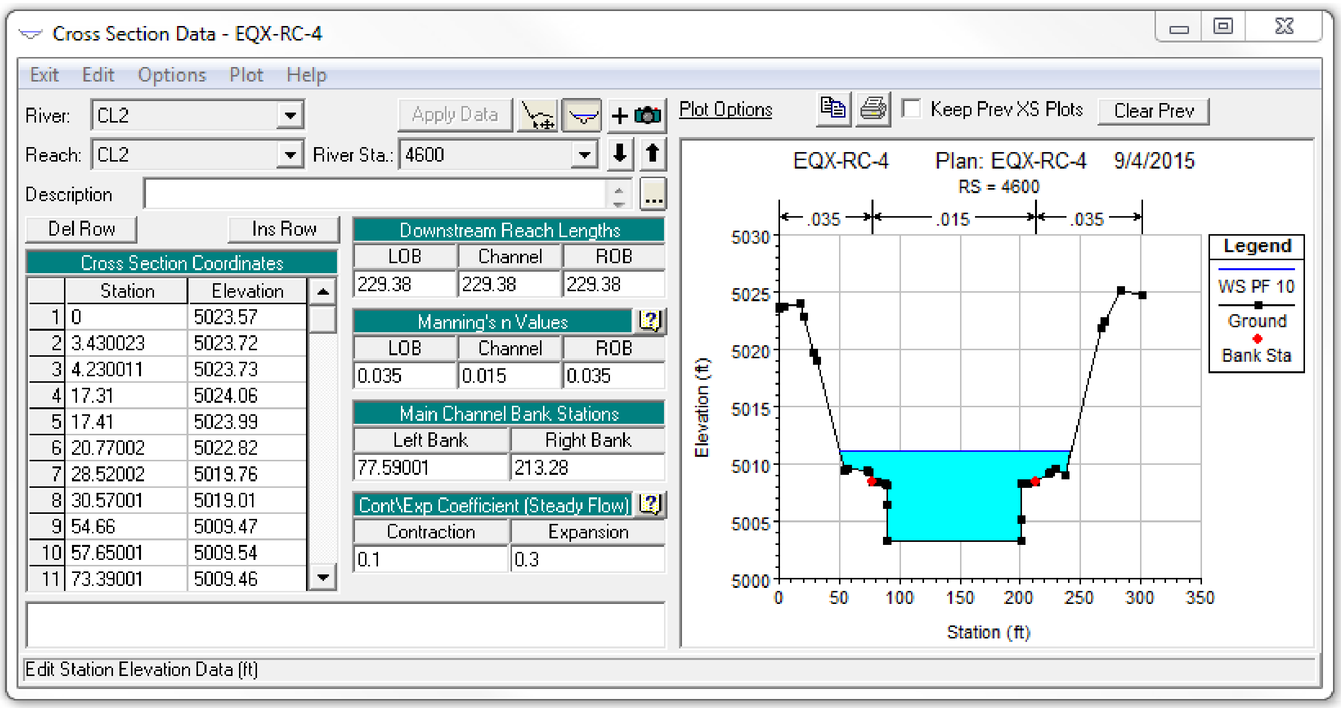

Figure 4: Example Cross-Section (Vertically Exaggerated) Imported into HEC-RAS

5.4 Import flow data into HEC-RAS

The objective of this model was to create a rating curve relating water depth at the Equipment Crossing to the flow across the crossing in 0.1-foot increments. To that end, 31 different flows, ranging from 50 cfs to 10,000 cfs, were entered into the steady flow editor (see Section 4). Reach Boundary Conditions were set at “Critical Depth” for the upstream boundary, and to “Normal Depth, s = 0.0001” for the downstream boundary (see Figure 5).

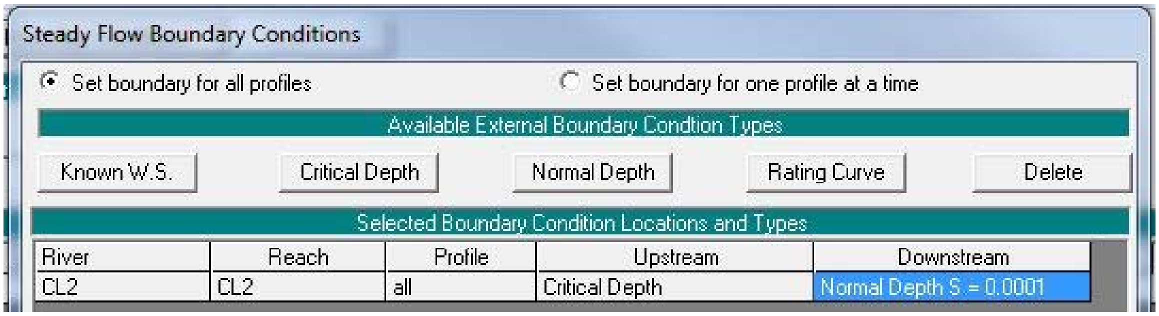

Figure 5: Reach Boundary Conditions

5.5 Perform Hydraulic Simulation for the Input Flow Rates

Once the geometric data and all of the flow parameters had been input into the model, it was run on a “mixed” flow regime (see Figure 6).

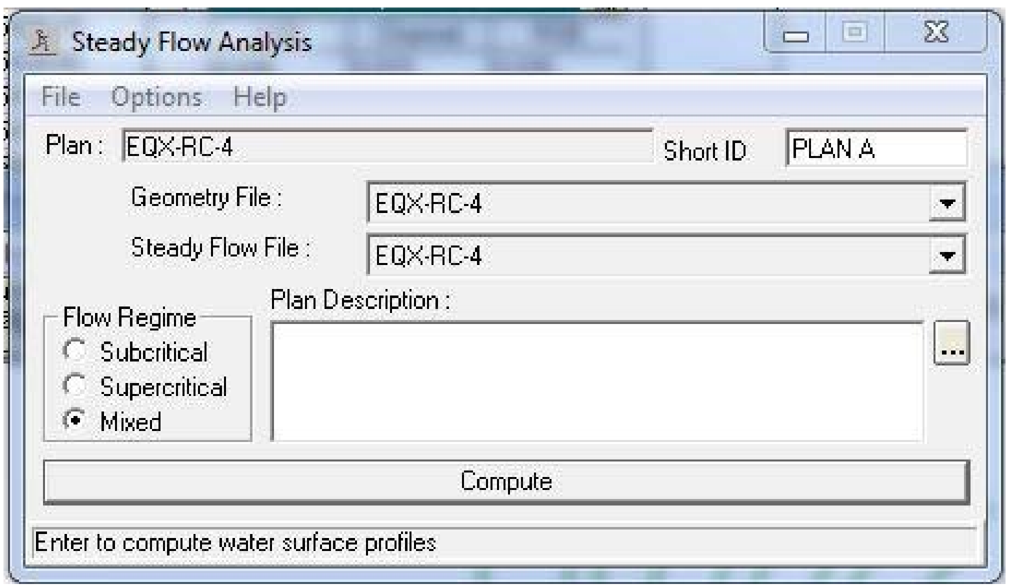

Figure 6: Reach Boundary Conditions

6 Results and Conclusions

The output water surface perspective plot (see Figure 7) and profile plot (see Figure 8) at the highest calculation flow rate (10,000 cfs) for the project shows that the flooding is confined to the channel until it is past the Equipment Crossing, after which it will spread across the Bosque, primarily to the north. On both figures, flow is from right to left.

The HEC-RAS water surface profile output table (see Figure 9) for RS 1997 provided the data points used to create the rating curve and table for the Equipment Crossing. RS 1997 is at the downstream edge of the top of the Equipment Crossing, which is the “weir” section of the structure (Figure 10).

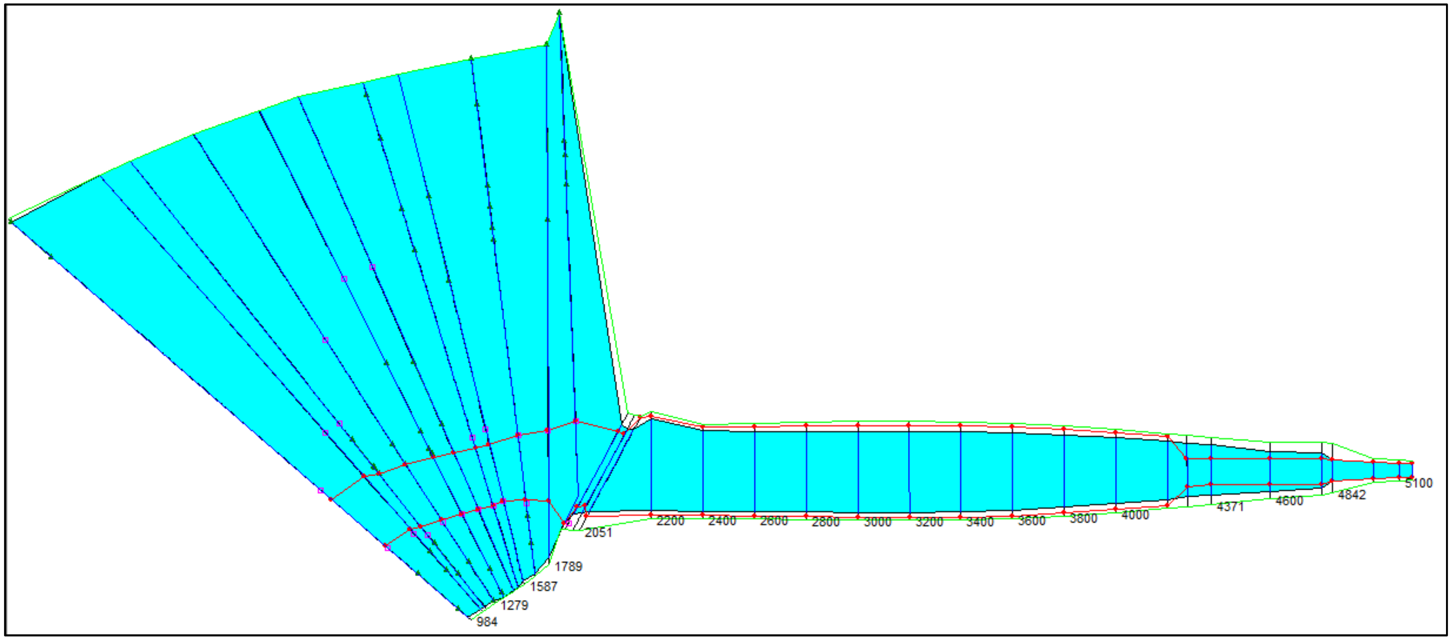

Figure 7: HEC-RAS Output Perspective Plot at 10,000 cfs

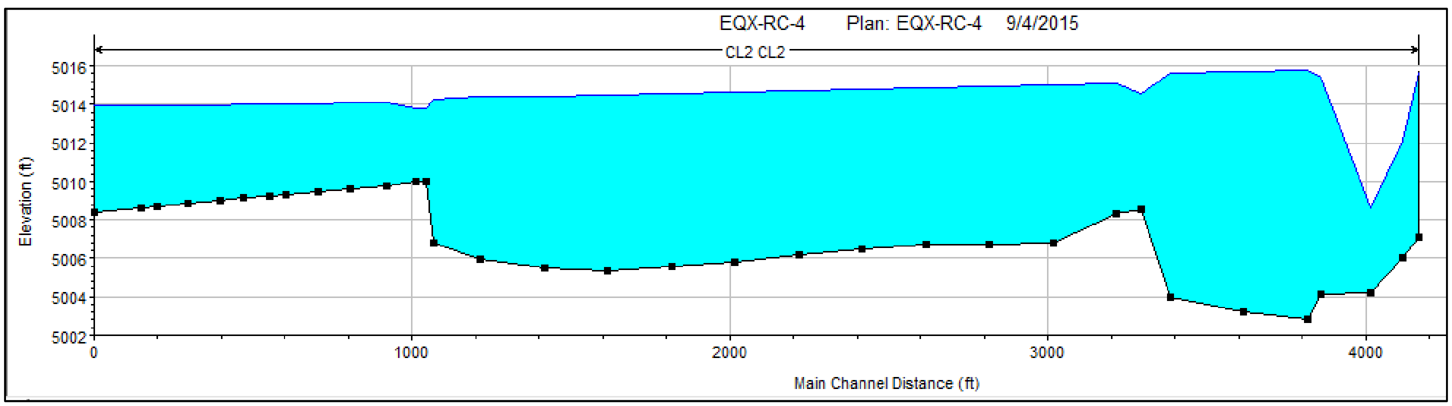

Figure 8: HEC-RAS Output Profile Plot at 10,000 cfs

River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
		(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
1997	PF 1	50.00	5010.00	5010.15	5010.07	5010.16	0.000826	0.79	63.10	431.25	0.36
1997	PF 2	100.00	5010.00	5010.24	5010.12	5010.25	0.000655	0.98	102.95	436.78	0.35
1997	PF 3	150.00	5010.00	5010.32	5010.16	5010.34	0.000555	1.09	138.53	441.15	0.34
1997	PF 4	200.00	5010.00	5010.40	5010.20	5010.42	0.000467	1.16	173.98	443.37	0.32
1997	PF 5	250.00	5010.00	5010.47	5010.22	5010.49	0.000432	1.24	204.09	443.91	0.32
1997	PF 6	300.00	5010.00	5010.54	5010.25	5010.57	0.000386	1.29	235.98	444.49	0.31
1997	PF 7	400.00	5010.00	5010.67	5010.31	5010.70	0.000332	1.38	294.00	445.70	0.30
1997	PF 8	500.00	5010.00	5010.80	5010.35	5010.83	0.000292	1.45	350.34	448.77	0.29
1997	PF 9	600.00	5010.00	5010.93	5010.39	5010.96	0.000254	1.50	408.61	451.81	0.27
1997	PF 10	700.00	5010.00	5011.06	5010.44	5011.09	0.000223	1.53	466.78	454.14	0.26
1997	PF 11	800.00	5010.00	5011.18	5010.48	5011.22	0.000200	1.56	524.13	456.48	0.25
1997	PF 12	900.00	5010.00	5011.29	5010.52	5011.33	0.000188	1.61	574.40	458.53	0.25
1997	PF 13	1000.00	5010.00	5011.38	5010.56	5011.42	0.000185	1.67	615.22	460.19	0.25
1997	PF 14	1500.00	5010.00	5011.86	5010.73	5011.91	0.000154	1.86	836.64	469.07	0.24
1997	PF 15	2000.00	5010.00	5011.58	5010.87	5011.71	0.000472	2.91	707.04	463.89	0.41
1997	PF 16	2500.00	5010.00	5011.76	5011.02	5011.92	0.000511	3.26	791.84	467.28	0.43
1997	PF 17	3000.00	5010.00	5011.95	5011.16	5012.14	0.000523	3.53	880.47	470.80	0.45
1997	PF 18	3500.00	5010.00	5012.01	5011.28	5012.26	0.000638	3.99	910.62	472.00	0.50
1997	PF 19	4000.00	5010.00	5012.15	5011.40	5012.43	0.000670	4.27	974.63	474.52	0.51
1997	PF 20	4500.00	5010.00	5012.26	5011.51	5012.58	0.000715	4.56	1027.81	476.60	0.53
1997	PF 21	5000.00	5010.00	5012.46	5011.62	5012.79	0.000664	4.65	1123.59	480.33	0.52
1997	PF 22	5500.00	5010.00	5012.60	5011.72	5012.95	0.000670	4.84	1189.20	482.76	0.53
1997	PF 23	6000.00	5010.00	5012.73	5011.81	5013.12	0.000670	5.01	1255.84	485.16	0.53
1997	PF 24	6500.00	5010.00	5012.88	5011.91	5013.28	0.000664	5.16	1324.24	487.61	0.54
1997	PF 25	7000.00	5010.00	5013.02	5012.00	5013.44	0.000655	5.29	1393.46	490.07	0.54
1997	PF 26	7500.00	5010.00	5013.16	5012.11	5013.60	0.000646	5.41	1461.89	493.59	0.54
1997	PF 27	8000.00	5010.00	5013.29	5012.20	5013.76	0.000637	5.53	1529.38	497.26	0.54
1997	PF 28	8500.00	5010.00	5013.43	5012.30	5013.91	0.000628	5.64	1597.37	500.92	0.54
1997	PF 29	9000.00	5010.00	5013.56	5012.39	5014.06	0.000618	5.74	1664.88	504.54	0.54
1997	PF 30	9500.00	5010.00	5013.70	5012.47	5014.21	0.000609	5.84	1732.12	508.11	0.54
1997	PF 31	10000.00	5010.00	5013.82	5012.52	5014.35	0.000604	5.94	1794.85	511.42	0.54

Figure 9: HEC-RAS Profile Output Table for RS 1997

Figure 10: Location of RS 1997 on the finished Equipment Crossing

7 Rating Curve

The output data for RS 1997 was used to create a graph in Microsoft Excel of the depth versus flow rate. A trendline (also referred to as a "best fit line") was created of that data, which Excel used to generate an equation. The data showed an area of "transition" between 1,000 cfs and 2,000 cfs, where the water depth increased, decreased, and then increased again, all with increasing flow rates. This is likely caused by the Embayment overflowing its banks, which drastically increased the available cross-sectional flow area in a short span of time. HEC-RAS would continue the computation, and show a drop in flow depth with an increase in flow rate, which is counter intuitive.

To address this transition zone, two separate trendlines were created; one for flows ranging from 0 cfs to 1,000 cfs, and another for 2,000 cfs to 10,000 cfs. The gap between the lines was labeled as a "transition zone" and it is assumed that linear interpolation is the best method for estimating flow rates between 1,000 cfs and 2,000 cfs. The following interpolation equation was used:

$$y_2 = \frac{(x_2 - x_1)(y_3 - y_1)}{(x_3 - x_1)} + y_1$$

Where data points 1 and 3 are the bounding data, x_2 is the known depth (D, in feet), and y_2 is the flow rate calculated corresponding to the known depth (Q, in cfs). Using the data computed by HEC-RAS, the interpolation equation was simplified to a single linear equation as follows:

$$y_2 = \frac{(x_2 - x_1)(y_3 - y_1)}{(x_3 - x_1)} + y_1 \quad \gg \quad Q = \frac{(D - 1.40\,ft)(1{,}925\,cfs - 1{,}020\,cfs)}{(1.60\,ft - 1.40\,ft)} + 1{,}020\,cfs \quad \gg$$

$$Q = 4{,}525 \times D - 5{,}315$$

Figure 11 is the resulting rating curve and table using the above approach.

8 References

Chow 1959. Chow, Ven Te, *Open-Channel Hydraulics*, 1959

USACE 2010. U.S. Army Corps of Engineers (USACE), Hydraulic Engineering Center, *HEC-RAS River Analysis System, Hydraulic Reference Manual*, Version 4.1, January 2010

CALCULATION SUMMARY

PROJECT: NDC Outfall GCS Modifications	WO NUMBER: 14580.003.001.0070	
SUBJECT: Equipment Crossing Rating Curve/Table	CALC. STATUS: Issued for Review CALC. NO.: 1	
BY: David "Sonny" Cooper, PE / Richard Waters	DATE: 9/9/2015	SHEET NO. 11 OF 11

EQUIPMENT CROSSING RATING TABLE

Depth (ft)	Flow Rate (cfs)	Depth (ft)	Flow Rate (cfs)
0.0	0	2.1	3,755
0.1	46	2.2	4,113
0.2	96	2.3	4,471
0.3	151	2.4	4,829
0.4	209	2.5	5,187
0.5	272	2.6	5,545
0.6	338	2.7	5,903
0.7	409	2.8	6,261
0.8	484	2.9	6,619
0.9	563	3.0	6,977
1.0	646	3.1	7,335
1.1	733	3.2	7,693
1.2	825	3.3	8,051
1.3	920	3.4	8,409
1.4	1,020	3.5	8,767
1.5	1,473	3.6	9,125
1.6	1,965	3.7	9,483
1.7	2,323	3.8	9,841
1.8	2,681	3.9	10,199
1.9	3,039	4.0	10,557
2.0	3,397		

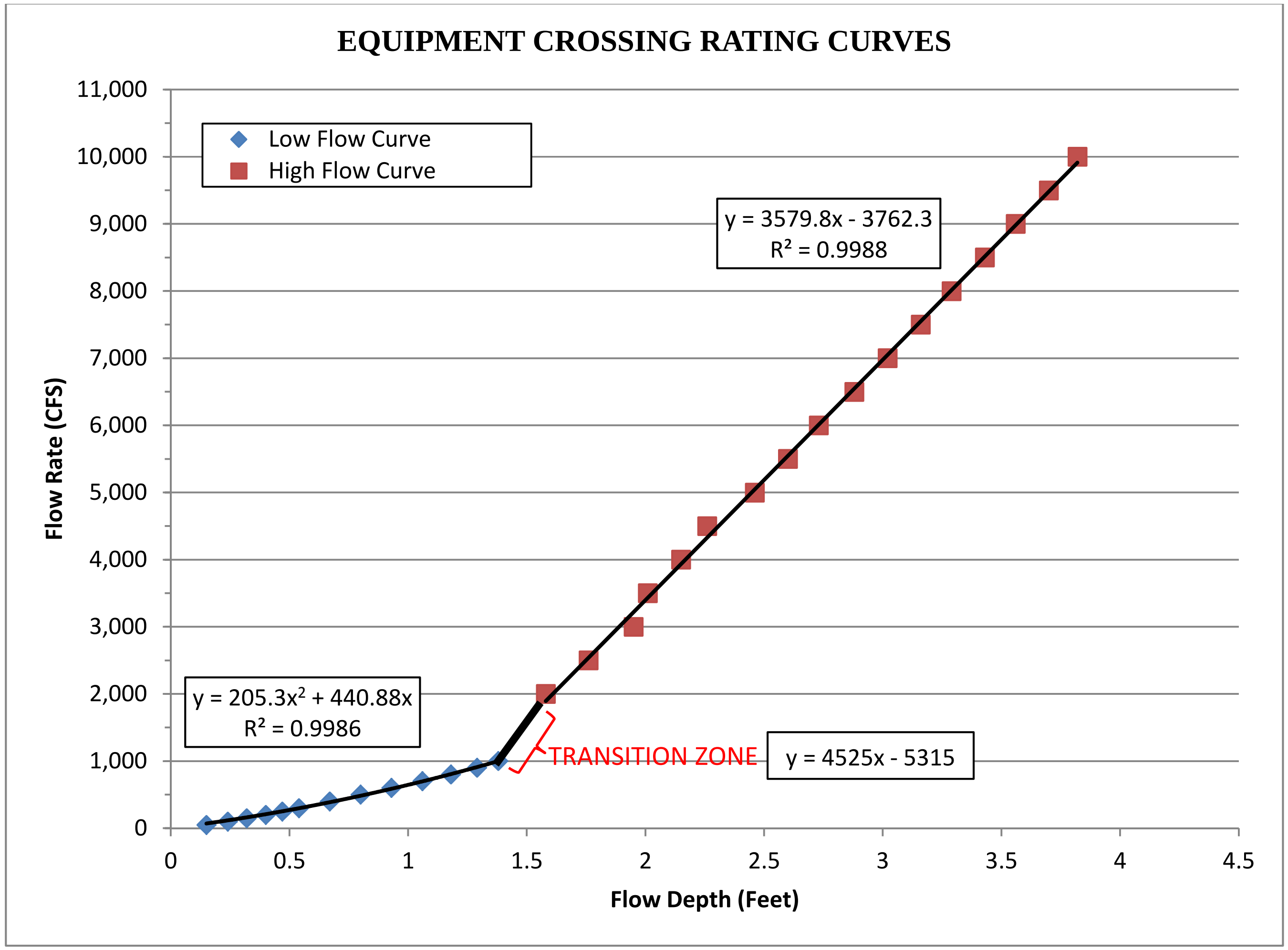

Figure 11: NDC Equipment Crossing Rating Curve and Table