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Memorandum

Date:	6 July 2018
To:	Paul Costa and Jeff Wokurka, the Boeing Company
From:	Robert Gearheart, Ph.D., P.E., Jonathan Jones, P.E., D.WRE., Michael Josselyn, Ph.D., Robert Pitt, Ph.D., P.E., BCEE, D.WRE., and Michael Stenstrom, Ph.D., P.E., BCEE, Santa Susana Field Laboratory Stormwater Expert Panel, and Geosyntec Consultants
Subject:	Evaluation of Drainage Patterns at Outfall 002

SUMMARY

The following analysis was prompted by a reasonable question that was raised by a member of the public concerning the perception of missed discharge sampling at Outfall 002 during recent rainy seasons. The Santa Susana Field Laboratory (SSFL) Stormwater Expert Panel appreciates the public participation in the ongoing work at SSFL and hopes that further communication and discussion will promote transparency and continued collaboration during remaining remediation and restoration activities at the site. The purpose of this analysis is to answer the following questions. For the purpose of this evaluation, emphasis is placed on the 2016/17 rainy season that experienced above average rainfall, in contrast to other recent years which were substantial drought years.

1. How many times did Outfall 002 flow during the 2016/17 rainy season?
2. How does the hydrology of the Outfall 002 watershed compare to the similarly undeveloped Outfall 008 watershed?
3. Why are flows at Outfall 002 infrequent?
4. What storm characteristics result in flow at Outfall 002?

The findings of this analysis conclude that:

1. Outfall 002 produced measurable flow during four of the 11 rain events in the 2016/17 rainy season.

2. The Outfall 002 watershed exhibits a pattern of natural undeveloped hydrology (with the additional influence of releases and overflows from upstream storage ponds above Outfall 018) similar to that of the Outfall 008 watershed. For example, the Outfall 002 watershed produced measurable runoff during four rain events this past rainy season, while Outfall 008 produced measurable runoff during three of these four events.
3. Flows at Outfall 002 are infrequent due to: 1) two large upstream storage ponds (Silvernale and R-2A) that capture and detain runoff from the upper watershed (Outfall 018) and 2) downstream of these ponds and Outfall 018, the watershed is undeveloped and well vegetated "buffer zone" (i.e., without significant former development or activity) that supports natural infiltration, evapotranspiration, and depression storage. In addition, building and pavement demolition activities have further reduced the impervious area within the Outfall 018 watershed, thus reducing the runoff generated during storm events, which ultimately reduces flows at Outfall 002.
4. In the 2016/17 rainy season, Outfalls 002 and 008 both flowed for the first time on 1/20/17, when the season's first significant rainfall occurred (daily rainfall = 1.73 inches; cumulative rainfall from 1/16 – 1/20/17 = 2.9 inches). That storm was preceded by seven events with a cumulative total rainfall of 9.5 inches. Therefore, significant soil saturation is needed before the Outfall 002 watershed can generate runoff. In contrast, Outfall 009, a more developed watershed, flowed for the first time that season when a smaller daily rainfall was recorded on 12/23/16 (daily rainfall = 1.2 inches; cumulative rainfall from 12/21 – 12/23/16 = 1.75 inches). That storm was preceded by five events with a total depth of 2.9 inches. Additionally, Outfall 009 flowed for even smaller subsequent events with daily rainfall as low as 0.77 inches. The flow pattern of the undeveloped Outfall 002 and 008 watersheds as compared to the more developed Outfall 009 watershed indicates that runoff generation occurs less frequently and during larger rainfall events (when followed by greater cumulative rainfall) at Outfalls 002 and 008 than Outfall 009.

Concern has also been expressed about the siting of Outfall 002. However, as noted below, Outfall 002 is located on Boeing property as close as possible to the property boundary as is accessible based on existing unpaved access roads. Such criteria (i.e., based on road access and proximity to property boundaries) is consistent with the siting of all other external outfalls in the NPDES permit.

INTRODUCTION

The purpose of this memorandum is to review and evaluate the drainage patterns of the Outfall 002 watershed at Boeing's Santa Susana Field Laboratory (Site) to address a question raised by a member of the public as to why flows at Outfall 002 are reported less frequently than at other Site

outfalls. Primary objectives include summarizing the effects of the upstream Outfall 018 storage ponds on Outfall 002 flow and evaluating whether and why Outfall 002 flows infrequently as compared to other Site outfalls.

A map of the Site watersheds and outfall locations is provided in Figure 1. Outfall 002 is located on SSFL property within the undeveloped buffer area as far downstream as feasible given road accessibility limitations. The area potentially contributing to flow at Outfall 002 is approximately 900 acres, and includes the undeveloped Outfall 002 watershed, the Outfall 018 watershed, and the Outfall 003, 004, 005, 006, 007, 009 (limited to runoff from the Helipad), and 010 watersheds, which are pumped to ponds in the Outfall 018 watershed.

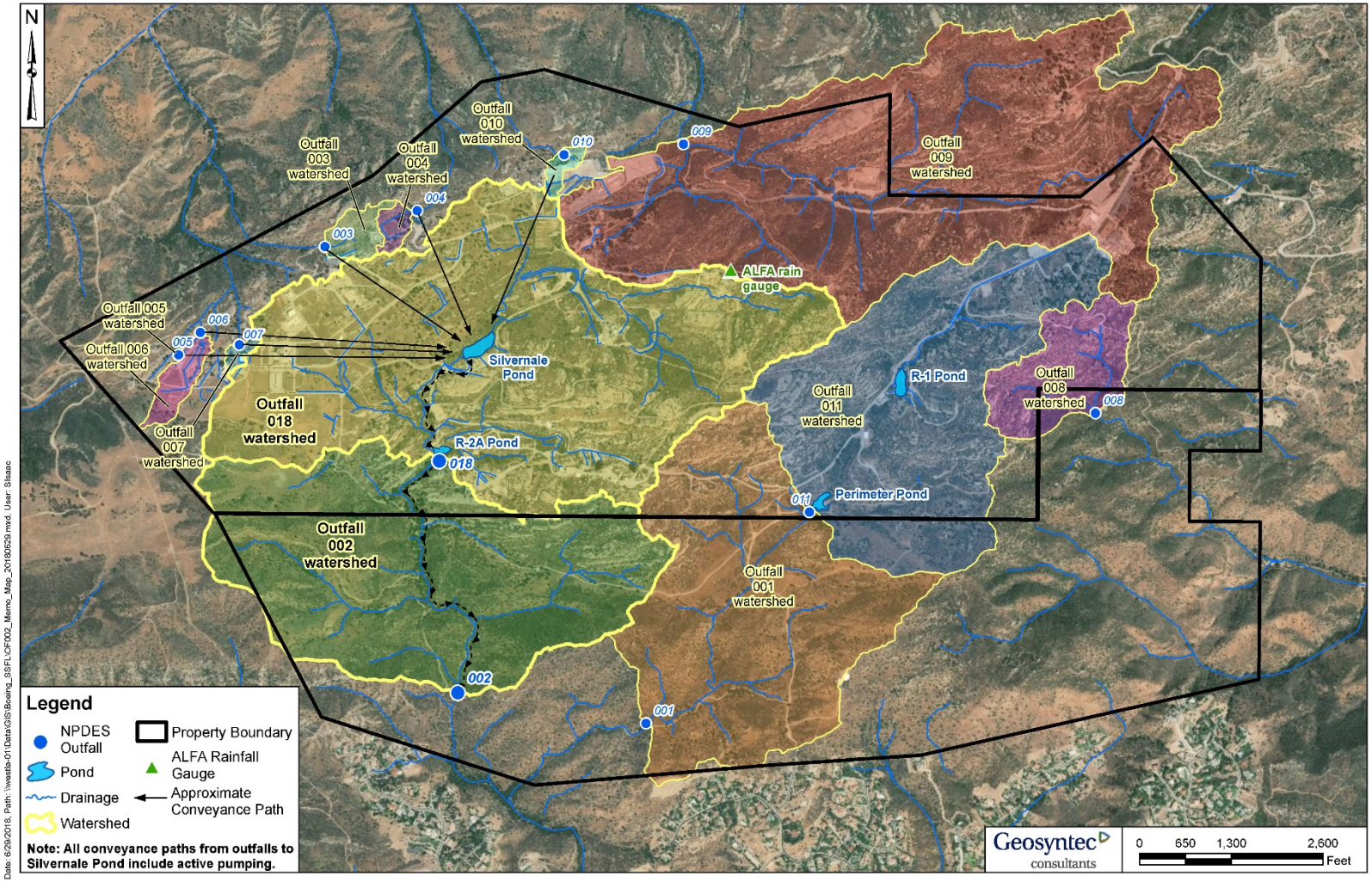

Figure 1: SSFL Outfall Watersheds and Drainage Patterns, 2016/2017 Rainy Season

The Outfall 002 watershed downstream of Outfall 018 is 360 acres of mostly undeveloped area (~5% impervious area). The Outfall 018 watershed consists of approximately 540 acres (27% impervious area) and includes two ponds:

1. The Silvernale Pond (5.7M gallons) which collects pumped runoff from Outfalls 003, 004, 005, 006, 007, 009 (limited to runoff from the Helipad), and 010 during most storms for treatment; and
2. The R-2A pond[1] (2.2M gallons) which collects runoff from the Outfall 018 watershed and recirculates it to the Silverdale Pond for treatment.

In total, Outfall 018 receives runoff from a total of 582 acres (from the watershed itself and pumped conveyance from other watersheds). In recent years, considerable demolition of existing structures, buildings and pavement has been completed site-wide including portions of the Outfall 018 watershed. The removal of buildings, roads, and other hardscape results in decreased imperviousness, more onsite retention, and less runoff conveyed downstream than in the condition prior to demolition.

Figure 2 illustrates the areas removed from the Boeing administrative areas as of 2011, when the bulk of the demolition work was completed. Figures 3 and 4 present aerial images of the area upstream of Outfall 018, taken in 2003 and 2016, respectively, illustrating before and after the removal of buildings and other structures during that period. Figures 5 through 7 provide photographs of the CTL-III area, which is upgradient of Outfall 011, but illustrates the process of demolition (building and structure removal), site stabilization, and revegetation.

[1] R-2B pond is also adjacent to R-2A; however, for simplicity, these ponds will be referred to in combination as the 'R-2A pond'.

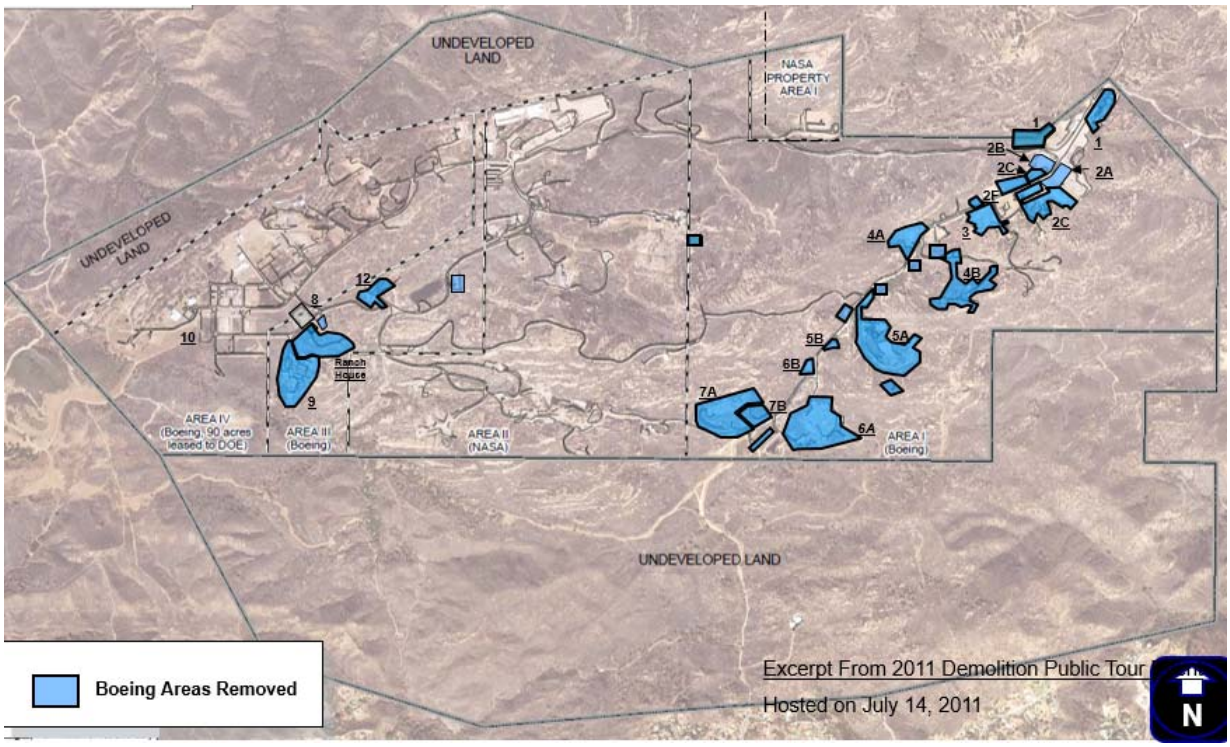

Figure 2: Boeing Demolition Areas, as of 2011

Figure 3: Area IV Portion of Outfall 018 Watershed, 2003

Figure 4: Area IV Portion of Outfall 018 Watershed, 2016

Figure 5: CTL3 – Original Buildings/Structures

Figure 6: CTL3 – Stabilization after Demolition

Figure 7: CTL3 – Revegetation (2017)

Downstream flows at Outfall 002 are sometimes impacted by planned releases from the upstream storage ponds at Outfall 018. These releases are fully treated except in large events (typically greater than the 2.5-in, 24-hour design storm) when a portion of the runoff bypasses the treatment system. Even in that case, the bypassed flow receives backup treatment through the passive flow-through media filter at Outfall 018.

ANALYSIS

This analysis is limited to the 2017 rainy season (October 2016 through February 2017), which included more rainfall than in an average year (total of 24.8 inches as compared to 16.8 inches on average) and a high number of individual storms (11 storms) with variable hydrologic characteristics and a wide range of storms to evaluate. Continuous flow data were extracted from the gauges at Outfalls 002 and 018 and pumping and pond capacity data were extracted from Site totalizers and flow meters. Flow data from Outfall 008, representing another undeveloped watershed without the influence of an upstream pond, were also extracted for comparative purposes. All flow gauges are located such that runoff does not bypass the gauge and, to Geosyntec and the Expert Panel's knowledge, were fully and continuously operational during the analysis year. The ALFA rainfall gauge was selected as most representative local gauge due to its proximity to Outfalls 018 and 002, as well as its completeness over the selected period of record.

Figure 8 illustrates the daily and event-cumulative rainfall measured at the onsite ALFA gauge, Outfall 002 flow, and Outfall 018 flow plotted over time between October 2016 and February 2017 (the approximate end of the rainy season). In addition, the measured Outfall 002 flow with the Outfall 018 flow removed (or subtracted) is shown and represents the approximate flow that could be directly attributed to the undeveloped Outfall 002 watershed below Outfall 018. Additionally, the cumulative capacity throughout the rainy season for both storage ponds is presented at the bottom of the chart.

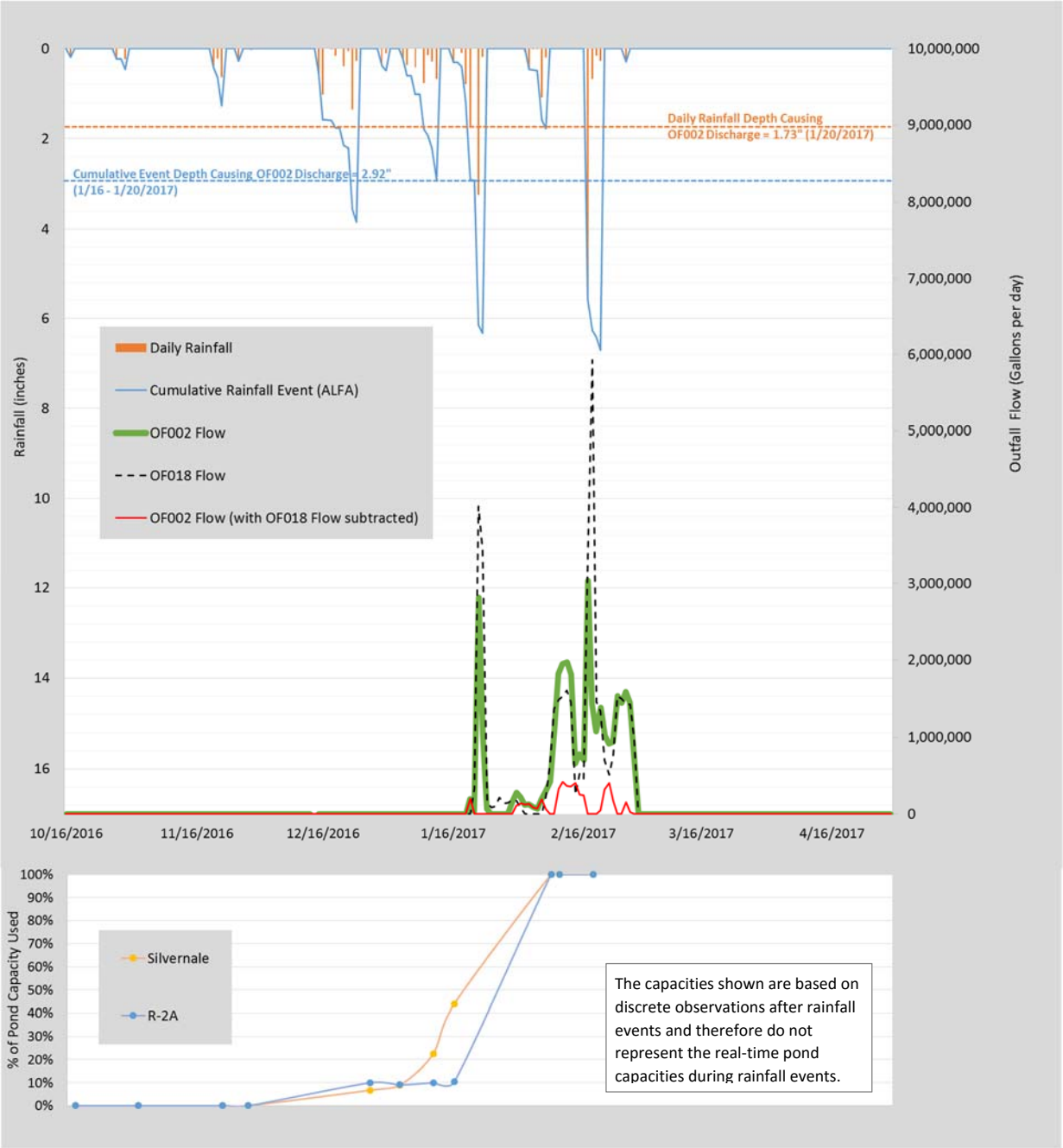

Figure 8: Outfall 002 and 018 flowrates compared to rainfall and pond storage (each cumulative rainfall event is separated by 72 hours of dry conditions [a requirement of the 2015 NPDES Permit])

As shown in Figure 8, the smaller storms during the earlier months did not result in flow at Outfall 002 because 1) runoff from the upper watershed was retained in the storage ponds, without exceeding pond capacities, and/or 2) these storms were not large enough to produce runoff from the undeveloped Outfall 002 watershed (i.e., runoff was stored in localized depressions and infiltrated before reaching the outfall). Table 1 summarizes the characteristics of each rain event recorded by the ALFA gauge that occurred between October 2016 and February 2017. Outfall 002 flowed for the first time in the 2016/17 rainy season when a daily rainfall depth of 1.73 inches was recorded on 1/20/17 (the highest daily measurement that year). A cumulative multi-day rainfall depth of 2.92 inches was recorded during this event between 1/16 – 1/20/17. This Outfall 002 flow was determined to be a result of runoff from the Outfall 002 watershed downstream of Outfall 018, as all runoff from the upstream Outfall 018 watershed was captured and stored in the upstream storage ponds.

Table 1 also demonstrates how runoff generation is a function of several variables including the rainfall depth, intensity, and the antecedent dry weather period.

Table 1: Characteristics of ALFA Gauge Storms, 2016/17 Rainy Season

Event*	Start Date	End Date	Antecedent Dry Weather Period (days)	Total Event Rainfall (inches)	Outfall 002 (OF002) Flow	Maximum Event-Specific Daily Rainfall (inches)
1	10/17/2016	10/17/2016	16**	0.19	None	0.19
2	10/28/2016	10/30/2016	10	0.46	None	0.23
3	11/20/2016	11/22/2016	20	1.27	None	0.63
4	11/26/2016	11/26/2016	3	0.28	None	0.28
5	12/15/2016	12/24/2016	18	3.84	None	1.36
6	12/30/2016	12/31/2016	5	0.49	None	0.38
7	1/4/2017	1/12/2017	3	2.90	None	0.77
8	1/16/2017	1/23/2017	3	6.34	Yes	1.73
9	2/3/2017	2/7/2017	10	1.78	Yes	1.09
10	2/17/2017	2/20/2017	9	6.71	Yes	5.59
11	2/26/2017	2/26/2017	5	0.30	Yes	0.3
Total	**10/1/2016**	**2/26/2017**	**N/A**	**24.56*****		

* Rain events are defined as greater than 0.1 inches is received in a 24-hour period and preceded by 72 hours of dry weather.
** May be greater but this value is based on the beginning of rainy season 2016/17 (10/1/2016)
*** This total does not include rainfall not classified as a rain event. Therefore, the total rainfall during the 2016/17 rainy season was greater than the total shown in Table 1.

Figure 9 is focused on the period in the 2016/17 rainy season in which measurable flow was recorded at Outfall 002 (i.e., no other rain events resulted in measurable discharge). Outfall 002 NPDES composite samples are also identified, along with the flow measured at Outfall 018, which is upstream of Outfall 002. Flows at Outfall 002 are highly controlled by releases and overflows from the Outfall 018 storage ponds. As required by the 2015 NPDES Permit, a sample must be collected during each flow event, defined as when rainfall greater than 0.1 inches is received in a 24-hour period and preceded by 72 hours of dry weather. In addition, the 2015 NPDES Permit indicates that only one sample per week is required to be collected during extended periods of rainfall during the same rain event. As shown in Figure 9, as required, each individual rain event that resulted in discharge at Outfall 002 was sampled at least once.

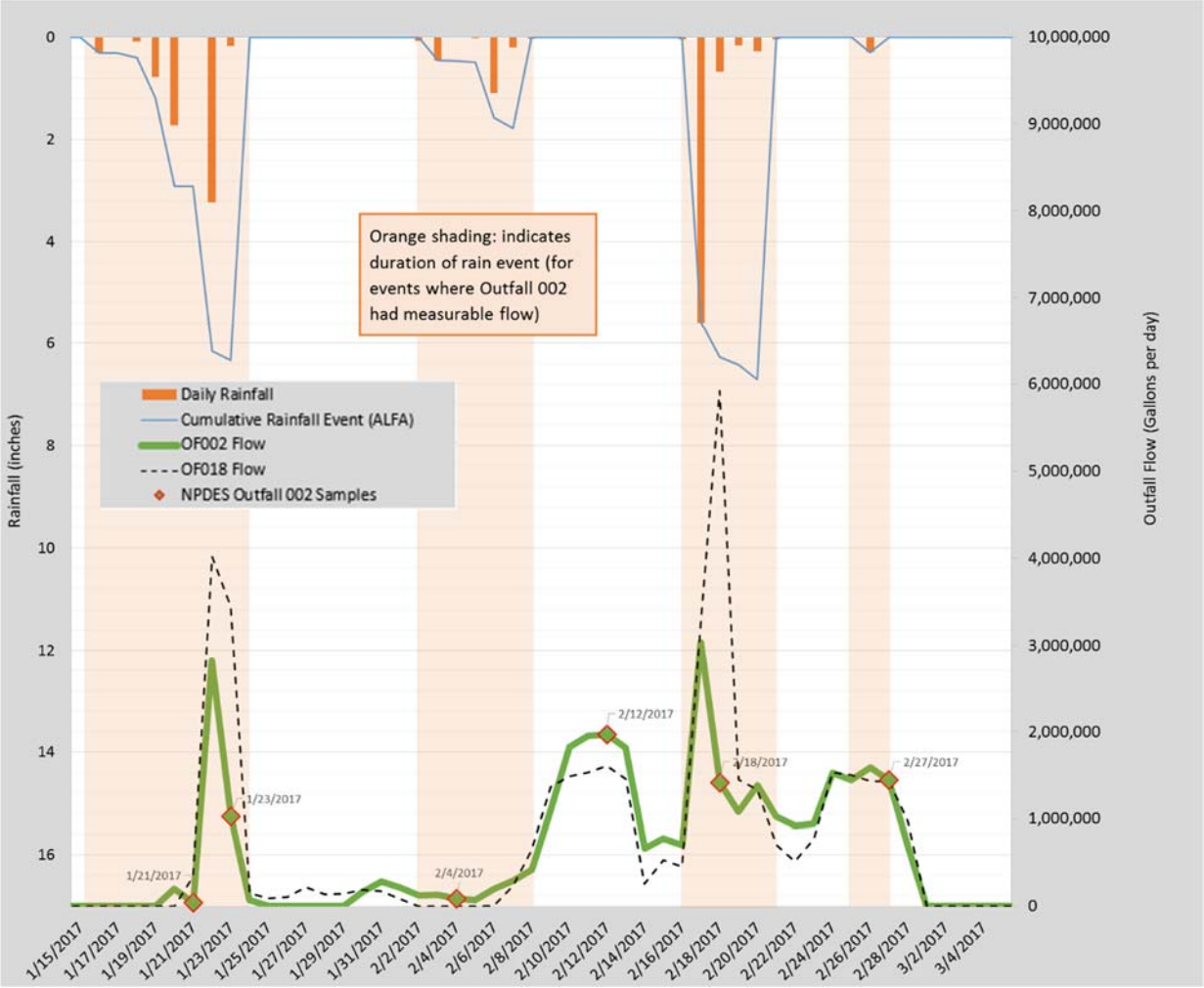

Figure 9: Outfall 002 and Outfall 008 flowrates compared to rainfall and Outfall 002 NPDES 24-hour composite sample dates

Figure 10 compares the flow patterns at Outfall 002 to the flow patterns at Outfall 008, which similarly represents a mostly undeveloped watershed, with minimal historic human activities. The Outfall 008 watershed area is 62 acres, with approximately 12% impervious area (much of this is natural exposed bedrock and dirt roads), while the Outfall 002 watershed area is 360 acres and also mostly undeveloped, with approximately 5% impervious area (mostly dirt roads). Other characteristics of the Outfall 008 and 002 watersheds are also similar, such as their predominant hydrologic soil groups (HSGs) and slopes. HSGs define the runoff potential of each soil type, where HSG A is defined by a high saturated hydraulic conductivity (i.e., high infiltration potential) and therefore has low runoff potential, and HSG D is defined by a low saturated hydraulic conductivity and therefore has a high runoff potential. The Outfall 008 watershed is entirely comprised HSG D soils, while the Outfall 002 watershed is also predominately HSG D soils, but also has approximately 10% each B and C soils. The average slopes in the 008 and 002 Outfall watersheds are also very similar (approximately 10% average slope throughout the watersheds).

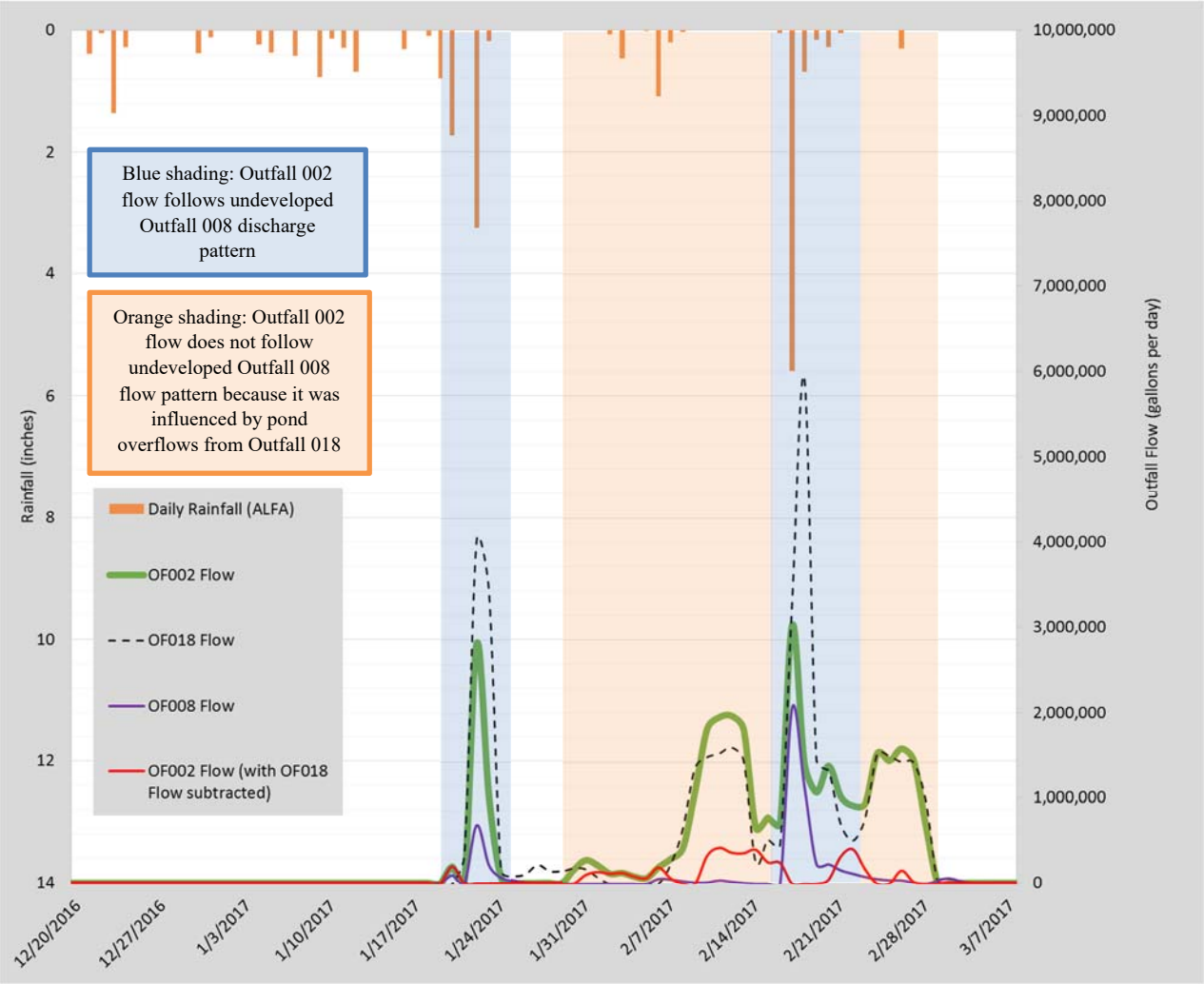

Figure 10: Outfall 002, 008, and 018 flows compared to rainfall

As shown in Figures 9 and 10 above, Outfall 002 flowed and was sampled during four of the 11 rain events in the 2016/17 monitoring season. When upstream flows from Outfall 018 are subtracted from Outfall 002 flows (red line on Figure 10), the resulting flowrates show that the buffer zone portion of the Outfall 002 watershed (i.e., area downstream of Outfall 018) contributes little additional runoff beyond the flows from Outfall 018 and exhibits a pattern of natural undeveloped watershed hydrology similar to that of the Outfall 008 watershed. The timing of the peak flows at Outfall 002 is noticeably delayed as compared to the peak flows at Outfall 008 due to its relatively greater area which causes a higher time of concentration (i.e., the time for rainfall to flow, via runoff, from the furthest point in a watershed to the watershed outfall). Similar to the

undeveloped portion of the Outfall 002 watershed, the Outfall 008 watershed produced measurable discharge during three of those same four rain events in the 2016/17 rainy season.

Additionally, both the Outfall 002 and 008 watersheds rarely flow, particularly during dry years. For example, between 2011/12 and 2015/16, a five-year period in which below average rainfall was measured each year (average annual rainfall was 9.3 inches for those years, as compared to 24.8 inches for the period between October 2016 – February 2017), only two events generated runoff at Outfall 002. As noted previously, the flow at Outfall 002 is also impacted by releases from the upstream storage ponds at Outfall 018, which is fully treated except in large events (typically greater than the 2.5-in, 24 hr design storm) when a portion of the runoff bypasses the active treatment system and receives backup treatment through the passive flow-through media filter at Outfall 018.

CONCLUSION

In summary, Outfall 002 discharged during four of the 11 rainfall events recorded during the 2016/17 rainy season; each of these discharge events was sampled at least once. The historical data show that the undeveloped portion of the Outfall 002 watershed did not produce discharge during most storms, especially those that followed a long antecedent dry weather period, both as a result of the watershed's generally undeveloped condition, combined with upstream storage provided by site ponds (7.9 MG total capacity). When pond capacity is available, the ponds prevent flow from the upper watersheds from being conveyed to Outfall 018, and subsequently to Outfall 002. Runoff contributed by the 360-acre buffer area of the Outfall 002 watershed alone (i.e., the Outfall 002 watershed downstream of the Outfall 018 discharge point) has been shown to respond hydrologically similarly to the undeveloped Outfall 008 watershed, a comparison that further supports the record of infrequent discharges at Outfall 002. Lastly, the recent removal of impervious surfaces in the Outfall 018 watershed has increased the watershed depression storage, evapotranspiration loss, and natural infiltration capacity. This transition to a more natural and pervious watershed condition results in decreased runoff at the downstream outfalls (i.e., a storm with the same size, duration, and intensity will now generate less runoff than it would have before demolition).

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