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December 30, 2020

To: CalOES Hazard Mitigation Assistance Branch
Re: RFI #2 for BRIC 2020, City of Menlo Park, Menlo Park SAFER Bay

Purpose of document: This document details the analysis that Pacific Gas and Electric Company conducted in November 2020 to qualitatively and quantitatively describe how the bulk electric system would perform in the event the Ravenswood Substation required de-energization due to flooding. This document provides a description of the Ravenswood Substation and vulnerabilities to flooding, and details a power flow analysis, customer impact assessment, and use of Public Safety Power Shutoff tools to determine the geographic extent and verify the number of customers affected by such an outage. It assesses how flooding would damage equipment and estimates the time to repair and reenergize the substation.

Key Takeaways:

- PG&E tested and validated all assumptions related to Ravenswood Substation's vulnerability to flooding, customer impact, and estimated equipment damage and repair times.
- A power flow analysis to assess customer impact confirms that 79,338 PG&E customer accounts[1] and 29,140 accounts served by the City of Palo Alto's electric utility would lose power. The total population that would lose power is 296,183.
- PG&E updated its estimates of expected damage to Ravenswood Substation at different flood scenarios. PG&E assessed how such damage can be temporarily mitigated with emergency equipment while replacement parts are procured and installed. Under a scenario in which 1 to 1.5 feet of water inundate the substation, we estimate that once flood waters have receded, repair crews will need one day to clean, order and install emergency equipment, and re-energize the substation. For flood levels 2 feet and above, we estimate that a minimum of two days will be required to clean up, order and install emergency equipment, and re-energize.
- The total loss of service days at Ravenswood Substation is equivalent to the number of days of the storm event, the number of days for water to recede, and the number of repair days (described in Table 2). We believe that these are very conservative estimates and are reflective of *minimum* repair time.

Description of Ravenswood Substation

There are two tiers of substations owned and operated within PG&E's electric grid. The first and most critical tier, called transmission substations, transmit high-voltage electricity from large power plants to the second tier of substations, called distribution substations. Transformers in distribution substations step down the voltage from transmission levels and the power is then split in multiple directions and

[1] A "customer account" refers to the individual within a household or business holding the account.

sent along the web of distribution lines to the customer, where energy is delivered at an appropriate voltage for consumption. Even though some system redundancy exists, when a transmission substation goes offline it has the potential to impact numerous downstream distribution substations, and customers connected to those distribution substations will lose power.

Ravenswood Substation is a first tier critical 230 KV transmission substation that connects high-voltage transmission lines to PG&E's distribution system. Second tier distribution substations that are connected to Ravenswood Substation provide electricity service for cities and communities in the area including the cities of Menlo Park, Palo Alto, Redwood City, Belmont, East Palo Alto and San Carlos, and the town of Atherton.

Power flow analysis: Methodology for customer impacts
In the event of an unplanned or planned outage at a substation, PG&E's electric operations department oversees the switching of operations to reroute the flow of electricity around the areas experiencing an outage. This ensures that as many customers as feasible can continue to receive electricity while repairs are made to the grid and/or substation.

In November 2020, PG&E's electric operations department applied a power flow analysis to the region served by Ravenswood Substation, simulating what would happen if the Ravenswood Substation was required to go offline (de-energized) due to flooding and associated damage to equipment.

The power flow analysis assessed both "direct impact" (customers directly connected to Ravenswood Substation), as well as "indirect impact" (customers downstream of Ravenswood Substation that would lose electricity in order to maintain the reliability and safety of the remaining system).

The study took into account that some redundancy exists in PG&E's electric grid and considered that a share of electricity demand served by Ravenswood Substation would be transferred to surrounding circuits to compensate for the loss of load at Ravenswood. Even so, there are limits to the amount of electricity that can be rerouted without overloading and damaging equipment, which is part of the power flow analysis.

The power flow analysis used the following assumptions:

1. **The entire Ravenswood Substation will need to go offline if flooding of 1 foot or more inundates the substation**.

Substations such as Ravenswood contain bulk oil storage containers and oil-filled electrical equipment, such as transformers, regulators, circuit breakers, and capacitors.[2] Should one of these components suffer a failure and subsequent oil leak, a Spill Prevention Control and Countermeasure (SPCC) plan prevents the discharge of oil into or upon "navigable waters", such as San Francisco Bay, in conformance with federal Environmental Protection Agency regulations (CFR 40, Part 112[3]). The requirements and procedures for establishing and implementing an SPCC plan are contained within

[2] Pictures of equipment at Ravenswood Substation are in the document, "Location Attachment 8 - Menlo Park SAFER Bay_Ravenswood Substation Site Photos".
[3] Code of Federal Regulations (CFR) 40, Part 112, "Oil Pollution Prevention". Available at: https://www.epa.gov/sites/production/files/2014-04/documents/b_40cfr112.pdf

PG&E’s established design criteria. Should the Ravenswood Substation flood with a measurable amount of water (PG&E estimates that flooding of 1 foot or more would overwhelm the system), the spill prevention controls and countermeasures would not function as designed. A potential component oil leak, concurrent with a flooding event, would likely result in the uncontrolled release of oil into San Francisco Bay as flood waters recede. Based on experience, PG&E is aware that energized equipment is much more likely to suffer catastrophic failure and a subsequent oil leak. To mitigate the risk of an uncontained release of hazardous substances, PG&E would take the Ravenswood Substation offline for the duration of any flooding event and would need to wait until water has receded to re-energize equipment.

The de-energization of Ravenswood Substation would be necessary to comply with PG&E’s Spill Prevention Control and Countermeasure (SPCC) plans. If Ravenswood Substation were to be flooded with water, the water would fill the spill retention ponds outlined in the substation’s SPCC plans (see Figure 1), jeopardizing the effectiveness of the plan. As a precautionary measure, all oil-filled equipment (such as circuit breakers and other infrastructure crucial to a transmission substation, as shown in Figure 2 below) must be de-energized in the event of flooding, as described above and PGE&E would need to wait until water has receded to re-energize the substation.

Figure 1: Spill retention pond

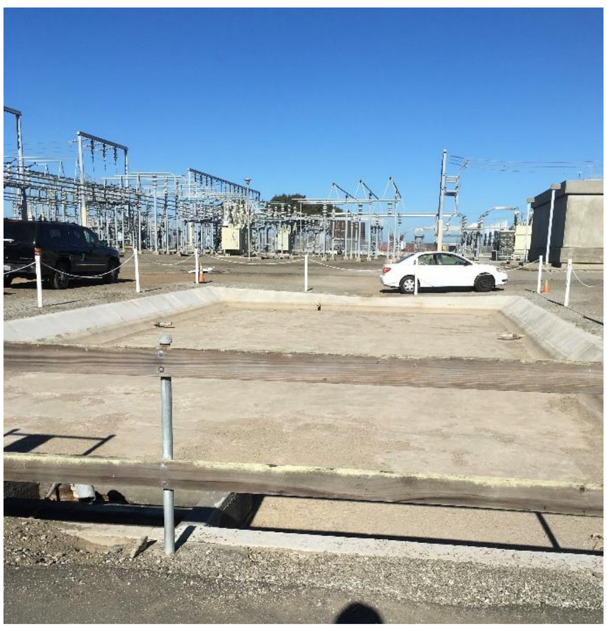


Figure 2: Circuit breakers (filled with oil)

2. Electricity demand based on projected peak demand in 2025 (5-year horizon)

This time period was selected because the US Fish & Wildlife Service estimates that the outer berm surrounding Pond R2 may not provide adequate protection to Ravenswood Substation for more than a 5-year time period due to existing condition of the berm. The projected peak demand was used given the low risk tolerance for critical infrastructure, the importance of serving all customers, and expectations for growing electricity demand due to regional decarbonization and transportation electrification plans.

Power flow analysis: Results

The power flow study found that in order to prevent damage to the system if Ravenswood Substation is de-energized, the total electricity load drop required is 341.1 megawatts (MW).

First, 147.9 MW of electricity would be dropped to the Palo Alto Substation, which is a distribution substation serving the entire City of Palo Alto. Following this, the analysis found that additional circuits would still be overloaded, as shown in Table 1.

Table 1: Power flow analysis results: overloaded circuits and base voltage. Load on a line above 100% is overload.

Monitored Facility	Base Voltage	Overload
Bair 115/60	60 kV	112.5%
Bair – San Carlos	60 kV	141.4%
San Carlos- Oracle60	60 kV	223.3%
Oracle 60-San Mateo	60 kV	216.3%
Bair-RedwoodTP1	60 kV	103.5%
RedwoodTP1-BLHVNTP1	60 kV	148.2%
Bair-RedwoodTP2	60 kV	135.4%
RedwoodTP2-BLHVNTP2	60 kV	114.4%
San Mateo/Belmont	115 kV	217.5%
San Mateo-East Shore	230 kV	100.9%

To mitigate the expected overloads for the affected 60 kV, 115 kV and 230 kV lines shown in Table 1, an additional 193.2 MW of electricity load would have to be dropped from the system (341.1 MW – 147.9 MW = 193.2 MW). This electricity would be dropped by de-energizing four PG&E distribution substations that are connected to Ravenswood Substation. The distribution substations that would be de-energized are San Carlos, Redwood, Belle Haven, and Belmont. These substations were selected for de-energization since they collectively provide the necessary load shedding required.

Customer impact assessment

Each of these distribution substations – and all the customers connected to them -- would lose power. As such, the analysis tabulated impacted customer counts for all transformers at the four PG&E distribution substations to arrive at an estimated 75,530 PG&E customer accounts.

Additionally, the City of Palo Alto has 29,140 electric meters within the City's electric utility district. This is the number of customer accounts that would be dropped when Palo Alto Substation is disconnected. By combining the number of PG&E and Palo Alto customers, an estimated 104,670 (75,530+29,140) customer accounts would lose power if Ravenswood Substation is de-energized.

Use of the Public Safety Power Shutoff viewer tool to verify Customer Counts

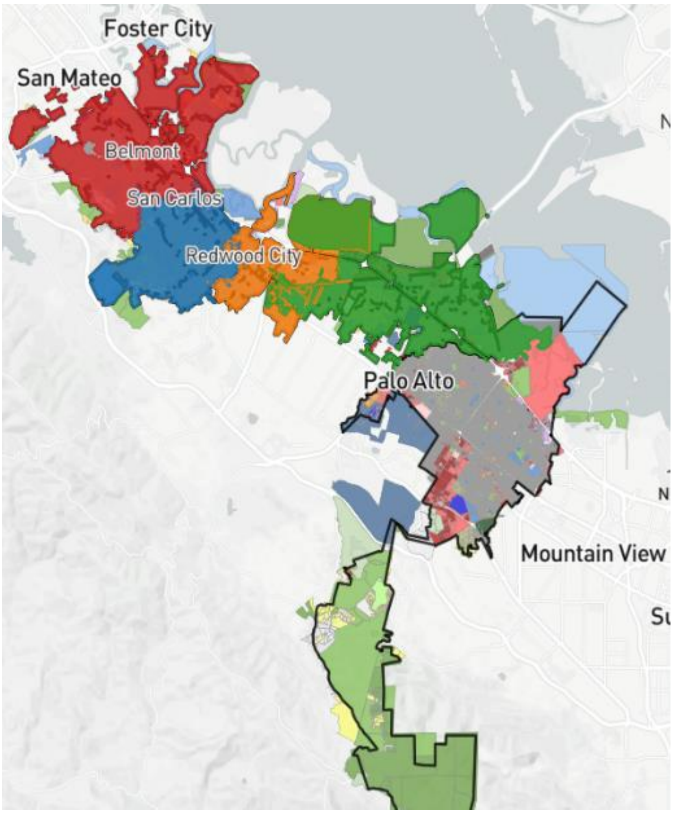
PG&E cross-checked this customer count using its internal Public Safety Power Shutoff (PSPS) viewer tool, which can compile information on customers, including critical infrastructure customers and medical baseline customers (which are customers that require life-support equipment that relies on electricity, such as ventilators). This tool is used by PG&E to prepare customers, local governments, and state agencies such as CalOES with information on community impacts in the event of a PSPS.

This database, which is more accurate than the transformer-based count utilized above, found that 79,338 PG&E accounts are linked to the San Carlos, Redwood, Belle Haven, and Belmont substations and would be de-energized. (This number is referenced in *SOW Attachment 1 - Menlo Park SAFER Bay Population Impacted*).

PG&E also created a Geographic Information Systems (GIS) shapefile that encompasses every individual distribution level circuit that would be de-energized when the Ravenswood transmission substation and the five distribution substations (Palo Alto, San Carlos, Redwood, Belle Haven, and Belmont) go offline. Figure 3 demonstrates the extent of customer impact. The colors reflect the customer outages for the San Carlos (blue), Redwood (orange), Belle Haven (green), and Belmont (red) substations. The colors within the city limits of Palo Alto reflect data from the UrbanFootprint land use planning tool; all of Palo Alto would be de-energized.

Using the GIS shapefile (geographic extent of the outages), PG&E worked with UrbanFootprint to determine the number of households and individuals within the project impact area. The geographic area defined by the circuit outage map shown in Figure 3 reveals that the number of households within the project impact area is 104,602 households. Using census data for the average number of residents per household within the geographic area (2.83 residents per household), this equates to 296,183 people (for further explanation, please see *SOW Attachment 1 - Menlo Park SAFER Bay Population Impacted*). Census data is based on the 2018 U.S. Census Bureau's American Community Survey.

Figure 3. Substation and circuit outage map. Cities (San Mateo, Foster City, and Palo Alto) are bolded. PG&E Substations customer areas are colored to reflect the customer outages for San Carlos (blue), Redwood City (orange), Belle Haven (green), and Belmont (red) substations.



Testing and Validation of Estimated Time to Repair and Re-energize Ravenswood Substation

In order to determine the number of days the Ravenswood Substation would be out of service, PG&E's Substation Asset Management team and members of the Transmission Substation Operations and Maintenance teams with two decades of experience at Ravenswood Substation assessed how different flooding amounts at Ravenswood Substation would damage equipment and how long it would take to repair or replace equipment to get the substation up and running again. This information is summarized in Table 2 below.

Key assumptions include:

- **Flooding height:** As explained in "BCA Attachment 4 - Menlo Park SAFER Bay - Ravenswood Substation Hydraulic Analysis Technical Memo", flooding inundation depths are calculated from the average ground surface elevation within the substation's footprint (9 ft NAVD), subtracted from the water level during that event and then rounded up to the nearest half foot. The levees and Highway 84 embankment surrounding the substation are assumed to have a crest elevation of 11 ft NAVD. Therefore, the inundation depth was capped at 2 feet, the difference between the surrounding levees and the substation elevations. This surrounding levee and embankment would detain flood waters and is assumed to set the typical depth during an inundation event.

- For larger events, such as the 500-yr existing conditions scenario or all the events with 3.5 feet of sea-level rise, the peak water level would briefly surge higher than 2 feet and cause greater inundation for a few hours. As the high tide receded, the water would rapidly drain from the peak water levels until it is detained by the surrounding levees and embankment.
- **De-energization is required during a flooding event** that overwhelms the Spill Prevention Control and Countermeasures (SPCC) in the substation. PG&E estimates that 1 foot of flooding would overwhelm the retention ponds in the substation. When these SPCC measures are overwhelmed, the substation must be de-energized to prevent possible oil spills from leaving the substation and entering nearby waterways.
- **Inspection, clean-up, and re-energization will take a minimum of 1-2 days**. This time depends on the amount of debris left behind by flooding and availability of personnel to take part in clean up and inspection. PG&E personnel cannot access the substation to safely conduct inspections, conduct repairs, or re-energize the substation until water has receded. As explained below, PG&E estimates that inspection and cleanup of a foot or foot and a half of flooding will take a minimum of 1 - 2 days if enough personnel are available and emergency equipment is available.
- Total loss of electricity service time amounts to the sum of 1) the days of the flood event, 2) the days for the waters to recede; 3) the time to inspect the substation for damage before safely re-energizing; 4) time to conduct cleanup necessary to access equipment; 5) time to procure and install emergency equipment.

Table 2: Flooding timing, inundation depth, and impacts to PG&E Ravenswood Substation. Total loss of service time (days) is equal to the sum of flood event duration (days), drainage duration (days), and repair time (days).

Existing conditions (2020)						
Recurrence interval scenario	**Substation Inundation depth, feet.**	**Impact to Substation**	**Flood event duration, days**	**Drainage duration, days**	**Repair time, days**	**Total loss of service time, days**
Scenario 1 10-year (10% Annual Chance of Exceedance, ACE)	1	SPCC system overwhelmed by water: De-energization required Battery charger destroyed	1	2	1	4
Scenario 2 50-year (2% ACE)	1.5	SPCC system overwhelmed by water: De-energization required Battery charger destroyed	2	4	1	7
Scenario 3 100-year (1% ACE)	2	SPCC system overwhelmed by water: De-energization required Battery charger and DC system destroyed.	3	5	2	10
Scenario 4 500-year (0.2% ACE)	2	SPCC system overwhelmed by water: De-energization required Battery charger and DC system destroyed.	3	5	2	10

Future conditions w/ 3.5ft. Sea Level Rise (SLR)						
Recurrence interval scenario	**Substation Inundation depth, ft.**	**Impact to Substation**	**Flood Event duration, days**	**Drainage duration, days**	**Repair time, days**	**Total loss of service time, days**
Scenario 5 10-year + 3.5 ft SLR (10% ACE)	2	SPCC system overwhelmed by water: De-energization required Battery charger and DC system destroyed.	1	5	2	8
Scenario 6 50-year + 3.5 ft SLR (2% ACE)	2	SPCC system overwhelmed by water: De-energization required Battery charger and DC system destroyed.	2	5	2	9
Scenario 7 100-year + 3.5 ft SLR (1% ACE)	2	SPCC system overwhelmed by water: De-energization required Battery charger and DC system destroyed.	3	5	2	10
Scenario 8 500-year + 3.5 ft SLR (0.2% ACE)	2	SPCC system overwhelmed by water: De-energization required Battery charger and DC system destroyed.	3	5	2	10

Explanation of repair times under different scenarios

PG&E engineers with specific expertise in Ravenswood Substation estimated what components of the substation would be damaged and require repair based on the expected amount of flooding. Emergency measures to re-energize the substation while repairs are made are also explained.

Scenarios 1 and 2: 1 - 1.5 feet of flooding inside the Substation (10-year and 50-year interval)
Estimated time to repair and re-energize: 1 day

- Under a scenario of 1 – 1.5 feet of flooding at Ravenswood Substation, water would enter the battery room, which is located on the ground level of the substation (please see Figure 4 below). Inside the battery room are DC batteries and battery chargers. The battery chargers, which are essential for the substation to function, are located on the floor inside the battery room and would be damaged by water (see Figure 5).
- If flooding destroys the battery charger, PG&E will seek to procure an emergency battery trailer that can provide temporary power to the DC battery system. PG&E has three emergency battery trailers in the San Francisco Bay Area. It is likely that Ravenswood Substation would be prioritized to receive one of these three emergency battery trailers.
- PG&E estimates that it will take a minimum of one day to assess damage to the battery charger, order the emergency battery trailer, secure access to the emergency battery trailer in the substation (timing will depend on access to the battery room and whether floodwaters left significant debris that must be cleaned to get access to the room). This is a very conservative estimate that also depends on the ease of road access and available personnel.
- Once the emergency battery trailer is installed and tested, the substation can be re-energized.

Figure 4: Battery room in Ravenswood Substation

Figure 5: Battery charger on right, ground level

Scenarios 3 - 8: 2 feet of flooding inside the Substation
(Present day 100-year and 500-year intervals; All flood events under 3.5 feet of sea level rise).
Estimated time to re-energize and repair: 2 days

- As explained above, flooding inundation height in Scenarios 3 - 8 is capped at 2 feet.
- Two feet of flooding at Ravenswood Substation would allow water to enter the battery room, which is on the ground level. Inside the battery room are DC batteries and battery chargers. The battery chargers are located on the floor of the room and would be damaged by water. Two feet of flooding or more will also destroy the main DC battery system. The height of the batteries from the floor is 23.5 inches. At water above 23.5 inches, water will enter the batteries through the sponge vent that sits on top (as shown in Figure 6 below: the vent is the tall round cylinder behind the ruler). These batteries direct power to other critical equipment and are essential for the substation to function.
    - In order to re-energize the substation, an emergency battery trailer would be sourced, brought in, and installed, while repairs were conducted. This is estimated to take one repair day as described in Scenarios 1 and 2.
    - A major flood is expected not just to damage equipment due to water inundation but also to bring mud and debris onto the site. Additionally, nearby roads are likely to be damaged and could delay sourcing of the battery trailer or the availability of personnel to support clean up and restoration efforts. Under these conditions, PG&E estimates an additional day will be needed for a flood of two feet or greater, reflected in an additional day of “repair time” before other repairs could commence.

Figure 6. Batteries vulnerable to flooding levels of 2 feet

Estimating the number of days for repair is difficult and there is some uncertainty. PG&E stresses that the days to repair shown in Table 2 and described above are conservative and are regarded as best-case scenarios. The number of days for repair may be greater as they are dependent on the conditions of nearby roads and personnel available to return the substation to normal operating conditions. Indeed, flooding during Hurricane Harvey in 2017[4] and Hurricane Florence in 2018[5] damaged numerous substations across Texas, North Carolina, and South Carolina, with some substations inaccessible and de-energized for multiple weeks.

During an extreme storm event that would lead to the flooding scenarios described above in Table 2, PG&E's system is likely to experience multiple instances of damaged equipment beyond Ravenswood Substation. The repair time assumes that enough engineers are available to work on repairing the station and flooding damage to nearby roads (such as Highway 84) does not prevent access to the substation. While a large storm may reduce the availability of trained personnel that can conduct repairs at Ravenswood Substation, work would be prioritized at Ravenswood Substation given its criticality to the system. This would include access to a battery charger trailer. PG&E has, once more, used a best-case scenario approach in determining days of repair for each flood event. PG&E is committed to providing safe and reliable electricity to its customers and quickly restoring service in the safest way possible.

[4] "Hurricane Harvey Floods Entergy's Substations and Infrastructure", TDWorld.com, 15 Sept 2017, available at: https://www.tdworld.com/electric-utility-operations/media-gallery/20970184/hurricane-harvey-floods-entergys-substations-and-infrastructure

[5] "Soaked substations trip up post-hurricane power restoration", Rod Kuckro, E&E News. 4 Oct 2018, available at: https://www.eenews.net/stories/1060100456

If additional information is needed, please feel free to reach out to us.

Regards,

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