Attachment C

Descriptions of Proposed Project and Enhanced Compliance Action As Part of Settlement of North Coast Regional Board ACL, Prepared By Russian River County Sanitation District Staff, December 2015

Proposed Compliance Project for Violation No. 1

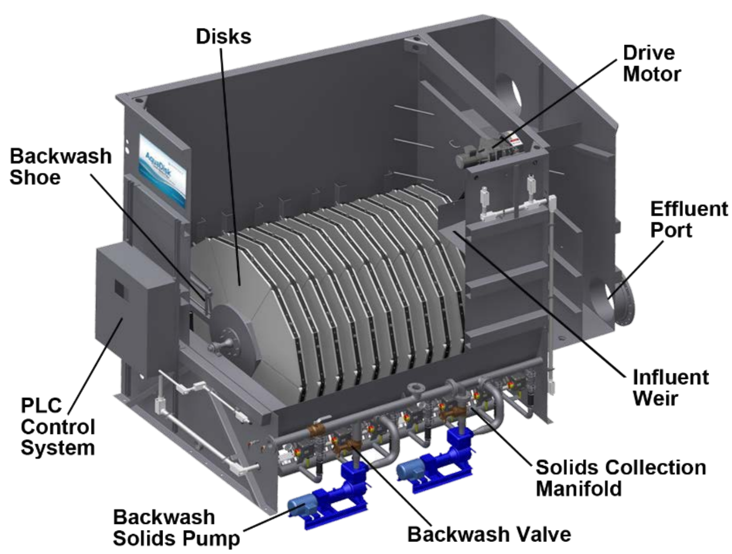
According to the State Water Resources Control Board Water Quality Enforcement Policy (Enforcement Policy), a Compliance Project (CP) is a project designed to address problems related to the violation(s) and bring the discharger back into compliance in a timely manner. The Enforcement Policy specifies that the discharger must propose the CP and must abide by the following:

1) The CP is designed to correct the violations with five years;
2) The CP is in accordance with the Enforcement Policy; and
3) The discharger has demonstrated that it has sufficient funding to complete the CP.

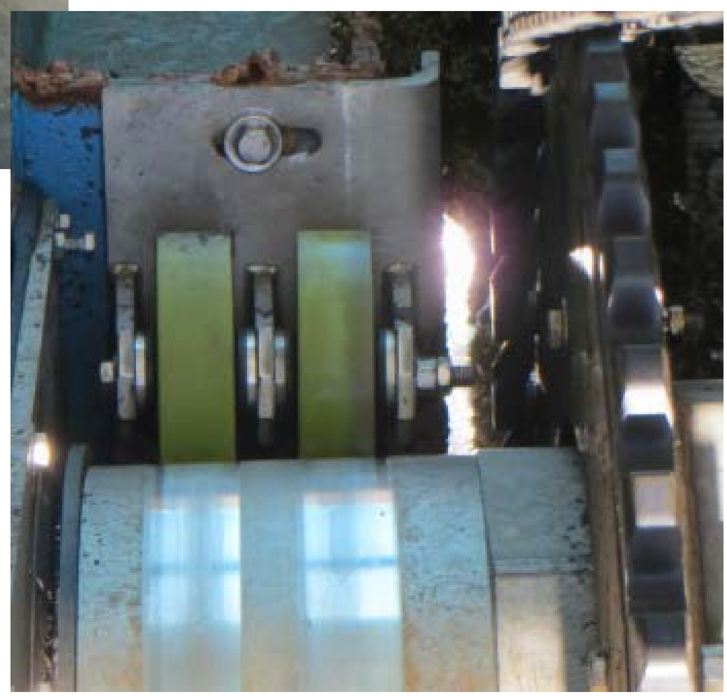
The following description provides how the proposed CP, the Tertiary Filter Media Upgrade and Rehabilitation Compliance Project, will comply with and be in accordance with the Enforcement Policy.

Background:

The Tertiary Filters were installed as part of the Russian River County Sanitation District (RRCSD) Third Unit Processes Project completed in 2005. The tertiary filters are manufactured by Aqua-Aerobic Systems and utilize cloth media filtration in their AquaDisk product (see rendition for example), the filters had a one year manufacturer's warranty. While RRCSD has continually completed the manufacturer's recommendations for maintenance and has electronic records dating back to 2008 documenting the required maintenance the two filters are showing signs of needing rehabilitation. In 2013 Aqua-Aerobic Systems performed a complimentary filter assessment and provided a brief field service report. That report acknowledged issues with rust and electrical components but did not go into the detail that a thorough mechanical inspection would. RRCSD staff have taken many photos of severe corrosion within the filters and are concerned that without replacing some structural steel, the filters could catastrophically fail at which time replacement may be the only alternative. RRCSD staff contacted Aqua-Aerobic Systems to discuss several items, one of which was the expected life span of the filter modules and while there is not an expected lifespan, it is often the case that units do require rehabilitation including sand blasting, re-welding and re-coating. Until the units are taken offline it is not known exactly what repairs and upgrades will be needed, however if rehabilitation is selected rather than replacement it is anticipated that the CP may include: replacing the filter media with Aqua-Aerobics OptiFiber cloth media; new roof



structure; metal removal and replacement, sand blasting and recoating of the unit's interior and exterior; bearing and drive shaft replacements, control system upgrades, pipe manifold rehabilitation, various pumps and motors rebuilt or replaced; and sensor component replacement. The pictures to the left and below were taken in May 2013, severe rust/corrosion can be seen on a major structural member and severe wear can be seen on the center drum drive assembly. In general and while not as severe as these two photos depict, there are many other instances that exist both on the interior and exterior of the filter modules. This type of corrosion is not atypical and can be expected to occur given the operating conditions both relative to waste water and the moist environment that the treatment plant exists in, even with preventative and corrective maintenance, 24 hour, 7 day a week operation will eventually wear out many mechanical appurtenances. The modules are not experiencing failure but given the observations of RRCSD staff, rehabilitation or replacement of the modules is imminent. As required by the Enforcement Policy, this project is a project that the RRCSD is obligated to perform, independent of the ACL.



Link between the violations and the CP:

Effluent violations identified in the revised Attachment A are predominantly Total Coliform violations that occurred in early 2010. Since that time the RRCSD installed an ultra violet disinfection system (UV) that has helped meet total coliform effluent limits. However, while the disinfection system is now able to provide adequate disinfection during high wet weather flows, the tertiary filters without rehabilitation could inundate the UV system with potentially partially filtered or non-filtered effluent. Both the tertiary filters and the UV system are capable of providing treatment during high wet weather flow events, but the tertiary filters are the final barrier prior to disinfection. The proposed CP will provide upgrades and repairs needed for the tertiary filters to continue to operate as they were originally designed. The nexus between tertiary filtration and total coliform is physical solids removal. If failure of any of the mechanisms in either of the filter modules were to occur, physical filtration becomes jeopardized. The CP will provide needed repairs and upgrades and reduce the potential for future total coliform violations.

Estimated budget and timeline of the CP:

Table 1 – Estimated Costs for Rehabilitating AquaDisk Filter Modules

Description	Hours*	Cost*
Project Management, Administration	40	$6,800
Remove filter interior appurtenances, prepare steel for blasting and welding	100	$17,000
Sand Blast, cut out, fabricate and weld new steel	100	$17,000
Replace filter cloth media	16	$2,800
Recoating Interior (outside contractor)	40	$20,000
Exterior preparation for sand blast and recoat	30	$5,100
Replace miscellaneous parts (includes cost of parts/equipment, filter media)	40	$25,000
Reinstall interior appurtenances	100	$17,000
New roof structure		$12,500
Total Estimated Cost for One Filter Module		**$123,200**

* Hours and Cost are for a single filter

The costs to replace a filter module both with and without the interior parts in both coated steel and stainless steel units are presented in Table 2 below. Replacement of both modules would be double these amounts.

Table 2 – Costs for New AquaDisk Units

Description	Cost*
Painted Steel Tanks, no interior parts	$76,810
Painted Steel Tanks all new interior parts including filter media	$132,104
Stainless Steel Tanks, no interior parts	$138,647
Stainless Steel Tanks all new interior parts including filter media	$193,941

* Costs are for a single filter, delivered to RRTP but does not include sales tax

Given the estimated costs shown in Tables 1 and 2, the RRCSD has not determined whether to rehabilitate the existing filters or purchase new filters. This will be determined from a field assessment, described below and identified in Table 4. Rehabilitation would take staff away from their current daily duties and existing projects, thus pushing out the schedule on other needed maintenance. While it may seem wasteful to simply replace the filter modules with new, the comparable cost and new lifespan estimates seem to justify that decision. Whether the RRCSD decides to rehabilitate or purchase new, it has budgeted the CP over a three year period. Funding will come from the RRCSD Construction Fund, however funding for other projects including collection system improvements will decrease. As shown in Table 3, funding has been budgeted in the long range financial plan for fiscal years 15/16 and 17/18 and is inclusive of minimum mandatory penalties.

Table 3 – Funding for tertiary filter compliance project

Fiscal Year (July 1 thru June 30)	Funding Available for Tertiary Filter Compliance Project*
2015/2016	$150,000
2016/2017	$0
2017/2018	$150,000

* Inclusive of mandatory minimum penalty

The CP timing and logistics make it so that the physical work must occur during the dry season when influent to the plant is at a minimum, usually between June and October. RRCSD staff have determined that the choice to either rehabilitate or purchase new filters is going to necessitate performing an assessment on the filter modules. This will require that the filter(s) be taken offline, one at a time, drained and cleaned so staff can inspect the interior and mechanical parts. The outcome of the assessment will determine whether the RRCSD wants to take on the rehabilitation or replace with new filters. The assessment will also provide an opportunity to see if improvements or additions to the filters could be made to reduce the amount of corrosion. The timeline includes completion of the filter assessment between June 2016 and October 2016, and the filter rehabilitation/replacement to be completed for both filters by October 2018. By allowing the CP to occur over a three year period, the RRCSD will be able to budget and allow for the accommodation of other projects that may arise including an enhanced compliance action. Table 4 provides a timeline to complete the CP.

Table 4 – Timeline to complete tertiary filter rehabilitation/replacement

Task Description	**Date Completed**
Tertiary Filter Assessment	October 1, 2016
Filter Assessment Report (to include rehabilitate/replace determination)	November 15, 2016
Filter One rehabilitate/replace	October 31, 2017
Filter Two rehabilitate/replace	October 31, 2018

Proposed Enhanced Compliance Action for Violations No. 2 and No. 3

According to the Enforcement Policy, Enhanced Compliance Actions (ECAs) are projects that enable a discharger to make capital or operational improvements beyond those required by law, and are separate from projects designed to merely bring a discharger into compliance. The Enforcement Policy specifies that the discharger, must propose the ECA and must abide by the following:

1) The ECA must be clearly identified with goals, costs, milestones and completion dates;
2) The ECA is in accordance with the Enforcement Policy and the rules that apply to Supplemental Environmental Projects; and
3) The discharger has demonstrated that it has sufficient funding to complete the ECA.

The following description provides how the proposed ECA, the Manway Installation on Force Main at Main Lift Station, will comply with and be in accordance with the Enforcement Policy.

Background:

The RRCSD operates a lift station at 17484 Riverside Drive, Guerneville, known as “Main Lift”. Between Main Lift and the RRCSD wastewater treatment plant there exists a 16-inch force main. Wastewater is pumped into the force main at Main Lift and by the Vacation Beach lift station located at 17826 Orchard Avenue, Guerneville. Installed in the 1978/1979 time period, the force main is an active, pressurized pipeline that pumps raw wastewater to the treatment plant located at 18400 Neeley Road, Guerneville. The force main has no appurtenances to access the interior of its approximately 9,030 feet of concrete mortar lined steel pipe.

Following the sewage spill (Violation No. 3), the RRCSD contracted with a consultant to perform a review and submit a report with recommendations for performing an assessment of the force main. That report documented many technologies and recommended that an external assessment be conducted utilizing Ultrasonic testing and soil resistivity testing. The assessment could be conducted while the force main remained in service, but would only assess the force main in five or six discrete locations and would not assess the interior of the pipe. RRCSD staff reviewed the recommendations and determined that the logistics of performing the Ultrasonic testing would require additional work and potential impacts to the force main that would ultimately require the RRCSD to bypass the force main. Given those concerns, the RRCSD reviewed additional, newer and more costly technologies. The resulting review identified two technologies that would provide a complete assessment of the force main. One of the two technologies required that the pipeline be internally cleaned prior to being assessed, that technology was determined not feasible. The second would identify leaks and gas pockets utilizing an internal free floating sensor and an internal corrosion inspection utilizing an electromagnetic technology that could be inserted into the live force main. The attached document “Russian River Force Main Condition Assessment – Proposed Approach” describes the assessment technology the RRCSD would like to utilize. This assessment would be above and beyond any normal maintenance program or external assessment, however, it would determine the health of the force main, if it needs to be replaced or if discrete sections are in need of repair. This assessment will be used with the RRCSD Natural Hazard Reliability Assessment, also attached to this document, to determine priority areas for repair or replacement of the force main.

As noted previously, there exists no appurtenances to access the interior of the pipeline. This project would allow for the permanent installation of a manway allowing interior access to the force main for advanced assessment purposes.

Description of the ECA:

Prior to the actual installation of the manway into the 16-inch force main several mechanisms need to be put in place to be able to shut down the force main and bypass the Main Lift station. The bypass will involve outfitting one of the pumps in Main Lift with the ability to bypass the force main and pump into temporary storage facilities. Temporary storage is necessary for two reasons: 1) as described above it will be used to temporarily store wastewater entering Main Lift so it can be hauled safely to the treatment plant while the manway is being installed, and 2) the force main needs to be dewatered prior to the manway being installed in the force main. Logistically, it is proposed that three baker tanks be utilized so that the bypass and dewatering can occur. Some of the necessary piping will be installed underground for future use for similar bypass operations. The RRCSD owns the adjacent property to the east and historically it appears there was a roadway on this property and it will be developed to allow the baker tanks to be driven in, parked and connected as simply as possible. Following baker tank installation, dewatering and bypass can occur to allow for cutting into the force main for the installation of the manway. The manway is essentially a section of vertical pipe isolated with valves on either end, this will allow one to insert a device into the manway, close the upper valve and then open the lower valve and let the device enter the force main for assessment. To minimize flows into Main Lift, this work will occur during the night hours, likely between 9 pm and 6 am. Contracted pumper trucks will be used to transfer the temporarily stored wastewater from the baker tanks to the treatment plant. To minimize the distance the pumper trucks need to travel, the project will also need to occur during the period that the temporary river crossing is installed at Vacation Beach, roughly between late-May and mid-September.

Goal, budget and timeline of the ECA:

The installation of a manway and the appurtenances needed for bypass will allow for an advanced condition assessment to be conducted on the force main in an environmentally safe and timely manner.

The RRCSD has budgeted $110,000 for the installation of the manway on the force main, inclusive of the penalty amount available (~$67,885). However, in order to accommodate other projects, including the compliance project described above, this project is budgeted for fiscal year 16/17. It is expected that the construction of the manway will occur during the June 2017 through October 2017 timeframe and be completed by November 2017. Table 5 includes estimated costs for the tasks and equipment necessary to complete the ECA and Table 6 includes timelines for the ECA tasks described above.

Table 5 – Estimated Costs for Manway Installation

Task/Description	**Estimated Cost**
Administrative/Design	$10,000
Site development	$15,000
Piping, valves, fittings	$30,000
Construction	$25,000
Baker Tank Rental	$5,000
Contracted Pumper Trucks	$25,000

Table 6 – Timeline for Completion

Task/Description	**Date Completed**
Design	December 31, 2016
Construction	October 1, 2017

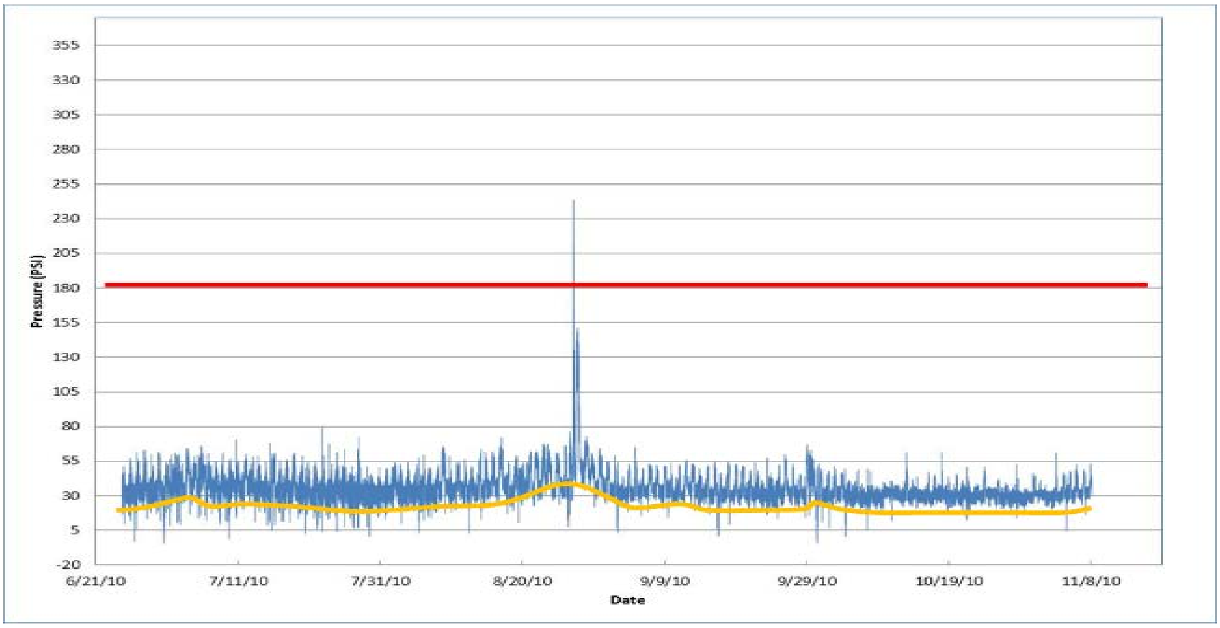
Russian River Force Main Condition Assessment- Proposed Approach

Pressure Transient Monitoring

Pure Technologies recommends the inclusion of a pressure transient monitoring within the pressure pipe assessment of the Russian River Force Main.

Hydraulics and their relationship to pressure pipe condition and operation have historically been one of the lease understood and analyzed aspects of pipeline management. When pipe wall degradation is combined with either the operational pressure or surge pressure, the likelihood of failure significantly increases. Data loggers with a high rate of sampling (20Hz) can provide beneficial operational information within the pump station to allow the District to develop operational protocols that minimizes the deterioration of the pumps and pipelines.

Figure 1. Pressure Transient Monitoring



Hydrogen Sulfide Monitoring

It has been well documented that high concentrations of hydrogen sulfide gas within wastewater is of significant concern as this gas may be released from solution into the atmosphere and subsequently cause corrosion and eventual breakdown of the pipe's exposed surface for all non-corrosive pipe materials. Installation of the hydrogen sulfide monitoring equipment can be conducted as part of the general assessment of the pressure main. As part the hydrogen sulfide monitoring program, Pure Technologies typically conducts a manned inspection of the discharge structure to evaluate the condition of the pipe connection and structure.

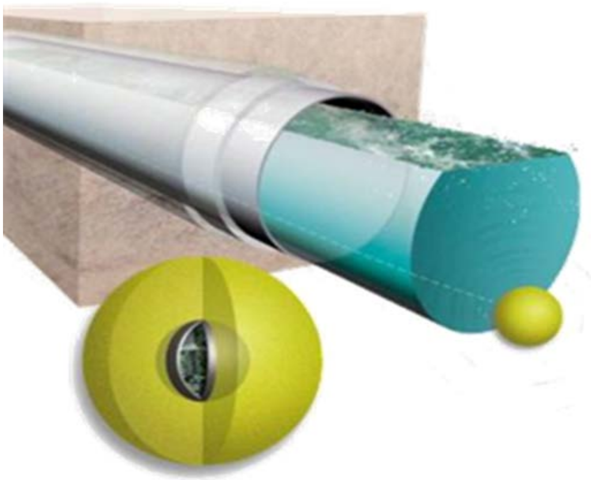
Leak and Gas Pocket Detection

While there are several mechanisms for the failure of sewer pressure pipe, research conducted as part of the *Water Environment Research Foundation: 2010 Guidelines for the Inspection of Wastewater Force Mains*, shows that the most common failure mode is internal hydrogen sulfide corrosion. This form of corrosion starts by a gas pocket forming in the pipeline, which develops the environmental conditions necessary to corrode the pipe wall, eventually leading to a failure. In non-corrosive materials, hydrogen sulfide is ordinarily not a major concern however, the primary concerns for these materials are joint defects (leakage), deflection, fatigue from cyclical pressures, and collapse due to vacuum. Strain corrosion associated with excessive deflection in an acidic environment in a GRP pipe is a concern. Collapse due to vacuum has a higher risk of occurrence at gas pocket locations should a transient pressure wave traverse the pipeline. With the exception of deflection and fatigue, these potential failure modes can be evaluated using inline leak and gas pocket detection tools.

Gas pockets can also impact the operation of a pump station system by reducing capacity of the pipeline. Pure Technologies has performed an analysis of force mains inspected using acoustic based technologies in order to better characterize the frequency and location of gas pockets. Based on the analysis, it was found that 72% of gas pockets were not at known high points or air release valves.

Pipeline leaks are of concern for all pipe materials as they are often found to be the precursor of major failures. A pipeline failure can begin with weakening of the joint or barrel that may include a small leak. As constant use of the pipeline continues and pressure surges occur, the leak may grow possibly leading to a catastrophic failure or undermining the support of the pipeline. Therefore, identification of both gas pockets and leaks may eliminate these potential failures.

Figure 2. SmartBall Free Swimming Gas Pocket Detector



Pure Technologies recommends the acoustic based SmartBall® tool for the assessment of the Russian River force main. The device is capable of identifying areas where conditions may lead to internal pipeline corrosion (gas pockets) and leaks.

The tool identifies leaks and gas pockets traversing an active pipeline with a device capable of recording changes in the background acoustical profile of a pressurized main. Surveys are conducted under live operating conditions, with no or minimal disruption to service. Nearly 20,000 kilometers of pressure pipeline have been inspected with acoustic based tools, with hundreds of leaks and gas pockets identified.

The SmartBall tool is inserted into a pipeline, typically at a check valve in the pump station on a sewer force main or at air valves on treated sewage effluent pipelines, and allowed to traverse an active pipeline with a device capable of recording changes in the acoustic profile of a pressurized pipeline. A custom screen is typically used to retrieve the tool in a discharge manhole or wet well.

The only available technology for identifying and locating the limits of all gas pockets is an inline inspection tool such as the SmartBall. Pure Technologies has conducted research using other techniques such as noise loggers or correlators and found that while these devices may identify a single gas pocket between each sensor, they cannot accurately locate the limits of the anomaly nor identify multiple pockets of trapped gas. Identification of the limits of a gas pocket is crucial since hydraulic jumps in the flow frequently occur at the beginning and end of each gas pocket where a higher probability of hydrogen sulfide emission exists, thereby increasing the potential for pipe wall degradation.

Direct Assessment Technologies

There are several methods to obtain a direct assessment of a pipe wall. Deploying the "right" technology depends on pipeline risk, available budget, and logistical constraints (i.e. pipeline accessibility). In general, wall assessment methods can be divided into three categories: low, medium and high-resolution techniques. The required budget and logistical constraints often increase as the resolution of the tools increase. However, so does the level of reliability associated with the assessment. Due to the failure history of the Russian River force main, as well as its criticality, it is suggested that an inline tool be employed to gather information about internal and external corrosion.

Pure's electromagnetic inspection technique is a non-destructive, in-line assessment technology that provides the relative wall thickness data for the steel cylinder along the circumferential and axial direction of each pipe. The data provides these defect locations in a pipe-by-pipe format along the force main alignment. Pure has applied the electromagnetic technology to its established fleet of free-swimming, robotic, and manned inspection platforms, making it available in a convenient and economical manner.

PipeDiver® The PipeDiver platform is ideal for critical large-diameter pipelines that cannot be removed from service due to lack of redundancy or operational constraints, and is thereofr the prefect choice for the Russian River force main. It can be effectively deployed for long inspections on several types of pipe to determine baseline condition. On concrete pressure pipe, the tool can identify and locate broken prestressing wire wraps, which are the main indication that this type of pipe will eventually fail. For metallic pipes that utilize a steel cylinder as the main structural component, the tool can locate and detect areas of cylinder corrosion. When inserted into a live pipeline through a hot tap connection, an existing access or a submerged tank, the tool travels with the product flow and is able to navigate most butterfly valves and bends in the pipeline

Figure 3. Defects Identified, Validated, and Repaired from PipeDiver Inspection

Inspection Benefits:

- Medium to high resolution inspection of pipe structural integrity (when calibrated with UT and or BEM measurements resolution is greatly increased)
- Inspection can detect defect both internal and external
- Inspection can be performed with pipeline in service
- Long inspection distances can be covered in a single deployment
- Accurate results that pinpoint areas of distress help optimize repair planning
- Effective on PCCP, BWP, ductile iron, cast iron and steel pipe

Figure 4. Free-Swimming PipeDiver EM Tool

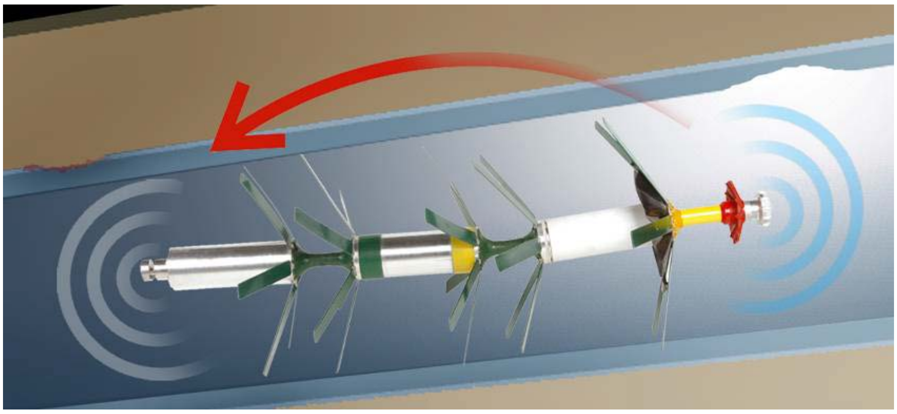
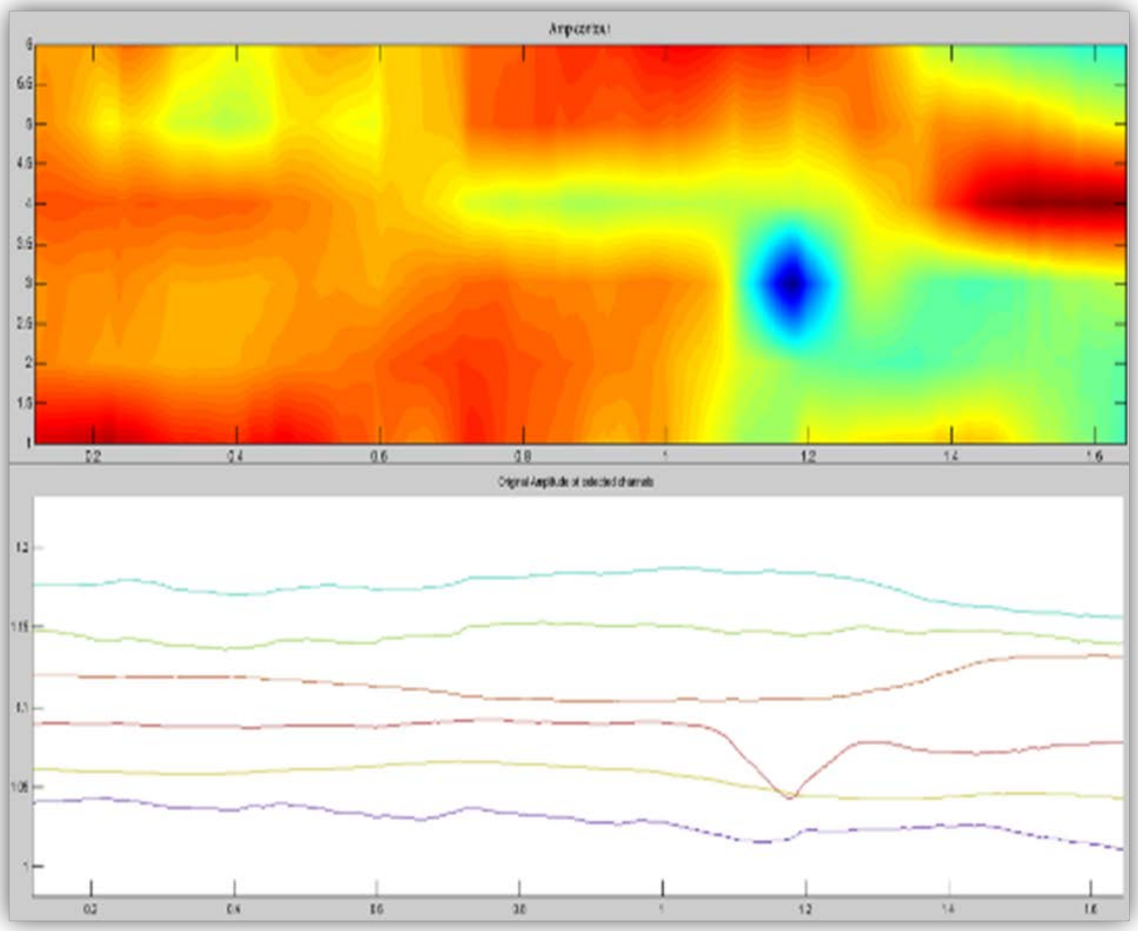


Figure 5. Example of Pipe Wall Data (Blue Locations Represent Defects)



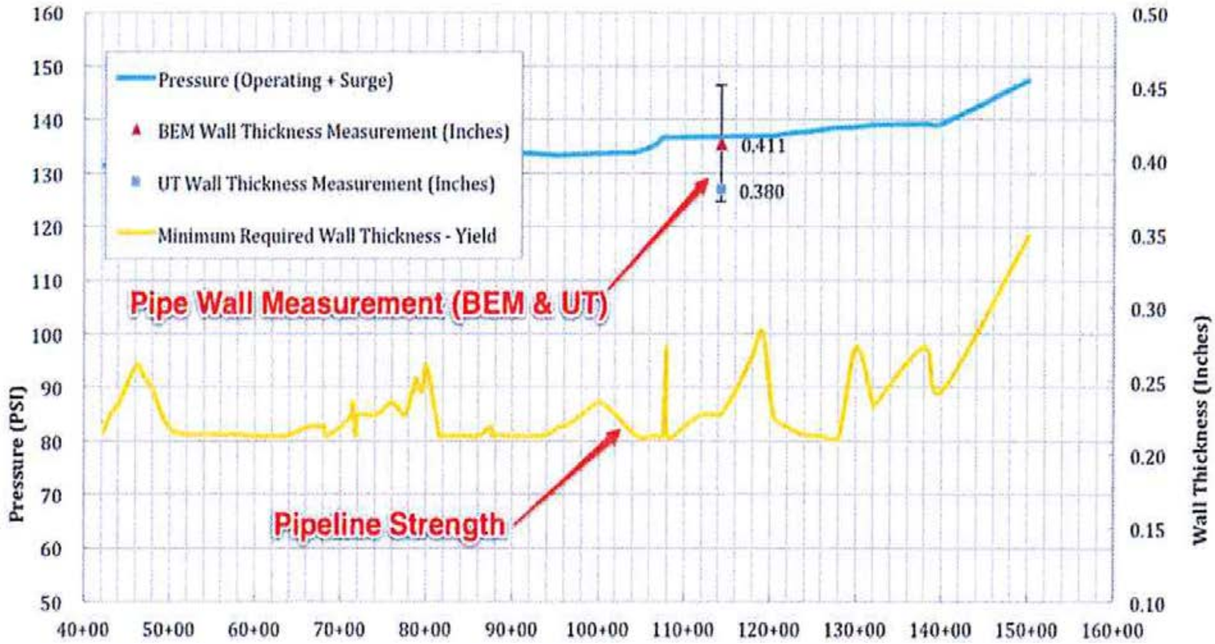
Structural Evaluation and Risk Assessment

Pipeline Condition Curves

While the inspection techniques described above provide data regarding areas of pipe deterioration and internal forces; this information alone does not provide the condition of a pipe. The condition of a pipe should be ascertained through a structural evaluation to determine the severity of the deteriorated areas relative to the actual loads that act on the pipeline. To develop actionable information from the inspection data, Pure Technologies has developed an innovative series of structural analysis models. These models incorporate the information collected as well as industry design specifications for each pipeline. The models are presented in a pipeline condition curve that allows for both the localized and systemic condition evaluation of the pipeline.

An example of a condition curve is shown in the figure below.

Figure 6.1 Pipeline Condition Curve



This curve represents the yield strength limit of a ductile iron pipeline along its length, which identifies the specific wall thickness required for the pipe to remain in the elastic zone. This parameter is used to determine the safety of the pipeline. Any wall thickness measurement less than this curve should be considered for repair or rehabilitation in the near future. If the pipe wall thickness measurements are above the yield strength limit, there is no immediate need for repair or replacement (absent of consequence of failure findings). Once acquired, the wall thickness measurements will be incorporated into the model, it will then be determined if the minimum wall thickness for the yield limit are approached or exceeded. Pure Technologies has developed similar curves for other pipe materials which can be provided during the assessment process.

Condition Grades

In order to fully evaluate the risk associated with areas found to have damage based on the pipeline assessment, a risk analysis can be developed in order to provide a decision making tool for rehabilitation or replacement planning. Pure Technologies will establish a likelihood and consequence of failure grading system in close coordination with the County to develop a comprehensive risk based ranking system for individual assets. Repair recommendations, as well as long term management strategies will be developed using the risk based assessment in order to provide a comprehensive pipeline management protocol for each asset. Risk tolerance will be defined by the County and Pure Technologies as part of the data evaluation process in order to establish an effective pipeline management strategy. It is also important to consider any asset management or strategic planning that the County has undertaken so the assessment work conducted will fall within guideline already established. This is critical when considering capital budget planning as well as operational and maintenance budgets. Pure Technologies has extensive experience with incorporating condition assessment with an owner's asset management and planning strategies.

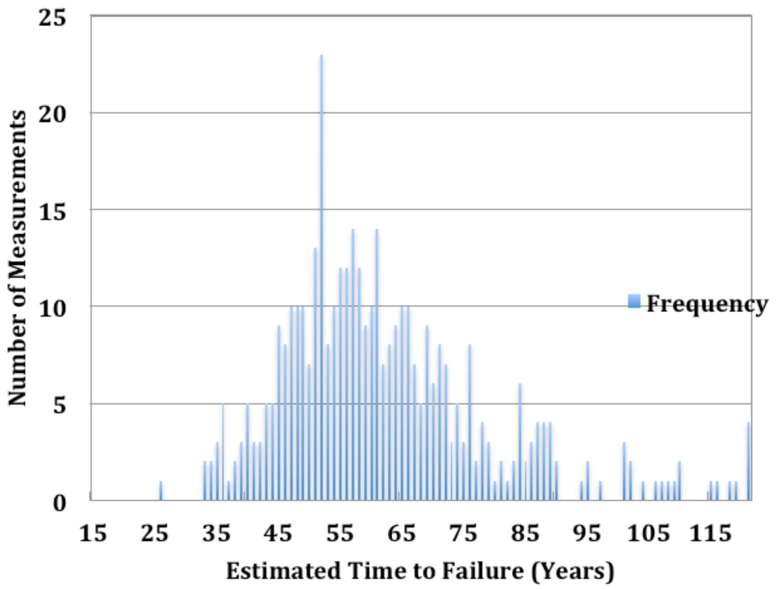
Utilizing this grading system developed from the condition data, structural analysis, and consequence of failure evaluation, Pure Technologies will develop a prioritized list of rehabilitation strategies for the pipeline. As previously noted, it is the experience of Pure Technologies that pressure pipelines typically do not deteriorate at a consistence rate for their full alignment; rather, localized areas of deterioration are common. Condition assessment experience has shown that less than 10% of a pipe will have identifiable deterioration with less than 1% requiring repair. Therefore, the prioritized list of repairs generally does not focus on full pipeline alignments, but localized repairs. This is good news, as assessment an isolated repair provides a utility with significant cost reductions as compared to full length rehabilitation techniques.

Remaining Useful Life Evaluation

Life-Cycle Analysis

By combining the structural analysis with condition data, estimates of when the pipeline should next be inspected along with a remaining service life of the asset can be completed. To do this, Pure has developed a statistical simulation that utilizes failure history, inspection data, and structural analysis. An example of the output of this model is shown in Figure 7, which shows the number of failures predicted (y-axis) by year into the future (x-axis). The simulation data indicates that based on the data collected, no failures are expected to occur for at least 25 years. However, Pure always recommends that remaining useful life estimates should be used as guidance for re-inspection interval planning as collection of subsequent condition data can be used to better refine the asset life estimates. Once another inspection is completed, the data collected in that inspection should be analyzed in conjunction with the data presented in this report to provide a more accurate and robust remaining useful life evaluation. In the example below, re-inspection was recommended within 10 years from the original data collection (based on condition, failure history, and budget).

Figure 7.2 Monte Carlo Simulations and Finite Element Analysis can provide estimates of the remaining useful life



Russian River County Sanitation District

Natural Hazard Reliability Assessment

June 2015

For accessibility assistance with this document, please contact GHD Engineering Department at (707) 523-1010, Fax at (707) 527-8679.

PREPARED BY

GHD

2235 Mercury Way, Suite 150
Santa Rosa, CA 95407
(707) 523-1010

G&E Engineering

6315 Swainland Road
Oakland, CA 94611
(510) 595-9453

KLEINFELDER
Bright People. Right Solutions.

2240 Northpoint Parkway
Santa Rosa, CA 95407
(707) 571-1883

June 2015

Table of Contents

List of Tables

List of Figures

List of Abbreviations

ABS	Acrylonitrile Butadiene Styrene Pipe
AC, ACP	Asbestos Cement Pipe
ADWF	Average Dry Weather Flow
ALA	American Lifelines Alliance
ASK	Abrahamson-Silva-Kamai Model for ground motion
BSSA	Boore-Stewart-Seyhan-Atkinson Model for ground motion
CB	Campbell-Bozorgnia Model for ground motion
CI, CIP	Cast Iron Pipe
cm	centimeters
CY	Chiou-Youngs Model for ground motion
DI, DIP	Ductile Iron Pipe
DSOD	Division of Safety of Dams
g	acceleration of gravity (= 32.2 feet per second squared)
gpm	Gallons per Minute
FEMA	Federal Emergency Management Agency
FHSZ	Fire Hazard Severity Zones
FIRM	Flood Insurance Rate Maps
GIS	Geographic Information System
HDPE	High Density Polyethylene Pipe
I	Idriss Model for ground motion
IBC	International Building Code
m	meters
mm	millimeters
m/ sec	meters per second
M	Magnitude (moment magnitude)
MG	Million Gallons
MGD	Million Gallons per Day
MH	Manhole
N.A.	Unknown Pipe Material
NEHRP	National Earthquake Hazards Reduction Program
NFIP	National Flood Insurance Program
NOAA	National Oceanic and Atmospheric Administration
PEP	Polyethylene Pipe
PGA	Peak Ground Acceleration (measured in g)
PGD	Permanent Ground Deformation (measured in cm)
PGV	Peak Ground Velocity (measured in cm/second)
PG&E	Pacific Gas and Electric
PVC	Polyvinyl Chloride Pipe
RAS	Return Activated Sludge
RC	Rogers Creek Fault
RCP	Reinforced Concrete Pipe
SC	Steel Cased Pipe

SCWA	Sonoma County Water Agency
sec	seconds
SVCSD	Sonoma Valley County Sanitation District
UBC	Uniform Building Code
VCP	Vitrified Clay Pipe
V, Vs	Seismic Base Shear Force
W	Weight
WAS	Waste Activated Sludge
WWTP	Wastewater Treatment Plant

Appendices

1. Introduction

1.1 Background

Hazard mitigation, as defined by the Russian River County Sanitation District (RRCSD), is a way to limit or eliminate damage to infrastructure and facilities that occur as a result of natural disasters. Hazard mitigation plans are often executed through developing long- and short-term strategies, establishing a program to address potential hazards, and through commencing a program or projects to mitigate the potential impacts of specific and identified hazards to infrastructure and facilities.

The Disaster Mitigation Act (DMA) of 2000 (Public Law 106-390) requires state and local governments to develop hazard mitigation plans as a preliminary measure in order to receive federal disaster grant assistance. Prior to 2000, federal disaster funding was primarily appropriated towards disaster relief and recovery programs after an incident. Through the establishment of the DMA, there is now an increased emphasis on proactive planning for disasters before they occur; municipalities are encouraged to put mitigations in place in order to reduce damages due to hazards identified in a Natural Hazard Reliability Assessment and a Hazard Mitigation Plan.

The DMA encourages state and local authorities to work together on pre-disaster planning by identifying and developing mitigation actions to minimize damage from hazards. Mitigation actions are based on short-term and long-term activities and goals, which include reducing the cause or occurrence of hazards, reducing exposure to hazards, reducing the effects of hazards through preparedness, and reinforcing response and recovery activities. Through thoughtful planning and implementation of an effective plan, mitigation actions will effectively reduce the adverse impacts to infrastructure and facilities, which will therefore minimize the costs of rebuilding damaged structures should a disaster occur.

In January 2008, the Sonoma County Water Agency (SCWA) Board of Directors adopted a Local Hazard Mitigation Plan (LHMP) in accordance with the DMA. In 2012, an update to the LHMP was completed by MMI Engineering, Inc. and InfraTerra, Inc. in conjunction with SCWA in order to review the natural hazards that may impact SCWA facilities, and to complete a vulnerability assessment of the infrastructure to the identified hazards. The LHMP documents the progress towards the mitigation of hazards identified, and provides a vision for the next five years to further reduce SCWA's exposure to the identified hazards. The 2012 update provides an overview of hazards that relate to the SCWA facilities, including the water supply system, sanitation system, flood control, emergency power and administrative infrastructure.

1.2 Purpose of the Natural Hazard Reliability Assessment

SCWA's sanitation system includes a combination of systems owned by SCWA (referred to as Sanitation Zones) and independent Special District's operated by SCWA (referred to as Sanitation Districts).

The purpose of this Natural Hazard Reliability Assessment is to further develop an assessment of the potential hazards that could affect the RRCSD and to evaluate the extent of vulnerability that each hazard has on existing infrastructure and facilities. GHD along with sub consultants G&E Engineering, Inc. and Kleinfelder, Inc. have been retained to complete the Natural Hazard Reliability Assessment. This report provides the following information developed as a part of GHD's scope of services:

- A review of existing data including reports, plans and GIS mapping of the RRCSD facilities. A review of available documentation was completed by GHD, G&E Engineering and Kleinfelder. The documents reviewed included both hard copy engineering reports, drawings, specifications and available geotechnical data and available electronic documents located on the Sonoma County Water Agency ImageSilo website.
- An overview of the Russian River County Sanitation District (RRCSD) facilities including the collection and wastewater treatment system (Chapter 2). Field visits of the wastewater treatment plant and collection system were completed to review and identify potential hazards.
- Natural hazard identification and background summary information for the RRCSD for:
  - Geologic and seismic hazards, including earthquakes (Chapter 3);
  - Flood hazards (Chapter 4);
  - Fire hazards (Chapter 5); and
  - Low risk and other hazards, including tornadoes, hurricanes, tsunamis, and climate change (Chapter 6).
- Identification of the vulnerability of the various components, including pipelines, wastewater treatment plant, and lift stations in the RRCSD to geologic, earthquake, flood and fire hazards.

Recent worldwide events have provided examples and outcomes of hazards that have the potential to affect communities in California. A report in Appendix A describes the seismic performance of the Christchurch, New Zealand wastewater system during the 2010 and 2011 earthquakes. The Christchurch wastewater system sustained heavy damage to the pipe collection system, lift stations and wastewater treatment plant, and much of the damage was caused by liquefaction. Appendix A also includes a comparison of the seismic issues in Christchurch, New Zealand with those possible in the Russian River County Sanitation District.

2. Russian River County Sanitation District System Description

The Russian River County Sanitation District (RRCSD) began operations in 1983, and now serves an area of about 2,700 acres. The sewer service area includes the unincorporated areas of Rio Nido, Guerneville, Guernewood Park and Vacation Beach. There are approximately 3,160 equivalent single family dwelling units in the RRCSD service area. Figure 1 shows an aerial view of the primary service area for the RRCSD and Figure 2 shows the topographical relief of the area served by the RRCSD. Figure RR-1 (Appendix B) contains an overall map with the District Boundaries.

The current design capacity of the RRCSD wastewater treatment plant (WWTP) is 0.71 million gallons per day (MGD) under average dry-weather flow conditions. The WWTP includes primary, biological (secondary), and tertiary levels (filtration) of treatment, followed by UV disinfection.

Between October 1 and May 14, recycled water from the WWTP is discharged into the Russian River. Between May 15 and September 30, the recycled water is used for irrigation on forested land adjacent to the WWTP and on the Northwood Golf Course.

The following sections provide more details on the RRCSD wastewater collection system and wastewater treatment facilities.

Figure 1: Russian River CSD Regional Area

Figure 2: Russian River CSD Regional Area – Topographical Relief

2.1 Collection System

Figure RR-1 highlights the main features of the collection system. Raw sewage is collected by a series of small diameter (typically 4" to 8" diameter) collection pipes. A single backbone sewer main (with 12", 15", 16", and 21" segments) transfers collected wastewater to the WWTP. The 16" pipeline is a force main that terminates at the Headworks Building at the WWTP. An 8" ductile iron pipeline takes effluent from the WWTP to a tank, and delivers the treated effluent to the Northwoods Golf Course.

Treated (tertiary treatment) sewage leaves the WWTP via an outfall to enter the Russian River when discharge is allowed between October 1 and May 14.

There are a total of 39.3 miles of pipe in the collection system shown in Figure RR-1. Table 1 provides a breakdown of the pipe by diameter and material, and highlights that the most common pipe material is ABS (38.4 miles), representing nearly 98% of all pipes. There are small amounts of Cast Iron, Ductile Iron, PVC and VCP.

The ABS pipe material was most likely chosen due to its light weight (ease of installation) and corrosion protection for raw sewage.

Table 1: Pipe Collection System RRCSD

Pipe Material*	Length (Miles)	Diameter (Inches)
	33.89	4, 6, 8, 10, 12, 15, 21, 24, 27, 30
ACP	.05	6
CIP	0.03	4
CMLCS	1.98	8, 16
DIP	0.41	4, 6, 8
PVC	2.33	2, 4, 6, 8, 12
VCP	0.37	21, 24
Total	**39.06**	

* ABS: Acrylonitrile Butadiene Styrene
ACP Asbestos Cement Pipe
CIP: Cast Iron Pipe
CMLCS: Cement Mortar Lined and Coated Steel
DIP: Ductile Iron Pipe
PVC: Polyvinyl Chloride Pipe
VCP: Vitrified Clay Pipe

Figures RR-2 through RR-5 show the sewer collection system along with local creeks (blue lines). The soils at many creeks are Holocene age, and are prone to seismic-induced liquefaction, which is discussed further in Chapter 3. The potential for pipeline damage and the consequences of pipe failure are larger at creeks because pipe damage would entail release of raw sewage into the potentially sensitive creek environment.

Furthermore, there are 11 lift stations in the collection system:

- S57. Drake Estates (2 pumps)
- S56. Rio Nido (3 pumps)
- S58. Drake Road (2 pumps)

- S54. Laughlin Road (2 pumps)
- S55. Watson Road (2 pumps)
- S53. Guerneville Lift (3 pumps)
- S59. Beanwood (3 pumps)
- S60. Center Way (2 pumps)
- S52. Guernewood Park (2 pumps)
- S51. Main (3 pumps)
- S61. Vacation Beach (2 pumps)

2.1.1 Wastewater Treatment Plant

The Russian River County Sanitation District WWTP is located on 18400 Neeley Road, Guerneville, CA and covers an area of approximately 12.5 acres. The wastewater treatment plant and facilities are shown in the aerial view of Figure 3. The wastewater treatment process and the major facilities are described below:

- Preliminary Treatment
  - Preliminary treatment includes screening, grit removal and flow measurement.
  - Headworks. Raw sewage from domestic and commercial sources enters at the Headworks through a 16" force main. At this point, large inorganic solids in the waste stream are removed.
- Secondary Treatment
  - Aeration basins. There are three rectangular reinforced concrete aeration basins on the western side of the developed site. The wastewater undergoes biological treatment in the aeration basins. Air is injected into the wastewater to promote the growth of microorganisms that feed on organic materials in the sewage. The aeration basins are also configured to remove nutrients (nitrogen and phosperous) from the waste stream.
  - Secondary clarifiers. There are three circular concrete tanks (two smaller and one larger) called the secondary clarifiers. The wastewater from the aeration basins is pumped into these clarifiers to separate the wastewater from the mixed liquor suspended solids. The suspended heavier materials settle to the bottom of the clarifiers as sludge, and the sludge is then returned to the aeration basins. The secondary-treated water flows over the weirs of the clarifiers and is then sent to the tertiary filters.
- Tertiary Treatment
  - Tertiary filters. The secondary-treated water from the clarifiers flows by gravity into the tertiary filter complex to produce the effluent (tertiary-treated water, also called recycled water). This filtering process removes the remaining suspended solids in the effluent. To prevent clogging, the solids that accumulate in the filters are occasionally flushed out during a backwash cycle and returned to the aeration basins.
- Disinfection. The clear effluent from the tertiary filters is disinfected using an ultraviolet system.
- Solids Handling. The excess sludge in the wastewater after secondary treatment is mixed with polymer and dewatered in a press for disposal to landfill.

- Storage reservoirs. Two reservoirs with a combined capacity of 4.5 million gallons are used to store recycled water from the tertiary filers. The recycled water is transported directly from the 3.5 million gallon holding pond to the seasonal discharge locations, including nearby forests and the Northwood Golf Course. Tertiary effluent that does not meet water quality standards is automatically diverted to a 1 million gallon emergency pond, where it is then pumped back to the headworks or to an aeration basin for retreatment.
- Control Buildings
  - The normally occupied buildings at the site include the operations building, generator building and maintenance building. There is a transformer pad to the north of the generator building. The original 1982-vintage oil fuel tank and generator have both been replaced since the original plant construction.

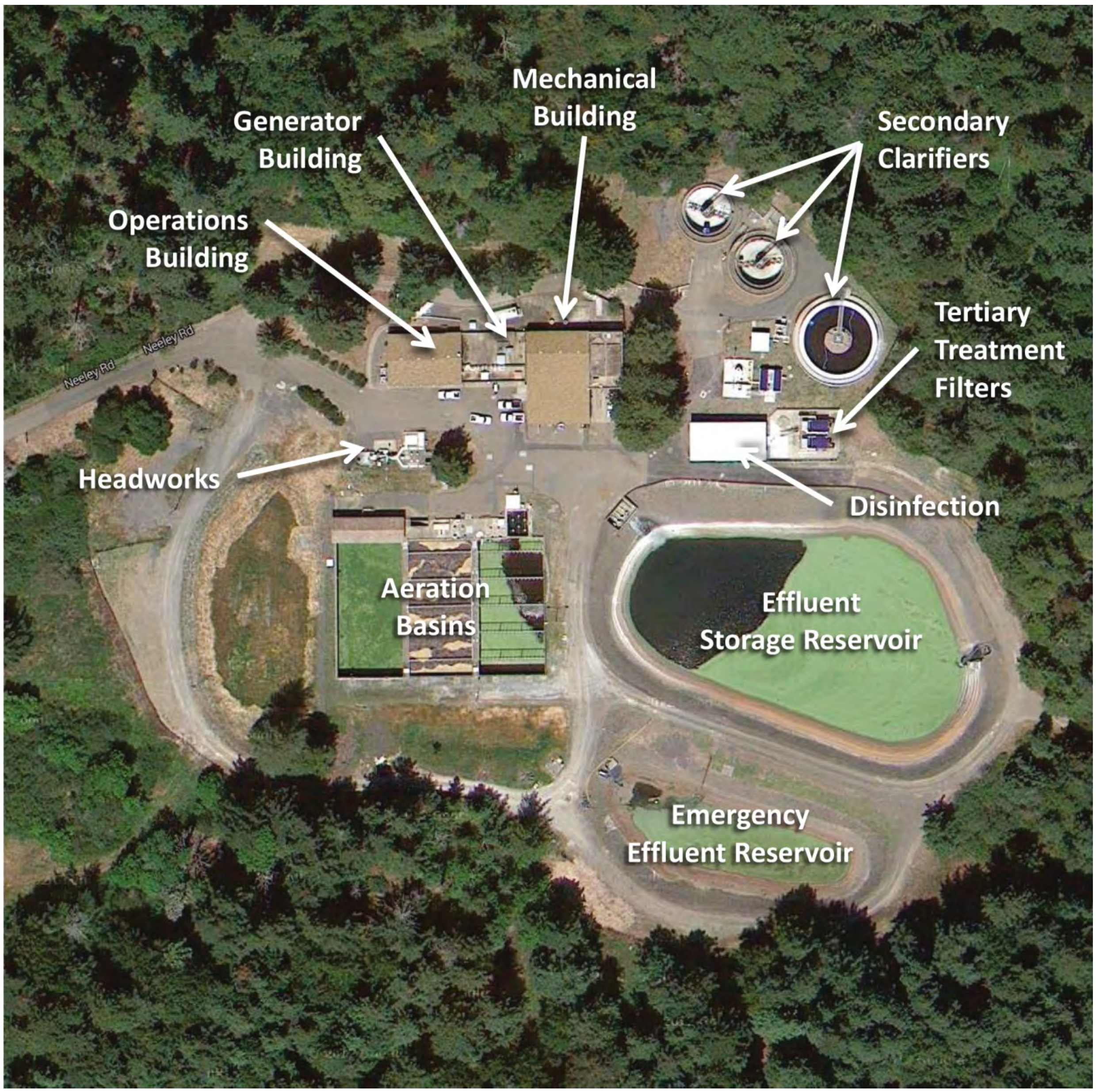


Figure 3: Russian River CSD WWTP, Aerial View

3. Geologic and Seismic Hazard

3.1 General Background

In order to provide an assessment of the geologic and seismic hazards for the Russian River County Sanitation District (RRCSD) for system-wide vulnerability identification, several resources were utilized in the study. The scope included a review of available published geologic and seismic literature and maps, review of selected unpublished consultant reports, review of aerial photographs (particularly Google Earth images) and a geologic reconnaissance along the entire system. The literature review provided the basis for a region-wide, broad-scale assessment of potential geologic and seismic hazards and the geologic reconnaissance provided location-specific identification of existing and/or potential geologic hazards along the collection pipeline system and the Wastewater Treatment Plant (WWTP). This study did not include any subsurface exploration, sampling, laboratory testing or quantitative analysis of hazards.

3.1.1 Regional Geology

The site is located within the Coast Range Geomorphic Province of Northern California. This province is generally characterized by northwest-trending mountain ranges and intervening valleys, which are a reflection of the dominant northwest structural trend of the bedrock in the region. The basement rock in the northern portion of this province consists of the Great Valley Sequence, a Jurassic (200 to 145 million years old) volcanic ophiolite sequence with associated Jurassic to Cretaceous (200 to 65 million years old) sedimentary rocks and the Franciscan Complex, a subduction complex of diverse groups of igneous, sedimentary and metamorphic rocks of late Jurassic to early Tertiary age (161 to 34 million years old). The Great Valley Sequence was tectonically juxtaposed with the Franciscan Complex most likely during subduction accretion of the Franciscan and these ancient fault boundaries are truncated by a modern right-lateral fault system that includes the San Andreas, Hayward-Rodgers Creek and Maacama faults. The San Andreas Fault defines the westernmost boundary of the local bedrock and is located approximately 10 miles southwest of the RRCSD. In the site vicinity, the Franciscan Complex is overlain by Tertiary age continental and marine sedimentary and volcanic rocks. These Tertiary age rocks are locally overlain by younger Quaternary alluvial, colluvial and landslide deposits.

3.1.2 Local Geology

The local geology has been mapped by Huffman and Armstrong (1980) and Blake, et al. (2002). These references generally agree that the majority of the site and vicinity is underlain by bedrock of the Jurassic-Cretaceous age Franciscan Complex. The northeastern portion and the southernmost end of the system are underlain by Franciscan Coastal Belt sandstone. The southwestern part of the system is shown to be underlain by Franciscan Central Belt graywacke sandstone and mélange. Mélange typically consists of resistant blocks of variable lithology within a highly sheared argillite or shale matrix. The central, north-central and location adjacent to the Russian River are underlain by Pleistocene and Holocene alluvium. That part of the Blake, et al. (2002) map that includes the site is presented in Figures RR-2 through RR-5. In addition, landslide deposits have been mapped on many of the slopes in the project vicinity. Most of the elevated portions of the system have been designated by Huffman and Armstrong (1980) as having a high susceptibility to landsliding.

The alluvial deposits in the vicinity have been further separated into distinct Quaternary deposit designations by Knudson, et al. (2000). That portion of the Knudson, et al. (2000) map that includes the site is presented in Figures RR-6 through RR- 9.

3.2 Earthquake Hazards

There are five primary hazards induced by earthquakes:

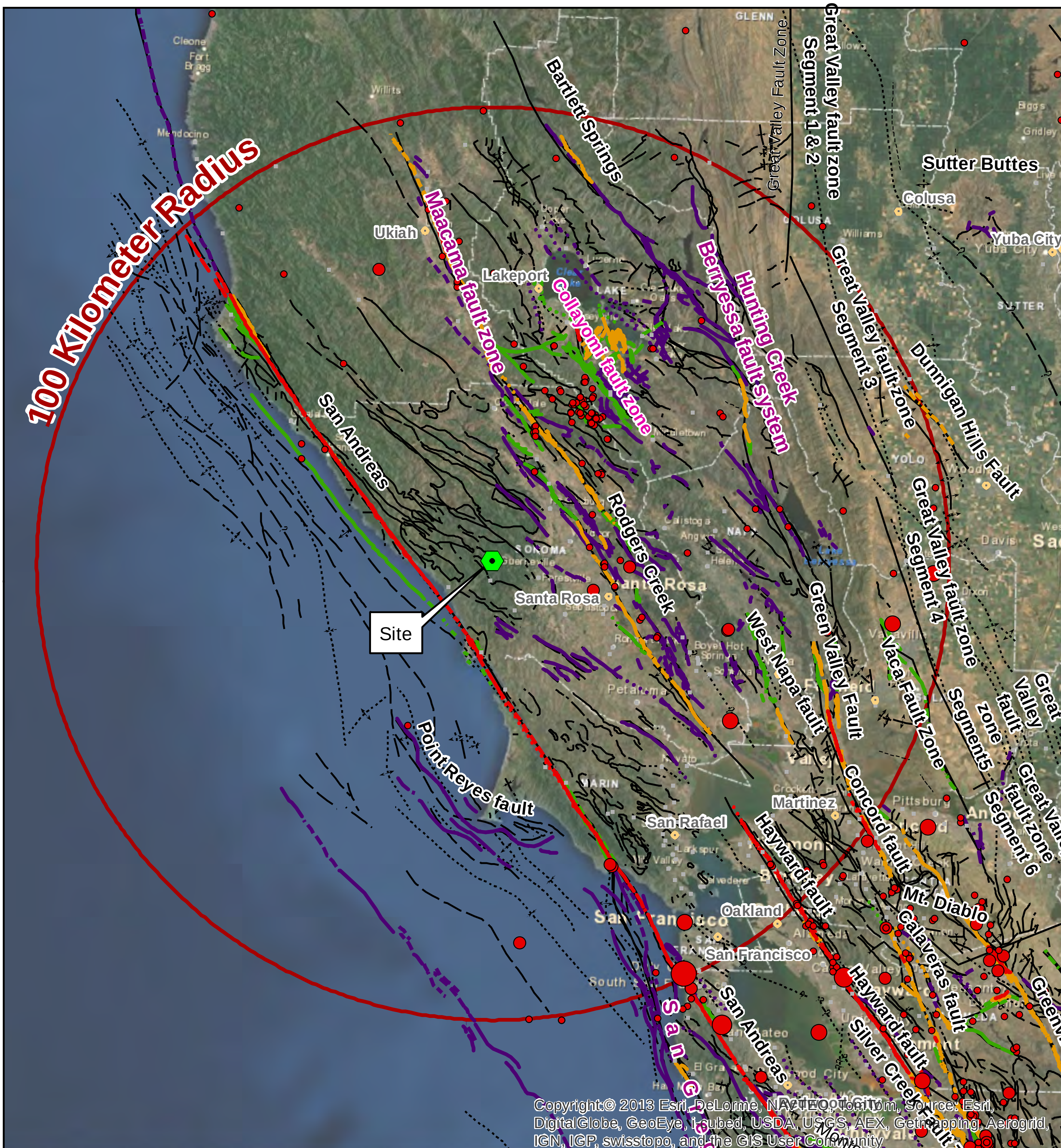
- Ground Shaking
- Liquefaction
- Creek Hazards
- Landslide
- Surface Faulting

To varying extents, the RRCSD wastewater system is exposed to four of these five hazards (ground shaking, liquefaction, creek hazards, and landslides). For purposes of the current work, the approach to quantify these hazards was as follows:

- Ground shaking. Section 3.2.2 describes how ground motion shaking will affect the wastewater treatment plant, pump stations and collection pipelines. For WWTP facilities and buildings, the ground shaking hazards are best quantified in terms of Peak Ground Acceleration (PGA) with accompanying response spectral shape. PGA is reported as a percentage, or decimal, of gravity (g). For the buried pipe network, the ground shaking hazard is best quantified in terms of Peak Ground Velocity (PGV).
- Liquefaction. Section 3.2.3 describes how the strength and stiffness of soils are reduced by earthquake shaking, and how that affects the RRCSD collection system and WWTP facilities, in terms of liquefaction and lateral spreading. Areas at risk of liquefaction were determined from liquefaction susceptibility maps.
- Creek Hazards. Section 3.2.4 describes how sewer mains and service laterals at creek crossings can be damaged during earthquakes. Locations of main creek crossings were provided for analysis.
- Landslides. Section 3.2.5 describes the landslide hazard and quantifies how it is treated within context of this report.
- Surface Faulting. Discussed in Section 3.2.6, the likelihood of surface rupture occurring within the RRCSD is very low. As of 2014, there are no known active faults that traverse the RRCSD.

3.2.1 Seismology

Based on its record of historic earthquakes and its position astride the North American - Pacific plate boundary, the San Francisco Bay region, within which the RRCSD is located, is considered to be one of the more seismically active regions of the world. During the historical period (approximately 170 years), faults within the region have produced 14 moderate to large magnitude ($M > 6$) earthquakes affecting the Bay Area, as well as many significant smaller magnitude ($5 < M < 6$) earthquakes (ref. Toppazada et al 1979, Toppazada et al 1981 and Real et al 1978.) Faults within the 100 km (62-mile) wide North American - Pacific plate boundary zone that may influence potential earthquake ground shaking and other earthquake-related hazards within the RRCSD area are illustrated in Figure 4.



Quaternary Faults (Bryant, 2005; USGS, 2009)

Historic displacement (< 200 years)
- Mapped Fault Location
- Dashed were Approximated
- Concealed

Holocene displacement (< 11,000 years)
- Mapped Fault Location
- Dashed were Approximated
- Concealed

Late Quaternary displacement (< 750,000 years)
- Mapped Fault Location
- Dashed were Approximated
- Concealed

Quaternary displacement (< 1,600,000 years)
- Mapped Fault Location
- Dashed were Approximated
- Concealed

Pre-Quaternary Geologic Structures (CGS, 2000)
- fault, approx. located
- fault, approx. located, queried
- fault, certain
- fault, concealed
- fault, concealed, queried
- fault, inferred, queried

ANSS Earthquakes Magnitude
- 4.0 - 4.9
- 5.0 - 5.9
- 6.0 - 6.9
- 7.0 - 7.9
- 8.0 - 8.9

Paper Size 8.5" x 11" (ANSI A)
0 50,000 100,000
Feet
Map Projection: Lambert Conformal Conic
Horizontal Datum: Clarke 1866
Grid: Clarke 1866 Lambert Conformal Conic

N

GHD

G&E Engineering Systems, Inc.

KLEINFELDER

Sonoma County Water Agency
Natural Hazard Reliability Assessment

Russian River CSD - Regional Fault and Earthquake Epicenters

Job Number	8410200
Revision	1
Date	08 Oct 2014

Figure 4

2235 Mercury Way Suite 150 Santa Rosa CA 95407 USA T 707 523 1010 F 707 527 8679 E santarosa@ghd.com W www.ghd.com

N:\US\Santa Rosa\Projects\02243 - SCWA\02243-8410200 - Russian River CSD\08-GIS\Maps\Figures\Figure 4 Fault and Earthquake.mxd

Data source: Kleinfelder, Fault and Earthquake, 2013. Created by:afisher2

3.2.2 Ground Shaking Hazard

Among the historically active regional faults, those anticipated to have potential significance to the performance of the RRCSD wastewater facilities include the following:

- San Andreas Fault
- Rodgers Creek - Healdsburg Fault
- Maacama Fault
- Hayward Fault

Brief discussions of each of these sources are presented in the following paragraphs. Unless otherwise noted, magnitude (M) refers to moment magnitude.

San Andreas Fault. The San Andreas Fault, which extends over 750 miles from the Gulf of California to Cape Mendocino, is the major fault within the region and has generated four moderate to large earthquakes during the historical period (approximately 170 years): a M 7 event in June 1838, a M 6.3 event in October 1965, the great M 8 earthquake in April 1906, and the recent M 6.9 Loma Prieta earthquake on October 17, 1989. The Southern Santa Cruz Mountains segment of the San Andreas fault, on which the Loma Prieta earthquake is thought to have occurred, is situated about 62 miles south of the RRCSD. The Working Group on California Earthquake Probabilities (Working Group 2003) has estimated that during the 30 year time period between 1990 and 2020, there is a 23 percent probability of a M 7 or larger earthquake occurring on the San Francisco Peninsula segment of the San Andreas fault, which extends northward from the Loma Prieta rupture segment, and a less than 5 percent probability of a M 8 earthquake along the north coast segments of the fault. More recent work (Working Group 2008) by the U.S. Geological Survey (USGS) has confirmed that these probabilities are still considered suitable. The maximum earthquake for the San Andreas Fault is judged to be in the range of M 7.75 to M 8 (moment magnitude); recent work (Niemi and Hall, 1992) indicates that on the average, an event of such magnitude can be expected to occur approximately every 200 to 300 years.

There are no traces of the San Andreas Fault that traverse or bisect any of the RRCSD pipelines. The north coast segment of the San Andreas fault is located about 10 miles southwest of Guerneville.

This report assumes an M 8 event on the north coast segment of the San Andreas Fault is the controlling event for the purposes of planning.

Rodgers Creek - Healdsburg Fault. The Rodgers Creek – Healdsburg Fault is a major component of the San Andreas Fault system in the Bay Area and extends from San Pablo Bay in the south to about Santa Rosa in the north. The fault extends to the Healdsburg fault in the north. It is well-defined locally by numerous sag ponds and linear trends in the topography. The Rodgers Creek – Healdsburg Fault is interrupted in places by landslide topography and may consist of a zone of en echelon faults. The fault runs through the hills immediately west of the City of Sonoma. The fault is considered capable of M 7 events, and if the fault breaks at the same time as the Hayward fault to the south (considered less likely), as high as M 7.2 to M 7.4 earthquake can occur.

There are no traces of the Rodgers Creek - Healdsburg fault that are known to traverse or bisect any of the RRCSD pipelines or the RRCSD WWTP. The fault is located east of the RRCSD, about 11 miles from the RRCSD WWTP. Any earthquake on the Rodgers Creek – Healdsburg Fault with M 6.25 or larger is likely to produce surface rupture in Sonoma County. While it would create surface rupture in Sonoma County it would not in the RRCSD. Overall, surface faulting hazard in the RRCSD system is not likely from any earthquake on the Rodgers Creek – Healdsburg Fault.

The Working Group on California Earthquake Probabilities (Working Group 2014) has estimated that during a 30 year time period following 2014, there is a 32 percent probability of a M 6.7 or larger earthquake occurring along the Rodgers Creek Healdsburg Fault. For preliminary planning purposes, a Rodgers Creek M 7 might be assumed to occur within the next 100 to 300 years. Even higher magnitude events are considered possible, especially if the Rodgers Creek - Healdsburg and Hayward faults break in the same event, although the return period for such events is likely in excess of 1,000 years. For the RRCSD, the Rodgers Creek – Healdsburg fault is not controlling; a larger magnitude event on the closer San Andreas Fault is likely the controlling event.

Maacama Fault. This fault extends from near Laytonville in Mendocino County to near Mark West Creek in Sonoma County. It has been interpreted as a right stepping extension of the Rodgers Creek - Healdsburg Fault. Fault creep has been measured near Ukiah and Willits at about 5.6 to 7.6 mm per year. The most recent event is prehistoric and occurred between 1520 AD and 1650 AD. Trenches suggest a long term slip rate of between 11 and 14 mm per year.

The southern section of the fault that is closest to the RRCSD, is about 33 miles long, and could produce M 7 earthquakes. If the Maacama Fault breaks along both its southern, central and northern segments, magnitude could be M 7.7.

There are no traces of the Maacama Creek Fault that are known to traverse or bisect any of the RRCSD pipelines. The fault is located east of the RRCSD, about 15 miles from the RRCSD WWTP.

For planning purposes for the RRCSD, an M 7.7 event on the Maacama fault would represent the maximum credible earthquake from that fault. No specific return period has been provided for earthquakes on the Maacama fault system. Earthquakes on the Maacama fault system will not be as severe for the RRCSD as compared to an M 8 or larger event on the San Andreas Fault. The seismic hazard in Table 2 includes contribution from the Maacama Fault.

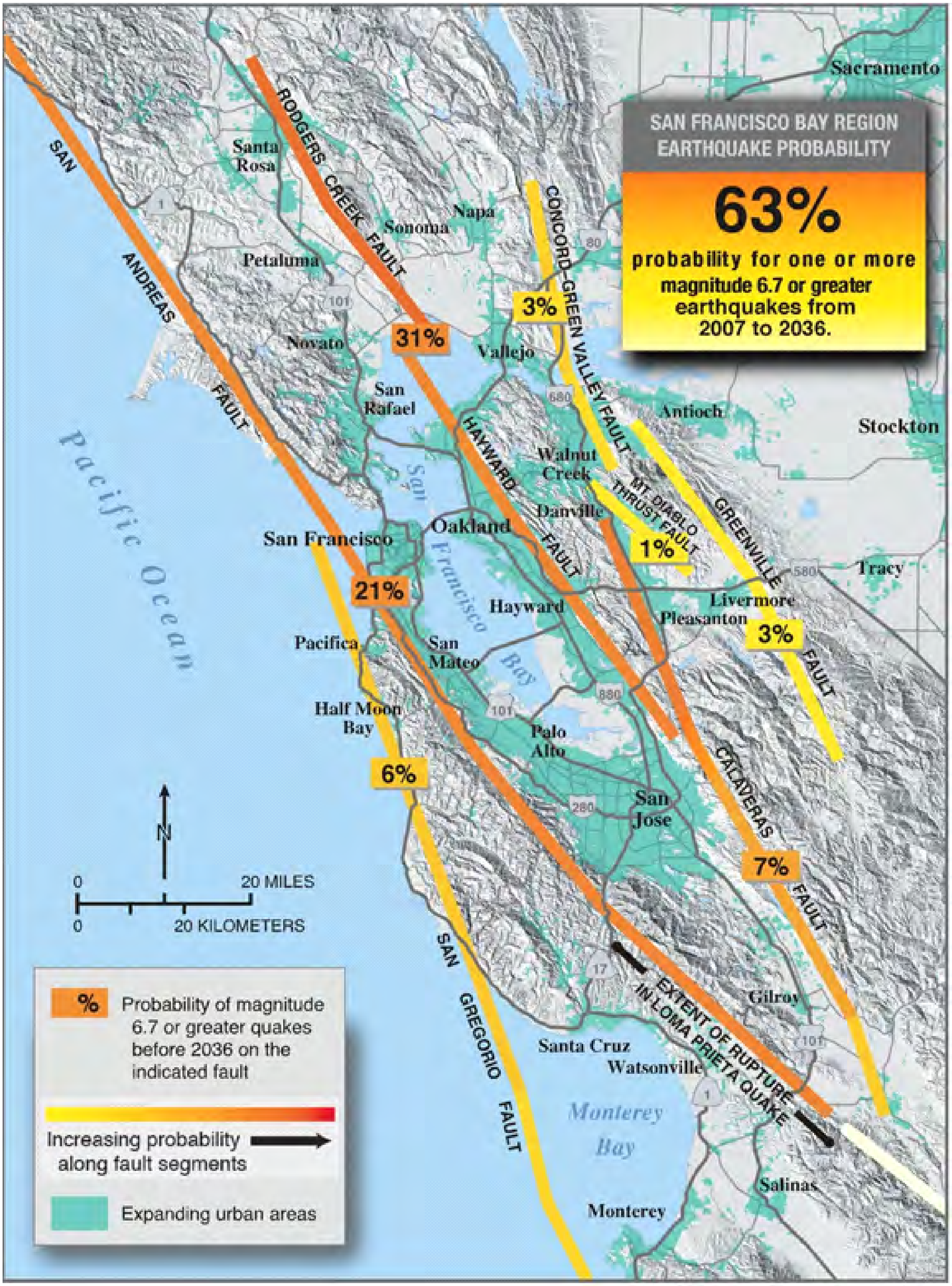
Hayward Fault. The Hayward Fault is situated about 44 miles to the southeast of the RRCSD WWTP. The Hayward Fault is a major component of the San Andreas fault system in the Bay Area and extends approximately 71 miles from its intersection with the Calaveras fault southeast of San Jose, northward through and along the East Bay hills, to San Pablo Bay. It has been suggested on the basis of micro-seismicity data that the Hayward Fault may connect with the Rodgers Creek-Healdsburg Fault beneath San Pablo Bay (Ellsworth et al, 1982), although such a connection requires an en echelon jump between the faults. It is commonly postulated that there are two potential rupture segments for the Hayward Fault, a southern segment extending from Warm Springs (Fremont) to the San Leandro-Mills College area (or perhaps as far north as northern Oakland), and a northern segment extending from the this transition point to San Pablo Bay. The southern segment has been the source of a large (M 6.8) earthquake during the historical period (October 1868). The Working Group (2008) has estimated that during the 30 year time period from 2006 to 2036, there is a 31 percent probability of a M 6.7 (or larger) earthquake occurring on the Hayward fault. The maximum earthquake for the Hayward Fault is judged to be in the range of M 7 to M 7.25; the average recurrence of such events is estimated to be approximately 150 to 250 years.

Other Potentially Active Faults. There are a number of potentially active faults that are as close to Guerneville as the San Andreas, Rodgers Creek or Maacama faults. The activity rates for these faults are relatively low, with the last large rupture over M 5, thought to be between 11,000 and 1,600,000 years ago. Generally (except for the reclamation pond), there is no requirement to design any part of the RRCSD collection system, nor the WWTP, for such rare earthquake events. The reclamation pond is under the jurisdiction of the California Division of Safety of Dams (DSOD). DSOD makes periodic inspections and completed an inspection and report in 2013.

For completeness, some of the known mapped faults are listed below:

- Joy Woods. About 6 miles south of the WWTP. Could produce M 5 to M 6 events.
- Bloomfield. About 9 miles south - southeast of the WWTP. Could produce M 5 to M 6.5 events.
- Americano. About 16 miles south - southeast of the WWTP. Could produce M 5 to M 6.5 events.
- Tolay. About 19 miles southeast of the WWTP. Could produce M 5 to M 6.5 events.
- Point Reyes. Under the Pacific Ocean, about 19 miles southwest of the WWTP. Could produce M 5 to M 7.5 events.
- Alexander. About 15 miles northeast of the WWTP. Could produce M 5 to M 6.8 events.
- Unnamed. Several unnamed faults, about 5 to 7 miles northeast of the WWTP. Could produce M 5 to M 6.5 events.

Figure 5 shows a map of the major faults in the San Francisco Bay area with associated probabilities of occurrence by the year 2036 (Working Group, 2008).



Paper Size 8.5" x 11" (ANSI A)

Map Projection: Lambert Conformal Conic
Horizontal Datum: Clarke 1866
Grid: Clarke 1866 Lambert Conformal Conic

N

G&E Engineering Systems, Inc.

KLEINFELDER

Sonoma County Water Agency
Natural Hazard Reliability Assessment

Russian River CSD
Earthquake Probabilities

Job Number	8410200
Revision	0
Date	10 Feb 2014

Figure 5

2235 Mercury Way Suite 150 Santa Rosa CA 95407 USA **T** 707 523 1010 **F** 707 527 8679 **E** santarosa@ghd.com **W** www.ghd.com

N:\US\Santa Rosa\Projects\02243 - SCWA\02243-8410200 - Russian River CSD\08-GIS\Maps\Figures\Figure 5 Earthquake Probabilities.mxd

Data source: Kleinfelder, Fault and Earthquake, 2013. Created by:afisher2

The common seismic design philosophy for earthquakes at the time when many of the RRCSD wastewater system facilities were built (mid-1980s) was to design for a base shear value (V) that is 18% of the effective seismic weight (W) (V = 0.18W), implying a design for reasonable structural performance for reasonably well detailed buildings for ground motions of about PGA = 0.30g. The average shear wave velocity (V or Vs) is reported in meters per second (m/sec) at the top 30 meters of soil at a specific site. Common design codes (such as the 1976 UBC code, which was the original design basis for the WWTP) require design of new buildings to the 475-year motions. The most recent code for buildings (the IBC 2012) specifies that new buildings should be designed for 2/3 of the 2,475 year motion.

The potential level of ground shaking is evaluated in several ways. First, a probabilistic design motion is assumed, using common code-type assumptions, with return periods of 475, 975 or 2,475 years. Most RRCSD facilities are on soils, ranging from thin layers of firm soil to medium-deep layers of relatively softer soils.

Table 2 provides the PGA values for three return periods, following the USGS 2002 National seismic hazard model.

Table 2: Probabilistic Ground Motions (Horizontal PGA, NEHRP Class B, in g)

Facility Name	PGA 475 Years	PGA 975 Years	PGA 2475 Years
Russian River WWTP	0.42	0.53	0.67

The numeric values in Table 2 are based on pre-2000 ground motion prediction equations, and ignore the factors of soil, basin effects, and directivity. All these factors can be locally important at the WWTP, and elsewhere in the RRCSD service area.

Another approach to establish the ground motions is to presume occurrence of a specific earthquake, and then select a suitable non-exceedance level. For the RRCSD, the governing scenario earthquake is a magnitude M 8 event on the nearby San Andreas Fault, North Coast segment. The San Andreas Fault produces earthquakes that are strike slip, right lateral.

Most of the RRCSD sites can be characterized as having local soil conditions bounded as having Vs30 = 450 m/sec (stiffer soil sites) or 250 m/sec (softer soil sites). Tables 3 through 6 give the median expected horizontal ground motion (median of two horizontal directions). Considering the orientation and natural period of the RRCSD facility (buried pipe, buildings, tanks, water basins, etc.), the effectiveness of directivity should be considered.

In Tables 3 through 6, the PGA and PGV values are reported using five different ground motion models (ASK13, I13, CY13, CB13 and BSSA13). The I13 model is not suitable for softer soil sites and therefore not used in Tables 5 and 6.

For purposes of evaluating system-wide performance, the average of the relevant ground motion prediction models (right most columns) is used. As shown, the average PGA = 0.34g value for Vs30 = 450 m/sec is based on median motion for a M 8 event on the San Andreas Fault (Table 3). The PGA = 0.59g value is based on the 85th percentile motion for an M 8 event on the San Andreas Fault (Table 4). These PGA values were used for the vulnerability assessment for the RRCSD infrastructure in Chapter 7.

Table 3: Deterministic Motions, Median, Vs30 = 450 m/sec, Median

Seismic Parameter	ASK13	I13	CY13	CB13	BSSA13	Average
PGA (g)	0.24	0.52	0.34	0.28	0.31	**0.34**
PGV (cm/sec)	37.76	53.39	57.25	45.85	42.80	**47.41**

Table 4: Deterministic Motions, Median, Vs30 = 450 m/sec, 84th

Seismic Parameter	ASK13	I13	CY13	CB13	BSSA13	Average
PGA (g)	0.44	0.97	0.48	0.47	0.57	**0.59**
PGV (cm/sec)	71.33	110.80	94.90	81.59	82.10	**88.14**

Table 5: Deterministic Motions, Median, Vs30 = 250 m/sec, Median

Seismic Parameter	ASK13	CY13	CB13	BSSA13	Average
PGA (g)	0.25	0.36	0.26	0.31	**0.30**
PGV (cm/sec)	54.89	91.37	54.85	52.83	**63.48**

Table 6: Deterministic Motions, Median, Vs30 = 250 m/sec, 84th

Seismic Parameter	ASK13	CY13	CB13	BSSA13	Average
PGA (g)	0.42	0.47	0.41	0.55	**0.46**
PGV (cm/sec)	102.92	69.51	93.84	97.75	**91.01**

To evaluate the existing system for emergency planning purposes, it is recommended to use the median values reported in Tables 3 and 5. Lacking site-specific conditions, it would be reasonable to assume Vs30 = 250 m/sec at locations where pipes are in alluvial materials near the Russian River, or cross creeks.

For design of non-redundant new pipes, it is recommended to use the 84th percentile motions as listed in Table 4 or Table 6.

For design of new buildings and pump stations that should remain functional after a large earthquake (once power is restored), it is recommended to use the 84th percentile motions, coupled with limiting "response modification coefficients" in common codes to no more than 3 for ductile structures; or 1 for brittle structures (unreinforced masonry, segmented precast vaults).

Lacking site-specific subsurface date, it is recommended to use Vs30 = 250 m/sec values for pipes at creek crossings and suspected deeper soil sites, and the Vs30 = 450 m/sec values at all other sites.

For design of future new buried pipelines, in cases where there is no site-specific geotechnical / geologic investigations, and at locations where there is low to moderate liquefaction potential (see Section 3.2.3), it is recommended that the pipes 10" diameter and smaller be designed for PGV = 64 cm/sec for ground shaking; and pipes 12" diameter and larger be designed for PGV = 91 cm/sec. For sites with high to very high liquefaction potential, and at locations near open cuts / creeks, the pipes should be designed for the effects of liquefaction, including imposed permanent ground displacements (PGDs). PGDs are a substantial source of damage to wastewater facilities, and types of PGDs include fault rupture, settlement, and liquefaction-induced lateral spreading or landslide deformations, which are discussed in the following sections of this chapter.

Considering that the RRCSD system is located more than 6 miles of active faults, the following approximation is used for consideration of vertical ground motions. The vertical response spectrum may be taken as equal to the horizontal spectrum for periods less than 1 second, or ½ the horizontal spectrum for periods greater than 2 seconds, and linearly interpolated for intermediate periods. Alternately, the vertical spectrum can be calculated using suitable vertical attenuation models. Alternatively, the vertical spectrum can be assumed to be 2/3 of the horizontal spectrum.

3.2.3 Liquefaction Hazards

Liquefaction describes a condition in which saturated soil loses shear strength and deforms as a result of increased pore water pressure induced by strong ground shaking during an earthquake. Dissipation of the excess pore water pressures will produce volume changes within the liquefied soil layer, which causes settlement. Factors known to influence liquefaction include soil type, structure, grain size, relative density, confining pressure, depth to groundwater and the intensity and duration of ground shaking. Soils most susceptible to liquefaction are saturated, loose sandy soils, and low plasticity clays and silts. If liquefaction occurs, pipelines above the liquefiable layers may undergo settlement. Within liquefiable soils, a pipeline can become buoyant or lose support and settle if it is not buoyant. The degree of buoyancy or settlement will be affected by the fines content of the soil. More fines generally result in less susceptibility to buoyancy and settlement due to the residual soil strength that may be present.

Lateral spreading is a term describing the permanent deformation of sloping ground that occurs during earthquake shaking as a result of soil liquefaction. Depending on depth to liquefiable layers and slope geometry (free-face gradient and height) deformations can range from millimeters to several meters, with the greatest displacements usually occurring near free-faces, such as creek banks. Therefore, structures and pipelines adjacent to bodies of water are usually at the greatest risk of experiencing damage due to lateral spreading.

3.2.3.1 Liquefaction Information from Previous Geotechnical Reports

The available geotechnical reports prepared for SCWA by others were reviewed and the following summarizes some of the pertinent information.

- Giblin Associates (1997a) prepared a geotechnical investigation as part of the waste disposal expansion project. The sites that were investigated are adjacent to the WWTP at 18400 Neeley Road, Guerneville. The sites are located at elevations of about 700 feet, or about 400 feet higher than the WWTP. Giblin noted that landsliding had been observed in a portion of the study area. Debris flow chutes were noted. The purpose of the study was to examine the hillside locations for possible treated wastewater disposal. No discussion is made of the geotechnical hazards and conditions within or immediately adjacent to the WWTP site.
- Giblin (1997b) examined the soils for a proposed equalization pond and aeration facility (31-acre-feet) at the WWTP, located immediately to the west of the existing WWTP aeration basins (within the area mapped red (very high) in Figure RR-11. The aeration facility was to include a one-story reinforced masonry block building with concrete slab-on-grade. The pond was to have embankment fills to about 20 feet high on the downhill side, with cuts on the uphill side. The pond was to be lined with concrete, gunite or similar hard-shell surfacing. Six borings were advanced. In the top 15 feet, one boring shows loose, wet sandy clayey gravel, with 6 blows per foot; another boring shows soft, wet brown sandy clay with abundant

organics; one boring shows wet, medium dense sandy clayey gravel. Giblin noted that liquefaction could occur in this area.

- EBA (2002) advanced 10 borings at the WWTP to perform testing of the soils, looking for soil contaminants potentially associated with the originally-installed buried diesel fuel tank. EBA reports the site is underlain at depth by the Franciscan complex (confirmed by Giblin borings). EBA reports that there are gravelly silty sands to depths of 18 to 25 feet at the site, with clays beneath that; the soils are alluvial deposits; the lithology of the site includes several discontinuous layers (generally consistent with Giblin observations, although there may also be colluvial deposits).
- Giblin (2002) considered the earthquake hazards at the RRCSD WWTP as part of the Aeration Basin 3 and Clarifier 3 upgrade project (2002). Giblin noted the following:
  - Clarifier 1, 2 and part of 3 are located at the base of a hill, at the confluence of two south-flowing ravines. These ravines had previously produced debris flows affecting the clarifier and aeration basin areas.
  - Clarifier 3 area is underlain by sandy silts and clays and clayey sands with gravels, overlying highly weathered and sheared rocks of the Franciscan Complex. Soils show cobbles, indicating past debris flows.
  - Aeration Basin 3 area is underlain by sandy clays and gravels, clayey sands and gravels and sandy clays. Native soils below existing fills consist of medium dense clayey sands and soft to medium stiff sandy clays, with gravel, to depths of 18 to 29 feet. These are underlain by very stiff to hard sandy clay alluvial soils with high strength. Groundwater was observed at 13-14 feet below grade.

The above reports suggest that the WWTP site likely has a high ground water table (within about 10 feet of the surface, but can vary quite a bit seasonally), there may be old logging debris locally under undeveloped parts of the site (including roadways). A 2007 Supplemental Report, by Giblin (2007), and a 2011 Geologic Technical Memorandum, by Cotton, Shires & Associates (2011), have also been completed for a proposed equalization basin. These reports further discuss liquefaction, landslide, and debris flow potential at the WWTP.

3.2.3.2 Liquefaction Areas

The majority of the RRCSD system is located within young (Holocene) alluvial deposits that have been categorized as having a high liquefaction potential. A few localized segments within the collection system also cross into areas considered to have very high liquefaction susceptibility. It should also be noted that the majority of the WWTP is underlain by young alluvium that is considered to have very high liquefaction susceptibility.

Areas that are categorized as having high or very high liquefaction susceptibility and that are located adjacent to creek banks should also be considered to have a high susceptibility for lateral spreading. Because lateral spreading is dependent on the liquefaction susceptibility as well as the distance from, and the height of a particular creek bank, it is not possible to determine how far away from the creek banks the effects of lateral spreading may occur. For preliminary vulnerability assessment, it is or opinion that collection segments/improvements within 200 feet of creek banks with high or very high liquefaction susceptibility (and underlain by such deposits), should be considered to have a high lateral spread susceptibility as well.

There is also an increased vulnerability for pipeline segments that cross boundaries of geologic deposits/materials that have drastically different liquefaction susceptibilities. This is mainly due to the differential movements that would occur in each of these deposits, relative to the other deposits. As such, segments that cross from very low susceptibility zones into very high susceptibility zones would have the greatest risk for differential settlement due to liquefaction, and hence potential for pipeline/improvement damage or rupture.

Youd (1978) reports that there was liquefaction and lateral spread near Duncan's Mills in the 1906 San Andreas earthquake; extensive ground cracking and sand boils occurred 200 to 250 feet back from the river. This site is about 4 miles downstream of the Russian River from the WWTP. This brings into question whether the mapped liquefaction zones in the RRCSD are similarly prone to liquefaction and lateral spreads.

Knudson, et al. (2000) have produced liquefaction susceptibility maps that include the RRCSD system locations. The liquefaction susceptibility maps are presented in Figures RR-10 through RR-13 with an overlay of the RRCSD pipeline system. Areas in red have "Very High" liquefaction susceptibility; orange have "High"; yellow have "Moderate", and white have "Very low (none) – not mapped". The maps show that the "High" and "Very High" zones are concentrated next to active creeks, including the Russian River and its tributaries. From a pipeline point of view, the main issues will be:

- Pipes in the red (Very High) and orange (High) zones. These zones can liquefy locally when PGA > 0.15g, or liquefy over major areas when PGA > 0.5g.
- Non-seismically-designed pipes in the liquefied zones that are located within 200 feet of an open cut / slope, where lateral spreads occur, will suffer great amounts of damage.
- Pipes in the white zones are generally not susceptible to liquefaction-caused damage.
- Pipes in the yellow zones might be locally susceptible to ground settlements under very strong ground shaking (PGA > 0.3g), but damage will be sporadic.
- Pipes in white areas might be susceptible to landslides

Based on the available information, it is estimated that possibly 10% to 20% of the overall WWTP site is liquefiable for PGA > 0.2g. The slope of the site would allow a lateral spread should liquefaction occur. The discontinuous nature of the soils suggests that lateral spreads that mobilize a large part of the site are unlikely. Debris flows from the hillside to the north are likely to occur in the future, posing threat to people and to facilities; the debris flows can be triggered by intense rainfall, or by earthquakes.

3.2.4 Creek Hazards

As previously described, the creeks pose hazards to the collection pipes, both because creeks have propensity to have softer soils and soils prone to liquefaction, as well as the consequences should the pipe fail (i.e., release of raw sewage into a sensitive environment). Figures RR-14 through RR-17 can be used to locate the areas where segments of the sewer cross a creek. As shown in the figures, there are numerous creek crossings within the RRCSD collection system that pose potential hazards.

Geologic reconnaissance along the RRCSD collection system has identified location-specific geologic hazards, other than more regional seismic-related liquefaction hazards. Such hazards include areas of static or seismically-induced landsliding (i.e. existing or imminent landslides), creek bank failures, slope creep hazards, and erosion or drainage flow debris impact hazards. Nine location-specific areas have been identified and are in Figures RR-2 through RR-5. Generally the geologic hazards identified include areas where:

1. Creek bank failures were observed where static and embankment failure (landslide) potential exists with possible damage to mains, manholes and laterals.
2. Sewer mains constructed beneath drainage channels in multiple locations and the burial depth is assumed shallow exposing the pipeline to damage due to erosion or debris impact during periods of rapid stream flow.
3. Sewer mains that extend through culverts, bridge abutments or are located near thalweg of creeks have potential for debris build-up during high creek flows, and there can be damage to the main.

3.2.5 Landslide Hazards

The landscape in the RRCSD is characterized by steep ridges and canyons, as evidenced by the topography of the area shown in Figure 2. Local drainage is mostly into the Russian River. The service area receives much greater rainfall than eastern parts of Sonoma County.

Landslide movements in and near the hillside portions of the RRCSD wastewater system have been reported in the past and have been identified generally and as described above from the geologic reconnaissance of the system.

Active landsliding located along the north edge of the treatment plant has previously inundated a portion of the plant improvements. The remaining landslide mass is contained by concrete rails (k-rail) adjacent to the plant property line at the toe, but the feature extends upslope onto the private property north of the plant. Landslide potential is high on all slopes above plant. Southward-facing slopes have static and seismic landslide potential with potential impact to the plant facilities

3.2.5.1 Deep Seated Landslides

Landslides of most concern to the wastewater system are deep seated slides that cause rotation slumps of the top 5 to 30 feet of soils. These movements, also sometimes called lateral spreads, can result in inches to several feet of downslope movements of streets. Pipes in these streets will be highly stressed. Unless specifically designed for large lateral movements, most pipelines will break under lateral movements of more than a few inches.

3.2.5.2 Debris Flows

Debris flows can also damage RRCSD facilities, primarily by inundation of materials (such as at the WWTP). Debris flows can also impact non-RRCSD structures and roads, hampering RRCSD's response to an emergency. Debris flows in stream channels can also impact overhead pipes, and also result in scour that could impact buried pipes.

3.2.5.3 Avalanche / Rockfall

Avalanche / rockfall-type landslides are not likely a hazard to the RRCSD.

3.2.5.4 Earthquake Landslide Characteristics

Earthquakes can trigger landslides. This reflects that the inertia shaking will create additional lateral and vertical forces on the terrain.

Ultimately, the parameters of a deep-seated landslide of concern to the wastewater system are the amount and spatial extent of soil movement that includes the pipe.

For deep seated landslides, the amount of movement is generally correlated to the level of shaking, as well as the duration of shaking. Terrains on a stable slope generally have a safety factor greater than 1; a slope with a static safety factor of 1.5 is sufficiently safe against landsliding. Terrains that have a factor of safety greater than 1 also have higher loads on them during the time of ground shaking. Whenever ground shaking forces increase, the driving force of the soil block downhill is greater than the resisting friction, such that the factor of safety against a landslide decreases below 1, causing the soil block to move downhill for the duration of ground shaking. In most cases, once the inertial motion reverses itself (often multiple times per second), the sliding stops; however, landslides can be re-triggered if there are subsequent high levels of shaking.

For debris slides, once the material/ soil block starts to move with sufficient velocity, the movement is self-propagating until the slope flattens out. Debris flows that impact wastewater treatment facilities can pile up debris; with sufficient debris and/ or with sufficient velocity, the debris can damage above-grade facilities.

For rock falls, once the materials start to move, the materials will continue moving until the slope flattens out.

The prevalence of earthquake-triggered landslides will be highest when the underlying hillside soils are saturated. In the RRCSD service area, soils become saturated on an annual basis, once there has been sufficient winter rains. In a typical winter season, soils become saturated near the end of December, and remain so until April. For the current project, it was assumed that the scenario earthquake occurs when the soils are saturated, and hence there could be landslide movements.

Should landslide debris enter a creek (or the Russian River), the debris can form a dam, impounding water upstream. This impounded water can reach sufficient depths before breaking the dam, which causes a sudden release of water downstream. The sudden release of the water can be a life safety threat to all people caught in the release. Additionally, the release of water can destroy most above-grade wood structures and can cause rapid erosion that can undermine foundations and buried pipelines.

Regional scale landslide maps for Sonoma County include the map prepared by David Ramsey and Jonathan Godt (1999), which maps the landslides resulting from the 1997-1998 El Niño rainstorms. Rio Nido is located at the northern edge of the RRCSD service area. This community is in and along the margins of several steep canyons. In February 1999, a rotational and translational rock slump began to move high on a ridge above the town following heavy rains of early February. The frontal part of the slide slumped and liquefied, forming debris flows that crashed into homes along Upper Canyon Three Road. Three homes were destroyed and four more were severely damaged with damage to another 32 properties. The road and all underground and above-ground utilities were destroyed. The threat of further slippage of the main slide and resulting debris flow activity forced the evacuation of 140 homes downslope from the slide. The landslides in Sonoma County, from January – April 1999, caused about $21 million in losses in Sonoma County with most of this loss concentrated near Rio Nido Figure 6 shows the locations of mapped debris flows (red dots) from the winter of 1999 (Ramsey et al, 1999).

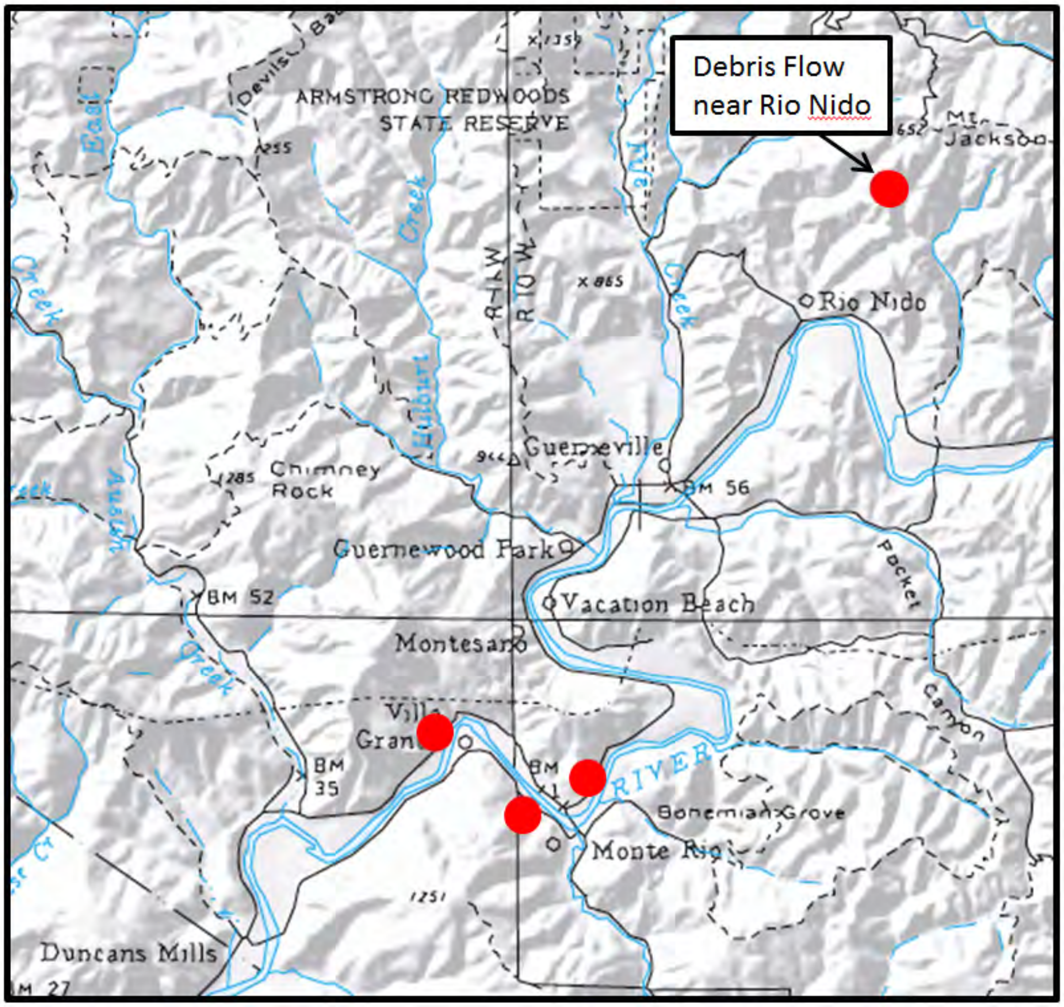


Figure 6: Mapped Debris Flows near RRCSD, adapted from Winter (1999)

According to Giblin (2002), a debris flow occurred at the WWTP in 1992 during periods of heavy rainfall, with debris deposited between Clarifier 1 and the Mechanical Building, extending to the effluent storage reservoir. A San Andreas earthquake that occurs during the winter time, with PGA > 0.3g and ground-saturated conditions, could trigger multiple debris flows.

No site specific geotechnical investigations or landslide mapping have been performed as part of this effort; such investigations can provide improved estimates of landslide susceptibilities and probabilities based on future seismic events at different magnitudes. This report does not map the landslide risk, although this should be done to support part any material future pipeline design effort. Regional maps (including Wills et al, 2011) should not be used for evaluating the potential of landslides at any specific pipeline or facility location in the RRCSD service area.

3.2.6 Surface Faulting Hazards

Surface faulting, also known as surface rupture, occurs if movement of an earthquake causes a crack to form from the fault line to the ground surface. Not all faults intersect Earth's surface, and most earthquakes do not cause a rupture to the surface. When a fault does intersect the surface, objects may be offset or the ground may become cracked, or raised, or lowered. Because there are no known active faults that traverse the RRCSD service area, there is a minimal chance of fault offset through any RRCSD pipeline or facility.

3.3 Ground Motions in Sonoma County in Past Earthquakes

Sonoma County has undergone a number of earthquake events over the recorded history of past 170 years. A summary of the issues experienced in Santa Rosa from these earthquakes are highlighted below (note that both the terms "intensity" and "magnitude M" were used to describe ground motions[*]). It should be recognized that the modern Russian River wastewater system was in only put in place after 1983.

- 1865 March 8, 6:00 a.m. Intensity VIII at Santa Rosa and upper Bennett Valley. Plaster cracked, clocks stopped, and chimneys fell.
- 1868 October 21, 7:53 a.m. The Hayward Earthquake. Maximum intensity X at Hayward. Surface breakage was observed on the Hayward fault from Warm Springs to San Leandro. The shock was perceptible over an area of roughly 100,000 square miles. At Santa Rosa, the earthquake was reported as the "severest shock yet felt." Nearly all brick buildings in town were damaged and many chimneys demolished.
- 1888 February 29, 2:50 p.m. Intensity VII at Petaluma, where walls cracked; VI at Santa Rosa, where the shock was violent and people reportedly ran out of houses.
- 1891 October 11, 10:28 p.m. Maximum intensity VIII to IX at Napa and at Sonoma, where people were shaken out of their beds, chimneys demolished, windows broken, and considerable damage to plaster occurred. At Santa Rosa, one observer reported the shock as the "severest in four years" (presumably a recollection of February 29, 1888); the oscillations lasted 45 seconds; slight trembling perceptible for 3 or 4 minutes.
- 1892 April 19, 2:50 a.m. Intensity IX to X at Vacaville, Dixon, and Winters. The Holden catalogue (1898) estimated the intensity was VII at Santa Rosa, where many windows were broken, some plaster was damaged, and "panic prevailed at hotels."
- 1892 April 21, 9:43 a.m. Large aftershock of the foregoing earthquake on April 19, 1892. Maximum intensity IX at Winters. At Santa Rosa (VII) many brick buildings were cracked, more plaster damage occurred, two brick walls slightly bulged out, iron columns shifted, and in some parts of town, chimneys were wrecked.
- 1893 August 9, 1:15 a.m. Sonoma County, VII to VIII at Santa Rosa, where this was said to have been the most severe shock since 1868. Chimneys fell and windows were broken. The plaster in the courthouse was extensively damaged.
- 1898 March 30, 11:43 p.m. The Mare Island Earthquake (intensity VIII). At Santa Rosa, the vibrations lasted fully one and three-quarters minutes. Heavy plate glass windows in many business houses were broken; throughout the city, plaster was shaken from walls and ceilings.
- 1899 October 12, 9:00 p.m. Maximum intensity VII to VIII at Santa Rosa, where plaster was knocked from walls and some chimneys fell.
- 1906 April 18, 5:12 a.m. Moment Magnitude 7.8. One of the greatest shocks on record in California; caused by movement of the San Andreas Fault from San Benito County to Humboldt County. Maximum fault offset was a 21-foot horizontal shift near the head of Tamales Bay. Extensive damage at San Francisco, Santa Rosa, San Jose, Sebastopol, and many other

[*] In reviewing the historical record of ground motions, the terms Intensity (MMI scale), Magnitude (Moment magnitude unless otherwise noted) and PGA (Peak Ground Acceleration) are used. Instrumentation to measure PGA was generally non-existent prior to about 1940. Intensity scales were commonly used for earthquakes pre-1960. Intensity is a measure of observed damage; PGA is a measured value of ground motion. It is not straightforward to assign PGA values to older earthquakes, as there is no precise conversion from PGA to MMI.

places. In the opinion of Townley and Allen, Santa Rosa, 20 miles from the San Andreas Fault, sustained more damage, in proportion to its size, than any other city in the state. The duration of strong ground shaking was about 45 to 60 seconds. This earthquake exposed the then small city of Santa Rosa water system to strong ground shaking. There was one fire ignition reported in Santa Rosa.

Mercalli Intensity X (intense ground shaking with some ground failure) was noted in Santa Rosa. Simulation models by the USGS for a repeat of the 1906 event show additional intensity in Santa Rosa than would otherwise be predicted using common attenuation models, owing to the basin and other effects.

- 1906 to 1968. Many smaller earthquakes felt in Santa Rosa, the strongest being in 1919, 1929, and 1956. With the possible exception of the earthquake at 2:39 p.m. on February 25, 1919 (intensity VI), none was as severe as the earlier shocks in this tabulation. Seismic activity of interest to the residents of Santa Rosa was clearly at a much lower level throughout the 62 years following the major shock of April 18, 1906, than it had been in the 41 years preceding that event.
- 1968 April 25, 11:49 a.m. Epicenter 36° 28'N, 122° 40'W. Magnitude 4.6. This earthquake, with the epicenter just north or northwest of Santa Rosa, damaged some chimneys, broke windows, and rotated or overturned a number of tombstones. Maximum intensity VIII, at Santa Rosa.
- 1969 October 1, 9:56 p.m. and 11:20 p.m. Two earthquakes, magnitudes 5.6 and 5.7, respectively. Epicenters 38° 28'N, 122° 41.5'W, and 38° 27.3'N, 122° 41.5'W, respectively. Extensive light damage in the Santa Rosa area, where some chimneys fell, many windows broken, and a half dozen frame houses with shifted or overturned foundations. Partial collapse of several brick building walls occurred, and minor structural damage was noted in one reinforced concrete building. There was damage to the Santa Rosa water system, and cracks in the Lake Raphine Dam. Some minor ground cracking occurred on the northeast edge of Santa Rosa. One fire ignition occurred in Santa Rosa. The fault is thought to have occurred in a step-over between the Rodgers Creek and Healdsburg Faults.

Between 1969 and 2013, ground shaking in Sonoma County has been relatively quiescent, with light levels of shaking in the 1989 Loma Prieta M 6.9 earthquake, and the 2000 Napa M 5.2 earthquake. In Napa, the 2000 earthquake damaged more than 20 buried water pipes, and knocked down many chimneys (see Eidinger, 2001, for a complete report on the Napa 2000 earthquake).

On August 24 2014, a M 6.0 earthquake occurred on the West Napa fault. This earthquake was located about 70 km east of Guerneville. Ground motions in most of Napa exceeded PGA > 0.2g (places directly over the fault as high as PGA 0.6g). Preliminary review shows that there were more than 110 water pipe failures, or a failure of about 0.5 repairs per km of water pipe for the City of Napa; damage data for the sewer system is still being collected.

3.4 Seismic Performance Goals

One of the tasks of the seismic assessment of the RRCSD wastewater system is to develop a suitable set of earthquake performance goals. A performance goal reflects the desire to provide some level of adequate service following an earthquake, which reflects upon the balance of needs to provide service at a reasonable level of cost.

The "balance" between service and cost will vary on a case-by-case basis. For example, if the only function of a pipeline is to move storm water between two locations, an earthquake-induced temporary closure of that pipeline may be completely adequate, because temporary disruption of storm water transport may be acceptable once every 475 years. On the other hand, if damage to this same pipeline causes large sewage spills in populated areas that would inflict a significant life-safety impact (including disease) to people located near the leak, or serious release of raw sewage to the environment, damage may not be tolerable.

The RRCSD system will be assessed for a San Andreas M 8 earthquake as described in Section 3.2.2. Depending on the findings, the RRCSD system may be assessed for a more probable earthquake, which in the case of the performance goals, is defined as an earthquake that produces ground motions that are not expected to be exceeded more than once every 100 years. The potential level of ground shaking can be approximated by evaluating the system for 60% the motions (and assuming 8 to 10 seconds of strong ground motions) using the values presented in Tables 2 through 6.

Another example for achieving a balance between service and cost for wastewater facilities would be the case where the performance goal is to provide hydraulic flow through a wastewater treatment plant. In this case, significant damage to non-redundant pipes necessary for primary treatment and disinfection would not be tolerable, whereas damage to pipes that are part of secondary (or tertiary) treatment might be tolerable.

While useful for establishing selected design parameters, no explicit performance goals are suggested for earthquakes that produce ground motions that are not expected to be exceeded more than once every 2,475 years, as experience has shown that mitigation for a 2,475 year event is generally not a cost effective allocation of scarce capital resources.

Table 7 provides suggested performance goals for the Probable and Maximum Earthquakes for the RRCSD wastewater system, which includes three main service categories: (1) life safety, (2) public health, and (3) protection of receiving waters under dry- and wet-weather conditions. These goals should be adjusted to meet the particular needs of RRCSD, once an understanding of the capital cost to achieve these goals is established.

1. Life safety is defined as no loss of life or serious injury to the public or to RRCSD staff. Due to the type of facilities involved, in most cases, the concern for life safety is primarily related to RRCSD's own personnel and typically involves preventing the collapse of RRCSD's structures. In addition, the release of hazardous chemicals (e.g., chlorine) into the atmosphere must be avoided.
2. Most collection systems are primarily linear systems for which failure at key locations results in overflows. The concern for public health can be addressed by:
   - Maintaining hydraulic flow at the treatment plants and in the major collection sewers, and thus preventing sewage from backing up into the local streets.
   - Maintaining minimal chlorination and thus preventing bacterial contamination of the receiving water.
   - This goal can be achieved by maintaining the major collection sewers and pump stations, permitting treated discharge at the wastewater treatment plants (and possibly other temporary locations), and maintaining flow and disinfection through the wastewater treatment plants.
3. The protection of receiving waters, under both dry- and wet-weather conditions, requires either maintaining primary or secondary treatment processes to prevent bacterial contamination of the receiving water.

Table 7: Post-Earthquake System Performance Goals for the RRCSD System

Service Category	Probable Earthquakes	Maximum Earthquake San Andreas M 8.0
Life Safety	Minimal life-safety risk	Minimal life-safety risk
Public Health	Maintain hydraulic flow and disinfection within 24 hours.	Maintain hydraulic flow and disinfection within 72 hours.
Protection of Receiving Waters (Dry Weather Conditions)	Provide primary treatment continually. Provide secondary treatment within 2 weeks. Provide tertiary treatment within 4 weeks.	Provide primary treatment within 2 weeks. Provide secondary treatment within 3 months. Provide tertiary treatment within 6 months.
Protection of Receiving Waters (Wet Weather Conditions)	Provide primary treatment within 2 weeks.	Provide primary treatment within 6 months.

Based on observations to date, it is apparent that meeting the Public Health goal with no releases will require lift stations to be operable within the time noted in Table 7 and that buried pipe cannot break near creeks. Based on the initial assessments, the existing pipeline network may be highly vulnerable to liquefaction damage.

It is often useful to provide a matrix that corresponds to specific structural performance for different types of structures as indicated in Table 8, where:

- Class I structures are structures which are essential to the maintenance of wastewater flow. Loss of use of Class I structures would cause a major impact to the operation. Significant damage could result in sewage backup and environmental and public hazards.
- Class II structures are structures which are not directly necessary to preserve wastewater flow through the system. Loss of use of Class II structures would not result in immediate wastewater backup. Repairs or replacement would be required, but not need be immediate (hours or days).

Table 8: Structural Performance Objectives

Facilities	Probable Earthquake (60% of motions in Table 2)	Maximum Earthquake (median motions in Tables 3 and 5)	Maximum Earthquake (84th percentile motions in Tables 4 and 6)
Class I	No structural damage; superficial non-structural damage only. No environmental damage. No loss of facility use.	Minor structural damage; minor to moderate non-structural damage only. Minimum partial temporary shutdowns possible, but not probable.	Minor to some moderate damage locally. No major structural damage, partial collapse or threatening conditions. Moderate non-structural damage possible. Limited partial shutdowns possible. Structural and non-structural damage repairable within days.
Class II	Minimal structural damage. Minor non-structural damage. Minimal partial temporary shutdowns possible, but not probable.	Minor-moderate structural damage. Moderate non-structural damage. Only limited partial shutdowns possible. Repairable within days to weeks.	Moderate structural damage. Moderate-major non-structural damage. No partial collapse or life threatening conditions. Structural and non-structural damage repairable within weeks to months.

3.5 Potential Hazard Related Issues

Based on the data review and filed reconnaissance the following geologic and seismic related issues relevant to the planning area should be considered:

1. The RRCSD wastewater system is exposed to four of the five identified geologic hazards (ground shaking, liquefaction, creek hazards and landslides) which present hazards that could result in damage to RRCSD facilities including the WWTP, collection system and pump stations with the potential of sewage spills and loss of use of the WWTP.
2. The RRCSD WWTP, which is located at the end of Neely Road at the south end of the system, has a series of geologic and seismic conditions that could adversely affect the improvements and operations of the plant, both in a static and seismic situation. The plant has already been adversely affected by a debris flow circa 1992 that originated off-site on the slopes and travelled between the clarifier area of the plant and the mechanical building, into the downslope effluent storage reservoir. All of the slopes bordering the northern boundary of the site should be considered to have a high potential for landsliding, both statically (due to seasonal heavy rains) and seismically (due to intense shaking). There is little to no protection from such slope movements to protect the facility at this site.
3. It should also be noted and emphasized that based on subsurface data from Giblin (1997a, 1997b) and from published geologic and seismic references, the southern half of the WWTP site is underlain by fill over young alluvium; which has a very high liquefaction potential and at least a moderate lateral spread susceptibility. Groundwater has also been demonstrated to be shallow, varying from 5 to 15 feet below existing ground surface. If such phenomena were to occur, differential settlement and lateral movement would most likely disrupt pipelines and other infrastructure and may result in slope failure or rupture of reservoirs.

4. Many pipes within the RRCSD collection system are located in areas of moderate to high liquefaction areas which poses the potential for loss of use of a portion of the collection system or the potential for sewage spills.
5. There are locations within the RRCSD system with specifically identified areas with geologic hazards including potential for damage from landslides, flooding or creek related hazards.

4. Flood Hazard

4.1 General Background

The RRCSD is located within the Russian River watershed, where the Russian River meanders through the area served by the RRCSD; floodwaters from Russian River poses a potential hazard to the RRCSD facilities.

Flooding is the overflow of excess water from a river, stream or adjacent body of water onto an adjacent floodplain. When floodwaters recede after a flood event, layers of rock and mud are left behind. The rock and mud gradually build up to create a new floor of the floodplain, which generally contain unconsolidated sediments that are accumulations of sand, gravel, loam, silt, and/or clay that often extend below the streambed. Because of the fertile soil, flat reclaimed floodplain lands are commonly used for agriculture. Floodplains have also been developed over time for commerce and residential development, which puts these areas and the infrastructure that supports them at risk for flood damage. Depending on the severity of a flood, impacts to development and infrastructure contained within a floodplain can be significant.

Connections between a river and the adjacent floodplain are most apparent during and after major flood events. These areas form a complex physical and biological system that not only supports a variety of natural resources but also provides natural flood and erosion control. When a river is separated from its floodplain with levees and other flood control facilities, natural, built-in benefits can be lost, altered, or significantly reduced which can increase the potential for flood damage to facilities.

4.1.1 Definitions

Flood — The inundation of normally dry land resulting from the rising and overflowing of a body of water.

Floodplain — The land area along the sides of a river that becomes inundated with water during a flood. Floodplains may be broad, as when a river crosses an extensive flat landscape, or narrow, as when a river is confined in a canyon

100-Year Floodplain — The area flooded by a flood that has a 1-percent chance of being equalled or exceeded each year. This is a statistical average only; a 100-year flood can occur more than once in a short period of time. The 1-percent annual chance flood is the standard used by most federal and state agencies.

Return Period — The average number of years between occurrences of a hazard (equal to the inverse of the annual likelihood of occurrence).

Riparian Zone — The area along the banks of a natural watercourse.

4.1.2 Measuring Floods and Floodplains

The frequency and severity of flooding are measured using a discharge probability, which is the probability that a certain river discharge (flow) level will be equalled or exceeded in a given year. The flood frequency equals 100 divided by the discharge probability. For example, the 100-year discharge has a 1-percent chance of being equalled or exceeded in any given year. The “annual flood” is the greatest flood event expected to occur in a typical year. These measurements reflect statistical averages only; it is possible for two or more floods with a 100-year or higher recurrence interval to occur in a short time period. The same flood can have different recurrence intervals at different points on a river.

The extent of flooding associated with a 1-percent annual probability of occurrence (the base flood or 100-year flood) is used as the regulatory boundary by many agencies. Also referred to as the special flood hazard area, this boundary is a convenient tool for assessing vulnerability and risk in flood-prone communities. Many communities have maps that show the extent and likely depth of flooding for the base flood. Corresponding water-surface elevations describe the elevation of water that will result from a given discharge level, which is one of the most important factors used in estimating flood damage.

4.1.3 Flood Mapping

The National Flood Insurance Program (NFIP) makes federally funded flood insurance available to homeowners, renters, and business owners in participating communities. For most participating communities, the Federal Emergency Management Agency (FEMA) has prepared a detailed Flood Insurance Study. The study presents water surface elevations for floods of various magnitudes, including the 1-percent annual chance flood and the 0.2-percent annual chance flood (the 500-year flood). Base flood elevations and the boundaries of the 100- and 500-year floodplains are shown on Flood Insurance Rate Maps (FIRMs), which are the principal tool for identifying the extent and location of the flood hazard. FIRMs are the most detailed and consistent data source available, and for many communities, FIRMs represent the minimum area of oversight under their floodplain management program. Participants in the NFIP must, at a minimum, regulate development in floodplain areas in accordance with NFIP criteria. Before issuing a permit to build in a floodplain, participating jurisdictions must ensure that three criteria are met:

- New buildings and those undergoing substantial improvements must, at a minimum, be elevated to protect against damage by the 100-year flood.
- New floodplain development must not aggravate existing flood problems or increase damage to other properties.
- New floodplain development must exercise a reasonable and prudent effort to reduce its adverse impacts on threatened salmonid species.

Sonoma County entered the NFIP in January, 1982. The ordinance provisions, definitions, and requirements were modeled after language recommended by the NFIP and were reviewed and found fully compliant by the NFIP. The County's flood zones and mapping in the General Plan Safety Element and other documents are based on the 100-year flood zones and floodways shown in the FIRMs. The Water Agency participates in the NFIP under the umbrella of Sonoma County.

Floods along the Russian River and within the RRCSD boundaries generally result from intense rainfall that lasts for a short period, or typically up to 6 hours for a longer duration storm. Figures RR-14 through RR-17 show the 100-year floodplain that lies within the RRCSD boundary. The floodplain is generally confined to the area nearby Russian River within the RRCSD boundary and expands up several of the low lying creeks that drain to the Russian River.

4.2 Hazard Profile

4.2.1 Principal Flooding Hazard

The principal source of flooding within the RRCSD is the Russian River. Figures RR-14 through RR-17 show areas where sections of the RRCSD collection system, lift stations, and force mains from pump stations intersect creeks.

Several pump stations are located along creek crossings and within the 100 year floodplain. These areas pose the highest risk of flood damage to the RRCSD facilities. Debris flowing within the Russian River and its tributaries where the pipelines cross presents a hazard to damaging the crossings. Potential for scour also presents a hazard. As discussed and listed as geologic hazards in Chapter 3, there are specific locations identified where damage to the system could occur.

Based on the FIRMs, the RRCSD WWTP is located outside of the 100 year floodplain, and outside the 500-year (0.2% annual chance) floodplain. However, pump stations and equipment, including pumps and controls, can potentially be damaged in the event of a flood. It is important to ensure that all electrical components are elevated above the 100-year flood elevation.

4.2.2 Secondary Hazards

The most problematic secondary hazard for flooding is bank erosion, which in some cases can be more harmful than the actual flooding. This is especially true in the upper courses of rivers with steep gradients, where floodwaters may pass quickly and without much damage, but the banks can be left scoured, edging properties closer to the floodplain or causing them to fall in. Flooding is also responsible for hazards, such as landslides, when high flows over-saturate soils on steep slopes, causing them to fail. Hazardous materials spills are also a secondary hazard of flooding if storage tanks rupture and spill into streams, rivers or storm sewers. Additionally, sewer systems can be backed up, causing wastewater to spill into homes, neighborhoods, rivers and streams.

4.3 Potential Hazard Related Issues

The following flood-related issues relevant to the planning area should be considered:

The risk associated with the flood hazard overlaps the risk associated with other hazards such as earthquake, landslide and wildfire losses. This potentially provides an opportunity to seek mitigation alternatives with multiple objectives that can reduce risk for multiple hazards.

1. Climate change may cause more extensive flood problems due to possible sea level rise and more severe weather patterns. Consequently, the flood zone boundaries can move or expand, causing the 500-year floodplain inundation area to become a higher probability risk, and the WWTP subject to floods. Coastal flood hazard ratings may also need to be reviewed in order for the RRCSD to adapt to climate change effects.
2. More information is needed on flood risk to support the concept of risk-based analysis of capital projects.
3. Ongoing flood hazard mitigation will likely require funding from multiple sources.

5. Fire Hazard

5.1 General Background

Wildfire is any uncontrolled fire occurring on undeveloped land that requires fire suppression and is a relevant hazard to the RRCSD facilities. Wildfires can be ignited by lightning, faulty or damaged electrical facilities or by human activity such as smoking, campfires, equipment use, and arson. Fire hazards present a considerable risk to vegetation, wildlife habitats, private and public facilities and public infrastructure. Short-term loss and long term effects caused by a wildfire can include the damage to and destruction of community infrastructure. In addition wildfire can cause increased vulnerability to flooding due to the destruction of watersheds. The potential for significant damage to life and property exists in areas designated as “wildland urban interface areas,” where development is adjacent to densely vegetated areas.

5.1.1 Definitions

Conflagration — A fire that grows beyond its original source area to engulf adjoining regions. Wind, extremely dry or hazardous weather conditions, excessive fuel build-up and explosions are usually the elements behind a wildfire conflagration.

Fire Hazard — The potential for fire in a given area, based on the fuels available to burn and how intense the fire would burn. It can be influenced by past disturbances or management activities that alter the hazard for better or worse by changing the overall site moisture. It is also affected by the volume and spatial arrangement of fuels. Fire hazard is distinguished from fire risk; fire risk incorporates the probability of wildfire occurrence—or ignitions—with fire hazard.

Interface Area — An area susceptible to wildfires and where wildland vegetation and urban or suburban development occur together. An example would be smaller urban areas and dispersed rural housing in forested areas.

Wildfire — Fires that result in uncontrolled destruction of forests, brush, field crops, grasslands, and real and personal property in non-urban areas. Because wildfires can occur at a distance from firefighting resources, wildfires can be difficult to contain and can cause a great deal of destruction.

5.1.2 Fire Hazard Mapping

Areas of significant fire hazards are mapped based on factors such as the following:

- **Fuel** —- Fuel may include living and dead vegetation on the ground, along the surface as brush and small trees, and above the ground in tree canopies. Lighter fuels such as grasses, leaves and needles quickly expel moisture and burn rapidly, while heavier fuels such as tree branches, logs and trunks take longer to warm and ignite. Trees killed or defoliated by forest insects and diseases are more susceptible to wildfire.
- **Weather** — Relevant weather conditions include temperature, relative humidity, wind speed and direction, cloud cover, precipitation amount and duration, and the stability of the atmosphere. Of particular importance for wildfire activity are wind and thunderstorms:
  - Strong, dry winds produce extreme fire conditions. Such winds generally reach peak velocities during the night and early morning hours.

- The thunderstorm season typically begins in June with wet storms, and turns dry with little or no precipitation reaching the ground as the season progresses into July and August.

- **Terrain** — Topography includes slope and elevation. The topography of a region influences the amount and moisture of fuel; the impact of weather conditions such as temperature and wind; potential barriers to fire spread, such as highways and lakes; and elevation and slope of land forms (fire spreads more easily uphill than downhill).

Taking these factors into consideration, a fire hazard severity scale has been devised that characterizes zones by the number of days of moderate, high and extreme fire hazard. These zones, referred to as Fire Hazard Severity Zones (FHSZ), define the application of various mitigation strategies to reduce risk associated with wildfires. The FHSZ map for the RRCSD is shown in Figures RR-18 through RR-21. This map is the basis for the wildfire risk assessment.

The FHSZ model is built from existing data and hazard constructs developed by CAL FIRE's Fire and Resource Assessment Program. The model refines the zones to characterize fire exposure mechanisms that cause ignitions to structures. The model characterizes potential fire behavior for vegetation fuels, which are by nature dynamic. Since model results are used to identify permanent engineering mitigations for structures, it is desirable that the model reflect changes in fire behavior over the length of time a structure is likely to be in place. Significant land-use changes need to be accounted for through period maintenance routines.

The model output of fire probability also is based on frequency of fire weather, ignition patterns, expected rate-of spread, and past fire history. It also accounts for flying ember production, and hazards based on the area of influence where embers are likely to land and cause ignitions. This is the principal driver of hazard in densely developed areas. A related concern in built-out areas is the relative density of vegetative fuels that can serve as sites for new spot fires within the urban core and spread to adjacent structures.

5.2 Hazard Profile

5.2.1 Past Events

Fire has been a significant factor in Sonoma County's history due to the local climate and geography. Figure RR-22 shows historical fires that have occurred nearby the RRCSD.

5.2.2 Frequency

The wildfire season in Sonoma County generally begins in June and ends in mid-October; however, wildfires have occurred in every month of the year. Drought, light snow pack, and local weather conditions can expand or shorten the length of the fire season. The early and late shoulders of the fire season are usually associated with human-caused fires. The peak months of July, August, and September are usually related to thunderstorms and lightning strikes.

5.2.3 Critical Facilities and Infrastructure

Structures, above-ground infrastructure, critical facilities and natural environments are all vulnerable to the wildfire hazard.

Critical facilities of wood frame construction are especially vulnerable during wildfire events. In the event of wildfire, there would likely be little damage to most infrastructure. Most roads and railroads would be without damage except in the worst scenarios. Power lines are the most at risk from wildfire because most poles are made of wood and susceptible to burning.

Fires can create conditions that block or prevent access and can isolate residents and emergency service providers. Wildfires typically do not have a major direct impact on bridges, but it can create conditions in which bridges are obstructed. Bridges in areas of high to moderate fire risk are important because bridges provide the only ingress and egress to large areas and in some cases to isolated neighborhoods.

Wildfires can also generate a range of secondary effects, which in some cases may cause more widespread and prolonged damage than the fire itself. Secondary effects of concern to the RRCSD include flooding. Wildfires strip slopes of vegetation, exposing them to greater amounts of runoff. This in turn can weaken soils and cause failures on slopes. Major landslides can occur several years after a wildfire. Most wildfires burn hot and for long durations that can bake soils, especially those high in clay content, thus increasing the imperviousness of the ground. This increases the runoff generated by storm events, which thereby increases the chance of flooding

To further complicate the problem, heavy rains could follow, causing flooding and landslides and releasing tons of sediment into rivers, permanently changing floodplains and damaging sensitive habitat and riparian areas. Such a fire followed by rain could release millions of cubic yards of sediment into streams for years, creating new floodplains and changing existing ones. With the forests removed from the watershed, stream flows could easily double. Floods that could be expected every 50 years may occur more frequently. With the streambeds unable to carry the increased discharge because of increased sediment, the floodplains and floodplain elevations would increase.

5.3 Potential Hazard Related Issues

The major issues for wildfires are the following:

1. Access to District Facilities may become difficult for maintenance and fire suppression.
2. Wildfires could cause landslides as a secondary natural hazard, which can induce additional sediment loading with potential risk to facilities.
3. Critical facilities in the planning area are at risk and have the potential of functional downtime post-event. This creates not only a need for mitigation but also a need for continuity of operations planning to develop procedures for providing services without access to essential facilities.
4. Fire department water supply may be at high risk in wildfire hazard areas.

6. Low Risk and Other Hazards

6.1 Tornadoes

Tornado intensities are rated on a Fujita Scale that goes from 0-5. A Fujita Scale F0 tornado is defined by a wind speed range from 40-72 mph and is classified by; light damage, broken tree branches, and shallow rooted trees being pushed over. A Fujita Scale F1 is defined by wind a speed range from 73-112 mph and is classified by moderate damage; roof panels start to tear from houses, mobile homes are pushed of their foundations, or moving vehicles pushed off the road. A Fujita Scale F2 is defined by wind a speed range from 113-157 mph and is classified by considerable damage; roof tear from houses, mobile homes demolished , large tree snaps, or light-object missiles generated.

Tornadoes do not regularly occur in California. Tornadoes pose minimal to the SVCSD. In the last 60 years, there have been 292 tornadoes in 42 counties of California, but no deaths have occurred from the incidents. Over half of the tornadoes in California have been rated F0 on the Fujita Scale; about 40% have reached F1; and less than 10% were rated F2 or above. Based on historical tornado data files from the Storm Prediction Center (operating under the National Oceanic and Atmospheric Administration – NOAA), thirteen tornadoes occurred between 1958 and 2011 in Sonoma County, with the highest intensity of F2 from the June 1, 1958 tornado, which resulted in 1 injury.

6.2 Hurricanes

California is at low risk for hurricanes, primarily because the sea surface temperatures of waters off of California are cold even during the summer months. Hurricane, or tropical cyclone, formation requires very warm waters that extend to a depth of 160-feet. Additionally, the general path of hurricanes in the eastern Pacific tends to move north-westward or westward due to steering by the prevailing upper level winds; therefore even if a hurricane does form near the coast of California, the wind would steer the hurricane out to sea and away from land. While no hurricanes have been found in NOAA's recorded history, tropical storms do result from low pressure waves generated from the Gulf of Mexico. The tropical storms that occur are typically a result of subsided hurricanes, but would still cause heavy rainfalls that may lead to flooding. Unlike floods or earthquakes, hurricanes primarily cause localized damage that also makes them a low hazard risk for the RRCSD.

In the event of a hurricane or tropical storm, the RRCSD has the ability to continue the system operations using its SCADA system at two alternative locations: the Water Agency's Concourse Boulevard facility and at the Sonoma Valley CSD's WWTP. Radio communications between the three facilities is maintained at the Concourse Boulevard facility. Damage to the Concourse Boulevard facility would result in loss of the SCADA link between the operation centers.

6.3 Tsunamis

Water displacement that occurs from earthquakes can cause a series of rapid, hazardous waves called tsunamis. As indicated on USGS Tsunami Inundation Maps, areas of tsunami danger in Sonoma County are limited to those with coastal exposure, namely in Archer Rock, Duncan Mills, Bodega Head, Valley Ford, Petaluma River, Sears Point, Cuttings Wharf, Petaluma Point, Mare

Island, and Novato. The RRCSD does not have coastal exposure and therefore is not anticipated to be affected by tsunamis.

6.4 Climate Change

Climate change over the next century may have a significant impact to both the natural and built environments in Sonoma County. Although Sonoma County has developed the Community Climate Action Plan and Climate Action 2020 to mitigate greenhouse gas emissions that cause climate change, the effects of climate change, such as rising sea levels and intensified storms, are imminent. Due to sea level rise, flooding in the Russian River watershed is likely to increase. As discussed in Chapter 4, flooding can change stream hydraulics and sediment carrying capacity of waterways, which may cause streamwater backup flooding. Climate change also has potential to decrease precipitation in the Russian River watershed, which would increase fire hazards. While the effects of climate change remain uncertain, it is speculated that its effect on flooding and wildfire hazards could pose significantly increased risk to RRCSD infrastructure. Flood and wildfire hazards to RRCSD are discussed in Chapters 4 and 5, respectively.

7. Vulnerability Assessment

The purpose of completing the Vulnerability Analysis is to assess the extent to which the RRCSD facilities can withstand the applicable hazards discussed in Chapters 2 through 6. The facilities include gravity and pressure pipelines, lift stations and the wastewater treatment plant (including treatment, storage, reclamation, irrigation and related facilities). Mitigations and future emergency operations plans will serve as a guide for planning and developing a response to natural hazards; effects of hazards on the RRCSD system will be based on the identified vulnerabilities of the system.

The vulnerability assessment included a review of data collected, as-built drawings of the system, and a field review of the system. Potholing as well as underground and in-pipe investigations were not included in the assessment. As additional data is developed and vulnerabilities of the RRCSD system are identified, the RRCSD will prioritize the vulnerable components of the system with the most relevant hazards; additional investigations will be completed as necessary in order to refine the assessment and develop a plan to mitigate the potential damages from the relevant hazards.

The vulnerability analysis presented is meant to meet the following objectives:

1. Identify and quantify the hazards that may affect the RRCSD system;
2. Quantify the susceptibility of essential sewer service and treatment facilities to the effects of natural disasters;
3. Develop measures that will be included in a mitigation plan to decrease the vulnerability of the system.

The following sections describe the significant vulnerabilities of the RRCSD facilities and lift stations. This vulnerability assessment emphasizes the geologic and seismic hazards (including earthquake and creek hazards) discussed in Chapter 3 because earthquakes pose the highest risk to RRCSD facilities. Additionally, the vulnerabilities associated with the lower risk hazards would be similar to those identified and associated with earthquakes. Specific vulnerabilities to the collection system which are related to flooding, high creek flow and seismic related events are also identified. Low risk hazards are not discussed in the vulnerability assessment because efforts to protect the RRCSD facilities against low hazards would not justify the costs.

7.1 Collection System Pipelines and Lift Stations

Hazards to the collection system and lift stations are generally directly related to the after-effects of seismic events, floods and fires. Specifically, landslides can occur due to geologic and seismic events, inundation due to flooding, and/or erosion from exposure of hillsides after fires. The existing collection system was reviewed via mapping and field reconnaissance. Field visits of areas with potential for landslides, creek crossings and other potentially vulnerable areas were completed. Hazards were identified and then discussed with the field operations staff. Areas of potential vulnerabilities were noted and mapped. The identified locations are presented in Figures RR-2 through RR-5.

7.1.1 Vulnerabilities

The site specific vulnerable areas identified and listed as Hazard Reconnaissance Points on Figures RR-2 through RR-5 are described below:

Point 1: The sewer main was constructed beneath the existing drainage channel in multiple locations; the burial depth below the channel thalweg is unknown and assumed shallow.

Hazard: There is a potential for exposure and damage of the pipeline due to erosion and debris impact during periods of rapid stream flow.

Point 2: The sewer main and manholes are located/founded within young alluvium (Holocene) and are locally proximal (less than 10') to the creek/drainage channel embankment. The embankments are generally steeper than 1H: 1V (Horizontal:Vertical) and the channels are up to 20 feet in depth below the roadway. Localized embankment undermining and failure were observed.

Hazard: Static and seismic embankment failure (landslide) potential with possible damage to sewer main, manholes and laterals.

Point 3: The sewer main and manholes are constructed within generally contour-parallel roadways. The slopes above and below the roadways are generally steeper than 2H:1V (Horizontal:Vertical). Abundant edge parallel and arcuate (curved) cracking of the pavement (due to fill prism settlement and creep on ridge flanks) and through colluvial swales were observed. Overland sections of the sewer main and associated manholes are potentially found in creep or failure prone colluvial soil and weathered bedrock.

Hazard: There is static and seismic landslide potential with possible damage to main, manholes and laterals.

Point 4: The 16 inch force main between the Main Lift Station and Vacation Beach Lift Station is a concrete-encased, mortar-lined, rigid steel cylinder truss pipeline that has had a recent failure and is susceptible to failure during seismic events and landslides. In addition, it is advisable to upgrade and replace the force mains at the Beanwood Lift Station up to MH 37-17, Guernewood Lift Station up to MH 23-16 and the Rio Nido Lift Station up to MH 72-6 due to similar reasons.

Hazard: The potential exists for static and seismic failure potential of the force mains resulting in sewage spills.

Point 5: Active land sliding located along the north edge of the treatment plant has previously inundated portions of the plant improvements and is discussed further in Sections 3.2.5 and 7.2.9

Hazard: The southward-facing slopes have static and seismic landslide potential with potential impact to the plant facilities.

Point 6: The gravity line along the alignment between MH 31-3 and MH 31-4 is potentially shallow.

Hazard: The potential exists for undermining and exposure of the pipeline during high flow events and during a flood.

Point 7: The sewer main was constructed beneath the existing drainage channel. The burial depth below the channel thalweg is unknown and is assumed to be shallow.

Hazard: There is potential exposure and damage of the pipeline due to erosion and debris impact during periods of rapid stream flow.

Point 8: The sewer main and manholes are constructed within generally contour-parallel roadways. The slopes above and below the roadways are generally steeper than 2H:1V (Horizontal:Vertical). Abundant edge parallel and arcuate cracking of pavement due to fill prism settlement and creep on ridge flanks and through colluvial swales was observed. Overland sections of the sewer main and associated manholes are potentially founded in creep/failure prone colluvial soil and weathered bedrock.

Hazard: There is static and seismic landslide potential with possible damage to the main, manholes and laterals.

Point 9: The sewer main and manholes are located/founded within young alluvium (Holocene) and are locally proximal (less than 10') to the creek/drainage channel embankment. The embankments are generally steeper than 1H:1V (Horizontal:Vertical) and the channels are up to 15 feet in depth below the roadway, locally. There is localized embankment undermining and failure observed.

Hazard: There is static and seismic embankment failure (landslide) potential with possible damage to main, manholes and laterals.

The highest vulnerability to the collection system is due to the potential damage due to seismic events, which also translates to the highest potential cost to the RRCSD. In order to quantify the potential for the seismic hazard, the length of pipelines in the Very High, High and Moderate liquefaction zones were estimated, using the maps referenced in Chapter 3 of this report. Within each of the zones, the pipelines were assumed to be installed in an open cut trench adjacent to a stream or river, where significant lateral spreads can occur. An occurrence of an M 8 event on the San Andreas Fault was assumed, which on average produces PGA = 0.34g at the ground surface near each pipe. For the pipeline inventory, the typical style of pipe installation uses cemented joints (ABS pipes) or non-seismic push-on joints (CIP, DIP, PVC, VCP pipes).

The number of pipe failures was then estimated, given the level of shaking (PGA = 0.34g), and the pipe fragility models of ALA (2001). Given these assumptions, approximately 42 pipe repairs will be required, of which about nearly all will occur in the areas mapped as having high to very high liquefaction susceptibility. Of these repairs, approximately half can be assumed to be full breaks, and half will be leaking joints (ALA, 2001). These repairs exclude damages to customer's service laterals. Table 9 quantifies the extent of pipe damages to the RRCSD collection system, should a M 8.0 earthquake occur along the San Andreas Fault. Uncertainties in the ground motions and pipe performance suggest these median-based quantities may vary ±50%.

Table 9: Pipe Damage – San Andreas M 8.0 Earthquake

Liquefaction Zone	Total Pipe Length (miles)	Total Pipe Repairs	Pipe Breaks	Pipe Leaks
Very High	1.6	15	7	8
High	28.0	27	14	13
Moderate	1.9	< 1	<1	<1
Low, None	7.8	< 1	< 1	<1
Total	**39.3**	**42**	**21**	**21**

Equipment at the lift stations (pumps, motors, controls) are well anchored and therefore not subject to damage from seismic shaking. The lift stations themselves, and the connected piping are, however, vulnerable to damage from liquefaction, typically due to flotation and/or rotation of the lift station.

7.1.2 Mitigations

The vulnerable areas of the collection system have the potential for a significant number of failures. If pipe breaks are identified after an earthquake, flooding or due to high stream flow, full repair is required before the sewer can be re-used. In contrast, pipes with leaks can be kept in service while repairs are made. The general approach to pipe repair will be as follows:

- Identify obvious damage at the surface (i.e. sewage backups, readily seen at the surface). Damage at the surface may happen infrequently, but it is important to conduct an investigation, and/or notify property owners to report sewage backups to the RRCSD.
- From the WWTP, trace back to find locations where there is no flow. Visual inspection under manholes can often identify no flow conditions.
- Map out locations where manholes have floated. Manholes will float (rise up) when the pore pressure exceeds the weight of the manhole for a period of time. This will typically only occur at locations with Very High (or High) liquefaction susceptibility and a high ground water table. At these locations, there will almost certainly be broken pipes attached to the manhole at depth. For a gravity flow system, floated manholes will need to be replaced. For purposes of this assessment, assume 2 or 3 such manholes will float for each significant earthquake event (Previous earthquakes in Japan, and the 2011 Christchurch earthquake caused a number of manholes to float. Given the available liquefaction maps, and assuming a high magnitude earthquake during ground saturated / high water table conditions, it would be prudent to plan for flotation of manholes. In order to provide a more precise/ quantified value of floated manholes, additional assessments will need to be performed using precise manhole weights and geometries and local soil borings).
- Use video cameras to perform a visual inspection of all pipes suspected to be damaged. Start video inspection on all pipes within the mapped High and Very High zones, then proceed to the moderate and low liquefaction zones, respectively.
- At key locations where there is a sewage blockage or broken pipe, isolate the manhole, and use pumps and flexible hose to move the sewage between usable manholes.
- Working radially from the WWTP, repair broken pipes, and where initially convenient, repair leaking pipes. Depending on site-specific conditions, leaking pipes might be left in service. Repair crews can be used to expeditiously repair broken pipes first (while leaving the street open), and then ultimately returning to the leaking pipes to make permanent repairs.
- Jet-flush the repaired pipes to clean out accumulated silts and sands and debris.

Pipe replacement might be the most effective solution in a few highly damaged locations. Where repairs are made, some common approaches are:

- Install a pipe repair clamp for a small leak or break;
- Replace a short section of damaged pipe (a few feet to one segment) and insert a new length of pipe with collars at each end to make leak-tight joints; or
- Replace an entire length of sewer line if there are multiple damage points between two manholes.

Post-earthquake replacement of entire lengths of pipe between manholes can be the most cost effective strategy where:

- Manholes or lift stations have floated
- Multiple breaks between manholes have occurred
- Known hydraulic / flow issues are known to exist

While pipe repairs will be satisfactory to return the pipe to service, it will not prevent further damage due to future earthquakes (or large aftershocks). Unless the replacement pipe is seismically designed, the replacement pipe will remain vulnerable to be damaged in aftershocks or future earthquakes. It is recommended that seismic resistant pipes be installed in the Very High and High liquefaction zones, in areas closest to creek crossings, or where the pipe runs parallel to creeks, such that the pipe will not leak or break under a 1% soil strain. All overhead pipes that are self-supporting or on bridges over creeks should be replaced or upgraded to sewers that can sustain PGA = 0.59g. Pipe replacements can be installed piece-meal post-earthquake, or done prior to future earthquakes as part of a planned pipe replacement program.

7.2 Wastewater Treatment Plant

The wastewater treatment plant is vulnerable to several hazards including geologic, seismic and fire. Seismic hazards include ground shaking, water impulsive and sloshing forces; differential ground displacements due to landslide or liquefaction, and debris flow.

Vulnerability to wildfire includes limitations on access to RRCSD facilities for maintenance and fire suppression. The access to the RRCSD WWTP site is restricted and limited. Alternate access is desirable to allow easier access for emergency vehicles, but availability of right-of-way is limited. Wildfires also could cause landslides as a secondary natural hazard and therefore mitigations discussed for geologic and seismic-induced landsliding are similar for wildfires.

A description of the flow process in the RRCSD WWTP was provided in Chapter 2. The following paragraphs discuss the WWTP structures and systems that are at risk primarily during earthquake hazards.

7.2.1 Aeration Basins

The aeration basins are part of a reinforced concrete rectangular structure with three basins.

The two eastern-most basins are used for aeration. The western-most basin was empty at the time of inspection, and had no equipment within it (no baffles, no aeration).

Vulnerabilities

If the aeration basins are full at the time of the earthquake, the water impulsive and sloshing forces will load the downcomers. If the downcomers are deteriorated, a few might break. The header air-pipe above the water level might be impacted by sloshing forces.

Mitigations

None recommended.

7.2.2 Clarifiers

There are three clarifiers in use at the treatment plant: two original (1980s) 40-foot diameter clarifiers, and a newer (2003) 60-foot diameter clarifier. These are circular reinforced concrete structures, located in the northeast part of the site, along the bottom of the slope of the mountainous terrain to the north of the site.

Vulnerabilities

Circular clarifiers commonly experience significant damage during major earthquakes. During earthquakes, water sloshing in the clarifiers result in waves that over-top the clarifier and increases the forces applied to the central tower, baffles, and launders. Figure 7 shows the typical clarifier layout and Figure 8 shows the key dimensions. Barring liquefaction under the concrete tanks, the concrete tanks can sustain inertial loads without damage. With sufficient lateral forces due to sloshing, there will be overturning moments applied to the central tower; if the tower cannot sustain these forces, it will be damaged, rendering the clarifier inoperable until repairs are made.

An earthquake with a PGA of 0.34 g at the treatment plant will likely cause yielding of the clarifiers' rake arms lattice structure, the central tower, and the anchor bolts (weakest component), resulting in the clarifiers being inoperable.

From an inertial point of view, all three tanks are considered adequate for PGA = 0.34g. The remaining weaknesses include:

- Damage of the rotating mechanisms within the clarifiers due to seismic inertial and wave loading;
- Damage to attached inlet – outlet pipes due to differential soil movements;
- Damage to attached ladders due to differential soil movements;
- Damage due to deep-seated landslide; and
- Damage due to debris flow.

Mitigations

Ways to mitigate the vulnerabilities include:

- Keep one clarifier empty in order to eliminate the sloshing effect.
- Reinforce the central tower by bracing the top of the tower to the outer concrete tank walls. Additional bracing of the baffles may also be required.

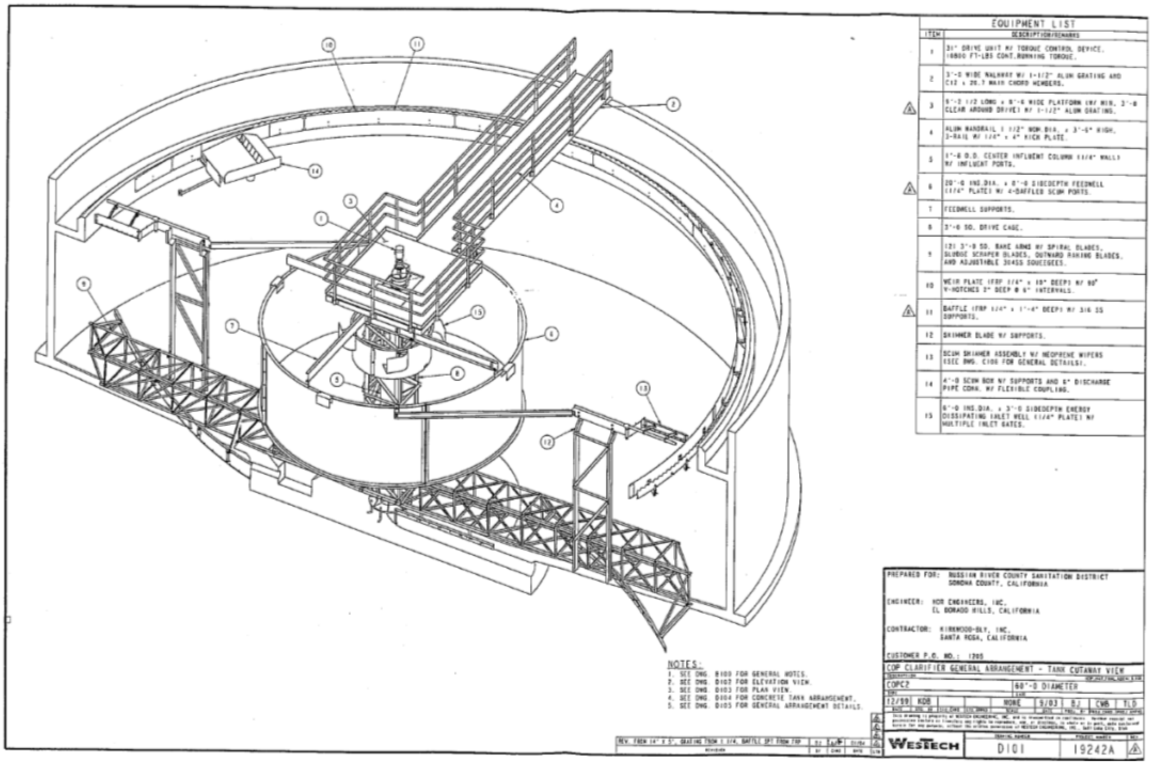


Figure 7: RRCSD WWTP 60 ft. Clarifier (2003) – General Layout

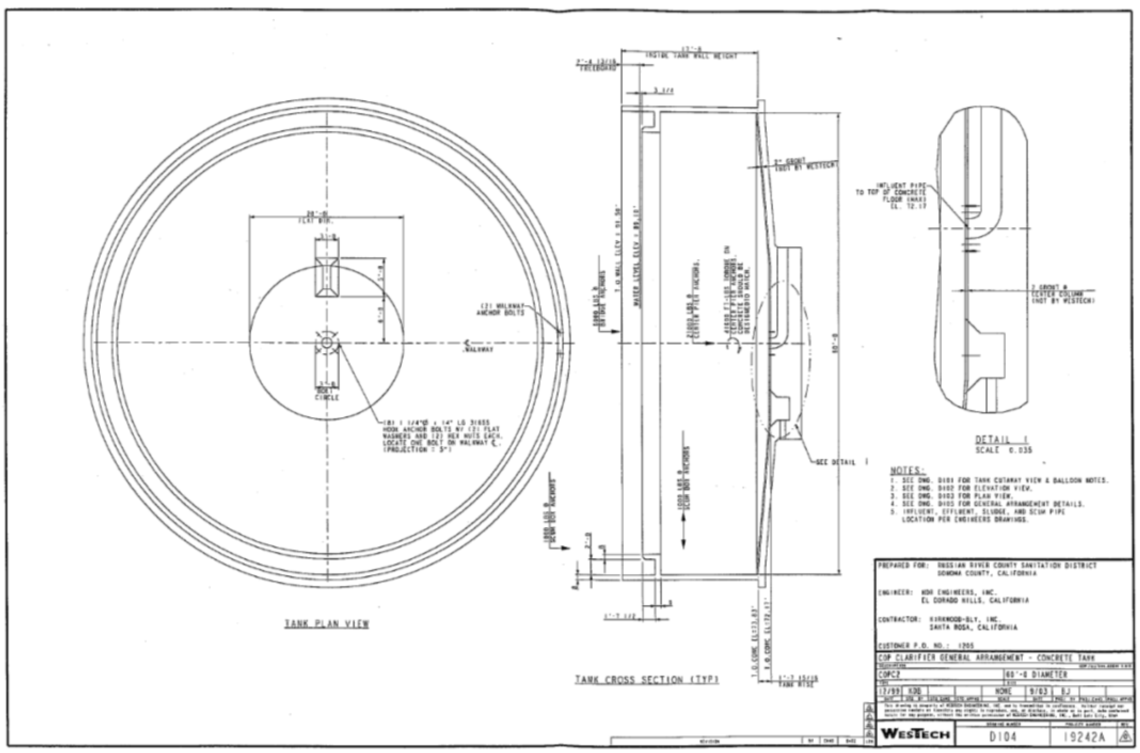


Figure 8: RRCSD WWTP 60-foot Clarifier – Key Dimensions

7.2.3 Buried Piping

The pipes installed at the WWTP are generally welded steel, with bolted connections for valves, and dresser couplings used occasionally where pipes enter / exit concrete tanks. Due to a lack of available records and calculations for the original WWTP design, it cannot be ascertained that any of the buried piping was specifically designed to handle earthquake loads. Figure 9 shows a plan of the WWTP as of 2013.

Vulnerabilities

Assuming ground shaking at the site of PGA = 0.34g and firm soil conditions without liquefaction or landslide, buried pipe will survive the shaking, except where the pipe has become distressed due to corrosion (internal or external) or if the pipe has construction defects (like improper welds).

However, the northern part of the site appears to be exposed to ongoing slope movements, and the site might also be exposed to liquefaction. The primary locations where pipes will be damaged are: where pipes enter tanks / structures, and where tanks are founded on deep foundations but adjacent pipes buried just a few feet underground.

There is a strong possibility that given PGA = 0.34g, there will be differential displacements exceeding an inch between some of the concrete tanks / structures and the surrounding soil.

Consequently, there might be multiple pipe failures at the WWTP site, with PGA = 0.34g (San Andreas M 8), but there is insufficient information to highlight the specific location where this might occur. The pipe failure could manifest itself in imposed distortions on a valve such that the valve becomes inoperable.

Additionally, there are two geotechnical issues that can lead to differential soil movements at the site:

- In the northern part of the site, near the clarifiers, there are steep slopes. Long term creep of the slopes can impose differential movements on the pipes, especially where the pipes connect to concrete structures (like the clarifiers) that are founded on deeper, more stable soils. Earthquake triggered movements can be larger than the long term soil movement. Figure 10 shows one such pipe connection where there is already evidence of differential movement; this pipe has some flexible connections already. Figure 11 shows another set of pipe connections, where the differential movements would result in increasing stress in the pipe.
- In the central and southern parts of the site, where the ground surface is flatter, there is potential for liquefaction-induced settlements; the potential of a lateral spread towards the river exists, especially for the southern part of the site.

The specifications and designs for the existing buried piping for this site were unavailable for review; but the drawings and specifications for several recent upgrades, including the 2003 Third Process Project, the 2011 Disinfection Upgrade, and the 2013 Biological Nutrient Removal Project were available for review. It is clear that these projects implemented current code requirements for seismic shaking, but there is no evidence that the piping, buried or above ground, was designed for differential displacement. It appears that most pipe installations do include Dresser (or similar) couplings where the pipes enter structures; these couplings are usually able to absorb about an inch of movement. However, under strong shaking, there can be much more than an inch of movement, and the existing pipes would be challenged.

A few locations in the northern part of the site (high slope area) have above-ground piping. These pipes were not traced back to drawings/ pipe-specific calculations, but it is suspected that the above-ground configuration were used to address ongoing movement of the steeper slopes. As-installed, these installations are adequate for inertial shaking, but are still subject to failure should there be imposed PGDs or a debris flow.

Given these observations, it is therefore anticipated that there will be damage to buried piping during an earthquake. The probability of pipe breaks at the RRCSD WWTP as a result of a San Andreas event is high. These pipe breaks can occur nearly anywhere in site, concentrated at where the pipes enter structures.

Mitigations

Given the significant chance of pipeline damage at the plant and current uncertainty in assessing which portions are the most vulnerable, pre-earthquake mitigation to the buried large bore conveyance pipes at the plant are not recommended at this time. Any such mitigation improvements would likely still remain vulnerable to damage following a significant San Andreas event, and thus not likely prove to be a cost effective mitigation approach without a more detailed analysis of the piping systems. However, a prudent approach would be to have an emergency response plan that factors in that there might be the need to mobilize a pipe repair crew to the plant site to make pipe repair(s). Once mobilized, a 5-man crew (including dump truck, excavator, pipe welder, and other necessary equipment and parts) could make a repair within 24 hours.

For planning purposes, assuming one day to activate (identify damage, authorize a contractor to start work) the pipe repair crew is reasonable, presuming a well-implemented emergency response plan. Assuming the causative earthquake is a San Andreas M ~8 earthquake, there will be extensive pipe damage in Sonoma County (as well as other parts of the greater Bay Area), so having a pre-set agreement to mobilize pipe repair crews will be useful; or getting crews via mutual aid from other lesser-impacted agencies in the Bay Area (in the Bay Area, only EBMUD has a large in-house crew capable of repairing 24" to 48" steel pipe; in Southern California, the Metropolitan Water District of Southern California has the ability to roll spare pipe to any size diameter). Although steel pipe will not likely need to be replaced, having the ability to roll steel shapes will likely be needed for repairs. Larger pipe contractors might have this capability, but from a planning perspective, RRCSD should assume that there will be much more demand for their services than normal.

Going forward, when RRCSD makes modifications at the WWTP, unless otherwise recommended by site-specific geotechnical assessment, it is recommended that all pipes (including chemical pipes and water conveyance pipes) be designed to accommodate 3 inches of knife-edge settlements when entering concrete vaults. This can usually be accommodated using a combination of bellows, ball-joints with slip joints; Dresser-like couplings (at least two per pipe, generally restrained); expansion loops in vaults, etc.

In order to mitigate the geotechnical vulnerabilities and until geotechnical investigations can be done to provide better quantification of the hazard, it is recommended that for future water (including wastewater / sludge) pipe installations, that all pipe-structure connection points be designed to accommodate 3 inches of differential "knife-edge" type movements at soil-structure connection points (where ground slope is more than 5 degrees); all buried pipe throughout the plant be designed assuming liquefaction and slope movement occurs (resulting in a 1% strain on the pipe). All buried chemical pipes should be similarly designed. Above ground pipe installations can be used, but such pipe should be checked for inertial loads per ASME B31 provisions, assuming elastic limits (no pipe stress over yield) for PGA = 0.34g / firm soil spectra in each of the two horizontal directions; and a corresponding vertical spectra. By following the recommendations in this paragraph, future pipe installations will be much more robust to withstand future earthquakes.

This still leaves open the question of how vulnerable the pipe network is at the existing WWTP, and what to do to lessen the impacts. The choices include:

- Do nothing.
- Improve emergency response capability, including the ability to quickly repair broken pipes, or to use above ground temporary hose to bypass damaged pipe.
- Do modest level of mitigation, where the costs are lowest and the existing vulnerability the highest.
  - First priority. From influent / grit chamber to aeration to discharge to the river. This reinforces the primary treatment process.
  - Second priority. From influent to secondary clarifier (at least clarifier 3, 60-foot) to disinfection to discharge to the river. This reinforces secondary treatment process. Included are the sludge pipes from the secondary clarifier.
  - Third priority. From secondary clarifiers to tertiary treatment to the disinfection to discharge to the river or to tertiary water users (golf course).
  - Fourth priority. Pipeline from the WWTP to the tank serving the tertiary water user (golf course).
  - Fifth priority. Ensure tank at Northwood Golf Course is seismically robust.

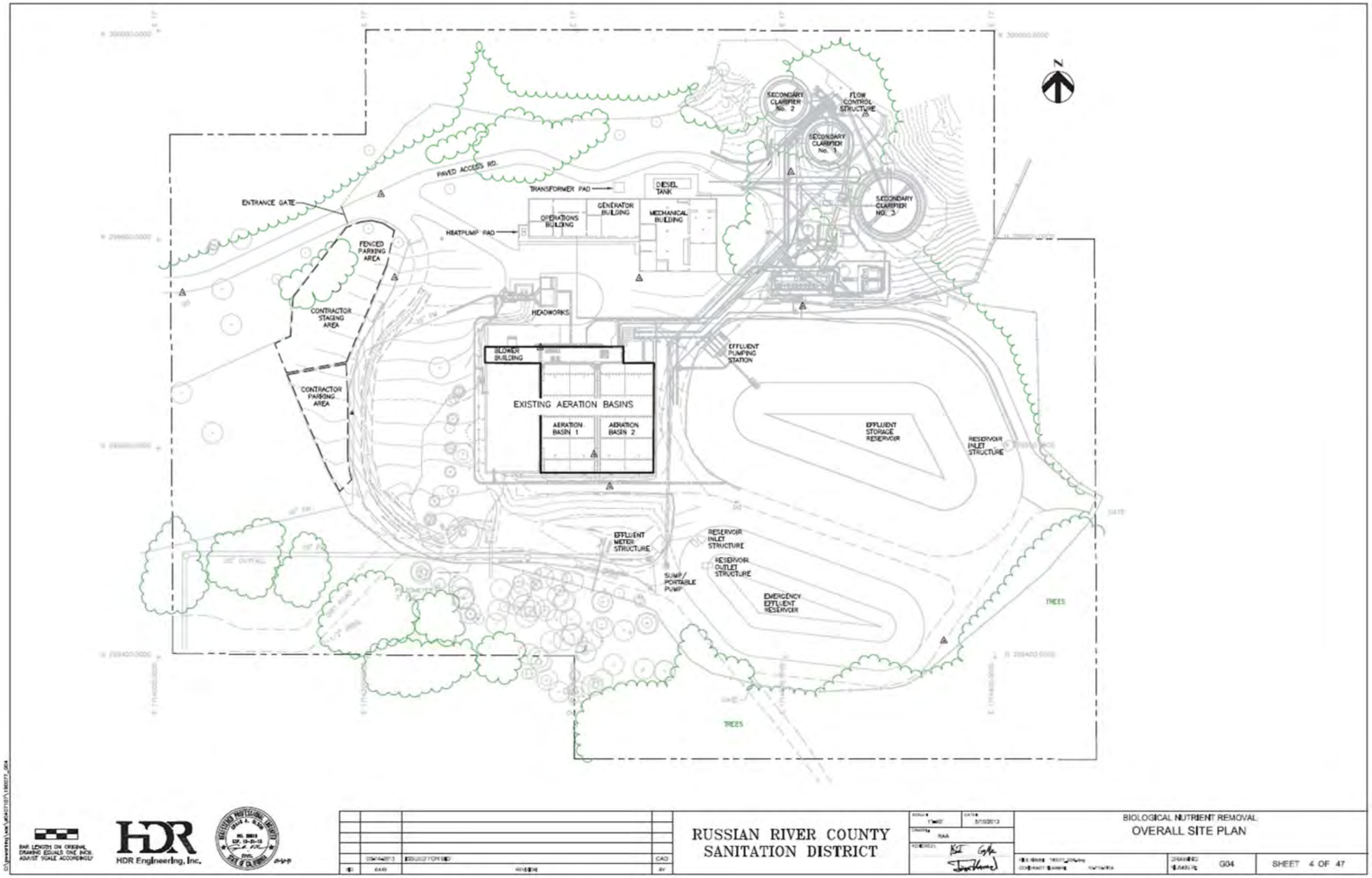


Figure 9: RRCSD WWTP Site Plan in 2013

Figure 10: Buried Piping for Clarifier – note offset of top-most coupling

Figure 11: Attached Piping for Filter Tanks (no flexible connections)

7.2.4 Structures at the WWTP

There are several buildings at the WWTP, and most date to the original plant construction. The style of construction is reinforced masonry.

There are three building structures on the north side of the plant as shown on Figure 3:

- The westernmost building includes control, administration and water quality lab. This is a two story building with a gable roof and is labeled the Operations Building.
- The central building contains the emergency generator and is labeled the Generator Building. It is a single story building with a flat roof. The fuel tank for the emergency generator is

currently located uphill of the building, and an above-grade steel tank is anchored. The original 1980s-vintage fuel tank that was buried just to the south of the building was leaking, and was therefore replaced with the current fuel tank. The fuel pipe from the fuel tank to the emergency generator building is supported by the fuel tank that sits on two small concrete blocks on fill.

- The easternmost building contains chemical mixing equipment and is labeled the Mechanical Building. This is a tall single story building with a gable roof.

To accommodate the slope of the site, each of these three buildings is partially buried on the north site. The solid waste handling building is a rectangular two story building. It is reinforced masonry. It appears to have been constructed separately from the original control buildings. Pipes and conduits between the solid waste building and the adjacent control building should be able to sustain at least 1 inch of differential movement between the buildings.

The blower building is a single story reinforced masonry structure.

Vulnerabilities

All of these buildings were apparently designed for seismic forces consistent with 1979 UBC, or about V = 0.18W. For inertial loading, this should be sufficient to provide reasonably good performance at PGA = 0.34g for long duration shaking.

It is suspected that there is ongoing slope movement in this area of the site, and this has led to partial separation between the solid waste building and the adjacent control building (Figure 12).

Mitigations

Upgrading the fuel pipe that provides fuel from the fuel tank to the emergency generator to accommodate up to 3 inches of differential movement is recommended.

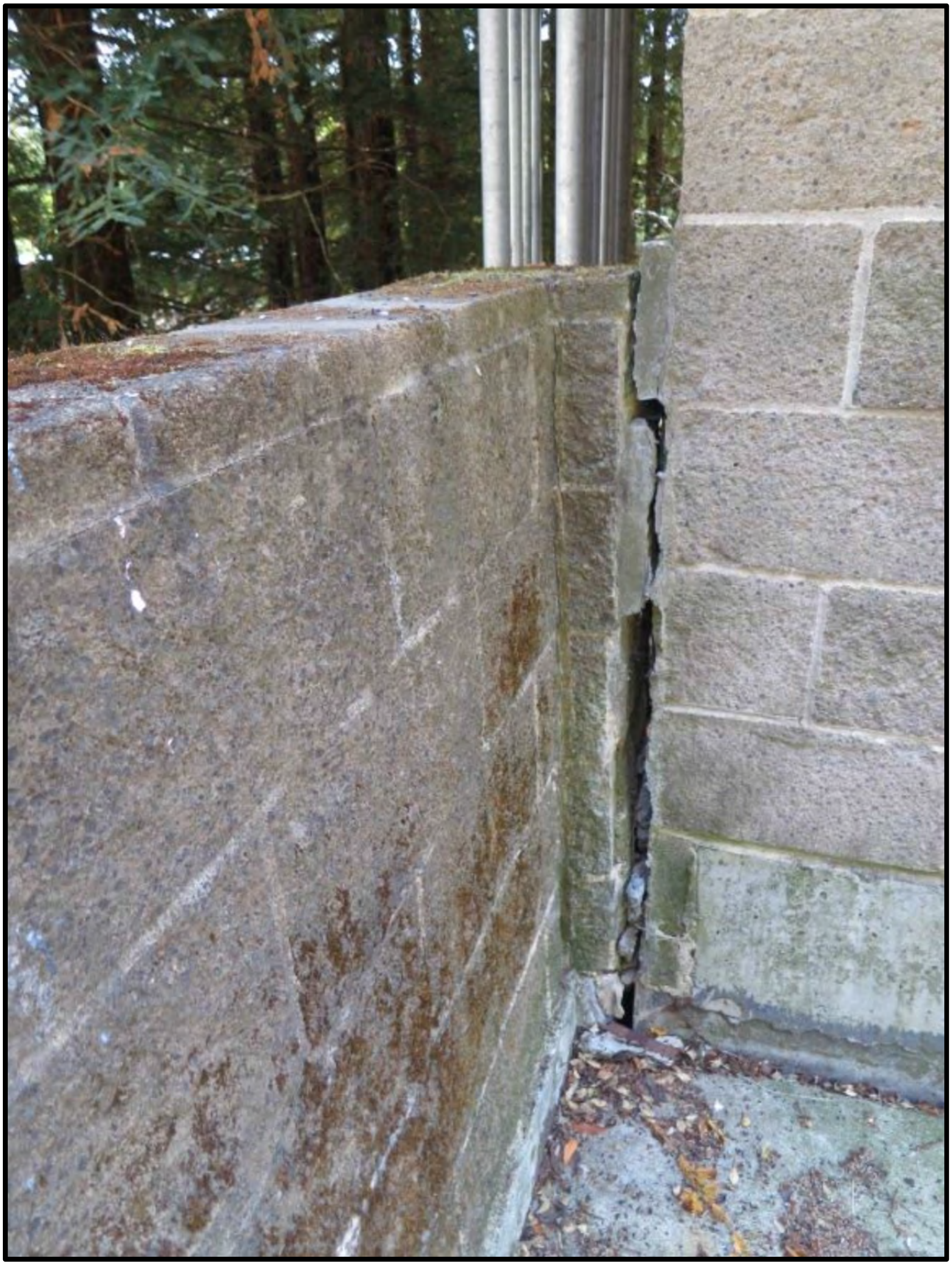


Figure 12: Separation of Parapet Wall (control building) from Solid Waste Building

7.2.5 Flocculation Tank

There is a flocculation tank in a rectangular concrete vault. From an inertial point of view, the concrete vault is adequate to handle ground shaking hazards.

Vulnerabilities

Adjacent to the flocculation tank is a vertical chemical tank (plastic). The plastic tank is tied down with steel cables, to prevent rocking (and sliding to a lesser extent) under seismic motions. Although the steel cables are adequate for inertial loads, the attached pipes may be damaged if there are PGDs.

Mitigations

None recommended.

7.2.6 Ultraviolet Treatment and Filters

Vulnerabilities

The UV system is composed of several arrays of vertically-oriented glass tubes that are inserted into the water. It is unknown if such a system has undergone strong earthquake shaking in the past, and it is possible that rattling of the glass tubes within or above the water will result in occasional glass breakage.

The UV treatment system is located under a steel frame, which is adequate for inertial loading.

Adjacent to the UV system are two steel water-holding tanks for the tertiary filters resting on a concrete pad that do not appear to be anchored. Assuming the tanks are full of water during an earthquake, the tanks could slide sideways a few inches; this would lead to damage to several of the attached pipes.

Mitigations

For purposes of this report, it is suitable to allow for UV System damage under an earthquake, and have plans to make repairs within 2 weeks (for sporadic damage of tubes) or 12 weeks (for major damage).

It is recommended that the water-holding tanks be anchored and all attached pipes be upgraded to accommodate up to 3 inches of differential movement.

7.2.7 Ponds

There are two ponds to store recycled water from the tertiary filers. The larger pond has 3.5 MG capacity; the smaller pond has 1.0 MG capacity.

The recycled water is transported directly from the 3.5 MG holding pond to the seasonal discharge locations, including nearby forests and the Northwood Golf Course. Tertiary effluent that does not meet water quality standards is automatically diverted to the 1 million gallon emergency pond, where it is then pumped back to the headworks or to an aeration basin for retreatment.

Vulnerabilities

The ponds are formed by cut into the site; possibly with fill at the southern embankments. The slopes are lined with asphalt-type material. Under strong shaking, sloshing of water out of the ponds (if full) will occur; this is considered acceptable.

Mitigations

None recommended.

7.2.8 Housekeeping

The term "housekeeping" refers to two types of seismic issues:

- Equipment with inadequate anchorage / restraint, and whose failure would impact plant operations. For example: switchgear.
- Items with inadequate anchorage / restraint, and whose failure might result in some losses, but unlikely to impact plant operations. For example: storage cabinets, suspended ceilings over office areas.

Vulnerabilities

The following housekeeping items were assessed:

- The emergency generator uses manufacture-supplied isolation mounts. The start-up battery for the emergency generator is adequately installed.
- Air blowers and blowers were adequate.
- A chemical mixing tank is anchored.
- A water heater tank is not anchored.
- Electric switchgear cabinets in the control building (9 bays) and the blower building have unknown anchorage.
- Two vertical air tanks are unanchored.
- House transformers were anchored.
- The suspended ceiling over an office room (containing SCADA equipment) is likely non-seismic. There are no fire sprinkler heads through the tiles.
- A 6-bay switchgear cabinet is located in the control building in the SCADA room; anchorage was not confirmed.
- A SCADA cabinet is marginally anchored.
- There is a loose computer in the SCADA room.
- There are several unanchored storage shelves in the water quality lab.
- There are counter-top ovens (and similar) devices in the water quality lab. These devices have small counter-top lips to prevent slippage to the floor below. There are several floor-mounted storage shelves and fridges that are unanchored / on wheels in the water quality lab.
- There is a counter-top oven / device in the water quality lab. This has no counter-top lip to prevent slippage to the floor below.
- The SCADA cabinets in the blower building are anchored.
- There is an unanchored cabinet in the blower building.

Mitigations

All cabinets that are unanchored/ marginally anchored should have anchors/ restraints based on PGA = 0.34g with Ip = 1.5, where anchor bolts have a factor of safety of at least 2 for these loads (R = 1). All shelves and racks are recommended to be anchored and the shelves should be modified to have restraints to prevent items from sliding onto the floor. Adding low cost restraint devices to lab equipment would prevent the equipment from rocking during ground shaking.

For very strong shaking, it is recommended to install supplemental snubbers to the emergency generator.

A seismic-rated ceiling could be installed, but this is considered low priority because falling tiles can be readily addressed post-earthquake, and there is little life safety risk.

7.2.9 Landslides

There are series of geologic and seismic conditions that could adversely affect the improvements and operations of the plant, both in a static and seismic situation. The plant has already been adversely affected by a debris flow circa 1992 that originated off-site on the slopes and traveled between the clarifier area of the plant and the mechanical building, into the downslope effluent storage reservoir.

Vulnerabilities

There is little to no protection from such slope movements to protect the facility at this site. The slopes immediately adjacent and upslope of the site are prone to landsliding, including relatively fast-moving and laterally extensive debris flows Giblin Associates (2002) performed an evaluation of the site in preparation for the 2003 Third Process Line Project, and reported that debris from earlier flows were approximately 6 feet deep at the site of the 60-foot clarifier. Additionally, a large debris flow in 1992 was triggered by heavy rains when debris extended into the effluent reservoir. The paths of debris flows are shown on Figure 13.

Mitigations

All of the slopes bordering the northern boundary of the site should be considered to have a high potential for landsliding, both statically (due to seasonal heavy rains) and seismically (due to intense shaking). Giblin recommended improvement in upslope drainage to reduce the risk of future rain-initiated debris flows. Debris slides can be initiated by seismic shaking, and although improved drainage will reduce the risk, the risk remains substantial.

A comprehensive geologic and geotechnical assessment should be performed on these slopes, which include offsite properties, to refine the areas of existing and potential landsliding and development of mitigation alternatives to protect the plant from impact due to landsliding. Design mitigation scheme could include construction of debris diversion/catchment walls or impact fences to protect the essential operations of the treatment plant. See Figure 14. These could be deep-founded structures (possibly soldier-pile walls) intended to deflect the debris away from the primary operational areas of the plant or catchment type fences that prevent the debris from crossing the site or impacting improvements.

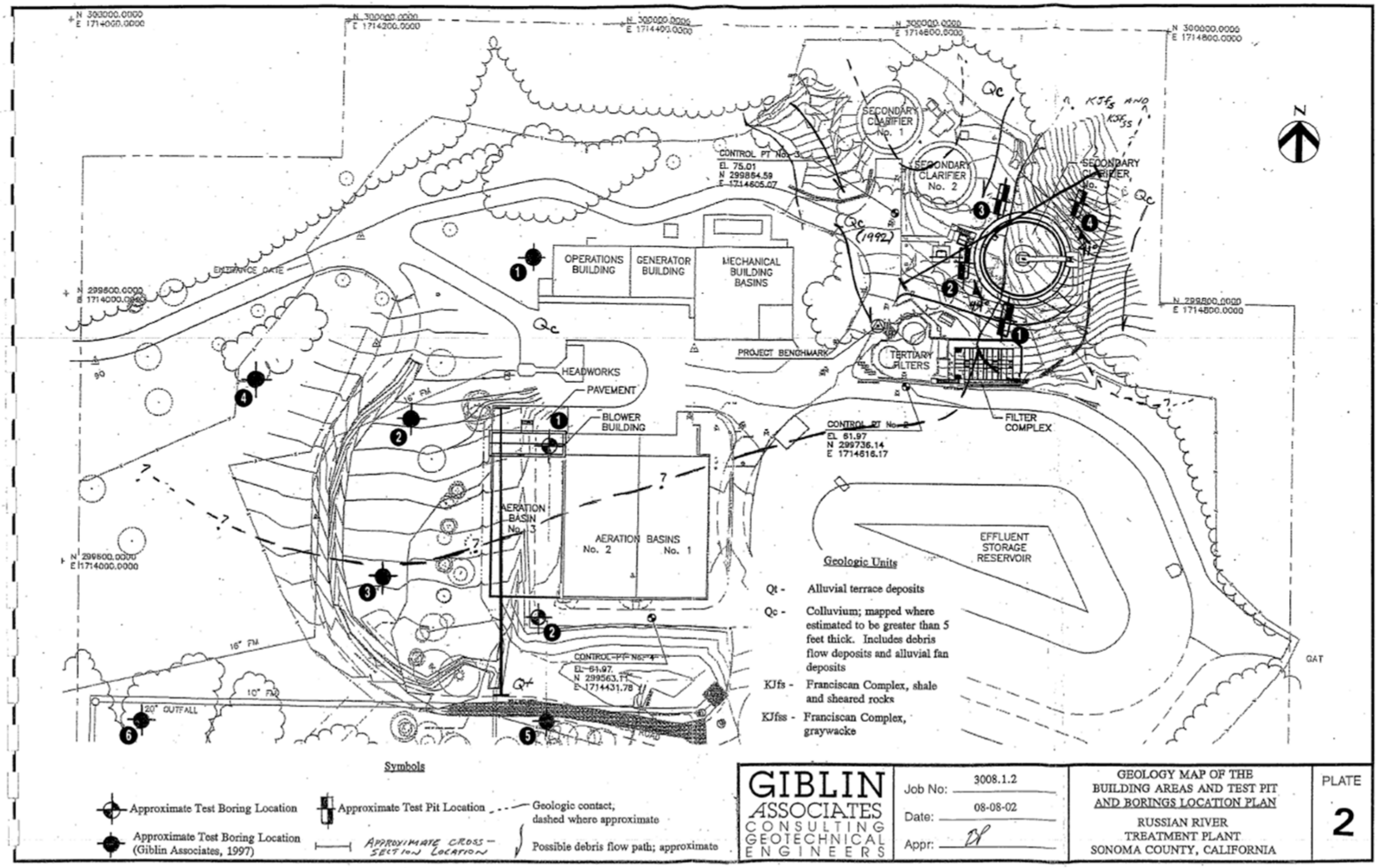


Figure 13: Debris Slides at Russian River WWTP

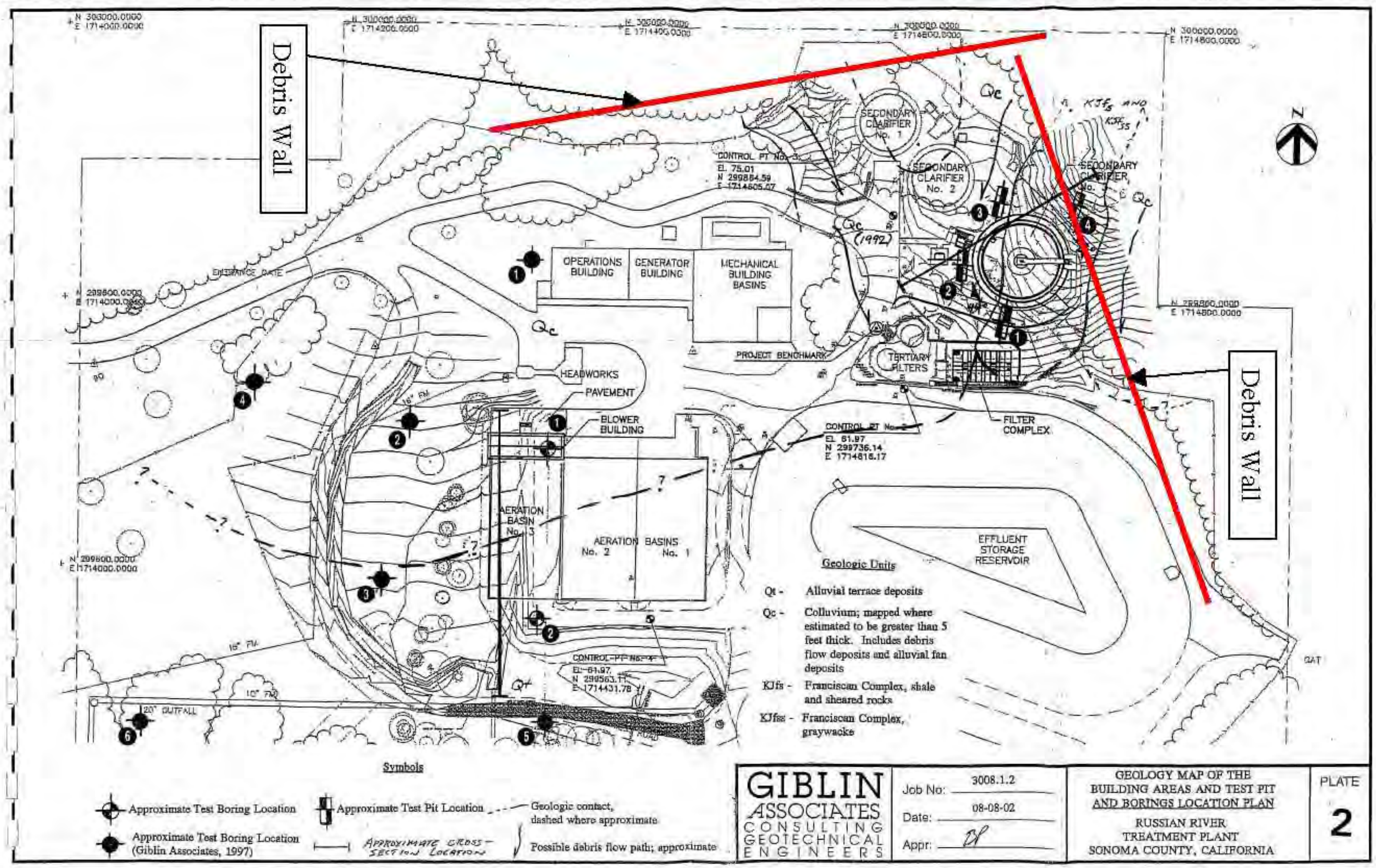


Figure 14: Recommended Debris Diversion Structures at RRCSD WWTP

7.3 Lift Stations

There are 11 lift stations in the RRCSD collection system. The lift stations are generally seismically rugged, being comprised of a wet well, pumps and motors and switchgear. All lift stations have submersible pumps. The following is a listing of the lift stations:

- S57. Drake Estates (2 pumps)
- S56. Rio Nido (3 pumps)
- S58. Drake Road (2 pumps)
- S54. Laughlin Road (2 pumps)
- S55. Watson Road (2 pumps)
- S53. Guerneville Lift (3 pumps)
- S59. Beanwood (3 pumps)
- S60. Center Way (2 pumps)
- S52. Guernewood Park (2 pumps)
- S51. Main (3 pumps)
- S61. Vacation Beach (2 pumps)

Vulnerabilities

As part of this project, several lift stations were visited but in-depth inspections were not completed, nor were the design drawings for the lift stations. However, based on the limited inspections, the following assumptions have been made:

- The lift stations are located in areas not prone to liquefaction; or were designed to not become buoyant should liquefaction occur.
- The lift stations are not prone to lateral spreads due to liquefaction.
- As part of implementation of a seismic improvement plan, these assumptions should be validated.

Mitigations

It is recommended that RRCSD make provisions to have on hand, a sufficient number of emergency generators to operate critical lift stations in the system within 48 hours following a San Andreas M 8 earthquake. In particular, the Vacation Beach Lift Station that is powered by the Russian River Treatment plant generator. Guernewood Park, Guerneville, and Beanwood Lift Stations are powered by the Main Lift Station which contains an old generator. The generator at the Main Lift Station should be replaced, the system providing the distribution of power should be evaluated and portable generators should be made available depending on the results of evaluation of the electrical distribution system. This presumes dry weather flows at the time of the earthquake. By "critical", it is meant that a lift station that is needed to operate, under dry weather flows, within 48 hours of the earthquake, otherwise a sewage backup and spill will occur. This presumes there will generally be potable water flowing after the earthquake.

After 120 hours, it is reasonable to assume that PG&E power will be restored to the Main Lift station; but having emergency generators may still be needed for a couple of lift stations. All lift stations should be outfitted with quick connect couplings (sometimes called "pigtails") to allow rapid hook-up to an emergency generator (i.e., just plug in, use a manual transfer switch; and not requiring an electrician to wire the emergency generator into the bus).

7.4 Emergency Response

This report addresses only the Russian River District. For emergency response planning, it would be prudent to collectively use the resources from all parts of the SCWA sanitation systems.

Vulnerabilities

A number of pipes in the RRCSD collection system may be damaged or broken due to liquefaction.

Mitigations

It is recommended that RRCSD have on hand at least two sets of portable pumps and suitable lengths of large diameter hose (typically 12-inch diameter) so that emergency bypass around broken pipes in the RRCSD can be made. Specifically, the following equipment is recommended:

- 2 sets of pumps (with engine sets).
- 1,200 feet of 12-inch diameter hose. This should be enough hose to bypass two sets of manholes spaced about 500 feet apart. The hose should be in variable lengths to allow for different actual lengths that might be needed.
- Include in the emergency response plan the ability to obtain additional pumps and hose from other agencies, should the need arise.
- Include one pump / engine set and half the hose as "high" priority; the second pump / engine set and the remaining hose as "moderate" priority.

8. References

8.1 General References

ALA, Seismic Fragilities for Water Systems, American Lifelines Alliance, March 2001.

ALA, Seismic Guidelines for Water Pipelines, American Lifelines Alliance, NIBS and FEMA, March 2005. http://www.americanlifelinesalliance.org/Products.htm#Guidelines

ASK 13. Abrahamson N., Silva W., Kamai, R., Update of the AS08 Ground-Motion Prediction Equations Based on the NGA2-West Data Set, Pacific Earthquake Engineering Research Center, PEER 2013/04, May 2013.

Benuska, L., Ed., Loma Prieta Earthquake Reconnaissance Report, Earthquake engineering Research Institute, Supplement to Volume 6, 90-01, 1990.

Blake, M. C., Graymer, R. W., and Stamski, R. E., Geologic Map and Map Database of Western Sonoma, Northernmost Marin, and Southernmost Mendocino Counties, California. USGS Miscellaneous Field Studies MF 2402, 2002.

BSSA13. Boore D., Steward, J., Seyhan, E., Atkinson G., NGA-West2 Equations for Predicting Response Spectral Accelerations for Shallow Crustal Earthquakes, Pacific Earthquake Engineering Research Center, PEER 2013/05, May 2013.

CB 13. Campbell, K., Bozorgnia, Y., NGA-West2 Campbell-Bozorgnia Ground Motion Model for the Horizontal Components of PGA, PGV and 5% Damped Elastic Pseudo-Acceleration Response Spectra for Periods Ranging from 0.01 to 10 sec, Pacific Earthquake Engineering Research Center, PEER 2013/06, May 2013.

CY 13. Chiou, B., Youngs, R., Update of the Chiou and Youngs NGA Ground Motion Model for Average Horizontal Component of Peak Ground Motion and Response Spectra, Pacific Earthquake Engineering Research Center, PEER 2013/07, May 2013.

Eidinger, John (Editor), TCLEE, No. 19, Gujarat (Kutch) India, M7.7 Earthquake of January 26, 2001 and NAPA M5.2 Earthquake of September 3, 2000, June 2001.

Ellsworth, W. L., J. A. Olsen, L. N. Shijo and S. M. Marks, "Seismicity and Active Faults in the Eastern San Francisco Bay Region," Conference on Earthquake Hazards in the Eastern San Francisco Bay Area, California Division of Mines and Geology, Special Publication 62, 1982.

Geomatrix Consultants Inc., Seismic Ground Motion Study for San Mateo - Hayward Bridge, San Mateo and Alameda Counties, California: Final Report, prepared for Caltrans, Division of Structures, Sacramento, Contract No. 59N772, Project No. 2016G, California, February, 1993.

Huffman, M.E., and Armstrong, C.F., 1980, Geology for planning in Sonoma County: California Division of Mines and Geology Special Report 120, 31 p., 5 pls., scale 1:62,500.

I 13. Idriss, I. M., NGA-West2 Model for Estimating Average Horizontal Values of Pseudo-Absolute Spectral Accelerations Generated by Crustal Earthquakes, Pacific Earthquake Engineering Research Center, PEER 2013/08, May 2013.

International Building Code (IBC). International Code Council, Inc. 2012.

Kleinfelder, Regional Maps for Russian River County Sanitation District, prepared for GHD, 2013.

Knudson, Keith, Sowers, Janet, Witter, Robert, Wentworth, Carl, and Helley, Edward, Preliminary maps of quaternary deposits and liquefaction susceptibility, nine-county San Francisco Bay region, California, U.S. Geological Survey Open file Report 00-444, V. 1.0, 2000.

Niemi, T.M., and Hall, N.T., "Late Holocene Sliprate and Recurrence of Great Earthquakes in the San Andreas Fault in Northern California," Geology, v. 20, 1992.

Ramsey, D.W., and Godt, J.W., 1999, Map showing locations of damaging landslides in Sonoma County, California, resulting from 1997-98 El Nino rainstorms: US geological Survey MF Field Studies Map MF-2325-F.

Real, C.R., Toppozada, T.R., and Parke, D.L., Earthquake Catalog of California, January 1, 1900 - December 31, 1974, California Division of Mines and Geology, Special Publication 52, 1978.

Toppozada, T.R., C.R. Real, S.P. Bezore, and D.L. Parke, Compilation of pre-1900 California Earthquake History: Annual Technical Report - Fiscal Year 1978-79, California Division of Mines and Geology, Open-File Report OFP 79-6 SAC., 1979.

Toppozada, T.R., C.R. Real, and D.L. Parke, Preparation of Isoseismal Maps and Summaries of Reported Effects for pre-1900 California Earthquakes: Annual Technical Report - Fiscal Year 1980-81, California Division of Mines and Geology, Open-File Report OFP 81-11 SAC., 1981.

Wills, C.J., Perez, F., Gutierrez, C, 2011, Susceptibility to deep-seated landslides in California, CGS Map 58, MS58.pdf

Witter, R.C., Knudsen, K.L., Sowers, J.M., Wentworth, C.M., Koehler, R.D., and Randolph, C.E., Maps of Quaternary deposits and liquefaction deposits in the central San Francisco Bay region, California: U.S. Geological Survey Open-File Report 06-1037, 2006.

Working Group on California Earthquake Probabilities, 2003, Earthquake Probabilities in the San Francisco Bay Region: 2002 to 2031, U.S. Geological Survey, Open-File Report 03-214.

Working Group on California Earthquake Probabilities, The Uniform California Earthquake Rupture Forecast, Version 2 (UCERF 2), The 2007, USGS Open File Report 2007-1437, CGS Special Report 203, SCEC Contribution #1138, 2008.

Youd, T.L. and Perkins, D.M., Mapping of liquefaction induced ground failure potential: Journal of the Geotechnical Engineering Division, ASCE, B. 104, no. 4, p. 433-446, 1978.

8.2 SCWA References

Cotton, Shires and Associates, Inc., Engineering Geologic Technical Memorandum - Equalization Basin Russian River County Sanitation District Facility, Guerneville, California, February 16, 2011.

Earth Sciences Associates. Geotechnical Report associated with original WWTP plant design (c. 1978). This report is references in the original plant drawings, but was not available for review.

EBA Engineering, Additional Soil and Groundwater Assessment Report, Russian River Treatment Plant, 18400 Neeley Road, Guerneville, California, prepared for the Sonoma County Water Agency, July 2002.

Giblin Associates, Geotechnical Investigations, Russian River County Sanitation District, Disposal Expansion Project, Study Area A, January 27, 1997a.

Giblin Associates, Geotechnical Investigations, Russian River County Sanitation District, Disposal Expansion Project, Study Area B, January 27, 1997b.

Giblin Associates, Geotechnical Investigation, Russian River Treatment Plant Expansion Project, Sonoma County, California, prepared for HDR, September 6, 2002.

Giblin Associates, Supplemental Report Soil Engineering Consultation Russian River Equalization Basin, Sonoma County, California, prepared for Sonoma County Water Agency, January 15, 2007.

8.3 Drawings

Emergency Generator Replacement, (15 sheets), Russian River County Sanitation District, 2009.

HDR, Biological Nutrient Removal, (48 sheets), Russian River County Sanitation District, 2013.

HDR, Disinfection Upgrade, (35 sheets, with specifications and addenda), Russian River County Sanitation District, 2011.

HDR, Tertiary Upgrade – Clarifier, (17 sheets), Westech, Russian River County Sanitation District, 2003.

HDR, Third Unit Processes Project (75 sheets), Russian River County Sanitation District, (Third clarifier, third aeration basin, blower building, filters) 2003. James Montgomery, Volume 2, Drawings (123 sheets), Russian River County Sanitation District, As-Built Drawings, 1978.

SCWA, Installation of Above Ground Storage Tank, (4 sheets), (Fuel Oil for Diesel Generator) Russian River County Sanitation District, 1995.

Appendices

Appendix A - Performance of the Wastewater System in the Christchurch, New Zealand Earthquakes of 2010 - 2011

Appendix A

A. Performance of the Wastewater System in the Christchurch, New Zealand Earthquakes of 2010 - 2011

Appendix A describes the performance of the wastewater systems in Christchurch and nearby Kaiapoi, New Zealand in the earthquakes of September 2010 and February 2011. This report is adapted from Eidinger and Tang (2014, in press).

Relative to the Russian River County Sanitation District (RRCSD), there are number of similarities:

- Facilities were originally designed for earthquake inertial loading. In New Zealand, the buildings were commonly designed for about PGA = 0.3g. For RRCSD, buildings were commonly designed for about PGA = 0.4g (original construction) to 0.5g (newer construction). In New Zealand, actual ground motions at the WWTP were about PGA = 0.2g (September 2010 earthquake) or PGA = 0.5g (February 2011 earthquake). With only a few exceptions, there was little damage in either earthquake caused by strong earthquake inertial loading.

- Liquefaction was pervasive in the Christchurch area. Underground collection pipes, manholes and lift stations were not designed for liquefaction. For the RRCSD, liquefaction can occur in future earthquakes in the collection system, and at the WWTP.

The key observations are as follows:

- Damage to the wastewater systems in New Zealand was pervasive, costly to repair, and time consuming to restore regular service. There were many raw sewage spills into creeks and the ocean. Tens of thousands portable toilets had to be used to provide temporary human waste facilities.

- Of the damage to all utilities, including power, water, telecommunications, liquid fuels, highways or natural gas, the damage to the sewer system caused the most pervasive disruption to people.

- The primary hazard that led to the disruption was liquefaction. Liquefaction destroyed many buried pipes in the collection system. None of New Zealand's buried pipes were designed to accommodate liquefaction. Liquefaction at the Bromley WWTP damaged pipes at the site, as well as clarifiers. Liquefaction uplifted manholes and lift stations, destroying the ability to pump and move sewage. Damage to buried pipes led to large infiltration of sands and silts, clogging up the WWTP.

- Repair of buried sewers takes 3 to 10 times as long as repair to buried water pipes, even if the pipes have the same style of construction This is because most gravity sewers are buried 10 feet (or more), whereas most water pipes are buried 3 to 4 feet. With the deeper burial for sewer pipes, repair requires more costly and time consuming excavations and dewatering.

To avoid the adverse consequences that occurred in New Zealand, RRCSD needs to do the following:

- Quantify the damage to buried collection pipes and sewers due to liquefaction caused by earthquakes on the nearby Rodgers Creek fault.

- Quantify the damage to buried pipes and tanks at the WWTP due to ground shaking caused by earthquakes on the nearby Rodgers Creek fault.

- Determine if the damage is repairable within target restoration times. Determine if coincident sewage releases, are environmentally acceptable.

- Develop a suitable emergency response plan that can address the potential damage. This might include a combination of portable toilets; pipe and facility inspection and repair capability.

If the existing consequences are not acceptable, develop a pre-earthquake mitigation plan. The mitigation plan should likely concentrate on the installation of liquefaction-resistant pipelines such as HDPE; or ground improvement. These mitigations should be implemented where they are suitable and prioritized considering cost effectiveness.

A.1 Overview of the Wastewater Systems

There are two major wastewater operators in the affected area. The Christchurch City Council (CCC) operates the wastewater system for Christchurch and the Waimakariri District Council (WDC) operates the wastewater systems for Kaiapoi and Rangiora (population about 45,000 people).

Section A.2 discusses the wastewater system performance in the September 4, 2010 earthquake. Section A.3 discusses the wastewater system performance in the February 22, 2011 earthquake. Section A.4 summarizes the performance over the two earthquakes. Section A.5 provides Observations. Sections A.6, A.7, A.8 provide acknowledgements, list of abbreviations and references.

While both earthquakes created a lot of damage to the wastewater systems, the February 22, 2011 event was far more catastrophic as liquefaction was far more extensive. The more widespread liquefaction caused many more pipe failures in the February 22 2011 earthquake, as well as damage to a few additional sewer lift stations. This led to:

- Far more infiltration of sand and silts into the broken sewer pipes, which eventually made it downstream to:

- The Bromley WWTP. The huge amount of silts and sands entering the primary settling tanks at Bromley led to constant failures of the grit removal system. In the 6 weeks after the February 22 2011 earthquake, it is estimated that about 1,000 tons of silts and sands were removed from the primary setting tanks at Bromley using excavators. Compounding this was:

- Liquefaction seriously damaged three (possibly all four) circular clarifiers (secondary treatment) at the WWTP. These were not functional months after the earthquake.

- Water velocity (sloshing) forces were the likely cause of many pipe breaks of the aeration pipes at the WWTP.

- The trickling filters and digesters were non-operational two months after the earthquake.

- High BOD in the effluent through the limited settling action from the primary settling basins was being discharged into the aeration ponds. Unless this could be mitigated, there was concern that the ponds would turn anaerobic within a few more months. If this happened, the site would smell like a cesspit; as the prevailing winds are from the east, the smell would drift over the central business district and many other parts of Christchurch, which would likely hamper restoration efforts.

- Damage to the sewer pipes and treatment plant has required about 2/3 of the raw sewage to be discharged directly into the rivers and estuaries.

A.2 Earthquake of September 4 2010

Figures A-1 to A-4 show the Christchurch City Council (CCC) Bromley wastewater treatment plant (WWTP). This facility treats most of the sewage for urban Christchurch, treating from 130 million to 160 million liters per day (33 to 42 MGD). The treated effluent was formerly discharged into the Avon-Heathcoate Estuary, with plans for a 3 km-long ocean outfall. Processes at the WWTP include removal of debris and grit; aeration to minimize odors; primary sedimentation to remove settleable organic matter and suspended solids; biological treatment in trickling filters and an activated sludge process; and oxidation pond treatment to reduce pathogen content.

Figure 7-1. Christchurch WWTP at Bromley

The primary damage to the WWTP in the September 2010 earthquake was State Highway 71 between Ponds 2 and 4 (Figure A-2) was closed due to 50 cm cracks. The pipe between oxidation ponds 2 and 4 had to be replaced. The levee between Ponds 1 and 2 cracked and slumped. There were sand boils in many placed, with observed PGDs of 30 cm horizontal and 20 cm vertical.

Figure A-2. Christchurch WWTP at Bromley

Figure A-3. Bromley WWTP

The Christchurch wastewater system includes about 1,767 km of sewer mains, 950 km of laterals, and 86 pump stations. Available data shows that 1,337 km of collection pipe are "brittle" (including concrete pipe, vitrified clay pipe) and 430 km are "ductile". There are about 26,000 manholes. Rates at the WWTP are about 2.5 to 2.8 m^3/second during dry weather, peaking to about 8 m^3/sec during 2-year storms. The system is sized with recognition that overflows from large storm events will occur about once every two years.

The common styles of sewer pipelines in the CCC system include segmented concrete and vitrified clay pipes. The common styles of sewer pipelines in the WDC system include AC and PVC of the same type of construction as water pipes.

Through October 14, 2011 (6 weeks post-earthquake), there had been about 200+ repairs (CCC) and 100+ repairs (WDC) made to wastewater pipes and their service connections; most of these repairs were in the liquefaction zones. The order of repair, using substantially the same work crews, was water pipelines first, followed by wastewater pipes.

While both CCC and WDC suspect damage to their storm water drain pipes, their priority to repair such damage was lower than for water or wastewater pipes, and actual repair efforts for drain pipes are not yet known.

Two of CCC's wastewater dry well lift stations (Figures A-4, A-5) next to the Avon River were subjected to liquefaction and lateral spreads, and they floated and tilted. While the equipment within the lift stations may not have been damaged, the sewers leading to and from the lift stations were broken, and CCC bypassed these lift stations using portable pumps and flex hose.

Figure A-4. Floated and Tilted Wastewater Life Station 26, Porritt Park, Avonside

Figure A-5. Floated and Tilted Wastewater Life Station 27, Avonside

Damage to sanitary sewers (Figures A-6 and A-7) in many places led to direct discharge of untreated sewage into local rivers, leading to contamination warnings. Damage to the sewers has also resulted in substantial inflows of silts, leading to clogging of sewers, as well as infiltration of ground water.

Figure A-6. Floated Sewer Manhole, Brooklands (one of fifteen)

Figure A-7. Floated Sewer Manhole, Brooklands (one of fifteen)

Figure A-8 shows a lift station in the Brooklands area. It appears that there was as much as 6 to 10 inches of settlement around the concrete wet well.

Figure A-8. Settlement due to Liquefaction, Lift Station in Brooklands

Figures A-9 to A-12 show typical images from CCTVs as to the type of damage within sewer pipes. The damage to brittle pipe is obvious. High volume infiltration of ground water, taking with it silts and sands of the streets, was problematical in the September 4 2010 earthquake, and an absolutely critical problem in the February 22 2011 earthquake.

Figure A-9. CCTV picture of Broken Sewer, WDC

Figure A-10. CCTV picture of Broken Sewer, WDC

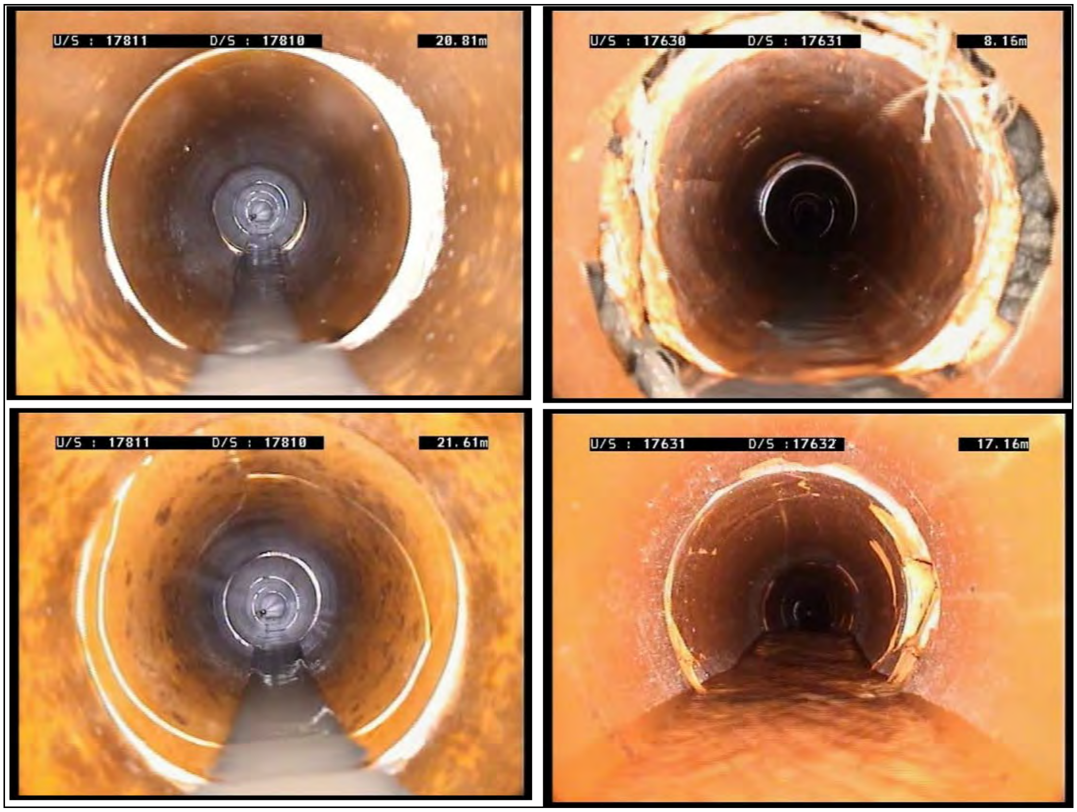


Figure A-11. CCTV picture of Broken Sewers, WDC

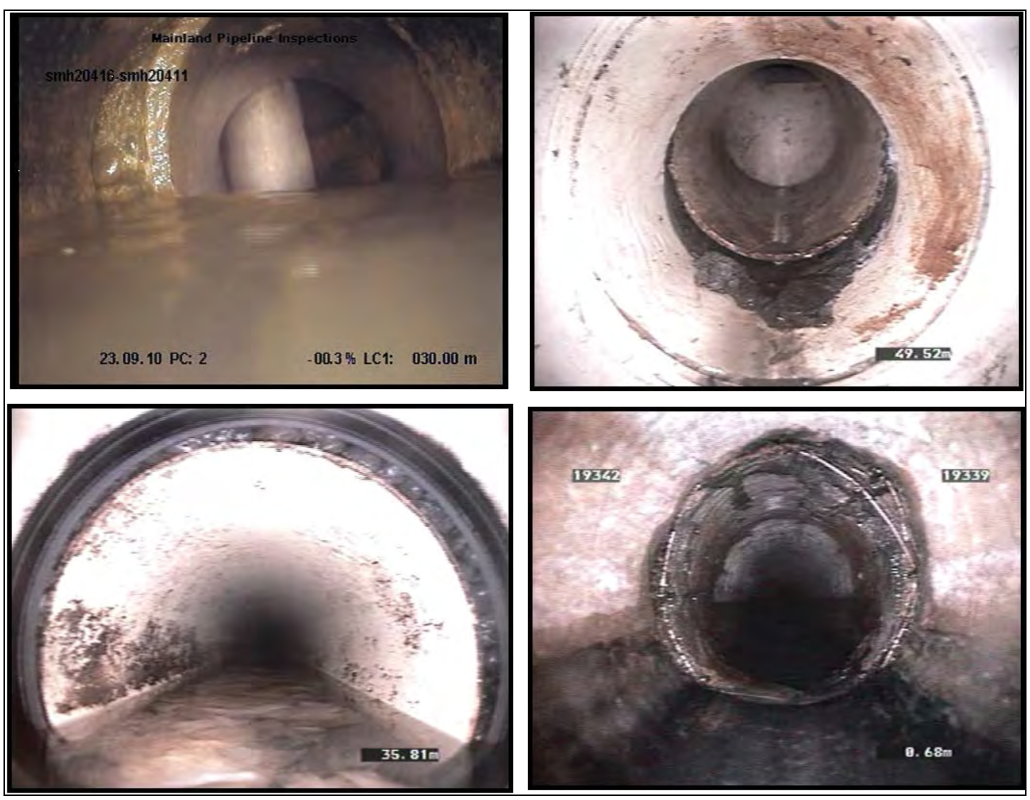


Figure A-12. CCTV picture of Broken Sewers, WDC

Figure A-13 shows a map for Kaiapoi highlighting where the wastewater collection had failed and portable toilets were still in use 6 weeks after the earthquake; more than 200 structures were also so-affected in Christchurch. As of September 29, 2010, there were 150 customers in Kaiapoi and 50 in Pines Beach without any piped sewage service; with the remaining ~95% having piped sewage service.

Through mid-October, 2010, the CCC had spent about $12 million ($NZ) on repairs to water and wastewater pipes. A much higher cost will be required to completely restore CCC's wastewater systems entirely. CCC staff estimate that as much as 70 km of wastewater pipes will have to be eventually replaced entirely; the location of these replacements coincides with the zones that underwent substantial liquefaction-caused settlement or lateral spread. The majority of the cost for these long term improvements will be to replace deeply-buried (commonly about 10 feet) sanitary sewers.

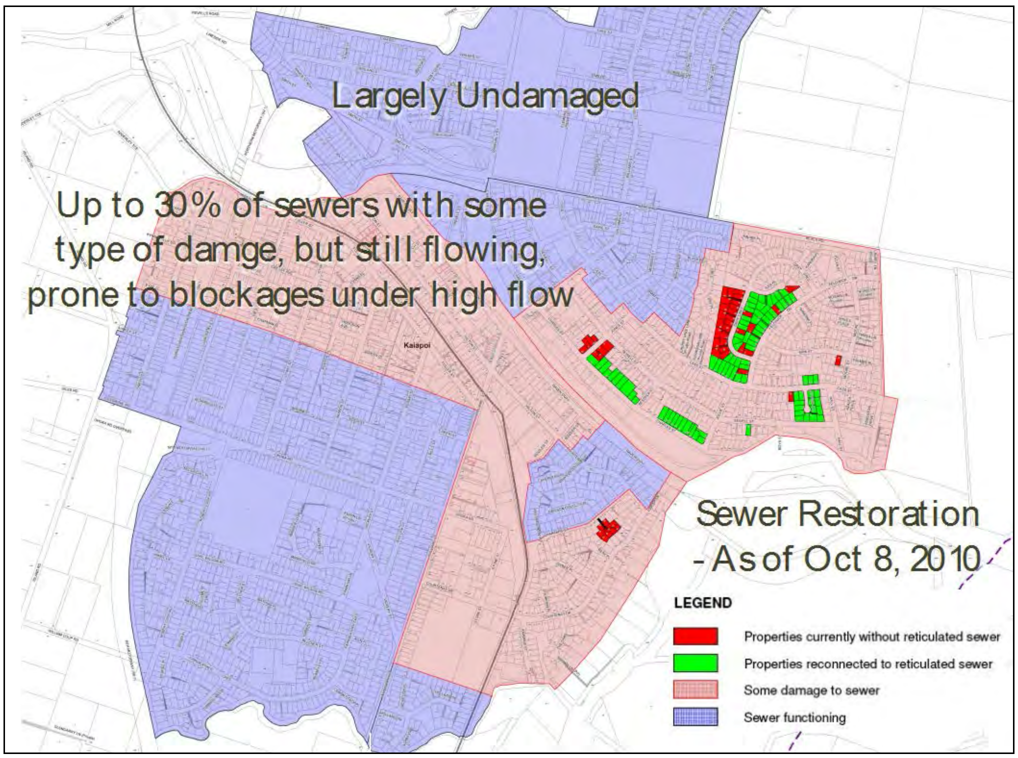


Figure A-13. Map of Sewer Restoration, Kaiapoi, WDC, as of October 8, 2010

Figure A-14 shows a broken sewer pipe that was hung on the side of a bridge. The blue "flex hose" was added to the broken pipe to direct sewer discharges directly into the creek. According to the design of this bridge, the bridge was originally built in the 1960s; it suffered no damage (except for settlement of the roadway of a couple of inches at each abutment). At the time it was originally built, it had no attached pipes. The broken sewer pipe is attached to the bridge at several points using both gravity-only as well as lateral supports; nominally, it would "be acceptable" per the IBC 2012 code. However, the pipe was too rigidly supported, and settlement of one abutment (far side in this photo) led to failure of the pipe.

Figure A-14. Broken Sewer Pipe

Releases of raw sewage into rivers was not uncommon. In Kaiapoi, the discharge pipe from the Charles Street pump station broke where it crossed underneath the Kaiapoi River. WDC repaired the pipe, and then it was damaged again. It took weeks to replace the pipe under the river, all the while discharge was going directly into the river.

It was estimated in early October that it would take until late October 2010 to repair the sewer pipes form Pines Beach / Kairaki to the Kaiapoi WWTP; until that time, sewage was being discharged directly into the lower Waimakariri River.

The Avon/Otakaro, Heathcoate, Styx and Halswell Rivers were all considered polluted with raw water sewage spills as of October 8, 2010. Also affected were the Kaiapoi River, Kairaki / Saltwater Creek and Lower Waimak Rivers. There was concern that heavy rainfall may flush accumulated sand and silt from the storm water drains into the rivers, creating high turbidity. By mid-October 2010, it was felt that the remaining broken sewers could "mostly" be bypassed during dry weather, but spills would be much harder to control in wet weather.

All Oceanside areas from Sefton in the north, including Christchurch, Lyttleton Port, the entire Banks Peninsula, to Tumutu in the south, were considered to have high coliform / bacteria counts and deemed unsafe for swimming.

Figure A-15 shows a common approach to repairing the damaged sewers. First, the site had to be dewatered. Second, as the pipes are buried deeply (commonly 3 meters of cover), sheet piles (or trench shields) needed to be installed. Finally, the pipe could be repaired / replaced. This is both a time consuming and expensive effort. Figure A-16 shows a crew working on repair of a deep sewer. Figure A-17 shows a damaged vitrified clay pipe waiting to be repaired.

Figure A-15. Repair of Sewer Pipe

Figure A-16. Repair of Sewer Pipe

Figure A-17. Repair of Vitrified Clay Sewer Pipe

Figure A-18 shows a map with the location of repairs made to water (blue dot), wastewater (red dot) or storm water (green dot) pipes in Pine Beach. Much of the Pines Beach community underwent some amount of liquefaction. Figure A-19 shows a similar map for the main urban area of Kaiapoi.

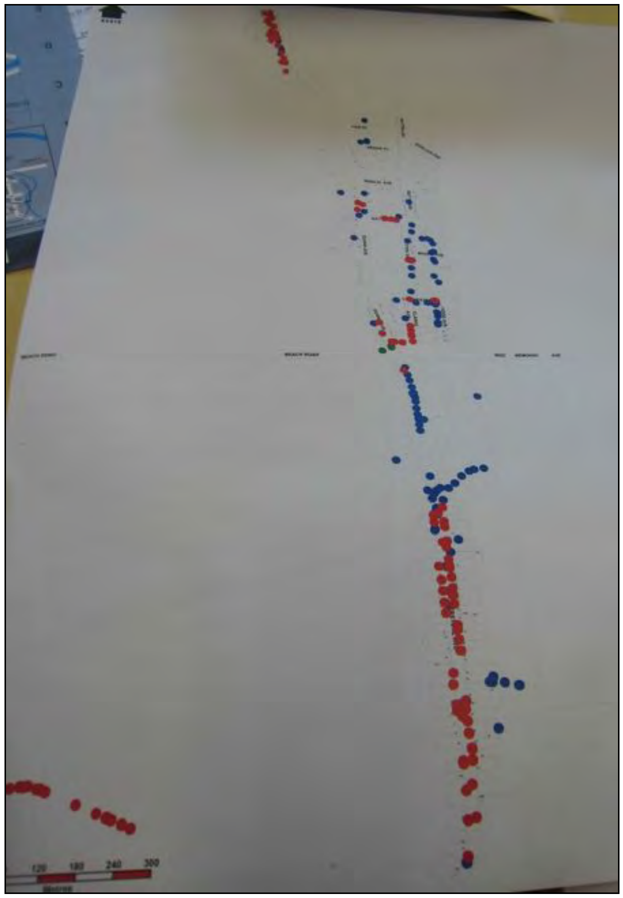


Figure A-18. Pipe Repairs in Pine Beach

Figure A-19. Pipe Repairs in Kaiapoi

In Christchurch, the sewer repair strategy included the following:

- Portable toilets were placed outside houses that lost sewer service, generally one portable for two houses (Figure A-20).

- By October 15, small tanks were installed on berms or in front of properties without sewer service, where the sewer mains were so badly damaged that they could not be repaired. These portable tanks were attached to the sewer from the house, to allow the households to use internal toilets, showers and washing machines. By October 15, 37 households had these tanks installed, and the goal was to install these tanks for all 235 households still out of service. Five crews worked on this effort

- By October 15, 2010, limited wastewater service had been restored in the CCC area to 2,518 properties.

For permanent repair, CCC was considering installing pressure pipes (force mains) at the affected houses in the liquefaction zones. These pressure pipes would require a pump to be installed at each house. It was felt that a pressure system, while costlier in terms of electricity and pumps, would be faster to install than a traditional deeply buried gravity main. The issues as to who pays for the pressure pipes, pumps and ongoing maintenance was not resolved as of October 15, 2010.

Figure A-20 shows the locations where portaloos were in use as of October 11, 2010, in the Dallington / Avonside / Burwood area of Christchurch. The colored dots reflect the agency that provided the portaloos (numbers indicate the number of portaloos at the site). The color road lines indicate roads where sewage service has been fully restored (blue), partially restored (green) or remained out of service (yellow). Figures A-21 to A-26 show similar information for the Bexley, Brooklands, Halswell, South New Brighton / Southshore, Spencerville and Kainga areas. It would be reasonable to assume that all streets indicated by colored lines in these four maps suffered at least 1 inch, and in many cases several inches, or settlements at depths of the sewers (commonly 3 meters deep).

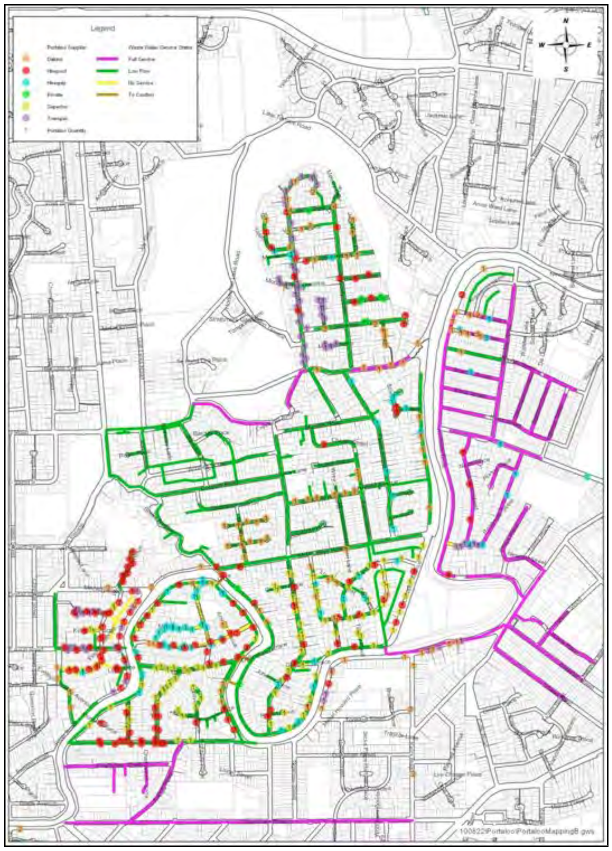


Figure A-20. Portaloos in Service, October 11, 2010

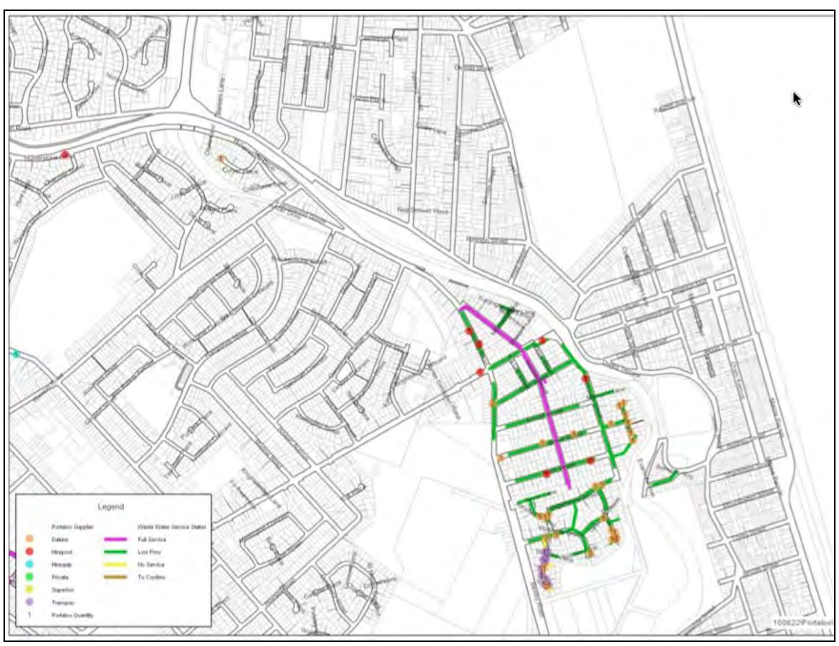


Figure A-21. Portaloos in Service, Bexley / New Brighton, October 11, 2010

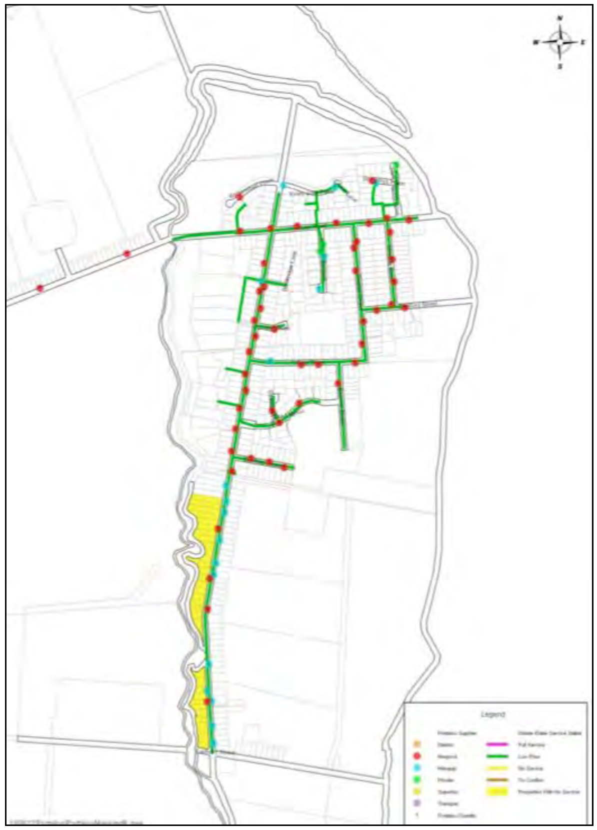


Figure A-22. Portaloos in Service, Brooklands, October 11, 2010

Figure A-23. Portaloos in Service, Halswell, October 11, 2010

Figure A-24. Portaloos in Service, South New Brighton, Southshore, October 11, 2010

Figure A-25. Portaloos in Service, Spencerville, October 11, 2010

Figure A-26. Portaloos in Service, Kainga, October 11, 2010

A.3 Earthquake of February 22 2011

Following the February 22, 2011 earthquake, the CCC sewer system was investigated. There were no reported building collapses in the sewer system, but several were damaged from liquefaction and the CCC main headquarters was damaged from shaking. Due to the distance from the February 2011 earthquake to Kaiapoi, there was no reported liquefaction or incremental to the WDC sewer system.

The CCC wastewater system was heavily damaged in the February 22 2011 earthquake.

As of April 2, 2011, the sewerage system was on the "brink of failure", threatening the city with an "almighty stink" by Christmas 2011. CCC was requesting residents to work harder to conserve water, or risk overloading the sewage ponds.

The choke point is the Bromley WWTP, which as of April 2 2011, was operating at 30% of normal capacity.

Damage to the sewer pipe collection system was so extensive that as of early April 2011, it was estimated to take 8 months to identify and suitably repair the pipe damage. Interior inspection of sewer pipes was hampered by having so many of them clogged with sand. The repair strategy for the sewer system was to first restore the larger downstream mains then continue working their way upstream. In this way CCC could take as much sewage as possible to the WWTP and also contain as much sands as possible in the pumping station wet wells, thus removing a significant sand load from the WWTP. Seven of eight reinforced concrete cylinder pipe force mains leading to the WWTP were damaged from the earthquake (the eighth was leaking); as of April 2011 all of these mains were functioning.

Six percent, or about 96 km of the collection pipes were not working, with a further 27%, or 474 km, working only slowly. As of early April, 2011, CCC had 92 trucks flushing sand out of the collection pipes, and 11 crews putting cameras through pipes to survey the damage. Figure A-27 shows a crew working to flush sewer pipes with a water jetting method. The jetting cleans the pipes and cameras are deployed after the jetting process to inspect the pipes. Waste from this process is hauled in trucks and disposed at the WWTP. At locations where large sewer pipe breaks occurred, the jetting process sometimes effectively mined the sand from the ground surrounding the pipes and resulted in sink holes in the roadway above. Some cars fell into sink holes. The process was modified to reduce the possibility of creating sink holes by monitoring the rate of progress of the jetting holes, when the rate significantly slows the crews stop the jetting and report a location of potential significant damage.

Figure A-27. Crew flushing sewer pipes.

Figure A-28 shows the status of the jet cleaning effort, as of May 11, 2011. The colored pipes correspond nearly one-to-one with portions of the city that has moderate to major liquefaction; and the thin grey pipes are located in parts of the city that had no (or rare) liquefaction). The red lines indicate pipes that had been jet cleaned 3 or more times (8 km); orange lines indicate pipes that had been cleaned 2 times (52 km); and green lines indicate pipes that had been cleaned 1 time (370 km).

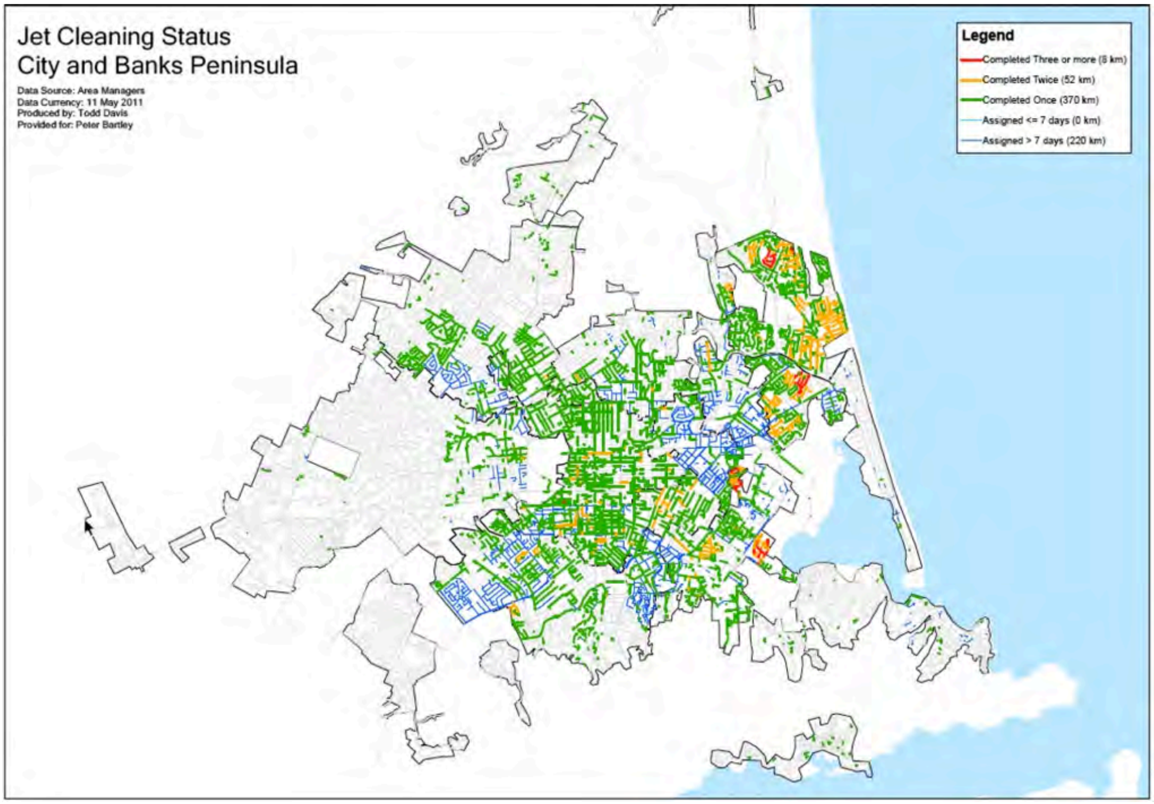


Figure A-28. Jet Cleaning of Sewer Pipes (Status as of May 11 2011)

Figure A-29 shows the portions of Christchurch that have functional piped sewer service to the WWTP, as of May 11 2011. This map is based on functioning sewers, 6" and larger, and excludes damage of laterals to mains. Figure A-30 shows a similar map, but highlighting the parts of the city with piped sewer service, except that the sewage is being discharged into local streams, as there remains damage in the sewer mains to the WWTP.

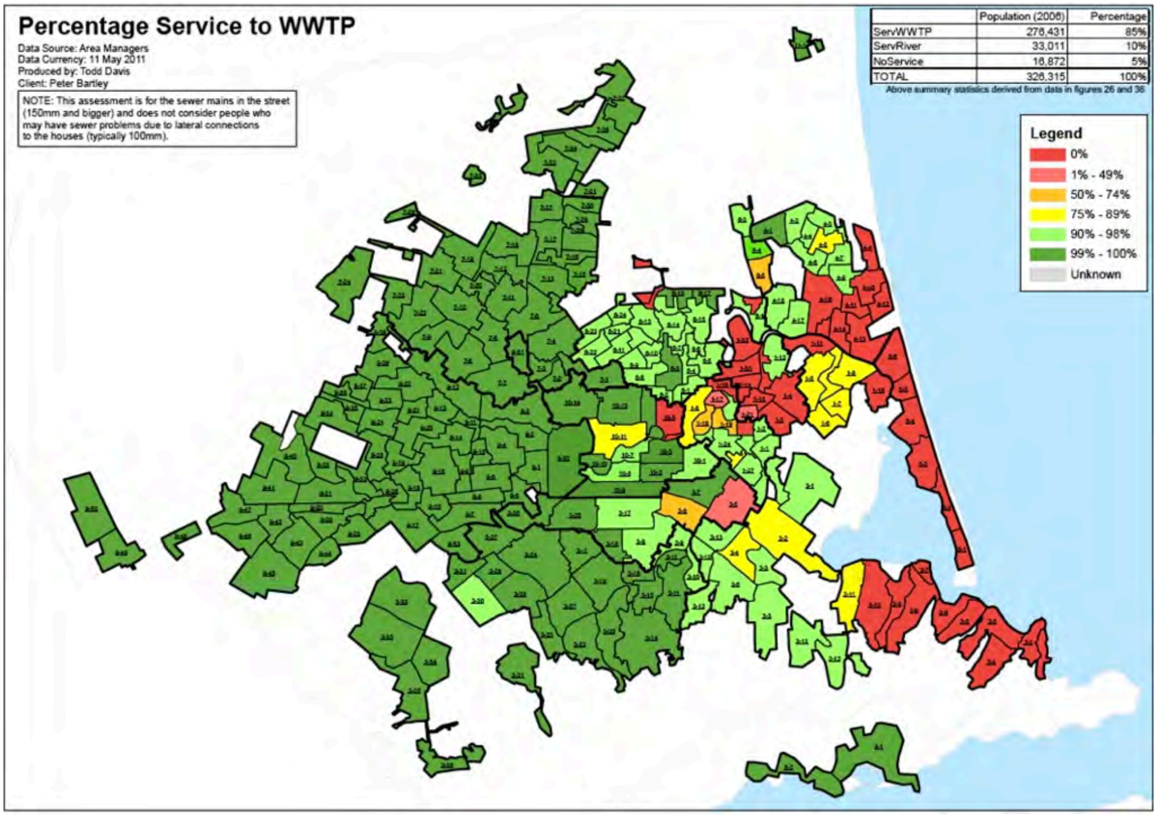


Figure A-29. Portion of Christchurch with Piped Sewer Service to the WWTP (Status as of May 11 2011)

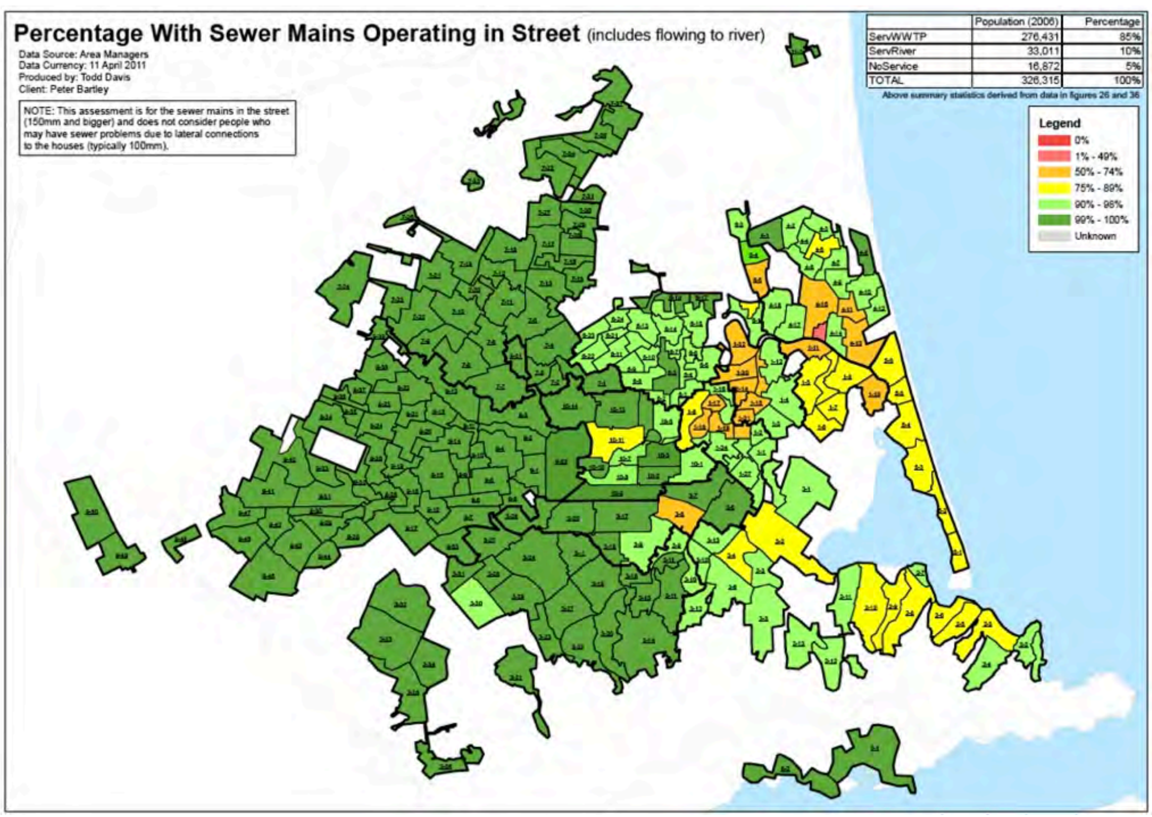


Figure A-30. Portion of Christchurch with Piped Sewer Service, either discharging to local streams or to the WWTP (Status as of May 11 2011)

The slow moving effluent in the pipes was the biggest headache, both for CCC as well as health authorities, because the sewers were still leaking millions of liters of raw sewage into backyards, rivers and the sea. It was estimated that as of April 2 2011, about 25% of total sewage volume, or a leak rate of about 40 million liters per day, was leaking out of the damaged sewer pipes; this leak rate was down from about 60 million liters per day two weeks previously. At this rate of repair, it was estimated to take months before rivers and beaches would be found safe enough to swim or surf in. The estimated time to restore piped sewage for residences in eastern Christchurch ranged from one month to one year.

Ground water infiltration has increased about 100%. This increased the load on the WWTP, thus magnifying the sewage treatment problems.

For residents in eastern Christchurch, the use of chemical toilets and portaloos (portable toilets) was common as of April 3, 2011. Figure A-31 shows the deployment of portable toilets. Figure A-32 shows deployed chemical toilets and portable toilets. About 30,000 chemical toilets have been placed in homes and in excess of 10,000 portable toilets mobilized. At the time of the February 2011 earthquake, Kaiapoi still had portable toilets being used since the September 2010 earthquake; although very few, if any, portable toilets remained in Christchurch as a result September 2010 earthquake.

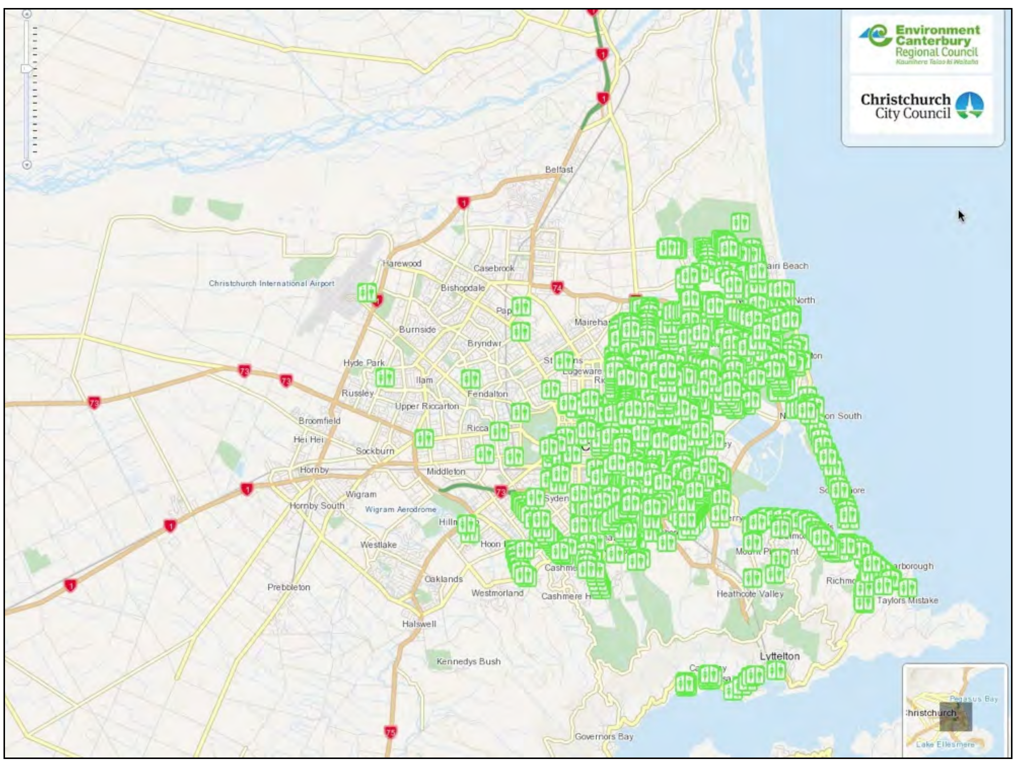


Figure A-31. Portaloos in Service, March 2011

Figure A-32. Portable toilet and chemical toilet tank deployed in residential neighborhoods.

Figure A-33 shows raw sewage being spilled into the Avon River (note the ducks). The sight of solids floating on the river surface has been judiciously cut-out of the images in this report.

Figure A-33. Raw Sewage in Local River, April 2011

Figure A-34 shows the additional movement of a sewer dry well lift station, due to the February 2011 earthquake. Compare this with the movement of the same lift station from the September 4 2010 earthquake, Figure A-4.

Figure A-34. Rotation and Sewer Lift Station, April 2011 (see Fig A-4 for Comparison)

Figure A-35 shows another dry well lift station that floated in the February 2011 earthquake. Several other dry well pumping stations floated during the February, 2011 earthquake due to the more extensive liquefaction. The total uplift between the two earthquakes at some stations was measured at about 0.6 m and could exceed a meter at other stations.

Figure A-35. Flotation of Sewer Lift Station, April 2011

Figure A-36 shows the Pages Road Sewage Pumping Station. The pump station site suffered severe liquefaction. The suction well floated about 4" to 6" and connections with the sewage pipes broke outside the station, but the pumps and internal piping remained functional. Measurements on the outside indicated differential movements of 4" to 10" across the entire building. There were no flexible connections for piping at this station. Figure A-37 shows the interior wall differential movement.

Figure A-38 shows uplift of the suction well at sewer Pumping Station No. 36. The concrete pumping station was not damaged by the earthquake, but liquefaction in the area damaged the inlet and outlet pipes and kept the station from functioning. CCC began sucking sewage from the wet well to dispose of the sewage in a truck. As they were sucking out the sewage the wet well began to float (should have been no surprise!)

Sewer pipelines were damaged at bridge crossings where the bridge abutments were damaged by lateral spreading. Figure A-39 shows a HDPE pipe used as a temporary bypass line placed overtop of the Brighton Bridge.

Figure A-36. Pages Road Pumping Station

Figure A-37. Pages Road Sewer Pumping Station differential movement

Figure A-38. Sewer Pumping Station No. 36

Figure A-39. Sewer pipe bypass over the Avon River at Brighton Bridge

Figure A-40 shows the process flow diagram for the Bromley WWTP. Figure A-41 shows an aerial view of the WWTP following the February 2011 earthquake. Figure A-42 provides a close up from the areal above the digester tanks showing how one of the two tanks had its roof thrown off during the earthquake.

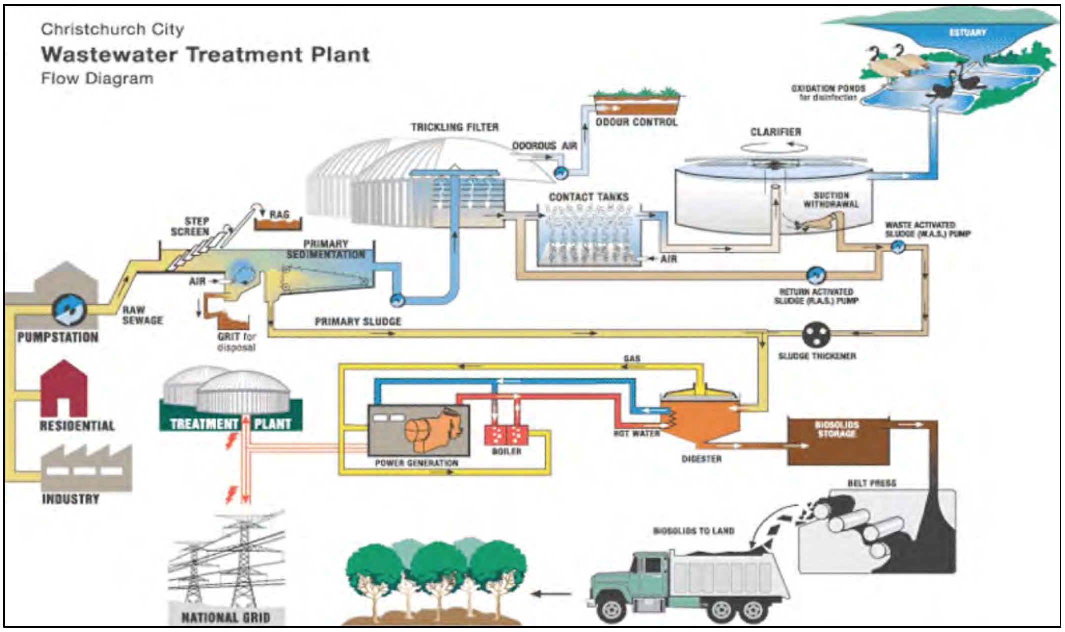


Figure A-40. Process Flow Diagram, Bromley WWTP

Figure A-41. Aerial view of Bromley WWTP following the Feb. 2011 earthquake

Figure A-42. Aerial view of digester tanks at Bromley WWTP

Figure A-43 shows a cracked pipe leading to one of the digesters. There was no leak, as the pipe has an internal liner (and the digester was out of service).

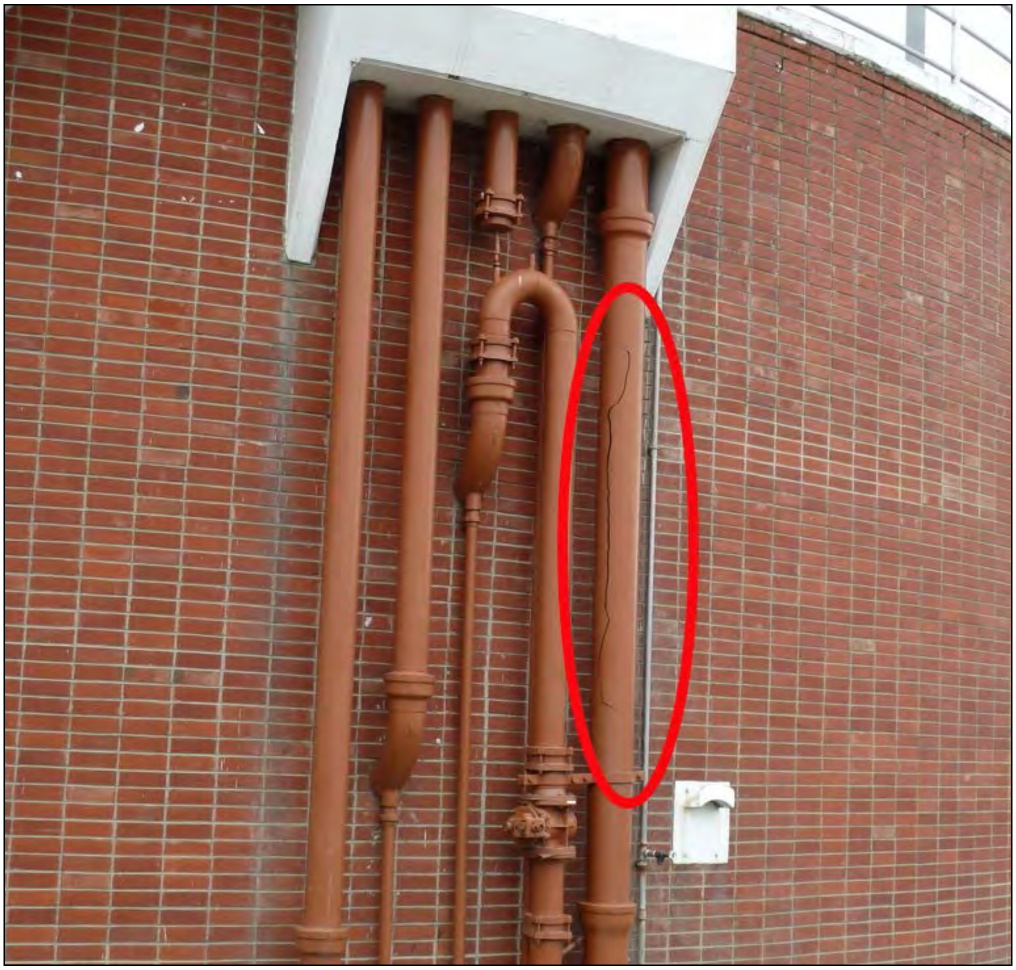


Figure A-43. Cracked Pipe to Digester, Bromley WWTP

Figure A-44 shows a cable spreading area at the Bromley WWTP. While the facility shook with PGA = 0.5g, there was no damage to these rod-supported trays and pipes; showing that intelligent New Zealand engineers have recognized the wastefulness of ASCE 7 2010 and related non-structural code that would require seismic lateral braces in such a situation.

Figure A-45 shows damage to the scrapers in the primary sedimentation tanks. The tank on the right has wood scrapers, reflecting that the original metal channels have buckled and failed. This photo was taken in April 2011, while repairs were being made to these basins.

Figure A-44. No Damage to Rod-Hung Cable Trays, Bromley WWTP

Figure A-45. Scrapers, Bromley WWTP

Figures A-46 and A-47 show workers cleaning sand from the grit chambers and the primary settling basins, respectively. These basins were reportedly completely filled with sand and were at the end of cleaning at the time of photos taken in early April 2011. The depth of sand reached about 6 meters, completely filling the grit chamber in Figure A-46 to the top water mark notable near the top of column. One set of grit chambers and primary settling basins were restored within about 1.5 to 2 weeks after the earthquake. Since then the plant has been working at about 1/3 capacity and the different sets of grit chambers and primary settling basins have been rotated between cleaning of sands and treating of sewage.

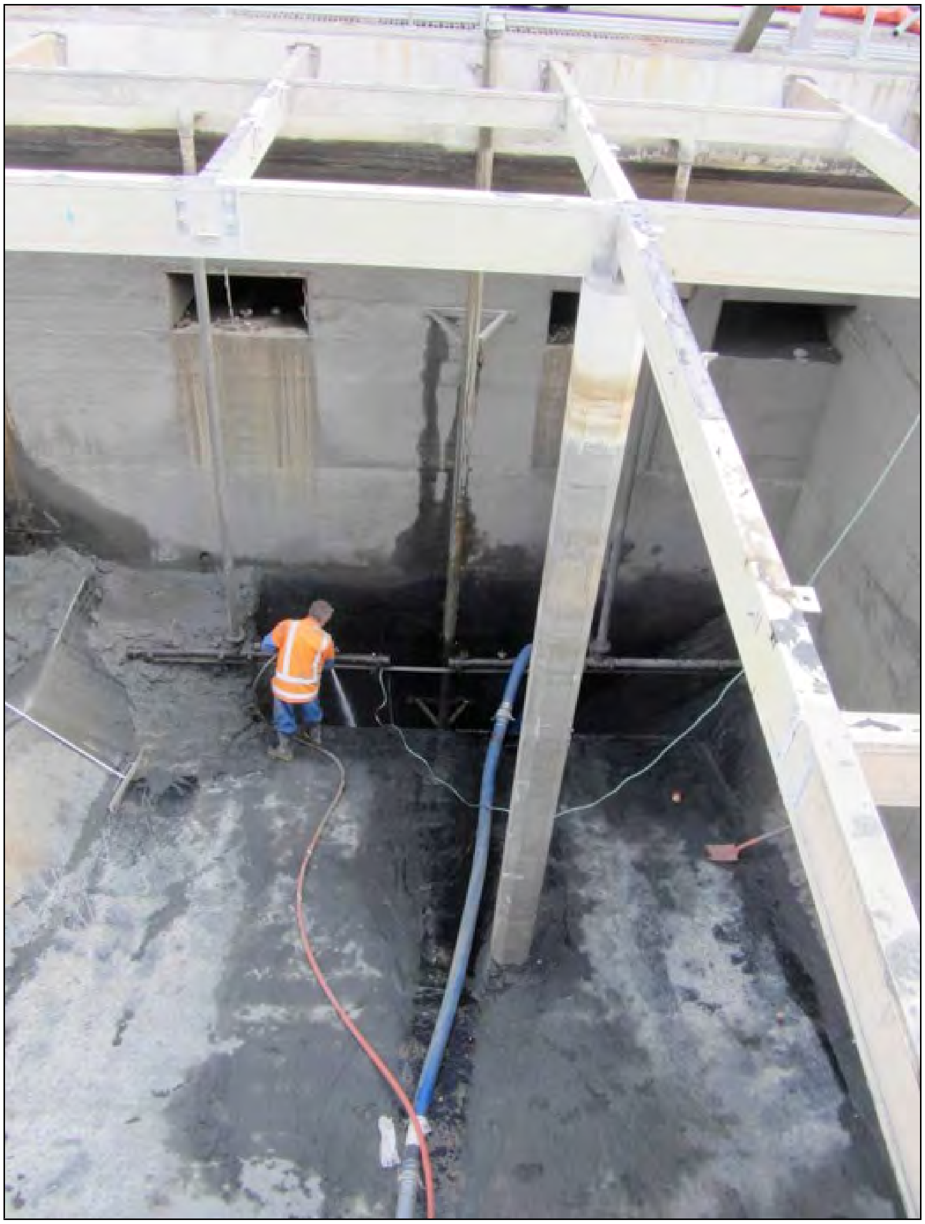


Figure A-46. Grit Chamber cleaning, Bromley WWTP

Figure A-47. Primary Settling Basins Cleaning, Bromley WWTP

The Bromley WWTP has two pumping stations called Pumping Station A and Pumping Station B. There was no damage reported to pumping Station A. Pumping Station B had damage to a mechanical coupling shown in Figure A-48 that allowed sewage to leak and fill up the station. The cause of damage to the coupling was not known as of April 2011, but was suspected to be from small differential movements, as observed by the author of this report when he visited the plant in April 2011.

Figure A-48. Pumping Station B leak at mechanical coupling, Bromley WWTP

Figure A-49 shows damaged 6" PVC pipe in the aeration contact tank. This type of damaged PVC pipe was seen at several other places in this tank.

Figure A-49. Broken PVC Pipe in Aeration Tank, Bromley WWTP

Figure A-50 shows one of the four secondary clarifiers. Three of four clarifiers were heavily damaged, due to a combination of liquefaction and sloshing forces on the sludge mechanisms. CCC believes that some of the clarifier floors have experienced up heaving. Dewatering is necessary prior to emptying the tanks for inspections, thus significantly delaying ability to determine needed repairs/replacements. These will likely have to be rebuilt entirely.

Figure A-50. Broken Secondary Clarifier, Bromley WWTP

Figure A-51 shows external clamps placed on leaking reinforced concrete pipes (3-foot diameter) at the WWTP.

Figure A-51. Broken Secondary Clarifier, Bromley WWTP

The Bromley WWTP has an underground gallery constructed of reinforced concrete, and used for housing piping and conduits. The gallery was damaged and separated at construction joints as shown in Figure A-52. Water and sand flowed into the gallery through the drainage pipe system and the joint separations.

Figure A-52. Gallery Damage, Bromley WWTP

The overall damage at the WWTP required CCC to release untreated wastewater into the 230 hectares of oxidation ponds. Water from the ponds is disposed in an ocean outfall. The sewage can bypass the treatment plant to the ponds, but the ponds cannot be bypassed to send sewage directly to the outfall. CCC estimated that there was a 50% chance that the oxygen levels would drop below functional levels, turning the normally placid ponds into a vast cesspit. Should this happen, CCC estimated it would be difficult to reverse and the smell could linger for months. The Bromley WWTP has also been dealing with an influx of debris and sand which has infiltrated the crippled wastewater collection pipe system, putting pressure on the already-distressed filtering tanks. Through early April 2011, CCC estimated that the WWTP had sucked about 400,000 tons of sand from the sewerage pipe network. The WWTP received up to 1000 tons of sand in one day. This is compared to about 30,000 tons of sand removed in total after the September 2010 earthquake.

Damage at the Bromley WWTP itself could take between 6 months to 2 years to fix.

A.4 Wastewater System Performance – Two Earthquakes

Cumulatively over the two earthquakes, the following damage occurred and recovery actions taken:

- 12 km of pressure main (force main) will have to be built; CCC normally renews about 10 km per year.

- Immediately after the February 2011 earthquake, the wastewater treatment plant received zero flow. As of August 2011, all processes were back in service, except for UV. It was estimated it would take until mid 2012 before the plant would be back to pre-earthquake standards.

- Silt from the WWTP is being stored at the Burwood landfill.
- Solid waste service was not disrupted.
- There was damage at the composting plant; tunnels were damaged, but with temporary fixes in place. The plant was re-opened in May 2011.
- It was hoped that by the end of August 2011, all residents would be off chemical toilets.
- It was hoped that by August 31 2011, all major (but not all) overflows of raw sewage into local streams and rivers would be halted. It was hoped that beaches and rivers would be back to bathing standards by November 2011.

A.5 Observations

Relative to other lifelines, sewer systems have often been neglected with regards to seismic vulnerability assessments and mitigation. In the Christchurch earthquake sequence of 2010 to 2011, the extent of liquefaction has proven that this neglect might be misplaced. Most citizens would say that the damage to the sewer system had the most severe impacts to daily life, as compared to the damage to power, water, telecom, gas, bridges, etc.

The extent of pipeline damage to the sewer system rivals or exceeds that of the water system; and yet takes 3 to 10 times as long to repair, owing to the depth of gravity sewers. The damage due to liquefaction at the WWTP in Bromley is very expensive to repair. The combination of sewer and WWTP damage can lead to a big stink; big repair costs; ongoing inconvenience for citizens to use portable toilets, etc.

Rebuilding of 100 mm to 300 mm diameter water and wastewater pipes in liquefaction zones using fusion butt-welded HDPE or clamped electric-welded HDPE or ductile iron pipe with chained joints might be considered. It would be fair to say that previous use of push-on-rubber-jointed AC, PVC, vitrified clay or concrete pipe in liquefaction zones resulted in most of the adverse impact to buried utilities in Christchurch and Kaiapoi; a similar observation was made in Adapazari, Turkey in the Anatolian fault earthquake of 1999 (Tang, 2000). This lesson learned needs to be communicated so that it is not repeated again.

A.6 Acknowledgements

The author acknowledges Mark Christison, James Feary, Terry Howes, Ian Johnson, Richard McCracken, and John Noonan from the Christchurch City Council and thank them for generously sharing their information and time to explain the earthquakes affects on the Christchurch sewer system and provide access to their facilities. Some of the information in this report was developed by Dr. Craig Davis of the Los Angeles Department of Water and Power (Figures A-35 to A-38). The remaining photos were taken by John Eidinger. Maps were developed by the GIS department of the CCC.

A.7 Abbreviations

AC	Asbestos Cement pipe
BOD	Biochemical Oxygen Demand
CCC	Christchurch City Council (owner of the wastewater system for Christchurch)

CCTV	closed circuit television
HDPE	High Density Polyethylene pipe
km	kilometer
m	meter
mm	millimeter
MGD	Million gallons per day (U.S. measure)
PGA	Peak Ground Acceleration (g)
PGD	Permanent Ground Deformation (cm)
PVC	Polyvinyl Chloride pipe
WDC	Waimakariri District Council (owner of the wastewater system for Kaiapoi and Pines Beach)
WWTP	Wastewater treatment plant
VCP	Vitrified Clay pipe
$NZ	New Zealand dollars (about $1 NZ = $0.80 US as of 2013)

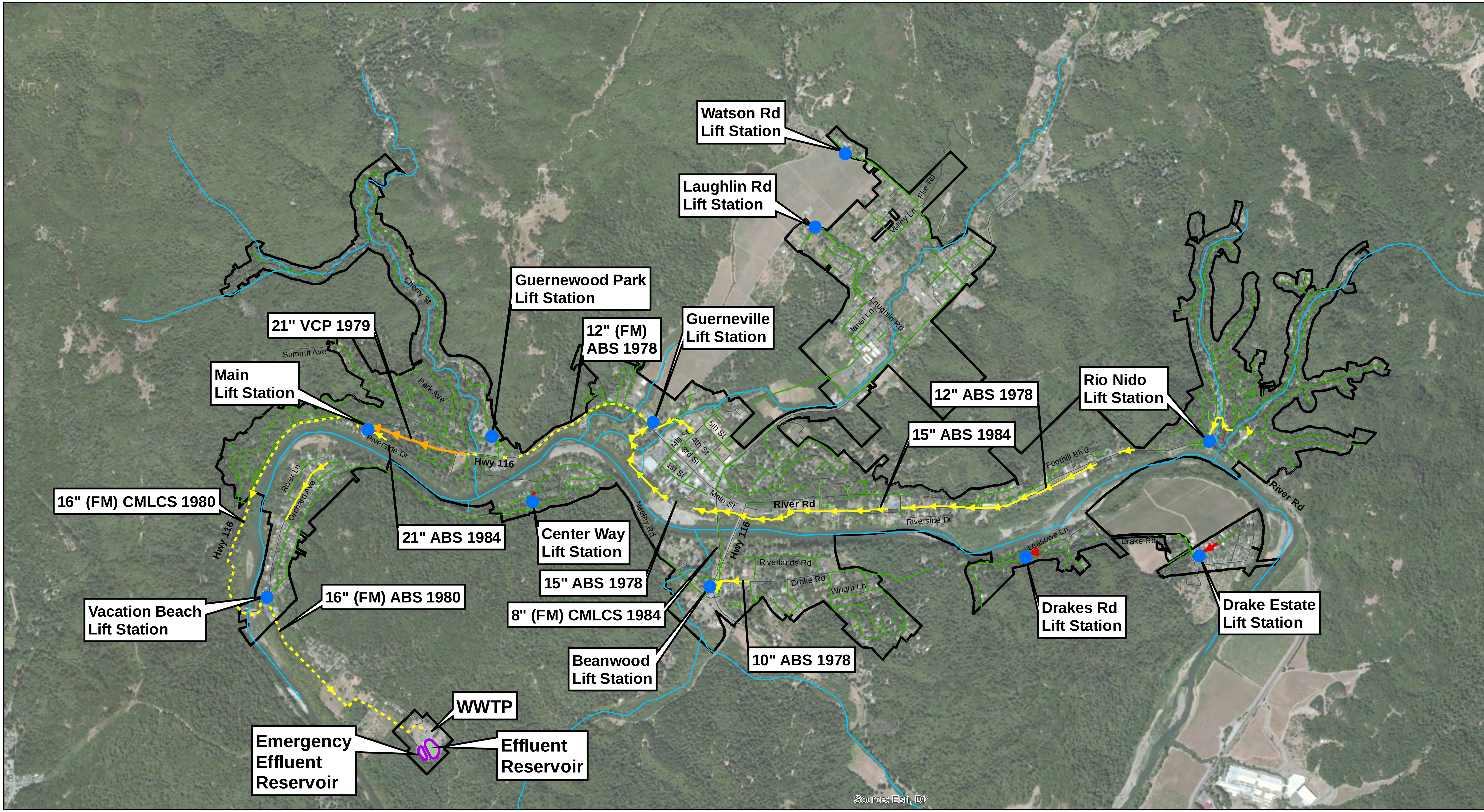
A.8 References

Tang, Alex, (Editor), TCLEE, No. 17, Izmit (Kocaeli), Turkey Earthquake of August 16, 1999, Including Duzce Earthquake of November 12, 1999 -Lifeline Performance, September 2000.

Eidinger, John and Tang, Alex (Editors), TCLEE, No. 40, Earthquake Sequence of Mw 7.1 September 4 2010, Mw 6.3 February 22 2011, Mw 6.0 June 13, 2011: Lifeline Performance, ASCE, 2014 (in press).

IBC 2012. International Building Code, 2012.

Appendix B – RRCSD FIGURES



Paper Size 11" x 17" (ANSI B)

0 375 750 1,125 1,500

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California II FIPS 0402 Feet

N

Legend	
RRCSD Boundary	<= 4" Force Main
Street	<= 4" Sewer Main
Creek	6" - 8" Force Main
Pump Station	6" - 8" Sewer Main
10" - 16" Force Main	10" - 16" Sewer Main
18" - 21" Sewer Main	24" - 30" Sewer Main

G&E Engineering Systems, Inc.

KLEINFELDER

SONOMA COUNTY WATER AGENCY

Sonoma County Water Agency
Natural Hazard Reliability Assessment

Russian River CSD Collection System

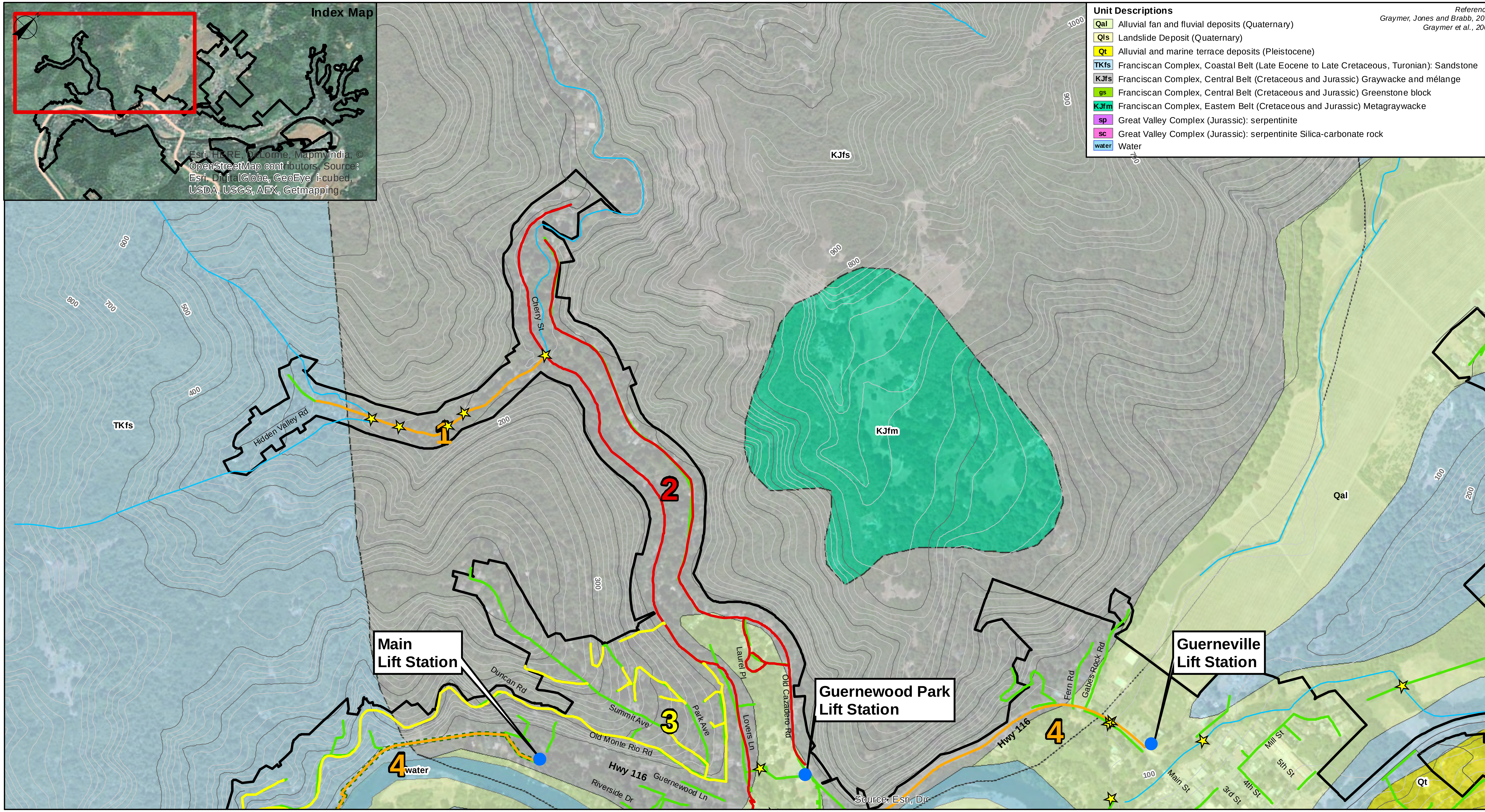
Job Number	8410200
Revision	2
Date	11 Jun 2015

Figure RR-1

N:\US\Santa Rosa\Projects\02243 - SCWA\02243-8410200 - Russian River CSD\08-GIS\Maps\Figures\Figure RR-1 Collection System.mxd

Data source: SCWA, Sanitary Sewer, Street, Creek, Boundary, 2013. Created by:afisher2

2235 Mercury Way Suite 150 Santa Rosa CA 95407 USA T 707 523 1010 F 707 527 8679 E santarosa@ghd.com W www.ghd.com



Paper Size 11" x 17" (ANSI B)

0 200 400 600 800
Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California II FIPS 0402 Feet

RRCSD Boundary
Street
Creek
100' Contour
20' Contour
Force Main (2" - 10")
Sewer Main (2" - 10")
Force Main (12" - 30")
Sewer Main (12"- 30")

Geologic Hazard Recon Lines & ID
1
2
3
4

Geologic Hazard Recon Point
Pump Station
Crossing Location

G&E Engineering Systems, Inc.

Sonoma County Water Agency
Natural Hazard Reliability Assessment

Russian River CSD
Geology (1 of 4)

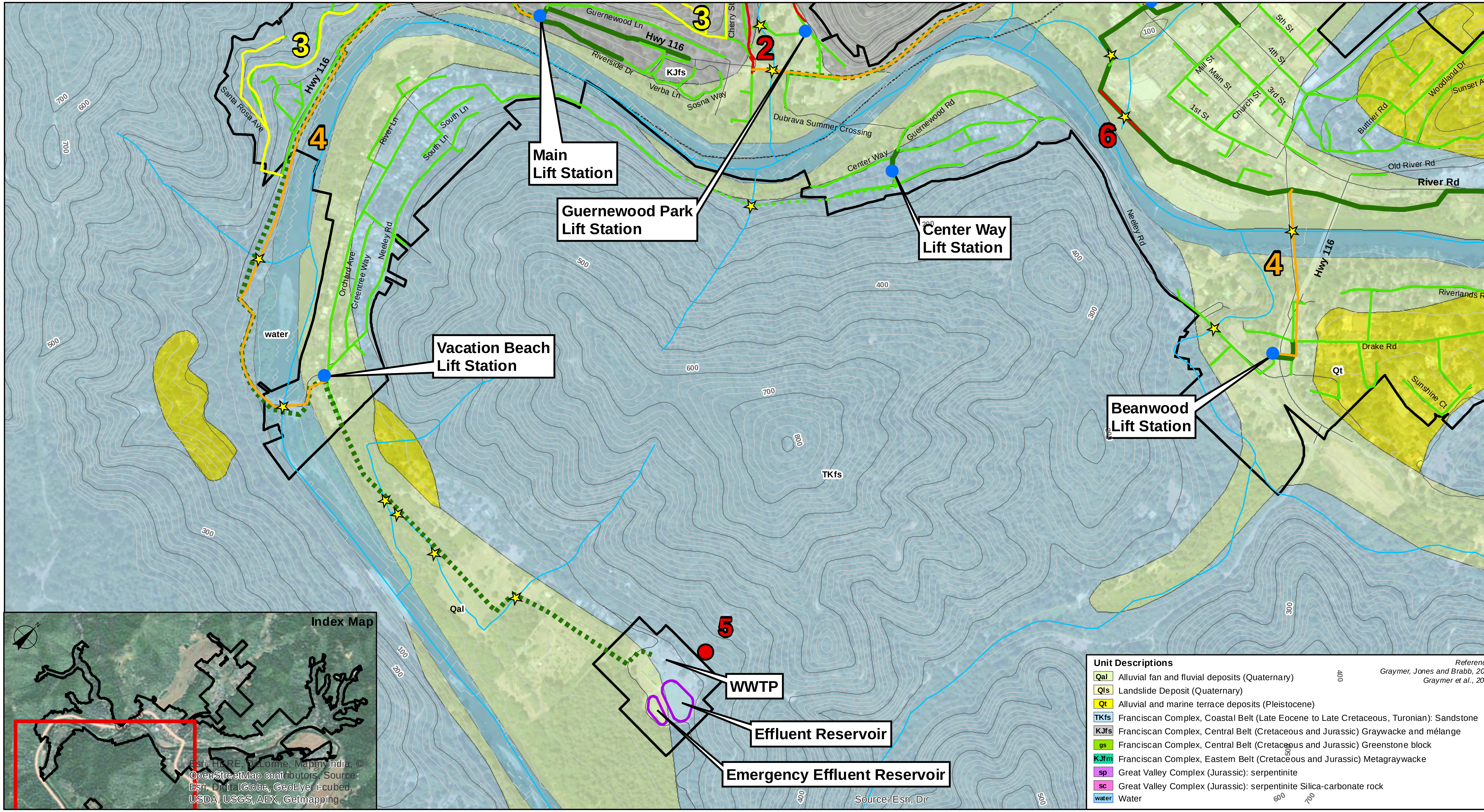
Job Number	8410200
Revision	3
Date	11 Jun 2015

Figure RR-2

2235 Mercury Way Suite 150 Santa Rosa CA 95407 USA T 707 523 1010 F 707 527 8679 E santarosa@ghd.com W www.ghd.com

N:\US\Santa Rosa\Projects\02243 - SCWA\02243-8410200 - Russian River CSD\08-GIS\Maps\Figures\Figure RR-2 Geology 1.mxd

Data source: SCWA, Sanitary Sewer, Street, Creek, Boundary, 2013; Kleinfelder, Geology, 2014; GHD, Crossings, 2014. Created by:afisher2



Paper Size 11" x 17" (ANSI B)

0 200 400 600 800

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California II FIPS 0402 Feet

RRCSD Boundary
Street
Creek
100' Contour
20' Contour
Force Main (2" - 10")
Sewer Main (2" - 10")
Force Main (12" - 30")
Sewer Main (12"- 30")

Geologic Hazard Recon Lines & ID

2
3
4
6

Geologic Hazard Reconnaissance Point
Pump Station
Crossing Location

G&E Engineering Systems, Inc.

KLEINFELDER

Sonoma County Water Agency
Natural Hazard Reliability Assessment

Russian River CSD
Geology (2 of 4)

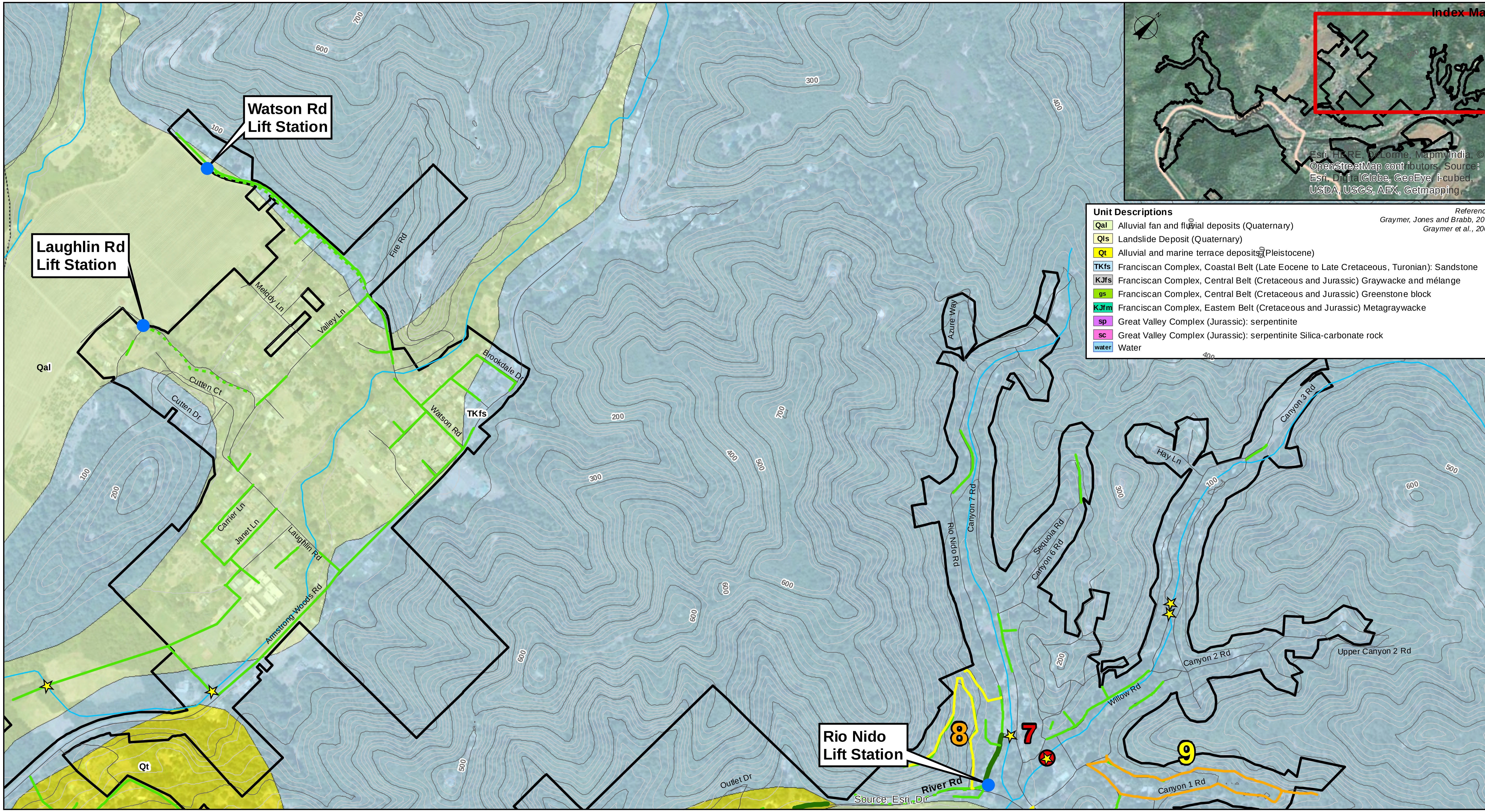
Job Number	8410200
Revision	3
Date	11 Jun 2015

Figure RR-3

N:\US\Santa Rosa\Projects\02243 - SCWA\02243-8410200 - Russian River CSD\08-GIS\Maps\Figures\Figure RR-3 Geology 2.mxd

2235 Mercury Way Suite 150 Santa Rosa CA 95407 USA T 707 523 1010 F 707 527 8679 E santarosa@ghd.com W www.ghd.com

Data source: SCWA, Sanitary Sewer, Street, Creek, Boundary, 2013; Kleinfelder, Geology, 2014; GHD, Crossings, 2014. Created by:afisher2



Paper Size 11" x 17" (ANSI B)

0 200 400 600 800

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California II FIPS 0402 Feet

RRCSD Boundary
Street
Creek
100' Contour
20' Contour
Force Main (2" - 10")
Sewer Main (2" - 10")
Force Main (12" - 30")
Sewer Main (12"- 30")
Crossing Location

Geologic Hazard Recon Lines & ID

8
9
Geologic Hazard Reconnaissance Point
Pump Station

G&E Engineering Systems, Inc.

Sonoma County Water Agency
Natural Hazard Reliability Assessment

Russian River CSD
Geology (3 of 4)

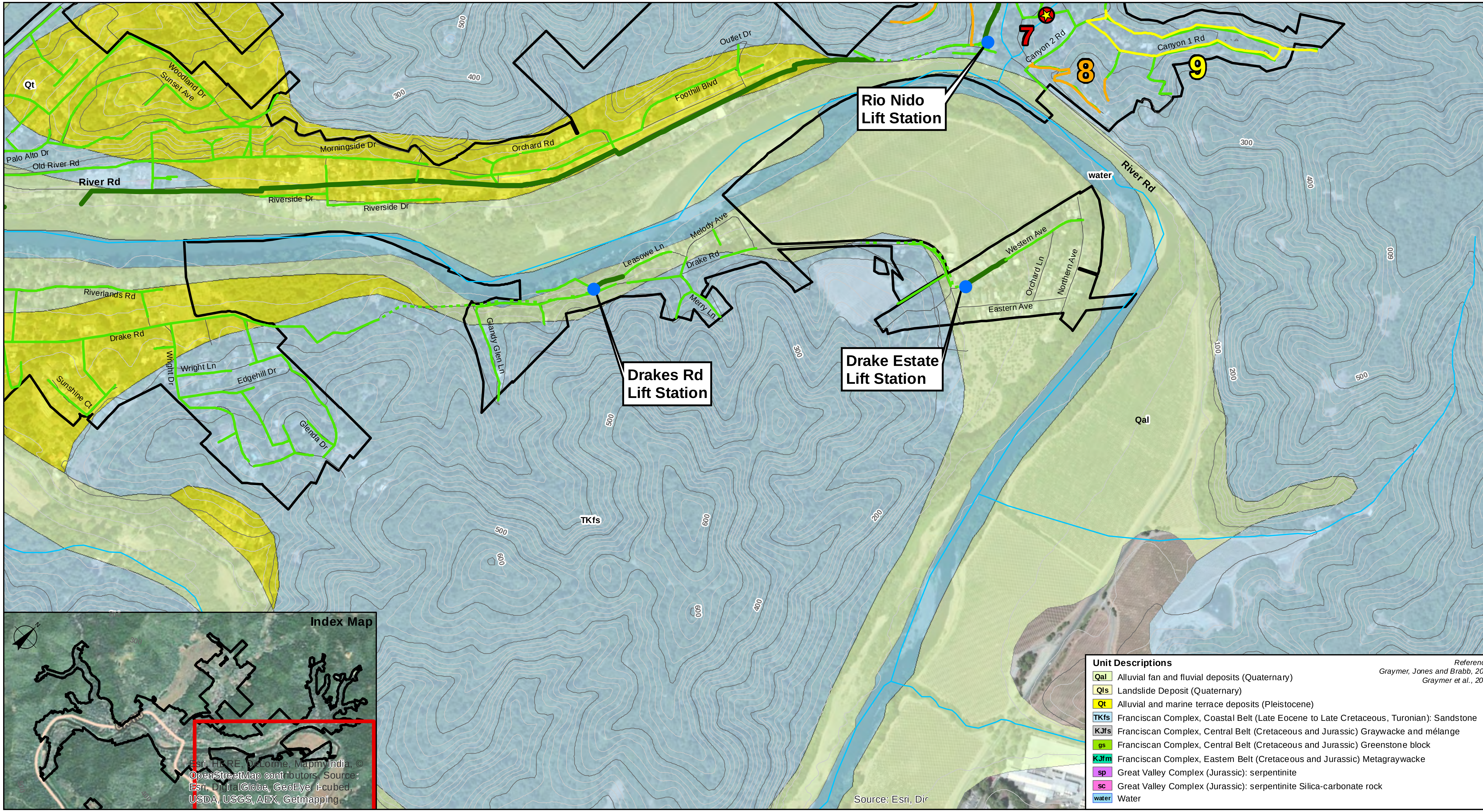
Job Number	8410200
Revision	3
Date	11 Jun 2015

Figure RR-4

N:\US\Santa Rosa\Projects\02243 - SCWA\02243-8410200 - Russian River CSD\08-GIS\Maps\Figures\Figure RR-4 Geology 3.mxd

Data source: SCWA, Sanitary Sewer, Street, Creek, Boundary, 2013; Kleinfelder, Geology, 2014; GHD, Crossings, 2014. Created by:afisher2

2235 Mercury Way Suite 150 Santa Rosa CA 95407 USA T 707 523 1010 F 707 527 8679 E santarosa@ghd.com W www.ghd.com



Paper Size 11" x 17" (ANSI B)

0 200 400 600 800

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California II FIPS 0402 Feet

RRCSD Boundary
Street
Creek
100' Contour
20' Contour

Force Main (2" - 10")
Sewer Main (2" - 10")
Force Main (12" - 30")
Sewer Main (12"- 30")
Crossing Location

Geologic Hazard Recon Lines & ID
8
9
Geologic Hazard Reconnaissance Point
Pump Station

G&E Engineering Systems, Inc.

KLEINFELDER

Sonoma County Water Agency
Natural Hazard Reliability Assessment

Russian River CSD
Geology (4 of 4)

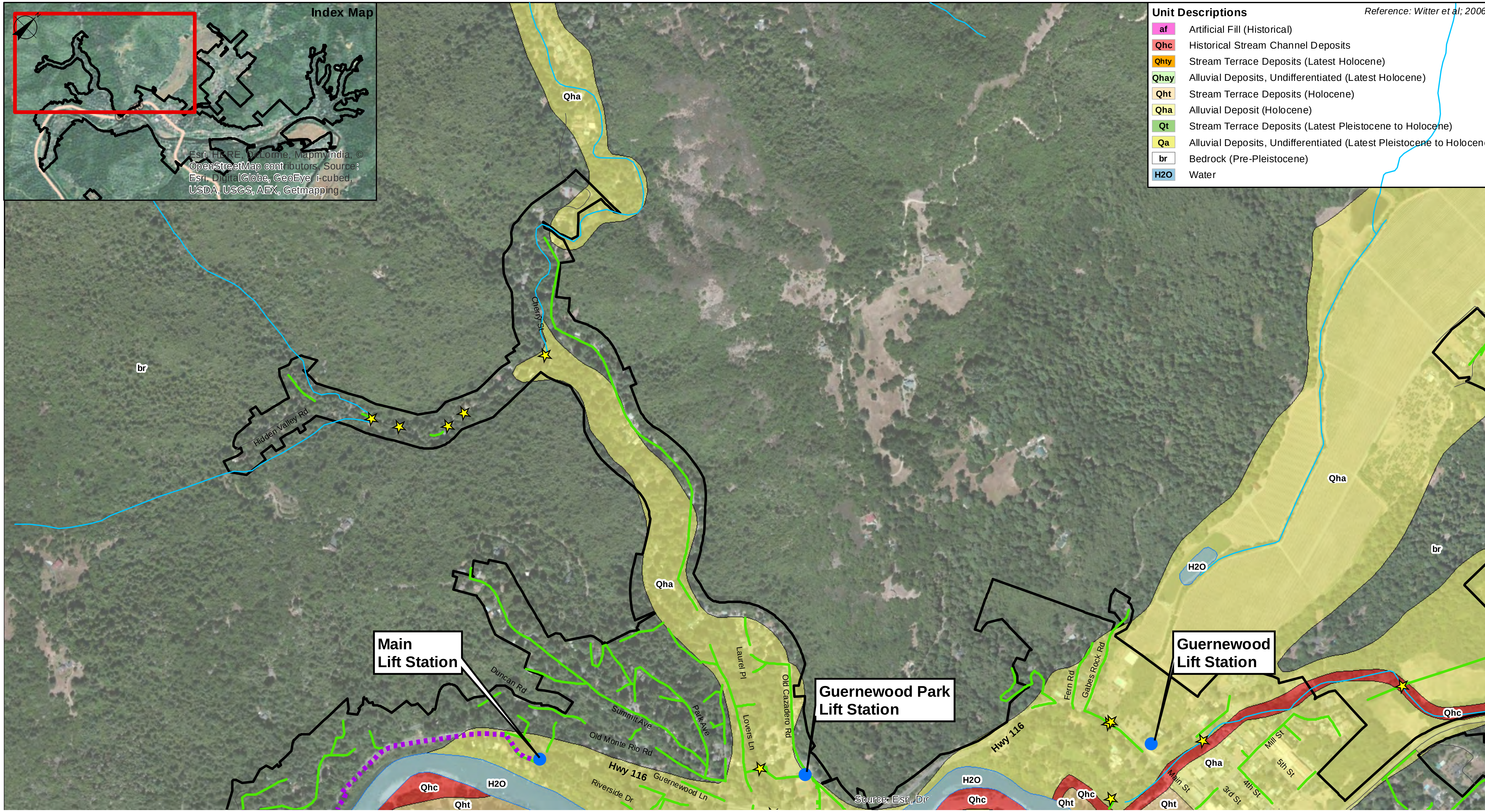
Job Number	8410200
Revision	3
Date	11 Jun 2015

Figure RR-5

N:\US\Santa Rosa\Projects\02243 - SCWA\02243-8410200 - Russian River CSD\08-GIS\Maps\Figures\Figure RR-5 Geology 4.mxd

Data source: SCWA, Sanitary Sewer, Street, Creek, Boundary, 2013; Kleinfelder, Geology, 2014; GHD, Crossings, 2014. Created by:afisher2

2235 Mercury Way Suite 150 Santa Rosa CA 95407 USA T 707 523 1010 F 707 527 8679 E santarosa@ghd.com W www.ghd.com



Paper Size 11" x 17" (ANSI B)

0 200 400 600 800

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California II FIPS 0402 Feet

RRCSD Boundary	Crossing Location	Force Main (2" - 10")
Street	Pump Station	Sewer Main (2" - 10")
Creek		Force Main (12" - 30")
		Sewer Main (12"- 30")

G&E Engineering Systems, Inc.

KLEINFELDER

Sonoma County Water Agency
Natural Hazard Reliability Assessment

Job Number 8410200
Revision 2
Date 11 Jun 2015

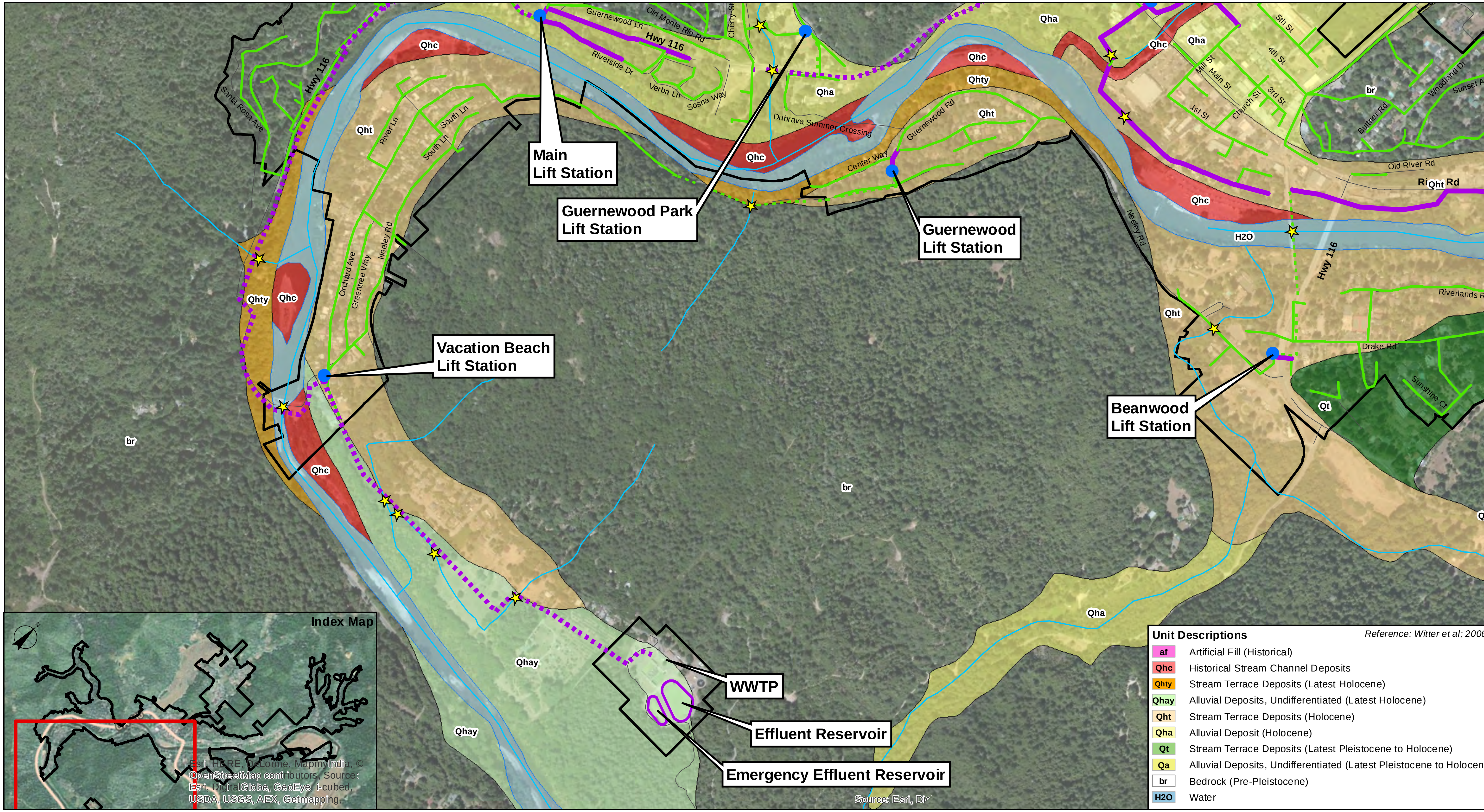
Russian River CSD
Quaternary Deposits (1 of 4)

Figure RR-6

N:\US\Santa Rosa\Projects\02243 - SCWA\02243-8410200 - Russian River CSD\08-GIS\Maps\Figures\Figure RR-6 Quaternary Deposits 1.mxd

Data source: SCWA, Sanitary Sewer, Street, Creek, Boundary, 2013; Kleinfelder, Geology, 2014; GHD, Crossings, 2014. Created by:afisher2

2235 Mercury Way Suite 150 Santa Rosa CA 95407 USA T 707 523 1010 F 707 527 8679 E santarosa@ghd.com W www.ghd.com



Paper Size 11" x 17" (ANSI B)

0 200 400 600 800

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California II FIPS 0402 Feet

- RRCSD Boundary
- Street
- Creek
- Force Main (2" - 10")
- Sewer Main (2" - 10")
- Force Main (12" - 30")
- Sewer Main (12"- 30")
- Crossing Location
- Pump Station

G&E Engineering Systems, Inc.

Sonoma County Water Agency
Natural Hazard Reliability Assessment

Job Number	8410200
Revision	2
Date	11 Jun 2015

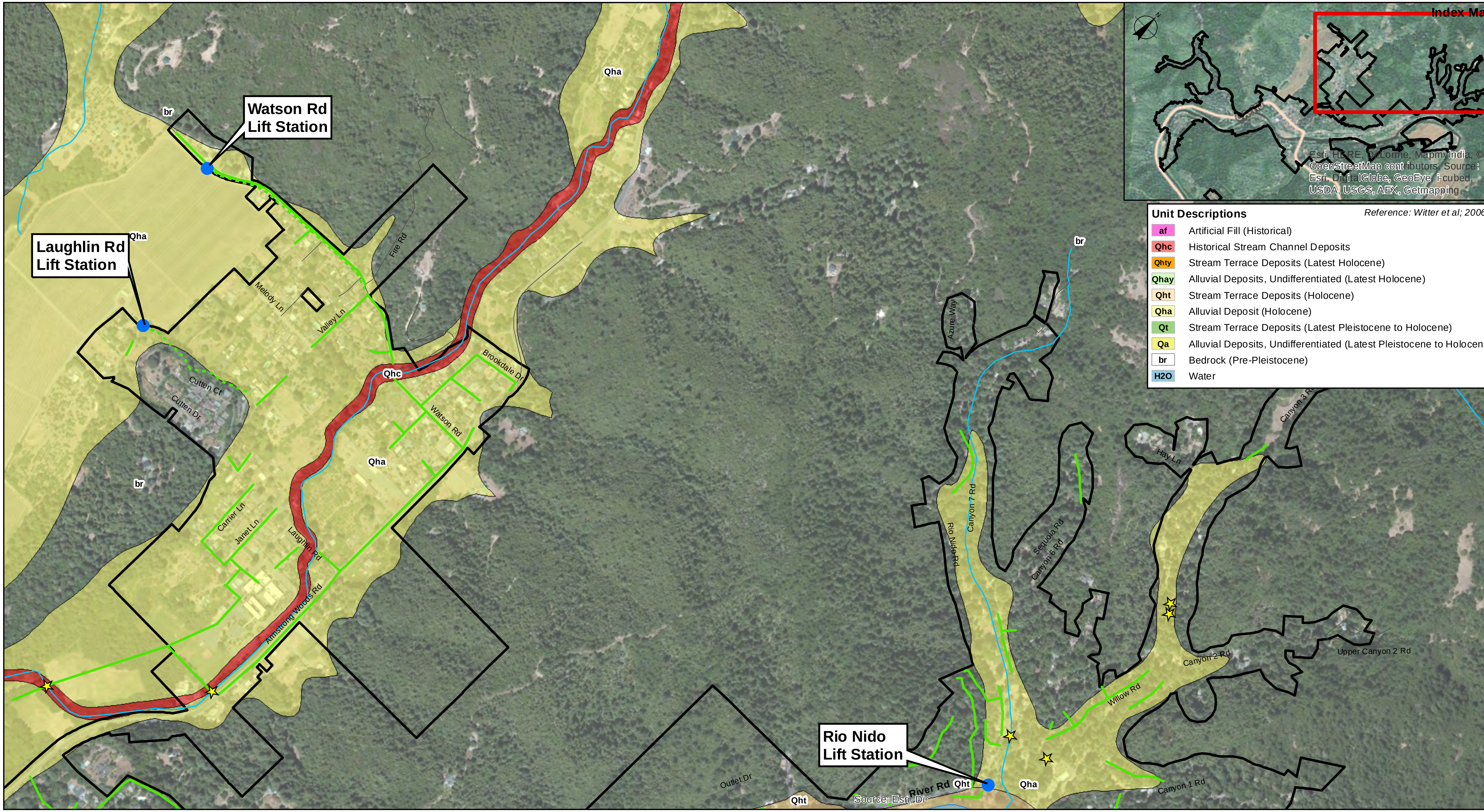
Russian River CSD
Quaternary Deposits (2 of 4)

Figure RR-7

N:\US\Santa Rosa\Projects\02243 - SCWA\02243-8410200 - Russian River CSD\08-GIS\Maps\Figures\Figure RR-7 Quaternary Deposits 2.mxd

Data source: SCWA, Sanitary Sewer, Street, Creek, Boundary, 2013; Kleinfelder, Geology, 2014; GHD, Crossings, 2014. Created by:afisher2

2235 Mercury Way Suite 150 Santa Rosa CA 95407 USA T 707 523 1010 F 707 527 8679 E santarosa@ghd.com W www.ghd.com



Paper Size 11" x 17" (ANSI B)

0 200 400 600 800
Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California II FIPS 0402 Feet

RRCSD Boundary
Street
Creek
Force Main (2" - 10")
Sewer Main (2" - 10")
Force Main (12" - 30")
Sewer Main (12"- 30")
Crossing Location
Pump Station

G&E Engineering Systems, Inc.

KLEINFELDER

Sonoma County Water Agency
Natural Hazard Reliability Assessment

Job Number	8410200
Revision	2
Date	11 Jun 2015

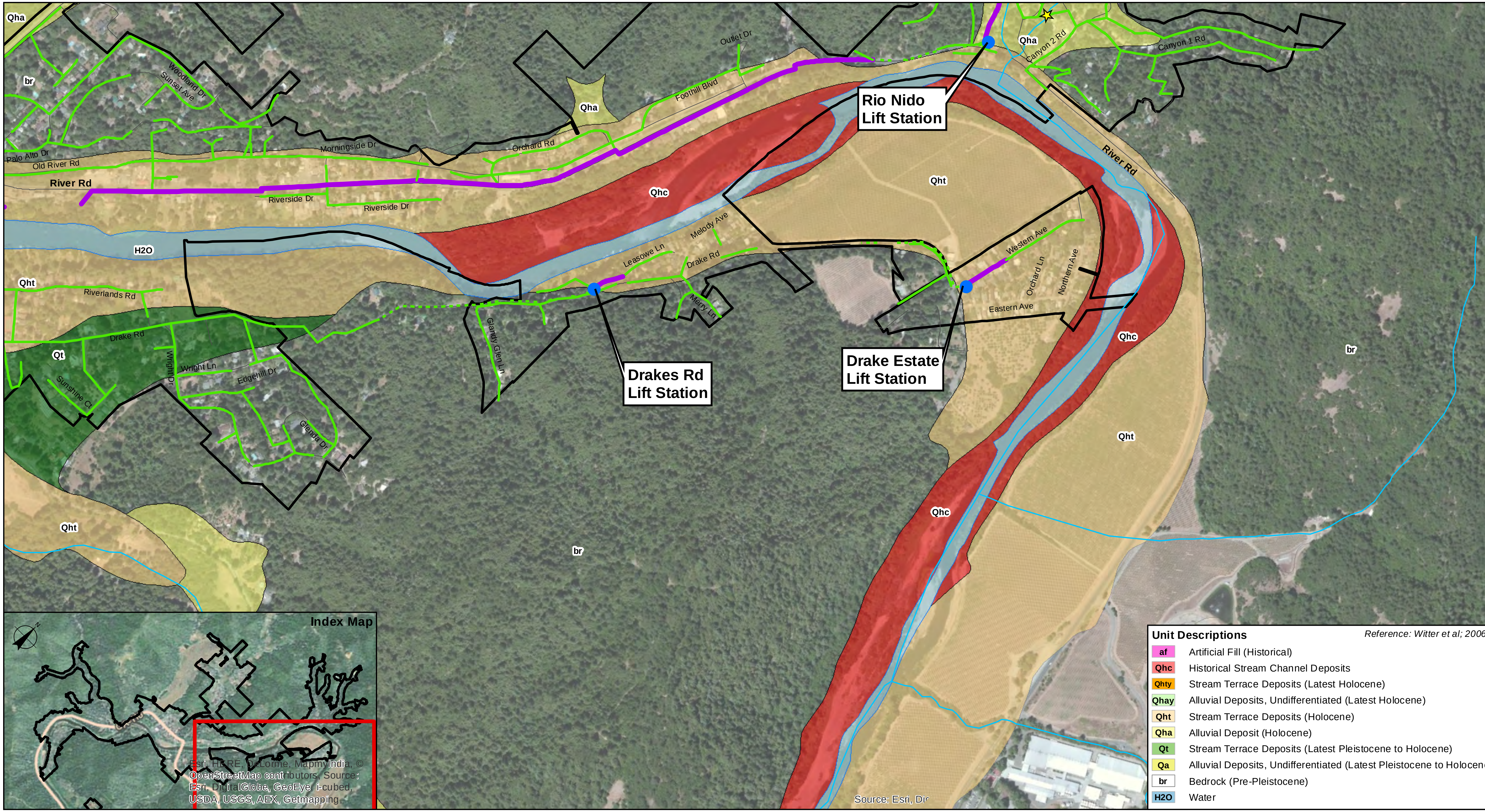
Russian River CSD
Quaternary Deposits (3 of 4)

Figure RR-8

N:\US\Santa Rosa\Projects\02243 - SCWA\02243-8410200 - Russian River CSD\08-GIS\Maps\Figures\Figure RR-8 Quaternary Deposits 3.mxd

Data source: SCWA, Sanitary Sewer, Street, Creek, Boundary, 2013; Kleinfelder, Geology, 2014; GHD, Crossings, 2014. Created by:afisher2

2235 Mercury Way Suite 150 Santa Rosa CA 95407 USA T 707 523 1010 F 707 527 8679 E santarosa@ghd.com W www.ghd.com



Paper Size 11" x 17" (ANSI B)

0 200 400 600 800

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California II FIPS 0402 Feet

RRCSD Boundary — Street — Creek — Force Main (2" - 10") — Sewer Main (2" - 10") — Force Main (12" - 30") — Sewer Main (12"- 30") — Crossing Location — Pump Station

G&E Engineering Systems, Inc.

KLEINFELDER

SONOMA COUNTY WATER AGENCY

Sonoma County Water Agency
Natural Hazard Reliability Assessment

Job Number	8410200
Revision	2
Date	11 Jun 2015

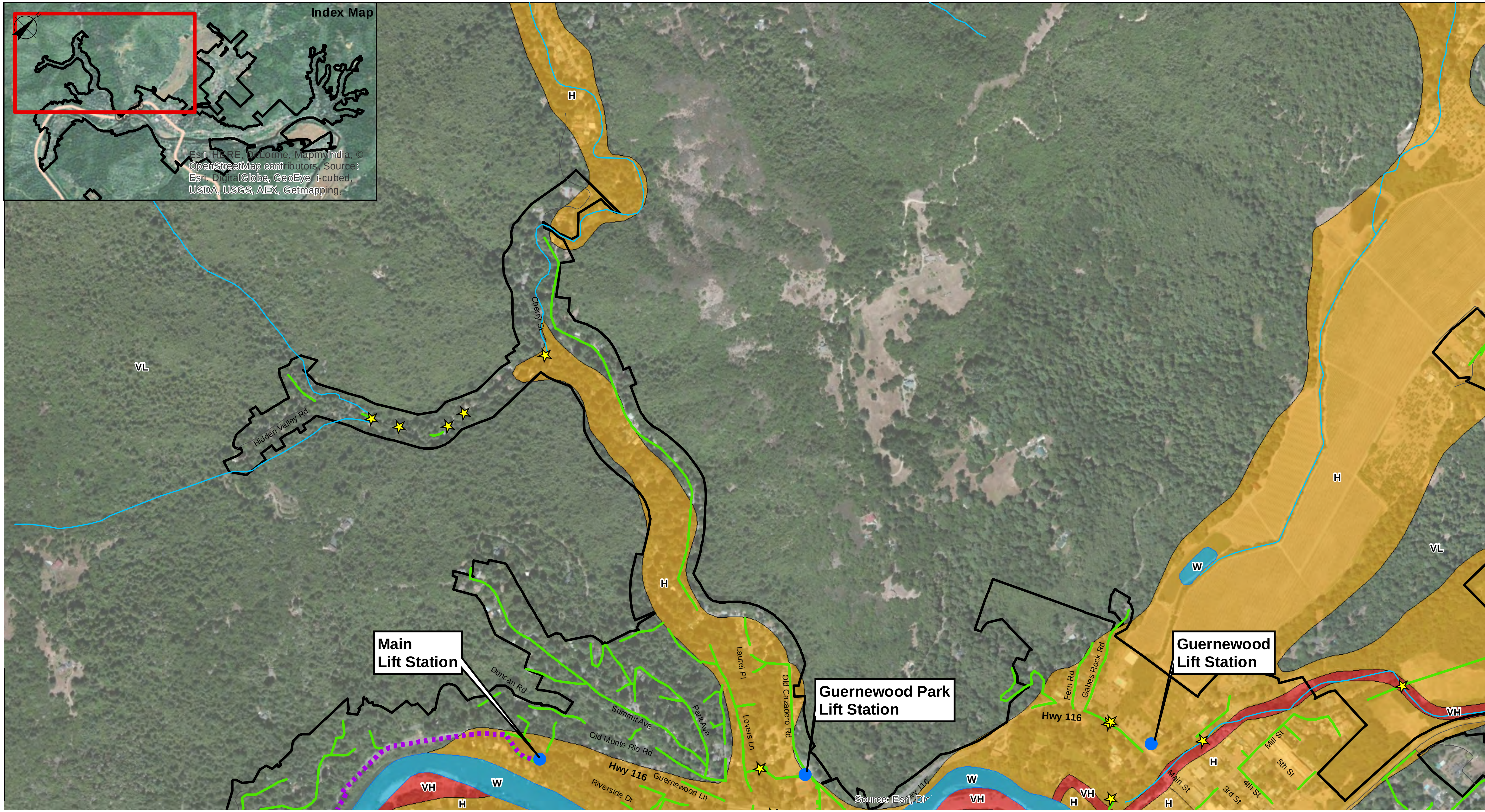
Russian River CSD
Quaternary Deposits (4 of 4)

Figure RR-9

N:\US\Santa Rosa\Projects\02243 - SCWA\02243-8410200 - Russian River CSD\08-GIS\Maps\Figures\Figure RR-9 Quaternary Deposits 4.mxd

Data source: SCWA, Sanitary Sewer, Street, Creek, Boundary, 2013; Kleinfelder, Geology, 2014; GHD, Crossings, 2014. Created by:afisher2

2235 Mercury Way Suite 150 Santa Rosa CA 95407 USA T 707 523 1010 F 707 527 8679 E santarosa@ghd.com W www.ghd.com



Paper Size 11" x 17" (ANSI B)

0 200 400 600 800

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California II FIPS 0402 Feet

RRCSD Boundary
Street
Creek
Crossing Location
Pump Station
Force Main (2" - 10")
Sewer Main (2" - 10")
Force Main (12" - 30")
Sewer Main (12"- 30")
contact, well located
water boundary

Liquefaction Susceptibility

VH Very High
H High
M Moderate
L Low
VL Very Low
W Water

G&E Engineering Systems, Inc.

Sonoma County Water Agency
Natural Hazard Reliability Assessment

Russian River CSD
Liquefaction (1 of 4)

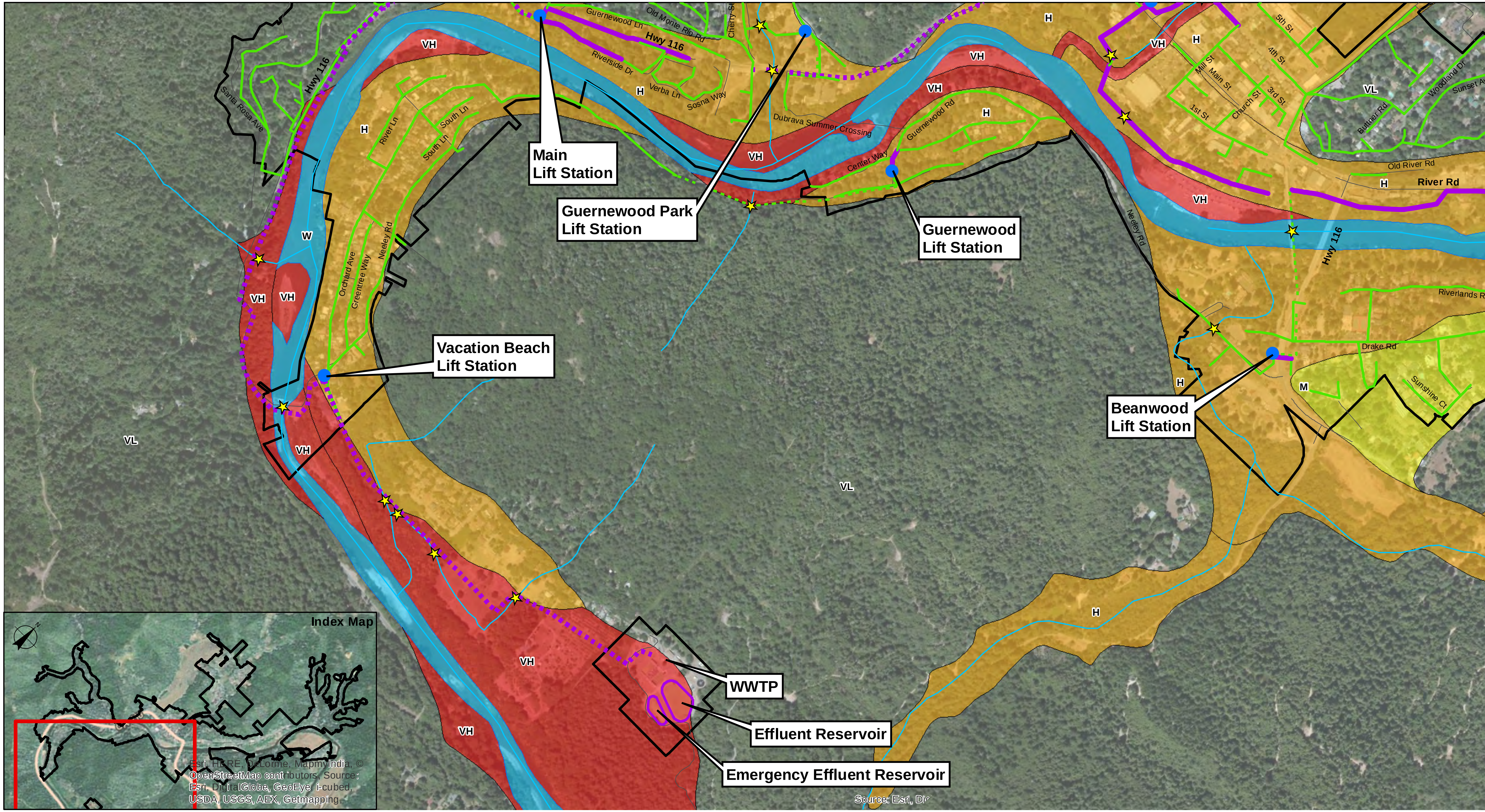
Job Number 8410200
Revision 2
Date 11 Jun 2015

Figure RR-10

N:\US\Santa Rosa\Projects\02243 - SCWA\02243-8410200 - Russian River CSD\08-GIS\Maps\Figures\Figure RR-10 Liquefaction 1.mxd

Data source: SCWA, Sanitary Sewer, Street, Creek, Boundary, 2013; Kleinfelder, Geology, 2014; GHD, Crossings, 2014. Created by:afisher2

2235 Mercury Way Suite 150 Santa Rosa CA 95407 USA T 707 523 1010 F 707 527 8679 E santarosa@ghd.com W www.ghd.com



Paper Size 11" x 17" (ANSI B)

0 200 400 600 800

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California II FIPS 0402 Feet

RRCSD Boundary
Street
Creek
Crossing Location
Pump Station
Force Main (2" - 10")
Sewer Main (2" - 10")
Force Main (12" - 30")
Sewer Main (12"- 30")
contact, well located
water boundary

Liquefaction Susceptibility

VH Very High
H High
M Moderate
L Low
VL Very Low
W Water

G&E Engineering Systems, Inc.

Sonoma County Water Agency
Natural Hazard Reliability Assessment

Job Number	8410200
Revision	2
Date	11 Jun 2015

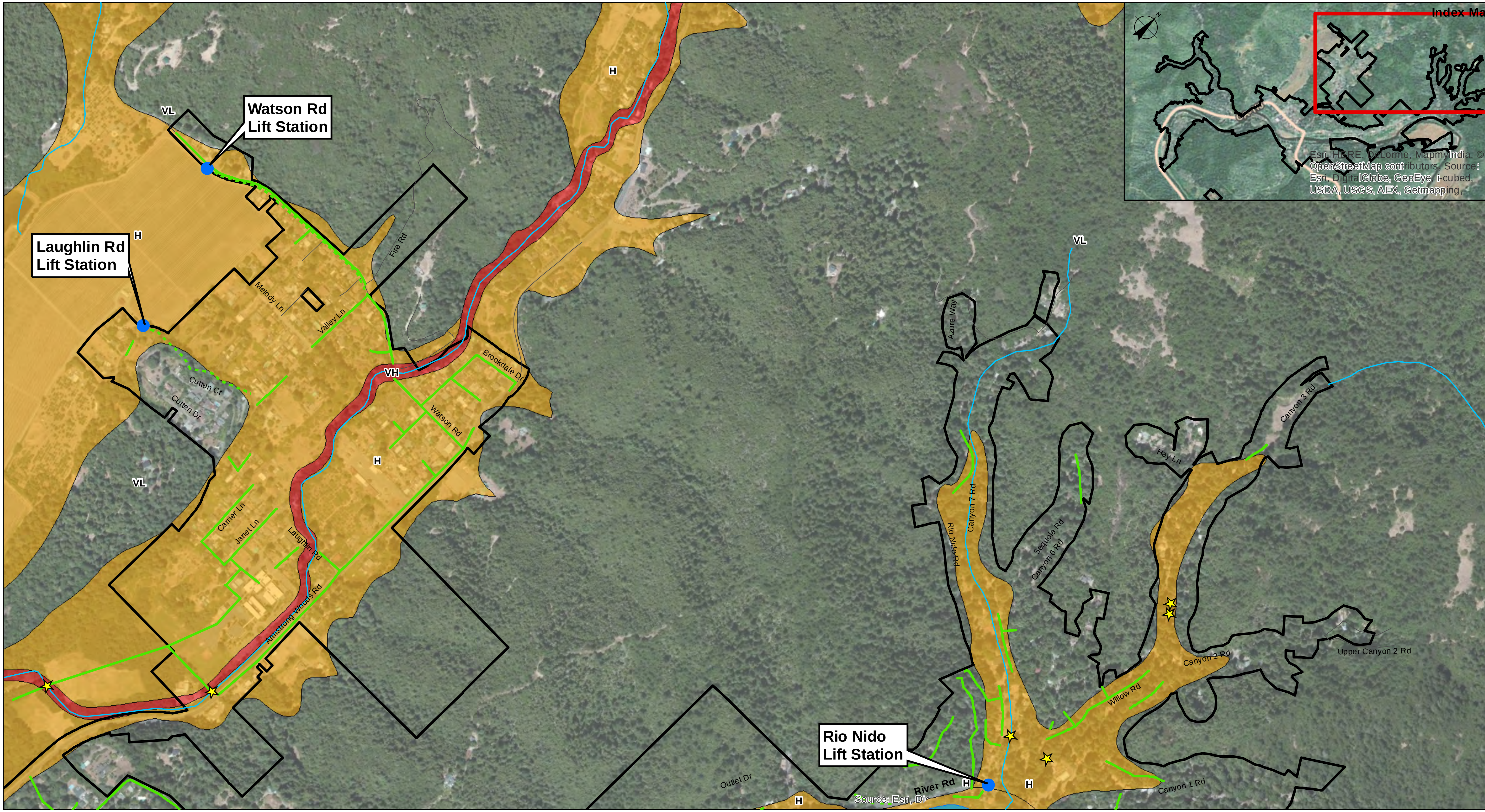
Russian River CSD Liquefaction (2 of 4)

Figure RR-11

N:\US\Santa Rosa\Projects\02243 - SCWA\02243-8410200 - Russian River CSD\08-GIS\Maps\Figures\Figure RR-11 Liquefaction 2.mxd

2235 Mercury Way Suite 150 Santa Rosa CA 95407 USA T 707 523 1010 F 707 527 8679 E santarosa@ghd.com W www.ghd.com

Data source: SCWA, Sanitary Sewer, Street, Creek, Boundary, 2013; Kleinfelder, Geology, 2014; GHD, Crossings, 2014. Created by:afisher2



Paper Size 11" x 17" (ANSI B)

0 200 400 600 800

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California II FIPS 0402 Feet

Legend			
RRCSD Boundary	Force Main (2" - 10")	contact, well located	M Moderate
Street	Sewer Main (2" - 10")	water boundary	L Low
Creek	Force Main (12" - 30")	**Liquefaction Susceptibility**	VL Very Low
Crossing Location	Sewer Main (12"- 30")	VH Very High	W Water
Pump Station		H High	

G&E Engineering Systems, Inc.

KLEINFELDER

SONOMA COUNTY WATER AGENCY

Sonoma County Water Agency
Natural Hazard Reliability Assessment

Russian River CSD Liquefaction (3 of 4)

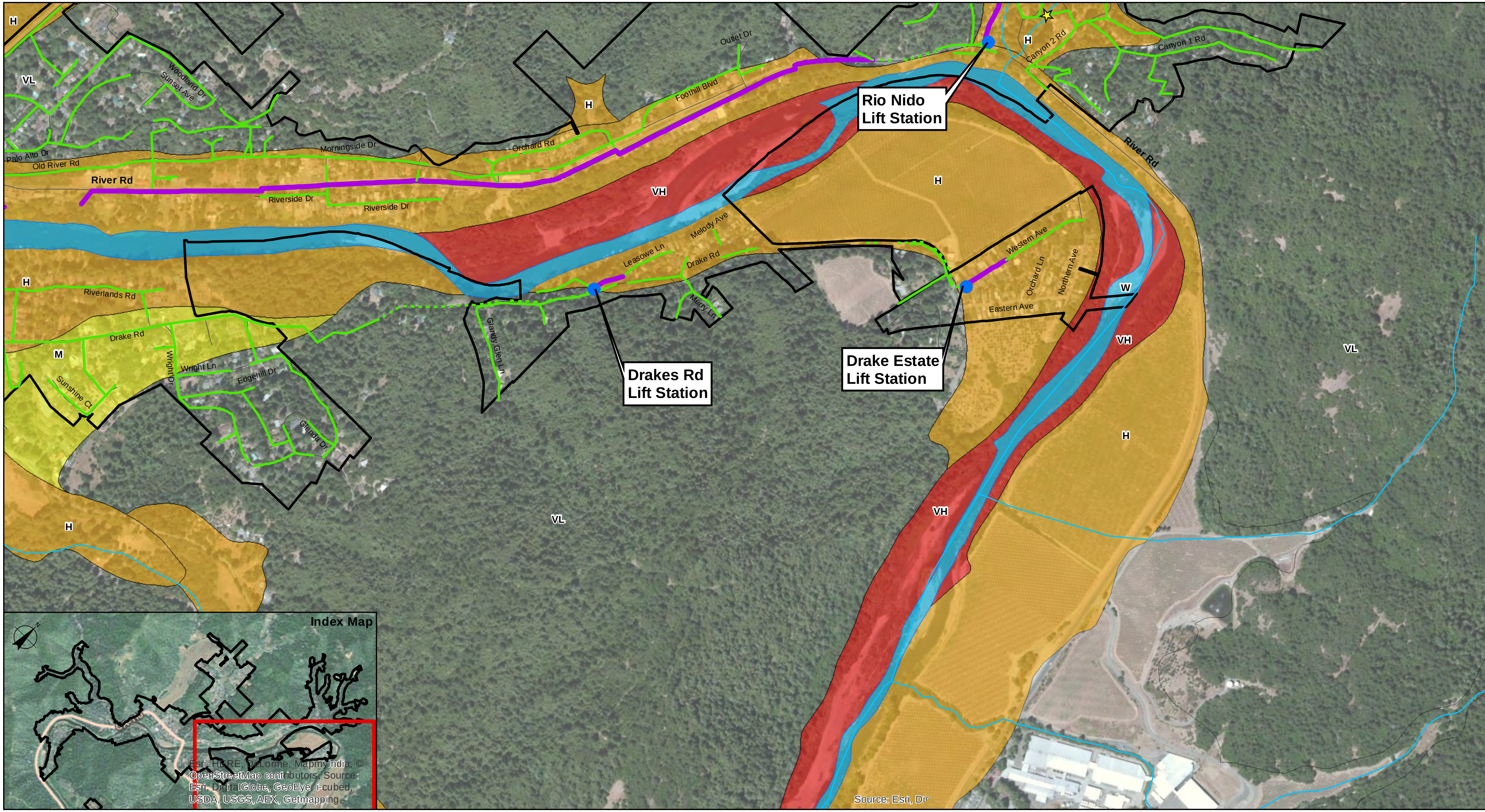
Job Number	8410200
Revision	2
Date	11 Jun 2015

Figure RR-12

2235 Mercury Way Suite 150 Santa Rosa CA 95407 USA T 707 523 1010 F 707 527 8679 E santarosa@ghd.com W www.ghd.com

N:\US\Santa Rosa\Projects\02243 - SCWA\02243-8410200 - Russian River CSD\08-GIS\Maps\Figures\Figure RR-12 Liquefaction 3.mxd

Data source: SCWA, Sanitary Sewer, Street, Creek, Boundary, 2013; Kleinfelder, Geology, 2014; GHD, Crossings, 2014. Created by:afisher2



Paper Size 11" x 17" (ANSI B)

0 200 400 600 800

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California II FIPS 0402 Feet

N

RRCSD Boundary
Street
Creek
Crossing Location
Pump Station
Force Main (2" - 10")
Sewer Main (2" - 10")
Force Main (12" - 30")
Sewer Main (12"- 30")
contact, well located
water boundary

Liquefaction Susceptibility

VH Very High
H High
M Moderate
L Low
VL Very Low
W Water

G&E Engineering Systems, Inc.

KLEINFELDER

SONOMA COUNTY WATER AGENCY

Sonoma County Water Agency
Natural Hazard Reliability Assessment

Russian River CSD
Liquefaction (4 of 4)

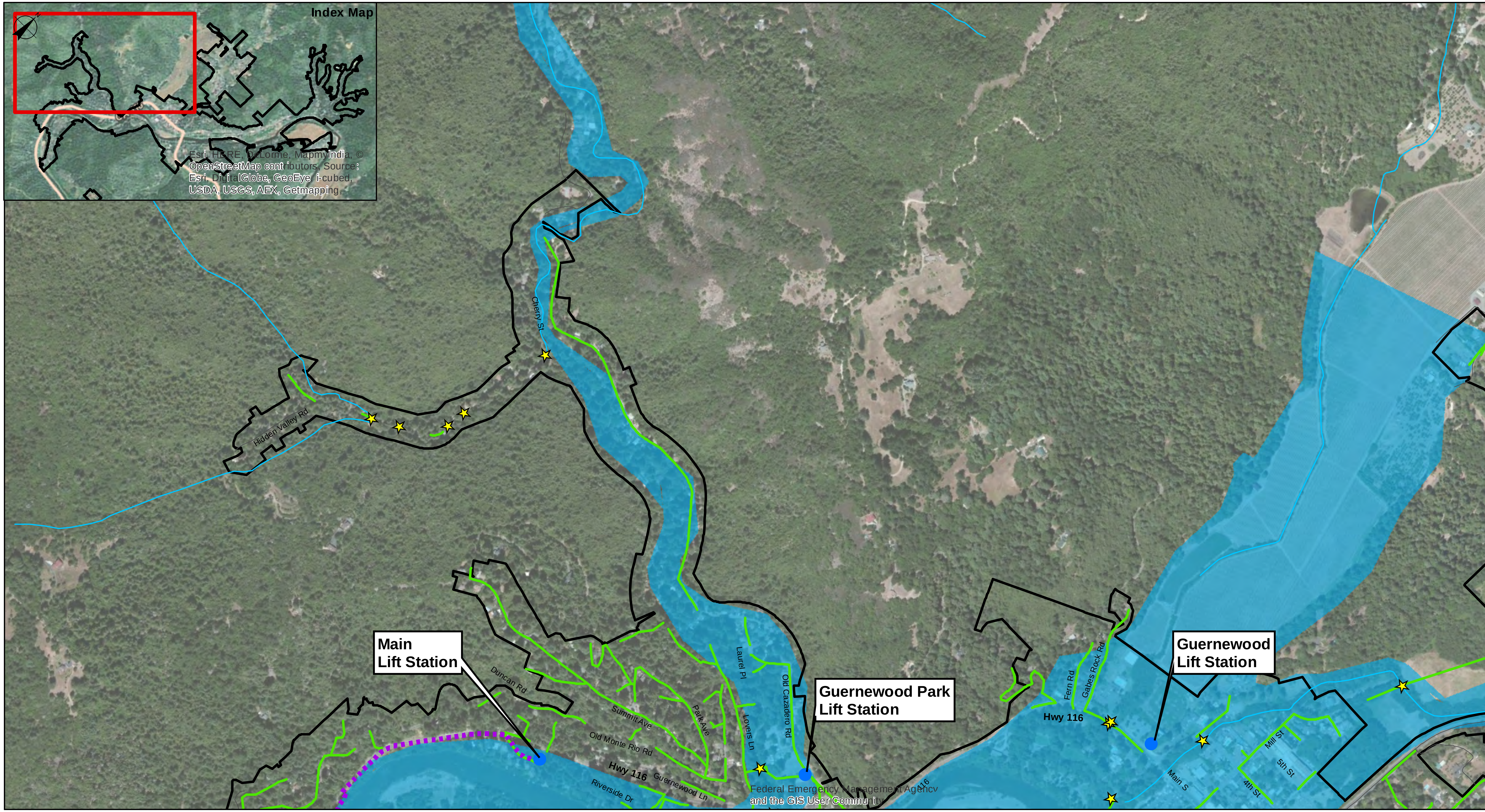
Job Number 8410200
Revision 2
Date 11 Jun 2015

Figure RR-13

N:\US\Santa Rosa\Projects\02243 - SCWA\02243-8410200 - Russian River CSD\08-GIS\Maps\Figures\Figure RR-13 Liquefaction 4.mxd

Data source: SCWA, Sanitary Sewer, Street, Creek, Boundary, 2013; Kleinfelder, Geology, 2014; GHD, Crossings, 2014. Created by:afisher2

2235 Mercury Way Suite 150 Santa Rosa CA 95407 USA T 707 523 1010 F 707 527 8679 E santarosa@ghd.com W www.ghd.com



Paper Size 11" x 17" (ANSI B)

0 200 400 600 800
Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California II FIPS 0402 Feet

- RRCSD Boundary
- Street
- Creek
- Crossing Location
- Pump Station
- Force Main (2" - 10")
- Sewer Main (2" - 10")
- Force Main (12" - 30")
- Sewer Main (12"- 30")
- 100 Year Flood Zones

G&E Engineering Systems, Inc.

Sonoma County Water Agency
Natural Hazard Reliability Assessment

Russian River CSD
Flood Zone (1 of 4)

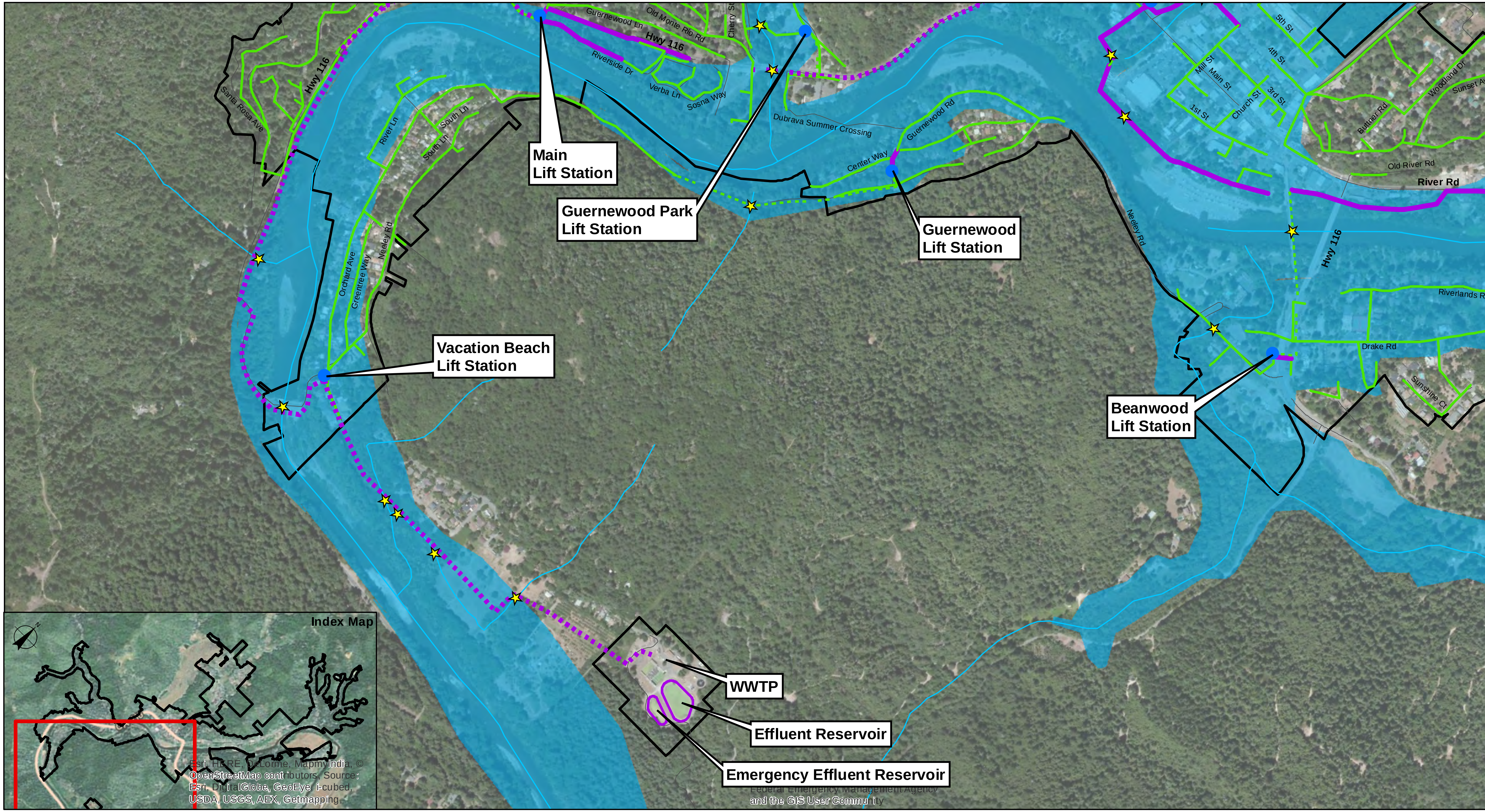
Job Number	8410200
Revision	2
Date	11 Jun 2015

Figure RR-14

N:\US\Santa Rosa\Projects\02243 - SCWA\02243-8410200 - Russian River CSD\08-GIS\Maps\Figures\Figure RR-14 Flood Zone 1.mxd

Data source: SCWA, Sanitary Sewer, Street, Creek, Boundary, 2013; Kleinfelder, Geology, 2014; GHD, Crossings, 2014. Created by:afisher2

2235 Mercury Way Suite 150 Santa Rosa CA 95407 USA T 707 523 1010 F 707 527 8679 E santarosa@ghd.com W www.ghd.com



Paper Size 11" x 17" (ANSI B)

0 200 400 600 800

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California II FIPS 0402 Feet

RRCSD Boundary	Crossing Location	Force Main (2" - 10")	100 Year Flood Zones
Street	Pump Station	Sewer Main (2" - 10")	
Creek		Force Main (12" - 30")	
		Sewer Main (12"- 30")	

G&E Engineering Systems, Inc.

KLEINFELDER

SONOMA COUNTY WATER AGENCY

Sonoma County Water Agency
Natural Hazard Reliability Assessment

Job Number 8410200
Revision 2
Date 11 Jun 2015

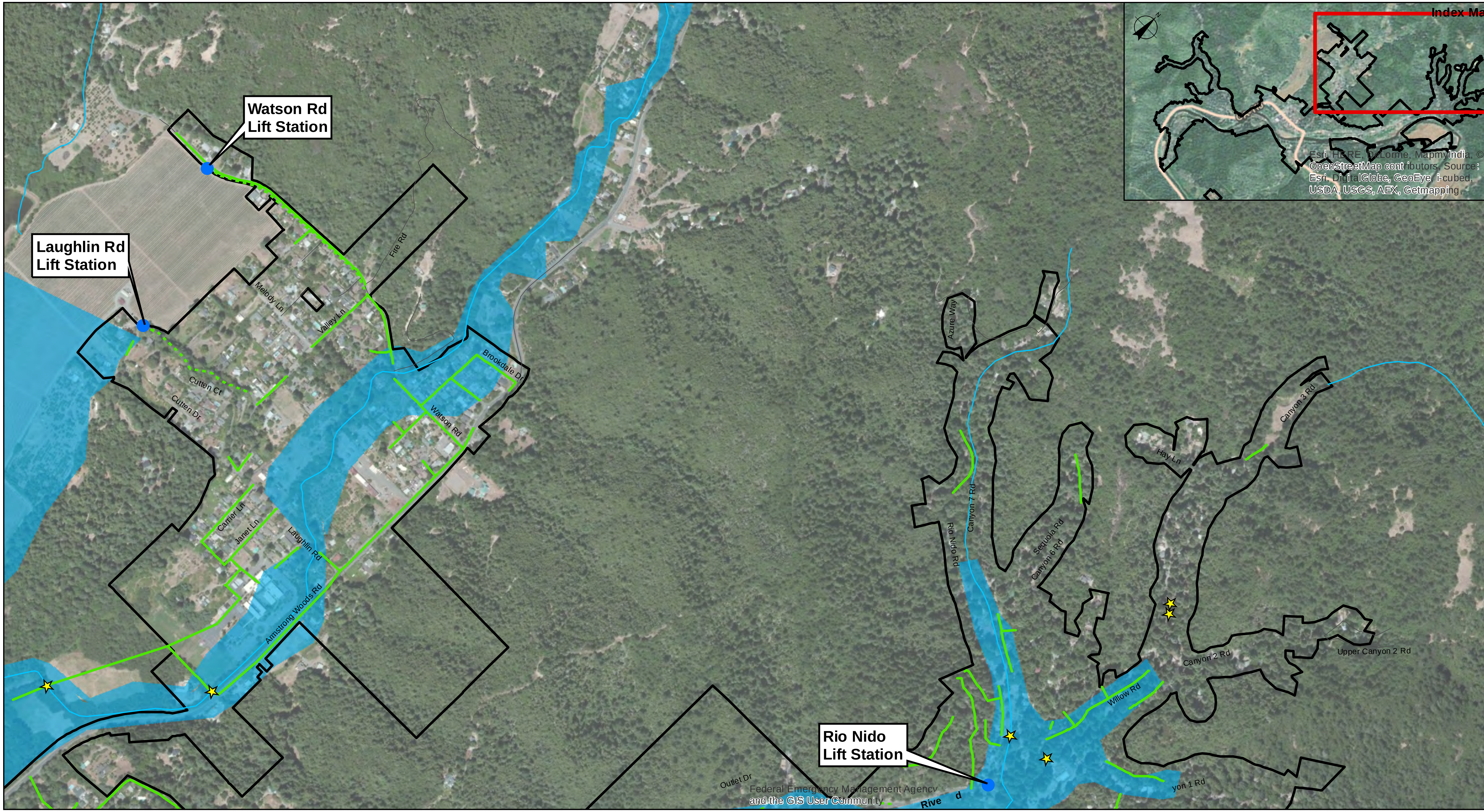
Russian River CSD
Flood Zone (2 of 4)

Figure RR-15

N:\US\Santa Rosa\Projects\02243 - SCWA\02243-8410200 - Russian River CSD\08-GIS\Maps\Figures\Figure RR-15 Flood Zone 2.mxd

Data source: SCWA, Sanitary Sewer, Street, Creek, Boundary, 2013; Kleinfelder, Geology, 2014; GHD, Crossings, 2014. Created by:afisher2

2235 Mercury Way Suite 150 Santa Rosa CA 95407 USA T 707 523 1010 F 707 527 8679 E santarosa@ghd.com W www.ghd.com



Paper Size 11" x 17" (ANSI B)

0 200 400 600 800

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California II FIPS 0402 Feet

RRCSD Boundary
Street
Creek
Crossing Location
Pump Station
Force Main (2" - 10")
Sewer Main (2" - 10")
Force Main (12" - 30")
Sewer Main (12"- 30")
100 Year Flood Zones

G&E Engineering Systems, Inc.

Sonoma County Water Agency
Natural Hazard Reliability Assessment

Russian River CSD
Flood Zone (3 of 4)

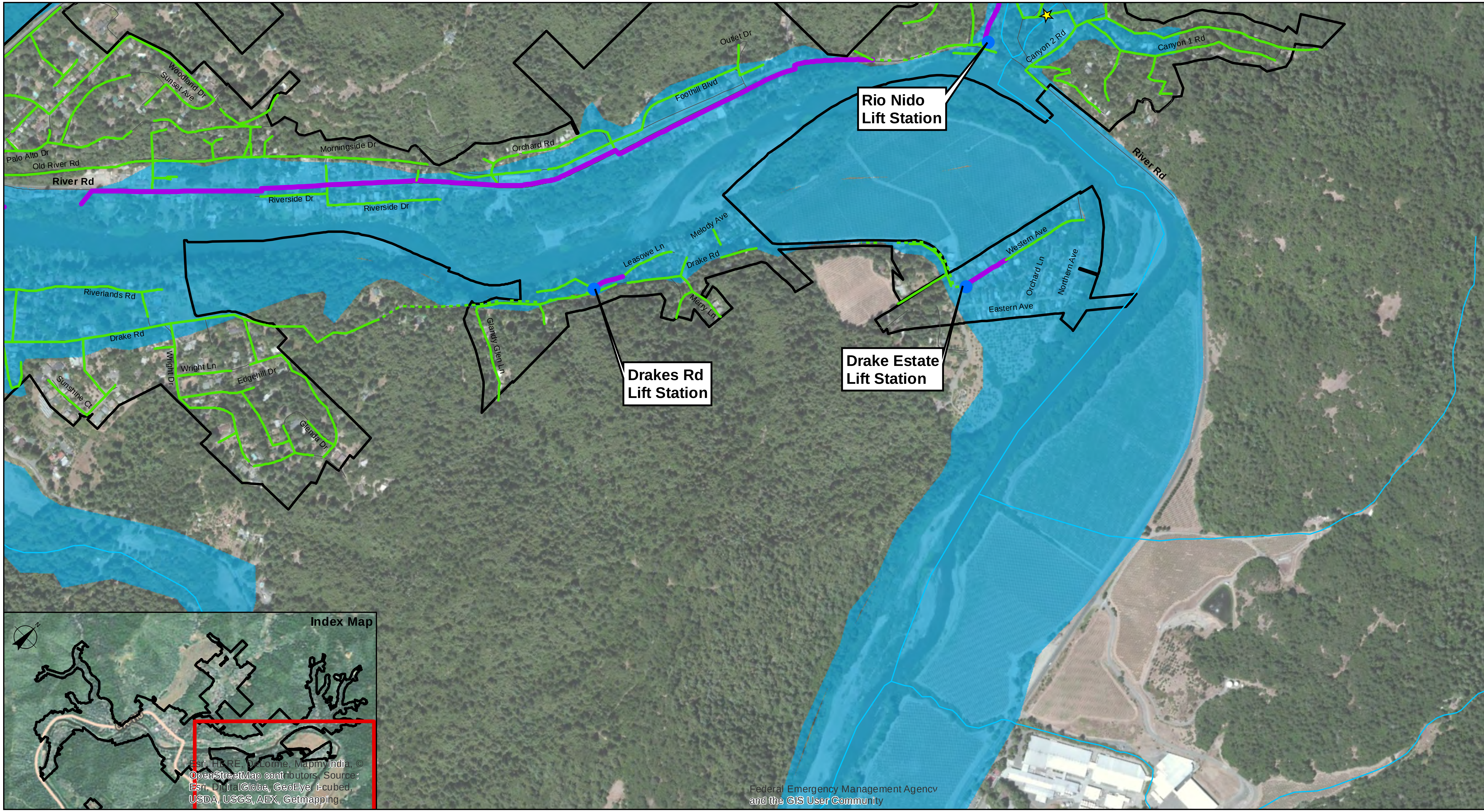
Job Number	8410200
Revision	2
Date	11 Jun 2015

Figure RR-16

N:\US\Santa Rosa\Projects\02243 - SCWA\02243-8410200 - Russian River CSD\08-GIS\Maps\Figures\Figure RR-16 Flood Zone 3.mxd

Data source: SCWA, Sanitary Sewer, Street, Creek, Boundary, 2013; Kleinfelder, Geology, 2014; GHD, Crossings, 2014. Created by:afisher2

2235 Mercury Way Suite 150 Santa Rosa CA 95407 USA T 707 523 1010 F 707 527 8679 E santarosa@ghd.com W www.ghd.com



Paper Size 11" x 17" (ANSI B)

0 200 400 600 800

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California II FIPS 0402 Feet

RRCSD Boundary
Street
Creek
Crossing Location
Pump Station
Force Main (2" - 10")
Sewer Main (2" - 10")
Force Main (12" - 30")
Sewer Main (12"- 30")
100 Year Flood Zones

G&E Engineering Systems, Inc.

Sonoma County Water Agency
Natural Hazard Reliability Assessment

Russian River CSD
Flood Zone (4 of 4)

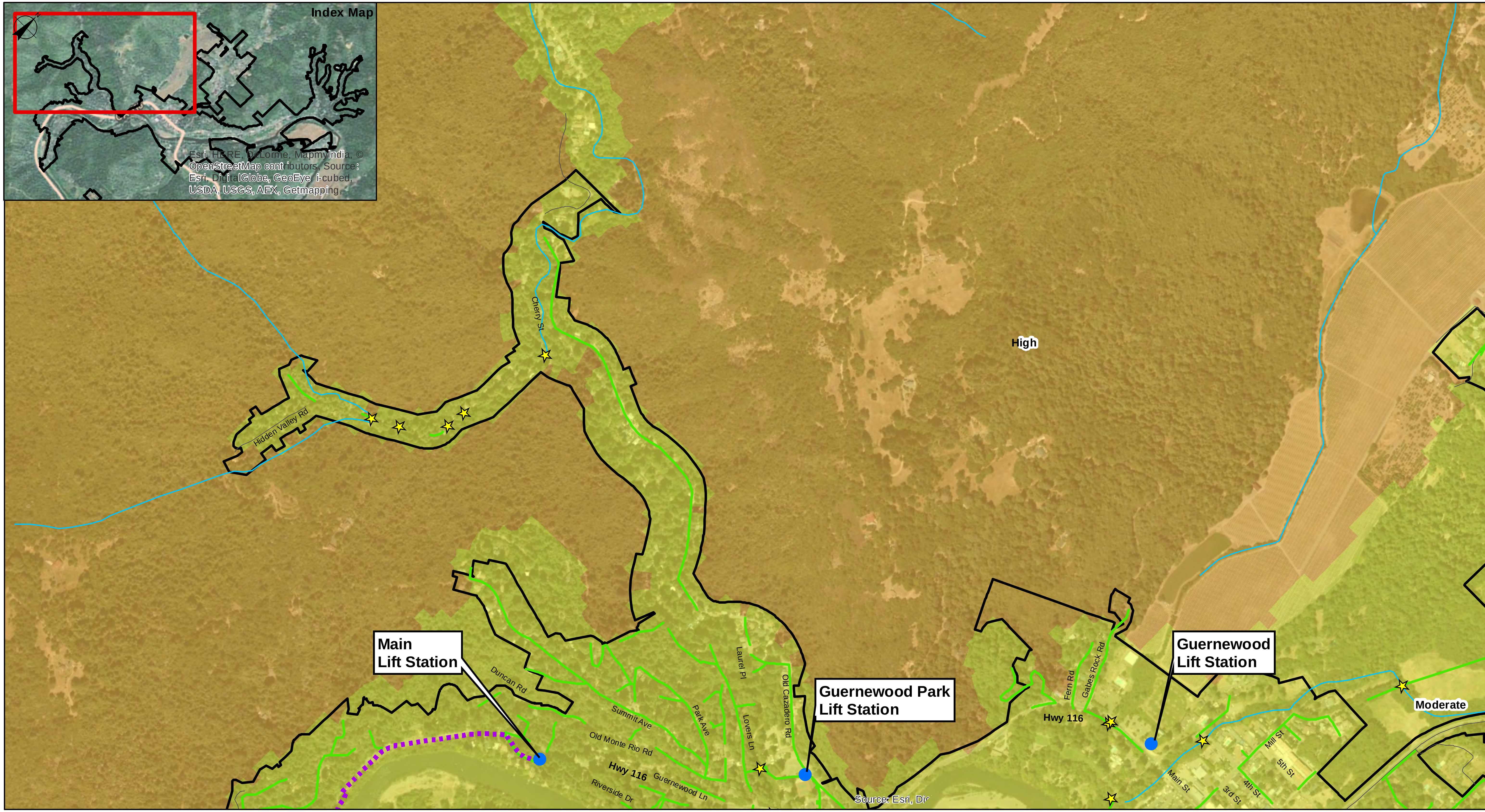
Job Number	8410200
Revision	2
Date	11 Jun 2015

Figure RR-17

N:\US\Santa Rosa\Projects\02243 - SCWA\02243-8410200 - Russian River CSD\08-GIS\Maps\Figures\Figure RR-17 Flood Zone 4.mxd

Data source: SCWA, Sanitary Sewer, Street, Creek, Boundary, 2013; Kleinfelder, Geology, 2014; GHD, Crossings, 2014. Created by:afisher2

2235 Mercury Way Suite 150 Santa Rosa CA 95407 USA T 707 523 1010 F 707 527 8679 E santarosa@ghd.com W www.ghd.com



Paper Size 11" x 17" (ANSI B)

0 200 400 600 800

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California II FIPS 0402 Feet

N

RRCSD Boundary
Street
Creek
Crossing Location
Pump Station
Force Main (2" - 10")
Sewer Main (2" - 10")
Force Main (12" - 30")
Sewer Main (12"- 30")

Fire Hazard Class

Very High
High
Moderate
Non-Wildland/Non-Urban
Urban Unzoned

HI

G&E Engineering Systems, Inc.

KLEINFELDER

SONOMA COUNTY WATER AGENCY

Sonoma County Water Agency
Natural Hazard Reliability Assessment

Russian River CSD
Fire Hazard Zone (1 of 4)

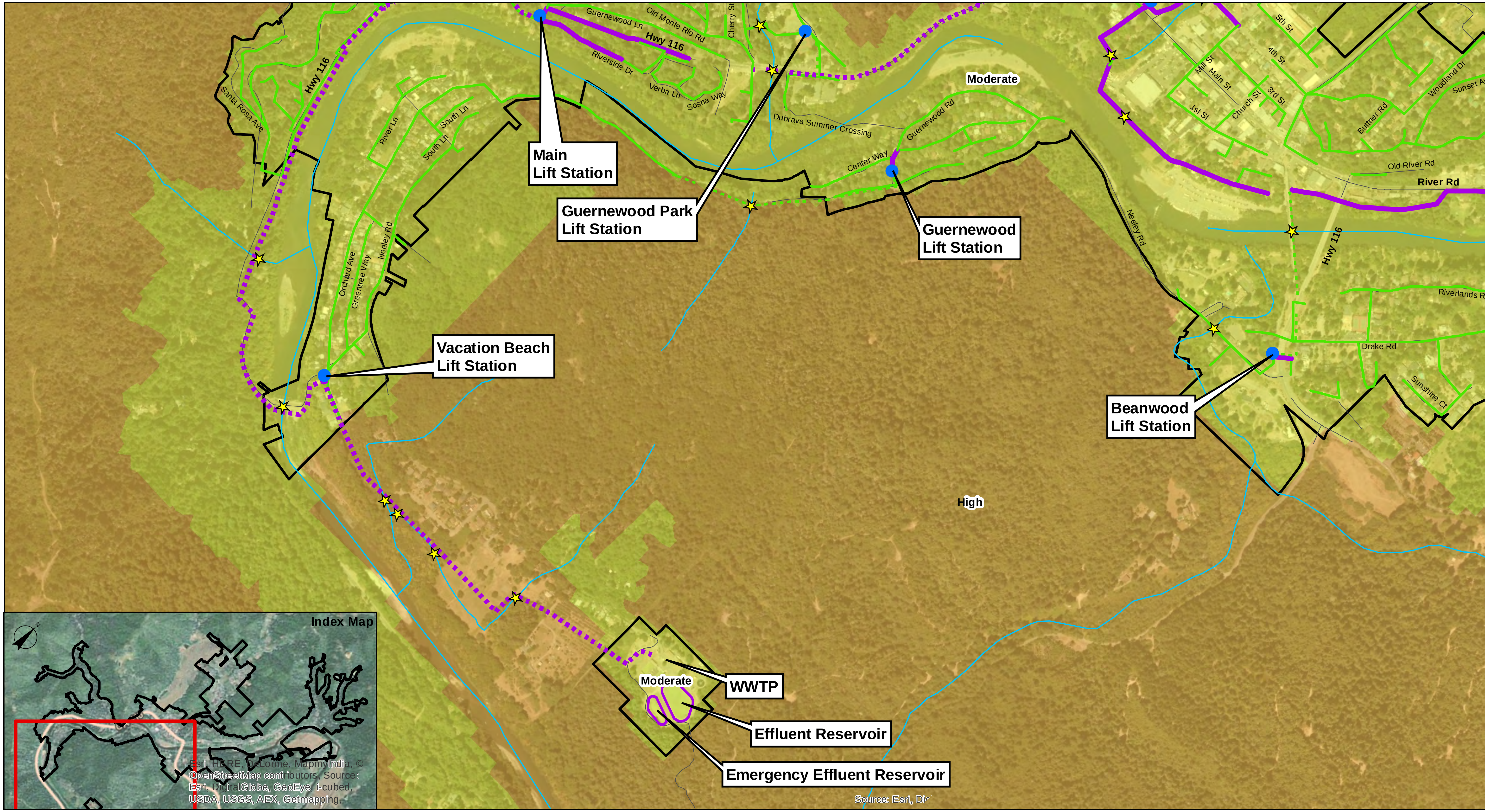
Job Number	8410200
Revision	2
Date	11 Jun 2015

Figure RR-18

N:\US\Santa Rosa\Projects\02243 - SCWA\02243-8410200 - Russian River CSD\08-GIS\Maps\Figures\Figure RR-18 Fire Hazard 1.mxd

2235 Mercury Way Suite 150 Santa Rosa CA 95407 USA **T** 707 523 1010 **F** 707 527 8679 **E** santarosa@ghd.com **W** www.ghd.com

Data source: SCWA, Sanitary Sewer, Street, Creek, Boundary, 2013; Kleinfelder, Geology, 2014; GHD, Crossings, 2014. Created by:afisher2



Paper Size 11" x 17" (ANSI B)

0 200 400 600 800

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California II FIPS 0402 Feet

RRCSD Boundary
Street
Creek
Crossing Location
Pump Station
Force Main (2" - 10")
Sewer Main (2" - 10")
Force Main (12" - 30")
Sewer Main (12"- 30")

Fire Hazard Class

Very High
High
Moderate
Non-Wildland/Non-Urban
Urban Unzoned

G&E Engineering Systems, Inc.

Sonoma County Water Agency
Natural Hazard Reliability Assessment

Job Number 8410200
Revision 2
Date 11 Jun 2015

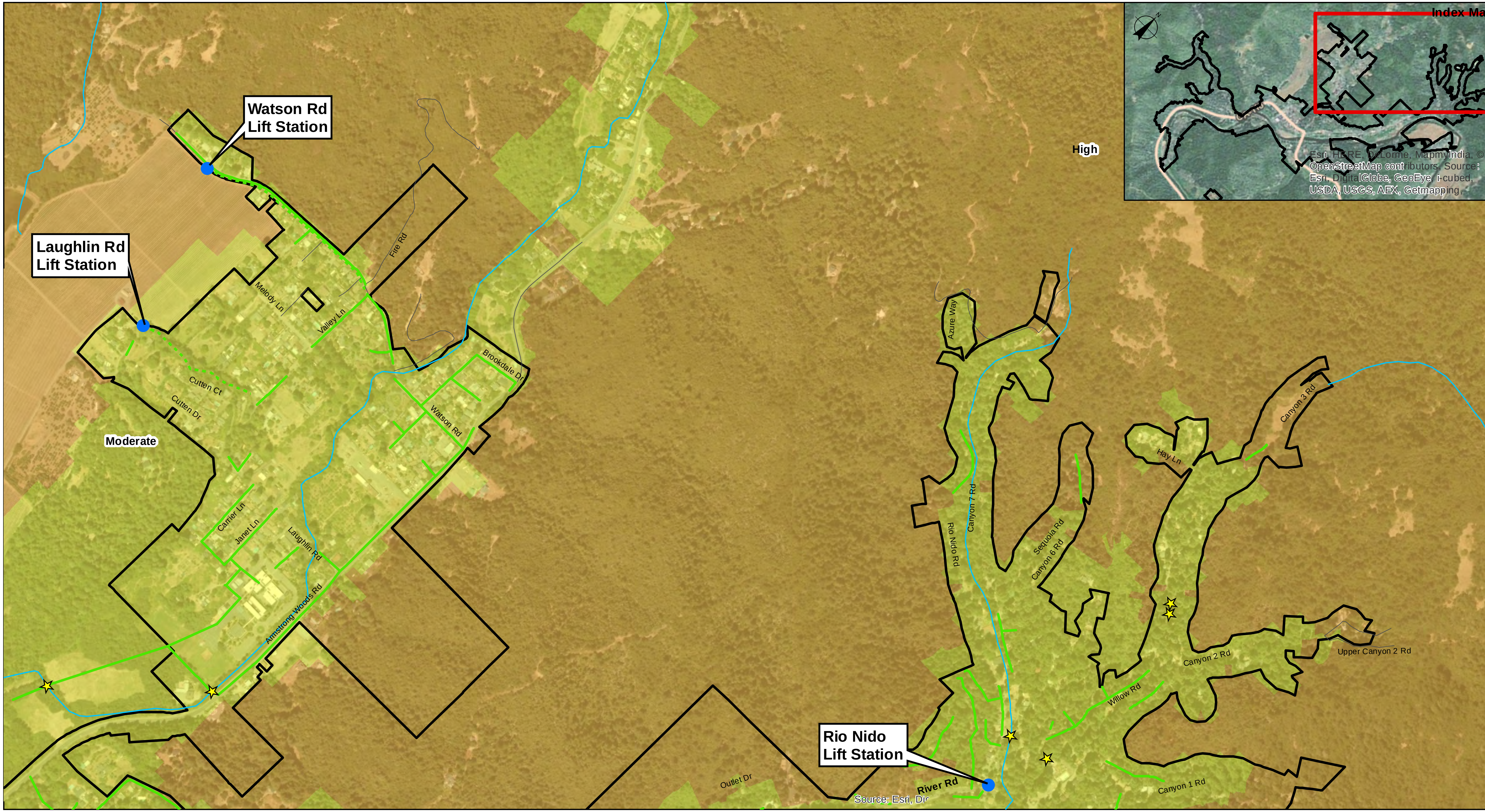
Russian River CSD
Fire Hazard Zone (2 of 4)

Figure RR-19

N:\US\Santa Rosa\Projects\02243 - SCWA\02243-8410200 - Russian River CSD\08-GIS\Maps\Figures\Figure RR-19 Fire Hazard 2.mxd

Data source: SCWA, Sanitary Sewer, Street, Creek, Boundary, 2013; Kleinfelder, Geology, 2014; GHD, Crossings, 2014. Created by:afisher2

2235 Mercury Way Suite 150 Santa Rosa CA 95407 USA T 707 523 1010 F 707 527 8679 E santarosa@ghd.com W www.ghd.com



Paper Size 11" x 17" (ANSI B)

0 200 400 600 800

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California II FIPS 0402 Feet

RRCSD Boundary
Street
Creek
Crossing Location
Pump Station
Force Main (2" - 10")
Sewer Main (2" - 10")
Force Main (12" - 30")
Sewer Main (12"- 30")

Fire Hazard Class

Very High
High
Moderate
Non-Wildland/Non-Urban
Urban Unzoned

G&E Engineering Systems, Inc.

Sonoma County Water Agency
Natural Hazard Reliability Assessment

Russian River CSD
Fire Hazard Zone (3 of 4)

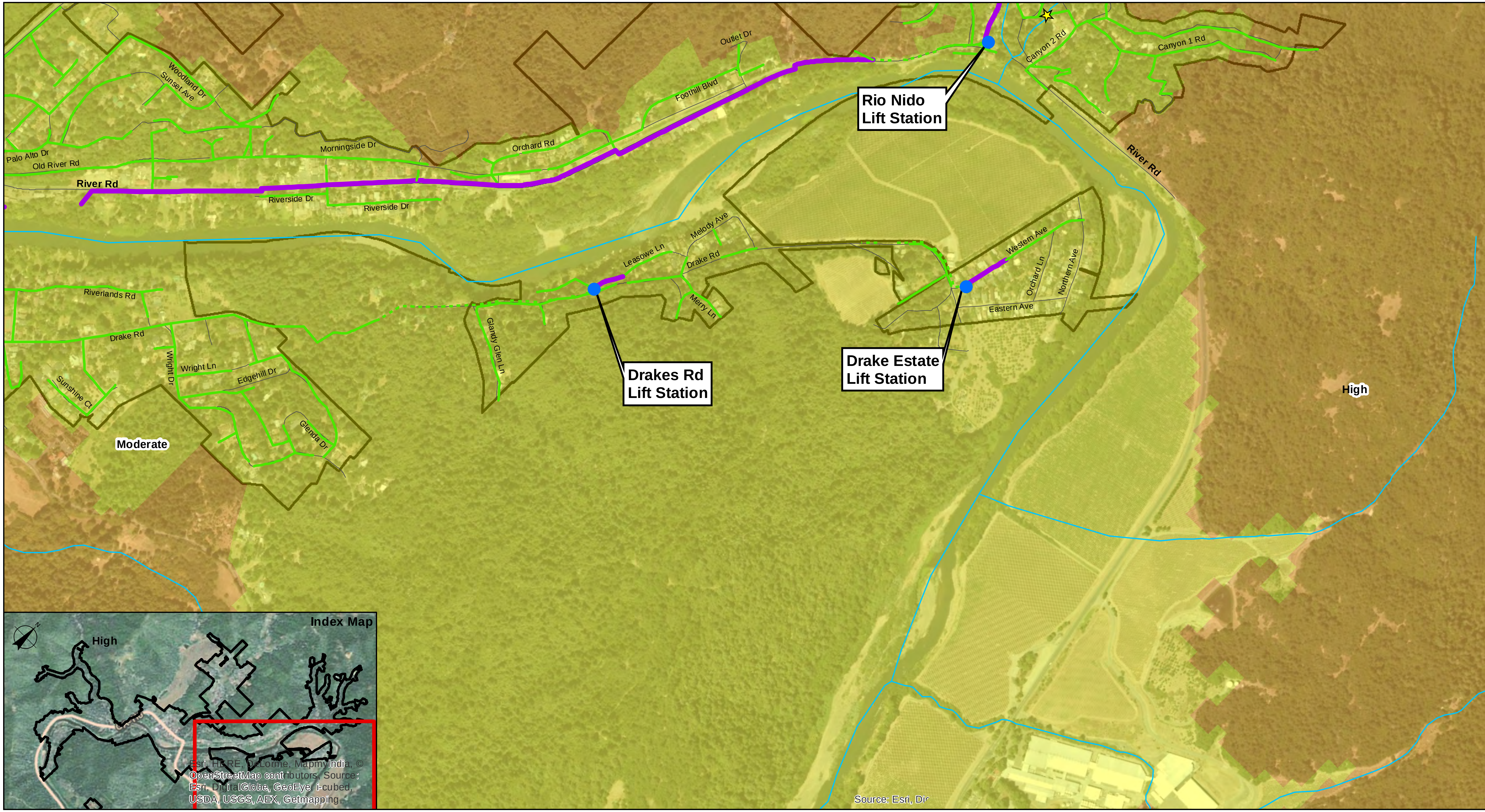
Job Number	8410200
Revision	2
Date	11 Jun 2015

Figure RR-20

2235 Mercury Way Suite 150 Santa Rosa CA 95407 USA T 707 523 1010 F 707 527 8679 E santarosa@ghd.com W www.ghd.com

N:\US\Santa Rosa\Projects\02243 - SCWA\02243-8410200 - Russian River CSD\08-GIS\Maps\Figures\Figure RR-20 Fire Hazard 3.mxd

Data source: SCWA, Sanitary Sewer, Street, Creek, Boundary, 2013; Kleinfelder, Geology, 2014; GHD, Crossings, 2014. Created by:afisher2



Paper Size 11" x 17" (ANSI B)

0 200 400 600 800

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California II FIPS 0402 Feet

RRCSD Boundary	Pump Station	Force Main (12" - 30")	High
Street	Force Main (2" - 10")	Sewer Main (12"- 30")	Moderate
Creek	Sewer Main (2" - 10")	**Fire Hazard Class**	Non-Wildland/Non-Urban
Crossing Location		Very High	Urban Unzoned

G&E Engineering Systems, Inc.

KLEINFELDER

SONOMA COUNTY WATER AGENCY

Sonoma County Water Agency
Natural Hazard Reliability Assessment

Job Number 8410200
Revision 2
Date 11 Jun 2015

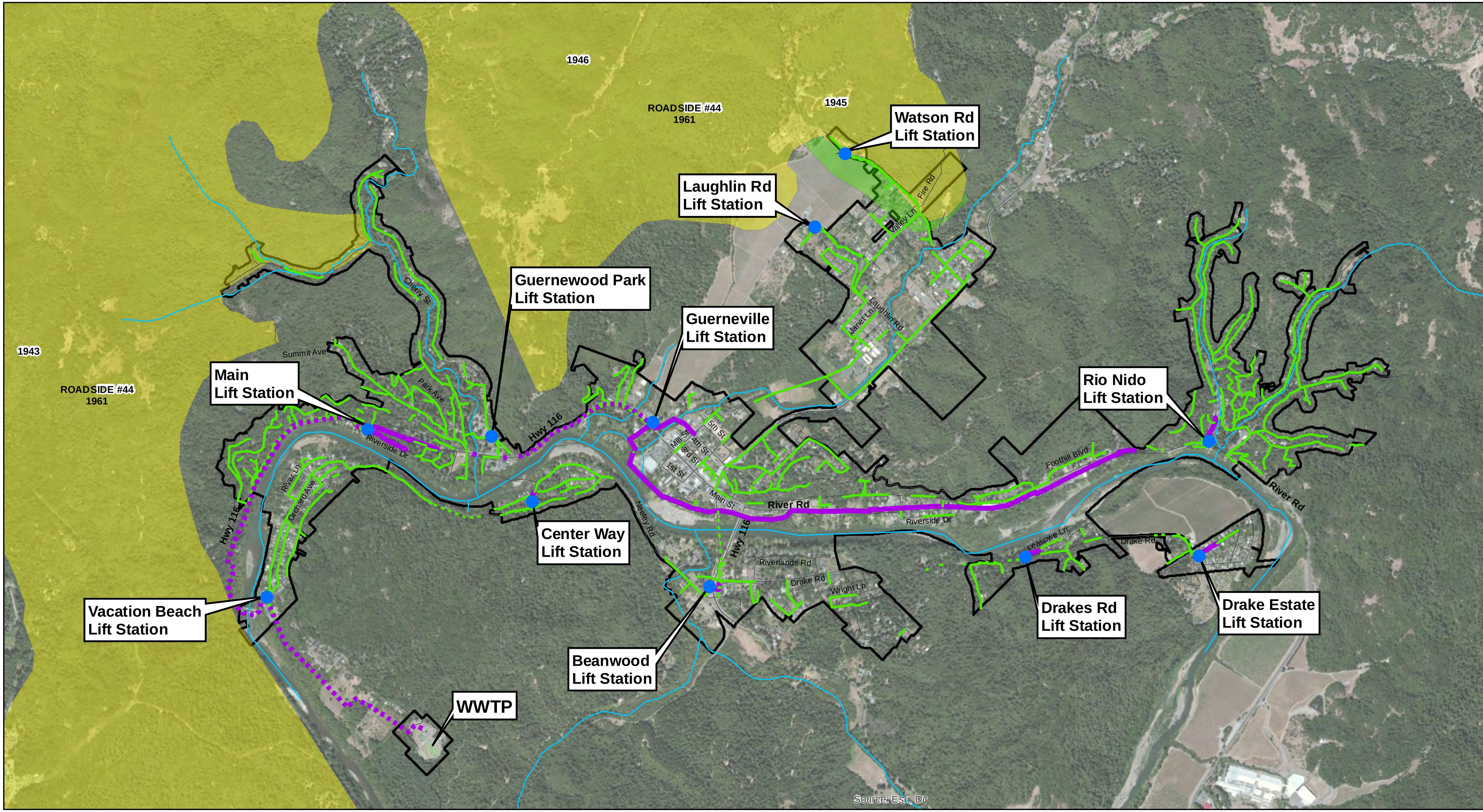
Russian River CSD
Fire Hazard Zone (4 of 4)

Figure RR-21

N:\US\Santa Rosa\Projects\02243 - SCWA\02243-8410200 - Russian River CSD\08-GIS\Maps\Figures\Figure RR-21 Fire Hazard 4.mxd

Data source: SCWA, Sanitary Sewer, Street, Creek, Boundary, 2013; Kleinfelder, Geology, 2014; GHD, Crossings, 2014. Created by:afisher2

2235 Mercury Way Suite 150 Santa Rosa CA 95407 USA T 707 523 1010 F 707 527 8679 E santarosa@ghd.com W www.ghd.com



Paper Size 11" x 17" (ANSI B)

0 375 750 1,125 1,500

Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane California II FIPS 0402 Feet

N

Legend		
RRCSD Boundary	Force Main (2" - 10")	
Street	Sewer Main (2" - 10")	
Creek	Force Main (12" - 30")	
Pump Station	Sewer Main (12"- 30")	

Historical Wild Fires

Oldest

Most Recent

G&E Engineering Systems, Inc.

KLEINFELDER

SONOMA COUNTY WATER AGENCY

Sonoma County Water Agency
Natural Hazard Reliability Assessment

Russian River CSD
Historical Wild Fires

Job Number	8410200
Revision	2
Date	11 Jun 2015

Figure RR-22

N:\US\Santa Rosa\Projects\02243 - SCWA\02243-8410200 - Russian River CSD\08-GIS\Maps\Figures\Figure RR-22 Historical Fires.mxd

Data source: SCWA, Sanitary Sewer, Street, Creek, Boundary, 2013. Created by:afisher2

2235 Mercury Way Suite 150 Santa Rosa CA 95407 USA T 707 523 1010 F 707 527 8679 E santarosa@ghd.com W www.ghd.com

www.ghd.com

GHD Inc.

2235 Mercury Way, Suite 150

Santa Rosa, CA 95407

T: 707 523 1010 F: 707 527 8679   E: Alex.Culick@ghd.com

G:\02243 - SCWA\02243-8410200 - Russian River CSD\04-Technical Work\Hazard Assessment\Draft RR Haz Assessment Report_Oct2014.docx

Document Status

Rev No.	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date