Technical Memorandum

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Section 1: Introduction

In 2013, Seattle Public Utilities (SPU) began a Stage Gate 2 process to develop and select a preferred option for the South Park Water Quality Facility (WQF). Target pollutant load reductions for the WQF for total suspended solids (TSS) and other constituents were developed in a water quality workshop. These load reductions are consistent with the Integrated Plan (IP) for combined sewer overflow (CSO) and stormwater runoff management being developed by SPU. In February 2014, a technology screening and Value Analysis identified the following potential WQF technology alternatives: chemically enhanced primary treatment (CEPT), enhanced filtration, ballasted sedimentation, and electrocoagulation (EC).

The Value Analysis recommended pilot testing of candidate systems. Pilot testing was recommended to confirm the performance of the candidate systems with the actual water quality conditions for the full-scale system, compare the performance of short-listed candidate systems to each other, and establish design criteria for the full-scale system. The purpose of this memorandum is to present the rationale and objectives for pilot testing, outline the scope and criteria of testing, and provide a planning-level assessment of the test schedule and costs.

Section 2: Pilot Testing Rationale and Objectives

Pilot testing provides quantitative evidence that a full-scale system can meet performance objectives. It also reveals risks and establishes design criteria that may not be apparent without testing a system with site-specific conditions. While the costs of pilot testing can be significant, they are typically low in comparison to the costs of addressing unanticipated performance problems or misapplied design criteria in a full-scale system after construction.

There are three primary objectives for the pilot test: confirm the performance of the short-listed technologies with the actual influent quality for the system, establish design criteria for the full-scale system, and compare the performance of short-listed technologies. This section discusses the rationale and objectives for pilot testing.

2.1 Performance Confirmation

The first objective is to confirm that the short-listed technologies can achieve the treatment objectives. Treatment objectives for the system are based on the performance targets in the IP, and include targets for oils and greases, TSS, copper, zinc, and polychlorinated biphenyls (PCBs). Preliminary planning for the WQF has sized the system for 6.0 cubic feet per second (cfs) peak capacity, which corresponds to 75 to 100 MG/yr depending on the operational parameters selected. 74 MG/yr is the annual treatment volume required by the IP, while 100 MG/yr is the median annual volume if all runoff events of 2.0-cfs peak flow or greater are treated. Treatment beyond the minimum annual flow volume may aid in meeting the required pollutant load removal targets.

The IP developed target pollutant load reductions for TSS and other constituents. Target load reductions for selected constituents in terms of lower confidence limit (LCL) and upper confidence limit (UCL) are shown in Table 2-1.

Table 2-1. Target Load Reductions and Corresponding Effluent Concentration / Percent Removal.

Constituent	IP Load Reduction LCL and UCL	
Copper (dissolved)	0.5-0.9	kg/year
Copper (total)	3.8-5.2	kg/year
Oil and grease	450-950	kg/year
PCBs	5-9	g/year
TSS	21,000-29,000	kg/year
Zinc (dissolved)	9.4-19	kg/year
Zinc (total)	24-34	kg/year
Volume	67-81	Mgal/year

A related goal to confirming the load reductions is to assess performance of the technologies at low and high influent solids loadings. Flocculation efficiency decreases at low solids concentrations as collisions between destabilized particles are less frequent, and it takes more time for flocs to form. Conversely, effluent concentration and overall effluent load for filters and clarifiers typically increases at heavy solids loadings, even though flocculation and removal efficiencies are greater, simply due to the higher loads and concentrations. Stormwater water quality can vary considerably over the course of a rainfall event, and understanding the performance of the technologies at the range if solids concentrations experienced during actual rainfall events is important in fully assessing the ability of the technologies to meet the IP performance targets.

2.2 Design Criteria

The second objective is to design establish criteria that will be applied to the full-scale design. Key design criteria to be assessed during the pilot test include the following:

Pretreatment. Pretreatment may include screening, degritting, or removal of floatables. The level of pretreatment required will influence the design of the full-scale system.

Hydraulic loading. Hydraulic loading is the volumetric rate at which water is fed to a clarifier or filter, per unit of surface area. The average and maximum hydraulic loading rates are key parameters in selecting a clarifier or filter that is sized appropriately for the design flow.

Coagulant and polymer selection and dosage. Commonly used chemical coagulants include ferric chloride, alum, and polyaluminum chloride (PAC). Ballasted sedimentation systems may operate with any of these coagulants. These coagulants may be used in conjunction with chitosan to enhance metals removal. High molecular-weight anionic polymers are typically used in conjunction with coagulants to enhance flocculation or aid filtration; many different polymers are available. Identifying the best coagulant and polymer combination and dosage are important design considerations. Potential combinations of coagulant and polymer can be identified through bench-scale jar testing. However, these combinations should be confirmed in the pilot test to select the best combination. The dosing rates of coagulant and polymer are related to the coagulant and polymer selection. Typically different dosing rates are tested to develop response curves relating performance to dosing rate. These will guide sizing of the chemical handling system, including components such as the dosing pumps and storage tanks as well as provide a starting point for full-scale dosing.

pH and alkalinity. A key water quality parameter in coagulation and flocculation is pH. In general, the best coagulation occurs when the pH of the water is closest to the pH where minimum solubility of the precipitate formed by the coagulant occurs. However, pH also affects dissolved particle charges and colloidal and floc particle surface charges, and the best flocculation may not necessarily occur at the pH that minimizes precipitate solubility. Alkalinity and pH are related; metal salt-based coagulants are acidic, and their addition consumes alkalinity and can lower the pH of the influent. For low-alkalinity water, coagulant addition may consume all available alkalinity and depress the pH of the water to a value too low for effective treatment. When treating low-alkalinity water, buffering is often necessary to maintain coagulation. For high-alkalinity waters, high doses of coagulant may be required to depress the pH to a value where effective coagulation and flocculation occurs. Therefore, the need for pH or alkalinity adjustment should be evaluated during pilot testing.

Coagulation and flocculation residence time. Residence times in the coagulation and flocculation tanks are a third factor affecting performance. Pilot testing will determine the optimum residence times for different coagulant and polymer combinations and dosages. Residence time impacts the sizing of these unit processes in the full scale facility.

Sludge properties. Pilot test sludge properties can be assessed to determine characteristics during thickening and dewatering. This will affect the selection and sizing of potential solids handling unit processes.

Conductivity and voltage (EC only). Like ballasted sedimentation, EC induces coagulation by adding metal ions to the influent. However, the ions are introduced electrochemically from iron or aluminum electrodes, rather than as a chemical solution. Conductivity and voltage are therefore important parameters, since they affect the rate at which metal ions are introduced. Conductivity is adjusted by dosing with a sodium chloride solution. Pilot testing will help determine the sizing of the sodium chloride system.

Separation stage (EC only). EC is a technology for inducing coagulation. A separation stage is still required to remove coagulated solids. The separation stage may be clarification (conventional or lamella plate), filtration, or another technology such as dissolved air flotation. The best performing separation stage is determined through pilot testing.

2.3 Comparative Performance

The third objective is to compare the relative performance of candidate technologies. Assuming the systems meet the required performance criteria described in Section 2.1, criteria for comparison include cost effectiveness, non-cost operations and maintenance (O&M) considerations, and future adaptability.

If pilot test data are used for system comparison, it is important to recognize the effect of influent conditions on system performance. Stormwater pilot testing differs from wastewater or potable water pilot testing in that the influent quality can vary significantly over the course of a rainfall event. Abnormal events, such as seasonal first flush events with high solids concentrations, long-duration storm events, or high-intensity storm events can complicate the direct comparison of systems if all systems are not treating the same set of rainfall events. A side-by-side test of technologies eliminates this issue by ensuring that the performance of different systems is compared relative to the same set of influent water quality data.

The remainder of this section discusses comparative performance criteria.

2.3.1 Cost Effectiveness

Cost effectiveness between systems can be compared on the basis of lifecycle-cost dollars per unit of pollutant removed. Hydraulic loading rates and chemical dosages will influence the capital and operating costs of systems. By providing actual data on performance and chemical consumption, pilot testing will help refine the cost estimates for unit removal of pollutants.

2.3.2 Non-cost O&M Considerations

Pilot testing can also reveal operational issues that, while not necessarily cost impacts, affect the overall usability of the system or the ability of the system to operate unstaffed. These issues will be specific to the technologies tested. Potential issues that can be assessed during pilot testing include start-up times, frequency of cleaning or maintenance, the need to adjust chemical dosing in response to influent conditions, or common system faults or alarms.

Pilot plants in general require a higher level of operator involvement than full-scale systems; full scale active water treatment systems can be designed with automated controls that are not necessary or desired for pilot-scale plants. Caution should be used when drawing direct comparisons between the level of staffing required for the pilot system and the level of staffing for the full scale system. However, some inferences can be made related to operational and staffing requirements based on pilot testing. For example, a system that requires frequent chemical dose adjustment at the pilot scale would either need to have an automated means of performing this function for the full scale plant, or would need to rely on staff.

2.3.3 Future Adaptability

One criterion for comparison of treatment systems is their adaptability to future changes in regulations or basin development. Pilot testing will provide information on future adaptability. Systems that are able to meet the required performance criteria in Section 2.1 but have a limited ability to achieve removal rates beyond those required or remove other constituents can be interpreted as having limited adaptability. These systems could potentially require a second treatment stage to meet more restrictive regulatory limits or performance targets. Systems that can achieve removal rates that significantly exceed those required and can remove additional constituents can be interpreted as being adaptable to future basin or regulatory changes.

Section 3: Pilot Test Scope

This section describes the scope of the pilot test.

3.1 Pilot Systems

Pilot plants are small-capacity treatment plants that utilize the same treatment process as full-scale systems, but are designed to facilitate testing and data collection. Pilot system capacities for the South Park project are expected to be in the 100 to 200 gallon per minute (gpm) range. Pilot units will typically consist of trailer-mounted or containerized systems, or skid mounted equipment connected by temporary plastic piping or flexible hosing that can be easily assembled and disassembled on-site.

Major ancillary equipment would likely need to be provided by SPU. Ancillary equipment will likely include power supply equipment, pumps and temporary piping to convey water from the existing vault to the pilot systems, and potentially additional sampling equipment. Site power requirements will be specific to individual pilot systems and should be discussed with vendors; however, the site power system already supplied for a previous EC pilot test is likely to be sufficient. Storage tanks and any chemical storage and handling equipment should be included in the vendor's scope. Procedures for chemical delivery, storage, and handling will need to be developed based on individual pilot systems. Temporary secure storage and containment equipment may be required, either as part of the vendor's scope or provided by SPU. SPU would be responsible for overall site security.

Consumables will include chemicals (including coagulants, polymers, pH and alkalinity adjustment chemicals, and cleaning chemicals) and EC cells. Provision of consumables should be within the vendor's scope.

Mobilization to the site and assembly of pilot units should be included in each prospective vendor's scope for the pilot test, as should disassembly and demobilization.

3.2 Jar Testing

Jar testing should be performed on South Park basin stormwater samples before beginning pilot testing. Jar testing is a laboratory procedure used to assess the effectiveness of varying coagulant types and dosages under conditions that approximate those of the full-scale system. Jar testing also assesses required coagulation and flocculation residence time. Note that dosages can be reliant on the system itself; for instance, the required dosage for a filtration system would typically be lower than the dosage required for a chemically-enhanced primary treatment system to achieve the same removal. The system vendors should provide input on the starting point for pilot test dosages based on jar test results. The effectiveness of different polymers, as well as the effect of factors such as pH, can also be assessed with jar testing. As part of a full testing program, jar testing is used to make the most efficient use of limited pilot or full-scale testing time by identifying, in advance, the chemistries most likely to achieve the required performance.

In a jar test, an influent sample is placed in a jar, and coagulant and polymer are dosed at the test concentrations. The jar is then mixed rapidly at conditions that approximate flash mixing, followed by slower mixing that approximates flocculation mixing. Mixing is then stopped and the flocs allowed to settle. The clear supernatant is then tested for removal efficiencies of the constituents of interest to determine the most effective dose, flocculation time, etc. Observations are made noting the size and strength of flocs, and speed of settling.

Testing should be performed on actual influent samples. This takes on added importance for a stormwater system, where the influent quality can vary over the course of a rainfall event. For a stormwater system, collecting and testing multiple samples over the course of a rainfall event provides a more complete set of jar testing results.

3.3 Test Parameters

Test parameters should generally be those required to confirm performance, establish design criteria, and compare systems as discussed in Section 2. Test parameters should include:

- Hydraulic loading.
- pH and alkalinity adjustment.
- Chemical dosing, including the coagulant and polymer used and the respective dosages. Chemical dosing assessment may include jar testing.
- Contact time and mixing energy for coagulation and flocculation.
- Optimum conductivity and cell voltage (for EC only).
- Separation stage used (for EC only). The EC cells are a system for dosing metal ion coagulants that replaces conventional chemical storage and metering. EC requires a separation stage following coagulation, such as settling, filtration, or dissolved air flotation. A number of different separation systems can be used with EC, and the EC vendor should be consulted to determine which separation systems should be used during the pilot test.
- Sludge quality, including thickness, ability to resist shear, and ability to dewater. Sludge quality will provide information for sizing and design of the solids handling processes.

3.4 Pilot System Operations

Operation and maintenance duties will vary depending on the type of system, but will typically include monitoring startup and shutdown, adjustment of operating parameters, adjustment of chemical type and dose in response to system performance, routine cleaning and maintenance operations, sample collection, and troubleshooting.

Although pilot systems can be partially automated and should be configured to start and stop automatically, certain operations will need to be staffed. Stormwater pilot testing presents a challenge in that, unlike wastewater or potable water pilot testing, work cannot be scheduled in advance. Pilot systems will need to start up and operate in response to rainfall events, which can occur at anytime. Further, since rainfall events may last longer than 24 hours, pilot systems need to be able to operate continuously for long periods. Since vendor pricing is based on 40 hour per week operation, it may be necessary to supplement vendor operators with consultant staff.

Trained vendor operators would need to perform functions that are critical to getting optimum performance from the pilot systems, while SPU operators, after training, would supplement vendor-trained operators by performing routine check-ins and maintenance. Since optimization of hydraulic loading and chemical dosing (or, for EC, cell voltage and influent conductivity) is critical to get good performance from the pilot systems, it is expected that vendor-trained operators will take an active roll in these operations. It is also expected that vendor-trained operators will monitor the system during startup and shutdown. Regular, scheduled check-ins during operation can be made by vendor-trained operators or by SPU operators.

Sampling can be automated through the use of ISCO-type automated samplers, but operators will need to periodically check in to confirm samples are being collected as planned.

3.5 Sampling, Analysis, and Data Quality Requirements

Sample locations and the number of samples collected will be specific to individual pilot systems, and will be determined as the pilot test scope and objectives are further defined. Samples may include:

- **Raw influent samples.**
- **Influent samples following pretreatment.** These samples are taken to assess the contribution of pre-treatment (screening, degritting, or floatables removal) to overall system performance.
- **Effluent samples.** Effluent samples are taken to assess the overall system performance and the contribution of the treatment system to overall system performance.
- **Returned residual samples.** Some systems may incorporate a separate stage to remove residuals (solids) from water; for example, a backwash clarifier may be used to separate filter backwash water supernatant liquid from solids. If a system incorporates a residuals separation stage, the returned supernatant should be sampled to assess the pollutants returned to the main treatment train.

A sample process flow diagram with sample collection locations is shown in Figure 3-1.

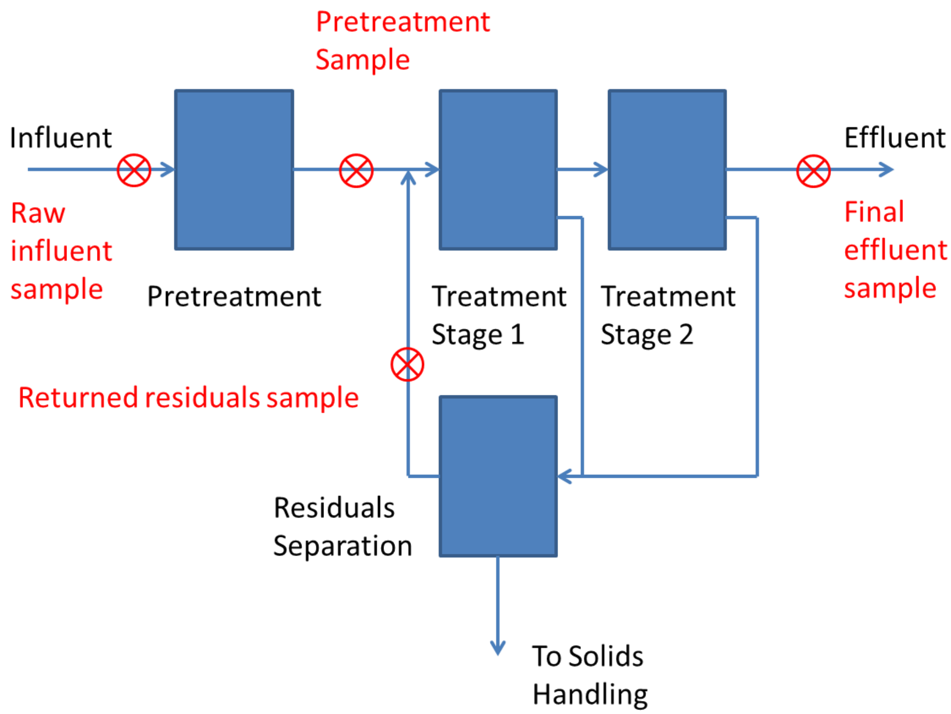

Figure 3-1. Pilot test process flow diagram.

A testing plan establishing the number of samples and analytical requirements will be develop prior to testing. It is expected that samples will include the following:

- **Flow-weighted composite samples.** Flow-weighted composite samples should be collected from each sampling point for each rainfall event. These samples will be analyzed for the full suite of IP pollutants.
- **Grab samples.** Since influent water quality can vary significantly over the course of a rainfall event, grab samples can be used to provide information about the instantaneous performance of the system. The analysis suite for grab samples can also be limited to key constituents. Grab samples are recommended for several purposes:
    - For several rainfall events, grab samples should be collected at regular time intervals over the course of the event to establish the relationship between instantaneous influent concentration and instantaneous effluent concentration.
    - Hourly influent samples should be collected for 24 hours for several rainfall events to develop influent pollutographs of important constituents.
    - Several grab samples should be collected from the residuals stream for each system to assess residuals concentrations.
- **Continuous monitoring.** Influent and effluent flow rate as well as water quality variables such as turbidity, pH, and conductivity should be monitored continuously. Turbidity monitoring is important because a site-specific correlation between turbidity and TSS can sometimes be developed, allowing TSS to be approximated over the duration of rainfall events. Monitoring of pH and conductivity will provide information that may help interpret the results of pilot testing.

Analysis will include pollutants with load reduction targets specified in the IP: TSS, total copper, total zinc, hardness, and PCBs. Additional constituents may include volatile or semivolatile organics, cPAHs, additional metals, additional conventional pollutants (such as conductivity, pH, turbidity, chloride, , and surfactants), and petroleum hydrocarbons. Sampling may also include residual chemicals from coagulation and flocculation to determine the degree of treatment chemical pass-through. The specific list of analytes will be developed as the pilot test objectives and scope are further defined.

Sampling and analysis requirements will be documented in a Test Plan, which will be comprised of a Sampling and Analysis Plan (SAP) and Quality Assurance Project Plan (QAPP). The SAP will define sample methodology, equipment, procedures, locations, analytical procedures, and other procedures. Requirements for data quality will be documented in a QAPP. The purpose of the QAPP is to define data quality assurance and quality control (QA/QC) procedures to ensure that the precision, accuracy, representativeness, completeness, and comparability of data meet project objectives. Elements typically included in a QAPP include project management, measurement and data acquisition procedures, assessment and oversight procedures, and data validation and usability procedures.

3.6 Schedule and Duration

Pilot testing should be scheduled for the duration of the 2015-16 wet season, which begins in October and ends in April. To provide a sufficient data set for evaluation and comparison of the tested systems, the pilot study should aim to capture 10-15 rainfall events of varying sizes. The number of runoff events of different sizes and with minimum durations of four hours occurring during one-month periods was tabulated from the results of a PCSWMM model for the 7th Avenue South basin (*South Park Hydraulic Modeling* Report, 2014). Runoff events were generated historical data for rainfall events from 1978-2013 using data from rainfall gauges RG16 (lower basin) and RG17 (upper basin). Results are shown in Table 3-1.

Table 3-1. Number of Runoff Events within Selected Periods, 1978-2013

Period	Events greater than 4-cfs peak flow			Events greater than 8-cfs peak flow		
	Min. Year	Median Year	Max. Year	Min Year	Median Year	Max. Year
October 1 – October 31	1	5	10	0	4	10
November 1 – November 30	4	10	18	3	9	17
December 1 – December 31	2	9.5	14	0	7.5	13
January 1 – January 31	2	10	18	2	7.5	16
February 1 – February 28	0	7	17	0	6	16
March 1 – March 31	2	7	15	1	6	12
April 1 – April 30	0	5	11	0	5	10

Minimum duration of 4 hours for all events.

Runoff events based on output from a PCSWMM model of the 7th Avenue South Basin (*South Park Hydraulic Modeling Report*, 2014). Runoff events generated using historical rainfall data for 1978-2013 from rainfall gauges RG16 (lower basin) and RG17 (upper basin).

3.7 Roles and Responsibilities

This section describes roles and responsibilities for the pilot test.

3.7.1 Vendor Responsibilities

Vendor responsibilities will include design of the pilot plants, furnishing required equipment (with the exception of equipment used by all vendors, discussed below), coordinating shipping of equipment to and from the site, setup and temporary construction of pilot systems, and removal of systems at the conclusion of the test. System vendors will have the primary responsibility for startup of systems and should provide guidance on chemical dosages and coagulation and flocculation times throughout the test through regular scheduled meetings or calls.

Vendor operators would provide training to consultant staff prior to consultant staff assuming any operational responsibilities.

3.7.2 SPU Responsibilities

SPU responsibilities will include furnishing and installation of elements common to all pilot units. This will include a submersible pump to supply influent to the systems, temporary influent distribution piping, site power, and fencing and other security. Providing a common system for storing and handling pilot system solids may also help facilitate testing. SPU would also be responsible for furnishing consumables such as coagulant and polymer.

3.7.3 Consultant Responsibilities

Consultant staff will lead test planning. A Test Plan consisting of a SAP/QAPP is recommended to document goals of the test and procedure or requirements for operations common to all systems, sample collection and analysis, and recordkeeping. Consultants will lead preparation of the SAP/QAPP. Additionally, consultants will coordinate with vendors prior to the test, review of pilot plant designs, coordinate with the laboratory, and assist with coordination site requirements such as utilities and security prior to the test. Consultants may also perform jar testing prior to the test.

After the startup period, consultant staff will have primary responsibility for operation of the systems. This will include adjustment of chemistries or other operating parameters, sample collection, routine system monitoring and check-ins, and troubleshooting with vendor assistance. Consultant staff will perform data quality reviews and interpretation of results on an ongoing basis throughout the test. Consultant staff will also lead coordination with vendors and the laboratory before and during the test.

Following the test, the consultant will prepare a pilot test report summarizing the test and interpreting the results.

3.7.4 Laboratory Support

To reduce sources of data variability between systems, it is recommended that a single laboratory contracted directly with SPU be used for all analyses.

Section 4: Pilot Test Costs

Preliminary costs for a 5 month pilot test are summarized in Table 4-1. Test equipment costs assume rental of common equipment used for all systems (influent pumps, influent storage tank, and solids storage tank), plus rental of vendor specific equipment. Since the costs will depend on the specific vendor systems chosen for the pilot test, costs are provided in terms of the cost range for a 2-system and 3-system test. Consultant costs assume operation of systems by consultant staff, plus oversight time for coordination with SPU, vendors, and the laboratory and for ongoing review of results. Supplementary cost information for the individual vendor systems is provided Attachment A.

Table 4-1. Pilot Test Estimated Costs, 5 Month Pilot Test				
Item	2 System Pilot Test		3 System Pilot Test	
	Lower Limit	Upper Limit	Lower Limit	Upper Limit
Equipment [a]	$134,800	$279,000	$231,400	$348,000
Mobilization, Demobilization, and Freight [a]	$15,000	$29,000	$36,300	$43,800
Startup and Training [a]	$3,200	$3,200	$6,400	$6,400
Consumables [a]	$7,700	$11,400	$15,200	$15,300
Lab Costs [b]	$71,200	$71,200	$86,600	$71,200
Consulting, including operations staffing	$141,800	$141,800	$166,500	$166,500
Subtotal	$373,700	$535,600	$542,400	$651,200
Contingency (20%)	$74,700	$107,100	$108,500	$130,200
Total	$448,400	$642,700	$650,900	$781,400

a. Vendor-specific information for equipment, mobilization, demobilization, freight, startup and training, and consumables included in Attachment A.

b. Lab costs assume:

Influent, pretreatment, and effluent composite samples for up to 30 rainfall events.

5 Residuals grab samples per system.

120 total influent grab (5 events x 24 samples per event)samples to establish influent pollutographs.

16 pretreatment and effluent grabs per system to establish instantaneous removal rates.

Analysis for alkalinity, conductivity, carcinogenic polycyclic aromatic hydrocarbons (composites samples for 8 rainfall events only), metals, PCBs (composite samples for 8 rainfall events only), TSS, and turbidity.

Section 5: Conclusions and Recommendations

Brown and Caldwell recommends pilot testing of, at minimum, two candidate system based on the results of the Water Quality Facility Technical Memorandum currently in preparation. The pilot test may be expanded to include multiple systems if candidate technologies are closely ranked. If multiple systems are tested, testing should be done in a side-by-side manner to ensure that each system is tested under the same set of influent conditions. Testing should confirm performance, establish full-scale design criteria, and, if multiple systems are tested, provide a basis for comparison between systems. The scope of the test should be establish as objectives are refined; the testing scope will need to define the system and site requirements, operations, sampling and analysis, schedule and duration, and cost of the test. Testing for the duration of the 2015-2016 wet weather season is recommended to give the highest likelihood of a satisfactory number of significant rainfall events, Test costs are estimated to range from $448,000 to $643,000 for two systems or $651,000 to $781,000 for three systems.

References

South Park Hydraulic Modeling Report. Brown and Caldwell, 2014.

Attachment A: Vendor Cost Summary

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Table 4-1. Vendor Cost Summary, Low Range				
Item		2 System Pilot Test	3 System Pilot Test	4 System Pilot Test
Equipment	Common Equipment	$25,600	$25,600	$25,600
	Actiflo (ballasted sedimentation)	NA	NA	$133,000
	CoMag (ballasted sedimentation)	$60,000	$60,000	$60,000
	Clear Water Services (chitosan-enhanced sand filtration)	$31,600	$31,600	$31,600
	Water Techtonics (electrocoagulation)	NA	$84,000	$84,000
	Subtotal	$117,200	$201,200	$334,200
	Equipment Maintenance (15%)	$17,600	$30,200	$50,100
	Equipment Subtotal	**$134,800**	**$231,400**	**$384,300**
Mobilization, Demobilization, and Freight	Common Equipment	$3,500	$3,500	$3,500
	Actiflo (ballasted sedimentation)	NA	NA	$7,500
	CoMag (ballasted sedimentation)	$7,500	$7,500	$7,500
	Clear Water Services (chitosan-enhanced sand filtration)	$7,300	$7,300	$7,300
	Water Techtonics (electrocoagulation)	NA	$18,000	$18,000
	Mob., Demob., and Freight Subtotal	**$18,300**	**$36,300**	**$43,800**
Startup and Training	Actiflo (ballasted sedimentation)	NA	NA	$3,200
	CoMag (ballasted sedimentation) [a]	$0	$0	$0
	Clear Water Services (chitosan-enhanced sand filtration)	$3,200	$3,200	$3,200
	Water Techtonics (electrocoagulation)	NA	$3,200	$3,200
	Startup and Training Subtotal	**$3,200**	**$6,400**	**$9,600**
Consumables	Actiflo (ballasted sedimentation)	NA	NA	$3,900
	CoMag (ballasted sedimentation)	$3,900	$3,900	$3,900
	Clear Water Services (chitosan-enhanced sand filtration)	$3,800	$3,800	$3,800
	Water Techtonics (electrocoagulation)	NA	$7,500	$7,500
	Consumables Subtotal	**$7,700**	**$15,200**	**$19,100**

a. Training included in 1st month equipment rental.

Table 4-2. Individual Vendor System Costs, High Range				
Item		2 System Pilot Test	3 System Pilot Test	4 System Pilot Test
Equipment	Common Equipment	$25,600	$25,600	$25,600
	Actiflo (ballasted sedimentation)	$133,000	$133,000	$133,000
	CoMag (ballasted sedimentation)	NA	$60,000	$60,000
	Clear Water Services (chitosan-enhanced sand filtration)	NA	NA	$31,600
	Water Techtonics (electrocoagulation)	$84,000	$84,000	$84,000
	Subtotal	$242,600	$302,600	$334,200
	Equipment Maintenance (15%)	$36,400	$45,400	$50,100
	Equipment Subtotal	**$279,000**	**$348,000**	**$384,300**
Mobilization, Demobilization, and Freight	Common Equipment	$3,500	$3,500	$3,500
	Actiflo (ballasted sedimentation)	$7,500	$7,500	$7,500
	CoMag (ballasted sedimentation)	NA	$7,500	$7,500
	Clear Water Services (chitosan-enhanced sand filtration)	NA	NA	$7,300
	Water Techtonics (electrocoagulation)	$18,000	$18,000	$18,000
	Mob., Demob., and Freight Subtotal	**$29,000**	**$36,500**	**$43,800**
Startup and Training	Actiflo (ballasted sedimentation)	$3,200	$3,200	$3,200
	CoMag (ballasted sedimentation) [a]	NA	$0	$0
	Clear Water Services (chitosan-enhanced sand filtration)	NA	NA	$3,200
	Water Techtonics (electrocoagulation)	$3,200	$3,200	$3,200
	Startup and Training Subtotal	**$6,400**	**$6,400**	**$9,600**
Consumables	Actiflo (ballasted sedimentation)	$3,900	$3,900	$3,900
	CoMag (ballasted sedimentation)	NA	$3,900	$3,900
	Clear Water Services (chitosan-enhanced sand filtration)	NA	NA	$3,800
	Water Techtonics (electrocoagulation)	$7,500	$7,500	$7,500
	Consumables Subtotal	**$11,400**	**$15,300**	**$19,100**

a. Included in 1st month equipment rental.