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FINAL PROJECT REPORT

DEMONSTRATION OF I50 WASTEWATER TREATMENT AND WATER RECYCLING SYSTEM

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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

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Demonstration of i50 Wastewater Treatment and Water Recycling System is the final report for the Demonstration of i50 Decentralized Wastewater Treatment/Water Recycling project (contract number PIR-11-011) conducted by Great Circle Industries, Inc. The information from this project contributes to Energy Research and Development Division's Industrial/Agricultural/Water End-Use Energy Efficiency Program.

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ABSTRACT

This project tested the i50 wastewater treatment module developed by Great Circle Industries, Inc. to treat and recycle municipal wastewater for irrigation reuse on a decentralized, energy efficient basis, while meeting applicable California regulatory standards. The unit energy consumption targeted was less than 4 kilowatt-hours per 1,000 gallons of recycled water, which is less than 50 percent necessary to transport water from northern to southern California by the State Water Project.

The system was installed and tested at the Dublin San Ramon Services District wastewater treatment plant in Pleasanton, California and ran nearly continuously for almost two years. Samples were collected and analyzed to verify compliance with the Title 22 disinfection criteria for restricted access irrigation reuse. On a few occasions, under ideal conditions, the system met the relevant total coliform count criteria. Most of the time, however, rapid fouling of ultraviolet lamp sleeves and the intermittent presence of particulate led to poor disinfection results. Both of these problems have been traced to anaerobic organisms in various parts of the system.

The project team is pursuing a system modification that uses concentrated facultative bacteria strains that have a track record of solving such problems for other wastewater treatment systems. If the subject modification is successful, and the system is approved for California use, installing 100 units can potentially save California ratepayers 10.8 megawatt-hours of electrical energy and 1.8 billion gallons of water, annually.

Keywords: Wastewater, Water, Recycling, Irrigation, Reuse

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EXECUTIVE SUMMARY

Introduction

Approximately 80 percent of the water consumed in California is used for irrigation purposes. Water-related energy use consumes 19 percent of the state's total electricity use ("California's Water-Energy Relationship", California Energy Commission, 2005). Transferring water from northern California to southern California by the California Aqueduct consumes approximately 10 to 12 watt-hours per gallon. Recycling municipal wastewater on a decentralized basis has historically been cost prohibitive and has not been widely used due to this reason.

Great Circle Industries, Inc. developed the i50 wastewater treatment/water recycling system to provide an energy efficient method to recycle 50,000 gallons municipal wastewater into irrigation water on a cost effective and energy efficient basis. The original design used a physical process that does not require ongoing supplies, chemicals or membranes. Typically, more energy intensive and costly technologies for wastewater treatment and recycling are used in California.

Project Purpose

The project demonstrated the i50 prototype's compliance with California's Title 22 disinfection standards through formal third party testing at the wastewater treatment plant of the Dublin San Ramon Services District in Pleasanton, California. Based on this demonstration, the technology would receive regulatory approval from the California Department of Public Health. Once regulatory approval was obtained, the remaining project intent was to pursue several other tasks dependent upon proof of such compliance: planning of a subsequent beta site installation, technology transfer to prospective stakeholders, and preparations for production readiness.

Project Results

The i50 prototype was operated for approximately two years, testing out numerous equipment configurations and system parameters. Water quality data was collected with the assistance of personnel from Carollo Engineers, the Dublin San Ramon Services District, and Great Circle Industries. Laboratory results intending to demonstrate compliance with the California Title 22 disinfection standards for restricted access irrigation reuse were unsuccessful. Several times the total coliform were close to, or below, the 23 total coliform limit criteria for restricted access irrigation reuse. The problems were traced to fouling of the water storage vessel, pipe, and ultraviolet reactor interior surfaces by anaerobic slime growths. These growths were associated with high levels of Biochemical Oxygen Demand, higher than anticipated by the designer of the floating bead biofilter used in the i50. Increasing air blower feed to the bioclarifier did not resolve the problem.

Although the study concluded that under some circumstances the process was capable of meeting the target limit, Great Circle Industries, at its own costs, installed and began evaluating modifications to an i50 system that promises significant improvement of effluent water quality and disinfection. This includes using facultative bacteria (bacteria able to live under various external conditions) to augment/replace the troublesome anaerobic organisms encountered. The

cultures and incorporated equipment are off-the-shelf, and have an impressive track record in solving similar problems for other wastewater treatment systems.

The modification being pursued, however, requires the system process use more aerobic biological digestion than was originally envisioned, reducing the effluent flows and increasing unit energy consumption. Nevertheless, if this modification is successful, Great Circle Industries believes the i50 will cost less to own and operate, and will consume less energy on a unit basis, than other products that may enter the "water harvesting" market with products based on current wastewater treatment technologies.

The project has been effective in significantly advancing the readiness of the i50 technology, bringing it closer to commercialization and pointing to design areas that require refinement. Numerous technical problems have been resolved with design improvements.

Project Benefits

The i50 technology has the potential to bring major savings in energy, water, and capital and operating costs to the ratepayers of California. As a modular, fully automatic, and compact system, the technology promotes wastewater treatment and recycling on a decentralized basis, near a sewer source of wastewater and an intended reuse location. This satellite treatment approach minimizes major barriers to cost-effective water recycling, such as infrastructure costs and energy consumption.

The technology can contribute in a major way to meeting California's goal of recycling an additional 500,000 acre-feet of water annually within the next decade. The energy consumption of the i50 is estimated to be less than 50 percent of the unit electrical energy consumption (kilowatt-hours per 1,000 gallons) to pump water to southern California via the State Water Project. If only 10 percent of the targeted 500,000 acre-feet per year are provided by the i50 modules for irrigation reuse in southern California, 50,000 acre-feet of water and 162 megawatt-hours of electrical energy can be saved annually. Assuming an energy rate of 15 cents per kilowatt-hour, ratepayers can save approximately $24.3 million per year.

CHAPTER 1: Introduction

Great Circle Industries, Inc. developed a product prototype, the i50, for treating and recycling municipal wastewater on a decentralized, modular, point-of-need basis. It is designed primarily for irrigation reuse applications. The system uses a variety of physical treatments to produce product water that retains soluble plant nutrients, while meeting the microbial effluent disinfection standards per the State of California Title 22 Secondary 23 disinfection criteria for restricted access irrigation reuse. The product water can be used "as is", for irrigation applications having high nutrient demands, can be blended with fresh water, or can be biologically stabilized in an aerated effluent storage basin for irrigation applications requiring limited nitrogen content. Simple enhancements can be added to the aerated basin treatment to produce water of high quality that will consistently meet standards for the most critical reuse applications, as well as for disposal to surface water bodies, per NPDES standards, and for groundwater recharge. The applicable regulations for treatment and reuse of municipal wastewater are contained in Title-22: California Water Recycling Criteria". A table summarizing allowed uses for recycled water of various categories is summarized in Appendix A.

It is designed to offer these attributes required for practical, decentralized point-of-need applications:

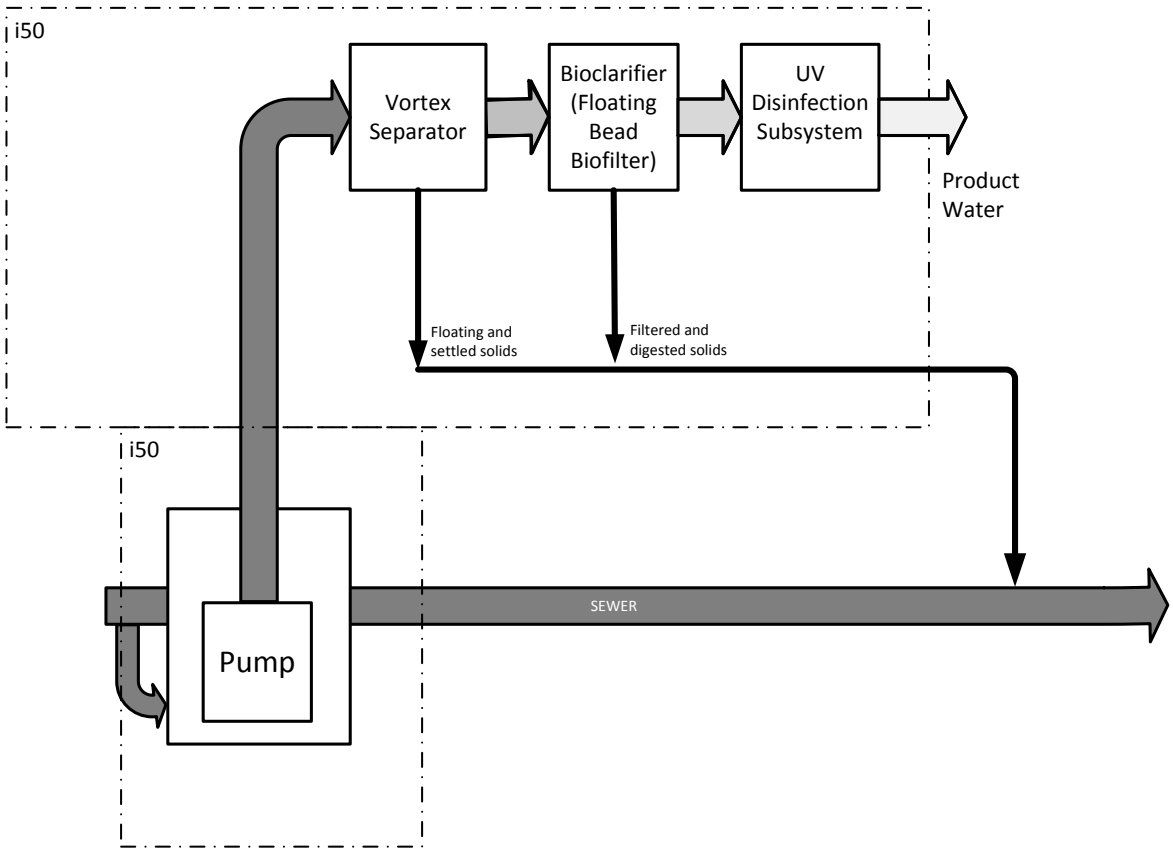
- Low capital and operating costs per gallon of recycled water produced
- Low energy consumption per gallon of recycled water produced
- Small installation area per gallon of recycled water produced
- Adaptability to many applications and treatment volumes
- Automatic, unattended operation
- Remote supervisory control and monitoring
- Process and equipment reliability

The system is designed to be housed in a shipping container for both shelter and transport, with equipment modules that can also be skid-mounted for use in a building or structure.

1.1 Process Description

The i50 uses a physical/biological sequence that incorporates developed technologies in a unique configuration, well suited for "water harvesting" from existing municipal sewers (Figure 1).

Figure 1: i50 System Block Diagram



The main elements of the system are as follows:

1. A submersible pump drawing from a sewer.
2. A vortex separator (Figure 2) stage for removing settleable and floating solids.
3. A "bioclarifier" (floating bead bio-filter) (Figure 3) stage that both filters and provides limited biological digestion of the clarified effluent from the vortex separator stage.
4. An ultraviolet (UV) radiation stage, that disinfects clarified effluent from the bioclarifier stage.
5. A common drain that returns solids residuals from the vortex separator and bioclarifier stage back to the sewer.

The system is automatic and unattended, under the control of a microprocessor-based remote terminal unit (RTU). The system software includes supervisory control and data acquisition (SCDA) capability that allows close monitoring and control of system operation from remote locations, accessible by any personal computer or portable device connected to the internet and equipped with a web browser. System security is protected by multiple level access codes.

The system includes three pumps and a blower motor under control of variable frequency drives.

Figure 2: Vortex Separator

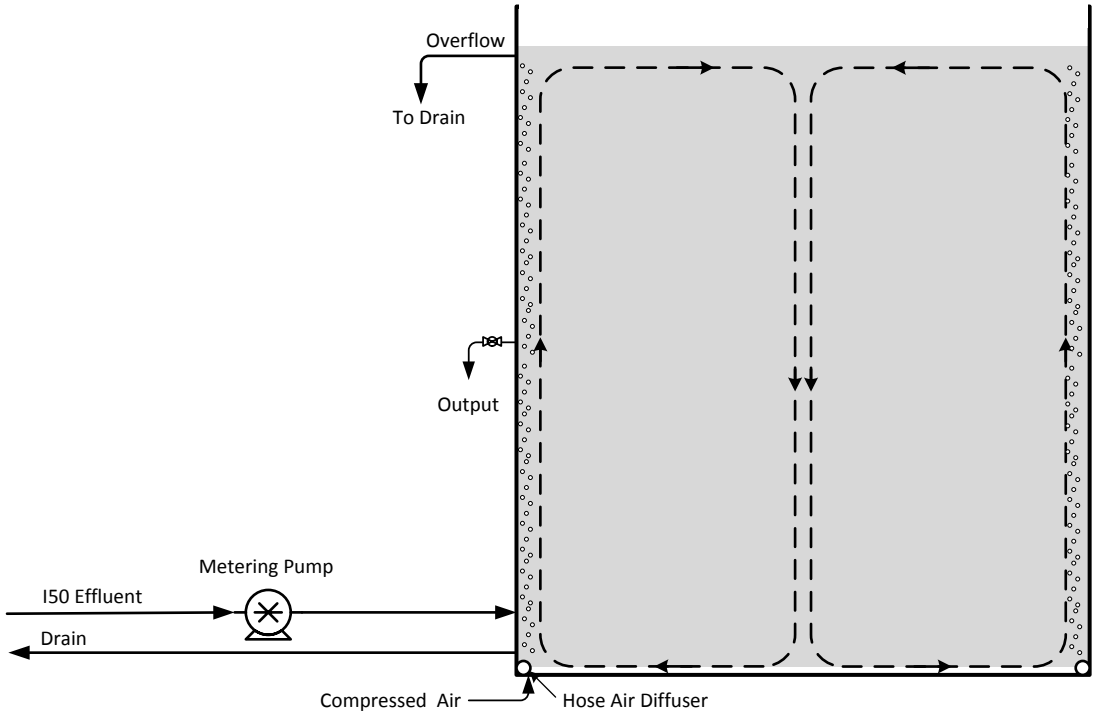
Figure 3: Bioclarifier

1.2 Aerated Effluent Storage

Effluent of the i50 was conveyed to a storage tank with effluent aerated using a subsurface air diffuser. The effluent was fed to the storage tank by a peristaltic metering pump, with overflow of the tank returned to the system drain, and with manual adjustment of the pump flow allowing for regulation of hydraulic retention time within the tank. The storage tank has a volume of 1,200 gallons, a liquid level of 7 feet, and a diameter of 6 feet. The tank is modified to have an open top, exposed to daylight to simulate pond conditions.

A schematic diagram of the aerated storage subsystem is shown in Figure 4.

Figure 4: Aerated Storage Subsystem



1.3 Irrigation Demonstration

The stored and aerated effluent was used to irrigate a planter bed in which a variety of ornamentals and vegetables were grown. The planter bed was filled with washed sand as the growing medium, which was completely devoid of plant nutrients. The bottom of the bed was equipped with a commercially-available subsurface application/drainage system.

The planter bed was hand irrigated by gravity flow using a hose with applicator connected to the output spigot of the storage tank. Irrigation was applied at intervals of from one- to two weeks, when the top inch of sand was found to have become dry.

CHAPTER 2:
Project Purpose

The overriding goals of this project were to formally test and demonstrate the i50 system, and then obtain State of California Title 22 regulatory approval for, at least, the Title 22 "Secondary 23" applications involving restricted access irrigation. The unique modular processes and equipment developed by Great Circle Industries, Inc. for wastewater treatment and water reuse, conserve energy, water, and, where beneficial, provide plant nutrients. Related objectives of the proposed project were:

- To obtain that body of data needed to fully demonstrate and characterize the product and technology, in terms of: product water quality and pathogen destruction/inactivation, unit electrical energy consumption of effluent; and process and equipment reliability;
- To measure and analyze the performance, unit energy consumption and water quality achievable with aerated storage as a post treatment;
- To demonstrate, on a reduced-scale basis, the reuse potential of both the water and nutrients for irrigation of plants with differing nutrient requirements; and
- If the above tasks were completed successfully, to pursue the following:
    - Future installation at a local beta site where the test unit could be installed after the conclusion of the project, for commercial demonstration and for productive water reuse;
    - Technology transfer to major prospective stakeholders; and
    - Preparations for production readiness.

CHAPTER 3:
Project Results

3.1 General

Water quality testing was performed with the assistance of qualified third parties to conduct tests and take samples for analyses by certified laboratories, with controlled chain of custody. Two testing phases were involved, described below.

The i50 prototype system was first installed on March 11, 2013. The project commenced Phase 1 testing on August 20, 2013. Phase 1 testing included dose response testing. Phase 2 testing started July 29, 2014. Throughout the entire project, operation of the unit revealed a variety of issues that had to be resolved, involving system equipment, control software, and site-specific influent extraction challenges. The problems resulted in a variety of system configuration changes, with associated pauses in operation and testing.

Configuration changes made and evaluated during this period included the following:

- Comparing the use of either one or two bioclarifier units
- Comparing the use of either series or series/-parallel hydraulic configurations where two bioclarifiers were used.
- Comparing the use of two types of UV disinfection units from two different manufacturers
- Comparing the use of either pumped or gravity output flow
- Adding disk filter units between bioclarifier and UV disinfection stages

When the manufacturer, model and design features of the UV disinfection units were changed, a change was also made in the means used to evaluate UV system performance; instead of passing the entire effluent flow through the UV disinfection stage, two units in hydraulic series were used to disinfect a sidestream that represented only a fraction of the total effluent flow. By this means, the UV flow rate used during testing could be varied independently of the effluent flow.

Parametric changes made to the system during testing therefore included the following:

- Bioclarifier feed flow (close to targeted effluent flow)
- UV disinfection stage flow
- Air blower drive, which controlled bioclarifier circulation flows, dissolved oxygen levels, and thereby, aerobic digestion achieved.
- Bead filter cleaning intervals
- Sludge purge intervals and durations

All problems encountered were substantially resolved and are providing satisfactory performance, except for two process/equipment issues, for which Great Circle Industries is now pursuing associated equipment modifications and testing. These two issues, excessive coliform counts and visible particulate in the effluent, are related, and will be described more fully in later sections.

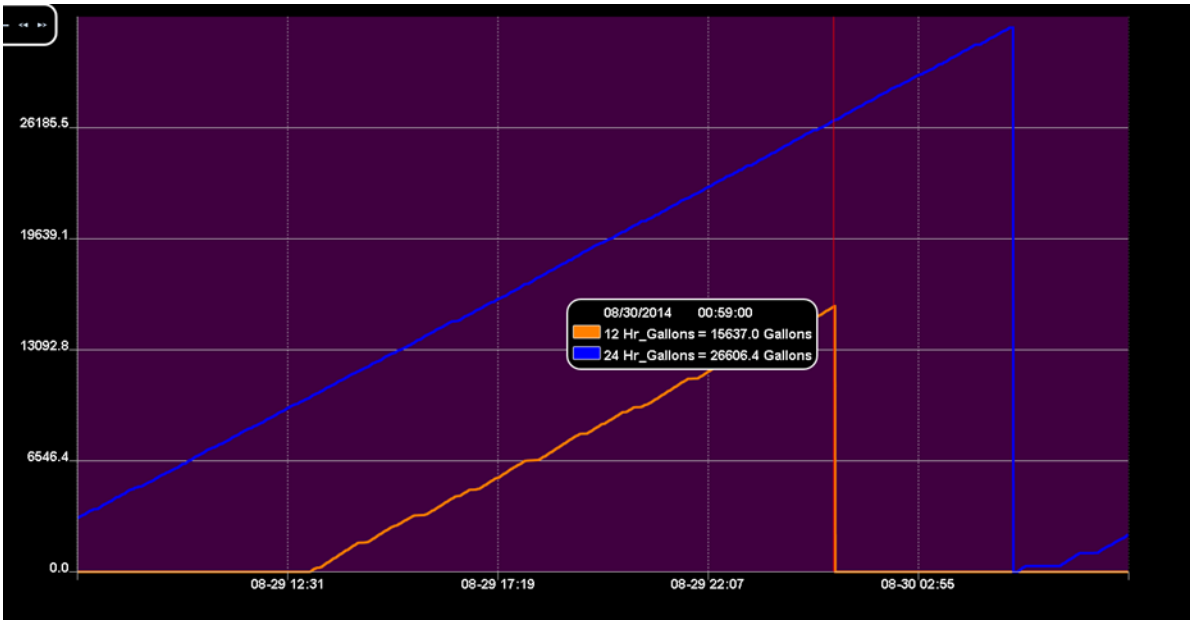
3.2 Effluent Flows and Unit Energy Consumption

The research team collected abundant data measuring effluent flows, power usage, and unit energy consumption for a variety of system configurations and control parameters. For 25,000 gallons per day output and above, the unit energy consumption was found to be 3.5 watt-hours per gallon or less, which was consistent with the original target of 3 watt-hours per gallon, equivalent to 3 kilowatt-hours (kWh) per 1,000 gallons. The effluent coliform counts, however, exceeded the permissible limits for water reuse in California for most of the samples, and the effluent corresponding to these flow rates was therefore unusable. The equipment modifications being pursued hold the prospect of allowing attainment of 25,000 gallons per day output, which will be significantly below the 9.3 + kilowatt hours per 1,000 gallons associated with water transport from northern California to southern California via the California Water Project.

Figure 5 and 6 show trend graphs of cumulative flows and unit energy consumption, respectively. The system was monitored remotely using a personal computer (PC). Notes following the graphs describe how liquid flows and unit energy consumption are computed.

Figure 5: Effluent Flow Trend Graphs

Effluent Volume (Gallons)



Date and Time of Day

Notes:

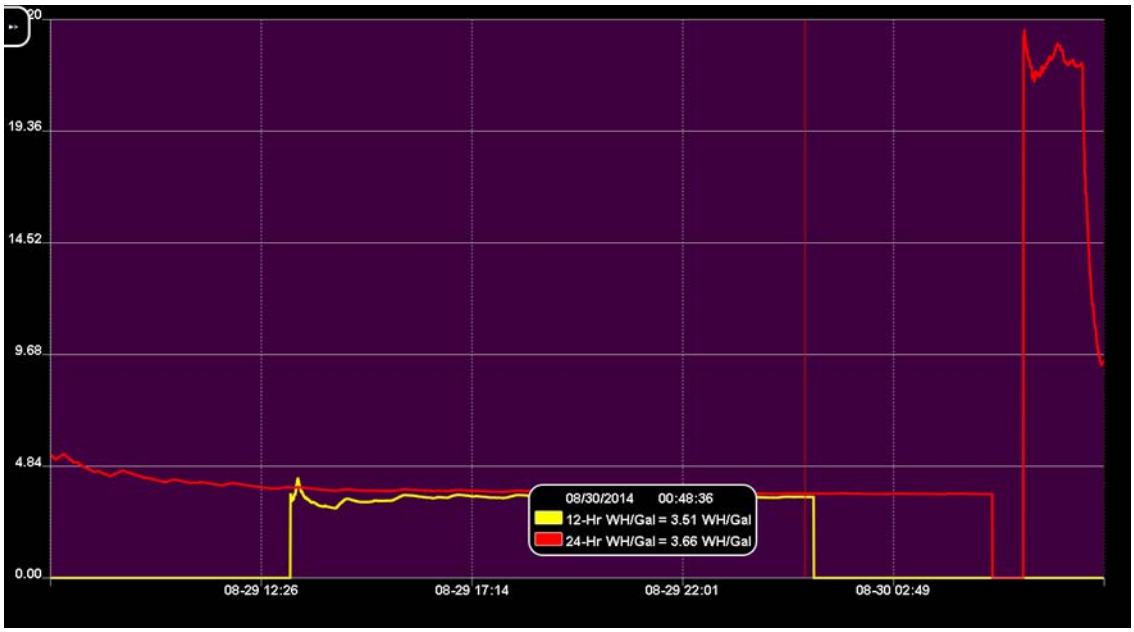
This screen image was taken on August 30, 2014, for 12 gallons per minute (gpm) feed flow. The previous system configuration involving pumped (rather than gravity flow) output and Neo Tech UV reactor system were used.

Cumulative flow is calculated by summing the product of instantaneous measured output flow by the interval between samples, to yield total gallons from a reference start time.

Two moving averages of cumulative flow are computed: one for 12 hours, starting at noon each day, and one for 24 hours, starting at midnight. The 12-hour flow computation is the more meaningful, since it involves a period of continuous flow, whereas the 24 hour average includes periods where influent liquid levels are too low to permit pumping.

Figure 6: Unit Energy Consumption Trend Graphs

Unit Energy Consumption (kwh per 1,000 gallon)



Date and Time of Day

Notes:

1. This screen image was taken on August 30, 2014, for 12 gpm feed flow. Previous system configuration involving pumped (rather than gravity flow) output and Neo Tech UV reactor system were used. The Watt-Hour per gallon is calculated within the RTU used to control the i50 system, as follows:

    a. On a periodic polled basis, instantaneous current readings are supplied by variable speed drives that power pump and blower motors.

    b. The instantaneous currents measured are multiplied by the root mean square (RMS) voltage times the measured power factor for each device. This computation yields the instantaneous power being consumed by the associated pumps and blowers.

c. The power consumed for the fixed power devices, principally the UV reactors, and to a much smaller extent, electrically powered valves, and controls power supplies. The sum of the power consumptions of these fixed power devices, with the variable powers of pumps and blowers, yields total instantaneous power consumption.

d. The instantaneous power consumption is multiplied by the interval between polled samples, to provide the added incremental watt-hours for each sample.

e. Similarly, cumulative flow is calculated by summing the product of instantaneous measured output flow by the interval between samples, to yield total gallons. Watt-hours per gallon are calculated as a moving average by dividing cumulative watt-hours from the reference starting time, by cumulative flow from the reference time.

2. Two moving averages are computed: one for 12 hours, starting at noon each day, and one for 24 hours, starting at midnight. The 12-hour computation is the most meaningful, since it involves a period of continuous flow, whereas the 24 hour average includes periods where influent flows are too low to permit pumping.

3.3 Water Quality Testing

3.3.1 Phase 1

Phase 1 tests were made to characterize baseline system parameters of water quality and disinfection levels at the various stages of treatment for the equipment as first delivered and installed. The tests were performed by Carollo Engineers over a period of three days. The types of measurements made were as follows:

- Particle size distributions
- Conventional water quality parameters
- Special measurements before and after UV radiation, with injection of MS2 coliphage test viruses prior to UV radiation, and measuring organism counts before and after the radiation, using:
    - Laboratory-based "collimated beam" apparatus; and
    - Installed UV disinfection products used in the i50 at the time, testing "insitu"
- An associated measurement made of the process effluent is UV "transmittance" indicates what percentage of UV radiation passes through a centimeter of process liquid, a measure that affects UV disinfection effectiveness

3.3.2 Phase 2

Phase 2 involved testing the i50 in continuous operation, treating municipal wastewater drawn from an influent channel of the wastewater treatment plant. Samples were collected by qualified staff of the Dublin San Ramon Services District at designated points in the i50 process sequence, with samples picked up by Alpha Analytical Laboratories for analysis on a scheduled three-day per week basis. The equipment configuration used was changed several times during the Phase

2 period, in the attempt to improve system performance. Informal tests were also made by Great Circle personnel during the Phase 2 testing period. Analyses made were: Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS), turbidity, pH, and total and fecal coliform. One set of effluent samples per week were also made for the stored and aerated effluent contained in final treatment stages, with analyses of plant nutrients and miscellaneous metals of importance. Phase 2 water quality analyses performed by Alpha Analytical Laboratories, along with chain of custody forms, are presented in Appendix C.

3.3.3 Coliform Counts

Effluent total and fecal coliform counts, unfortunately, exceeded 1,600 counts per 100 milliliters, using the most probable number method. This is above the limit of 23 total coliform per 100 milliliters, most probable number, the limit specified by the California Title 22 Secondary 23 disinfection criteria for restricted access irrigation reuse (see Appendix A).

These high coliform levels were correlated with anaerobic growths that formed on pipe and vessel surfaces, and also, that fouled sleeves that encased UV lamps within the UV disinfection units. The fouling was associated with high levels of BOD in the bioclarifier outputs, which persisted despite high aeration levels from the air blower used to aerate and circulate the bioclarifier contents. The levels of BOD also far exceeded the predictions made for the i50 bioclarifier (floating bead biofilter) by its developer. The bioclarifier design has been used successfully for over 30 years in primarily aquaculture applications, and has been extensively researched at Louisiana State University.

The substandard performance encountered with the bioclarifier is attributed to two factors:

3. The organic loading associated with the short hydraulic retention times of the i50 far exceed those normally used with floating bead biofilters in aquaculture applications.
4. The dominant tributaries to the sewer channel supplying influent to the i50 were two sewage lift stations that delivered the wastewater through pressurized “forced main” pipes. Forced mains, which exclude air, harbor highly anaerobic conditions, especially in the late night and early morning, at which time sewer odors experienced were found to be foul and intense.

Those cases in which tests yielded less than 200 total coliform, and in two cases, less than the 23 total coliform criterion of Title 22, “Secondary 23” class of treatment for restricted irrigation reuse, have only been obtained under the following conditions:

1. Within hours of a chemical cleaning of the UV system; thereafter, the UV lamp system sleeves would foul rapidly (after several hours of use) (Figure 7).

Figure 7: Fouled UV Lamp System

2. Output flow was limited to the 12 to 20 gpmrange, approximately 28 percent to 57 percent of the originally targeted 35 gpm(50,000 gallons per day). The reduction in flow was due to two limitations encountered with the bioclarifier product supplied by others: (1) an internal plumbing bottleneck: and (2) aerobic biological digestion that was below expectations at the original design flow rate.

3.4 Data

A tabulation of representative i50 data for the various points in the process train is displayed in Tables 1 and 2. Measurements made by Carollo Engineers are shown in Appendix A. Supporting analyses provided by Alpha Analytical Laboratories for Phase 2 operations is presented in Appendix B. Phase 2 water quality analyses performed by Alpha Analytical Laboratories, along with chain of custody forms, are presented in Appendix C.

Table 1: Comparison of Effluent Water Quality Parameters for Different Treatment Stages

						Water Quality Measurements (mg/l)				
	Date	Samples Taken By:	UV System Type	Output Flow (gpm) [A]	UV Flow (gpm) [A]	Vortex Separator Effluent [B]	Bead Filter Effluent [C]	Post Filter Effluent [D]	UV System Effluent [E]	Stored Effluent Effluent [G]
BOD (mg/l)										
	8/20/2013									
	8/21/2013	Carollo	Neo Tech	22.2-26.7	22.2-26.7	140-230	97-100	N/A		
	9/10/2013									
	4/23/2014	"	"	30	30			"		
	7/29/2014	"	"	35	35	280	170	160	190	
	8/6/2014	DSRSD	"	30	30	210	180	180	180	
	8/19/2014	"	"	25	25					
	10/3/2014	"	"			210	170	180	150	
	10/22/2014	"	"			220	72	120	150	59
	10/29/2014	"	Salcor			94	88	83	97	23
TSS (mg/l)										
	8/21/2013	Carollo					87-97		37-55	
	4/23/2014	"		30	30				60	
	7/29/2014	"		35	35	47	78	120	78	
	8/6/2014	DSRSD		30	30	170	59	88	66	
	8/19/2014	GCI		25	25					
	10/3/2014	DSRSD				67	130	72	38	
	10/22/2014	"				160	57	52	58	71
	10/29/2014	"	Salcor			83	46	47	40	79
Total Coliform (MPN/100mL)										
	8/21/2013	Carollo	Neo Tech					"	80-22,000	
	4/23/2014	GCI	"	30	30				17	
	7/17/2014	"	"						300	
	7/29/2014	"	"	35	35			>1600	>1600	
	8/1/2014	"	"	30	30			"	30	
	8/19/2014	"	"	25	25				130/540[F]	
	10/3/2014	DSRSD	"	12	12	1.3 x 10E8	4.9x 10E7	3.3 x 10E7	79	
	10/22/2014	"	"	"	"	7.9 x 10E7	7.9 x 10E7	4.9 x 10E7	>1600	>1600
	10/27/2014	"	Salcor	"	"	2.4 x 10E8	7.9 x 10E7	1.1 x 10E8	>1600	
	10/29/2014	"	"	12	"	7.9 x 10E7	4.9 x 10E7	1.7 x 10E7	"	>1600
	10/30/2014	GCI	"	"	0.45				"	
	10/30/2014	"	"	"	1.09				"	
	10/30/2014	"	"	"	1.4				9.2 x E8	
	10/30/2014	"	"	"	2.02				"	
	11/3/2014	"	"						33	
	11/3/2014	"	"						130	
	11/3/2014	"	"						350	
	11/3/2014	"	"						110	
	11/4/2014	"	"						>1600	
	11/4/2014	"	"						"	
	11/4/2014	"	"						"	
Fecal Coliform (MPN/100mL)										
	8/21/2013	Carollo	Neo Tech		10-53				23-17,000	
	4/23/2014	"	"		30				6.8	
	7/29/2014	DSRSD	"	30	35		>1600	>1600	350	
	8/1/2014	GCI	"	"	"		"	"	13	
	8/9/2014	"	"		25				130/540[F]	
	10/3/2014	DSRSD	"			2.3 x 10E7	1.7 x 10E7	7.8 x 10E6	22	
	10/22/2014	"	"			7.9 x 10E7	2.2 x 10E7	1.3 x 10E7	>1600	>1600
	10/27/2014	"	Salcor	10	0.5	4.9 x 10E7	4.9 x 10E7	1.7 x 10E7	>1600	
	10/29/2014	"	"	"	"	4.9 x 10E7	1.7 x 10E7	7.0 x 10E6	"	>1600
	10/30/2014	GCI	"	"	0.57				"	
	10/30/2014	"	"	"	0.88				"	
	10/30/2014	"	"	"	1.68				"	
	10/30/2014	"	"	"	2.14				"	
	11/3/2014	"	"	"	0.57				13	
	11/3/2014	"	"	"	0.88				23	
	11/3/2014	"	"	"	1.66				110	
	11/3/2014	"	"	"	2.14				49	
	11/4/2014	"	"	"	0.51				>1600	
	11/4/2014	"	"	"	0.98				"	
	11/4/2014	"	"	"	1.48				"	

Table 1 (continued)

Notes:

A For 8/21 tests, Output Flow equates to influent flow and Output flow equates to BC feed flow for Phase 2 tests.
Output flow setpoint lowered from 35 gpm to 30 gpm on 8/6/2014.
Output flow flow setpoint lowered from 30 gpm BC feed flow to 25 gpm on 8/9/2016.

B Influent pump control strategy changed from flow control on 8/21/2014, to both level and flow control for Phase 2 tests.
Influent pump basket strainer removed for Phase 2 tests, using instead cutter pump for BC feed pumping.
Influent pumping strategy changed also for Phase 2 testing to incorporate improved flotsam decant sequence.

C Two bead filters in series used for 8/21/2013 reduced to 1 bead filter for Phase 2 testing because of hygraulic flow limitations.
Bead filter operation during 8/21/2013 suffered from short circuiting problems that were substantially eliminated for Phase 2 testing.
Output control problems encountered in 8/21 testing substantially reduced for early Phase 2 testing.

D Post filter added after 8/21 tests, but is being eliminated as of 11/18/2014 along with output pump.

E Neo Tech UV system used for 8/21/2014 tests involved 8 lamps treating total output flow.
UV system given hand cleaning with LimeAway on 8/5/2014.
Neo Tech UV system went from 8 lamps to 7 lamps on 8/5/2014, when one lamp and one sleeve were damaged.
On 8/19/14, Neo Tech UV system returned to 8 lamps from 7 lamps.
On 8/19/14, UV system given acid CIP cleaning.
Prior to 10/27/2014, Neo Tech UV reactors used to treat entire output flow stream; thereafter, 0.5 gpm side stream treated for unattended operation, with two Salcor 3G units in hydraulic series in place of Neo Tech UV system, with balance to drain.
The Salcor 3G unit sleeves were chemically cleaned on 11/3 just prior to testing.
The tests of the Salcor 3G system made on 11/3 and 11/4 suggest that the i50 will be able to meet Title 22 Secondary 23 coliform criteria if equipment changes now underway correct the fouling and particulate issues being encountered. The high coliform counts on 11/4 were due toUV sleeve fouling that occurred overnight.

F For tests of 8/9/14, 130 Total & Fecal Coliform MPN/100 ml with Post Filter; 540 Total & Fecal Coliform MPN/100 ml without Post Filter.

G Excessive coliform prevailing for UV Effluent led to all Stored Effluent counts being excessive. Title 22 coliform criteria apply only to effluent of i50 treatment unit.
More data on stored effluent water quality is contained in next table.

Table 2: Comparison of Water Quality Parameters for Bead Filter and Stored/Aerated Effluents

		Conventional Chemistry Parameters					Nitrogen				Metals								
Sample Location	**Sampling Date**	**Biochemical Oxygen Demand (BOD)**	**pH**	**Total Dissolved Solids (TDS)**	**Total Suspended Solids (TSS)**	**Turbidity**	**Ammonia as NH3**	**Total Kjeldahl Nitrogen**	**Nitrate as NO3**	**Nitrite as NO2**	**Phosphorus**	**Potassium**	**Boron**	**Cadmium**	**Calcium**	**Iron**	**Magnesium**	**Manganese**	**Sodium**
Bead Filter Effluent																			
	8/6/2014	180	7.57	N/A	59	130	50	61	ND	ND	5.7	19	0.71	ND	76	0.17	42	0.041	150
	8/20/2014	150	7.66	N/A	77	84	65	65	ND	ND	6.5	24	0.064	ND	87	0.13	45	0.034	160
	10/22/2014	72	7.64	N/A	57	82	63	72	ND	ND	6	22	0.4	ND	56	0.17	32	0.032	190
	10/29/2014	88	7.75	N/A	46	73	64	70	ND	ND	6.1	23	0.38	ND	40	0.16	26	0.031	150
Stored Effluent																			
	8/6/2014	31	7.99	950	84	41	50	57	ND	ND	5.7	21	0.78	ND	76	0.24	43	0.048	150
	8/20/2014	77	7.4	800	19	19	ND	ND	8.8	150	4.9	25	0.89	ND	90	0.03	49	0.03	160
	10/22/2014	59	7.52	720	71	16	29	19	17	92	6.4	21	0.43	ND	46	0.26	26	0.037	140
	10/29/2014	23	5.9	810	79	27	64	70	ND	ND	6.1	23	0.38	ND	40	0.16	26	0.031	150

Notes:

A The spread in values for stored effluent are a result of variations in both i50 parameter settings, and in hydraulic retention times and weather affecting digestion during storage.

B Hydraulic retention times for aerated effluent storage ranged from approximately 7 to 28 days.
Low BOD values correspond to longer retention times.

C The high pH values result from the hardness of the local water supply.

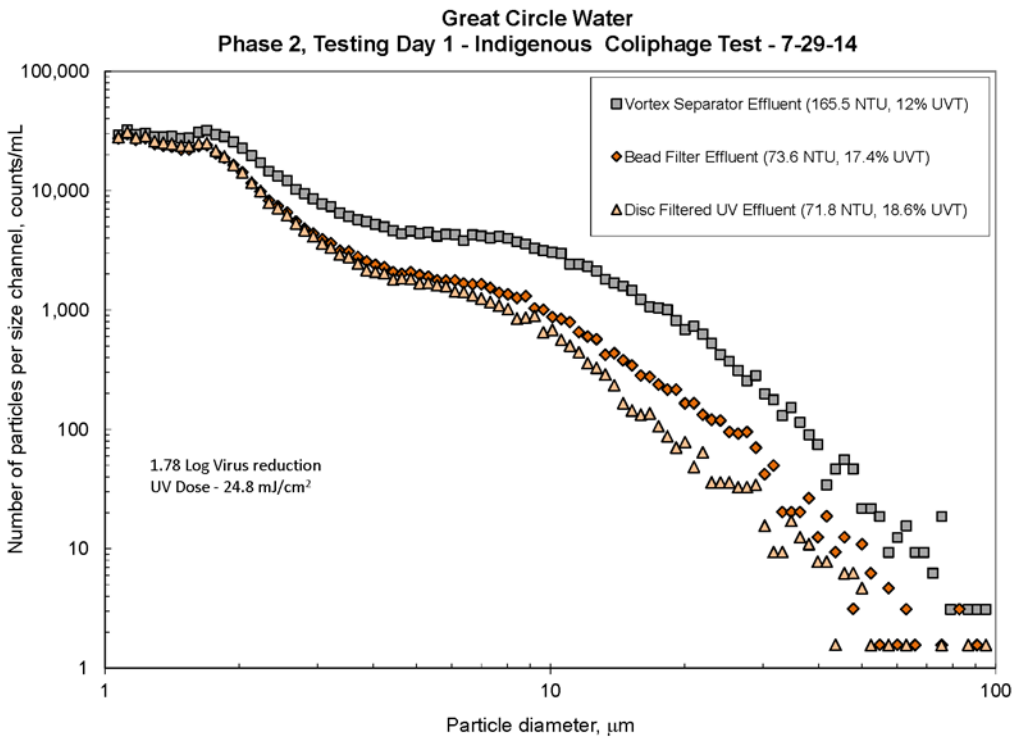
D The sodium content of the effluent is primarily a result of the extensive use in the local service area of water softeners, which are ionically recharged using sodium chloride.

E Both the high pH and the excessive sodium content of the effluent created salt buildup in the sand growing medium used in the planter bed; this needed to be periodically corrected by the addition of sulfuric acid to the effluent.

F The addition of sulfuric acid to the stored effluent is responsible for the low pH reading shown for 10/29/2014.
In commercial applications this pH correction can be provided cost-effectively by "sulfur burner" equipment.

Figure 8, below, is an example of several particle size distributions sampled and analyzed for several points within the treatment sequence taken during Phase 1 of testing. This and a comparable distribution taken during Phase 2 of the testing program are contained in Appendix B. The various plots did indicate large variations in particle sizes, pointing to a contributing cause of the excessive coliform counts measured after UV disinfection.

Figure 8: Particle Size Distribution



3.5 Aerated Effluent Storage

Data collected from stored and aerated effluent indicated that for hydraulic retention times that exceeded seven days, the stored effluent achieved significant reductions in BOD and TSS. Levels of nitrite and nitrate measured for the stored and aerated effluent, however, were non-detectable much of the time. Such low levels of nitrite and nitrate, along with high levels of ammonia, are further indications that the influent received by the i50 had excessive content of anaerobic organisms that interfered with the intended aerobic digestion.

Figure 9: Aerated Effluent Storage Subsystem

Figure 9 provides two views of the aerated effluent storage subsystem. At the left is a 1,200 gallon storage tank, with associated air compressor and metering pump; at the right is a front view of the tank, showing our technician associate, Jim Rose, holding a sample of the stored and aerated effluent.

3.6 Irrigation Demonstration

Vegetation irrigated with the i50 effluent thrived at first, but then later suffered from an excessive build-up of salts and alkaline hardness minerals in the sand. The effects of salts and alkaline hardness had to be neutralized with the infrequent addition of sulfuric acid. One significant source of salt-buildup was the sodium concentration in the effluent, which was measured in the 150 - 200 milligrams per liter range. This high sodium level is primarily attributed to the widespread use of ion exchange water softeners in the sewer service area.

The growth and vigor of the plants raised in the pH-adjusted sand was remarkable, demonstrating the significant ecological and commercial value achievable by irrigating with the i50 process effluent, and adjusting pH as necessary (Figures 10 and 11).

Figure 10: Planter Bed Vegetation

Figure 11: Planter Bed Vegetation

3.7 General Project Accomplishments

The project has been effective in advancing the readiness of the technology significantly, bringing it far closer to commercial readiness, and pointing to design areas that need, and are still undergoing, refinement.

Important advances made by the project include the following:

- Demonstrating that under ideal conditions, the i50 is capable of producing effluent water meeting the California Title 22, Secondary 23 total coliform requirement.
- Developing a stilling well design that solved site-specific problems of extracting influent from a wastewater channel with high velocities and multiple tributary directions.
- Optimizing vortex separator operation for purging floating and settled solids.
- Controlling flows and liquid levels throughout the treatment train.
- Identifying and solving short-circuiting problems of the bioclarifier stage
- Refining software control logic and remote monitoring that is accessible from any internet-connected personal computer or portable device with a web browser

- Demonstrating unit energy consumption associated with different parametric settings and equipment configurations.
- Demonstrating plant growth and vigor when irrigating washed sand with the process effluent.
- Creating a highly flexible software-controlled modular system that can be adapted to many wastewater treatment and water reuse applications.

CHAPTER 4:
Project Benefits

The subject technology has the potential to bring major savings in energy, water, and capital and operating costs to the ratepayers of California. By virtue of being modular, fully automatic, and very compact, the technology facilitates wastewater treatment and recycling on a decentralized basis, near both a sewer source of wastewater and an intended reuse location. This satellite treatment approach minimizes major impediments to cost-effective water recycling, which are transport facilities construction and energy consumption.

The technology can contribute in a major way to meeting California's goal of recycling an additional 500,000 acre-feet of water annually within the next decade. The energy consumption of the i50 is estimated to be less than 50% of the unit electrical energy consumption (kilowatt-hours per 1,000 gallons) to pump water to southern California via the State Water Project. If only 10% of the targeted 500,000 acre-feet per year are provided by Great Circle Industries i50 modules for irrigation reuse in southern California, this will save 1,000 acre-feet of water annually, and correspondingly, 162 megawatt-hours of electrical energy. At an assumed energy rate of $0.15 per kilowatt-hour, this corresponds to total cost savings to ratepayers of approximately $24.3 million per year. Relative to the $750,000 grant awarded for this project, the grant represents a very low risk/reward ratio.

In addition to the above, there are other less obvious benefits to California:

- A modular decentralized option for increasing wastewater treatment and water supply needs on an incremental, modular and cost-effective basis.
- A product that involves high shipping costs, but low manufacturing costs, and that therefore is resistant to competition from distant labor and manufacturing sources.
- A source of employment for small-scale fabricators, assembly plants, installers and remotely-based operators.
- A means for municipal wastewater treatment plants facing capacity limits to expand capacity through the use of satellite "water harvesting" plants.

CHAPTER 5:
Resolution of Remaining Technical Issues

Great Circle Industries has already completed installation and has begun evaluation of an i50 system modification that promises significant improvement of effluent water quality and disinfection. This involves the use of facultative bacteria to augment/replace the troublesome anaerobic organisms encountered. The cultures and equipment incorporated are off-the-shelf, and have an impressive track record in solving similar problems for other wastewater treatment systems.

The research team anticipates that to get the levels of biological performance desired, even with the beneficial facultative bacteria, i50 hydraulic retention times must be increased. This will correspond to either: (a) using a larger footprint than the original 160 square feet chosen; or (b) use the existing equipment with a lower flow rating than the original 50,000 gallons per day. Either way, Great Circle Industries believes our prospective product will be substantially less costly to own and operate, with less unit energy consumption, than other products that may decide to enter the "water harvesting" market using prevailing technologies.

The test site installation that was created as part of this project is an invaluable platform for solving and testing the product/process issues that remain. The Dublin San Ramon Services District has graciously agreed to extend our use of their wastewater treatment plant facility for this work. The company intends to continue such work from its own resources until conclusive results are obtained.

GLOSSARY

Term	Definition
BOD	Biochemical Oxygen Demand
gpm	Gallons per minute
kWh	Kilowatt-hours
NPDES	
PC	Personal computer
RD&D	Research, Development, and Demonstration
RMS	Root Mean Square
RTU	Remote Terminal Unit
SCDA	Supervisory Control and Data Acquisition
TSS	Total Suspended Solids
UV	Ultraviolet

REFERENCES

"A Preliminary Evaluation of a Type III PolyGeyser® Filter for inclusion in the Great Circle i50". Bioclarifier Engineering Analysis and Design

APPENDICES

Appendix A: Title 22 Recycled Water Uses Allowed in California

Appendix B: Carollo Engineers Water Quality Analysis Reports

Appendix C: Alpha Labs Water Quality Analysis Reports

These appendices are available as a separate volume, publication number CEC-500-2015-054-AP.