**W4E HYDROPOWER DIRECT DRIVE IN-LINE
HYDROTURBINE GENERATOR
FULL SCALE PROTOTYPE VALIDATION
TESTING REPORT
MAY 2013
ALDEN LABORATORIES**

PREPARED FOR:
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Re: W4e Hydropower Direct Drive In-Line Hydroturbine Generator
Full Scale Prototype Validation Testing Report

Mr. Russell:

As per our proposal to you dated March 22, 2013 and approved by you on April 1, 2013, GZA GeoEnvironmental, Inc. (GZA) is pleased to provide you with this report on our observations during the testing of the 28- inch prototype W4e Hydropower Direct Drive In-Line Hydroturbine Generator at Alden Laboratories in Holden, Massachusetts in May 2013. This report is provided to you in support of the terms of your grant from the U.S. Department of Energy.

GZA was present during all testing times at Alden Labs to observe the procedures and take independent data measurements of turbine performance. Head and flow measurements were made by Alden labs and have been relied upon in this report. The data collection results reported in this report were independently observed by GZA personnel by the methods reported herein. Data reduction and estimates of power production were also independently performed by GZA using standard methods. GZA field work and the production of this report were supervised by Chad W. Cox, P.E.

We have been pleased to support Walker Wellington in this testing program. Please feel free to direct any questions or concerns to Mr. Cox at 781-278-5787 or chad.cox@gza.com.

Very truly yours,

GZA GEOENVIRONMENTAL, INC.

A handwritten signature in blue ink that reads "Kristina Ekholm".

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Principal-in-Charge

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TURBINE TEST REPORT

1.0 INTRODUCTION

1.1 BACKGROUND

Walker Wellington LLC (Walker Wellington) has secured the exclusive hydropower application use rights to a new patent-pending, direct-drive, variable force turbine/generator designed by Benjamin Brickett/ Blue Water and referred to herein as the W4e.

In November 2011 Walker Wellington submitted a grant application to the U.S. Department of Energy Wind and Water Power Program. The grant application was for funding to allow Walker Wellington to employ and otherwise utilize the testing capabilities of Alden Research Laboratory Inc, Holden, Massachusetts) and the technical expertise of GZA GeoEnvironmental Inc. Norwood, Massachusetts to validate the design predictions/intention for the W4e hydroturbine generator by examining and documenting full-scale prototype turbine performance under actual service conditions. The grant application included a preliminary Levelized Cost of Energy (LCOE) comparison that was prepared by GZA. Walker Wellington was awarded the grant.

Turbine testing was performed between May 20 and May 31, 2013. Installation, configuration and testing at the Alden facilities were conducted for five total days. Two test hiatus periods were used to make adjustments to the prototype turbine to address performance issues revealed during operation under full-scale head and flow conditions.

Subsequent to the testing, GZA evaluated the data gathered and produced tables and graphs to summarize the data. GZA has developed this report to document the testing and to provide the results of the testing (graphs and tables).

1.2 GZA SCOPE

GZA's services were performed in accordance with our proposal dated March 22, 2013 and executed on April 1, 2013. GZA's role in the project has been to provide independent observation and reporting of the turbine testing. This turbine testing report is subject to the limitations in **Appendix A**.

1.3 ACKNOWLEDGEMENTS

This full scale prototype testing program required the efforts of numerous personnel from several organizations, including:

- Walker Wellington
- Blue Water Concepts
- Alden
- GZA

Valuable Contributions were made by the individuals listed below:

- Chief of Test- Benjamin Brickett, Blue Water
- Test Facility Manager- Gregory Allen, Alden
- Independent Engineer- Chad Cox, GZA

2.0 PURPOSE, GOALS AND OBJECTIVES

2.1 TEST PURPOSE AND GOALS

The purpose of the test was to collect data on the performance of a prototype W4E turbine / generator package under controlled full-scale testing conditions. The five (5) general goals of the testing were:

1. Demonstrate that technologically advanced components comprising the W4E system can be effectively integrated into larger systems;
2. Validate design assumptions / predictions;
3. Quantify the overall water-to-wire efficiency of the turbine/generator package over a range of heads and flows expected to be typical of anticipated applications;
4. Obtain data on turbine / generator settings which maximize efficiency at particular heads and flows; and,
5. Identify unforeseen design and performance issues apparent during testing at an early state to allow for correction in future system iterations so as to reduce risk at later stages of technology development.

2.2 TEST OBJECTIVES

Accomplishment of the five overall goals of the test will require several objectives to be met and documented during the testing procedure, as shown in **Table 1**:

Table 1. Testing Goals and Objectives

Goal	Objective
1. Demonstrate System Integration	1a) Successfully install W4e turbine / generator on full-scale testing facility using simple “bolt on” methods
	1a) Successfully generate power which can be conditioned to grid-compatible energy
2. Validate Assumptions / Predictions	2a) Generate power at a wide range of flows and heads, including low heads and low flows.
	2b) Generate power under open channel conditions
	2c) Demonstrate that efficiencies presented in Preliminary Levelized Cost of Energy are achievable
	2d) Run turbine at high speeds without damage to system
3. Quantify Water-to-Wire Efficiency	3a) Determine power output from total turbine generator system through measurement of voltage and amperage
	3b) Compute theoretical power under test conditions and compare to actual indirectly measured power output to compute efficiency.
	3c) Apply standard efficiency losses for power conditioning equipment to compute “water-to-wire” efficiency
4. Obtain data for turbine efficiency optimization	4a) Optimize power output at various heads and flows through adjustments to generator engagement and blade position
	4b) Plot data to indicate relationships between efficiency and flow, head, generator engagement, and blade position
5. Identify unforeseen design and performance issues	5a) Record all test results, unanticipated difficulties, and conditions under which these occurred.

3.0 DESCRIPTIONS OF TESTING PARTNERS, EQUIPMENT, AND FACILITIES

3.1 TESTING PARTNERS

Walker Wellington, LLC – Turbine Developer and DOE grant recipient.

Blue Water, LLC – Turbine designer and manufacturer

Alden Research Labs – Testing facilities owner and manager.

GZA GeoEnvironmental, Inc. – Independent Engineer

A summary of qualifications for GZA and Alden are provided in Appendix B, along with resumes for supervisory personnel.

3.2 TURBINE / GENERATOR EQUIPMENT BEING TESTED

The W4E is a patent-pending, direct-drive, variable force turbine/generator. The equipment generates electricity through the water dependent engagement of a ring of rotating magnets with coils mounted on a stator ring. The equipment has a passive axial control mechanism to eliminate the high static starting forces (start-up torque). This enables it to turn and produce power at lower flow rates. The equipment has a variable pitch control mechanism to assist in maximizing power generation. This is done through the adjustment of the pitch of the turbine blades to vary head and flow.

The W4E's design may allow it to have applications at conventional low-head hydropower sites, pressurized conduits, man-made canal control structures, and open-channel discharge pipes. The W4E device may be able to address several technical challenges which currently affect the potential for hydropower generation at low-head sites, including the inability of traditional turbines to generate at very low flows and the inability of traditional turbines to generate in open channel situations. Additionally, the W4E system has the potential to be a true "bolt on" system which can function over a range of heads and flow. **Figure 1** is a rendering of the turbine/generator.

The full-scale prototype turbine which was tested was a 28-inch I.D. W4e turbine with three in-series permanent magnet generators with variable engagement. The turbine runner included eight blades with simultaneous variable pitch control. All generator engagement and turbine pitch control was performed manually using hand pumped hydraulic cylinders. The assumed maximum capacity of the generator is 15kW **Figure 2** is a section diagram, including attachment and support details.

Figure 1. Isometric Rendering of W4E Turbine/generator.

Figure 2 Turbine / Generator Unit Section Diagram

3.3 TEST FACILITIES

Turbine testing was performed at Alden's Hooper Test Facility at 30 Shrewsbury Street Holden, Massachusetts 01520-1843 USA. (508-829-6000 <http://aldenlab.com/>) At the Test Facility, water is conveyed from a 150 acre reservoir (headpond) via a 36-inch penstock. This system can provide up to approximately 28 ft. of static head; however a supplemental booster pump system rated at 200 ft. of head can be used to provide additional head. **Figure 3** is an overview of the test facility and headpond. **Figure 4** is a section view of the testing facility showing the portions of the equipment supplied by Alden.

Figure 3. Overview of Alden's Hooper Test Facility

Figure 4 Section View of Hooper Test Facility

***Notes:**

In final testing configuration, the penstock pipe diameter reduction occurred within enclosed test area and the turbine was connected directly to the 28-inch penstock section

4.0 TESTING PLAN MEETING AND TESTING PROTOCOL

A testing plan meeting/ site visit was held at the Alden Research Laboratory, Inc (Alden) on April 4, 2013. Parties in attendance included representatives of Walker Wellington, Blue Water, Alden, and GZA. During the meeting, parties discussed the details of the testing effort. Some of the details discussed included specifics on how the equipment would be installed (including the need for a reducer and matching flanges, the type of data recording equipment and signals produced, and the available range of heads and flows at the facility). Details also included how the testing parameters could be varied while holding other parameters constant.

Subsequent to the test plan meeting, GZA prepared a testing protocol for the laboratory-scale testing of the W4e at the Alden facility. A copy of the testing protocol is included in **Appendix C**. The testing protocol included the following: a description of the equipment and test facilities; an outline of the roles and responsibilities of project partners; an initial schedule for the five day test period, a description of the test parameters; a description of the instrumentation and how data would be collected. The protocol provided a preliminary procedure for performing the tests; and described the post-test data reduction and reporting. The testing protocol was performed in accordance with ASME PTC18-2011, Hydraulic Turbines and Pump Turbines- Performance Test Codes. All testing team partners agreed that the protocol would form the basis of the testing plan but adjustments to the plan could be made as conditions warranted. The Chief of Test was designated as Miles Amaral of Blue Water.

5.0 TESTING

Testing of the W4e was scheduled to occur during the five days between May 20 and May 24, 2013. However, due to the need for adjustments and modification to the turbine control equipment during the test period no testing was performed on May 20th, May 23rd or on May 24th. Alden permitted additional testing on May 29th, May 30th and May 31st. GZA maintained a log of testing activities, which is presented below. A photolog of the testing is included in **Appendix D**. The following is a summary of the testing activities and observations from each day.

5.1 TEST OBSERVATIONS

Testing Day 1- May 21, 2013

The first day at the Alden Hooper facility commenced with a meeting comprised of members from Blue Water, Walker Wellington, Alden, and GZA GeoEnvironmental. The discussions included a health and safety talk, a discussion of roles and responsibilities of each of the members, and a discussion of the installation/ attachment of the W4e turbine to Alden's penstock, as well as the schedule for the week. It was determined that Blue Water would be the chief of test. It was also noted that synchronization of Blue Water and Alden data recorders was not feasible at this time.

The W4e turbine was successfully unloaded from the pickup truck and lowered into position by Alden personnel. GZA verified the turbine to be a 28-inch diameter unit with three permanent magnet generator rings. The installation of the gasket and bolts to connect the flanges of the W4e and the penstock required approximately 22 minutes. The next 2 hours and 40 minutes were used by Blue Water personnel to perform multiple wiring tasks on the W4e. These activities included measuring the resistances of the heating elements used as the dump load (independently verified by GZA), wiring the high voltage leads to these resistive elements, grounding of the W4e and load bank tank, wiring the two linear position sensors for piston position data, and installing data cables to the '16 Channel NI DAQ bus' data acquisition system (DAQ). Simultaneously, personnel from Alden supplied potable water, via hoses, that subsequently Blue Water connected to the W4e's bearings and water bath tank.

The resistances of each of the three resistive elements located in the load bath tank were measured using four instruments. The results varied from those expected when both the clamp meters supplied by GZA and Blue Water were used to measure the resistance. These models were the Klein CL-1000 and CM-450. Two additional meters (UL-DT830 and Fluke 7-600) used by Blue Water and GZA respectively, each closely produced the expected value of resistance of 1.6 Ohms for all three resistors. The UL-DT830 read 1.6 Ohms for all three resistors and the Fluke 7-600 read 1.5 Ohms for resistors one and three and 1.6 Ohms for resistor two.

GZA manually measured the displacements of each of the cylinders corresponding to blade actuation and generator engagement during the interval when Blue Water was testing the linear position sensors. The range of the blade cylinder was recorded to be approximately ½" and the generator engagement cylinder range was recorded to be approximately 1-15/16".

Blue Water closed the vanes of the W4e and disengaged the generators prior to instructing Alden's employees to commence opening of their flow valve. As the penstock filled with water, a small amount of leakage was observed through the turbine blades. After 15 minutes, Alden employees indicated that 25 feet of head was backed up behind the W4e. Despite this pressure, the W4e did not freely rotate. Flow was subsequently shut off and the W4e inspected for blockage, bearing stiffness, and potential misalignment of the three generators. It was concluded that no debris was present but the bearings were quite stiff due to low tolerances of 0.002". It was speculated that misalignment may exist. It was noted that with tight tolerances, the parts are expected to wear into each other through W4e use. The generators were spun with difficulty using a wooden pole. It was thought that perhaps giving the turbine an initial torque using the pole would be enough to initiate self-perpetual rotation. A member from Alden suggested that there may be too much force impinging on the main bearing to allow for free rotation.

Blue Water requested that Alden restart the flow, but the attempts to provide initial torque to the generators with the wooden poles were unsuccessful as a large physical effort by Blue Water produced no rotation. It was additionally suggested that the blade angle may not be sufficient to generate the proper initiation torque. Flow again ceased and Blue Water again began troubleshooting the W4e. Blue Water addressed the possible generator misalignment issue by rotating the six turnbuckles connected to the W4e compression rods while periodically manually rotating the generators to physically determine if the shaft could spin with less effort. Blue Water also tried wrapping a strap around the generator several times to be later pulled by Blue Water personnel in an attempt to produce a startup torque at the same time the W4e vanes are opened. The flow was later restarted with no change in outcome. At 12:58 it was decided that mechanical adjustments to the W4e were required and that further attempts to continue testing at the Alden facility would cease for the day. The W4e was removed from the penstock and loaded into Walker Wellington's truck via the Alden forklift. The engineer at Alden noted that the flow rates that were being regulated were too low for their currently installed venturi meter and accurate measurements could not be ensured.

It was later arranged amongst Blue Water, Walker Wellington, Alden, and GZA that the next attempt to test would occur on Wednesday, May 22, 2013. This would allow sufficient time for Blue water to implement the structural changes to the W4e turbine as well as give Alden a day to install a smaller venturi meter within the penstock that will have the resolution to accurately measure the expected lower flows during testing.

Testing Day 2- May 22, 2013

On Wednesday, May 22, 2013, Walker Wellington and Blue Water successfully reinstalled the turbine and the controls after approximately 30 minutes. Blue Water reported that they had rectified the unexpected mechanical deficiencies. They reported that third radial bearing set (furthest downstream) was misaligned by a 1/4" relative to generators one and two. They repaired the unit by cutting the stainless steel stabilizer bars and fitting adjustable bolts into them while all three generators were properly aligned to ensure structural integrity. The thrust bearing was also machined down to allow for faster wearing in. An additional modification performed included relocating the pitch control bearing to a different position along the shaft to allow the blades to rotate to a further open position. The previous bearing position prohibited a wide a range of blade angle

adjustment. Blue Water measured the range of the blade cylinder and the generator engagement cylinder. The generator engagement had not changed from the Day 1 measurement but the blade cylinder range increased to 21/32”.

Prior to flow initiation, the headpond was again checked for debris following several thunderstorm events. No floating debris was observed. Upon initiation of flow, very rusty water flowed for several minutes as a result of the installation of the new venturi meter by Alden personnel on May 21, 2013. Once the flow cleared up in color, the blades of the W4e were closed and head was built up behind it. GZA observed that more water appeared to leak past the turbine blades with respect to the Day 1 testing. This was due to the pitch adjustment modifications performed the day before. It was noted by Walker Wellington that adjustments could be made to close the vanes tighter if desired.

The W4e began to rotate when flows were in the range of 1-3 cfs, but would not sustain its rotational motion with time. The blade angles were manually adjusted by Blue Water using the hydraulics to attempt to find a self-sustaining rotation until they ultimately closed and could not be reopened. Flow was stopped through the penstock and the blades checked for debris. A small 1/4” stick was removed from the blades, but it was speculated that the stick was of insignificant dimension to halt the blade movements. Blue Water indicated that the restoring force of the spring in the rotor hub may be insufficient due to its current adjustment. The spring could be adjusted by removing the W4e from the penstock, removing the nose cone at the inlet to the turbine, and accessing the spring inside. The spring was noted to be only partially engaged, and was subsequently compressed to a new length. The cone and W4e were reinstalled, and adjustments to the exposed rear spring were considered, but no action was taken.

The flow was restarted and again the W4e blades would not open under water loading. The blades were manually opened and the turbine was initially spun by external forces at flows between 2-3 cfs. The blades again were adjusted to a position that would allow the W4e to wear itself in for some time. The W4e however continued to spin for 15 minutes as flows dropped to approximately 1 cfs, after which the turbine abruptly stopped. Walker Wellington decided that a double acting cylinder would be required to overcome the resisting water forces upon the closed blades. This bi-directional hydraulic actuator would allow the blades to be actively opened or shut during the testing process. Also noted was that a more significant spring would be required to produce the fail safe blade open condition in the event of a hydraulic failure.

Blue Water and Walker Wellington had decided to cease activities at Alden for the day at 10:35 hours and they would implement the required changes to parts of the W4e at their shop overnight. However, at 20:43 hours Walker Wellington informed GZA that the required parts would not be available for testing the next day (May 23, 2013).

Testing on May 23 and May 24, 2013 was subsequently canceled. Alden agreed to allow for testing to resume on May 29 and to continue through May 31, 2013.

Day 3- May 29, 2013

Blue Water made the necessary modifications to the equipment (including the installation of the double acting valve and the spring stiffener) and testing resumed on Wednesday, May 29, 2013. Upon arrival, GZA measured the headpond elevation and determined it to

be 1' 8.5" below the top of the concrete at right upstream corner of intake (looking downstream).

Upon initiation of flow, Blue Water observed that the turbine blades were not spinning freely, and were hesitating due to the water forces on the runner blades. The unit at this time was rotating at approximately 100 rpm. After about 15 minutes of flow, the turbine blades suddenly shut. After inspection, it was determined that there may have been air in the hydraulic lines that allowed the water pressure to compress the air within, thereby forcing the blades shut. Additionally, there was approximately ¼" of play in the bolt that connected the double action pitch cylinder where it connects to the frame. Blue Water fastened the bolt tight using JB Qwik Weld.

The flows were again initiated and after nearly 15 minutes when flows were approximately 5 cfs, the turbine came to a complete stop. Upon flow reduction to 3 cfs the blades reopened and rotated on their own. Blue Water reported that they felt that the blade design was flawed on the trailing edge. Blue Water disassembled the blade assembly and utilized Alden's 20 ton press to flatten the trailing edge of the blades to improve performance. Blue Water suggested that water was separating behind the blades causing vacuum forces (cavitation) and pulling them shut. Blue Water pressed the blades, reinstalled them and ran the turbine at 5 cfs and 9.4 feet of net head. The power readings were unstable due to grounding issues at Alden's facility. Wires were also melted at BW's breadboard. Alden promised to resolve the issue by the next morning.

Day 4- May 30, 2013

Testing on Day 4 began at 9:55 am. Fifteen production tests were run at heads between approximately 9 and 34 feet and flows between approximately 4 and 7 cfs. After approximately 2.5 hours of testing, the blades suddenly opened up and the rotational rate quickly reduced. Investigations found that the shaft collar that fastens the shaft to the bearing had slipped relative to the shaft. Once this loosened up, the force of the water was able to force the shaft longitudinally into the center of the thrust bearing and exhibited punching shear to the inner black material of the bearing (the stiff material that separates the two metal plates). When the shaft was forced axially towards the rear of the turbine, the shaft connected to the generators was forced to engaged (imparting magnetic drag), and thereby slow its rotation.

Blue Water also noted that the bolts may not have been tightened enough on the shaft collar. Upon retightening of the bolts, Blue Water noticed that their pitch control mechanism was not functioning properly. As a result of the shaft slippage and the following axial thrust, the Blue Water turbine operator manually forced the generators out of engagement so that the machine could be brought under control. Upon doing this, an aluminum threaded portion of the pitch control mechanism was stripped of its threads because the pitch cylinder was maxed out (it stopped when Blue Water forced this generator disengagement). The part was later replaced with a stainless steel component.

Day 5- May 31, 2013

Day 5 of testing began with immediately successful testing. Eight production tests were run at net heads between approximately 9 and 28 feet at flows between approximately 4 and 8 cfs. Approximately two hours into the testing, there was a sudden decrease in the

rotational rate of the turbine. The linear position sensor for the blade pitch indicated that the blades suddenly opened from 35% to 68% open. Upon investigation, it was determined that the rear mounting bolt for the double acting cylinder was not secure. Blue Water welded the bolt into a fixed position and testing resumed. After 45 minutes, a high pitch sound was heard from the turbine as it spun (at 115 RPM) at high flows of approximately 11.5 cfs. The flows were then stopped and investigation revealed that one of the blades was not in alignment with the others. Upon disassembly, Blue Water noted that a loose part that had accidentally been left in the turbine shaft got behind the arm and caused it to bend when the hydraulic cylinders acted on it. After approximately one hour Blue Water had reassembled the turbine and Alden indicated that Blue Water had approximately one hour left of testing prior to demobilization. Four final tests were run to capture flows between 7 and 9 cfs. At the termination of testing, the generator engagement was checked again for calibration and was found to be in error. When the shaft had shifted again earlier, it had adversely varied the position of the linear position sensor. Therefore these measurements of generator engagement are likely in error. . Following testing, the resistances of the three heat loads were measured to be 1.5, 1.6, and 1.6 respectively.

5.2 TEST PARAMETERS

During the testing Blue Water recorded data for each test using the DAQ. Blue Water also verbally communicated the test parameters and result for each individual test to GZA who manually recorded the results. Analysis of the DAQ records after the tests showed that the DAQ incorrectly recorded the data. Therefore the system parameters and test results provided by Blue Water (for generator engagement, blade position, rotor speed, and power) and manually recorded by GZA are considered the “official” test data for these parameters.

Head – Gross head is a function of the difference in elevation between the free water surface in the head pond and the centerline of the turbine. The gross head at the Hooper Testing Facility is 28 ft. without use of pumping to increase head. A variable frequency drive pump was installed in the length of 36-inch pipe just upstream of the turbine. The pump is rated for a maximum of 200 ft. of head and 1,750 rpm. Net head was measured in feet and is equal to the gross head, less headlosses. Headlosses increase as flows to the turbine increase due to pipe friction losses. Headlosses were also artificially created by operating the valve. Valve operations were performed by Alden. Test results utilize Net Head. Alden measured head in psi and converted it to feet. Alden supplied the “official” net head for the purpose of this test. Head was measured using two yoked taps located in the 28-inch pipe, 4.5 feet upstream of the flange connector to the turbine. Inlet head was measured using a differential pressure transmitter referencing a water column set at the centerline of the 28 inch inlet pipe. For each test, head was averaged over an approximately two minute period to obtain a precise differential head. Alden reported that the measured head measurement uncertainties were within 0.05% of the true value for each test.

Flow – Flow is measured in mgd. The amount of flow through the turbine is a function of the rotor speed and generator engagement. The amount of flow influences the net head. Alden measured flow in mgd and converted it to cfs. Alden supplied the “official” flows for the purpose of this test. Flow was measured using a calibrated venturi meter.

Alden reported that the measured flow measurement uncertainties were within 0.20% of the true value for each test.

Generator Engagement – Generator position/ engagement is the distance between the generator magnets and stator coil. Generator engagement was controlled by Blue Water using manual hydraulics. Generator engagement influences rotor speed, and thus flow (which then influences head). Generator position was measured in inches and converted to percent engaged by Blue Water. GZA observed Blue Water’s manual confirmation measurements. Blue Water supplied the “official” generator engagement for the purpose of this test.

Blade Position – Blade position represents how open the turbine blades are. Blade position is controlled by Blue Water. It was measured in inches using an electronic linear position indicator and then converted to percent open by Blue Water. Blade position influences rotor speed, flow, and thus head. GZA observed Blue Water’s manual confirmation measurements. Blue Water supplied the “official” blade position for the purpose of this test.

Rotor Speed – Rotor speed is a measure of how quickly the turbine shaft and blades rotate. Rotor speed is a function of the blade position, net head and flow. It is measured in rpm. Blue Water supplied the “official” rotor speed for the purpose of this test.

Power – Power was measured by Blue Water using two methods: 1) voltage from each generator was measured across resistive load bridges at the data acquisition bus and 2) current was measured through a transducer with a known resistance. The second method used was intended to be a check of the first method. Voltage was measured at all three generators and current was measured at Generator 1. Note that Blue Water’s current transducer malfunctioned during the testing; therefore method two could not serve as a check of the method 1 measurements. GZA also performed independent redundant measurement of voltage and current and calculated power. GZA did this as a check of Blue Water’s measurement. Power is reported in watts. The “official” power for the purpose of this test is the power measured by Blue Water using Method 1.

Water-to-Wire Power – Water-to-wire power is equal to the amount of power produced under a given net head and flow condition times a factor for voltage correction. It represents the actual usable power that the equipment would produce. GZA calculated the water-to-wire power.

Turbine/Generator Efficiency – Turbine/ generator efficiency is equal to the amount of power produced under a given net head and flow condition divided by the amount of power that would theoretically be produced under such condition. It represents the efficiency of the equipment at producing power.

Water-to-Wire Efficiency – Water to wire efficiency is equal to the amount of power produced under a given net head and flow condition divided by the amount of power that would theoretically be produced under such condition times a factor for voltage correction. It is reported as a percent. It represents the efficiency of the equipment at producing usable power. GZA calculated the “official” efficiency for the purpose of this test.

5.3 TEST RESULTS

Thirty one successful test runs were completed during the five day test period. Test flows ranged from approximately 3 cfs to 12 cfs and test heads ranged from 9 to 34 ft. The official results of the tests including head, flow, and power, water to wire power, turbine / generator efficiency and water-to-wire efficiency are summarized in **Table 2**. The water to wire power and efficiency account for the assumed losses in conditioning the power so that it is compatible with grid power (i.e. putting it through a rectifier to convert it to DC and then through an inverter it to bring it back to AC at the proper voltage).

The full suite of results is included in **Appendix E**. This includes all of the data recorded by GZA during the testing and the heads and flows recorded by Alden. Note that in some cases a measurement is presented in multiple units. Also note that power was measured by GZA and by Blue Water. During the testing Blue Water notified GZA of the parameters for each test and the results of each test (i.e. Power) as measured by Blue Water's equipment. GZA recorded the results reported by Blue Water. After the testing it was noted that much of the data recorded by the DAQ was unusable. Data displayed by the DAQ and manually recorded by GZA is the official data (with the exception of flow and head). Official head and flow were measured and recorded by Alden. The official power is the power measured by Blue Water and recorded by GZA.

A curve depicting the water to wire efficiency of the unit at varying head and flow conditions is included as **Figure 5**. The limited quantity of data and the inconsistent trends did not allow for development of a typical hill curve. GZA used engineering judgment in developing the efficiency curves (discounting the results of runs with results that were widely inconsistent).

Figure 6 is a plot of power vs. flow at three distinct heads. These plots demonstrate that power increases as flow increases for a given head. It also demonstrates that lower heads produce a greater power. The curve at a head of 15 feet levels off (flattens) above 8 cfs indicating that additional flows will not result in additional power production.

Figure 7 is a plot of generator engagement and blade position vs. efficiency. This plot is based upon four data points that were collected at approximately the same heads and flows. GZA notes that it is not possible to perform a series of tests where the blade position or generator position is varied independently of all other variables. The intent of this plot was to demonstrate the relationship between generation engagement and efficiency and between blade position and efficiency. However, because of the limited data, these relationships could not be developed.

Appendix F contains an updated the levelized cost of energy analysis and a comparison of the W4e with a traditional turbine/ generator set. This update uses the limited amount of data developed during this limited test period. It is noted that the updated comparison of levelized costs may not be representative of the ultimate potential of the W4e turbine due to unanticipated difficulties encountered during prototype testing.

Table 2. Summary of Test Results

Run #	Flow (cfs)	Head (ft)	Power (Watts)	Turbine/ Generator Efficiency (%)	Water to Wire Efficiency (%)
1	3.28	8.21	170	7.5	7.1
2	3.64	10.08	300	9.6	9.2
3	4.12	13.80	480	10.0	9.5
4	4.61	16.86	750	11.4	10.9
5	5.10	20.02	1,050	12.1	11.5
6	5.12	20.11	920	10.6	10.0
7	5.11	20.11	950	10.9	10.4
8	5.12	20.11	900	10.3	9.8
9	5.05	18.75	1,220	15.2	14.5
10	6.06	23.59	1,680	13.9	13.2
11	6.55	27.73	2,020	13.1	12.5
12	6.40	30.10	2,075	12.7	12.1
13	6.48	28.80	2,100	13.3	12.6
14	7.12	34.29	2,550	12.3	11.7
15	7.14	34.05	2,700	13.1	12.5
16	4.59	9.06	75	2.1	2.0
17	4.37	10.83	530	13.2	12.6
18	5.43	16.89	1,100	14.2	13.5
19	6.40	24.93	1,900	14.1	13.4
20	6.85	28.19	2,350	14.4	13.7
21	6.36	14.36	1,350	17.5	16.6
22	6.69	18.68	1,775	16.8	15.9
23	7.04	22.89	2,200	16.1	15.3
24	11.08	2.12	230	11.6	11.0
25	10.62	11.77	2,250	21.3	20.2
26	10.84	14.31	2,800	21.3	20.3
27	10.14	22.65	3,550	18.3	17.4
28	7.00	14.76	1,650	18.9	17.9
29	7.74	20.27	2,600	19.6	18.6
30	8.40	26.26	3,600	19.3	18.3
31	9.21	26.77	3,000	14.4	13.7

Notes:

Water-to-wire efficiency calculation assumes a 99.6 percent rectifier efficiency and 95.5 percent inverter efficiency.

Figure 5 W4e Efficiency Curves

Notes: Dotted Lines indicate power estimate has been extrapolated.

Figure 6 W4e Power Curves

Figure 7 Efficiency vs. Generator and Blade Position

6.0 DISCUSSION

An evaluation of the accomplishment of testing goals and objectives was performed as follows.

Goal	Objective
1. Demonstrate System Integration	1a) Successfully install W4E turbine / generator on full-scale testing facility using simple “bolt on” methods
	1b) Successfully generate power which can be conditioned to grid-compatible energy
<u>Goal/ Objective Evaluation</u> The equipment can easily be integrated into an existing system. Minimal modifications (such as the use of an expansion or reduction section) may be required. 1a) The W4e was successfully installed at the Alden facility using simple “bolt on” procedures. Installation takes less than one half hour. The installation is impressively simple. 1b) The testing protocol called for producing wild AC and for accounting for the losses in conditioning by applying efficiency factors for conditioning equipment to the measured power values. Subsequent to the test, Blue Water identified a rectifier and inverter that can be used to condition power so that it is grid- compatible. Cut sheets for the rectifier and inverter are included in Appendix G . GZA applied the efficiency factors for generic conditioning equipment (total efficiency of 95 percent) to the measured power values. Electricity was successfully generated and commercial equipment is available which could be used to create grid-compatible energy.

2. Validate Assumptions / Predictions	2a) Generate power at a wide range of range of flows and heads, including low heads and low flows.
	2b) Generate power under open channel conditions
	2c) Demonstrate that efficiencies presented in the preliminary LCOE are achievable
	2d) Run turbine at high speeds without damage to system
<u>Goal/ Objective Evaluation</u> <p>The tests demonstrated that the W4e prototype testing validated several of the assumptions about the equipment but could not validate other assumptions. Due to equipment difficulties, fewer tests were performed than had been anticipated at the start of the test.</p> <p>2a) The testing w4e is capable of generating electricity over a wide range of heads (9 to 30 ft.) and flows (3 cfs to 12 cfs) which are appropriate for a machine intended for relatively low head/ low flow conditions.</p> <p>2b) During testing, the turbine was observed to turn and generate electricity during periods when flow in the penstock was under open channel conditions. Due to instrumentation configurations, effective measurement of generation under these conditions was not possible</p> <p>2c) Efficiencies calculated from the testing results were lower than anticipated. At this time, the W4e could not produce the efficiencies presented in the preliminary LCOE Analysis. It is anticipated that further vetting of the equipment after additional modifications may result the equipment performing at improved efficiencies.</p> <p>2d) The turbine was run at speeds up to approximately 500 rpm.</p>

3. Quantify Water-to-Wire Efficiency	3a) Determine power output from total turbine generator system through measurement of voltage and amperage.
	3b) Compute theoretical power under test conditions and compare to actual measured power output to compute efficiency.
	3c) Apply standard efficiency losses for power conditioning equipment to compute “water-to-wire” efficiency.
<p><u>Goal/ Objective Evaluation</u></p> <p>GZA calculated the water-to-wire efficiency for the W4e from the results of the turbine testing and generic power conditioning equipment efficiencies. The water to wire efficiencies were significantly lower than Blue Water and Walker Wellington anticipated (2 to 20 percent vs. 85 percent).</p> <p>3a) Blue Water attempted to measure power output using two different methods. The voltage produced by each of the three generators was measured over load bridges. The amperage for generator three was measured through a current transformer. The ammeter did not function correctly during the test. GZA independently measured both current and amperage independently using a clamp meter. The power calculated by GZA was compared with the power reported by Blue Water after each test. GZA’s estimates of power were within 12 percent of the power values reported by Blue Water. GZA’s direct measurements and calculated power are reported in Appendix E.</p> <p>3b) Theoretical power was calculated for each of the test conditions at which a run was performed using the Power Equation ($\text{Power} = \text{Head} \times \text{Flow} / 11.81$ where Power is in KW, Head is in feet and Flow is in cfs.) GZA divided the calculated power (from the testing) by the theoretical power to estimate the turbine-generator efficiency. Power results for all successful tests are listed in Table 2.</p> <p>3c) Standard efficiency losses for power conditioning equipment were applied to the calculated equipment efficiency to estimate water-to-wire efficiency. These standard efficiency losses were obtained from the cut sheets in Appendix G. An efficiency of 99.6 percent was used for the rectifier and an efficiency of 95.5 percent was used for the inverter. Turbine/ generator and water-to-wire efficiencies for all successful tests are listed in Table 2.</p>

<p>4. Obtain data for turbine efficiency optimization</p>	<p>4a) Optimize power output at various heads and flows through adjustments to generator engagement and blade position</p> <p>4b) Plot data to indicate relationships between efficiency and flow, head, generator engagement, and blade position</p>
<p><u>Goal/ Objective Evaluation</u></p> <p>This testing was partially successful in obtaining data for efficiency optimization. Due to equipment difficulties, fewer tests were performed than had been anticipated at the start of the test, reducing the available data needed to program operating curves of the unit. Additionally, the power output of the unit was lower than Blue Water and Walker Wellington had anticipated. It is anticipated that modifications will be made to future prototypes to increase the efficiency prior to programming operations curves.</p> <p>4a) Blue Water manually “optimized” power output at the heads and flows by adjusting the generator engagement and blade position (pitch control) during the testing.</p> <p>4b) GZA plotted the relationships between efficiency and flow and head in Figure 3. GZA plotted the relationship between power and flow for three different heads in Figure 4. Figure 4 demonstrates that for a given head, turbine efficiency increases as flow increases. The tests performed at 15 ft. of head indicate that the power begins to levels off at flows above 8 cfs. Figure 5 is a plot of generator position and blade position vs. efficiency.</p>	
<p>5. Identify unforeseen design and performance issues</p>	<p>5a) Record all test results, unanticipated difficulties, and conditions under which these occurred.</p>
<p><u>Goal/ Objective Evaluation</u></p> <p>The testing was highly effective in identifying unforeseen design and performance issues. Alden’s testing facility simulated an environment where the turbine is spun by water flowing under pressure. The testing environment revealed several design and fabrication issues which reduced efficiency and occasionally caused turbine stoppage. Blue Water was able to quickly address the design and fabrication issues.</p> <p>5a) All test results and unanticipated difficulties and conditions under which they occurred were documented. Recording these results and difficulties will aid Blue Water in reconciling design and fabrication issues and improving the performance of the W4e.</p>	

While the power output and the efficiency of the W4e were significantly lower than expected and fewer tests could be performed than had been expected, the test program was successful, in GZA's opinion. The test met many of the objectives and goals that were set prior to the test. Without a true testing environment (such as that available at the Alden facility) it would not have been possible for Blue Water and Walker Wellington to identify the deficiencies observed during the tests. The testing showed that demonstration of equipment operation under actual design conditions (i.e. in the water) is critical.

APPENDIX A
LIMITATIONS

LIMITATIONS

1. The observations reported in this report describe and document the testing of a turbine and were made under the conditions stated herein. The conclusions presented in the report were based solely on the services described therein, and not on scientific tasks or procedures beyond the scope of described services or the time and budgetary constraints imposed by Walker Wellington, LLC. (Client).
2. In preparing this report, GZA GeoEnvironmental, Inc. (GZA) has relied on certain information provided by the Client as well as Federal, state, and local officials and other parties referenced therein. GZA has also relied on certain information contained in the files of the Client, Federal, state, and local officials and other parties which were available to GZA at the time of report preparation. Although there may have been some degree of overlap in the information provided by these various sources, GZA did not attempt to independently verify the accuracy or completeness of all information reviewed or received during the course of this work.
3. In preparing this report, GZA GeoEnvironmental, Inc. (GZA) has relied on certain information provided by the Client. Specifically, GZA has relied upon the client for providing information about the proposed turbine including but not limited to information about efficiency, information about the range of flows that the turbine can operate and information about how the turbine can be integrated into an existing site.
4. In reviewing this Report, it should be realized that the reported efficiencies are based on observations of field conditions during the course of this study along with data made available to GZA by Alden Laboratories and by Blue Water Concepts. The observations of equipment performance reflects only the situation present at the specific moment in time the observations were made, under the specific conditions present. It may be necessary to reevaluate the efficiency of the equipment when subsequent phases of modification and improvement alter the performance of the equipment.
5. Cost estimates prepared for report are approximate only and meant for planning purposes by the Client. Actual costs of design and construction may vary based on conditions encountered, economic circumstances, and final scope of work. In preparing cost estimates, GZA has relied upon typical unit costs and historic data which may vary over time and between projects.
6. This report has been prepared for the use of the Client for specific application to the conceptual development of the W4e turbine in accordance with generally accepted engineering practices. No other warranty, express or implied, is made.

APPENDIX B
RESUMES AND QUALIFICATIONS

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Rtlpelr cūlp/Ej cti g."Kuy lej "TlkgT "J { f tqnlpgvle "Hgcukldk { "Uwf { . "Kuy lej . "O C0 "Vj g"qy pgt"qh" c"o clqt" lpf wutkrlheklk { "qp"vj g"Kuy lej "TlkgT"y cu'lpvgtgungf "lp"vj g'r tqf wvklp"qh"j { f tqr qy gt"cv'ku'ukg0 "I \ C"r tqf wegf "c" ðhewl"mry uö"cpn'uku'y j lej "lpf lecvgf "vj cv'tcf klqpnclj { f tqr qy gt"y cu'pqv"ci qqf "qr vqp"cv"vj g'ukg0 "J { f tqnlpgvle" r qy gt. "qp"vj g"q'vj gt"j cpf . "y cu"lwf i gf "r qvqvlcm "hgcukldg0 "I \ C"eqo r rvgf "c"hgcukldk { "uwf { "y j lej "mqnqf"cv" xctkqu"eqphl wcvkpu"cpf "j { f tqnlpgvle"i gpgtcvqp"gs wkr o gpw0 "Rqy gt"cpf "gpgti { "r tqf wvklp"guno cvgu'y gtg"o cf g" dcugf "qp"vj g"j { f tqnqj { "qh"vj g"tlkgT"cpf "gzr gevdf "xgmeklgu0 "C"FE"i gpgtcvqt"cpf "f ggr/egni'cwgT { "wqtci g'u' uvg0 " y cu'tgego o gpf gf O'Rgo kwlp i "pggf u'cpf "guno cvgf "equu'cpf "dgpghku'y gtg" f kuwuwgf O'

Rt kpelr culp/Ej cti g" ("Rt qlgev" O cpci gt. "Uqwj y qt yj " J { f tqggevte k" Rt qlgev" T guqwt eg" Cuguo gpv" cpf " Hgcukdkrk { "Uwf { "Vwt pgt u Hcmu" O C0" I \ C"y cu'cungf "d { "Uqwj y qt yj "vq"cuukw/Uqwj y qt yj "kp"r tgr ct kpi "c"i tcpv' cr r decvqp"vq"yj g" O VE" hqt "yj g'r wtr qug"qh'tgj cdkrkcvpi "yj gk"j { f tqr qy gt "ucvqp"qh'h'qh'yj g"Vwt pgt u Hcmu"Rqy gt" Ecpnf" I \ C'r tgr ct gf "c'uweguu hwi' tcpv'cr r decvqp0" I \ C'au' hgcukdkrk { "uwf { "cuugugf "yj g'dgpghku'qh'kpucn kpi "pgy " i pggtcvpi " gs wkr o gpv0" " Vj g" uwf { " kpenf gf " kpxguki cvkpu" qh"y cvgt" tki j w" cpf " Uqwj y qt yj au" y cvgt" gzej cpi g" ci tggo gpv'cpf "c'r gpuxqenilpur gevqp0"C'r tghgtgf "cngtpcvkxg'y cu'ugrevgf "cpf " I \ C'r tgr ct gf "c'ugeqpf "O VE"i' tcpv' cr r decvqp0"Vj g'f guki p"cpf "eqpntwvqp"i' tcpv'y cu'cy ct gf gf. "dw'hqt" dwukpuw'tcguqpu"Uqwj y qt yj "cungf " I \ C"vq" cuuguu' yj g'dgpghku'qh'tgj cdkrkcvqp'qh'yj g'gzkukpi "gs wkr o gpv0"Vj ku'uwf { "y cu'tgegpfw' "eqo r rvgf O'

Rtlpekr cñlp/Ej cti g' 'Rt qlgev'O cpci gt. F qf i gxlng'F co 'Rt qlgev'Tguwt eg'Cuguo gpv.'Hgcukdkrk{'Uwff {'čpf "' HGTE'"Hkpi u'"Cwgdqt q."O C"F qf i g'O kni'Tgcm{'ku'kpwtgungf "kp"r wtuwpi "j {f tqr qy g" f gxnqr o gpv'c v'j gk' gzkukpi "f co "qp"j g'Vgp'O kng'Tkgt0Vj g'r tqlgev'y kni'penwf g'j g'eqpuv wdkap'qhi'c'pgy "kp'vng'ut wewt g."r gpuvqem" cpf "r qy gtj qwug'cu'y gni'cu'y g'kpucm'wkp'qhi'"pgy "j {f tqgngtke"gs wkr o gpv'O t0Eqz"o cpci gf "j g'r tg/hgcukdkrk{' cpf 'hgcukdkrk{'uwff ku'cpf'ugtxgf'cu'Rtlpekr cñlp/Ej cti g'ht'r gthqto kpi "j g'loklci HGTE'"Hkpi u0'"

"

Rt qlgev'O cpci gt."Emeni'Vqy gt "Rræg"J { f tqrgewtle "Rt qlgev'Hgcukdkk\ "Uwfw { "cpf "Rt gño kþct { "F guki p." O c{ pctf."O C0"C"r tqlgev"q"tgj cdkkcvg"cpf "wri tcf g"cpq/hwpevqkplpi "j { ftqrgewtle"i gpqctvqpp"heekdkk\ "cv'cp" j kwqtle"o kmukg"qp"vj g'Cuucdgv'Tkxgt0"O t0Eqz"o cpci gf "vj g'r tgr ctcvqpp"qh'c'r tg/hgcukdkk\ "uwfw { "cpf "y qtnqf "y kj" vj g'Qy pgt"q"ugewtg"c"hgucdkdkk\ "uwfw { "i tcvp'ht qo "vj g'O cuucej wugwu"Vgej pqrqi { "Eqmcdqctvkg"o VE-0"O t0Eqz" vj gp"o cpci gf "I \ C\ai'r tgr ctcvqpp"qh'c'hwai'Hgcukdkk\ "Uwfw { . "kpf lecvkpi "vj cv'c'etquw/hqy "wtdlpg"kpucncvqpp"eqwf" r tqxf g'w'r "q"522mY "qh'r qy gt"r tqf wevqpp"cv'vj g'ukg0"Vj g'uwfw { "y cu'uwdo kwgf "q"vj g'O VE"cpf "wugf "kp"vj g'Qy pgt\ai" y kppkpi "cr r decvqpp"ht"i"c"F guki p"cpf "Eqpwtwevqpp"i tcvp0"I \ C"vj gp"r tgr ctf g"c'r tgrño kþct { "F guki p"ht"vj g'r tqf qugf" r tqlgev."kpenw kpi "r rcpu"cpf "ur gekhecvkpu0" "I \ C"cuq"r tgr ctf g"c"Rt gño kþct { "Rgt0 k" cr r decvqpp"y j kej "y cu" uwdo kwgf "q"HGTE"cpf "tguwngf "kp"HGTE"i tcvkpi "vj g'r tgrño kþct { "r gto k0'

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Rkpkrculp/Ejctig.Yqtegwgt.Ycwt.Vtgcwo gpvRrcp/Kp/Nlpg'Eqpf wk/J {ftqrqygt'I gpgtcvkp'Hgcukldk ('Uwf {'J qf gp.'O C'''C'r tqlgcv'q'cuuguv'y g'hgcukldk ('qh'c'j {ftqngwt'k'i gpgtcvkp'r tqlgcv'p/rkp'lp'cp'gzknkpi "tcy 'y cwt'eqpf wk/cv'y g'Ek' a'y cwt'vgcwo gpvr rcp'0''

"

Rtpepr cnp/Ej cti g." Pqt vj co rwp." Y cvgt " Vt gco gpv' Rcpv' Kp/Npg" Eqpf wks' J { f t q r qy gt " I gpgtcvqp" Hgcukdkks' 'Uwf { . 'Pqt vj co rwp.' O C'''C'r tqlgvev'q'cuugu'v' g'Hgcukdkks' 'qh'c'j' { f tqrgvev'le'i gpgtcvqp'r tqlgvev'p/ rpg'kp'cp'gzknkpi "tcy "y cvgt"eqpf wks'cv'v'j g'Eks'au'y cvgt'vtgco gpv'r rcpv'0"I gpgtcvqt'y qwf "tgr nceg'cp'gzknkpi " Rtgumt g'Tgf wevqp'Xcng'cv'v'j g'r rcpv'0

Rtqlgev'O cpci gt.'Dremwpg'Xcng{ 'Xlksqt u'Egpgt 'J { f t qngvte' Hgcukdkk{ 'Uwlf { . 'Y qt egugt. 'O C' "C" r tqlgev'v'cuugu'v'j g'hcukdkk{ 'qh'c'uo cni'j { f tqr qy gt' i gpgtcvqp' r tqlgev'v' dg'eqpwtvegf "cu'r ctv'qh'v'j g'xkksqtu' egpgt'dgkpi 'eqpwtvegf "qp'v'j g'Dremwpg'Tkxgt0"

Rtqlgev'O cpci gt.'O wugwo "qh'Uelgpeg"J { f t qnlpgvle' Tguwt eg' Cuguo gpv. 'Dquqp. 'O C' "Cu' r ctv' qh' ku' uwucpckdkk{ 'I' i tggp' gpgti { 'lpkckvkg. 'v'j g' O wugwo "qh'Uelgpeg"lp' Dquqp'cungf 'I \ C' "v'gxcnecv'v'j g' r qvgpckn' hqt" i gpgtcvqp'qh'j { f t qnlpgvle' r qy gt' hqt "v'j g' hny 'qh'v'j g' Ej ctng' Tkxgt'v'j tqwi j "v'j g' qnf "unwleg c { u'wpf gt' ku' r ctnkpi " i cctci g' utwewt g' O t0Eqz' o cf g' hgrf' o gcuwtgo gpw'qh'ewtgpv'xgngkx{ 'cpf' ecnecwv' r qy gt' cpf' gpgti { 'r qvgpckn' " "

Rtqlgev'O cpci gt.'Dgpg glo /I kldc' Rwo r gf 'Uqtci g' Wp/Y cvgt lpi 'Rtqlgev'Kpxgumi cvkpu' O cugpc. 'P [0" C' " r tqlgev'v'cuugu'v'j g'P gy "I qtni'Rqy gt' Cwj qtk{ 'lp'eqpuk' gt lpi "v'j g' lo r rdecvqp'qh'c' r tqr qugf "r tqi tco "v'q'wp/y cvgt" v'j g' r wo r gf "uqtci g' i gpgtcvqp' hckkx{ 'hqt' o ckpvcpeg' cpf' tgr ckt0" P [RC' u' r tqr qucn' ku' v'q' f tclp' xktwcm{ 'cni'qh'v'j g' W' r gt' Tguwt xqk' cpf' eqo r ngv' f gy cvgt' c' eqpetgv/ rkp' g' xgvckn' i' ch'qh' o qtg'v'j cp' 3.222' hgv'lp' f gr v'j . 'cu' y gni'cu' c' j qtk' qp'cn' wppgn' ugecvqp' cpf' hqt' ugg' n' kpgf "r gpucqen' wdgu0" I \ C' eqpf vev'f "cpn' ugu' v'q' kpxgumi cvg' r qvgpckn' lo r ceu' qh' wpcmpcgf "j gcf "eqpf kkp' u' qp' eqpetgv' cpf "ugg' n' kpgtu' cpf "uwi i gungf "r qvgpckn' o gv' qf qm' k' u' hqt" o qpkqtkpi "cpf" o kki cvkpu0" I \ C' kpuv'cgf "cpf" o qpkqtkf "kpu'w' gpvcvqp' cv'v'j g' uksg' f wtkpi "hqt' uweeguuksg' wp/ y cvgt lpi u' y j lej "qewt' gf' y kj "pq' f co ci g' v'q' v'j g' r gpucqen' " "

Rtqlgev'O cpci gt.'Tqdg'v' O qugu' Rqy gt' F co 'I tqw lpi 'Kpxgumi cvkpu' cpf 'F guli p. 'O cugpc. 'P [0" C' " r tqlgev'v' kpxgumi cvg' ugg' ci g' cpf' "w' r h'lp' v'j g' hq'wpf cvkqp' qh'v'j g' Tqdg'v' O qugu' Rqy gt' F co . 'c' n'eti g' j { f tqr qy gt' hckkx{ 'qy pgf" d { "v'j g' P gy "I qtni'Rqy gt' Cwj qtk{ "P [RC' +qp' v'j g' U0' Ncy tpeg' Tkxgt0" Vj g' f co "ku' qp'g/ j ch'qh' cp' kpytpcvkpcn' j { f tqr qy gt' i gpgtcvqp' r tqlgev'v'j lej "ur cpu' v'j g' WU0Ecpfc' d' dqt' gt0" I \ C' t'gxlgy gf "gzknkpi "kph'qto cvkqp' cpf' f cv" r tqxkf gf "d { "P [RC' "v'q' f g' xgnr "cp' wpf gtucv'p' lpi "qh' r quukdg' f co "uchv'f "kuu'gu' etgcvgf "d { "h'q'wpf cvkqp' ugg' ci g' lp' c" uqndrg' h'q'wpf cvkqp' r { gt' wpf gt' v'j g' eqpetgv' f co "utwewt g' O I \ C' f g' xgnr gf "cpf' r t'gugp' v'f "c' r t'gko kpc' t { "r tqi tco "hqt" cf f t'guukpi "v'j g' ugg' ci g' kuug' d { "o gcpu' qh' i tqw lpi "v'j g' uqndrg' r { gt' v'j tqwi j "gzknkpi "w' r h'lp' t'gkgh' y gmu0" I \ C' ku' p'qy " f g' xgnr lpi "h'p'cn' i tqw lpi "r n'pu' cpf' ur gekh'ecv'kpu' " " "

Rt lpekr cnlp/Ej cti g. 'O cucej wugwu'Y cvgt 'Tguwt egu' Cwj qtk{ 'J { f tqr qy gt' Rtqlgev'F g' xgnr o gpv0" I \ C' j' cu' dggp' eqpwtcev'f "v'q' cuugu'v'j g' Cwj qtk{ 'y kj "f g' xgnr lpi "j { f tqr qy gt' i gpgtcvqp' cv'xctk' qwu' uksgu0' "

FCO 'UCHGV' ('F GUL P "

Rtqlgev'O cpci gt.'Rqpn' r qci 'Rqpf 'F co 'Tgj cdkkscvqp. 'Ecpvqp. 'O C' "O cpci gf "v'j g' v'q'cn' r tqlgev'v' e { eng' hqt' v'j g' "tgj cdkkscvqp" qh'v'j g' FET/qy pgf "Rqpn' r qci "Rqpf 'F co . "y kj "c" ueqr g' qh' y qtn' l'pen' f lpi "Rj cug' K' K'ur gev'kqp. " Go gti gpe { "Cev'kqp" Rrnp' r tgr ctcvqp. "Rj cug' K' Gpi kpggt lpi "cpf "Cngt'pcv'kxg' Cpcn' uku. "H'p'cn' F guli p. "cpf "Rgto k' Cr r rdecvqp' Rtgr ctcvqp' Rtqlgev'v'ksg' r t'gugp' v'f "c' p'wo dgt' qh' e'j cngpi gu' f w'g' v'q' h'qecvqp' y kj lp' cp' CE'GE' cpf' r t'gugpeg' qh' o wnk' ng' gpf cpi gt gf "ur geku' lp' v'j g' r qpf "cpf' cv'v'j g' f co "uksg0' "

Rtqlgev'O cpci gt.'TRt lpekr cnlp/Ej cti g. 'W' r gt' O { u'ke' Ncng' F co 'Tgj cdkkscvqp. 'Ctn' lpi v'p' IO g' h' t' f . 'O C' "C' " r tqlgev'v' f guli p' cpf' "r gto k' v'j g' t'gj cdkkscvqp" qh'v'j g' FET/qy pgf "W' r gt' O { u'ke' Ncng' F co 0" F guli p' o wu' cf f t'guu' kpc' f gs wcv'g' ur kny c { "ecr cek{ . 'kpu' w' h'ekgp' v'ur' g' u'cdkx{ . "cpf' r qvgpckn' "rks wgh'cdng' uqni'eqpf kkp' u0' "

Rtqlgev'O cpci gt.'Wp'kpxkng' Rqpf 'F co 'Gzr gf ksg' K'p'vgtlo 'Tgr ckt u' J qf gp. 'O C' "C' " r tqlgev'v' k'pur gev'v'j g' f co " cpf "f guli p' k'p'vgtlo "tgr ckt u' v'q' eqtt' gev' uqto /lp' vev'f "f co ci g' v'q' v'j g' utwewt g0" F gvt' k' t'cvkqp' v'q' v'j g' EOR' ur kny c { " eqpf vku' j' cf "ng'f "v'q' c' "quu' qh' o cvgt' kn' i' h'qto "v'j g' f co "cpf "v'j g' h'qto cvkqp' qh' c' ukpn' qng' lp' v'j g' t'qcf "qp' v'q' qh' v'j g' f co 0" I \ C' f guli pgf "cp' k'p'vgtlo "tgr ckt u' r tqlgev'v' rkp' g' v'j g' g' zknkpi "eqpf vku' y kj "n'eti g' J FRG' r k' gu' cpf' i tqw' lp' r rneg0' Y cvgt' cpf' "tcl' h'le' eqpwt' qnly gt g' ng { "kuu'gu0' Rtqlgev'v' cu' uweeguuh'w' n' "lo r ngo gpv'f "qp' v'ko g' cpf' wpf gt' dw' f i g' v0' "

Rtqlgev'O cpci gt.'F co 'Uchv'f 'Go gti gpe { 'Tgur qpug. 'Ucv'g/ y k' f' O cucej wugwu' "K' Qev'qdg' 4227" cpf "ci ck' lp' " O ctej "4228. "j g' x { 'tcl'pu' ecwug' go gti gpe { "ukw'cvkpu' cv' o cp { "f co u' v'j tqwi j qw' O cucej wugwu0' C' v'j g' t'gs wgu' qh' v'j g' " O cucej wugwu' Qh' h'eg' qh' F co 'Uchv'f . 'O t0Eqz' r gtuqpcn' { 't'gur qpf gf "v'q' v'j g' W' r gt' H'lp' v' Rqpf 'F co 'lp' V { pi udt' q' w' j . " O C' "v'q' r tqxkf g' f co "gpi kpggt lpi "cf xleg' v'q' v'j g' k'pek' gp' v'eqo o cpf gt' f wtkpi "pgct/ qxgt' v'q' r lpi "g' xgpv0' "F wtkpi "v'j g' " O ctej "4228" g' xgpv. "O t0Eqz' t'geqo o gpf gf . "f guli pgf . "cpf "q' xgtucy "eqpwt' vev'kqp' qh' cp' go gti gpe { "d { r cu' e'j cpgn' v'q' "

j gr "r t g x g p v" q x g t q r r k p i "q h" y j g" f c o 0" "H q m y k p i "y j g" Q e v d g t "4227" g x g p u "O t 0" E q z" o c p c i g f "I \ C a i" g h t w u" v q" t c r k f n" "k p u r g e v" o q t g" y j c p" y q" f q l g p" r q q t" q t" w p u c h g" e q p f k k q p u" f c o u" c u" r c t v" q h" y j g" q x g t c m" g o g t i g p e{ "k p u r g e v k q p" g h t q t v" q t f g t g f" d{ "y j g" I q x g t p q t 0"

Rt qlgev'O cpci gt. 'FET/Qy pgf 'Fco 'Kpur gevqpu'Ucvy/y kf g'O cucej wugwu' "C" r tqlgev'vq' kpur gev'82' fco u' qy pgf "d{ "y j g" E q o o q p y g c n j "q h" O c u c e j w u g w u" y t q w i j q w v" y j g" U c v g 0" R t q l g e v" k p e n f g f "c" x g t{ "c i i t g u k x g" v l o g r k p g" h q t" y j g" u w d o k u k q p" q h" y j g" k p u r g e v k q p" e j g e m k u u. "y j k e j "y c u" o g v d{ "I \ C 0" O t 0" E q z" o c p c i g f "c" r t q l g e v" v g c o "q h" o q t g" y j c p" c" f q l g p" I \ C "g p i k p g g t u" y j q" k p u r g e v g f" o w n k r g" f c o u" c p f" r t q f w e g f" R j c u g" K k p u r g e v k q p" T g r q t w u" w u l p i "y j g" p g y " h q t o c v o c p f c v g f" d{ "y j g" O c u c e j w u g w u" Q h k e g" q h" F c o "U c h g v{ O"

Rt qlgev'O cpci gt. 'Hqmy /Wr 'Kpur gevqpu'qhiRqqt'cpf 'Wpuchg'Fco u'Ucvy/y kf g'O cucej wugwu' "C" r tqlgev'vq' r g h q t o "8/ o q p y "h q m y /w r "k p u r g e v k q p u" q p" 48" f c o u" y j t q w i j q w v" y j g" E q o o q p y g c n j "y j k e j "j c f" r t g x k q w u" d g g p" e r c u k k h g f" c u" k p" o R q q t o" q t" o W p u c h g o" e q p f k k q p 0" "K p u r g e v k q p u" g x c n c v g f" e j c p i g u" k p" e q p f k k q p" u l p e g" y j g" r t g x k q w u" k p u r g e v k q p 0" Y j g t g" y c t t c p y g f. "I \ C" o c f g" t g e q o o g p f c v k p u" h q t" k o o g f k c v g" c e v k q p" l w f i g f" p g e g u c t{ "v q" r t q v g e v" y j g" r w d r e" u c h g v{ O" I \ C" r t g r c t g f" c" o c v k z" y j k e j "r t k t k k k g f" c e v k p u" c v y j g" k u g f" f c o 0" V j g" o c v k z" y c u" w u g f" d{ "y j g" O C" Q h k e g" q h" F c o "U c h g v{ v q" k u u g" F c o "U c h g v{ Q t f g t u" t g s w k l p i "e q t t g e v k x g" c e v k p" c v y j g" f c o u 0"

Rt qlgev'O cpci gt. 'Rqpnrc qci 'Rqpf 'Fco 'Kpur gevqpu'cpf 'GCR'Ecwpqp. 'O C' "C" r tqlgev'vq' r t q f w e g" c" Rj cug'K' k p u r g e v k q p" q h" y j g" f c o 0" D c u g f" q p" y j g" t g e q o o g p f c v k p u" e q p v c l p g f" k p" y j g" R j c u g" K t g r q t v" y j g" Q y p g t. "y j g" O C" F g r v l q h" E q p u g t x c v k p" c p f" T g e t g c v k p. "e q o o k u k p p g f" I \ C" v q" r t q f w e g" c" R j c u g" K K G p i k p g g t k p i "G x c n c v k p" T g r q t w u" O t 0" E q z" o c p c i g f" y j k u" g h t q t v" c p f" y c u" y j g" r t k p e k c n" c w j q t" q h" y j g" R j c u g" K K t g r q t v" y j k e j "k p e n f g f" c" u g v" q h" e q p e g r v r g x g n i" t g j c d k k c v k p" r n p u 0" C n q" d c u g f" I \ C" t g e q o o g p f c v k p u. "F E T" e q p t c e v g f" y k j "I \ C" v q" r t q f w e g" c p" G o g t i g p e{ "C e v k p" R n p" h q t" y j g" f c o 0" V j g" r n p" y c u" r t q f w e g f" c p f" u w d o k w g f" v q" E c p w p" G o g t i g p e{ "O c p c i g t u" c p f" O G O C 0"

Rt qlgev'O cpci gt. 'Y j kgj cniTgugt xqk'Fco. 'J qrnlpqp. 'O C' "Rj cug'K' kpur gevqpu'cpf 'kpxguki c v k p u. 'kpenf kpi " d q t k p i u" c p f" j{ f t c w l e" u w f l g u. "c v y j g" h c k g f" Y j k g j c n i T g u g t x q k" F c o. "y j k e j" k u" o c p c i g f" d{ "y j g" O c u c e j w u g w u" F g r v l q h" E q p u g t x c v k p" c p f" T g e t g c v k p 0" F g x g n r g f" e q p e g r w e n i c n g t p c v k x g u" h q t" t g r c k" c p f" r t g u g p y g f" v q" q y p g t" c p f" x e t k q w u" u c n g j q r f g t u 0" C h g t" c e j k x k p i "e q p u g p u u" q p" r t g h t t g f" c n g t p c v k x g. "e q o r r g v g f" c p f" u w d o k w g f" o w n k r g" r g t o k v" c r r n e c v k p u" c p f" c w g p f g f" r w d r e" o g g v k p i u" k p" u w r r q t v" q h" y j g" c r r n e c v k p u 0" E q o r r g v g f" h k p e n f g u k i p" r n p u" c p f" u r g e k h e c v k p u" h q t" t g r c k u" c p f" k o r t q x g o g p u" v q" y j g" f c o "c p f" w r u t g c o" e q h t g f c o 0" O c p c i g f" t g f g u k i p" g h t q t w u" v q" t g u r q p f" v q" t g s w u v" h q o" e q o o w p k v{ "v q" r t g u g t x g" j k n q t l e" i c v g j q w u g" u t w e w t g 0" R t q x k f g f" F E T" y k j "e q p u t w e v k p" q x g t u k i j v u g t x l e g u" f w l p i "r t q l g e v" k o r r g o g p v c v k p" c p f" y j t q w i j "r t q l g e v" e q o r r g v k p 0"

Rt qlgev'O cpci gt. 'Dwemg{ 'F wpwqp'Ncng'Fco. 'Dgengv. 'O C' "Kpur gevqpu'cpf 'tgj cdkkxcv k p" q h" c' h c k k p i "fco "qy pgf " d{ "y j g" E q o o q p y g c n j "q h" O c u c e j w u g w u" V j g" F g r c t v g p v" q h" E q p u g t x c v k p" c p f" T g e t g c v k p" g p i c i g f" I \ C" v q" r t q x k f g" k p u r g e v k q p. "f g u k i p u. "r g t o k v" c r r n e c v k p u. "c p f" e q p u t w e v k p" c u k u c p e g" h q t" y j g" g z r g f k g f" t g e q p u t w e v k p" q h" y j k u" f c o "k p" Q e v d g t" O q w p c l p" U c v g" R c t n 0" F g x g n r g f" c p" k p p q x c v k x g" c r r t q c e j "v q" t g r c k" f g u k i p" y j k e j "k u" g u k o c v g f" v q" j c x g" u c x g f" y j g" q y p g t" o q t g" y j c p" &382.2220" "F g u k i p g f" t g r c k u. "r t g r c t g f" v e j p l e c n" u r g e k h e c v k p u. "c p f" o c p c i g f" y j g" r g t o k v" c r r n e c v k p" r t q e g u 0" R t q x k f g f" e q p u t w e v k p" r j c u g" u g t x l e g u" f w l p i "r t q l g e v" k o r r g o g p v c v k p" c p f" y j t q w i j "r t q l g e v" e q o r r g v k p 0" R t g r c t g f" c p f" r t g u g p y g f" r c r g t" f g v c k k p i "r t q l g e v" c v C U F U Q" p c v k p c n i F c o "U c h g v{ E q p h g t g p e g 0"

Rt qlgev'O cpci gt. 'Gagxgp' Rqqt 'I' Wpuchg'Fco 'Kpur gevqpu'Uqwj gcugt p' 'O C' "Kpur gevqpu'cpf 'eqpf k k q p" x g t k h e c v k p" q h" g r g x g p" f c o "r t g x k q w u" h q w p f" v q" d g" k p" o r q q t o" q t" o w p u c h g o" e q p f k k q p 0" V j g" O C" Q h k e g" q h" F c o "U c h g v{ " g p i c i g f" I \ C" v q" k p u r g e v" c p f" r t g r c t g f" k p u r g e v k q p" t g r q t w u" h q t" f c o u" q h" u r g e k c n" e q p e g t p 0" F c o u" y j g" k p u r g e v g f" q p" c" t c r k f" u e j g f w g" c p f" k p u r g e v k q p" t g r q t w u" r t g r c t g f" c u" r g t" Q h k e g" q h" F c o "U c h g v{ H q t o c v 0"

Rt qlgev'O cpci gt. 'Cuj qncp'Fco 'Xcnwcv k p'Uwf{. 'Cuj qncp. 'P[0" "C" r tqlgev'w p f g t w n g p" h q t" y j g" P[E" F G R" v q" g u v c d r k u j "y j g" e w t g p v" x c n g" q h" y j g" C u j q n c p" F c o "k p e n f k p i "y j g" Q r k x g" D t k f i g" F c o "i t c x k v{ "u t w e w t g" c p f" c n i" g c t v j h n i" f k n g u" u w t t q w p f k p i "y j g" t g u g t x q k t" c p f" c p e k n c t{ "u t w e w t g u" h q t" r w r q u g u" q h" v z" x c n w c v k p 0" O c p c i g f" y j g" s w c p v k v{ "g u k o c v g" c p f" e q p f k k q p" c u g u u o g p v r q t v k p" q h" y j g" y j q t n l y j k e j "k p x q r k x g" o c n k p i "k p f g r g p f g p v" g u k o c v g u" q h" y j g" o c v g t k c n i" s w c p v k l g u" k p" y j g" u t w e w t g u" c p f" c u g u k p i "y j g" e w t g p v" e q p f k k q p" q h" g c e j "u t w e w t g 0"

Rtqlgev'Gpi lpggt.'Y cvgt'Uwr rñ'Fco u'Y guv'qhlJ wf uqp.'P gy '[qtnlEk{ 'Y cvgt'Uwr rñ'U'ungo "'Uchgv'qhf'co u'" Rj cug" Kkxgrñ'kpur gevqap" r tqlgev' hqt" P [E" F gr v' qh' Gpxktqpo gpvñ' Rtq'gevqap0" " Kpñf gf " Qrkxg" Dtkf i g" F co " *Cuj qñep+ "I kldqc" F co . "O gttko cp" F co . "P gxgtulpmi' F co . "F qy puxkmg" F co . " (" Ecpgpuxkmg" F co 0' "Tgugtqxktu" uwr rñ " ; 2' "qh'P [Eñ' y cvgt' uwr rñ' 0' "Rctv' qh' kpur gevqap" vgo " hqt" f co u' "cm' Ncti g. "J ki j " J c| ctf " utwewtgu+ " cpf " cuuqekcvg' y cvgt' eqpvtqn' utwewtgu' Ugtxgf " cu' I \ C' tgr tguvpcvkg' f wtkpi " f kxkpi " cpf " TQX" wpf gty cvgt' kpur gevqapu0" F guki pgf " r tgrko kpc{ " i gqvgj plecti' dqtłpi " cpf " kpwtwo gpvcvqap" r rcp0' " F gxgnr gf " rcdqtcvqt{ " vgułpi " r tqi tco " hqt" eqpetgvg" cpf " tqeni' uco r ngu' Rgthqto gf " ucdkxk{ " cpcñ' uku' qh' i tckxk{ " utwewtgu. " kpnf kpi " I kldqc" F co " cpf " Qrkxg" Dtkf i g' F co . " włpi " o gvj qf qmji kgu' r tguetkdgf " d{ " WUDT. " WUCEG. " cpf " HGTE0" kpgtcevgt' y kj " yj g' Ekx' qh' P gy '[qtnl' gpi kpggtu' dqj " cvj gcf s vctvgtu' cpf " kpi' yj g' hkgf " v' eqo r kpg' hku' eqo r tgi gpukxg' ksgtcwgt' t' gxlgy " qh' r tqlgev0" Rtgr ctgf " uki pñkcpv" r qtvkpu' qh' eqo r tgi gpukxg' kpur gevqap" tgr qtu. " kpnf kpi " kpur gevqap" uwo o ctkgu. " utwewtñ' cpcñ' ugu. " eqpwtvewkqap" j kxktłgu. " cpf " t' geqo o gpf cvkpu0 Rtgr ctgf " eqpegr wcnf' guki pu' cpf " equv' guko cvgu' hqt" f co " tgi cdkkcvkqap0" "

Rtqlgev'Gpi lpggt.'I kldqc'Fco 'Kpvtko 'Ur kny c{ 'Tgr ckt' Rtqlgev.'I kldqc.'P [0" C" r tqlgev' v' tgr ckt' ncti g' gtqulqp" j qngu' cv' yj g' vq' qh' yj g' o cuqpt { " qxgthny " r qtvkpu' qh' I kldqc' F co 0' F guki pgf " kpgtko " tgr cktu' v' I kldqc' F co " Ur kny c{ " F kxj cti g' Ej cpgn " kpnf kpi " o cuu' eqpetgvg' hknkpi " qh' o clqt " gtqulqp" j qngu' cv' vq' qh' f co " cpf " t' gkphqtegf " eqpetgvg" ej cpgnñ' cxkpi 0' Rgthqto gf " uwtxgf " v' cuugui' g' v' qh' f co ci g' cpf " r tqxkf g' dcuku' hqt" f guki p0' Cr r kxgf " hqt" cpf " ugewt gf " g' r gf kxgf " r gto ku' hqo " P [F GE " hqt " g' zgewkqap" qh' y qtn0' " Rtgr ctgf " ur gekñkcvkpu" cpf " gpi kpggtu' equv' guko cvg0" F guki p' y qtnleqo r rvgf " qp' ceegrtcvgt' u' ej gf wgo "

Rtqlgev' O cpci gt. 'Y kny 'O kñf co . 'Uqwj 'Ngg. 'O C0' C" r tqlgev' v' kpur gev' cpf " kpxguñi cvg' yj g' uvcv' qh' c' twp/ qh' yj g' t' kxgt " o cuqpt { " o kñf co . " f gxgnr " eqpegr wcn' cngtpcvkxgu' hqt" pggf gf " tgr cktu. " yj gp' f guki p' cpf " ko r ngo gpv' yj g' r tqlgev0" F guki pgf " g' r r tcvkqap" r tqi tco " cpf " cevgt' " cu' hkgf " gpi kpggt' f wtkpi " i gqvgj plecti' g' r r tcvkqap" r j cug' qh' yj g' r tqlgev0" Ugtxgf " cu' hkgf " gpi kpggt' cpf " nji i gf " dqtłpi u' yj tqwi j " f co " hqto " c' h' kxkpi " dcti g' kpi' yj g' ko r qwpf o gpv' cpf " kpuvngf " xldtcvki " y k' g' r k' q' go gvgu0' " Rgthqto gf " i tckxk{ " ucdkxk{ " cpcñ' uku' cu' r gt' HGTE " tgs vktgo gpw0' " Y tqvg" uki pñkcpv" r qtvkpu' qh' h' kpcñ' kpur gevqap" tgr qtv' cpf " f gxgnr gf " equv' guko cvgu' hqt" eqpegr wcnf' f guki p' cngtpcvkxgu0" F gxgnr gf " cpf " uwo kvgf " v' enkgpv. " c' o wñk { gct' r rcp' hqt" ko r ngo gpvki " tgi cdkkcvkqap" r tqi tco 0' "

Rtgr ctgf " f guki pu. " v' g' j plecti' ur gekñkcvkpu. " cpf " eqpvtcev' f qewo gpw' hqt" o wñk { gct' tgr ckt' cpf " ko r tqxgo gpv' r tqlgev0" Uwo kvgf " cr r r tcvkqap" hqt" cpf " qdvcłpgf " r gto ku' pggf gf " hqt" f co " tgr cktu0" F guki pgf " Rj cug" 3' r tqi tco " v' tgr ckt' t' kxgt " qwwv' utwewtgu= Rj cug" 4' r tqi tco " v' dwtguu' cdwo gpv' cpf " cvz kktct { " ur kny c{ = Rj cug" 5' r tqi tco " v' h' reg' dwtguugu " y kj " uqpg " h' c' f g= Rj cug" 6' r tqi tco " v' f t' kñ' cpf " kpucñi' cuukxg' v' g' f qy p' cpej qtu= cpf " Rj cug" 7' o cuqpt { " tgr qkvpki " r tqi tco 0' " Tgeqo o gpf gf " r qvgpñ' eqpvtcevqtu' v' Qy pgt' cpf " cuukngf " Qy pgt' kpi " gxcñvki " dñf u' hqt" dqj " Rj cugu0" O cpci gf " I \ Cñ' eqpwtvewkqap" qdugtxcvqap" r tqi tco " cpf " r tgr ctgf " h' kpcñ' tgr qtv' w' qp' uweeguihñ' r tqlgev' eqpwtvewkqap0' "

Rtqlgev' O cpci gt. " Ncnf c' F co . " Mwf tgo wñj " Kqap" Qtg' O kpg. " Mctpcvñ. " Kpf k0' " C" r tqlgev' v' kpxguñi cvg' i gqvgj plecti' cpf " y cvgt' t' guqwtgu' r tqdrgo u' cv' yj g' Ncnf c' Vckłpi u' F co " y j lej " eqwñf " r qvgpñ' cñ' " ko o gf k' vñf " ko r cev' r tqf vewkqap" cv' qpg' qh' yj g' rñti guv' o kpgu' kpi " Uqwj " Cuk0' Vj g' Ncnf c' F co " ku' c' 522/ hqjv' j ki j . " gcty h' kñ' go dcpñ' gpv' y j lej " ko r qwpf u' j { f t' wñkcmf / r rnegf " v' kłpi u' cpf " r tqxkf gu' c' t' gugtqxkt " hqt" d' gpgñkcvkqap" r tqegu' y cvgt0' " O t0' Eqz " rñcf " c' I \ C' v' go " qp' c' uksg' t' geappcku' c' peg' xkuk' v' yj g' f co " cpf " o kpg' v' q' o ggv' yj kj " yj g' Qy pgt' cpf " eqmgev' g' z' kpi " cpf " hkgf " f c' v0' " Wf qp' t' gwtp' hqo " Kpf k. " O t0' Eqz " cwj q' tgf " tgr qtv' f guetkłpi " yj tgg' r tko ct { " f co / t' g' v' gf " u' j qtv' v' gto " ko r gf ko gpw' v' q' eqpvtv' w' gf " o kpg' r tqf vewkqap" cpf " qh' t' kpi " cngtpcvkxgu' hqt" cf f t' gułpi " g' c' j " kuwgo "

Rtqlgev' O cpci gt. 'O eCf co u' F co . 'Dctpctf . 'XV0' C" r tqlgev' v' f guki p' cpf " eqpwtvew' c' pgy " f co " hqt" c' r t' kxgv " rcpf qy pgt' hqt' yj g' r wtr qug' qh' t' g' cvki " c' rñng' hqt' t' g' t' g' cvkqap" cpf " h' k' g' r tq' gevqap0' Y qtngf " y kj " Qy pgt' cpf " Ctej kgev' v' f gxgnr " c' ugt' kgu' qh' eqpegr wcnf' guki pu' hqt" f co 0' Wñkñ' gf " uduwñ' h' reg' f c' v' hqo " I \ C' f t' kłpi " r tqi tco " v' ugv' h' reg' v' kqap" cpf " cñi po gpv' qh' f co 0' " F guki pgf " o cuqpt { / h' reg' eqpetgvg' ur kny c{ " v' r cuu' v' r k' cñi' hny u0' " F guki p' h' q' f " ceeqo o qf cvgt' d { " ur kny c{ " cpf " uqto y cvgt' d { / r cuu' r k' rñpg0' " Ur kny c{ " f guki pgf " v' q' o ko k' x' kuñ' cr r gctcpeg' qh' p' gctd { " qñf " ño kñf co u0' " F guki pgf " cf l' cegpv' gcty h' kñ' go dcpñ' gpv' yj kj " v' q' f t' cłp' v' q' ugtxg' cu' r tko ct { " y cvgt' t' g' cvkłpi " utwewtgu0' " F guki pgf " r tqi tco " v' d' cuv' cpf " g' z' c' x' cvg' j ki j n' " h' c' ewt' gf " dgf t' qeni' kpi " cdwo gpv' cpf " tgr rneg' y kj " ko r g' t' x' k' wu' h' kñ' o cvt' k' cñ' v' cev' cu' u' g' r ci g' d' r' p' ngv0' Rtgr ctgf " eqpwtvewkqap" r rcpu' cpf " h' ko k' gf " ur gekñkcvkpu0" O cpci gf " I \ Cñ' eqpwtvewkqap" qdugtxcvqap" r tqi tco " cpf " y qtngf " y kj " eqpvtcevqt' f wtkpi " eqpwtvewkqap0" Rtgr ctgf " eqo r r' g' v' kqap" tgr qtv0' "

Rtqlgev'O cpci gt.'Rcm gt'Fco 'Xcmg'Gpi lpggt lpi 'cpf 'Rggt'TgxlgY.'Uvqplpi vqp.'EV' 'Cs wctkqp' Y cvgt' Ego rcp{ 'qhEqppgekw'gpi ci gf'I \ C'q'r gthqto 'c'xcmg'gpi lpggtlpi 'uwf { 'cpf 'r ggt'tgxlgY 'qh'f guki p'ecrewcvkpu. r rpu.'ur gekhecvkpu.'cpf 'eqptcev'f qewo gpw'r tgr ctgf 'd{ 'cpqj gt'gpi lpggt'hqt'yj g'tgj cdkkcvkqp'qh'Rcm gt'Fco 0' O cpci gf 'rtqlgev'cpf 'eqqtf lpcvgt'yj g'y qtnlqh'qj gt'gpi lpggtu'lp'yj g'tgxlgY 'qh'ucdkk'f'ecrewcvkpu.'j { f tqmji le'cpf " j { f tcvle'cpcn'uku.'cpf 'tgxlgY 'qh'r wo r 'f guki pu0'"TgxlgY gf 'r rnp'ugv.'ur gekhecvkpu.'cpf 'eqptcev'f qewo gpw'cpf " o cf g'c'pwo dgt'qh'tgeqo o gpf cvkpu'hqt'w i gungf 'ej cpi gu'q'r tqlgev'f guki p'cpf 'eqptcev'f 'r tqegf wtgu0'

Rtqlgev'O cpci gt.'Ctnlpi vqp'Tgugt xqlt'Fco . 'Ctnlpi vqp.'O C'"C'r tqlgev'v'hwj gt'kpxguki cvg'f ghelkpelgu'cv'c' o vplekr cnf'co 'cpf 'f gxgnr'eqpegr wcn'uwkpu0'O cpci gf 'rj cug'KKlpxguki cvkpu'cpf 'eqpegr wcn'f guki p'uwf { "qp" yj g'Ctnlpi vqp'Tgugt xqlt'Fco 'cpf 'uy ko o lpi 'ctgc'f kng0'F gxgnr gf 'i gqvej plectn'kpxguki cvkqp'r tqi tco 0'Cpcn' | gf " uggr ci g'y tqwi j "cpf 'ucdkk'f'qh'go dcpno gpv'cpf 'f kng0'F gxgnr gf 'eqpegr wcn'f guki pu'hqt'tgj cdkkcvkqp'cpf 'y tqvg" tgr qtv'r tugpvkpi 'hpf lpi u'cpf 'qr vkpu0'

Rtqlgev'Gpi lpggt.'I tgc'vRqpf 't'pf 'W'r gt'Tgugt xqlt'Fco u'Dtclpvtgg.'O C0'C'r tqlgev'v'kpxguki cvg'yj g'ucv'g'qh' wy q'gct'yj gp'y cvgt'uw'r n'f'fco u'cpf 'f gxgnr'eqpegr wcn'cngt'pckxgu'hqt'pggf gf 'tgr cku0'Cpcn' | gf 'y g'w'q'fco u." y j lej 'ctg'k'ugt'gu.'hqt'yj g't'gur qpug'q'322/{ t'cpf " 'RO H'huqf u'wukpi 'J GE/3'o qf gr0'F gxgnr gf 't'cvkpi 'ewxgu'hqt' ur kny c{ u'vpf gt'xctkqu'huuj dqctf 'eqphk wcvkpu0'Rgthqto gf 'kpetgo gpv'Fco ci g'Cuuguo gpv'wukpi 'F C O D T M' uqlhy ctg'k'qtf gt'v'gxcn'wcv'uk'g'qh'yj g'Ur kny c{ 'F guki p'huqf 0'O cf g'eqpegr wcn'tgeqo o gpf cvkpu.'kpen'f lpi 'equv' guko cvgu.'hqt'xctkqu'tgo gf kcn'cngt'pckxgu0'F gxgnr gf 'r qtv'kpu'qh'GCR0'Y tqvg'fco "qr gtcvkpu' ("o clp'gpcpeg" i vkf g'v'dg'wugf 'd{ 'qr gtcvkpu'r gtuqppgr0'

Rtqlgev'Gpi lpggt.'Tknllpf gz lpi 'hqt'F GO /o cpci gf 'Fco u'lp'O cucej wugwu0'C'r tqlgev'v'f gxgnr o gpv'c'pgy " o gj qf "cpf "cuqekcvgt'eqo r wgt"o qf gr' hqt" r tktkkl lpi "tgo gf kcn'cvkpu'cv'gzkukpi "uo cni'go dcpno gpv'fco u0' Cuukngf 'y kj 'y g'vukpi 'qh'yj g'eqo r wgt'o qf gr0'F gxgnr gf 'c'r tktkkl cvkqp'kuv'hqt'v'gp'fco u'hqt'wug'd{ 'F GO 'Qihleg" qh'Fco "Uchgv'lp" tgs wukpi "hwpf lpi "cmqecvkp0'Y tqvg'tgr qtv'cpf "cnuq" r tugpvgt' "r cr gt'cv'CUF UQ" pcvkpcn' eqpxgpkp0'

Rtqlgev'Gpi lpggt.'Tclpdqy 'Rqpf 'Fco .Y cnr qng.'O C0'C'r tqlgev'v'uwf { "cp'gct'yj hknf co 'cpf 'f gxgnr'eqpegr wcn' cngt'pckxgu'hqt'tgr cku0'F gxgnr gf 'eqpegr wcn'f guki p'hqt'ur kny c{ "ko r tqxgo gpv0'Rtgr ctgf "s wcp'v'f'cpf "equv' guko cvgu'hqt'xctkqu'tgo gf kcn'cngt'pckxgu0'"

Rtqlgev'Gpi lpggt.'O F E'Fco 'kpur gev kpu'O cucej wugwu0'Rctvlekr cvgt'lp'kpur gev kpu'qh'o wnr rg'O gvtqr qrkcp" F kntlevEqo o kuukp'fco u'lp'gcuqtp'O cucej wugwu0'

F CO 'FGEQO O KUKQPRPI "

Rtqlgev'O cpci gt.'Qif 'Dgtmij ktg'O knf'Fco 'Tgo qxcn'F cnqp.'O C0'C'r tqlgev'v'dtgcej "c'eqpetgv.'twp/qh'yj g/ tkxgt'o knf co 'cpf 'tguqtg'pccwcn'huqy "v'yj g'tkxgt0'Gzco lpgf 'uchgv'f ghelkpelgu'cpf 'cpcn' | gf 'qr vkpu'qh'tgr ckt'qh' yj g'fco "xu0'dtgcej lpi 'qh'yj g'fco 0'kpxguki cvgt'gpxkqpo gpv'neqpu'g'wpegu'qh'fco "dtgcej lpi 0'Y tqvg'eqpegr wcn' f guki p'tgr qtv'tgeqo o gpf lpi "dtgcej lpi "cpf 'tgo qxcn'qh'yj g'fco 0'Rtgr ctgf "Gpxkqpo gpv'P qv'hecvkqp'Hqto "hqt" tgo qxcn'r tqlgev0'Rtgr ctgf 'ugf ko gpv'uco r rnp' r rnp'cpf 'eqngevg'uco r rgu'itqo "huqcvkpi 'r rnv'qto 'lp'ko r qwpf o gpv0' Rtgr ctgf 'ugf ko gpv's wcrk'f'tgr qtv'Y tqvg'F tch'v'cpf 'Hkpcn'Gpxkqpo gpv'k' r cev'Tgr qtv'w'cpf 'r tgr ctgf 'pgegu'ct{ 'ucv'g" cpf 'hgf gcn'r gto k'cr r rncv'kpu0'Rtgr ctgf 'r tgr ko lpc'f' 'cpf 'Hkpcn'dtgcej 'f guki pu0'Rctvlekr cvgt'lp'pwo gtv'w' o ggvkpi u' y kj 'tgi wcv'f' { 'ci gpekuv'q'o qxg'r tqlgev'huqy ctf 0'Rtqxf gf 'gpi lpggtlpi 'uw'r qtv'f wtkpi "f g'eqpustwcvkqp'r j cug0'

Rtqlgev'Gpi lpggt.'Ej co r nlp'Rqpf 'Fco 'Dtgej lpi '('Ej co r nlp'Hcto 'Rqpf 'Fco 'Tgo qxcn'Tqej gugt.'PJ 0'C" r tqlgev'v'dtgcej "qpg'uo cni'gct'yj hkn'go dcpno gpv'cpf 'eqo r rvg'f'tgo qxg'cpqj gt'cu'o kki cvkqp'hqt'c'hw'w'g'ckr qtv' ko r tqxgo gpv'r tqlgev0'O t0'Eqz'f guki pgf 'y j g'dtgcej lpi "cpf 'tgo qxcn'ucv'g { "cpf 'r tgr ctgf 'y j g'Eqptcev'Rrpu0' F guki p'o cf g'gz'v'puk'g'wug'qh'oDkq/Gpi lpggtlpi o'v'g'j pks wgu'cpf 'hgcw'gu'w'uj 'cu'eqk'huq' u'dcpn'ucdkk'f'cvkqp.'rkxg" ucngu.'cpf 'y g'w'cpf u'uggf lpi 0'O t0'Eqz'r tgr ctgf 'y j g'r tqlgev'f gto k'cr r rncv'kpu'wdo kvgf 'v'yj g'PJ F GU0'"

Rt q l g e v G p i l p g g t . ' O k l R a p f ' F c o . ' P q t y g m ' O C 0 " C " r t q l g e v " q " t g o q x g " c " u o c m l g c t y j h m l g o d c p m o g p v " q y p g f " d { " c " p a p / r t q l h " q t i c p k c v k a p 0 " C u u k u g f " y k j " f g x g m r o g p v " q h " e q u " g u k o c v g u . " r q p f " t g e n c o c v k a p " r t q i t c o . " G p x k a p o g p v c n " P q w h e c v a p H q t o . " c p f " q j g t r t g t o k w k p i " k u u g u 0 " R c t v e k c v g f " l p " p w o g t q w u r w d n e " j g c t l p i u h t " r g t o k w k p i " q h " r t a l g e w 0

Rtlo ct{ 'Cwj qt{ 'Rtqlgev O cpei gt.' O curej wgwu f co 'Tgo qxcnI wlf g.' Ucvgy f gO'' Wpf gt' eqptcev' v' q' y' g' f gr ctvo gpv' qh' Hkuj gtgu' cpf' Y kf rkg' Tlxgty c{ u' Rtqi tco. 'I \ C' f gxngr gf' c' i' gpgtk' o cpwcn' q' cuukn' f co 'qy pgtu' kp' y' g' f gclukp/ o cnkpi 'r tqegu' tgi ctf lpi 'f co 'tgo qxcnO'' Vj g' o cpwcn' f gvcku' ugr u' pggf gf' v' q' r gto kx' f guki p. ' cpf' ko r ngo gpv' c' f co 'f gego o kuukp lpi 'rtqlgevO'

Y CVGT"TG UQWTEGU"

Rt qłgev'O cpci gt.'Rqpnrc qci 'DtqqnlJ { f t cwłe'Cpcnl uku'Ecpwqp.'O C''Vj ku'r tqlgevlpxqnxgf 'y g'f gxnqr o gpv'qh' c'j { f t cwłe'cpcnl uku'eqr wgr'o qf gnl'J GE/TCU+hqt'y g'Rqpnrc qci 'Dtqqnlđgy ggp'y g'f co 'cpf'y g'O J F'ewxgtv' etqułpi 'cvT'035: 'lp'Ecpvqp0''Vj g'o qf gnlpxnf gf'o wnx rg'ewxgtv'cpf'uo cniđtkf i g'etqułpi u0''O qf gnl cu'wugf 'v' guko cvg'y cvgt'uwłceg'grxclvpu'cpf'hnqy 'xgrqeklg'u'y tqwi j qw'y g'dtqqnl'lp'tgur qpug'v'ut gco 'hnqy u't guwłpi ' hqo 'xctkqu'łrg vgpelgu'qh'utqto u0''Vj g't guwł'u y gtg'wugf 'v'o cng'f gekłqu'łgi ctf łpi 'tgo qxcl'qh'qdutwclvpu'lp' y g'dtqqnl'j cpggn'v'o kki cvg'hnqf łpi 'r tqđrgo u0'

Rt qlgev'O cpci gt. "Kpwt dcup"Vt cpulgt "Cev'Cr r necvqp"O qf gnpI "Uwf { .Eaj cuvg. "O cucej wugwu" "Wpf gt" eqpvtcev"q"y j g'Eaj cuvgY cvgt "Eqo o kuikqp. "I \ C'f gxgrqr gf "c'tgugtxqk"qr gtcvkpu"t"utgco hqy "uko wrvqp"o qf grI vq"uwr r qt v'y j g'Ego o kuikqpau'ts wguv/hqt "c'F gvgto kpcvkp"qh'Kpuki plhcepeg"htgo "y j g'O cucej wugwuY cvgt "Tguwtegu" Eqo o kuikqp0"t \ C'etgcvgf "c'f gvgto kpkule"o qf grI vq"uko wrvg" f qy pwtgco "utgco hmq u"cpf "tgugt xqk"y cvgt "uwt hceg" grgxcvkpu"y j lej "o ki j v'tguwu"htgo "ej cpi gu"lp"tgugt xqk"y kj f tcy cni"cpf "qr gtcvpi "etkgtlc0" Dcuqf "qp"y j g'o qf grI tguwu. "I \ C'tgeqo o gpf gf "tgugt xqk"tgrgcugu"q"r tqgev'f qy pwtgco "j cdkcv'cpf "eqpugt x'y cvgt "hqt"y cvgt "uwr r n" wugu0"t \ C'au'tgeqo o gpf cvkpu'y gtg'ceegr vgf "d { "y j g'Y TE"cpf "y j g'F gvgto kpcvkp"qh'Kpuki plhcepeg'y cu'kuwgf 0

Rt qłgev'O cpci gt.'HhpvRqpf'F tcy f qy p'Hgcukdkk{'Uwff{'Y qt egugt.'O cucej wugwu'}Vj g'Ekk'qh'Y qteguqt' Qthleg'qh'Rrcppki "cpf"Ego o wpkf"F gxgqr o gpv'eqptcevgf'I \ C"q'r gthqto "c"f gvckrgf"lpxgwki cvkp"cu"q"vj g' hgcukdkk{"qh"vj g"f tcy f qy p"vej pls vg'tgrcvxg"q"j {ftqni le lj {ftcwle'hgcukdkk{."r qvgpvcri'uj qtv'cpf"mipi/vgtto " gpvkqpo gpvcrl'o r ceu."r gto kwpi "tgs vkt go gpw"cpf"equ0'"O t0Eqz"ugt xgf"cu'r tqłgev'o cpci gt"hqt"vj g'uwwf{"cpf" r gthqto gf"gpi lpggtkpi "y qntltgrcvf"q"vj g'fxgqr o gpv'qh"c"f tcy f qy p'cevqp'r mpcpf"lpxgwki cvkp"qvj gt'r quukdg" y ggf'eqptqnlcnrgtpcvxu0'

Rt qłgev'O cpcl gt.'Łqtł cp'Rqpf 'T gıwqt cıłqı'Uwł {.'Uj tgy ułwł {.'O cıwej wıgwł'"}Vj g'Vqy p'qh'Uj tgy ułwł {
gpi ci gf "I \ C"v"eqpf wev'c'f kci pıwke łgcukłkłł{"uwł {"qh'Łqtł cp'Rqpf O"}Vj g'r qpf "y cu'npqy "v'g'zr gıłpıg'ıgıxtg'
cs wełe'xgi gıvıłp'r tqdıgo u'cpf "j cf "dgıp'wıgf "łt'r wıłke'uy ko o kpi "dghıtg'dgłpi "erııgf "f wıg'v'dcevtgııııı kccı'
eqpıco kpcıłp O' "I \ C'f gıgıııı gf "c" S CRR"cpf "eqpf weıgf "c'y cıgt"s wekł{"ıco r rıpi "r rıp O' "I \ C"cnıq'r tqf weıgf "
dcıj {o gııle'cpf "ıgf ko gıv'ıo cr u'cpf "eqpf weıgf "y cıgt"s wekł{"o qf gııpi "cpcı'ıgu'wıłpi "ıj g'I Y NH'o qf gıı O' "I \ C"
r tıgıııııı "ıj g'tıgıııııı'qh'ıj g'uwł {"v'ıj g'Vqy p'cpf "Y cıgtıı gf "Cıııekııııı O'"}"

[illegible]

Rtlqgev'Ocpci gt.'Y gk'Tlkgt'Y cvgtuj gf 'Uwfw {'.J lpi j co.'O cucej wugwu'Vj g'O cucej wugwu'F gr ctvo gpv'qh' Gpxkqpo gpcn' Ocpci go gpv.' Qhleg' qh' Y cvgt' Tguwtegu' *F GO/QY T+' j k gf' 'j g' I \ C' vco " vq" r gthqto " c" eqo r tgi gpxkq' lphny lqwnny 'cpnc' uku' hqt' 'j g' Y gk' Tlkgt' y cvgtuj gf 'cpf' ku' uwd/ dculpu' Vj ku' r tqlgev'y cu' eqpf wvfg' wpf gt' 'j g' O cucej wugwu' Y cvgtuj gf 'Kpkkvxg' y kj " c" pwo dgt' qh' i qcnu' <3+ " vq" tgugetej " guugpvkn' d' ceni tqwpf 'y cvgt' wug' f c'v' hqt' 'j g' Y gk' Tlkgt' y cvgtuj gf = 4+ " vq" gxcncv' g' kpetgcugf' y cvgt' pggf u' hqt' hmw' g' r rcpplpi = cpf' 5+ " vq" guwdrkj " o lpo wo " utgco hny " vcti gw= 6+ " vq" guko cvg' 'j g' r qvgpvkn' ko r cew' qh' y cvgt' y kj f tcy cni' qp' utgco hny 0' " I \ C' f gnpvcv' y cvgtuj gf 'uwd/ dculpu' cpf' guko cvg' 'dcugnpg' cxgtci g' r tgf g' gxnqr o gpv' hny u' lp' 'j g' wp/ i ci gf' y cvgtuj gf' 'j tqwi j " j { f tqm' i le" o g' j qf u' 0' " Vj g' uwfw { " 'j gp' ecvni wv' 'j g' uwthceg' y cvgt' cpf' " i tqwpf y cvgt' y kj f tcy cni' lp' 'j g' y cvgtuj gf' cpf' " c" y cvgt' dwf i gv' o qf gn' y cu' ewuqo / etgcvgf' d { " I \ C' " vq" gxcncv' g' j g' lphwvpeg' qh' ewtgpv' cpf' hmw' g' y cvgt' f go cpf' qp' nqeci uwthceg' y cvgt' cpf' " i tqwpf y cvgt' j { f tqm' i { 0' T guwnu' h' tqo " 'j gug' cpnc' ugu' y gtg' wugf' " vq" cuugu' 'j g' r qvgpvkn' tkni' f v' g' " vq" d' lqmi keni' utguugu' qp' " cs wvle" ur gelgu' uw' j " cu' v' qw' " j g' tklpi . " dcuu. " cpf' " ugxgtci' o cetqlpxgtgdctv' u' 0' Dcugf' qp' 'j g' tguwnu' qh' 'j g' uwfw { . " I \ C' f g' gxnqr gf' " c" ugv' qh' ugcupcn' utgco hny 'vcti gw' ur gelhe' vq' 'j g' Y gk' Tlkgt' y cvgtuj gf 0' " Vj g' gpf' r tqf wv' qh' 'j ku' r tqlgev'y cu' " c" uqwpf " i wv' cpegr rcpplpi " f qewo gpv' vq' dg' wugf' d { " 'j g' Dquvq' J ctdqt' Y cvgtuj gf " Vgco " cpf' " qj gt' ucn' j qrf gtu' vq' uwuclp' 'j g' ctgcw' y cvgt' tguwtegu' lp' vq' 'j g' 43^{uu} egpwt { 0' " I \ C' r tguv' g' l' h' l' p' i u' qh' 'j g' uwfw { " cv' c' r wdrle" o ggv' lpi " lp' J lpi j co " cpf' r ctv' kl' cvg' lp' ucn' j qrf gt' o ggv' lpi u' y kj 'j g' y cvgtuj gf 'cuuqekv' qp. 'j g' y cvgt' uwr r ngt. 'j g' Ucv' g' cpf' qj g' tu' 0'

Rtqlgev'Gpi lpggt.'Lqpgu'Tkxgt'Y cvgtuj gf 'Uwff {.'Mlpi uwqp.'O C0'C"y cvgtuj gf "uwff { 'uko kct"vq"vj g"Y ght"Tkxgt" Uwff { 'lpxqnxkpi "vj g"cuuguuo gpv'qh"vj g"ko r cew"qh"j wo cp"y cvgt"f go cpf "qp"pcwtctn'y cvgt"dqf lgu0"Cpcn| gf "y cvgt" uwr r n| "cpf"f go cpf "ltqo "vj g"Lqpgu'Tkxgt"y cvgtuj gf 0"Ueqr g"qh'r tqlgev'lpenwf gu'Ukxgt'Ncng."y j lej "ku"vj g'r tko ct { " y cvgt"uqwteg"ht"vj g'Ek{ 'qh'Dtqemqp0"Uwff lgf 'lpvgtcevkp"dgy ggp'ewttgpv/cpf "hwwt"y' cvgt"uwr r n| "f go cpf u'cpf "lp" utgco "hny u'lp"vj g'Lqpgu'Tkxgt0""

RtqlgevGpi lpggt. 'Tqwg'5'Uqwj 'Gzrcpukp'Y cvgt 'S wrk{ 'Uwf { . "O cucej wgwu"Y cvgt's wrk{ 'lo rcev'uwf { "hqt"tqcf "y kf kplpi "rtqlgev'lpvgp gf "q"lpetcgug"j g'ecrcek{ "qh'Tqwg"5"uqwj "qh'Dquwp0"K gpwkhgf "ukz"uwd/dculpu"eqppgev"q"j g'r'tqlgev'tgc"j y lej "eqpvlwug"y cvgt "q'r'wdike"y cvgt'uwrrn "u'urgo u0""Etgcvgf "o qf gnu'hqt"gcej "uwd/dculp"y j lej "rtgf'leu"j g"ewt'gpv"cpf "r'tqr'qugf "ko r'cew"qh'tqcf "ucw"qp"j g"uqf kwo "eqpegp'cvkpu"qh'gcej "y cvgt"uwrrn "uqwtg"y kj kp'uwd/dculp0'Tgr'qtv"q'dg'lpexgf gf "lp"j g'Tqwg'5'Uqwj 'Gzrcpukp'Rtqlgev'GK0"

“

UKVG'FGUH P'TFTCKPCI G'

11

Rtqlgev'O cpci gt.'Kpf kp'RqpvGpgti { 'Egpgvt 'KHUKhrekks{' 'Dwej cpcp.'P[0'Vj ku'r tqlgev'lpemf gf "j {f tqmji le' cpf" j {f tcrwle' cpcnf ugu" cpf "f tclpci g'f guki p" hqt' Gpvgti { "P werget' P qtjv gcuv' Kpe0u' r tqr qugf' "eqpuxwvqap" cpf " qr gtcvqap' qh'cp' Kpf gr gpf gpv'Ur gpv'Hvgi'Uqtci g'Kpuvncvqap'*KHUK0'O t0Eqz'o cpci gf "vj g'ghqt'v'q'gxcnwcg'vj g' r tqr qugf "f tclpci g'r np'vq'gpuwv'vj cv'k'y cu'lp'ceeqtf cpeg'y kj 'P gy "[qtm'Ucvg'Uqto y cvgt'O cpci go gpv'F guki p' Tgs wkt go gpw0'Gtquqap.'ugf ko gpvcvqap.'cpf "y cvgt's wcrw' "eqpvtqno gcuvtgu'y gtg'f guki pgf "vq'j grr "o gg'vj g'pggf u'qh' vj g'edgpv'cu'y gni'cu'ucvg'cpf "hqcndtgi wrcvpu0'O t0Eqz'uwduvpcvcm{ 'r tgr ctgf "vj g'Uqto y cvgt 'Rqmwkqap'Rtqxpvcvqap' Rrep'cpf "vj g'f tclpci g'tgr qtvhqt'vj g'r tqr qugf 'KHUKUqtci g'Ref 0"

Rtqlgev'O cpci gt."I tcfp "I whi'Pwerget"Ucvkqp"KHUK'hreklk\.'I tcfp "I wh"O U0"'Vj k' r tqlgev' kpenf gf " j {f tqriq le"cpf "j {f tcvle"cpcl ugu"cpf "i tcf kpi "cpf "f tclpci g'f guki p"ht "Gpvti { "P werget"P qt y gcuv."kpeku'r tqr qugf " eqpuwewkqp"cpf "qr gtcvqp"qh'cp"kp gr gpf gpv'U' gpv'Hvgrl'Uqtc i g'kpuwewkqp"*KHUK0"O t0Eqz"o cpci gf "y g'ghqt v' vq"gxenwcv"y g'r tqr qugf "f tclpci g'r rcp"vq"gpwtg"y cv'k'y cu"kp"ceeqtf cpeg"y kj "O kuuku'r k'ku'ucvq"uqto y cvgt" ucpf ctf u"cpf "I gpgtcn' Rcto k' Eqpf kkpqu."cu"y gni'cu" I tcfp "I whu"kpvtpcn' gpxkqpo gpvcl's wvkl\ "ucpf ctf u0" Gtqukqp."ugf ko gpvckqp."cpf "y cvgt" s wvkl\ "eqpuqnl'o gcuwgu"y gtg"f guki pgf ."cu"y gni'cu"uwthceg"cpf "uudwthceg" f tclpci g'ut wewtgu0"O t0Eqz"uudwcpvclm"r tgr ctgf "y g"Uqto y cvgt"Rqnmwqp"Rt xgpvqp"Rrcp"cpf "y g'f tclpci g' tgr qtv'ht "y g'r tqr qugf "KHUKUqtc i g'Rcf 0"J g'cuq'f guki pgf "y g'i tcf kpi "cpf "f tclpci g'uej go g'ht "y g'hreklk\.'cpf " r tgr ctgf "r rcpu."f gckku."cpf "ur gekhccvku0"

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UQNF'Y CUVG"

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Rtqlgev'Gpi lpggt.'Etqy 'Ncpg'Ncpf hml'Emumtg.'Pgy dwt{ r qtv.'O C0"C"rtqlgev"vq"emug"cpf"ecr"cp"gzknkpi " o wplekr cn'y cug"ncpf hml' "Rtgr ctgf "uli plklecpv" r qtvkpu" qh' kpkcn' Ukg" Cuuguu gpv' f qewo gpv' hqt" uwd o kuukp" vq" O cuucej wugwu'F gr ctvo gpv'qh'Gpxkqpo gpwn'Rtqvgevkp0"

"

GZRGTKGPEG'RTKQT'VQ'I \ C'"

FCO 'UCHGV['CPF'FGUH P"

Rtqlgev'Gpi lpggt.'Fco "Uchgv"("Fgukip."Llecthnc"Crcej g"Y cvgt "Tguqwtegu"Rtqi tco ."Llecthnc"Crcej g" Tgugtxcvkp"Rtqlgev'kpxqrgf "kpur gevqp"qh'F wreg'Ncng'Fco ."Nqy gt"O wpf q"Ncng'Fco ."NcLctc"Ncng'Fco "y j lej " r tqxkf g"ktki cvkqp."tgetcvkqp."cpf "i tqwpf y cvgt "tegej cti g" hqt" y j g" Llecthnc"Crcej g"eqo o wpkf."c"uqxgtgk p"P cvkxg" Co gtkecp"pcvkp0" F kueqxt { "qh'o wnr ng'f ghlekpekgu"ngf "vq"tgf guki p"cpf "tgr ckt"qt"tgeqpustwevkp0"

"

Cpcn[| gf "fco u" hqt" j { f tcwle."i gqvgj plecn"cpf "ugkuo le" f ghlekpekgu0"Y tqvg'F ghlekpe { "Xgtkhlecvkp" Tgr qtv' hqt" cni" y j tgg" fco u" hqt" uwd o kuukp" vq" y j g" WU0Dwtgcw'qh' Tgerco cvkq0" F guki pgf "WU0& "o knkqp" tgo gf kcvkqp" r tqi tco "hqt" cni" fco u" kpenf kpi " ego gpv'dgpvqpksg" unwt { " y cmu." tqngt" eqo r cevgt " eqpetgvg" qxgtvqr r kpi " r tqvgvkp." gprcti gf " ur kny c { u" pgy "qwwgv'y qtmu."cpf "hqqf "y ctpkpi "u{ ugo u0" Rctvlekr cvgt "kp" r tgr ctcvkqp"cpf "y tkkpi "qh'Gpxkqpo gpwn' Cuuguu gpv' tgr qtv' cpf "f guki pgf "tgr n ego gpv' y gwpf 0" Rtgr ctgf "r ncpu"cpf "ur gekhlecvkpu0" Rtqf wegf "Gpi lpggt'au" Equv'Gunko cvgt"cpf "tgr tguvgvgf "gpi lpggtkpi "hko "cv'y j g"qr gpkpi "qh'eqpustwevkp"dkf u0" P gi qvkvgtf "y kj "eqpvtcevgt"vq" tgf weg' r tleg'qh'NcLctc' r tqlge0" Y tqvg' Hkpcn'F guki p" Tgr qtv' u0"

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Rtqlgev'Gpi lpggt.'Rgpureqne" Fco "cpf "Mgtt" Fco ."Qm: j qo c0" Cpcn[| gf " fcv" hqo " kputwo gpvcvkp" hqt" r tgr ctcvkqp"qh' HGTE"uchgv' tgr qtv'0" F guki pgf "r tgrko kpct { "rc { qw' hqt" pgy "kputwo gpvcvkp" r ncpu0"

"

Y CVGT'UWRRN["

J { f tcwle'Gpi lpggt.'Uchpc'Rwo rdcentcy 'Y cvgt 'Uwr r n' 'Rkgrkpg'Uwf { .'Qm: j qo c0" Rgthqto gf " r tgrko kpct { " r kgrkpg" f guki p"qr vko k cvkqp"qp", 8/kpj "f lco gvg. "32/o kg'y cvgt' uwr r n' "r kgrkpg"vq"dg'wugf "vq"gpj cpeg"y cvgt' uwr r n' " qh'ekv' "qh'Vwnc0"

"

Y cvgt'cpf "Ucpkcvkqp"Gpi lpggt.'Xetkqu'Y cvgt 'Uwr r n' 'Rtqlgeu'J k' O clgu' ai' I qxgtpo gpv'qh'Pgrcn0" O t0' Eqz"y qtngf "cu" c"y cvgt"cpf "ucpkcvkqp" gpi lpggt"y kj "y j g"pcvkpcn'F gr ctvo gpv'qh'Y cvgt' Uwr r n' "cpf "Ugy gtci g"kp" P gr cn'y j krg'ugt xkpi "kp" y j g" WU0Rgceg'Eqtr u0" O t0'Eqz" r gthqto gf "c"y k' g' tci g"qh' f wkgu"kp" y j k' u'ecr cels { "kpenf kpi " f guki plpi " r krg" f kntkdwkqp" u{ ugo u" cpf "uqtcig" vcpm" hqt" c" pwo dgt" qh' twten' y cvgt" uwr r n' "u{ ugo u0" O t0'Eqz" r gtupcm { "qxgtucy "y j g"eqpustwevkp"qh' c" pwo dgt"y cvgt" uwr r n' "u{ ugo "utwewtgu." kpenf kpi "dqj "tgkphqtegf "cpf " hgttqego gpv'eqpetgvg"vcpm0" O t0'Eqz"ugt xgf "cu" y j g" T gi kpcn' O clpvgpcpeg'Eqqtf kpcvt" hqt" y j g" O k' / Y guwtp' T gi kqp" qh'P gr cn0" Cu' uwej . "j g" j cf "tgr qpuklkrk { "hqt" r ncpu kpi "cpf "dwf i gvki "tgr cktu" hqt" cni" qh' y j g" WP KEGH'eqpustwevgf " y cvgt" u{ ugo u"kp"34" f kntleu"cu" y gni'cu'qxgtuki j v'qh' y j g" v'ckkpi "qh' f kntle'v0 clpvgpcpeg'vgj plekcpu0"

"

RWDNE CVKQPUCPF'RTGUGPVCVKQPU'

"

Cpf gtugp."I 0F0"Ej qwlpctf."N0G0"J qxgt."Y 0 0"Eqz."E0Y 0"0C"Tkuni'Kpf gz kpi "Vqqn'hqt"vj g"Rtkqtkk'cvkqp"qh'K0 r tqxgo gpv'u"q"
Kpxgvpqtkgu'qh'Go dcpno gpv'F co u0'ASCE Journal of Geotechnical and GeoEnvironmental Engineering."Cr tki42230'

Cpf gtugp."I 0F0"Eqz."E0Y 0"Ej qwlpctf."N0G0"J qxgt."Y 0 0"0Rtkqtkk'cvkqp"qh'Vgp"Go dcpno gpv'F co u'Ceeqtf kpi "v"Vj gk"
Rj {ulecniF ghekgpelgu0'"ASCE Journal of Geotechnical and GeoEnvironmental Engineering."Cr tki42230'

Eqz."E0Y 0"gv'cni'0l gqvegej plecni'Cpcni'uku'cpf"Kpxwto gpv'cvkqp"O qpkqtkpi "F wtkpi "vj g"F tcy /F qy p"cpf" Tgy cvgtkpi "qh'vj g"
Dngpj glo /I kndqc'Rwo r gf"Uqtcni g'Rqy gt'Rtqlgeu0'"Proceedings of the USSD National Conference."422: 0'

Eqz."E0Y 0"0Uo cni'J {f tqr qy gt"0"Rcu:"Rtugpvc"cpf" Hwwtgo'Rtugpvcv'q"vj g"Dquvq"Uqelgv' "qh'Ekkni'Gpi kpggtu"Ugevkp"l"
CUEG'I gqkpxwto'Eqphgtgpeg0'Qevqdg't5."422; 0"

Eqz."E0Y 0"0kpetgo gpv'ni'Tkuni'Cuuguo gpv'Vgej pls wgu'hqt"Ej qqukpi "Kpniqy "F guki p"Hiqqf u'c'F wreg"Ncng"F co "cpf"Nqy gt"
O wpf q"Ncng"F co 0'"Proceedings of ASDSO Western Regional Conference."r0395/3: 403; ; 90'

Eqz."E0Y 0'Dlctpi ctf."C0D0"J qxgt."Y 0 0"Kpxguki cvkqp"qh'Tqeni'Hqwpf cvkqp"cpf" E{enqr gcp"Eqpetgvg"cv'I kndqc"F co 0"
Proceedings of Soil/Rock America Conference0'4225"

Eqz0'E0Y."R0'Dctni"Y 0'Ucniqo cc."cpf" T0'F 0'Eicni0'0C"Rqukdng'Rctcf ki o "hqt"Rwdrie'Rtkxcvg'Rctvpgtuy k u0'"Proceedings of the
ASDSO National Conference."42260'

Eqz."E0Y 0'cpf" Hc{."E0P 0"0O qf gtp"J {f tqr qy gt"cpf"Ncng"O cpci go gpv'0"Vqi gvj gt"cv'Ncuw0'"Rtugpvcv'q"vj g"4; 0"
Kpvtgpcv'kpcni'U{o r qukwo "qh'vj g'P qtvj "Co gtlecp"Ncng"O cpci go gpv'Uqelgv'."Qevqdg't."422; 0'

Eqz."E0Y 0'cpf" Ngqpg."F 0 0"42240'0Y cvgt" Cmqecv'kqp" Rncppkpi "cpf" Wug0' Rtugpvcv'q"v'Eqphgtgpeg"qp" Y cvgtuj gf"
Eqpugtxcv'kqp"4224<"Y cvgt"Uwr r n'."Cs wcvle'Gequf ugo u."cpf" Rncppkpi ."WO cuu'Co j gtuv0'Ugr vgo dgt."42240'

Eqz."E0Y 0'cpf" Ngqpg."F 0 0"42280'0F co "Go gti gpe{ "Tgur qpug"0"Uwi i gukqu"hqt" c" F co "Uchgv' "Gpi kpggtu"Vqqmki'cpf"
Ej gemku0'"Proceedings of ASDSO National Conference0'42280'

Eqz."E0Y 0'cpf" Ngqpg."F 0 0"42250'0Y cvgt"Uwr r n' "cpf"Cs wcvle"J cdkcv0'"Rtugpvcv'q"v'Engcp"Y cvgt"Cevkqp"Eqphgtgpeg"qp"
Y cvgtuj gf"Rtqvev'kqp0'."Qevqdg't."42250'

Eqz."E0Y 0'0Gepqo leu' qh' Uo cni' J {f tqr qy gt0' Rtugpvcv'q"v' P qtvj gcu' Uwucv'kpcdng' Gpgti { " Cuuqekcv'kqp" *P GUGC+ "
Dwklf kpi Gpgti { "29'CpwwniEqphgtgpeg."O ctej ."42290'

Eqz."E0Y 0'F kl /Tgem"F 0'cpf" Gnj qm ."M0'0Uo cni'J {f tqr qy gt"Rqvgpvcni'0"K'o c{ "dg"Ncti gt"vj cp" {qw'Vj kpn0'Rtugpvcv'q"v"
P gy "Gpi ncpf"Y cvgt"Y qtmu'Hcni'Y cvgt" Tguqwtgu'U{o r qukwo "422: 0'

J cvgo /O qwuucngo ."O 0'I chtpg{."Eqz."{ "Dc'v q0'0Uqnw'kqu"v'Y cvgt"Uectek{ "kp"vj g" Tgr wdrie"qh'E {r twa'0'C"Rtqr qucni'ht"Y cvgt"
Dcpnki 0'0 K'F gr 0'qh'Ekkni' "Gpxkqpo gpv'ni'Gpi kpggtkpi "O cvgtu'qh'Gpi kpggtkpi "Rtqi tco ."3; ; 0"

J gtuj ."G0'cpf"Eqz."E0Y 0'0F co "O clpvgpcege"ht"Ncng"O cpci go gpv'0'"Rtugpvcv'q"v'P qtvj "Co gtlecp"Ncng"O cpci go gpv"
Uqelgv' "P cvkqpcniEqphgtgpeg"0'42250'P qxgo dgt."42250'

J qxgt."Y 0 0"Eqz."E0Y 0"Erctm" T0'F 0" Cpf gtugp."I 0F0"Ej qwlpctf."N0G0'0Tkuni'Kpf gz kpi "0"C"Vgej pls wg"ht"Rtkqtkk'kpi "qh"
Tgo gfkni'Cevkqu0'"Proceedings of ASDSO National Conference0'42220'

J qxgt."Y 0 0"Eqz."E0Y 0"0F guki p."Rgto kvlpi ."cpf"Eqpwtv'v'kqp"qh'vj g"Dtgecej kpi "qh'vj g"Qrf "Dgtmuj ktg"O kni'F co ."F cnqp."
O cuucej wugwu0'"Proceedings of the USSD National Conference."42230'

J qxgt."Y 0 0"Dlctpi ctf."C0D0"Eqz."E0Y 0"Eqvuc."R0'"0Ucdkkl{ "Cpcni'uku'cpf" Kpvtko "Uchgv' "K0 r tqxgo gpv."I kndqc"F co "
Ur kny c{."Uej qj ctlg" Tgugtqkt."P gy "l qtn0'"Proceedings of the USSD National Conference."42250'

Ngqpg."F 0 ."Eqz."E0Y 0" Mgghg."Vl0'0Ecug"Uwv { "kp"Rtcevecni'Cr r tqcej gu"ht"Y cvgt"Uwr r n' "xu0'Cs wcvle"Dcug"Hiqy "P ggf u0'"
Rtugpvcv'q"v'P gy "Gpi ncpf"Y cvgt"Y qtmu'Cuqekcv'kqp"4227'CpwwniEqphgtgpeg."Ugr vgo dgt."42270'

O cteknpxci g."E0"Mtgej o gt."F 0" Mgppgf { ."O 0"O el qxgtp."V0"Eqz."E0"Dgpqk"l0'0Rwv'kpi "F co u'lp"Qtf gt<"C"Rtqi tco "ht"
Eqo r tgi gpukxg"K gpv'v'kcv'kqp"cpf"Rtkqtkk'cvkqp"qh'F co "O cpci go gpv'Cevkqu0'Rtugpvcv'q"v'CUF UQ" P qtvj gcu' Tgi kpcni'
Eqphgtgpeg."Lwpg."422; 0'

Project Highlights

- DfcdcgYX`Unci hg'Zf'h fYY' gYdUfUH' [YbYfUH'b[' ZWY]H'Yg'Z'W gYX'cb' i H']n]b['Y] [gh]b['cdYfUH]b['VebX]H'cbg'
- Dfcj]XYX'jbbcj UHj Y' gc'i H'cbg'hc'a YYh'h Y' 5i h cf]m'g'j Uf]ci g' [YbYfUH]cb'fYghf]W]cbg'
- Dfcj]XYX'Ugg]ghUbW'k]h' : 9F7 'DfY'ja]bUfmiDYfa]h' 5dd'jWU]cb'

Ur tweg'Twp'cpf 'Tqwpf 'Xcng{ 'Tgugt xqkt u'J { f tqgrgevt le''
Hgcuklklk{ 'Uwf lgu''

ENR'VQP'VQY PUW R'PGY 'LGTUG' "

Vj g'P gy 'Lgtug{ 'Y cvgt 'Uwr r n{ 'Cwj qtk{ '*Cwj qtk{ '+qy pu'cpf 'qr gtcvgu'vj g' Ur tweg' Twp' cpf ' Tqwpf' 'Xcng{ ' Tgugt xqkt u' cu' r ctv' qh' c' o wnk'tgugt xqkt' eqo r rgez' 'v' r tqxkf' g' c' f gr gpf cdr'g' uwr r n{ 'qh' y cvgt 'v' egpvtcn' P gy 'Lgtug{ ' tgu'f gpw'U'Vj g' 'Cwj qtk{ 'kf gpv'khgf 'vj g' r qv'pvcn' hqt' j ctpgu'kpi 'vj g' gpgti { ' eqpvc'kpgf 'kp' vj g' g'z'k'kpi 'y cvgt 'tgrgcugu' hqt' qo 'vj g'k' 't'gugt xqkt u' cpf 'gpi ci gf' I \ C' v' kpxguki cvg' vj g' r qv'pvcn' hqt' f g'xgnr kpi 'j { f tqgrgevt le' i gpgtcv'kq'p' "

Vj g'Ur tweg' Twp' Tgugt xqkt 'ku' cp' qp' utgco 'y cvgt 'uqtci g' t'gugt xqkt 'y j krg' vj g' Tqwpf 'Xcng{ ' Tgugt xqkt' qr gtcvgu' cu' c' r wo r gf 'uqtci g' u' ugo' U'Vj g' Ur tweg' Twp' Tgugt xqkt' j cu' qpg' y cvgt 'tgrgcug' utwewt' g' cpf ' vj g' Tqwpf 'Xcng{ ' Tgugt xqkt' j cu' y q' *P qt vj 'cpf 'Uqwj -0' "

I \ C' eqo r rgez' vj tgg' ugr ctcvg' j { f tqgrgevt le' hgcuklklk{ ' uwf lgu' hqt' vj g' Cwj qtk{ 'y j k'j 'h'ewugf' qp' vj g' Ur tweg' Twp' Tgugt xqkt. 'vj g' Tqwpf 'Xcng{ ' Tgugt xqkt' P qt vj 'F co ' cpf ' vj g' Tqwpf 'Xcng{ ' Tgugt xqkt' Uqwj 'F co' U' Cp' cpcn{ uku' qh' vj g' v'ej plecn' vj g' g'eqp'qo le' cpf ' vj g' gp'x'k'qpo gpvcn' r gto k'kpi ' hgcuklklk{ ' qh' vj g' k'pucm'v'k'p' qh' c' j { f tqgrgevt le' i gpgtcv'kq'p' u' ugo' y g'g' eqo r rgez' hqt' g'cej 'ukg'U'Vj g' v'ej plecn' g'x'c'ncv'k'p' k'p'cn' gf' cp' g'uko cv'k'p' qh' vj g' i' tqu'j gcf 'cpf' j gcf 'h'qugu'v' q' r r tqz'ko cvg' vj g' g'x'c'k'cd'g' p'g'v'j gcf 'cu' y gni' cu' cp' cpcn{ uku' qh' j k'v'k'le' h'qy ' tgrgcugu' cv' g'cej ' f k'uej cti g' uk'g'U' Rwo r u' qr gtcv'kpi ' cu' wtd'k'p'gu' *RC'Vu+ k'p' cf f k'k'q'p' v' u'gx'gt'cn' f k'ht'g'p'v' v' r gu' qh' v'cf k'k'q'p'cn' wtd'k'p'gu' y g'g' g'x'c'ncv'g' hqt' xct { kpi ' r gth'qto c'peg' ej c'tc'ev'g't'k'v'k'eu'U' Vj g' xct'k'qu' r qv'pvcn' gp'x'k'qpo gpvcn' k'o r c'eu' qh' vj g' r t'ql'geu' y g'g' k'p'x'guki cvg' k'p'cn' kpi ' vj g' cu'q'ek'cv'g' r gto k'kpi ' t'gs'v'k't'go gp'v' hqt' h'q'ecn' u'cv'g' cpf ' h'g'f'gt'cn' t'gi w'v'kpi ' ci g'p'ek'gu'U' h'k'p'cm'f. 'c' r t'ql'geu' g'eqp'qo le' cpcn{ uku' y cu' eqp'f w'ev'g' hqt' g'cej ' uk'g'U'Vj k'p'cn' gf' c' e'qu'v' g'uko cvg' c'x'g'tci g' t'g'w't'p' qp' k'p'x'guo gp'v' cpf ' u'ko r r g' r c' { d'c'cn' r g't'k'q'f'U' "

"Vj g' t'gu'w'u' qh' vj g' hgcuklklk{ ' cpcn{ ugu' k'p'f k'ecv'g' vj cv'f w'g' v' vj g' J k' j r'p'f' u' C'ev' o q'f k'h' kpi ' g'z'k'kpi ' utwewt'gu' v' q' qr gtcv'g' cu' r qy g'tj q'w'ugu' y cu' vj g' r t'gh'gt'g'f' q' r v'k'p' qh' cp { ' k'pucm'v'k'p'U'F w'g' v' vj k'p' e'q'p'k'f g't'c'v'k'p' cu' y gni' cu' c' m'y g't' k'p'k'cn' e'c' r k'cn' e'qu'v' cpf ' uo c'mgt' g's v'k' o gp'v' h'q'v' r t'k'p'v' vj g' w'ug' qh' RC'Vu' cv' g'cej ' uk'g' y cu' vj g' r t'gh'gt'g'p'v'k'cn' g's v'k' o gp'v' q' r v'k'p'U'Vj g' r t'gh'gt'g'f' i' g'p'g't'c'v'k'p' m'q'ec'v'k'p' hqt' Ur tweg' Twp' y cu' y k'j k'p' vj g' q'w'g'v' x'c'wn' utwewt'g' hqt' Tqwpf 'Xcng{ ' P qt vj 'y cu' vj g' e'q'p't'q'n' x'c'k'g' x'c'wn' cpf ' hqt' Tqwpf 'Xcng{ ' Uqwj 'y cu' vj g' J co f gp' Rwo r 'U'c'v'k'p'U'Vj g' g'uko cv'g' r g'cn' r qy g't' cpf ' c'x'g'tci g' c'p'p'w'cn' gpgti { ' i' g'p'g't'c'v'k'p' y cu' g'uko cv'g' v'q' dg' 97' mY 'I' 643' O Y j ' hqt' Ur tweg' Twp. ' 522' mY 'I' 343' O Y j ' hqt' vj g' P qt vj 'F co ' cpf ' 642' mY 'I' 94' O Y j ' hqt' vj g' Uqwj 'F co' U' "

I \ C' r gth'qto kpi ' Rj' cug' k'k' qh' vj g' Cwj qtk{ u' J { f tqgrgevt le' k'p'x'guki cv'k'p'u' y j k'j ' g'z'r' m't'g' vj g' v'ej plecn' gp'x'k'qpo gpvcn' r gto k'kpi ' cpf' g'eqp'qo le' r qv'pvcn' qh' j { f tqgrgevt le' i' g'p'g't'c'v'k'p' y k'j k'p' vj g' Cwj qtk{ u' T'ct'k'cp' E'c'p'cn' utwewt'gu' "

Project Highlights

- DYfZ:fa YX'hWw bJWU' UbUngjg'UbX'Vt:ghYghJa UhY cb'Ub'Yl dYXJhYX'hJa YHUV'Y''
- ÆYbHjZYX'Yei Jda Ybhih Uhi a YYtg'j 6 i mi5 a YfjWUbi' dfcj jgjcbg'Z:f'5FF5'Z bXYX' dfc'YVWg''

Hgcukdkk\ 'Uwvf { 'hqt 'Eqpf wk\J { f tqgngvle'U\ ungo 'lp'Rtqr qugf ''
Vtcpuo kukqp'Nlpg'ht qo 'Ej leqr gg'Xcng\ 'Cs wgf wev'vq''
OeNcwj j rlp'Hkuj 'J cvej gt { ''

Vj g" O cuucej wugwu" Y cvgt" Tguqwtugu" Cwj qtkv\ " *O Y TC+," y j lej " r tqxkf gu" c" f gr gpf cdng" uqwtg" qh' y cvgt" vq" vj g" i tgcvgt" Dquqp" ctgc. " ku" kpxgunki cvkpi "vj g'kf gc"qh'eqpwtvewkpi "c"vcpuo kukqp'rkpg'vq'eqpxg\ "y cvgt" htqo " vj g" Ej leqr gg' Xcng\ " Cs wgf wev' *EXC+ " vq" vj g" O cuucej wugwu" F kxkukqp"qh'Hkuj gtkgu"cpf "Y kf rkg" *F HY + "OeNcwj j rlp'Hkuj 'J cvej gt { 0'''' Vj g'eqpf wk\y qwf "r tqxkf g'j ki j "s wcrk\ "y cvgt'hqt "wug"cv'v'j g'j cvej gt { 0''k" r gthqto kpi "r tgrko kpct { " f guki p" qh' vj g" vcpuo kukqp" rkpg. " vj g" O Y TC" kf gpv'kkgf " c" tgukf wcn' j gcf " vj cv' eqwrf " dg" wkrk\ gf " vq" i gpgtcvg" j { f tqgngvle\ 0'' Vj g" r tqlgv' y qwf " uwr r n\ " r qy gt " hqt " qp/ukg" wug" vq" r ctvcm\ " qh'ugv' gz kuki " r qy gt " f go cpf u" cv' vj g" cf lcegpv' Y ctg" F kxkukqp' Hcekrk\ " *Y F H+0''''

Vj g" O Y TC" gpi ci gf " I \ C " vq" r gthqto " vj g" vgej plecn' cpcn\ uku" cpf " vq" f gxgrqr " c" equv' guko cvg" qp" cp" ggr gf kkgf " dcuku' uwej " vj cv' vj g" uwwf { " eqwrf " dg" eqo r ngvf " kp" vko g" vq" o gg' vj g" f gcf rkpg" hqt " hwpf kpi " htqo " vj g" O cuucej wugwu' Engcp' Gpgti { " E gpvt " *O cuuEGE-0''''''

I \ C" r gthqto gf " c" vgej plecn' gxcnvcvqp" qh' vj g" vcpuo kukqp' rkpg' kpenwf kpi " vj g" ko r cev' qh' eqpwtvewkpi " vj g" r tqlgv' wulpi " r kr gu' qh' f khtgtpv' f lco gvgtu0'' Vy q" r qvgp' kcr' mjevkvqp" y gtg' eqpukf gtgf " kpenwf kpi " cv' vj g" nqy " r qkp' v' kp" vj g" u\ ugo " *cf lcegpv' vq" vj g" Y F H+ " cpf " vj g" f kiej cti g" r qkp' v' vq" vj g" j cvej gt { 0'' Vj g" ukg" cf lcegpv' vq" vj g" Y F H' y cu' wko cvgn\ " ugrgevf " dcugf " wr qp" vj g" cdkrk\ " hqt " vj g" O Y TC" vq" wkrk\ g" vj g" gpgti { " qpukg" cu' y gmi' cu' vj gk' f gukt g' vq" f gxgrqr " vj g" r tqlgv' qp' O Y TC" r tqr gt v\ 0''''

Vj tgg" gs wkr o gpv' v' r gu" y gtg' eqpukf gtgf " kpenwf kpi " wkrk\ kpi " vcf kkp' cpi' Mcr rcp" wtdlpgu" y kj " gky gt " hzgf " qt" cf lwxcdng" twppgt" drcf gu. " wulpi " etquihqy " wtdlpgu. " cpf " wkrk\ kpi " r wo r u" cu' wtdlpgu" *RCV+ " " kq0" cp" qtf kpct { " r wo r " twppkpi " kp' t' gxtug+0'' RC Vu' y gtg' r tgrko kpct { " ugrgevf " hqt" vj g" r wtr qug" qh' vj g" hgcukdkk\ " uwvf { =j qy gxgt. " cf f kkp' cpi' eqpukf gtcvqp" y knidg' i kxgp" vq" vcf kkp' cpi' wtdlpgu' kp" vj g' f guki p' r j cug0''''

Vj g" r tghgttgf " cngtpcvkg" kpenwf gu" wkrk\ kpi " c" ukpi ng" RCV" vj cv' wugu" c" f guki p" j gcf " qh' : 6" hggv' cpf " c" f guki p" hqy " qh' 8" o i f 0'' Vj g" r tqr qugf " gs wkr o gpv' y qwf " i gpgtcvg" c" r gcm' r qy gt " qh' cr r tqzko cvgn\ " 72" mY " qh' r qy gt" cpf " r tqf weg" cr r tqzko cvgn\ " 5; 8.222" mY j " qh' gpgti { " f wtkpi " cp" cxgtci g" { gct0''''

I \ C" guko cvgf " vj g" vqcn' equv' qh' f gxgrqr kpi " vj g" r tghgttgf " cngtpcvkg. " kpenwf kpi " guko cvgf " gpi kpggtkpi " equu" " *dw' pqv' kpenwf kpi " r gto wulpi " equu+ " vq" dg" cr r tqzko cvgn\ " &822.2220' O Y TC" ku" cy cklpi " vj g" cppqwp' go gpv' qh' vj g" O cuuEGE" i tcpv' cy ctf u. " vq" gxcnvcg" o qxkpi " vj g" r tqlgv' hqty ctf " vq" vj g' f guki p' r j cug0''''''

Key Capabilities

- Hydropower Feasibility Studies
- Hydropower Project Design
- Dam Safety Inspection and Engineering
- Environmental Studies
- Permitting

HYDROPOWER ENGINEERING SERVICES

I \ C "I gqGpxkqpo gpvcn" kpe0 j cu" dggp" r tqxkf lpi " ugtxlegu" vq" vj g" j { f tqr qy gt" kpf wwt { "hqt" f gecf gu0" Vj g" j { f tqr qy gt" kpf wwt { "ku" c" o wnk/ f kuekr nkpct { "ugevqt." cpf " I \ C" ku" c" o wnk/ f kuekr nkpct { "ht o 0" Qy pgtu" qh" j { f tqgrgevtle" f co u" j cxg" nqpi "eqwpvgf" qp" I \ C ai" gzvgpukxg" gzt gtlpep" kp" vj g" hgrf u" qh" f co " gpi kpggt lpi " cpf " j { f tqnqi { "vq" cuukv" vj go " kp" eqput vevkpi . " tgr ctkpi . " cpf " o clpvc kpi " vj gk" unt wewt gu0" I \ C" ku" cnuq" r tqxkf lpi " y kf gt" ugtxlegu. " kpenw lpi " r gto kvlpi . " gpxkqpo gpvcn" uwf lgu. " cpf " gxgp" vj g" f guki p" qh" pgy " qt" tgi cdtkxcvgf " uo cmj { f tqgrgevtle" hcekrklgu0"

< nXfcY YWf j WGH X j Yq UbX' 8 Yq j b' "

I \ C" ecp" r gthqto " c" hwm t cpi g" qh" uwf lgu" cpf " f guki p" cumi" vq" cuukv" kp" vj g" cuuguu gpv" cpf " f gxgnr o gpv" qh" j { f tqr qy gt" r tqlgeu" ht qo " eqpegr vqp" vq" eqo o kuukqkpi <

- Rtgrko kpct { "Tguqwtg" Cuuguu gpv"
- Hgcukdkkx { "Uwf { "
- J { f tqnqi { "Cpcn" uku"
- Vwdkpg" Ugrgevkp"
- Hkpcn" F guki p"
- F co " cpf " Ekxkl" Utwewtg" Wf i tcf g" F guki pu"
- Eqput vevkq/ Rj cug" Ugtxlegu"

DYfa jhtb["

I \ C" wpf gtucpf u" vj cv" r gto kvlpi " ecp" qhgp" dg" vj g" dki i guv" ej cmepi g" vq" uweeguu hwm { " dtlpi lpi " c" j { f tqgrgevtle" r tqlgev" qp/ nkg0" " I \ C" ecp" i wkf g" c" erkgpv" vj tqwi j " vj g" Hgf gtcn" Gpgti { "Tgi wrcvt { "Ego o kuukq" *HGT E+ " nkgpukpi " r tqeguu" d { " r tqxkf lpi " vgej plecn" gpxkqpo gpvcn" cpf " htkpi " r tgr ctv kq" ugtxlegu" cmj vj g" y c { " ht qo " vj g" Rtgrko kpct { "Rgto k" cr r nkgv kq" vj tqwi j " vj g" Nkgpug" qt "Gz go r vqp" r tqeguu0" " Nqecn" r gto ku" ctg" ko r qtcvpv" vq. " cpf " I \ C ai" gzt gtlpep" kp" f gcnkpi " y kj " o wnk/ ci gpe { " r gto kvlpi " ukwcvkpu" ku" kpxcnwcdng" hqt" uwej " r tqlgeu0"

@ f j Y h c' Ga U' "

I \ C" j cu" r tqxkf gf " gpi kpggt lpi " ugtxlegu" cv" r tqlgeu" ht qo " ; 22" O Y " vq" 62" nY " kp" uk g0" Y g" wpf gtucpf " vj cv" gcej " r tqlgev" j cu" c" wpls wg" ug v" qh" ej cmepi gu" cpf " qr r qt wplkgu0" I \ C" j cu" ng { " npqy ngf i g" cdqw" vj g" r ctvewrt " kuuwgu" kpxqkxg" y kj " tgf gxgnr lpi " j { f tqr qy gt" cv" gzt kvlpi " f co u0" Y g" ctg" r tgr ctgf " vq" y qtni y kj " erkgpv" qp" c" y kf g" t cpi g" qh" r tqlgev" ukgu" cpf " r tqlgev" uecrgu0" Qwt" i qcn" ku" vj g" gr " dtlpi " erkgp. " tgpvy cdng. " equv" ghg v kxg" r qy gt" qp/ nkg" kp" c" y c { " vj cv" dggpghu" vj g" qy pgt. " vj g" gpxkqpo gpv. " cpf " vj g" pcv kpp0"

Project Highlights

- DfcdcgYX'%*_K`ga U`
 \ nXfcdck Yf`dfc`YVW
- Gi VVWggZ ``mdfcj JXYX`
 gYj YfU`UgdYVWg`cZ; N5Ej`
 Yb[]bYYf]b[`UbX`gVYbHjZW
 gYfj JWG`]bWi X]b[ `.
 \ nXfc`c[ nX nXfUi `VWgZ
 k YhUbX`UbX`Uei UhjW
 \ UV]HuHjUggYgga YbH`UbX`
 VVj]`Yb[ ]bYYf]b[ `.
- Gi VVWggZ ``mi`Ugg]ghYX`H`Y`
 W]Ybh]b[]Yh]b[`Ub`A H7`
 : YUg]V]`JmZ8 Yg]] bZUbX`
 7cbglfi VVjcb`; fUblg`
- : 9F7`9I Ya dhjcb`
 Udd`JWUjcb`dfcVWgg`
 i bXYfk Uri

Dt{ qp'Y guvqp'O kniF co 'P q04'J { f tqgrgevtle'Rt qlgev' F CNVQP.'O CUUCEJ WUGVVU'

Etcpg"("Eq0'ku'yj g"qy pgt"qh'c'pwo dgt"qh'f co u'qp'yj g"GcuV'Dtcpej "qh'yj g"
J qwucvqple"Tkxgt0"Vj gug'f co u'ctg"cuuqekcvgf"y kj "Etcpg/qy pgf"r cr gt"
o kmu'yj lej "ctg"cf lcegpv"vq"vj g"tkxgt0"Vj g'f co u'y gtg"qtki kpcmf"dwkm"vq"
rtqxf g'y cvgt"cpf"j { f tqo gej cplecnr qy gt"vq"vj g'pgctd{ "o kmu'dwi' gpgtcmf"
pq"npi gt"ugt xg"cp{ "hwpexqp"tgrcvf"vq"o km'qr gtcvqpu0" "Etcpg"("Eq0'
gpi ci gf"l \ C"vq"cuukv'lp"gzr nrtkpi "vj g'r quukdkk{ "qh'wr i tcf kpi "vj g'gz kuki "
hckkkgu" cv' qp"gt" dqj "qh' yj g" D{tqp" Y guvqp" F co u" vq" r tqxf g" hqt"
j { f tqgrgevtle'i gpgtcvqp0'
"

D{tqp"Y guvqp"O kniF co "P q0'3"ku'yj g"htvj guv'wr utgco "f co "qy pgf"d{ "
Etcpg"qp"vj g"GcuV'Dtcpej "qh'yj g"Tkxgt."cpf"ko r qwpf u'Egpgvt"Rqpf 0"Vj g"
twp/qh'yj g/tkxgt"f co "ku'cp"ctej gf"uvpg"o cuqpt{ "utvewtg0"D{tqp"Y guvqp"
O kniF co "P q04"ku'c"eqpetvg"cpf"uvpg"o cuqpt{ "twp/qh'yj g/tkxgt"ctej "f co "
lwv'f qy pntgco "qh'F co "P q030"
"

I \ C"eqo r ngvf"cp"lpkkn'tguqwtg"cuuguuo gpv'uwf{ "lp"4229'yj lej "hqt o gf"
vj g'dcuku'qh'cp"cr r nccvqp"vq"vj g'O cuucej wugwu"Vgej pqrqi { "Eqmcdqtcvkg"
*O VE+"Hgcukdkk{ "I tcpv'cr r nccvqp0"Vj g"i tcpv'y cu'cy ctf gf"cpf"l \ C"
rtgrctgf" c" hwn' Hgcukdkk{ "Uwf{ "vq"htvj gt"lp xguki cvg"vj g'r qvgpvkn'hqt"
j { f tqr qy gt"i gpgtcvqp"cv'qp"gt"dqj "f co u'dcugf"qp"vj g'cxckrdng"j gcf."
cxckrdng"hty."cpf"rj { ulecn'eqphi wtcvqp"qh'yj g'hckkkgu0"l \ C"r tqxf gf"
vgej plectn' cpf" geqpqo ke" cuuguuo gpv' qh' j { f tqr qy gt"i gpgtcvqp" cpf"
fgxgnr gf"cp"qr vko k gf"eqphi wtcvqp"yj lej "o czko k gu"Etcpgau'tgwtp"qp"
lp xguo gpv0"l \ C"cuq"lp xguki cvgf"r qvgpvkn'gpxkqpo gpvncpf"tgi wrcvt{ "
eqpuk gtcvqpu'eqppgevgf"y kj "lpucmvqp"qh'j { f tqr qy gt"i gpgtcvqp"cv'yj g"
ukg0"l \ C"etgcvgf" c"eqpegr v'ngxgn'f guki p"ht"vj g'r tghgtgf"j { f tqr qy gt"
cngtpcvkg0'
"

Vj g'tguwn'qh'yj g"Hgcukdkk{ "Uwf{ "rtqegui'cu'vj g'ugrgevp"qh'c"rtghgtgf"
cngtpcvkg"lp xqkpi "lpucmvqp"qh'j { f tqr qy gt"i gpgtcvqp"gs wkr o gpv'cv"
D{tqp"Y guvqp"F co "P q0'40"Vj ku'cngtpcvkg"y cu'ugrgevgf"dcugf"qp"r qy gt"
i gpgtcvqp"r qvgpvkn'cxckrdk{ "qh'gz kuki "lphcutwewtg."cpf"hxqtedng"
r gto kuki "eqpf kkpui0"Vj g'gzr gevfg"j { f tqr qy gt"i gpgtcvqp"r qvgpvkn'ku"
398"nY 0"Vj g'vqcn'cppwcn'gpgti { "qwr w'ht"vj g'hckkk{ "y cu'guko cvgf"cv"
cr r tqzko cvgn{": 59"O Y j "fwtkpi "cp"cxgtci g"hty" { gct0"l \ C"rtgrctgf"cp"
O VE"F guki p"cpf"Eqpntwvqp"l tcpv'cr r nccvqp"ht"vj g'r tqr qugf"rtqlgev"
cpf"Etcpg"y cu'cy ctf gf"&722.2220"Y kj "O VE"pqy "TGV+"cuukcpeg."vj g"
rc{dcenir gtkf"ku'gzr gevfg"vq"dg"cr r tqzko cvgn{ "8" { gct0'
"

I \ C"cuukvgf"Etcpg"y kj "fgxgnr kpi "c'r ncp'ht'uwf{ kpi "vj g'y cvgt's wcrk{ 0"
I \ C"ku'ewtgpw{ "hpkuj kpi "vj g'f tch'gzgo r vqp"cr r nccvqp"cpf"vj g'hk{ "
r gtegpvf guki p'f tcy kpi u0"
"

Alden Laboratories

Modeling & Consulting

Alden has been conducting physical hydraulic model studies since 1894 to solve flow problems for utilities, engineering firms, the federal government, and vendors of hydraulic equipment. More recently, Computational Fluid Dynamics (CFD) has become a reliable, cost-effective tool for solving many complex hydraulic, hydrodynamic, and heat and mass transfer problems. This unique combination of computational expertise with over a century's worth of experience in physical flow modeling can be applied in concert to provide cost-effective, practical solutions to your flow problems.

Projects in this service area are generally categorized as follows:

- Hydropower intakes
- Pump intakes
- Flood and drainage canals
- Spillway and discharge systems
- Fish passage facilities
- Complex piping systems
- Wastewater and stormwater systems
- Hydrokinetic technologies

The above mentioned flow modeling techniques provide a cost effective means to evaluate the performance of hydraulic facilities before they are constructed. The cost of the modeling effort is almost always recovered through improved operating efficiency and longer equipment life.

"If I need a physical model, they're the first people I think of." - *Lloyd Fitzpatrick, Vice President, Burk-Kleinpeter*

"They'd be the only people I'd consider. You don't mess around with something that works. We have established such a good working relationship. I know that if there was a problem, I could pick up the phone and get it resolved quickly." - *Edmond Pepper, Vice President, Pepper & Associates*

Alden Laboratories

Hydrokinetic Turbine Testing, Evaluation, and Optimization

Alden uses Computational Fluid Dynamics (CFD) and its large physical test facilities to study biological, hydraulic, and engineering details of ocean energy and hydroelectric systems. Various-sized flumes and tanks allow physical evaluation of large equipment in static or flowing water.

The recent excitement about ocean renewable energy has led to a spike in venture capital funding. There are many small companies developing hydrokinetic technologies, but as with wind power, only a few are likely to remain in the market after the initial development phase. **How will you make sure your technology withstands the test of time?**

Alden is using its unique facilities to help developers test and improve their equipment. Performance, as well as mooring or mounting techniques, can be evaluated for hydrokinetic systems on full-scale prototypes or pilot-scale models. Together with highly-trained staff and state-of-the-art analysis capabilities, such testing is aiding developers to enhance and refine their designs. Assistance from Alden ranges from providing testing support to being responsible for an entire development and testing program. Our staff has decades of experience in fluid flow and machinery operation.

Laboratory Fish Testing

Detailed monitoring of fish mortality and behavior in the field is not only expensive, but fraught with technical difficulties. Laboratory testing prior to field installation can put fish protection field monitoring in the proper context and facilitate resource agency approval.

Alden is the premier source for laboratory testing of fish response and mortality for a wide range of industrial equipment, from cooling water intakes to turbines. Our flumes are used regularly for fish testing and contain the necessary infrastructure for upstream injection and downstream collection of fish. In addition, we have extensive experience in underwater photography and videography to document fish behavior with various devices. The staff includes world renowned fisheries biologists well respected by industry and regulatory agencies alike.

World Class Test Facilities and CFD Analysis

Alden's numerous test flumes, tanks, and support facilities are available to assist in developing and optimizing the performance of your equipment. Our primary test flume is 80 ft. long X 20 ft. wide X 10 ft. deep, large enough to test most turbines at full-scale. An additional flume measures 56 ft. long X 6 ft. wide X 6 ft. deep.

Project Field Services

Field measurement is critical to feasibility determination, environmental assessment, anchoring, and system performance optimization. Alden provides experienced field oceanographic and riverine services, including bathymetry, wave height and direction measurements, current velocity measurements, water and tide level data acquisition, sediment-water interface monitoring, and biological surveys.

Large Test Flume

CFD Simulation of Full Rotor

Alden Laboratories

Field Services

Along with the technology and skills needed to take measurements in the field, Alden's engineers and biologists boast extensive experience in the application and utilization of gathered information. This powerful combination provides clients with the means to reduce both cost and time. By having application-ready data and one-stop shopping for field measurement, analysis, and feasibility studies clients reap the benefits of convenience and cost-effectiveness.

Services include:

- Hydropower monitoring and performance testing
- Bathymetry, physical oceanography, sediment sampling/coring
- Current management
- Fish sampling and tracking
- Fish passage monitoring and evaluation
- Hydroacoustics and habitat mapping
- Thermal plume studies and dye studies
- Hydrokinetic site feasibility field data/site selection
- Constructed and floating wetland evaluation
- Water intake pilot-scale testing (including §316 (b))
- Dam structural inspections
- Water quality monitoring and studies
- Cooling water condenser evaluation
- Vibration analysis
- Post-installation verification
- Debris, biofouling and silt control
- Field calibration of measurement devices

APPENDIX C
TESTING PROTOCOL

**TURBINE TESTING PROTOCOL FOR W4E
AT ALDEN LABS
MAY 20 – 24, 2013**

PREPARED FOR:
Walker Wellington, LLC.

PREPARED BY:
GZA GeoEnvironmental, Inc.

May 2013
File No. 01.171602

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Appendices

Appendix A Testing Plan Sheet

Appendix B Testing Record Sheet

TURBINE TESTING PROTOCOL

1.0 PURPOSE

1.1 TEST PURPOSE AND GOALS

The purpose of this test is to collect data on the performance of a prototype W4E turbine / generator package under controlled full-scale testing conditions. There are five (5) general goals to be accomplished through this testing:

1. Demonstrate that technologically advanced components comprising the W4E system can be effectively integrated into larger systems;
2. Validate design assumptions / predictions;
3. Quantify the overall water-to-wire efficiency of the turbine/generator package over a range of heads and flows expected to be typical of anticipated applications;
4. Obtain data on turbine / generator settings which maximize efficiency at particular heads and flows; and,
5. Identify unforeseen design and performance issues apparent during testing at an early state to allow for correction in future system iterations so as to reduce risk at later stages of technology development.

The test will be observed and documented by representatives of an independent engineering firm who will observe the testing and collect data necessary to achieve the test purpose and provide independent verification of test results.

1.2 PROTOCOL PURPOSE

The purpose of this testing protocol is to describe the methodologies and procedures to be used during testing and to describe the data to be collected to accomplish the test purpose and objectives.

1.3 TEST OBJECTIVES

Accomplishment of the five overall goals of the test will require several objectives to be met and documented during the testing procedure, as shown in Table 1:

Goal	Objective
1. Demonstrate System Integration	
	1a) Successfully install W4E turbine / generator on full-scale testing facility using simple “bolt on” methods
	1a) Successfully generate power which can be conditioned to grid-compatible energy
2. Validate Assumptions / Predictions	
	2a) Generate power at a wide range of range of flows and heads, including low heads and low flows.
	2b) Generate power under open channel conditions
	2c) Demonstrate that efficiencies presented in Preliminary Levelized Cost of Energy are achievable
	2d) Run turbine at high speeds without damage to system
3. Quantify Water-to-Wire Efficiency	
	3a) Indirectly determine power output from total turbine generator system through measurement of voltage and amperage
	3b) Compute theoretical power under test conditions and compare to actual indirectly measured power output to compute efficiency.
	3c) Apply standard efficiency losses for power conditioning equipment to compute “water-to-wire” efficiency
4. Obtain data for turbine efficiency optimization	
	4a) Optimize power output at various heads and flows through adjustments to generator engagement and blade position
	4b) Plot data to indicate relationships between efficiency and flow, head, generator engagement, and blade position
5. Identify unforeseen design and performance issues	
	5a) Record all test results, unanticipated difficulties, and conditions under which these occurred.

2.0 REFERENCES

- 1) ASME PTC 18-2011 “Hydraulic Turbines and Pump-Turbines – Performance Test Codes.” American Society of Mechanical Engineers. June 10, 2011.
- 2) “Proposal for Hydropower System and Component Model Development Assistance – W4E Hydropower Turbine” GZA GeoEnvironmental, Inc., March 22, 2013.
- 3) “Preliminary Levelized Cost of Energy Comparison – W4E Hydropower Turbine” GZA GeoEnvironmental, Inc., June 1, 2011

3.0 GENERAL TEST DESCRIPTION NARRATIVE

Personnel will make a visit to the Hooper test facility and obtain information (such as dimensions) needed to prepare for test.

Equipment and personnel will mobilize to nearby the site in advance of Testing Day 1 (Monday). On the morning of Testing Day 1, equipment and personnel will mobilize to Alden’s Hooper Test Facility and equipment will be offloaded to the test area. Equipment will be set up during the morning of Testing Day 1 and testing will begin as soon as the equipment is ready.

Testing will be performed by manipulating system variables and then recording the system parameters and resultant power. System efficiency will be calculated from the power.

The first set of tests is considered the variable head test. Flows will be maintained between 1 and 5 mgd by adjusting generator engagement. Heads will start at 8 ft and will be increased to the system maximum (approximately 28 ft). Blades and generator engagement will be adjusted to optimize efficiency. Variable head tests will be performed to collect as much data as possible at various heads, flows, and turbine/generator engagements and blade angles during the remaining time.

The second set of tests is considered the variable flow test. These tests will be performed at high heads (as close to 28 ft. as the system will allow). Flows (as controlled by generator engagement and blade position) will be varied.

If time allows, additional testing will be performed to determine the limits of the turbine. Testing will be performed to observe the maximum speed and the maximum flow that the turbine can pass.

Equipment/ test breakdown will begin no later than 1 pm on Testing Day 5 (Friday) so that all equipment and personnel are offsite at the close of business (4:30 pm).

4.0 DESCRIPTIONS OF TESTING PARTNERS, EQUIPMENT, AND FACILITIES

4.1 Testing Partners

Walker Wellington, LLC – Turbine Developer and DOE grant recipient.

Blue Water, LLC – Turbine designer and manufacturer

Alden Research Labs – Testing facilities owner and manager.

GZA GeoEnvironmental, Inc. – Independent Engineer

4.2 Turbine / Generator Equipment being Tested

The W4E is a patent-pending, direct-drive, variable force turbine/generator. The equipment generates electricity through the water dependent engagement of a ring of rotating magnets with coils mounted on a stator ring. The equipment has a passive axial control mechanism to eliminate the high static starting forces (start-up torque). This enables it to turn and produce power at lower flow rates. It is able to produce power in all flow ranges. The equipment has a variable blade pitch control mechanism to assist in maximizing power generation. This is done through the adjustment of the pitch of the turbine blades to vary head and flow.

The W4E's design may allow it to have applications at conventional low-head hydropower sites, pressurized conduits, man-made canal control structures, and open-channel discharge pipes. The W4E device may be able to address several technical challenges which currently affect the potential for hydropower generation at low-head sites, including the inability of traditional turbines to generate at very low flows and the inability of traditional turbines to generate in open channel situations. Additionally, the W4E system has the potential to be a true "bolt on" system which can function over a range of heads and flow. **Figure 1** is a rendering of the turbine/generator. **Figure 2** is a section diagram, including attachment and support details.

Figure 1. Isometric Rendering of W4E Turbine/generator.

UNLESS OTHERWISE SPECIFIED		NAME	DATE	BLUE WATER CONCEPTS	
DIMENSIONS ARE IN INCHES		M.A.		TITLE:	
TOLERANCES:		DRAWN:	CHECKED:	Turbine test layout	
FRACTIONAL ±		ENG APPR.	MFG APPR.	SIZE	DWG. NO.
ANGULAR MACH ±		O.A.	COMMENTS	A	1
TWO PLACE DECIMAL ±.02				SCALE: 1:32 WEIGHT:	SHEET 1 OF 1
THREE PLACE DECIMAL ±.002					
INTERPRET GEOMETRIC TOLERANCING PER:					
MATERIAL					
FINISH					
USED ON					
NEXT ASSY					
APPLICATION					
DO NOT SCALE DRAWING					
PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF BLUE WATER CONCEPTS. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF BLUE WATER CONCEPTS IS PROHIBITED.					

Figure 2 Turbine / Generator Unit Section Diagram

4.3 Test Facilities

Turbine testing will be performed at Alden's Hooper Test Facility at 30 Shrewsbury Street Holden, Massachusetts 01520-1843 USA. (508-829-6000 <http://aldenlab.com/>) At the Test Facility, water is conveyed from a 150 acre reservoir via a 36-inch penstock. This system can provide up to approximately 28 ft. of static head. **Figure 3** is an overview of the test facility and headpond. **Figure 4** is a section view of the testing facility showing the portions of the equipment to be supplied by Alden.

Figure 3 Overview of Alden's Hooper Test Facility

Figure 4 Section View of Hooper Test Facility

5.0 ROLES AND RESPONSIBILITIES

5.1 Responsibilities of Testing Partners

Blue Water

- Review and approve full testing plan
- Design and fabricate W4E turbine and 28-inch diameter flange to meet ASME Class 150 standards.
- Establish an installation methodology
- Mobilize equipment and personnel to perform testing at site.
- Install turbine at test facility and setup of dump load.
- Manage overall testing program
- Turbine testing
 - Perform all turbine/ generator set adjustments.
 - Perform measurements of and record flow and head.
 - Calibrate and verify instrumentation (other than head and flow)
 - Measure variables (generator engagement, blade position and rotor speed).
 - Record variables (head, flow, generator engagement, blade position and rotor speed).
 - Calculate and record power and efficiency.
 - Observe and document performance of unit
- Disassembly of W4E components and removal of components from Alden facilities.

Alden

- Review and approve aspects of testing plan related to testing facilities
- Provide testing facility, including headpond, penstock, flow controls, testing building, turbine mounting beam, and tailrace.
- Provide equipment and personnel to offload turbine equipment at site.
- Provide two technicians and one engineer to operate the facility.
- Fabricate conical reducer with ASME Class 150 flange to mate with Blue Water flange.
- Turbine testing
 - Adjust test facility valve to modify flow and head.
 - Provide calibrated sensors for head and flow and provide leads to Blue Water's 16 Channel NI DAQ bus.
 - Record head and flow and provide records to Blue Water and GZA.
- Assist Blue Water with loading turbine/generator set for demobilization.

GZA

- Develop testing plan.
- Provide an engineer to observe test.
- Turbine Testing
 - Observe and document verification of instrumentation readings
 - Manually measure and record voltage and current when levels have to corroborate automated readings
 - Manually record variables (head, flow, generator engagement, blade position and rotor speed) from automated data collection during stabilized test periods.
 - Calculate and record power and efficiency.
 - Observe and document performance of unit
- Develop “hill” curves or similar using data recorded.
- Prepare report including:
 - Description of testing protocols, data collected, observations made during testing and installation and reduced efficiency values
 - Information on the completion of testing purpose and goals.
 - Comparison of W4E with other traditional turbines and identification of potential performance problems.

5.2 Personnel

Individuals have been assigned the following responsibilities. The name of a single individual to serve in each of the following roles shall be provided prior to the start of testing. These individuals will be identified on the Testing Plan sheet in **Appendix A**.

Chief of Test (Blue Water):

- Supervise and conduct the test in accordance with ASME PTC 18-2011 and this testing plan.
- Report testing conditions and ensure computation of results and the preparation of the final report.
- Ensure that test instruments have been properly calibrated for have valid calibration documents.
- Assume responsibilities for all test measurements.
- Make every reasonable effort to ensure that any controversial matters pertaining to the test are resolved.

Test Facility Manager (Alden):

- Provide working test facility.
- Address concerns about facility performance.
- Provide engineer and staff to assist in test performance and operate Alden's facilities.

Independent Testing Field Engineer:

- Perform independent measurement of current and voltage.
- Record data as the test is performed.
- Review data to identify potential measurement errors and report potential issues to Chief of Test.

Independent Engineer Project Manager:

- Supervise reduction of data and develop "hill" curves.
- Provide written validation of test results and testing report

6.0 PRE-TEST PREPARATION

The following actions shall be undertaken in advance of mobilizing to the site:

Hold Test Planning Site Meeting – A meeting at the testing facility should be held with representatives of the turbine developer, test facility, and independent engineer. Testing objectives should be discussed, as well as preliminary testing methodologies, schedule, roles and responsibilities, control systems, instrumentation, available head and flow ranges, equipment installation requirements, and safety. All parties should visit the actual location where the turbine unit will be installed to confirm the need for and dimensions of any transition pieces, adaptors, supports, or other hardware which will be needed to connect the unit to the testing penstock and to understand potential rigging requirements.

Confirm Testing Schedule – Formally schedule the use of the testing facilities and execute any contractual documents necessary between the turbine developer and test facilities.

Develop draft and final protocol – A draft testing protocol should be developed which defines the means and methods for performing the test and identifies the responsibilities of the testing partners during the test.

Develop installation methodology- Fittings must be provided for both the penstock and turbine to allow the unit to be mounted and provided with appropriate thrust restraint.

The physical nature of the turbine/generator (i.e. not having a casing and water exiting in all directions) necessitates that the turbine be suspended from an overhead railing system. A means shall be established to stabilize and prevent movement of the equipment and to resist thrust.

Prepare safety plan (each party)- Each party shall be responsible for developing their own safety plan. Safety hazards may include, but are not limited to the following: slips, trips, falls; physical hazards; electrical shocks; heated water; cuts, scrapes, lacerations; moving machinery; rotating parts; cables and ropes; etc. A safety plan should address these and any other hazards that may be present at the site.

Develop data collection instrumentation plan and data collection sheets- A plan shall be established to collect and record data at each test interval on hydropower inputs (head and flow), the turbine / generator settings (blade position and generator engagement), and system electrical output (voltage and current). The plan should provide for automatic data collection and storage with manual verification and recording.

7.0 SCHEDULE

The testing program is scheduled for five (5) days. Typical days will begin at 8:00 am and end at 4:30 pm. The general schedule will be as follows:

Day 1:

- Pre-Test Mobilization, Meeting, and Safety Review
- Equipment Installation
- Pre-Test Inspection
- Pre-Test Instrumentation Validation and Preliminary Runs
- First Test Runs (Variable Head) and Data Collection

Days 2-4:

- Daily Inspection and Safety Review
- Test Runs and Data Collection

Day 5:

- Daily Inspection and Safety Review
- Test Runs and Data Collection, including Full Speed Tests until approx. 1:00 pm
- Equipment Breakdown, Removal, and Demobilization

Adjustments to the schedule will be made as necessary based on the actual time required to install and remove equipment and the time necessary for head and flow to stabilize during each test interval. Initial indications are that up to ½ hour may be required for each discrete test in order to allow for turbine adjustments to be made and head and flow values to stabilize sufficiently for steady-state parameter measurements to be made.

8.0 TEST PARAMETERS

The performance data being collected through the testing protocol are:

Head – Gross head is a function of the difference in elevation between the free water surface in the head pond and the centerline of the turbine. The gross head at the Hooper Testing Facility is 28 ft. Net head is measured in feet and is equal to the gross head, less headlosses. Headlosses increase as flows to the turbine increase due to pipe friction losses. Headlosses can also be artificially be created by operating the valve. Valve operations are to be performed by Alden. Test results will utilize Net Head.

Flow – Flow is measured in mgd. The amount of flow through the turbine is a function of the rotor speed and generator engagement. The amount of flow influences the net head.

Generator Engagement – Generator position/ engagement is the distance between the generator magnets and stator coil. Generator engagement will be controlled by Blue Water using manual hydraulics. Generator engagement influences rotor speed, and thus flow (which then influences head). Generator position is measured in inches and converted to percent

Blade Position – Blade position represents how open the turbine blades are. Blade position is controlled by Blue Water. It is measured in inches and then converted to percent. Blade position influences rotor speed, flow, and thus head.

Rotor Speed – Rotor speed is a measure of how quickly the turbine shaft and blades rotate. Rotor speed is a function of the generator engagement, blade position, net head and flow. It is measured in rpm.

Power – Power will be calculated by Blue Water using two methods: 1) voltage from each generator will be measured across resistive load bridges at the data acquisition bus and 2) current measured through a transducer with a known resistance. Voltage will be measured at all three generators and current will be measured at Generator 1. It is reported in kW.

Water-to-Wire Efficiency – Water to wire efficiency is equal to the amount of power produced under a given net head and flow condition divided by the amount of power that would theoretically be produced under such condition times a factor for voltage

correction. It is reported as a percent.

9.0 INSTRUMENTATION AND DATA COLLECTION

All data collection shall be performed in accordance with Section 3.6.2, Original Data, of ASME PTC 18-2011. Data shall also be maintained in accordance with the standard.

9.1 AUTOMATIC DATA COLLECTION

Calibration and verification

Measured Quantity	Sensor Type	QTY	Supplied by
Voltage (V), Frequency (Hz)	Resistive bridge	3	BWC
Current (A)	4-20mA current transducer	1	BWC
Head (ft H2O)	4-20mA pressure sensor	1	Alden
Flow (MGD)	4-20mA flow sensor	1	Alden
Blade position	4-20mA linear position sensor	1	BWC
Generator position	4-20mA linear position sensor	1	BWC
Rotor Speed (RPM)	Digital tachometer	1	BWC

Notes:

Alden will provide the head and flow sensors and provide leads to Blue Water's DAQ. The reading collected by Blue Water will use an approximate calibration curve and thus should not be considered the correct and final readings. These readings will be of sufficient quality to assist Blue Water in optimizing turbine performance during the test. Alden's readings of Head and Flow will be considered definitive.

The data will be read and stored from these sensors in real time using a 16 channel NI DAQ bus.

9.2 MANUAL DATA COLLECTION

GZA will independently take discrete measurements of the voltage and current intended for data verification. A Klein Tools CL 1000 AC clamp meter will be used and can measure up to 400 amps and 600 volts.

10.0 TEST PROTOCOL

10.1 Pre-Test Mobilization, Meeting, and Safety Briefing

On Day 1 (Monday) of the test schedule, all testing partners shall mobilize to the testing facility site at approximately 8 am. Blue Water shall be responsible for bringing the turbine/generator unit with appropriate flange and its instrumentation. Alden will have pre-fabricated the penstock transition piece for mounting of the W4E unit.

Before beginning the installation of equipment, a pre-test meeting shall be held to clarify roles and responsibilities, confirm equipment availability and configurations, discuss the schedule for the day and week, and review the testing protocol. Data collection and recording protocols should be discussed and agreed upon.

Before the meeting concludes, a safety briefing shall be held to review health and safety procedures and emergency contact information.

10.2 Equipment Installation

Equipment installation will begin after the pre-test meeting on Day 1. Alden will have already or will install additional pipe segments on its penstock such that the penstock extends outside of the testing building. Alden will have already or will install a concentric reducer with connection flange at the end of the penstock to accept the W4e unit. Blue Water will then mount the turbine/generator unit at the end of the penstock reducer, with the weight of the unit supported by tension members connected to the overhead wide-flange beam. Installation shall be as per Blue Water's installation plan and will include sufficient restraints against thrust and vibration to prevent movement of the unit under full flow and unexpected instantaneous blade closure. Note that the discharge end of the turbine is open so water spray will be expected. Test partners shall adjust the tailrace covers as needed to facilitate flow into the tailrace. Alden will provide potable water for unit bearings.

Blue Water will provide a water bath for use with three load bank heaters. Alden will provide supply water. The water bath tank should be installed in a stable location where it will not present a safety hazard but where it can be periodically inspected.

Connect instrumentation to data cables and then connect to Blue Water's multiplexer/data logger.

10.3 Pre-Test Inspection

Prior to running any flow through the system, thoroughly inspect all connections and supports for the turbine/generator unit, including but not limited to flange connection, thrust restraints, and vertical supports. Verify that the turbine/generator can freewheel and no debris is present. Confirm that the turbine blade adjustment and generator engagement apparatus are functional. The headworks area should also be visually inspected to verify pond level and confirm the absence of debris or safety hazards. All electrical wiring and connections should be inspected for safety (insulation, grounds, etc.). Confirm water for bearing lubrication is flowing. Confirm that water bath for the load bank heater is secure and water is flowing. An exclusion zone should be established and discussed to delineate areas where personnel should not be present during testing unless specifically needed.

Inspect all instrumentation and connections to data cables and data logger. Verify that all data collection systems are on and functional.

Confirm any necessary personal protective equipment and/or safety equipment is in place or available. Confirm that the site is ordered and tidy, such that trip hazards and other possible issues are minimized.

10.4 Pre-Test Instrumentation Validation and Preliminary Runs

Prior to production testing, all instrumentation should be confirmed as operational and validated as accurate. Procedure shall be as follows:

Measured Quantity	Verification Methodology
Voltage (V), Frequency (Hz)	Duplicate manual measurement with clamp meter (requires flow)
Current (A)	Duplicate manual measurement with clamp meter (requires flow)
Head (ft H2O)	Verification under static head via elevation calculations
Flow (cfs)	Alden to Verify
Blade position	Manual confirmatory measurements
Generator position	Manual confirmatory measurements
Rotor Speed (RPM)	Cross-check with frequency

All instrumentation validation shall be witnessed and documented by the independent engineer.

Verify time synchronization between Alden and Blue Water data recorders.

Preliminary turbine runs shall be performed to confirm operation and allow for instrumentation verification. Preliminary runs should be started at low flows, with Alden adjusting the regulating valve to create low flow (5 cfs or less) conditions. The turbine/generator unit should be initially configured with the blades fully closed and the generator fully engaged to act as a brake. Some minor leakage and low speed rotation is expected. Once the penstock has filled, operations can begin by slowly opening the blades to confirm free rotation and support integrity. Then the generator can be engaged to confirm power generation. Run the unit through a full range of safe turbine and blade positions prior to bringing unit back to initial position (generator fully engaged and blades fully closed).

10.5 Turbine Testing

Section 3-5.1 of ASME PTC 18-2011 states: “The tests should be conducted as closely as possible to specified operating conditions and thus reduce and minimize the magnitude and number of corrections for deviations from specified conditions. Each run shall be conducted under the best steady-state conditions obtainable at the operating point. Once a test has started, adjustments to the machine under test or the test equipment, which may affect test results, shall not be permitted. Should adjustments be deemed necessary by the parties to the test, prior runs shall be evaluated and voided if necessary and the test restarted.”

To avoid the potential for loss of data, all hardware modifications to the turbine mechanisms should be completed prior to the start of production testing runs on Day 1. During the testing process prior to data collection, Blue Water will make adjustments to blade position and generator engagement while collecting real-time data via a computer “efficiency gage” application for the purpose of “optimizing” efficiency at various positions. Because of the multiple correlated variables, exact incremental changes may not be possible. Test data collection for recording purposes will be started when Blue Water designates that a blade / generator position combination has been achieved which “maximizes” efficiency under a particular set of head and flow combinations. It is the intent of Blue Water, that a PLC will be used in production units which will automatically make similar adjustments.

Changes to the valves will be made by Alden personnel at the direction of Blue Water. Data collection shall only start once Blue Water has completed its adjustments to both blade position and generator engagement and all parties have agreed that steady state conditions with respect to flow, head, rotational speed, and power output have been

achieved. The time to achieve steady state may vary. Once all parties have agreed that steady state has been achieved, the time will be noted and conditions maintained and data collected for a minimum of 2 minutes. Steady state is defined in ASME PTC 18-2011 as follows:

- (a) Variations in measured speed should not exceed $\pm 0.5\%$ of the average speed measured.
- (b) Variations in measured head should not exceed $\pm 1.0\%$ of the average head measured. (While not specified, flow variation limit should be similar).
- (c) Variations in measured power output or input should not exceed $\pm 1.5\%$ of the average measured power.

10.5.1 Reduced Head / Variable Flow

The first series of tests shall be conducted under reduced head. Net head shall be reduced by Alden by adjusting the control valve. Head losses will occur as water flows through the control valve upstream of the unit (and upstream of the pressure transducers). Head losses and flow are correlated so one will change in response to a change in the other until steady state is achieved. Changes to the blade and generator positions will also affect head and flow. Data collection under this series of test should be as systematic as possible but will necessarily involve some variation in all parameters.

Testing will begin with the unit in the initial position as defined above. Alden will adjust the control valve to a position which will result in a low flow rate (in the range of 1 to 5 mgd). Open the blades to position which results in slowest rotational speed and then change generator engagement while monitoring "efficiency gauge" until peak efficiency is reached. Allow system to reach steady state as defined above then begin test data collection to obtain discrete data point

Incrementally change blade position and generator engagement. Alden will then adjust the control gate to attempt to maintain flow at rate near the initial data point. Repeat process to obtain additional data points at full range of blade positions (up to a flow rate of approximately 20 MGD).

Repeat full test series at least once at the approximate first flow rate interval. Upon completion, repeat test series with control valve adjusted to increase flow rate by approximately 5 MGD for each series. Testing shall continue on Days 1, 2, & 3 with as much data collected as possible.

Note that if adjustment process is found to be too difficult or time consuming then process may be changed such that no adjustments are made to the control valve during each series of test. The control valve will remain in a fixed position through a full range of blade positions, and flow will be allowed to vary more substantially.

10.5.2 Full Head / Variable Flow

The next series of tests will be conducted with the head pond in as full a condition as possible and will be conducted with the head gate and control valve fully open. This condition will provide for as close to a full and constant net head as possible. There will be some minor variation due to increasing losses as flow increases. Static head will be approximately 28 feet.

Testing will begin with the unit in the initial position as defined in Section 10.4. Open the blades to position which results in slowest rotational speed and then change generator engagement while monitoring “efficiency gauge” until peak efficiency is reached. Allow system to reach steady state as defined above then begin test data collection to obtain discrete data point.

Incrementally change blade position and repeat process to obtain additional data points at full range of blade positions (up to a flow rate of approximately 20 MGD).

Repeat “Full Head / Variable Flow” full test series at least once and possibly twice as time allows during Day 4.

10.5.3 Repeat Reduced Head / Variable Flow

On Day 4 or 5 repeat the reduced head / variable flow test series for 1 or 2 flow rates (as time allows) to assess potential changes in efficiency from “wearing in” of the bearings.

10.5.4 Open Channel Test

Day 5, Alden will adjust the control valve to create flow conditions that result in open channel flow in the penstock downstream of the valve with maximum turbine blade opening. Run at least one test under partial flow conditions in the penstock to demonstrate that power can be generated under open channel flow conditions.

10.5.5 Full Speed Test

Mid-day on Day 5, immediately before demobilization, make a “full speed test” to measure “runaway” speed under full head. Start with unit in initial position. Adjust blades to produce maximum rotational speed and slowly disengage generator. Stop test immediately if excessive vibration or other distress is noted.

10.6 Test Period Monitoring

During all periods of unit operations, all data from the instruments shall be recorded. The time at which a data point measurement period begins shall be recorded. The Independent Engineer shall be given access to all data readings and allowed to manually record readings prior to the end of the test period. The Independent Engineer shall also be allowed to take manual readings as necessary to supplement/verify the automated readings.

Periodically during the unit operations, all equipment should be visually inspected and photographed. Indications of distress, unusual pressure conditions, or other unanticipated conditions should be noted and documented. In the event of unexpected conditions, test procedures may be modified to accommodate or further investigate the circumstances.

10.7 Daily Shutdown

Working hours at the test facility terminate at 4:30 pm. Daily shutdown should begin at 4:15 so that shutdown can be complete and all personnel offsite by 4:30. Shutdown activities include taking actions to prevent the turbine from engaging during off-hours. Alden should close the valve to empty the penstock and prevent flow through the pipe and turbine. Alden should restrict access to the valve so that operation is not performed by someone who is not authorized to operate the valve.

Blue Water should set the turbine blade in the closed position to prevent flow through the turbine should the valve fail or accidentally be opened. Blue water should also disengage the generators completely so that electricity cannot be generated.

10.8 Daily Startup

Working hours at the test facility begin at 8:00 am. The first action item of the day should be to review the safety plan and determine if conditions encountered during the prior day warrant any changes in health and safety procedures. The second daily setup activity

shall include setting up the head load dump for the generated electricity. Alden shall supply Blue water with flowing water at the start of each day to serve as the heat load dump.

Daily startup activities shall also include assessing the condition of the turbine/generator and confirming that the condition appears suitable to continue testing (i.e. there has not been such excess wear and tear such that operation of the turbine/generator would be dangerous.

10.9 Grid-Ready Power Demonstration

Grid ready power demonstration will be performed by recording the voltage generated by the turbine/generator set during the testing. After the test, the recorded voltage will be compared with rectifiers in order to confirm that there is available equipment on the market that is capable of rectifying the power as needed to become grid ready.

10.10 Post-Test Breakdown/ Demobilization

Post-test demobilization / break down will begin at 1:00 pm on Friday, May 24, 2013 to ensure that all personnel and equipment are offsite in advance of closing at 4:30 pm. Alden shall close the valve to prevent flow. Blue Water is responsible for unbolting the turbine/generator from the penstock and removing supports. Alden will assist Blue Water with loading the turbine/generator onto a vehicle for removal from the site. Blue Water is responsible for removing all of its equipment and personnel from the site in advance of closing.

11.0 POST-TEST DATA REDUCTION AND REPORTING

11.1 Data Reporting / Recording

Data will be recorded in the field on the attached Testing Record Sheet (see **Appendix B**). Data will simultaneously be entered into a spreadsheet to retain an electronic copy of the data and allow for calculation of power and efficiency. The raw data (on the signed hand written sheet) will be included in the final report on the turbine testing.

11.2 Data Reduction

Preliminary data reduction will be performed in the field as the data become available. This will be done to assess if the test is performing as expected and identify potential anomalies or test errors. It will also aid the test operators in performing subsequent tests and identifying the operating parameters under which the turbine performs best. Reduction will be performed by entering the data into a spreadsheet, calculating the

power and efficiency and plotting the power and efficiency as a function of head and flow (under the various blade position and generator engagement conditions).

Data reduction will continue in the office once the tests are complete and unusable tests are removed from the dataset. The reduced data will be used to develop “hill” curves or similar for the turbine generator set.

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Appendix A

Testing Plan

HYDROTURBINE TESTING PLAN

1.0 TEST TURBINE INFORMATION

Describe actual unit installed at testing facility.

TURBINE MANUFACTURER: _____

TURBINE MODEL: _____

TURBINE SERIAL #: _____

TURBINE FAMILY: REACTION / IMPULSE / OTHER: _____

TURBINE TYPE: _____

TURBINE DIAMETER: _____

TURBINE ALIGNMENT: VERTICAL / HORIZONTAL / INCLINED: _____

GENERATOR TYPE: SYNCHRONOUS / INDUCTION

CURRENT: DC / AC: _____

GENERATOR NAMEPLATE CAPACITY:

TURBINE / GENERATOR CONNECTION:

2.0 TEST PERSONNEL

Identify names of personnel assigned to roles defined in Section 5.2 of the Testing Protocol.

TURBINE DEVELOPER: _____

CHIEF OF TEST:

TEST FACILITY: _____

TEST FACILITY MANAGER:

INDEPENDENT ENGINEER: _____

PRINCIPAL IN CHARGE

PROJECT MANAGER

DATA ANALYSIS ENGINEER

FIELD ENGINEER

3.0 PRE-TEST PREPARATION DOCUMENTATION

DATE OF TEST PLANNING SITE MEETING: APRIL 9, 2013

DATE OF START OF TESTING: MAY 20, 2013

DATE OF END OF TESTING: MAY 24, 2013

☐ FINAL TESTING PROTOCOL ATTACHED

☐ FINAL EQUIPMENT INSTALLATION METHODOLOGY ATTACHED

☐ SAFETY PLANS ATTACHED: _____

☐ SAMPLE DATA COLLECTION SHEETS ATTACHED

Appendix B
Testing Record Sheet

FIELD DATA SHEET
W4E TURBINE TESTING
(5/20/2013- 5/24/2013)

	Test No.	1	2	3	4	5	6
	Date						
	Time						
Hydropower Driver	Head (ft)						
	Flow (cfs)						
Equipment Settings	Generator Position (inches)						
	Blade Position (inches)						
Automatic Measurements	Rotor Speed (from proximity swich) (rpm)						
	Rotor Speed (off voltage lead) (rpm)						
	Generator 1 Voltage (volts)						
	Generator 2 Voltage (volts)						
	Generator 3 Voltage (volts)						
	Generator 1 Amperage (amps)						
Manual Measurements	Generator 1 Voltage (volts)						
	Generator 2 Voltage (volts)						
	Generator 3 Voltage (volts)						
	Generator 1 Amperage (amps)						
	Generator 2 Amperage (amps)						
	Generator 3 Amperage (amps)						
Calculations	Theoretical Power						
	Power (across load bridges) (kW)						
	Power (through current transformer) (kW)						
	Turbine/ Generator Efficiency (based on Power 1) (%)						
	Turbine/ Generator Efficiency (based on Power 2) (%)						

Notes:

Theoretical Power = Q X H (ft)/ 11.81 kW
Turbine/ Generator Efficiency = {Calculated Power/ Theoretical Power} X Inverter Losses
Power Across Load Bridges = (V₁²/ R) + (V₂² / R) + (V₃² / R)
Power Through Current Transformer = I₁ x (V₁ + V₂ + V₃)
(Assumes generators are wired in servies and voltage is additive)
Where:
Q = Flow (cfs)
H = Head (ft)
V_# = Voltage Measured Across Resistive Load Bridge #
R = Resistance of Load
I_# = Current Measured at Transformer #

APPENDIX D
PHOTOLOG

W4E TURBINE TESTING PHOTOLOG

Figure 1. Alden Facility 28" Penstock

Figure 2. Alden Facility Head Pond

W4E TURBINE TESTING PHOTOLOG

Figure 3. Head Pond Inlet to Penstock

Figure 4. Penstock Pressure Gauge Tap

W4E TURBINE TESTING PHOTOLOG

Figure 5. W4e Turbine Blade View Prior to Connection to Penstock

Figure 6. W4e Runner with Nose Cone Removed and Blade Spring Exposed

W4E TURBINE TESTING PHOTOLOG

Figure 7. Blade Mount Looking Upstream at Runner

Figure 8. W4e Flange Mounted to Penstock

W4E TURBINE TESTING PHOTOLOG

Figure 9. Thrust Bearing and Hydraulic Generator Engagement Cylinder

Figure 10. Hydraulic Blade Pitch One-Way Control Cylinder
(Prior to Replacement with Double-Acting Cylinder)

W4E TURBINE TESTING PHOTOLOG

Figure 11. Manual Hydraulic Testing Controls

Figure 12. Bearing Lubrication Water Lines

W4E TURBINE TESTING PHOTOLOG

Figure 13. Generators in Disengaged Position

Figure 14. Data Acquisition Center

W4E TURBINE TESTING PHOTOLOG

Figure 15. Water Load Bank Tank

W4E TURBINE TESTING PHOTOLOG

Figure 16. Current and Volt Clamp Meters

Figure 17. Electrical Instrument Used

APPENDIX E
TURBINE TESTING DATA

GZA Data			Hydropower Driver (Field Recorded)				Equipment Settings (As Measured by Blue Water Sensors and Manually Recorded by GZA)						Blue Water Measurements (As Manually Recorded by GZA)	
Test No.	Date	Time	Alden Head (psi)	Alden Head (ft)	Alden Flow (mgd)	Alden Flow (cfs)	Generator Position (Volts)	Blade Position (volts)	May 30th Generator engagement (% engaged)	May 30st Blade Pitch (% Open)	May 31st Generator engagement (% engaged)	May 31st Blade Pitch (% Open)	Frequency (Hz)	Rotor Speed (rpm)
1	5/30/2013	10:29	-	-	1.94	3.00	2.15	2.1	0.67	2.15			84	128
2	5/30/2013	10:37	4.1	9.5	2.35	3.64	2.15	2.1	0.67	2.15			91	138
3	5/30/2013	10:45	5.8	13.4	2.65	4.10	2.15	2.1	0.67	2.15			95	145
4	5/30/2013	10:52	7.3	16.8	2.98	4.61	2.15	2.09	0.67	3.23			103	156
5	5/30/2013	11:00	8.66	20.0	3.30	5.10	2.14	2.08	1.33	4.30			121	184
6	5/30/2013	11:11	8.7	20.1	3.30	5.10	1.79	1.7	24.67	45.16			116	176
7	5/30/2013	11:20	8.7	20.1	3.30	5.10	1.93	1.87	15.33	26.88			115	175
8	5/30/2013	11:27	8.7	20.1	3.30	5.10	2.15	2.07	0.67	5.38			117	178
9	5/30/2013	11:44	8.1	18.7	3.55	5.50	2.13	2.05	2.00	7.53			125	190
10	5/30/2013	11:51	10.2	23.5	3.88	6.00	2.14	2.05	1.33	7.53			132	200
11	5/30/2013	11:59	12	27.7	4.23	6.54	2.16	2.09	0.00	3.23			147	224
12	5/30/2013	12:05	13.02	30.0	4.14	6.40	1.95	1.87	14.00	26.88			118	180
13	5/30/2013	12:10	12.46	28.8	4.19	6.48	1.74	1.67	28.00	48.39			145	220
14	5/30/2013	12:17	14.83	34.2	4.60	7.12	1.7	1.65	30.67	50.54			155	235
15	5/30/2013	12:25	14.73	34.0	4.61	7.14	1.7	1.65	30.67	50.54			161	245
16	5/31/2013	9:42	3.92	9.0	3.81	5.90	3.18	2.06		6.45	0.00	2.08	132	200
17	5/31/2013	9:49	4.67	10.8	2.82	4.37	2.12	2.06		6.45	41.25	2.08	92	140
18	5/31/2013	10:00	7.3	16.8	3.51	5.43	2.02	2.05		7.53	45.14	3.13	118	180
19	5/31/2013	10:10	10.78	24.9	4.07	6.30	1.911	2.05		7.53	49.38	3.13	137	208
20	5/31/2013	10:25	12.18	28.1	4.43	6.85	1.89	2.05			50.19	3.13	155	235
21	5/31/2013	10:39	6.21	14.3	4.11	6.36	1.9	1.75			49.81	34.38	114	173
22	5/31/2013	10:48	8.07	18.6	4.32	6.69	1.82	1.75			52.92	34.38	121	184
23	5/31/2013	10:56	9.89	22.8	4.87	7.54	1.79	1.75			54.09	34.38	132	200
24	5/31/2013	12:03	0.91	2.1	7.41	11.47	3.11	1.4			2.72	46.67	76	115
25	5/31/2013	12:12	5.08	11.7	6.86	10.62	2.33	1.45			33.07	43.33	112	170
26	5/31/2013	12:19	6.18	14.3	7.00	10.83	2.2	1.5			38.13	40.00	114	174
27	5/31/2013	12:27	9.79	22.6	6.55	10.14	2.13	1.51			40.86	39.33	112	170
28	5/31/2013	13:46	6.38	14.7	4.52	6.99	3.09	1.53			3.50	31.65	155	235
29	5/31/2013	13:52	8.76	20.2	5.00	7.74	2.88	1.55			11.67	30.22	159	242
30	5/31/2013	14:00	11.35	26.2	5.42	8.39	2.83	1.46			13.62	36.69	161	245
31	5/31/2013	14:12	11.57	26.7	5.95	9.21	3.25	1.04			-2.72	66.91	184	280

Notes:

¹ Power as Measured Across a Resistance Load Bridge (V^2/R)

² Total Power as Measured Across Load Bridges = (V_1^2 / R) + (V_2^2 / R) + (V_3^2 / R)

³ Power as Measured Through a Current Transformer ($I \times V$)

⁴ Total Power As Measured Through Current Transformer = $I_1 \times (V_1 + V_2 + V_3)$

⁵ GZA utilized a clap meter to take manual measurements to validate the readings provide by Blue Water's DAQ (during the testing). In general, GZA's average power estimate was within 1 percent, with some exceptions.

⁶ Turbine/ Generator Efficiency = (Calculated Power/ Theoretical Power)

Where:

Q = Flow (cfs)

H = Head (ft)

V_R = Voltage Measured Across Resistive Load Bridge #

R = Resistance of Load

I_R = Current Measured at Transformer #

GZA Data			Manual Measurements for Power Calculation (Performed and Measured by GZA) ⁵						GZA Calculation of Power (Based Upon GZA Measurements of Voltage and Amperage) ⁵							
Test No.	Date	Time	Generator 1 Voltage (volts)	Generator 2 Voltage (volts)	Generator 3 Voltage (volts)	Generator 1 Amperage (amps)	Generator 2 Amperage (amps)	Generator 3 Amperage (amps)	Generator 1 Power ¹ (W)	Generator 2 Power ¹ (W)	Generator 3 Power ¹ (W)	Total ² Power (W)	Generator 1 Power ³ (W)	Generator 2 Power ³ (W)	Generator 3 Power ³ (W)	Total ⁴ Power (W)
1	5/30/2013	10:29	6.66	11.07	10.24	4.32	7.06	6.46	28	77	66	170	29	78	66	173
2	5/30/2013	10:37	8.42	14.02	12.91	5.54	9.2	8.53	44	123	104	271	47	129	110	286
3	5/30/2013	10:45	10.87	18.48	16.85	7.21	12.06	11.15	74	213	177	465	78	223	188	489
4	5/30/2013	10:52	13.36	22.92	21.21	9	15.42	14.22	112	328	281	721	120	353	302	775
5	5/30/2013	11:00	15.6	26.83	25.19	10.6	18.38	17.33	152	450	397	999	165	493	437	1095
6	5/30/2013	11:11	14.9	25.16	23.54	10.07	17.02	16.09	139	396	346	881	150	428	379	957
7	5/30/2013	11:20	15.44	25.77	24.2	10.61	17.76	16.34	149	415	366	930	164	458	395	1017
8	5/30/2013	11:27	15.02	25.42	23.84	10.3	17.54	16.23	141	404	355	900	155	446	387	987
9	5/30/2013	11:44	16.91	28.57	26.82	11.78	19.58	18.42	179	510	450	1138	199	559	494	1253
10	5/30/2013	11:51	19.65	33.62	31.91	13.75	23.1	21.91	241	706	636	1584	270	777	699	1746
11	5/30/2013	11:59	21.55	37.2	35.19	15.52	25.93	24.6	290	865	774	1929	334	965	866	2165
12	5/30/2013	12:05	23.28	37.4	35.52	16.13	25.18	24.18	339	874	789	2001	376	942	859	2176
13	5/30/2013	12:10	22.42	38.02	35.82	15.8	26.44	24.93	314	903	802	2020	354	1005	893	2252
14	5/30/2013	12:17	25.6	41.6	39.3	17.11	28.75	27.15	410	1082	965	2457	438	1196	1067	2701
15	5/30/2013	12:25	25.6	42.6	40.3	18.16	29.84	28.4	410	1134	1015	2559	465	1271	1145	2881
16	5/31/2013	9:42	4.47	7.14	6.62	3.11	4.84	4.5	12	32	27	72	14	35	30	78
17	5/31/2013	9:49	11.55	19.25	17.82	7.59	12.69	11.85	83	232	198	513	88	244	211	543
18	5/31/2013	10:00	16.2	27.28	25.6	11.07	18.5	17.47	164	465	410	1039	179	505	447	1131
19	5/31/2013	10:10	20.93	35.53	33.41	14.7	24.51	23.4	274	789	698	1760	308	871	782	1960
20	5/31/2013	10:25	23.58	39.67	37.49	16.63	27.63	26.27	348	984	878	2210	392	1096	985	2473
21	5/31/2013	10:39	18.18	30.3	28.71	17.57	20.55	19.61	207	574	515	1296	319	623	563	1505
22	5/31/2013	10:48	21.2	34.6	32.82	14.7	23.64	22.62	281	748	673	1702	312	818	742	1872
23	5/31/2013	10:56	23.4	38.06	36.33	16.5	26.34	25.33	342	905	825	2072	386	1003	920	2309
24	5/31/2013	12:03	7.69	12.65	11.72	4.9	8.01	7.45	37	100	86	223	38	101	87	226
25	5/31/2013	12:12	24.86	38.61	36.95	17.21	26.33	25.23	386	932	853	2171	428	1017	932	2377
26	5/31/2013	12:19	28.34	42.7	41.2	19.77	29.19	28.34	502	1140	1061	2702	560	1246	1168	2974
27	5/31/2013	12:27	33.37	47.4	46.1	23.12	32.51	31.6	696	1404	1328	3428	772	1541	1457	3769
28	5/31/2013	13:46	19.42	33.54	31.57	13.8	23.5	22.25	236	703	623	1562	268	788	702	1759
29	5/31/2013	13:52	25	41.7	39.79	17.77	29.46	27.93	391	1087	990	2467	444	1228	1111	2784
30	5/31/2013	14:00	30.42	48.9	46.9	21.69	34.27	32.96	578	1495	1375	3448	660	1676	1546	3881
31	5/31/2013	14:12	26.5	45.6	43	18.6	32.3	30.37	439	1300	1156	2894	493	1473	1306	3272

GZA Data			Official Results (Power Measured by Blue Water and Manually Recorded by GZA) (Theoretical Power and Efficiency Calculated by GZA)			Official Flow and Head (Provided by Alden)			
Test No.	Date	Time	Power (W)	Theoretical Power ^s (W)	Turbine/ Generator Efficiency (%)	Alden Run #	Time of Day	Turbine Flow (cfs)	Turbine Inlet Head (ft WC)
1	5/30/2013	10:29	170	2,280	7.5	5	10:31	3.28	8.21
2	5/30/2013	10:37	300	3,109	9.6	6	10:39	3.64	10.08
3	5/30/2013	10:45	480	4,814	10.0	7	10:47	4.12	13.80
4	5/30/2013	10:52	750	6,574	11.4	8	10:55	4.61	16.86
5	5/30/2013	11:00	1,050	8,652	12.1	9	11:03	5.10	20.02
6	5/30/2013	11:11	920	8,718	10.6	10	11:15	5.12	20.11
7	5/30/2013	11:20	950	8,696	10.9	11	11:23	5.11	20.11
8	5/30/2013	11:27	900	8,714	10.3	12	11:30	5.12	20.11
9	5/30/2013	11:44	1,220	8,018	15.2	13	11:47	5.05	18.75
10	5/30/2013	11:51	1,680	12,107	13.9	14	11:54	6.06	23.59
11	5/30/2013	11:59	2,020	15,368	13.1	15	12:02	6.55	27.73
12	5/30/2013	12:05	2,075	16,321	12.7	16	12:07	6.40	30.10
13	5/30/2013	12:10	2,100	15,807	13.3	17	12:13	6.48	28.80
14	5/30/2013	12:17	2,550	20,666	12.3	18	12:20	7.12	34.29
15	5/30/2013	12:25	2,700	20,580	13.1	19	12:27	7.14	34.05
16	5/31/2013	9:42	75	3,523	2.1	1	9:45	4.59	9.06
17	5/31/2013	9:49	530	4,011	13.2	2	9:52	4.37	10.83
18	5/31/2013	10:00	1,100	7,765	14.2	3	10:02	5.43	16.89
19	5/31/2013	10:10	1,900	13,499	14.1	4	10:13	6.40	24.93
20	5/31/2013	10:25	2,350	16,356	14.4	5	10:28	6.85	28.19
21	5/31/2013	10:39	1,350	7,731	17.5	6	10:42	6.36	14.36
22	5/31/2013	10:48	1,775	10,585	16.8	7	10:51	6.69	18.68
23	5/31/2013	10:56	2,200	13,644	16.1	8	10:59	7.04	22.89
24	5/31/2013	12:03	230	1,989	11.6	9	12:05	11.08	2.12
25	5/31/2013	12:12	2,250	10,584	21.3	10	12:15	10.62	11.77
26	5/31/2013	12:19	2,800	13,131	21.3	11	12:22	10.84	14.31
27	5/31/2013	12:27	3,550	19,445	18.3	12	12:30	10.14	22.65
28	5/31/2013	13:46	1,650	8,746	18.9	14	13:49	7.00	14.76
29	5/31/2013	13:52	2,600	13,288	19.6	15	13:55	7.74	20.27
30	5/31/2013	14:00	3,600	18,669	19.3	16	14:02	8.40	26.26
31	5/31/2013	14:12	3,000	20,868	14.4	17	14:15	9.21	26.77

GZA Data			Testing Notes									
Test No.	Date	Time	Resistance Through Load Bridges	Inverter losses factor								
1	5/30/2013	10:29	1.6	1								
2	5/30/2013	10:37										
3	5/30/2013	10:45	Specific									
4	5/30/2013	10:52	Weight of Water									
5	5/30/2013	11:00	62.4	<<<<-----Adjust this to the appropriate temperature if warranted								
6	5/30/2013	11:11										
7	5/30/2013	11:20										
8	5/30/2013	11:27										
9	5/30/2013	11:44										
10	5/30/2013	11:51										
11	5/30/2013	11:59	May 30th Calibration				May 31th Calibration					
12	5/30/2013	12:05	Voltage of GE cylinder full disengaged				Voltage of GE cylinder full disengaged					
13	5/30/2013	12:10	2.16				3.18 4.34					
14	5/30/2013	12:17	Voltage of GE cylinder full engaged				Voltage of GE cylinder full engaged					
15	5/30/2013	12:25	Range	0.66				Range	0.61 1.91			
16	5/31/2013	9:42		1.500					2.570			
17	5/31/2013	9:49										
18	5/31/2013	10:00	Voltage of Blade pitch cylinder full closed				Voltage of Blade pitch cylinder full closed					
19	5/31/2013	10:10	2.120				2.080 2.100 1.97					
20	5/31/2013	10:25	Voltage of Blade pitch cylinder full open				Voltage of Blade pitch cylinder full open					
21	5/31/2013	10:39	Range	1.190				Range	1.120 0.600 0.58			
22	5/31/2013	10:48		0.930					0.960 1.500 1.39			
23	5/31/2013	10:56										
24	5/31/2013	12:03				For Pitch Control Cylinder Only						
25	5/31/2013	12:12				indicates value used before 11:35 am on 5/31						
26	5/31/2013	12:19				indicates value used after 11:35 am on 5/31						
27	5/31/2013	12:27				indicates values used after 13:46 on 5/31						
28	5/31/2013	13:46										
29	5/31/2013	13:52										
30	5/31/2013	14:00	data is corrupt									
31	5/31/2013	14:12	These values coincide with an after test GE calibration									
as it turns out, the fixes made yesterday were inadequate as the pins failed in shear thereby causing the shaft to move with respect to the shrink disc												
shrink disc = shaft collar												
Generator position numbers are obviously compromised												

TESTING OF:
ONE HYDROELECTRIC TURBINE
SERIAL NUMBER 1

FOR:
ALDEN RESEARCH LABORATORY INC.
JOB PURCHASE ORDER 3132WWTRB
JULY 2013 - REPORT NO. 2131ARL006-R1

SPONSORED BY:
WALKER WELLINGTON

CERTIFIED BY
Philip S. Stacy

ALDEN RESEARCH LABORATORY, INC.
30 SHREWSBURY STREET
HOLDEN, MASSACHUSETTS 01520

All Client supplied information and calibration results are considered proprietary and confidential to the Client. If a third party is a witness during calibrations or if the Client requests transmittal of data to a third party, Alden considers that the Client has waived confidentiality for the Witness.

In the event the Client distributes any report issued by Alden outside its own organization, such report shall be used in its entirety, unless Alden approves a summary or abridgment for distribution.

No advertising or publicity containing any reference to Alden or any employee, either directly or by implication, shall be made use of by Client without Alden's written approval.

INTRODUCTION

One axial flow hydroelectric turbine was tested at the Alden Research Laboratory, Inc. (Alden), for Walker Wellington under contract dated March 22, 2013. Alden's standard test procedures, in QMSM-01 Revision 4¹, were used for testing. Additionally, tests were performed in accordance to the American Society of Mechanical Engineers Performance Test Codes on hydraulic Turbines (ASME PTC 18-1992) Turbine performance is shown in tabular format and includes measured flow and pressure data.

TEST TURBINE INSTALLATION

The turbine tested was installed in Test Line 3 in the Hooper Low Reynolds Number Facility shown in plan view in Figure 1. Water was provided through a 40 inch penstock from Chaffin pond resulting in a gross gravity head of approximately 28 feet at a maximum flow of 78 cfs. A calibrated Venturi meter was used to measure flow.

The piping upstream and downstream of the turbine is shown in Figure 2, including all significant fittings and pipe lengths. Careful attention was given to aligning all test line piping, and to assure no gaskets between flanged sections protruded into the flow. Vents were provided at critical locations of the test line to purge the system of air.

A single piezometer measurement was recorded for each test point. These data are listed under the column of Turbine Inlet Head in the data tables. Inlet head was measured using two yoked taps located in the 28 inch pipe, 4.5 feet upstream of the flange connector to the turbine. Inlet head (Tap 1) was measured using a differential pressure transmitter referencing a water column set at the centerline of the 28 inch inlet pipe. As such, the inlet pressure was measured relative to the turbine centerline.

FLOW MEASUREMENT METHOD

Flow was measured using a 12 inch Venturi meter installed in Test Line 1 for this testing and was gravimetrically calibrated prior to use using Alden's standard procedures. Following the calibration, the piping from the meter was reconfigured to supply flow to the basement Test Line 3 for the turbine testing. The Venturi performance is characterized by plotting the discharge coefficient versus pipe Reynolds number. Flow is calculated by Equation (1).

¹ Quality Management System Manual, Alden's internal QA program
Report No. 2131ARL006-R1

$$q_a = C_{MV} K_{MV} \sqrt{\Delta h_M} \quad (1)$$

where

q_a	=	actual flow, ft ³ /sec
C_{MV}	=	Venturi discharge coefficient, dimensionless
K_M	=	Venturi constant, $1.6264 \frac{\text{ft}^{2.5}}{\text{sec}}$
Δh_M	=	Venturi differential head, ft

The effect of fluid properties, viscosity and density, on the discharge coefficient is determined by Reynolds number; the ratio of inertia to viscous forces. Pipe Reynolds number, R_D , is determined by Equation (2).

$$R_D = \frac{q_a D}{a_p \gamma} \quad (2)$$

D	=	pipe diameter, ft
a_p	=	pipe area, $\frac{\pi D^2}{4}$, ft ²
γ	=	kinematic viscosity, $\frac{\text{ft}^2}{\text{sec}}$

TEST PROCEDURE

After checking the installation, water was introduced into the system to equalize the line and primary element temperature to water temperature. Flow and head on the test unit were controlled by a valve located in Test Line 1 (upstream of the flow conditioner plate in the basement Test Line 3, see Figures 1 and 2). Note: the piping connection of Lines 1 and 3 is not shown in Figure 1.

Prior to the test run, the control valve was set to the desired flow. After steady conditions were achieved, the differential head produced by the Venturi flow meter was averaged over about two minutes to obtain a precise differential head. The average differential head, water temperature, and test meter output were recorded on a data sheet. The control valve was then adjusted to the next flow and

the procedure repeated. During the time allowed to stabilize the new flow, the data were entered into the computer to determine the flow and head.

TEST RESULTS

The results are presented in tabular and graphical format. The measured flow and pressure (head) are listed in the table(s) in the following pages.

Analysis indicates that the flow and head measurement uncertainties are within 0.20% and 0.05%, respectively, of the true value for each test run. Calibrations of the test instrumentation (temperature, time, weight, and length measurements) are traceable to the National Institute of Standards and Technology (formerly the National Bureau of Standards) and Alden's Quality Assurance Program is designed to meet ANSI/NCSL Z540-1-1994 "Calibration Laboratories and Test Equipment-General Requirements" (supercedes MIL-STD-45662A).

REFERENCE

Alden Calibration Department. QMSM-01 Revision 4. Quality Manual. 2010.

American Society of Mechanical Engineers (ASME). ASME PTC 18-2002. Hydraulic Turbines and Pump-Turbines Performance Test Codes, An American National Standard. 2003.

American National Standards Institute / National Conference of Standard Laboratories (ANSI/NCSL) ANSI/NCSL Z540-1-1994. Calibration Laboratories and Measuring and Test Equipment—General Requirements. 1994.

Figure 1
Hooper Low Reynolds Number Facility Test Lines 1, 2 and 3

Plan View Hooper Facility Line 3

Figure 2

WALKER WELLINGTON
 Purchase Order Number: 3132WWTRB
 28" HYDROTURBINE
 Serial Number: 1
 May 27-31, 2013

WALKER WELLINGTON

Purchase Order Number: 3132WWTRB

HYDROTURBINE

Serial Number: 1

CALIBRATION

DATE: May 30, 2013

INLET PIPE DIAMETER = 27.25"

Run #	Time of Day	Line Temp Deg F	Air Temp Deg F	Run Duration secs.	Turbine Flow CFS	Turbine Inlet Head Ft WC
1	9:44	66	72	60	3.549	8.524
2	9:55	66	72	104	3.535	8.651
3	10:08	66	72	110	4.139	13.139
4	10:12	66	72	120	4.149	13.084
5	10:31	66	73	120	3.280	8.210
6	10:39	66	73	121	3.642	10.083
7	10:47	66	74	123	4.120	13.380
8	10:55	66	74	120	4.606	16.857
9	11:03	66	74	120	5.103	20.023
10	11:15	67	75	121	5.120	20.110
11	11:23	67	75	121	5.106	20.113
12	11:30	67	75	120	5.119	20.105
13	11:47	67	75	120	5.505	18.751
14	11:54	67	75	124	6.061	23.591
15	12:02	67	75	121	6.545	27.731
16	12:07	67	75	120	6.404	30.098
17	12:13	67	75	121	6.483	28.795
18	12:20	67	76	120	7.118	34.288
19	12:27	68	76	121	7.139	34.045

The data reported on herein was obtained by measuring equipment the calibration of which is traceable to NIST, following the installation and test procedures referenced in this report, resulting in a flow measurement uncertainty of +/- 0.25% or less.

CERTIFIED BY:

CALIBRATED BY: THL
Witnessed by a company representative

WALKER WELLINGTON

Purchase Order Number: 3132WWTRB

HYDROTURBINE

Serial Number: 1

CALIBRATION

DATE: May 31, 2013

INLET PIPE DIAMETER = 27.25

Run #	Time of Day	Line Temp Deg F	Air Temp Deg F	Run Duration secs.	Turbine Flow CFS	Turbine Inlet Head Ft WC
1	9:45	71	77	120	4.591	9.062
2	9:52	71	78	120	4.374	10.813
3	10:02	71	78	120	5.431	16.886
4	10:13	71	78	121	6.365	24.929
5	10:28	71	79	120	6.853	28.186
6	10:42	71	80	120	6.356	14.364
7	10:51	71	80	126	6.692	18.681
8	10:59	71	80	126	7.041	22.886
9	12:05	73	82	144	11.076	2.121
10	12:15	73	82	120	10.623	11.767
11	12:22	73	82	133	10.840	14.306
12	12:30	73	81	120	10.140	22.647
13	12:44	73	81	90	0.000	0.000
14	13:49	73	83	121	6.998	14.760
15	13:55	73	83	120	7.743	20.268
16	14:02	73	83	121	8.395	26.263
17	14:15	74	83	124	9.207	26.768
18	14:32	74	84	61	0.000	0.000

The data reported on herein was obtained by measuring equipment the calibration of which is traceable to NIST, following the installation and test procedures referenced in this report, resulting in a flow measurement uncertainty of +/- 0.5% or less.

CERTIFIED BY:

CALIBRATED BY: THL
Witnessed by a company representative

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WATER DENSITY*

Temperature Fahrenheit	Density lb _m /ft ³	Temperature Fahrenheit	Density lb _m /ft ³	Temperature Fahrenheit	Density lb _m /ft ³
32	62.4179	62	62.3549	92	62.0903
33	62.4201	63	62.3489	93	62.0788
34	62.4220	64	62.3427	94	62.0671
35	62.4235	65	62.3363	95	62.0552
36	62.4246	66	62.3296	96	62.0432
37	62.4255	67	62.3228	97	62.0311
38	62.4260	68	62.3157	98	62.0188
39	62.4262	69	62.3084	99	62.0063
40	62.4261	70	62.3010	100	61.9937
41	62.4257	71	62.2933	101	61.9810
42	62.4250	72	62.2855	102	61.9681
43	62.4240	73	62.2774	103	61.9551
44	62.4227	74	62.2692	104	61.9419
45	62.4211	75	62.2608	105	61.9286
46	62.4193	76	62.2522	106	61.9151
47	62.4171	77	62.2434	107	61.9015
48	62.4147	78	62.2344	108	61.8878
49	62.4121	79	62.2252	109	61.8739
50	62.4092	80	62.2159	110	61.8599
51	62.4060	81	62.2063	111	61.8458
52	62.4025	82	62.1966	112	61.8315
53	62.3988	83	62.1868	113	61.8172
54	62.3949	84	62.1767	114	61.8027
55	62.3907	85	62.1665	115	61.7880
56	62.3863	86	62.1561	116	61.7733
57	62.3816	87	62.1456	117	61.7584
58	62.3768	88	62.1348	118	61.7434
59	62.3716	89	62.1239	119	61.7284
60	62.3663	90	62.1129	120	61.7132
61	62.3607	91	62.1017	121	61.6978

* Distilled water values used in all calculations

APPENDIX – 12” VENTURI CALIBRATION

Plan View Hooper Facility Line 1

ALDEN RESEARCH LABORATORY
 Purchase Order Number: 3132WWTRB
 12" VENTURI METER
 Serial Number: 12x6-4
 May 21, 2013

ALDEN RESEARCH LABORATORY

Purchase Order Number: 3132WWTRB

12" VENTURI METER

Serial Number: 12x6-4

Manifolded taps

CALIBRATION
DATE: May 21, 2013
PIPE DIAMETER = 12.0000
THROAT DIAMETER = 6.0000

Run #	Line Temp Deg F	Air Temp Deg F	Net Weight lb.	Run Duration secs.	Flow GPM	H Line FT H2O	Pipe Rey. # x 10 ⁶	Coef
1	70	73	45719	58.739	5614.1	56.6788	1.5167	1.0215
2	71	74	45958	71.533	4634.2	38.6549	1.2567	1.0211
3	71	74	45904	90.727	3649.5	24.0032	0.9897	1.0204
4	71	75	42548	114.742	2674.8	12.9066	0.7263	1.0199
5	71	75	45988	124.374	2667.0	12.8451	0.7224	1.0194
6	70	74	42571	184.792	1661.6	4.9985	0.4467	1.0181
7	70	75	18319	195.232	676.7	0.8332	0.1814	1.0156

The data reported on herein was obtained by measuring equipment the calibration of which is traceable to NIST, following the installation and test procedures referenced in this report, resulting in a flow measurement uncertainty of +/- 0.25% or less.

CERTIFIED BY:

CALIBRATED BY: THL

$q_a = C F_a K_M \sqrt{\Delta h}$	
q_a = Actual Flow (ft ³ /sec)	
C = Discharge Coefficient (Dimensionless)	
Δh = Pressure Differential (Feet of Water at Run Temperature)	
K_M = Meter Constant = $\frac{a\sqrt{2g}}{\sqrt{1-\beta^4}}$	1.6264
F_a = Average Thermal Expansion Factor	1.0000
a = Throat Area (ft ²)	0.1963
g = Local Acceleration of Gravity (ft/sec ²)	32.1625
β = Ratio of Throat to Pipe Diameter (Dimensionless)	0.5000
Pipe Diameter (Inches)	12.0000
Throat Diameter (Inches)	6.0000
Dimensions By: ALDEN RESEARCH LABORATORY	

ALDEN RESEARCH LABORATORY
Purchase Order Number: 3132WWTRB
12" VENTURI METER
Serial Number: 12x6-4
May 21, 2013

Certified By: *Dalton*

APPENDIX F
LEVELIZED COST OF ENERGY COMPARISON
AND
COMPARISON WITH TRADITIONAL HYDROPOWER TURBINES
(UPDATED WITH TESTING DATA FROM MAY 2013)

LEVELIZED COST OF ENERGY COMPARISON AND COMPARISON WITH TRADITIONAL HYDROPOWER TURBINES

LEVELIZED COST OF ENERGY COMPARISON

As defined by the DOE funding opportunity documents, the Levelized Cost of Energy (LCOE) is the return per unit of energy production (\$ / MWh) required over the life-cycle of the hydropower project to recover all costs and satisfy investor revenue requirements. The calculation of the LCOE involves consideration of estimated annual energy generation, capital costs, annual costs, and discount rate. A preliminary LCOE analysis was performed in June 2011 and was included in Walker Wellington's application to the U.S. Department of Energy (DOE) for a grant under the Advanced Hydropower Development funding opportunity. This analysis updates those calculations based on efficiencies computed as a result of May 2013 testing.

Baseline Scenario

GZA utilized an actual site studied for low-head hydropower generation to establish a baseline scenario for the preliminary LCOE comparison. Due to the limiting flow and head conditions available at the turbine test site, the conditions were modified for the purpose of the LCOE analysis (in comparison to those presented during the preliminary LCOE analysis and at the actual site). GZA also revised the cost estimate from the preliminary analysis to reflect the revised construction cost associated with a project utilizing a lower head and flow and to reflect 2013 costs.

The overall site is a man-made water supply canal which includes multiple water control structures. These weir structures are fundamentally small dams which create backwater impoundments within the canal. At each control structure there are slide gates and an overflow weir which permit water to pass from the upstream headwater to the downstream tailwater. One specific control structure has been selected. Conditions at this structure provide an estimated net head of 15 feet and a flow rate of 10 cfs.

GZA has updated the LCOE based on the turbine testing results. The flow duration curve used for LCOE is shown in **Figure 1** and a peak design flow of 10 cfs has been assumed. A head of 15 feet has also been assumed.

The baseline scenario for hydropower generation at this control structure using conventional hydropower equipment involves the construction of a small powerhouse tower on the downstream side of the weir. The gatehouse substructure acts as an open "water box" containing a Francis or Kaplan-type turbine oriented vertically and directly connected to a vertical generator above. A trash rack system must be provided upstream.

This particular site was in a sensitive location from both an environmental and historic standpoint, so mitigations were judged likely to be necessary to construct the project. Interconnection to the electrical grid would be provided at nearby existing power distribution lines. No new dam or other water control structure is proposed to be constructed as part of the hydropower project. The Baseline scenario is shown in **Figure 2**.

Assumptions

For the LCOE calculations, GZA has assumed that both the conventional turbine system and the innovative W4e system have a design life of 30 years. We have assumed that system rehabilitations will be required at 15 years, representing approximately 50 percent of the original component costs. A cost estimate comparison is presented as **Table 1**. A comparison of power and energy production estimates is presented as **Tables 2a and 2b**. The DOE LCOE worksheet is presented in **Appendix B**.

Results

Based on the assumptions stated above, the cost estimates developed by GZA as shown in Table 1, and a 30 year design life, the LCOE for the baseline scenario and scenario utilizing the innovative W4e is as follows:

	<u>Baseline Scenario</u>	<u>with W4e Turbine</u>
LCOE	\$1,320 / MWh	\$3,489 / MWh

Means and methods of the analysis are in conformance with industry standards and typical engineering practices.

GZA notes that the LCOE presented above for the baseline scenario is greater (\$1,320/MWh vs. \$222/MWh) than what was presented in the preliminary analysis. This is because the project size considered in this analysis is smaller (15 ft of head and 10 cfs vs. 80 cfs and 20 ft of head) and generation is therefore less (10 kW vs. 106 kW). The fixed cost associated with the project do not scale. This results in a higher per MWh cost.

GZA notes that the LCOE presented above for the W4e Turbine is greater than what was presented in the preliminary analysis (\$3,489/MWh vs. \$69/MWh). Like the baseline scenario, this is in part due to the fact that the fixed costs do not scale and significantly increase the per MWh cost for small projects (in comparison with larger projects). The higher LCOE is also due to the lower efficiencies observed during the testing than had been assumed during the preliminary analysis (maximum of 20 percent over a range of flows vs. 85 percent for all flows). The lower efficiency results in a smaller power output and a greater LCOE.

COMPARISON WITH TRADITIONAL HYDROPOWER TURBINES

The proposed W4e system provides a “bolt on” installation ability which appears to be well suited for application at this site and also makes it well suited for many existing dams or for installation in a water supply or wastewater pipe. We have assumed that the W4e turbine/generator package could be mounted directly to the existing concrete weir immediately downstream of one of the slide gates. The entire package would therefore be submerged in the tailwater. This configuration eliminates the need for the construction of a new powerhouse tower thereby reducing costs. Additional advantages are that it is less visible (preferable from both a historic standpoint, for reducing the potential for vandalism, and for safety), less prone to damage by flooding, and less expensive than a conventional turbine/generator combination.

GZA notes that the W4e did not perform as expected during the turbine/ generator testing. Walker Wellington and Blue Water anticipated that the equipment would have a water to wire efficiency of 85 percent over the full range of tested flows (approximately 3.5 to 11 cfs). Results of the testing showed most efficiencies between approximately 10 and 21 percent over the tested range. Several equipment performance issues were identified during the testing. These deficiencies could not have been foreseen or identified under machine shop conditions. The opportunity to test the equipment under actual head and flow conditions allowed Walker Wellington and Blue Water to develop concepts for improving the equipment performance.

Blue Water and Walker Wellington believe that once they completely understand the equipment issues they will be able to generate power at a rate that is approximately 85 percent efficient over the full range of flows. Generation at an efficiency rate of 85 percent would result in a lower LCOE than the baseline scenario.

TABLES

For Topic 1.2 and 4.0 the applicant is responsible for adding values to all blue boxes. The green boxes will automatically calculate the variables required for the LCOE calculation based on the information provided by the applicant in the blue boxes. The methodology used to calculate LCOE is described in Appendix E - Calculating the Levelized Cost of Electricity.

Table 1: Itemization and Calculation of Installed Capital Costs

Installed Cost (2013 \$)			Applicant Input
Cost Category	Comparison Baseline	Proposed Configuration	
Capital Costs (\$):			Automatic Calculation
Licensing and Permitting	\$ 50,000	\$ 50,000	
Environmental Mitigation	\$ 2,000	\$ 2,000	
Dam and Related Civil Works	\$ 21,000	\$ 16,000	
Water Conveyance Civil Works	\$ 26,000	\$ 34,000	
Powerhouse Civil Works	\$ 66,000	\$ 11,000	
All Equipment	\$ 115,000	\$ 80,000	
Transmission and Interconnection	\$ 25,000	\$ 25,000	
Engineering and Management	\$ 50,000	\$ 15,000	
Contingencies	\$ 36,800	\$ 12,100	
Overnight Capital Costs (OCC)	\$ 391,800	\$ 245,100	
Development Schedule (% per year)	Schedule OK	Schedule OK	Partition your overnight costs into a development schedule of up to four years, assigning the percentage of costs incurred in each year. Year 1 is the first year of project development.
Year 1	10%	15%	
Year 2	20%	12%	
Year 3	15%	12%	
Year 4	55%	61%	
Total Installed Capital Costs (ICC)	\$ 416,085	\$ 259,694	

Table 2: Operations and Maintenance

Operations and Maintenance (O&M, \$ per year):	\$ 7,000	\$ 7,000
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Table 3: LRC Calculation

Replacement Cost Details	Comparison Baseline		Proposed Configuration	
Cost Category	Replacement Cost (2013 \$)	Replacement Timing (Years)	Replacement Cost (2013 \$)	Replacement Timing (Years)
Turbine (Rehab or Replacement)	\$ 25,000.00	15	\$ 23,000.00	15
Generator (Rewind or Replacement)	\$ 12,500.00	15	\$ 6,700.00	15
Electrical and Control Equipment	\$ 10,000.00	15	\$ 2,000.00	15
Pipeline (Rehab or Replacement)	\$ -	0	\$ -	0
Intake/Tailrace Improvement	\$ 12,000.00	15	\$ 12,000.00	15
Other	\$ -	0	\$ -	0
Present Value of Replacement Costs (PVRC)	\$ 4,349		\$ 4,349	

Table 4: Fixed LCOE Calculation Parameters

Variable	Value
Marginal Tax Rate	39.2%
Nominal Discount Rate	10.2%
Inflation	3.0%
Real Discount Rate	7.0%
Depreciation Schedule	MACRS 20 Year

Table 5: LCOE CALCULATION

LCOE Component	Variable	Baseline Configuration	Proposed Configuration
Plant Capacity (MW)		0.0100	0.0025
Capacity Factor		46%	47%
Project Lifetime (years)	<i>N</i>	30	30
Annual Generation (MWh per year)	<i>AEP</i>	40	10
Project Total Capital Costs (ICC+PVRC)	<i>TCC</i>	\$ 420,435	\$ 264,044
Annual O&M (\$ per year)	<i>O&M</i>	\$ 7,000	\$ 7,000
Total Project LCOE (\$ per MWh)	LCOE	\$ 1,320	\$ 3,498

TABLE 1
COST ESTIMATE COMPARISON

	Comparison Baseline (Waterbox)	Proposed Configuration (W4e)
Turbine, Generator, Electrical Equipment	\$75,000	\$60,000
Installation of Turbine, Generator & Electrical Equipment	\$20,000	\$5,000
Power house	\$50,000	\$0
Modification to Existing Structures	\$5,000	\$5,000
Interconnection	\$20,000	\$20,000
Commissioning	\$10,000	\$5,000
Penstock 30-inch	-	\$5,000
Flange for 30-inch penstock	-	\$2,000
Penstock Flange Transition	-	\$3,000
45° bend for 30-inch penstock	-	\$3,000
Contractor Mobilization/Demobilization	\$30,000	\$15,000
Temporary Facilities	\$5,000	\$5,000
Electrical	\$10,000	\$10,000
Sediment Removal	\$0	\$0
Sediment and Erosion Control (During Excavation)	\$4,000	\$2,000
Water Control	\$10,000	\$10,000
Trash Rack	\$10,000	\$10,000
Slide Gate & Gate Operator	-	-
Engineering Design	\$80,000	\$15,000
Transmission line (LF) (\$50 - \$85)	\$2,550	\$2,550
Utility Pole (\$1,500/pole installed)	\$2,000	\$2,000
Fish Passage	\$2,000	\$2,000
Permitting / Studies	\$50,000	\$50,000
SUBTOTAL	\$385,550	\$231,550
CONTINGENCY (5%)	\$19,300	\$11,600
TOTAL	\$404,850	\$243,150

TABLE 2A

Power and Energy Production Estimate- Comparison Baseline

Leffel Turbine Generator Set								
Duration	Q Fictional Site (cfs)	Q Turbine	Q/ Q Design	Turbine Efficiency	Generator Efficiency	Head (ft)	Power (kW)	Energy (kWH)
0	68	10.0	1.00	0.82	0.95	15	10	867
1	68	10.0	1.00	0.82	0.95	15	10	867
2	51	10.0	1.00	0.82	0.95	15	10	867
3	42	10.0	1.00	0.82	0.95	15	10	867
4	36	10.0	1.00	0.82	0.95	15	10	867
5	33	10.0	1.00	0.82	0.95	15	10	867
6	29	10.0	1.00	0.82	0.95	15	10	867
7	27	10.0	1.00	0.82	0.95	15	10	867
8	25	10.0	1.00	0.82	0.95	15	10	867
9	23	10.0	1.00	0.82	0.95	15	10	867
10	22	10.0	1.00	0.82	0.95	15	10	867
11	21	10.0	1.00	0.82	0.95	15	10	867
12	19	10.0	1.00	0.82	0.95	15	10	867
13	18	10.0	1.00	0.82	0.95	15	10	867
14	18	10.0	1.00	0.82	0.95	15	10	867
15	17	10.0	1.00	0.82	0.95	15	10	867
16	16	10.0	1.00	0.82	0.95	15	10	867
17	15	10.0	1.00	0.82	0.95	15	10	867
18	14	10.0	1.00	0.82	0.95	15	10	867
19	14	10.0	1.00	0.82	0.95	15	10	867
20	13	10.0	1.00	0.82	0.95	15	10	867
21	13	10.0	1.00	0.82	0.95	15	10	867
22	12	10.0	1.00	0.82	0.95	15	10	867
23	12	10.0	1.00	0.82	0.95	15	10	867
24	12	10.0	1.00	0.82	0.95	15	10	867
25	11	10.0	1.00	0.82	0.95	15	10	867
26	11	10.0	1.00	0.82	0.95	15	10	867
27	10	10.0	1.00	0.82	0.95	15	10	867
28	10	10.0	1.00	0.82	0.95	15	10	867
29	10	9.8	0.98	0.84	0.95	15	10	864
30	9	9.5	0.95	0.86	0.95	15	10	861
31	9	9.2	0.92	0.87	0.95	15	10	850
32	9	8.9	0.89	0.89	0.95	15	10	839
33	9	8.8	0.88	0.90	0.95	15	9	831
34	8	8.5	0.85	0.91	0.95	15	9	813
35	8	8.3	0.83	0.90	0.95	15	9	787
36	8	8.0	0.80	0.89	0.95	15	9	751
37	8	7.8	0.78	0.88	0.95	15	8	730
38	8	7.6	0.76	0.88	0.95	15	8	713
39	7	7.5	0.75	0.86	0.95	15	8	676
40	7	7.3	0.73	0.86	0.95	15	8	660
41	7	7.1	0.71	0.83	0.95	15	7	623
42	7	6.9	0.69	0.83	0.95	15	7	607
43	7	6.7	0.67	0.81	0.95	15	7	573
44	7	6.6	0.66	0.80	0.95	15	6	562
45	6	6.4	0.64	0.79	0.95	15	6	540
46	6	6.4	0.64	0.79	0.95	15	6	529
47	6	6.2	0.62	0.78	0.95	15	6	506
48	6	6.1	0.61	0.76	0.95	15	6	491
49	6	5.9	0.59	0.75	0.95	15	5	468
50	6	5.8	0.58	0.75	0.95	15	5	458
51	6	5.6	0.56	0.74	0.95	15	5	437
52	6	5.5	0.55	0	0.95	15	0	0
53	5	5.3	0.53	0	0.95	15	0	0
54	5	5.3	0.53	0	0.95	15	0	0
55	5	5.2	0.52	0	0.95	15	0	0
56	5	5.0	0.50	0	0.95	15	0	0
57	5	4.9	0.49	0	0.95	15	0	0
58	5	4.8	0.48	0	0.95	15	0	0
59	5	4.7	0.47	0	0.95	15	0	0
60	5	4.6	0.46	0	0.95	15	0	0

TABLE 2A

Power and Energy Production Estimate- Comparison Baseline

61	4	4.4	0.44	0	0.95	15	0	0
62	4	4.3	0.43	0	0.95	15	0	0
63	4	4.2	0.42	0	0.95	15	0	0
64	4	4.1	0.41	0	0.95	15	0	0
65	4	4.1	0.41	0	0.95	15	0	0
66	4	4.0	0.40	0	0.95	15	0	0
67	4	3.9	0.39	0	0.95	15	0	0
68	4	3.8	0.38	0	0.95	15	0	0
69	4	3.8	0.38	0	0.95	15	0	0
70	4	3.7	0.37	0	0.95	15	0	0
71	4	3.6	0.36	0	0.95	15	0	0
72	4	3.5	0.35	0	0.95	15	0	0
73	3	3.4	0.34	0	0.95	15	0	0
74	3	3.3	0.33	0	0.95	15	0	0
75	3	3.3	0.33	0	0.95	15	0	0
76	3	3.2	0.32	0	0.95	15	0	0
77	3	3.1	0.31	0	0.95	15	0	0
78	3	3.0	0.30	0	0.95	15	0	0
79	3	2.9	0.29	0	0.95	15	0	0
80	3	2.9	0.29	0	0.95	15	0	0
81	3	2.9	0.29	0	0.95	15	0	0
82	3	2.8	0.28	0	0.95	15	0	0
83	3	2.7	0.27	0	0.95	15	0	0
84	3	2.7	0.27	0	0.95	15	0	0
85	3	2.6	0.26	0	0.95	15	0	0
86	2	2.5	0.25	0	0.95	15	0	0
87	2	2.4	0.24	0	0.95	15	0	0
88	2	2.3	0.23	0	0.95	15	0	0
89	2	2.2	0.22	0	0.95	15	0	0
90	2	2.1	0.21	0	0.95	15	0	0
91	2	2.0	0.20	0	0.95	15	0	0
92	2	2.0	0.20	0	0.95	15	0	0
93	2	1.9	0.19	0	0.95	15	0	0
94	2	1.8	0.18	0	0.95	15	0	0
95	2	1.8	0.18	0	0.95	15	0	0
96	2	1.7	0.17	0	0.95	15	0	0
97	1	1.5	0.15	0	0.95	15	0	0
98	1	1.4	0.14	0	0.95	15	0	0
99	1	1.2	0.12	0	0.95	15	0	0
100	0	0.4	0.04	0	0.95	15	0	0
						Annual Energy (kWh)		40,319
						Theoretical Generation		86,730
						Capacity Factor		0.46

TABLE 2B

Power and Energy Production Estimate- Comparison Baseline

W4E Turbine

Duration	Q Fictional Site (cfs)	Q Turbine	Water to Wire Efficiency	Head (ft)	Power (kW)	Energy (kWH)
0	68	10.0	0.20	15.0	2.5	220
1	68	10.0	0.20	15.0	2.5	220
2	51	10.0	0.20	15.0	2.5	220
3	42	10.0	0.20	15.0	2.5	220
4	36	10.0	0.20	15.0	2.5	220
5	33	10.0	0.20	15.0	2.5	220
6	29	10.0	0.20	15.0	2.5	220
7	27	10.0	0.20	15.0	2.5	220
8	25	10.0	0.20	15.0	2.5	220
9	23	10.0	0.20	15.0	2.5	220
10	22	10.0	0.20	15.0	2.5	220
11	21	10.0	0.20	15.0	2.5	220
12	19	10.0	0.20	15.0	2.5	220
13	18	10.0	0.20	15.0	2.5	220
14	18	10.0	0.20	15.0	2.5	220
15	17	10.0	0.20	15.0	2.5	220
16	16	10.0	0.20	15.0	2.5	220
17	15	10.0	0.20	15.0	2.5	220
18	14	10.0	0.20	15.0	2.5	220
19	14	10.0	0.20	15.0	2.5	220
20	13	10.0	0.20	15.0	2.5	220
21	13	10.0	0.20	15.0	2.5	220
22	12	10.0	0.20	15.0	2.5	220
23	12	10.0	0.20	15.0	2.5	220
24	12	10.0	0.20	15.0	2.5	220
25	11	10.0	0.20	15.0	2.5	220
26	11	10.0	0.20	15.0	2.5	220
27	10	10.0	0.20	15.0	2.5	220
28	10	10.0	0.20	15.0	2.5	220
29	10	9.8	0.20	15.0	2.4	213
30	9	9.5	0.19	15.0	2.3	205
31	9	9.2	0.19	15.0	2.3	198
32	9	8.9	0.19	15.0	2.2	191
33	9	8.8	0.19	15.0	2.1	186
34	8	8.5	0.19	15.0	2.0	178
35	8	8.3	0.19	15.0	2.0	173
36	8	8.0	0.19	15.0	1.9	166
37	8	7.8	0.19	15.0	1.8	161
38	8	7.6	0.18	15.0	1.8	156
39	7	7.5	0.18	15.0	1.7	152
40	7	7.3	0.18	15.0	1.7	147
41	7	7.1	0.18	15.0	1.6	142
42	7	6.9	0.18	15.0	1.6	137
43	7	6.7	0.17	15.0	1.5	129
44	7	6.6	0.17	15.0	1.4	126
45	6	6.4	0.17	15.0	1.4	119
46	6	6.4	0.16	15.0	1.3	116
47	6	6.2	0.16	15.0	1.3	110
48	6	6.1	0.16	15.0	1.2	107
49	6	5.9	0.15	15.0	1.1	100
50	6	5.8	0.15	15.0	1.1	99
51	6	5.6	0.15	15.0	1.1	92
52	6	5.5	0.15	15.0	1.0	89
53	5	5.3	0.14	15.0	1.0	83

TABLE 2B

Power and Energy Production Estimate- Comparison Baseline

W4E Turbine

Duration	Q Fictional Site (cfs)	Q Turbine	Water to Wire Efficiency	Head (ft)	Power (kW)	Energy (kWH)
54	5	5.3	0.14	15.0	0.9	80
55	5	5.2	0.14	15.0	0.9	78
56	5	5.0	0.13	15.0	0.8	72
57	5	4.9	0.13	15.0	0.8	69
58	5	4.8	0.12	15.0	0.8	66
59	5	4.7	0.12	15.0	0.7	63
60	5	4.6	0.12	15.0	0.7	62
61	4	4.4	0.00	15.0	0.0	0
62	4	4.3	0.00	15.0	0.0	0
63	4	4.2	0.00	15.0	0.0	0
64	4	4.1	0.00	15.0	0.0	0
65	4	4.1	0.00	15.0	0.0	0
66	4	4.0	0.00	15.0	0.0	0
67	4	3.9	0.00	15.0	0.0	0
68	4	3.8	0.00	15.0	0.0	0
69	4	3.8	0.00	15.0	0.0	0
70	4	3.7	0.00	15.0	0.0	0
71	4	3.6	0.00	15.0	0.0	0
72	4	3.5	0.00	15.0	0.0	0
73	3	3.4	0.00	15.0	0.0	0
74	3	3.3	0.00	15.0	0.0	0
75	3	3.3	0.00	15.0	0.0	0
76	3	3.2	0.00	15.0	0.0	0
77	3	3.1	0.00	15.0	0.0	0
78	3	3.0	0.00	15.0	0.0	0
79	3	2.9	0.00	15.0	0.0	0
80	3	2.9	0.00	15.0	0.0	0
81	3	2.9	0.00	15.0	0.0	0
82	3	2.8	0.00	15.0	0.0	0
83	3	2.7	0.00	15.0	0.0	0
84	3	2.7	0.00	15.0	0.0	0
85	3	2.6	0.00	15.0	0.0	0
86	2	2.5	0.00	15.0	0.0	0
87	2	2.4	0.00	15.0	0.0	0
88	2	2.3	0.00	15.0	0.0	0
89	2	2.2	0.00	15.0	0.0	0
90	2	2.1	0.00	15.0	0.0	0
91	2	2.0	0.00	15.0	0.0	0
92	2	2.0	0.00	15.0	0.0	0
93	2	1.9	0.00	15.0	0.0	0
94	2	1.8	0.00	15.0	0.0	0
95	2	1.8	0.00	15.0	0.0	0
96	2	1.7	0.00	15.0	0.0	0
97	1	1.5	0.00	15.0	0.0	0
98	1	1.4	0.00	15.0	0.0	0
99	1	1.2	0.00	15.0	0.0	0
100	0	0.4	0.00	15.0	0.0	0
			Annual Energy (kWH)		10,450	
			Theoretical Generation		22,020	
			Capacity Factor		0.47	

FIGURES

FIGURE 1
FLOW DURATION CURVE

PROPOSED OPEN WATERBOX IN EXISTING BAY SECTION VIEW A - A'

SCALE APPROXIMATELY: 1 INCH = 4 FEET

PROPOSED OPEN WATERBOX IN EXISTING BAY LEVEL PLAN VIEW

SCALE APPROXIMATELY: 1 INCH = 4 FEET

PROPOSED OPEN WATER BOX IN EXISTING PLAN ELEVATION VIEW B - B'

SCALE APPROXIMATELY: 1 INCH = 4 FEET

PROJ MGR: KDE REVIEWED BY: CWC
DESIGNED BY: CNF OPERATOR: CHS

WALKER WELLINGTON LLC
DOE FUNDING OPPORTUNITY ANNOUNCEMENT NUMBER: DE-FOA-0000486

PLANS & SECTIONS COMPARISON BASELINE - WATER BOX			
Approximate Scale:	Date:	Project No.:	Drawing No.:
See Drawing	05-31-2011	01.P000148.12	2

**CONCEPT DRAWINGS
NOT FOR
CONSTRUCTION**

PROPOSED TUBE TURBINE IN EXISTING BAY PLAN ELEVATION VIEW A - A'

SCALE APPROXIMATELY: 1 INCH = 4 FEET
0 2' 4' 8'

PROPOSED TUBE TURBINE IN EXISTING BAY PLAN VIEW

SCALE APPROXIMATELY: 1 INCH = 4 FEET
0 2' 4' 8'

PROPOSED TUBE TURBINE IN EXISTING BAY ELEVATION VIEW B - B'

SCALE APPROXIMATELY: 1 INCH = 4 FEET
0 2' 4' 10'

PROJ MGR: KDE REVIEWED BY: CWC
DESIGNED BY: CNF OPERATOR: CHS

WALKER WELLINGTON LLC
DOE FUNDING OPPORTUNITY ANNOUNCEMENT NUMBER: DE-FOA-0000486

PLANS & SECTIONS
PROPOSED CONFIGURATION - W4E

Approximate Scale:	Date:	Project No.:	Drawing No.:
See Drawing	05-31-2011	01.P000148.12	3

CONCEPT DRAWINGS
NOT FOR
CONSTRUCTION

APPENDIX G

POWER CONDITIONING EQUIPMENT CUT SHEETS

15 kW WIND INTERFACE 25 kW WIND INTERFACE

GENERAL SPECIFICATIONS

This new product added to Power-One's Aurora wind accessories offers more flexibility for small wind applications.

The 25 kW Wind Interface is designed to be a 'smart' rectifier which once programmed with the turbine's power curve it can control the output of single or multiple inverters allowing scalability for installation.

Additionally it provides over-voltage protection and drives both a diversion load and a dumpload braking system.

Features

- Conversion efficiency at rating: 99.6%
- Three-Phase input from PMG
- Unfused path to brake load
- Automatic diversion load function proportionally introduced on an external dedicated output
- Adjustable brake and diversion load intervention thresholds
- Fused wind input to inverter (EU version only)
- Automatic brake function above adjustable threshold
- Activation function of external brake resistor
- Power curve owner

BLOCK DIAGRAM OF 25KW-WIND INTERFACE

Block Diagram

PARAMETER	15kW-WIND-INTERFACE	25kW-WIND-INTERFACE
Input Side		
AC Input Voltage Range (No damage) ($V_{acd,min}...V_{acd,max}$)	0...600 V	0...600 V
Operating AC Input Voltage Range ($V_{acmin}...V_{acmax}$)	35...600 V	35...600 V
Operating Frequency Range ($f_{min}...f_{max}$)	0...600 Hz	0...600 Hz
Maximum AC Input Current (I_{acmax})	55 A	85 A
Maximum Current in Main Brake Resistor ($I_{MBR,max}$)	30 A	50 A
Voltage Range in Main Brake Resistor ($V_{MBRmin}...V_{MBRmax}$)	0...1000 V	0...1000 V
Maximum Current in Auxiliary Brake Resistor ($I_{ABR,max}$)	15 A	30 A
DC Voltage Range in Auxiliary Brake Resistor ($V_{ABRmin}...V_{ABRmax}$)	0...850 V	0...850 V
Type of Inputs Connection	Screw terminal block Cable Gland	Screw terminal block Cable Gland
Input protection		
Input Over Voltage Portection - Varistor	4	4
Input Fuse Size	3 x 100 A	3 x 100 A
Output Side		
Maximum Output Power (P_{dmax})	15 kW	25 kW
Output Voltage Range ($V_{dc,min}...V_{dc,max}$)	50...850 V	50...850 V
Maximum Output Current ($I_{dc,max}$)	50 A	80 A
Type of Output Connection	Screw terminal block Cable Gland	Screw terminal block Cable Gland
Output Protection		
Output Over Voltage	Yes	Yes
Operating Performance		
Peak Efficiency (η_{peak})	99.6 %	99.6 %
Stand-by Consumption	< 14 W	< 14 W
Communication		
Local Monitoring System	RS 485	RS 485
Remote Control	-	-
User Interface	16 characters x 2 line LCD display	16 characters x 2 line LCD display
Environmental		
Ambient Temperature Range	-25...+50°C / -13...122°F	-25...+50°C / -13...122°F
Relative Humidity	0...98% non condensing	0...98% non condensing
Noise Emission	< 50 dB(A)	< 50 dB(A)
Maximum Operating Altitude without Derating	2000 m / 6560 ft	2000 m / 6560 ft
Physical		
Environmental Protection Rating	IP 65	IP 65
Cooling	Natural	Natural
Dimension (H x W x D)	650mm x 350mm x 265mm / 25" x 12.8" x 9"	650mm x 350mm x 265mm / 25" x 12.8" x 9"
Weight	22 kg / 48.5 lb	25 kg / 55.1 lb
Mounting System	Wall Bracket	Wall Bracket
Safety		
Marking	CE	CE
Safety and EMC standard	EN 50178, EN 61000-6-2, EN 61000-6-3	EN 50178, EN 61000-6-2, EN 61000-6-3

Remark. Features not specifically listed in the present data sheet are not included in the product

www.power-one.com

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WINDY BOY 5000-US / 6000-US / 7000-US / 8000-US

WB 5000US / WB 6000US / WB 7000US / WB 8000US

UL Certified

- For locations requiring UL certification (UL 1741/IEEE-1547)

High Yields

- 97% peak efficiency
- CEC efficiency of up to 96%
- OptiCool™ active temperature management

Easy to Use

- Automatic grid voltage detection*
- Programmable polynomial curve enables free selection of turbines

Reliable

- Rugged cast aluminum outdoor rated enclosure
- Compatible with Windy Boy Protection Box 600
- 10-year limited standard warranty

WINDY BOY 5000-US / 6000-US / 7000-US / 8000-US

The customized solution for wind turbine systems

Windy Boy inverters combine the same proven technology present in all Sunny Boy inverters with special firmware that permits direct grid-tied operation with a broad range of wind turbines—without batteries. This greatly reduces the overall system cost because components such as the charge controller, batteries and associated switch gear can be eliminated. Increased total energy capture combined with a reduction of balance of system components greatly reduces the installation and operating costs of a grid-tied wind system. Contact your local wind turbine supplier for information on compatible wind turbine models and system design considerations.

* US-Patent US7352549B1