Results and Lessons Learned from the ETV Pilot Test at NRLKW



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- NRL Staff: Tim Wier, Steph Robbins, Scott Riley, Luke Davis, Wayne Hyland, Tiffanee Denowick, Barron Stringham, BJ Kinee

ETV Pilot Test
Results Overview

- BWTE Test Parameters Defined by ETV Protocol – Key Elements and Facility Description
- BWTTF Pilot Test of Electrolytic Chlorination Treatment Technology – Test Setup
- Results of Pilot Test
- Lessons Learned and Challenges of Full Scale Testing
  - Validation of Methods and Procedures
  - Automation of Operations

Key Elements of ETV Pilot Test

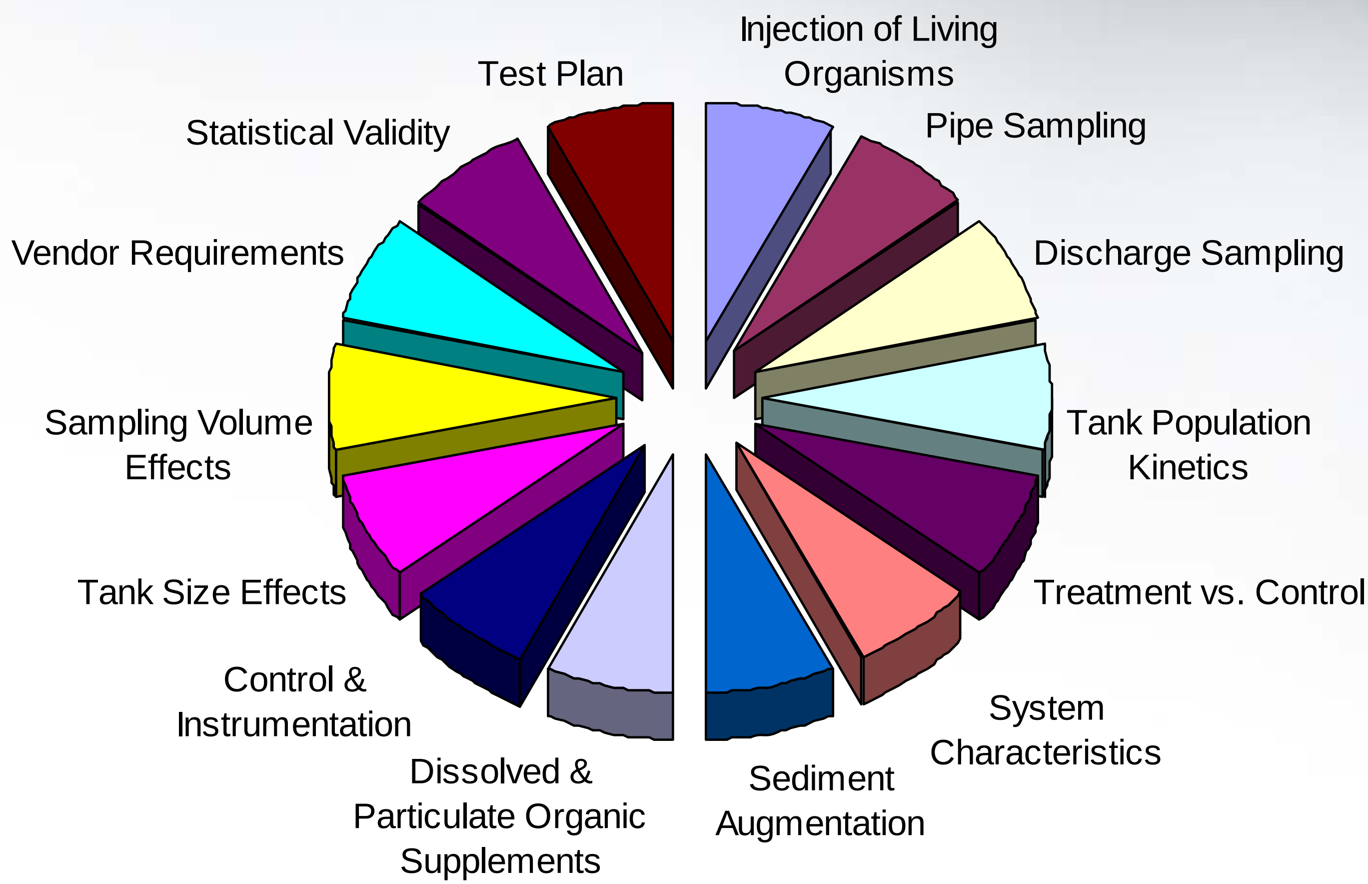
- Test Limited to Commercially Available Technology Suitable for Shipboard Installation and Operation
- Challenge Water Testing Specifies Minimum Requirements for Organism concentrations, Dissolved and Particulate Organics, and Suspended Solids
- Ballast Flow Rates of 300 m^3/hr with Ballasted Control Tank Volumes of 121 m^3 and Treatment Tank Volumes of 242 m^3
- Time Integrated 3 m^3 Sample Collection of Challenge Water Ballast and Deballast flows for Control and Treatment Tanks
- Maintenance and Operations Testing Specifies Operations for Minimum 10,000 m^3 of Ambient Water
- Seawater Testing Only: 6 Challenge Runs, 28 O&M Runs

Key Elements of ETV Pilot Test – Challenge Conditions

Parameter	Draft ETV Range	Nominal Test Value	Range	Units
Water Quality Parameters				
Salinity	28-33	36	33-38	PSU
Ambient water temperature	10 to 35	20	10 to 30	°C
Dissolved Organic Carbon (DOC)	8 to 12	5	4 to 6	mg/l
Particulate Organic Material (POM)	8 to 12	5	4 to 6	mg/l
Mineral Matter (MM)	16 to 22	20	16-22	mg/l
Total Suspended Solids (TSS)	24 to 34	24	20-28	mg/l
Surrogate Biological Densities in Ballast / Control Tank				
		Target value	Range	Min % live or viability
Artemia (organisms/l)		1.2×10^2	100-300	75%
Rotifers (organisms/l)		1.2×10^2	100-400	75%
Combined zooplankton (org/l)	*Min 100*	*Min 200*		
Tetraselmis (organisms/l)		1.1×10^4	10^4 to 10^5	90%
Thalassioira (organisms/l)		1.1×10^4	10^4 to 10^5	90%
Combined phytoplankton (org/l)	*Min 10,000*	*Min 20,000*		
Indigenous Bacteria (organisms/l)	Min 100,000	1.2×10^6	10^6 to 10^7	80%

ETV Testing Challenges
"Solving for the Pieces of the Pie"

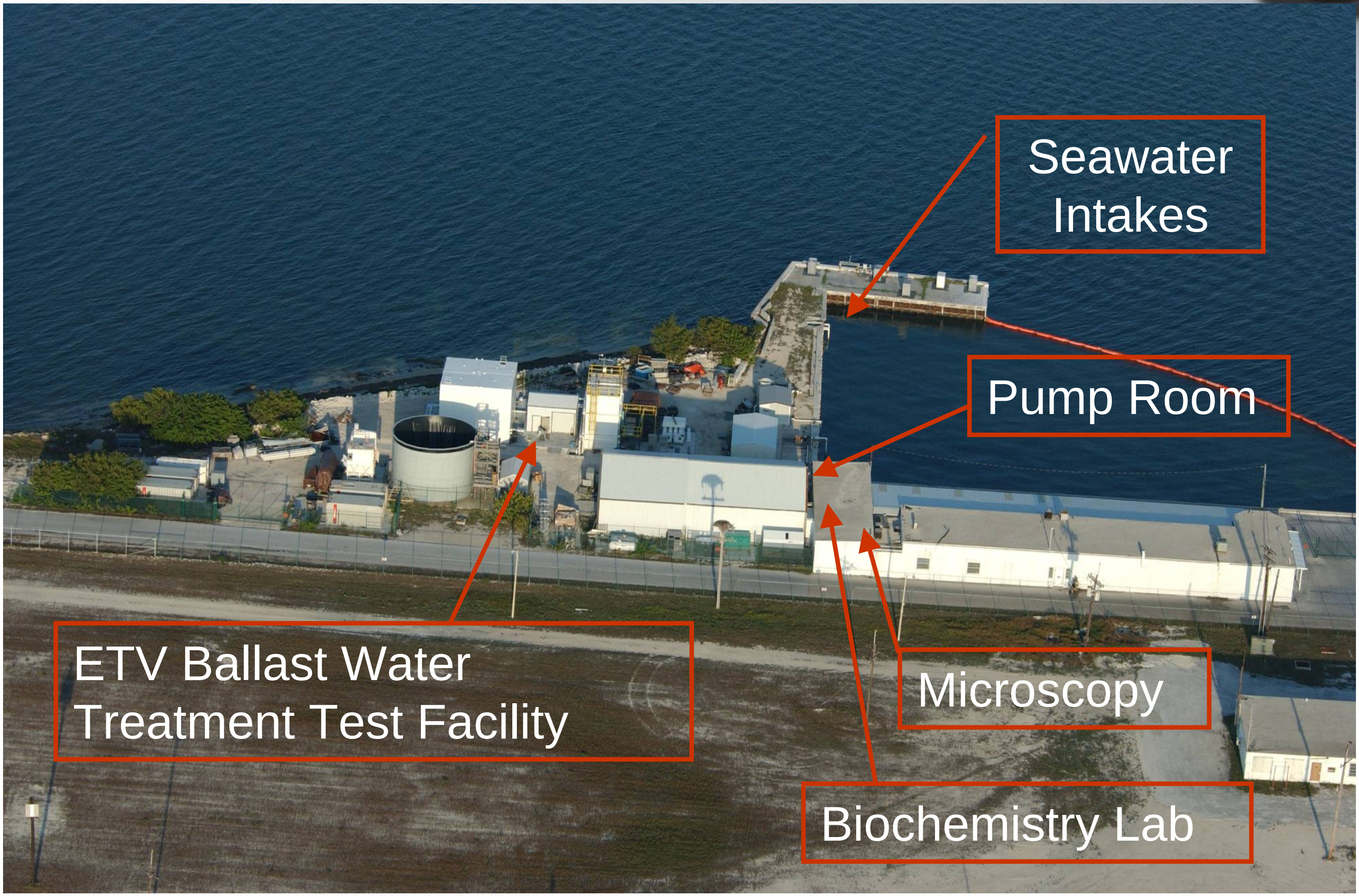
- Validation & Verification or Qualification Testing has not been done anywhere in the world at full-scale, in a standardized format and with statistical rigor.
- Therefore there are fundamental questions regarding "HOW-TO" perform the testing



Completed Experiments & Efforts since Jan 2005

- System Physical Properties and Performance
- Injection Methods
- Injection Automation and Integration
- Pipe Sampling Methods Evaluation
- Zooplankton Whole Tank Sampling
- In-tank Samples vs. In-line sampling
- Control Tank vs. Test Tank
- DOC & POC Augmentation
- Sediment Augmentation
- In-tank mixing
- Population kinetics
- Sample degradation
- Sample Point Effects
- Discharge Sampling
- Zooplankton Mobility Analyses
- Video Based Flow Cytometry for Cell Enumeration and Sorting
- Piping Component Effects
- Electrolytic Chlorine Generator Treatment Testing
- Phytoplankton Counting Methods

NRLKW Facility Overview



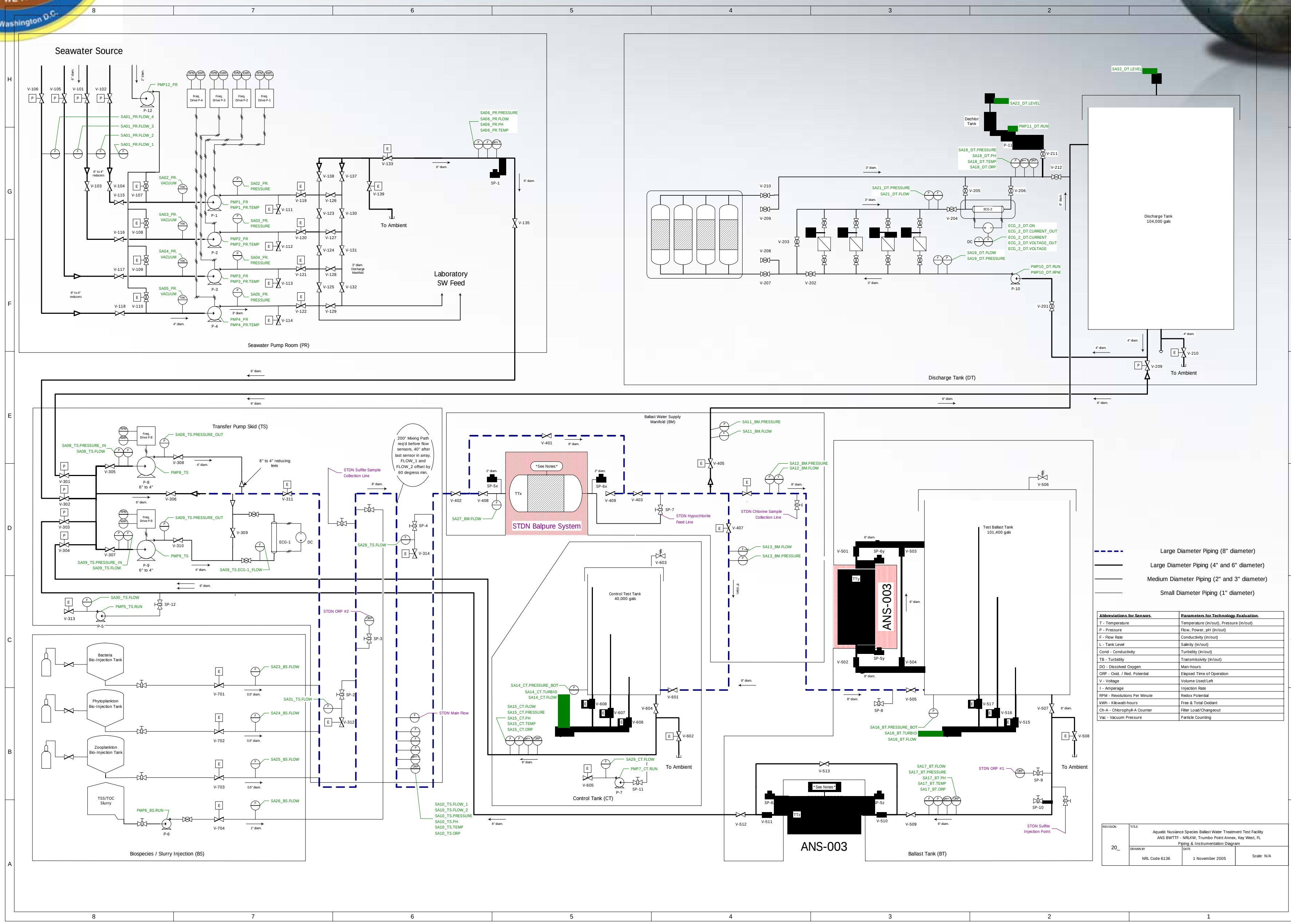
Major System Components

Main Pump Room

Ballast Pump, Sampling & Injection Skid

Mock Ballast Tanks

BWTTF Plant Diagram



BWTTF Control Room

ETV Pilot Test Setup

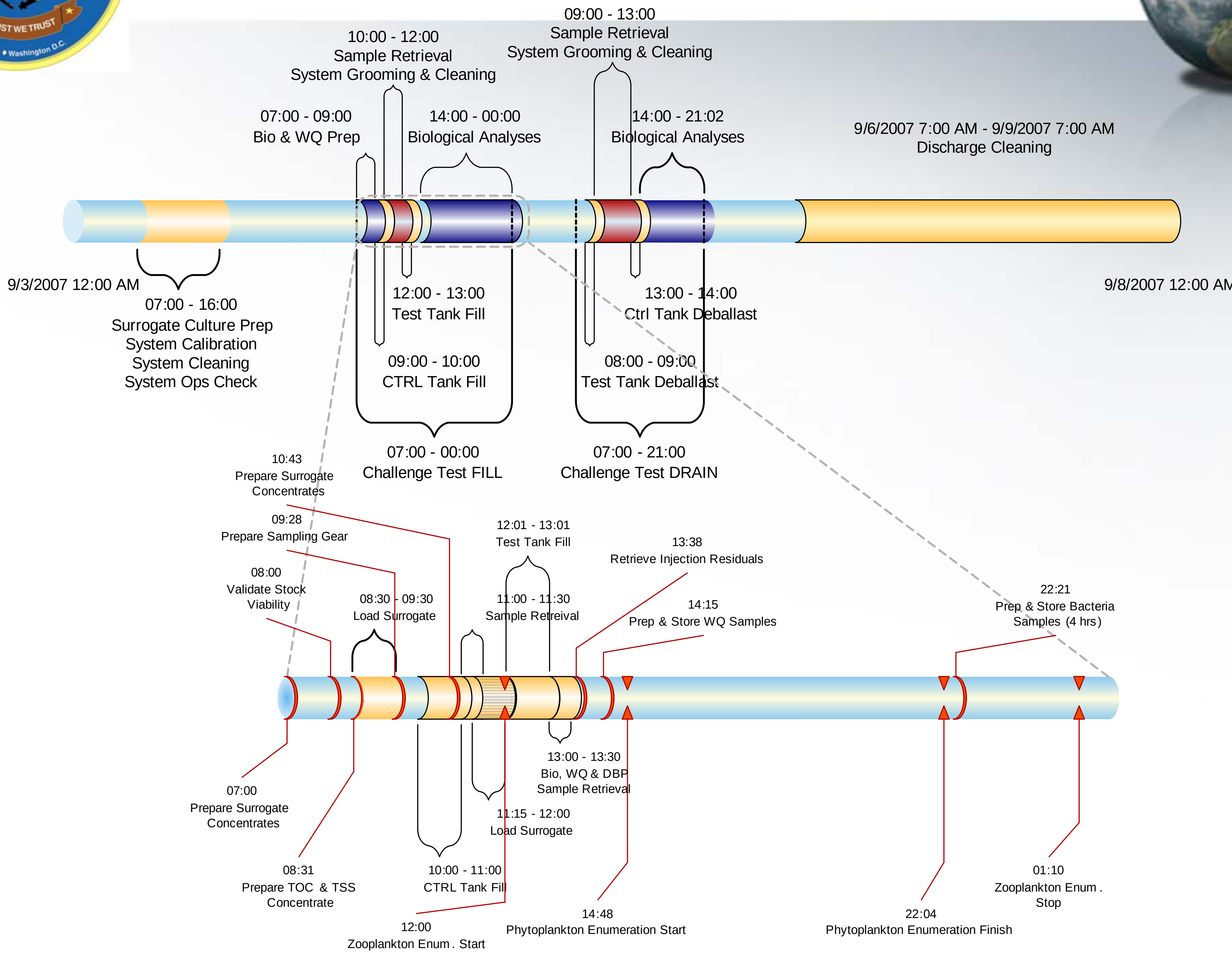
ETV Pilot Test of Vendor Equipment

- An Electrolytic Chlorine Generator, BalPure BP-1000, was selected.
  - Produced by Severn Trent DeNora, Houston, TX
  - Comprehensive data package
  - Well engineered and characterized system
  - Integration into the ETV test facility was straight forward
  - Sufficient automation and controls are supplied to make operation and monitoring of the unit challenging but achievable.
  - Well versed on the operation and mechanisms
  - The biological data indicate that chlorination was likely to achieve relatively high treatment/mortality of organisms.
  - No additional permitting would be required at NRLKW.
  - Severn Trent has participated in other ETV programs

ETV Pilot Test of Vendor Equipment

- Treatment by Chlorination on Ballast Uptake
  - Injects sodium hypochlorite produced from seawater back into ballast uptake line
  - Target residual of 18 ppm free chlorine in ballast tank, reduces to ~4 ppm after 24 hours
- Dechlorination on Deballast
  - Injection of sodium bisulfite into drain line to neutralize remaining free chlorine

A Day in the Life…



Results: Challenge Water Testing

Results – Biological Challenge Conditions

- ETV Protocol live zooplankton concentrations were achieved in C3-C6
  - 1.2-2.5 x 10^2 organisms/L including ambient populations and the surrogate organisms, *Artemia franciscana* and *Brachionus calyciflorus*.

- Total living phytoplankton concentrations of at least 10^4/L were achieved in C3-C6
  - 3.4 x 10^4 and 5.5 x 10^4 organisms/L. These include ambient populations and surrogate organisms *Tetraselmis spp*. and *Thalassioira weissflogii* .

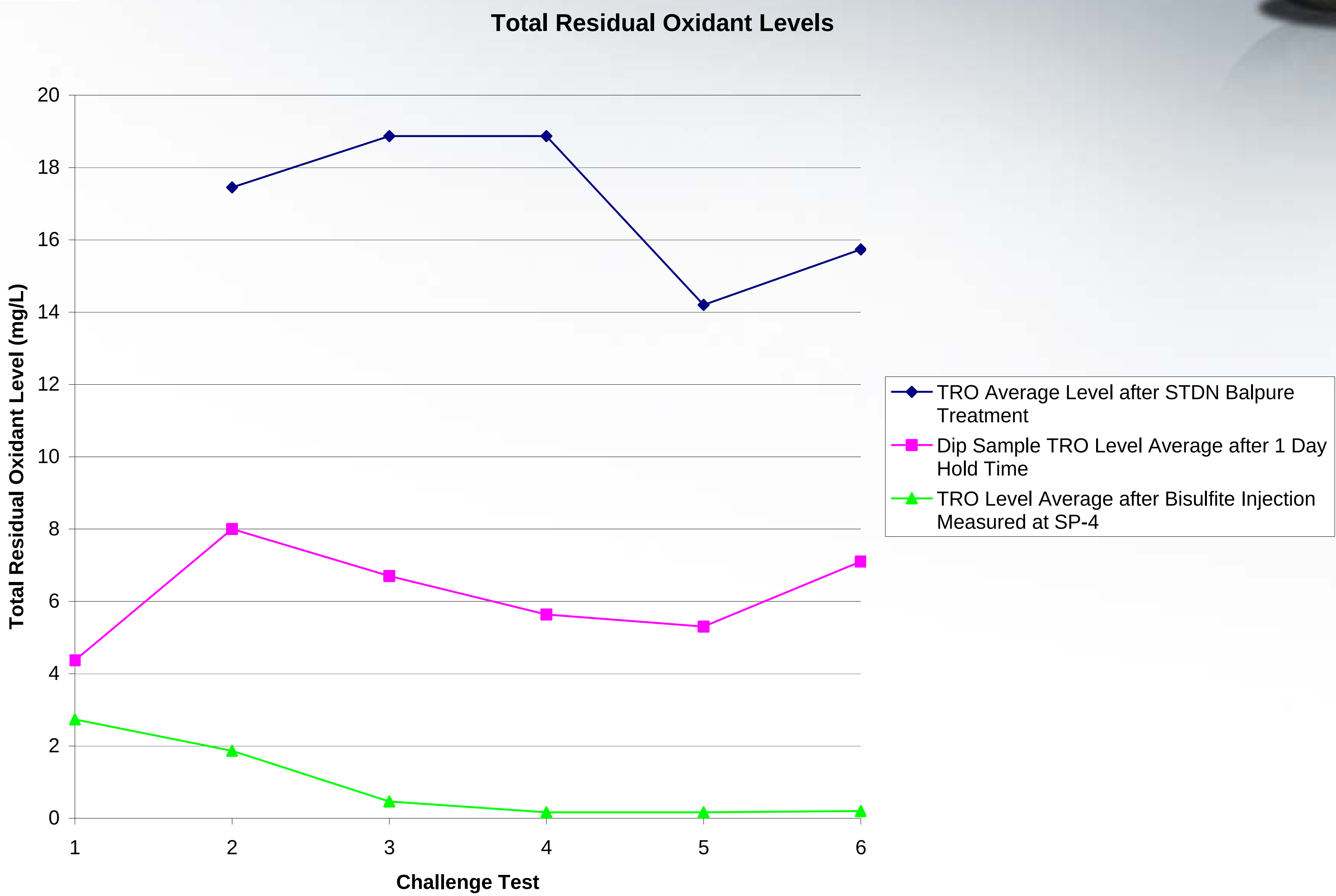
- No surrogate bacteria communities were utilized. Ambient, culturable bacteria were in excess of 10^2 CFU/ml.

- Criteria adopted for minimum living organism concentrations for phytoplankton and zooplankton in the control tank discharge after a one day incubation period.
  - Minimum of 100 living zooplankton/m3
  - Minimum 10 living phytoplankton/ml.
  - These criteria were met for each C3-C6.

Results – Challenge Water Quality Conditions

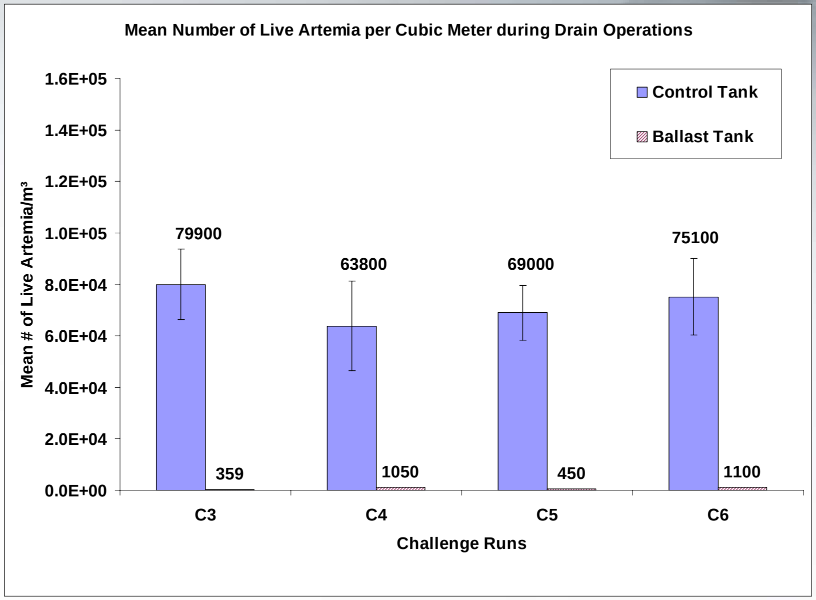
- Dissolved organic content was successfully augmented using *camellia sinesis* (decaffeinated iced tea) within 4-6 mg/l.
- Ambient levels of particulate organic matter were nearly sufficient to meet the Test Plan criteria of 4-6 mg/l. Subsequent to augmentation with humic acid, concentrations exceed this range during challenge tests C3 and C4. However, C5 and C6 particulate organic matter additions were successfully adjusted to within the 4-6 mg/l range.
- Mineral matter concentrations slightly exceeded the required range of 16-22 mg/l in C3 and C4, and were within the range for C5 and C6.

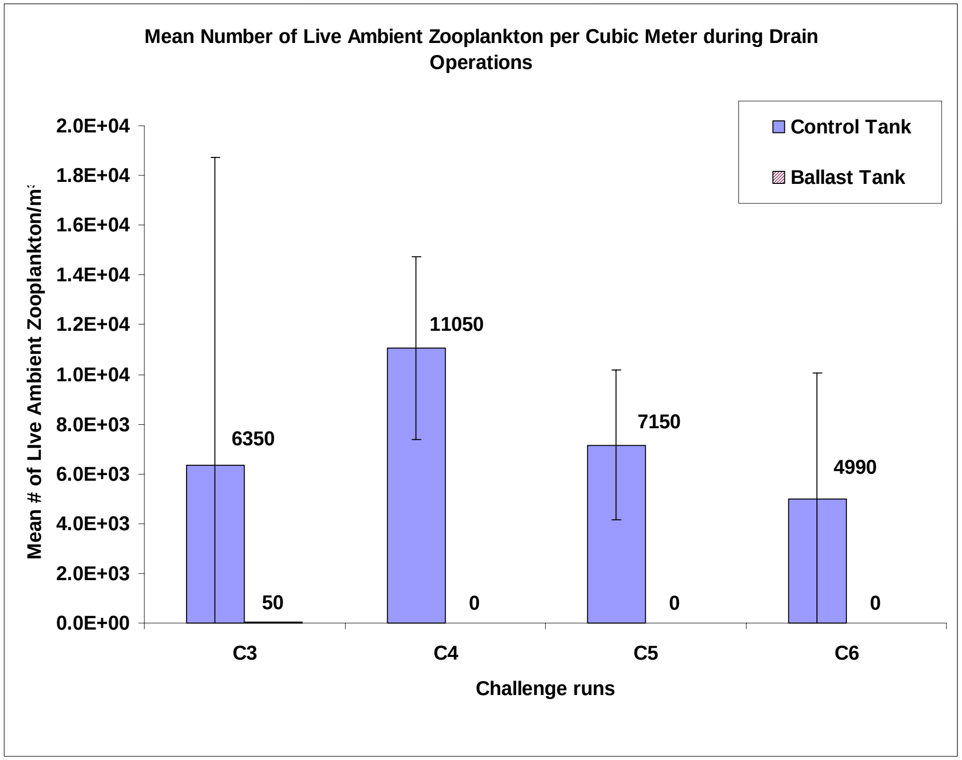
Results- Total Residual Oxidant

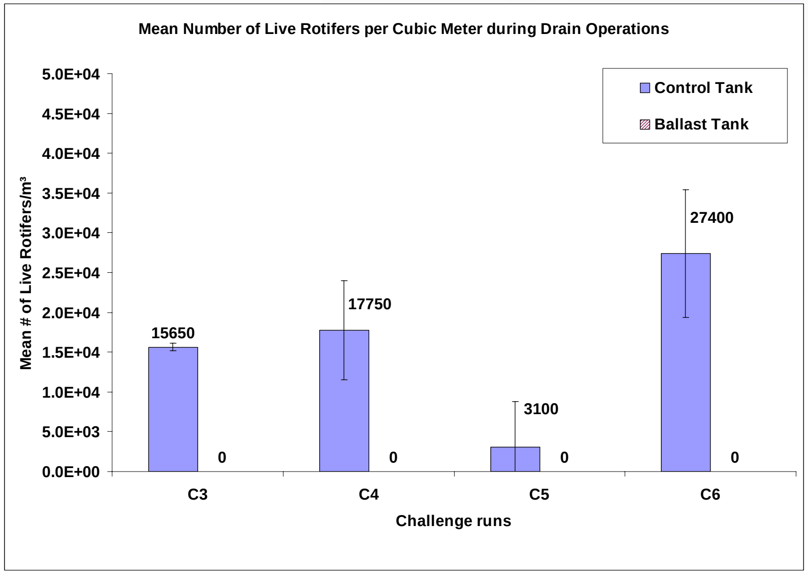


Results - Biological Efficacy, Zooplankton

- Ambient mortality was 99.1% for C3 and 100% for C4-C6
  - C3 mortality was a result a single living organism counted!
- Surrogate Indicator Organisms
  - *Artemia* Mortality 99.5% on average
  - Rotifer Mortality 100%

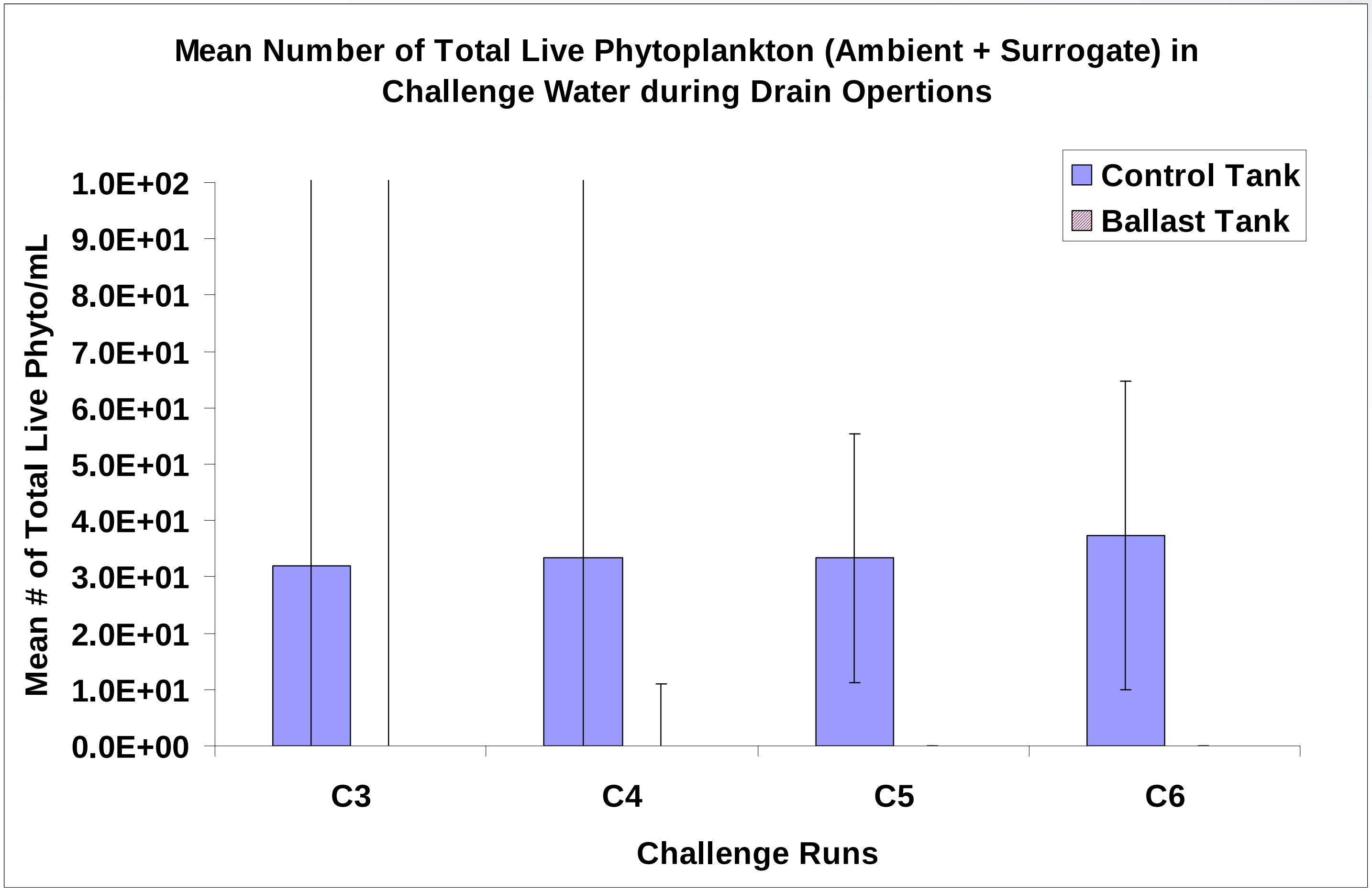






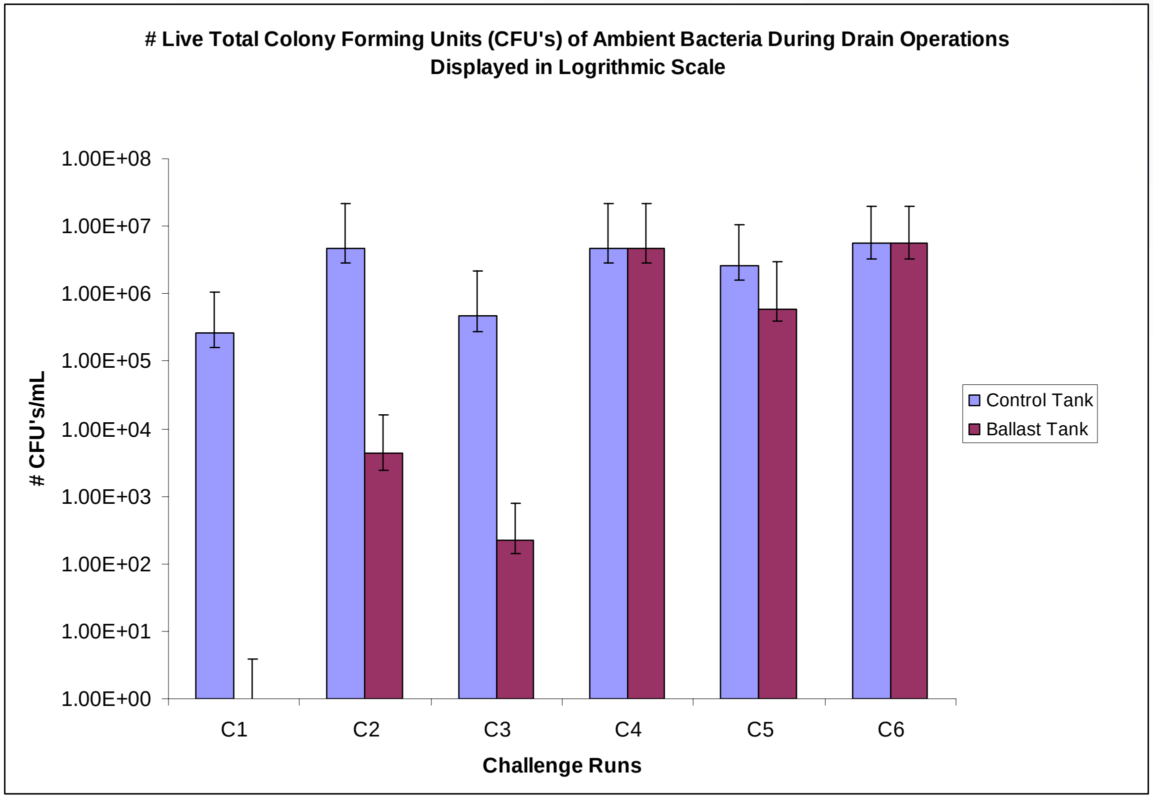
Results - Biological Efficacy, Phytoplankton/Protists

- Phytoplankton mortality was 100% for all organisms following treatment.



Results - Biological Efficacy, Bacteria

- Only C3 had substantial reductions in ambient, culturable bacteria.
- All others had negligible reductions.
- Several potential sources for contamination of deballast sample



Lessons Learned and Challenges of Full Scale Testing

Lessons Learned: Component Effects on Test System Must Be Assessed

- Mechanical Effects on Organism Mortality
  - Pumps, valves, sample ports can kill organisms directly or through shear and pressure differentials; must be sized appropriately for test flows and volume
  - Diaphragm valves and pumps are used in all control applications for organism injection and sampling
- Chemical Effects on Organism Mortality
  - Tank materials can affect organisms and must be evaluated
  - Augmentation of organic content required toxicity study, also do not want to add feedstock
- Design of Flow System
  - Sensor types and locations must be appropriate (especially flow sensors)
  - Appropriate mixing lengths must be provided

Lessons Learned: Methods and Procedures Must Be Validated and Well Rehearsed

- Surrogate Injection
  - Duplicate set of 3 tanks – one for control fill sequence and one for treatment fill sequence
  - Air pressure injection also provides aeration/mixing for surrogates in tank
- Test Operations – Ensure repeatable test conditions
  - Automation of flow control is key for both consistency and safety
  - Sample collection methods must be appropriate for a wide range of concentrations
  - Sequencing of test operations
- Analytical Methods
  - Sample handling for zooplankton, phytoplankton, bacteria, water chemistry, DBPs
  - Counting methods are time consuming and time limited
  - Live / dead staining dyes can be used for phytoplankton
  - Develop appropriate data reduction tools (easy input of manual count data, dilution volumes, actual test volumes for ballast and sample tanks)

Lessons Learned: Validation of Test Facility as a System

- Control Tank vs. Treatment Tank
  - There were no significant differences between test conditions (both input and output) in the Control vs. Treatment ballast tanks
- Organism Lifetime and Recovery vs. Tank Hold Time
  - "Population Kinetics" studies of one, three and five day hold times
  - Zooplankton surrogate Artemia showed significant mortality with three and five day hold times
  - Phytoplankton surogate Tetraselmis showed no organisms after five day hold time
- ETV Pilot Test was run with one day hold time to ensure sufficient live organisms were recovered upon deballast of Control Tank

Most Significant Remaining Technical Challenges

- Accurate and Robust Enumeration of Live Phytoplankton
  - NRL research revealed significant technical obstacle
  - Current measurement methods are inaccurate or have insufficient detection limit
  - No realistic solutions yet available
- Optimization of Land Based Testing
  - Time and Scale are significant technical and financial obstacle for future test facilities
  - NRL will conduct T&E during FY07 to determine minimum requirements
  - Automation of methods for organism enumeration and viability would provide significant benefit
- Facility Standardization and Comparability
  - Variability in standardized test results of treatment efficacy will result in a disservice to regulators, class societies and customers.
  - Current ETV Protocol details what is required but not how it should be achieved.