

# Naval Surface Warfare Center

## Carderock Division

West Bethesda, MD 20817-5700

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**NSWCCD-61-TR-2008/07**

24 February 2008

Survivability, Structures, and Materials Department

Technical Report

## Quantifying Thickness Change of Antifouling Coatings Upon Exposure to Artificial Seawater

by

Elizabeth G. Haslbeck, Elissa M. Bumiller, and Eric R. Holm



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| REPORT DOCUMENTATION PAGE                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                             |                              |                                       | Form Approved<br>OMB No. 0704-0188                                   |                                                           |
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| 14. ABSTRACT<br><br>Whether and by how much hull coating systems swell and whether or how this impacts paint thickness measurements has long been debated. If swelling does occur and it is significant, it could at least in part help explain unexpected variability observed in past data sets, especially if swelling is a function of environmental conditions such as exposure time, water chemistry, salinity, and water temperature. If swelling is not significant, then other potential factors that may impact DFT measurement accuracy must be explored. We quantified the impact of seawater exposure on paint thickness under controlled conditions of pH, temperature, and salinity on three replicate panels of four coating systems. In addition, we attempted to quantify the impact of coating and substrate roughness on measurement error. We used a precision template and probe stand to repeatedly quantify DFT at the same 12 spots on each panel over 90-days. Based on our results, copper ablative antifouling hull coatings exposed to artificial seawater for 3 months at room temperature do not significantly swell. If any DFT change does occur, it is < 1 mil. Hypothetical DFT changes of less than one mil due to swelling would not account for the much larger discrepancies between a subset of field data sets mentioned above which showed quite large decreases in DFT over very short periods of time or quite small increases in DFT over longer periods of time. We believe that measurement error, not paint swelling, was the most significant contributing factor to the error associated the reported data sets. In the end we summarize a series of "lessons learned" for both laboratory and field DFT measurement techniques. |                             |                              |                                       |                                                                      |                                                           |
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## **GLOSSARY**

|        |                                                                    |
|--------|--------------------------------------------------------------------|
| AF     | antifouling                                                        |
| ASTM   | American Society for Testing and Materials                         |
| DFT    | dry film thickness                                                 |
| mil    | one one-thousandth of an inch                                      |
| NEURS  | Navy Energy Usage Reporting System                                 |
| NREIP  | Naval Research Enterprise Intern Program                           |
| NRL    | Naval Research Laboratory, Washington DC                           |
| NSWCCD | Naval Surface Warfare Center, Carderock Division, West Bethesda MD |
| OECD   | Organization for Economic Co-Operation and Development             |
| ROV    | Remotely-operated vehicle                                          |
| SEAP   | Student Engineering Apprenticeship Program                         |
| SSPC   | The Society for Protective Coatings                                |

## INTRODUCTION

The Navy uses cuprous oxide based ablative antifouling (AF) coatings on underwater ship hulls to control the accumulation of biofouling and therefore minimize frictional resistance or drag. These systems are rosin-based where water soluble rosin is incorporated as a binder into a polymeric matrix and dissolves over time to create a pathway for copper dissolution. Copper in the form of cupric ions is then available to deter settlement of biofouling organisms.

The expected service life of these coatings, or the period between drydocking and coating system replacement, is 3-5 years, but has been extended to 10-12 through the development and implementation of a suite of inspection and maintenance protocols and procedures. These include in-water hull cleaning and close monitoring of performance and thickness. Paint dry film thickness (DFT) is a key component of the monitoring plan since, by design, both the normal ablation process and in-water hull cleanings contribute to paint thickness loss over time. DFT is thus a key indicator of remaining service life.

DFTs are routinely quantified in drydock and underwater by the use of magnetic induction technology. Underwater measurements are facilitated by waterproofing the probe by encasing it in a ceramic tube. Randomized DFT measurements are taken over various sections of the hull, and are typically presented as histograms by hull section. Typically 30 readings are taken per 1,000 ft<sup>2</sup>. Shifts in median DFT are tracked over time. These analyses have proven quite effective in facilitating maintenance planning by providing an indication of remaining coating service life.<sup>1</sup>

Past experience indicates that the following DFT changes are generally expected: less than 1 mil per year due to ablation only, 1-3 mils with each in-water hull cleaning, and about 1 mil with each power washing in drydock. Past experience also indicates that in-water hull cleaning results in a more uniform decrease in paint thickness over a whole ship hull, whereas DFT changes attributed to ablation alone decrease less uniformly over a whole ship hull. In the first few years of service, areas of thicker DFT tend to lose thickness at a higher rate than areas of thinner DFT (Wimmer, 1997).

In most cases, when DFT data sets are compared over time for the same vessel, DFT decrease tracks fairly well with time in service, in-water hull cleanings, and drydock powerwashings. Historically, based on data sets obtained by NSWCCD using both divers and remotely operated vehicles (ROVs), the approximate rate of DFT change over time, taking into consideration all of these conditions, ranges from 1-3 mils per year. However, a recent analysis of a large DFT data set from an array of fleet maintenance facilities proved difficult to explain. For example, sister ships operating from the same home port, having similar duty cycles, and

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<sup>1</sup> SSPC PA-2 requires the reporting of the mean of 3 DFT measurements in each of 10 spots per 1,000ft<sup>2</sup>. Most Naval Surface Warfare Center, Carderock Division (NSWCCD) data sets include a minimum of 30 readings per 1000 ft<sup>2</sup> with no averaging.

painted with the same coating system showed vastly different rates of DFT change over time, one ship showing an increase of 1-2 mils and the other a decrease of 8-10 mils. In several other cases, no change in DFT was observed even after 3-5 years of in-service activity combined with 1-2 in-water hull cleanings. This prompted maintenance planners and hull coatings experts to look for explanations for the variations in DFT. The list of possibilities included presence of biofouling or biofilms, swelling of the coating, and measurement error including improper calibration, improper probe orientation, and improper design of sampling plans.

This study was initiated to determine the impact of paint swelling, if any, on DFT data set reliability and error for Navy-relevant AF coating systems. Rosin, a major component of copper ablative antifouling coatings, is a natural resin obtained from pine trees and can swell when exposed to water or seawater. Whether and by how much it swells when incorporated into antifouling coatings and whether or how this impacts paint thickness measurements has long been debated. If swelling does occur and it is significant<sup>2</sup>, it could at least in part help explain unexpected variability observed in the data sets cited above, especially if swelling is a function of environmental conditions such as exposure time, water chemistry, salinity, and water temperature. If swelling is not significant, then other potential factors that may impact DFT measurement accuracy must be explored.

We quantified the impact of seawater exposure on paint thickness under controlled conditions of pH, temperature, and salinity on three replicate panels of four coating systems. In addition, we attempted to quantify the impact of coating and substrate roughness on measurement error. We used a precision template and probe stand to repeatedly quantify DFT at the same 12 spots on each panel over 90 days. Based on recommendations from industrial partners, initial tests were conducted with eddy current DFT gauges on coated stainless steel substrates. Later we determined that the eddy current technique was not suitable for quantifying DFT on panels wet with ASTM artificial seawater, and we repeated our efforts on coated steel panels using magnetic induction DFT measuring equipment.

A potential, separate, but related interfering factor in DFT measurement is the presence and thickness of the leached layer. As copper and rosin dissolve from the coating, a depleted polymeric backbone structure is left behind, referred to as the “leached layer” that can be up to 2 mils thick (Figure 1). This weakened layer tends to erode away during periods of ship activity, a process which helps to ensure the sustained efficacy of aging ablative AF coating systems. The impact of leached layer thickness on DFT measurements is not known. This is the subject of a parallel study being performed at SigmaKalon in The Netherlands, the results of which will appear in a separate report.

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<sup>2</sup> Significant swelling: for example, > 10% of the total applied paint thickness of approximately 25-30 mils.

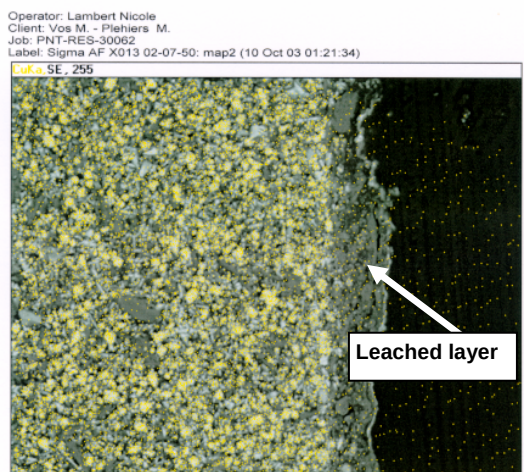


Figure 1. Cross Section of Aged Paint Film. Leached Layer Indicated With An Arrow.

## MATERIALS AND METHODS – MEASUREMENTS USING EDDY CURRENT GAUGE

### COATINGS

Three coating systems were selected for the paint swelling study (Table 1). All contained cuprous oxide as the main biocide, and two were based on ablative chemistry and one on self-polishing chemistry. Self-polishing coatings are based on seawater-reactive polymer technology such as metal or silyl acrylates. These coatings contain significantly less rosin than copper ablative chemistries. All three coatings were also evaluated by SigmaKalon as part of their parallel effort looking at impact of leached layer on DFT and biocide release rate (to be published in a separate report).

Table 1. Coatings Evaluated with the Eddy Current Measurement Technique

| Coating Name         | Navy QPL Status | Chemistry      | Biocide                      |
|----------------------|-----------------|----------------|------------------------------|
| International BRA640 | Yes             | Ablative       | Cuprous oxide                |
| Sigma Super-Ecol     | No              | Ablative       | Cuprous oxide + SeaNine 211® |
| Sigma Alphagen       | No              | Self-polishing | Cuprous oxide + Irgarol®     |

### PANEL PREPARATION

The coatings were spray applied to twelve 6" x 12" stainless steel panels at the Naval Research Laboratory (NRL) facility in Key West, FL. All panels were prepared with virtually no

anchor tooth profile (< 1 mil) in order to minimize potential variability in DFT measurements. Upon receipt from NRL, the panels were inspected for variability in applied coating thickness, warping of the panel, and coating defects. Nine replicates of each coating were selected for testing, and the other panels were used for preliminary evaluation.

## EXPERIMENTAL APPARATUS

Panels were exposed in nine test tanks filled with ASTM artificial seawater. Each 20-L test tank consisted of a panel rack (panels held vertically), a pump, a carbon filter, an ion exchange filter, and connective tubing as shown in the schematic (Figure 2) and photograph (Figure 3). The rate of seawater flow through the test tanks was approximately 1.7 L/min. Uniform flow was ensured through the use of a diffuser. The carbon and ion exchange filters effectively controlled particulate and copper levels respectively. Copper was held below 100 µg/L. Constant pH (8.1) and temperature (22°C) were maintained during the testing. To maintain constant temperature, a heat exchanger circulated fresh water through a copper tubing coil that wrapped around the test tank. Each coil-wrapped test tank was placed within a larger cooler filled with fresh water. The pH was adjusted as needed by adding small amounts of hydrochloric acid to lower the pH or sodium hydroxide to raise the pH. Salinity levels varied: 10 ppt, 22 ppt, and 33 ppt. The salinity was adjusted by adding fresh water to lower the salinity or adding ASTM sea salt to raise the salinity. Test tank parameters were checked frequently to ensure constant conditions.

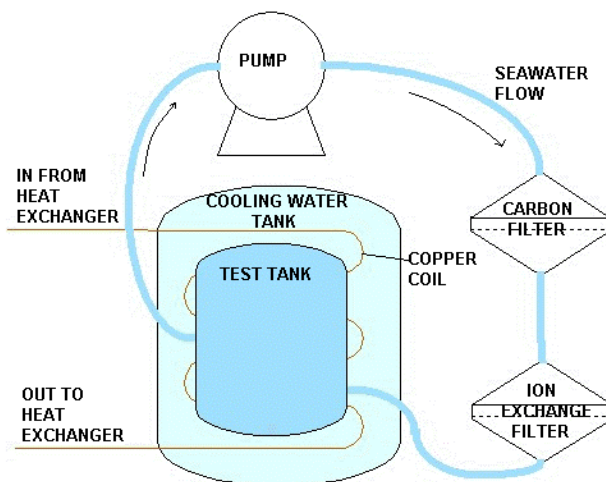


Figure 2. Tanks, Pump, And Filters Set-Up For Eddy Current Testing

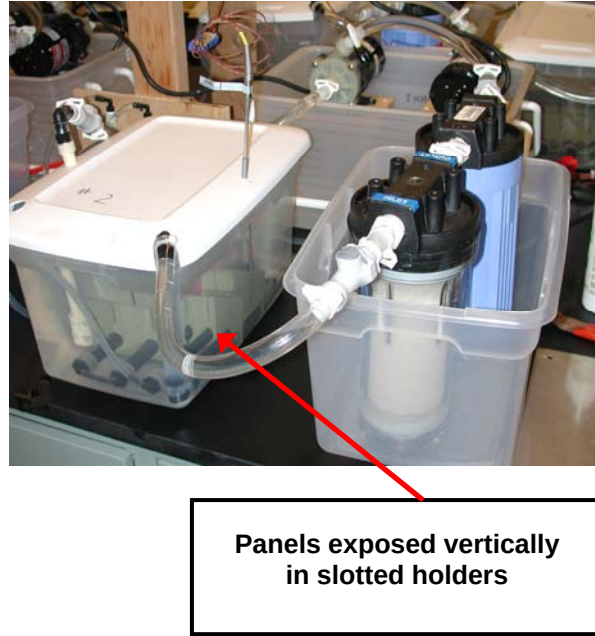


Figure 3. Test Tank and Filtration Setup

## DRY FILM THICKNESS MEASUREMENT SYSTEM

A Fischer MP40 DualScope paint thickness measurement system, shown in Figure 4, was used to measure DFT. This meter can accommodate both magnetic induction and eddy current probes. For the eddy current measurements we used two Fischer Technology, Inc. waterproofed probes: the ETA3.3H and ETA3.3F. The eddy current method uses a magnetic field to induce current in a non-magnetic substrate covered with a non-conductive coating. The electric field resulting from the current counters the magnetic field and a resistance change is monitored. This method is used in the lab and in the field, primarily on dry coatings. However, our measurements were to be made on damp or wet coatings, and therefore we worked with the manufacturer to waterproof the probes<sup>3</sup>.

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<sup>3</sup> The vast majority of historical DFT data sets were made with magnetic induction probes on steel hulls. When measurements were taken in-situ, the magnetic induction probe had been waterproofed.

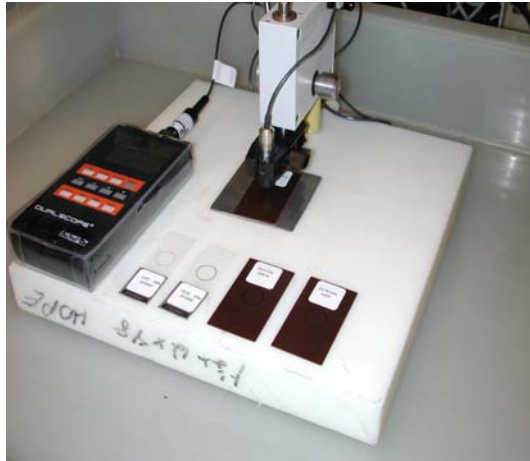


Figure 4. Fischer Technology MP40 Dualscope with Measuring Stand. Shims of Known Thickness Shown.

Using spare panels, preliminary experiments were conducted to determine whether or not thickness changes of 1 mil or less might be reliably quantified. Based on guidance from industry and field experience, we focused on techniques that allowed for repeated measurement of the same point versus random measurements over a larger area. We had difficulty obtaining repeatable data over several days, but within a day, data tended to be quite repeatable. In order to improve our ability to detect small thickness changes over time, we conducted several troubleshooting studies that addressed:

- Single measurement mode vs. continuous measurement mode
- Frequency of calibration
- Flat vs. ball bearing probe tip shapes
- Random vs. spot measurements
- Probe orientation in holder
- Potential interferences within the lab (indoor vs. outdoor measurements)
- Probe indentation into the panel during measurement
- Impact of probe starting height<sup>4</sup>

Results of these studies indicated:

- Single vs. continuous<sup>5</sup>: There were no significant differences in measurement error between single measurement mode (probe lowered to surface and raised immediately after; a

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<sup>4</sup> The significant impact of probe starting height was not discovered until we changed our focus to the magnetic induction technique, but is mentioned here due to suspected contribution to significant error over several measurement days. See below for more details.

<sup>5</sup> Probe starting height was not permanently fixed when conducting this study. We also believe variation in ion concentration impacts wet eddy current measurements. The manufacturer could not confirm either hypothesis.

measurement is taken instantaneously upon probe contact with surface) and continuous measurement mode (probe lowered to surface and left in contact with surface until reading “steadies”). Single measurement mode was much less time consuming, and was therefore used for the remainder of the experiments.

- Calibration frequency<sup>5</sup>: Daily calibration negatively impacted repeatability. DFT variability with no calibrations over 4 days ranged from 0.36 to 0.44 mils, whereas with multiple calibrations within a day over 4 days or each day for 4 days, variability ranged from 0.18 to 0.74 mils. Therefore, re-calibration frequency was minimized to the greatest extent practicable. Calibration was checked daily with shims.

- Tip shape<sup>5</sup>: Flat-tipped probe measurements were more repeatable than bearing-tipped probe measurements. Measurements taken with flat-tipped probes were consistently higher than those taken with bearing-tipped probes. The flat tipped probe tended to sit on top of peaks in coating roughness, and therefore these measurements limited our ability to track small changes in thickness at a single point on the panel. We therefore took all follow-on experimental data with bearing-tipped probes.

- Random vs. spot measurements<sup>5</sup>: Repeated single point measurement over the face of a panel showed better repeatability compared with averages of multiple readings within a “sector” on a panel. Tracking changes in DFT using spot measurements increased measurement reliability and reproducibility, allowing detection of smaller changes in DFT (Tables 2 and 3).

- Probe orientation in holder<sup>5</sup>: Error as a result of probe orientation in the holder (0, 90, 180, and 270 degrees) ranged from 0.05 to 0.45 mils (Figure 5). Therefore, probe orientation in the holder was fixed for the remainder of the testing.

Table 2. Pre-Exposure, DFT Study Using Precision Template – Quantify DFT at Single Spot. Spot Numbers 1 Thru 23, Odd. Panel BRA S-4. Each Reported Value (mils thickness) is the Average of 3 Measurements.

| Trial 1 |       | Trial 2 |       | Trial 3 |       |      |       |       |
|---------|-------|---------|-------|---------|-------|------|-------|-------|
| Point # | Meas. | Point # | Meas. | Point # | Meas. | Mean | Range | STDEV |
| 1       | 19.5  | 1       | 19.4  | 1       | 19.3  | 19.4 | 0.2   | 0.09  |
| 3       | 19.3  | 3       | 19.4  | 3       | 19.2  | 19.3 | 0.2   | 0.09  |
| 5       | 19.8  | 5       | 19.7  | 5       | 19.8  | 19.8 | 0.1   | 0.05  |
| 7       | 19.5  | 7       | 19.6  | 7       | 19.7  | 19.6 | 0.3   | 0.14  |
| 9       | 20.3  | 9       | 20.2  | 9       | 20.2  | 20.2 | 0.1   | 0.05  |
| 11      | 19.7  | 11      | 19.7  | 11      | 19.7  | 19.7 | 0.1   | 0.05  |
| 13      | 19.4  | 13      | 19.4  | 13      | 19.5  | 19.4 | 0.1   | 0.05  |
| 15      | 19.3  | 15      | 19.4  | 15      | 19.3  | 19.3 | 0.1   | 0.05  |
| 17      | 19.5  | 17      | 19.6  | 17      | 19.3  | 19.4 | 0.3   | 0.14  |
| 19      | 19.5  | 19      | 19.3  | 19      | 19.5  | 19.4 | 0.2   | 0.10  |
| 21      | 20.1  | 21      | 20.0  | 21      | 20.1  | 20.1 | 0.1   | 0.05  |
| 23      | 20.0  | 23      | 20.2  | 23      | 20.1  | 20.1 | 0.2   | 0.09  |

Table 3. Pre-Exposure, DFT Study Using 8-Sector Template. Panel BRA S-4. Each Sector Approximately 3 In<sup>2</sup>; 10 Random Measurements (in mils) Per Sector.

| Measurement | Sector 1 | Sector 4 | Sector 5 | Sector 8 |
|-------------|----------|----------|----------|----------|
| 1           | 20.0     | 21.8     | 21.6     | 22.0     |
| 2           | 20.3     | 21.4     | 21.8     | 21.4     |
| 3           | 21.0     | 21.8     | 21.4     | 21.1     |
| 4           | 20.8     | 22.0     | 21.7     | 21.0     |
| 5           | 20.6     | 21.6     | 22.0     | 21.0     |
| 6           | 20.3     | 21.4     | 21.9     | 21.2     |
| 7           | 20.3     | 21.6     | 21.7     | 21.4     |
| 8           | 20.4     | 21.4     | 21.3     | 21.2     |
| 9           | 20.6     | 21.9     | 22.1     | 21.3     |
| 10          | 21.1     | 21.6     | 22.1     | 21.0     |
| Mean        | 20.5     | 21.7     | 21.8     | 21.3     |
| Std. Dev    | 0.36     | 0.21     | 0.26     | 0.29     |

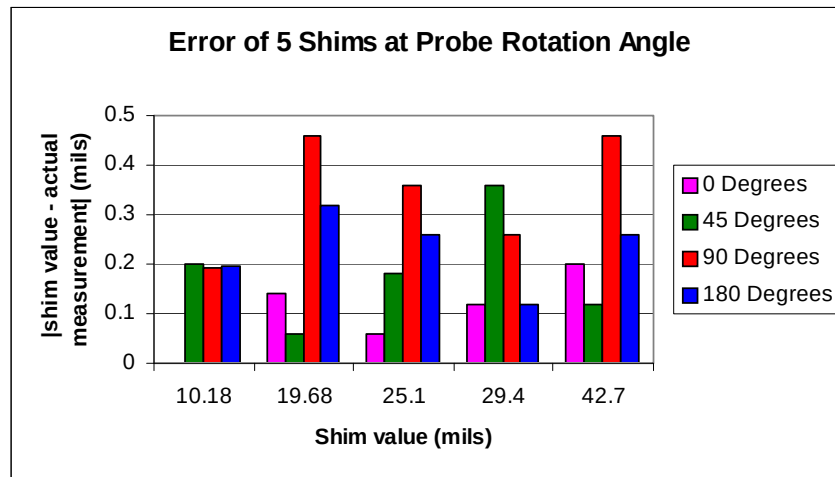


Figure 5. Impact of Probe Orientation On Shim DFT Measurements

- In-lab interferences<sup>5</sup>: Measurement variability was unacceptably high over multiple days. The probe manufacturer suggested that variation in electric fields in the laboratory may be contributing to error. Therefore, measurements with a fixed probe were taken on the same spots on the same panel both inside and outdoors. After three days of testing, measurements on a single spot on a single panel where the measurements were taken inside covered a range of 0.5 mils whereas that range was 0.3 mils when the measurements were performed outdoors. However, taking measurements outdoors was impractical, and therefore the remainder of the

testing was performed in the laboratory and care was taken to carry out all measurements on the same bench top area.

- Probe starting height: Although the impact of probe starting height on DFT was quantified for magnetic induction probes only, the issue is mentioned here due to the *significant* impact very small changes in probe starting height had on magnetic induction measurements.
  - o During the eddy current portion of our work, attempts to achieve the same starting height were inadequate. We placed a mark on the shaft of the probe holder assembly as an indicator of probe starting height. However, we believe this technique inadvertently resulted in a 1-2 mm variation in probe starting height. We thought this was inconsequential until we later analyzed the results of a probe height experiment using the magnetic induction equipment; this was after we had abandoned the eddy current technique. The probe starting height experiment for magnetic induction equipment was conducted at four starting height positions which covered a total range of approximately 2.5 mm. DFT measurements increased as much as 3 mils over the 4 starting height positions, and as the probe starting height was reduced (lowered) the DFT measurements increased. Details can be found in the section on Magnetic Induction.
  - o We did not conduct a comprehensive study of probe starting height using eddy current equipment since we had already discontinued eddy current measurements due to unexplained variation in data from measurement day to measurement day. However, we do feel that, at least in part, the erratic day-to-day DFT changes we observed with the eddy current method can be tied to the effect of slight differences in probe starting height or position.

Upon completion of these preliminary experiments, we believed we had established a standard protocol that minimized error. Therefore, we conducted the paint swelling study with the eddy current measurement protocol as originally planned. We standardized on single measurement mode, less frequent calibration, the bearing tip probe (ETA 3.3H), spot measurements, fixed probe orientation in the probe stand, indoor measurements (fixed bench space in lab), use of a mark on the probe stand shaft to (approximate) probe starting height, and use of the lever arm of the probe stand to minimize the chance of the probe tip indenting the wet (soft) coating.

## **EDDY CURRENT TESTING**

For the eddy current testing, salinity was varied among nine tanks. Temperature, pH, and substrate surface profile were constant. Three salinities (10 ppt for estuarine water, 22 ppt as a mid-value, and 33 ppt for seawater) were used with three replicate panels of each coating at each salinity. One panel of each of three coatings types was exposed in each of the nine tanks.

Using the Fischer MP40 Dualscope and ETA3.3H probe, measurements were taken in two sets of 24 points. The same points on each panel were measured before exposure, at 1, 7, 22, 25, 30, and 87 days of exposure, and again after the panels were removed from the tanks and allowed to dry. Pre-exposure measurements were taken on both dry and submerged panels. The intermediate measurements were taken submerged in seawater, except those for day 87 which

were taken on damp panels<sup>6</sup>. On a measurement day, panels were removed from the test environment, rinsed with water of the appropriate salinity, and placed in the precision template. The precision template was used to repeatedly quantify DFT at the same spot on each panel over time (Figures 6 and 7). The precision template apparatus was then submerged in a measurement tank filled with 33 ppt seawater. Not more than 3mm of water covered any panel during wet measurements. After recording two sets of measurements for each panel, the panels were rinsed using the correct concentration seawater and placed back in the test tanks. The post exposure measurements were taken after air drying for 13 days (measurements marked as “Day 100”). When necessary, the Dualscope was calibrated in the measurement environment using shims of certified thickness.

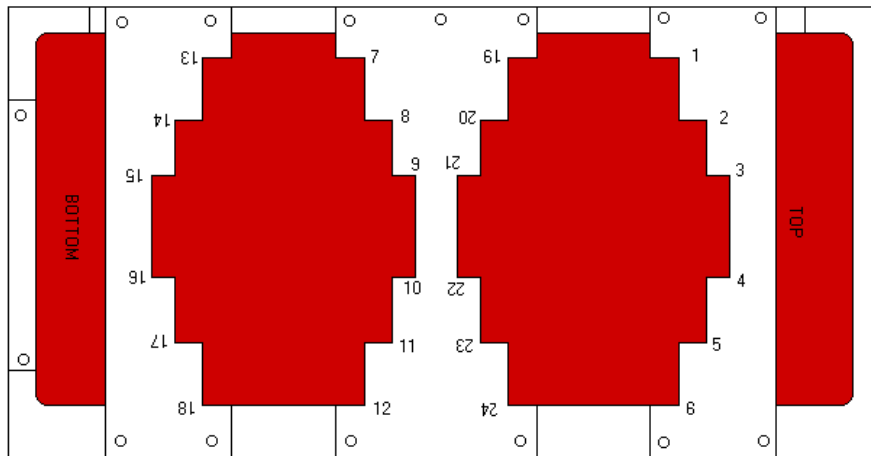


Figure 6. The precision template

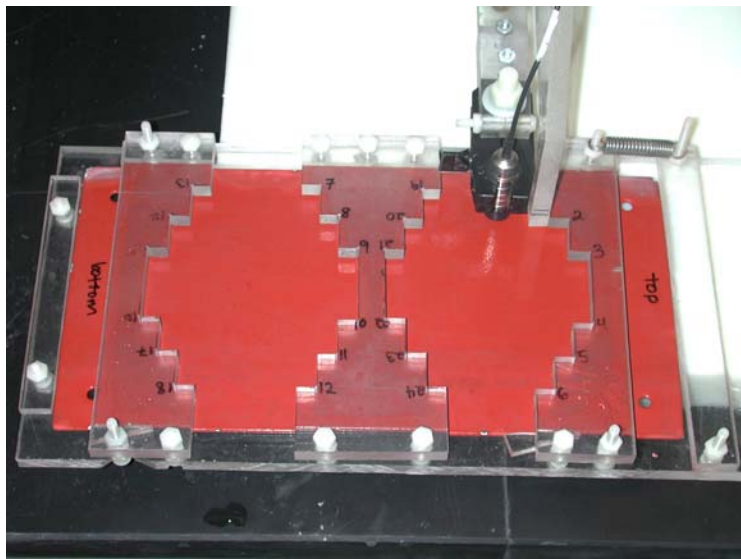


Figure 7. Precision Template and Panel, Eddy Current Probe, Probe Holder, and Probe Guide

<sup>6</sup> At no time were measurements taken on uncured paint. The term “damp” indicates visible wetness on the coating surface during the measurement, but the panel was not immersed in water.

## MATERIALS AND METHODS – MEAUREMENTS USING MAGNETIC INDUCTION GAUGE

### COATINGS

Four coating systems were selected for magnetic induction testing. Three had copper ablative topcoats and one a self-polishing topcoat (Table 4).

Table 4. Coatings Used In Magnetic Induction Testing. \* Indicates Panels Also Evaluated by SigmaKalon as Part of Their Parallel Effort

| Coating Name           | Navy QPL Status | Chemistry      | Biocide                      |
|------------------------|-----------------|----------------|------------------------------|
| International BRA640 * | Yes             | Ablative       | Cuprous oxide                |
| Sigma Super-Ecol *     | No              | Ablative       | Cuprous oxide + SeaNine 211® |
| Ameron ABC3            | Yes             | Ablative       | Cuprous oxide                |
| Sigma Alphagen*        | No              | Self-polishing | Cuprous oxide + Irgarol®     |

### PANEL PREPARATION

The coatings were spray applied to twelve 6" x 12" cold rolled steel panels by the Naval Research Laboratory in Key West, FL. Half of the panels were prepared with a relatively smooth profile or anchor tooth (< 1 mil) and the other half with a relatively rough anchor tooth profile (3 mils) in order to quantify the impact of anchor tooth profile on coating thickness measurement error. (Anchor tooth profile results are not included in this report). Upon receipt from NRL, the panels were inspected for variability in applied coating thickness, warping of the panel, and coating defects. Three of the best panels for each coating were selected for testing, and the other panels were used for establishing the measurement protocol.

### EXPERIMENTAL APPARATUS

Panels were exposed in test tanks filled with artificial seawater. Each 20-L test tank consisted of a panel rack (panels held vertically), a pump, a carbon filter, an ion exchange filter, and connective tubing (Figures 2 and 3). The rate of seawater flow through the test tanks was approximately 1.7 L/min. Uniform flow was ensured through the use of a diffuser. The carbon and ion exchange filters effectively controlled particulate and copper levels, respectively. Copper levels were held below 100 µg/L. Constant temperature (22°C), salinity (33 ppt), and pH (8.1) were maintained during the testing. To maintain constant temperature, a heat exchanger circulated fresh water through a copper tubing coil that wrapped around the test tank. Each coil-wrapped test tank was placed within a larger cooler filled with fresh water. Salinity was adjusted by adding fresh water or artificial sea salt. The pH was adjusted by adding small amounts of hydrochloric acid to lower the pH or sodium hydroxide to raise the pH as needed. Test tank

parameters were checked frequently to ensure constant conditions. An ultraviolet light filter was used to keep bacteria levels low.

## **DRY FILM THICKNESS MEASUREMENT SYSTEM**

A Fischer MP40 DualScope paint thickness measurement system was used to quantify DFT. This meter can accommodate both magnetic induction and eddy current probes. The magnetic induction method uses a magnetic attraction to steel with a nonconductive coating to generate a magnetic field. As the magnet is brought closer to the steel substrate, changes in the magnetic field result in changes in resistance. For the magnetic induction portion of the work, we used a modified EGB2 probe where the outer spring-loaded sleeve was removed and the probe was fixed into a waterproof ceramic tube with epoxy<sup>7</sup>. This is the same equipment commonly used by divers and on ROVs outfitted for hull inspections in the field. In order to account for the added thickness of the ceramic tube, steps were taken to ensure proper calibration and count rate verification using shims of known thickness (See Appendix A - Count Rate Comparison).

Using spare panels, preliminary experiments were conducted to better understand the suitability of this DFT measurement system for reliably quantifying very small changes in DFT. We expected no more than 3, and more likely < 1, mil changes in DFT due to swelling. Based on guidance from industry, field experience, and experience with the eddy current measurements, we focused on techniques that allowed for repeated measurement of the same point vs. random measurements over a larger area in order to improve reproducibility. The precision template arrangement was used (Figure 6). Refer to Appendix B for the precision template measurement protocol and calibration check. The probe was mounted in the probe holder assembly (Figure 7).

Based on the challenges encountered with the eddy current equipment, we conducted a suite of preliminary experiments in order to quantify reproducibility and identify sources of measurement error. The most important factor was probe starting height. Measurements increased as much as 3 mils over a 2.5 mm range in starting heights, and as the probe starting height was decreased, the DFT measurements increased. The DFT increase with each approximately 1 mm reduction in probe starting height was about 1 mil (Figures 8 and 9). Neither the probe manufacturer nor other experts in gage use could explain this effect. Although we had marked the probe holder assembly position on the shaft, we noted that a 1-2 mm swing in starting height was common over time, depending on how much care was taken to precisely re-align the holder assembly with the line indicated on the shaft. Therefore, all moveable parts of the DFT apparatus and stand were fixed except the lever arm action which was used to raise and lower the probe. This ensured the probe measured precisely the same spot on the panel and started at and returned to the exact same height for each measurement. With starting height fixed, DFT was more reproducible from day to day.

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<sup>7</sup> NSWCCD makes these modified probes and regularly uses them in the field.

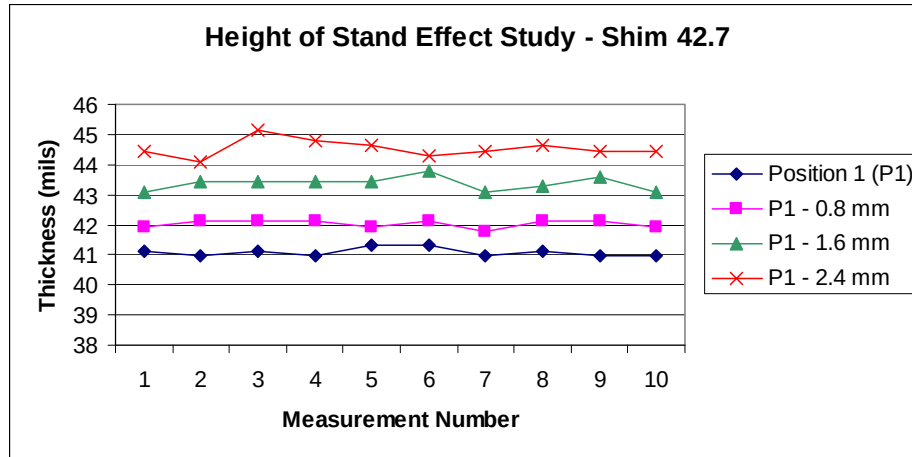


Figure 8. Probe Height Study – Impact of Probe Starting Height on DFT Measurements (Shim of Known Thickness)  
Where P1 is the Highest Probe Position.

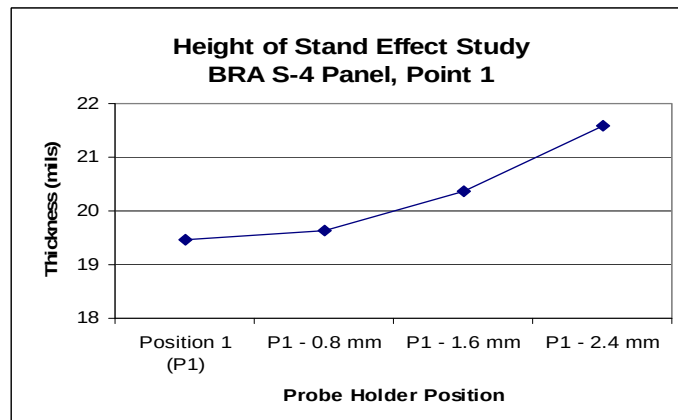


Figure 9. Probe Height Study – Impact of Probe Starting Height on DFT Measurements (Point 1 on BRA S-4 Panel)

The error of the probe for the range measured was calculated from the literature provided by the probe manufacturer as a function of probe accuracy and precision. The accuracy of the probe is given as 1% of the measurement and the precision of the probe is given as 0.3% of the measurement. The expected error was calculated as approximately 0.238 mils. Calibration of the probe for the magnetic induction tests was conducted on an epoxy panel at three points on the panel. The calibration plot is shown in Figure 10. At least ten measurements are averaged for every point shown on the calibration plot. Overall, the calibration data shows an approximate error of 0.5 mils.

Based on input from several coatings manufacturers, predicted DFT changes due to swelling, if any, would likely not exceed 10% of the total topcoat thickness since swelling greater than 10% may negatively impact coating integrity (personal communication: Alistair Finnie, International Paint Company; Santiago Arias, Hempel Coatings; Marcel Vos, SigmaKalon). The DFT of the antifouling coating on these panels and on in-service vessels ranges from approximately 15 to 21 mils, therefore the total DFT change due to swelling, if any, would not be expected to exceed 2 mils.

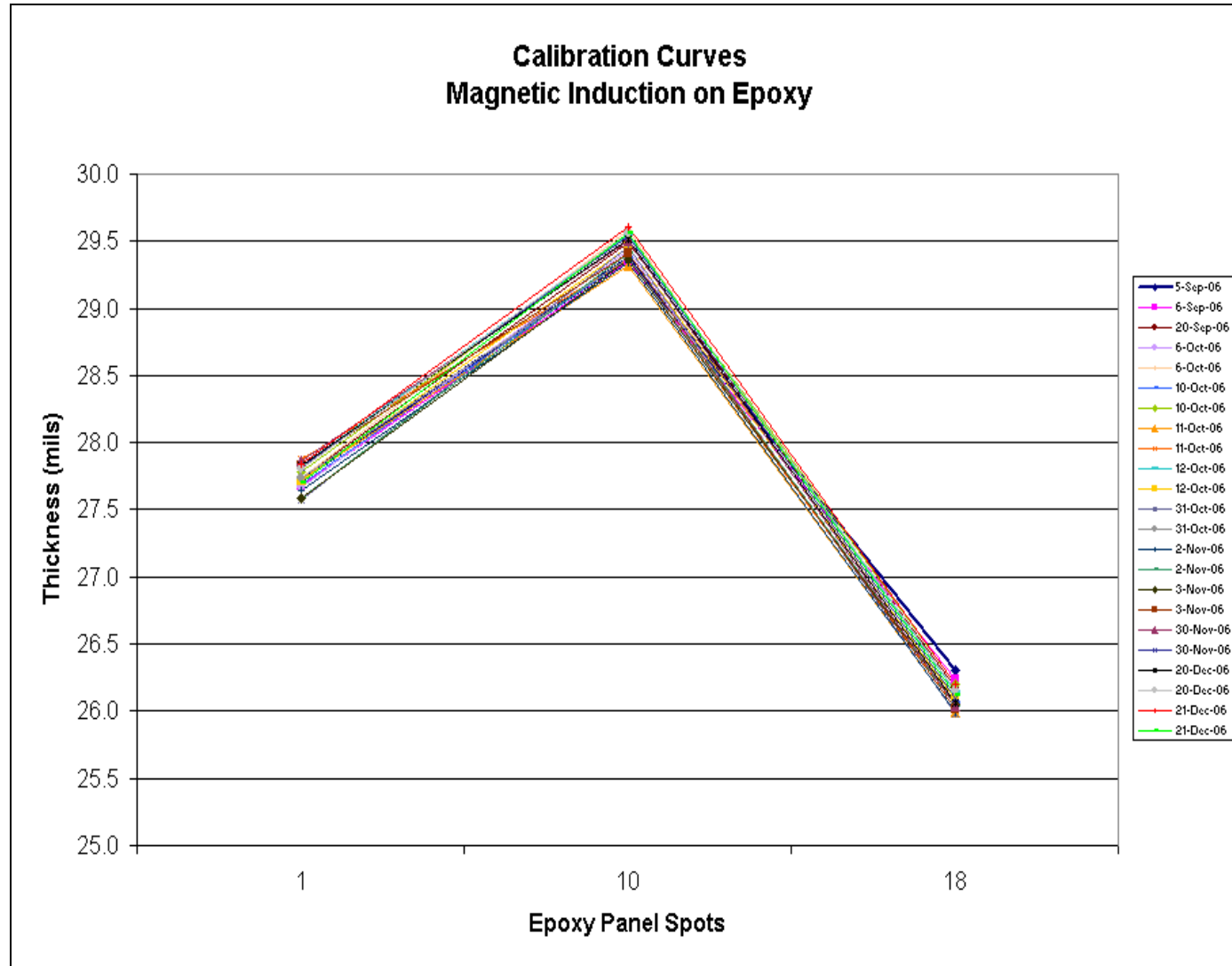


Figure 10. Calibration Curves of Magnetic Induction Probe on Epoxy

## **MAGNETIC INDUCTION TESTING**

For the magnetic induction testing, steel surface profile and coating were varied while pH, salinity and temperature were held constant at 8.1, 33 ppt, and 22°C, respectively. One replicate of each of the four coatings was exposed in a test tank. Panels with rough and smooth profiles were randomized among the tanks.

Coating thickness was quantified using the Fischer MP40 Dualscope and waterproofed EGB2 probe. The same points on each panel were measured before exposure and at approximately days 20, 45, 70, and again after the panels had dried for 5 days at the termination of the test (denoted as day 92). The pre-exposure measurements were taken dry, then damp with seawater. The intermediate measurements were taken damp with seawater. The post-exposure measurements were taken dry only.

In order to verify proper calibration and function of the gauge and probe throughout the course of the experiment, we routinely quantified the DFT of three spots on a single epoxy coated panel (Figure 10). Each check of the epoxy panel DFT comprised ten measurements at spots 1, 10, and 18 on the precision template. When measurements were greater than  $\pm 0.5$  mils of the pre-test measurements, adjustments to the probe holder assembly were made in order to bring the measurements within range. DFT checks were conducted at least three times on a given measurement day, once at the start of the day, once at mid day, and once at the end of the day. Measurements taken on days where the expected epoxy panel DFTs were not achieved were either re-taken or discarded.

On a measurement day, DFTs were quantified at twelve spots on each test panel (the odd numbered locations in Figure 6). After recording measurements, the panels were immediately placed back in their respective test tanks.

## **DATA ANALYSIS - MAGNETIC INDUCTION**

We compared dry film thicknesses measured over time to determine whether exposure to seawater caused significant changes in coating thickness either due to swelling or ablation. Ten replicate readings of DFT were taken at twelve points over the panel face. We compared different dates or exposure conditions by pairing the mean values for DFT at each of the points for each replicate panel, calculating the difference between the paired readings, then testing whether the distribution of the differences was centered around zero. The analysis was carried out using PROC UNIVARIATE in SAS (SAS Institute, Inc., 1999). The nonparametric Wilcoxon Signed-Rank test was used to determine if the distribution of differences was centered on 0. Tests producing a significant result ( $p \leq 0.05$ ) indicated a change in DFT, and thus swelling or thinning of the paint (depending on the sign of the mean or median difference).

## **DETERMINATION OF THE IMPACT OF ROUGHNESS ON DFT ERROR - MAGNETIC INDUCTION**

After the completion of the magnetic induction testing, a statistical analysis was performed examining the contribution of coating roughness to measurement error. Using untested panels of two paint types (BRA and ECOL) from both the rough and smooth panel sets, coating and (later) substrate roughness were quantified. Then, using the precision template,

30 DFT measurements were taken on a single spot on each panel. In addition, 30 DFT measurements were taken in a straight line approximately 2 inches long, starting at the single spot and moving to the left. A profilometer was used to quantify coating roughness along the line, and later, once the coating was removed, the panel roughness was quantified along that same line.

## RESULTS

### EDDY CURRENT TESTING

The DFT measurements taken on days 0, 1, 22, 25, 30, 49, and 87 and again on day 100 after the panels had dried for 13 days were reproducible within the same day (Figure 11). However, no trends in paint thickness were apparent over time. In contrast, seemingly random variation in thickness of up to 3 mils was observed on all measurement dates. For example, Figure 11 shows a DFT increase of 3 mils at individual spots from day 0 through 22, then a DFT decrease of 2 mils from day 22 to day 25, followed by a 1 mil decrease by day 30, and then an increase of 2 mils by day 49. In fact, at a given measurement point, random thickness variations over a 3 mil range were observed across all measurement dates. Slightly different random shifts in DFT were observed among replicate panels and treatments, but were not strongly related to coating, tank, or salinity (Figs. 12 and 13). Results from other panels and tank conditions can be found in Appendix C with wide variability in results. Some panels showed varied, sometimes large, thickness shifts displaying no particular trend or pattern over time while others did not. As such, it was not possible to determine if paint was swelling or ablating over time.

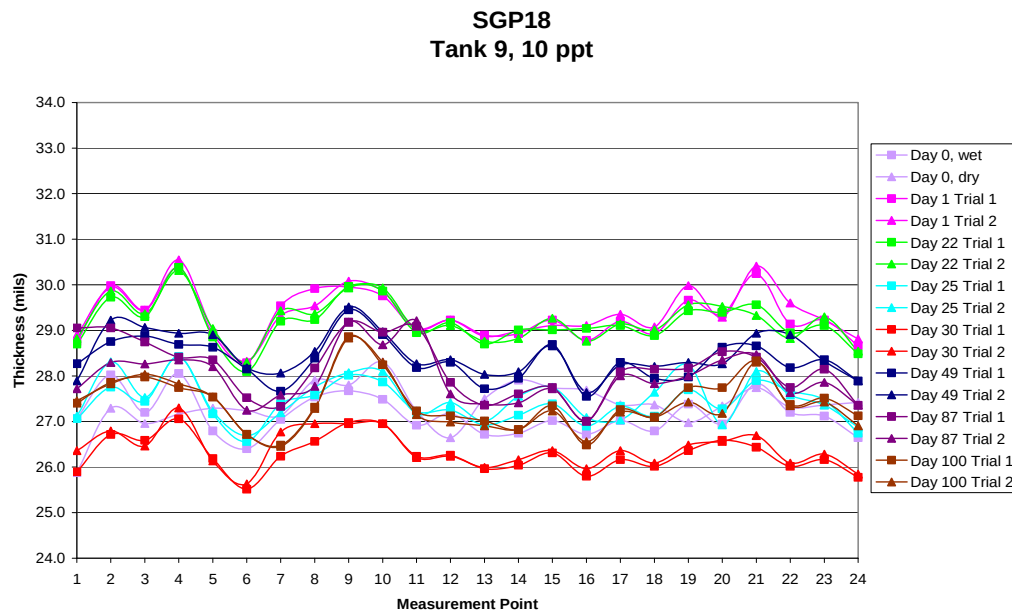


Figure 11. Dry Film Thickness Measurements, Comparisons Between Two Individual Trials; SGP Panel 18, Tank 9, 10 PPT

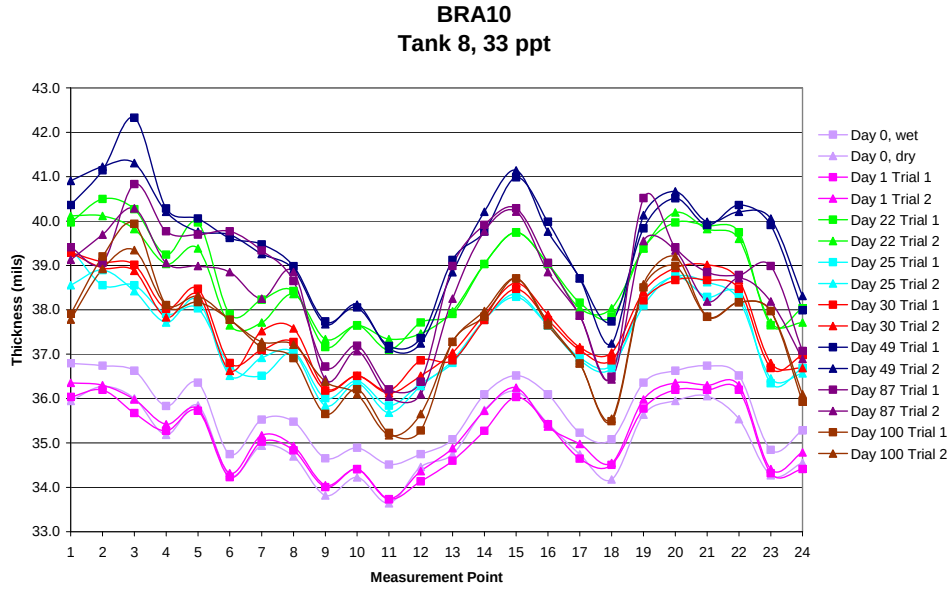


Figure 12. Dry Film Thickness Measurements, Comparisons Between Two Individual Trials; BRA Panel 10, Tank 8, 33 PPT

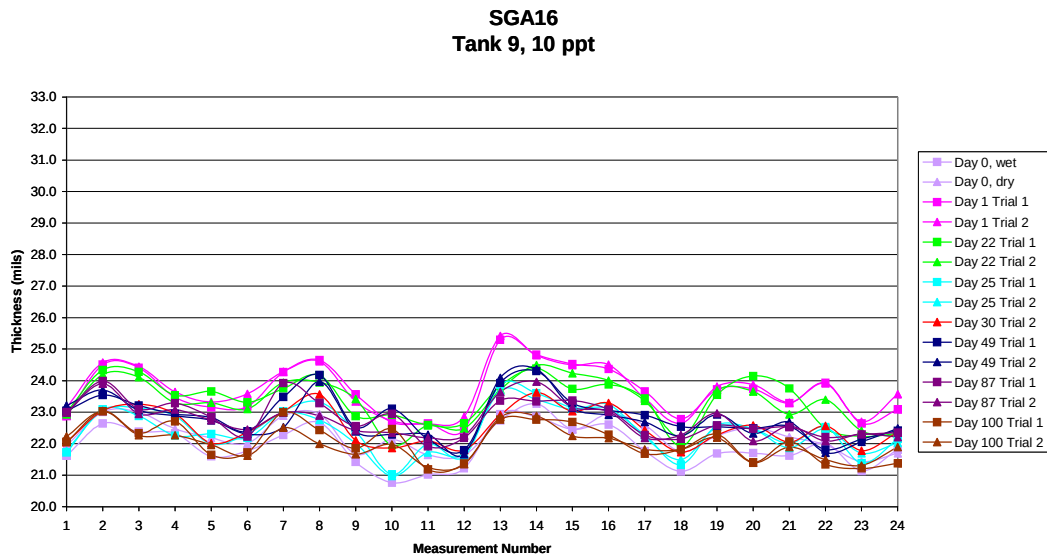


Figure 13. Dry Film Thickness Measurements, Comparisons Between Two Individual Trials; SGA Panel 16, Tank 9, 10 PPT

In summary, we could detect no relationship between thickness change and test conditions (pH, temperature, salinity, or coating) using the eddy current probes. Thickness fluctuated with no particular trend or pattern. However, reproducibility within the same day was good in most cases.

Neither the thickness gauge manufacturer nor the coating manufacturer could provide an explanation for our results. Initially we could find no systematic error in our measurement technique and no explanation for the variation in results on the different test dates. At the time, we suspected a failure of the probe waterproofing treatment. We later confirmed a failure of the waterproofing mechanism, but it is not clear if this occurred near the end or possibly after our eddy current testing was complete. Finding ourselves unable to explain the data set, we were left no choice but to change our focus to evaluation of thickness using a magnetic induction probe, a system with which we were much more familiar.

## MAGNETIC INDUCTION

The DFT measurements taken at days 0, 20, 45, 70, and 85 were fairly reproducible within the same day. A sample data set for each paint type is found in Figures 14-17. Each line on the graph shows the change in thickness over time at a single measurement point. Ten measurements were taken at each of the twelve points over the face of the panel on each date. Each point represents the average of the ten measurements taken<sup>8</sup>.

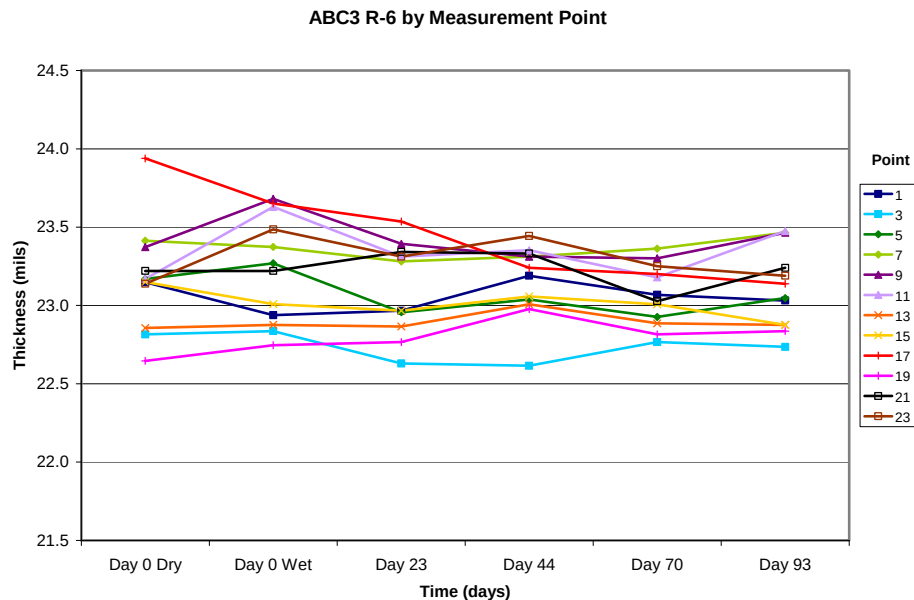


Figure 14. Dry Film Thickness Measurements Over 90 Days. Each Point Represents the Average of 10 Measurements. Each Line (Color) Represents Measurements Over Time at One Spot.

<sup>8</sup> During the analysis of the data, a three-sigma outlier reject analysis was conducted to remove any points that were not within three standard deviations of the average. Any data set with a reject point contained 9 points. There were no data sets with less than 9 points.

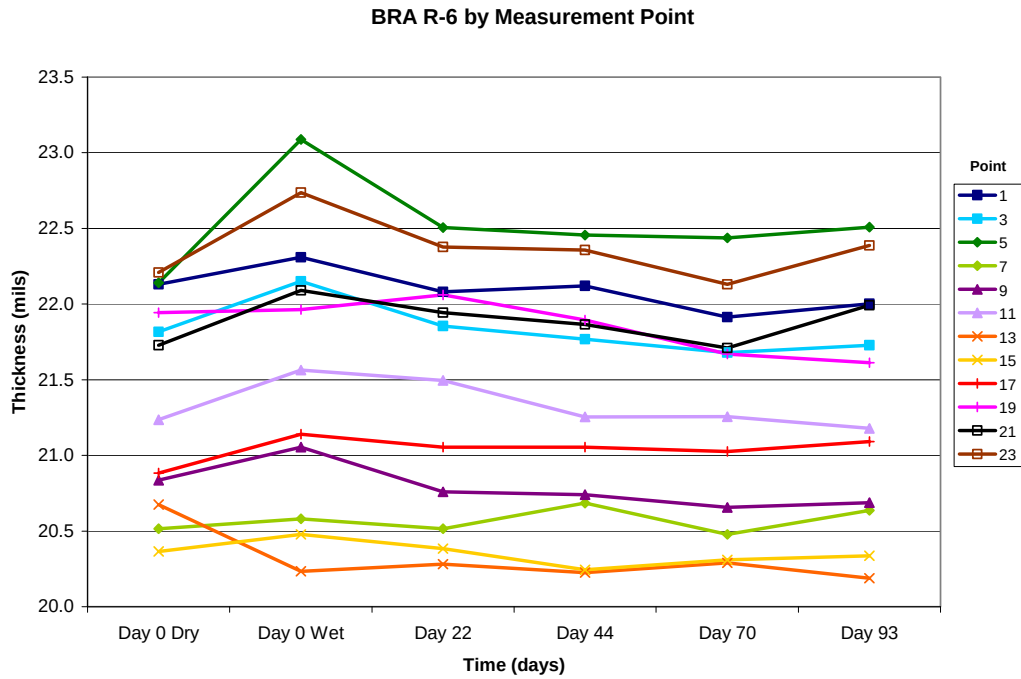


Figure 15. Dry Film Thickness Measurements Over 90 Days. Each Point Represents the Average of 10 Measurements. Each Line (Color) Represents Measurements Over Time at One Spot

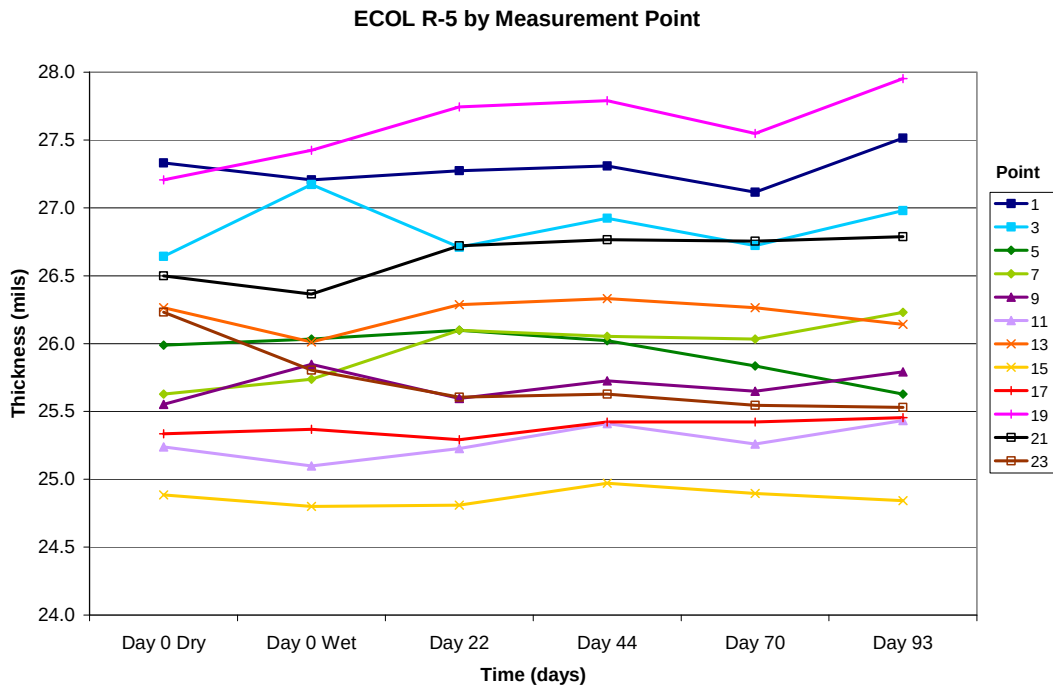


Figure 16. Dry Film Thickness Measurements Over 90 Days. Each Point Represents the Average of 10 Measurements. Each Line (Color) Represents Measurements Over Time at One Spot

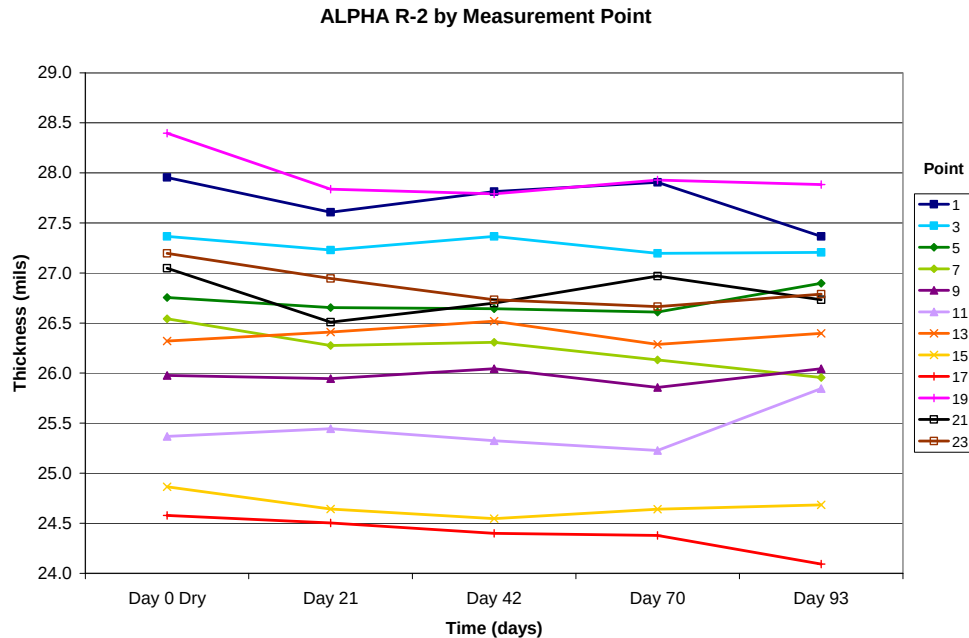


Figure 17. Dry Film Thickness Measurements Over 90 Days. Each Point Represents the Average of 10 Measurements. Each Line (Color) Represents Measurements Over Time at One Spot

Comparisons were made throughout the test period, and also between starting and ending thicknesses for both dry and wet data. Also, comparisons between the ending wet measurement and ending dry measurement were made in order to quantify impact of coating drying on DFT.

- The majority of comparisons (82 of 120, 68% of comparisons) showed no significant change in paint thickness. Significant changes in thickness (38 of 120, 32% of comparisons) ranged from -0.51 mils (thinning) to 0.46 mils (swelling), and 61% of these (23 of 38) were negative suggesting thinning or ablation, but these changes are small (Table 5). Only 15 of 120 comparisons (12%) suggested the occurrence of significant swelling.

- Measurement and analysis of thickness immediately after immersion (dry 0 to wet 0, Table 5) produced 10 significant changes in thickness, with 8 coating samples experiencing thinning and 2 experiencing swelling. In the long term, after initial immersion 46% (11 of 24) of coatings appeared to swell, while 8% (2 of 24) became thinner (wet 0 to wet 70, Table 5). However the mean DFT change was quite small, ranging from 0.46 mils to -0.32 mils. This level of change is smaller than the approximate 0.5 mil error inherent in the measurement.

- Drying after long-term immersion resulted in a significant decrease in paint thickness for 8 of the 24 coating samples tested (33%, wet 70 to dry 90, Table 5). Comparison of coating readings from dry panels, taken at the beginning and end of the experiment, revealed 4 of 24 coating samples (17%) becoming thinner, and 1 (4%) becoming thicker (dry 0 to dry 90, Table 5). Again, the mean DFT change was quite small, falling at or below the DFT range for which we thought we could reliably detect change.

Table 5. Change in Coating Thickness Under Various Conditions of Exposure Time and Immersion. Columns Represent Mean Change in Thickness, and P-Value for Wilcoxon Signed-Rank Test For  $H_0: \Delta = 0$ . Bolded Values are Significant ( $p < 0.05$ )

| surface | replicate | mean $\Delta$<br>(dry 0 to<br>dry 90) | p value       | mean $\Delta$<br>(dry 0 to<br>wet 70) | p value       | mean $\Delta$<br>(dry 0 to<br>wet 0) | p value       | mean $\Delta$<br>(wet 0 to<br>wet 70) | p value       | mean $\Delta$<br>(wet 70 to<br>dry 90) | p value       |
|---------|-----------|---------------------------------------|---------------|---------------------------------------|---------------|--------------------------------------|---------------|---------------------------------------|---------------|----------------------------------------|---------------|
| ABC3    | S1        | -0.11                                 | 0.57          | 0.26                                  | 0.15          | -0.2                                 | 0.34          | <b>0.46</b>                           | <b>0.005</b>  | <b>0.005</b>                           | <b>0.005</b>  |
|         | S3        | -0.13                                 | 0.52          | -0.09                                 | 0.47          | -0.06                                | 0.47          | -0.025                                | 1             | -0.04                                  | 0.68          |
|         | S5        | -0.08                                 | 0.38          | -0.09                                 | 0.38          | -0.01                                | 0.79          | -0.078                                | 0.34          | 0.009                                  | 0.97          |
|         | R3        | -0.13                                 | 0.2           | 0.06                                  | 0.52          | <b>-0.24</b>                         | <b>0.03</b>   | <b>0.3</b>                            | <b>0.0015</b> | <b>-0.2</b>                            | <b>0.034</b>  |
|         | R5        | -0.12                                 | 0.42          | 0.12                                  | 0.27          | -0.07                                | 0.52          | <b>0.19</b>                           | <b>0.04</b>   | <b>-0.24</b>                           | <b>0.002</b>  |
|         | R6        | -0.06                                 | 0.85          | -0.1                                  | 0.13          | 0.06                                 | 0.47          | <b>-0.16</b>                          | <b>0.03</b>   | 0.05                                   | 0.42          |
| ALPHA   | S3        | -0.08                                 | 0.97          | 0.08                                  | 0.38          | -0.23                                | 0.42          | <b>0.3</b>                            | <b>0.001</b>  | <b>-0.16</b>                           | <b>0.002</b>  |
|         | S4        | <b>0.26</b>                           | <b>0.016</b>  | <b>0.15</b>                           | <b>0.02</b>   | <b>0.32</b>                          | <b>0.03</b>   | -0.16                                 | 0.42          | 0.11                                   | 0.52          |
|         | S5        | -0.24                                 | 0.06          | -0.13                                 | 0.17          | 0.02                                 | 0.62          | -0.14                                 | 0.23          | -0.11                                  | 0.27          |
|         | R2        | -0.21                                 | 0.05          | <b>-0.21</b>                          | <b>0.0005</b> | <b>-0.2</b>                          | <b>0.009</b>  | -0.02                                 | 0.42          | 0.01                                   | 0.91          |
|         | R3        | <b>-0.27</b>                          | <b>0.0005</b> | -0.12                                 | 0.09          | <b>-0.51</b>                         | <b>0.0005</b> | <b>0.39</b>                           | <b>0.001</b>  | -0.15                                  | 0.05          |
|         | R5        | 0.04                                  | 1             | 0.12                                  | 0.11          | <b>-0.18</b>                         | <b>0.03</b>   | <b>0.31</b>                           | <b>0.007</b>  | -0.08                                  | 0.57          |
| BRA     | S2        | -0.07                                 | 0.23          | -0.06                                 | 0.3           | <b>-0.31</b>                         | <b>0.003</b>  | <b>0.25</b>                           | <b>0.001</b>  | -0.02                                  | 0.85          |
|         | S3        | 0.05                                  | 0.68          | 0.13                                  | 0.68          | -0.05                                | 0.34          | 0.18                                  | 0.2           | <b>-0.09</b>                           | <b>0.04</b>   |
|         | S4        | -0.06                                 | 0.2           | -0.06                                 | 0.2           | <b>-0.1</b>                          | <b>0.007</b>  | 0.04                                  | 0.3           | -0.05                                  | 0.42          |
|         | R4        | <b>-0.24</b>                          | <b>0.03</b>   | 0.01                                  | 0.85          | <b>-0.18</b>                         | <b>0.03</b>   | <b>0.19</b>                           | <b>0.03</b>   | <b>-0.25</b>                           | <b>0.03</b>   |
|         | R5        | 0.01                                  | 0.73          | 0.08                                  | 0.06          | 0.01                                 | 1             | 0.07                                  | 0.23          | -0.07                                  | 0.62          |
|         | R6        | -0.01                                 | 1             | -0.08                                 | 0.13          | <b>0.24</b>                          | <b>0.02</b>   | <b>-0.32</b>                          | <b>0.001</b>  | 0.07                                   | 0.15          |
| ECOL    | S3        | <b>-0.29</b>                          | <b>0.009</b>  | -0.02                                 | 0.73          | <b>-0.37</b>                         | <b>0.002</b>  | <b>0.36</b>                           | <b>0.0005</b> | <b>-0.27</b>                           | <b>0.0005</b> |
|         | S5        | <b>-0.47</b>                          | <b>0.003</b>  | -0.38                                 | 0.11          | -0.36                                | 0.11          | -0.01                                 | 0.47          | -0.09                                  | 0.47          |
|         | S6        | -0.13                                 | 0.15          | 0.19                                  | 0.23          | -0.11                                | 0.47          | <b>0.3</b>                            | <b>0.01</b>   | <b>-0.32</b>                           | <b>0.001</b>  |
|         | R3        | 0                                     | 0.73          | 0.19                                  | 0.13          | -0.15                                | 0.08          | <b>0.34</b>                           | <b>0.003</b>  | -0.19                                  | 0.06          |
|         | R5        | 0.12                                  | 0.27          | 0.02                                  | 0.38          | 0.01                                 | 0.91          | 0.015                                 | 0.85          | 0.1                                    | 0.13          |
|         | R6        | -0.02                                 | 0.79          | -0.02                                 | 0.79          | -0.03                                | 0.42          | 0.01                                  | 0.91          | 0                                      | 0.91          |

No paint swelling of greater than 1 mil was detected, and no trends were evident. Because the error given by the calibration was 0.5 mils, such DFT changes would be unlikely to significantly affect the results of single time-point surveys on ship hulls. Results are shown in Appendix D.

#### **IMPACT OF COATING ROUGHNESS ON MEASUREMENT ERROR**

There was no correlation between the variance in coating thickness and the magnitude of coating roughness when measured at a point or along a line. Thus, coating roughness did not affect the repeatability (reproducibility) of coating thickness measurements in any systematic way. The variance in thickness was 2-11 times greater when measured along the line than at a point.

#### **IMPACT OF SURFACE ROUGHNESS ON MEASUREMENT ERROR**

The correlation between coating thickness variance and roughness of the uncoated panel surface will be discussed in a follow-on report.

## DISCUSSION

Wide and unexpected variation has been observed in a subset of DFT data sets taken by shipyard (depot level) personnel. Given that the overwhelming majority of DFT data sets show decreases in paint thickness that can be attributed to normal ablation, in-water hull cleaning, and drydock washdowns (powerwashing), these errors are difficult to explain. Our research was targeted at determining if paint swelling is a contributor to the large variances observed, and to learn how we can improve field surveys to reduce errors and minimize variance. Besides swelling, other possible contributions to the error include improper calibration, improper probe orientation, and possibly improper design of sampling plans, and interference from biofouling. In addition, coating and substrate roughness as well as paint “softness” may contribute to measurement error.

In order to quantify the degree to which antifouling coatings used by the US Navy experienced swelling upon exposure to seawater, we assumed we would need to be able to reliably detect DFT changes of 1 mil or less. We also assumed we could accomplish this task by using waterproofed eddy current technology in combination with a precision template, and that the measurements could be taken on aged, coated, stainless steel panels wet with seawater.

According to industry technical experts, this should have been possible using a combination of waterproofed probes, a probe holder/stand combination, and a precision template arrangement in order to track DFT at specific “addresses” on test panels over time. Eddy current probes, however, proved incapable of measuring thickness changes with the appropriate precision under the experimental test conditions. Magnetic induction measurement devices were more suited for this task. The proper equipment and protocol combination ultimately allowed us to reliably detect DFT changes of 1 mil.

Based on our results, copper ablative antifouling hull coatings exposed to artificial seawater for 3 months at room temperature do not significantly swell. If any DFT change does occur, it is  $< 1$  mil. Hypothetical DFT changes of less than one mil due to swelling would not account for the much larger discrepancies observed in the anomalous field data sets mentioned above. For example, within the those data sets, thickness changes of less than 1 mil were observed on several active ships over as many as 5 years. By contrast, changes approaching 5 mils were observed after only 6-9 months of vessel activity. These aberrant data sets could not be related to the frequency of hull cleanings and powerwashings. We believe they resulted from measurement error and not any systematic change in paint thickness associated with swelling.

Part of our work included a preliminary analysis of the impact of coating roughness and coating softness on DFT measurements. As outlined above, the data suggest that any effect that coating roughness may have on DFT measurement error is overwhelmed by the overall error associated with DFT measurements taken over time and/or the error in the DFT measurement equipment alone.

Not previously discussed was our attempt to quantify coating indentation upon probe contact with aged (and presumably softened) coating systems. We conducted some preliminary nanoindentation testing at the Naval Research Laboratory in Washington, DC. The initial

indication was that a Berkovich-shaped tip<sup>9</sup>, at forces approximately equal to those generated by the lever arm action of our probe stand, did penetrate the coatings. The initial penetration depth was less than 0.2 mils (5 microns) on coatings aged more than 8 weeks in artificial seawater (Figure 18), and slightly less on un-aged coatings (Figure 19). The penetration depth should be less for a tip with the size and shape of the Fisher Technology EBG2 probe tip (personal communication – Irwin Singer, NRL – April 2006). Interestingly, when the Berkovich tip was lowered and then held in place and under a constant stress, the tip further penetrated the aged and un-aged coatings by up to 0.6-0.8 mils (15-20 microns) over the course of 5 minutes – a phenomenon known as creep. Creep would not have been a factor in our DFT measurements because the contact time required to complete a DFT measurement is less than one second. Probe tip penetration into the aged and softened AF coatings probably has no effect on the DFT measurements taken in these experiments or in the field.

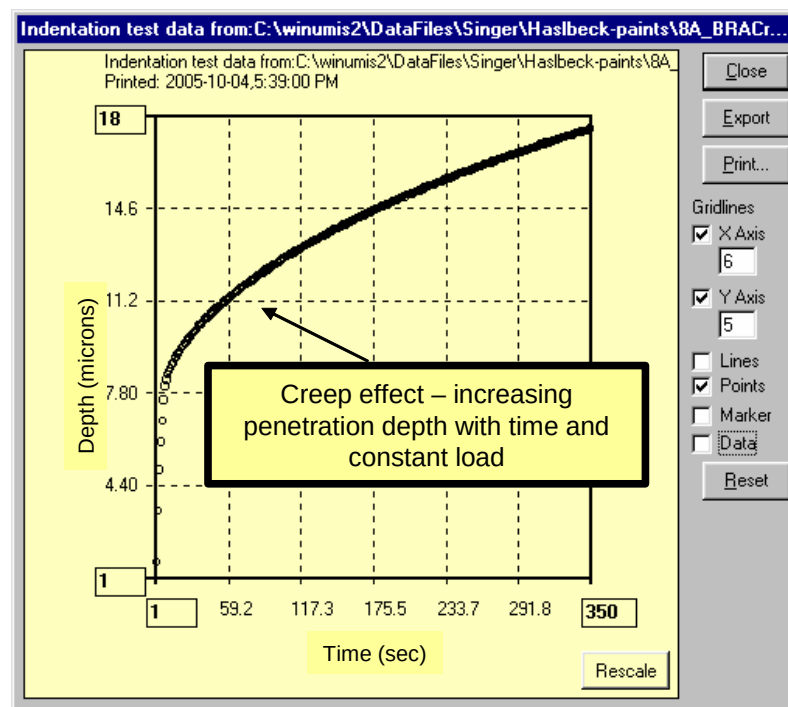


Figure 18. Nanoindentation Test. Berkovich Tip Indentation on Aged (8 Weeks In Seawater) BRA640 Coating Over 5.8 Minutes. Note “Creep” Effect

<sup>9</sup> A Berkovich tip is a reverse, 3-sided, pyramid-shaped tip. It has a relatively pointed profile (total included angle of 142.3 degrees and a half angle of 65.35 degrees). The Berkovich tip has the same projected area to depth ratio as a Vickers indenter.

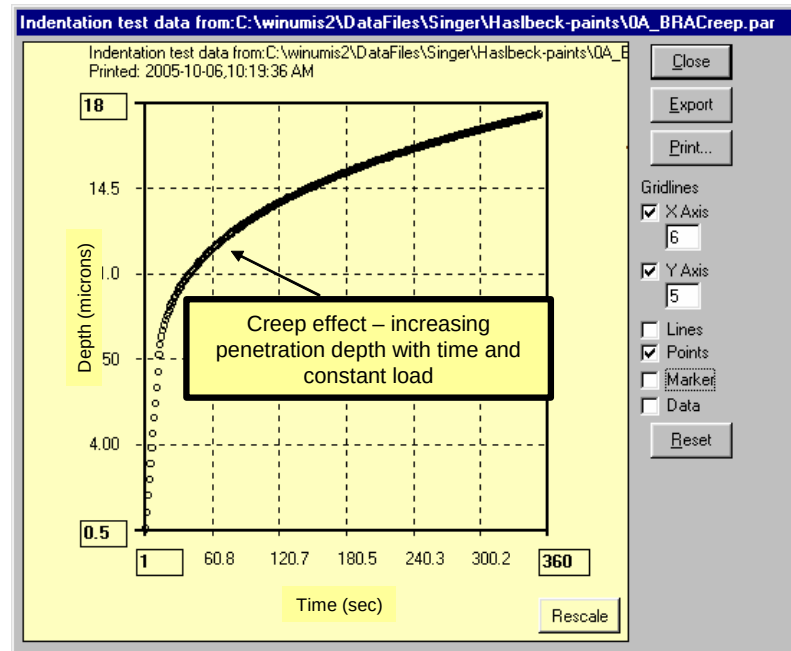


Figure 19. Naonindentation Test. Burkovich Tip Indentation on Unexposed BRA640 Coating Over 5.8 Minutes. Note “Creep” Effect

Given the degree to which probe starting height impacted magnetic induction measurements, most of the error associated with eddy current measurements may be attributable to small variations in probe starting height. Other possible contributors to measurement error using the eddy current equipment include failure of the waterproofing mechanism, conductivity shifts due to the release of copper, and probe sensitivity to wetness (even though the probe was “waterproofed”)<sup>10</sup>, none of which are a factor for the magnetic induction technique. We did not conduct comprehensive studies to confirm these suspicions. However, if the results of the definitive probe height study, performed using the magnetic induction probe and stand assembly, are indicative of the possible impact on eddy current measurements; the shifts we observed of up to 3 mils from day to day for eddy current testing could be explained largely by probe height.

The experience of SigmaKalon in part validates this thinking. They routinely use a robotic DFT measurement device to track small (0.3 mil) DFT changes on aged antifouling coating systems with time. This device has a fixed probe starting height and probe orientation and measurements are taken at specific addresses on panels that are not wet with water. DFTs of several single spots on standard epoxy-coated stainless steel panels (epoxy coating DFT does not change with time) measured using eddy current probes on dry paint (not wet with water), vary less than 0.2 mils (5 microns) over time.

SigmaKalon has used their robotic DFT equipment to quantify DFT of aged (via dynamic and static periods of exposure) coated test panels not only after allowing them to dry between

<sup>10</sup> Water-proofing provided by Fischer Technology, Inc. ultimately failed causing irreparable damage to the probe.

measurements but also while still damp with seawater. These were the same AF coatings we used in our testing (see Table 1). They noted that the eddy current measurements performed on coated panels that were still damp with seawater were erratic over the course of a year, and they could not reliably establish clear trends in DFT change over time. In contrast, when the same panels were allowed to dry, DFT changes were reliably quantified and there were significant reductions in DFT over time.<sup>11</sup>

Our results indicate that ablative antifouling coatings of the type used by the Navy are not likely to swell significantly, and gross measurement variation such as that observed in a subset of previous field surveys conducted at the depot level cannot be attributed to paint swelling. With respect to field surveys conducted by the fleet maintenance community and contractors, we believe we have identified a set of “lessons learned” that can significantly reduce variation in measured thickness by several mils. If implemented, these “lessons learned” will improve reliability of field DFT surveys. Important considerations and protocol limitations include:

- Ceramic encased probes - Encasing the magnetic induction probe in ceramic tubes provides a truly waterproofed probe, as is required in order to quantify DFT underwater or on surfaces wet with seawater. The presence of the ceramic tube does not negatively impact the reliability of the DFT measurement, but does increase the lower detection limit. Therefore, when a probe is encased in waterproof ceramic tubes, the count rate of the probe signal must be checked to ensure that the probe is calibrated within the proper limits (linear range). For instance, in this study, the particular EGB2 probe without the ceramic casing could reliably measure DFTs as low as 10 mils, but with the ceramic casing in place the lower detection limit shifted to approximate 19 mils<sup>12</sup>. The Count Rate Procedure is provided in Appendix A.

- Perpendicular probe alignment with coated surface during DFT measurement - Manufacturer data indicate that when quantifying DFT with a Fischer Scientific EGB2 probe, measurements taken when the probe is even a few degrees from perpendicular to the coated surface will result in significant measurement error (up to 10%). Note that a perpendicular orientation of the DFT probe is virtually ensured for measurements taken underwater by ROVs and divers because the waterproofed probe is embedded in a relatively wide (approximately 3” diameter) Plexiglas tube which must “sit flat” on the coated surface in order for the probe to make contact and take a measurement as shown in Figure 20.<sup>13</sup>

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<sup>11</sup> SigmaKalon has been tasked by ONR to quantify the impact of leached layer on DFT measurements. That study is still on-going. Results will be published under separate cover.

<sup>12</sup> Detailed instructions on how to check the count rate and determine lower thickness limits are included in Appendix A.

<sup>13</sup> We have observed at least one diver DFT probe assembly where the “forced orientation” was less than ideal. Any efforts to optimize perpendicular orientation while still ensuring probe contact with the painted surface will improve DFT accuracy and reproducibility.

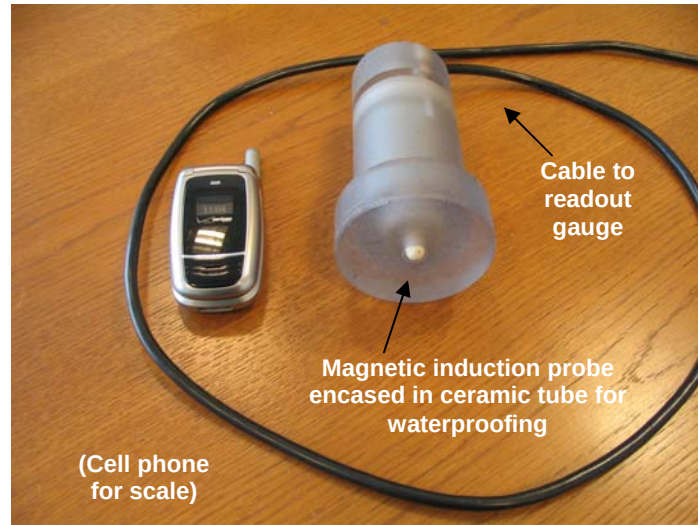


Figure 20. Magnetic induction probe within polycarbonate housing

- When Fischer EGB2 probes are hand held and used in drydock, a mechanism to ensure perpendicular orientation beyond the “sliding sleeve” will be beneficial. We found that physical fatigue was a concern when this equipment was used outside of the laboratory setting, especially when performing field DFT surveys wherein hundreds or thousands of data points are taken in succession. Note that some non-waterproofed gauge/probe combinations from other manufacturers include a more ergonomic mechanism to ensure perpendicular probe orientation during DFT measurements.
- Calibration – Daily calibration checks are required, but daily re-calibration is NOT recommended. Whether performing DFT surveys in the field or in the laboratory, shims of known thickness must be used to check calibration at the beginning and end of each day. If during the course of a day the equipment is found to have fallen out of calibration, then those data should be re-taken or eliminated from the data set.
  - o Users should be aware that the indicated thickness on shims from Fischer Technology is (only) guaranteed to be within 5% of the actual shim thickness. We found that for laboratory studies where detecting very small changes in DFT is required, it is prudent to quantify actual shim thickness prior to calibration. The actual shim thickness and not the indicated shim thickness should be entered into the DFT gauge when performing calibration procedures. We recommend this be done for field measurement surveys as well, although variation in shim thickness is probably not a significant source of measurement error.

For laboratory-based DFT studies where the goal is to detect small changes in thickness, not only does one need to account for the above factors, but the following points shall also be considered:

- Precision template vs. averaged random measurements: Only by using a precision template to quantify DFT changes over time at specific single spots across a panel face can one reliably detect small changes in DFT (< 1 mil). Tracking DFT change across a panel face by averaging random points may only allow relatively large DFT changes to be reliably detected, depending on variation in coating thickness, coating roughness, surface profile across the panel,

and sampling design. Limited improvements may be achieved by increasing the number of random measurement points or by dividing the panel surface into small sectors or areas.

- Probe starting height – When using a magnetic induction probe holder/stand combination and a precision template arrangement in order to quantify DFT at a particular location on a panel over time, care must be taken to fix probe starting height. For reasons unknown, even very small changes in probe starting height can significantly impact measured DFT. We determined that less than a 1-mm change in probe starting height can impact DFT measurements by approximately one mil. We could not reproduce this effect when measurements were taken randomly by hand on approximately the same point. This is likely due to the fact that the probe was not measuring the exact same point each time and again reflects the importance of spatial variation in thickness relative to the ability to reliably detect change in DFT.

- Breaking the magnetic field - While the probe remains close to the substrate, the magnetic field may remain “engaged” and false or skewed readings may occur due to residual magnetic field effects. The magnetic field induced by the probe must be “broken” by lifting the probe to a sufficient height (typically at least 1 inch) from the substrate between measurements. This issue seems to especially apply when measurements are taken using a measurement stand, but anecdotal evidence suggests that this can also occur in the field (personal observation, Eric Holm, NSWCCD). According to the manufacturer, the probe holder/stand combination sufficiently raises the probe to completely break the magnetic field. Additional studies would be required to validate the exact height at which the magnetic field is broken.

- Probe stand configuration – Some probe stands are fitted with magnetic platforms. These must be removed in order to avoid interference with DFT measurements. We modified our probe stand such that the shaft was fitted into a large, flat, inert resin base.

Our results highlight the challenges associated with accurately and reliably detecting very small changes in DFT (1 mil or less) under laboratory conditions. Although we are unable to provide a detailed technical explanation for these challenges, we believe we can reliably quantify DFT changes of less than 1 mil using magnetic induction equipment, by taking into account the combination of “lessons learned”, and by following the protocol outlined in this report including the use of a precision template together with probe holders and probe stands. The most puzzling unexplained issues include the impact of probe starting height on DFT measurement and the fact that very small changes in probe orientation or probe position on the panel can significantly impact measured DFT (yielding differences of 1 mil or more), even though the actual DFT is not likely to vary to that degree over such a small area. The use of a robotic DFT measurement system similar to the one used by SigmaKalon could improve our ability to reliably quantify DFT changes as little as 0.5 mils in the laboratory.

We cannot emphasize enough that the results of this study do not cast any doubt on the ability of modern DFT equipment to reliably detect change in in-service hull coating system thickness over time, especially since data sets tend to be either separated in time by years or separated by hull cleaning events, and thus the expected change in DFT between measurement events is on the order of several mils. Countless DFT surveys (by ROVs and divers) have been conducted both in drydock and in-situ on US Navy vessels, and have been and continue to be a useful if not required tool for ensuring adequate coating thickness of paint applications in the drydock, as well as for tracking coating service life and for ship hull maintenance planning.

Based on our findings, field DFT surveys as currently conducted on ships (random measurements using magnetic induction probes either in drydock or in-situ) can, in most cases, reliably detect the expected loss in hull coating system DFT over time due to ablation and/or in-water hull cleaning. By closely attending to calibration, probe orientation relative to the coated surface, count rate, and appropriate sampling design, unexpected variation in survey data can be minimized.

## **FUTURE WORK**

Reliable, quantitative documentation of DFT change over time is a necessary step on the path toward developing a mass balance model that can reliably predict harbor loading of copper (or other biocides) from in-service antifouling hull coating systems. Such a model would subtract the sum of copper a) lost during at-sea periods by physical ablation, b) lost during in-port periods by biocide dissolution or release, and c) removed during in-water hull cleaning and drydock wash-downs (hull husbandry events) from the initial total quantity of copper in the as-applied coating system.

At a minimum, essential model inputs include: (a) the starting quantity of copper in the as-applied hull coating system; (b) the cumulative DFT change of a hull coating system as a function of time in port, hull husbandry activity, and vessel duty cycle (time at sea vs. time in port); and (c) in-situ biocide release rate. Ablation losses can be estimated based on at-sea time, currently captured in the Navy Energy Usage Reporting System (NEURS) database. Biocide dissolution rate can be estimated from a combination of release rate measurement protocols, including ASTM and ISO methods (ASTM, 2006; ISO, 2000a; ISO 2000b), as well as proposed ISO calculation methods, with and without correction factors (Finnie, 2006), and also SPAWAR in-situ dome measurements (Valkirs et al., 2003). Biocide loss due to hull husbandry events can be inferred from existing NAVSEA 00C databases.

We recommend that future DFT data sets, collected in accordance with the recommendations outlined in this report, be combined with the already available quantitative data outlined above to develop a model for estimating harbor loading of copper. Model outputs can be compared and contrasted with predictions of harbor loading already projected based on ASTM laboratory as well as proposed ISO calculation methods, with and without correction factors, for quantifying copper release rate (Finnie, 2006). Mass balance predictions of harbor loading should provide a significantly more reliable indication of actual harbor inputs, especially given the weaknesses already associated with predictions based solely on ASTM rotating cylinder methods (Haslbeck and Holm, 2005; Arias, 1999) and the ISO calculation method (OECD, 2005). More accurate estimates of harbor loading provide more reliable inputs into and outputs from environmental fate and effects models such as those used by regulatory bodies for the establishment of registration and end use permit limits (Finnie, 2006).

## BIBLIOGRAPHY

Arias, S., “Round Robin Test for Antifouling Paints,” *European Coatings Journal*, H 1571 E, pp 122–128, 1999.

ASTM Method D6442-06, *Test Method for Copper Release Rates of Antifouling Coating Systems in Seawater*, ASTM 2006.

Finnie, A. F., “Improved Estimates Of Environmental Copper Release Rates From Antifouling Products,” *Biofouling*, Volume 22, Issue 5, 2006, pp 279 – 291.

Haslbeck E. G., J. A. Ellor, “Investigating Tests For Antifoulants: Variation Between Laboratory and In-Situ Methods For Determining Copper Release Rates From Navy Approved Coatings,” *J. Protect. Coat. Linings*, Aug 2005: pp 34-44.

Haslbeck, E. G., E. R. Holm, “Standard Methods: Tests on Leaching Rates From Antifouling Coatings Reveal High Level Of Variation In Results Among Laboratories.” *European Coatings Journal*, Oct 2005: pp 26-31.

ISO (2000a) *Determination Of The Release Rate Of Biocides From Antifouling Paints – Part 1: General Method For Extraction Of Biocides*, International Standard ISO 15181-1: 2000.

ISO (2000b) *Determination of the Release Rate of Biocides From Antifouling Paints – Part 2: Determination of Copper-Ion Concentration in the Extract and Calculation of the Release Rate*, International Standard ISO 15181-2: 2000.

OECD, “Environmental Health and Safety Publications - Series on Emission Scenario Documents No. 13, *Emission Scenario Document on Antifouling Products*, Annex,” 2006.  
<http://www.oecd.org/dataoecd/33/37/34707347.pdf>

SAS Institute, Inc., *SAS System for Windows Version 8*. SAS Institute, Inc., Cary, NC, 1999.

Valkirs, A.O., P. F. Seligman, E. G. Haslbeck, and J. S. Caso, “Measurement of Copper Release Rates from Antifouling Paint under Laboratory and In-Situ Conditions: Implications for Loading Estimation to Marine Water Bodies,” *Marine Pollution Bulletin* 46 (2003) pp 763-779.

Wimmer, James R., Lieutenant, USN, *Analyzing and Predicting Underwater Hull Coating System Wear*, MS Dissertation in Operations Research, United States Naval Academy, Annapolis MD, Mar 1997 (Advisor: Prof L. R. Whitaker, Dept of Operations Research).

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## **APPENDIX A**

### **PROCEDURE - COUNT RATE COMPARISON**

1. Check the count rate of the unmodified probe:

To check the count rate on the Fischer Dualscope MP-40:

- a. Press CAL to enter the calibration mode.
- b. Press FINAL-RES to enable the “continuous” display mode.
- c. Touch the probe to a foil of known thickness over an uncoated substrate.
- d. Record the number that shows on the display.
- e. Lift the probe from the foil.
- f. Press FINAL-RES to exit continuous mode.
- g. Press CAL to exit the calibration mode.

After probe modification, check the count rate again, using the methodology above. Note the shift in count rate. An increase in count rate indicates the detection limit of the probe has shifted higher and the effective range of the probe is smaller.

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## **APPENDIX B**

### **REVIEW MEASUREMENT PROTOCOL – PRECISION TEMPLATE**

1. Use measurement stand and “permanently” fix probe position and height.
  - a. Orient probe perpendicular to substrate.

If the probe is not perpendicular to the substrate, you get measurement error. This error has not been quantified. It is essential to maintain the probe perpendicular to the substrate for each measurement.
  - b. Use a stand for which you’re sure the magnetic field is broken.

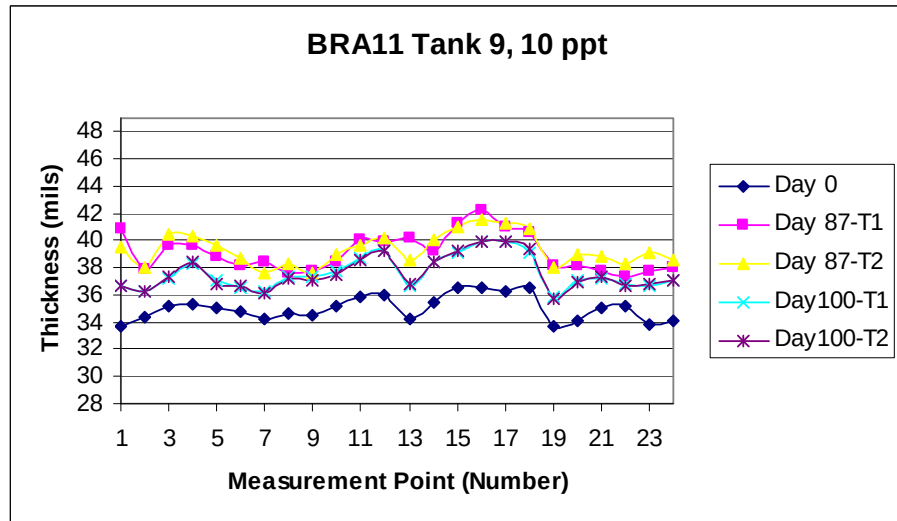
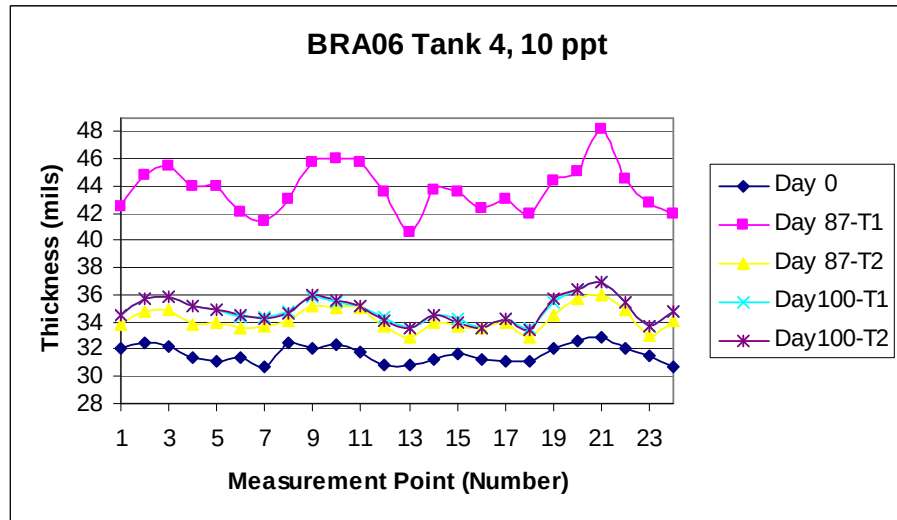
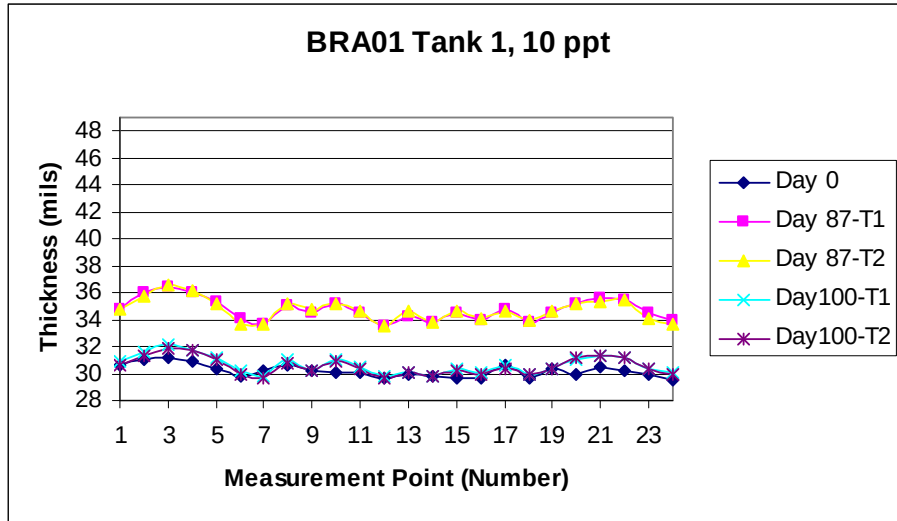
The magnetic field induced by the probe must be broken between measurements. If the magnetic field is not broken, a residual field may remain during following measurements and cause measurement error. The manufacturer suggests that lifting the probe at least 1” from the substrate will break the field.
2. Calibration check.
  - a. Calibration should be checked before each use of the meter.
  - b. We highly recommend if the meter is used for an extended period (8 hours or more) that calibration checks are conducted throughout the day as well.
  - c. Substrate selection for calibration.
    - Use same kind of substrate as will be used for test pieces.
    - Use same surface preparation (or smoother) as test pieces.
    - Substrate must be coated with a coating that will not change in thickness over time or upon seawater exposure (e.g. epoxy).
  - d. Using an appropriate panel (as described above), the DFT should be recorded for at least two different spots.
  - e. At least 30 measurements per spot should be taken initially. Then, each additional calibration check should use ten measurements per spot.
  - f. If during the calibration check, variation in the data is detected, measurements should not be taken until the source of variability is corrected. Check probe position/height and adjust if necessary. Re-calibrate using shims per manufacturer’s instructions only after eliminating other possible sources of variation.

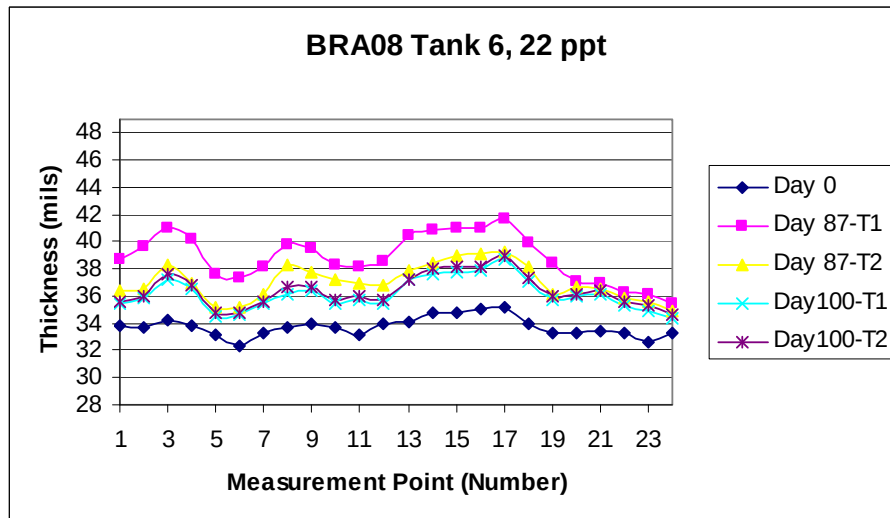
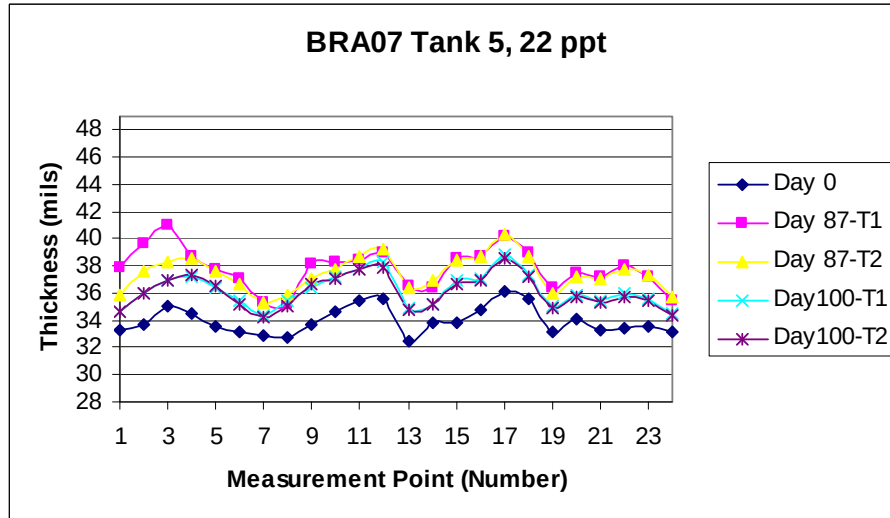
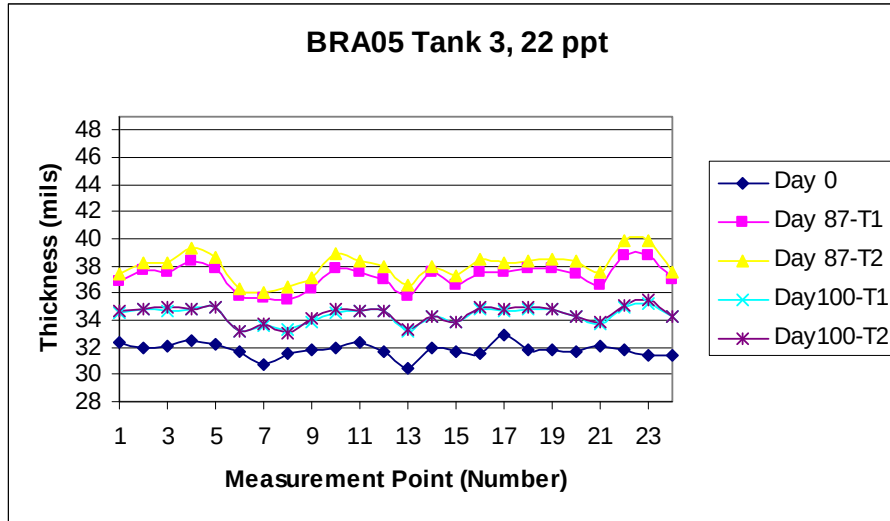
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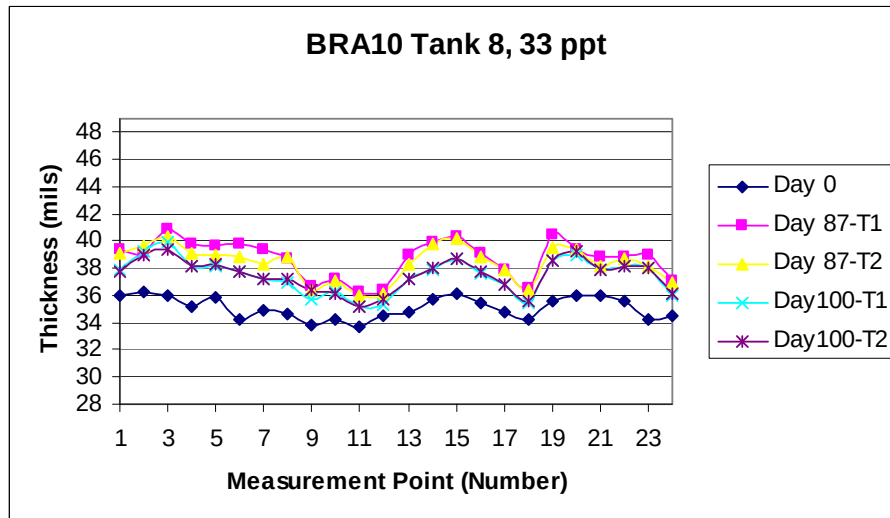
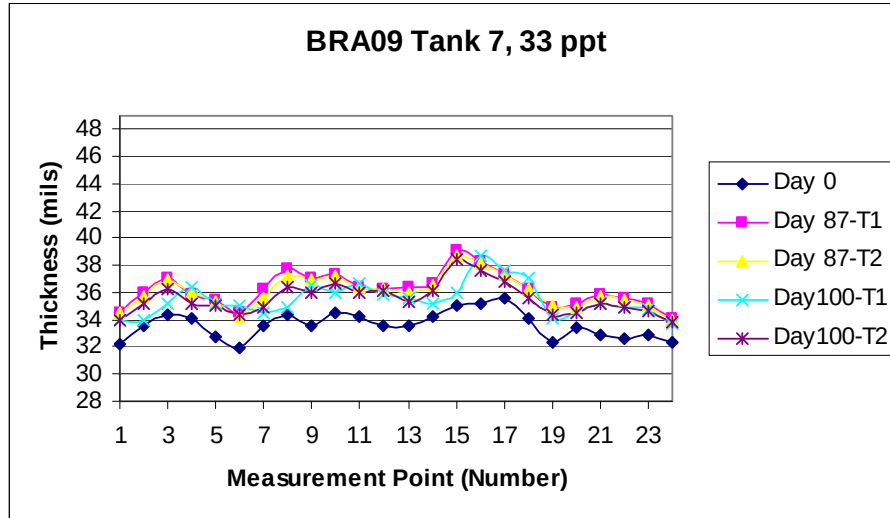
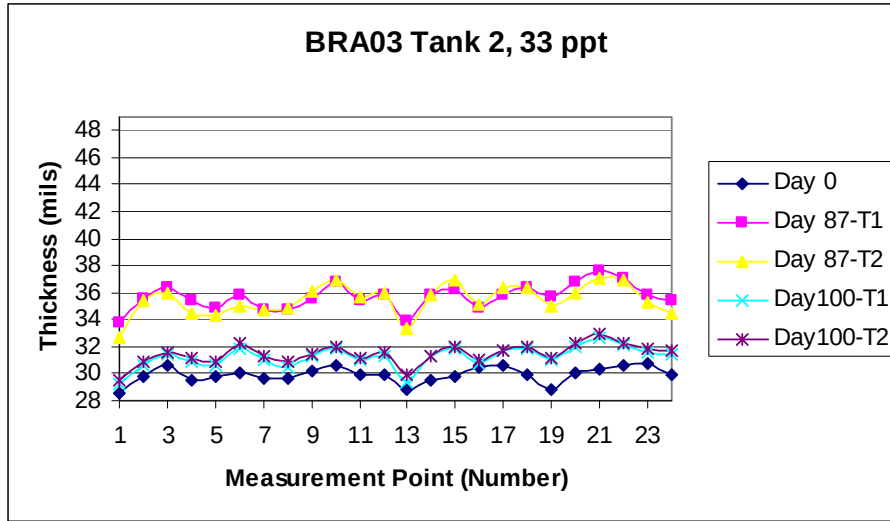
**APPENDIX C**

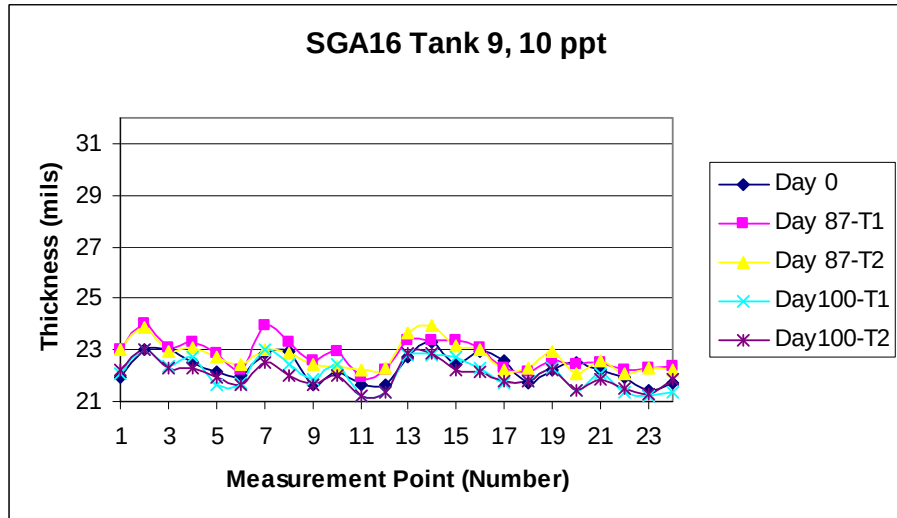
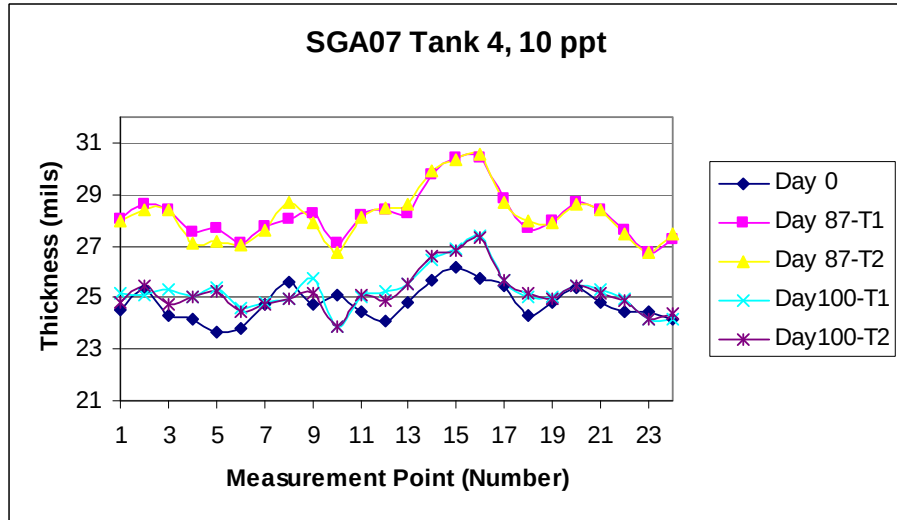
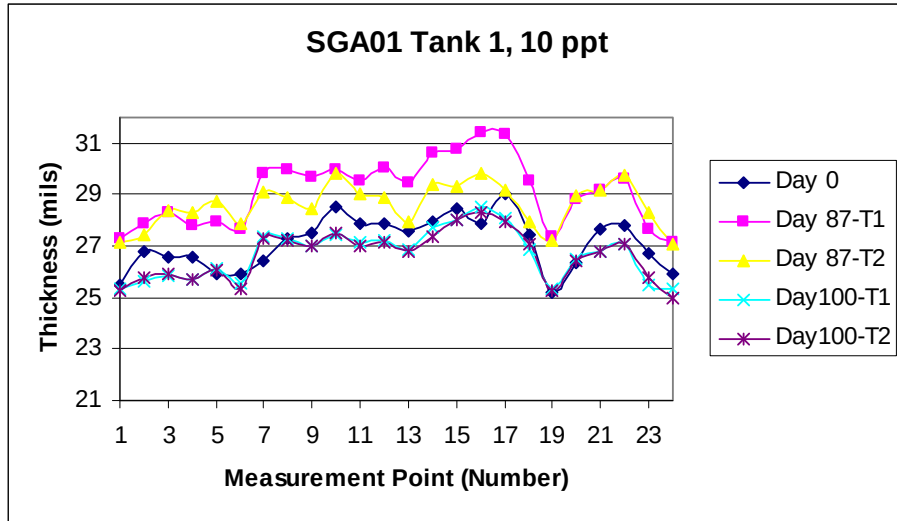
**DFT CHANGE OVER TIME – EDDY CURRENT TESTING RESULTS**

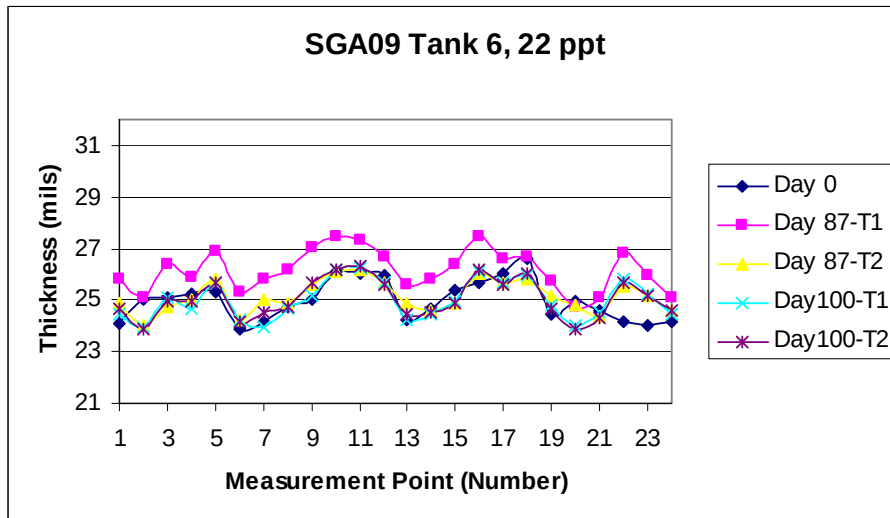
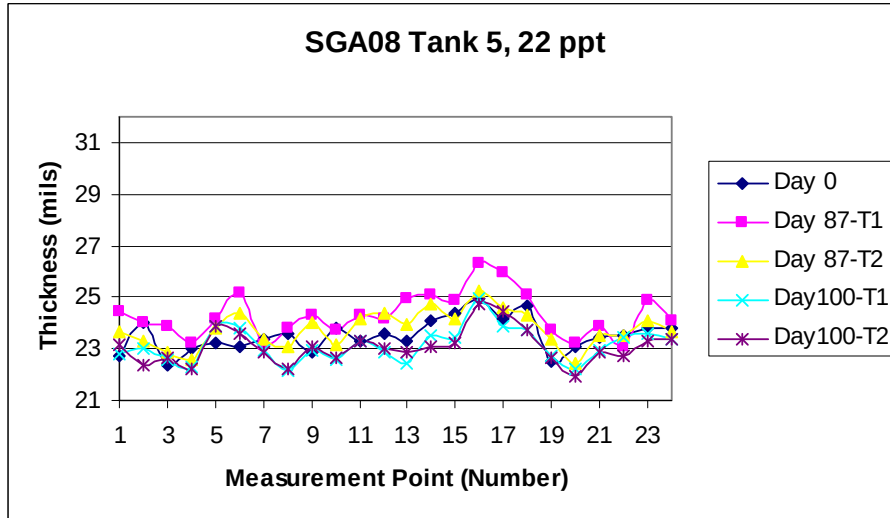
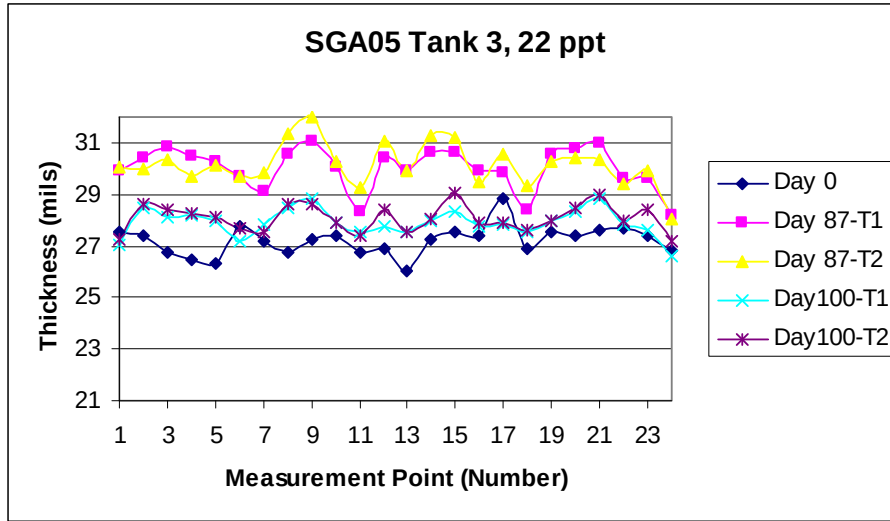
Each graph title indicates panel number, tank number, and salinity.

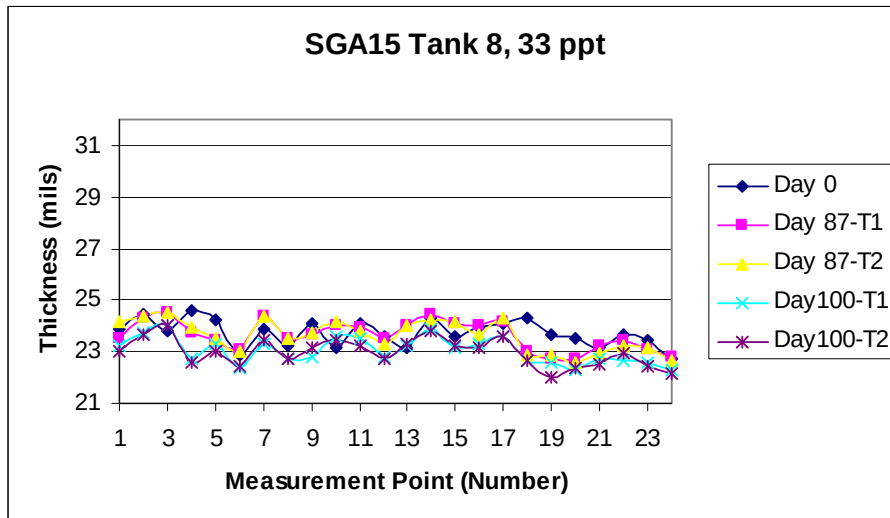
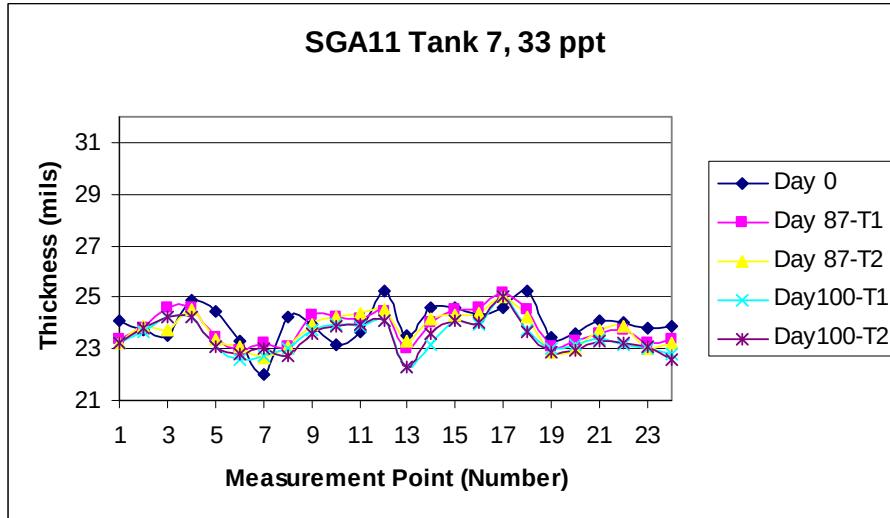
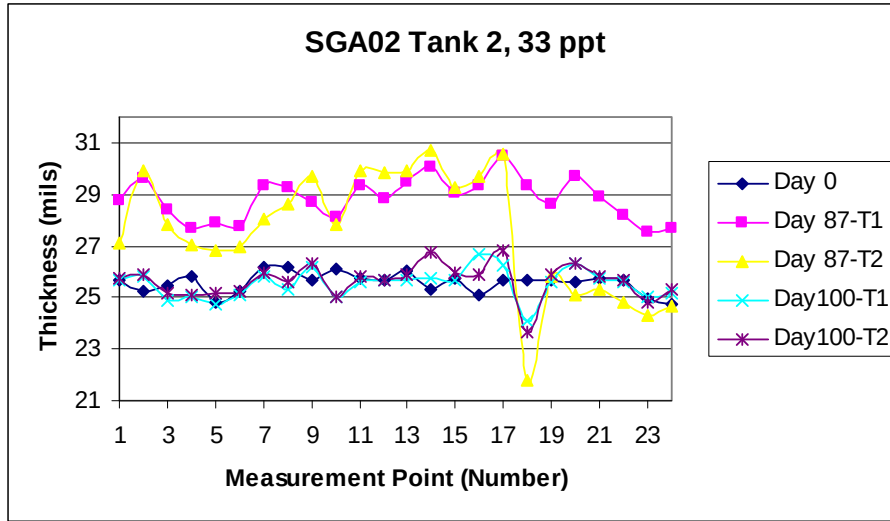


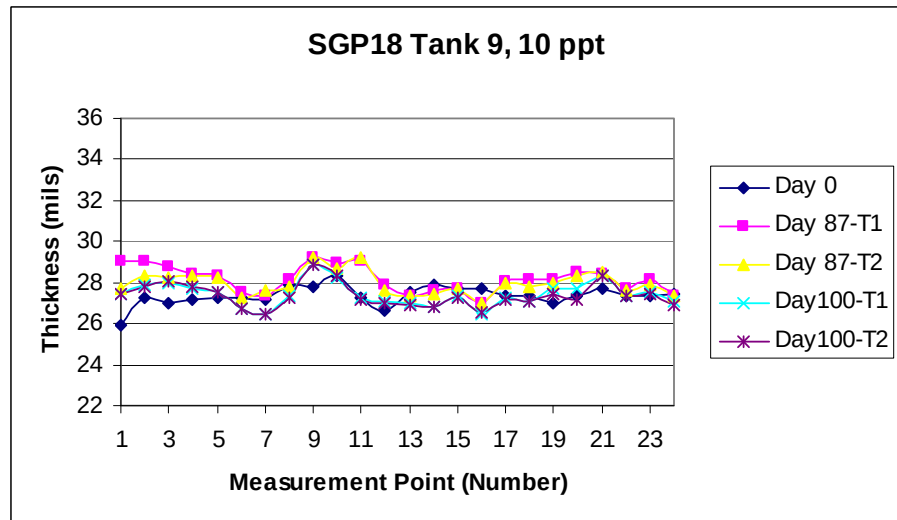
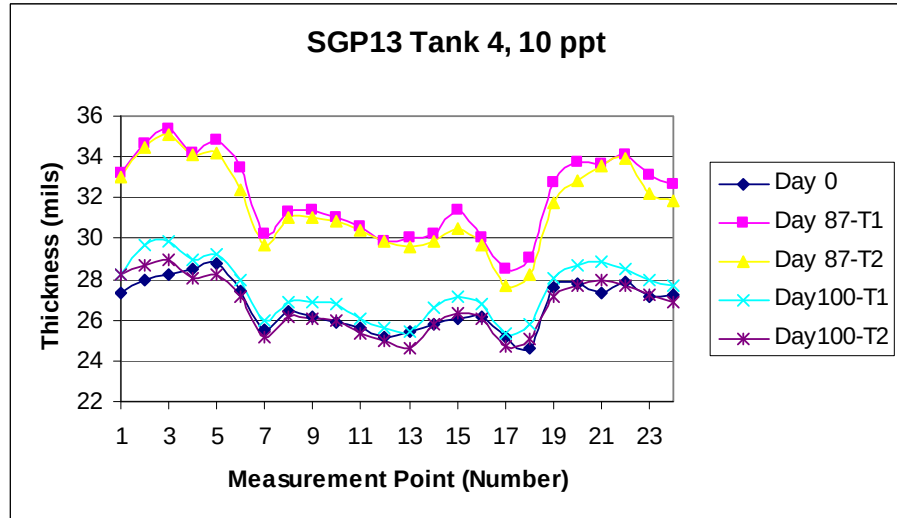
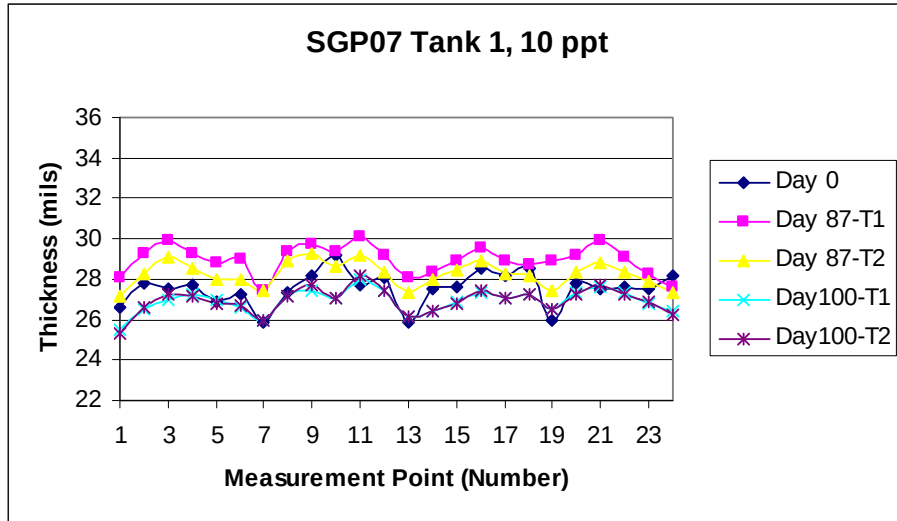


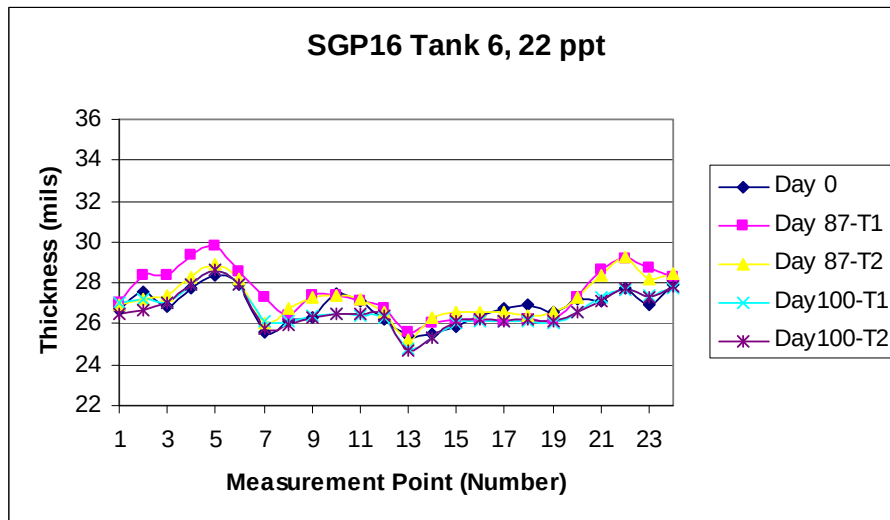
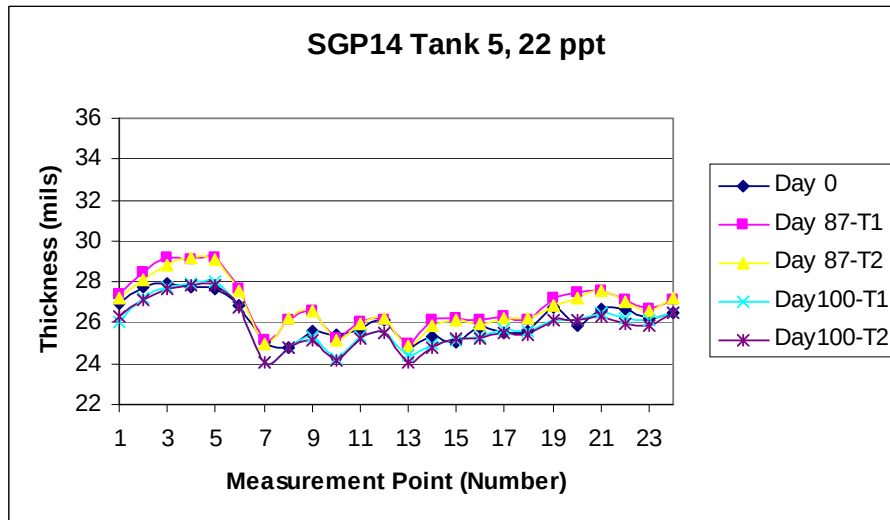
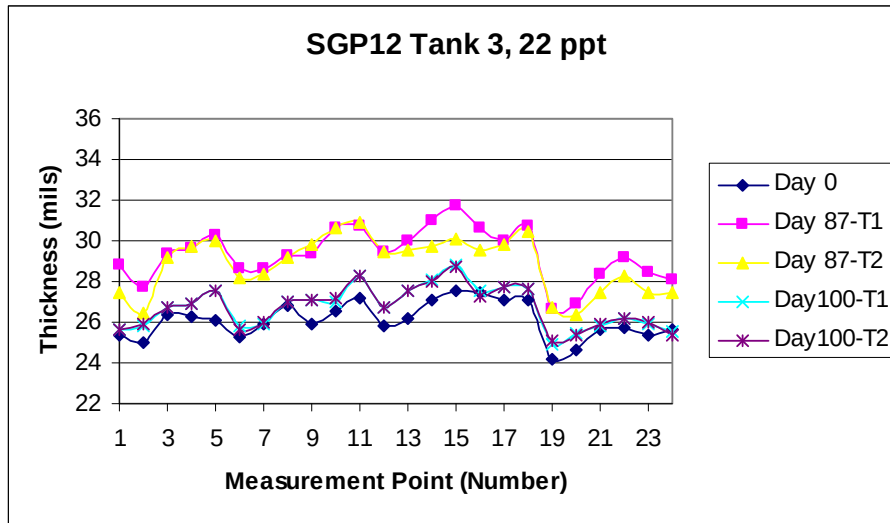


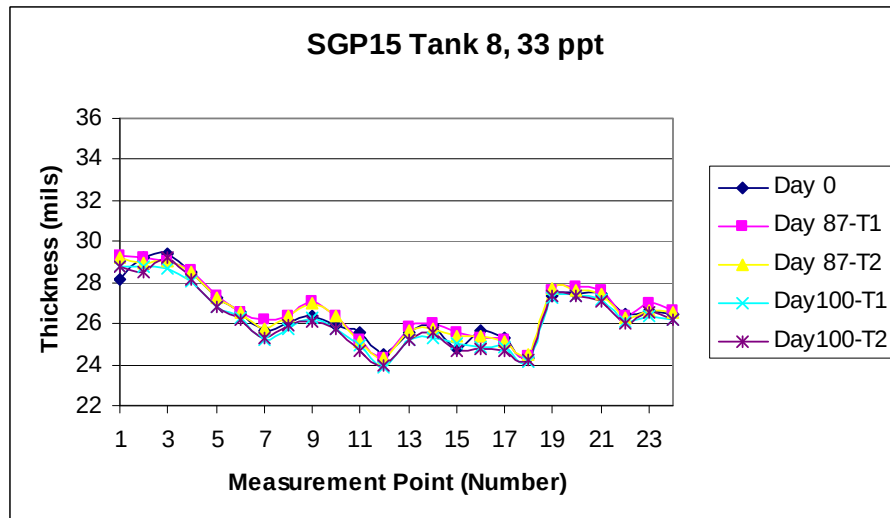
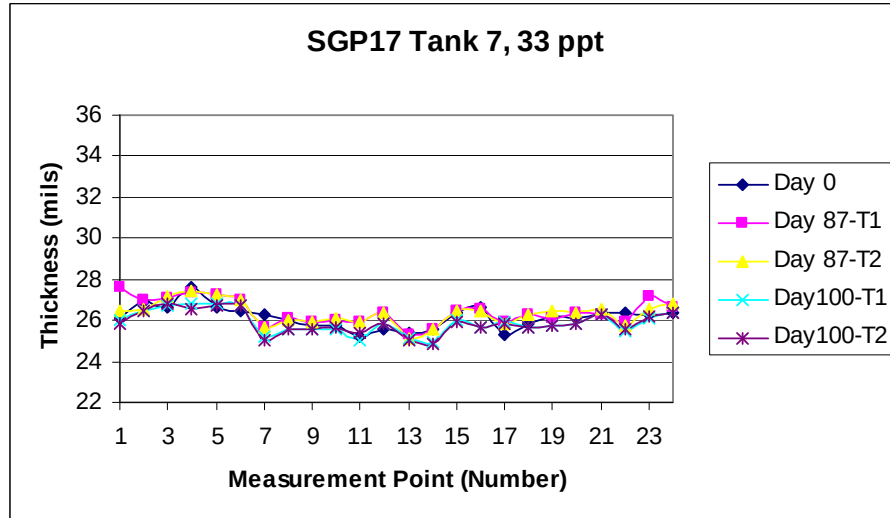
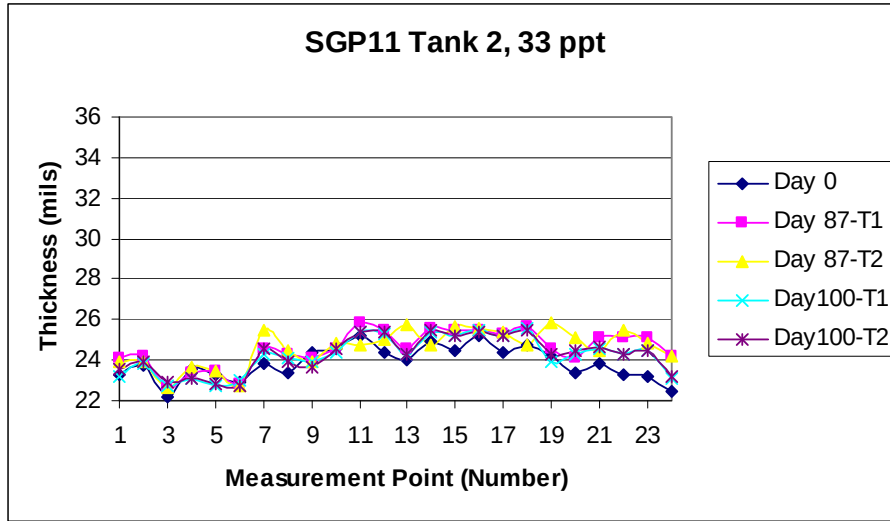












**APPENDIX D**

**RAW DATA – MAGNETIC INDUCTION DFT STUDY**

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Raw data – magnetic induction DFT study.

### BRA S-2

|           | 5-Sep-06  |        | 10-Oct-06 |        | 31-Oct-06 |        | 28-Nov-06 |        | 21-Dec-06 |        |
|-----------|-----------|--------|-----------|--------|-----------|--------|-----------|--------|-----------|--------|
|           | Day 0 Dry |        | Day 21    |        | Day 42    |        | Day 72    |        | Day 93    |        |
|           | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  |
| <b>1</b>  | 23.4551   | 0.2429 | 23.0883   | 0.1509 | 23.1388   | 0.0986 | 23.4033   | 0.0895 | 23.4444   | 0.1300 |
| <b>3</b>  | 22.4364   | 0.1575 | 22.2678   | 0.1022 | 22.5457   | 0.0840 | 22.6654   | 0.0631 | 22.6055   | 0.0917 |
| <b>5</b>  | 21.9335   | 0.1477 | 21.4281   | 0.0996 | 21.6215   | 0.0766 | 21.8845   | 0.1171 | 21.7284   | 0.0802 |
| <b>7</b>  | 21.7967   | 0.1464 | 22.1004   | 0.1702 | 21.9823   | 0.0858 | 22.0805   | 0.1081 | 22.1888   | 0.0929 |
| <b>9</b>  | 21.9237   | 0.1534 | 21.9041   | 0.1258 | 21.9823   | 0.0858 | 22.0019   | 0.0724 | 22.0609   | 0.1041 |
| <b>11</b> | 21.5347   | 0.1831 | 21.1303   | 0.0705 | 21.3895   | 0.0760 | 21.3413   | 0.0793 | 21.5344   | 0.1025 |
| <b>13</b> | 21.6216   | 0.1193 | 21.3317   | 0.0885 | 21.4570   | 0.0820 | 21.6214   | 0.0615 | 21.5248   | 0.1275 |
| <b>15</b> | 21.0160   | 0.1452 | 20.5714   | 0.1704 | 20.7785   | 0.0914 | 20.8258   | 0.0699 | 20.7502   | 0.0940 |
| <b>17</b> | 21.1590   | 0.0668 | 20.6936   | 0.1277 | 20.9780   | 0.1505 | 20.9778   | 0.0924 | 21.0542   | 0.1496 |
| <b>19</b> | 23.1593   | 0.1591 | 22.5359   | 0.1429 | 22.7758   | 0.1201 | 23.1106   | 0.0675 | 22.6356   | 0.1270 |
| <b>21</b> | 22.8770   | 0.2707 | 22.4962   | 0.1785 | 22.4562   | 0.1330 | 22.5759   | 0.1662 | 22.6655   | 0.0789 |
| <b>23</b> | 22.1497   | 0.1753 | 21.7965   | 0.0650 | 21.9725   | 0.0773 | 21.9040   | 0.0856 | 22.0118   | 0.1115 |

### BRA S-4

|           | 5-Sep-06  |        | 20-Sep-06 |        | 12-Oct-06 |        | 3-Nov-06 |        | 28-Nov-06 |        | 21-Dec-06 |        |
|-----------|-----------|--------|-----------|--------|-----------|--------|----------|--------|-----------|--------|-----------|--------|
|           | Day 0 Dry |        | Day 0 Wet |        | Day 23    |        | Day 45   |        | Day 70    |        | Day 93    |        |
|           | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  | Avg      | StDev  | Avg       | StDev  | Avg       | StDev  |
| <b>1</b>  | 21.4573   | 0.1659 | 21.3901   | 0.2401 | 21.1784   | 0.1368 | 21.4185  | 0.1062 | 21.1591   | 0.1029 | 21.0635   | 0.0667 |
| <b>3</b>  | 21.1976   | 0.1553 | 21.0255   | 0.1348 | 21.0255   | 0.1348 | 21.1208  | 0.0780 | 21.1499   | 0.1866 | 21.0254   | 0.0778 |
| <b>5</b>  | 21.7752   | 0.1814 | 21.5441   | 0.1137 | 21.5637   | 0.1722 | 21.8063  | 0.0971 | 21.6021   | 0.0913 | 21.4763   | 0.0652 |
| <b>7</b>  | 21.8561   | 0.2849 | 21.6806   | 0.2715 | 21.2262   | 0.1313 | 21.4184  | 0.0960 | 21.5149   | 0.0549 | 21.2261   | 0.0707 |
| <b>9</b>  | 22.1693   | 0.1527 | 22.2779   | 0.1580 | 22.3868   | 0.1482 | 22.4859  | 0.0812 | 22.3866   | 0.0810 | 22.3976   | 0.0596 |
| <b>11</b> | 21.7384   | 0.1847 | 21.4763   | 0.0795 | 21.6216   | 0.1278 | 21.7748  | 0.0650 | 21.6408   | 0.0501 | 21.7090   | 0.1070 |
| <b>13</b> | 21.1974   | 0.1178 | 21.1739   | 0.0844 | 21.3608   | 0.1452 | 21.2741  | 0.1033 | 21.2549   | 0.1032 | 21.3606   | 0.0681 |
| <b>15</b> | 21.4377   | 0.0795 | 21.4287   | 0.2311 | 21.0064   | 0.1081 | 21.5440  | 0.0935 | 21.4184   | 0.0844 | 21.1399   | 0.0878 |
| <b>17</b> | 21.3232   | 0.1013 | 21.1689   | 0.1706 | 21.2838   | 0.1285 | 21.4767  | 0.1823 | 21.3030   | 0.1238 | 21.4667   | 0.1038 |
| <b>19</b> | 21.4188   | 0.1903 | 21.3029   | 0.0709 | 21.1593   | 0.1510 | 21.4570  | 0.0820 | 21.3511   | 0.1216 | 21.0350   | 0.1050 |
| <b>21</b> | 22.2284   | 0.1489 | 22.1792   | 0.1706 | 22.1592   | 0.0934 | 22.3271  | 0.0692 | 22.1593   | 0.1319 | 22.2383   | 0.1338 |
| <b>23</b> | 21.9533   | 0.1921 | 21.8846   | 0.1560 | 22.0609   | 0.1315 | 22.2580  | 0.1237 | 22.0511   | 0.1154 | 22.2185   | 0.1235 |

**BRA R-4**

|           | 6-Sep-06  |        | 6-Oct-06 |        | 31-Oct-06 |        | 30-Nov-06 |        | 20-Dec-06 |        |
|-----------|-----------|--------|----------|--------|-----------|--------|-----------|--------|-----------|--------|
|           | Day 0 Dry |        | Day 17   |        | Day 42    |        | Day 72    |        | Day 92    |        |
|           | Avg       | Stdev  | Avg      | Stdev  | Avg       | Stdev  | Avg       | Stdev  | Avg       | Stdev  |
| <b>1</b>  | 20.8546   | 0.1664 | 20.4210  | 0.0904 | 20.5148   | 0.0907 | 21.0160   | 0.1383 | 20.6371   | 0.1211 |
| <b>3</b>  | 20.3278   | 0.1600 | 20.2810  | 0.1025 | 20.4304   | 0.1087 | 20.4585   | 0.0989 | 20.1972   | 0.0855 |
| <b>5</b>  | 20.0588   | 0.2511 | 19.7267  | 0.1525 | 19.7908   | 0.1285 | 19.7357   | 0.1206 | 19.4073   | 0.0765 |
| <b>7</b>  | 20.9304   | 0.1550 | 20.7882  | 0.1496 | 20.7598   | 0.1466 | 20.9873   | 0.0920 | 20.6088   | 0.1106 |
| <b>9</b>  | 20.8356   | 0.1733 | 20.6841  | 0.1107 | 20.7408   | 0.1178 | 21.0540   | 0.0785 | 20.6370   | 0.1036 |
| <b>11</b> | 20.6944   | 0.2758 | 20.2716  | 0.0761 | 20.1972   | 0.0855 | 20.6558   | 0.0826 | 20.2624   | 0.1351 |
| <b>13</b> | 20.4024   | 0.1182 | 21.1787  | 0.1022 | 20.2252   | 0.1182 | 20.4773   | 0.0969 | 21.2169   | 0.1806 |
| <b>15</b> | 20.4168   | 0.0493 | 20.0343  | 0.0488 | 19.9841   | 0.1016 | 20.2809   | 0.0926 | 20.0119   | 0.1291 |
| <b>17</b> | 20.5714   | 0.1818 | 20.4024  | 0.1098 | 20.2810   | 0.1199 | 20.4210   | 0.0903 | 20.1880   | 0.1113 |
| <b>19</b> | 21.4380   | 0.1826 | 20.9400  | 0.1582 | 21.0445   | 0.1081 | 21.1590   | 0.0807 | 20.7880   | 0.0805 |
| <b>21</b> | 20.8452   | 0.1923 | 20.7033  | 0.1797 | 20.6275   | 0.0743 | 21.1307   | 0.1830 | 20.7596   | 0.0746 |
| <b>23</b> | 20.2068   | 0.1864 | 20.0119  | 0.1364 | 20.0305   | 0.1523 | 20.2904   | 0.1303 | 19.9749   | 0.1136 |

**BRA R-5**

|           | 6-Sep-06  |        | 20-Sep-06 |        | 6-Oct-06 |        | 2-Nov-06 |        | 28-Nov-06 |        | 20-Dec-06 |        |
|-----------|-----------|--------|-----------|--------|----------|--------|----------|--------|-----------|--------|-----------|--------|
|           | Day 0 Dry |        | Day 0 Wet |        | Day 17   |        | Day 44   |        | Day 70    |        | Day 92    |        |
|           | Avg       | Stdev  | Avg       | Stdev  | Avg      | Stdev  | Avg      | Stdev  | Avg       | Stdev  | Avg       | Stdev  |
| <b>1</b>  | 21.8943   | 0.1301 | 21.7869   | 0.1166 | 22.1987  | 0.0982 | 22.3668  | 0.0910 | 22.2383   | 0.1338 | 22.2481   | 0.1251 |
| <b>3</b>  | 21.2934   | 0.1265 | 21.4477   | 0.1889 | 20.7974  | 0.0799 | 21.4860  | 0.0887 | 21.4282   | 0.1269 | 21.2455   | 0.1502 |
| <b>5</b>  | 20.7031   | 0.1420 | 20.5242   | 0.1175 | 20.7978  | 0.1743 | 20.7786  | 0.1017 | 20.6747   | 0.1180 | 20.8354   | 0.1263 |
| <b>7</b>  | 21.1400   | 0.1178 | 20.9684   | 0.1361 | 20.9018  | 0.1269 | 21.1112  | 0.0542 | 21.1303   | 0.0705 | 21.1974   | 0.0989 |
| <b>9</b>  | 20.9018   | 0.1189 | 21.1214   | 0.2300 | 20.9969  | 0.1105 | 21.1974  | 0.1087 | 21.0731   | 0.1031 | 21.1593   | 0.1508 |
| <b>11</b> | 20.6843   | 0.1556 | 20.6843   | 0.1492 | 20.7787  | 0.1489 | 20.8354  | 0.1000 | 20.7410   | 0.1607 | 20.8638   | 0.0900 |
| <b>13</b> | 20.3743   | 0.1119 | 20.3088   | 0.0482 | 20.2531  | 0.1225 | 20.4398  | 0.0860 | 20.5807   | 0.1541 | 20.3368   | 0.0451 |
| <b>15</b> | 19.7377   | 0.0891 | 19.9381   | 0.1456 | 19.5258  | 0.1691 | 19.8551  | 0.1318 | 19.9013   | 0.1564 | 19.4982   | 0.0978 |
| <b>17</b> | 20.0304   | 0.1250 | 19.9564   | 0.0992 | 19.8829  | 0.1671 | 19.9011  | 0.1065 | 19.8641   | 0.0644 | 19.8498   | 0.0485 |
| <b>19</b> | 21.5483   | 0.1096 | 21.9485   | 0.0712 | 21.9432  | 0.1058 | 21.8551  | 0.0823 | 21.6604   | 0.1043 | 21.7089   | 0.0968 |
| <b>21</b> | 21.5440   | 0.0816 | 21.3896   | 0.1269 | 21.2454  | 0.1362 | 21.6022  | 0.1120 | 21.5538   | 0.1230 | 21.5537   | 0.1047 |
| <b>23</b> | 21.2934   | 0.1090 | 21.2460   | 0.2513 | 20.8736  | 0.1746 | 21.1304  | 0.1144 | 21.3030   | 0.1151 | 20.8142   | 0.0789 |

**BRA R-6**

|           | 6-Sep-06  |        | 20-Sep-06 |        | 11-Oct-06 |        | 2-Nov-06 |        | 28-Nov-06 |        | 21-Dec-06 |        |
|-----------|-----------|--------|-----------|--------|-----------|--------|----------|--------|-----------|--------|-----------|--------|
|           | Day 0 Dry |        | Day 0 Wet |        | Day 22    |        | Day 44   |        | Day 70    |        | Day 93    |        |
|           | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  | Avg      | StDev  | Avg       | StDev  | Avg       | StDev  |
| <b>1</b>  | 22.1299   | 0.1483 | 22.3080   | 0.2420 | 22.0804   | 0.0726 | 22.1199  | 0.1142 | 21.9140   | 0.1654 | 22.0020   | 0.1346 |
| <b>3</b>  | 21.8162   | 0.1286 | 22.1498   | 0.1983 | 21.8551   | 0.0823 | 21.7674  | 0.1131 | 21.6799   | 0.1358 | 21.7284   | 0.1030 |
| <b>5</b>  | 22.1397   | 0.1413 | 23.0881   | 0.0877 | 22.5059   | 0.1223 | 22.4562  | 0.1055 | 22.4364   | 0.1346 | 22.5080   | 0.0440 |
| <b>7</b>  | 20.5147   | 0.0657 | 20.5810   | 0.2170 | 20.5148   | 0.0907 | 20.6844  | 0.1788 | 20.4774   | 0.1381 | 20.6370   | 0.1036 |
| <b>9</b>  | 20.8356   | 0.1734 | 21.0540   | 0.1106 | 20.7596   | 0.0745 | 20.7409  | 0.1479 | 20.6559   | 0.1129 | 20.6882   | 0.0685 |
| <b>11</b> | 21.2358   | 0.1263 | 21.5637   | 0.1723 | 21.4957   | 0.0960 | 21.2549  | 0.0810 | 21.2550   | 0.1294 | 21.1782   | 0.0670 |
| <b>13</b> | 20.6747   | 0.1093 | 20.2346   | 0.1655 | 20.2810   | 0.1025 | 20.2252  | 0.1182 | 20.2903   | 0.0963 | 20.1878   | 0.0686 |
| <b>15</b> | 20.3650   | 0.1246 | 20.4778   | 0.2245 | 20.3836   | 0.0737 | 20.2436  | 0.0628 | 20.3093   | 0.1974 | 20.3369   | 0.0769 |
| <b>17</b> | 20.8829   | 0.1360 | 21.1405   | 0.2249 | 21.0541   | 0.1275 | 21.0541  | 0.1278 | 21.0257   | 0.1680 | 21.0921   | 0.0786 |
| <b>19</b> | 21.9434   | 0.1618 | 21.9629   | 0.1538 | 22.0608   | 0.0663 | 21.8943  | 0.1221 | 21.6700   | 0.0921 | 21.6117   | 0.0551 |
| <b>21</b> | 21.7285   | 0.1302 | 22.0907   | 0.1915 | 21.9432   | 0.1155 | 21.8649  | 0.1134 | 21.7091   | 0.1409 | 21.9921   | 0.0925 |
| <b>23</b> | 22.2086   | 0.1119 | 22.7362   | 0.2381 | 22.3767   | 0.0867 | 22.3570  | 0.1326 | 22.1300   | 0.1747 | 22.3866   | 0.1047 |

**ABC3 S-1**

|           | 5-Sep-06  |        | 6-Oct-06 |        | 31-Oct-06 |        | 30-Nov-06 |        | 20-Dec-06 |        |
|-----------|-----------|--------|----------|--------|-----------|--------|-----------|--------|-----------|--------|
|           | Day 0 Dry |        | Day 17   |        | Day 42    |        | Day 72    |        | Day 92    |        |
|           | Avg       | StDev  | Avg      | StDev  | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  |
| <b>1</b>  | 27.3315   | 0.1449 | 27.5719  | 0.2036 | 26.9799   | 0.1427 | 27.5952   | 0.2642 | 26.7434   | 0.1065 |
| <b>3</b>  | 27.2410   | 0.2512 | 26.2643  | 0.1381 | 26.0222   | 0.2684 | 26.5867   | 0.0978 | 26.2421   | 0.1145 |
| <b>5</b>  | 27.9176   | 0.1748 | 26.9123  | 0.1749 | 27.1499   | 0.2031 | 28.3835   | 0.1261 | 27.8019   | 0.1462 |
| <b>7</b>  | 26.3535   | 0.2504 | 26.2870  | 0.2501 | 26.0437   | 0.1799 | 26.9459   | 0.0832 | 26.0545   | 0.1096 |
| <b>9</b>  | 27.1391   | 0.2957 | 27.2403  | 0.1078 | 27.5142   | 0.0845 | 28.0683   | 0.1279 | 27.8018   | 0.1241 |
| <b>11</b> | 26.5989   | 0.3084 | 26.2202  | 0.1662 | 26.0435   | 0.1273 | 26.3201   | 0.2172 | 26.2201   | 0.1398 |
| <b>13</b> | 26.0923   | 0.0581 | 26.9125  | 0.2180 | 26.7886   | 0.1838 | 27.0589   | 0.0990 | 26.8558   | 0.1068 |
| <b>15</b> | 26.5768   | 0.3415 | 26.0655  | 0.1353 | 26.4530   | 0.1290 | 26.4308   | 0.1505 | 26.0435   | 0.1271 |
| <b>17</b> | 26.6601   | 0.1494 | 25.7149  | 0.1259 | 26.1427   | 0.1322 | 26.7211   | 0.1537 | 26.6764   | 0.1675 |
| <b>19</b> | 27.1952   | 0.2005 | 27.6636  | 0.1457 | 27.4799   | 0.1300 | 27.8366   | 0.1675 | 27.3086   | 0.1081 |
| <b>21</b> | 27.7326   | 0.1437 | 28.3262  | 0.1088 | 28.0684   | 0.1498 | 28.0334   | 0.1363 | 28.1730   | 0.1204 |
| <b>23</b> | 27.6749   | 0.0815 | 26.9123  | 0.1746 | 26.9916   | 0.2454 | 27.6061   | 0.1478 | 27.3314   | 0.1108 |

**ABC3 S-3**

|           | 5-Sep-06  |        | 20-Sep-06 |        | 6-Oct-06 |        | 2-Nov-06 |        | 28-Nov-06 |        | 20-Dec-06 |        |
|-----------|-----------|--------|-----------|--------|----------|--------|----------|--------|-----------|--------|-----------|--------|
|           | Day 0 Dry |        | Day 0 Wet |        | Day 17   |        | Day 44   |        | Day 70    |        | Day 92    |        |
|           | Avg       | StDev  | Avg       | StDev  | Avg      | StDev  | Avg      | StDev  | Avg       | StDev  | Avg       | StDev  |
| <b>1</b>  | 26.6993   | 0.2673 | 26.3014   | 0.5725 | 26.1098  | 0.1737 | 26.3529  | 0.1019 | 26.1095   | 0.1064 | 25.3568   | 0.0889 |
| <b>3</b>  | 26.7325   | 0.1895 | 26.3317   | 0.3018 | 26.4976  | 0.1527 | 26.6651  | 0.1417 | 26.5312   | 0.1909 | 26.3086   | 0.1071 |
| <b>5</b>  | 26.3317   | 0.2978 | 26.3534   | 0.2214 | 25.9885  | 0.1187 | 26.2092  | 0.1825 | 26.3644   | 0.2057 | 26.2200   | 0.1188 |
| <b>7</b>  | 26.0992   | 0.2555 | 26.1436   | 0.3003 | 26.0324  | 0.0812 | 26.2974  | 0.0913 | 26.2203   | 0.1963 | 26.1978   | 0.0931 |
| <b>9</b>  | 25.9010   | 0.2005 | 26.2100   | 0.3136 | 25.8788  | 0.1183 | 26.6988  | 0.1708 | 26.6986   | 0.1113 | 26.6426   | 0.1203 |
| <b>11</b> | 26.1317   | 0.1252 | 26.5759   | 0.2032 | 26.3753  | 0.1568 | 25.9445  | 0.0961 | 26.0880   | 0.2215 | 26.4195   | 0.0777 |
| <b>13</b> | 26.6765   | 0.1908 | 26.5995   | 0.3734 | 26.2312  | 0.1657 | 26.5643  | 0.0919 | 26.7098   | 0.1293 | 26.3862   | 0.0972 |
| <b>15</b> | 25.8353   | 0.1965 | 25.6618   | 0.3540 | 25.8574  | 0.2377 | 25.7367  | 0.1127 | 25.9448   | 0.1827 | 25.9556   | 0.1350 |
| <b>17</b> | 26.0068   | 0.1099 | 25.7816   | 0.3352 | 25.8792  | 0.2082 | 25.8789  | 0.1485 | 26.0327   | 0.1679 | 26.2310   | 0.0747 |
| <b>19</b> | 26.6655   | 0.2256 | 26.3875   | 0.1032 | 26.0988  | 0.1743 | 26.2312  | 0.1481 | 26.1413   | 0.0663 | 25.9555   | 0.0866 |
| <b>21</b> | 26.2647   | 0.2220 | 25.9449   | 0.1894 | 25.7367  | 0.1239 | 25.8569  | 0.1270 | 25.7258   | 0.1201 | 25.8679   | 0.1387 |
| <b>23</b> | 26.2318   | 0.2771 | 26.5094   | 0.2730 | 26.5308  | 0.0781 | 26.3086  | 0.1403 | 25.9339   | 0.1940 | 26.4865   | 0.1575 |

### ABC3 S-5

|           | 5-Sep-06  |        | 20-Sep-06 |        | 6-Oct-06 |        | 2-Nov-06 |        | 28-Nov-06 |        | 21-Dec-06 |        |
|-----------|-----------|--------|-----------|--------|----------|--------|----------|--------|-----------|--------|-----------|--------|
|           | Day 0 Dry |        | Day 0 Wet |        | Day 17   |        | Day 44   |        | Day 70    |        | Day 93    |        |
|           | Avg       | StDev  | Avg       | StDev  | Avg      | StDev  | Avg      | StDev  | Avg       | StDev  | Avg       | StDev  |
| <b>1</b>  | 23.6812   | 0.2777 | 23.7640   | 0.3282 | 23.9805  | 0.1625 | 23.7116  | 0.1972 | 23.6598   | 0.1208 | 23.6495   | 0.1111 |
| <b>3</b>  | 23.5269   | 0.2567 | 23.3135   | 0.4010 | 23.5571  | 0.1387 | 22.9873  | 0.1781 | 22.8761   | 0.0881 | 22.9085   | 0.0444 |
| <b>5</b>  | 22.6960   | 0.2078 | 22.8767   | 0.2202 | 22.6755  | 0.0876 | 22.7860  | 0.1707 | 22.6257   | 0.1348 | 22.8563   | 0.1577 |
| <b>7</b>  | 22.7360   | 0.2013 | 22.3077   | 0.1794 | 22.2677  | 0.0780 | 22.7557  | 0.1161 | 22.5259   | 0.1260 | 22.1987   | 0.0865 |
| <b>9</b>  | 21.8172   | 0.3106 | 22.0324   | 0.2965 | 22.1889  | 0.1397 | 21.6702  | 0.1300 | 21.8944   | 0.1597 | 21.7773   | 0.1643 |
| <b>11</b> | 21.4957   | 0.0961 | 21.5638   | 0.2101 | 21.4957  | 0.0960 | 21.5152  | 0.1474 | 21.5538   | 0.1387 | 21.6702   | 0.1378 |
| <b>13</b> | 22.2381   | 0.0699 | 21.8751   | 0.2099 | 22.1003  | 0.1350 | 22.0904  | 0.1313 | 22.1299   | 0.1483 | 22.0709   | 0.1591 |
| <b>15</b> | 20.8922   | 0.0801 | 20.8547   | 0.1942 | 20.4398  | 0.0860 | 20.7692  | 0.1341 | 20.7313   | 0.0938 | 20.5712   | 0.1317 |
| <b>17</b> | 21.1978   | 0.1956 | 20.9401   | 0.1977 | 21.1114  | 0.1454 | 21.0161  | 0.1709 | 21.2360   | 0.1798 | 20.9207   | 0.0701 |
| <b>19</b> | 23.6707   | 0.2567 | 23.4275   | 0.1770 | 23.7112  | 0.1026 | 23.5777  | 0.1664 | 23.2708   | 0.0934 | 23.4852   | 0.0897 |
| <b>21</b> | 22.4274   | 0.3008 | 23.0480   | 0.1979 | 22.5859  | 0.1696 | 22.2976  | 0.1356 | 22.5659   | 0.1684 | 22.8159   | 0.1165 |
| <b>23</b> | 21.9930   | 0.2742 | 22.2501   | 0.4055 | 22.3075  | 0.1460 | 22.2777  | 0.0866 | 22.2481   | 0.1335 | 22.4960   | 0.1364 |

### ABC3 R-3

|           | 6-Sep-06  |        | 10-Oct-06 |        | 31-Oct-06 |        | 28-Nov-06 |        | 21-Dec-06 |        |
|-----------|-----------|--------|-----------|--------|-----------|--------|-----------|--------|-----------|--------|
|           | Day 0 Dry |        | Day 21    |        | Day 42    |        | Day 70    |        | Day 93    |        |
|           | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  |
| <b>1</b>  | 26.2518   | 0.0369 | 25.9116   | 0.1007 | 26.2311   | 0.1171 | 25.9667   | 0.1559 | 25.7803   | 0.1174 |
| <b>3</b>  | 26.3644   | 0.2063 | 26.1869   | 0.1477 | 26.4641   | 0.1149 | 26.4644   | 0.1878 | 26.2864   | 0.1145 |
| <b>5</b>  | 24.6513   | 0.1165 | 24.7360   | 0.0783 | 24.8849   | 0.1235 | 24.9491   | 0.1702 | 24.8316   | 0.0840 |
| <b>7</b>  | 26.9122   | 0.1386 | 26.5086   | 0.1025 | 26.9234   | 0.1241 | 26.8785   | 0.1613 | 27.1042   | 0.1100 |
| <b>9</b>  | 27.0705   | 0.1834 | 26.9576   | 0.2118 | 27.0591   | 0.1722 | 27.5142   | 0.1003 | 27.1721   | 0.0644 |
| <b>11</b> | 26.1170   | 0.1559 | 25.5627   | 0.1465 | 25.8352   | 0.1665 | 25.7041   | 0.1493 | 25.6385   | 0.0734 |
| <b>13</b> | 26.6317   | 0.1907 | 26.3307   | 0.0935 | 26.4418   | 0.1075 | 26.8672   | 0.1521 | 26.3419   | 0.1288 |
| <b>15</b> | 26.6316   | 0.1585 | 26.2424   | 0.2008 | 26.1868   | 0.1171 | 26.6475   | 0.0987 | 26.1095   | 0.1065 |
| <b>17</b> | 26.0558   | 0.1600 | 25.4760   | 0.1599 | 25.4216   | 0.0891 | 26.1649   | 0.1514 | 25.5518   | 0.1559 |
| <b>19</b> | 25.7590   | 0.2258 | 26.2311   | 0.1282 | 26.0214   | 0.1011 | 26.1649   | 0.1514 | 26.1537   | 0.1164 |
| <b>21</b> | 25.6834   | 0.3295 | 25.4541   | 0.1163 | 25.6716   | 0.1935 | 25.6605   | 0.1562 | 25.5734   | 0.1030 |
| <b>23</b> | 25.1849   | 0.2054 | 24.8743   | 0.1402 | 25.2167   | 0.0907 | 25.0557   | 0.0938 | 25.1522   | 0.0679 |

**ABC3 R-5**

|           | 6-Sep-06  |        | 12-Oct-06 |        | 31-Oct-06 |        | 30-Nov-06 |        | 21-Dec-06 |        |
|-----------|-----------|--------|-----------|--------|-----------|--------|-----------|--------|-----------|--------|
|           | Day 0 Dry |        | Day 23    |        | Day 42    |        | Day 72    |        | Day 93    |        |
|           | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  |
| <b>1</b>  | 24.4401   | 0.0776 | 24.5350   | 0.0996 | 25.0545   | 0.0643 | 24.8530   | 0.1123 | 24.5140   | 0.1475 |
| <b>3</b>  | 23.3018   | 0.1950 | 23.7321   | 0.1617 | 23.7526   | 0.1311 | 24.0011   | 0.1143 | 23.7352   | 0.0729 |
| <b>5</b>  | 23.2309   | 0.2679 | 23.2304   | 0.1675 | 22.8360   | 0.1186 | 22.8563   | 0.1780 | 22.8460   | 0.0971 |
| <b>7</b>  | 23.4856   | 0.2014 | 23.3322   | 0.1750 | 23.4852   | 0.0897 | 23.5057   | 0.1019 | 23.2403   | 0.0864 |
| <b>9</b>  | 22.9369   | 0.1858 | 22.8560   | 0.0954 | 23.0376   | 0.1191 | 23.2098   | 0.0934 | 23.0679   | 0.0929 |
| <b>11</b> | 22.3082   | 0.2725 | 22.4463   | 0.1340 | 22.4362   | 0.0844 | 22.4164   | 0.0941 | 22.2580   | 0.1237 |
| <b>13</b> | 23.3527   | 0.1996 | 22.6556   | 0.1253 | 22.8158   | 0.0953 | 23.1492   | 0.1734 | 22.7658   | 0.1403 |
| <b>15</b> | 21.7673   | 0.0924 | 21.7967   | 0.1378 | 22.2579   | 0.1047 | 22.2579   | 0.0937 | 21.8846   | 0.1562 |
| <b>17</b> | 22.3177   | 0.2044 | 22.0216   | 0.1228 | 22.0020   | 0.1174 | 21.9530   | 0.1322 | 21.8356   | 0.1049 |
| <b>19</b> | 24.5358   | 0.2682 | 24.3248   | 0.1561 | 24.5456   | 0.1161 | 24.5666   | 0.0510 | 24.1467   | 0.0704 |
| <b>21</b> | 23.4357   | 0.3724 | 23.0680   | 0.1243 | 23.2505   | 0.0857 | 23.2302   | 0.1093 | 22.7757   | 0.1104 |
| <b>23</b> | 22.8765   | 0.1870 | 23.1591   | 0.1177 | 23.1898   | 0.1854 | 23.4139   | 0.1727 | 23.4956   | 0.1527 |

**ABC3 R-6**

|           | 6-Sep-06  |        | 20-Sep-06 |        | 12-Oct-06 |        | 2-Nov-06 |        | 28-Nov-06 |        | 21-Dec-06 |        |
|-----------|-----------|--------|-----------|--------|-----------|--------|----------|--------|-----------|--------|-----------|--------|
|           | Day 0 Dry |        | Day 0 Wet |        | Day 23    |        | Day 44   |        | Day 70    |        | Day 93    |        |
|           | Avg       | Stdev  | Avg       | Stdev  | Avg       | Stdev  | Avg      | Stdev  | Avg       | Stdev  | Avg       | Stdev  |
| <b>1</b>  | 23.1491   | 0.1596 | 22.9379   | 0.3353 | 22.9669   | 0.1239 | 23.1896  | 0.1354 | 23.0680   | 0.1418 | 23.0319   | 0.0735 |
| <b>3</b>  | 22.8158   | 0.0953 | 22.8366   | 0.2385 | 22.6300   | 0.0881 | 22.6155  | 0.0948 | 22.7658   | 0.1402 | 22.7357   | 0.1355 |
| <b>5</b>  | 23.1692   | 0.0933 | 23.2693   | 0.2540 | 22.9568   | 0.0957 | 23.0377  | 0.1452 | 22.9266   | 0.1181 | 23.0476   | 0.0522 |
| <b>7</b>  | 23.4136   | 0.0940 | 23.3734   | 0.2444 | 23.2810   | 0.0891 | 23.3115  | 0.0803 | 23.3625   | 0.0689 | 23.4647   | 0.0843 |
| <b>9</b>  | 23.3728   | 0.1255 | 23.6809   | 0.2422 | 23.3932   | 0.1077 | 23.3116  | 0.0937 | 23.3014   | 0.1219 | 23.4647   | 0.1086 |
| <b>11</b> | 23.1693   | 0.1336 | 23.6290   | 0.1287 | 23.3116   | 0.1253 | 23.3523  | 0.0860 | 23.1794   | 0.0889 | 23.4752   | 0.1657 |
| <b>13</b> | 22.8563   | 0.1778 | 22.8762   | 0.1205 | 22.8661   | 0.0925 | 23.0073  | 0.1330 | 22.8862   | 0.0671 | 22.8761   | 0.0743 |
| <b>15</b> | 23.1498   | 0.2836 | 23.0079   | 0.2470 | 22.9669   | 0.1238 | 23.0577  | 0.0488 | 23.0074   | 0.1415 | 22.8762   | 0.1107 |
| <b>17</b> | 23.9390   | 0.1837 | 23.6513   | 0.3894 | 23.5365   | 0.1103 | 23.2406  | 0.1744 | 23.2001   | 0.2061 | 23.1388   | 0.0862 |
| <b>19</b> | 22.6466   | 0.2992 | 22.7460   | 0.2022 | 22.7665   | 0.2678 | 22.9770  | 0.1111 | 22.8159   | 0.1165 | 22.8360   | 0.1186 |
| <b>21</b> | 23.2205   | 0.2148 | 23.2200   | 0.1179 | 23.3422   | 0.1101 | 23.3319  | 0.0860 | 23.0274   | 0.0977 | 23.2403   | 0.0720 |
| <b>23</b> | 23.1390   | 0.1605 | 23.4856   | 0.1954 | 23.3115   | 0.0804 | 23.4442  | 0.0869 | 23.2505   | 0.0983 | 23.1896   | 0.1069 |

### ALPHA R-2

|           | 6-Sep-06  |        | 10-Oct-06 |        | 31-Oct-06 |        | 28-Nov-06 |        | 21-Dec-06 |        |
|-----------|-----------|--------|-----------|--------|-----------|--------|-----------|--------|-----------|--------|
|           | Day 0 Dry |        | Day 21    |        | Day 42    |        | Day 70    |        | Day 93    |        |
|           | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  |
| <b>1</b>  | 27.9538   | 0.3845 | 27.6061   | 0.1375 | 27.8135   | 0.1809 | 27.9059   | 0.1471 | 27.3656   | 0.1048 |
| <b>3</b>  | 27.3657   | 0.1296 | 27.2289   | 0.0959 | 27.3656   | 0.1178 | 27.1954   | 0.2336 | 27.2062   | 0.0958 |
| <b>5</b>  | 26.7551   | 0.2255 | 26.6538   | 0.1209 | 26.6426   | 0.1082 | 26.6094   | 0.1931 | 26.8970   | 0.0795 |
| <b>7</b>  | 26.5422   | 0.1511 | 26.2756   | 0.1844 | 26.3086   | 0.1071 | 26.1318   | 0.1629 | 25.9557   | 0.1702 |
| <b>9</b>  | 25.9777   | 0.1732 | 25.9447   | 0.1502 | 26.0434   | 0.0899 | 25.8568   | 0.0900 | 26.0436   | 0.1642 |
| <b>11</b> | 25.3677   | 0.1422 | 25.4432   | 0.0766 | 25.3245   | 0.1267 | 25.2274   | 0.0762 | 25.8460   | 0.1345 |
| <b>13</b> | 26.3206   | 0.2971 | 26.4084   | 0.0750 | 26.5198   | 0.1181 | 26.2864   | 0.1145 | 26.3974   | 0.1148 |
| <b>15</b> | 24.8642   | 0.2386 | 24.6408   | 0.1411 | 24.5455   | 0.0924 | 24.6407   | 0.1223 | 24.6830   | 0.0894 |
| <b>17</b> | 24.5778   | 0.2398 | 24.5034   | 0.1119 | 24.3981   | 0.0864 | 24.3772   | 0.1423 | 24.0923   | 0.0695 |
| <b>19</b> | 28.3968   | 0.3790 | 27.8368   | 0.2146 | 27.7902   | 0.0981 | 27.9289   | 0.0954 | 27.8826   | 0.0781 |
| <b>21</b> | 27.0481   | 0.2323 | 26.5089   | 0.1807 | 26.6985   | 0.0827 | 26.9684   | 0.0761 | 26.7323   | 0.1476 |
| <b>23</b> | 27.1957   | 0.2875 | 26.9462   | 0.1878 | 26.7322   | 0.1031 | 26.6650   | 0.1316 | 26.7883   | 0.1065 |

### ALPHA R-3

|           | 6-Sep-06  |        | 20-Sep-06 |        | 11-Oct-06 |        | 2-Nov-06 |        | 28-Nov-06 |        | 21-Dec-06 |        |
|-----------|-----------|--------|-----------|--------|-----------|--------|----------|--------|-----------|--------|-----------|--------|
|           | Day 0 Dry |        | Day 0 Wet |        | Day 22    |        | Day 44   |        | Day 70    |        | Day 93    |        |
|           | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  | Avg      | StDev  | Avg       | StDev  | Avg       | StDev  |
| <b>1</b>  | 27.3125   | 0.1277 | 27.1394   | 0.3419 | 27.4457   | 0.1453 | 27.5143  | 0.1473 | 27.3888   | 0.2086 | 27.0025   | 0.1616 |
| <b>3</b>  | 26.4755   | 0.1997 | 26.1101   | 0.2334 | 26.4419   | 0.1407 | 26.7105  | 0.2587 | 26.3530   | 0.1463 | 26.4754   | 0.1614 |
| <b>5</b>  | 25.9673   | 0.2749 | 25.6500   | 0.2359 | 26.0434   | 0.0899 | 25.7476  | 0.1036 | 25.7804   | 0.1476 | 25.9228   | 0.1673 |
| <b>7</b>  | 26.2890   | 0.4739 | 25.7268   | 0.3021 | 25.9008   | 0.1371 | 26.4643  | 0.1723 | 26.0218   | 0.2059 | 26.2088   | 0.0781 |
| <b>9</b>  | 26.8231   | 0.3181 | 25.6500   | 0.2366 | 26.9011   | 0.1766 | 26.5868  | 0.1335 | 26.8223   | 0.1759 | 26.4974   | 0.0822 |
| <b>11</b> | 25.6070   | 0.3000 | 25.0771   | 0.0790 | 25.7147   | 0.0000 | 25.5300  | 0.1029 | 25.6386   | 0.1153 | 25.2490   | 0.0727 |
| <b>13</b> | 25.7370   | 0.2049 | 25.0242   | 0.2268 | 25.5408   | 0.1049 | 25.4866  | 0.0949 | 25.8353   | 0.1891 | 25.5953   | 0.1733 |
| <b>15</b> | 25.0352   | 0.2769 | 24.7893   | 0.1598 | 24.9063   | 0.1355 | 25.0560  | 0.1784 | 25.0451   | 0.1317 | 25.0238   | 0.1442 |
| <b>17</b> | 25.0029   | 0.2481 | 24.2835   | 0.2670 | 24.6618   | 0.0972 | 24.6724  | 0.1123 | 24.5986   | 0.1665 | 24.1468   | 0.1106 |
| <b>19</b> | 27.2635   | 0.2179 | 26.4975   | 0.1109 | 27.0928   | 0.1094 | 27.0815  | 0.1199 | 26.8561   | 0.2059 | 27.0251   | 0.1488 |
| <b>21</b> | 26.8446   | 0.1382 | 26.8346   | 0.3515 | 26.7322   | 0.1159 | 26.6986  | 0.1232 | 26.8223   | 0.1838 | 26.5198   | 0.1058 |
| <b>23</b> | 26.1320   | 0.2070 | 25.5633   | 0.2667 | 25.8240   | 0.0893 | 25.9889  | 0.2092 | 25.8788   | 0.1291 | 25.6168   | 0.1082 |

### ALPHA R-5

|           | 6-Sep-06  |        | 20-Sep-06 |        | 12-Oct-06 |        | 3-Nov-06 |        | 28-Nov-06 |        | 21-Dec-06 |        |
|-----------|-----------|--------|-----------|--------|-----------|--------|----------|--------|-----------|--------|-----------|--------|
|           | Day 0 Dry |        | Day 0 Wet |        | Day 23    |        | Day 45   |        | Day 70    |        | Day 93    |        |
|           | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  | Avg      | StDev  | Avg       | StDev  | Avg       | StDev  |
| <b>1</b>  | 26.1765   | 0.2744 | 26.0220   | 0.2311 | 25.9006   | 0.0901 | 26.2421  | 0.1016 | 26.4419   | 0.1503 | 25.9228   | 0.1590 |
| <b>3</b>  | 24.8960   | 0.2087 | 24.8321   | 0.2230 | 25.3893   | 0.1248 | 25.6168  | 0.0952 | 25.4544   | 0.1924 | 25.5082   | 0.0800 |
| <b>5</b>  | 24.0019   | 0.2747 | 23.8252   | 0.2058 | 24.1991   | 0.1187 | 23.9387  | 0.1099 | 23.6086   | 0.1712 | 24.0218   | 0.1145 |
| <b>7</b>  | 25.4436   | 0.1854 | 25.2497   | 0.2590 | 25.6496   | 0.1555 | 25.7149  | 0.1258 | 25.1738   | 0.1134 | 25.2814   | 0.1245 |
| <b>9</b>  | 24.3162   | 0.4113 | 24.7683   | 0.2112 | 24.5248   | 0.1887 | 25.0024  | 0.1442 | 24.7679   | 0.1205 | 24.8636   | 0.1060 |
| <b>11</b> | 23.7123   | 0.0619 | 23.5778   | 0.1731 | 24.6620   | 0.1396 | 23.9699  | 0.1116 | 23.8041   | 0.0974 | 24.2094   | 0.0771 |
| <b>13</b> | 24.7681   | 0.1797 | 24.4718   | 0.1334 | 25.0452   | 0.1497 | 25.0069  | 0.0563 | 24.7787   | 0.1742 | 24.7359   | 0.0602 |
| <b>15</b> | 23.2203   | 0.1733 | 22.4761   | 0.1191 | 22.9066   | 0.1633 | 22.9870  | 0.0953 | 23.3730   | 0.1655 | 22.5656   | 0.0916 |
| <b>17</b> | 23.2006   | 0.2855 | 22.9676   | 0.2636 | 23.1897   | 0.1585 | 23.1997  | 0.1011 | 23.2608   | 0.1274 | 23.0983   | 0.1006 |
| <b>19</b> | 25.9016   | 0.2882 | 25.9213   | 0.0857 | 26.3640   | 0.1103 | 26.2642  | 0.0738 | 26.1869   | 0.1479 | 26.3307   | 0.1072 |
| <b>21</b> | 25.2601   | 0.1888 | 25.0346   | 0.1754 | 25.2167   | 0.1039 | 25.6168  | 0.0952 | 25.4001   | 0.1294 | 25.1094   | 0.1355 |
| <b>23</b> | 24.1580   | 0.2568 | 23.7114   | 0.1571 | 23.7423   | 0.1393 | 23.9803  | 0.1100 | 24.2933   | 0.1312 | 23.8765   | 0.0982 |

### ALPHA S-3

|           | 5-Sep-06  |        | 6-Oct-06 |        | 31-Oct-06 |        | 30-Nov-06 |        | 20-Dec-06 |        |
|-----------|-----------|--------|----------|--------|-----------|--------|-----------|--------|-----------|--------|
|           | Day 0 Dry |        | Day 17   |        | Day 42    |        | Day 72    |        | Day 92    |        |
|           | Avg       | StDev  | Avg      | StDev  | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  |
| <b>1</b>  | 26.3095   | 0.2964 | 25.9237  | 0.3092 | 25.8024   | 0.1613 | 26.0107   | 0.1802 | 25.7804   | 0.1380 |
| <b>3</b>  | 25.6936   | 0.2445 | 25.8483  | 0.0911 | 26.1209   | 0.2019 | 26.6206   | 0.1963 | 26.2864   | 0.1256 |
| <b>5</b>  | 25.3784   | 0.1073 | 25.0452  | 0.1497 | 25.3353   | 0.1371 | 25.5633   | 0.2671 | 25.4216   | 0.0890 |
| <b>7</b>  | 25.8684   | 0.2437 | 25.3140  | 0.1906 | 25.9945   | 0.0797 | 25.4651   | 0.1451 | 25.3029   | 0.1114 |
| <b>9</b>  | 25.4327   | 0.1703 | 25.5304  | 0.2174 | 25.7373   | 0.2561 | 25.9007   | 0.1268 | 25.7258   | 0.1305 |
| <b>11</b> | 25.2598   | 0.0989 | 25.3140  | 0.2038 | 25.9007   | 0.1039 | 25.4868   | 0.1570 | 25.5191   | 0.0855 |
| <b>13</b> | 25.5952   | 0.1490 | 25.0880  | 0.1320 | 25.5743   | 0.2947 | 25.0774   | 0.1635 | 24.8530   | 0.1123 |
| <b>15</b> | 24.7573   | 0.1168 | 24.7041  | 0.0740 | 25.0344   | 0.1238 | 25.2061   | 0.1527 | 25.1845   | 0.1181 |
| <b>17</b> | 26.8491   | 0.6205 | 24.8112  | 0.2701 | 24.7891   | 0.0743 | 25.1200   | 0.0912 | 25.0664   | 0.0714 |
| <b>19</b> | 26.1047   | 0.1244 | 26.4307  | 0.0945 | 26.6091   | 0.1230 | 26.6765   | 0.1910 | 26.5643   | 0.0919 |
| <b>21</b> | 26.3531   | 0.1638 | 26.4976  | 0.1527 | 26.7548   | 0.1690 | 26.9235   | 0.1545 | 26.6314   | 0.1186 |
| <b>23</b> | 25.5843   | 0.1234 | 25.9557  | 0.1620 | 26.2200   | 0.1069 | 26.0436   | 0.1466 | 25.8569   | 0.1161 |

### ALPHA S-4

|           | 5-Sep-06  |        | 20-Sep-06 |        | 6-Oct-06 |        | 2-Nov-06 |        | 28-Nov-06 |        | 20-Dec-06 |        |
|-----------|-----------|--------|-----------|--------|----------|--------|----------|--------|-----------|--------|-----------|--------|
|           | Day 0 Dry |        | Day 0 Wet |        | Day 17   |        | Day 44   |        | Day 70    |        | Day 92    |        |
|           | Avg       | StDev  | Avg       | StDev  | Avg      | StDev  | Avg      | StDev  | Avg       | StDev  | Avg       | StDev  |
| <b>1</b>  | 24.9812   | 0.1807 | 24.9493   | 0.2166 | 25.1311  | 0.1762 | 24.8530  | 0.1231 | 25.1200   | 0.0759 | 25.1310   | 0.1617 |
| <b>3</b>  | 25.7487   | 0.3141 | 26.0441   | 0.2436 | 26.0215  | 0.1138 | 25.9338  | 0.1715 | 25.6664   | 0.0960 | 26.1537   | 0.1165 |
| <b>5</b>  | 24.9240   | 0.1194 | 25.9131   | 0.3544 | 25.5952  | 0.1489 | 25.0879  | 0.0984 | 24.9169   | 0.1146 | 25.8901   | 0.2013 |
| <b>7</b>  | 24.5888   | 0.2962 | 24.4194   | 0.1748 | 24.5352  | 0.1652 | 24.9917  | 0.1430 | 24.8105   | 0.1343 | 24.5349   | 0.0497 |
| <b>9</b>  | 25.0558   | 0.1180 | 25.4220   | 0.2045 | 25.5627  | 0.1551 | 25.6168  | 0.1082 | 25.1953   | 0.1321 | 25.6389   | 0.1924 |
| <b>11</b> | 25.2383   | 0.1040 | 25.9009   | 0.1795 | 25.4869  | 0.1801 | 25.8349  | 0.0807 | 25.5522   | 0.2308 | 25.5191   | 0.0997 |
| <b>13</b> | 24.2203   | 0.1969 | 24.1577   | 0.2105 | 24.3456  | 0.0965 | 24.5455  | 0.0599 | 24.6197   | 0.1559 | 24.2305   | 0.1346 |
| <b>15</b> | 24.0462   | 0.1566 | 24.4938   | 0.2899 | 24.7999  | 0.1601 | 24.8636  | 0.1058 | 24.3878   | 0.1659 | 24.4179   | 0.0632 |
| <b>17</b> | 24.9810   | 0.1408 | 25.2171   | 0.1980 | 24.8959  | 0.1961 | 24.9490  | 0.1372 | 24.9386   | 0.2068 | 24.8636   | 0.1171 |
| <b>19</b> | 25.8790   | 0.1810 | 25.7804   | 0.1282 | 25.7370  | 0.1912 | 25.9994  | 0.1062 | 26.1208   | 0.1647 | 25.7585   | 0.1055 |
| <b>21</b> | 25.6664   | 0.0960 | 26.6774   | 0.3376 | 25.9667  | 0.1559 | 25.9116  | 0.1007 | 25.8132   | 0.1309 | 26.0214   | 0.1010 |
| <b>23</b> | 26.0105   | 0.1377 | 26.1545   | 0.2850 | 26.1758  | 0.1141 | 26.2200  | 0.1069 | 26.0106   | 0.1471 | 26.3529   | 0.0876 |

### ALPHA S-5

|           | 5-Sep-06  |        | 12-Oct-06 |        | 31-Oct-06 |        | 30-Nov-06 |        | 21-Dec-06 |        |
|-----------|-----------|--------|-----------|--------|-----------|--------|-----------|--------|-----------|--------|
|           | Day 0 Dry |        | Day 23    |        | Day 42    |        | Day 72    |        | Day 93    |        |
|           | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  |
| <b>1</b>  | 26.5980   | 0.1491 | 26.5644   | 0.1296 | 27.0933   | 0.2218 | 26.4867   | 0.2039 | 27.0024   | 0.1215 |
| <b>3</b>  | 25.5527   | 0.3033 | 25.5517   | 0.1172 | 25.5627   | 0.1465 | 25.2921   | 0.0795 | 25.1523   | 0.1110 |
| <b>5</b>  | 25.1953   | 0.1415 | 25.1203   | 0.1774 | 25.0450   | 0.0677 | 25.0560   | 0.1776 | 24.7255   | 0.1397 |
| <b>7</b>  | 26.2974   | 0.0748 | 26.4199   | 0.1977 | 26.2863   | 0.0874 | 26.0545   | 0.1317 | 26.4368   | 0.0586 |
| <b>9</b>  | 25.8933   | 0.5458 | 25.5520   | 0.1997 | 26.0434   | 0.1039 | 25.6821   | 0.0898 | 25.7694   | 0.1062 |
| <b>11</b> | 25.1204   | 0.1911 | 25.4650   | 0.1146 | 25.0348   | 0.2200 | 25.2814   | 0.1137 | 25.3245   | 0.1042 |
| <b>13</b> | 25.9452   | 0.2515 | 26.0546   | 0.1417 | 26.1979   | 0.1187 | 26.0655   | 0.1249 | 25.6170   | 0.1490 |
| <b>15</b> | 25.0452   | 0.1500 | 25.2382   | 0.0907 | 24.9810   | 0.1314 | 25.3570   | 0.1531 | 24.8210   | 0.1009 |
| <b>17</b> | 25.4616   | 0.1878 | 25.4013   | 0.1373 | 24.7043   | 0.1431 | 25.3028   | 0.0851 | 25.0130   | 0.1157 |
| <b>19</b> | 27.3658   | 0.1599 | 26.7548   | 0.1515 | 27.7212   | 0.1753 | 27.1269   | 0.1316 | 26.7209   | 0.0827 |
| <b>21</b> | 25.9233   | 0.2606 | 26.1538   | 0.1559 | 26.0987   | 0.1580 | 25.9994   | 0.0926 | 25.8240   | 0.0893 |
| <b>23</b> | 26.0876   | 0.1488 | 26.4085   | 0.1289 | 25.2276   | 0.1270 | 25.2706   | 0.1070 | 25.2490   | 0.1141 |

### ECOL R-3

|           | 6-Sep-06  |        | 20-Sep-06 |        | 6-Oct-06 |        | 2-Nov-06 |        | 28-Nov-06 |        | 20-Dec-06 |        |
|-----------|-----------|--------|-----------|--------|----------|--------|----------|--------|-----------|--------|-----------|--------|
|           | Day 0 Dry |        | Day 0 Wet |        | Day 17   |        | Day 44   |        | Day 70    |        | Day 92    |        |
|           | Avg       | StDev  | Avg       | StDev  | Avg      | StDev  | Avg      | StDev  | Avg       | StDev  | Avg       | StDev  |
| <b>1</b>  | 29.3099   | 0.2207 | 29.4419   | 0.1171 | 29.3578  | 0.1780 | 30.0497  | 0.1041 | 29.9763   | 0.1071 | 29.7204   | 0.1254 |
| <b>3</b>  | 29.2347   | 0.1000 | 29.4781   | 0.1246 | 29.0698  | 0.1007 | 29.5870  | 0.1403 | 29.6112   | 0.1334 | 29.5025   | 0.1801 |
| <b>5</b>  | 28.6424   | 0.1084 | 28.7846   | 0.1764 | 28.9034  | 0.2094 | 28.6661  | 0.1363 | 28.9510   | 0.2111 | 29.2975   | 0.1140 |
| <b>7</b>  | 30.0130   | 0.1265 | 29.3818   | 0.1607 | 29.6838  | 0.0857 | 30.0009  | 0.1465 | 29.8299   | 0.1526 | 29.7324   | 0.0690 |
| <b>9</b>  | 29.4661   | 0.1279 | 29.2254   | 0.0988 | 29.3336  | 0.1413 | 29.6596  | 0.1151 | 29.5628   | 0.1536 | 29.5873   | 0.2063 |
| <b>11</b> | 28.9627   | 0.1707 | 28.6072   | 0.1865 | 28.5244  | 0.0744 | 28.3952  | 0.1113 | 28.4422   | 0.1291 | 28.5741   | 0.0785 |
| <b>13</b> | 28.2550   | 0.1848 | 28.3841   | 0.2551 | 28.3952  | 0.0965 | 28.3132  | 0.1235 | 28.8561   | 0.2521 | 28.3600   | 0.0819 |
| <b>15</b> | 28.4043   | 0.0783 | 27.9293   | 0.1969 | 28.0798  | 0.0950 | 28.4304  | 0.1108 | 28.3599   | 0.0606 | 28.1613   | 0.0960 |
| <b>17</b> | 28.7963   | 0.1527 | 28.5245   | 0.1218 | 28.7134  | 0.1389 | 29.0341  | 0.1314 | 29.0461   | 0.1354 | 28.9268   | 0.0752 |
| <b>19</b> | 30.6931   | 0.2835 | 30.2597   | 0.3173 | 29.3336  | 0.1412 | 30.0014  | 0.2480 | 30.2344   | 0.2172 | 29.5145   | 0.1555 |
| <b>21</b> | 29.2616   | 0.1603 | 29.4783   | 0.1781 | 29.2257  | 0.1791 | 29.5386  | 0.1514 | 29.8911   | 0.2054 | 29.2495   | 0.1320 |
| <b>23</b> | 29.4315   | 0.3871 | 29.1187   | 0.3195 | 29.4057  | 0.0950 | 30.0007  | 0.0903 | 29.9643   | 0.1711 | 29.7935   | 0.1645 |

### ECOL R-5

|           | 6-Sep-06  |        | 20-Sep-06 |        | 11-Oct-06 |        | 2-Nov-06 |        | 28-Nov-06 |        | 21-Dec-06 |        |
|-----------|-----------|--------|-----------|--------|-----------|--------|----------|--------|-----------|--------|-----------|--------|
|           | Day 0 Dry |        | Day 0 Wet |        | Day 22    |        | Day 44   |        | Day 70    |        | Day 93    |        |
|           | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  | Avg      | StDev  | Avg       | StDev  | Avg       | StDev  |
| <b>1</b>  | 27.3314   | 0.0970 | 27.2074   | 0.3228 | 27.2745   | 0.1201 | 27.3091  | 0.2222 | 27.1157   | 0.1787 | 27.5142   | 0.1003 |
| <b>3</b>  | 26.6427   | 0.1312 | 27.1723   | 0.1554 | 26.7097   | 0.0747 | 26.9234  | 0.1242 | 26.7222   | 0.0876 | 26.9798   | 0.1090 |
| <b>5</b>  | 25.9885   | 0.1067 | 26.0324   | 0.0812 | 26.0986   | 0.1301 | 26.0214  | 0.0696 | 25.8352   | 0.1669 | 25.6277   | 0.1000 |
| <b>7</b>  | 25.6282   | 0.2284 | 25.7369   | 0.1843 | 26.0984   | 0.0779 | 26.0545  | 0.1210 | 26.0324   | 0.0964 | 26.2310   | 0.0912 |
| <b>9</b>  | 25.5519   | 0.1642 | 25.8463   | 0.2110 | 25.5951   | 0.1082 | 25.7259  | 0.1495 | 25.6495   | 0.1051 | 25.7913   | 0.1266 |
| <b>11</b> | 25.2383   | 0.1039 | 25.0991   | 0.2269 | 25.2275   | 0.0914 | 25.4111  | 0.1749 | 25.2600   | 0.1590 | 25.4326   | 0.1548 |
| <b>13</b> | 26.2642   | 0.0738 | 26.0120   | 0.3648 | 26.2864   | 0.1019 | 26.3307  | 0.0776 | 26.2642   | 0.1045 | 26.1428   | 0.1600 |
| <b>15</b> | 24.8849   | 0.1011 | 24.8000   | 0.1821 | 24.8104   | 0.1027 | 24.9703  | 0.1176 | 24.8956   | 0.1251 | 24.8422   | 0.0785 |
| <b>17</b> | 25.3354   | 0.1462 | 25.3685   | 0.2880 | 25.2920   | 0.0612 | 25.4218  | 0.1534 | 25.4217   | 0.1254 | 25.4541   | 0.0912 |
| <b>19</b> | 27.2065   | 0.1872 | 27.4235   | 0.2797 | 27.7442   | 0.1482 | 27.7902  | 0.0982 | 27.5486   | 0.1232 | 27.9521   | 0.1015 |
| <b>21</b> | 26.4988   | 0.1520 | 26.3646   | 0.2478 | 26.7210   | 0.1232 | 26.7661  | 0.1697 | 26.7546   | 0.0784 | 26.7885   | 0.1676 |
| <b>23</b> | 26.2314   | 0.2089 | 25.8043   | 0.4246 | 25.6061   | 0.1538 | 25.6278  | 0.1336 | 25.5456   | 0.0787 | 25.5299   | 0.0894 |

### ECOL R-6

|           | 6-Sep-06  |        | 20-Sep-06 |        | 12-Oct-06 |        | 3-Nov-06 |        | 28-Nov-06 |        | 21-Dec-06 |        |
|-----------|-----------|--------|-----------|--------|-----------|--------|----------|--------|-----------|--------|-----------|--------|
|           | Day 0 Dry |        | Day 0 Wet |        | Day 23    |        | Day 45   |        | Day 70    |        | Day 93    |        |
|           | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  | Avg      | StDev  | Avg       | StDev  | Avg       | StDev  |
| <b>1</b>  | 25.5408   | 0.0914 | 25.3680   | 0.2025 | 25.6714   | 0.1470 | 25.5625  | 0.0915 | 25.8349   | 0.0807 | 25.7261   | 0.2024 |
| <b>3</b>  | 25.5193   | 0.1516 | 25.4230   | 0.3417 | 25.1738   | 0.1341 | 25.7040  | 0.1401 | 25.4649   | 0.0731 | 25.3569   | 0.1253 |
| <b>5</b>  | 25.0242   | 0.2260 | 24.9284   | 0.2806 | 24.8318   | 0.1488 | 25.0025  | 0.1759 | 24.5771   | 0.0545 | 24.6302   | 0.1451 |
| <b>7</b>  | 25.2060   | 0.1247 | 25.2928   | 0.2662 | 25.6387   | 0.1456 | 25.4109  | 0.1117 | 25.3676   | 0.1116 | 25.3461   | 0.1265 |
| <b>9</b>  | 26.2029   | 0.1476 | 26.0437   | 0.1871 | 26.0215   | 0.1353 | 26.3307  | 0.0935 | 26.2754   | 0.1219 | 26.2310   | 0.1049 |
| <b>11</b> | 24.9596   | 0.1420 | 25.0023   | 0.1255 | 24.8957   | 0.1440 | 25.1096  | 0.1839 | 24.6936   | 0.1143 | 24.6406   | 0.0705 |
| <b>13</b> | 25.1959   | 0.2579 | 25.3572   | 0.2162 | 25.3137   | 0.1023 | 25.2707  | 0.1643 | 25.2599   | 0.1325 | 25.5300   | 0.1149 |
| <b>15</b> | 25.0246   | 0.2919 | 24.9808   | 0.0842 | 25.3460   | 0.0911 | 24.9596  | 0.1233 | 24.9062   | 0.1036 | 25.0129   | 0.0909 |
| <b>17</b> | 24.8424   | 0.1460 | 24.5145   | 0.2428 | 26.1097   | 0.1486 | 24.6618  | 0.0974 | 24.6830   | 0.1139 | 24.8324   | 0.2598 |
| <b>19</b> | 25.6387   | 0.1260 | 26.0000   | 0.2326 | 26.2312   | 0.1478 | 26.0106  | 0.1471 | 26.1318   | 0.1708 | 26.2199   | 0.0934 |
| <b>21</b> | 26.3505   | 0.1078 | 26.4420   | 0.1591 | 25.9885   | 0.1294 | 26.4308  | 0.1310 | 26.3197   | 0.1198 | 26.1978   | 0.0772 |
| <b>23</b> | 25.1310   | 0.1534 | 24.8744   | 0.1653 | 24.5984   | 0.1136 | 24.8317  | 0.1310 | 24.8316   | 0.0978 | 24.6300   | 0.0600 |

### ECOL S-3

|           | 5-Sep-06  |        | 6-Oct-06 |        | 31-Oct-06 |        | 30-Nov-06 |        | 20-Dec-06 |        |
|-----------|-----------|--------|----------|--------|-----------|--------|-----------|--------|-----------|--------|
|           | Day 0 dry |        | Day 17   |        | Day 42    |        | Day 72    |        | Day 92    |        |
|           | Avg       | StDev  | Avg      | StDev  | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  |
| <b>1</b>  | 28.6778   | 0.1036 | 27.9203  | 0.1683 | 27.6464   | 0.1457 | 28.1380   | 0.1125 | 27.8480   | 0.1219 |
| <b>3</b>  | 28.5133   | 0.2420 | 28.1673  | 0.1810 | 28.2255   | 0.0920 | 28.3134   | 0.1505 | 28.0074   | 0.1453 |
| <b>5</b>  | 27.6061   | 0.1574 | 27.2176  | 0.1222 | 27.4313   | 0.1298 | 28.0508   | 0.1079 | 27.6176   | 0.1666 |
| <b>7</b>  | 28.1966   | 0.1908 | 27.6322  | 0.2012 | 27.8770   | 0.1541 | 28.1090   | 0.1735 | 27.7326   | 0.1147 |
| <b>9</b>  | 28.0281   | 0.0612 | 28.1237  | 0.1716 | 28.0653   | 0.1103 | 28.3573   | 0.1664 | 28.2257   | 0.1739 |
| <b>11</b> | 27.5258   | 0.1408 | 27.0051  | 0.1356 | 27.4313   | 0.1469 | 27.7328   | 0.1576 | 27.3741   | 0.0842 |
| <b>13</b> | 26.8221   | 0.1402 | 26.4306  | 0.0938 | 26.7097   | 0.0827 | 26.7939   | 0.1237 | 26.5839   | 0.1232 |
| <b>15</b> | 26.8110   | 0.1796 | 26.7239  | 0.1299 | 26.4724   | 0.1195 | 26.7940   | 0.1161 | 26.6118   | 0.1184 |
| <b>17</b> | 26.7998   | 0.1741 | 26.2642  | 0.1144 | 26.5281   | 0.1077 | 26.7519   | 0.1190 | 26.5141   | 0.0470 |
| <b>19</b> | 28.3720   | 0.1682 | 28.1090  | 0.1392 | 28.1526   | 0.1133 | 28.2693   | 0.0985 | 27.8768   | 0.1119 |
| <b>21</b> | 28.7487   | 0.0976 | 28.6809  | 0.1653 | 28.5039   | 0.1137 | 29.1565   | 0.1048 | 28.8736   | 0.1875 |
| <b>23</b> | 28.2898   | 0.1075 | 27.5889  | 0.1436 | 27.3741   | 0.1078 | 27.7757   | 0.0808 | 27.6605   | 0.0804 |

### ECOL S-5

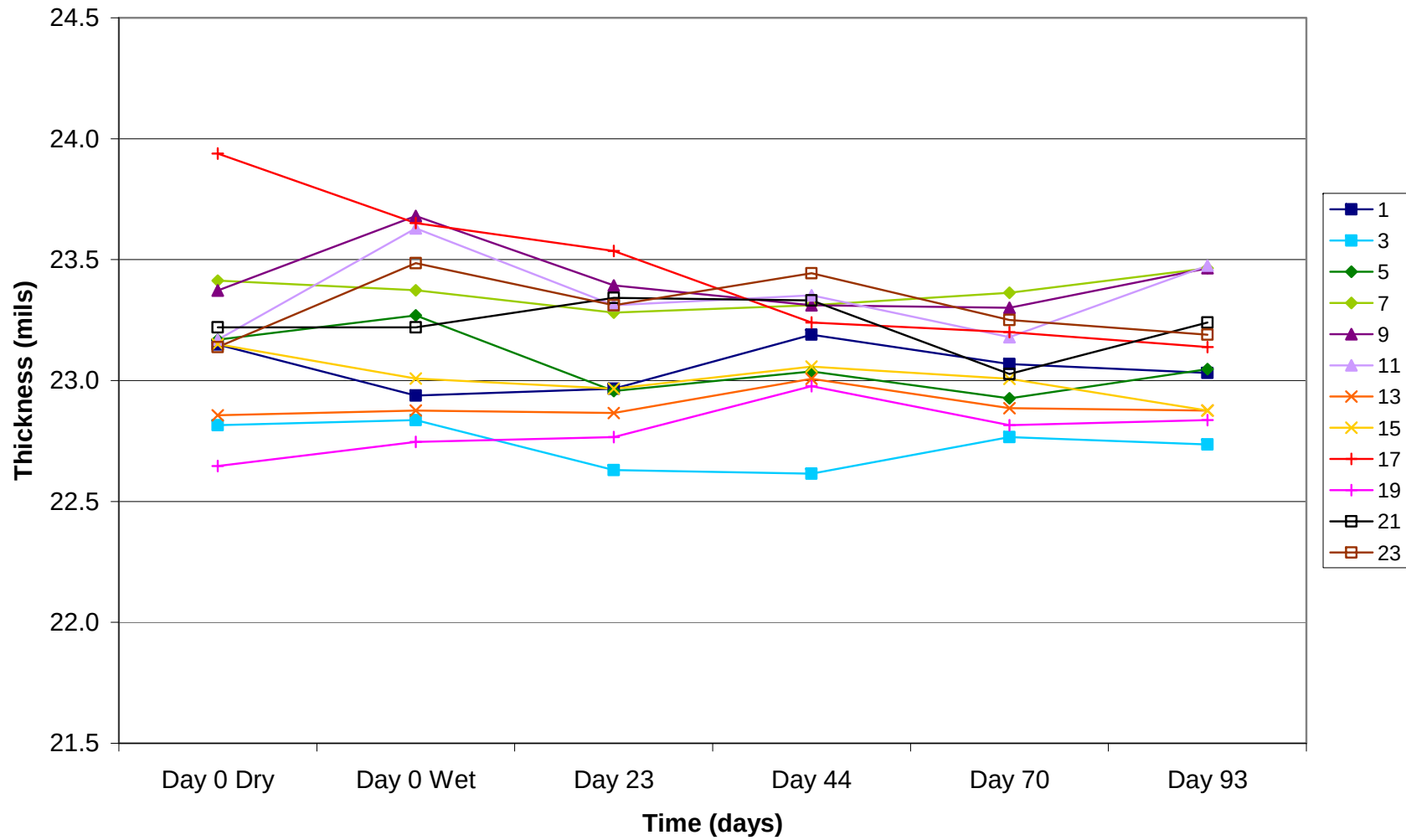
|           | 5-Sep-06 |        | 11-Sep-06       |        | 10-Oct-06 |        | 31-Oct-06 |        | 28-Nov-06 |        | 21-Dec-06 |        |
|-----------|----------|--------|-----------------|--------|-----------|--------|-----------|--------|-----------|--------|-----------|--------|
|           | Day 0    |        | Day 0 Dry (Rep) |        | Day 20    |        | Day 45    |        | Day 70    |        | Day 92    |        |
|           | Avg      | StDev  | Avg             | StDev  | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  |
| <b>1</b>  | 25.1420  | 0.2150 | 25.3785         | 0.1187 | 25.3568   | 0.1024 | 24.9383   | 0.1489 | 25.4000   | 0.0797 | 25.0665   | 0.1238 |
| <b>3</b>  | 25.0987  | 0.1433 | 24.8412         | 0.1456 | 25.4001   | 0.1189 | 24.4824   | 0.1336 | 24.5773   | 0.1338 | 24.6407   | 0.1116 |
| <b>5</b>  | 26.1979  | 0.1297 | 25.1858         | 0.1364 | 25.2922   | 0.1290 | 24.9598   | 0.1742 | 25.2599   | 0.1420 | 25.2453   | 0.0538 |
| <b>7</b>  | 24.5037  | 0.1792 | 24.0229         | 0.0813 | 24.2723   | 0.1235 | 24.3142   | 0.1042 | 24.3771   | 0.0893 | 23.9284   | 0.1272 |
| <b>9</b>  | 24.6534  | 0.4235 | 25.1310         | 0.1695 | 24.7891   | 0.1027 | 24.9919   | 0.1822 | 25.0454   | 0.1937 | 24.1154   | 0.0738 |
| <b>11</b> | 24.6199  | 0.2047 | 24.5352         | 0.1576 | 24.5561   | 0.1197 | 24.8317   | 0.1209 | 24.7467   | 0.1120 | 24.7360   | 0.0929 |
| <b>13</b> | 23.6085  | 0.1639 | 23.2811         | 0.1121 | 23.3933   | 0.1275 | 23.7216   | 0.1267 | 23.5058   | 0.1318 | 23.4749   | 0.0940 |
| <b>15</b> | 24.1786  | 0.2215 | 23.4444         | 0.1548 | 23.4545   | 0.1100 | 23.7731   | 0.0979 | 23.6804   | 0.1170 | 23.6598   | 0.1210 |
| <b>17</b> | 25.0791  | 0.4001 | 23.5782         | 0.2559 | 23.4956   | 0.1367 | 23.6704   | 0.2010 | 23.5364   | 0.0717 | 24.1572   | 0.0730 |
| <b>19</b> | 25.2384  | 0.1541 | 24.8962         | 0.2478 | 24.6514   | 0.1454 | 24.4824   | 0.1243 | 24.6512   | 0.0928 | 24.6830   | 0.1139 |
| <b>21</b> | 24.8637  | 0.1545 | 25.0459         | 0.2763 | 25.1845   | 0.0941 | 25.1203   | 0.1697 | 25.0773   | 0.1468 | 24.9061   | 0.0753 |
| <b>23</b> | 25.4764  | 0.2546 | 24.3564         | 0.1921 | 24.4404   | 0.1678 | 24.3354   | 0.1744 | 24.2934   | 0.1643 | 24.4401   | 0.0597 |

### ECOL S-6

|           | 5-Sep-06  |        | 12-Oct-06 |        | 31-Oct-06 |        | 30-Nov-06 |        | 21-Dec-06 |        |
|-----------|-----------|--------|-----------|--------|-----------|--------|-----------|--------|-----------|--------|
|           | Day 0 Dry |        | Day 23    |        | Day 42    |        | Day 72    |        | Day 93    |        |
|           | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  | Avg       | StDev  |
| <b>1</b>  | 25.7586   | 0.1563 | 25.4867   | 0.1296 | 25.5626   | 0.1371 | 26.0106   | 0.1643 | 25.6495   | 0.1279 |
| <b>3</b>  | 25.6611   | 0.2680 | 25.3894   | 0.1611 | 25.0560   | 0.1711 | 25.5848   | 0.2278 | 25.1308   | 0.1155 |
| <b>5</b>  | 24.8212   | 0.1512 | 24.9065   | 0.1761 | 25.2061   | 0.1525 | 25.3353   | 0.1273 | 24.7574   | 0.1620 |
| <b>7</b>  | 25.0454   | 0.1877 | 25.6930   | 0.1002 | 26.0105   | 0.1276 | 26.4975   | 0.1333 | 26.0433   | 0.0000 |
| <b>9</b>  | 26.4419   | 0.1502 | 25.8571   | 0.1797 | 26.0656   | 0.1540 | 26.1868   | 0.0911 | 25.8898   | 0.1288 |
| <b>11</b> | 25.4974   | 0.1082 | 25.2275   | 0.1164 | 25.5736   | 0.1623 | 25.8241   | 0.1263 | 25.4433   | 0.0920 |
| <b>13</b> | 25.7711   | 0.3842 | 25.9227   | 0.1503 | 25.0879   | 0.1216 | 25.8353   | 0.1825 | 25.5083   | 0.1195 |
| <b>15</b> | 24.6994   | 0.0559 | 24.5773   | 0.1240 | 24.1886   | 0.1213 | 24.6302   | 0.1267 | 24.4087   | 0.1293 |
| <b>17</b> | 24.4297   | 0.1214 | 24.8210   | 0.1009 | 24.2305   | 0.1433 | 24.6198   | 0.1785 | 24.6830   | 0.0894 |
| <b>19</b> | 26.2311   | 0.1385 | 25.1201   | 0.1264 | 25.3894   | 0.1529 | 25.7042   | 0.1883 | 25.3784   | 0.0946 |
| <b>21</b> | 25.2383   | 0.1264 | 25.0238   | 0.1529 | 24.9810   | 0.1495 | 25.3246   | 0.1624 | 25.1415   | 0.1137 |
| <b>23</b> | 25.8899   | 0.1567 | 26.1537   | 0.1275 | 25.9995   | 0.1290 | 26.2201   | 0.1398 | 25.9444   | 0.0623 |

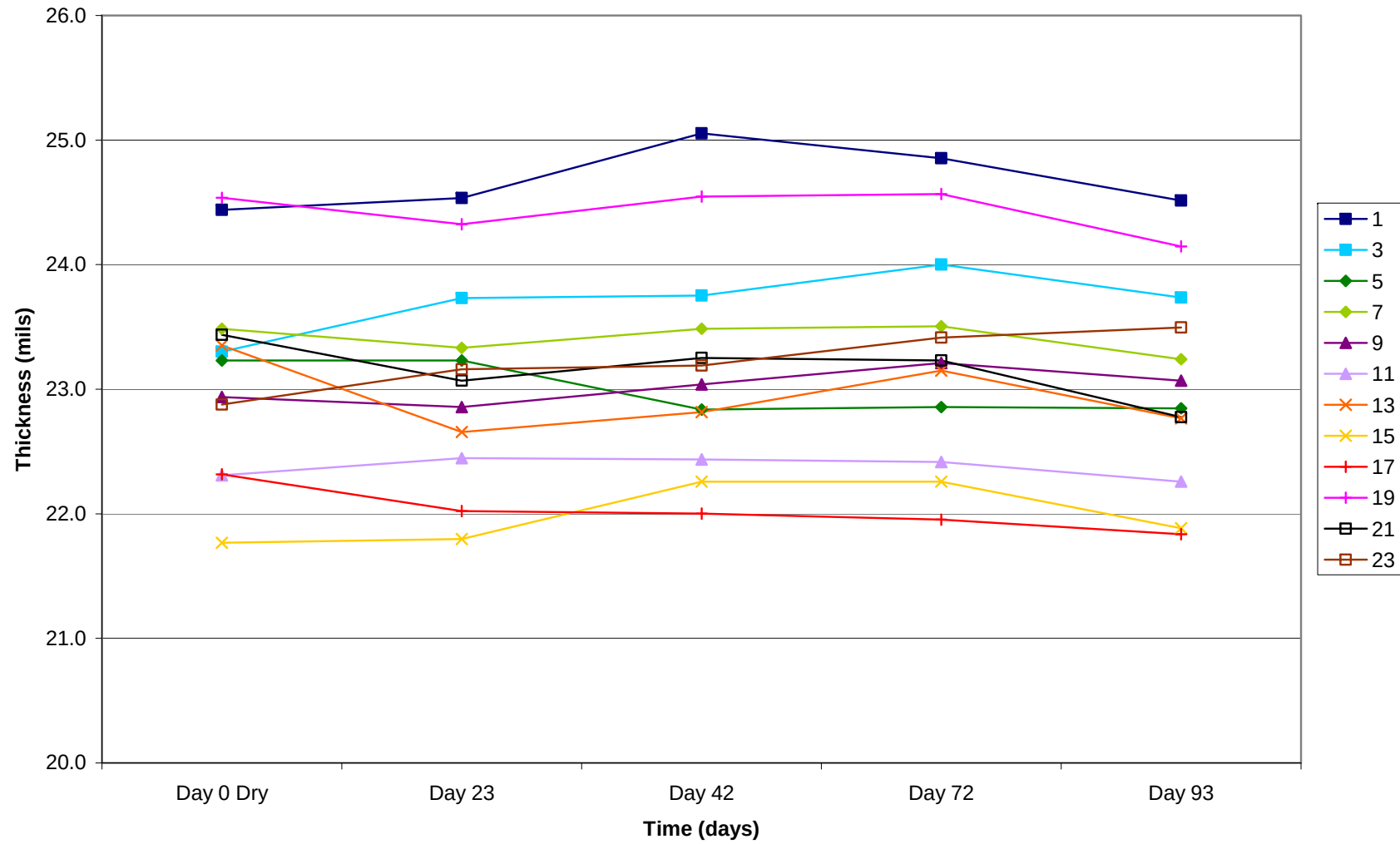
D-15

ABC3 R-6 by Spot Number

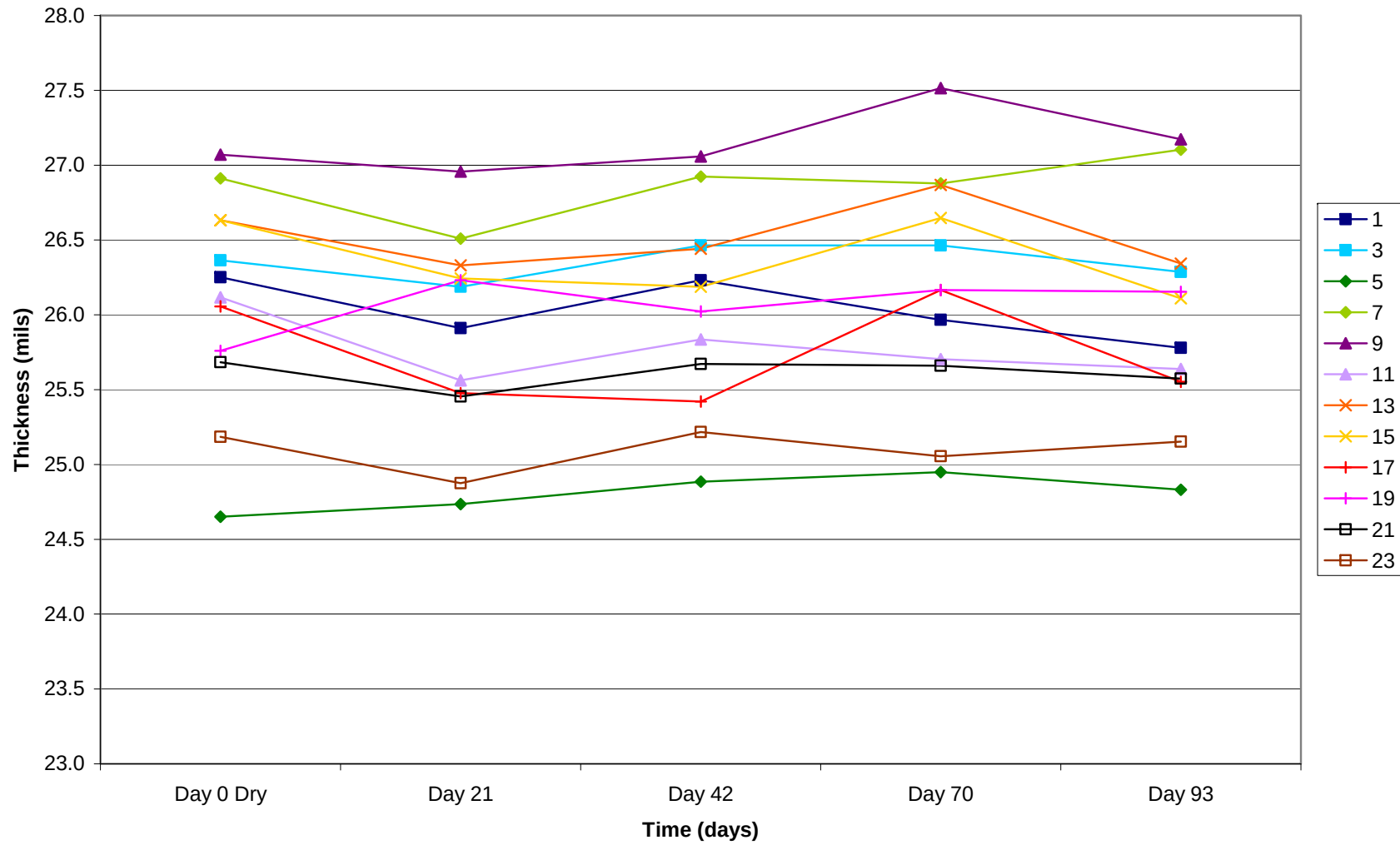


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ABC3 R-5 by Spot Number



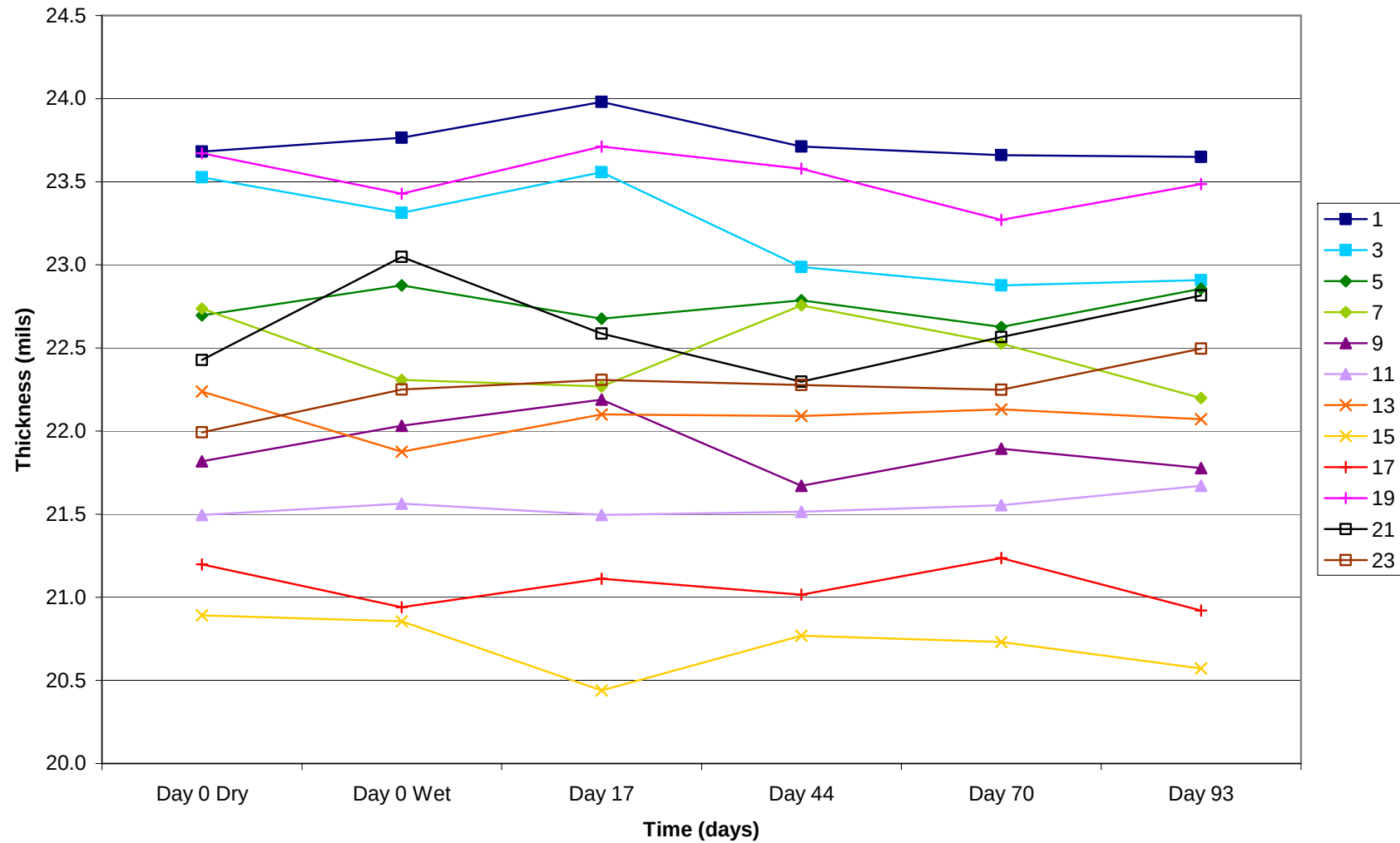
ABC3 R-3 by Spot Number



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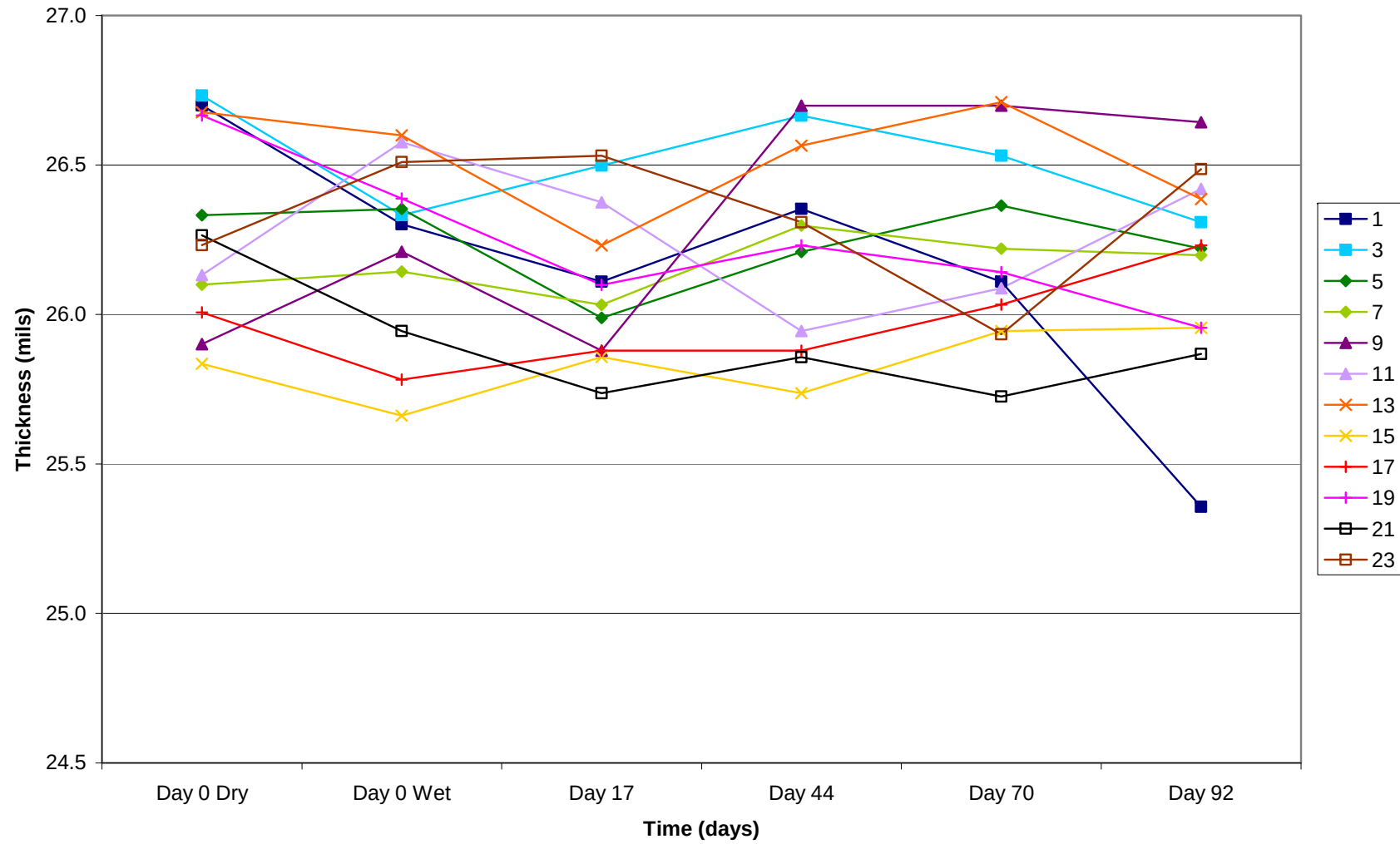
ABC3 S-5 by Spot Number



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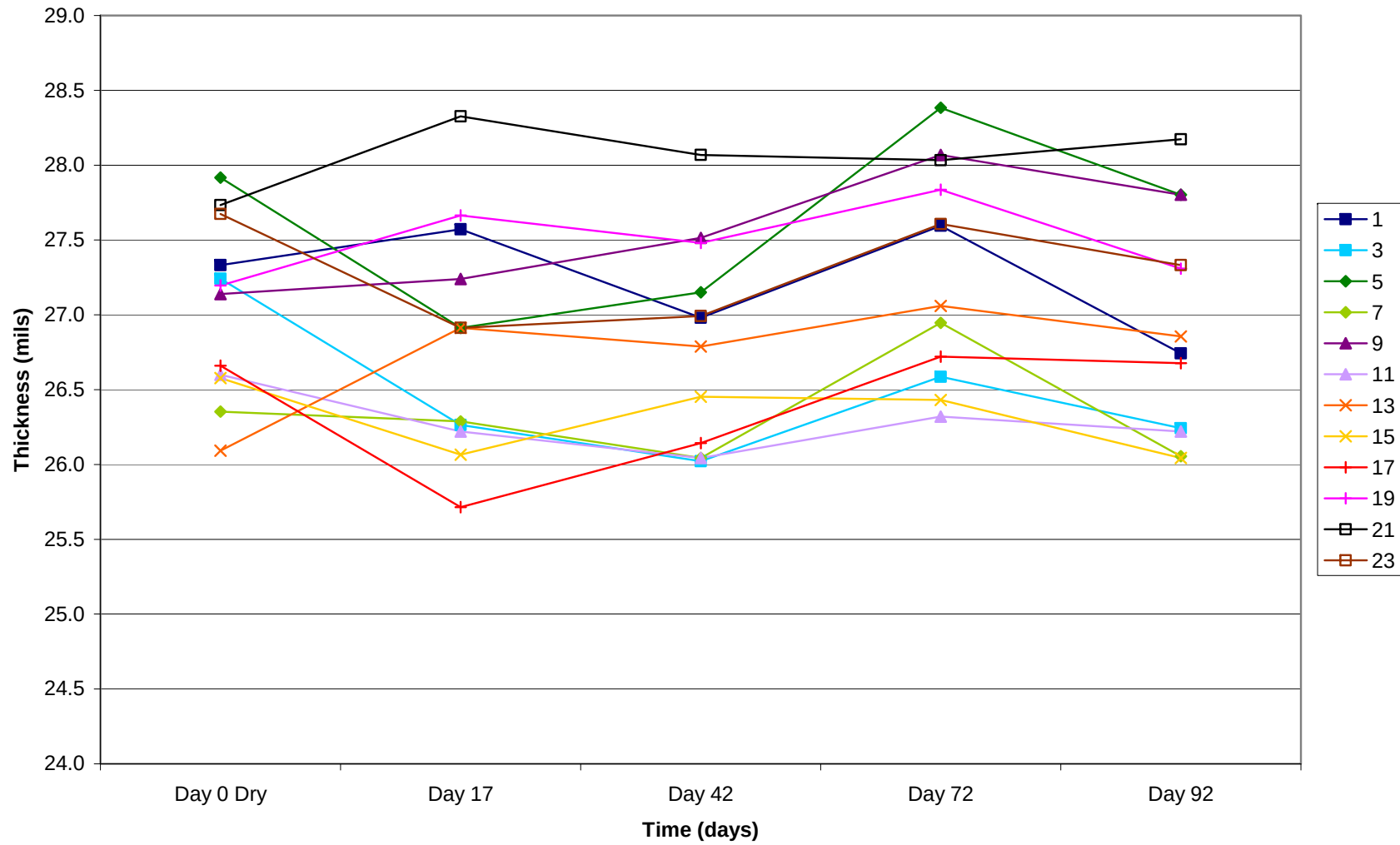
ABC3 S-3 by Spot Number



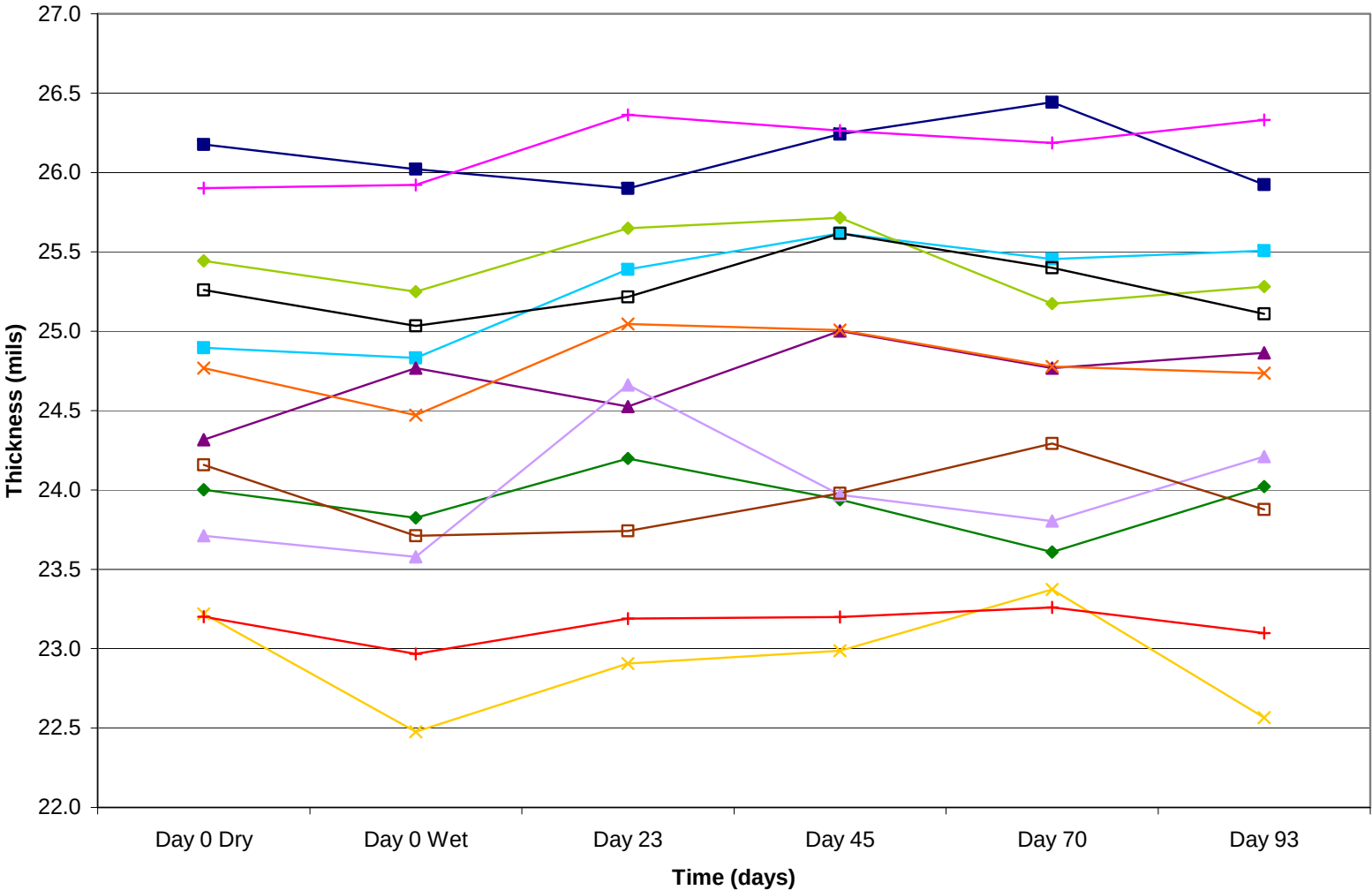
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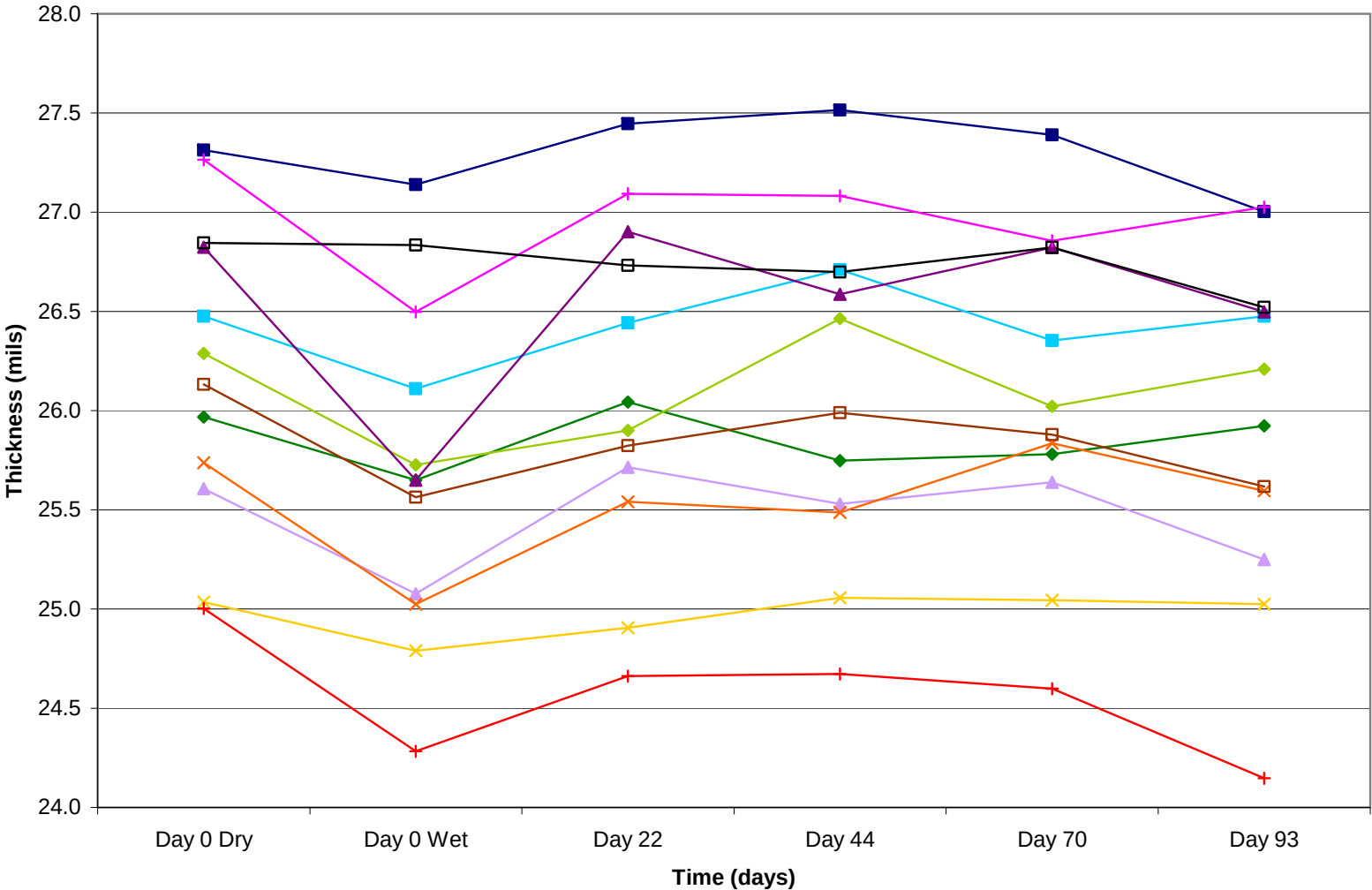
ABC3 S-1 by Spot Number



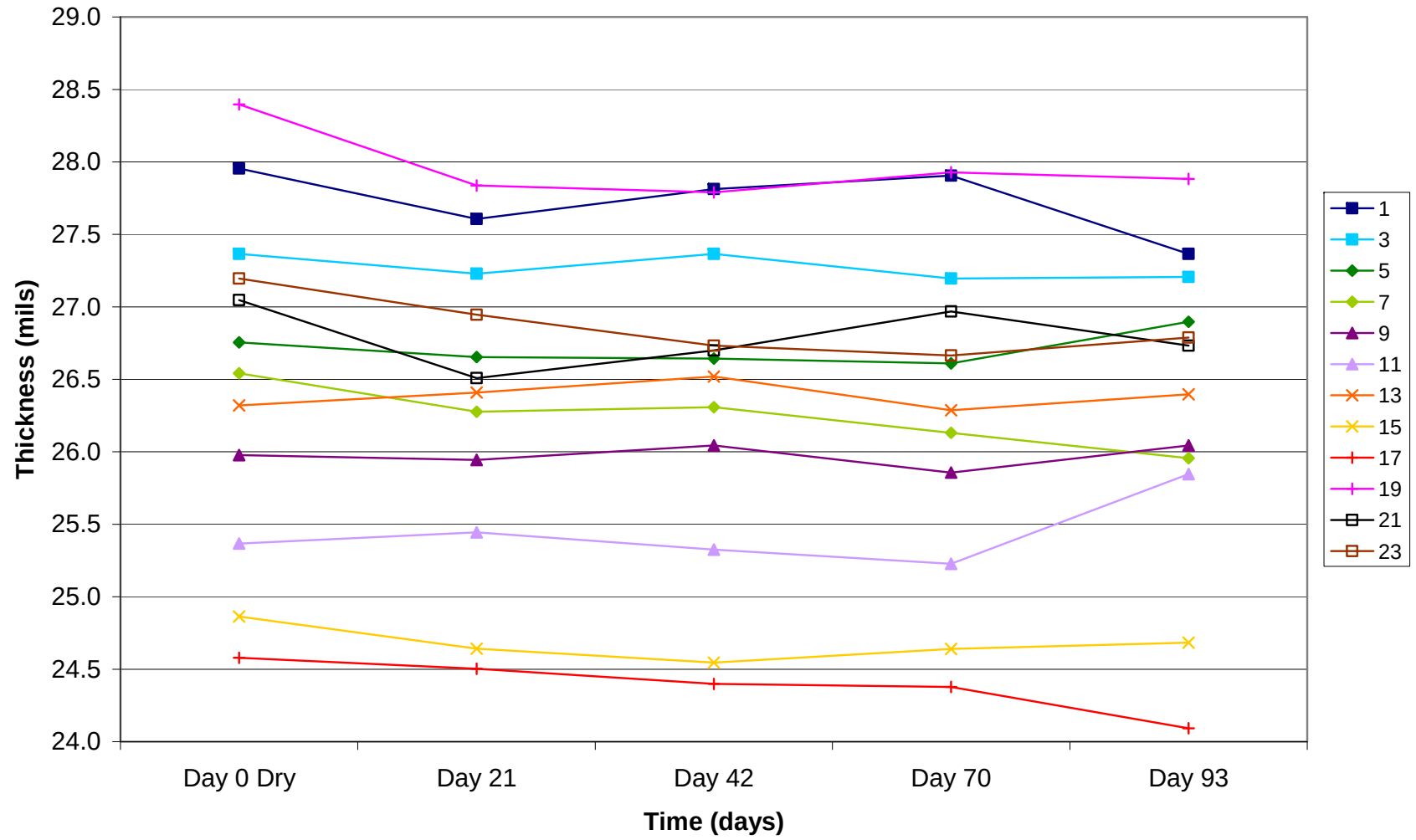
ALPHA R-5 by Spot Number



ALPHA R-3 by Spot Number



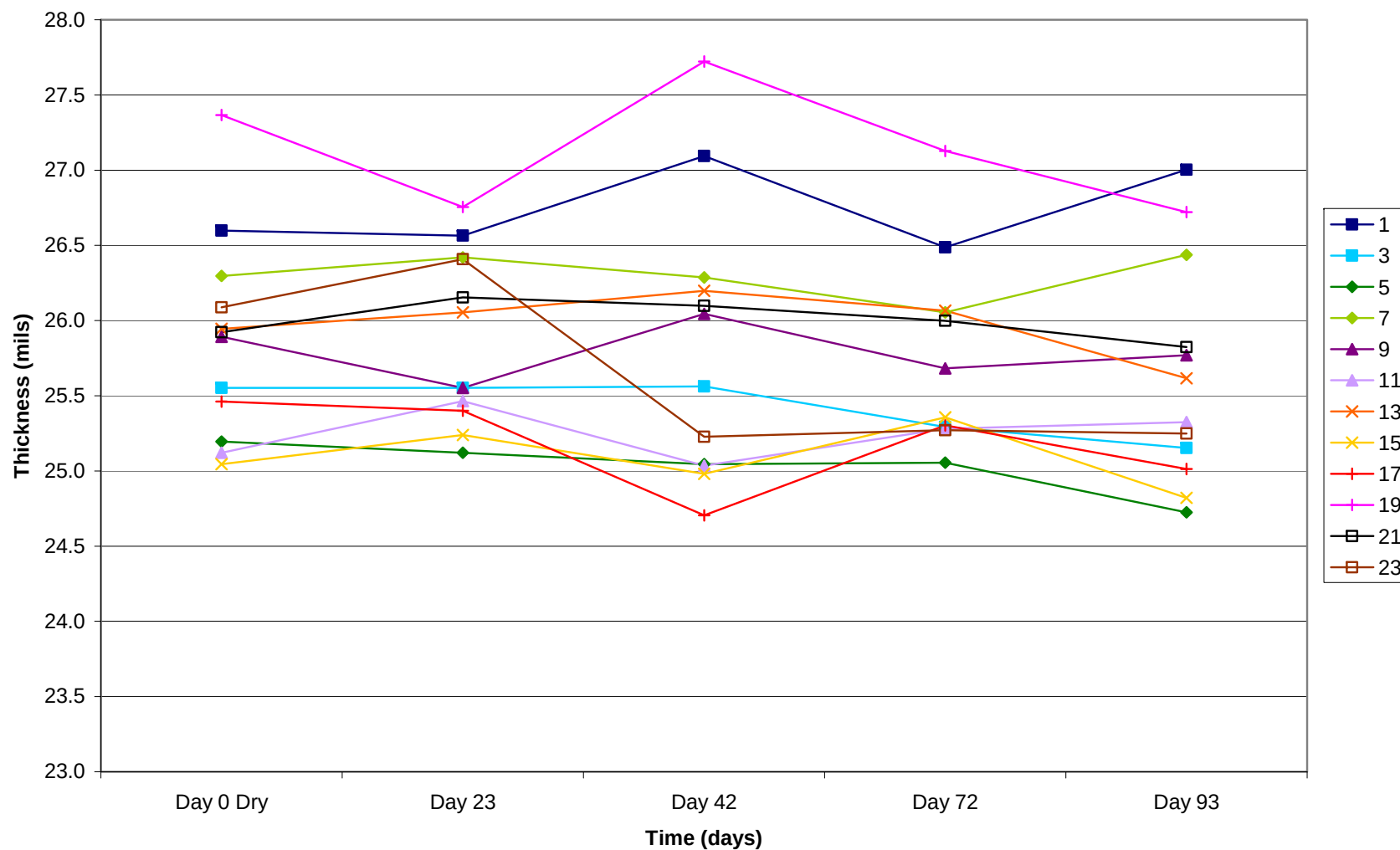
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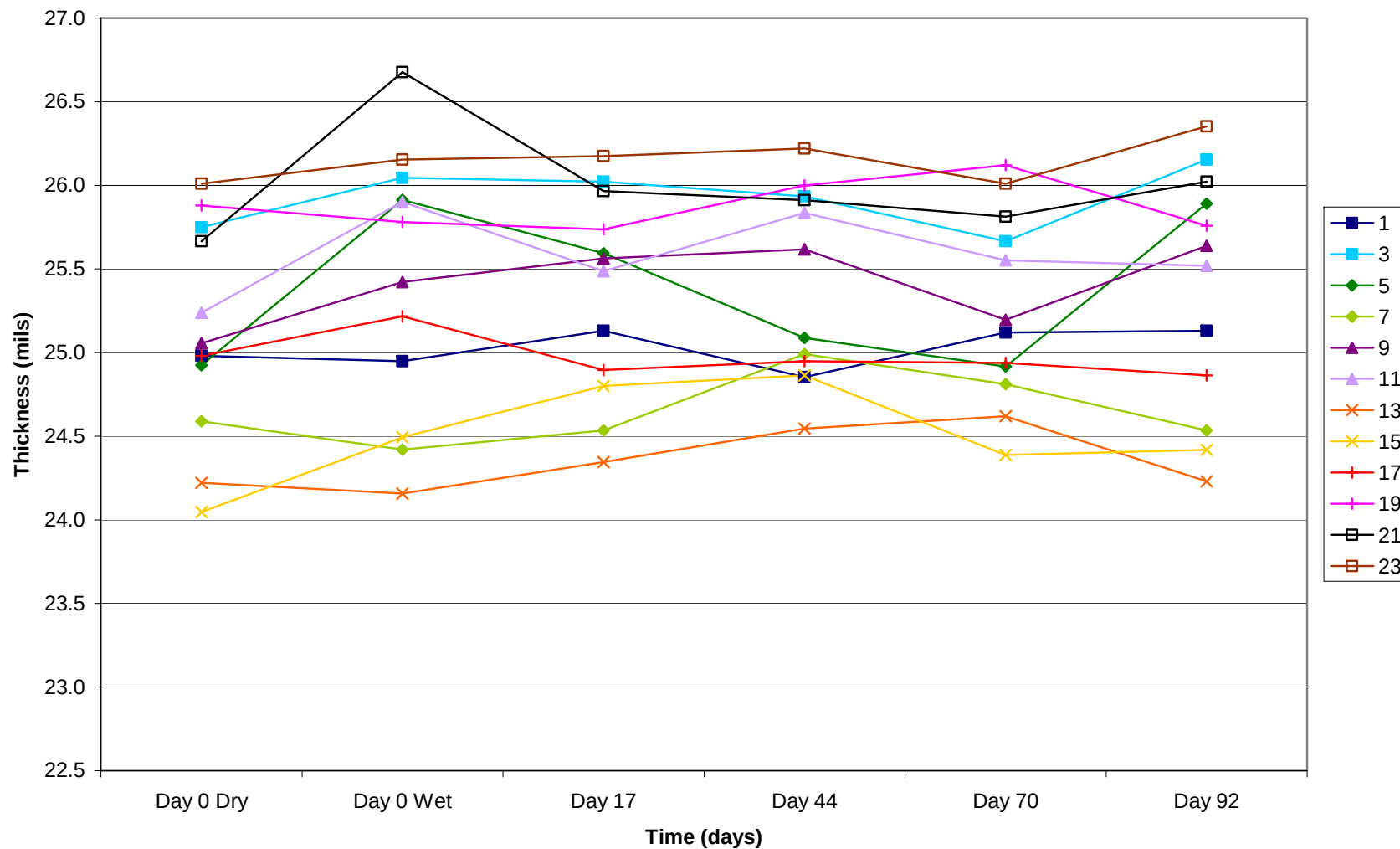
ALPHA S-5 by Spot Number



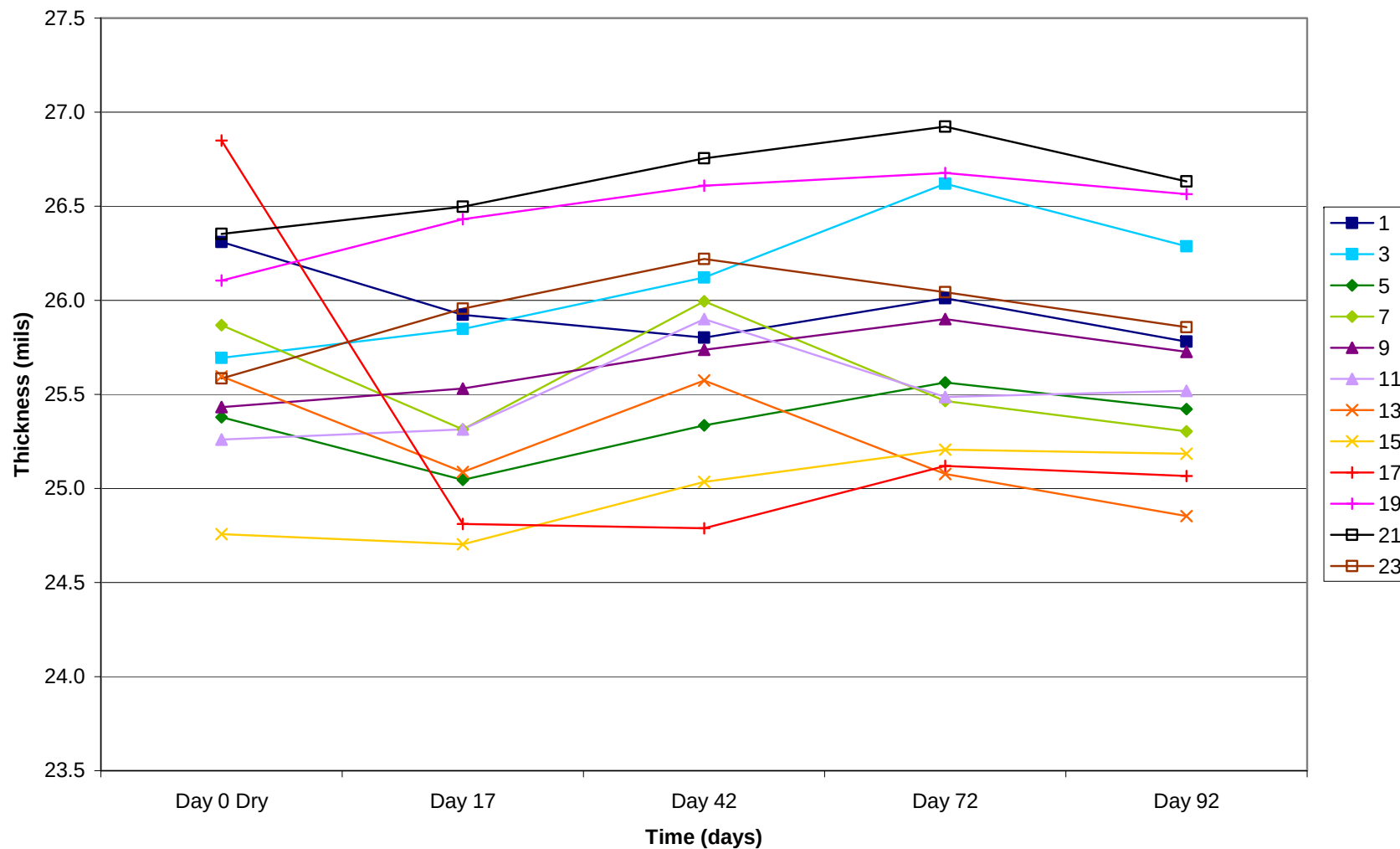
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D-24

ALPHA S-4 by Spot Number



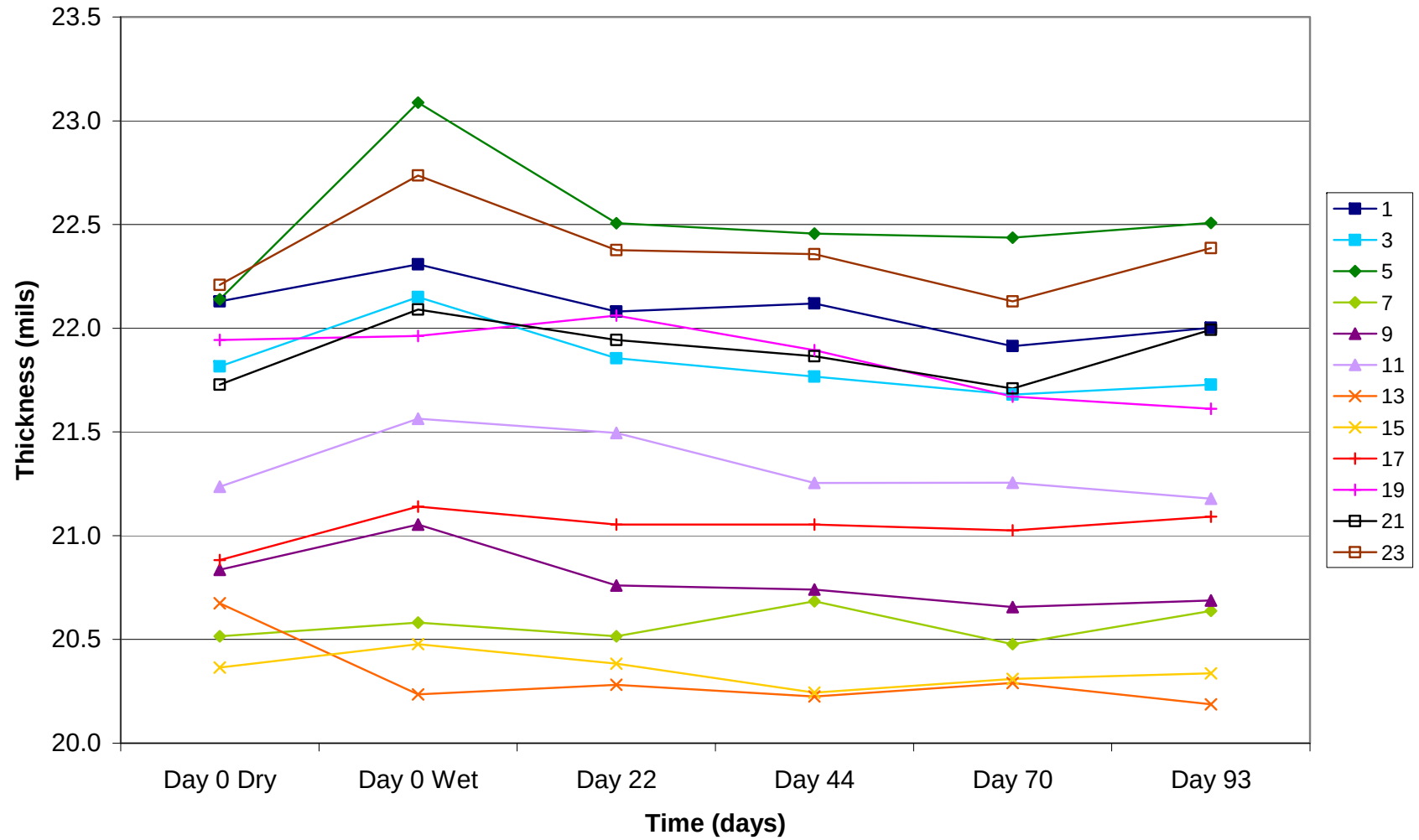
# ALPHA S-3 by Spot Number



D-26

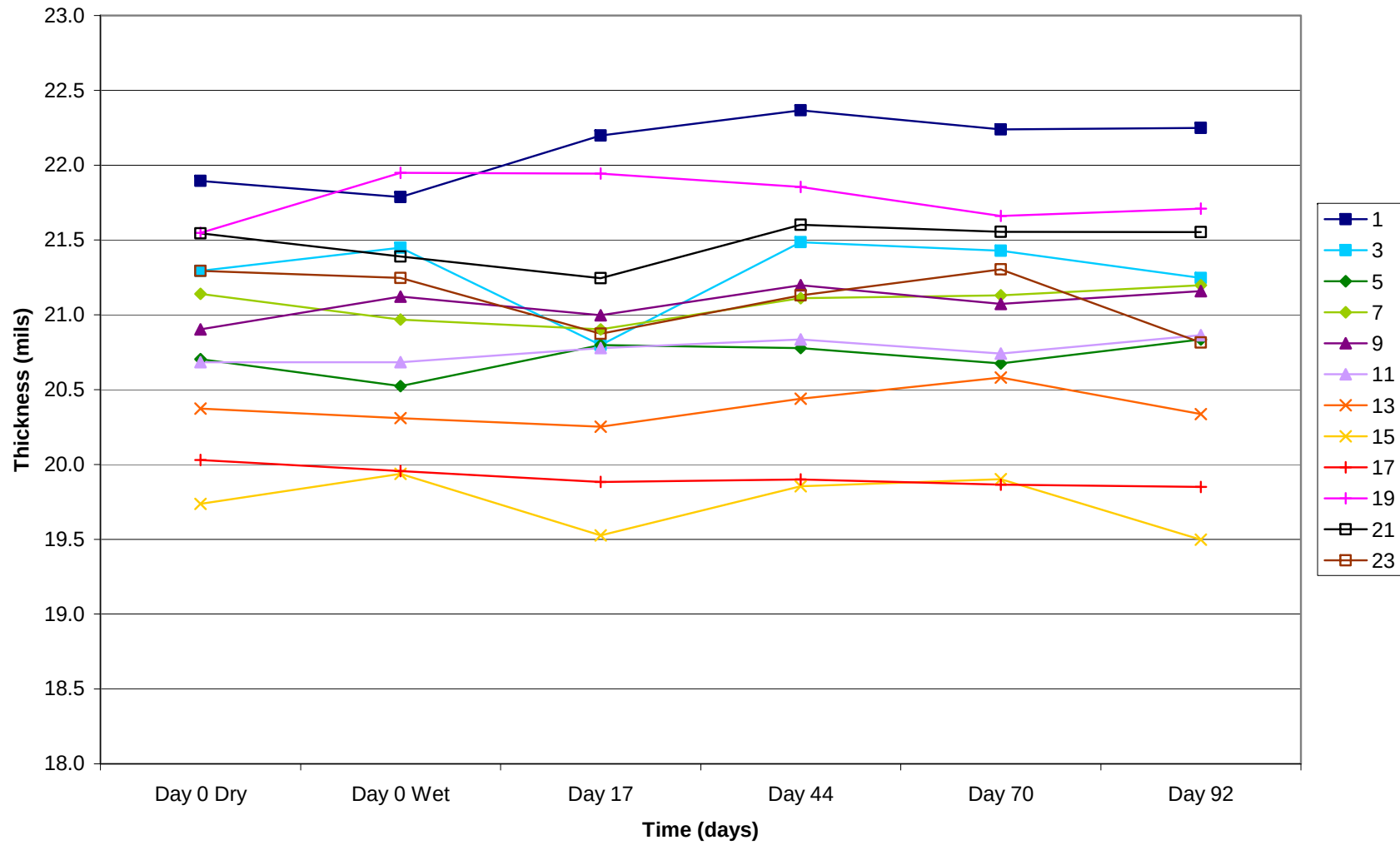
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BRA R-6 by Spot Number



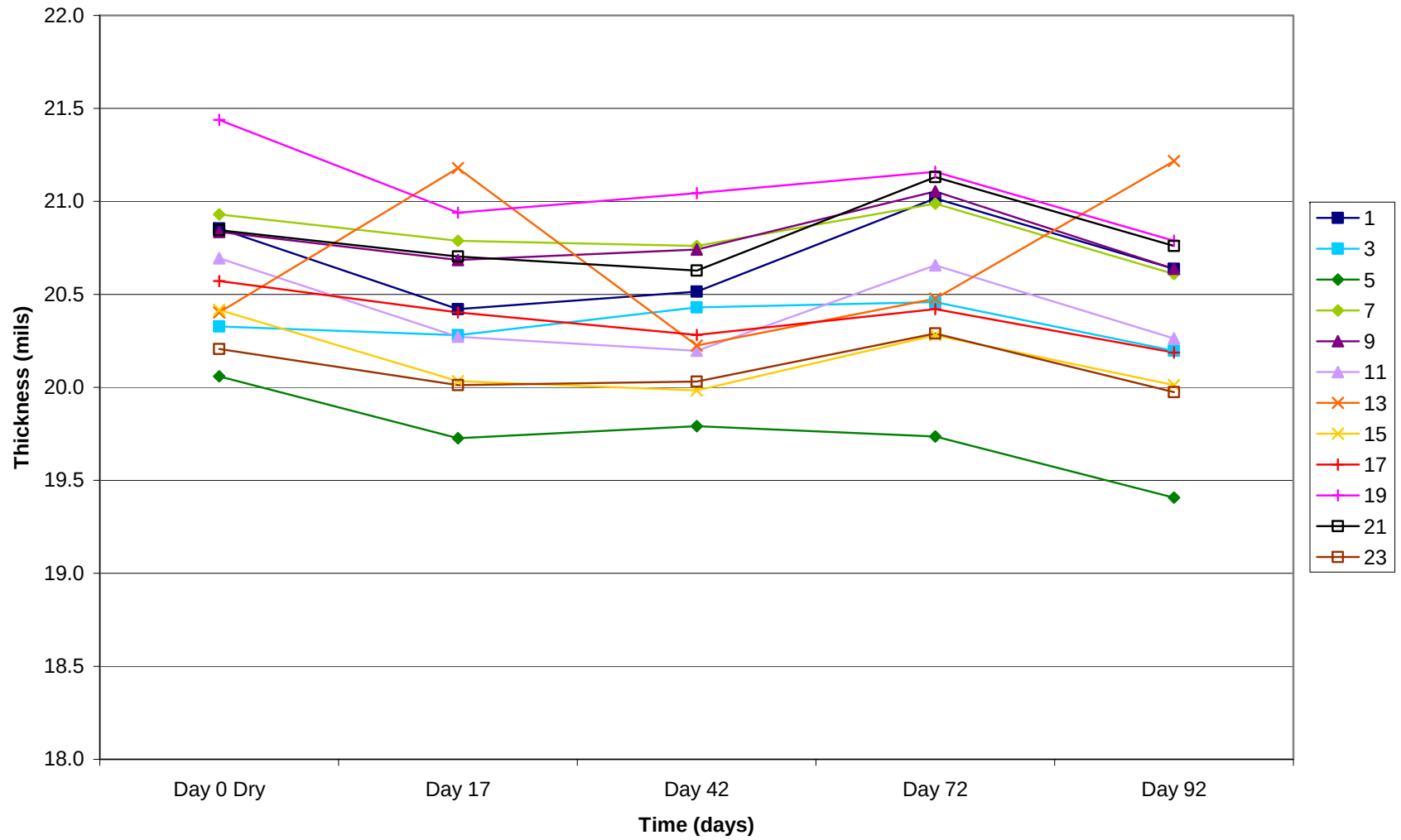
D-27

BRA R-5 by Spot Number

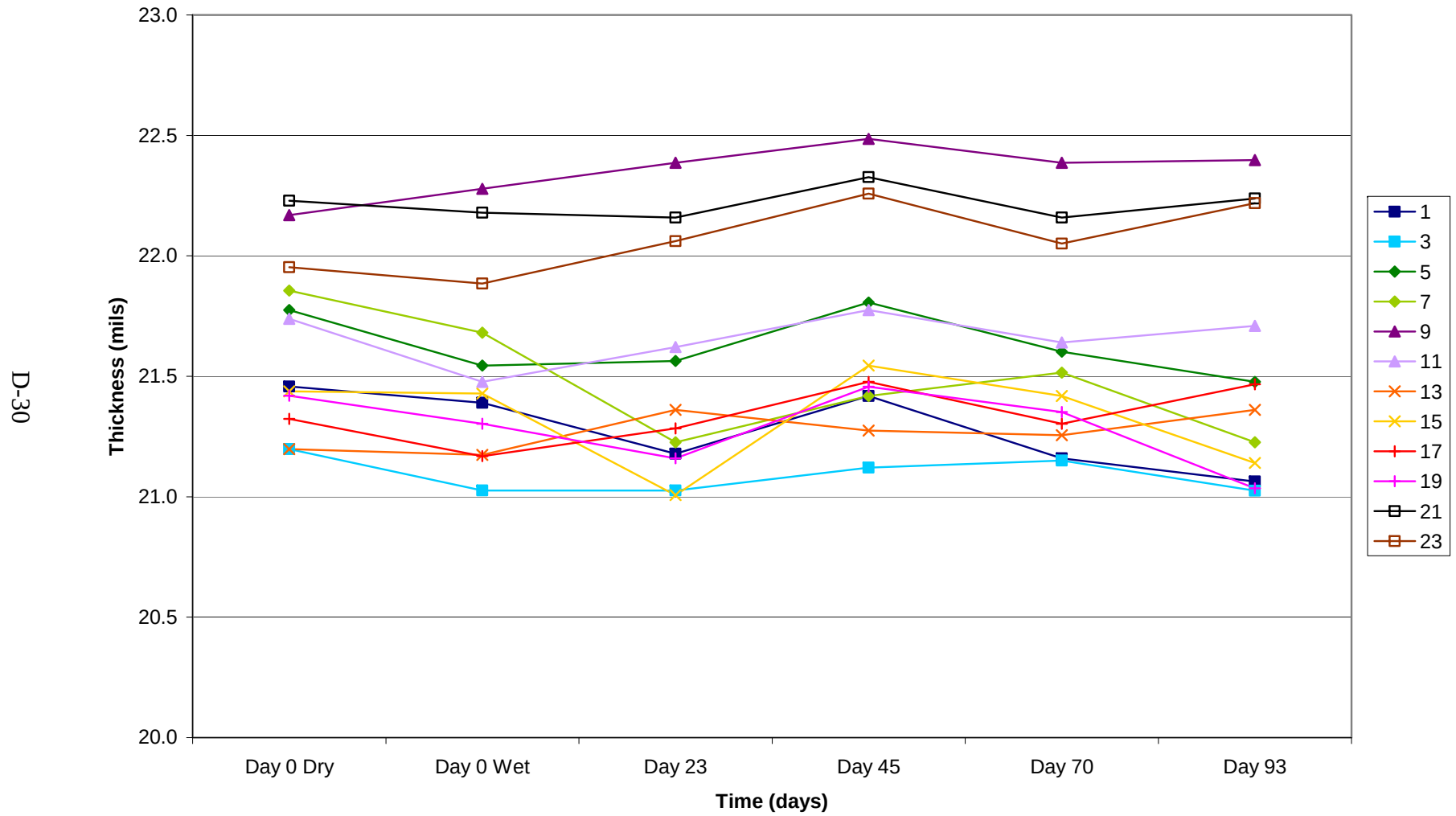


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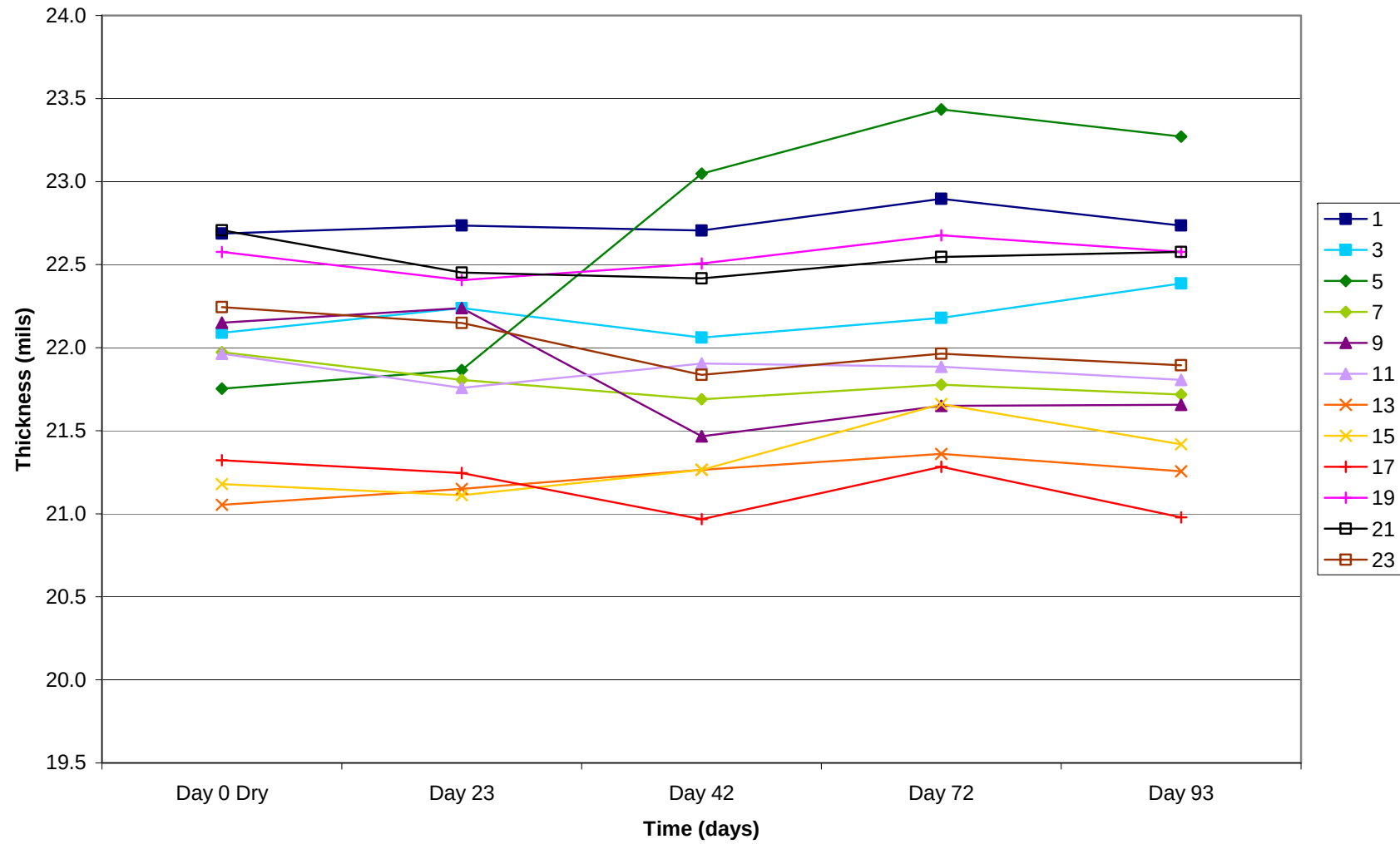
BRA R-4 by Spot Number



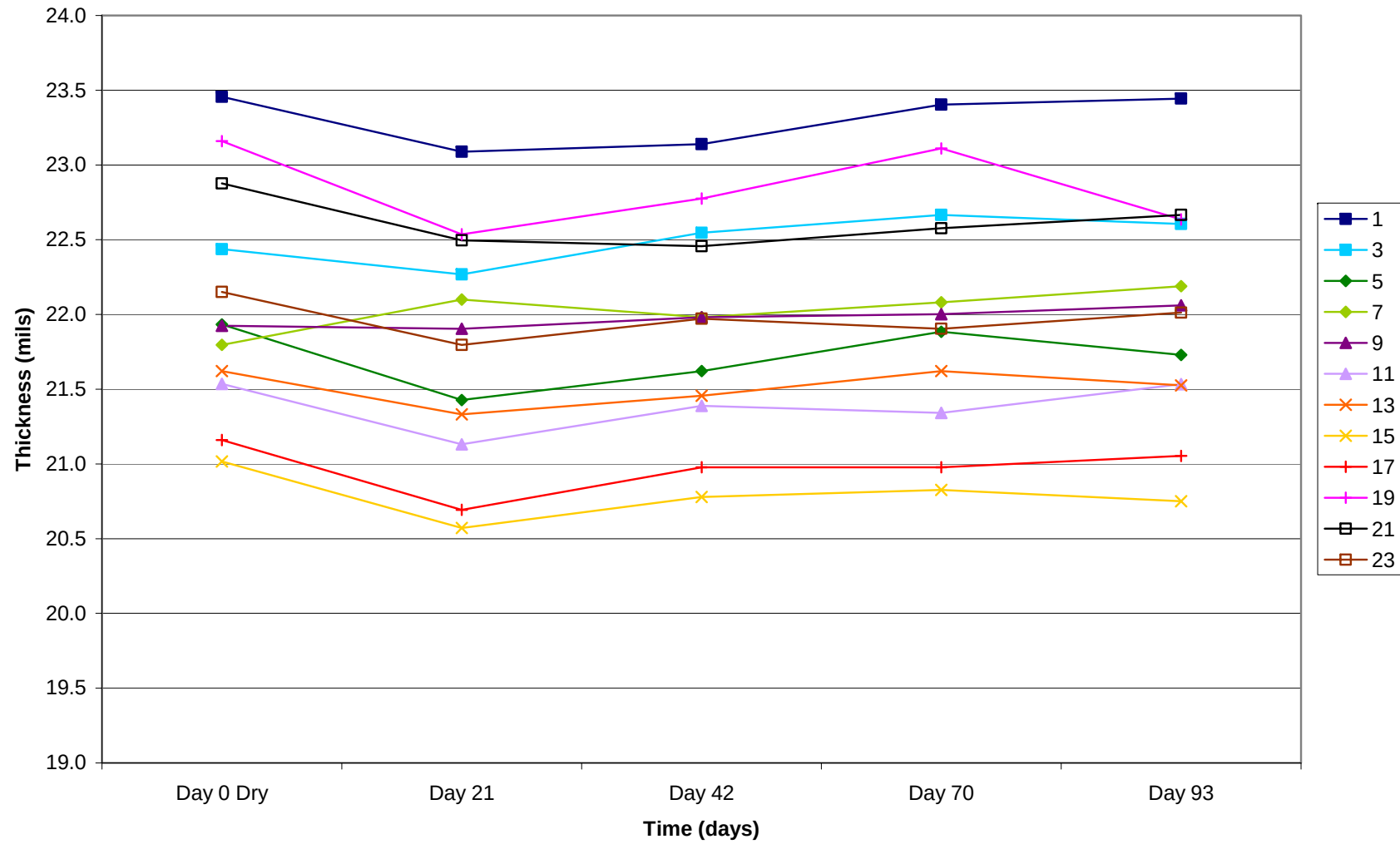
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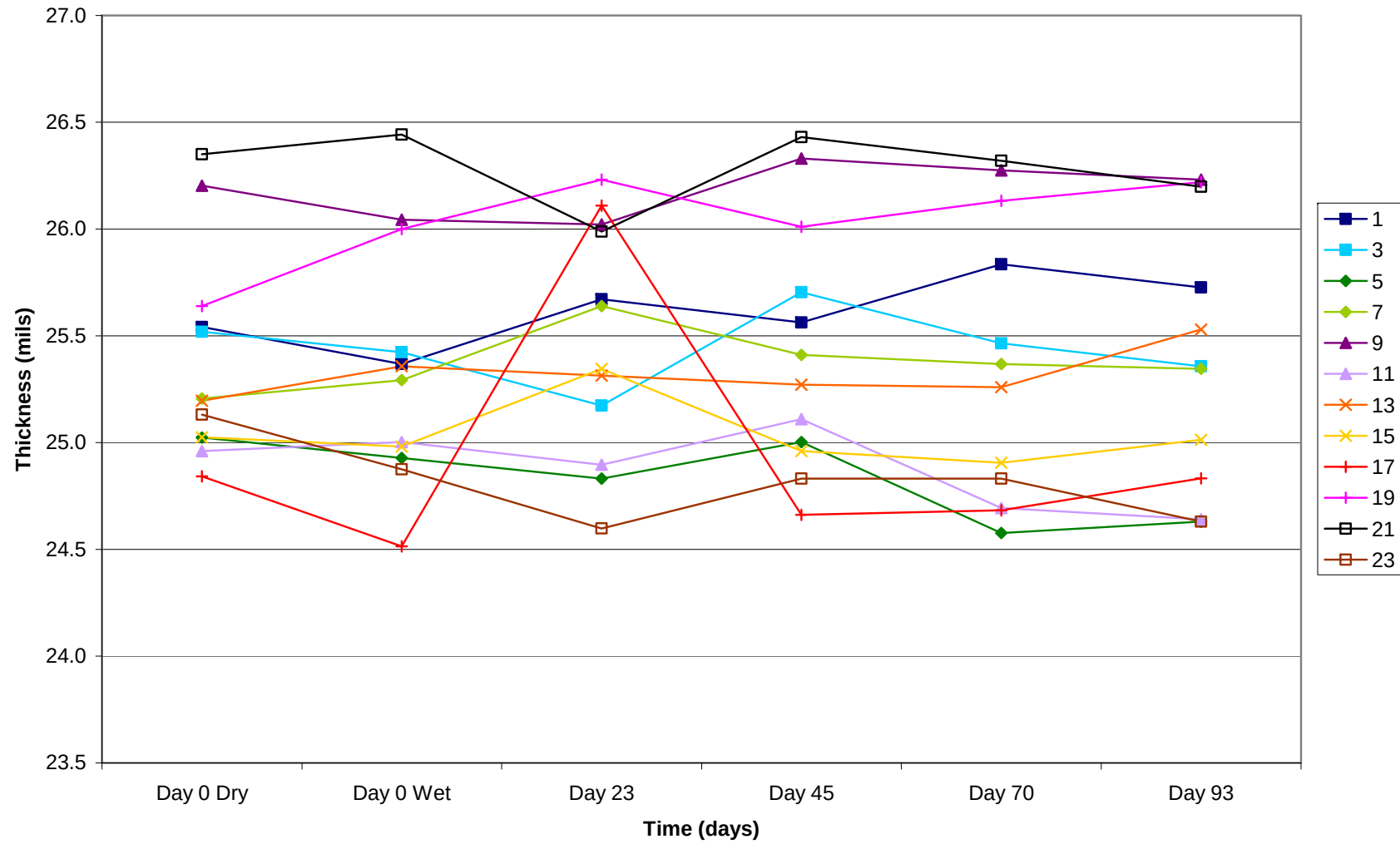
BRA S-3 by Spot Number



BRA S-2 by Spot Number

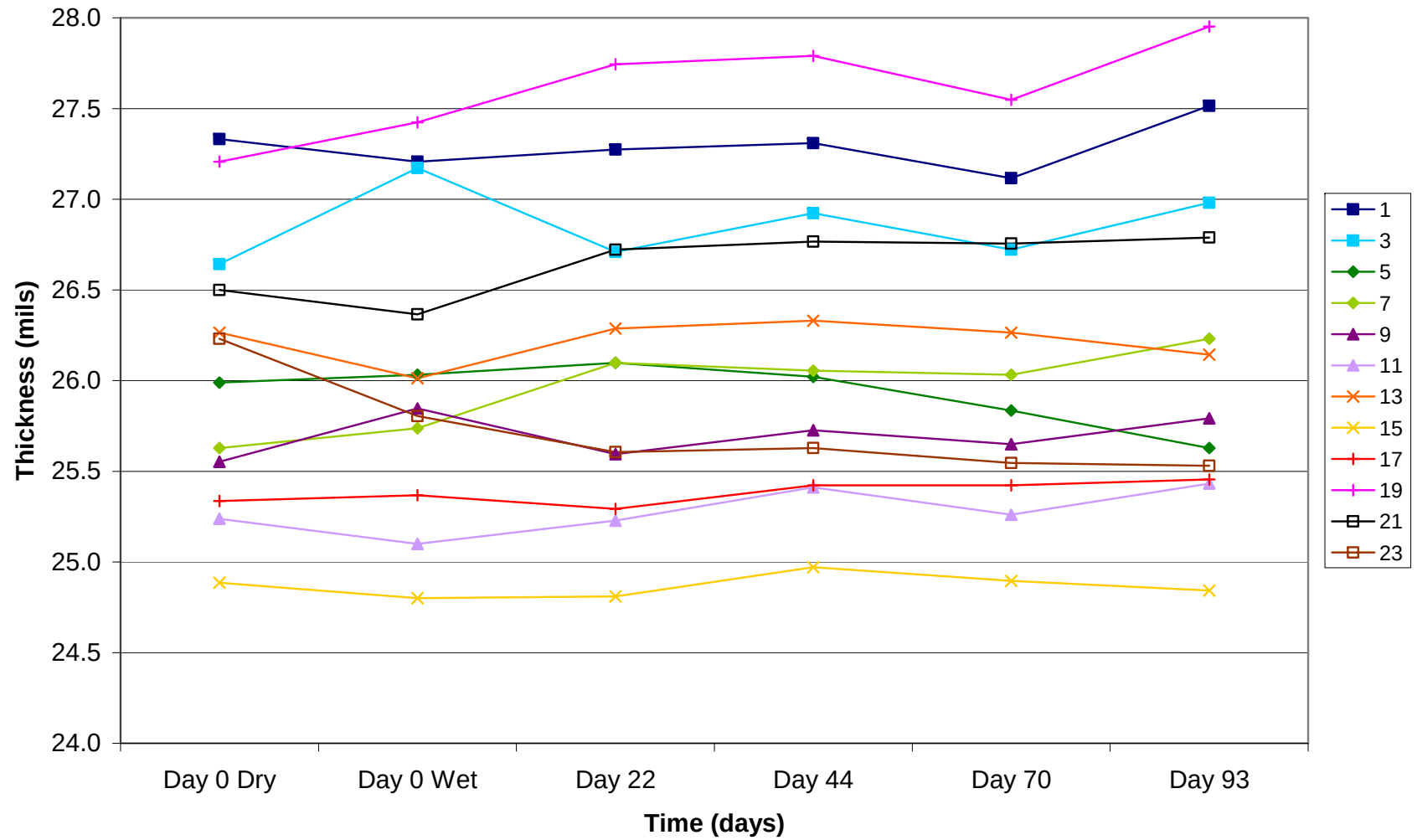


ECOL R-6 by Spot Number



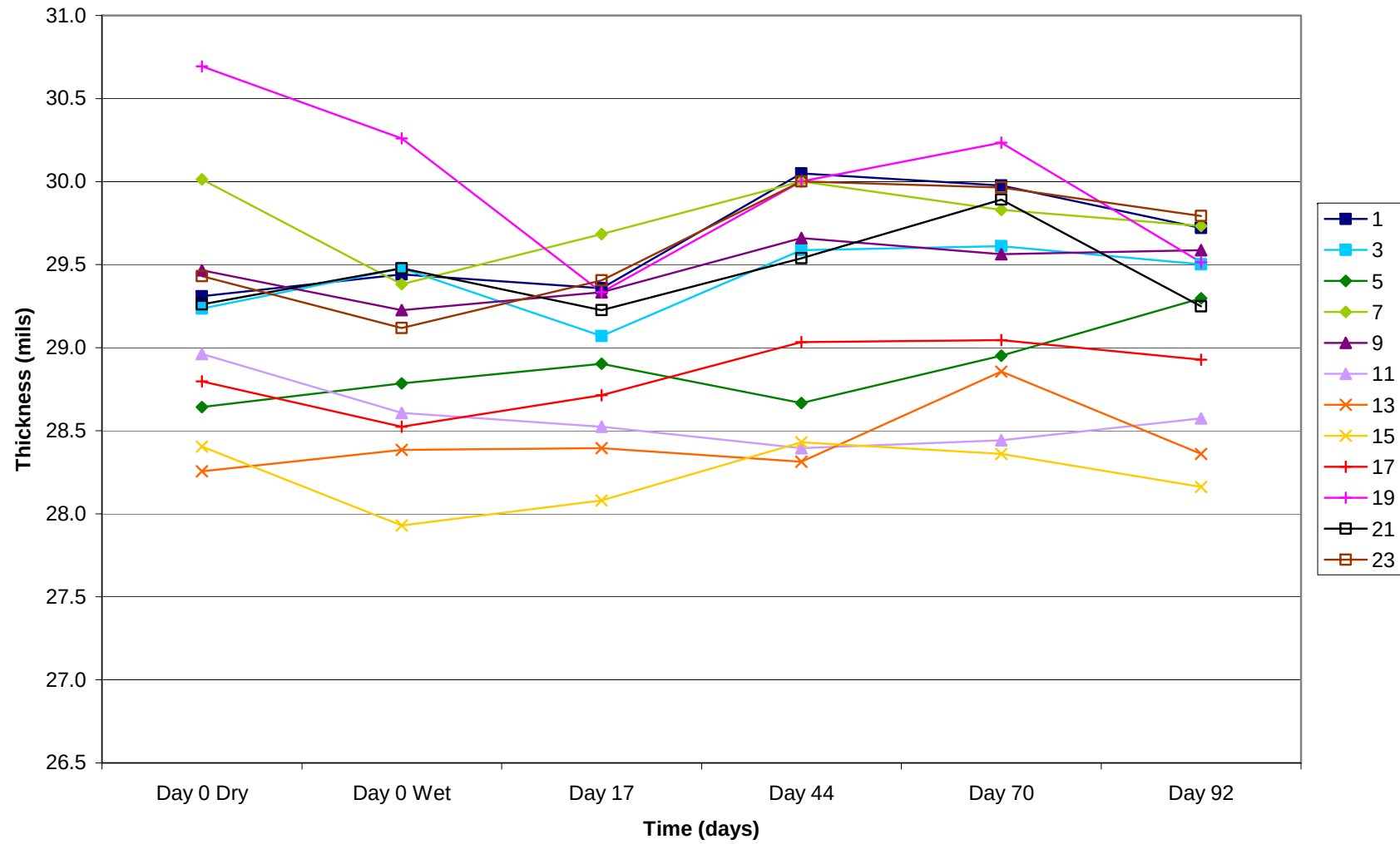
D-34

ECOL R-5 by Spot Number

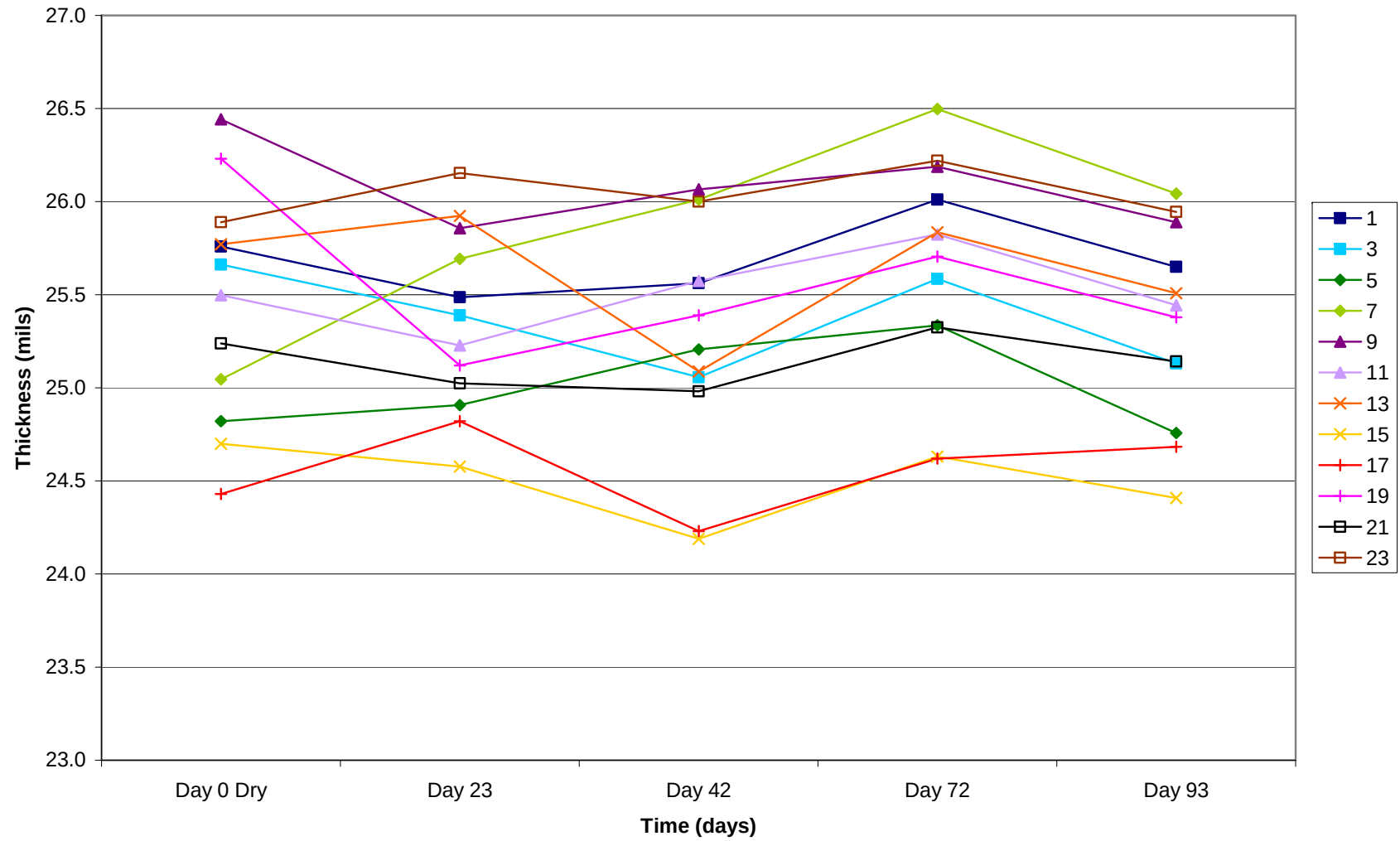


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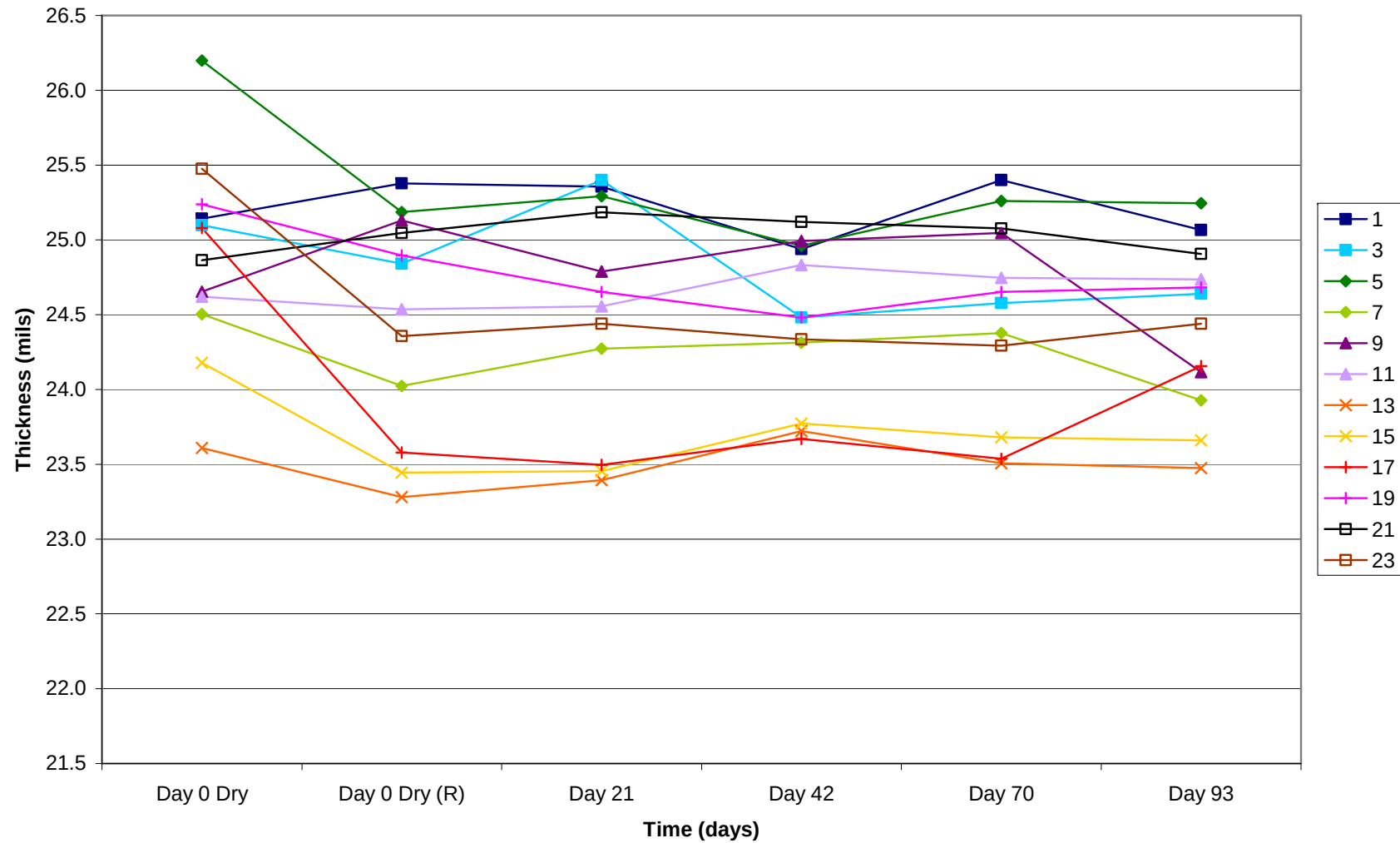
ECOL R-3 by Spot Number



ECOL S-6 by Spot Number



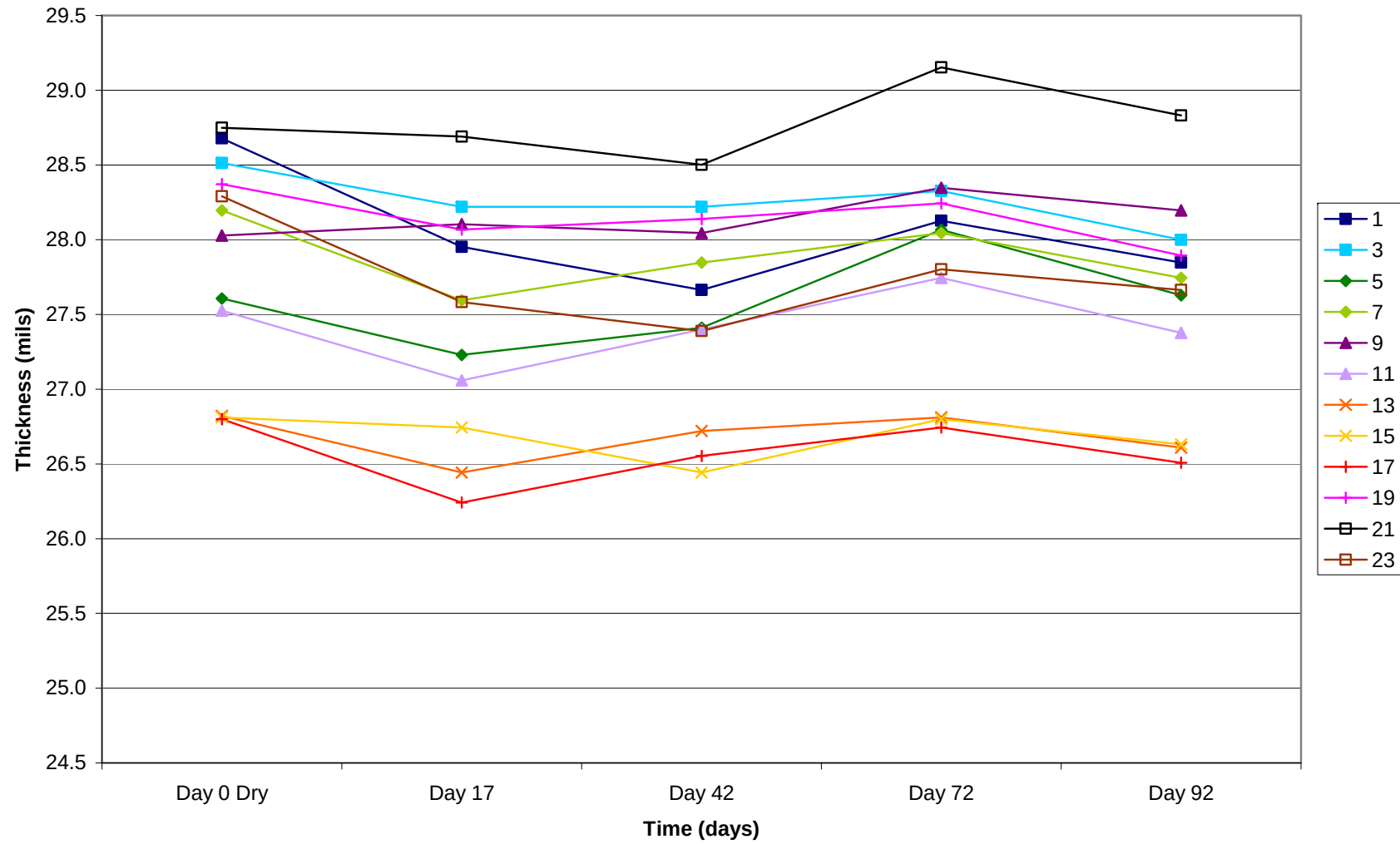
ECOL S-5 by Spot Number



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ECOL S-3 by Spot Number



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