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Surface Marking Durability Study: Phase I

June 2019

Final Report

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16. Abstract

Currently, the Federal Aviation Administration (FAA) does not have standards to compare the in-service durability of surface markings. In April 2017, the FAA Airport Technology Research and Development (ATRD) Branch initiated a three-phase research effort to address this issue. The objectives were to evaluate the performance of pavement marking materials, develop a recommendation of a classification system that reflects how pavement markings perform in service, and establish threshold limits for retro-reflectivity, color, and coverage, as well as evaluate rubber deposit buildup impact on marking performance.

A surface marking test deck consisting of various surface marking types, colors, and bead types was installed at a baseline location, Atlantic City International Airport (ACY) in Atlantic City, New Jersey, in April 2017. Additionally, a Phase I surface marking test deck was installed at Newark Liberty International Airport (EWR) in Newark, New Jersey, in April 2017. Both locations experience four distinct seasons, including cold and wet conditions. However, the ACY surface marking test deck was only exposed to occasional traffic, while the EWR test deck was exposed to frequent aircraft traffic, as well as rubber and snow removal operations. On a monthly basis between April 2017 and April 2018, the ATRD team collected retro-reflectivity and chromaticity data for the markings at ACY and EWR. Photographs were taken throughout the installation process to document the applications.

The data and analysis provided in this report, in conjunction with data to be obtained during Phase II and Phase III, will be used to develop a recommendation of a classification system that reflects how pavement markings perform in service and establish threshold limits for retro-reflectivity, color, and coverage. A final report will summarize all three surface marking durability study phases and include a classification system recommendation for surface markings.

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μ	Coefficient of friction
AC	Advisory Circular
ACC	Asphaltic cement concrete
ACY	Atlantic City International Airport
AMS	Aerospace Materials Specification
ATRD	Airport Technology Research and Development
CIE	International Commission on Illumination
EWR	Newark Liberty International Airport
FAA	Federal Aviation Administration
ICAO	International Civil Aviation Organization
$mcd/m^2/lux$	Millicandela per meter squared per lux
MMA	Methyl methacrylate
mph	Miles per hour
PCC	Portland cement concrete
SAE	Society of Automotive Engineers
SARSYS	Scandinavian Airport and Road Systems
SFT	Surface Friction Tester
SMMA	Structured methyl methacrylate
WJHTC	William J. Hughes Technical Center

EXECUTIVE SUMMARY

The Federal Aviation Administration (FAA) runway and taxiway marking specifications, as published in Advisory Circular (AC) 150/5370-10G, Item P-620, “Standards for Specifying Construction of Airports,” contain numerous marking materials, including waterborne, epoxy, methyl methacrylate (MMA), solvent-base, and preformed thermoplastic marking materials. Based upon previous tests and studies by the FAA, these marking materials meet visual performance standards. However, standards to compare the in-service durability of paints in the AC are currently nonexistent. The FAA Airport Technology Research and Development (ATRD) Branch initiated a three-phase research effort in April 2017 to address this issue. The overall objectives of this effort were to evaluate the performance of pavement marking materials, develop a recommendation of a classification system that reflects how pavement markings perform in service, and establish threshold limits for retro-reflectivity, color, and coverage, as well as evaluate rubber deposit buildup impact on marking performance.

A surface marking test deck was installed on the FAA ramp at Atlantic City International Airport (ACY), in Atlantic City, New Jersey in April 2017. This location experiences four distinct seasons, including cold and wet conditions; however, the ACY surface marking test deck is only subjected to occasional vehicular and aircraft traffic. As a result, the test deck will serve as a baseline for the three-phase study. Phase I of this effort involved the surface marking test deck installation on a high-speed turnoff taxiway for Runway 22L at Newark Liberty International Airport (EWR) in Newark, New Jersey in April 2017. The EWR taxiway is frequently used by a variety of aircraft types and was exposed to four distinct seasons, as well as snow and rubber removal operations.

The surface marking test decks at ACY and EWR included a matrix of six surface marking types (Waterborne Type I, Waterborne Type II, Waterborne Type III, MMA, Structured Methyl Methacrylate (SMMA), and Preformed Thermoplastic) in three colors (white, yellow, and red). For each surface marking type and color, one marking was installed with each of the following bead types: no beads, Type I beads, Type III beads, and Type IV beads. The Preformed Thermoplastic markings contained a mixture of Type I and Type IV beads. Additionally, for each surface marking type, one black marking was installed with no beads. Five additional lines were installed at ACY, which were used to compare the friction coefficient (μ) of various surface markings and bare concrete. The ATRD team collected retro-reflectivity and chromaticity data for the markings at ACY and EWR on a monthly basis between April 2017 and April 2018. Photographs were taken to document the applications.

First-year findings from data collection at ACY and Phase I at EWR included the following:

- Surface markings at ACY showed limited degradation after one year of data collection. Data collection at ACY will continue beyond April 2018.

- Retro-reflectivity values for 52% of the surface markings at ACY increased during the study. The red MMA marking with Type IV beads was the only marking at ACY that fell below the proposed retro-reflectivity minimums.

- The friction coefficient for the exposed concrete prior to the markings ranged from approximately 0.51µ to 0.71µ. The average friction coefficient for Waterborne Type I, Waterborne Type II, Waterborne Type III, and MMA friction lines was 0.42µ, which was lower than the exposed concrete. The average friction coefficient of the SMMA friction line was 0.75µ, which was higher than the exposed concrete prior to the marking. This was also significantly higher than the other markings.

- Retro-reflectivity values at EWR decreased significantly within one month of installation.

- All surface markings at EWR showed retro-reflectivity degradation after rubber buildup and recovery after rubber removal.

- Retro-reflectivity values for surface markings at EWR did not return to initial levels after rubber removal. Frequent exposure to aircraft wheel loads and forces from rubber removal may have caused some beads to be dislodged from the markings.

- Preformed Thermoplastic and Waterborne Type III markings with beads at EWR generally maintained retro-reflectivity better than other marking types. Though retro-reflectivity values for these markings fell below the proposed minimums as rubber deposits accumulated, the markings generally recovered above the proposed minimums after rubber deposit buildup removal.

- White and black markings maintained color over time.

- Yellow and red markings shifted away from their respective color zones on the color guide charts, towards the white zone, likely a result of fading.

- All surface markings at EWR were considered to be failed after one year by April 2018, ending Phase I.

The data and analysis provided in this report, in conjunction with future data obtained during Phase II and Phase III, will be used to develop a classification system recommendation that reflects how pavement markings perform in service, and establish threshold limits for retro-reflectivity, color, and coverage. A final report will summarize all three surface marking durability study phases and include a classification system recommendation for surface markings.

1. INTRODUCTION

Current Federal Aviation Administration (FAA) standards and specifications for the marking of airport runways, taxiways, and aprons are included in Advisory Circular (AC) 150/5340-1L "Standards for Airport Markings," dated September 27, 2013 [1], and AC 150/5370-10G "Standards for Specifying Construction of Airports, Runway and Taxiway Marking," Item P-620, dated July 21, 2014 [2]. These standards and specifications provide a means of compliance with Title 14 Code of Federal Regulations Part 139, "Certification of Airports" [3] for painting and marking of airport surfaces.

In general, AC 150/5340-1L [1] provides information regarding the location and geometry of paint and markings on airports, while AC 150/5370-10G [2] provides information on the physical properties of the paint and markings. These physical properties include the chemistry of three different types of paint, color specifications, weathering, abrasion resistance, and hardness. AC 150/5730-10G [2] also addresses application rates, thickness, and reflective media like glass beads or reflective silica sand. The combined goal of both ACs is to improve safety by providing pilots and airport operators with conspicuous and durable visual information during airport operations. This information is especially vital in the FAA's efforts to reduce the number of runway incursions.

1.1 BACKGROUND

Previous FAA Airport Technology Research and Development (ATRD) branch studies found that numerous marking materials like waterborne, epoxy, solvent-base, methyl methacrylate (MMA), and preformed thermoplastic marking materials can meet the visual standards for both color and retro-reflectivity found in Item P-620 [2]. FAA technical note DOT/FAA/AR-TN03/22 "Development of Methods for Determining Airport Pavement Marking Effectiveness," dated March 2003 [4], developed a manual method for quick and accurate evaluation of paint markings. The manual method includes the use of three devices:

- A retro-reflectometer for determining retro-reflectivity of the beads,
- A color spectrophotometer to determine whether or not the paint marking remains in tolerance, and
- A transparent grid to determine coverage of the paint or marking.

This manual method offers airport operators a means to determine if newly installed marking materials and beads meet current FAA performance standards. In addition, this same manual method provides airport operators a means of assessing performance characteristics over time and after exposure to weather, aircraft traffic, rubber deposit buildup removal and snow removal operations. A practical and reliable means of measuring and comparing the durability of different types of marking materials and beads can provide a quantifiable basis for selecting paints and marking types, as well as informing airport operators when conspicuity levels vary too far from original standards. The ATRD team referred to this as a classification of airfield pavement markings durability.

The ATRD team prepared a project plan entitled "Development of a Classification Method for Durability of Airfield Marking Materials" in January 2016 [5] to achieve this performance-based classification system. The plan envisioned a multi-airport, multi-year evaluation based on criteria that included:

- Climate
  - Hot and humid
  - Hot and dry
  - Cold and wet
- Fleet mix/traffic volume
  - Rubber deposit removal
  - High-speed runway turnoffs
- Pavement types
  - Asphaltic cement concrete (ACC)
  - Portland cement concrete (PCC)

As a result, the project plan included one baseline location and three separate phases:

- Baseline Location—Four distinct seasons, including cold and wet conditions, as well as low traffic.
  - Atlantic City International Airport (ACY)—Atlantic City, New Jersey
- Phase I—Northeast – Four distinct seasons, including cold and wet conditions
  - Newark Liberty International Airport (EWR)—Newark, New Jersey
- Phase II—Southwest – Hot and dry conditions
  - Phoenix Sky Harbor International Airport (PHX)—Phoenix, Arizona
- Phase III—Southeast – Hot and wet conditions
  - Orlando International Airport (MCO)—Orlando, Florida or
  - Hartsfield-Jackson Atlanta International Airport (ATL)—Atlanta, Georgia

The ATRD team specifically selected three climates of cold and wet (Northeast), hot and dry (Southwest), and hot and wet (Southeast).

This report addresses Phase I (Northeast United States) of the study and the first year of data collection at ACY. Phase II (Southwest United States) and Phase III (Southeast United States) and years two and three of data collection at ACY will be reported separately. All three phases will be summarized in a final report.

1.2 OBJECTIVES

The Project Plan [5] identified three objectives:

1. Evaluate performance of pavement marking materials.
2. Develop recommendation of a classification system that

   a. reflects how pavement markings perform in service and

   b. revalidates threshold limits for retro-reflectivity, color, and coverage that were established in DOT/FAA/AR-TN03/22.

3. Evaluate impact of rubber deposit buildup on marking performance.

1.3 RELATED DOCUMENTS

The following is a list of documents relative to pavement markings and the subject of this report.

- American Society for Testing and Materials (ASTM)-D-4541-17, "Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers," August 1, 2017.

- ASTM-E-2177-01, "Standard Test Method for Measuring the Coefficient of Retro-Reflected Luminance (R_L) of Pavement Markings in a Standard Condition of Wetness," December 10, 2001.

- ASTM-E-2380-05, "Standard Test Method for Measuring Pavement Texture Drainage Using an Outflow Meter," 2005.

- FAA report, DOT/FAA/AR-02/128, "Paint and Bead Durability Study," March 2003.

- FAA technical note, DOT/FAA/AR-TN03/22, "Development of Methods for Determining Airport Pavement Marking Effectiveness," March 2003.

- FAA technical note, DOT/FAA/AR-TN96/74, "Follow-On Friction Testing of Retro-Reflective Glass Beads," July 1996.

- FAA report, DOT/FAA/CT-94/119, "Evaluation of Alternative Pavement Marking Materials," January 1995.

- FAA report, DOT/FAA/CT-94/120, "Evaluation of Retro-Reflective Beads in Airport Pavement Markings," December 1994.

- FAA AC 150/5320-12C, “Measurement, Construction, and Maintenance of Skid-Resistant Airport Pavement Surfaces,” March 18, 1997.

- FAA AC 150/5340-1L, “Standards for Airport Markings,” September 27, 2013.

- FAA AC 150/5370-10G, “Standards for Specifying Construction of Airports,” Item P-620, “Runway and Taxiway Painting,” July 21, 2014.

- International Civil Aviation Organization (ICAO) Annex 14, Volume I, 5th edition, “Aerodrome Design and Operation,” July 2009.

- Federal Specification TT-B-1325D, “Beads (Glass Spheres) Retro-Reflective,” August 6, 2007.

- Society of Automotive Engineers (SAE) Aerospace Materials Specification (AMS)-STD-595, “Colors Used in Government Procurement,” February 14, 2017.

2. EVALUATION APPROACH

The ATRD team investigated the suitability of airports in the Northeast that met the following criteria:

- Four distinct seasons, including cold and wet conditions with snow and freeze/thaw cycles

- Variety of aircraft types

- Pavements comprised of both ACC and PCC surfaces

- Adequate real estate for the test deck to be installed

- Reasonable access to test surfaces for monthly data collection

ACY was used as the test site to establish baseline conditions. Representative markings at ACY were exposed to the elements but were not subjected to heavy aircraft traffic or rubber deposit removal operations. EWR was selected as the candidate airport for Phase I of the study because it is a wet and cold location.

2.1 METHOD

The following marking materials were selected for evaluation at both ACY and EWR:

- Surface Marking Material Types

  – Waterborne Type I
  – Waterborne Type II

– Waterborne Type III
– Methyl methacrylate (MMA)
– Structured methyl methacrylate (SMMA)
– Preformed Thermoplastic

- Colors

– White
– Yellow
– Red
– Black

- Beads

– Type I—low-index recycled glass bead
– Type III—high-index virgin glass bead
– Type IV—low-index direct-melt glass bead
– No bead—a no-bead condition

All marking materials and application rates meet the specifications found in AC 150/5370-10G, Item P-620 [2].

A surface marking test deck including a matrix of preformed thermoplastic markings and five paint types in four colors was installed at ACY and EWR. For each white, yellow, and red surface marking type, a series of four stripes, 1-ft wide by 6-ft long and separated by 1 foot, was installed. Figure 1 shows the sequence of the types of beads applied for each paint type and color. In each color grouping, the first stripe does not contain beads, whereas subsequent stripes contained Type I, Type III, or Type IV beads. White, yellow, and red preformed thermoplastic stripes contain a mixture of Type I and Type IV beads. A single black stripe with no beads was installed for each of the five marking material types and the preformed thermoplastic stripes. These test decks were used to study changes in retro-reflectivity, chromaticity, and rubber buildup.

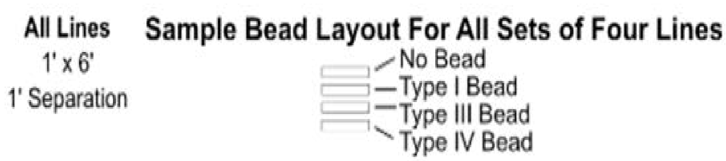


Figure 1. Typical Sequence of Beading for Paint Markings

In addition to the surface marking groups, five lines (one for each paint type) were installed at ACY. These lines, approximately 120-ft long by 1-ft wide, were used to measure and compare the friction of the lines. All the friction lines contained Type I beads and were white, except for the SMMA line, which was yellow.

2.2 APPLICATION TECHNIQUE

The ATRD team, which consisted of an FAA engineer and contract personnel, including an airport operations research analyst and engineering technician(s), monitored the surface markings application at ACY and EWR. Photographs were taken throughout the installation process to document the applications. The markings were installed per the specifications found in AC 150/5370-10G, Item P-620 [2]. The paint contractor provided the personnel and equipment required to complete the installation, as well as installing the markings.

Waterborne Type I, II, III, and MMA markings were installed using equipment with two application nozzles. As the applicator progressed along the marking area, the leading nozzle applied the paint while the rear nozzle applied beads at the desired rate [2]. Figure 2 shows the installation of red Waterborne Type I paint at EWR.

Figure 2. Red Waterborne Type I Marking Installation at EWR

SMMA markings were installed using a push-style applicator. To produce the desired structured characteristic of the marking, the applicator was equipped with an attachment with multiple holes that caused the paint to splatter on the surface. This resulted in a thicker, three-dimensional marking. Figure 3 shows the installation of a white SMMA marking at ACY.

Figure 3. White SMMA Marking Installation at ACY

The installation process for Preformed Thermoplastic markings involved the application of a sealer to the pavement surface. The markings were placed over the sealer and heated using a propane torch, which caused the markings to bond to the underlying pavement. Figure 4 shows the installation of a yellow Preformed Thermoplastic marking at EWR.

Figure 4. Yellow Preformed Thermoplastic Marking Installation at EWR

A sample panel, which serves as a baseline, was collected for each marking. These panels were stored indoors and, therefore, were not exposed to the elements, aircraft, or vehicular traffic. The sample panels allowed the ATRD team to visually compare markings in the field to the original marking application. Figure 5 shows the application of white Waterborne Type II paint without beads with a riding style applicator to a sample panel.

Figure 5. White Waterborne Type II Paint Application to Sample Panel

2.3 EQUIPMENT AND PROCEDURES

Beginning in April 2017, at ACY and EWR, the ATRD team collected retro-reflectivity and chromaticity data of the surface marking test cases on a monthly basis. Photographs were taken throughout the process to document the applications. The ATRD team also collected friction data on the friction lines at ACY on June 2, 2017.

2.3.1 Retro-Reflectivity Test

A 30-meter geometry LTL-X retro-reflectometer, built by Delta Light & Optics of Denmark (S/N 540), was used to measure the retro-reflectivity of the markings. The retro-reflectometer used for Phase I of the study is shown in figure 6.

Figure 6. Delta Light & Optics LTL-X Retro-Reflectometer

The LTL-X retro-reflectometer was used at both ACY and EWR. The LTL-X device was calibrated in the field before data collection began at each location. Additionally, the LTL-X device is sent to the original equipment manufacturer on an annual basis for calibration. To ensure accuracy and consistency of the retro-reflectivity data, the ATRD team ensured that data collection occurred when the pavement was dry. Readings were taken at the beginning, middle, and end of each marking in both directions, yielding a total of six readings for every marking. For each reading, the retro-reflectometer was placed on the surface marking and activated. Readings were recorded on a data sheet similar to the sheet shown in figure 7. Readings were also recorded by the LTL-X device and cross-referenced with the data sheets to ensure accuracy. The six retro-reflectivity readings for each marking were averaged and charted to identify how the retro-reflectivity values changed over time.

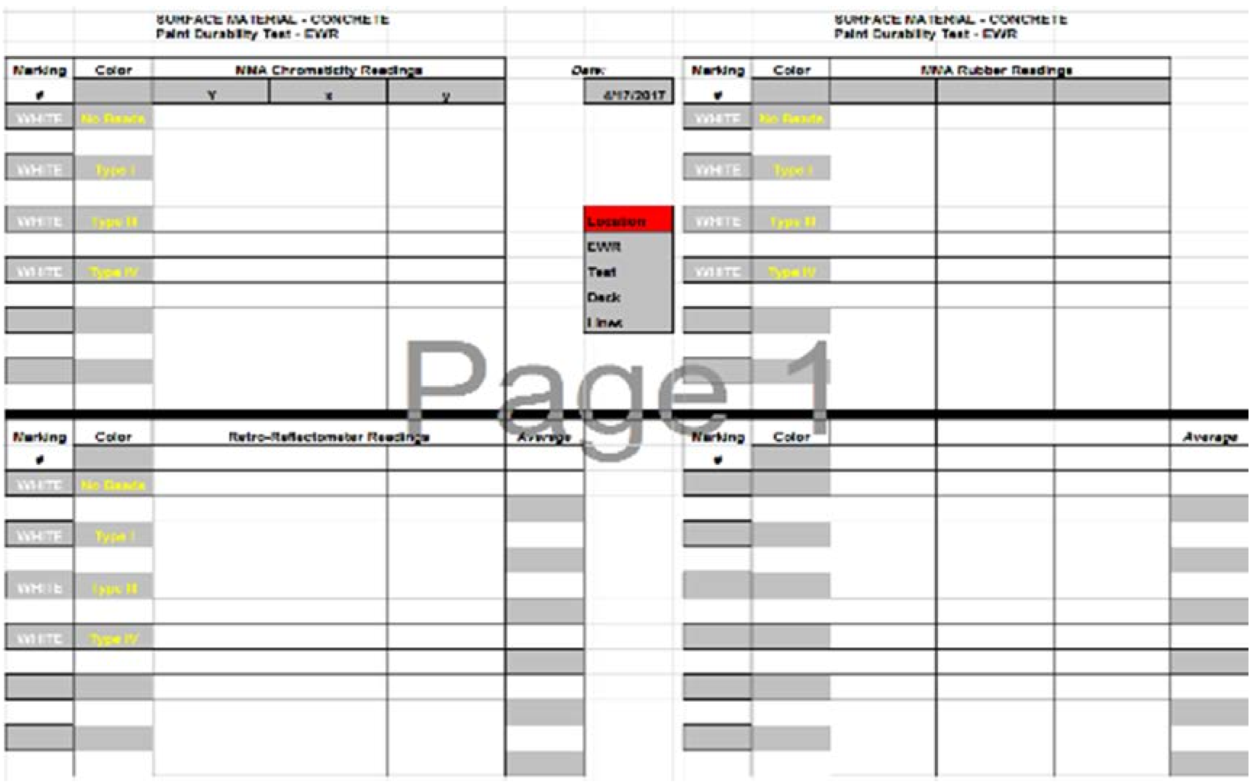


Figure 7. Sample Data Sheet

In 2003, the ATRD team proposed the establishment of minimum retro-reflectivity thresholds of 100 mcd/m^2/lx for white, 70 mcd/m^2/lx for yellow and 25 mcd/m^2/lx for red surface markings [4]. These minimum thresholds were based on discussions with personnel from the Federal Highway Administration and state transportation departments [4]. These minimum thresholds were tested per DOT/FAA/AR-TN03/22 [4]. Currently, the ATRD team is revalidating these proposed minimum thresholds for the airport environment for the FAA, as outlined in section 1.2, objective 2b.

2.3.2 Chromaticity Test

A BYK-Gardner of Germany Spectro-Guide 45/0 Gloss, 20-mm, 6801 color spectrophotometer (S/N 1042342) was used to measure the chromaticity of the markings and collect chromaticity data at ACY and EWR. The spectrophotometer was calibrated in the field before data collection began each month at each location. Additionally, the spectrophotometer is sent to the original equipment manufacturer on an annual basis for calibration. The color spectrophotometer that was used in Phase I of this study is shown in figure 8.

Figure 8. The BYK-Gardner Spectro-Guide 45/0 Spectrophotometer

A total of two readings were taken for each marking by placing the spectrophotometer on the marking and activating the device. Readings were recorded on a data sheet similar to the sheet shown in figure 7. The spectrophotometer also recorded the readings. These readings were cross-referenced with the data sheets to ensure accuracy. The two chromaticity readings for each marking were recorded on an International Commission on Illumination (CIE) standard illuminant D_{65} chart to identify changes in color over time.

2.3.3 Friction Test

A Saab® Scandinavian Airport and Road Systems (SARSYS) Surface Friction Tester (SFT), was used to measure the friction coefficient of the friction lines at ACY. The SARSYS SFT is shown in figure 9.

The friction data for Phase I was collected on June 2, 2017. Two friction runs were completed for each of the five friction lines. For each run, the water was turned on and the pressure was set to 18 kilopascals. Data collection for each run began approximately 100 feet before the marking and ended approximately at the end of the marking. Each run was conducted at 40 miles per hour (mph) and according to the manufacturer's specifications. The raw data were recorded by the SARSYS SFT and charted. Additional friction readings will be taken during Phase II of the study.

Figure 9. The SARSYS SFT

2.4 RUBBER THICKNESS TESTS

Two instruments were used to perform rubber thickness tests: an Elcometer® 456 S/N A456CFNFSI1 and a Delta marking thickness gauge. The results were not beneficial, so going forward, the ATRD team will no longer conduct rubber thickness tests.

3. BASELINE LOCATION—ACY: FIRST-YEAR OBSERVATIONS AND RESULTS

A surface marking test deck was installed at ACY on April 10 and 11, 2017. The markings were installed on the William J. Hughes Technical Center (WJHTC) ramp at Taxiway J, as shown in figure 10. The friction lines were also installed on the WJHTC ramp. This location is exposed to four distinct seasons, including cold and wet conditions; but it is only subjected to occasional vehicular and aircraft traffic because this taxiway is only used for the FAA shuttle and FAA test aircraft.

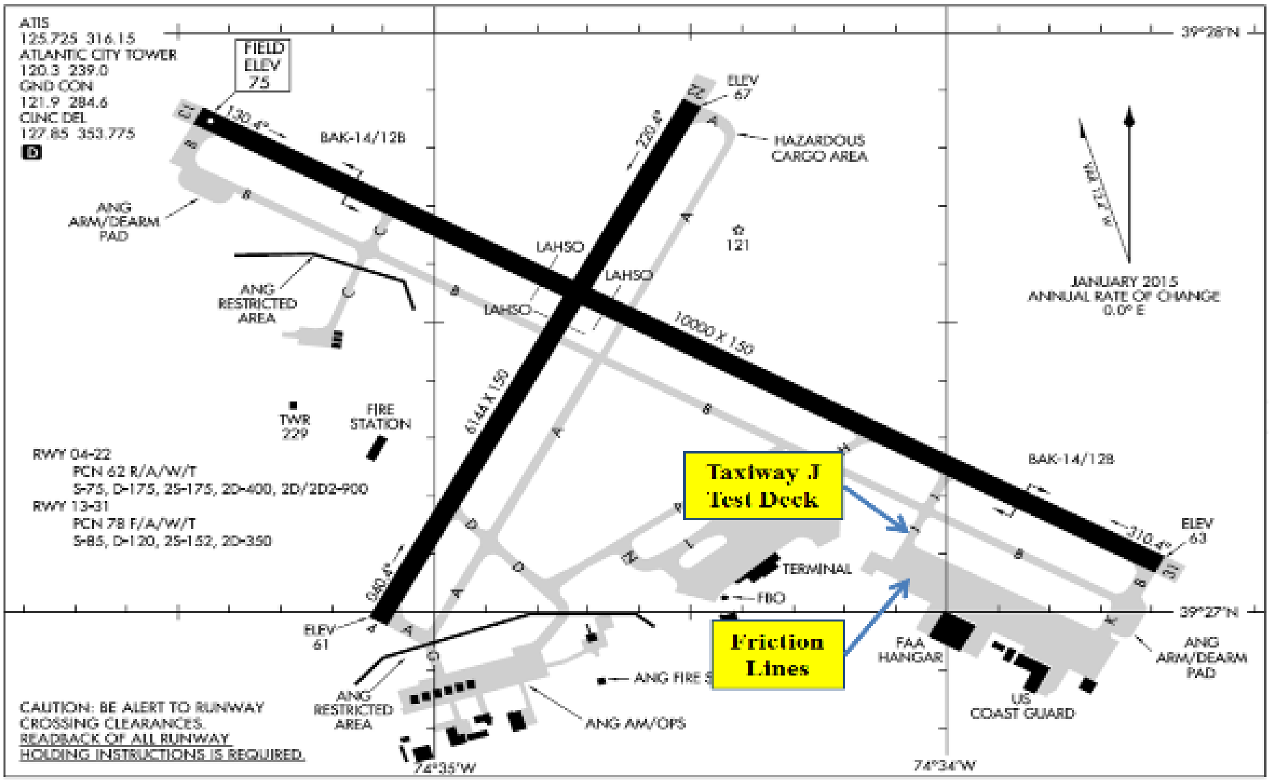


Figure 10. Test Locations at ACY

Figure 11 shows the surface marking test deck layout at ACY. A total of 69 surface markings were installed at WJHTC.

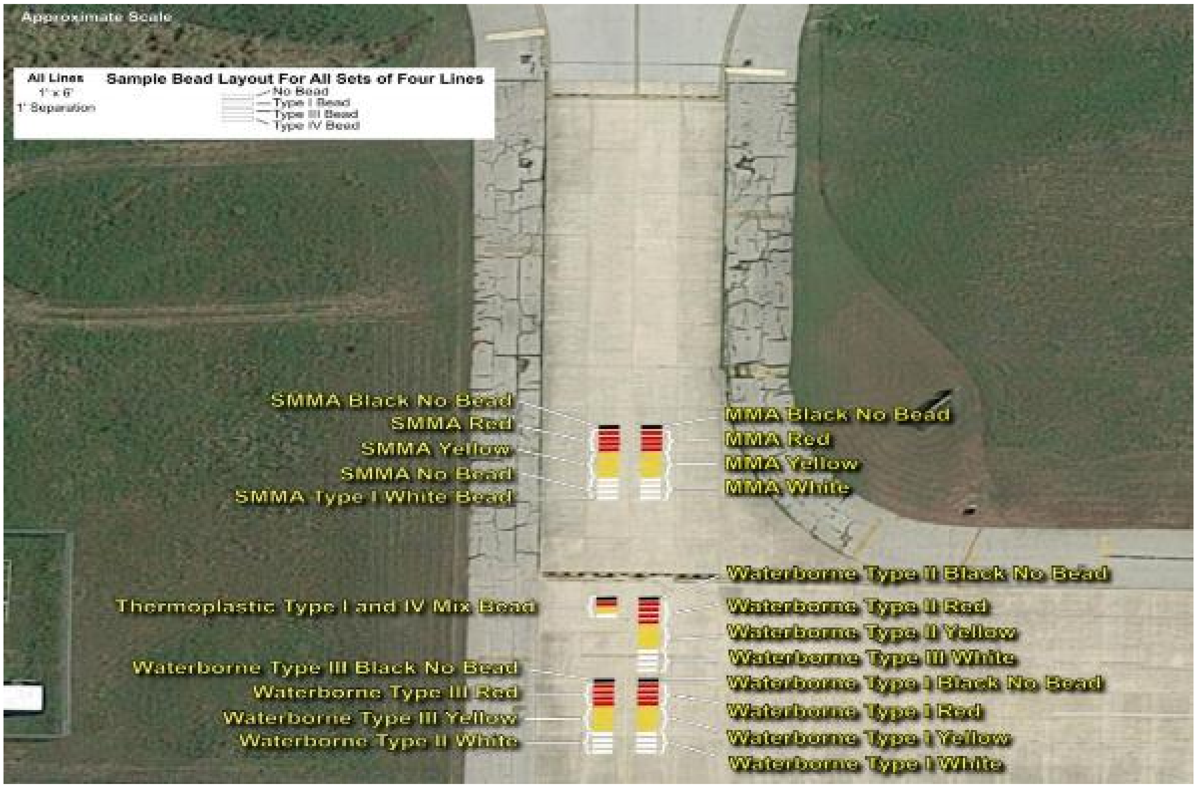


Figure 11. Surface Marking Test Deck Layout at ACY

Figure 12 provides a ground-level view of the surface marking test deck at ACY.

Figure 12. Surface Marking Test Deck on Taxiway J at ACY

The five friction lines were installed on the WJHTC ramp. Figure 13 shows the friction lines layout.

Figure 13. Friction Lines Layout on the WJHTC Ramp

Surface marking test deck installation at the baseline location (ACY) was completed on April 11, 2017, and initial retro-reflectivity and chromaticity readings were collected on the same date. Additional readings were collected on a monthly basis throughout the first year (April 2017-April 2018). Friction data were collected on June 2, 2017. Data collection at ACY will continue through Phases II and III of the study.

3.1 ACY RETRO-REFLECTIVITY FIRST-YEAR RESULTS

On a monthly basis, the average of the six retro-reflectivity readings that were collected for each marking type at ACY was calculated. This average value was charted in a Microsoft® Excel® spreadsheet to allow the ATRD team to monitor the retro-reflectivity performance of the markings over time. Overall, the ACY retro-reflectivity data showed minimal degradation during the first year of the study. In fact, the retro-reflectivity values for more than half (52%) of the surface markings increased. Table 1 shows the percentage change for retro-reflectivity readings between April 2017 and April 2018. The initial retro-reflectivity values and retro-reflectivity values after one year are shown in parenthesis. Surface markings with Type III beads showed the largest decrease overall; however, these markings had the highest initial retro-reflectivity readings. Additionally, the retro-reflectivity readings for markings with Type III beads remained higher than markings with other bead types after the first year. Surface markings with no beads started with low retro-reflectivity readings and remained low after the first year.

Table 1. The ACY Retro-Reflectivity Values Percentage Change After One Year

Marking Type/Color	No Bead	Type I Beads	Type III Beads	Type IV Beads	Type I and Type IV Bead Mix
White Waterborne Type 1	-4% (50; 48)	+10% (352; 386)	+1% (813; 818)	+5% (392; 413)	
Yellow Waterborne Type 1	-21% (42; 33)	+9% (249; 272)	-9% (575; 524)	+7% (366; 393)	
Red Waterborne Type 1	-27% (15; 11)	+9% (93; 101)	-18% (239; 196)	+7% (91; 97)	
Black Waterborne Type 1	-50% (6; 3)				
White Waterborne Type 2	-2% (43; 42)	+22% (414; 507)	+3% (1,144; 1,177)	+11% (682; 758)	
Yellow Waterborne Type 2	+7% (27; 29)	+20% (261; 312)	-30% (691; 483)	+10% (435; 477)	
Red Waterborne Type 2	+10% (10; 11)	+11% (119; 132)	-31% (341; 234)	+24% (146; 181)	
Black Waterborne Type 2	0% (2; 2)				
White MMA	-22% (54; 42)	+40% (286; 399)	+23% (802; 987)	+155% (175; 446)	
Yellow MMA	-45% (101; 56)	-2% (272; 266)	-59% (849; 352)	+25% (155; 193)	
Red MMA	0% (16; 16)	-33% (88; 59)	-82% (436; 78)	-56% (48; 21)	
Black MMA	+125% (4; 9)				
White Waterborne Type 3	-11% (46; 41)	+13% (416; 471)	-11% (986; 878)	+24% (522; 649)	
Yellow Waterborne Type 3	+3% (32; 33)	+37% (205; 280)	+3% (589; 604)	+11% (434; 480)	
Red Waterborne Type 3	0% (11; 11)	+24% (104; 129)	-7% (323; 300)	+7% (142; 152)	
Black Waterborne Type 3	-33% (3; 2)				
White Preformed Thermoplastic					+30% (528; 684)
Yellow Preformed Thermoplastic					+26% (215; 271)
Red Preformed Thermoplastic					+37% (86; 118)
Black Preformed Thermoplastic	+100% (2; 4)				

Table 1. The ACY Retro-Reflectivity Values Percentage Change After One Year (Continued)

Marking Type/Color	No Bead	Type I Beads	Type III Beads	Type IV Beads	Type I and Type IV Bead Mix
White SMMA	+9% (117; 128)	+8% (454; 492)	-28% (1,439; 1,036)	-26% (328; 242)	
Yellow SMMA	+12% (67; 75)	-1% (277; 275)	-41% (1,202; 711)	-38% (284; 176)	
Red SMMA	-24% (17; 13)	-9% (65; 59)	-56% (439; 195)	-55% (65; 29)	
Black SMMA	-60% (20; 8)				

Note: Items in ( ) are in units of $mcd/m^2/lux$.

All surface markings that contained beads remained above the established retro-reflectivity minimums except for the red MMA marking with Type IV beads. With a reading of 23 $mcd/m^2/lx$ in December 2017, this marking fell below the retro-reflective minimum of 25 $mcd/m^2/lx$ for red markings. Retro-reflectivity values for Preformed Thermoplastic markings that contained beads and retro-reflectivity values for Waterborne Type I, Waterborne Type II, and Waterborne Type III markings with Type I and Type IV beads increased over time. The retro-reflectivity charts for ACY are shown in figures 14 through 29. The threshold limits for retro-reflectivity, color, and coverage were established in technical note, DOT/FAA/AR-TN03/22 [4].

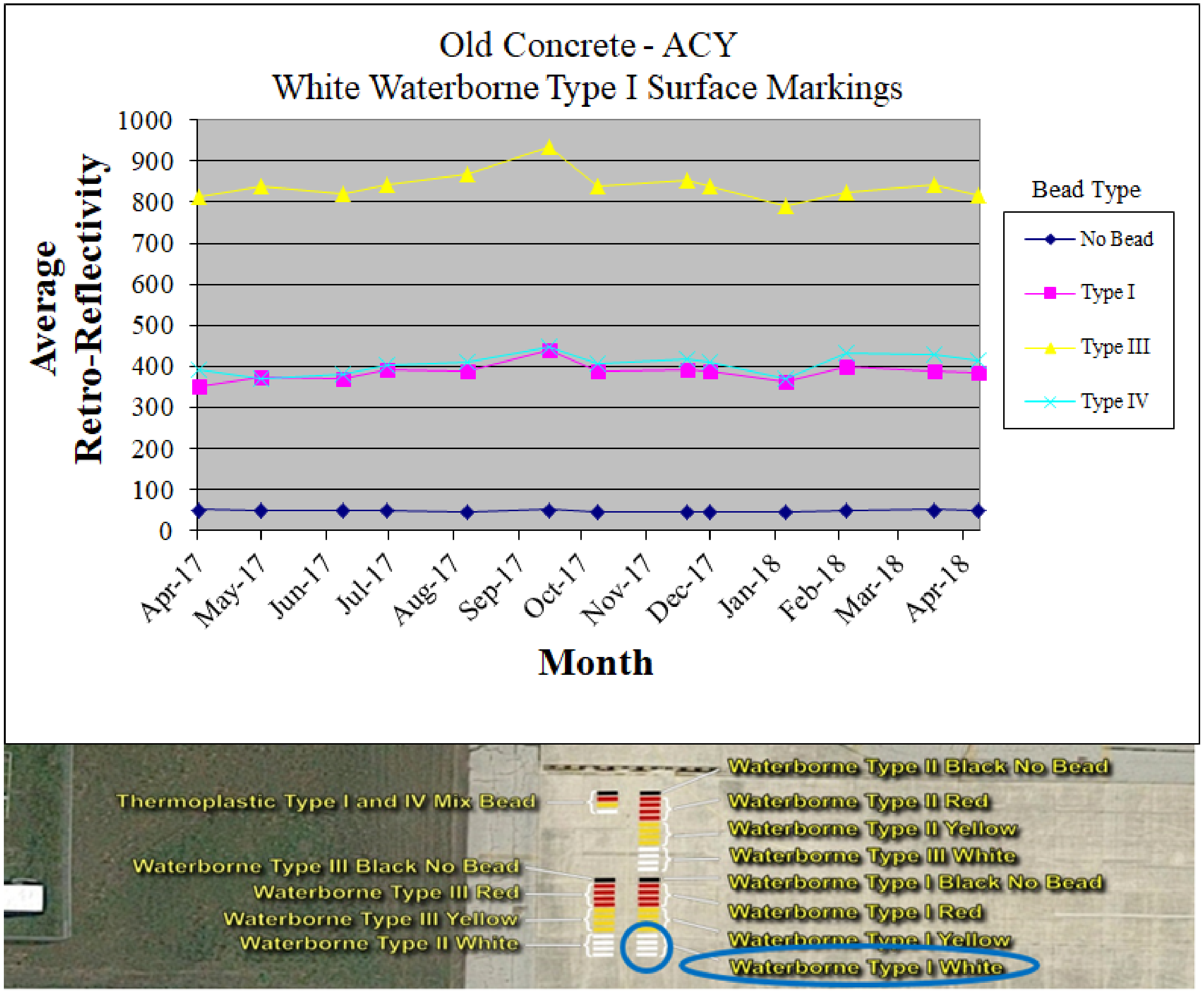


Figure 14. Retro-Reflectivity Readings: White Waterborne Type I Surface Markings at ACY

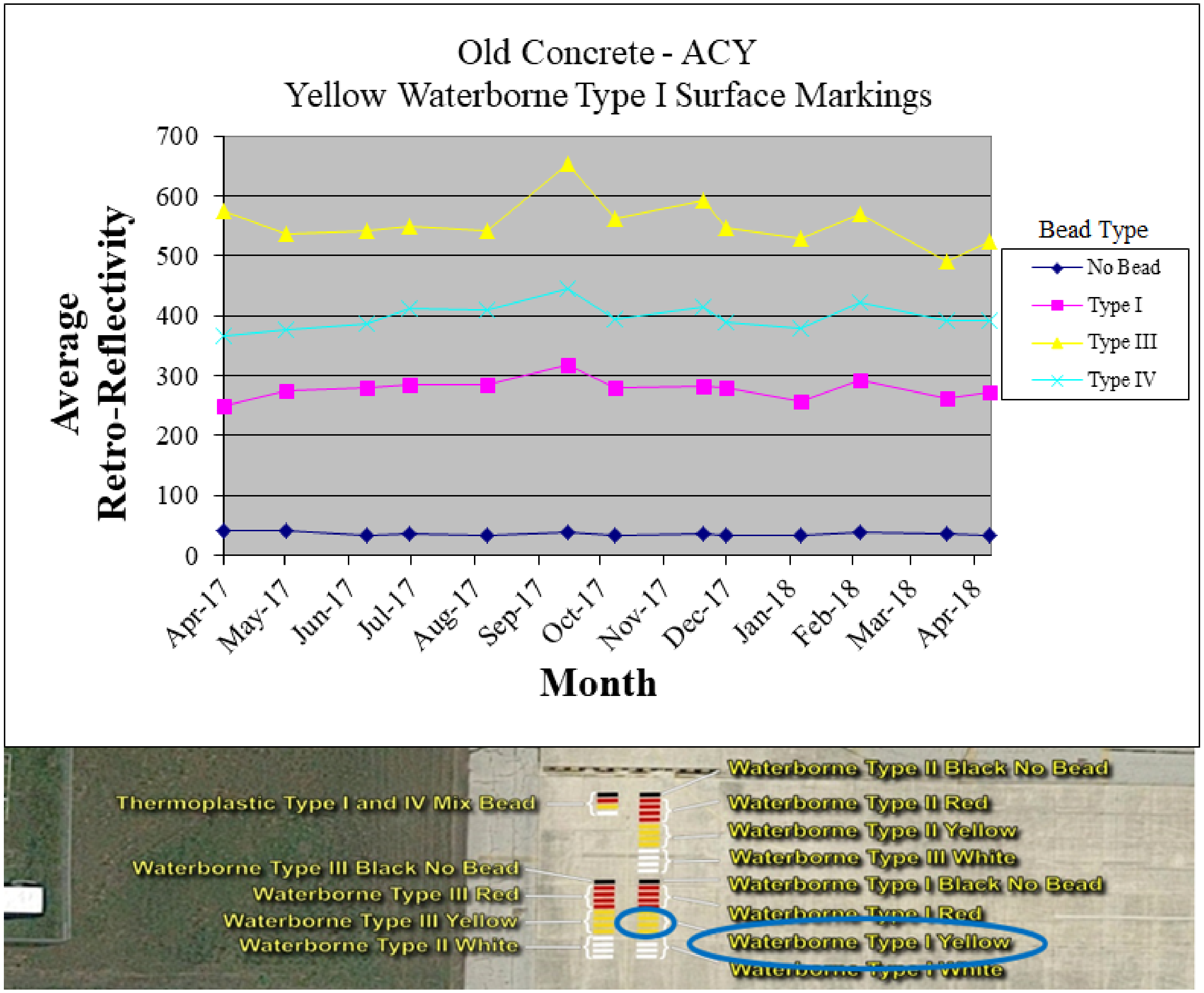


Figure 15. Retro-Reflectivity Readings: ACY Yellow Waterborne Type I Surface Markings

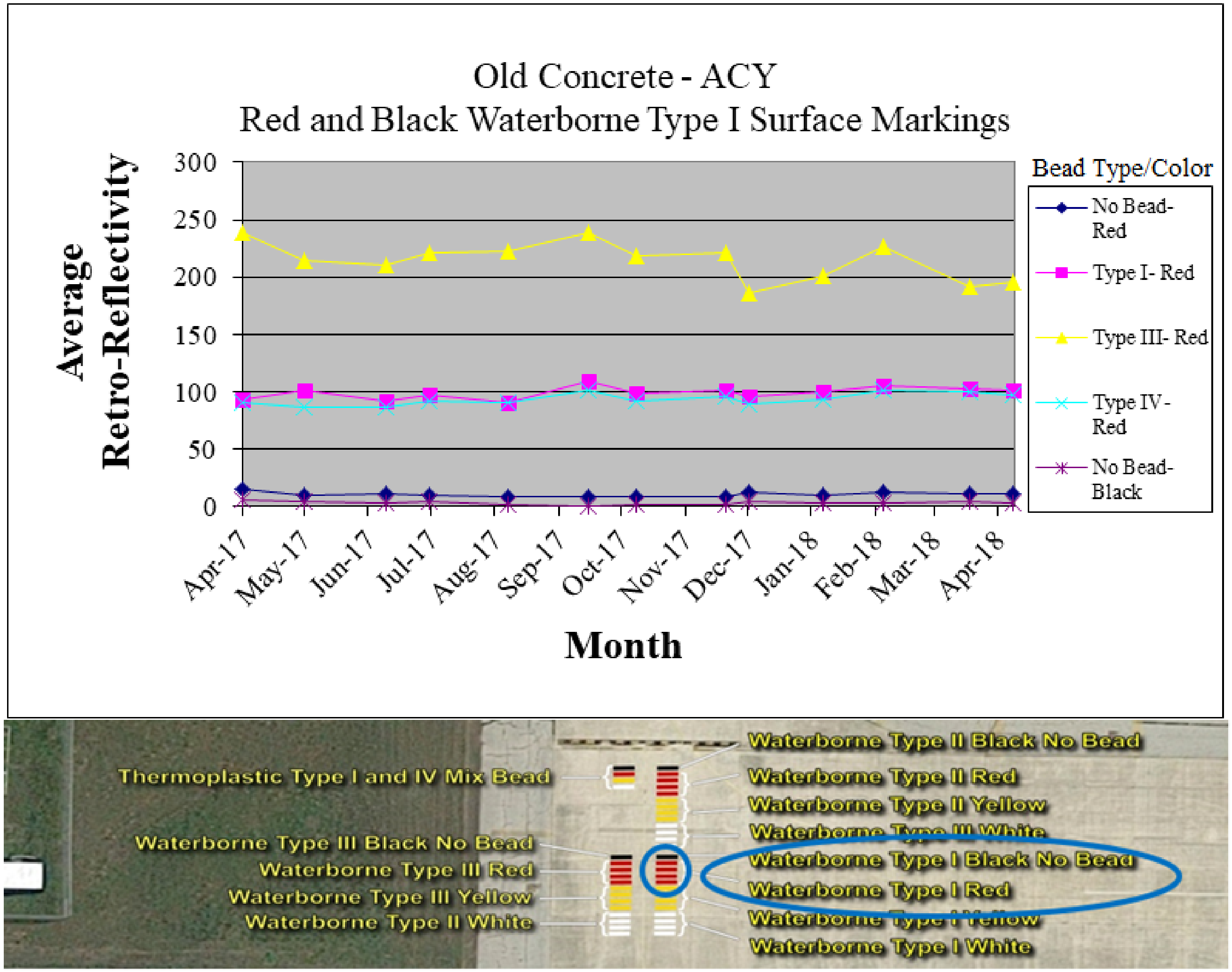


Figure 16. Retro-Reflectivity Readings: ACY Red and Black Waterborne Type I Surface Markings

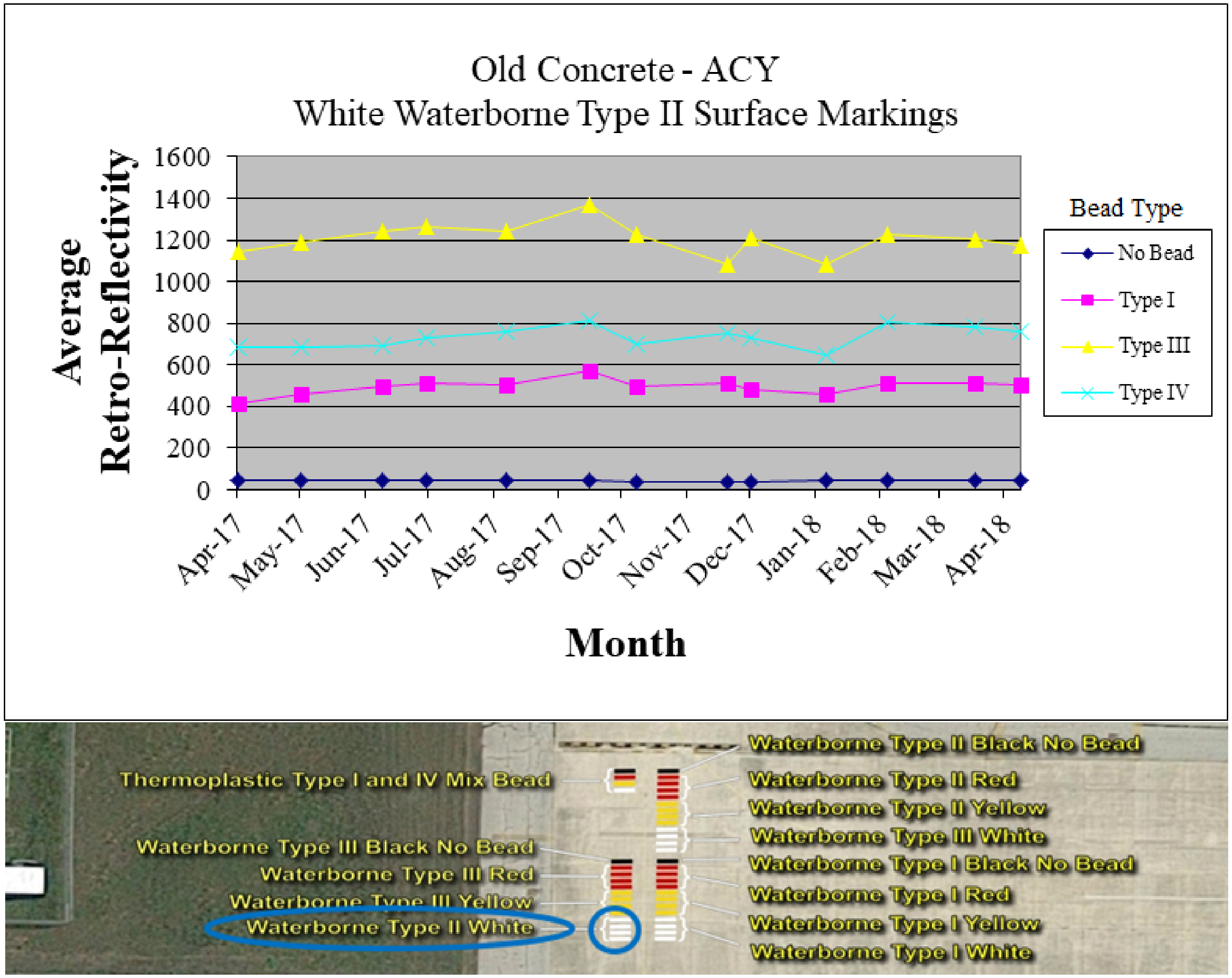


Figure 17. Retro-Reflectivity Readings: ACY White Waterborne Type II Surface Markings

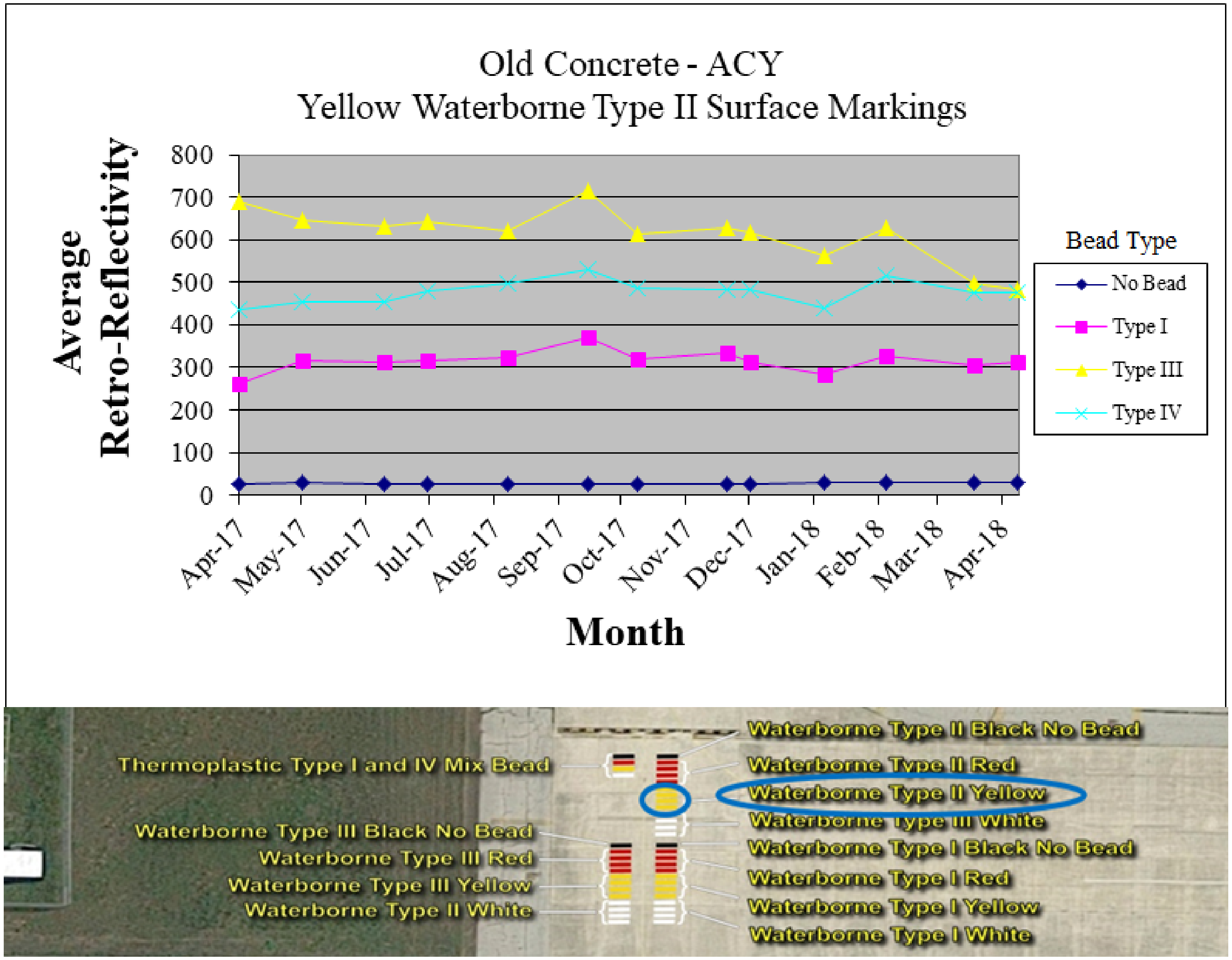


Figure 18. Retro-Reflectivity Readings: ACY Yellow Waterborne Type II Surface Markings

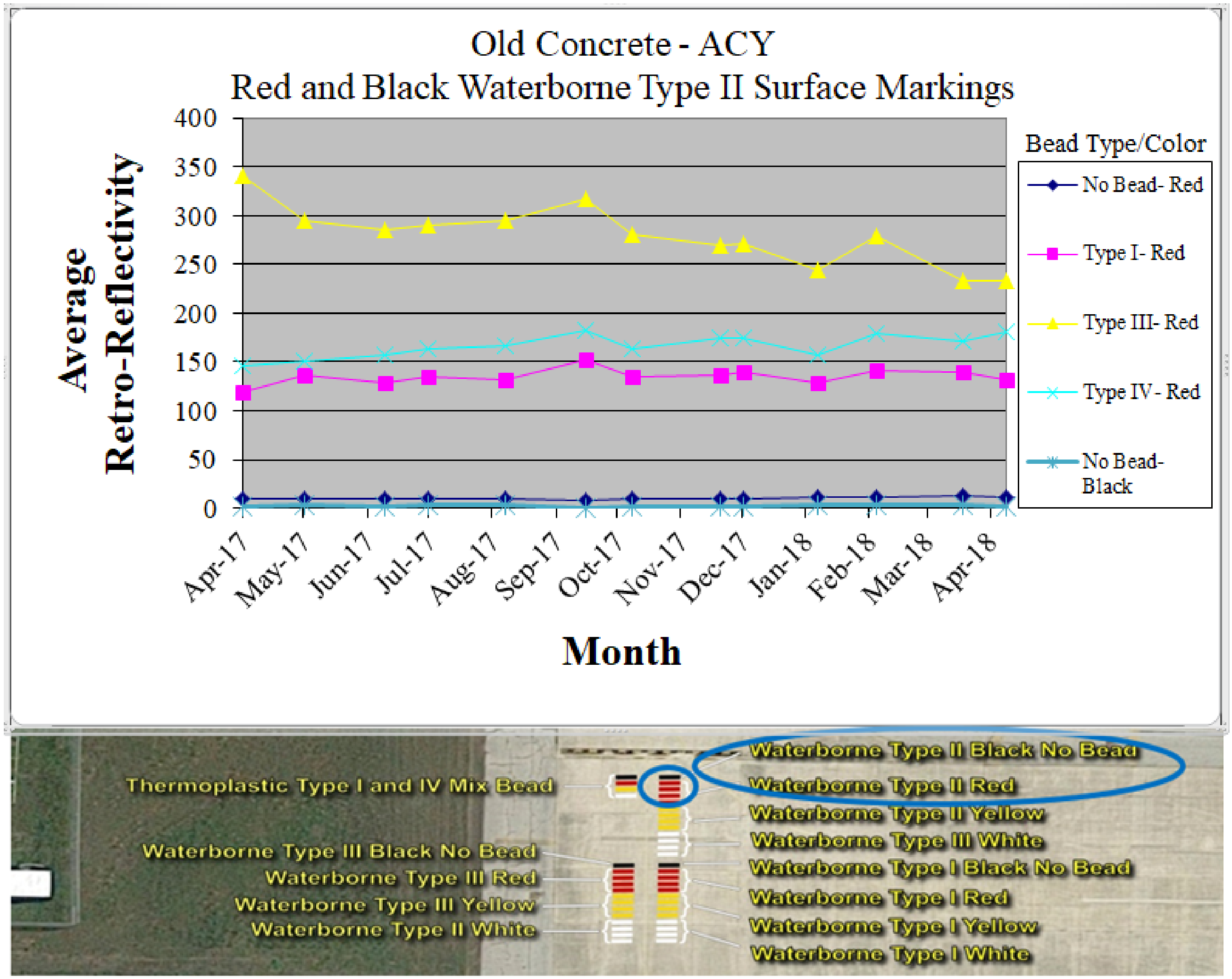


Figure 19. Retro-Reflectivity Readings: ACY Red and Black Waterborne Type II Surface Markings

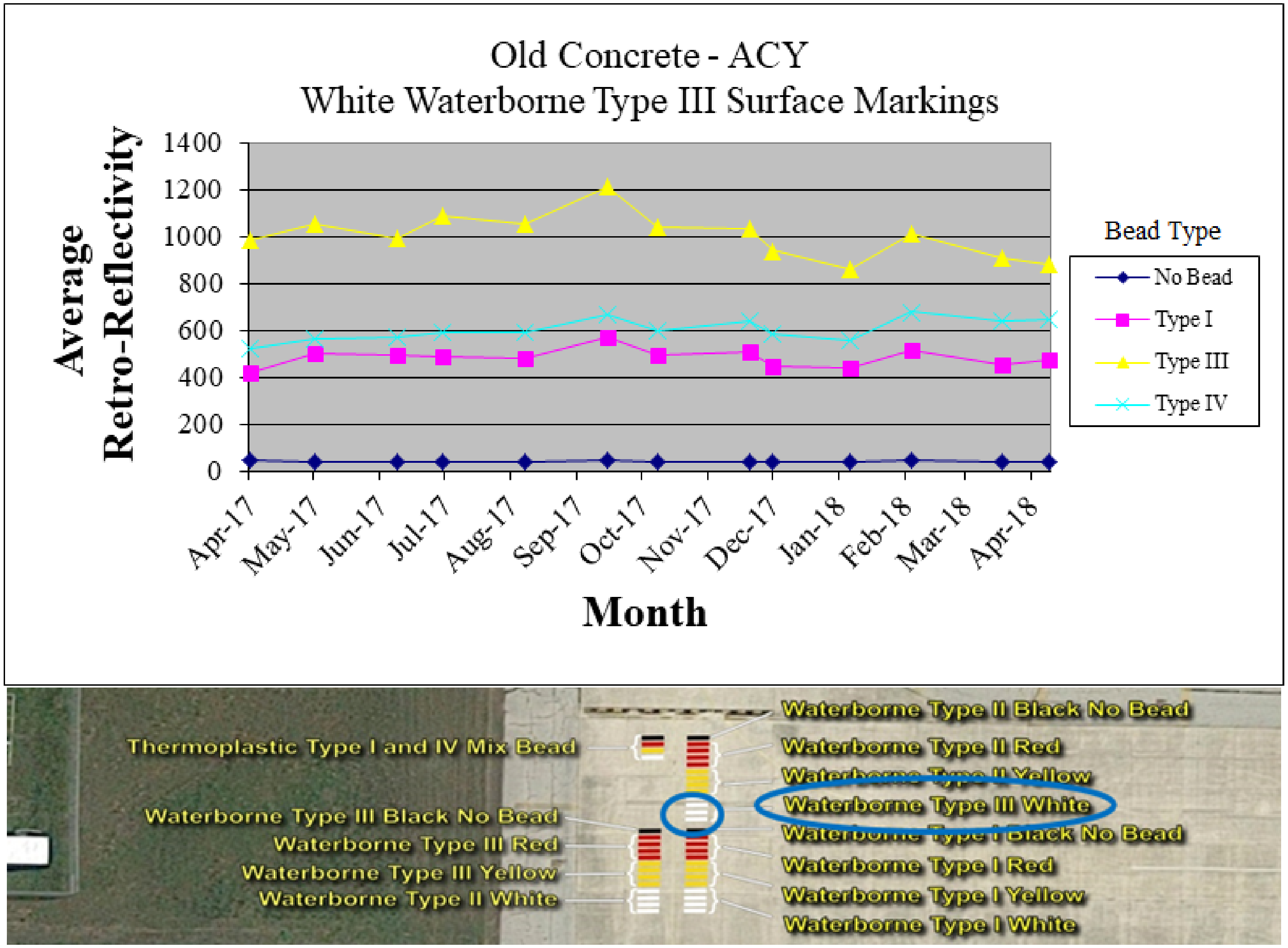


Figure 20. Retro-Reflectivity Readings: ACY White Waterborne Type III Surface Markings

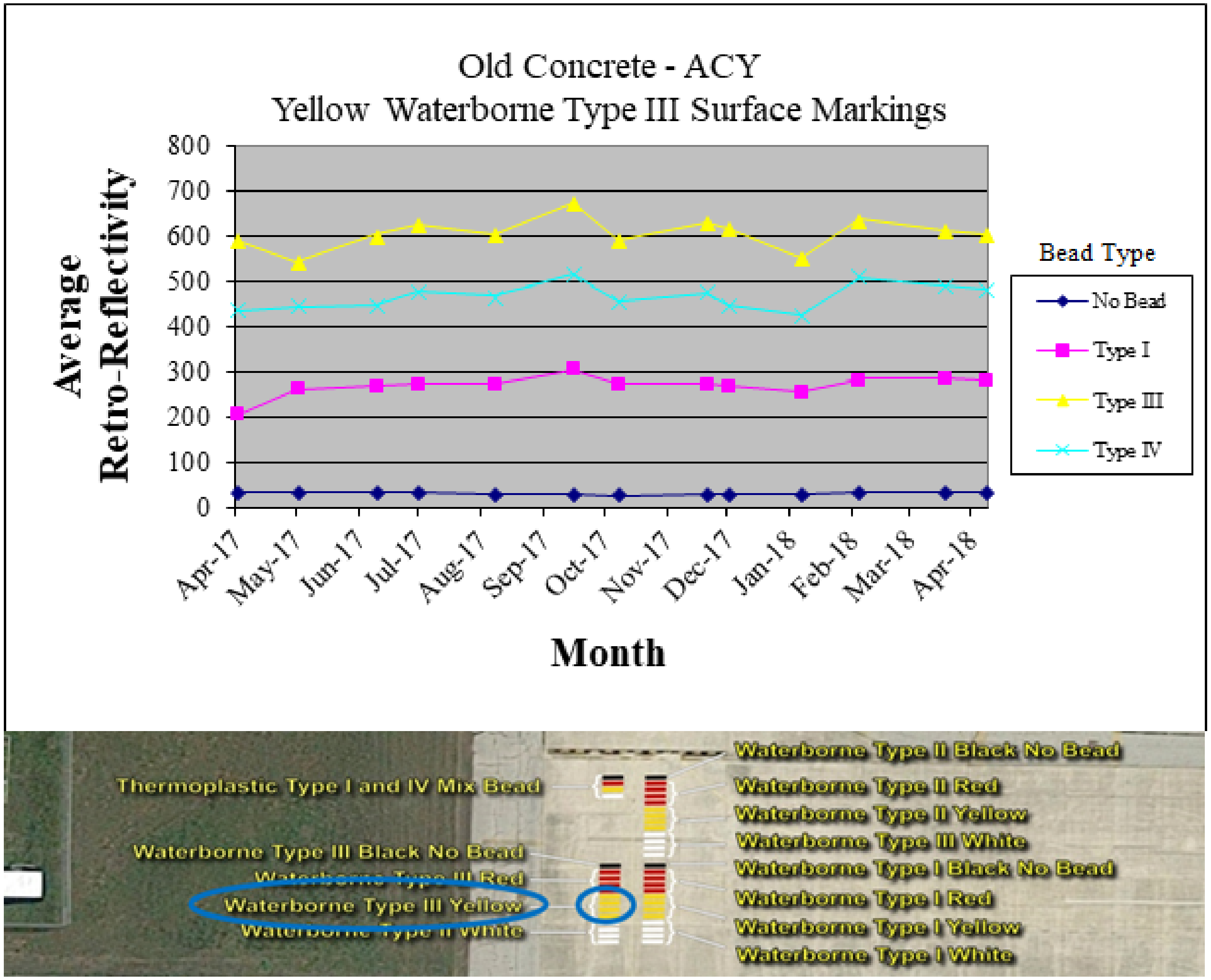


Figure 21. Retro-Reflectivity Readings: ACY Yellow Waterborne Type III Surface Markings

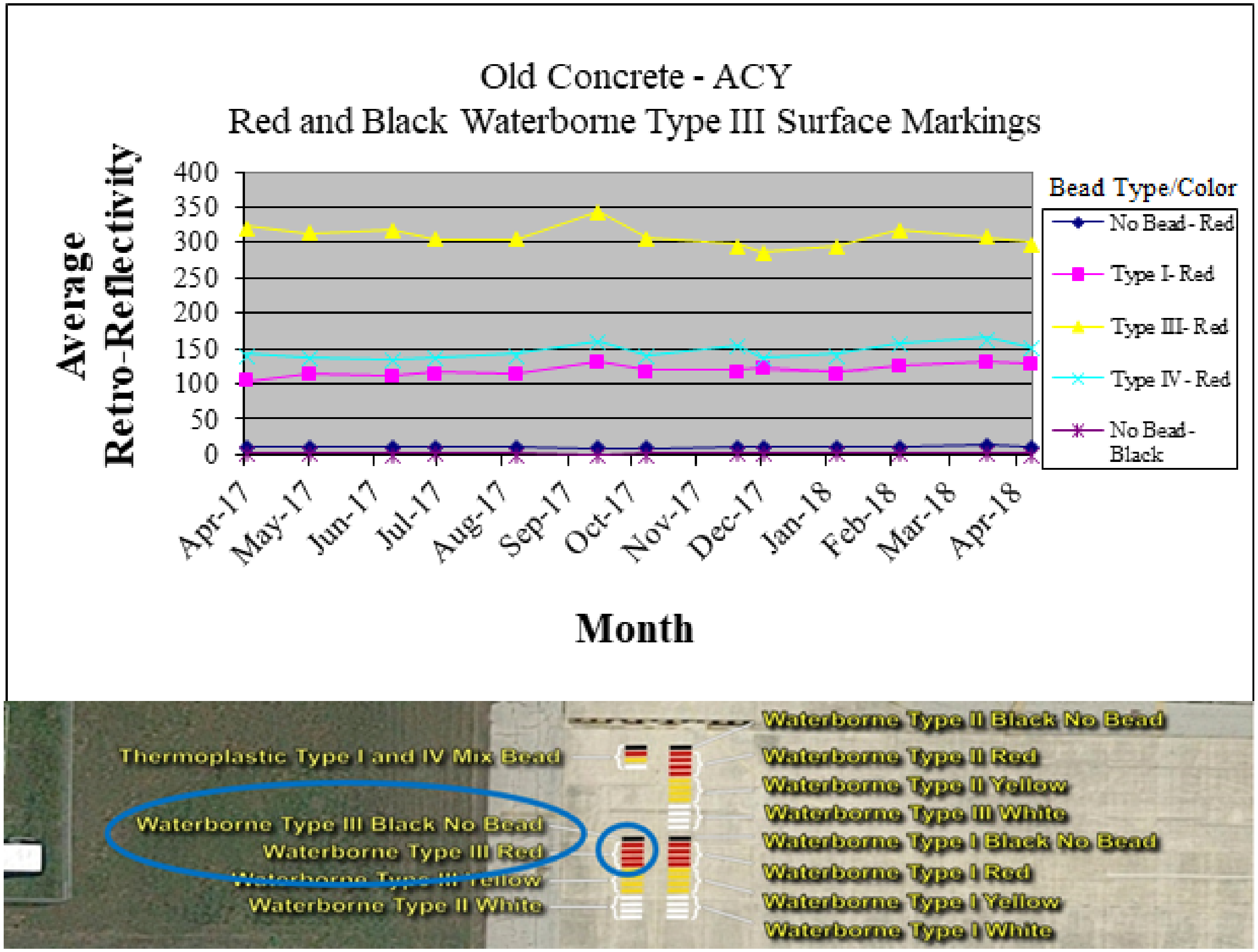


Figure 22. Retro-Reflectivity Readings: ACY Red and Black Waterborne Type III Surface Markings

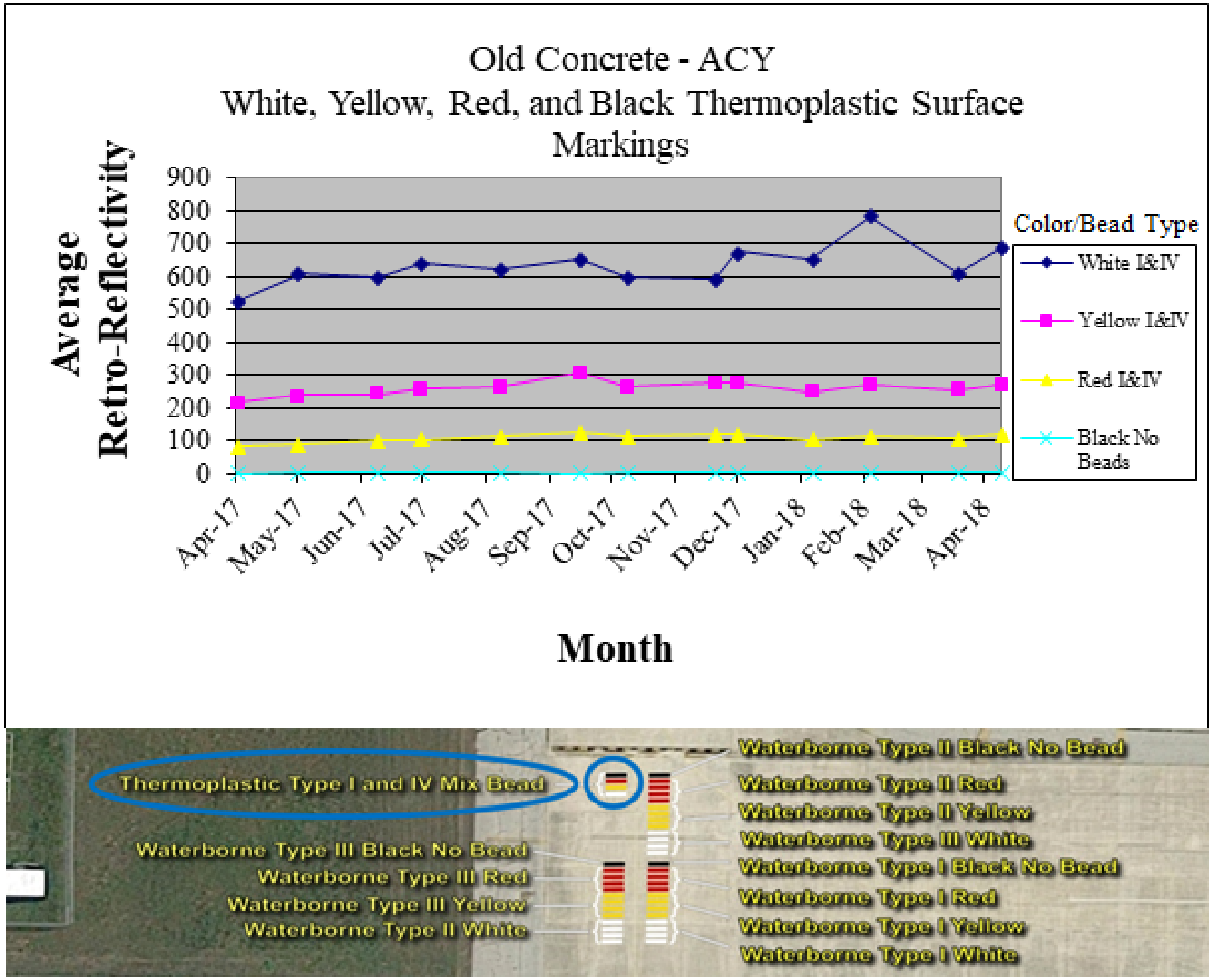


Figure 23. Retro-Reflectivity Readings: ACY Preformed Thermoplastic Surface Markings

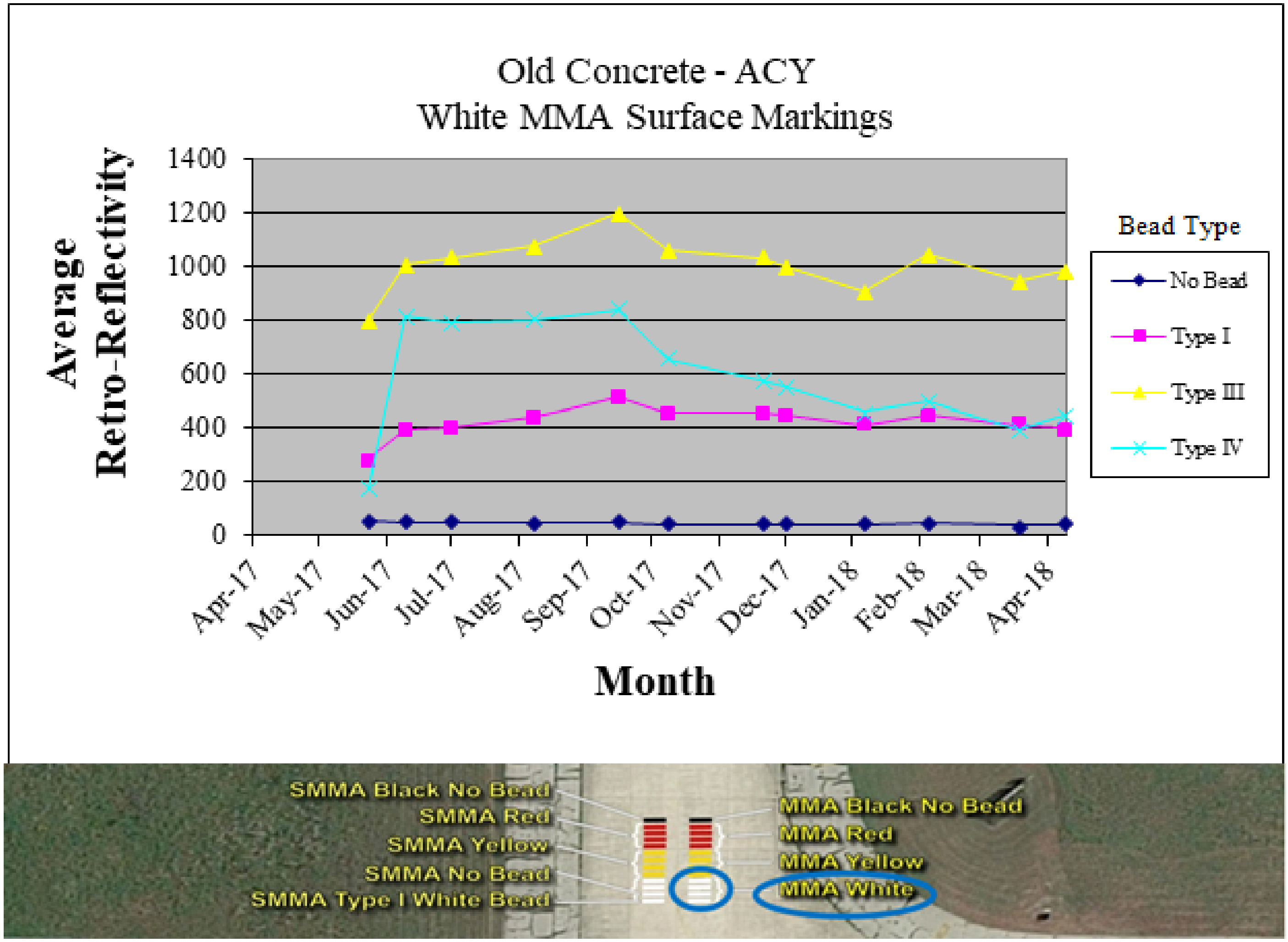


Figure 24. Retro-Reflectivity Readings: ACY White MMA Surface Markings

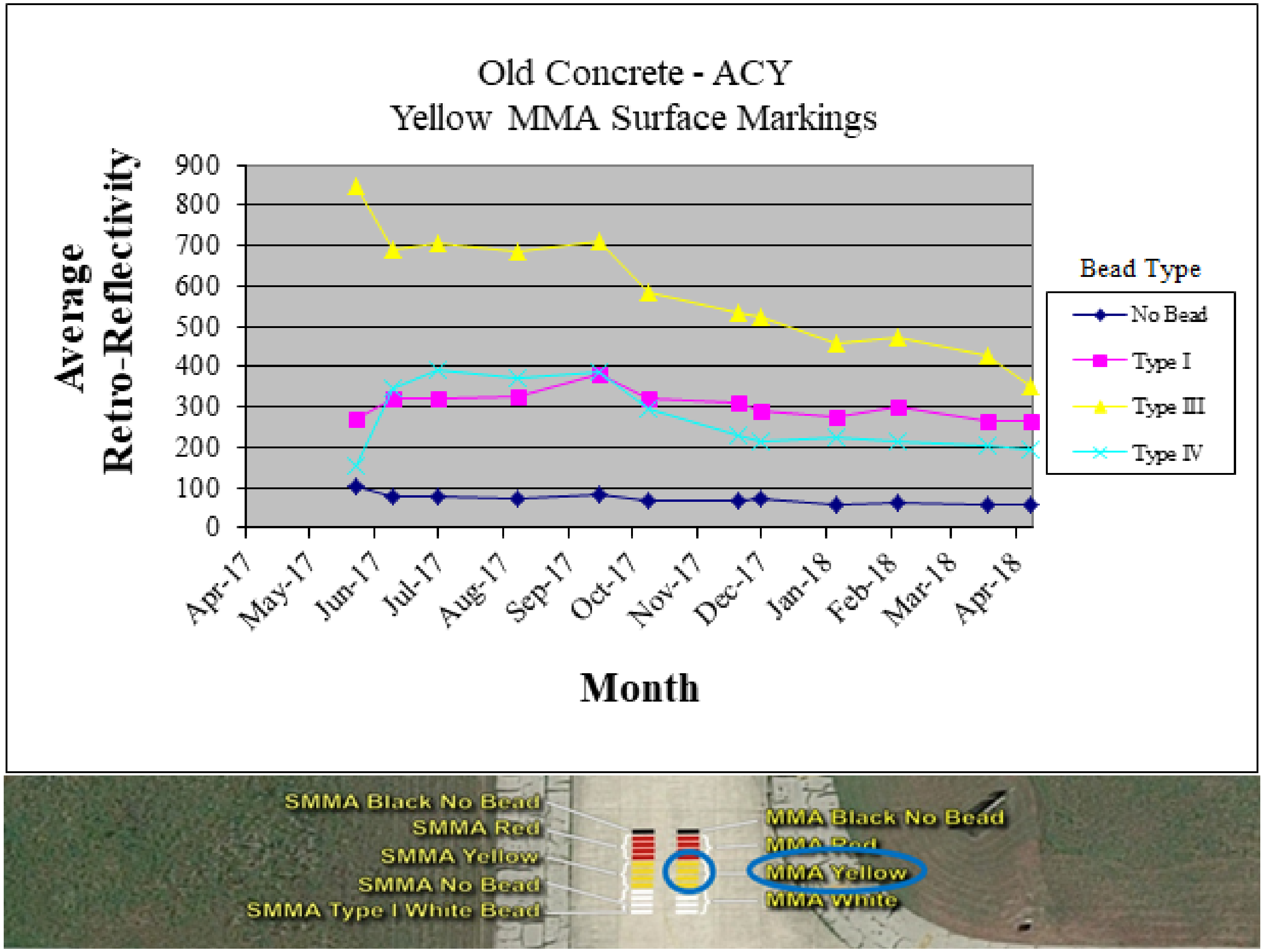


Figure 25. Retro-Reflectivity Readings: ACY Yellow MMA Surface Markings

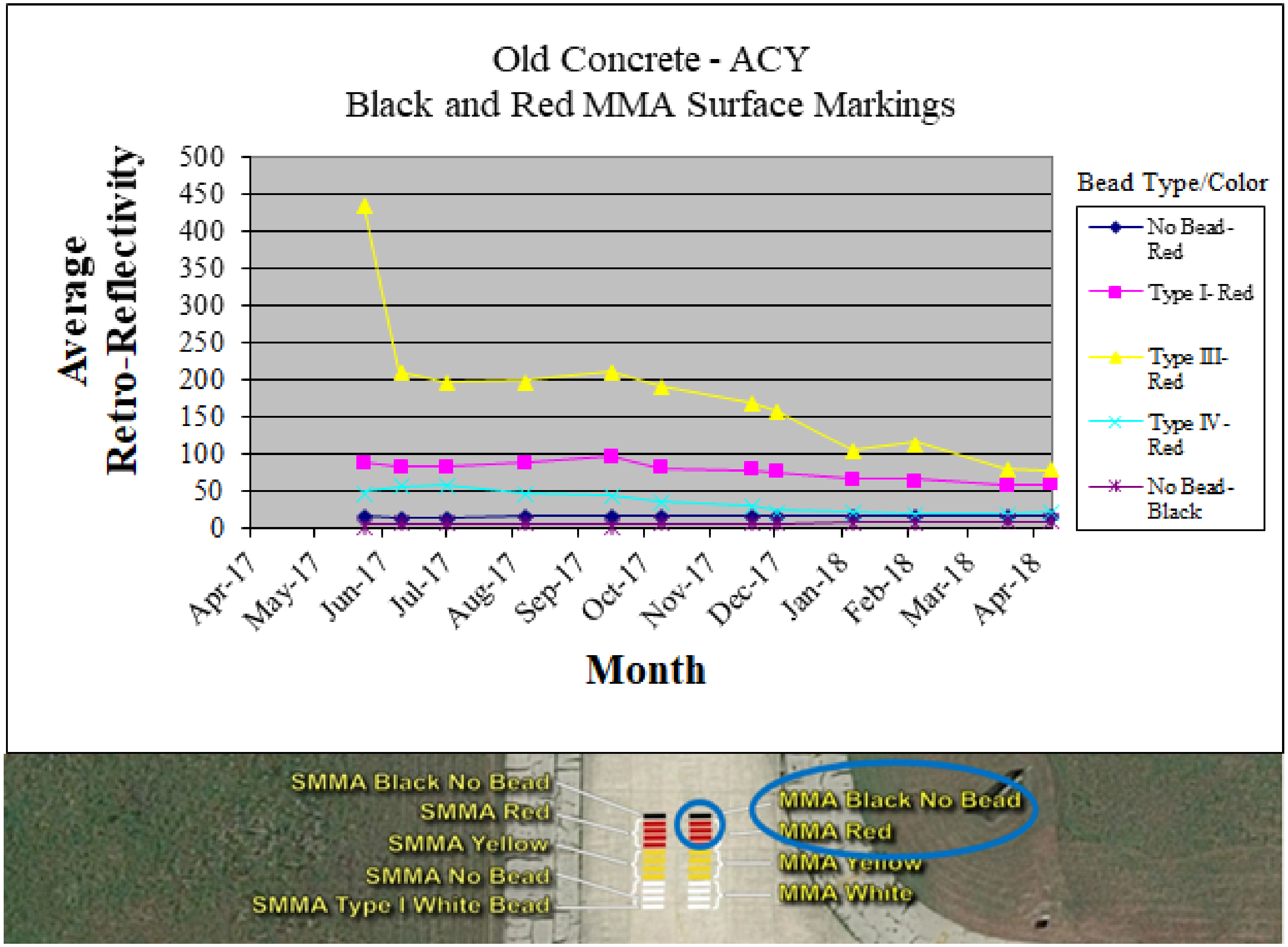


Figure 26. Retro-Reflectivity Readings: ACY Red and Black MMA Surface Markings

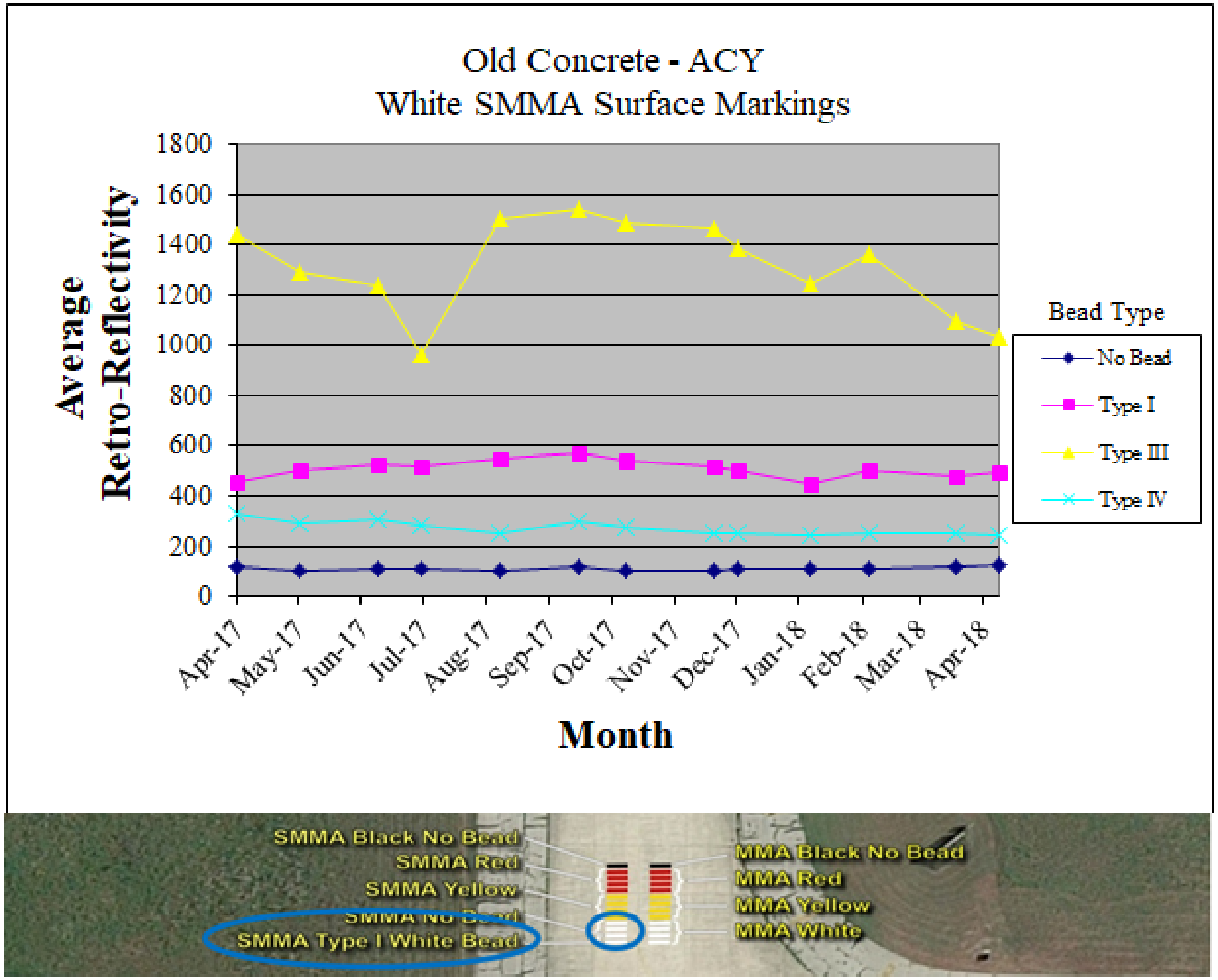


Figure 27. Retro-Reflectivity Readings: ACY White SMMA Surface Markings

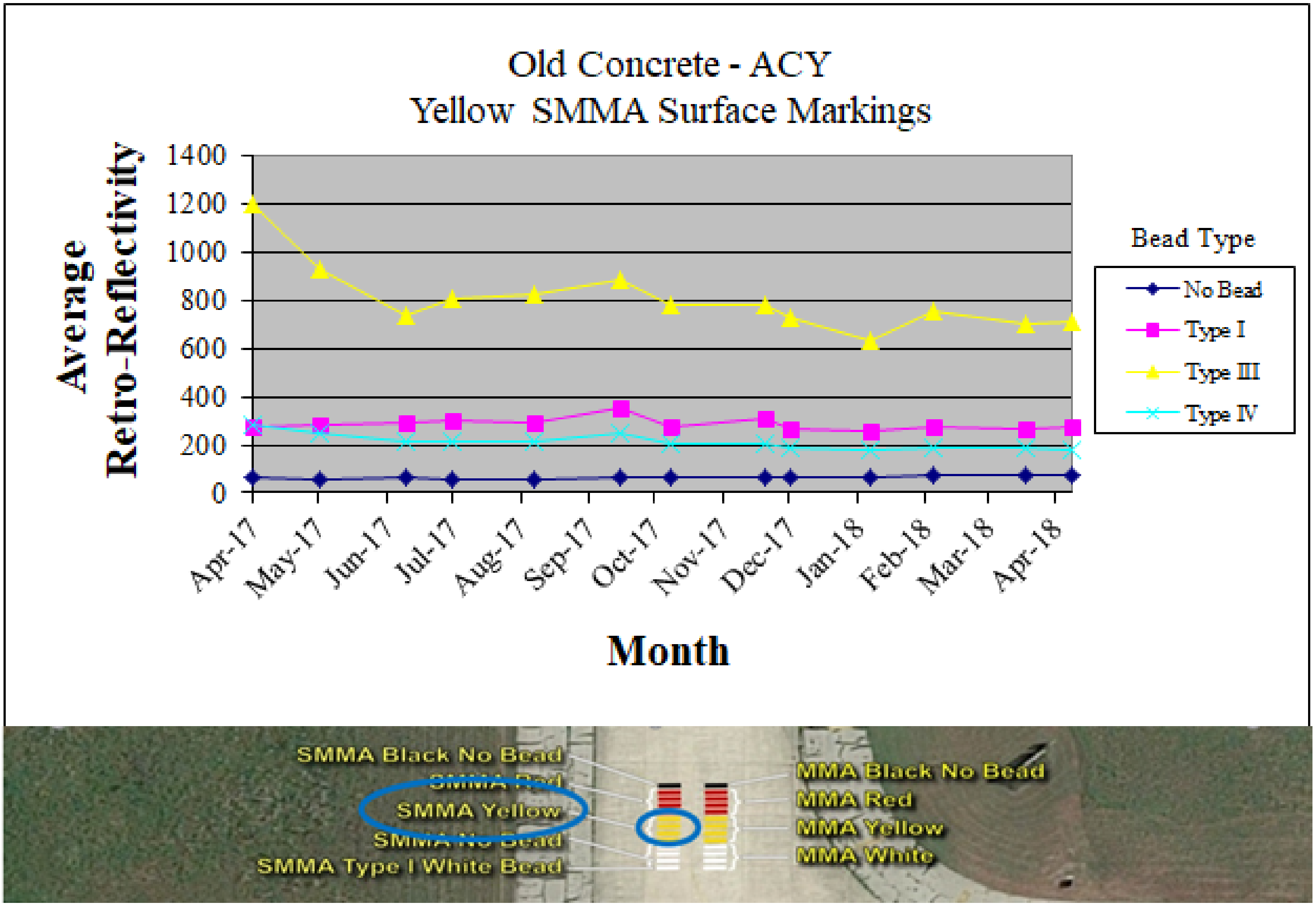


Figure 28. Retro-Reflectivity Readings: ACY Yellow SMMA Surface Markings

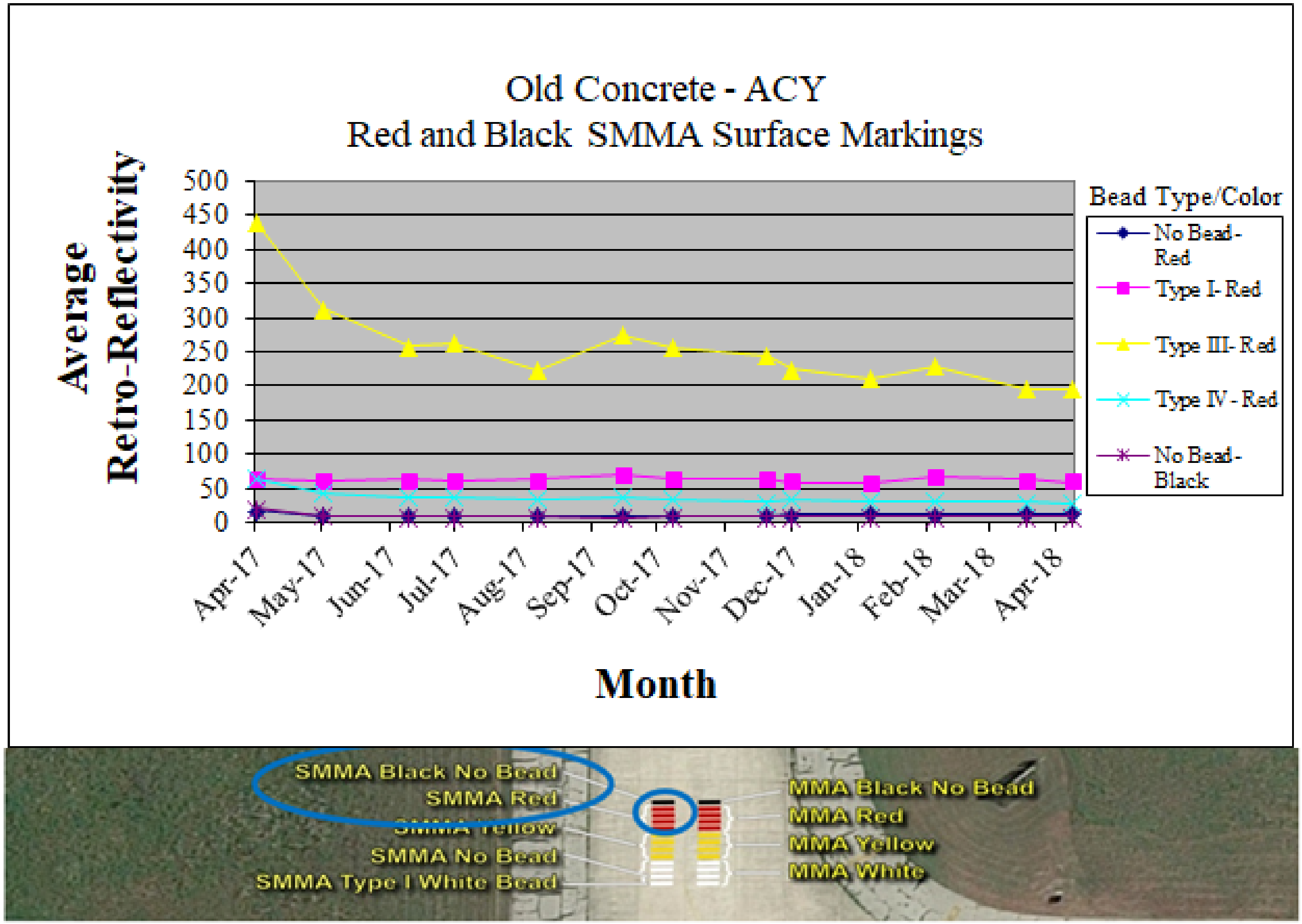


Figure 29. Retro-Reflectivity Readings: ACY Red and Black SMMA Surface Markings

3.2 ACY CHROMATICITY FIRST-YEAR RESULTS

On a monthly basis, the pavement markings evaluation for chromaticity was accomplished with a spectrophotometer by aiming the device at the pavement marking and checking the color against the CIE standard illuminant D_{65} (no bead and beaded retro-reflective paint) chromaticity chart, with two chromaticity readings collected for each marking type at ACY. The pavement markings were charted on a CIE standard illuminant D_{65} chart to identify changes in color over time. Pavement marking readings outside the color region on the chromaticity chart were considered failed. The chart in figure 30 shows the charted initial chromaticity readings for the Waterborne Type I white markings at ACY. The charts showing the initial chromaticity readings and the chromaticity readings at the end of the first year are provided in appendix A.

Overall, the white and black surface markings maintained color over time; however, the only white marking that did not remain within its respective color zone was the white SMMA marking with no beads.

The majority of the red and yellow measurements started slightly outside of the red and yellow color regions. The color regions in the CIE standard illuminant D_{65} chart depict standard colors for the CIE. The FAA uses SAE AMS-STD-595 number 33538 and 33655 for yellow markings, which are considered to be aviation yellow. Similarly, the FAA uses SAE AMS-595 number 31136 for red markings [6]. The colors used by the FAA for red and yellow markings differ somewhat from the ICAO standards, which is why these markings started outside of their respective color zones in the CIE standard illuminant D_{65} chart.

During the first year of the study, the yellow and red surface markings at ACY shifted slightly away from their respective color zones on the color guide charts. Red MMA and SMMA surface markings started halfway between the red and white zones and shifted toward the white. Overall, the red and yellow markings shifted more on the x-axis of the color guides than the y-axis. These colors shifted away from the yellow and red zones and closer to the white zone, likely a result of fading. As red markings fade, they begin to appear more pink than red. Figure 31 shows red MMA markings at ACY shortly after installation and at the end of the first year of the study. The markings were bright red at installation but were somewhat faded, particularly around the edges of the markings, by April 2018.

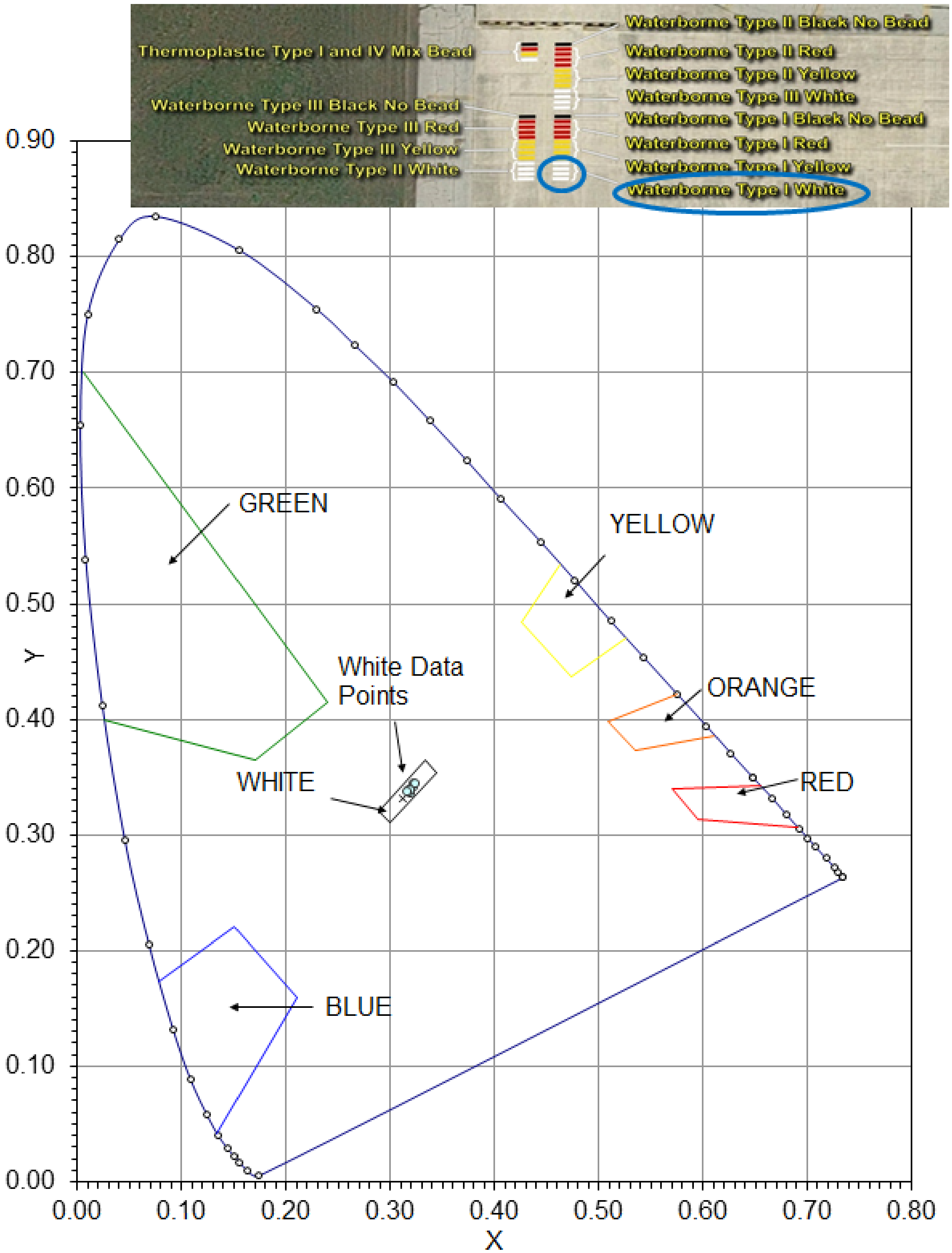


Figure 30. Initial Color Guide Readings for ACY Waterborne Type I White

Figure 31. Color Comparison: ACY Red MMA—June 2017 (Left) vs April 2018 (Right)

Similar to the red markings, yellow markings faded during the first year of the study. Figure 32 shows yellow SMMA markings shortly after installation and at the end of the first year. These markings visibly faded during that period.

Figure 32. Color Comparison: ACY Yellow SMMA—May 2017 (Left) vs April 2018 (Right)

3.3 ACY RUBBER COVERAGE FIRST-YEAR RESULTS

The surface marking test deck at ACY served as a baseline for this research effort because the location only experiences occasional aircraft and vehicle traffic. By the end of the first year, the surface markings at ACY had not accumulated significant rubber deposits. This, combined with infrequent exposure to aircraft wheel loads, likely explains why the retro-reflectivity readings at ACY were largely consistent throughout the year. However, as shown in figure 33, the yellow MMA markings had accumulated some dirt by April 2018. The other markings remained mostly uncontaminated throughout the year. Photos that provide a comparison of the markings at the beginning of the study and at the end of the first year are provided in appendix B.

Figure 33. Color Comparison: ACY Yellow MMA Markings—June 2017 (Left) vs April 2018 (Right)

3.4 ACY FRICTION FIRST-YEAR RESULTS

FAA AC 150/5320-12C "Measurement, Construction, and Maintenance of Skid-Resistant Airport Pavement Surfaces" [7] provides airport operators with guidance regarding acceptable friction levels for runway surfaces. At 40 mph, the average friction coefficient for each 500-ft section of the runway surface should be at least 0.50µ [7]. Friction data should be collected at 10 feet from the runway centerline [7]. For runways that are utilized by wide-body aircraft, data should be collected at 20 feet from the runway centerline [7]. The friction data collected at ACY were recorded by the SARSYS SFT and charted to measure the difference in the friction coefficient between the different surface marking types and the surrounding bare pavement. Each run was performed at 40 mph and according to the manufacturer's recommended settings. Friction data collection occurred on June 2, 2017. For each marking, the collection of friction data began approximately 100 feet before the beginning of the marking and ended roughly at the end of each marking. Two data collection runs were completed for each of the five friction lines. Friction data will be collected at ACY on an annual basis for the remainder of the study. Appendix C shows the SARSYS SFT Friction Data.

As shown in figure 34, the friction coefficient for the exposed concrete prior to the Waterborne Type I marking was between approximately 0.60µ and 0.65µ, while the average for the marking was 0.42µ. The second run for the Waterborne Type I marking produced similar results, as shown in figure 35. The friction coefficient for the concrete prior to the marking ranged from approximately 0.56µ to 0.64µ, while the average for the marking was 0.39µ. The average friction coefficient for the Waterborne Type I friction line between the two runs was 0.41µ.

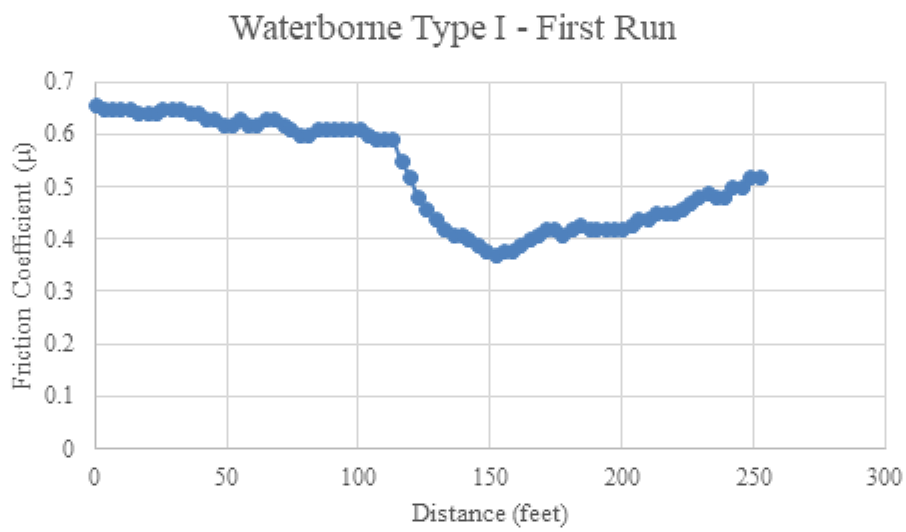


Figure 34. Friction Readings for Waterborne Type I Marking—First Run

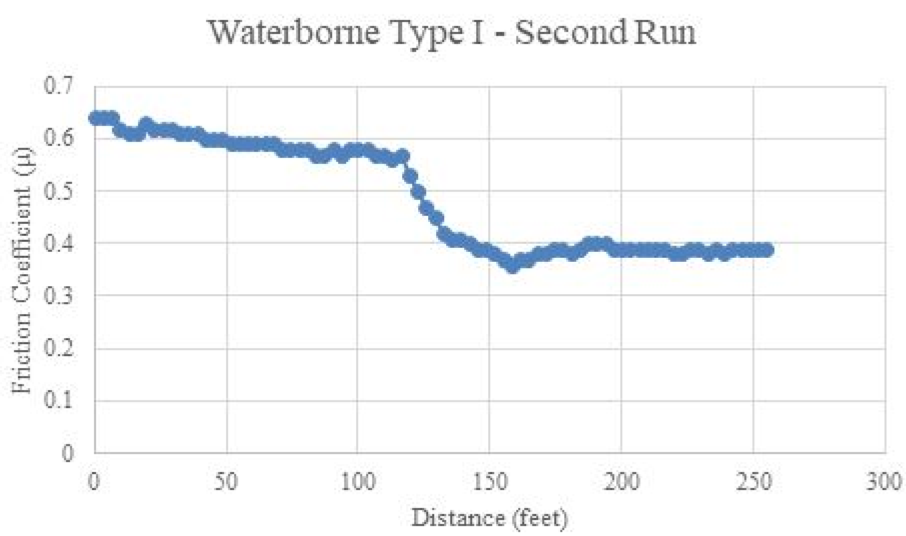


Figure 35. Friction Readings for Waterborne Type I Marking—Second Run

The friction coefficient for the concrete prior to the Waterborne Type II friction line ranged from approximately 0.56µ to 0.72µ, as shown in figures 36 and 37. The average friction coefficient for the Waterborne Type II friction line was 0.43µ for the first run and 0.40µ for the second run. The average for the two runs was approximately 0.42µ.

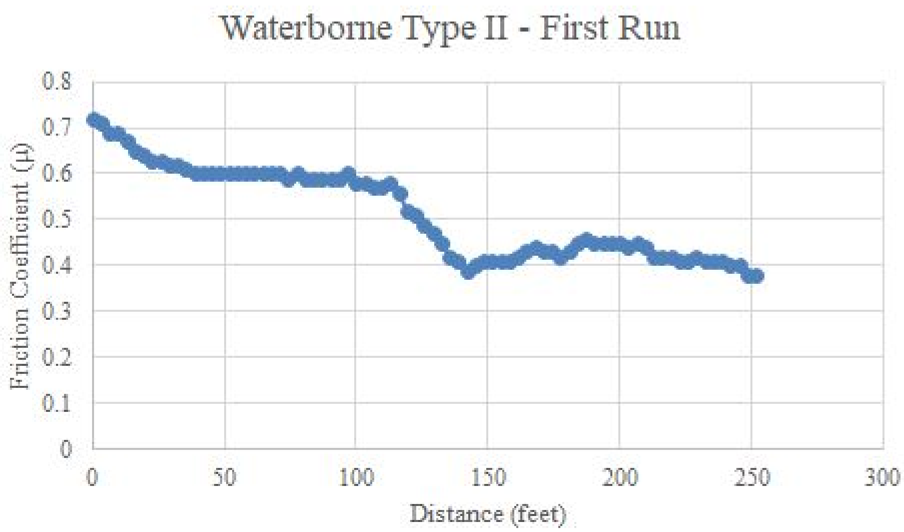


Figure 36. Friction Readings for Waterborne Type II Marking—First Run

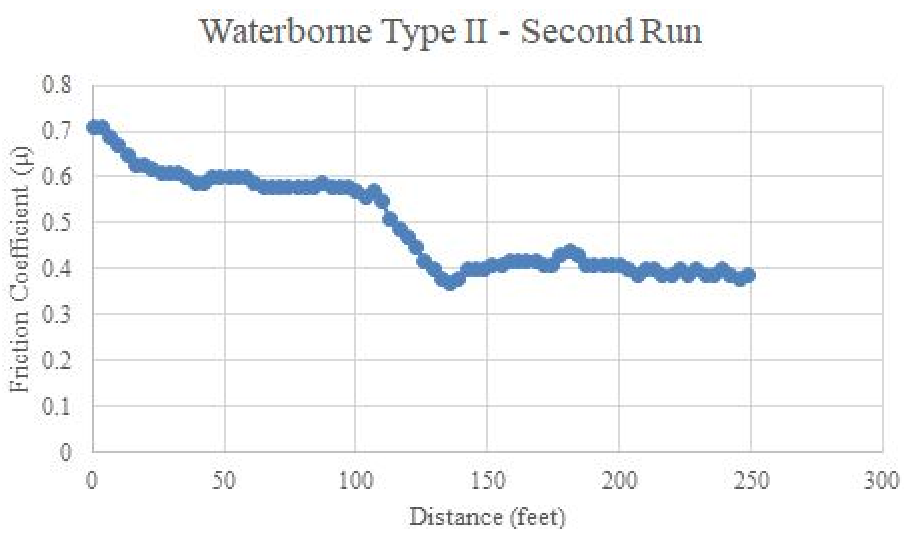


Figure 37. Friction Readings for Waterborne Type II Marking—Second Run

The friction coefficient for the concrete prior to the Waterborne Type III friction line ranged from approximately 0.58μ to 0.64μ, as shown in figures 38 and 39. The average friction coefficient was 0.47μ during the first run and 0.44μ during the second run. The average for the two runs was 0.46μ.

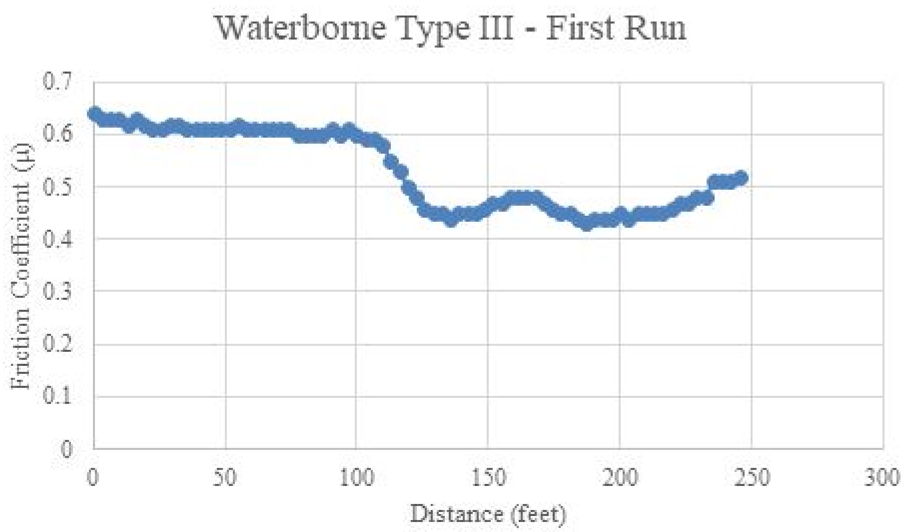


Figure 38. Friction Readings for Waterborne Type III Marking—First Run

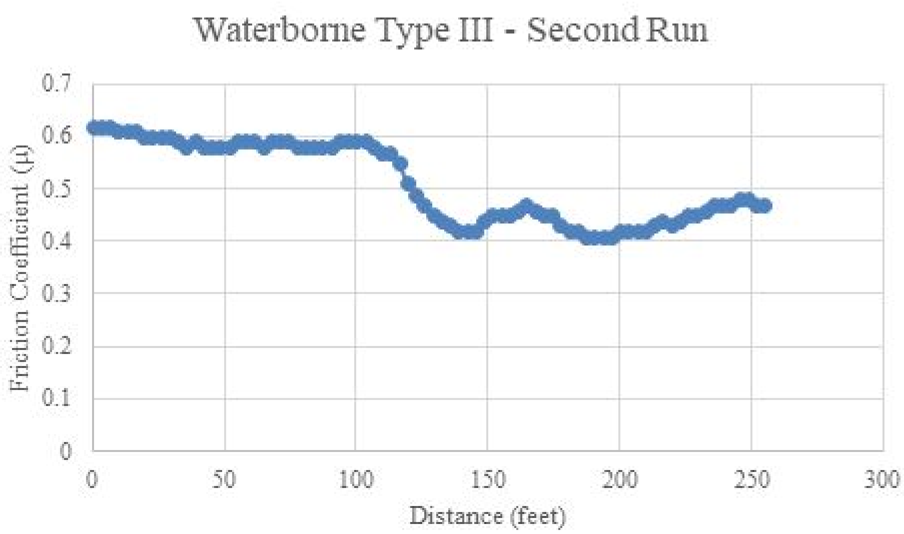


Figure 39. Friction Readings for Waterborne Type III Marking—Second Run

The friction coefficient for the concrete prior to the MMA friction line ranged from approximately 0.52µ to 0.60µ, as shown in figures 40 and 41. The average friction coefficient for the MMA friction line was 0.42µ during the first run and 0.41µ during the second run. The average for the two runs was 0.42µ.

Figure 40. Friction Readings for MMA Marking—First Run

Figure 41. Friction Readings for MMA Marking—Second Run

The friction data for the SMMA friction line is shown in figures 42 and 43. The friction coefficient for the concrete prior to the marking ranged from approximately 0.60µ to 0.64µ. Unlike the other surface marking types discussed previously, the average friction coefficient of the SMMA friction line was higher than the exposed concrete prior to the marking. The average friction coefficient was 0.71µ during the first run and 0.78µ during the second run. The average for the SMMA friction line was 0.75µ. This average is significantly higher than the average friction coefficient of 0.42µ for the Waterborne Type I, Waterborne Type II, Waterborne Type III, and MMA friction lines.

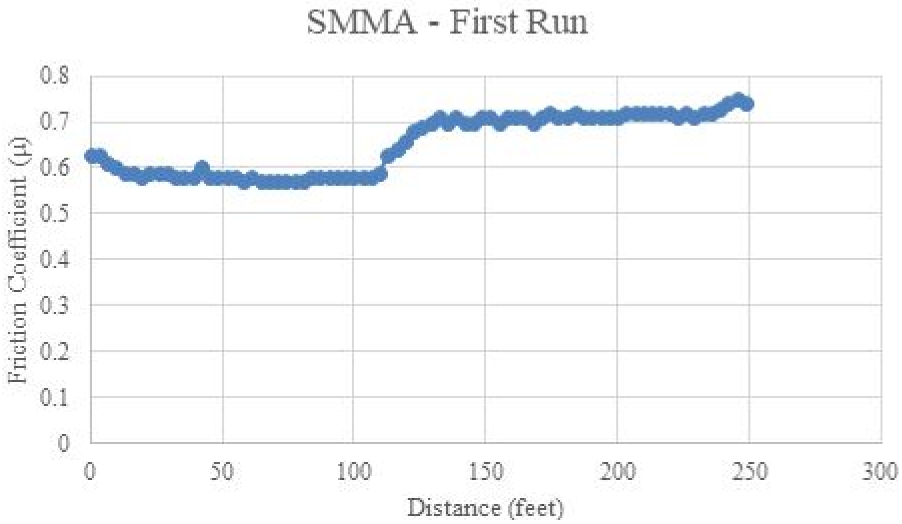


Figure 42. Friction Readings for SMMA Marking—First Run

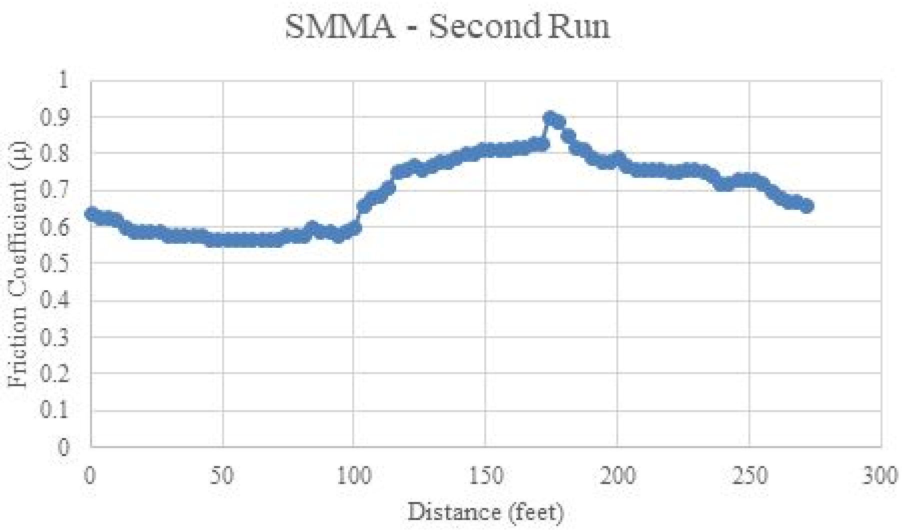


Figure 43. Friction Readings for SMMA Marking—Second Run

The average friction coefficient for the Waterborne Type I, Waterborne Type II, Waterborne Type III, and MMA surface markings was lower than the minimum of 0.50μ required in FAA AC 150/5320-12C [7]. However, in practice, runway surface markings at 10 to 20 feet from the runway centerline are generally not long enough to significantly impact the average friction levels of each 500-ft section of the runway.

4. PHASE I—EWR: OBSERVATIONS AND RESULTS

Phase I (April 2017-April 2018), began with a surface marking test deck installation at EWR between April 19 and 21, 2017. As shown in figure 44, the markings were installed on Taxiway N, which is a high-speed turnoff taxiway for Runway 22L. This taxiway is frequently used by a variety of aircraft types from small commuter to large wide-body aircraft. Similarly to

ACY, the taxiway was exposed to four distinct seasons including cold and wet conditions. During the winter months, the taxiway was subjected to snow removal operations. Additionally, rubber deposits were removed from the taxiway four times during the study, in accordance with FAA AC 150/5320-12C [7], which addresses how many movements before rubber removal is required.

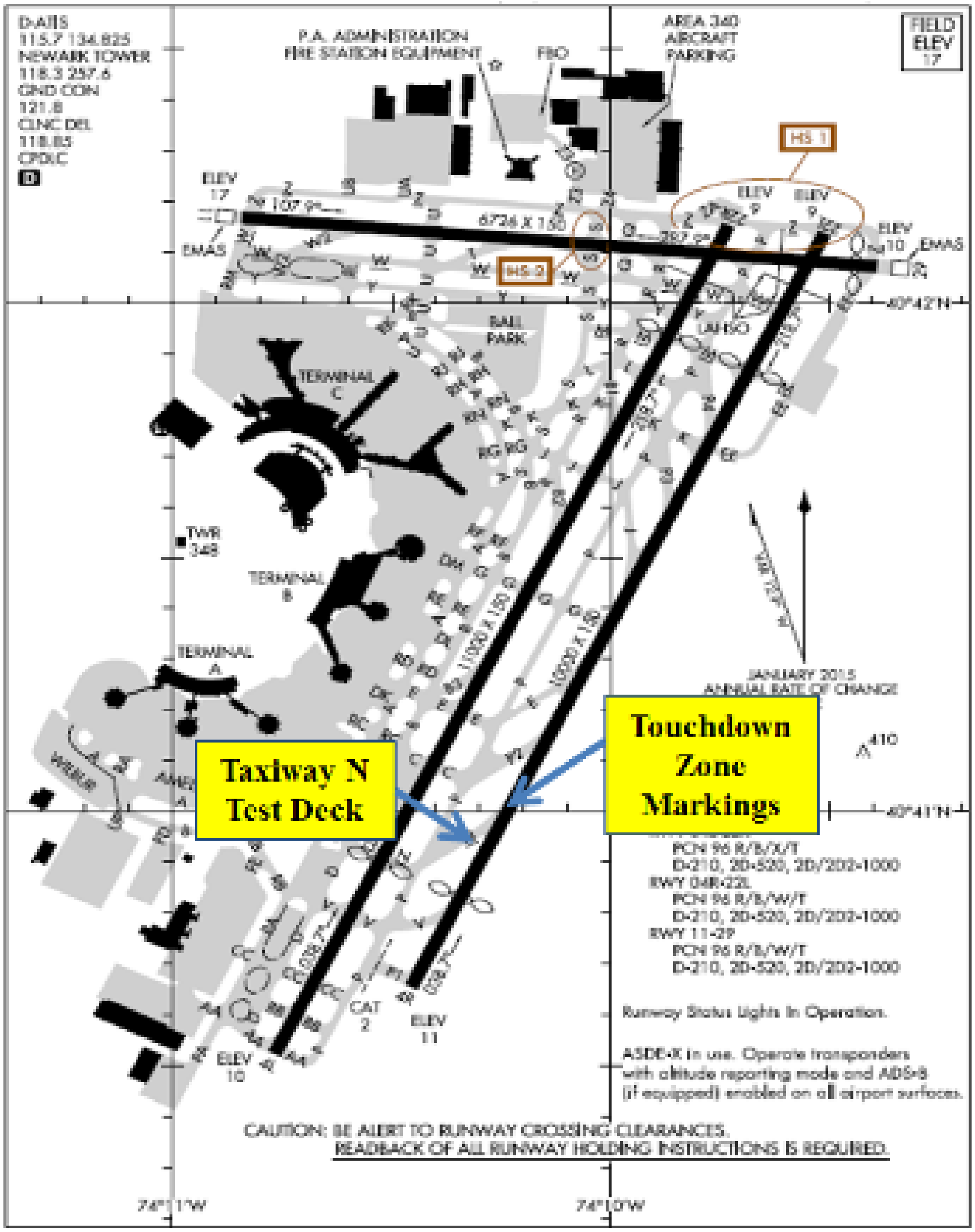


Figure 44. Test Locations at EWR

Figure 45 shows the surface marking test deck layout at EWR. A total of 74 surface markings were installed on Taxiway N.

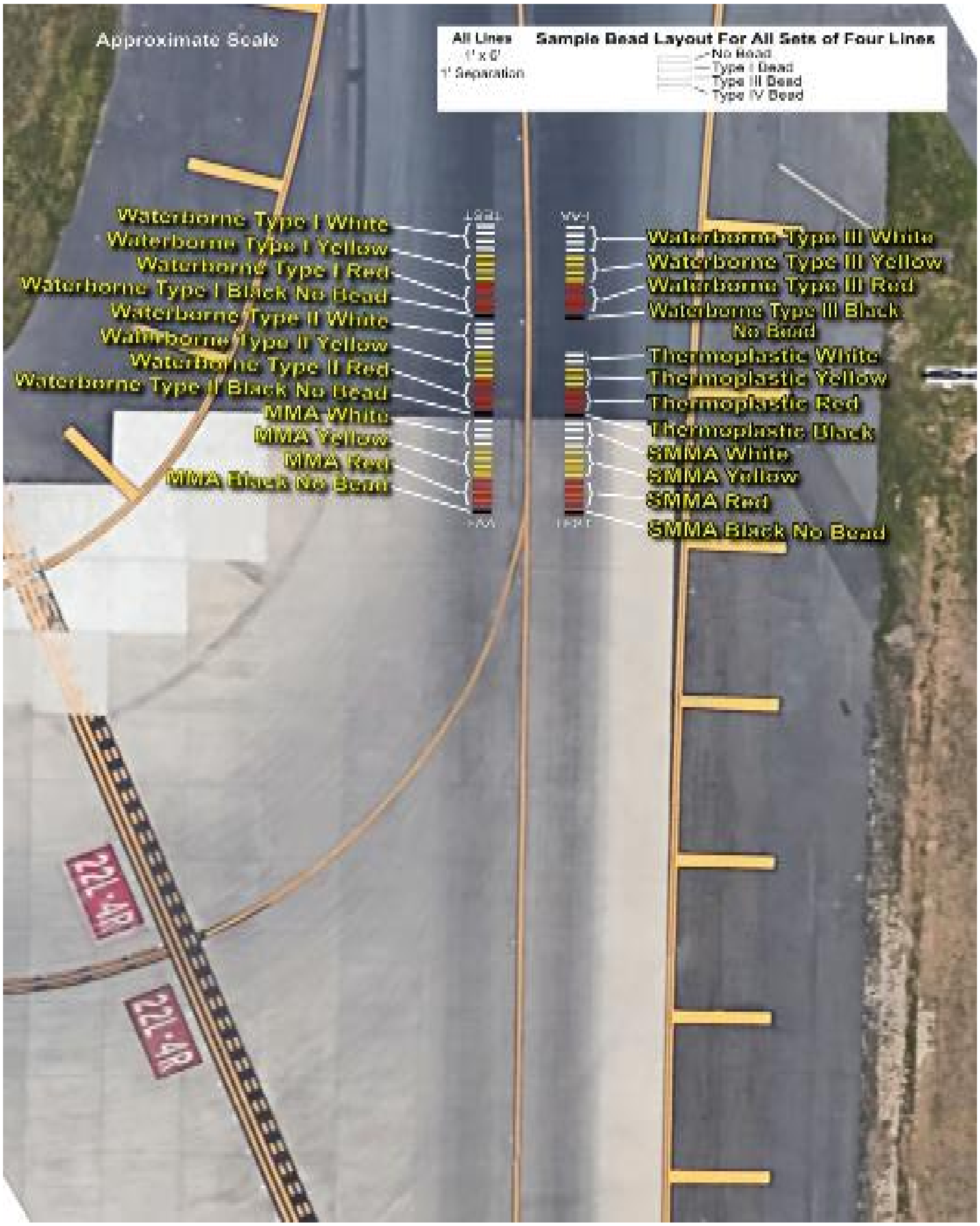


Figure 45. Test Deck Layout at EWR

Figure 46 provides a ground-level view of the surface marking test deck at EWR.

Figure 46. Surface Marking Test Deck on EWR Taxiway N

In addition to the surface marking test deck, a series of six white stripes to assess rubber deposit buildup were installed in the touchdown zone for Runway 4R, as shown in figure 46. The paint markings contained Type I beads, while the Preformed Thermoplastic marking contained a mix of Type I and Type IV beads. Each marking was 6-ft long and 1-ft wide with 1 foot between each marking. Figure 47 shows the Runway 4R markings layout.

Figure 47. Markings Layout at Touchdown Zone on EWR Runway 4R

The surface marking test deck installation at EWR was completed on April 21, 2017. Initial retro-reflectivity and chromaticity readings were collected on the same date. Additional readings were collected one week later on April 28, 2017, and on a monthly basis, weather-permitting, thereafter until April 2018, when all of the markings were considered to be failed. Unlike the baseline surface marking test deck at ACY, the test deck at EWR was located on a high-speed turnoff taxiway that is frequently used by various aircraft, including large air carrier aircraft. ASDE-X data from EWR estimated that, based on traffic figures from 2017, approximately 51,000 aircraft use Taxiway N annually. As a result, there were significant differences in the rate of surface marking deterioration between baseline location ACY and EWR.

Data collection analysis during Phase I (April 2017-April 2018) is provided in sections 4.2 through 4.4. The retro-reflective threshold limits were: <100 mcd/m^2/lux for white, <70 mcd/m^2/lux for yellow, and <25 mcd/m^2/lux for red. The coverage threshold pass/fail limit was 50%. These values were determined in technical note, DOT/FAA/AR-TN03/22 [4].

4.1 PHASE I RETRO-REFLECTIVITY RESULTS—EWR

On a monthly basis, the average of the six retro-reflectivity readings that were collected for each marking type was calculated. This average value was charted in a Microsoft Excel spreadsheet to allow the ATRD team to monitor the retro-reflectivity performance of the markings over time. Within one week of installation, 16 of the 54 (30%) surface markings that contained beads fell below the proposed retro-reflectivity minimums of 100 mcd/m^2/lx for white markings, 70 mcd/m^2/lx for yellow markings, and 25 mcd/m^2/lx for red markings. Within one month of installation, only the white MMA surface marking with Type III beads remained above the proposed retro-reflectivity minimum for only three months after installation.

EWR airport personnel advised the ATRD team that rubber deposits were removed from the surface markings between the May 2017 and June 2017 data collection, the July 2017 and August 2017 data collection, the September 2017 and November 2017 data collection, and the March 2018 and April 2018 data collection. AC 150/5320-12C addresses the frequency of removal in Section 3.1, Table 4.1; and Section 4.1 and 4.2 address the removal methods [7].

All surface markings showed retro-reflectivity degradation after rubber buildup and recovery after rubber removal. This likely explains the “zig-zag” appearance of the retro-reflectivity charts, shown in figures 48 through 64. For example, 27 of the 54 (50%) surface markings that contained beads were below the proposed retro-reflectivity minimums one month after installation recovered above the proposed retro-reflectivity minimums the following month after rubber deposit removal. This pattern continued for various markings throughout Phase I. However, although retro-reflectivity numbers increased after rubber removal, the pavement markings did not recover to their original values.

Several surface marking types remained below the proposed retro-reflectivity minimums, even after rubber removal, including white Waterborne Type I markings with all bead types, yellow Waterborne Type I markings with Type III beads, and all Waterborne Type I, Waterborne Type II, MMA, and red SMMA markings with Type IV beads. The combination of frequent exposure to aircraft wheel loads and forces from rubber removal may have caused beads to be dislodged from the markings.

Preformed Thermoplastic markings, which contained a mixture of Type I and Type IV beads, maintained retro-reflectivity better than most other marking types. Though these markings fell below the proposed retro-reflectivity minimums three times during the study, their retro-reflectivity readings recovered above the proposed minimums after rubber deposits were removed. However, like all other surface marking types at EWR, these markings fell below the proposed minimums after the final rubber removal, which occurred shortly before the April 2018 data collection.

Similar to Preformed Thermoplastic markings, Waterborne Type III markings with all bead types generally fell below the proposed retro-reflectivity minimums as rubber buildup increased, but recovered above the proposed minimums after rubber buildup removal. The yellow Waterborne Type II marking with Type I beads, red Waterborne Type II marking with Type I beads, yellow SMMA markings with Type I and Type III beads, red SMMA markings with Type III beads, white MMA markings with Type I and Type III beads, and yellow and red MMA markings with Type III beads generally followed this pattern. One year after installation, and shortly after the final rubber removal, retro-reflectivity readings for all surface marking types were below the proposed retro-reflectivity minimums, and all markings were considered failed.

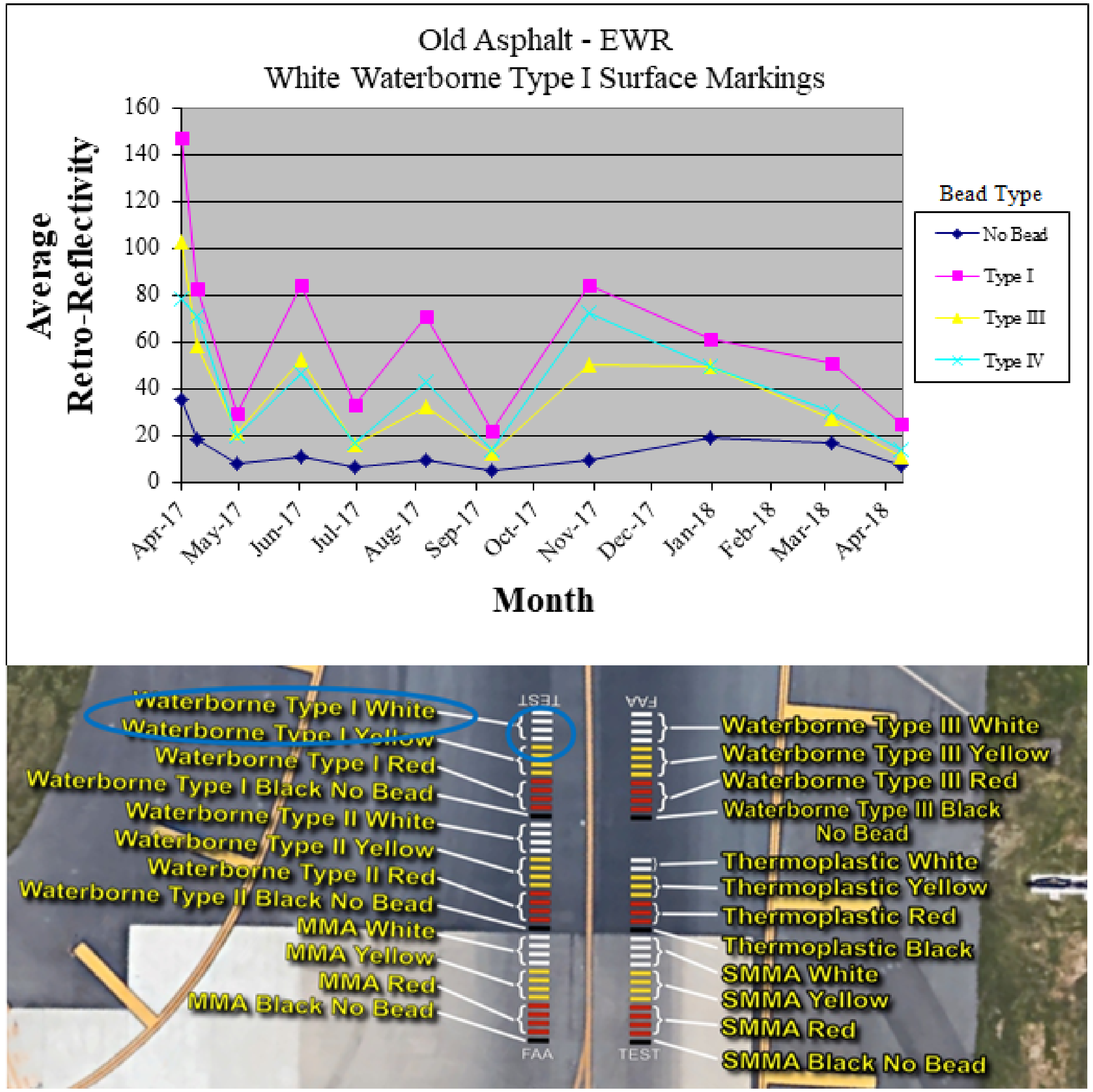


Figure 48. Retro-Reflectivity Readings: EWR White Waterborne Type I Surface Markings

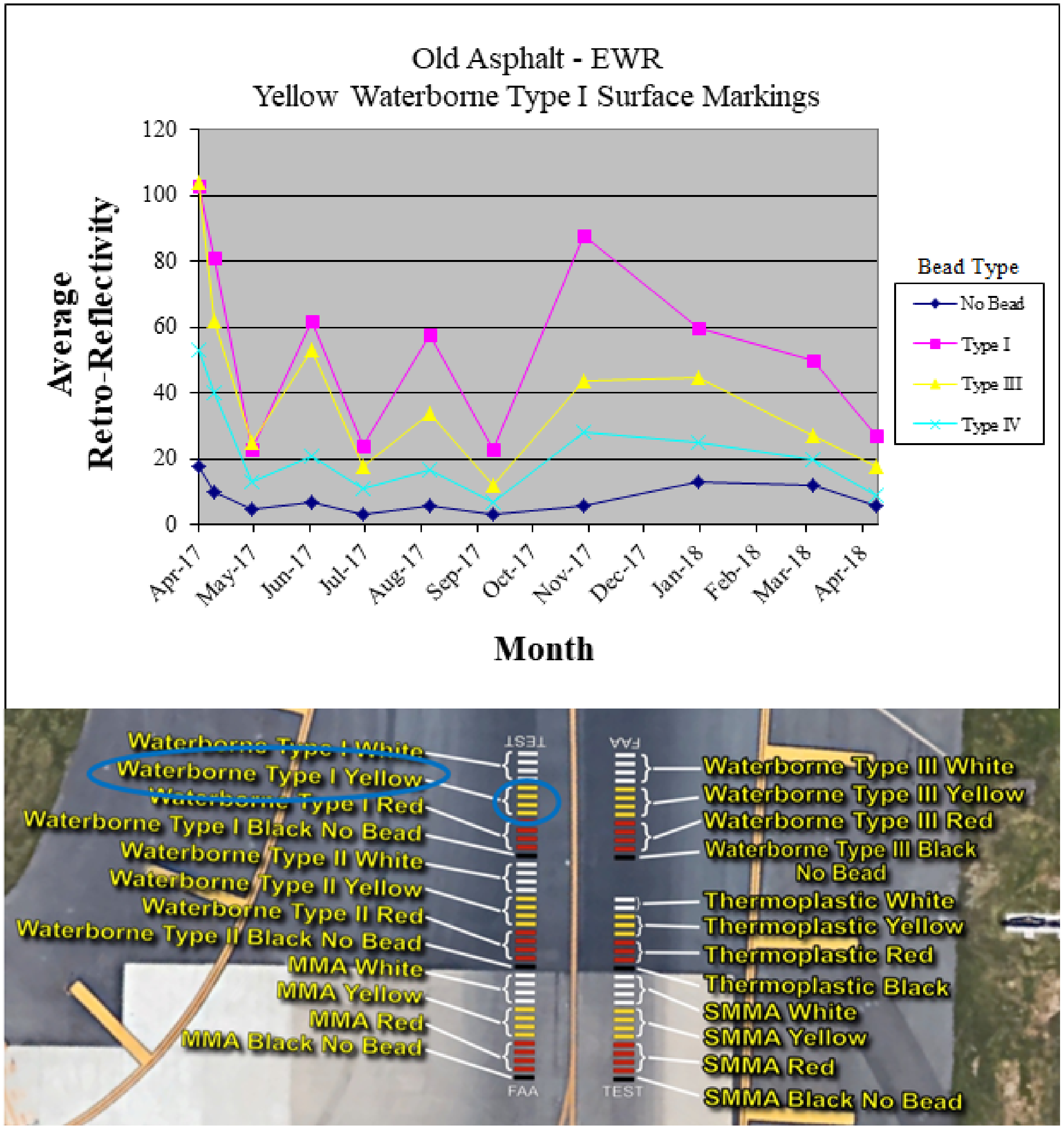


Figure 49. Retro-Reflectivity Readings: EWR Yellow Waterborne Type I Surface Markings

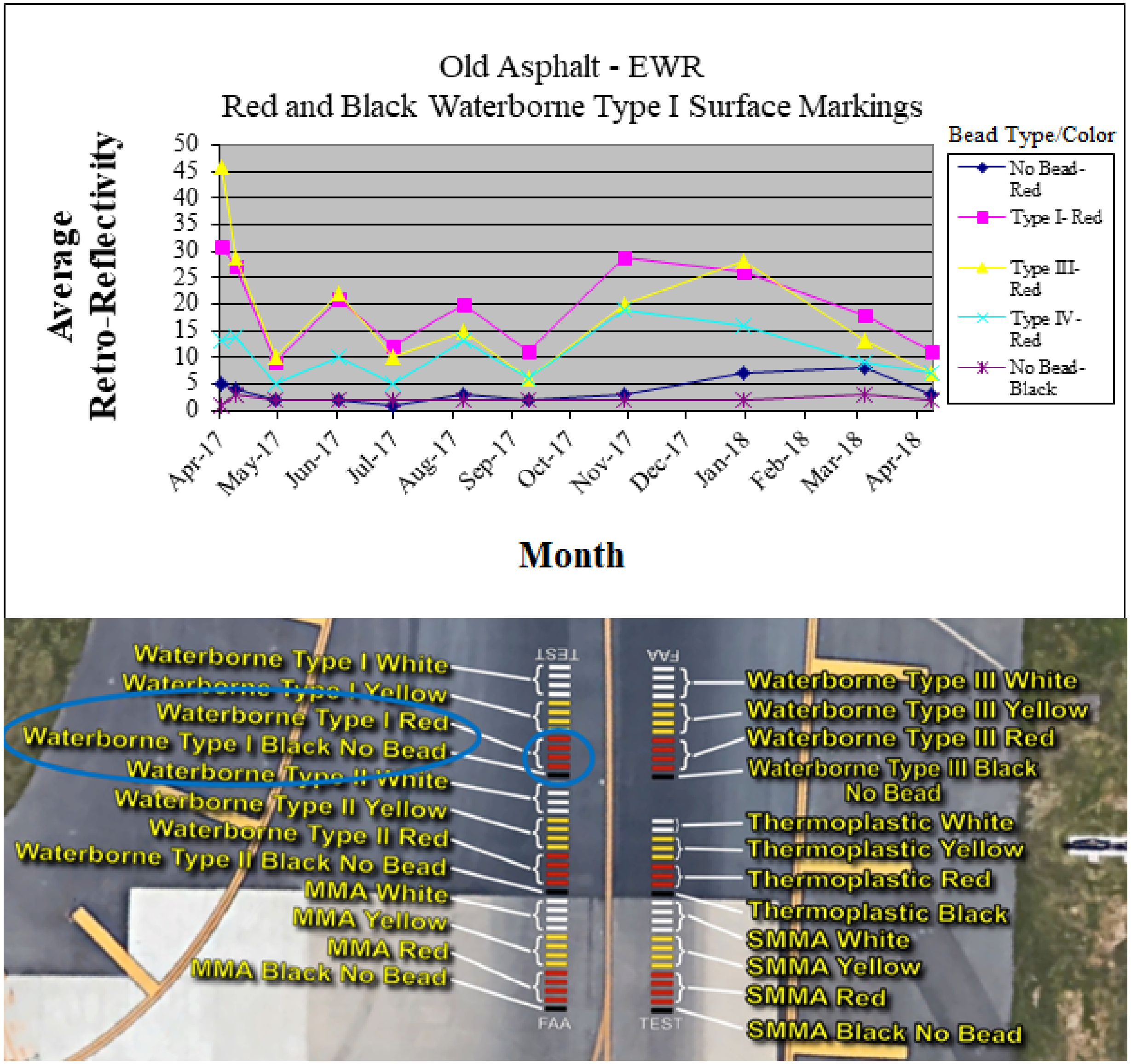


Figure 50. Retro-Reflectivity Readings: EWR Red and Black Waterborne Type I Surface Markings

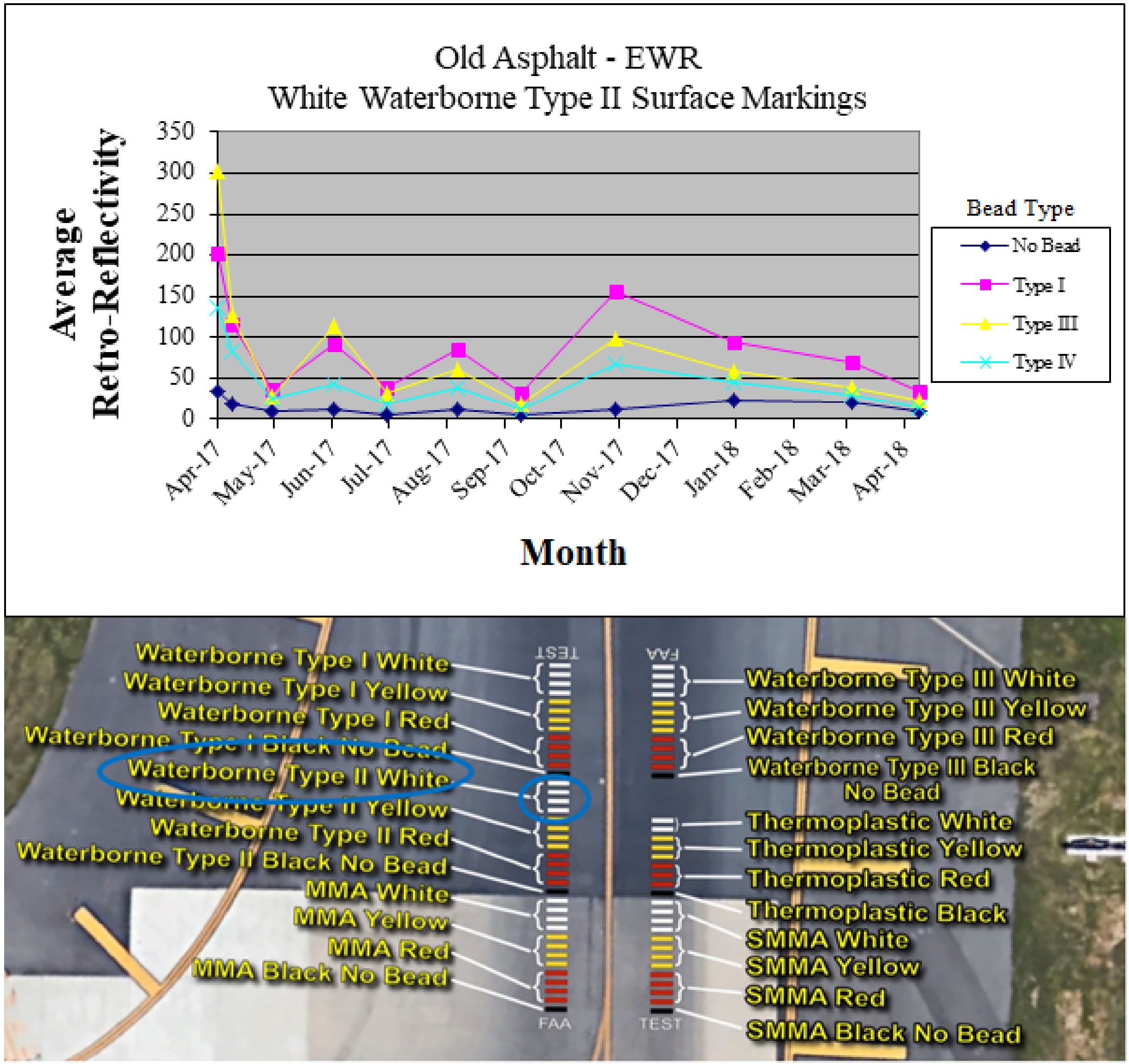


Figure 51. Retro-Reflectivity Readings: EWR White Waterborne Type II Surface Markings

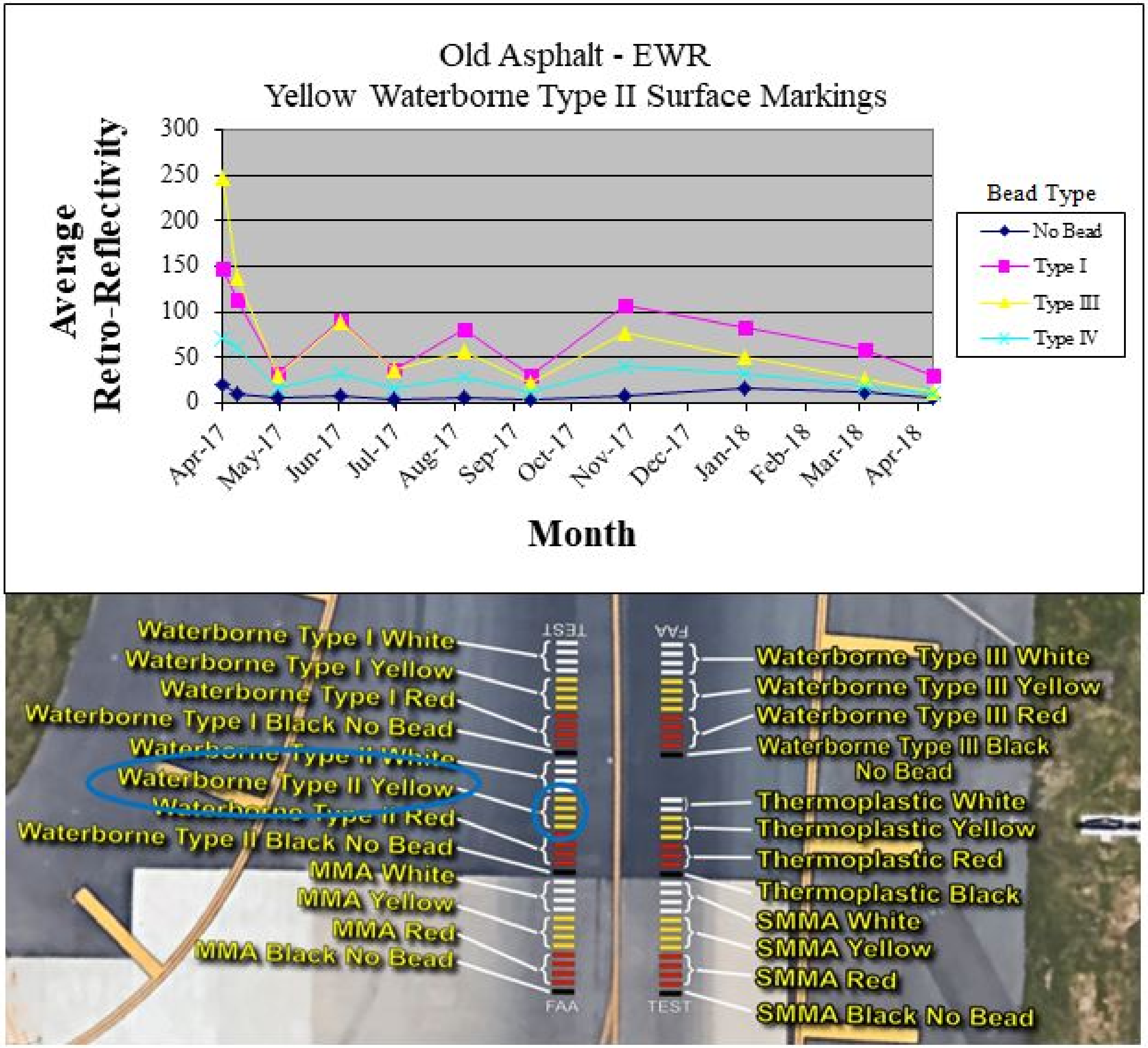


Figure 52. Retro-Reflectivity Readings: EWR Yellow Waterborne Type II Surface Markings

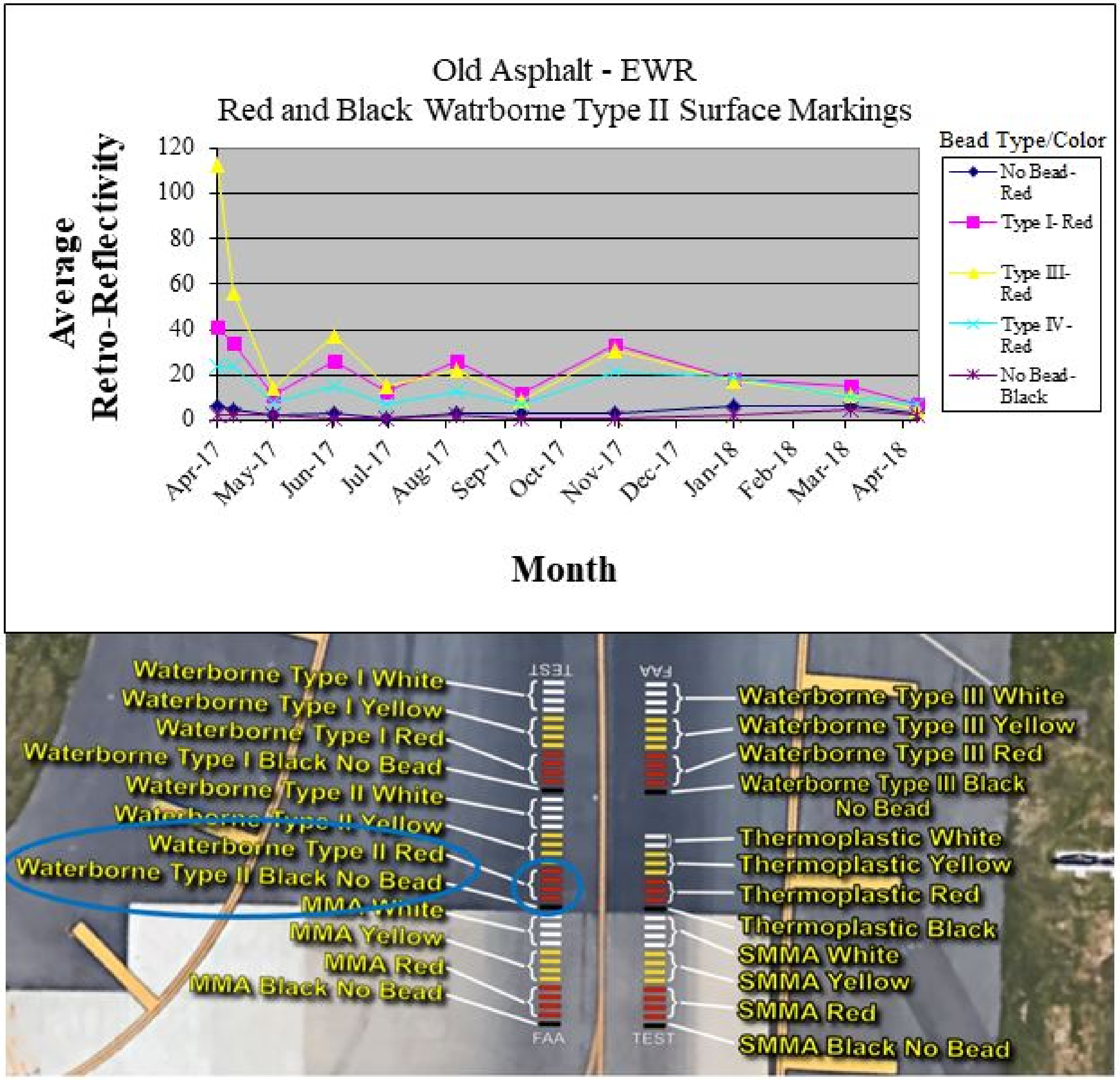


Figure 53. Retro-Reflectivity Readings: EWR Red and Black Waterborne Type II Surface Markings

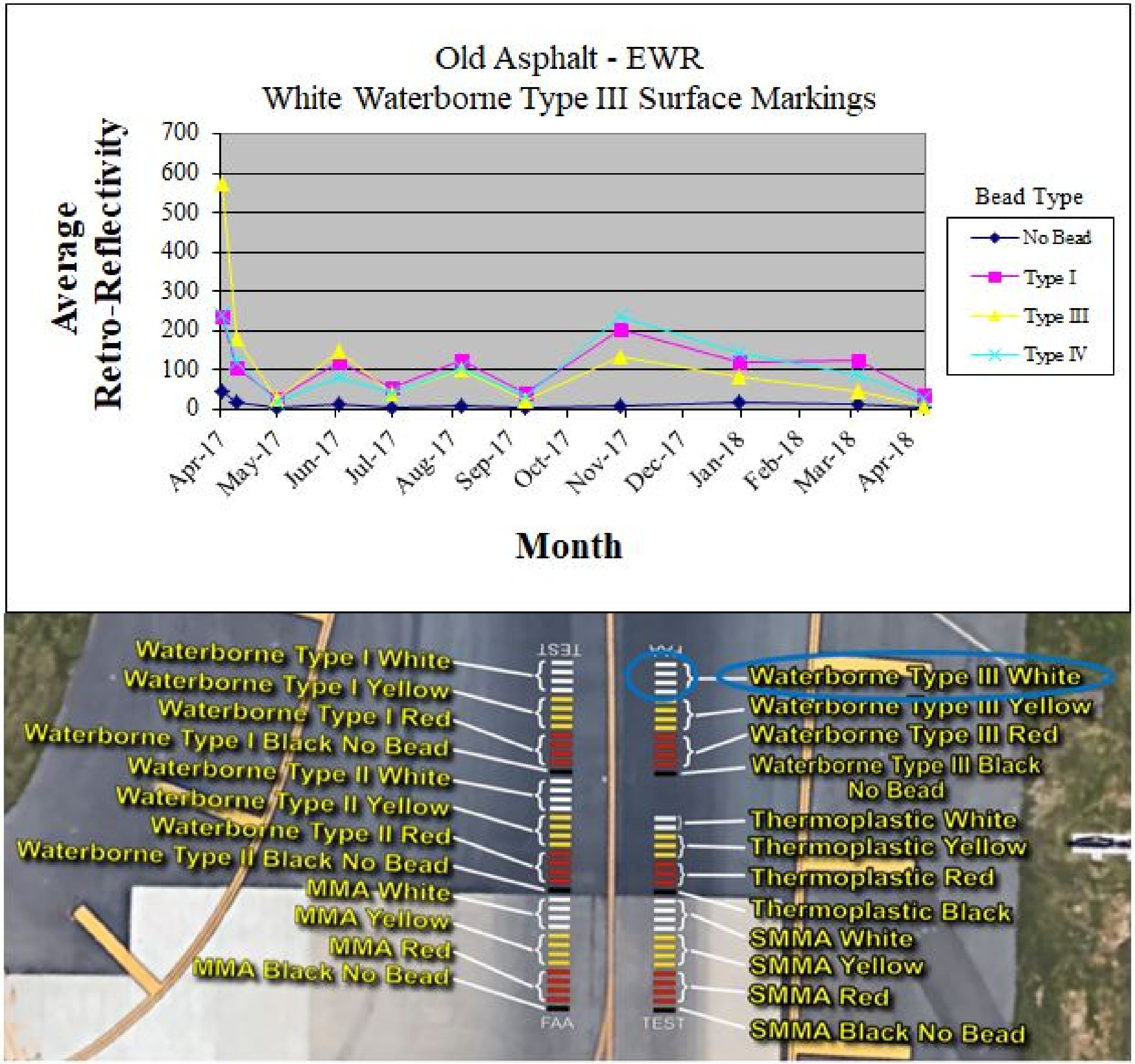


Figure 54. Retro-Reflectivity Readings: EWR White Waterborne Type III Surface Markings

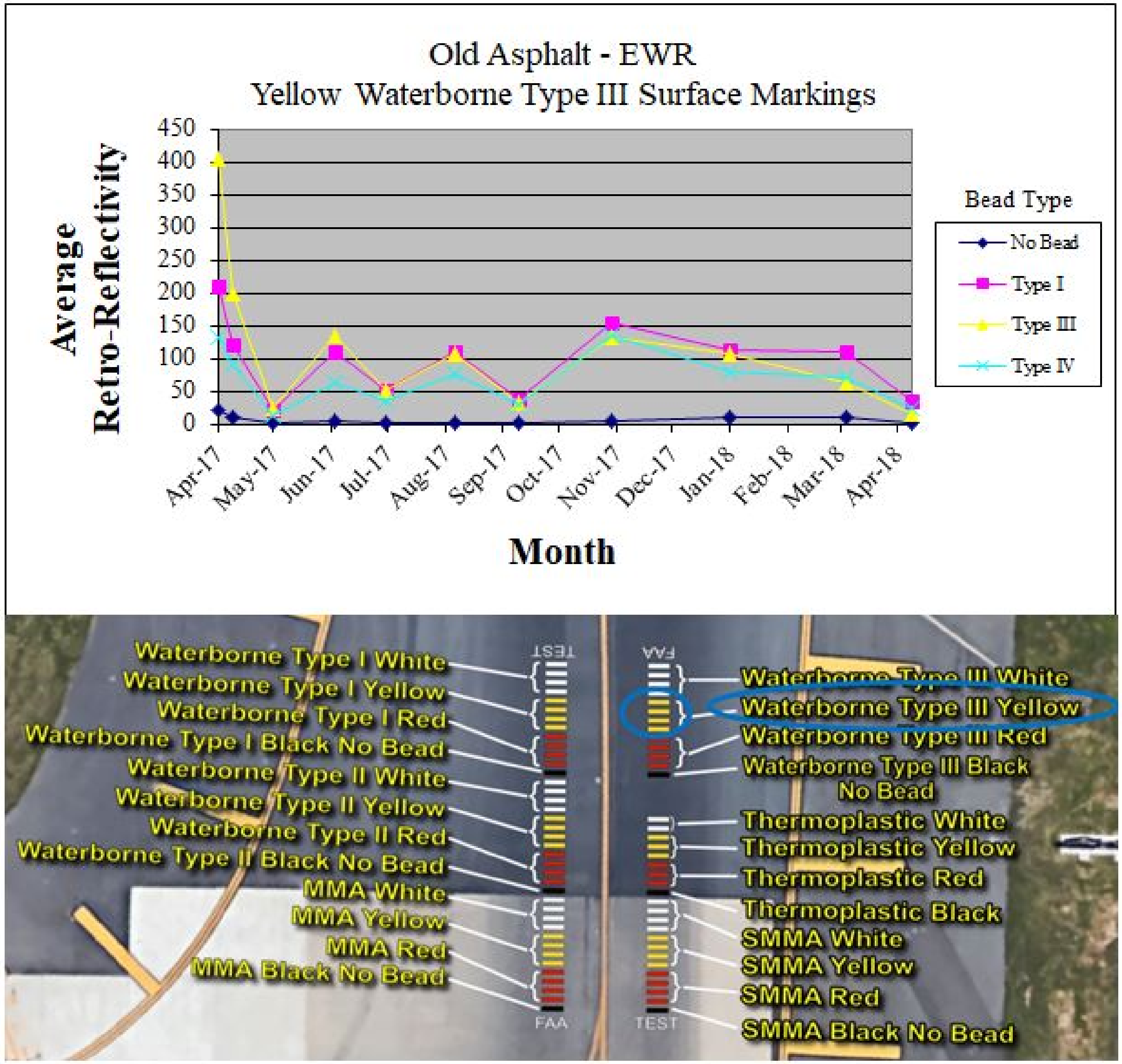


Figure 55. Retro-Reflectivity Readings: EWR Yellow Waterborne Type III Surface Markings

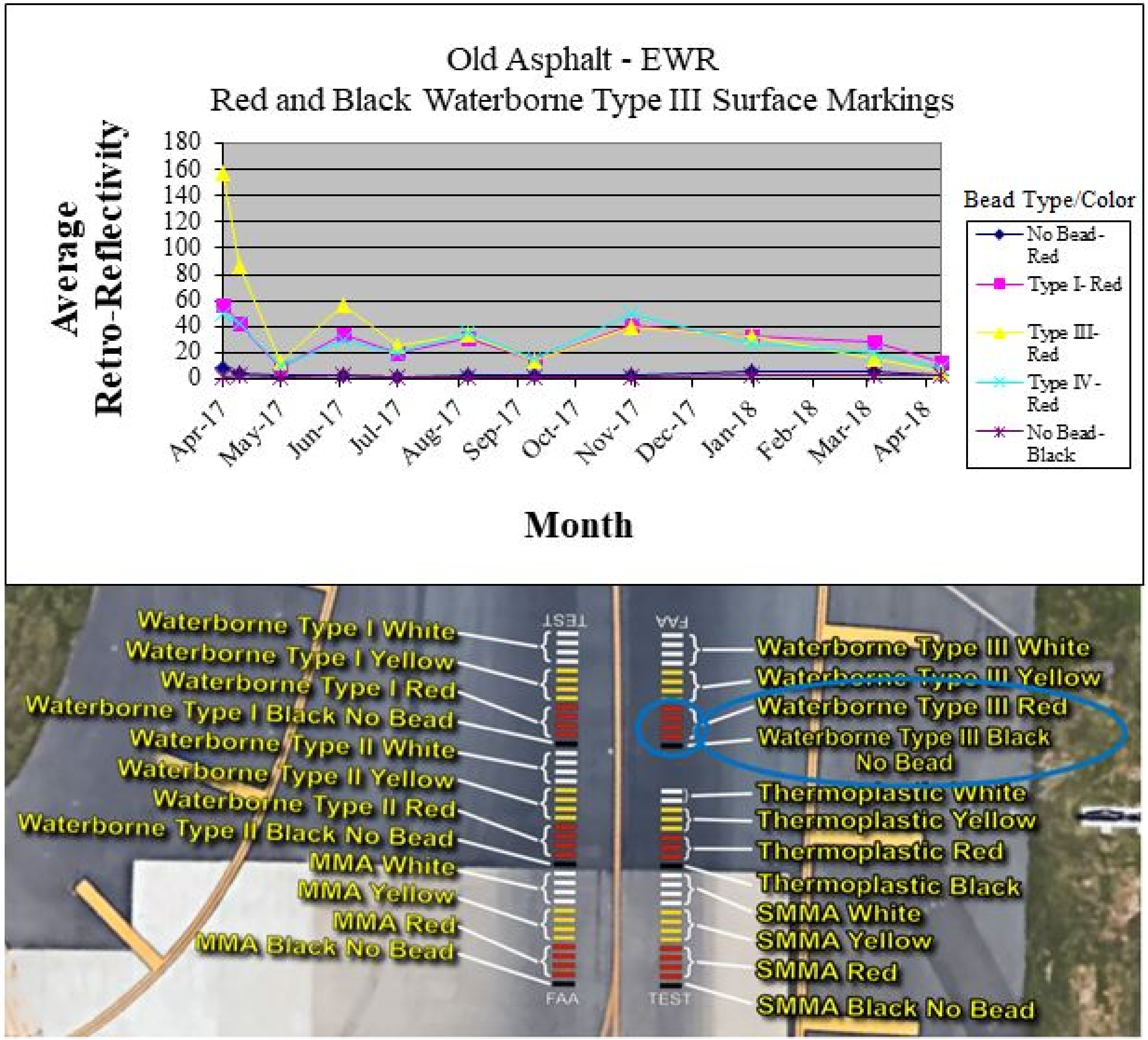


Figure 56. Retro-Reflectivity Readings: EWR Red and Black Waterborne Type III Surface Markings

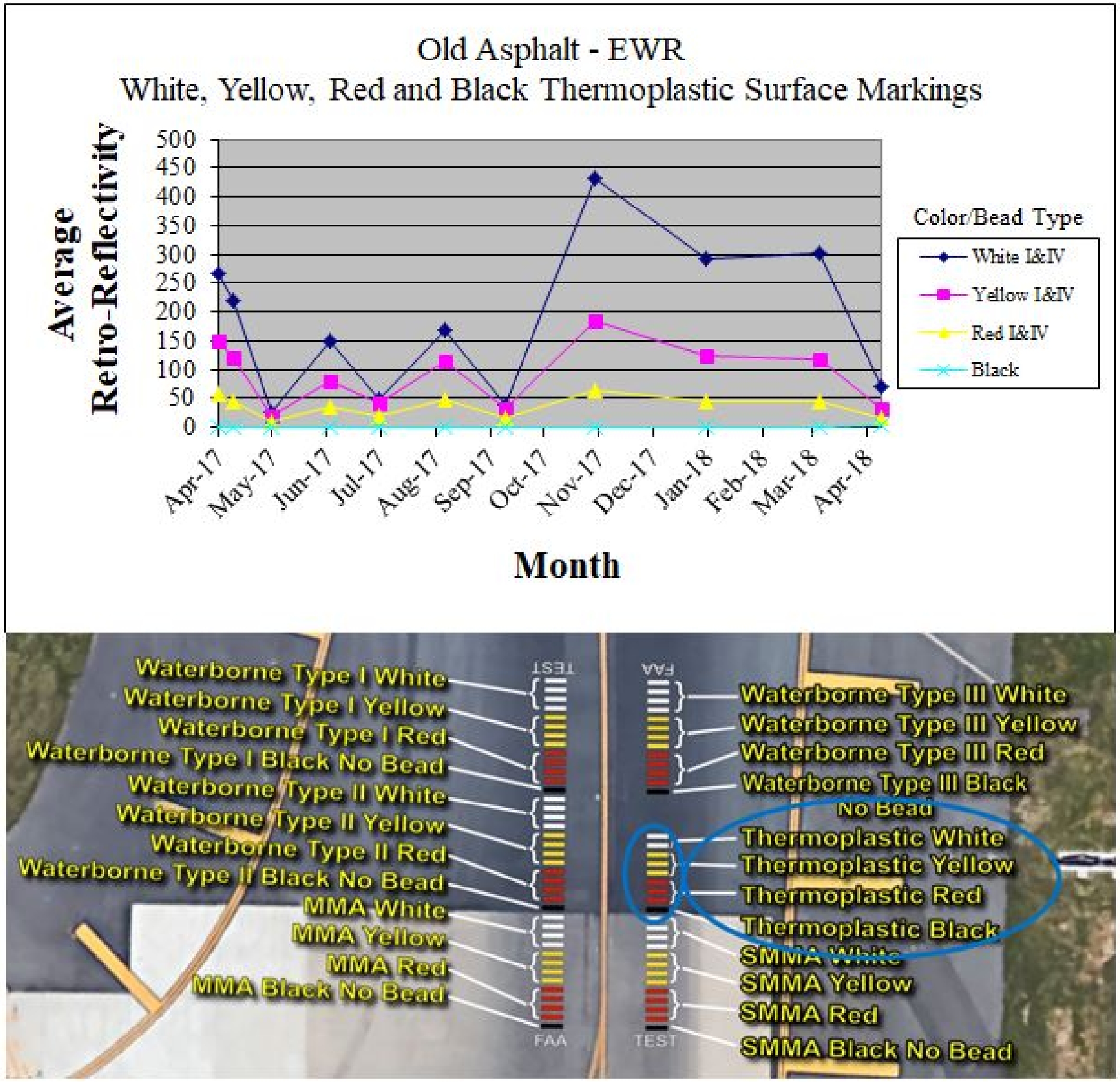


Figure 57. Retro-Reflectivity Readings: EWR Preformed Thermoplastic Surface Markings

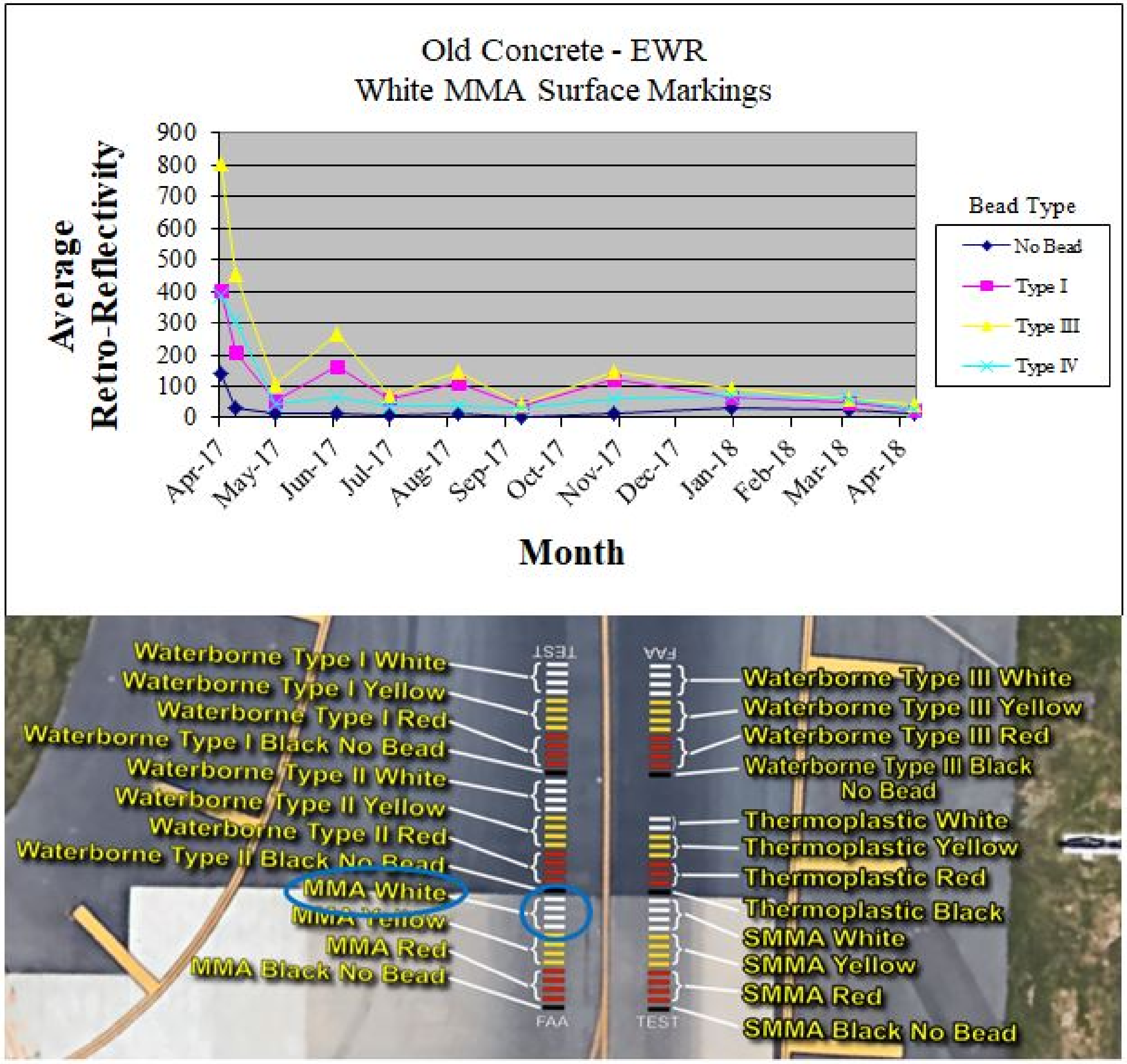


Figure 58. Retro-Reflectivity Readings: EWR White MMA Surface Markings

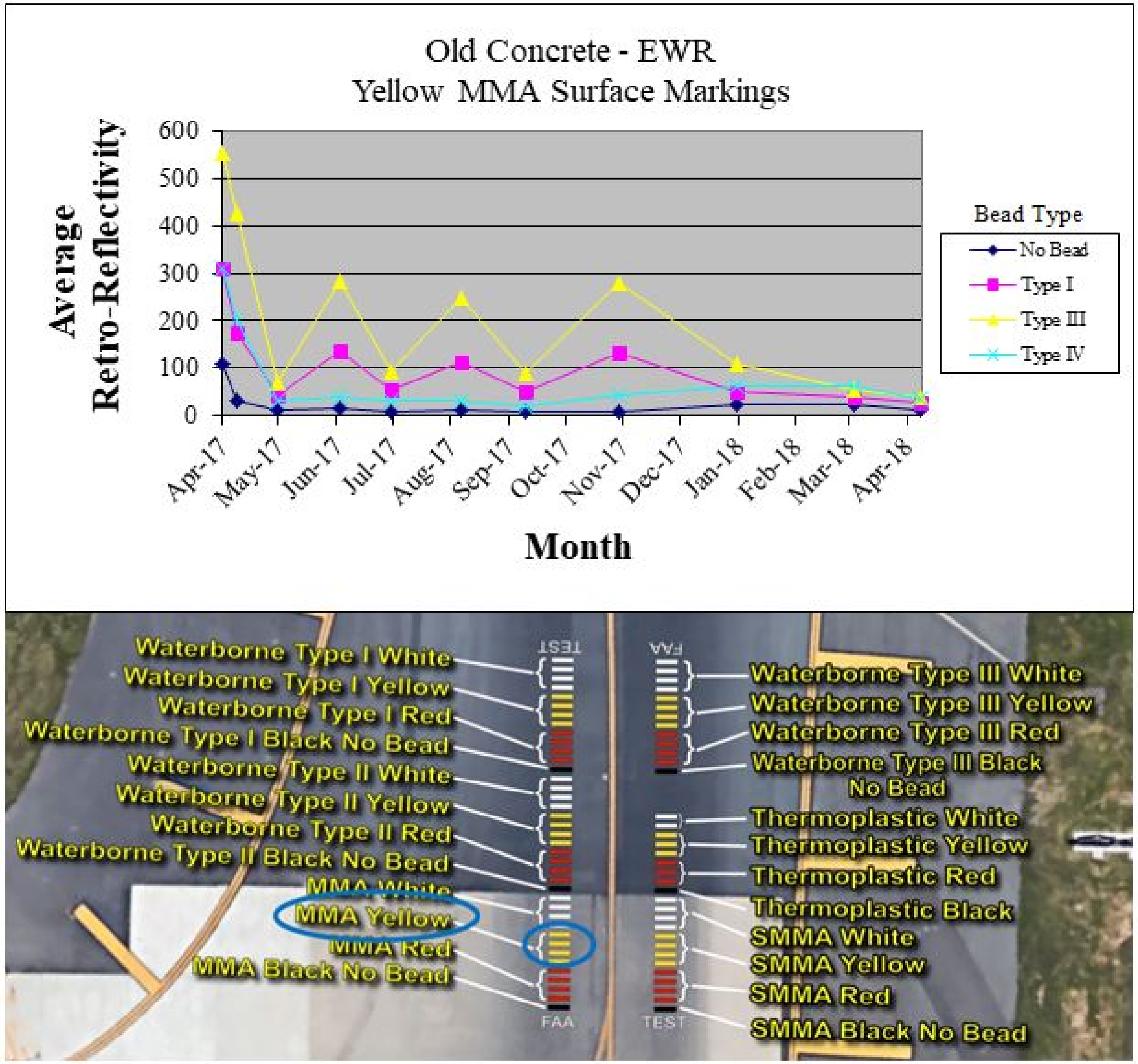


Figure 59. Retro-Reflectivity Readings: EWR Yellow MMA Surface Markings

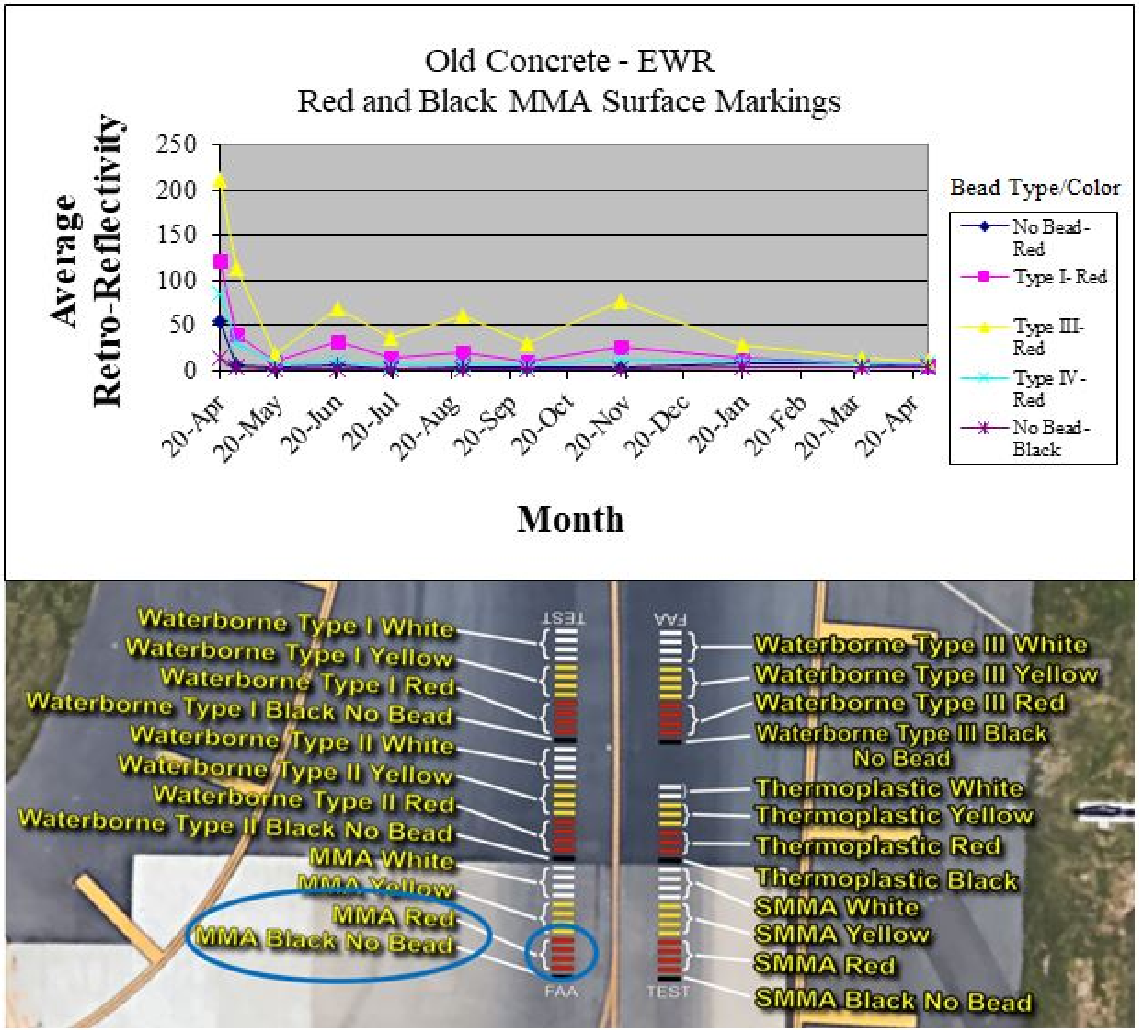


Figure 60. Retro-Reflectivity Readings: EWR Red and Black MMA Surface Markings

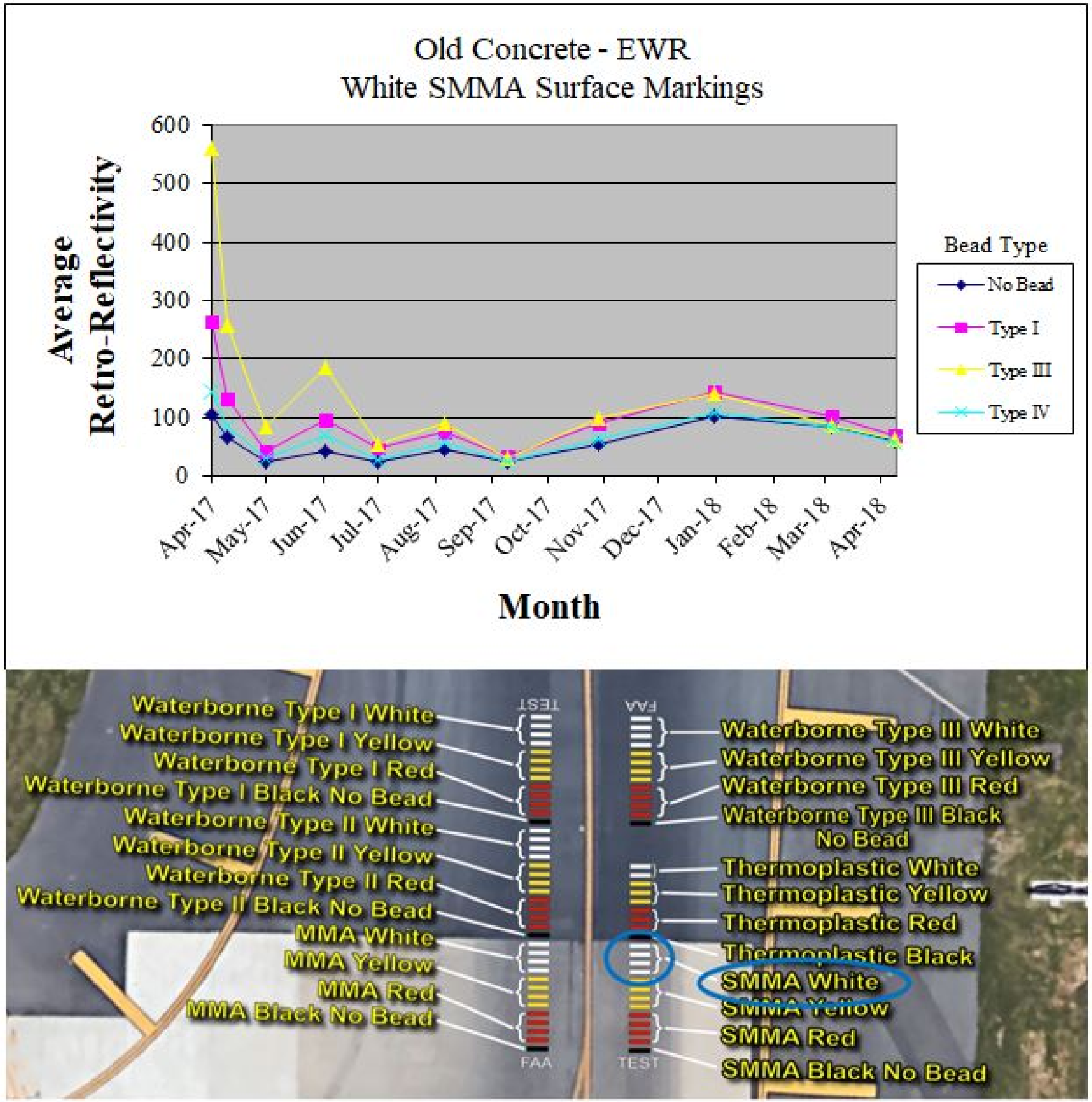


Figure 61. Retro-Reflectivity Readings: EWR White SMMA Surface Markings

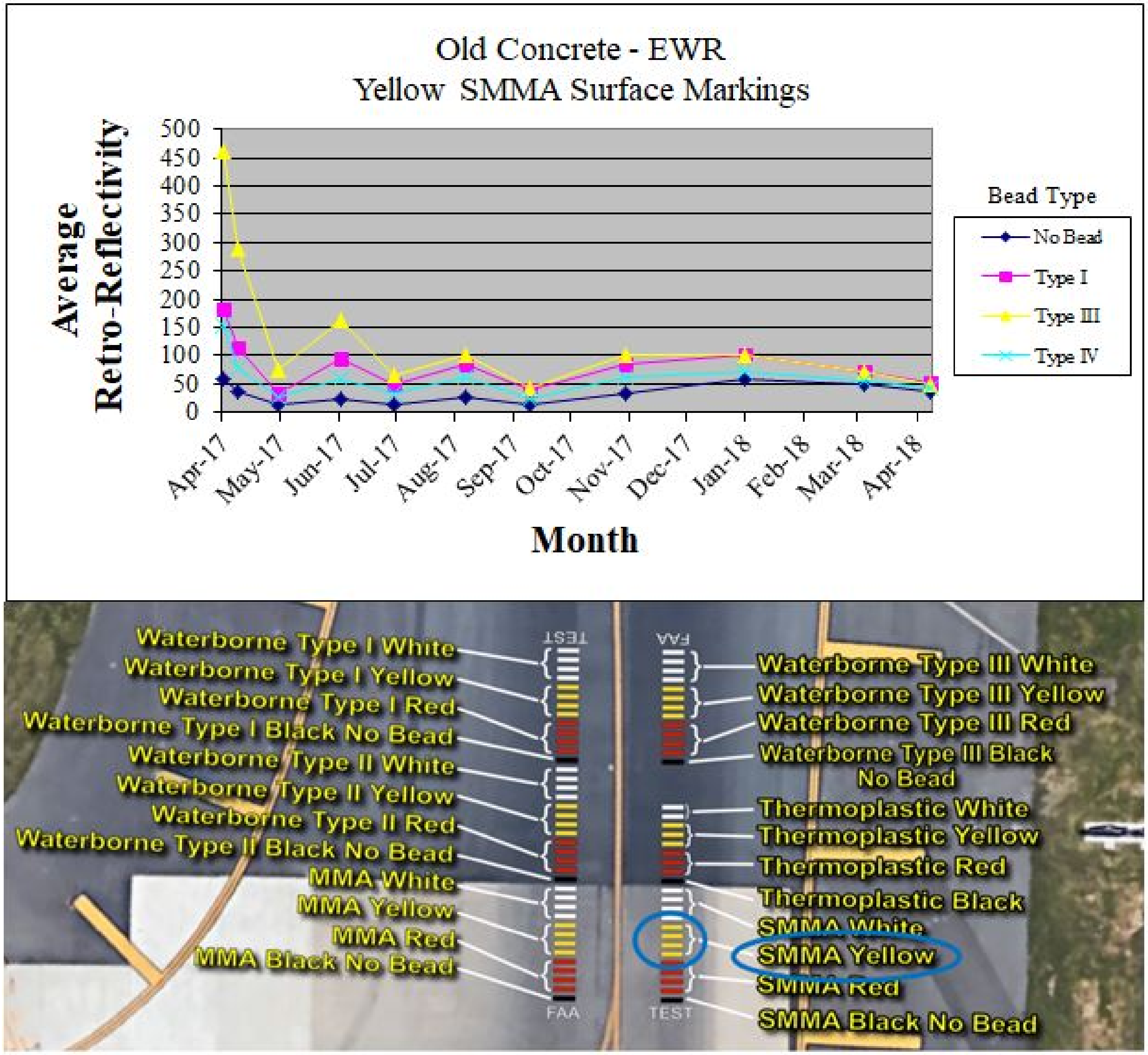


Figure 62. Retro-Reflectivity Readings: EWR Yellow SMMA Surface Markings

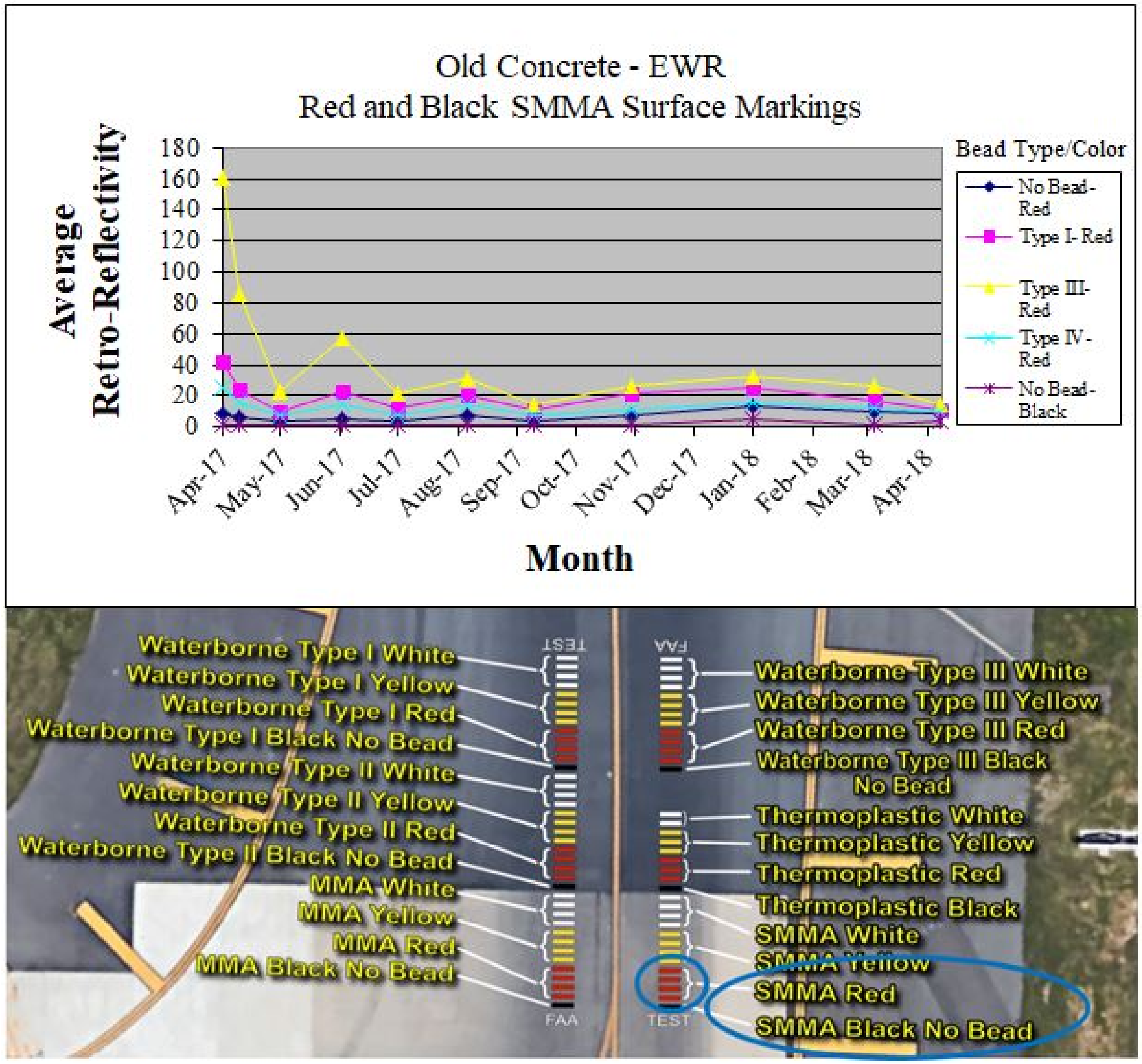


Figure 63. Retro-Reflectivity Readings: EWR Red and Black SMMA Surface Markings

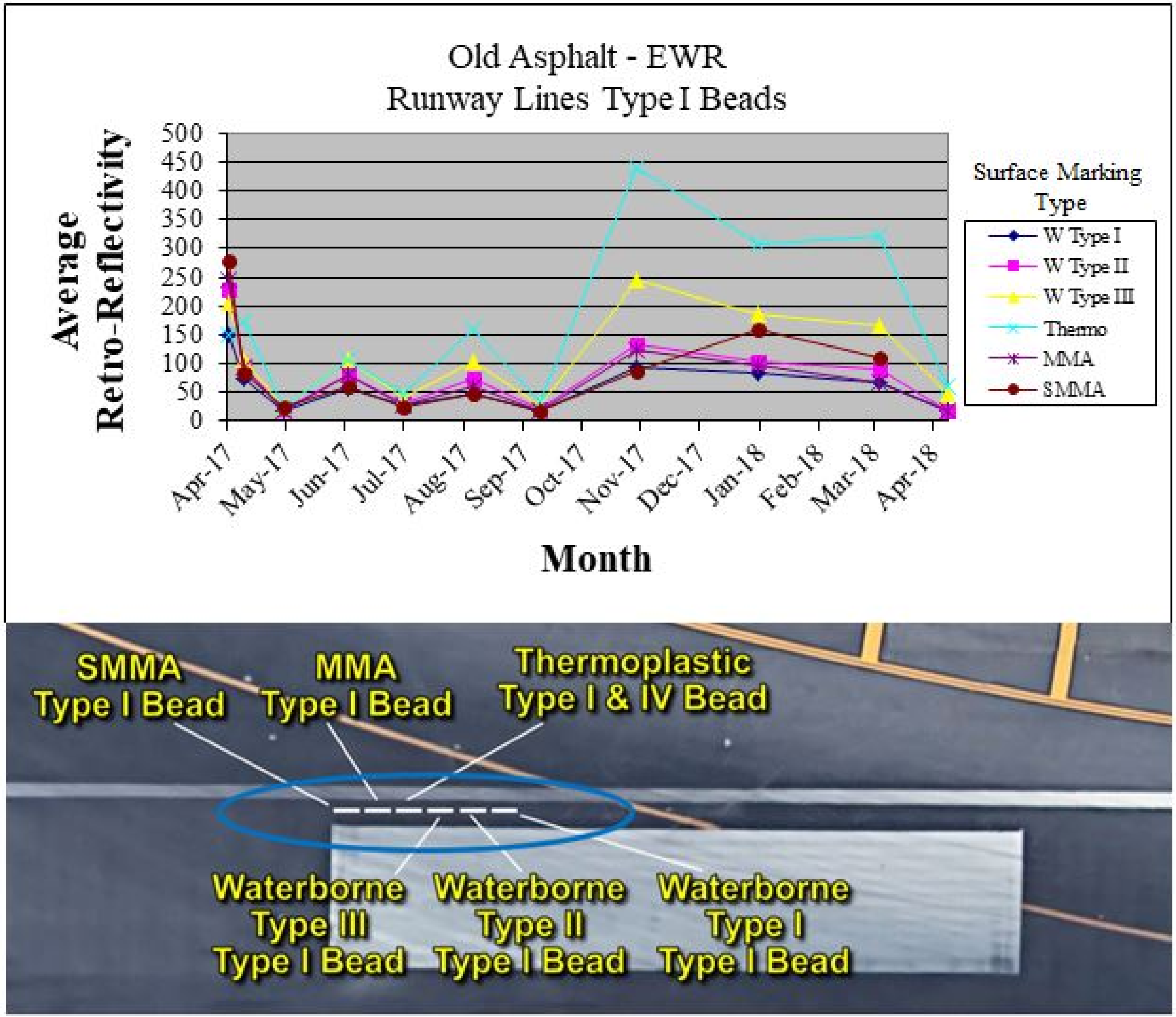


Figure 64. Retro-Reflectivity Readings: EWR White Runway Surface Markings

4.2 PHASE I CHROMATICITY RESULTS—EWR

The two chromaticity readings that were collected monthly for each marking type were recorded on a CIE standard illuminant D_{65} chart to identify changes in color over time. The white and black surface markings of all types maintained color through the year. The only white marking that did not remain within its respective color zone on the color guide chart was the white SMMA marking with Type IV beads. This marking had one reading outside of the white color zone at the end of Phase I.

As discussed in section 3.2, the color zones in the CIE standard illuminant D_{65} charts are based on ICAO standards. Because standard FAA red and yellow standard colors differ from ICAO standards, the majority of the red and yellow surface markings at EWR started slightly outside of the red and yellow zones on the color guide chart. Over the course of the one year study, these markings shifted away from their respective color zones on the color guide charts and towards the white/black zones on the chart, which is likely a result of fading. Only the yellow Preformed Thermoplastic marking maintained its color on the color guide chart. Figure 65 provides a visual comparison of the yellow Waterborne Type I markings at installation compared to the end of Phase I. As shown, the markings are faded and contain rubber deposits. Additionally, the marking coverage itself is reduced, exposing the underlying asphalt.

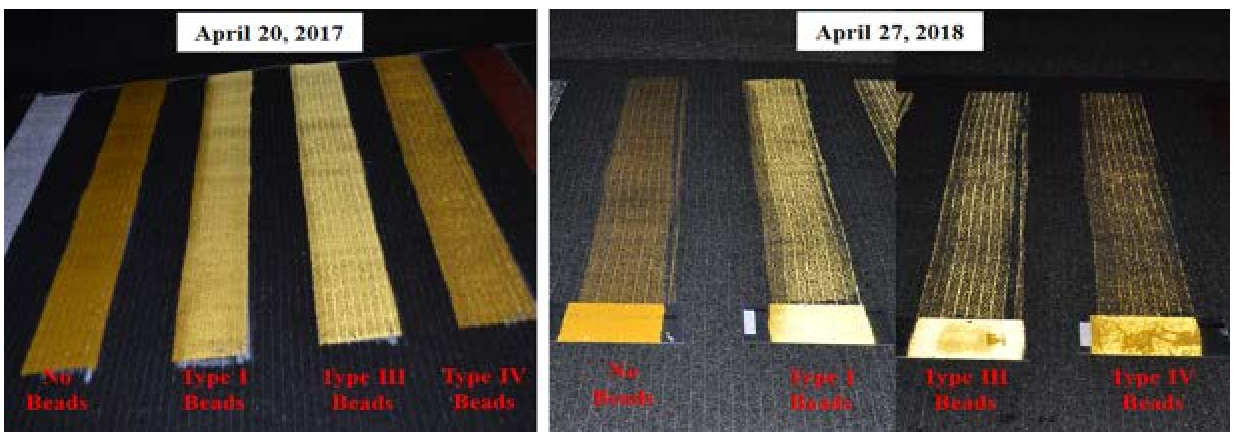


Figure 65. Yellow Waterborne Type I—April 2017 vs April 2018 at EWR

The charts showing the initial chromaticity readings and the chromaticity readings at the end of Phase I at EWR are provided in appendix D.

4.3 PHASE I RUBBER COVERAGE RESULTS—EWR

The surface marking test deck at EWR was located on a high-speed turnoff taxiway frequently used by various aircraft types. Within one week of installation, the surface markings began to accumulate rubber deposits. Figure 66 shows the Preformed Thermoplastic markings with rubber deposits one week after installation.

Figure 66. Rubber Deposits on Preformed Thermoplastic Surface Markings One Week After Installation

As discussed in section 4.1, rubber deposit accumulation on the markings likely contributed to a decrease in retro-reflectivity readings, and rubber buildup removal likely caused the readings to rebound. Figure 67 shows the white Waterborne Type III surface markings in July 2017. As shown, the markings were somewhat obscured by rubber deposits. When the image was taken, all the white Waterborne Type III markings were below the proposed retro-reflectivity minimum of 100 mcd/m^2/lx. Rubber removal occurred approximately one week later, and follow-up readings were taken approximately one month later. By the next data collection, all the white Waterborne Type III markings recovered above the proposed retro-reflectivity minimum.

Figure 67. Rubber Accumulation on White Waterborne Type III Surface Markings—July 2017

At various points throughout the study, surface markings became rubber contaminated and fell below the proposed retro-reflectivity minimums. However, these markings were not deemed failed because many returned to retro-reflectivity values above the minimum after rubber removal. For example, by September 2017, all markings were rubber contaminated and only two markings (red and yellow MMA with Type III beads) were above the proposed retro-reflectivity minimum. During the subsequent data collection, 30 of the surface markings returned above the proposed retro-reflectivity minimums. This pattern was followed by many marking types throughout the study. By April 2018, all of the markings were below the proposed retro-reflectivity minimums, even though rubber removal occurred shortly before the readings were taken. At that point, all markings were considered failed.

Appendix E provides photo comparisons of the markings at the beginning of the study and at the end of Phase I.

5. FINDINGS

Section 5.1 summarizes the findings from the first year of data collection at baseline location ACY, while section 5.2 summarizes the Phase I findings at EWR.

5.1 BASELINE LOCATION (ACY) YEAR-ONE FINDINGS

The surface marking test deck at ACY was installed on a taxiway that is exposed to four distinct seasons, including cold and wet conditions, but only occasional vehicle and aircraft traffic. Retro-reflectivity data showed minimal degradation during the first year of the study. The retro-reflectivity values for more than half (52%) of the surface markings actually increased. Surface markings with Type III beads showed the largest decrease. However, these markings had the highest initial retro-reflectivity readings. Additionally, the retro-reflectivity readings for markings with Type III beads remained higher than markings with other bead types after the first year. Surface markings with no beads started with low retro-reflectivity readings and remained low after the first year.

All surface markings that contained beads remained above the proposed retro-reflectivity minimums except for the red MMA marking with Type IV beads. This marking fell below the proposed retro-reflectivity minimum of 25 mcd/m^2/lx for red markings in December 2017, with a reading of 23 mcd/m^2/lx. Retro-reflectivity values for Preformed Thermoplastic markings increased over time. Additionally, retro-reflectivity values for Waterborne Type I, Waterborne Type II, and Waterborne Type III markings with Type I and Type IV beads increased over time.

Overall, the white and black surface markings maintained color over time. The only white marking that did not remain within its respective color zone in the color guide chart was the white SMMA marking with no beads. Because the color guide charts depict ICAO standard colors, not FAA standard yellow and red colors, the majority of the red and yellow measurements started slightly outside of their respective color guide zones. The yellow and red surface markings at ACY shifted slightly away from their respective color zones on the color guide charts and shifted more on the x-axis of the color guides than the y-axis. These colors shifted away from the yellow and red zones and closer to the white zone, likely a result of fading. For example, as red markings fade, they begin to appear more pink than red.

By the end of the first year of the study, the surface markings at ACY had not accumulated significant rubber deposits. This, combined with infrequent exposure to aircraft wheel loads, likely explains why the retro-reflectivity readings at ACY were largely consistent throughout the year.

The friction coefficient for the exposed concrete prior to the markings ranged from approximately 0.51µ to 0.71µ. The average friction coefficient of 0.42µ for Waterborne Type I, Waterborne Type II, Waterborne Type III, and MMA friction lines was lower than the baseline exposed concrete. Though the friction values for these markings were below the minimum of 0.50µ required for runway surfaces in AC 150/5320-12C [7], surface markings on runways generally are not long enough to significantly impact the average friction values of each 500-ft section of the runway. The average friction coefficient of the SMMA friction line was 0.75µ, which was higher than the exposed concrete prior to the marking and significantly higher than the other markings.

Data collection at ACY will continue through Phase II and Phase III of the surface marking durability study.

5.2 PHASE I FINDINGS—EWR

The surface marking test deck at EWR was installed on a high-speed turnoff taxiway that was exposed to four distinct seasons, including cold and wet conditions, and frequent aircraft traffic. The taxiway was used by a variety of aircraft, including large air carrier aircraft. According to a study conducted at EWR, by the Port Authority of New York and New Jersey using Airport Surface Detection Equipment, Model X (ASDE-X) data based on traffic figures from 2017, the taxiway was used by approximately 51,000 aircraft annually. This likely contributed to significant differences in the surface markings degradation rate at EWR compared to baseline location ACY.

EWR airport personnel advised that rubber deposits were removed from the surface markings on four occasions during the one year study. The rubber deposits were removed by waterblasting the pavement markings. All surface markings showed retro-reflectivity degradation after rubber buildup and recovery after rubber removal. For example, all surface markings, except for the white MMA surface marking with Type III beads, fell below the proposed retro-reflectivity minimums of 100 mcd/m^2/lx for white markings, 70 mcd/m^2/lx for yellow markings, and 25 mcd/m^2/lx for red markings within one month of installation. However, when retro-reflectivity readings were collected the following month, after EWR personnel removed rubber deposits, the retro-reflectivity readings of 50% of the markings that contained beads had recovered above the proposed minimums. This pattern continued for many markings throughout Phase I.

Even after rubber removal, white Waterborne Type I markings, yellow Waterborne Type I markings with Type III beads, and all Waterborne Type II, MMA, and red SMMA markings with Type IV beads remained below the proposed retro-reflectivity minimums. Additionally, the retro-reflectivity values did not return to initial levels for any of the markings. Frequent exposure to aircraft wheel loads and forces from rubber removal possibly caused some beads to be dislodged from the markings.

Preformed Thermoplastic markings, which contained a mixture of Type I and Type IV beads, maintained retro-reflectivity better than most other marking types. Though these markings fell below the proposed retro-reflectivity minimums three times during Phase I, retro-reflectivity readings recovered above the proposed minimums after rubber deposits were removed. Similar to Preformed Thermoplastic markings, Waterborne Type III markings with all bead types generally fell below the proposed retro-reflectivity minimums as rubber buildup increased, but recovered above the proposed minimums after rubber was removed. The yellow Waterborne Type II marking with Type I beads, red Waterborne Type II marking with Type I beads, yellow SMMA markings with Type I and Type III beads, red SMMA markings with Type III beads, white MMA markings with Type I and Type III beads, and yellow and red MMA markings with Type III beads also generally followed this pattern. One year after installation, retro-reflectivity readings for all surface marking types were below the proposed retro-reflectivity minimums, even though rubber deposits were recently removed from the markings. As a result of this and the overall condition of the markings, all markings were considered failed at the end of the study.

Nearly all the white and black surface markings maintained color throughout Phase I. The only white marking that did not remain within its respective color region on the color guide chart was the white SMMA marking with Type IV beads (figure D-32 in appendix D). This marking had one reading outside of the white color region at the end of Phase I.

Because the color guide charts depict standard ICAO colors and not FAA standard colors, the majority of the red and yellow surface markings at EWR started slightly outside of the red and yellow zones on the charts. Over the course of the Phase I study, these markings shifted away from their respective color zones on the color guide charts and towards the white zone on the chart, likely a result of fading. The only exception was the yellow Preformed Thermoplastic marking, which maintained its color through Phase I.

The final data collection at EWR occurred in April 2018, at which point all surface markings were considered to be failed.

6. CONCLUSIONS

The data collected at the baseline location, Atlantic City International Airport (ACY), and Phase I location, Newark Liberty International Airport (EWR), between April 2017 and April 2018 enabled the Airport Technology Research and Development (ATRD) team to evaluate the surface markings performance at these airports. After one year of data collection, the surface markings at ACY showed minimal degradation.

Rubber buildup affected the retro-reflectivity values at EWR. Retro-reflectivity values decreased as rubber accumulated on the surface markings but increased after rubber deposits were removed from the markings. However, retro-reflectivity values for markings at EWR did not recover to original levels after rubber buildup removal. The frequent exposure to aircraft wheel loads and forces from rubber removal caused some beads to become dislodged from the markings. Two types of thickness gauges (Elcometer 456 and Delta marking thickness gauges) were used to obtain readings of the rubber buildup, but could not correlate the readings with rubber removal. Going forward, photographs will be taken at initial application and at failure of the test deck to show the bead loss. At the baseline location, the retro-reflectivity values showed minimal degradation after one year of data collection because these surface markings were not exposed to rubber removal operations and only experienced minimal aircraft traffic. Data collection at ACY will continue through Phases II and III of this effort. Data collection at EWR ended when all of the surface markings were considered failed in April 2018.

The data and analysis provided in this report, in conjunction with future data obtained during Phase II and Phase III, will be used to develop a classification system recommendation reflecting how pavement markings perform in service and establish threshold limits for retro-reflectivity, color, and coverage. A final report will summarize all three surface marking durability study phases and include a surface markings classification system recommendation.

7. REFERENCES

1. Federal Aviation Administration (FAA), "Standards for Airport Markings," Advisory Circular (AC) 150/5340-1L, September 27, 2013, available at https://www.faa.gov/documentLibrary/media/Advisory_Circular/150_5340_1l.pdf (date last visited 03/13/19).

2. FAA, "Standards for Specifying Construction of Airports," AC 150/5370-10G, Item P-620, July 21, 2014.

3. United States Federal Register, Title 14 Code of Federal Regulations Part 139, "Certification of Airports," revised March 22, 2013, available at: https:// https://www.ecfr.gov/cgi-bin/text-idx?SID=67ace2dd2bb13ec2a9342bbffcc4647f&mc= true&node=pt14.3.139&rgn=div5 (date last visited 03/13/19).

4. Cyrus, H., "Development of Methods for Determining Airport Pavement Marking Effectiveness," FAA technical note DOT/FAA/AR-TN03/22, March 2003, available at http://www.tc.faa.gov/its/worldpac/techrpt/artn03-22.pdf (date last visited 03/13/19).

5. Cyrus, H. and King, R., "Project Plan: Development of a Classification Method for Durability of Airfield Marking Materials," January 4, 2016.

6. Society of Automotive Engineers (SAE), "Colors Used in Government Procurement," Aerospace Materials Specification (AMS)-STD-595, February 14, 2017 (superseding FED-STD-595C, January 16, 2008).

7. FAA, "Measurement, Construction, and Maintenance of Skid-Resistant Airport Pavement Surfaces," AC 150/5320-12C, March 18, 1997, available at https://www.faa.gov/ documentLibrary/media/advisory_circular/150-5320-12C/150_5320_12c.PDF (date last visited 03/13/19).

APPENDIX A—ATLANTIC CITY INTERNATIONAL AIRPORT CHROMATICITY CHARTS

Appendix A shows the Atlantic City International Airport (ACY) International Commission on Illumination (CIE) chromaticity charts with a photograph at installation (April 11, 2017) and one year later (April 18, 2018) for each surface marking material (Waterborne Type I, Waterborne Type II, Waterborne Type III, Methyl methacrylate (MMA), Structured methyl methacrylate (SMMA), Preformed Thermoplastic) for each color under test (white, yellow, red, and black).

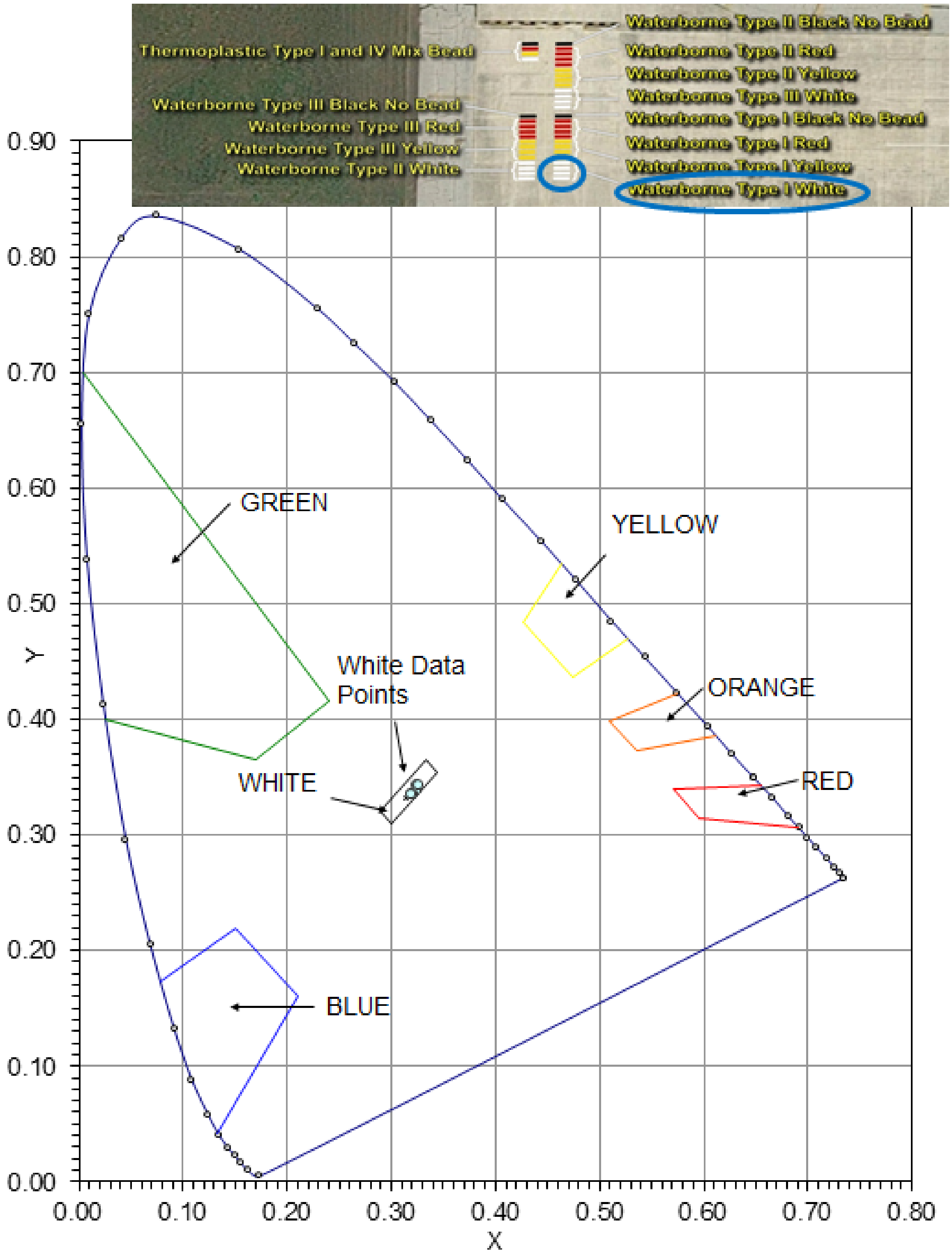


Figure A-1. April 11, 2017 Color Guide Readings for ACY Waterborne Type I White

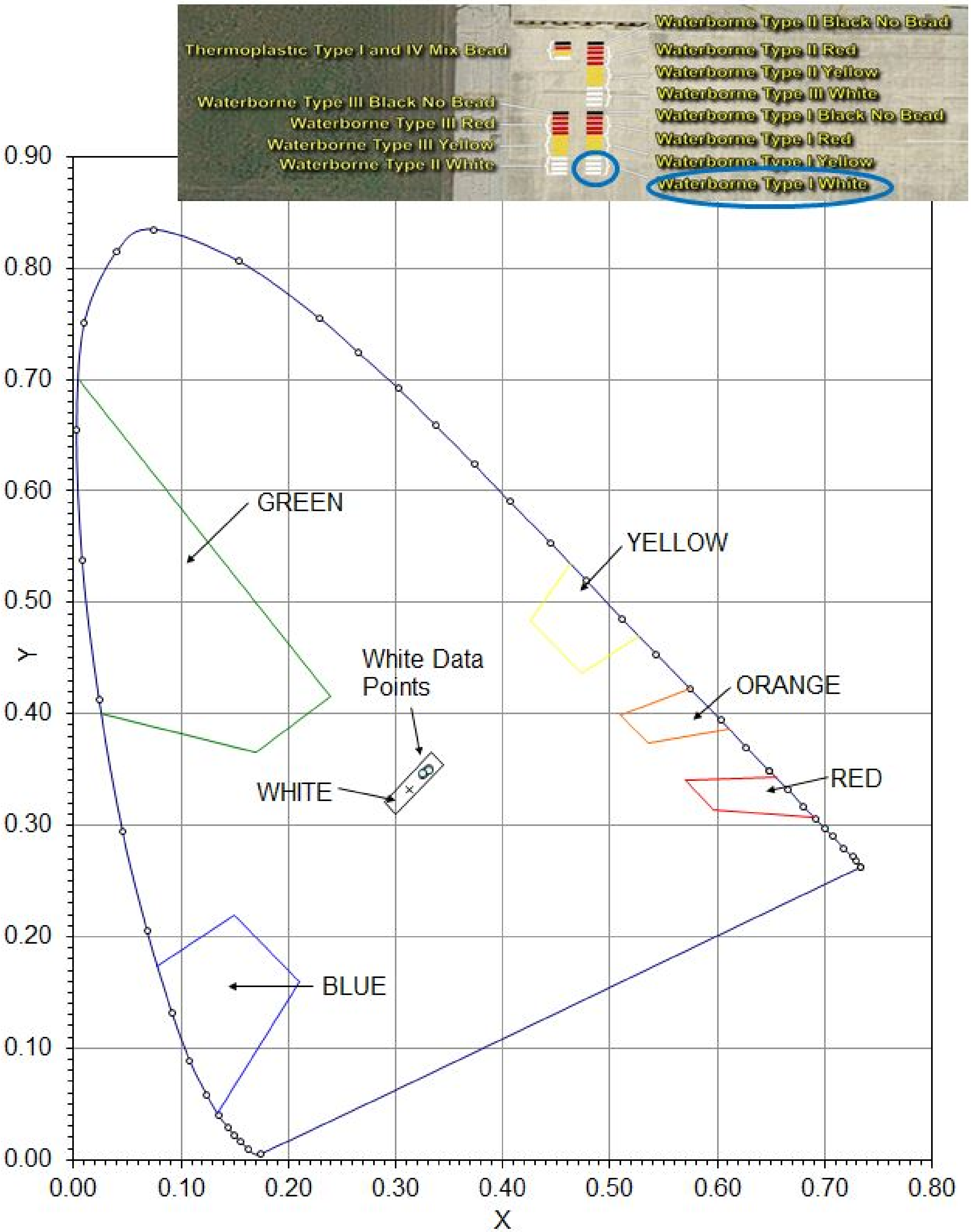


Figure A-2. April 18, 2018 Color Guide Readings for ACY Waterborne Type I White

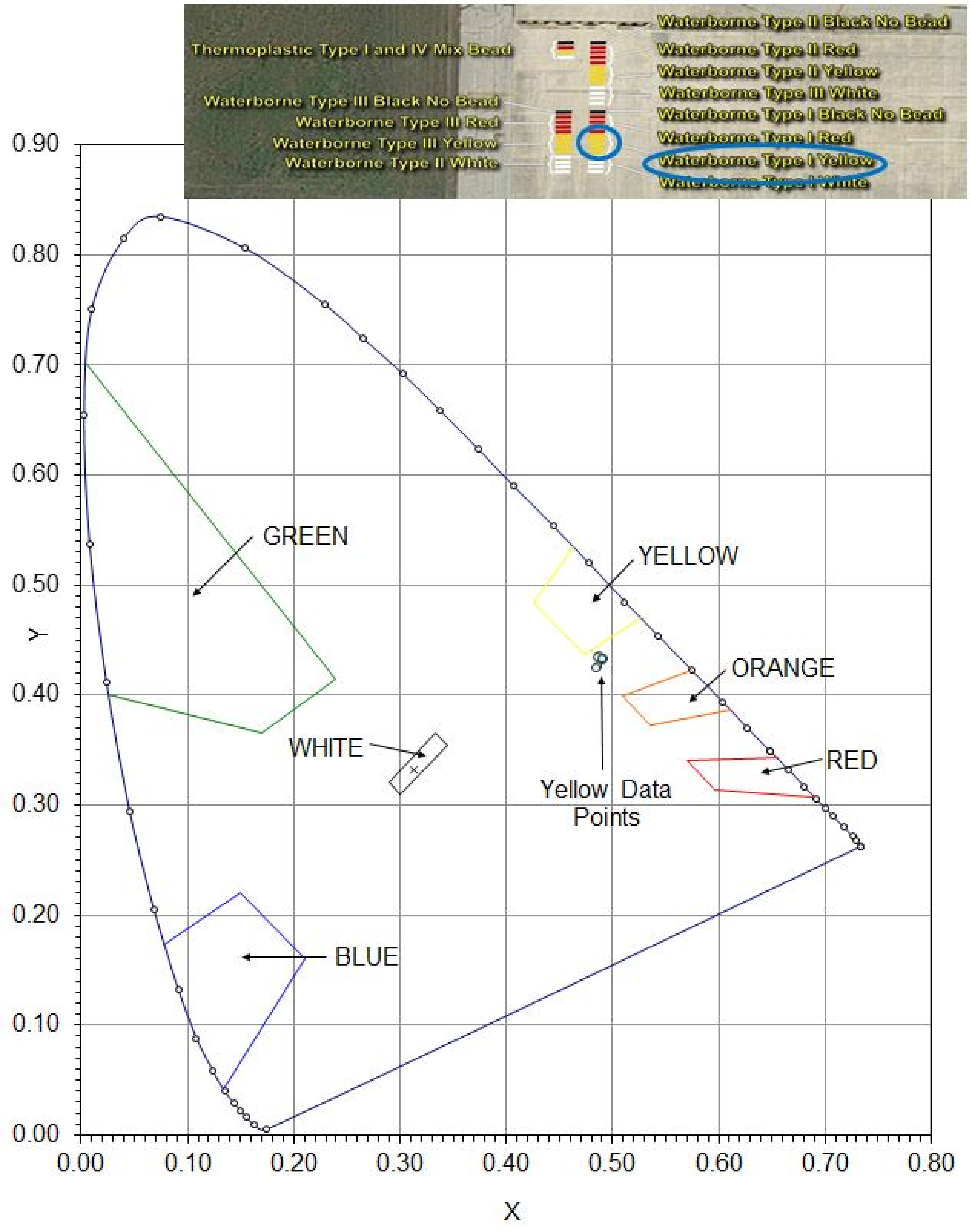


Figure A-3. April 11, 2017 Color Guide Readings for ACY Waterborne Type I Yellow

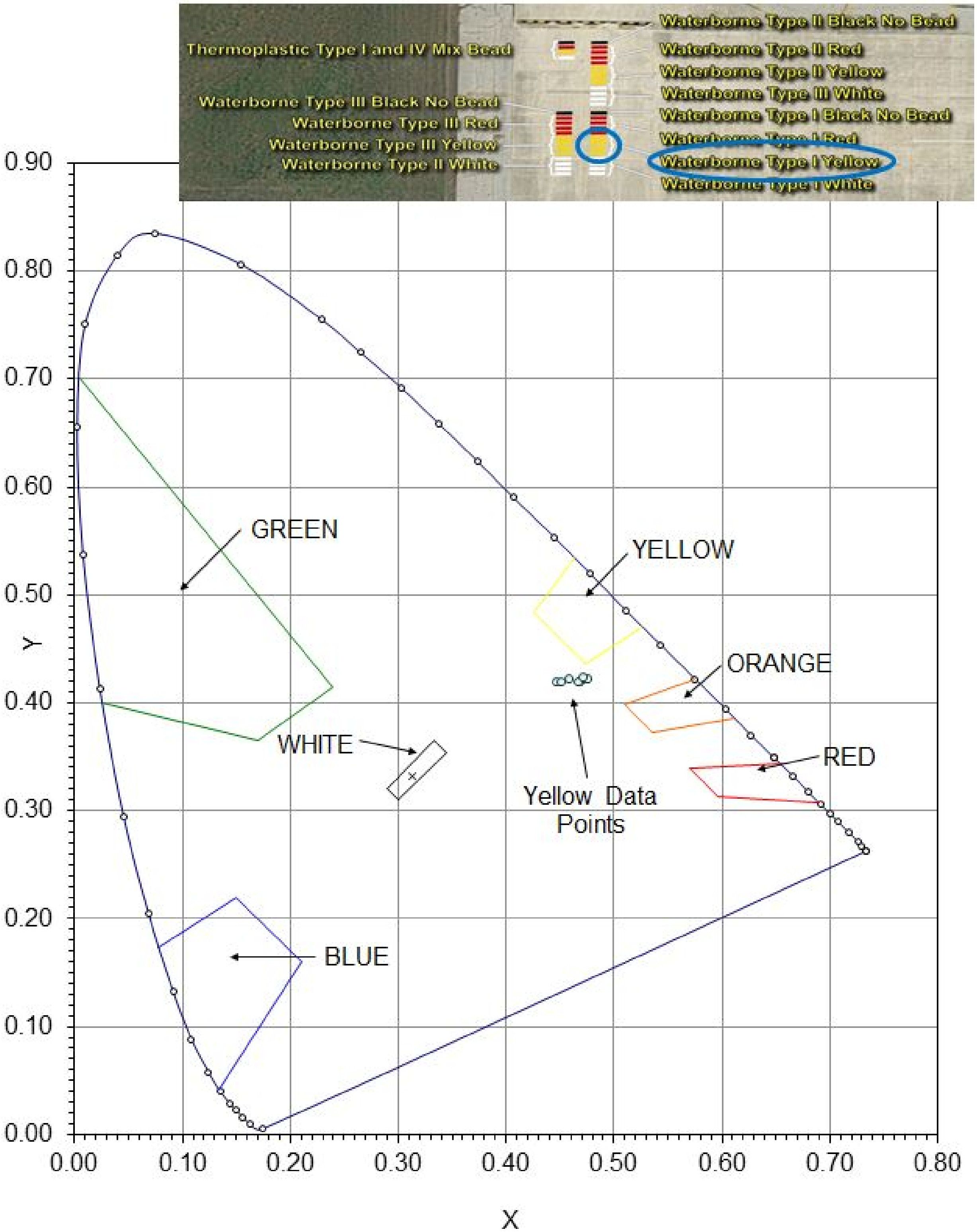


Figure A-4. April 18, 2018 Color Guide Readings for ACY Waterborne Type I Yellow

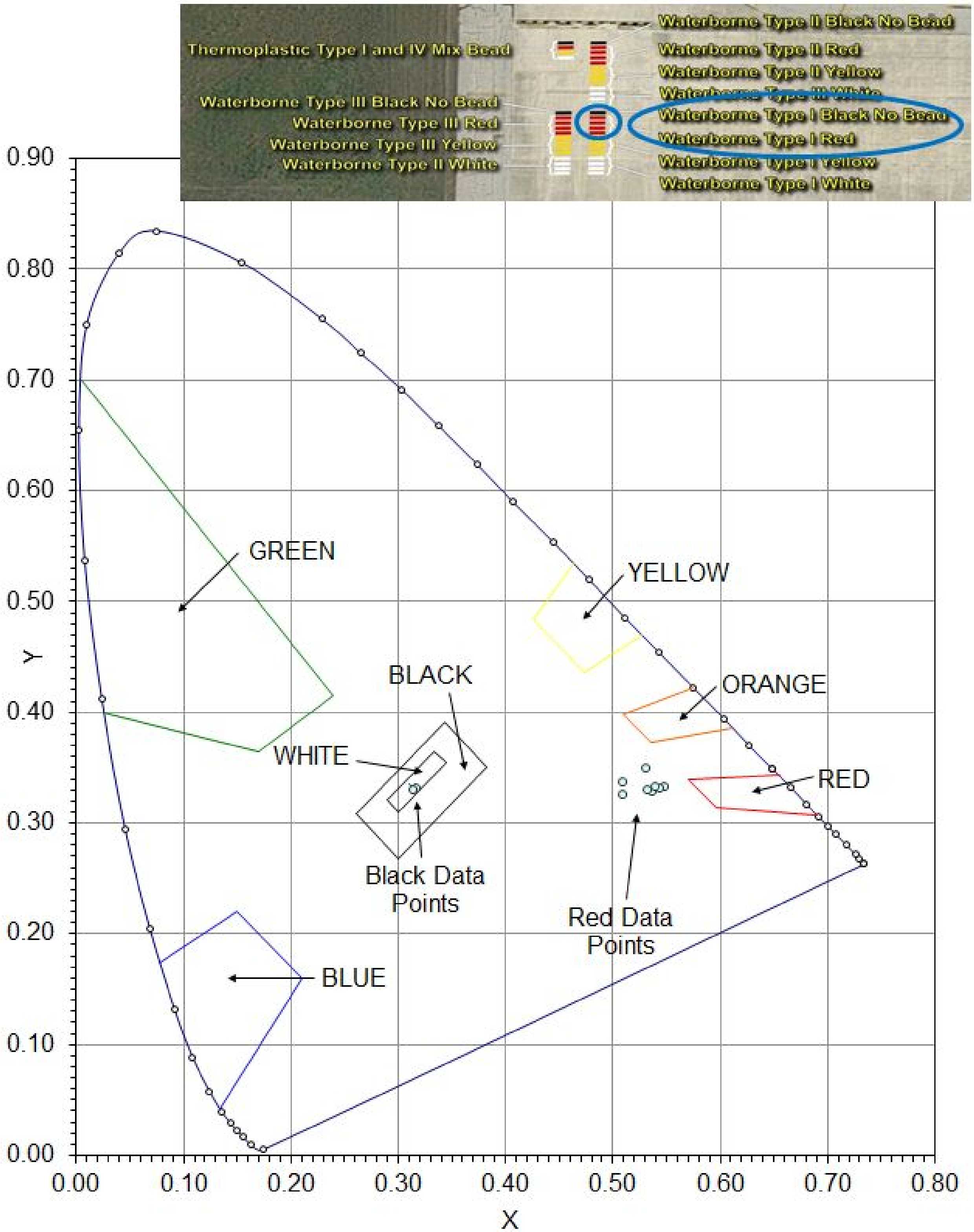


Figure A-5. April 11, 2017 Color Guide Readings for ACY Waterborne Type I Red and Black

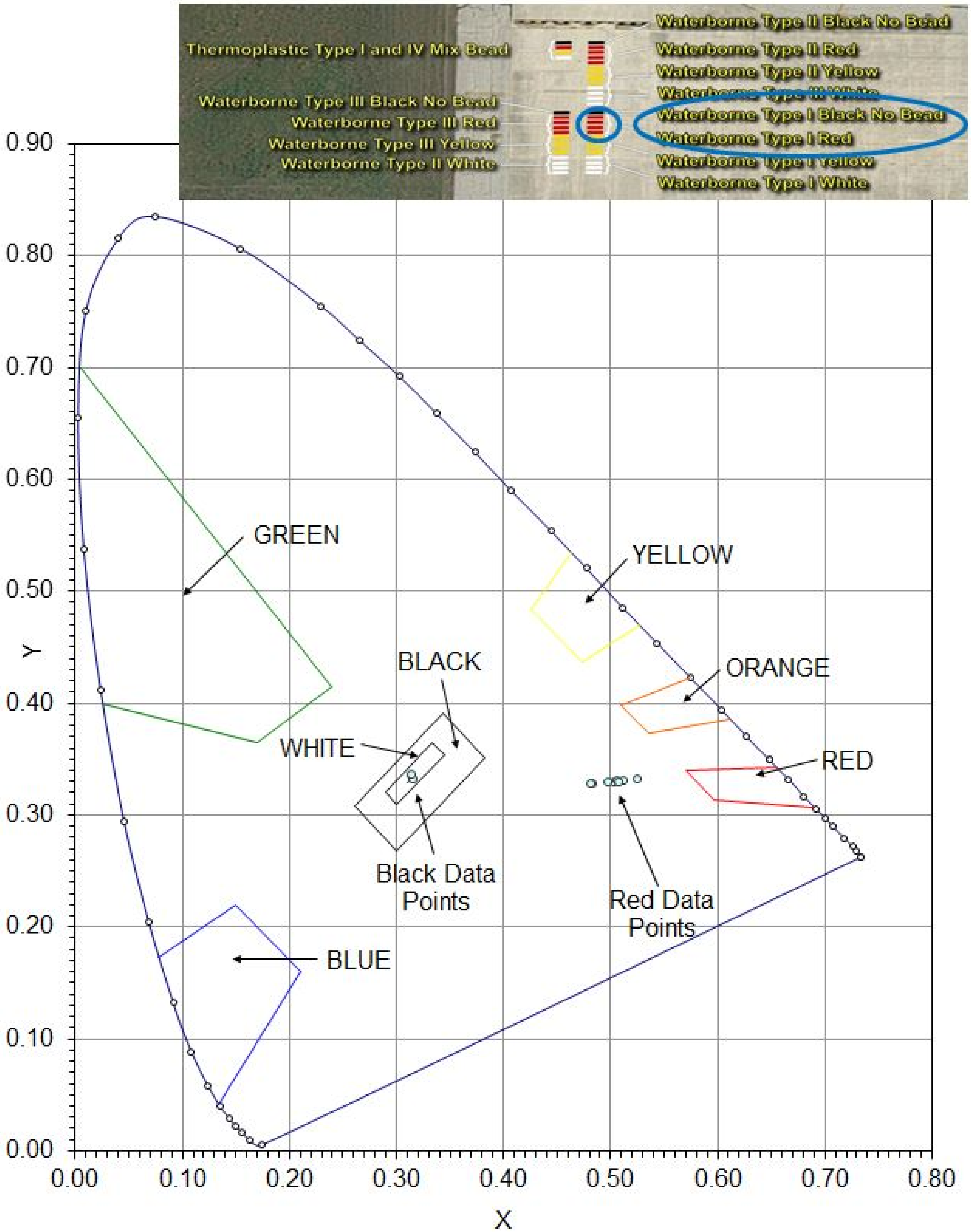


Figure A-6. April 18, 2018 Color Guide Readings for ACY Waterborne Type I Red and Black

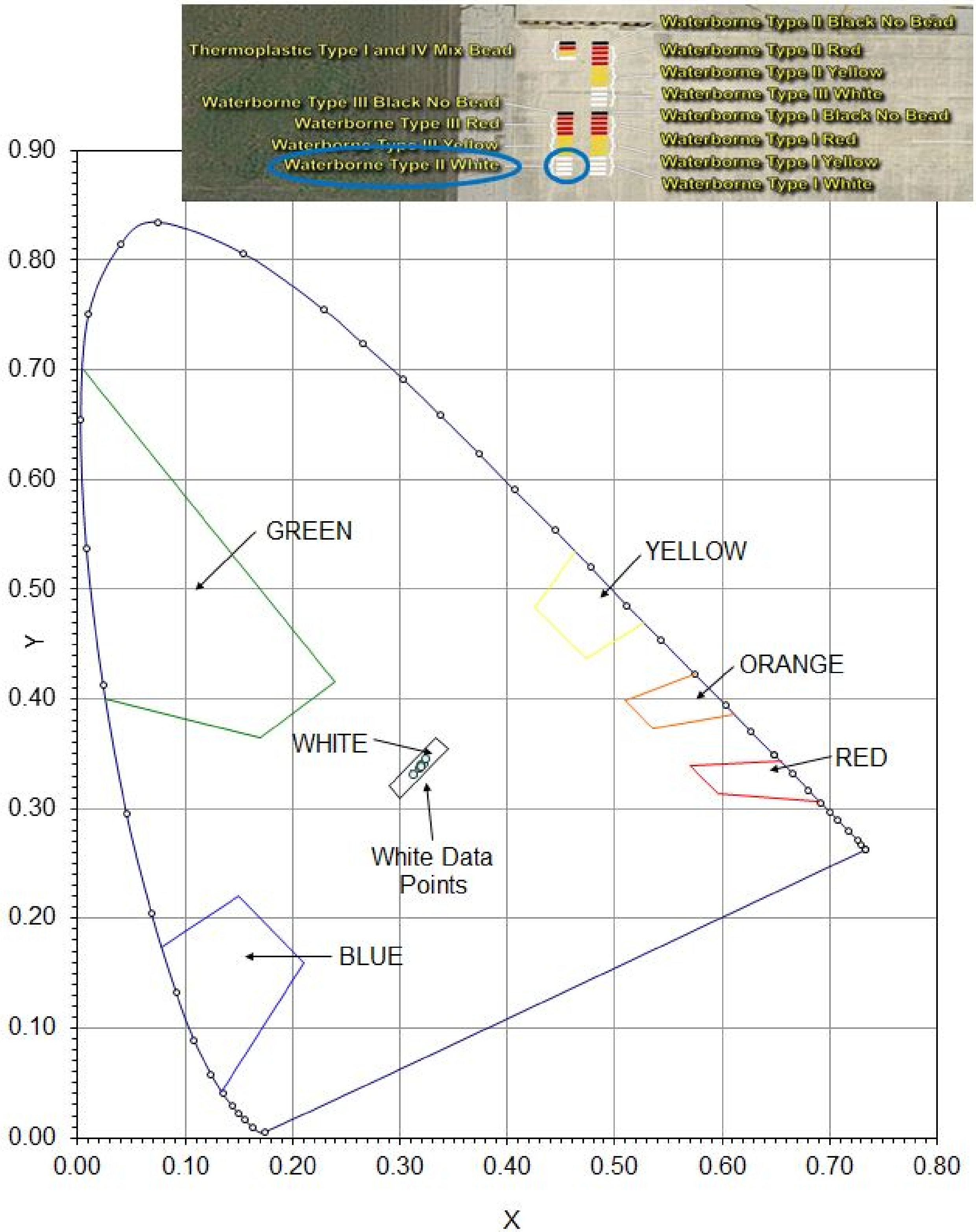


Figure A-7. April 11, 2017 Color Guide Readings for ACY Waterborne Type II White

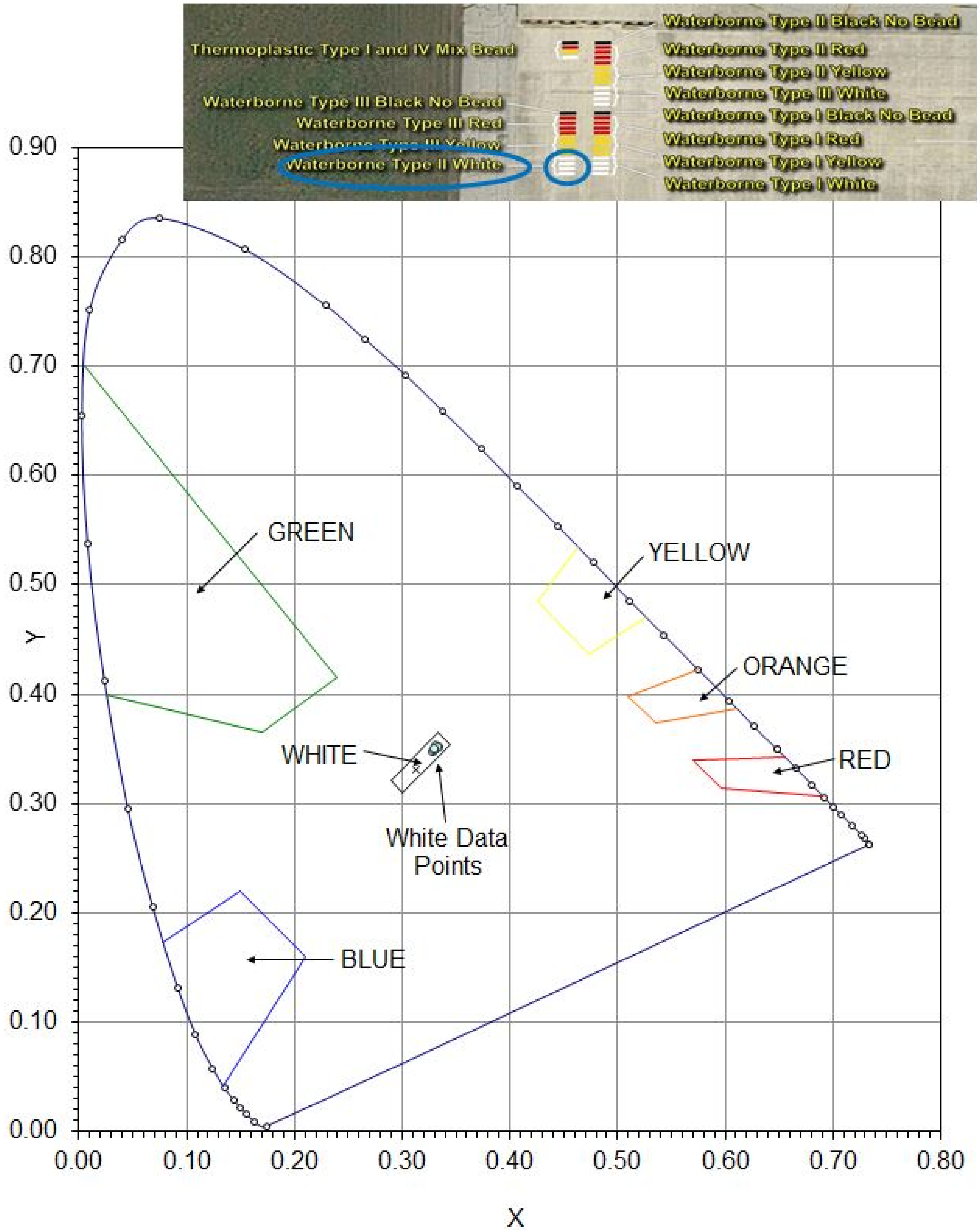


Figure A-8. April 18, 2018 Color Guide Readings for ACY Waterborne Type II White

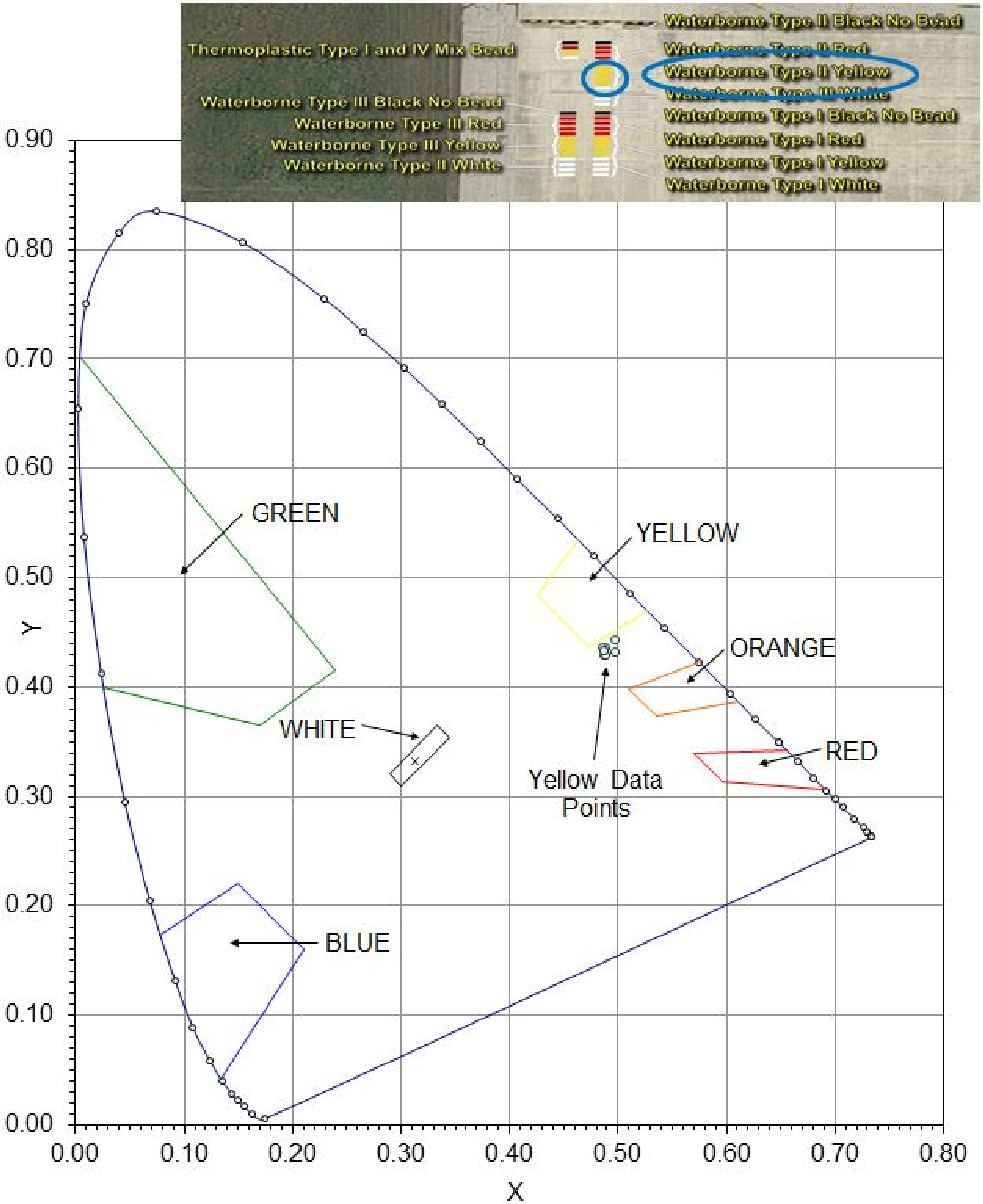


Figure A-9. April 11, 2017 Color Guide Readings for ACY Waterborne Type II Yellow

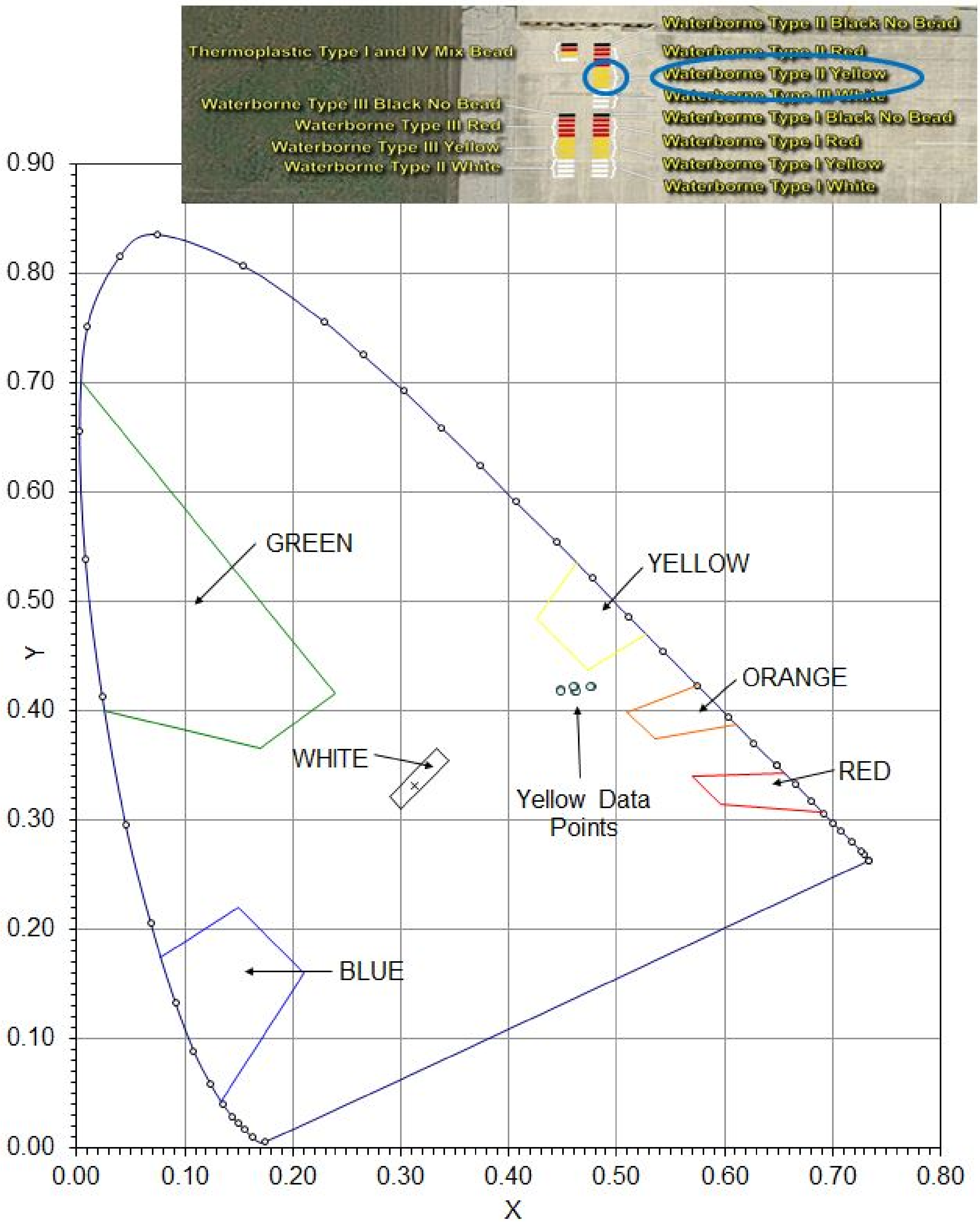


Figure A-10. April 18, 2018 Color Guide Readings for ACY Waterborne Type II Yellow

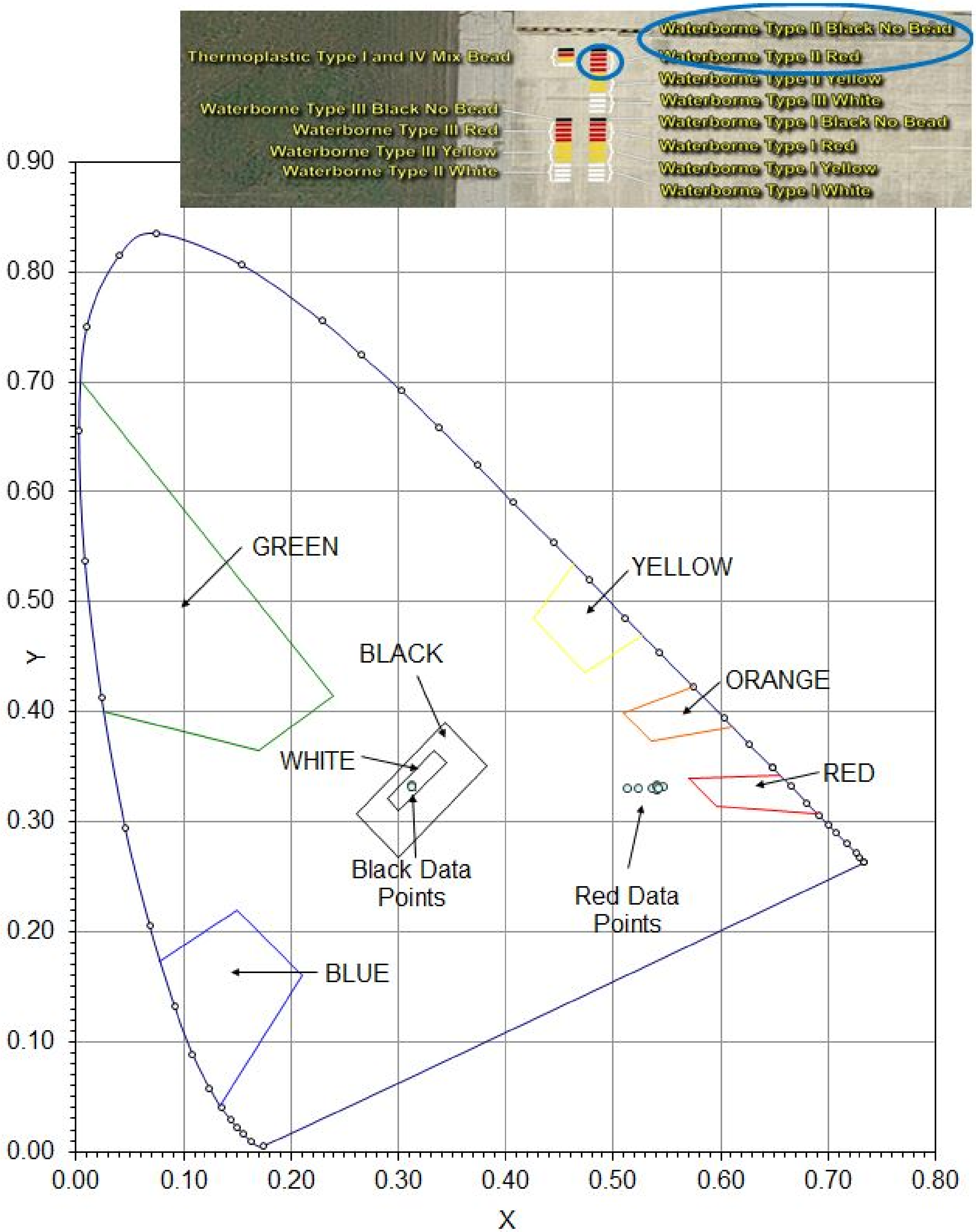


Figure A-11. April 11, 2017 Color Guide Readings for ACY Waterborne Type II Red and Black

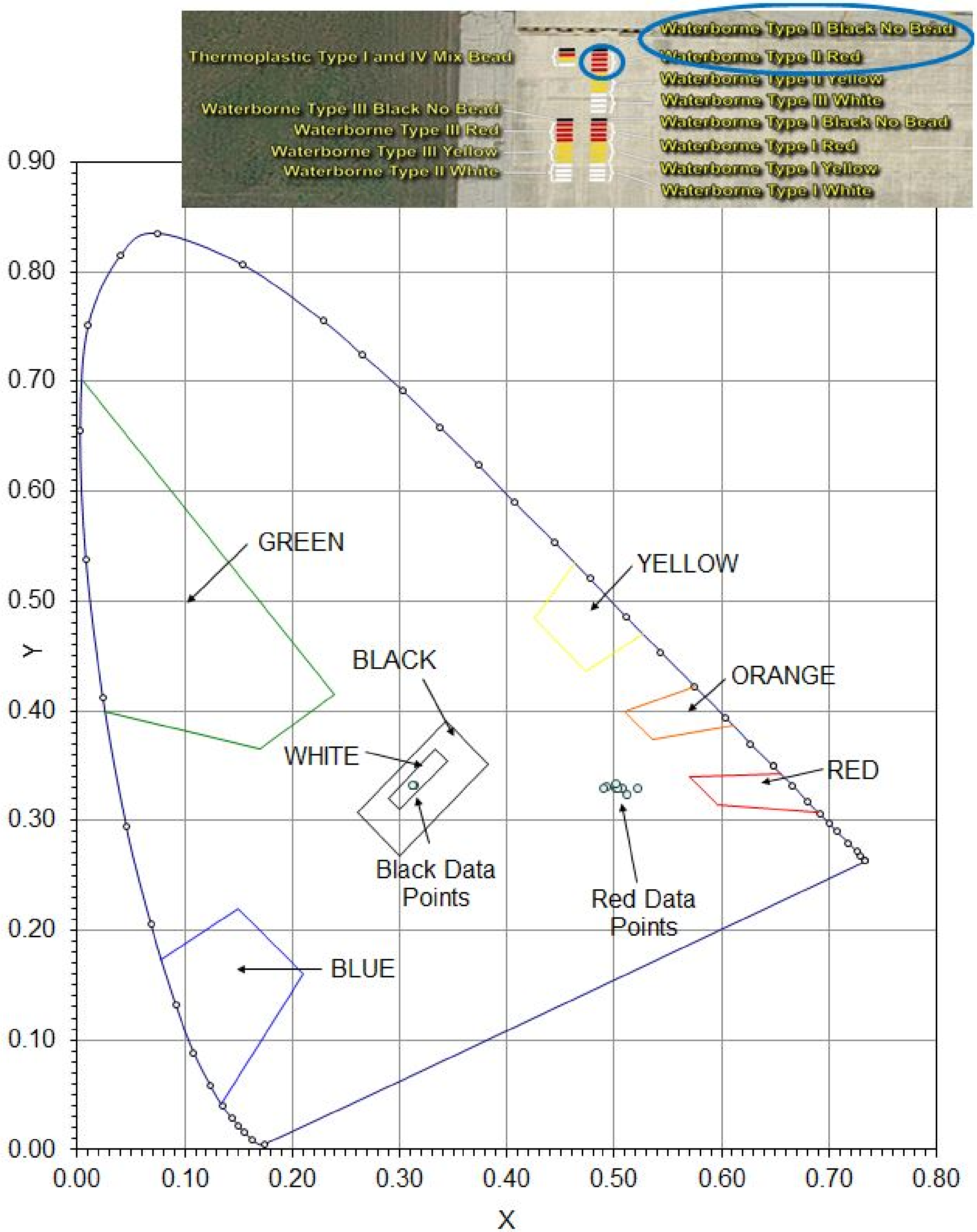


Figure A-12. April 18, 2018 Color Guide Readings for ACY Waterborne Type II Red and Black

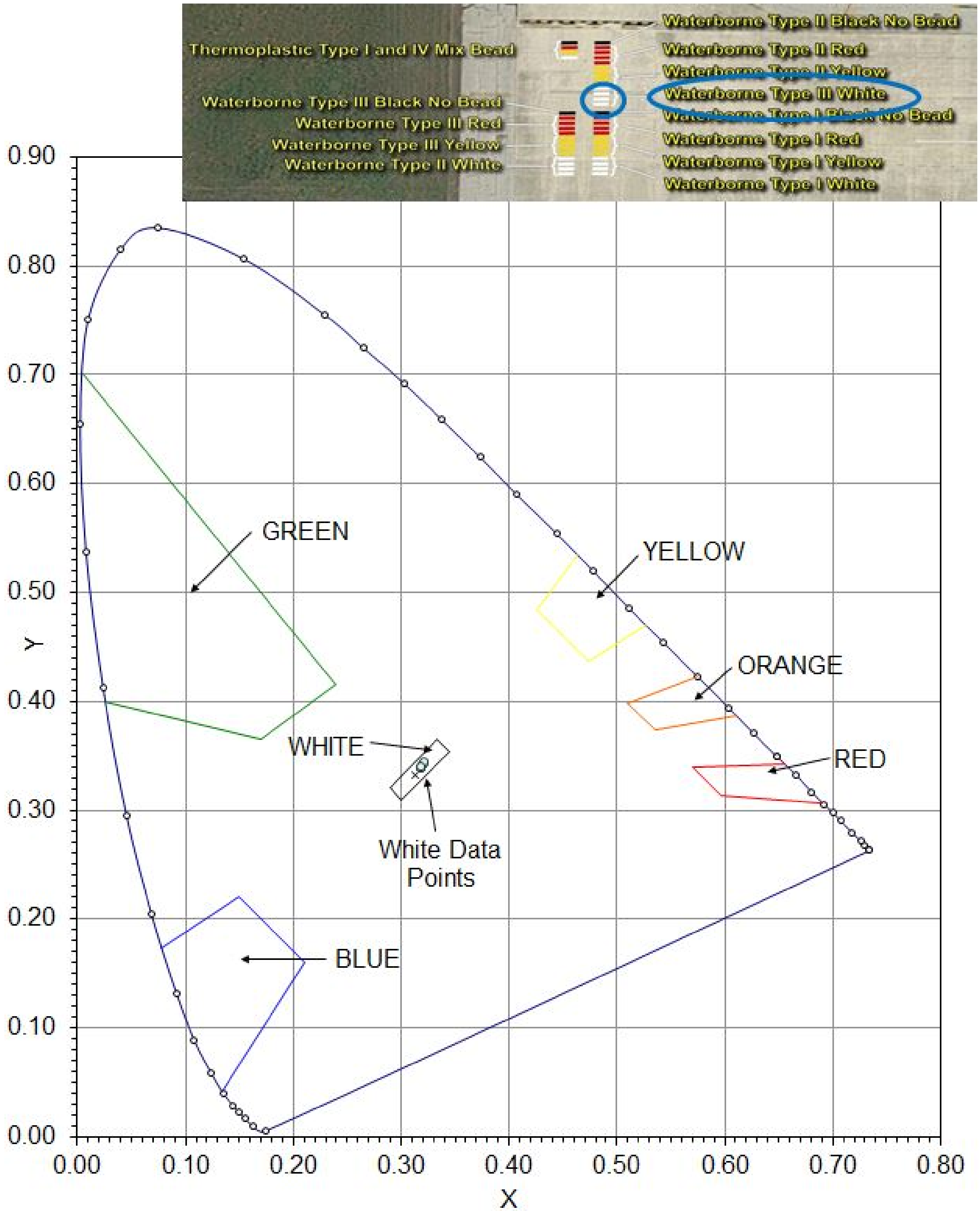


Figure A-13. April 11, 2017 Color Guide Readings for ACY Waterborne Type III White

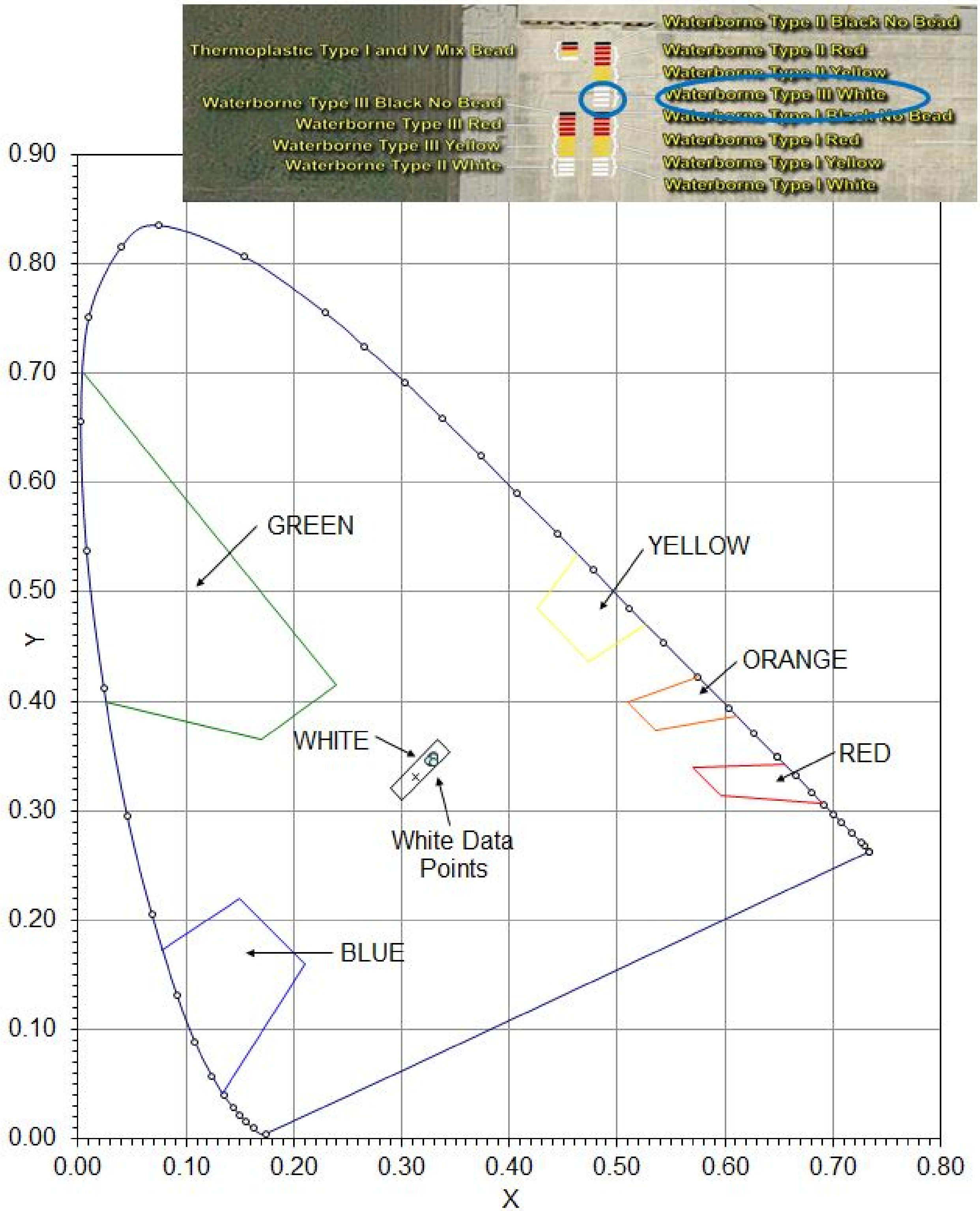


Figure A-14. April 18, 2018 Color Guide Readings for ACY Waterborne Type III White

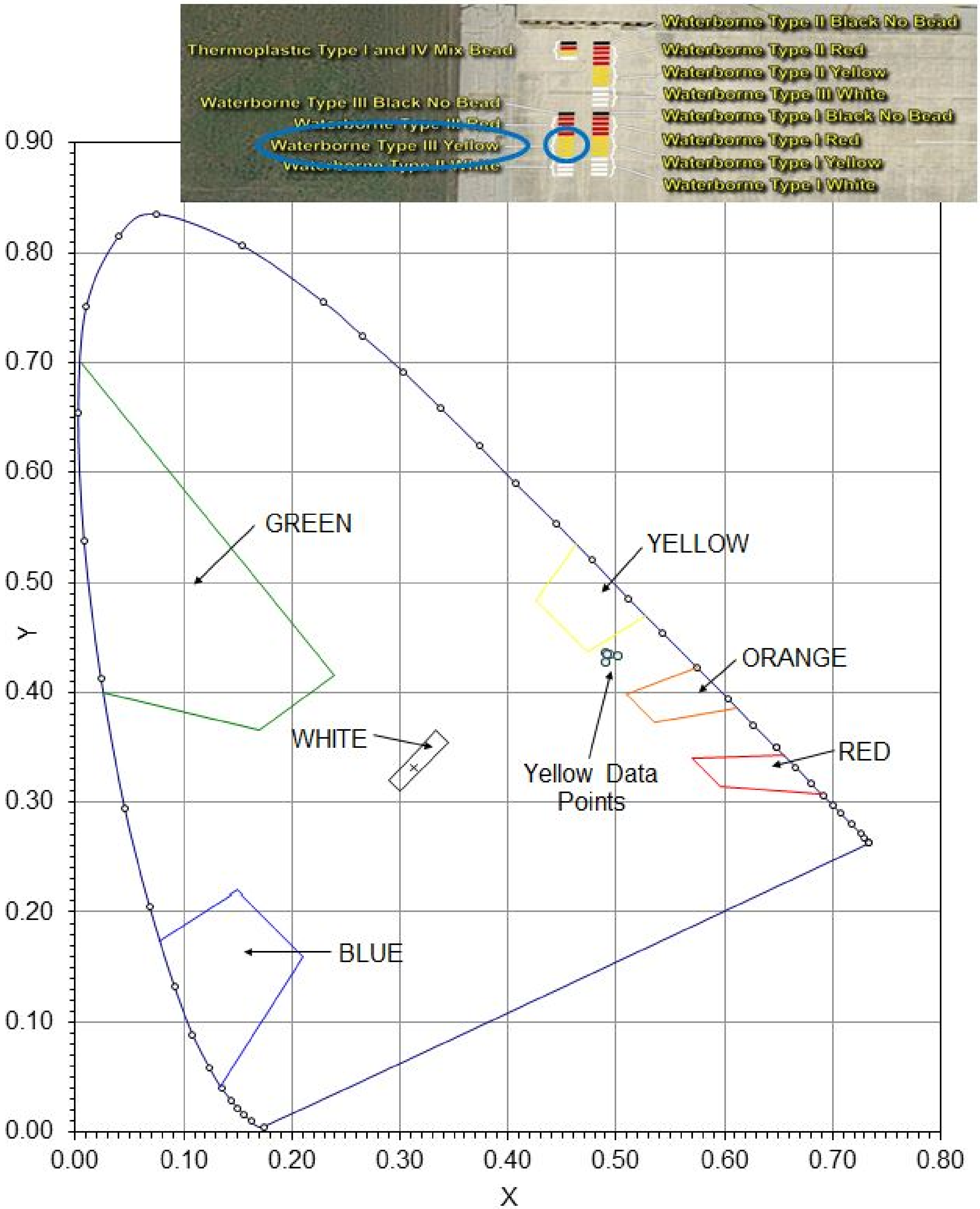


Figure A-15. April 11, 2017 Color Guide Readings for ACY Waterborne Type III Yellow

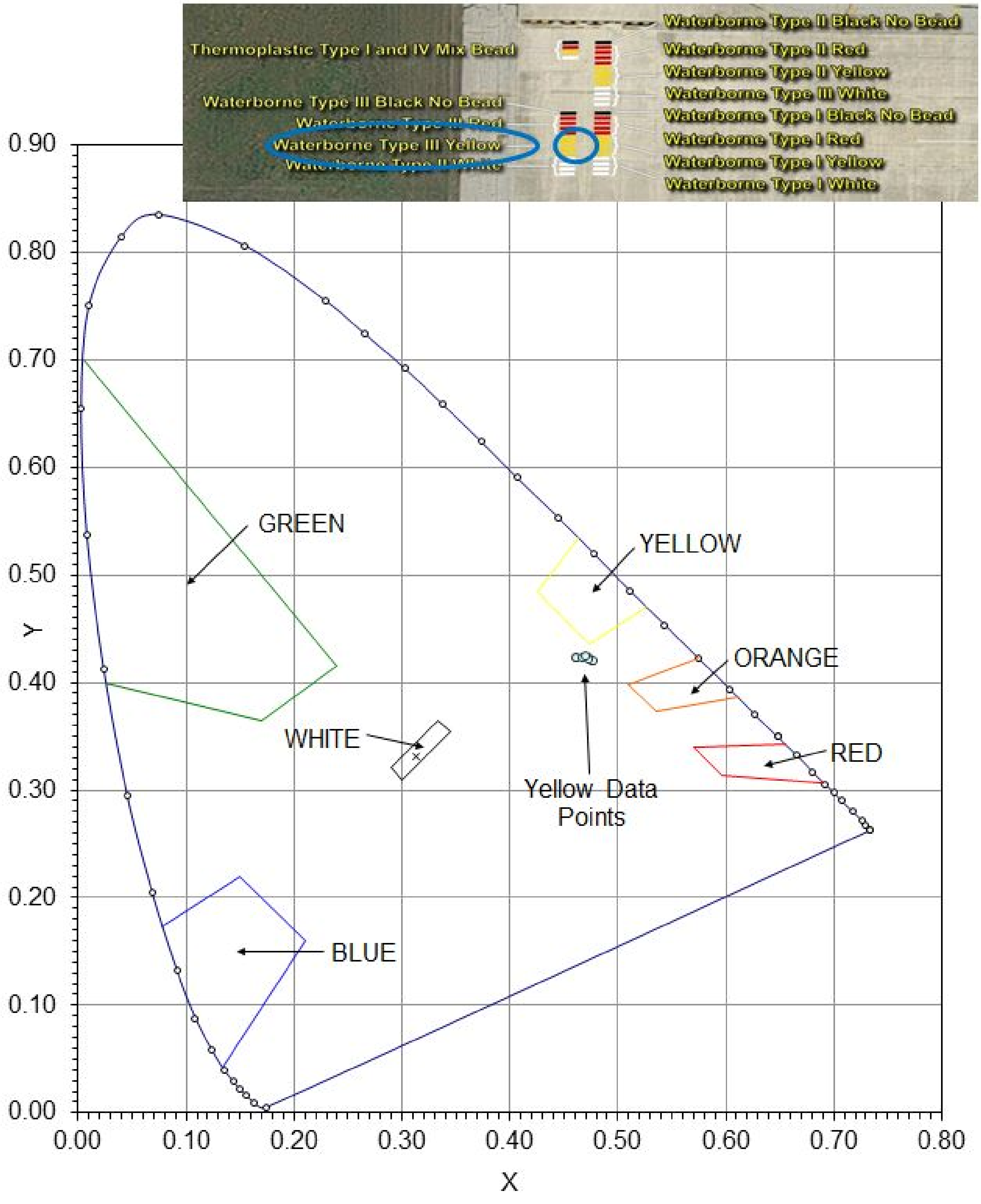


Figure A-16. April 18, 2018 Color Guide Readings for ACY Waterborne Type III Yellow

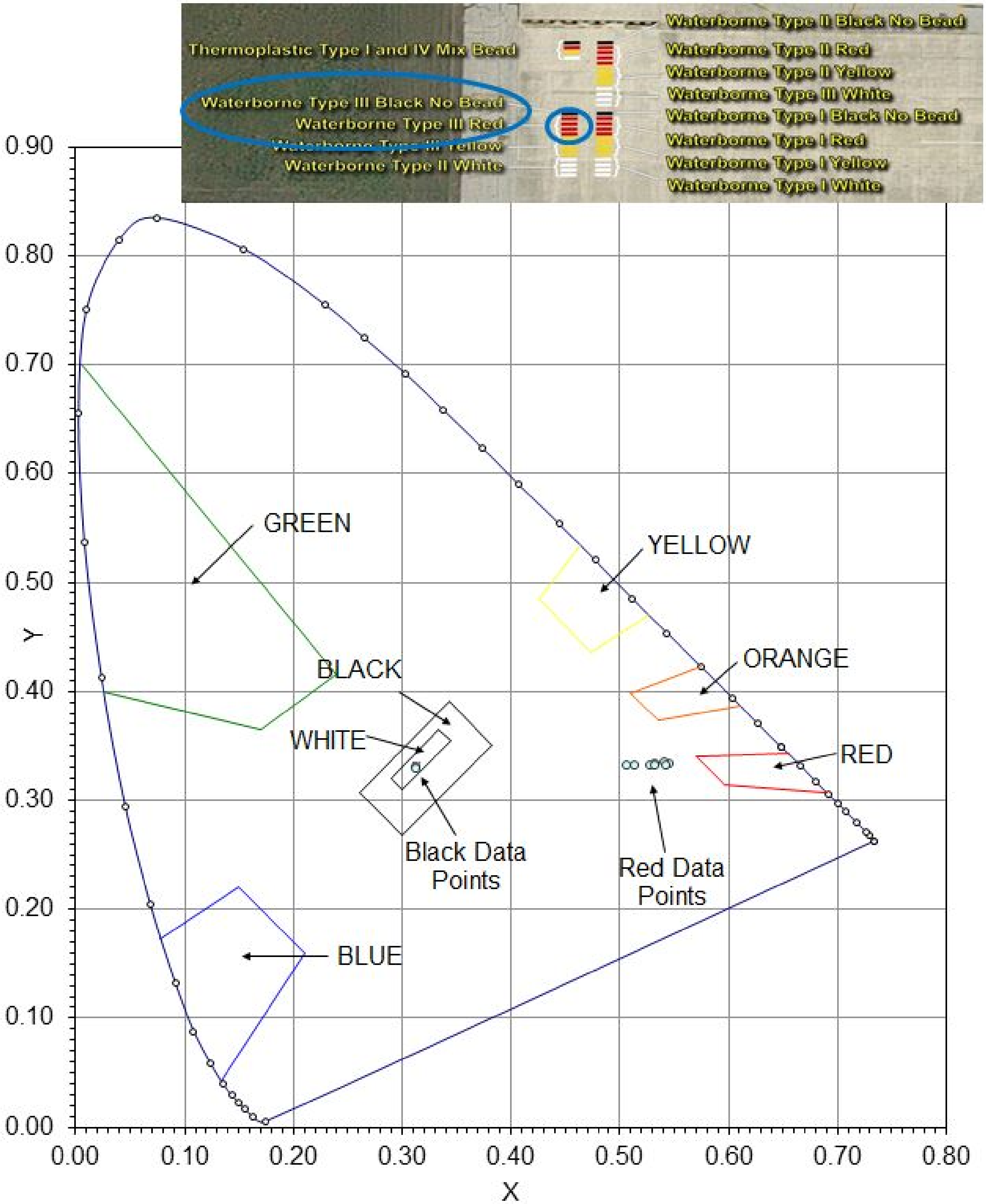


Figure A-17. April 11, 2017 Color Guide Readings for ACY Waterborne Type III Red and Black

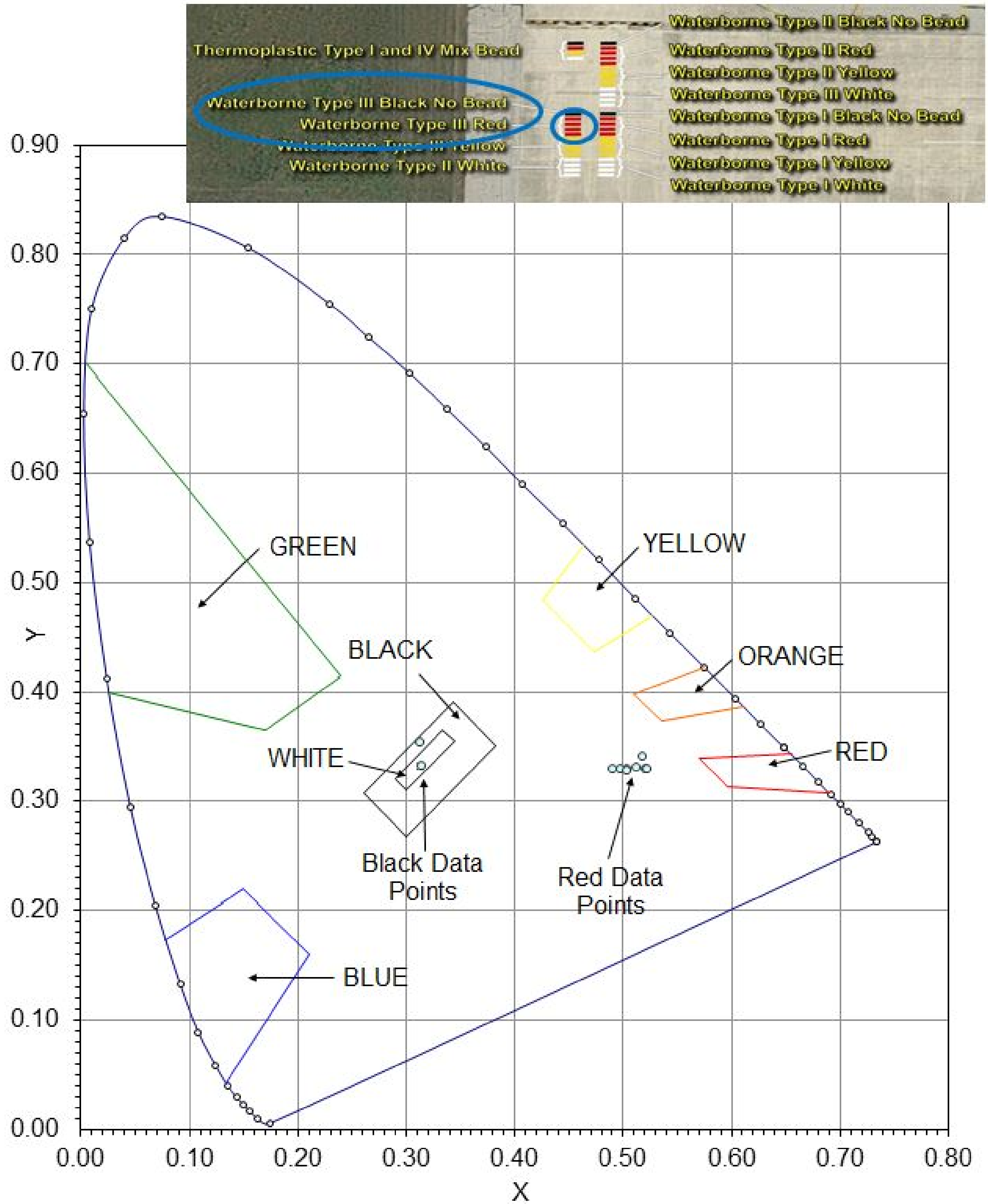


Figure A-18. April 18, 2018 Color Guide Readings for ACY Waterborne Type III Red and Black

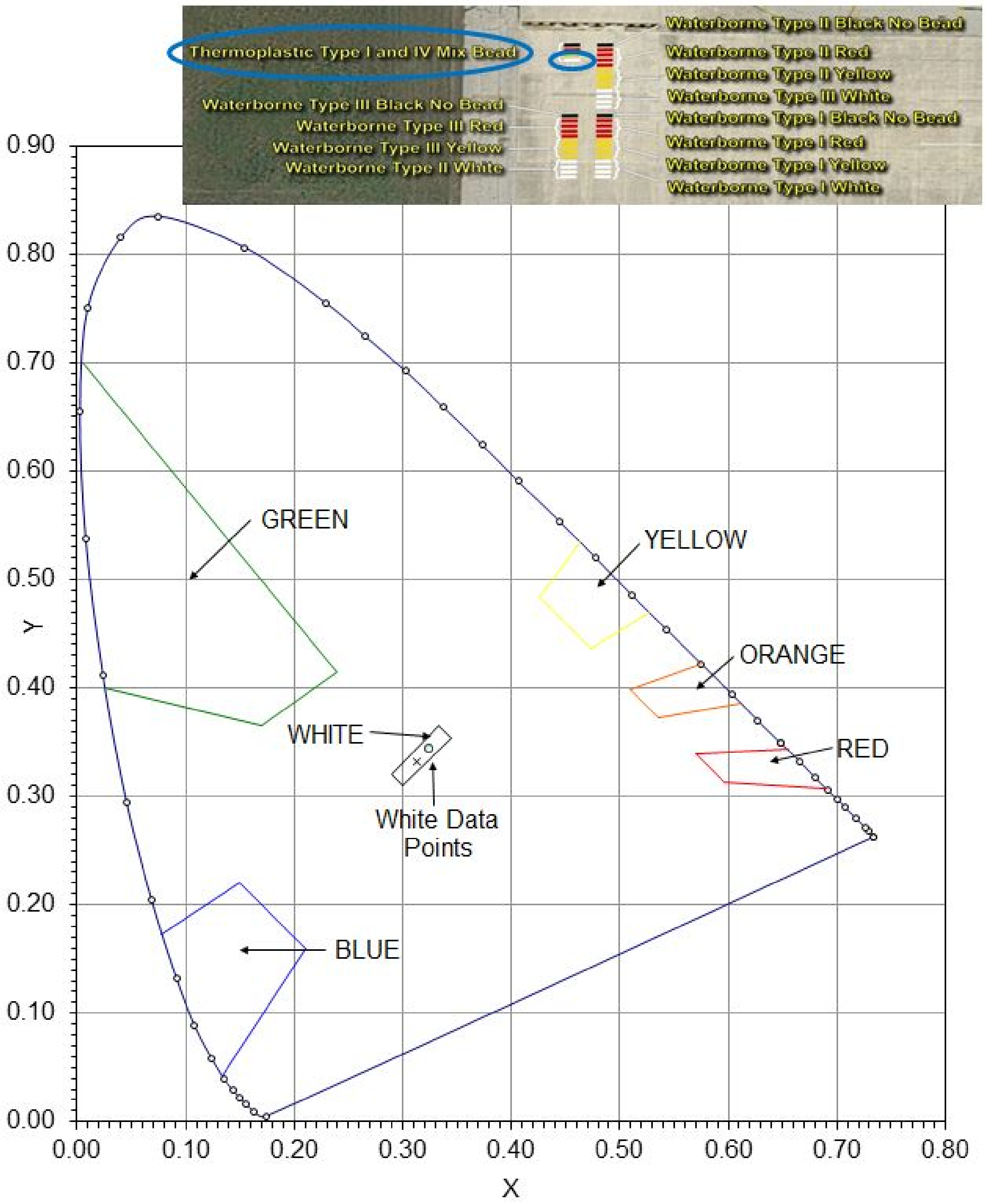


Figure A-19. April 11, 2017 Color Guide Readings for ACY Preformed Thermoplastic White

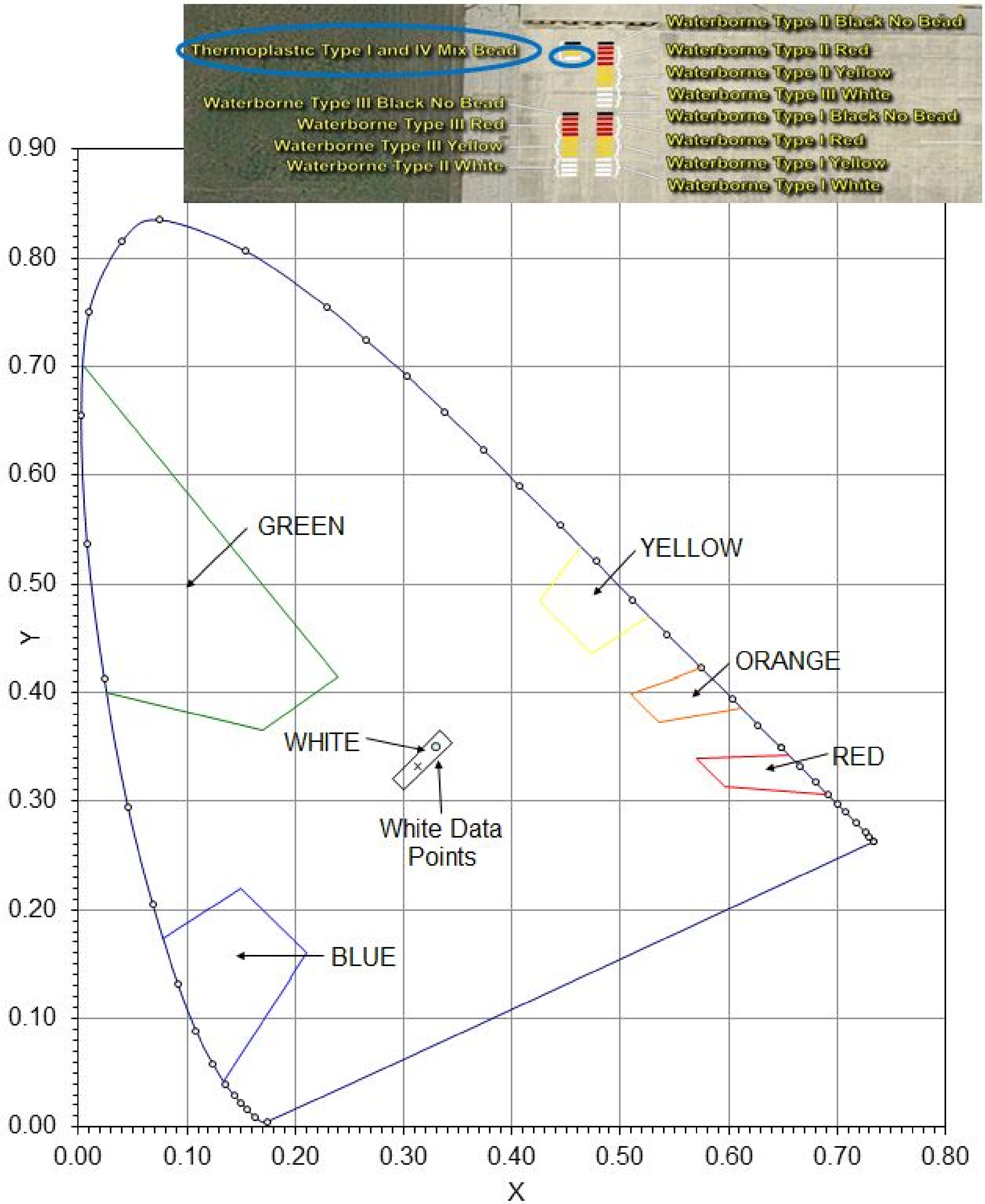


Figure A-20. April 18, 2018 Color Guide Readings for ACY Preformed Thermoplastic White

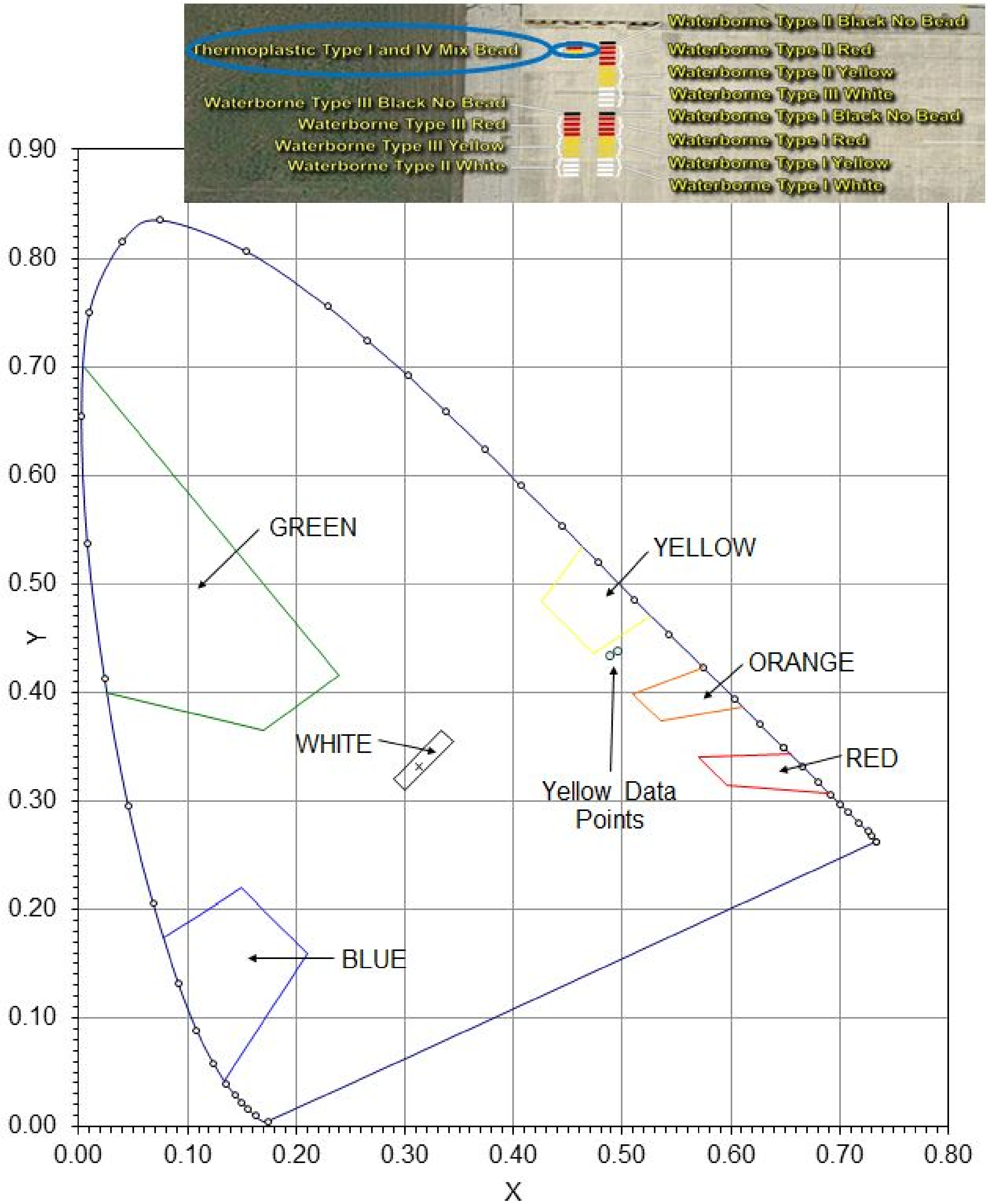


Figure A-21. April 11, 2017 Color Guide Readings for ACY Preformed Thermoplastic Yellow

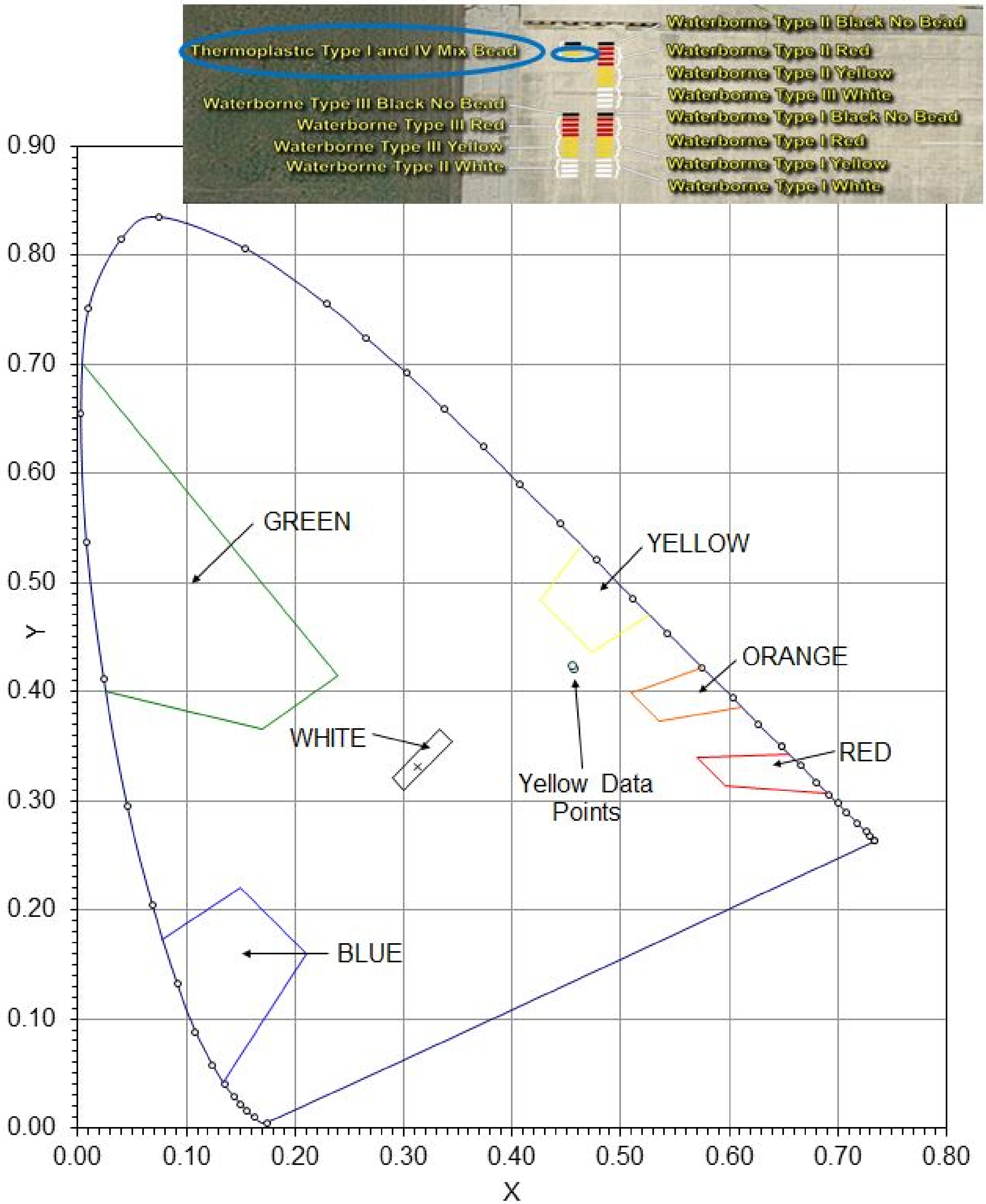


Figure A-22. April 18, 2018 Color Guide Readings for ACY Preformed Thermoplastic Yellow

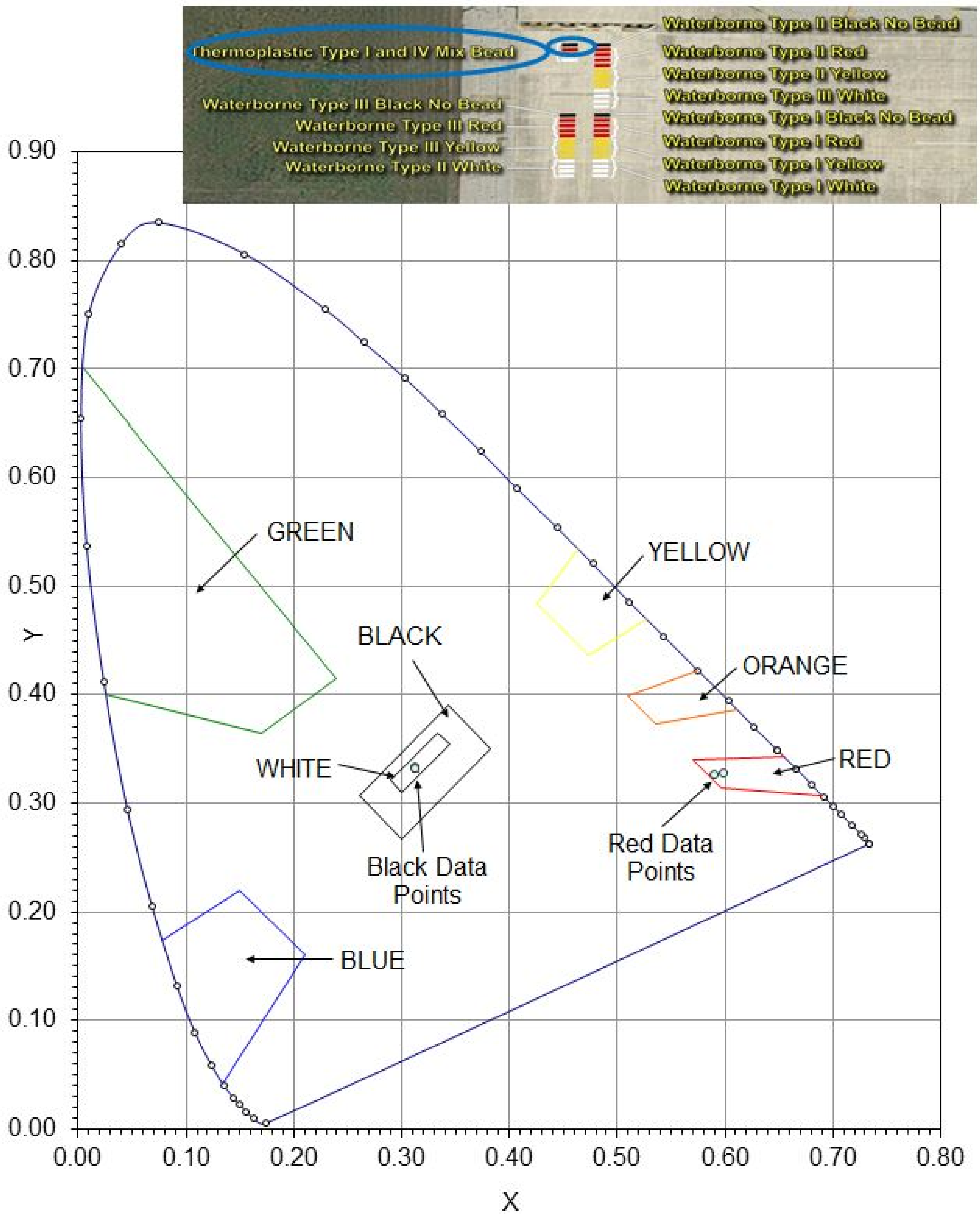


Figure A-23. April 11, 2017 Color Guide Readings for ACY Preformed Thermoplastic Red and Black

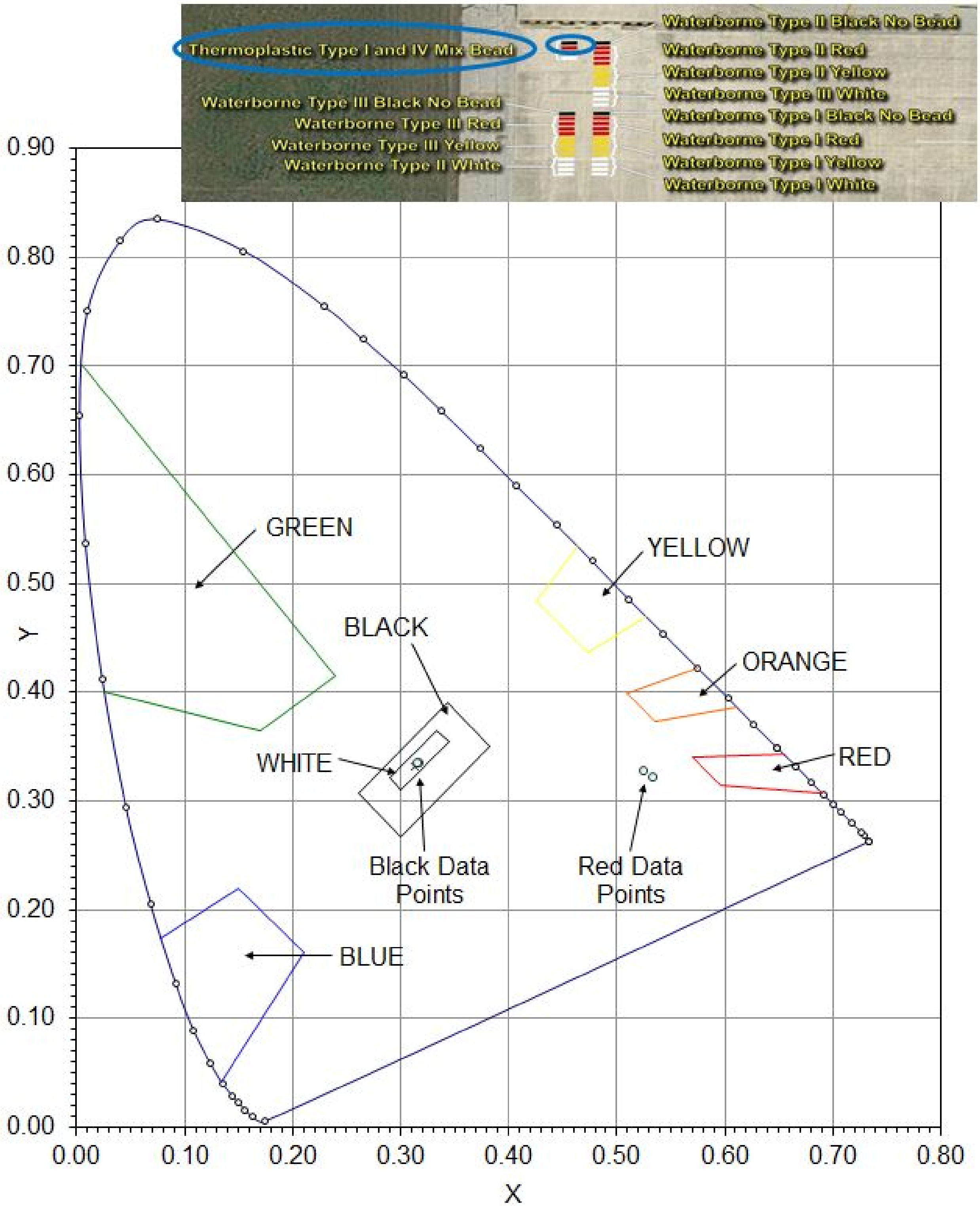
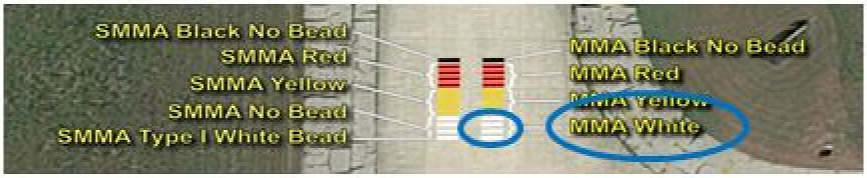


Figure A-24. April 18, 2018 Color Guide Readings for ACY Preformed Thermoplastic Red and Black



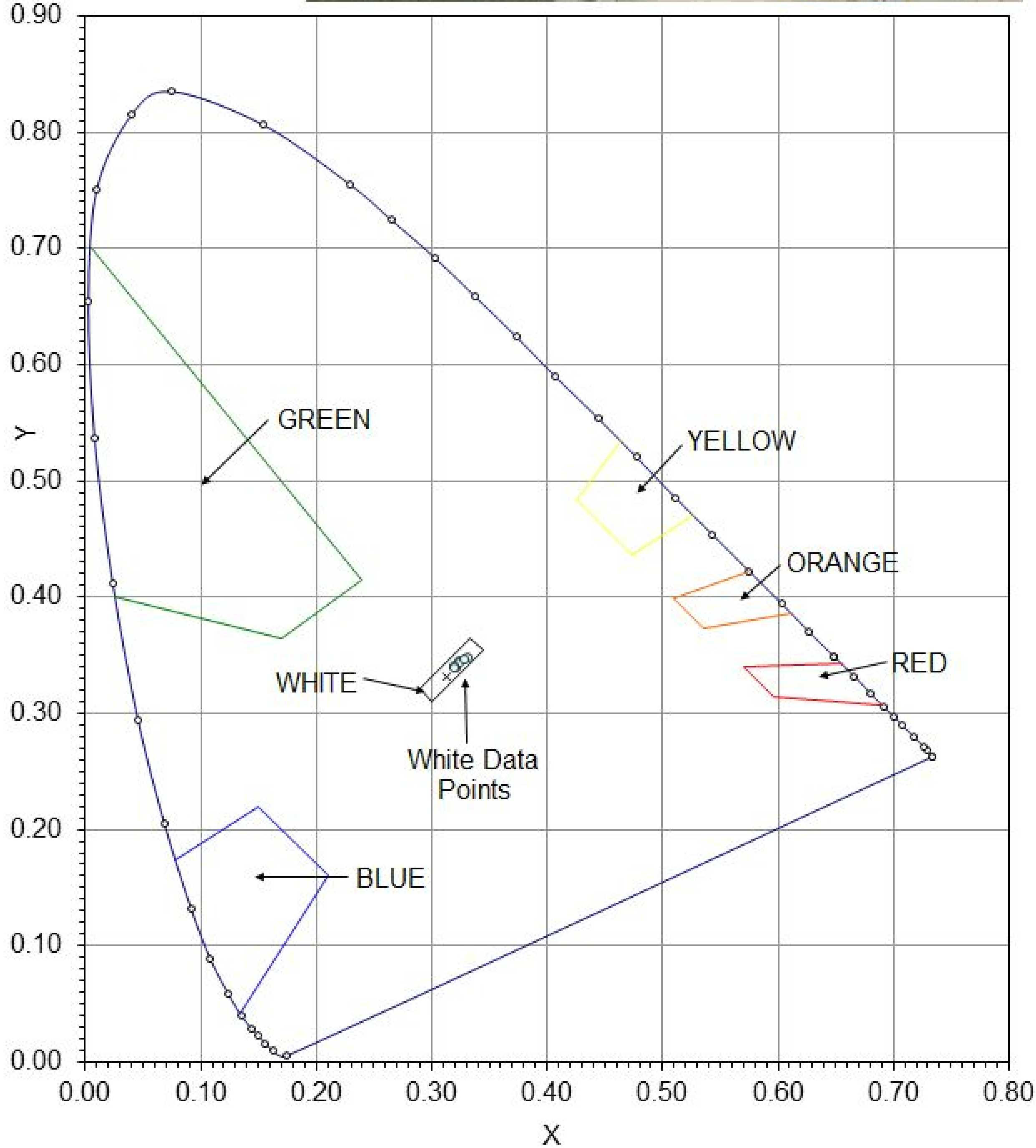


Figure A-25. June 19, 2017 Color Guide Readings for ACY MMA White

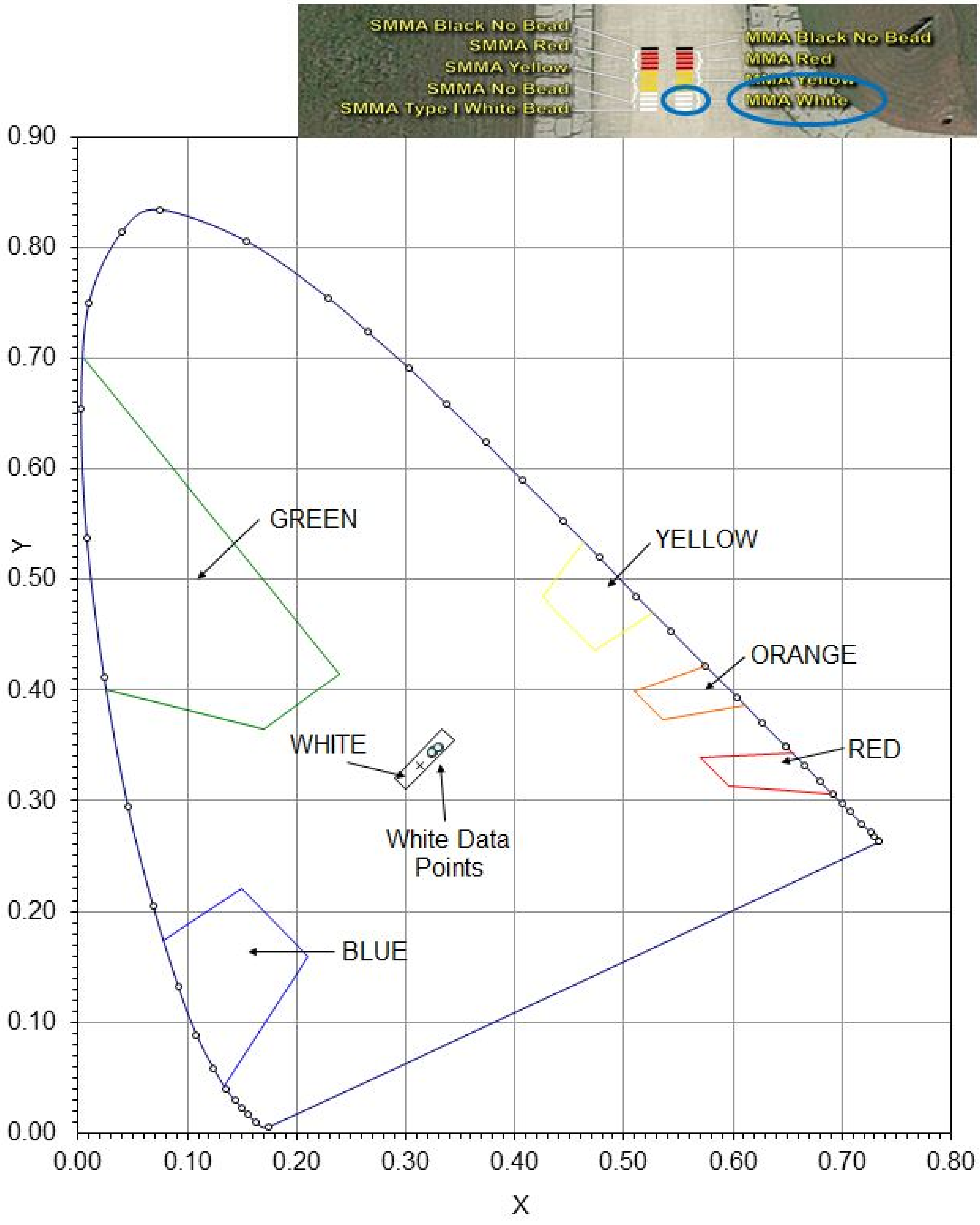


Figure A-26. April 18, 2018 Color Guide Readings for ACY MMA White

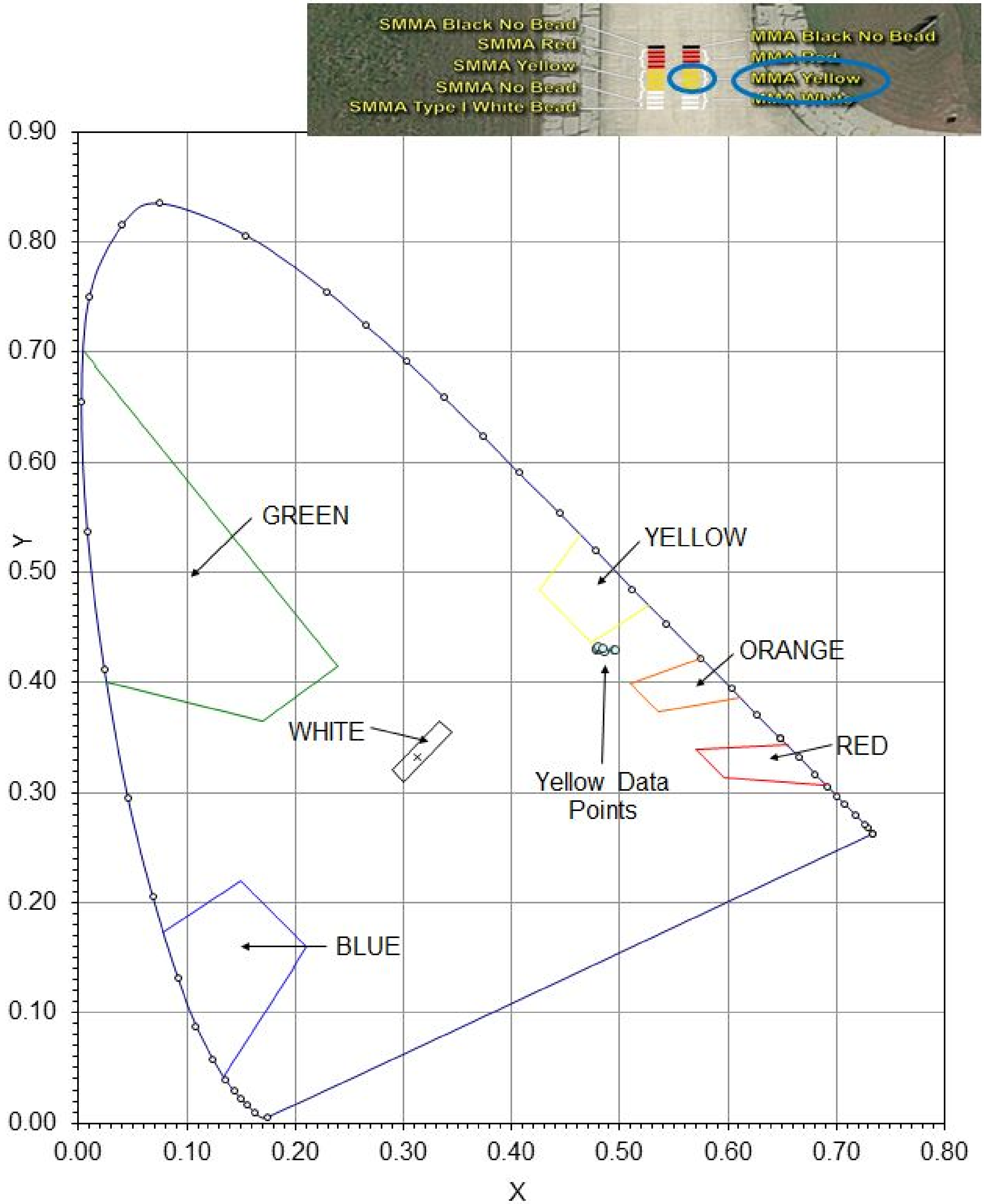


Figure A-27. June 19, 2017 Color Guide Readings for ACY MMA Yellow

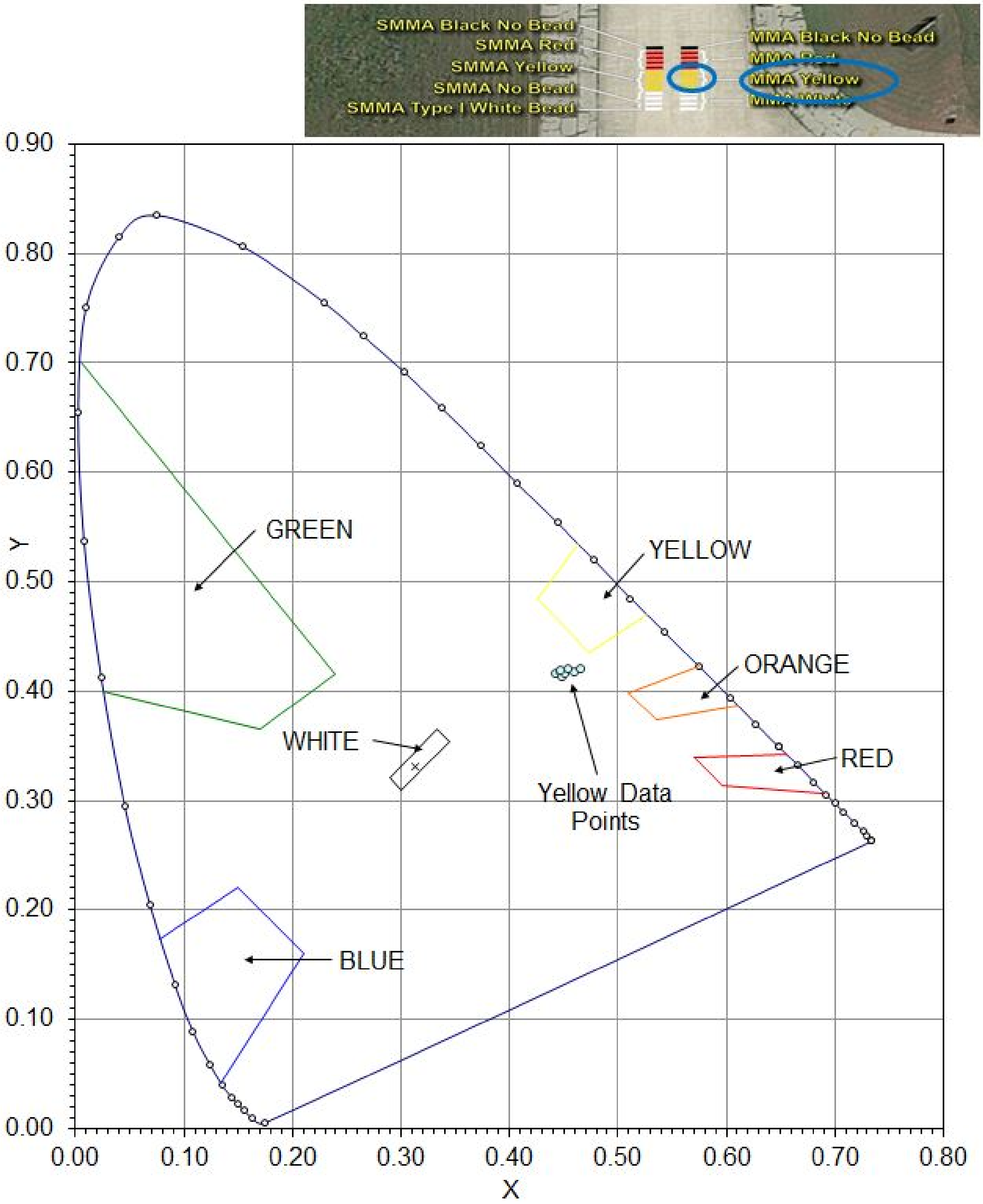


Figure A-28. April 18, 2018 Color Guide Readings for ACY MMA Yellow

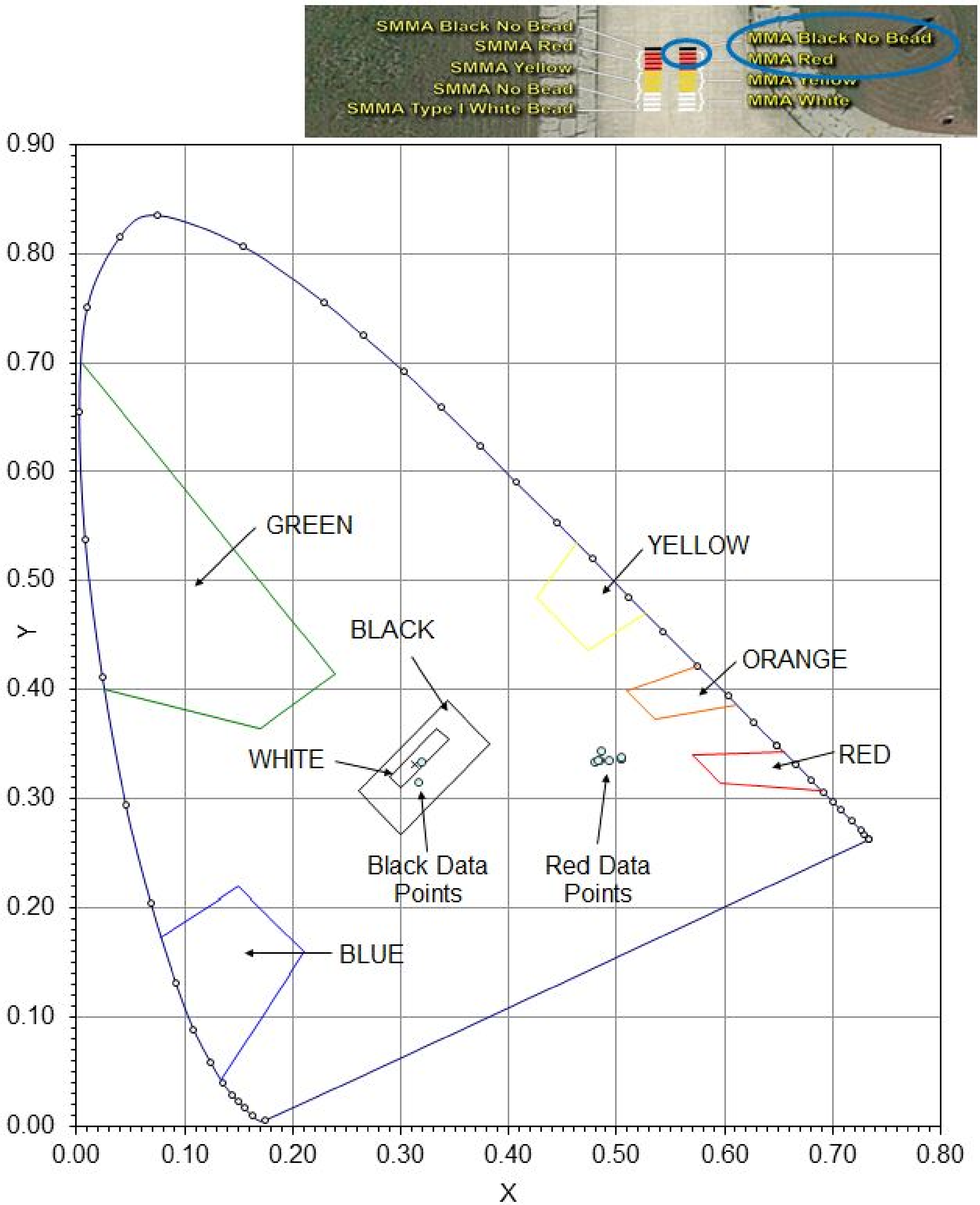


Figure A-29. June 19, 2017 Color Guide Readings for ACY MMA Red and Black

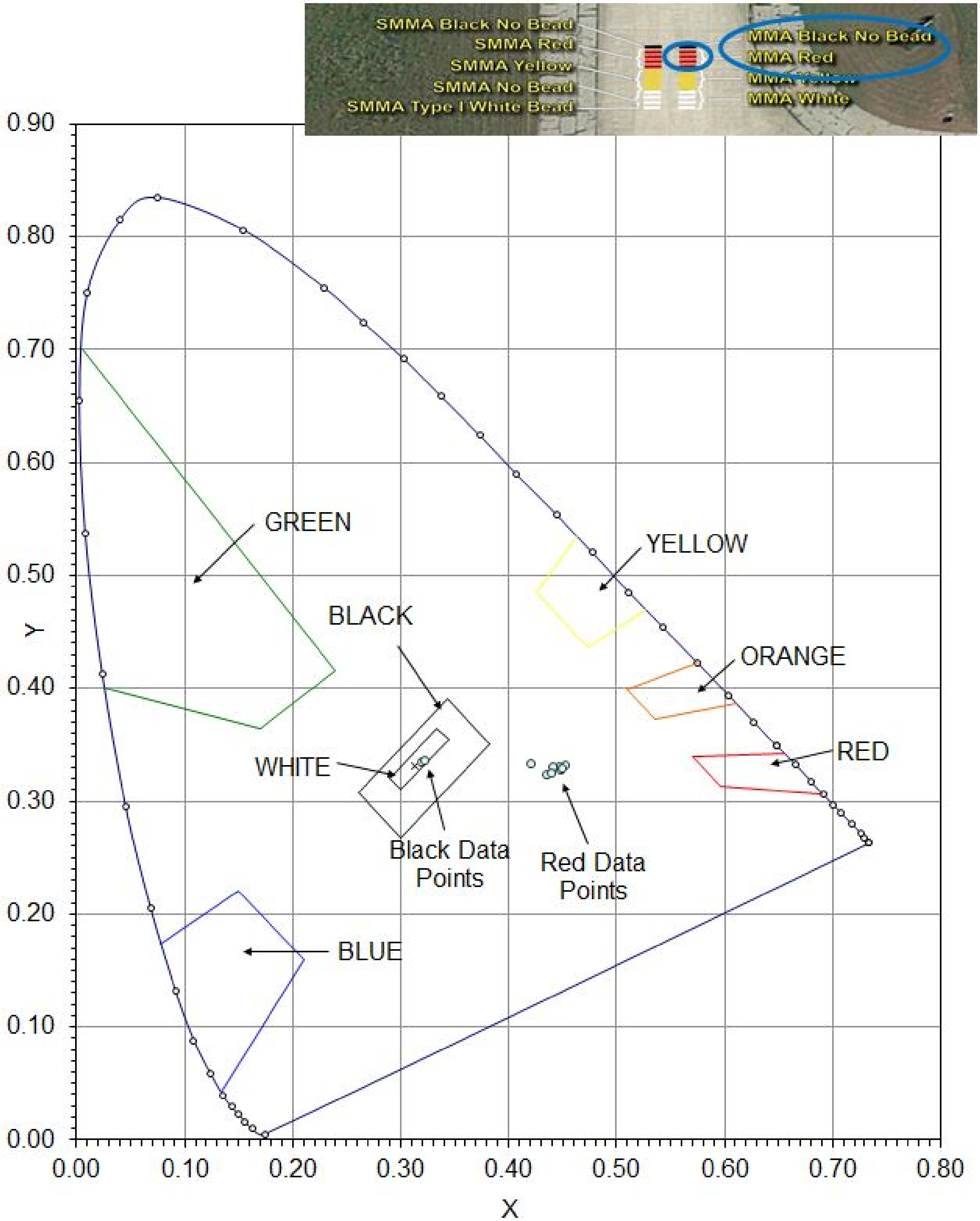


Figure A-30. April 18, 2018 Color Guide Readings for ACY MMA Red and Black

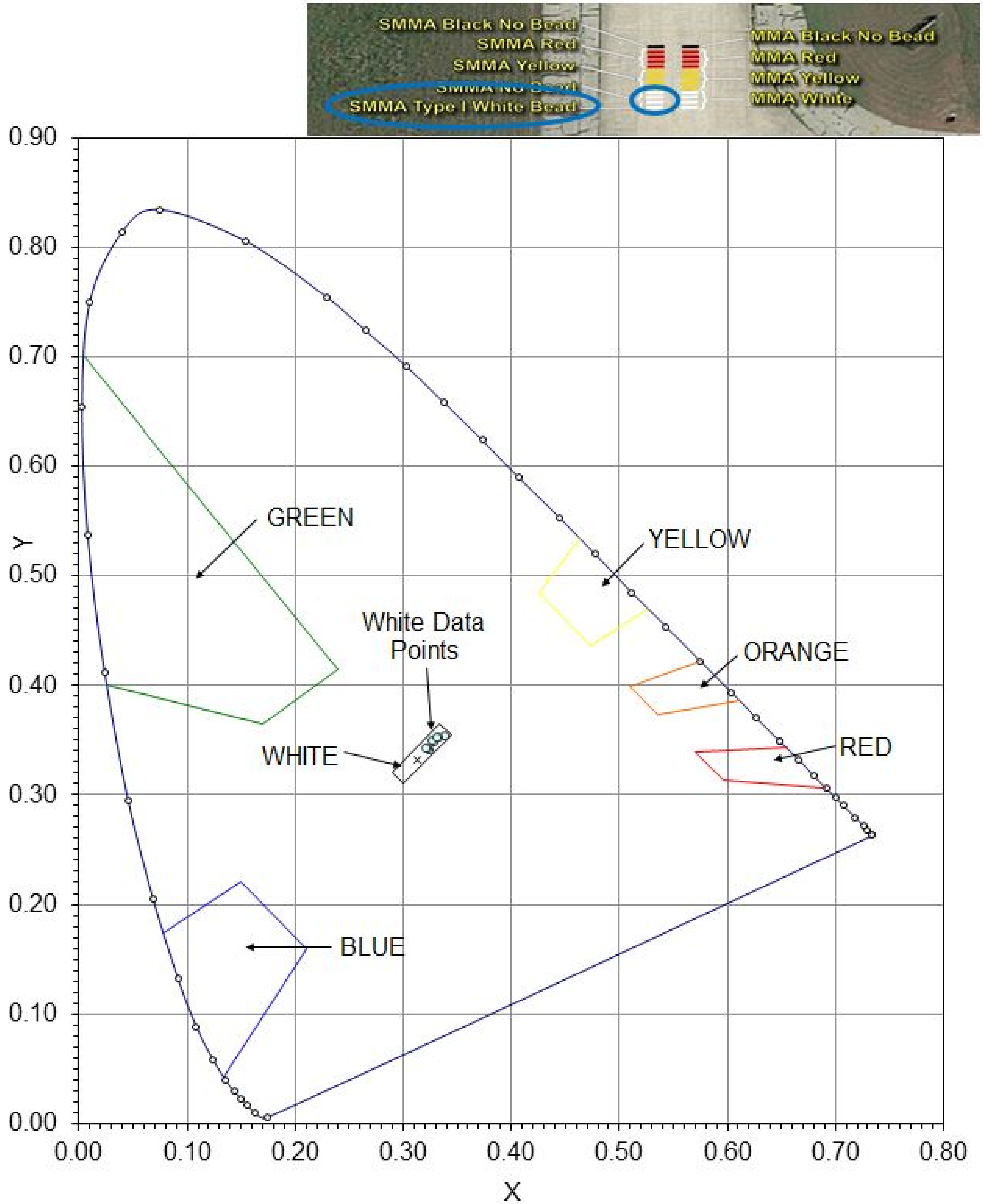


Figure A-31. April 11, 2017 Color Guide Readings for ACY SMMA White

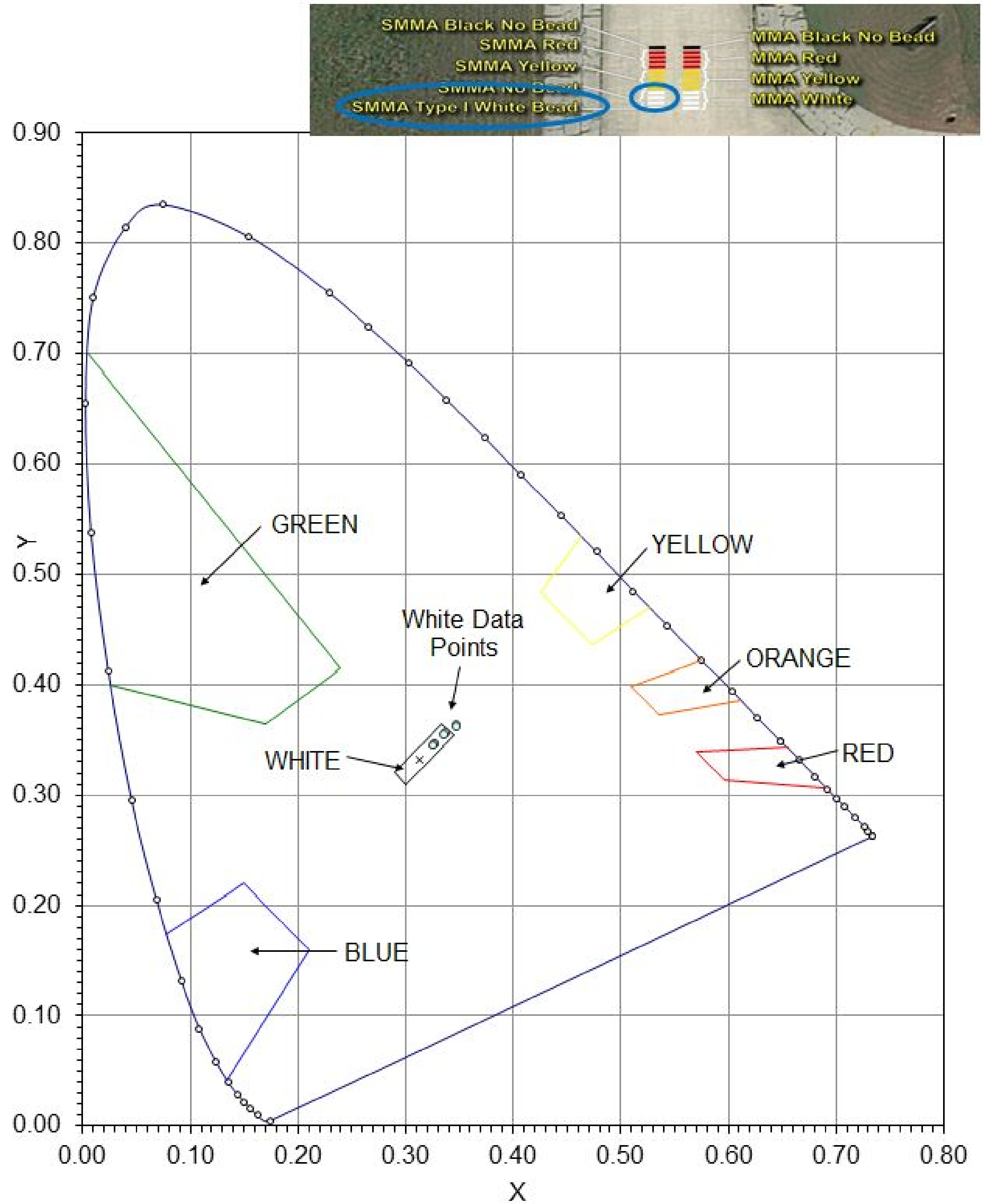


Figure A-32. April 18, 2018 Color Guide Readings for ACY SMMA White

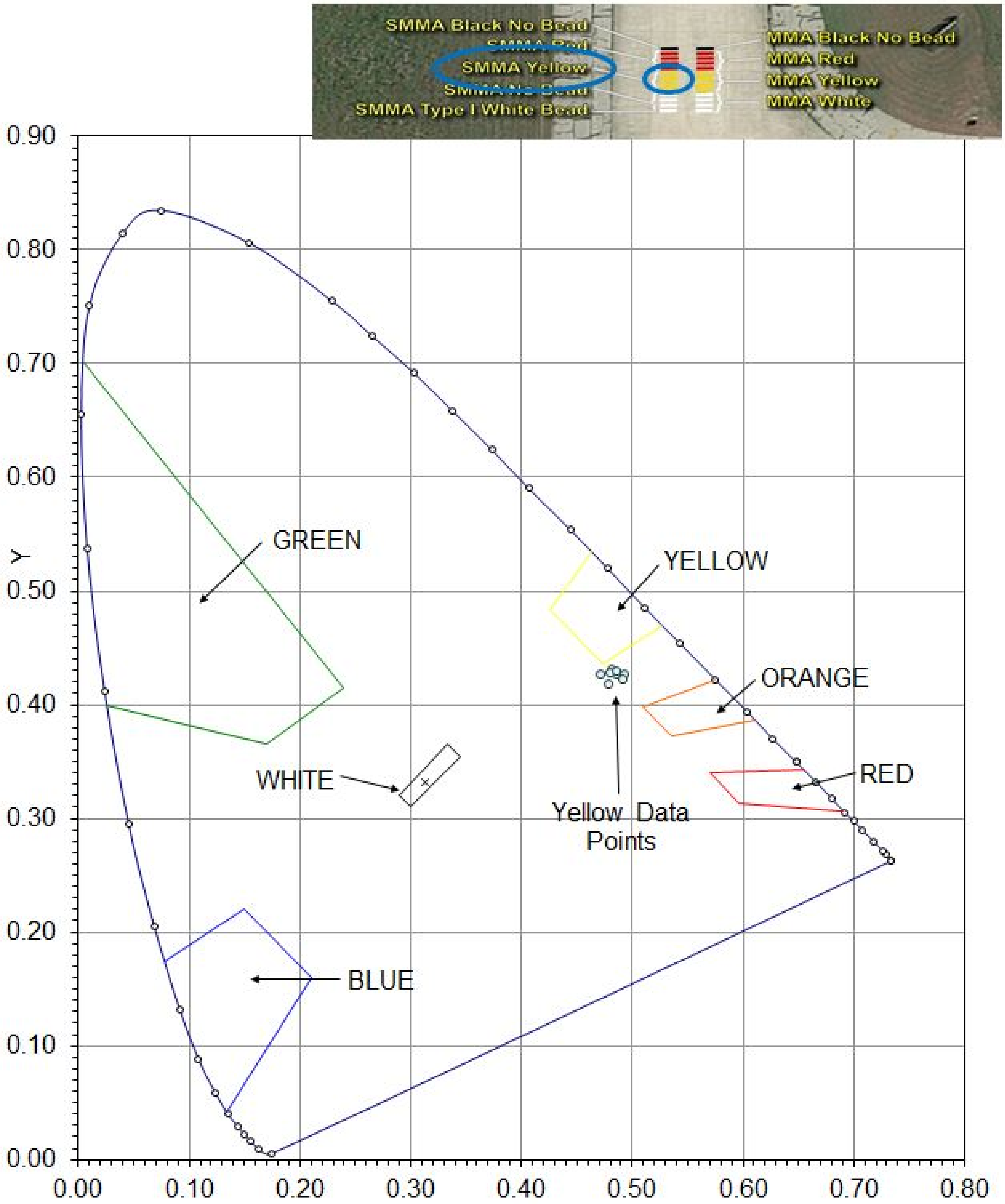


Figure A-33. April 11, 2017 Color Guide Readings for ACY SMMA Yellow

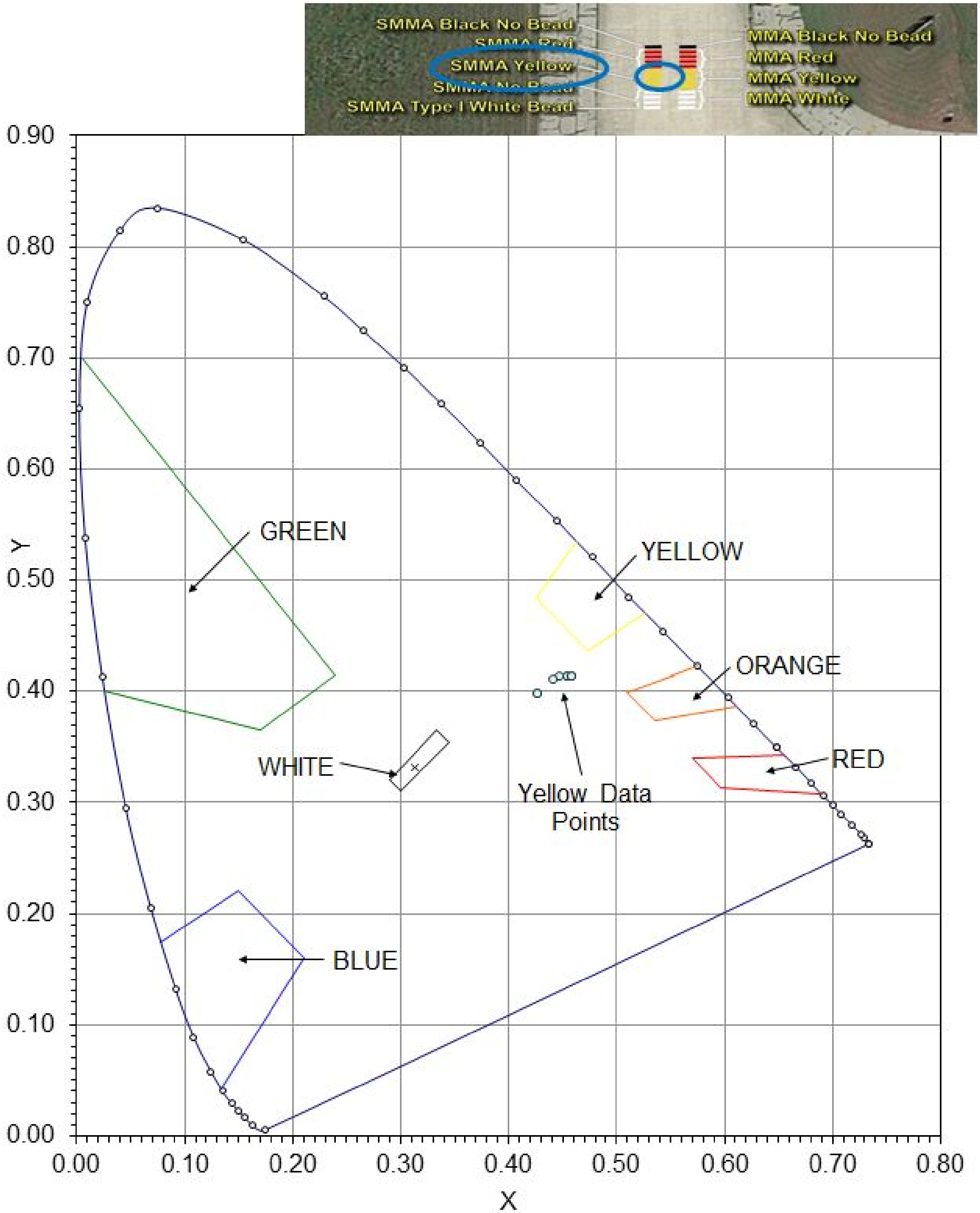


Figure A-34. April 18, 2018 Color Guide Readings for ACY SMMA Yellow

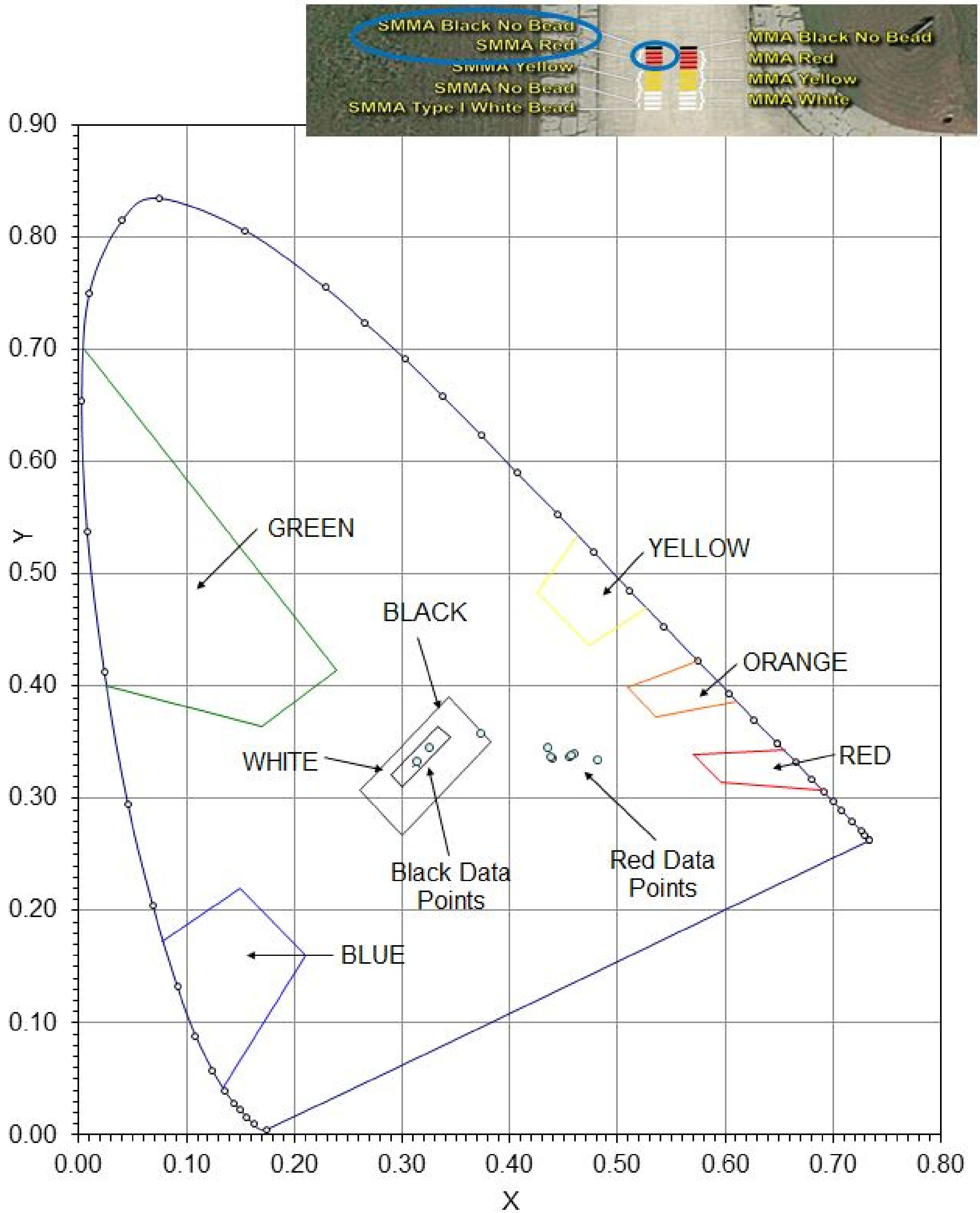


Figure A-35. April 11, 2017 Color Guide Readings for ACY SMMA Red and Black

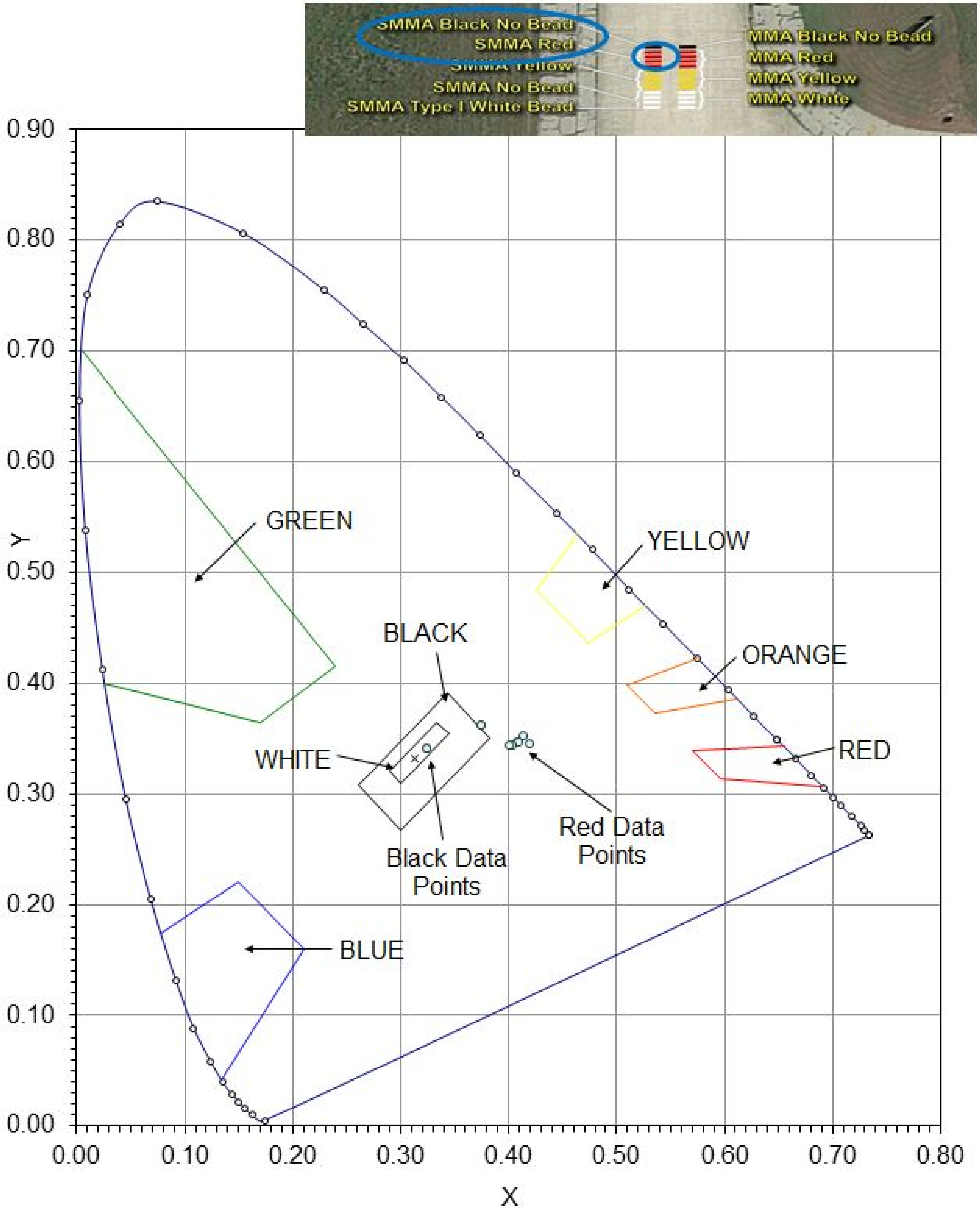


Figure A-36. April 18, 2018 Color Guide Readings for ACY SMMA Red and Black

APPENDIX B—ATLANTIC CITY INTERNATIONAL AIRPORT COMPARISON PHOTOS

Appendix B shows Atlantic City International Airport (ACY) comparison photographs at the beginning of the project (May 11, 2017) and one year later (April 18, 2018) for each surface marking material (Waterborne Type I, Waterborne Type II, Waterborne Type III, Methyl methacrylate (MMA), Structured methyl methacrylate (SMMA), Preformed thermoplastic) for each color under test (white, yellow, red, and black).

Figure B-1. White Waterborne Type I at ACY—May 2017 (Left) vs April 2018 (Right)

Figure B-2. Yellow Waterborne Type I at ACY—May 2017 (Left) vs April 2018 (Right)

Figure B-3. Red Waterborne Type I at ACY—May 2017 (Left) vs April 2018 (Right)

Figure B-4. Black Waterborne Type I at ACY—May 2017 (Left) vs April 2018 (Right)

Figure B-5. White Waterborne Type II at ACY—May 2017 (Left) vs April 2018 (Right)

Figure B-6. Yellow Waterborne Type II at ACY—May 2017 (Left) vs April 2018 (Right)

Figure B-7. Red Waterborne Type II at ACY—May 2017 (Left) vs April 2018 (Right)

Figure B-8. Black Waterborne Type II at ACY—May 2017 (Left) vs April 2018 (Right)

Figure B-9. White MMA at ACY—June 2017 (Left) vs April 2018 (Right)

Figure B-10. Yellow MMA at ACY—June 2017 (Left) vs April 2018 (Right)

Figure B-11. Red MMA at ACY—June 2017 (Left) vs April 2018 (Right)

Figure B-12. Black MMA at ACY—June 2017 (Left) vs April 2018 (Right)

Figure B-13. White Waterborne Type III at ACY—May 2017 (Left) vs April 2018 (Right)

Figure B-14. Yellow Waterborne Type III at ACY—May 2017 (Left) vs April 2018 (Right)

Figure B-15. Red Waterborne Type III at ACY—May 2017 (Left) vs April 2018 (Right)

Figure B-16. Black Waterborne Type III at ACY—May 2017 (Left) vs April 2018 (Right)

Figure B-17. Preformed Thermoplastic at ACY—May 2017 (Left) vs April 2018 (Right)

Figure B-18. White SMMA at ACY—May 2017 (Left) vs April 2018 (Right)

Figure B-19. Yellow SMMA at ACY—May 2017 (Left) vs April 2018 (Right)

Figure B-20. Red SMMA at ACY—May 2017 (Left) vs April 2018 (Right)

Figure B-21. Black SMMA at ACY—May 2017 (Left) vs April 2018 (Right)

APPENDIX C—ATLANTIC CITY INTERNATIONAL AIRPORT SAAB® SCANDINAVIAN AIRPORT AND ROAD SYSTEMS (SARSYS) FRICTION CHARTS

Appendix C shows the friction readings taken at Atlantic City International Airport (ACY) with a Saab® Scandinavian Airport and Road Systems (SARSYS) Surface Friction Tester (SFT) on June 2, 2017 for each surface marking material (Waterborne Type I, Waterborne Type II, Waterborne Type III, Methyl methacrylate (MMA), Structured methyl methacrylate (SMMA), Preformed Thermoplastic).

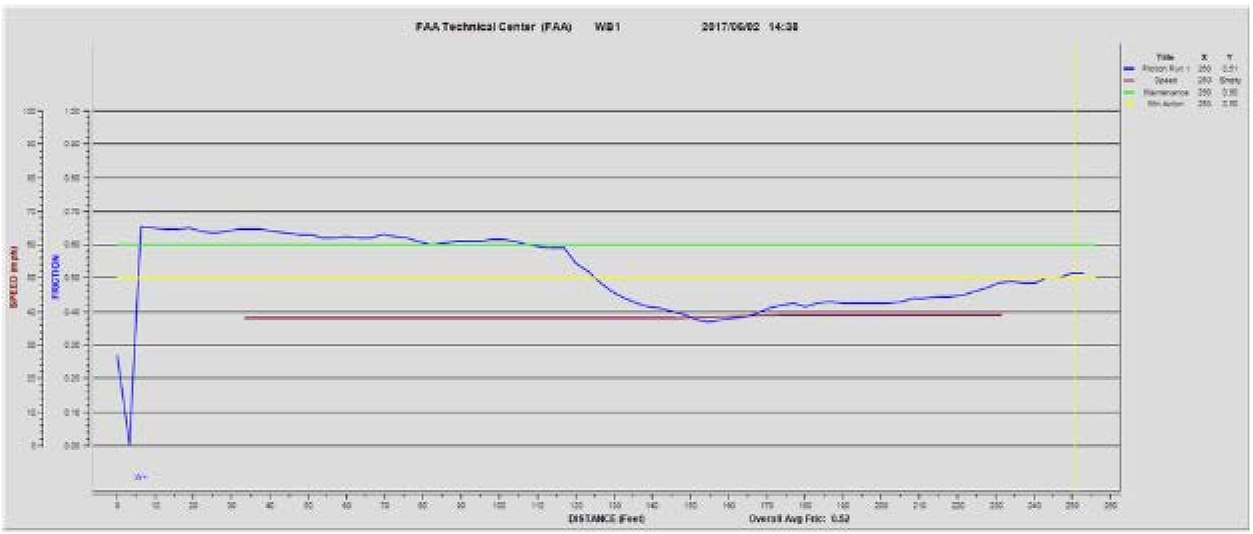


Figure C-1. The SARSYS SFT Friction Chart for Waterborne Type I Marking—First Run

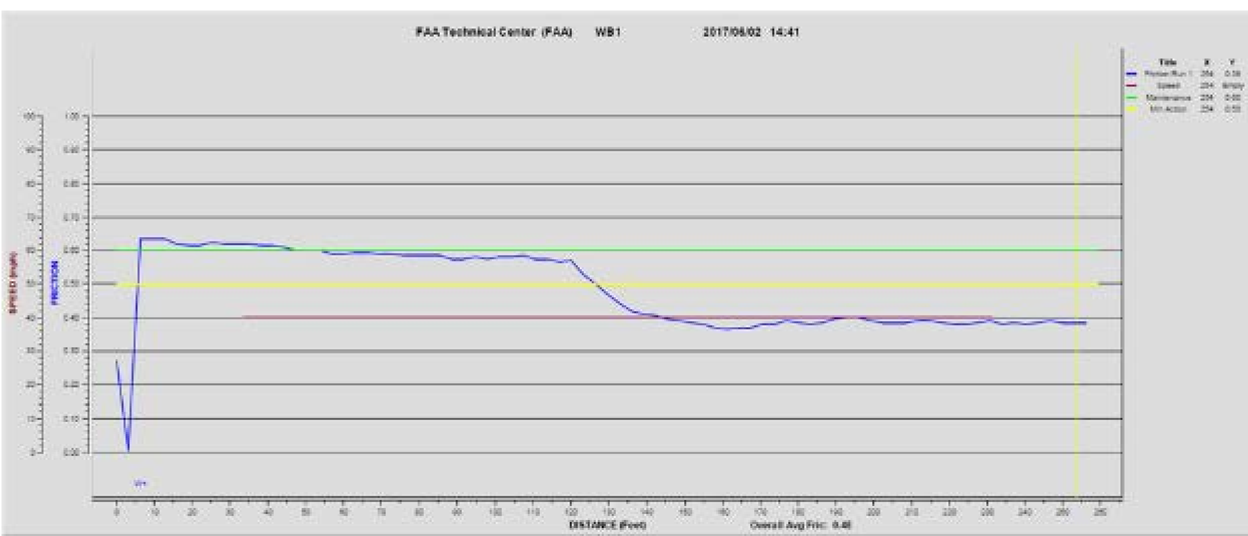


Figure C-2. The SARSYS SFT Friction Chart for Waterborne Type I Marking—Second Run

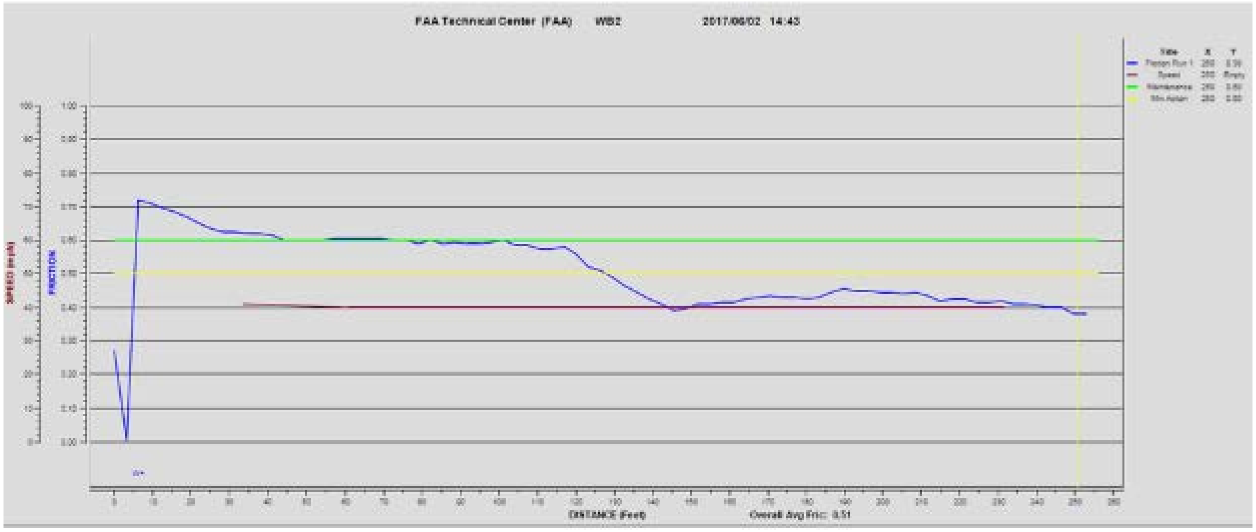


Figure C-3. The SARSYS SFT Friction Chart for Waterborne Type II Marking—First Run

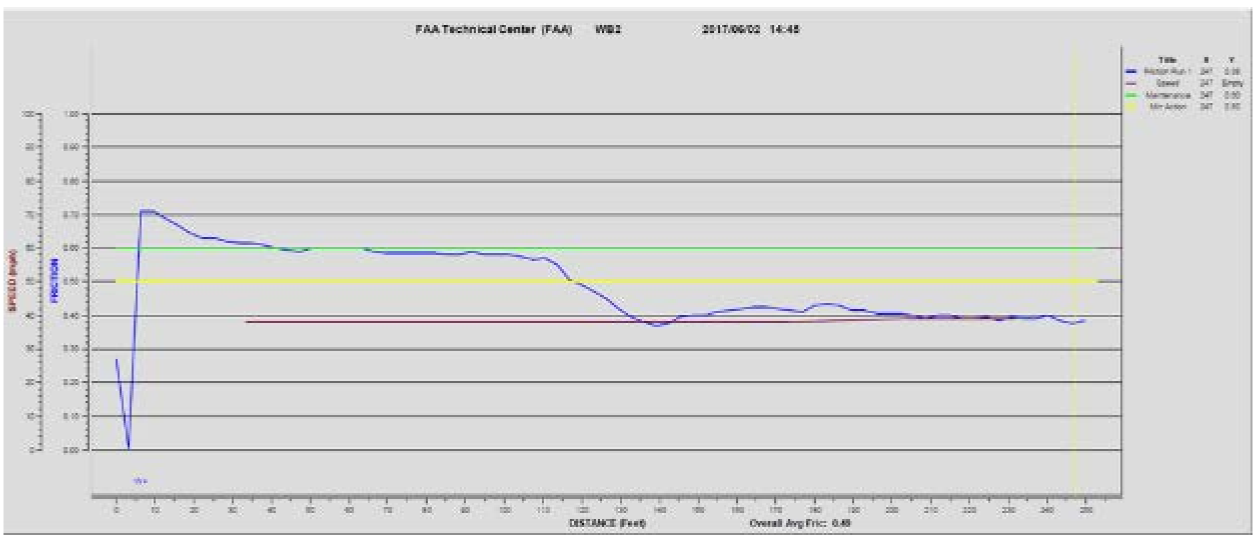


Figure C-4. The SARSYS SFT Friction Chart for Waterborne Type II Marking—Second Run

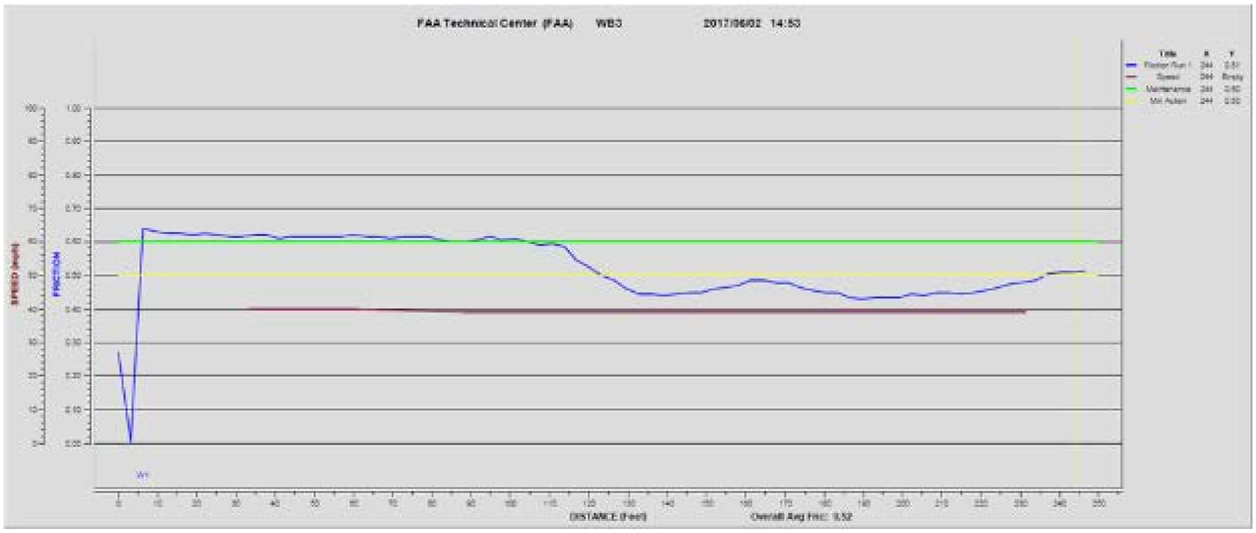


Figure C-5. The SARSYS SFT Friction Chart for Waterborne Type III Marking—First Run

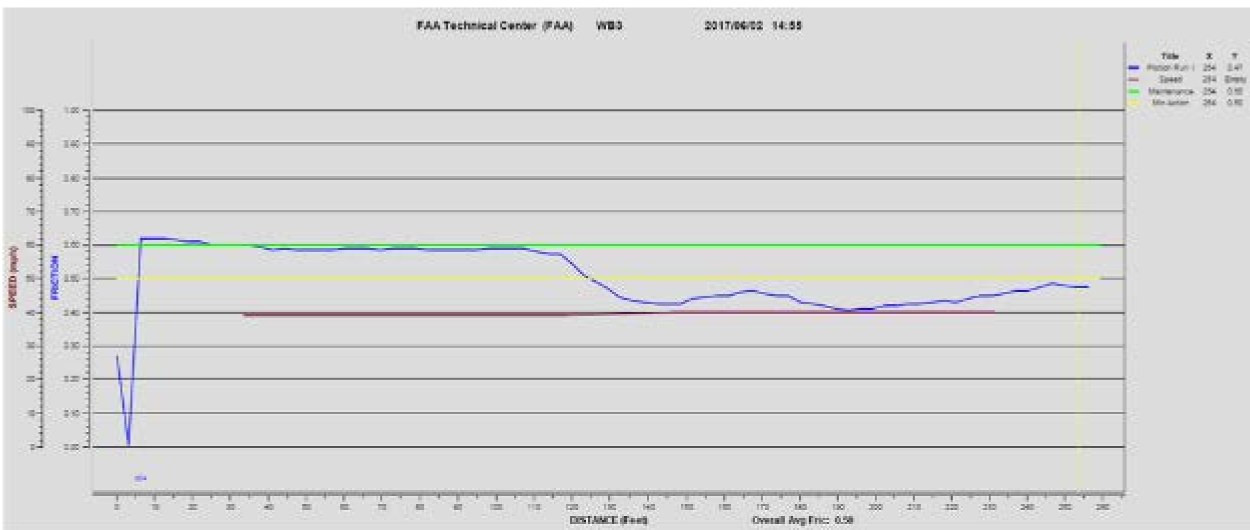


Figure C-6. The SARSYS SFT Friction Chart for Waterborne Type III Marking—Second Run

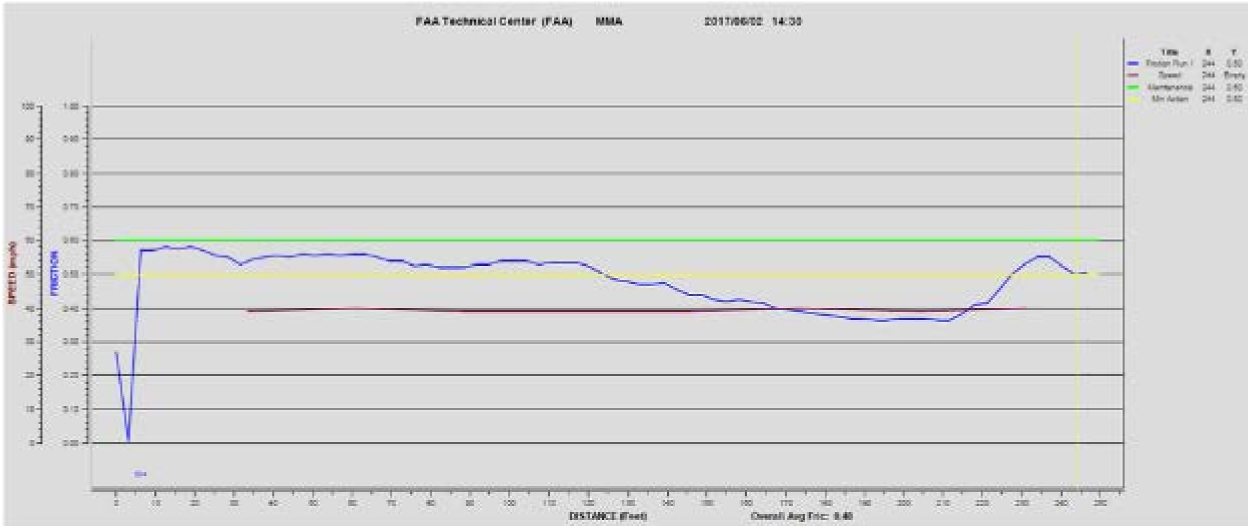


Figure C-7. The SARSYS SFT Friction Chart for MMA Marking—First Run

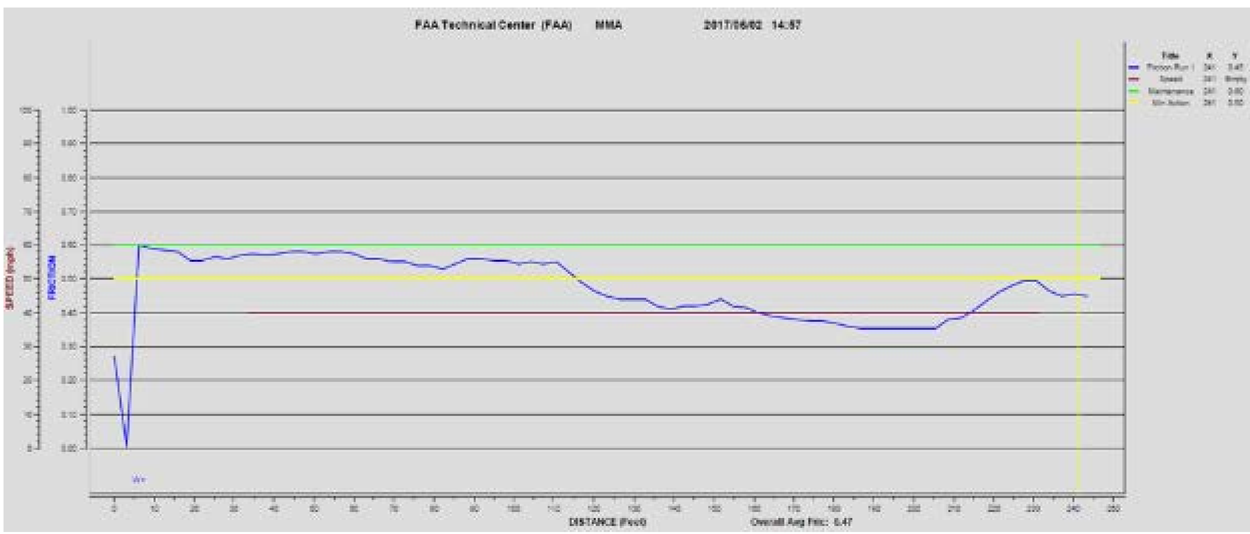


Figure C-8. The SARSYS SFT Friction Chart for MMA Marking—Second Run

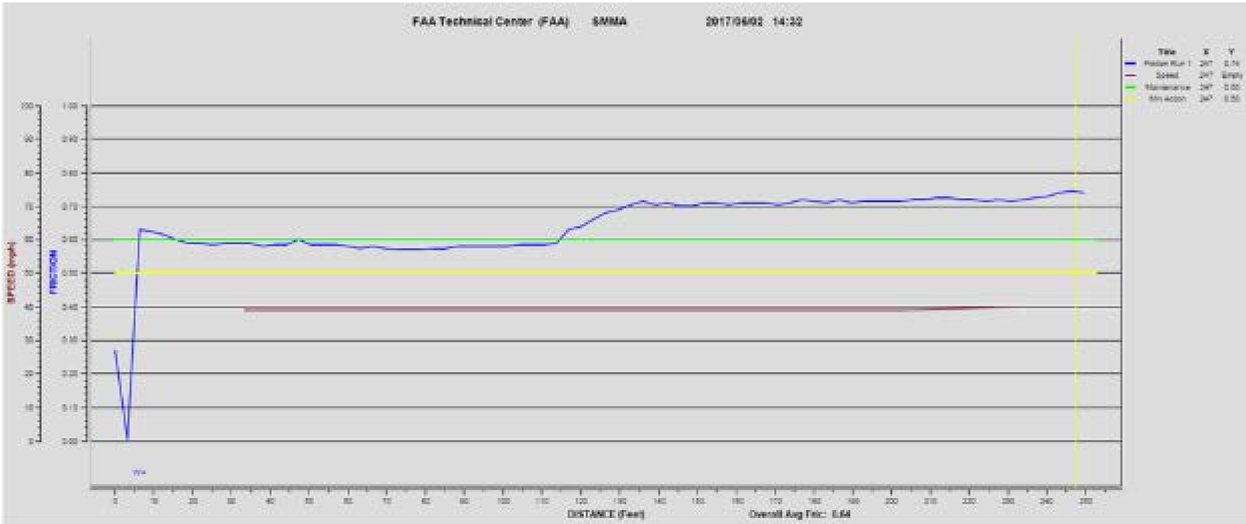


Figure C-9. The SARSYS SFT Friction Chart for SMMA Marking—First Run

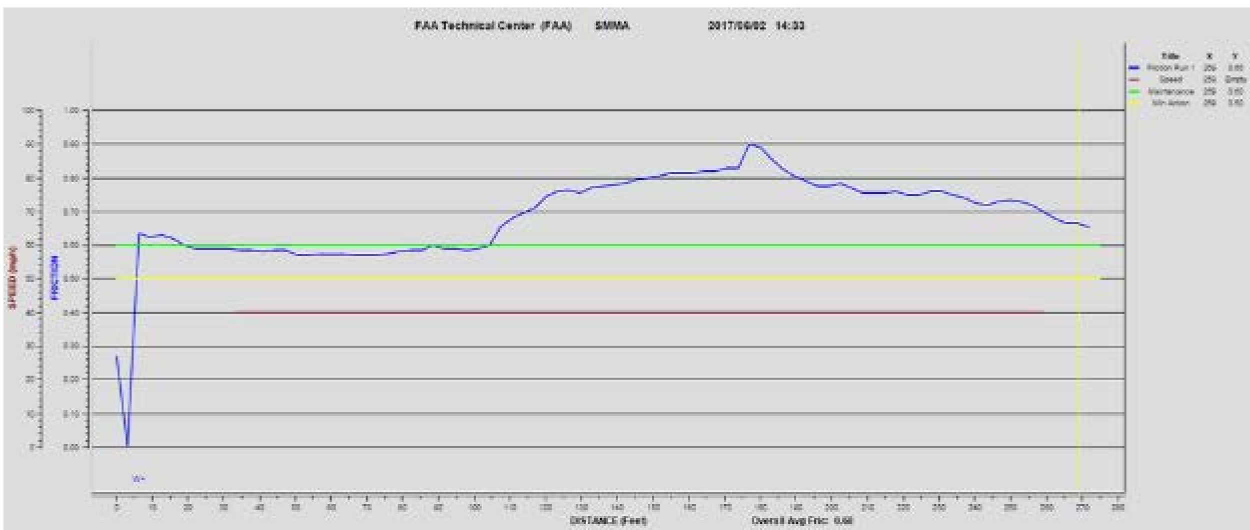


Figure C-10. The SARSYS SFT Friction Chart for SMMA Marking—Second Run

APPENDIX D—NEWARK LIBERTY INTERNATIONAL AIRPORT CHROMATICITY CHARTS

Appendix D shows the Newark Liberty International Airport (EWR) Chromaticity Charts at installation (April 20, 2017) and approximately one year later (April 27, 2018) for each surface marking material (Waterborne Type I, Waterborne Type II, Waterborne Type III, Methyl methacrylate (MMA), Structured methyl methacrylate (SMMA), Preformed thermoplastic) for each color under test (white, yellow, red, and black).

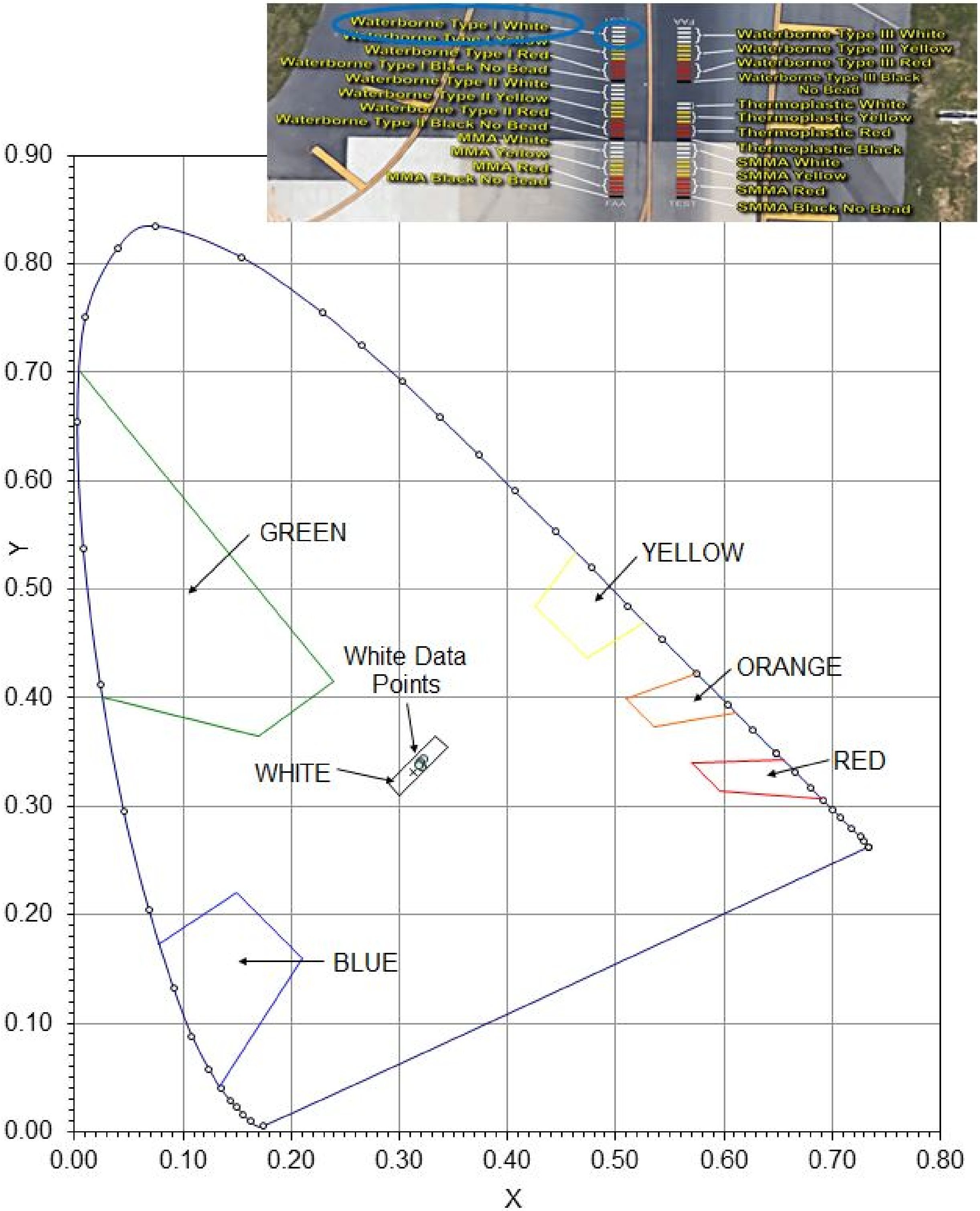


Figure D-1. April 20, 2017 Color Guide Readings for EWR Waterborne Type I White

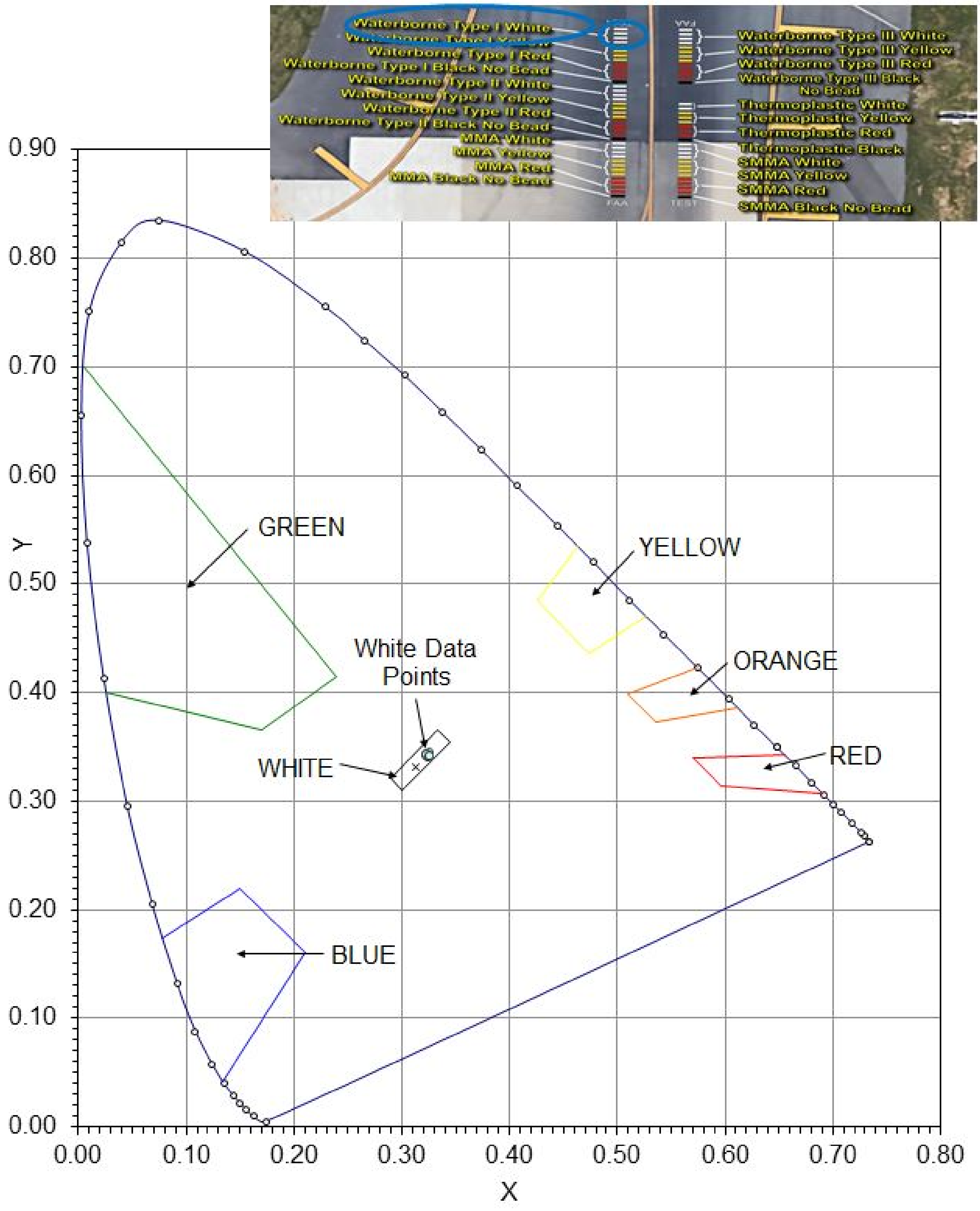


Figure D-2. April 27, 2018 Color Guide Readings for EWR Waterborne Type I White

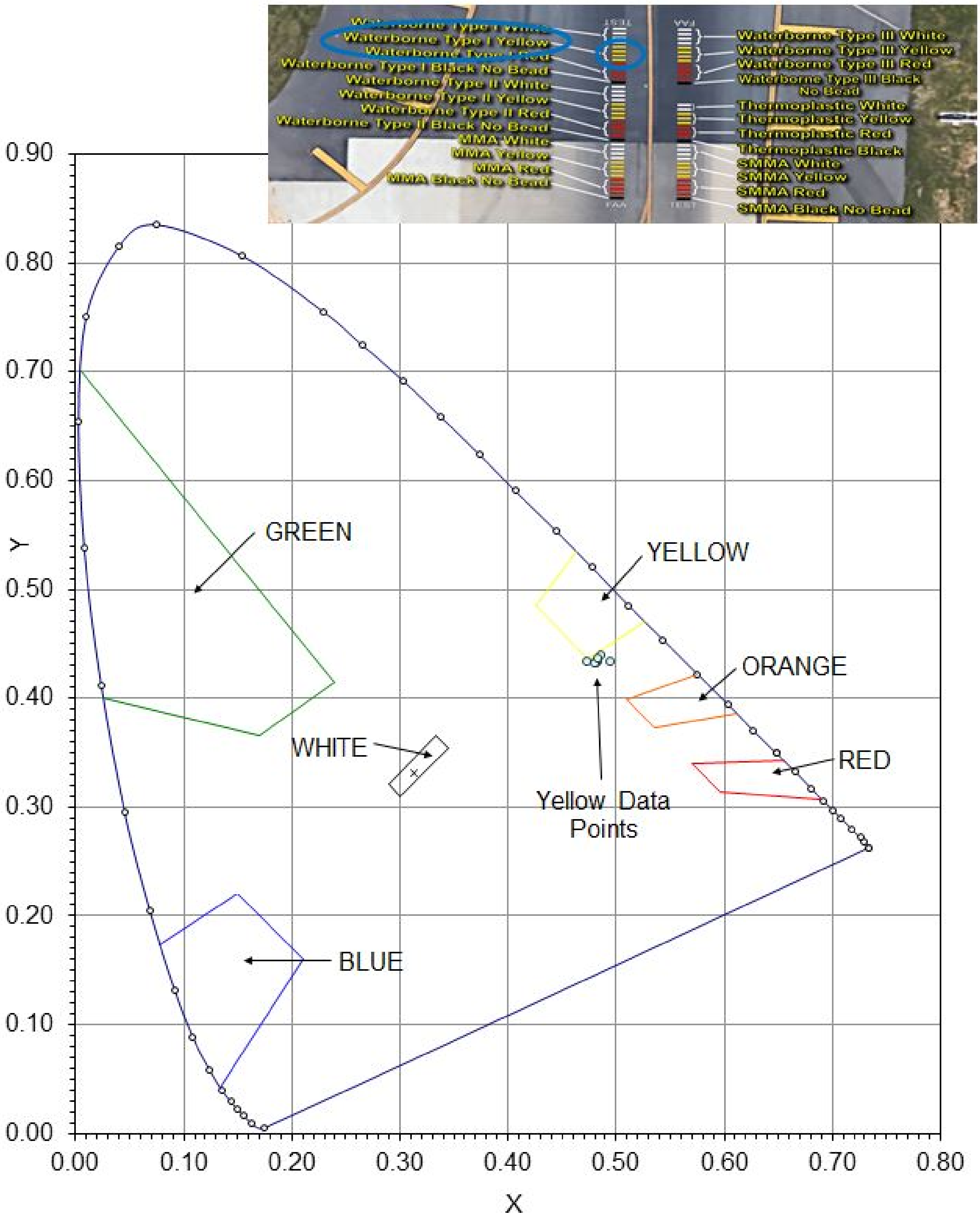


Figure D-3. April 20, 2017 Color Guide Readings for EWR Waterborne Type I Yellow

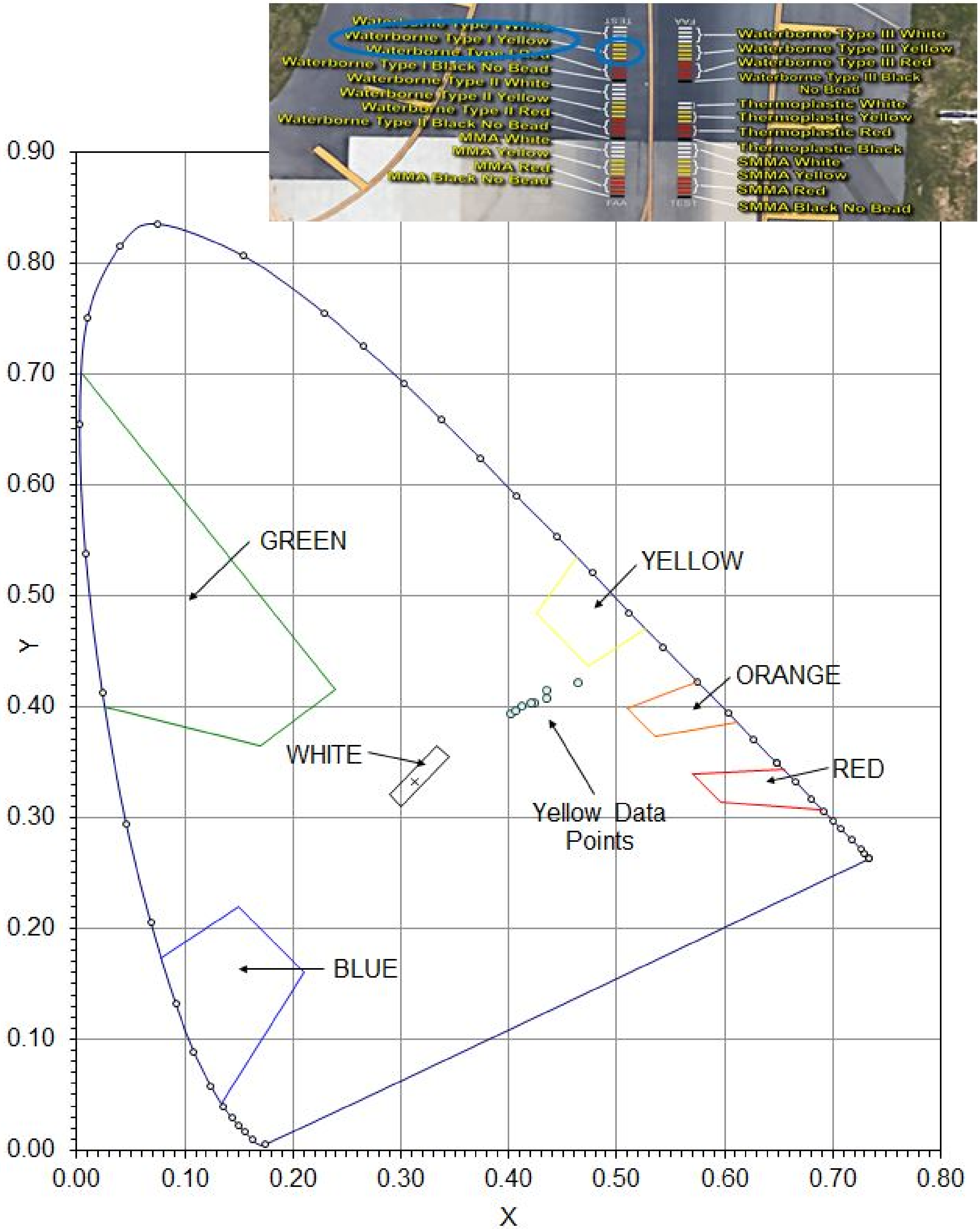


Figure D-4. April 27, 2018 Color Guide Readings for EWR Waterborne Type I Yellow

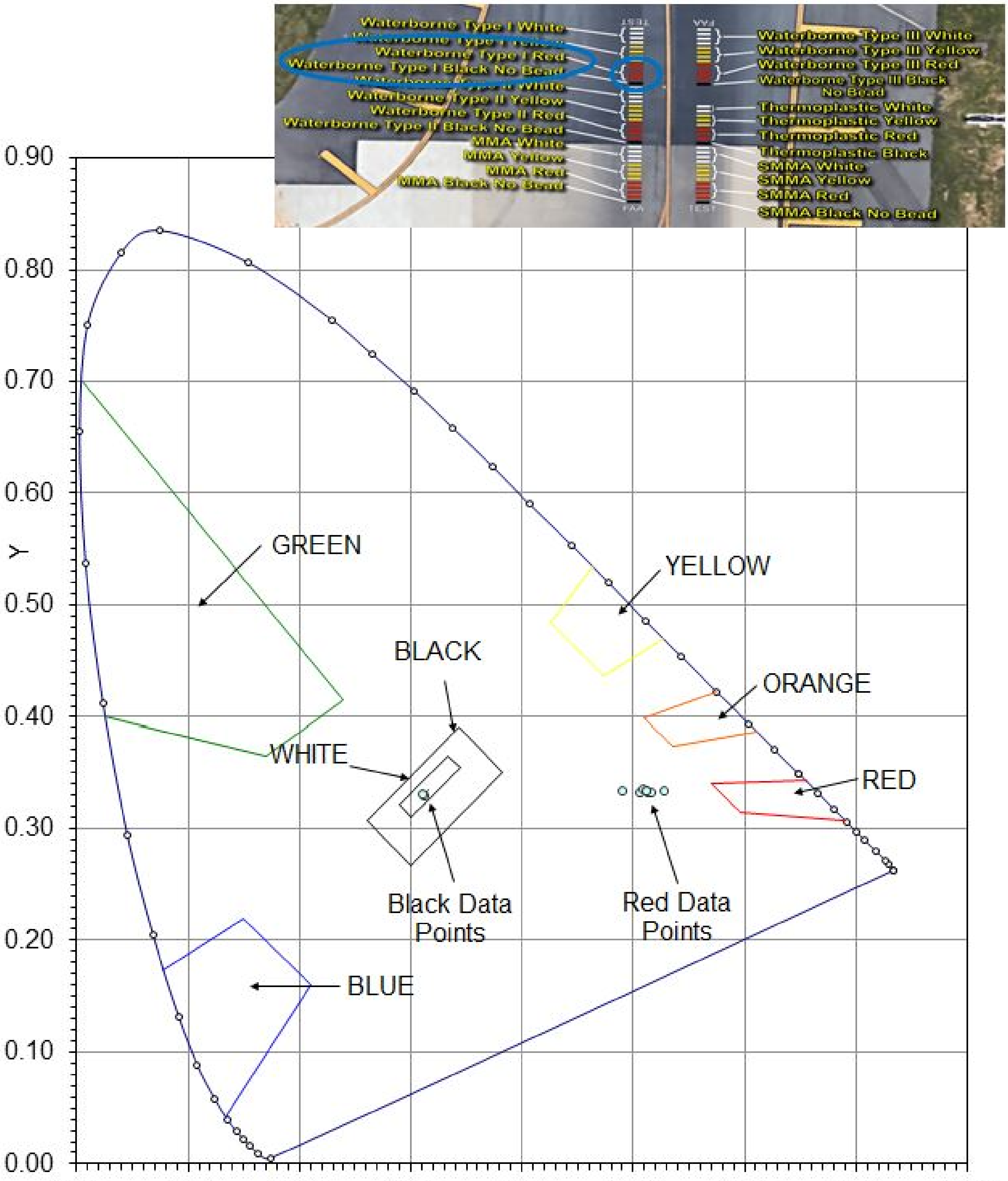


Figure D-5. April 20, 2017 Color Guide Readings for EWR Waterborne Type I Red and Black

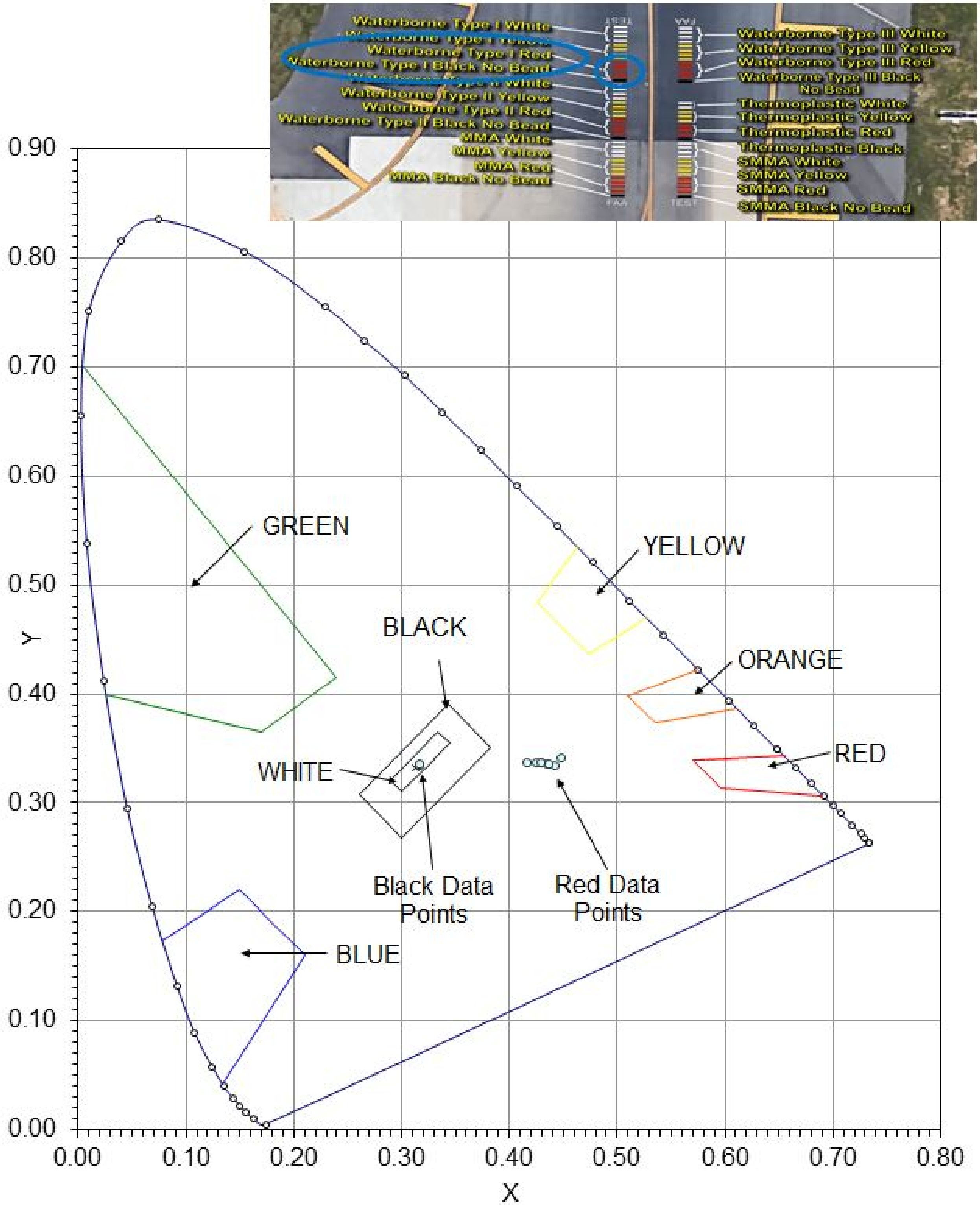


Figure D-6. April 27, 2018 Color Guide Readings for EWR Waterborne Type I Red and Black

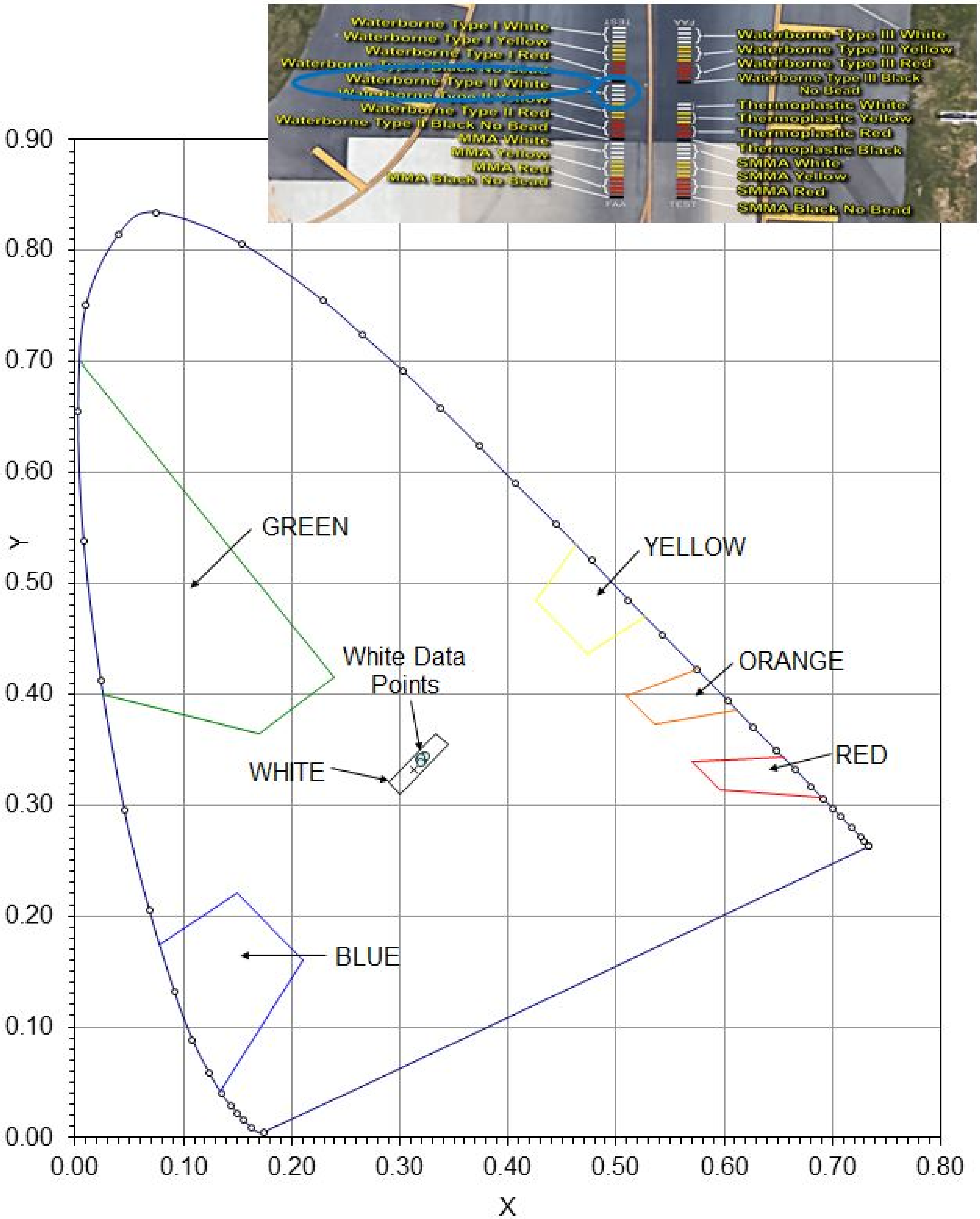


Figure D-7. April 20, 2017 Color Guide Readings for EWR Waterborne Type II White

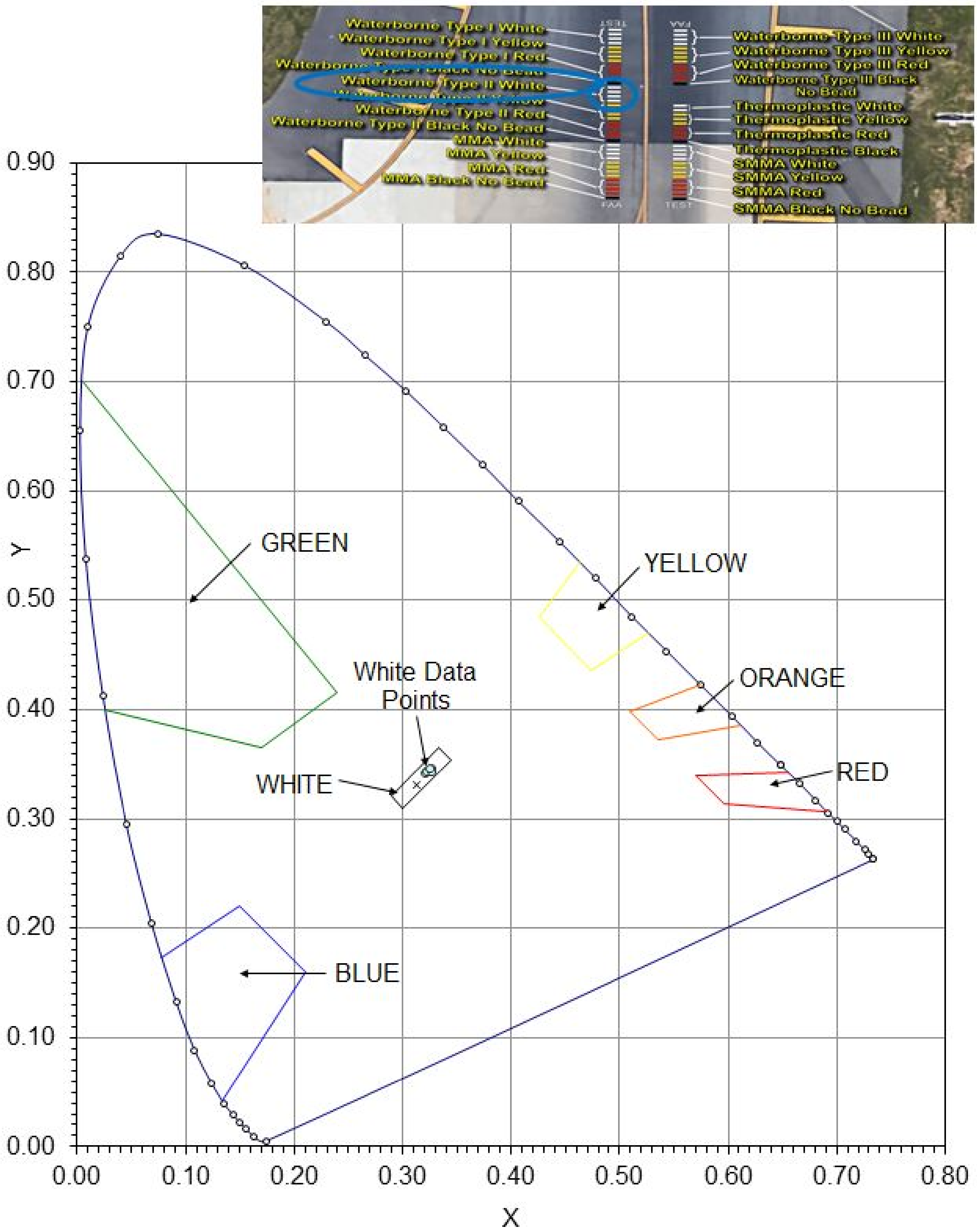


Figure D-8. April 27, 2018 Color Guide Readings for EWR Waterborne Type II White

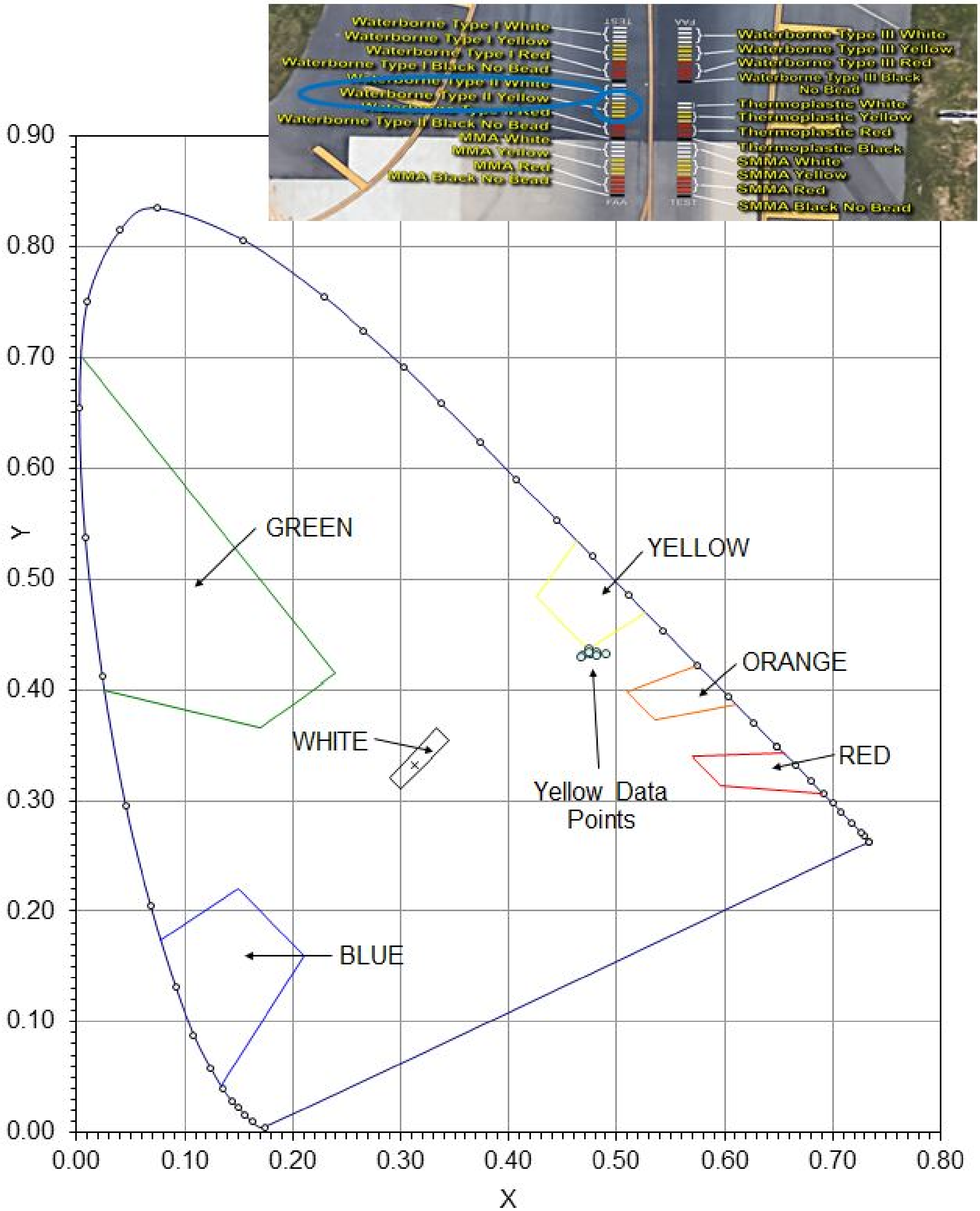


Figure D-9. April 20, 2017 Color Guide Readings for EWR Waterborne Type II Yellow

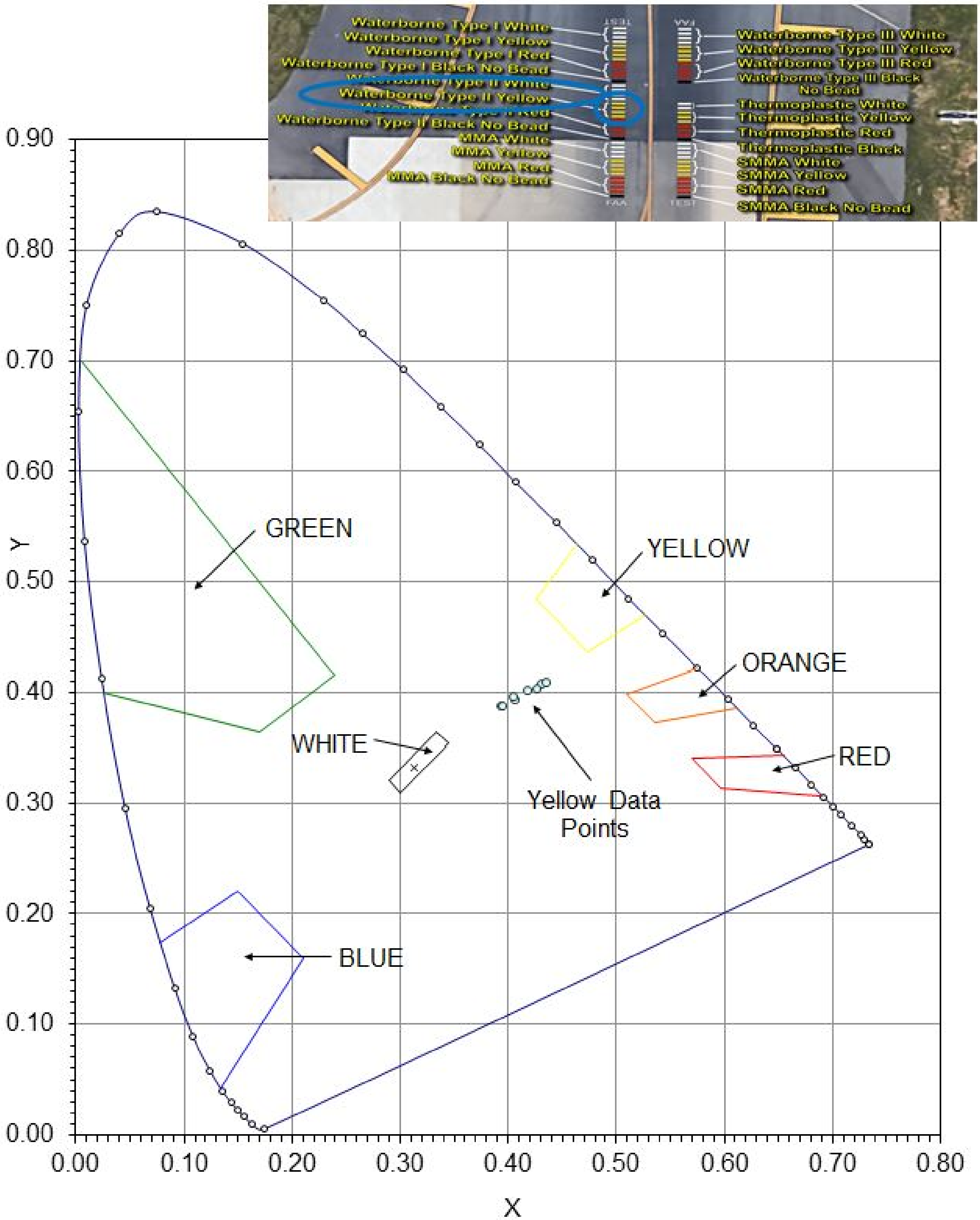


Figure D-10. April 27, 2018 Color Guide Readings for EWR Waterborne Type II Yellow

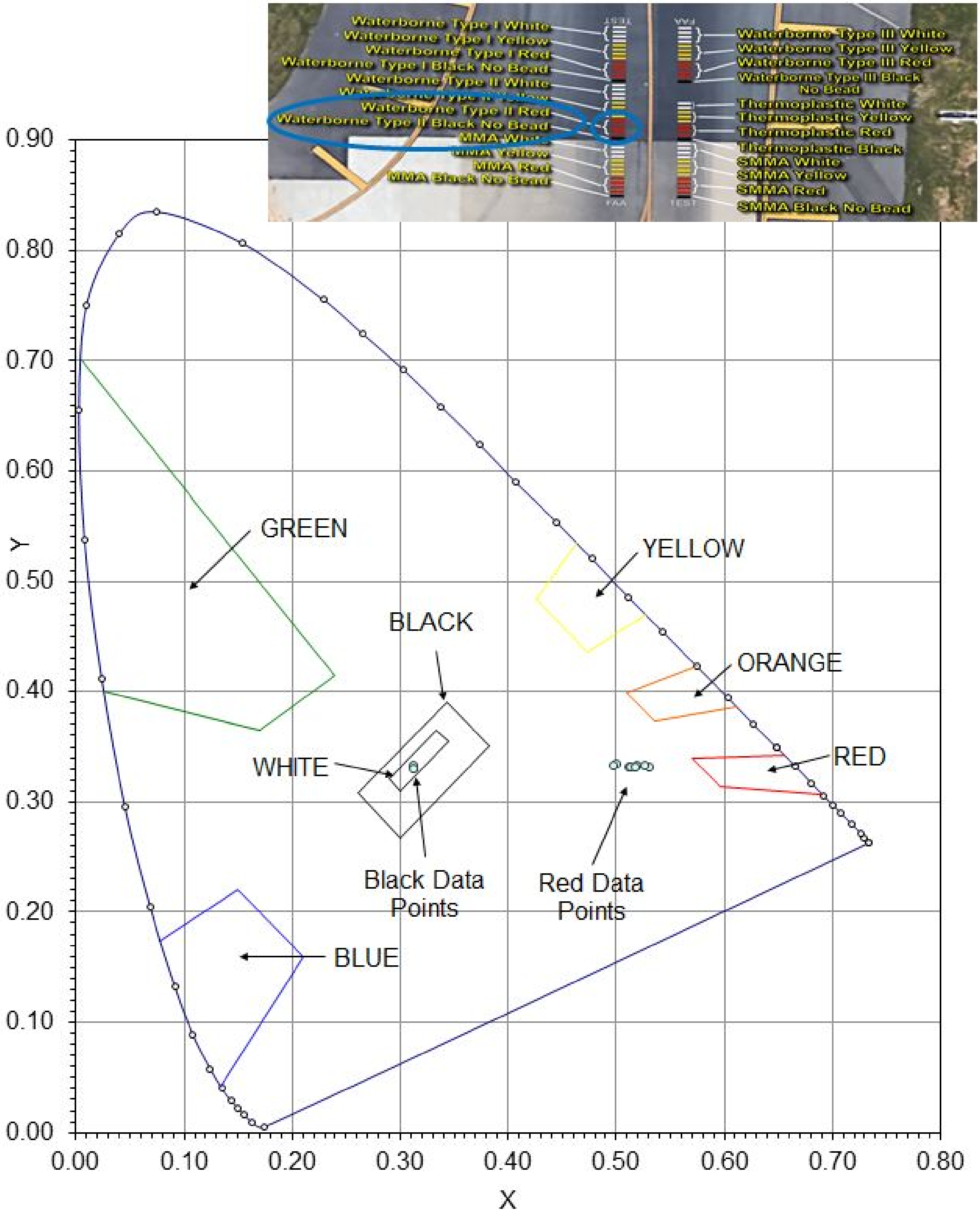


Figure D-11. April 20, 2017 Color Guide Readings for EWR Waterborne Type II Red and Black

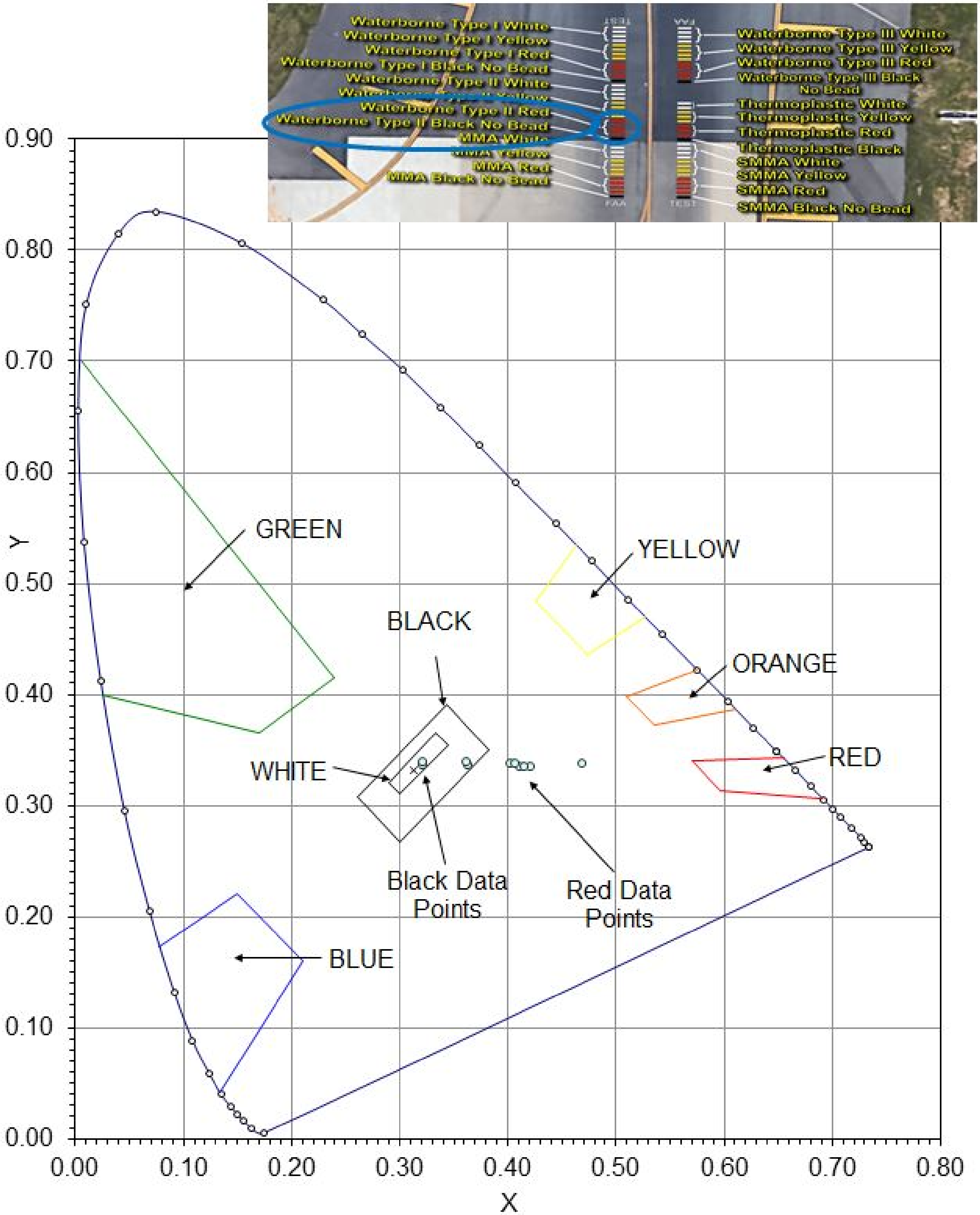


Figure D-12. April 27, 2018 Color Guide Readings for EWR Waterborne Type II Red and Black

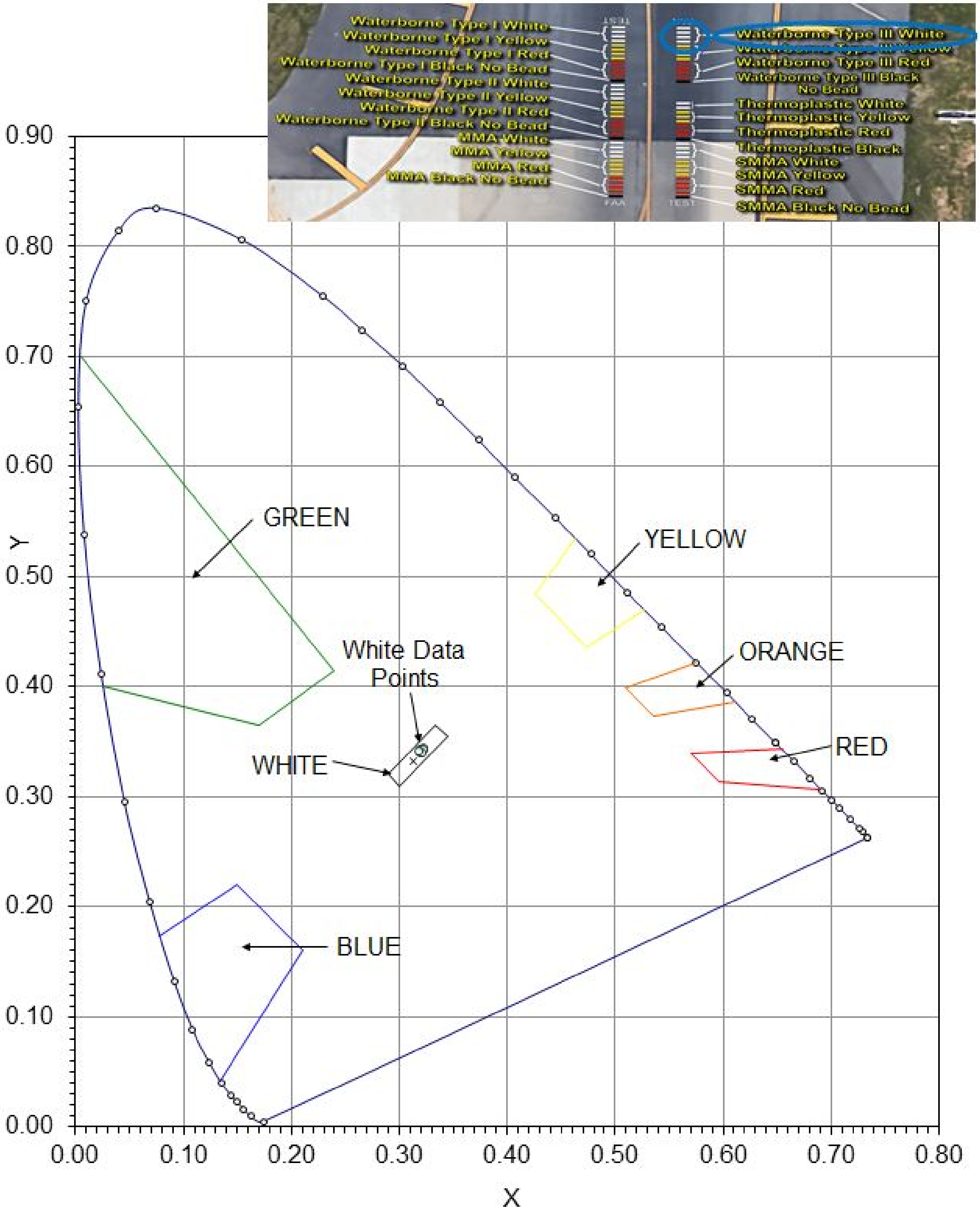


Figure D-13. April 20, 2017 Color Guide Readings for EWR Waterborne Type III White

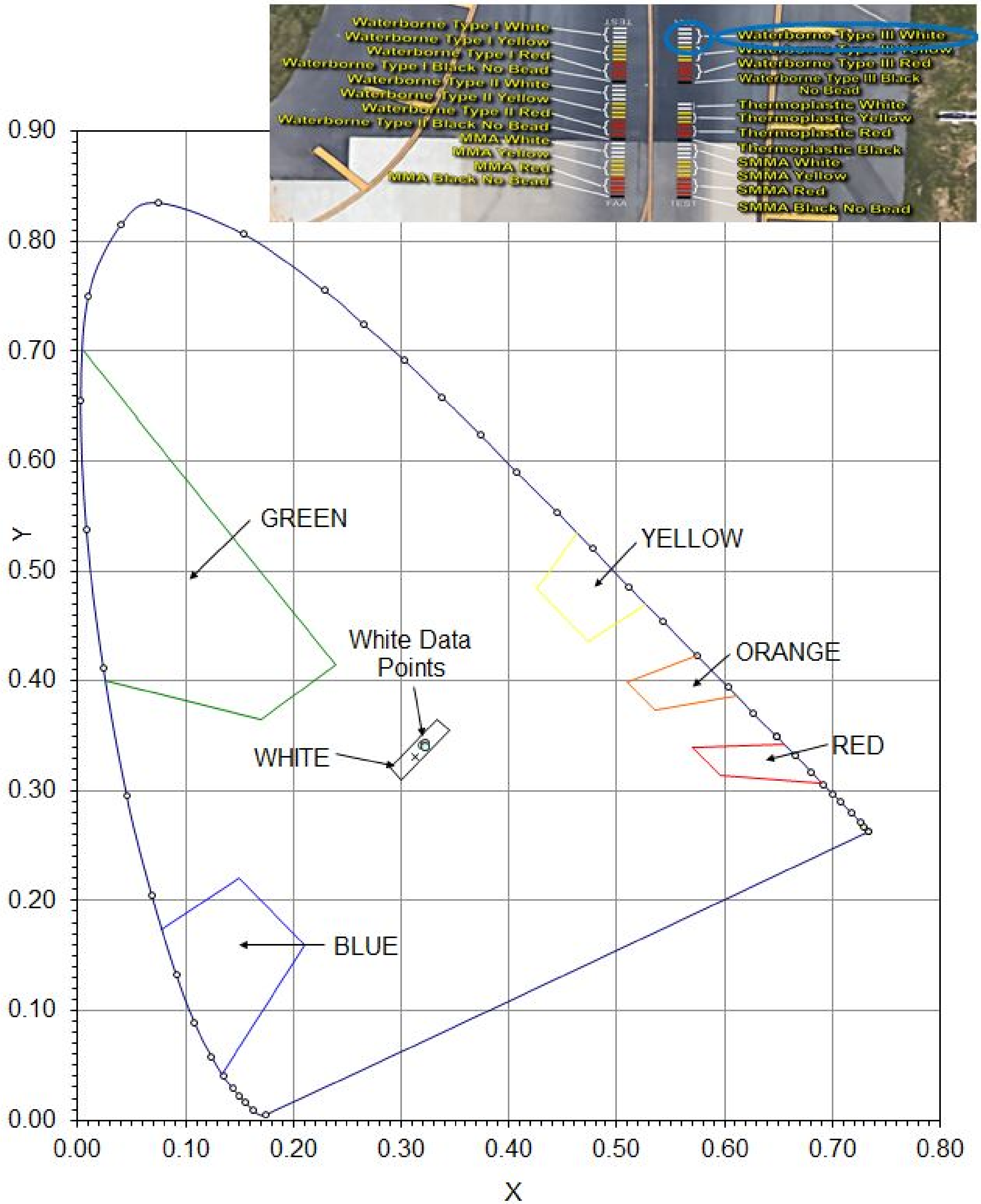


Figure D-14. April 27, 2018 Color Guide Readings for EWR Waterborne Type III White

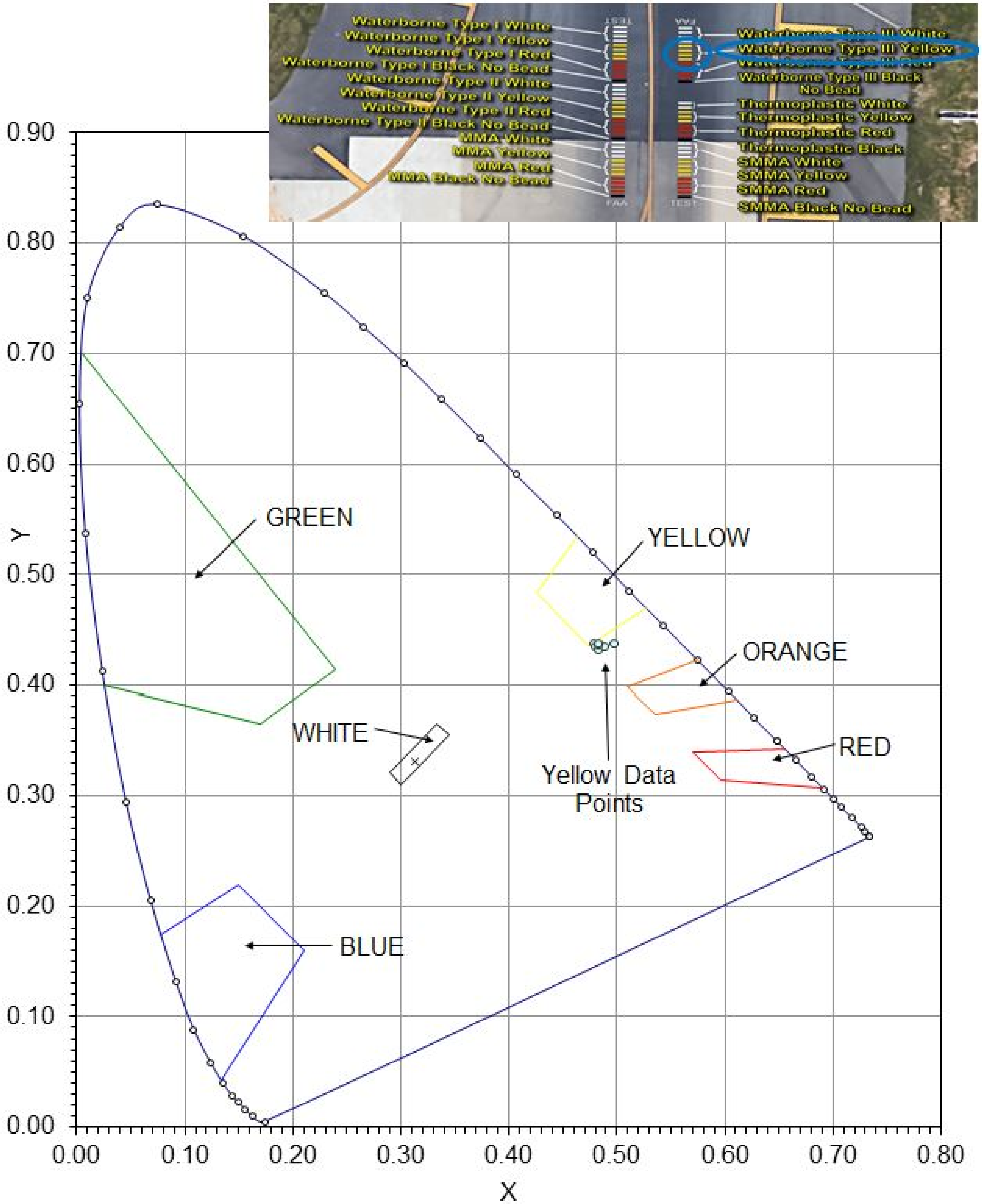


Figure D-15. April 20, 2017 Color Guide Readings for EWR Waterborne Type III Yellow

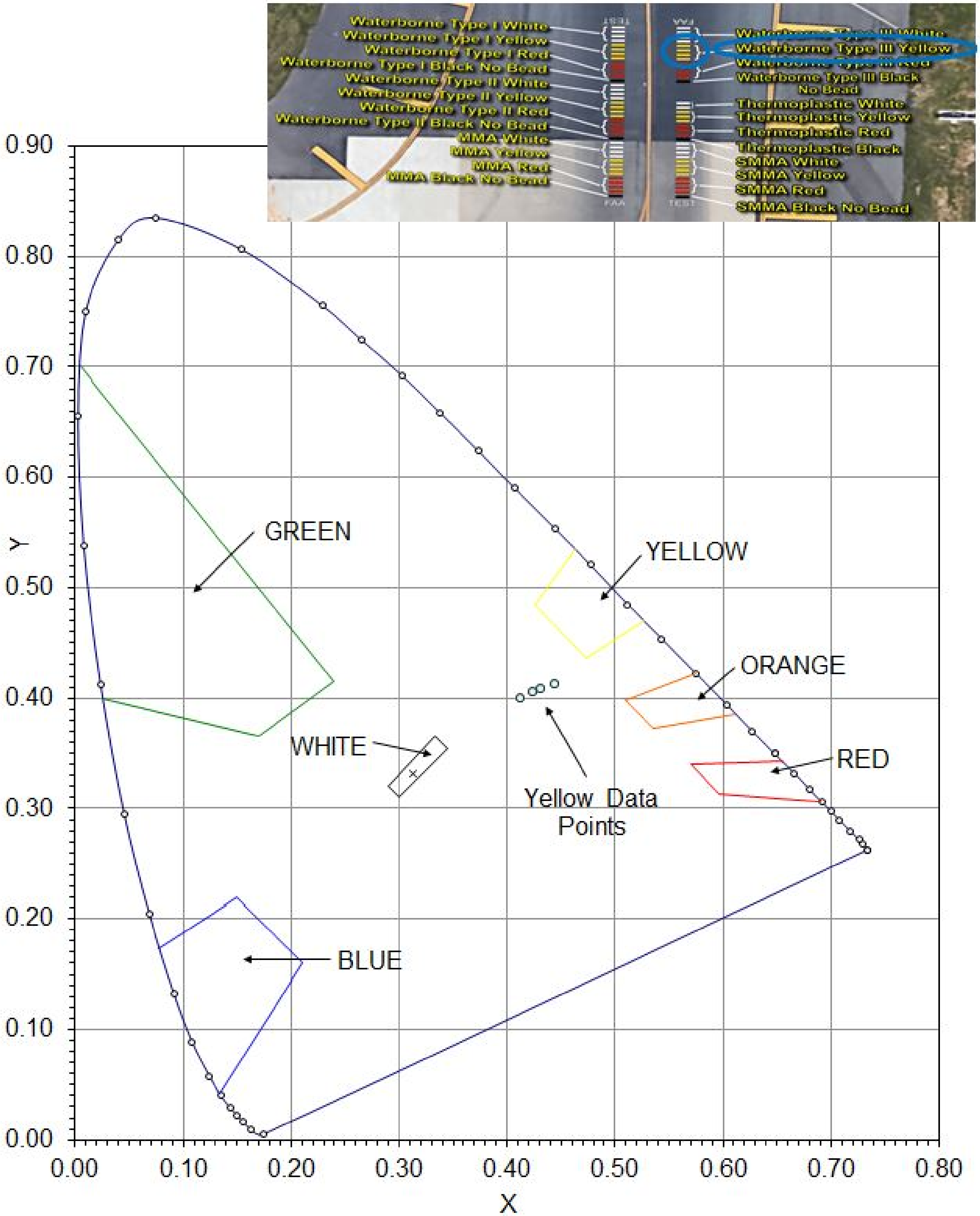


Figure D-16. April 27, 2018 Color Guide Readings for EWR Waterborne Type III Yellow

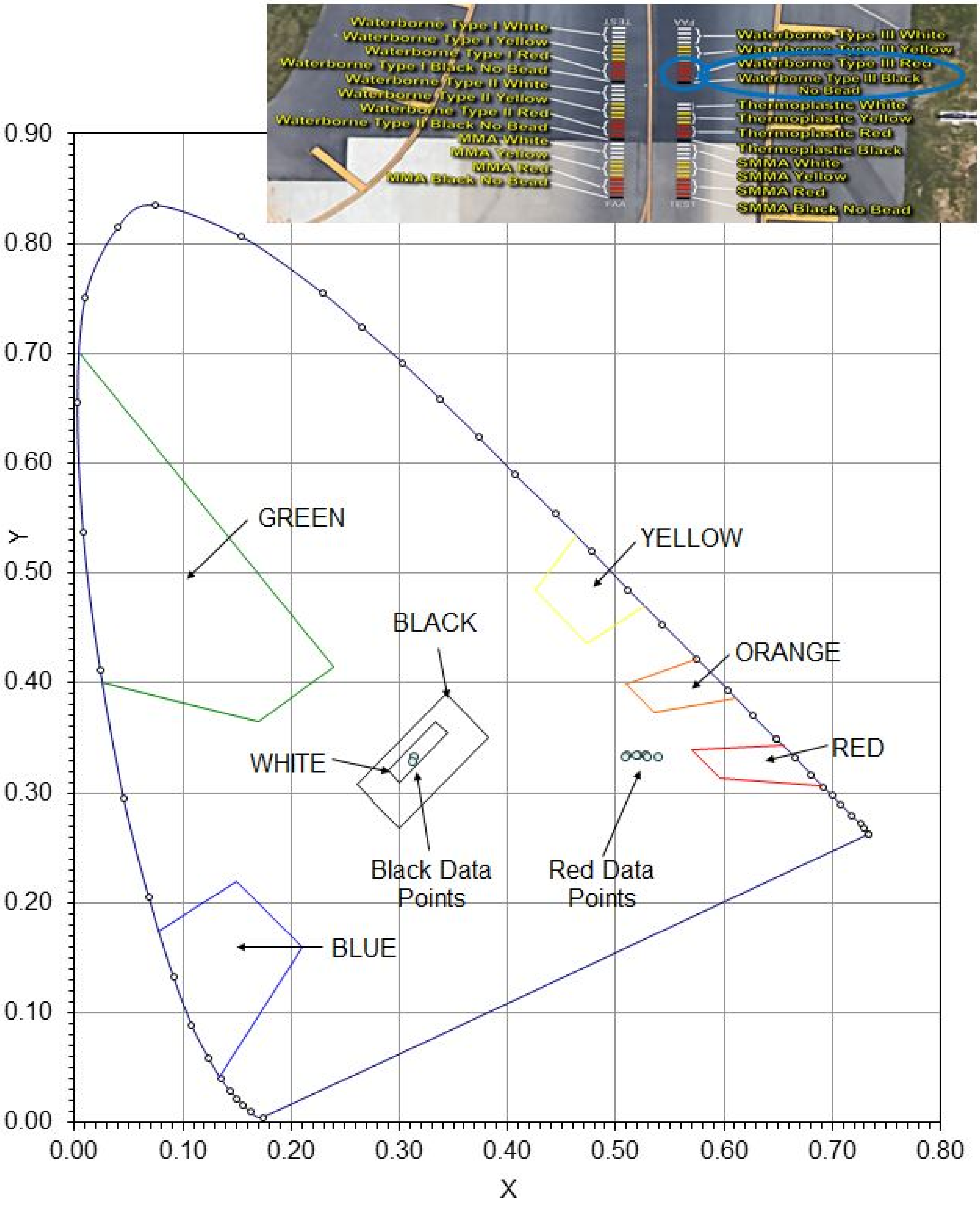


Figure D-17. April 20, 2017 Color Guide Readings for EWR Waterborne Type III Red and Black

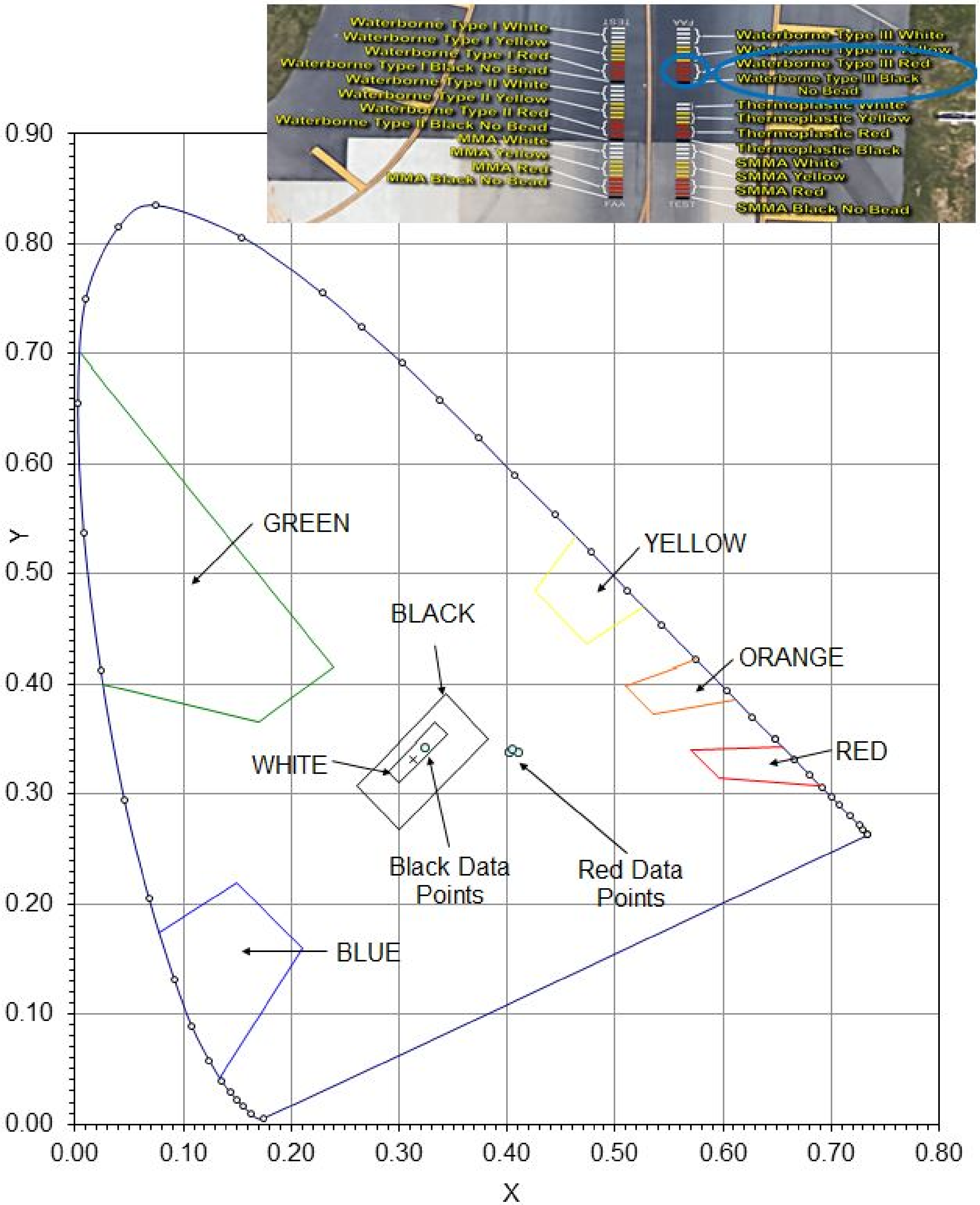


Figure D-18. April 27, 2018 Color Guide Readings for EWR Waterborne Type III Red and Black

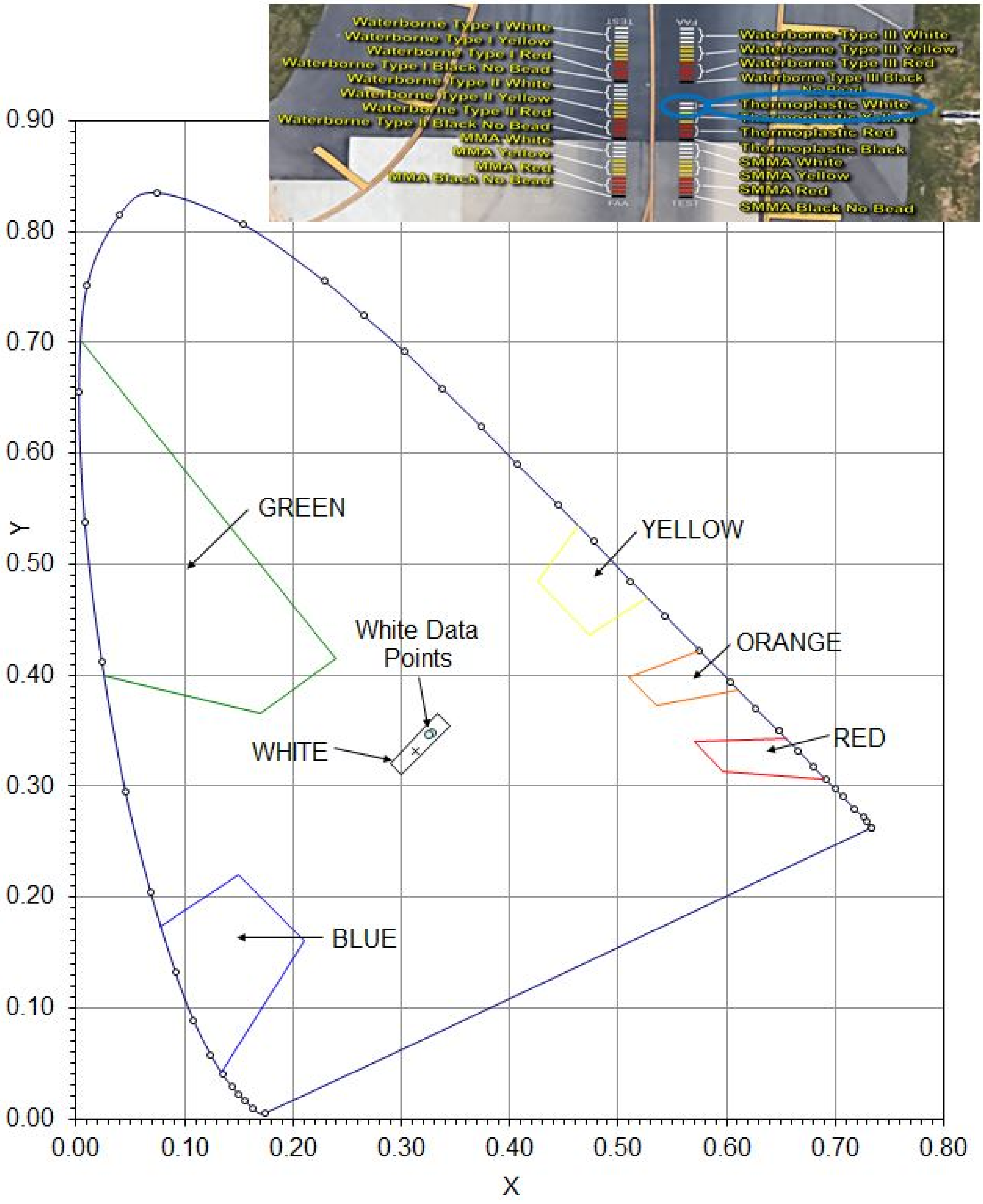


Figure D-19. April 20, 2017 Color Guide Readings for EWR Preformed Thermoplastic White

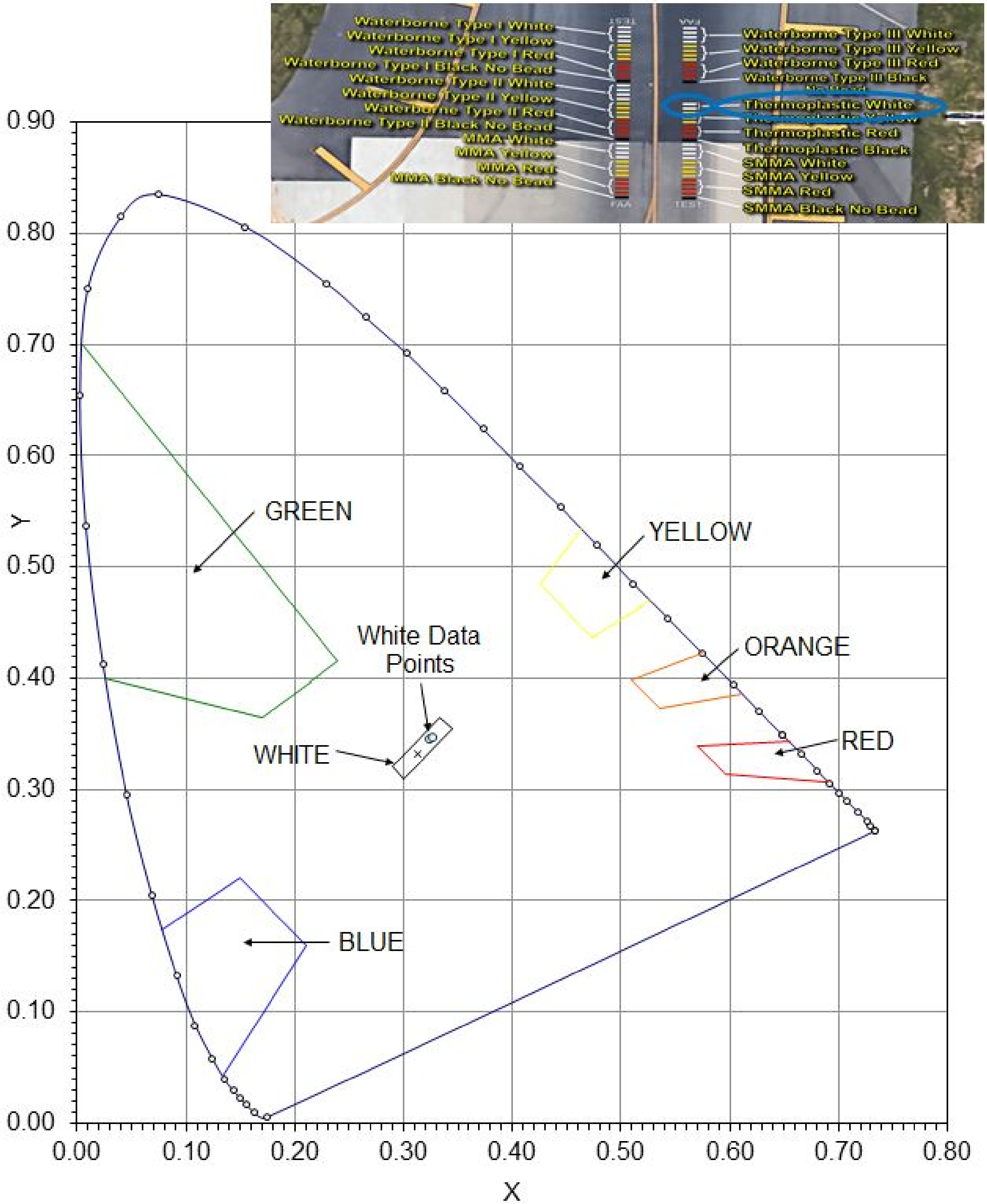


Figure D-20. April 27, 2018 Color Guide Readings for EWR Preformed Thermoplastic White

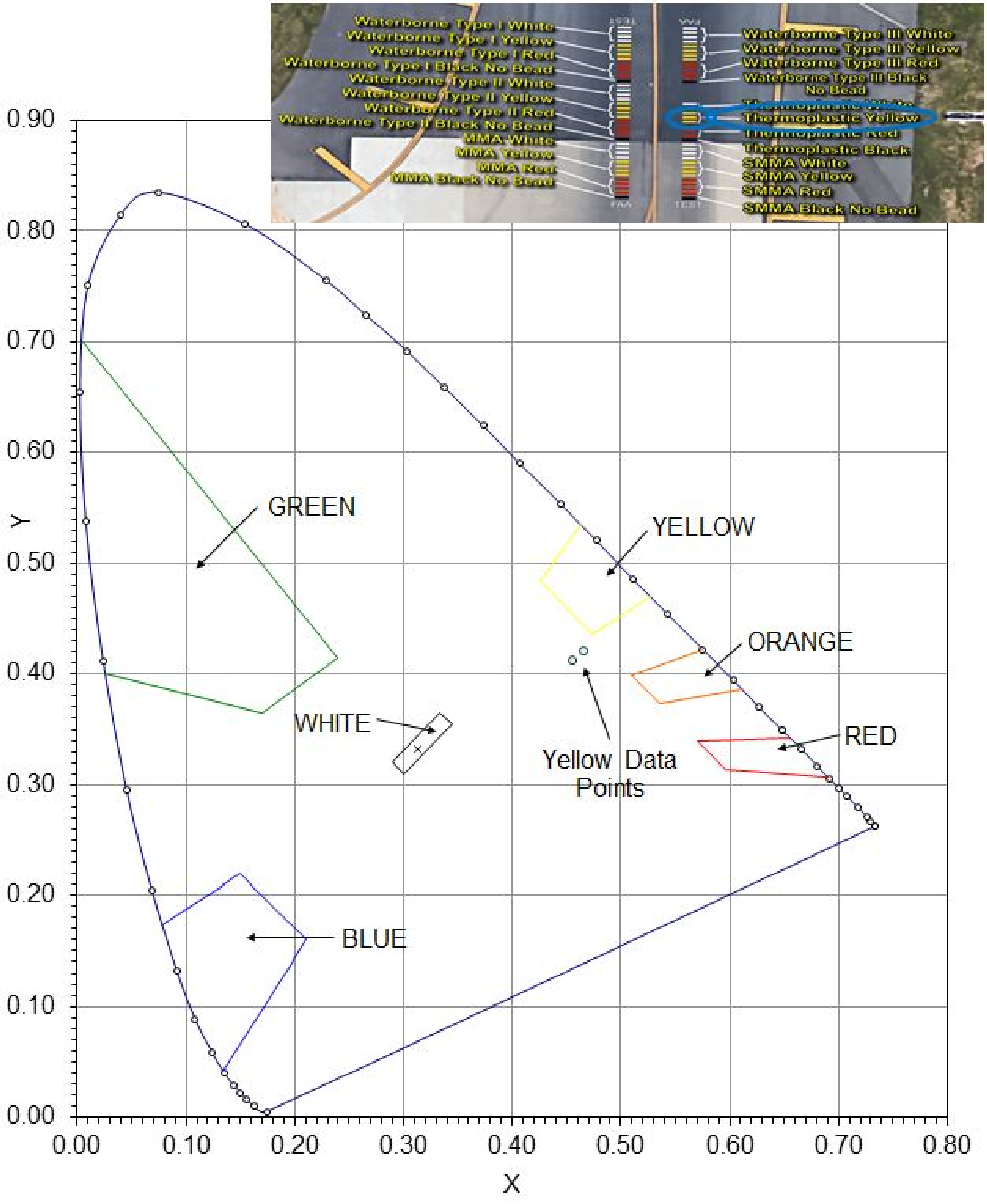


Figure D-21. April 20, 2017 Color Guide Readings for EWR Preformed Thermoplastic Yellow

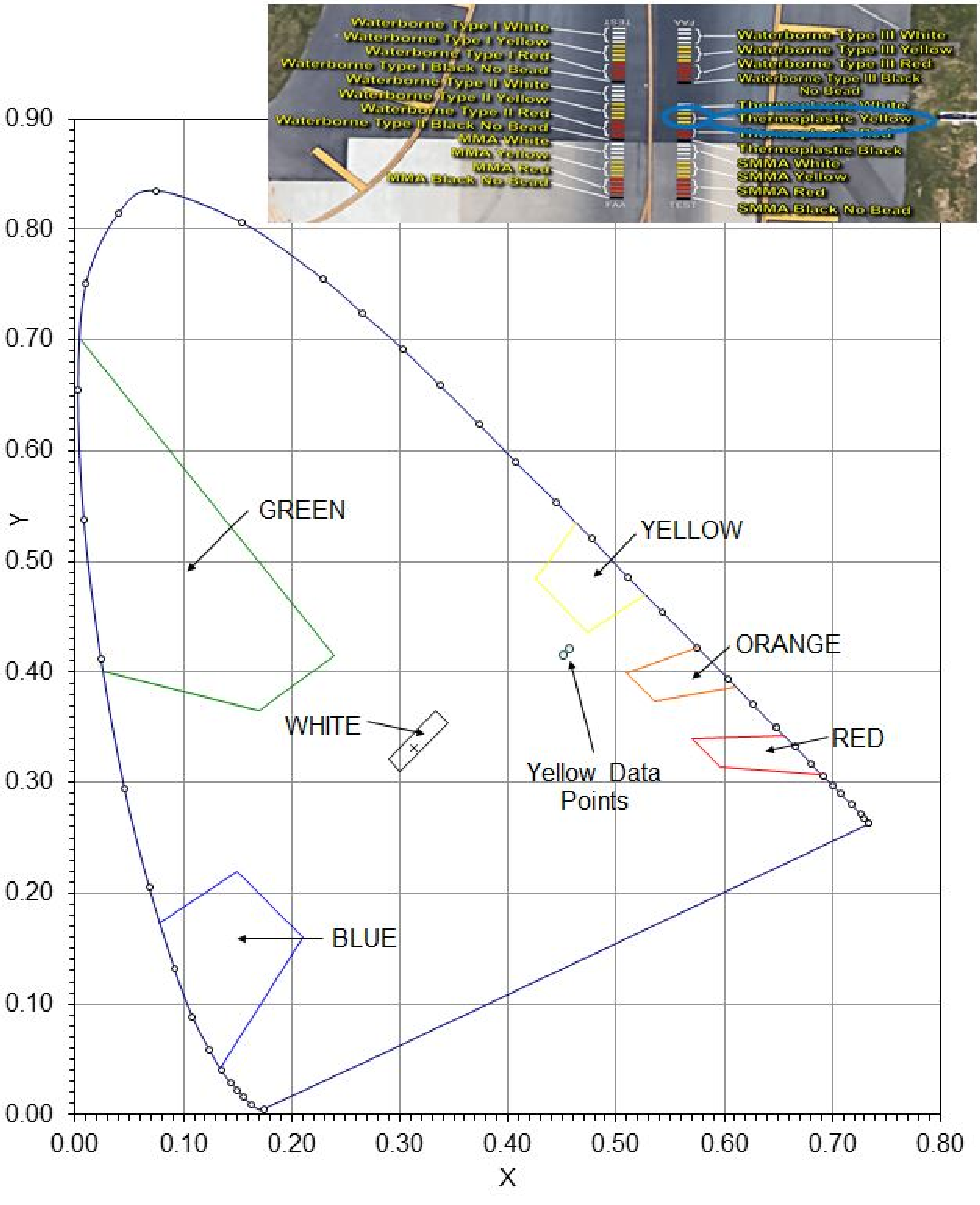


Figure D-22. April 27, 2018 Color Guide Readings for EWR Preformed Thermoplastic Yellow

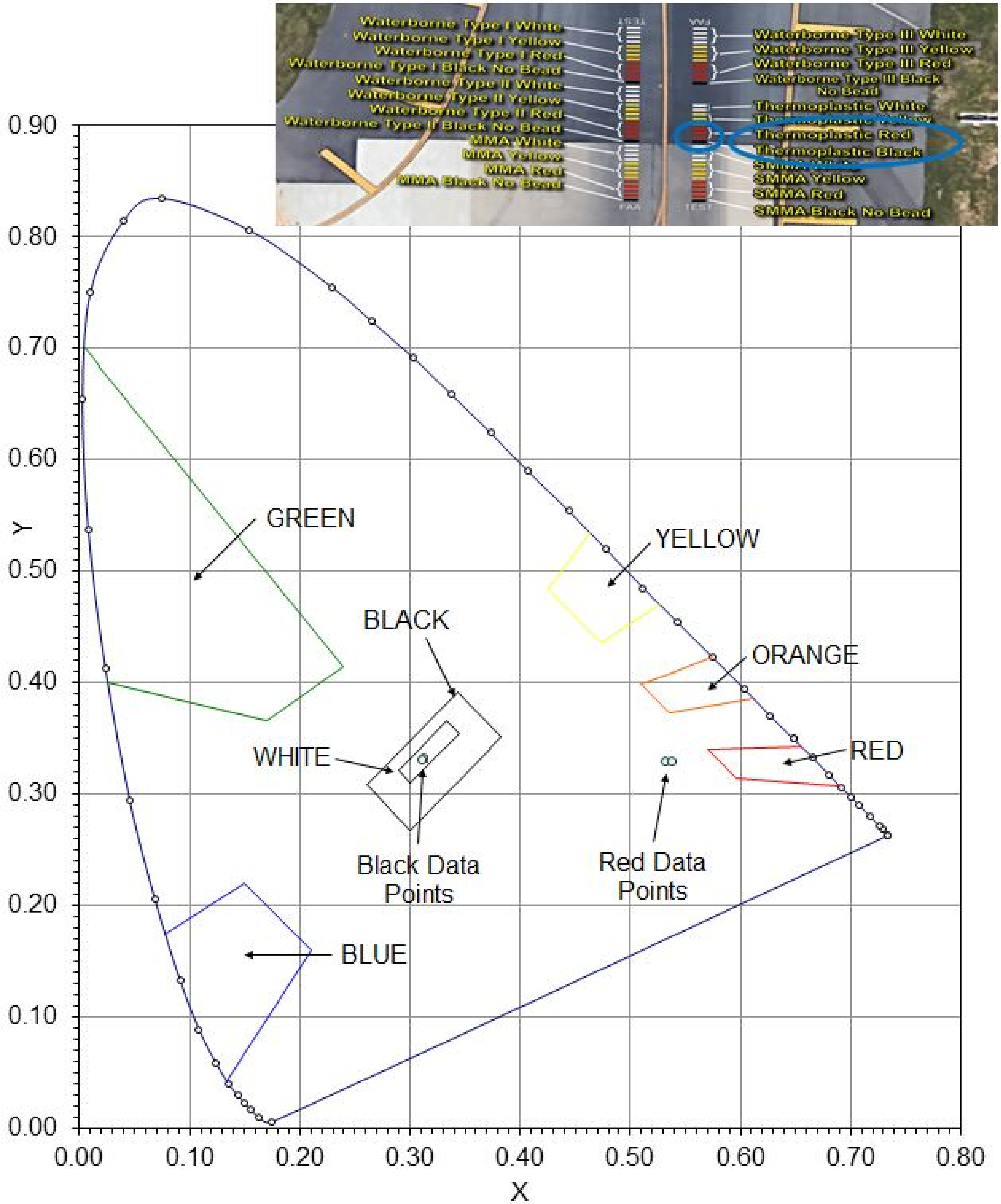


Figure D-23. April 20, 2017 Color Guide Readings for EWR Preformed Thermoplastic Red and Black

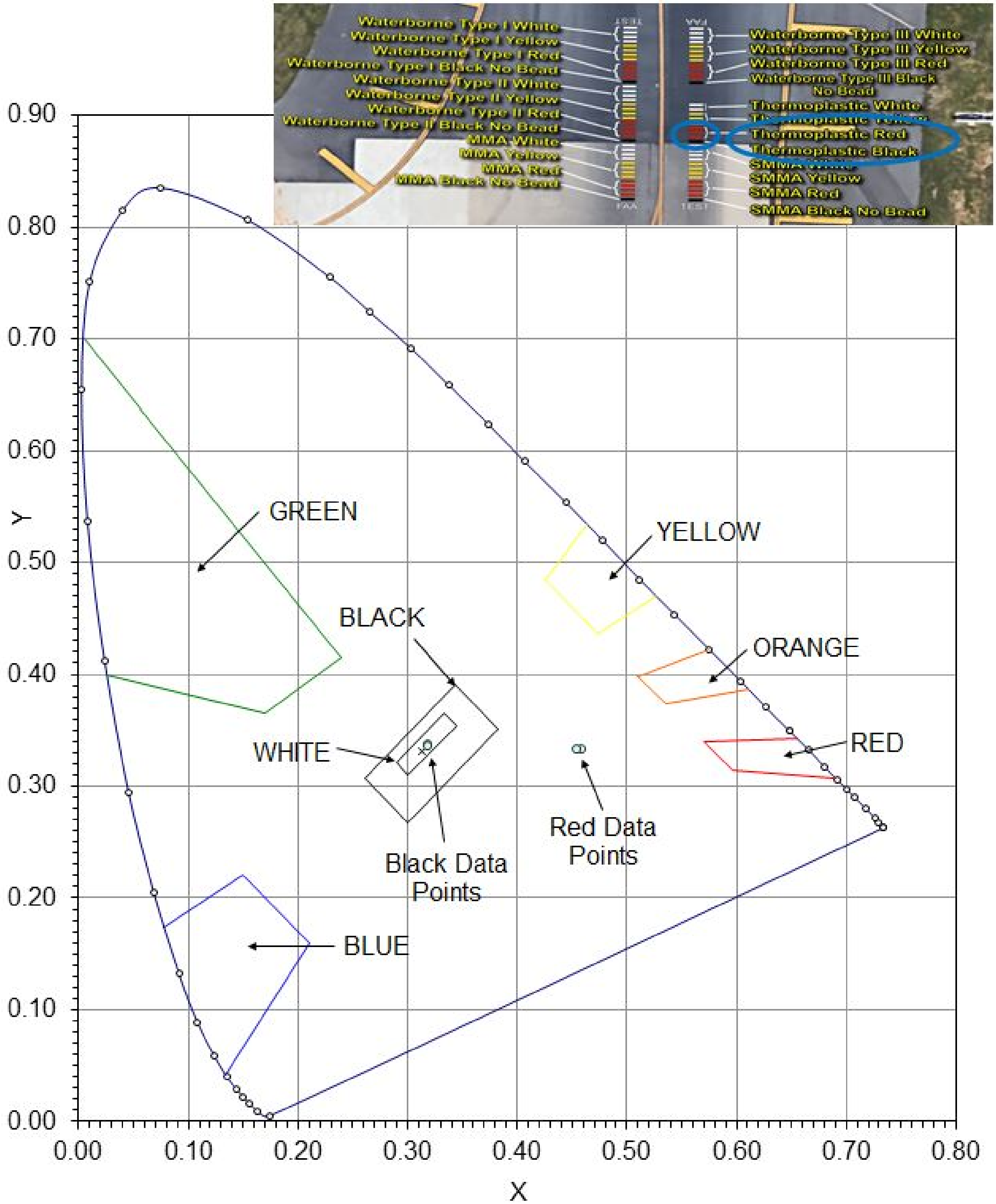


Figure D-24. April 27, 2018 Color Guide Readings for EWR Preformed Thermoplastic Red and Black

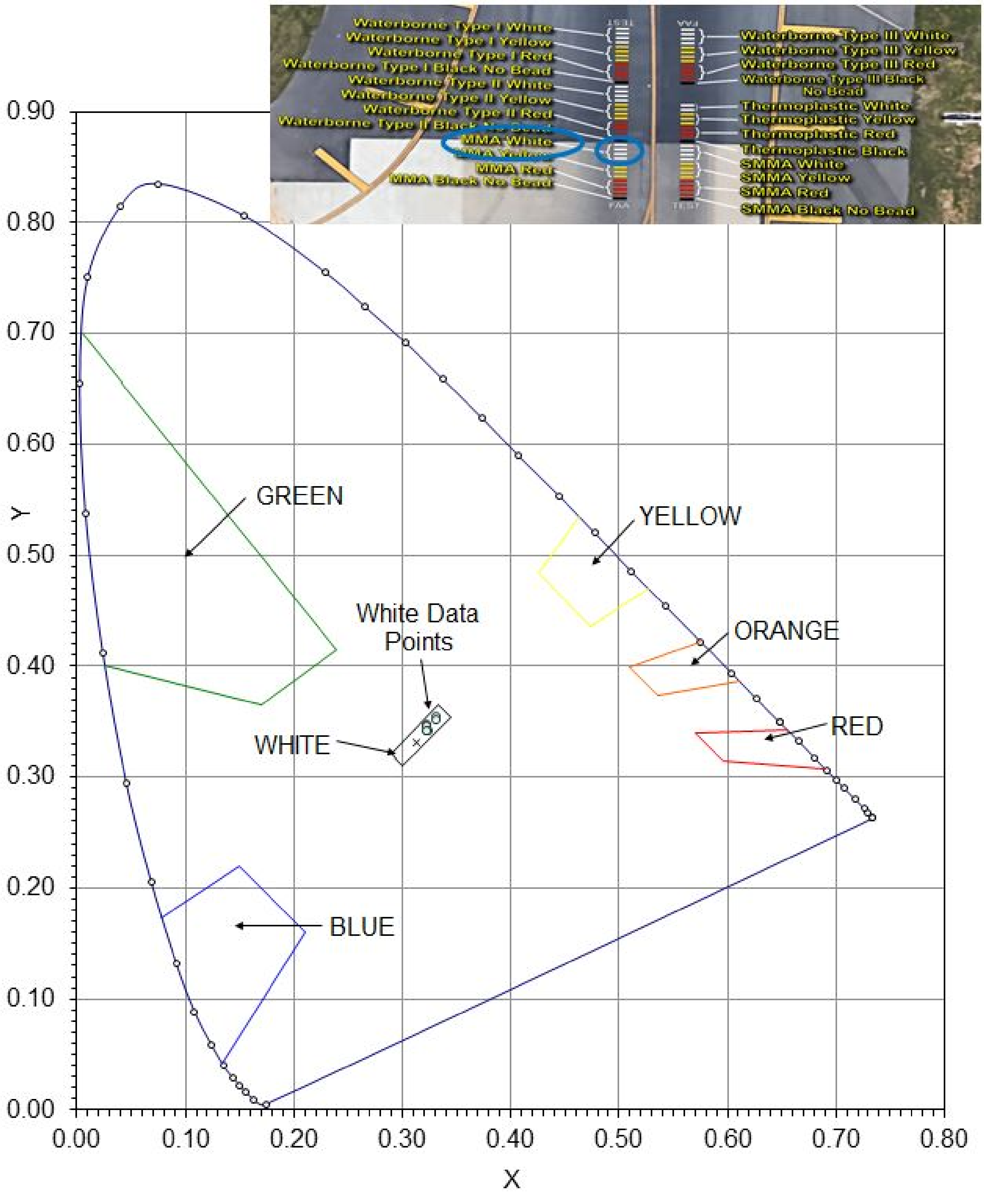


Figure D-25. April 20, 2017 Color Guide Readings for EWR MMA White

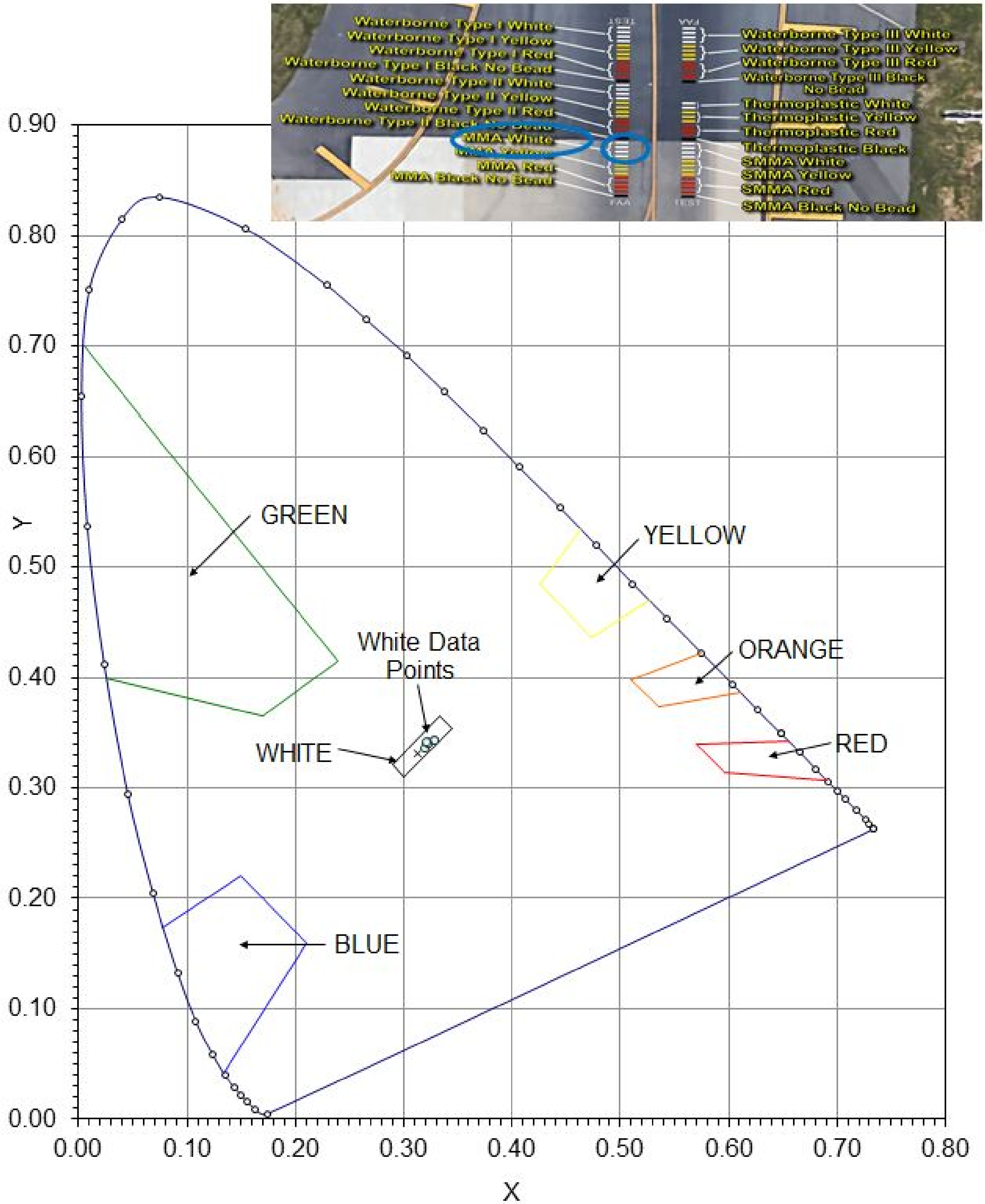


Figure D-26. April 27, 2018 Color Guide Readings for EWR MMA White

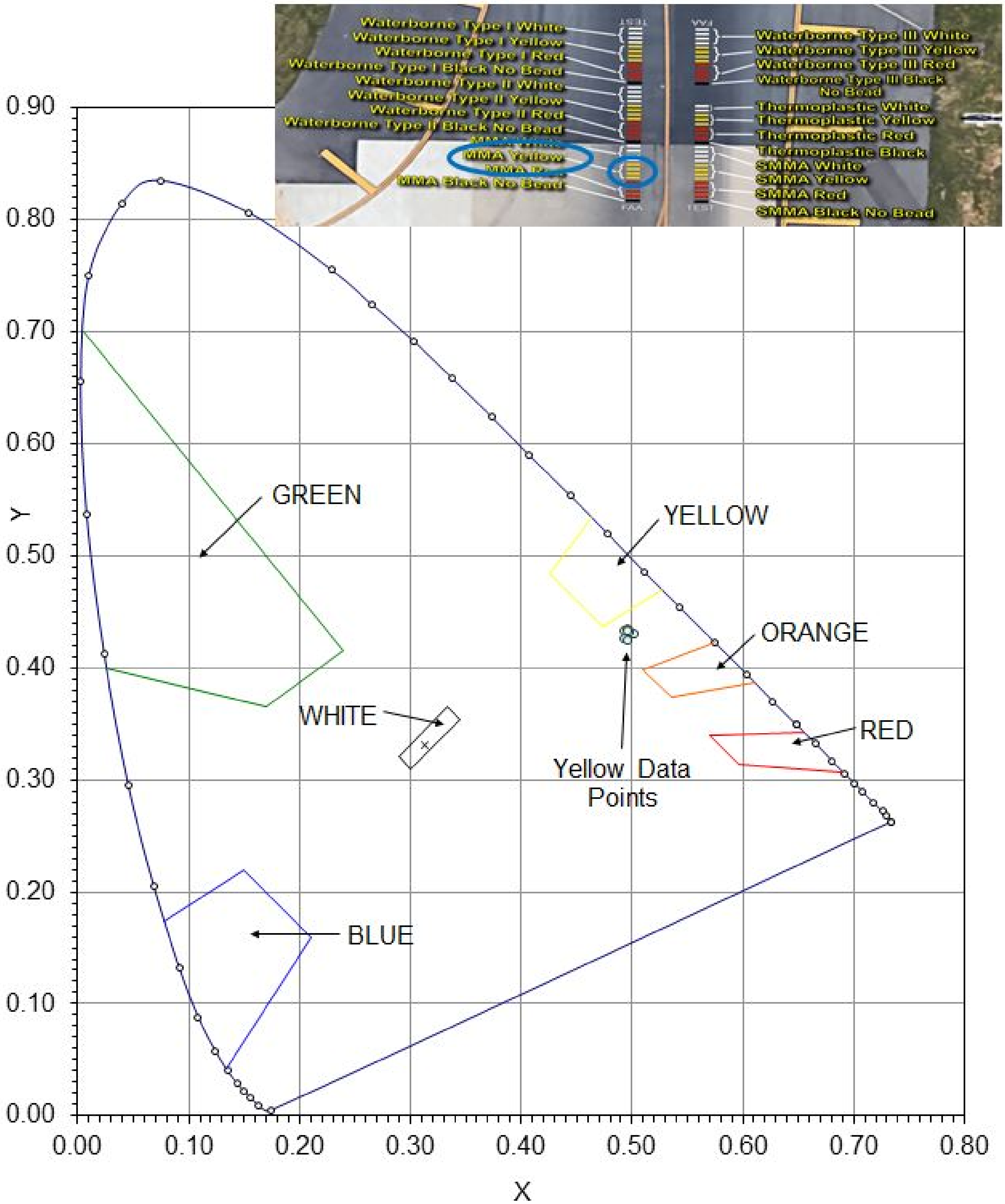


Figure D-27. April 20, 2017 Color Guide Readings for EWR MMA Yellow

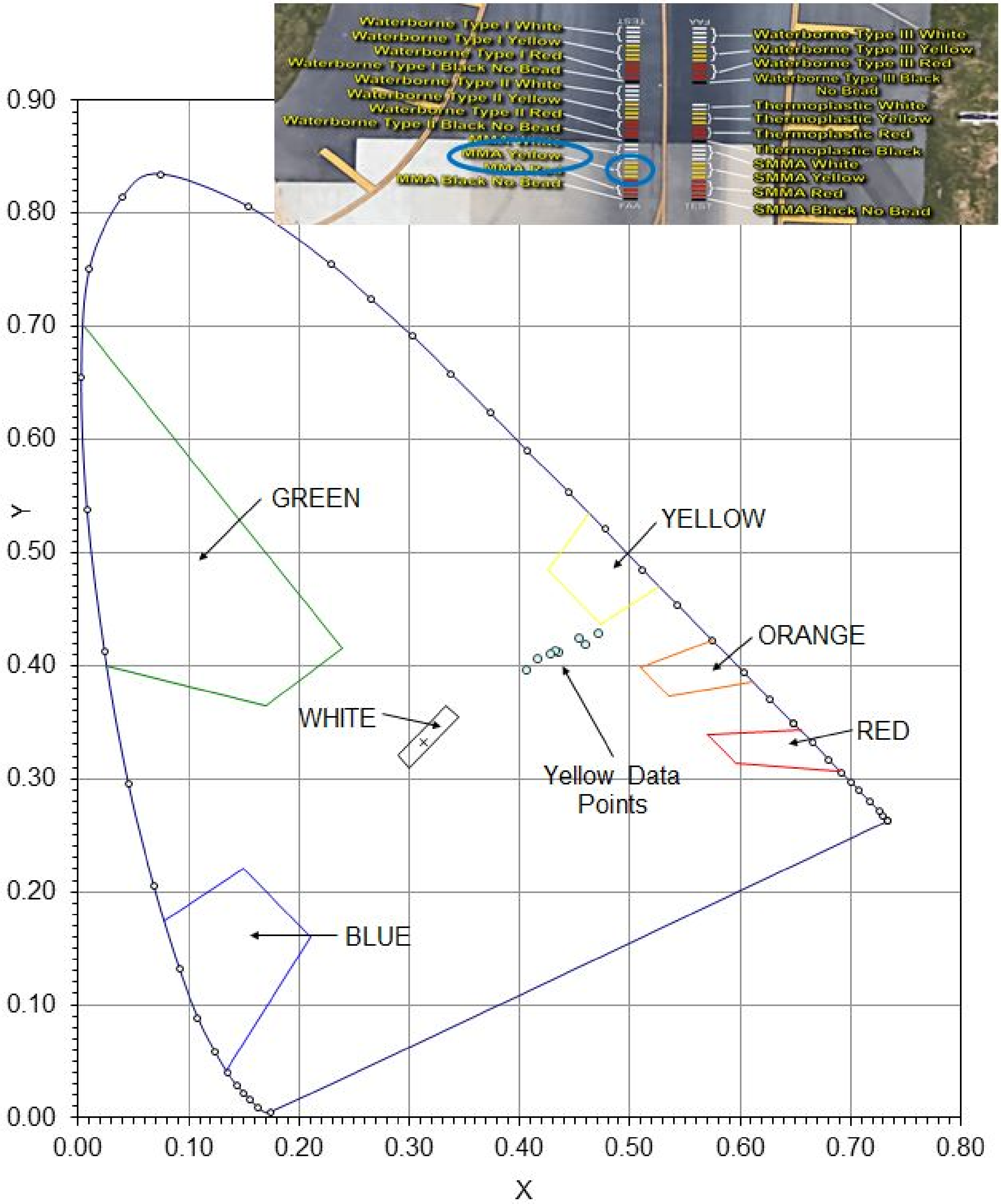


Figure D-28. April 27, 2018 Color Guide Readings for EWR MMA Yellow

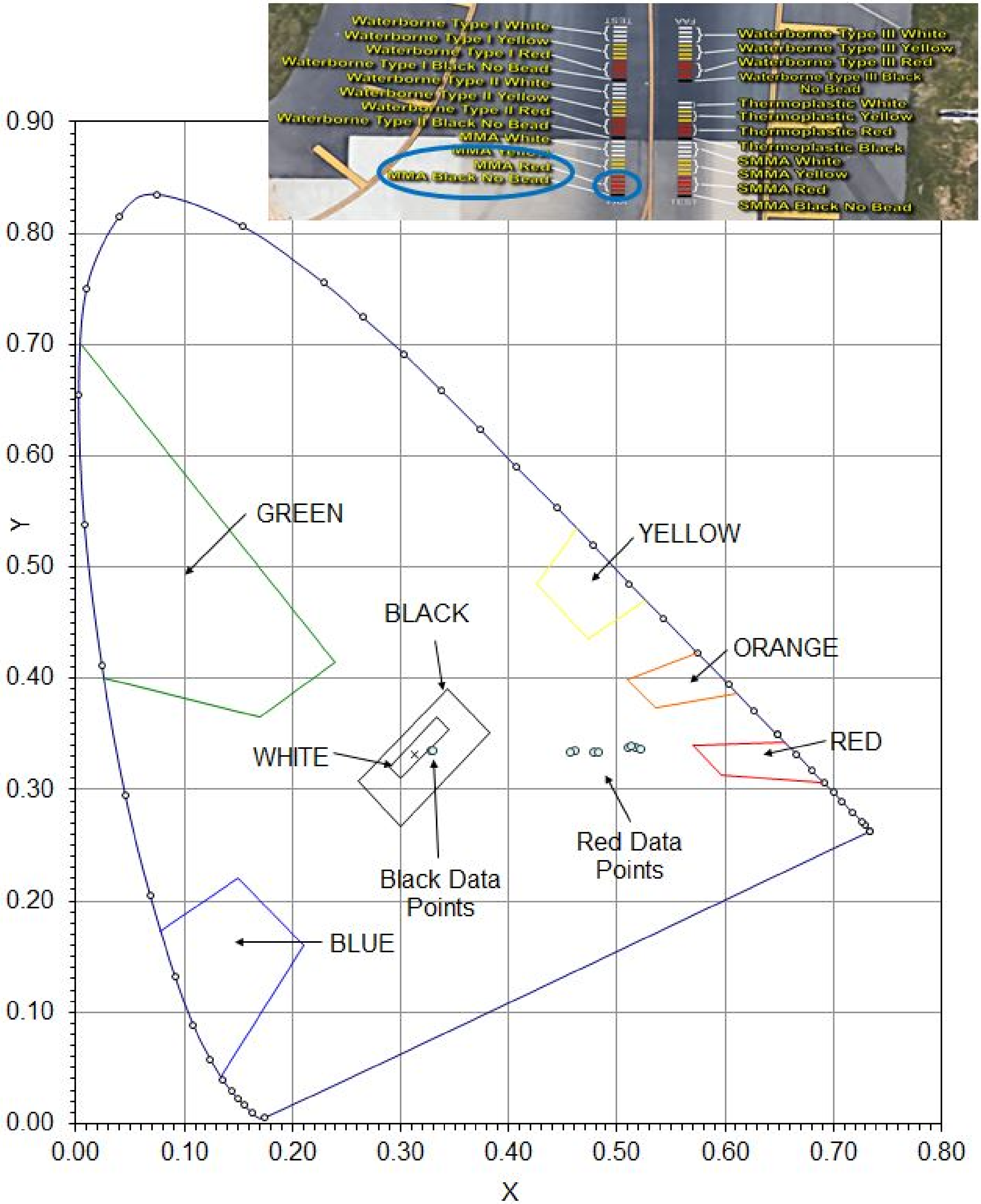


Figure D-29. April 20, 2017 Color Guide Readings for EWR MMA Red and Black

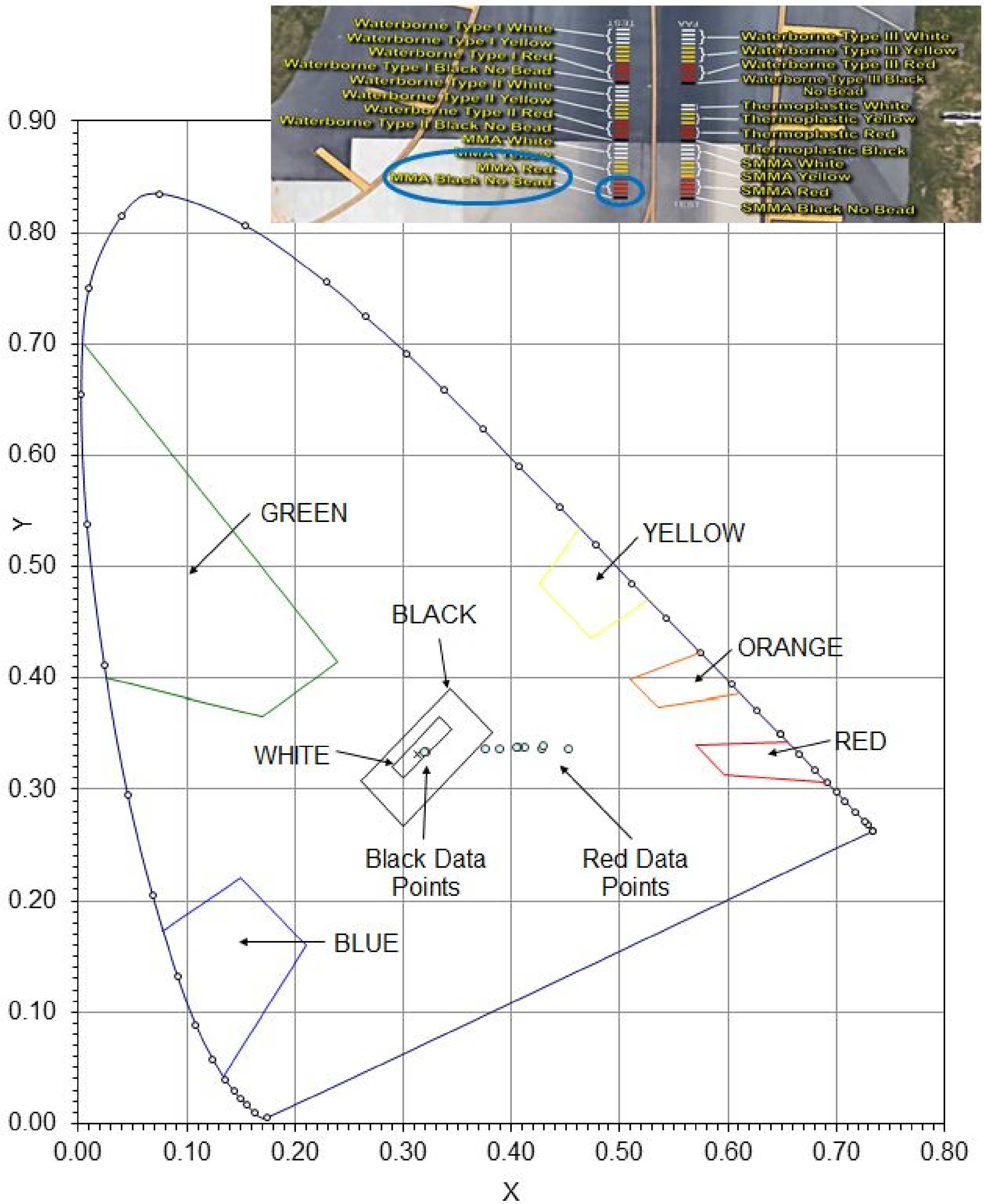


Figure D-30. April 27, 2018 Color Guide Readings for EWR MMA Red and Black

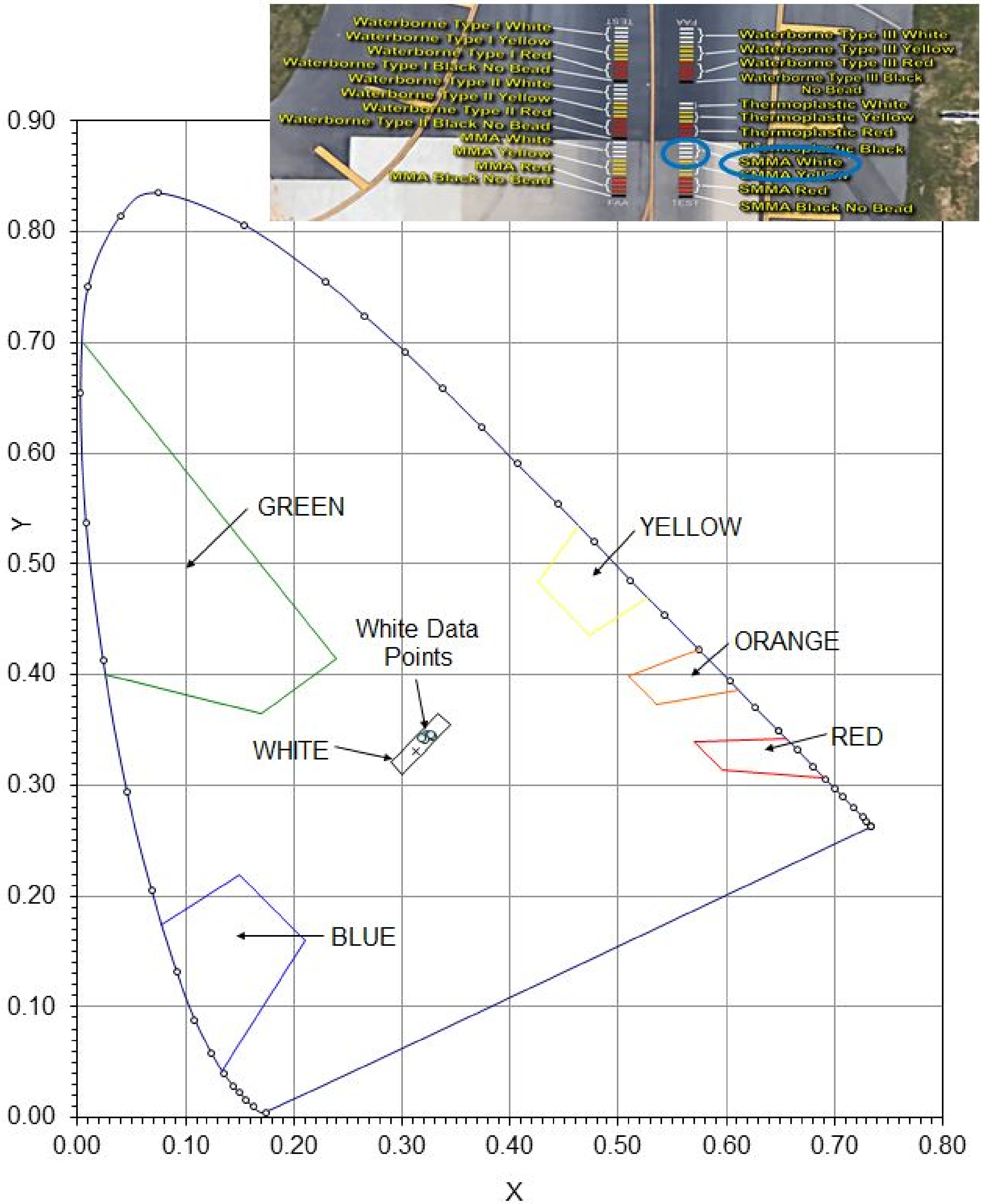


Figure D-31. April 20, 2017 Color Guide Readings for EWR SMMA White

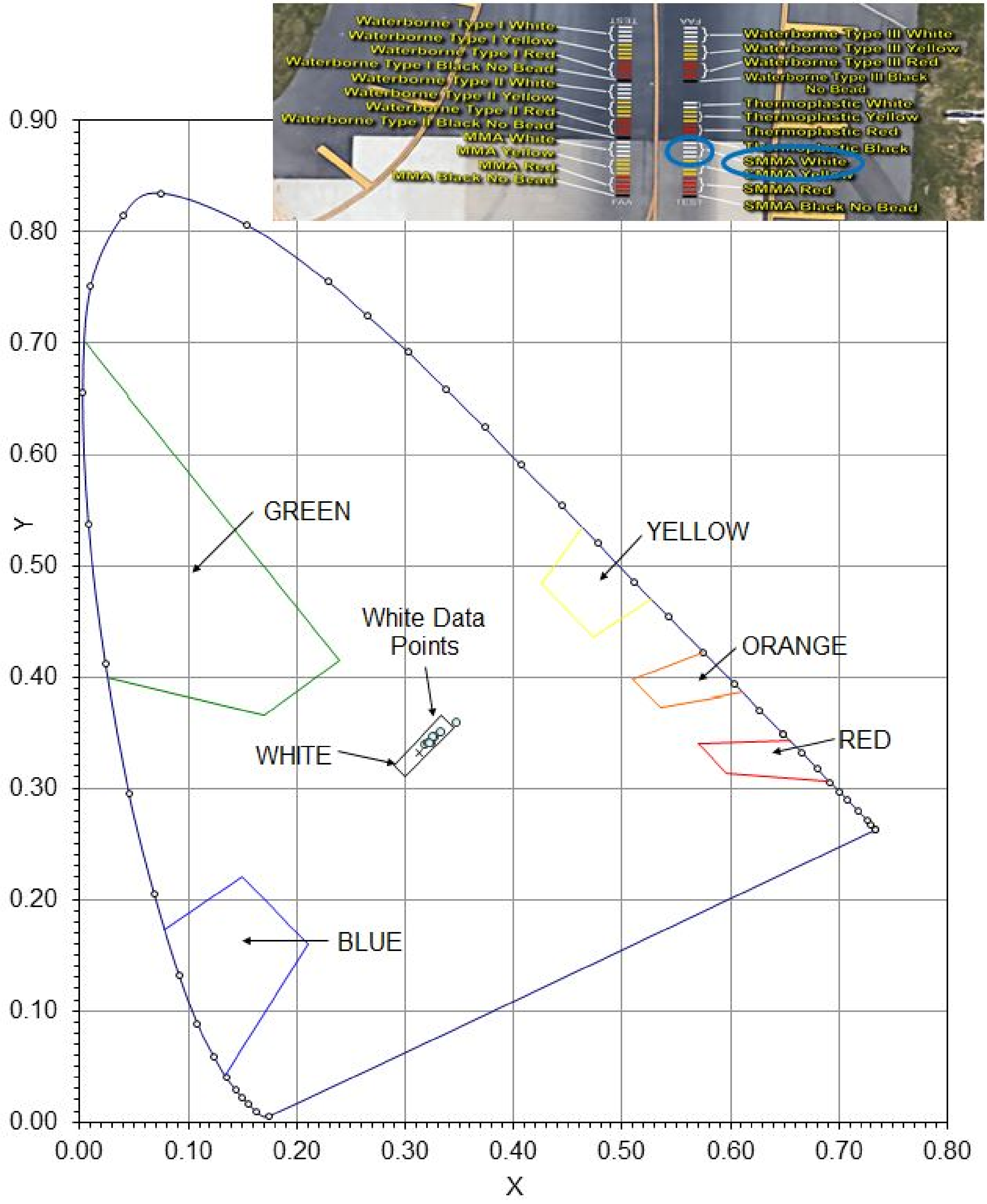


Figure D-32. April 27, 2018 Color Guide Readings for EWR SMMA White

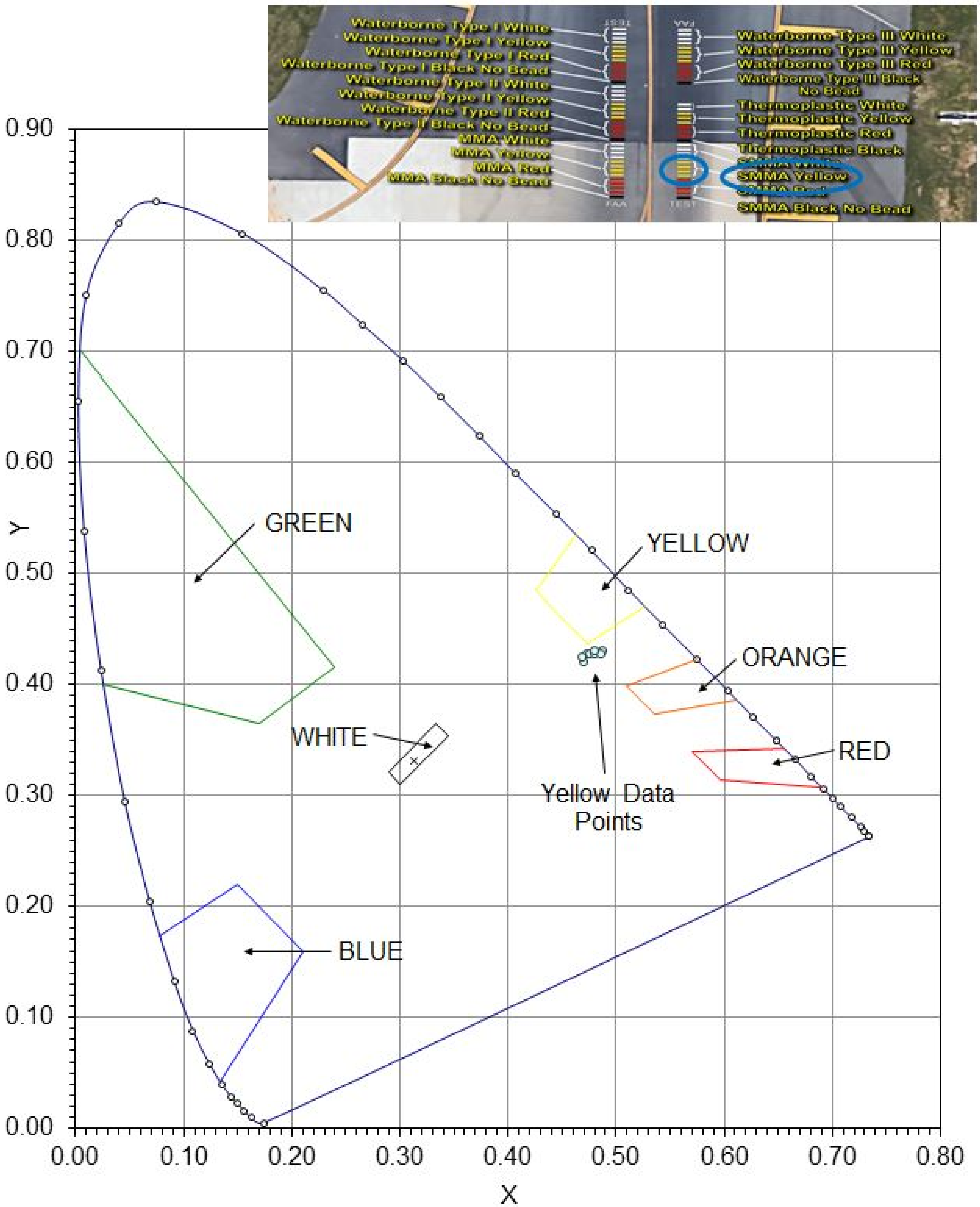


Figure D-33. April 20, 2017 Color Guide Readings for EWR SMMA Yellow

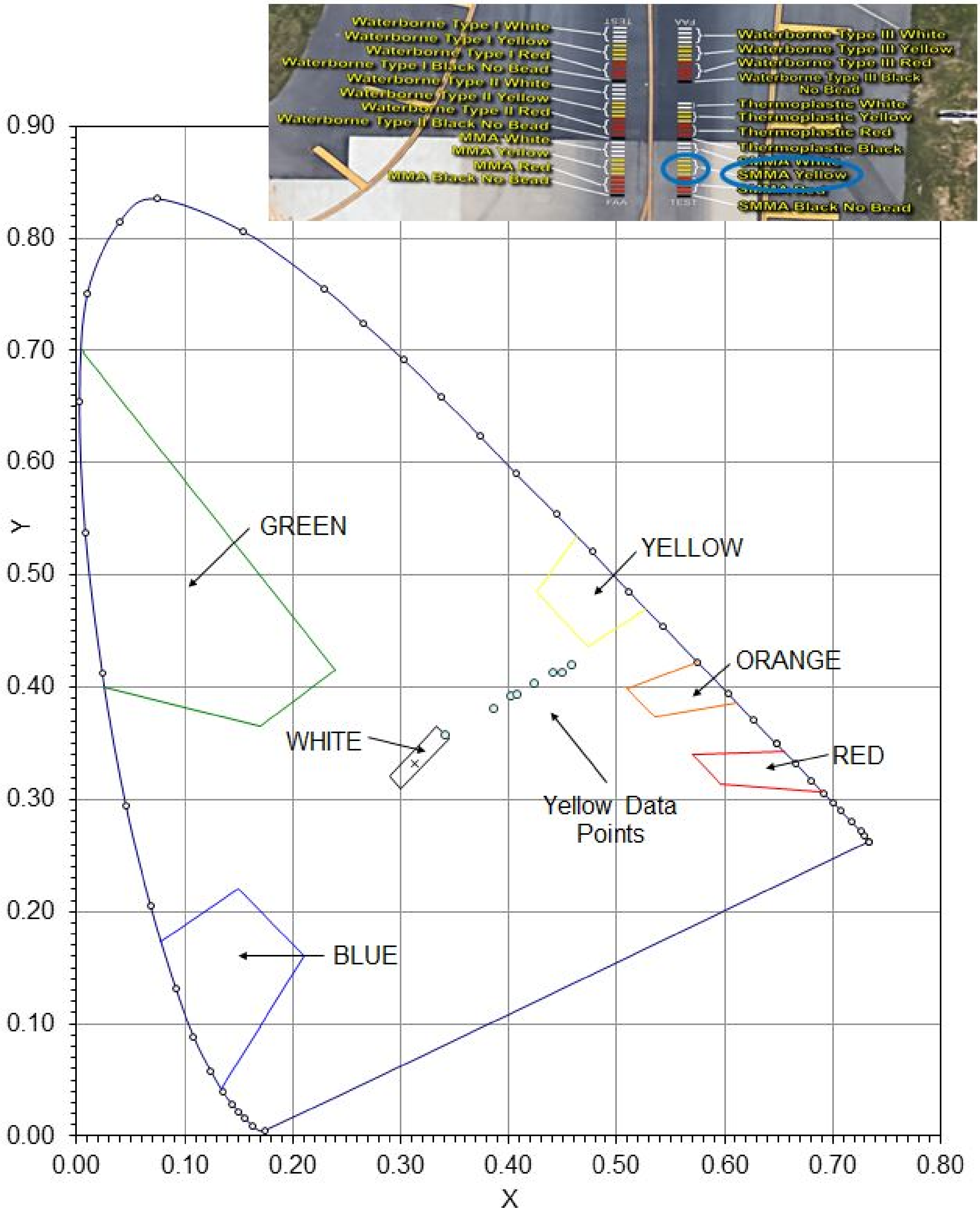


Figure D-34. April 27, 2018 Color Guide Readings for EWR SMMA Yellow

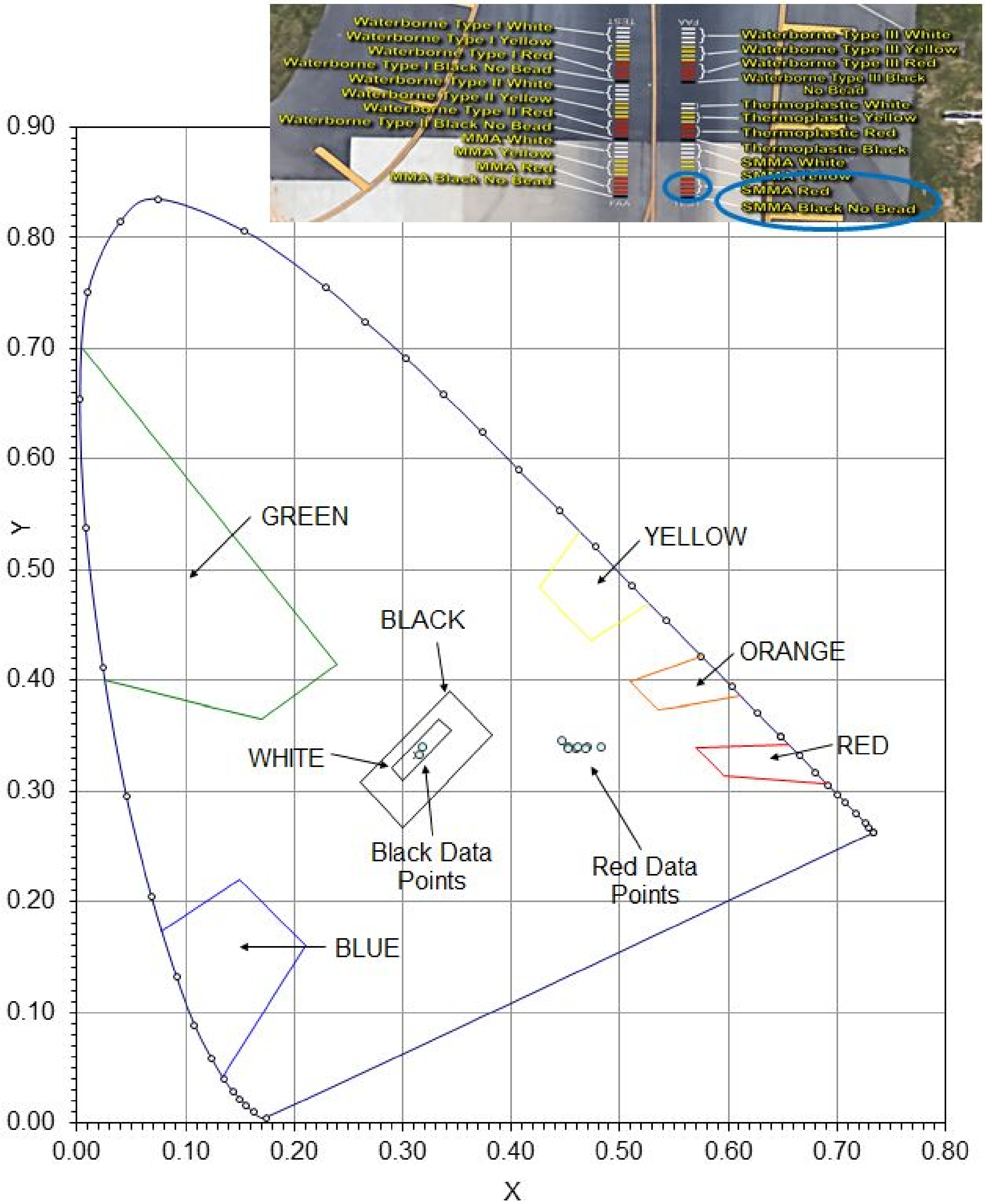


Figure D-35. April 20, 2017 Color Guide Readings for EWR SMMA Red and Black

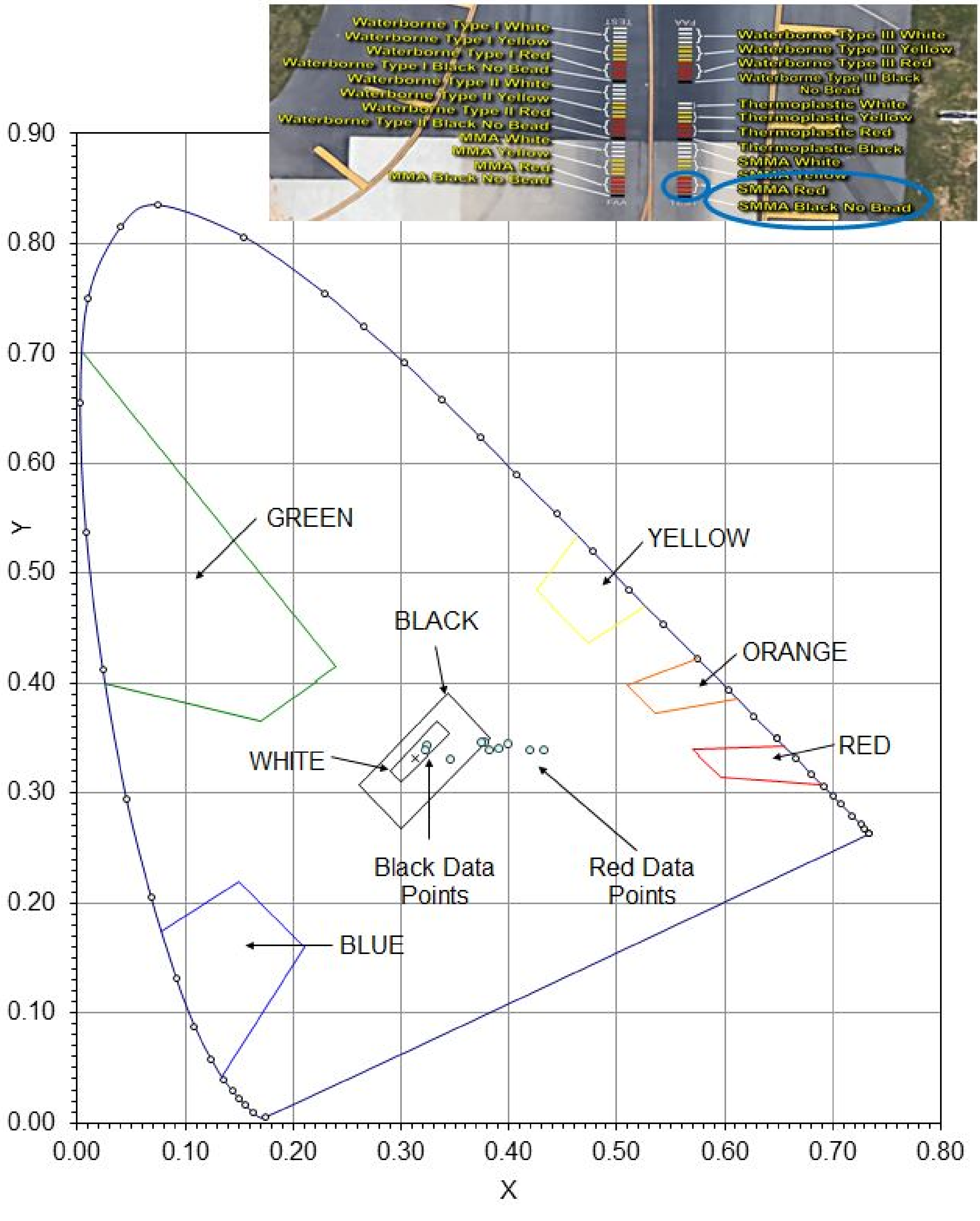


Figure D-36. April 27, 2018 Color Guide Readings for EWR SMMA Red and Black

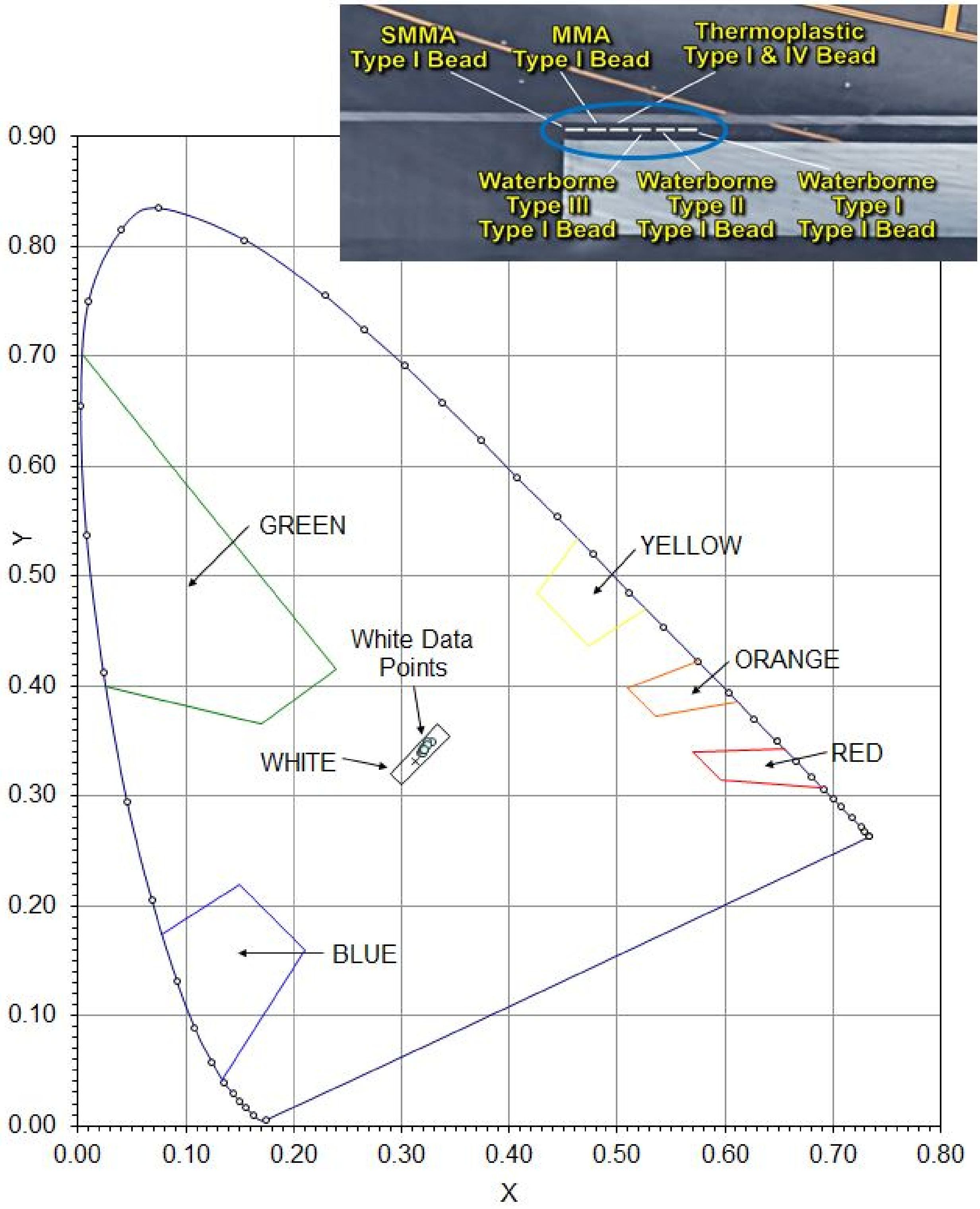


Figure D-37. April 20, 2017 Color Guide Readings for EWR White Runway Friction Lines

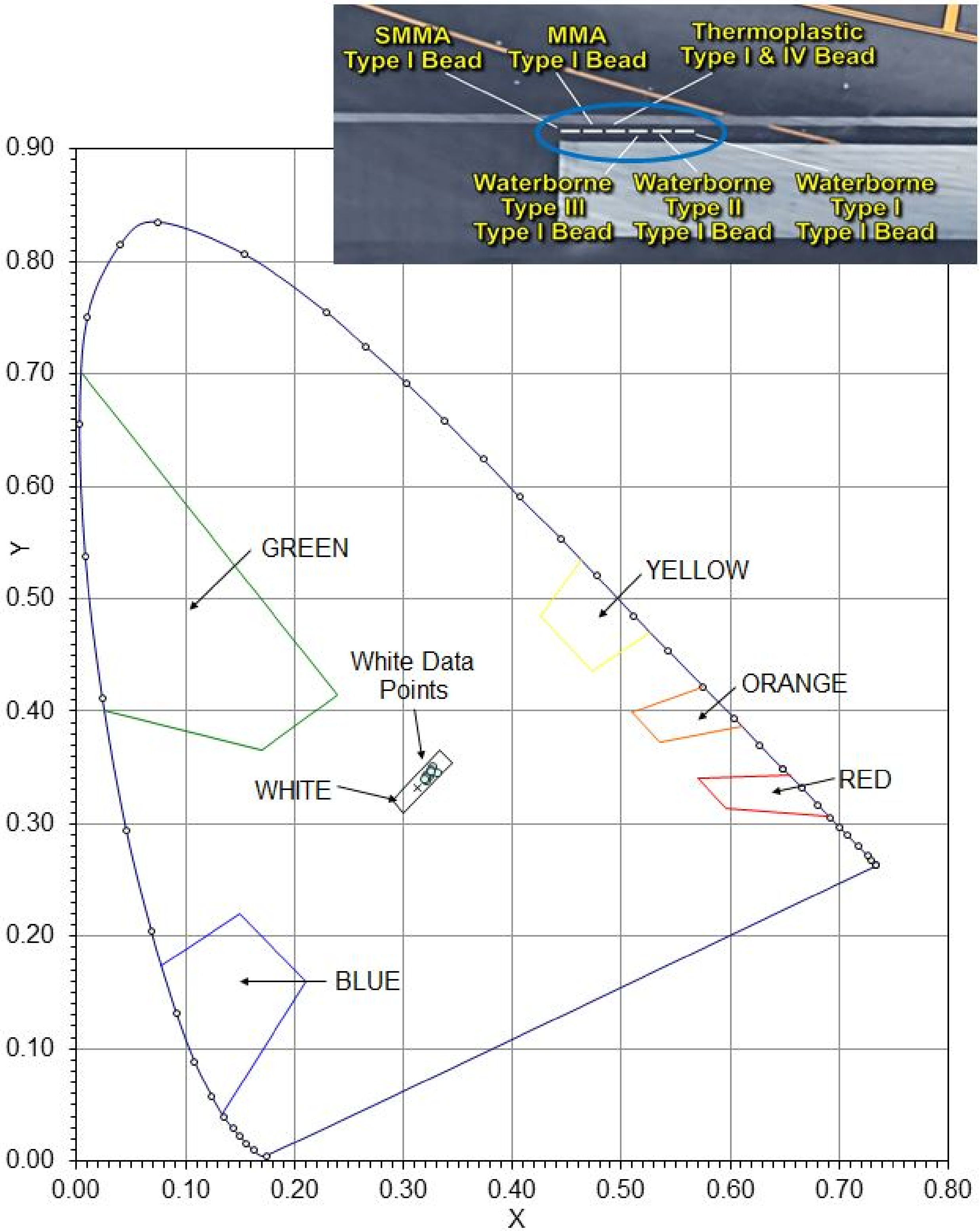


Figure D-38. April 27, 2018 Color Guide Readings for EWR White Runway Friction Lines

APPENDIX E—NEWARK LIBERTY INTERNATIONAL AIRPORT COMPARISON PHOTOS

Appendix E shows pictures at Newark Liberty International Airport (EWR) at installation (April 20, 2017) and one year later (April 27, 2018) for each surface marking material (Waterborne Type I, Waterborne Type II, Waterborne Type III, Methyl methacrylate (MMA), Structured methyl methacrylate (SMMA), Preformed Thermoplastic) for each color under test (white, yellow, red, and black).

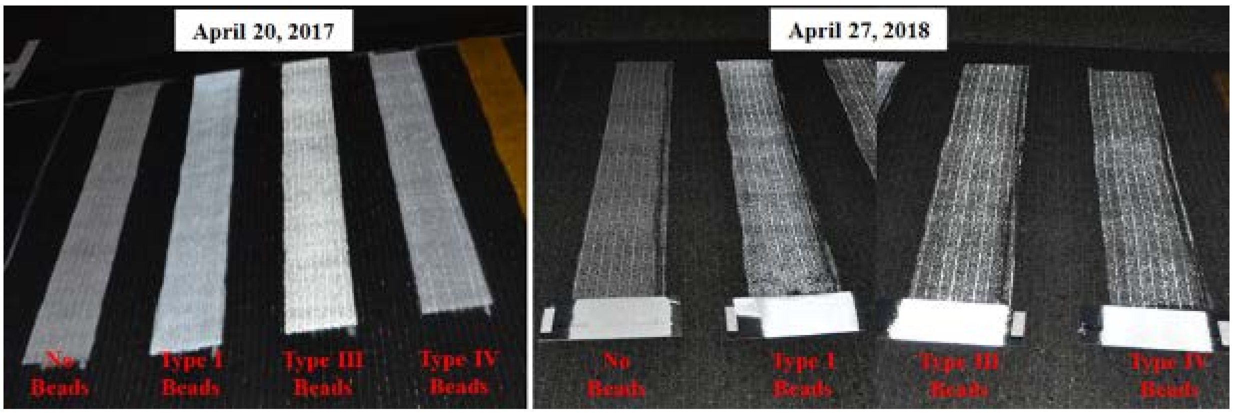


Figure E-1. White Waterborne Type I at EWR—April 2017 (Left) vs April 2018 (Right)

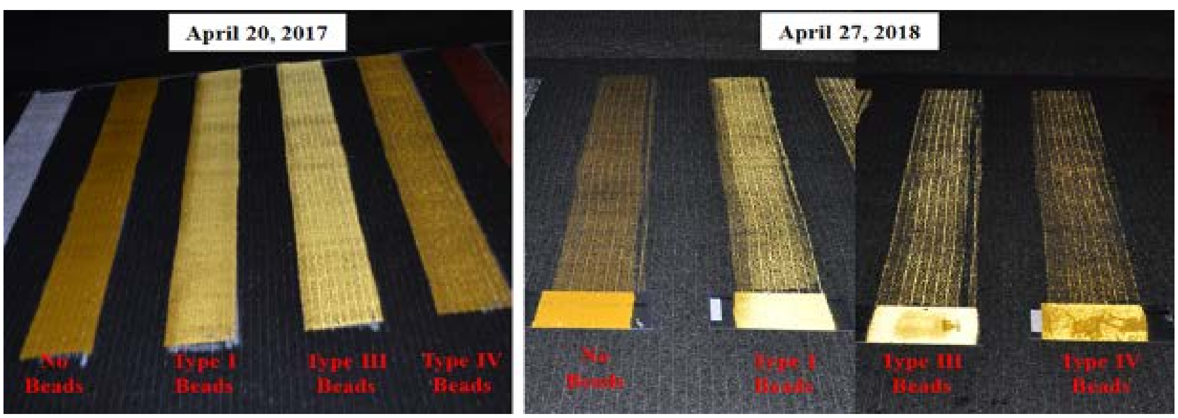


Figure E-2. Yellow Waterborne Type I at EWR—April 2017 (Left) vs April 2018 (Right)

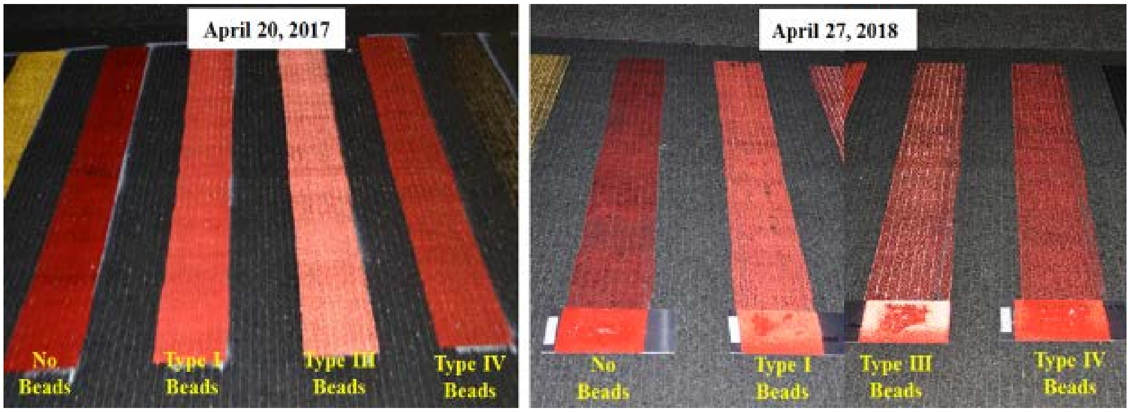


Figure E-3. Red Waterborne Type I at EWR—April 2017 (Left) vs April 2018 (Right)

Figure E-4. Black Waterborne Type I at EWR—April 2017 (Left) vs April 2018 (Right)

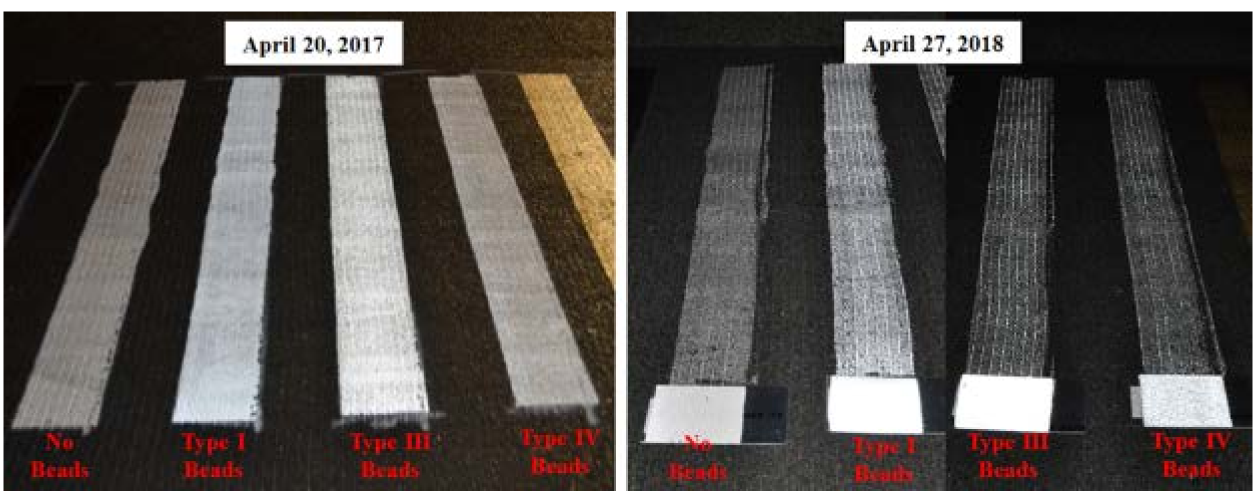


Figure E-5. White Waterborne Type II at EWR—April 2017 (Left) vs April 2018 (Right)

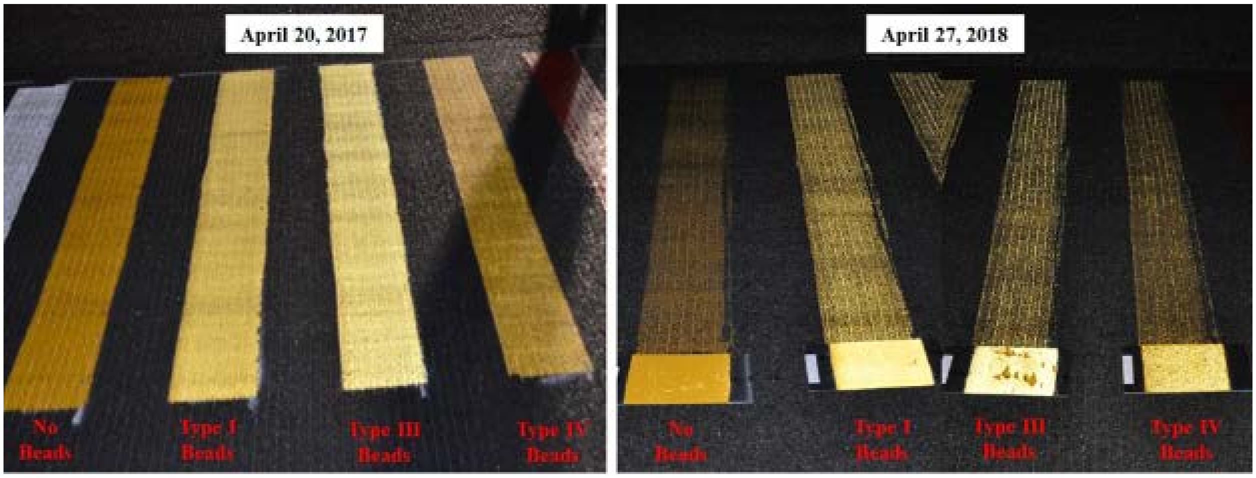


Figure E-6. Yellow Waterborne Type II at EWR—April 2017 (Left) vs April 2018 (Right)

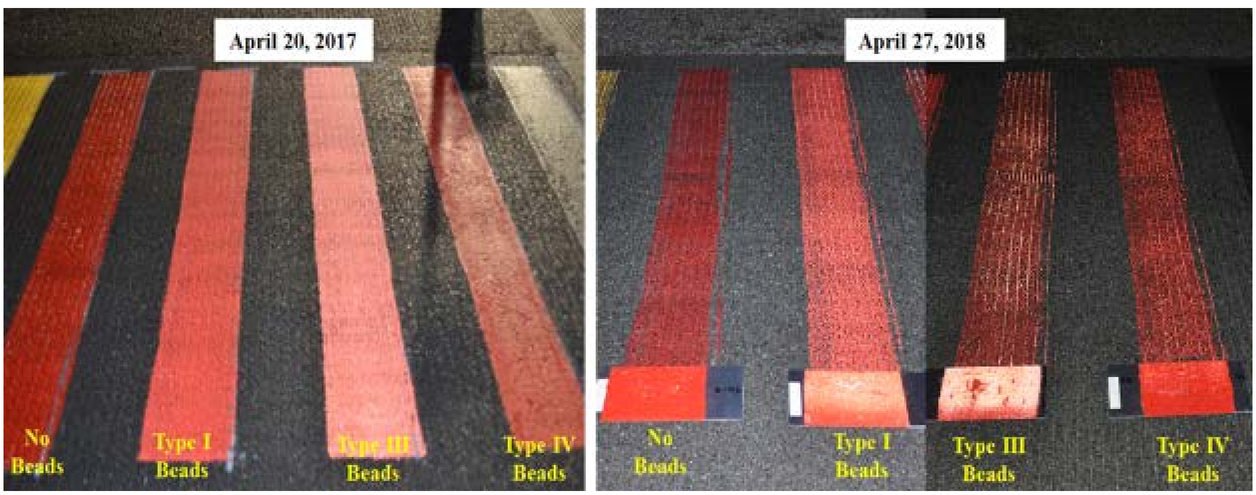


Figure E-7. Red Waterborne Type II at EWR—April 2017 (Left) vs April 2018 (Right)

Figure E-8. Black Waterborne Type II at EWR—April 2017 (Left) vs April 2018 (Right)

Figure E-9. White MMA at EWR—April 2017 (Left) vs April 2018 (Right)

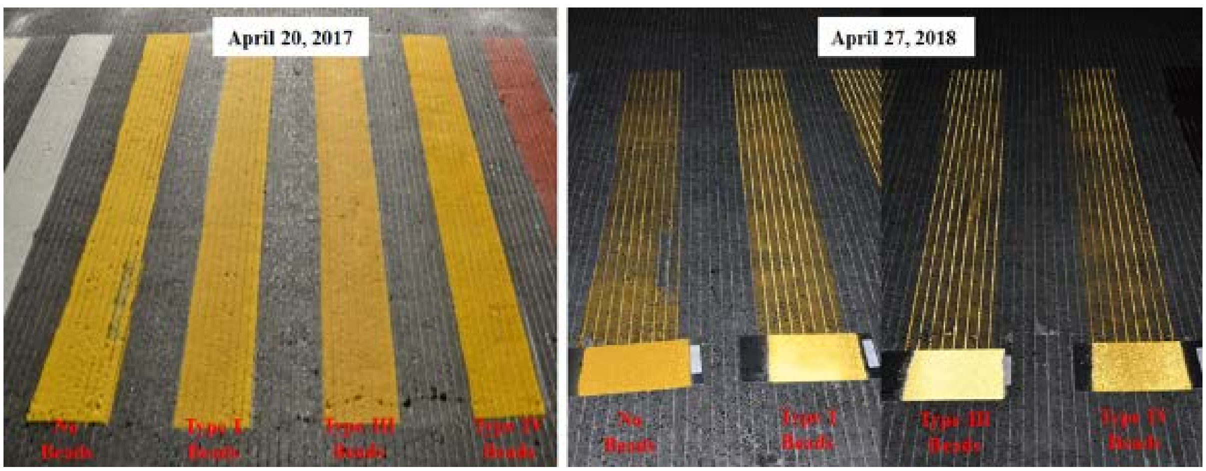


Figure E-10. Yellow MMA at EWR—April 2017 (Left) vs April 2018 (Right)

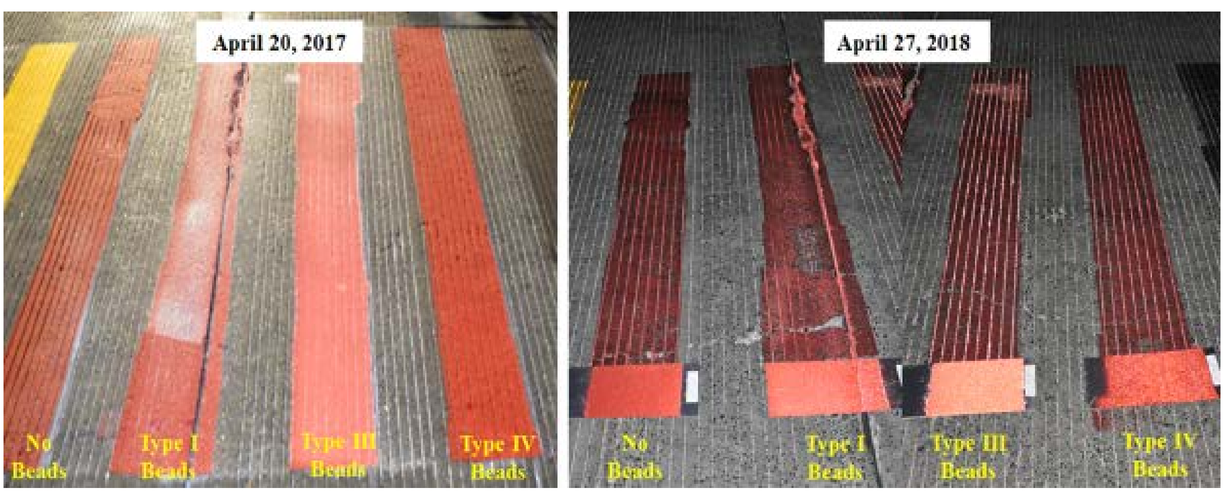


Figure E-11. Red MMA at EWR—April 2017 (Left) vs April 2018 (Right)

Figure E-12. Black MMA at EWR—April 2017 (Left) vs April 2018 (Right)

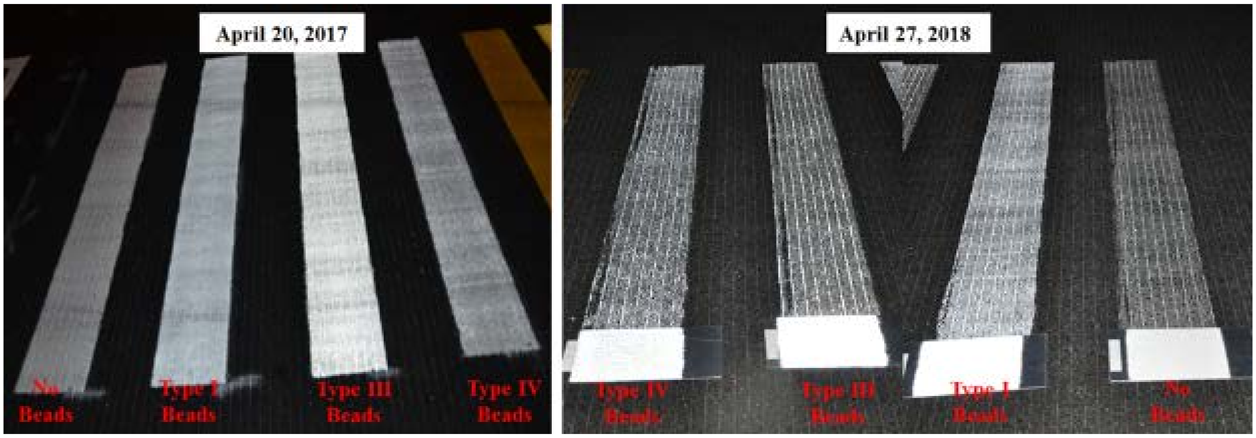


Figure E-13. White Waterborne Type III at EWR—April 2017 (Left) vs April 2018 (Right)

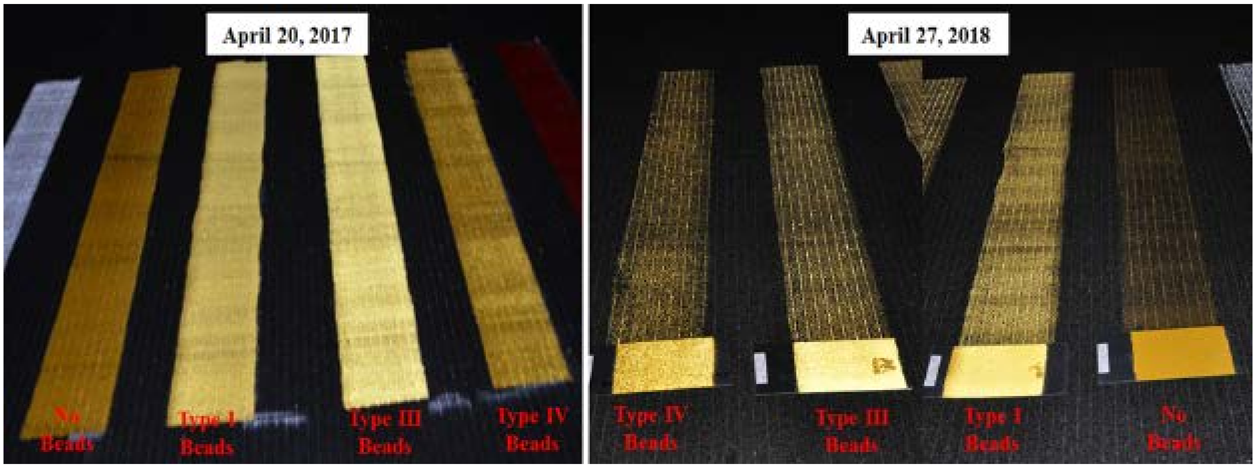


Figure E-14. Yellow Waterborne Type III at EWR—April 2017 (Left) vs April 2018 (Right)

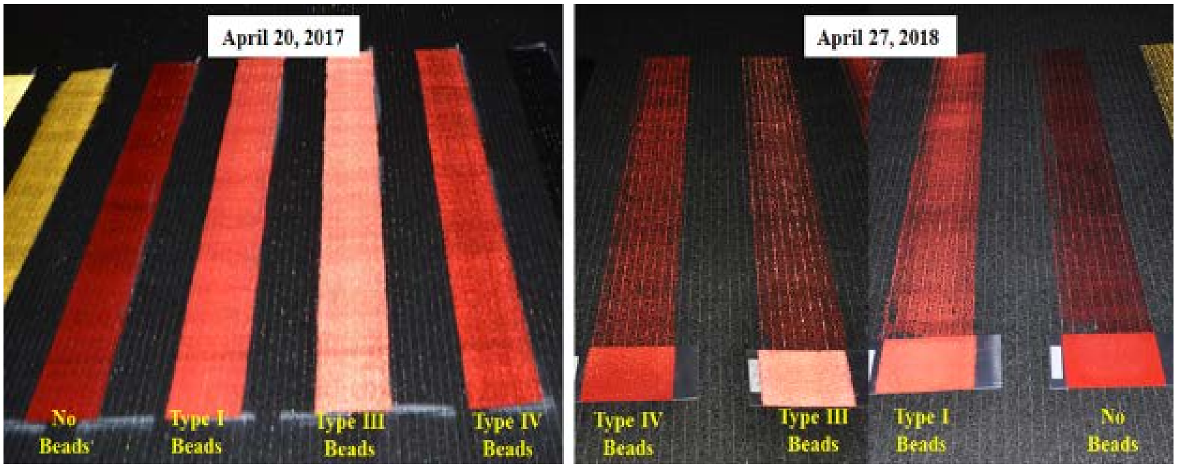


Figure E-15. Red Waterborne Type III at EWR—April 2017 (Left) vs April 2018 (Right)

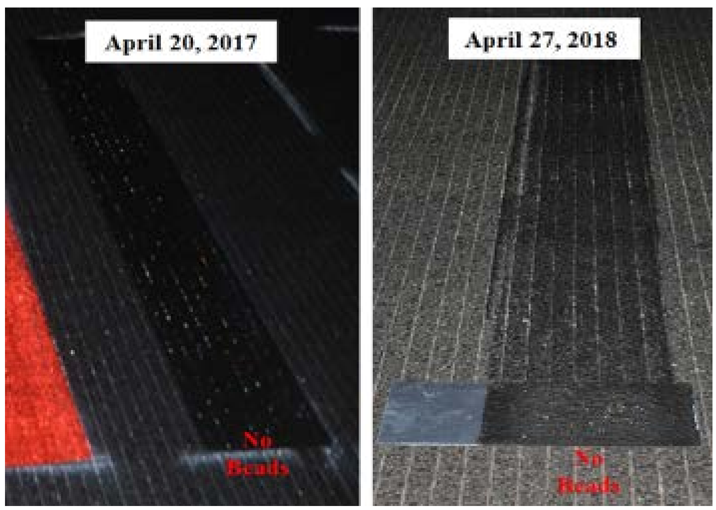


Figure E-16. Black Waterborne Type III at EWR—April 2017 (Left) vs April 2018 (Right)

Figure E-17. White Preformed Thermoplastic at EWR—April 2017 (Left) vs April 2018 (Right)

Figure E-18. Yellow Preformed Thermoplastic at EWR—April 2017 (Left) vs April 2018 (Right)

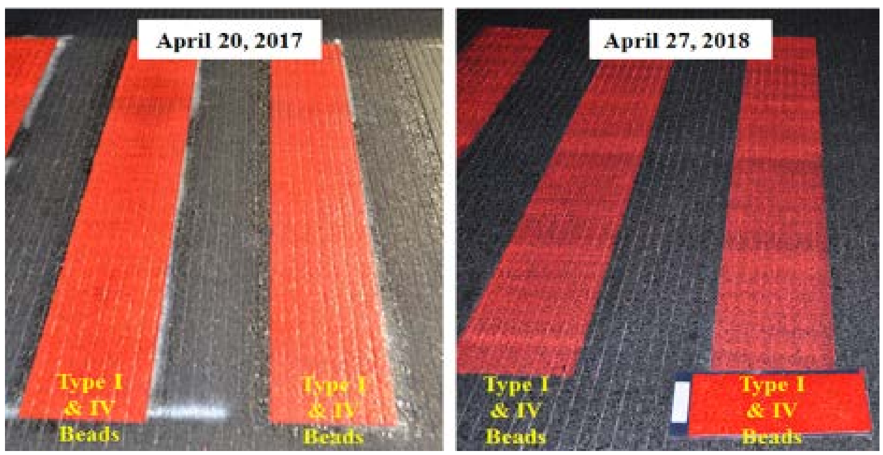


Figure E-19. Red Preformed Thermoplastic at EWR—April 2017 (Left) vs April 2018 (Right)

Figure E-20. Black Preformed Thermoplastic at EWR—April 2017 (Left) vs April 2018 (Right)

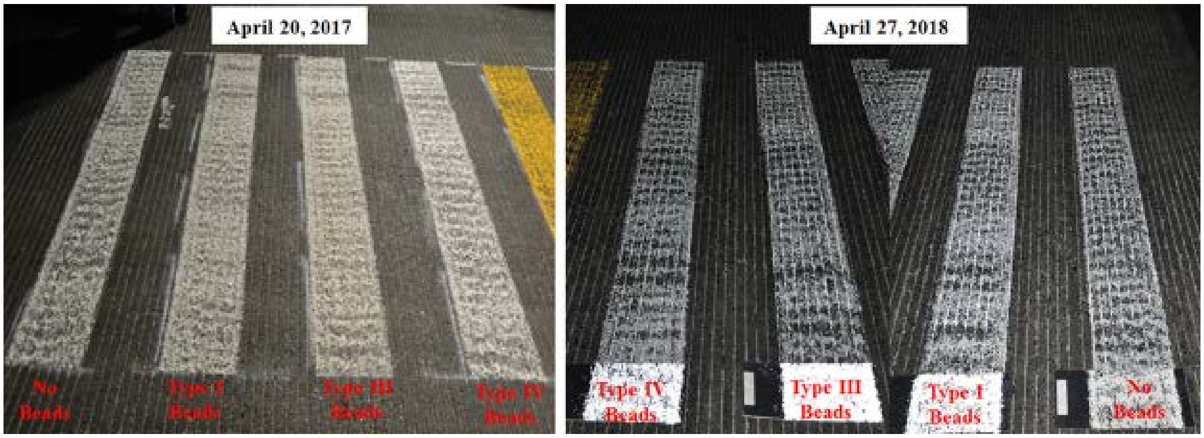


Figure E-21. White SMMA at EWR—April 2017 (Left) vs April 2018 (Right)

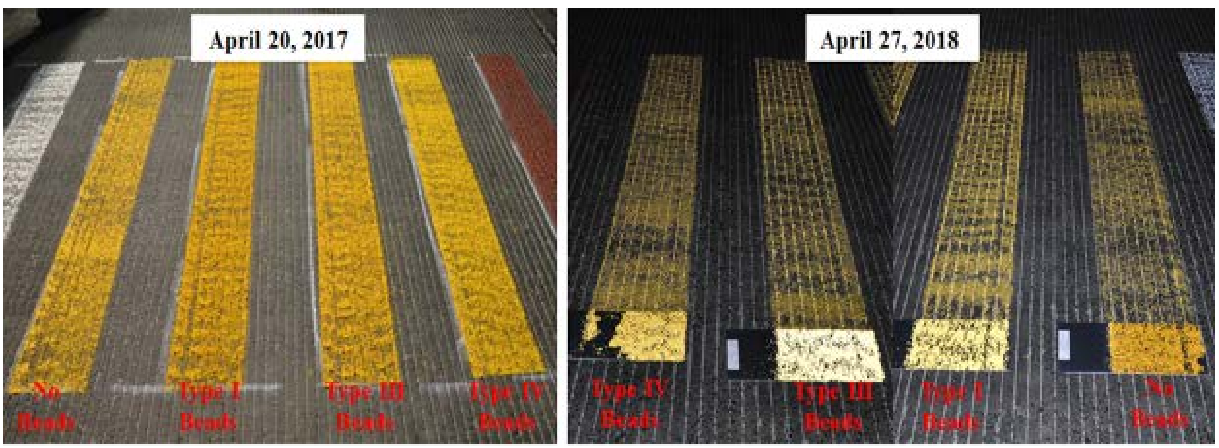


Figure E-22. Yellow SMMA at EWR—April 2017 (Left) vs April 2018 (Right)

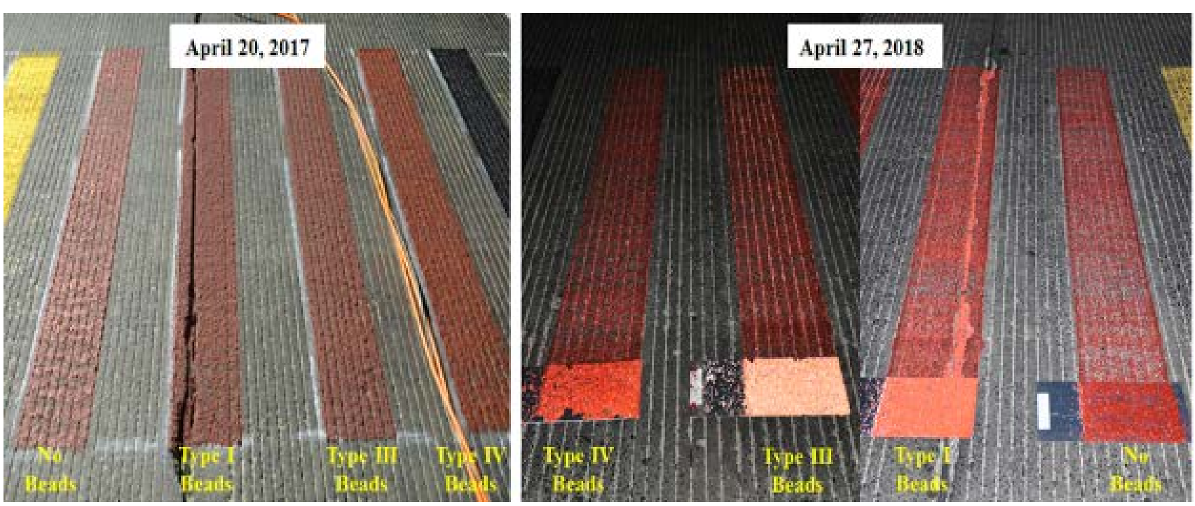


Figure E-23. Red SMMA at EWR—April 2017 (Left) vs April 2018 (Right)

Figure E-24. Black SMMA at EWR—April 2017 (Left) vs April 2018 (Right)