Development and Field Research on Next Generation Coatings for Mussel Mitigation on Infrastructure

Science and Technology Program
Research and Development Office
Final Report No. ST-2021-19196-01
Technical Memorandum No. 8540-2022-56

U.S. Department of the Interior

September 28, 2022

REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*
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1. REPORT DATE ***(DD-MM-YYYY)*** 09-28-2022	**2. REPORT TYPE** Research		**3. DATES COVERED** *(From - To)* October 1, 2019 to September 30, 2022
4. TITLE AND SUBTITLE Development and Field Research on Next Generation Coatings for Mussel Mitigation on Infrastructure		**5a. CONTRACT NUMBER** XXXR4524KS-RR4888FARD1901501 FA994	
		5b. GRANT NUMBER	
		5c. PROGRAM ELEMENT NUMBER 1541 (S&T)	
6. AUTHOR(S) Carter Gulsvig Allen Skaja, Ph.D., Coatings Specialist		**5d. PROJECT NUMBER** 196	
		5e. TASK NUMBER	
		5f. WORK UNIT NUMBER 86-68540	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Materials and Corrosion Laboratory Technical Service Center Bureau of Reclamation U.S. Department of the Interior Denver Federal Center PO Box 25007, Denver, CO 80225-0007			**8. PERFORMING ORGANIZATION REPORT NUMBER** TM No. 8540-2022-56
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Science and Technology Program Research and Development Office Bureau of Reclamation U.S. Department of the Interior Denver Federal Center PO Box 25007, Denver, CO 80225-0007			**10. SPONSOR/MONITOR'S ACRONYM(S)** Reclamation
			11. SPONSOR/MONITOR'S REPORT NUMBER(S) Final Report ST-2021-19196-01
12. DISTRIBUTION/AVAILABILITY STATEMENT Final Report may be downloaded from https://www.usbr.gov/research/projects/index.html			
13. SUPPLEMENTARY NOTES			

14. ABSTRACT

Bureau of Reclamation has been investigating solutions to combat the freshwater invasive quagga and zebra mussels. Reclamation employees at the Technical Service Center began investigating specialized foul-release and anti-fouling coatings, beginning in 2008, as a method to combat the mussels on Reclamation infrastructure. Initial research projects provided insight to what made a coating successful for combatting the mussels. This led to the development of partnerships and material transfer agreements for developing the next generation of foul-release coatings that have improved performance for combatting the mussels, increased durability, and increase service lives.

15. SUBJECT TERMS

Mussel, Mussels, quagga, quagga mussels, zebra mussels, foul-release, specialized coatings, coatings.

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Carter Gulsvig
a. REPORT U	**b. ABSTRACT** U	**THIS PAGE** U		67	**19b. TELEPHONE NUMBER** *(Include area code)* **303-445-2329**

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

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Acknowledgements

The Science and Technology Program, Bureau of Reclamation, sponsored this research. Parker Dam for facilitating the research by providing a field test site.

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prepared by

Technical Service Center
Carter Gulsvig, B.S. Coatings Specialist

Peer Review

Bureau of Reclamation
Research and Development Office
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Final Report ST-2021-19196-01
Technical Memorandum No. 8540-2021-55

CARTER GULSVIG Digitally signed by CARTER GULSVIG Date: 2022.09.28 20:55:58 -06'00'

Prepared by: Carter Gulsvig, B.S.
Coatings Specialist, Bureau of Reclamation, Materials and Corrosion Laboratory Group, 86-68540

SHERRI PUCHERELLI Digitally signed by SHERRI PUCHERELLI Date: 2022.09.29 07:40:00 -06'00'

Checked by: Sherri Pucherelli, M.S.
Biologist, Bureau of Reclamation, Materials and Hydraulic Investigations and Laboratory Group, 86-68560

ALLEN SKAJA Digitally signed by ALLEN SKAJA Date: 2022.09.29 07:29:28 -06'00'

Technical Review by: Allen Skaja, Ph.D.
Protective Coatings Specialist, Bureau of Reclamation, Materials and Corrosion Laboratory Group, 86-68540

JESSICA TORREY Digitally signed by JESSICA TORREY Date: 2022.09.29 10:43:42 -06'00'

Peer Review by: Jessica Torrey, Ph.D., P.E.
Supervisory Civil Engineer, Bureau of Reclamation, Materials and Corrosion Laboratory Group, 86-68540

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Executive Summary

Testing has shown that foul release coatings (FRCs) can be used as a viable means to prevent the fouling of Reclamation structures by quagga and zebra mussels. Commercial products from Jotun, PPG, Hempel, International Paints, NuSil Technologies, Chuguko Marine Paint have shown the best performance in both flowing water and quasi-static conditions. Damage was observed on several of these products in flowing and static water conditions. This suggests that improving durability is still the concern for FRCs. In addition to the previously noted damage, blistering was observed on two of the commercially available products (Intersleek 970 and BioClean) during the July 2022 inspection. This blistering suggests these coatings may be reaching the end of their service life.

Most of the panels coated with experimental formulations provided by North Dakota State University (NDSU) had adequate durability with no erosion or abrasion damage observed. However, these formulations had blistering and disbondment of the topcoat and need to be further developed before they can be recommended for service. Most coatings provided by NDSU also lost their foul release properties as time progressed, allowing increased mussel fouling and/or decreased cleanability. The exception was NDSU formulation C4-20% which prevented mussel fouling in both flowing and static water. The topcoat of formulation 8 was damaged meaning the durability of the coating needs to be improved before it can be recommended for service.

Experimental formulations from both Adaptive Surface Technologies and Pacific Northwest National Laboratories (PNNL) prevented mussel fouling and were easily cleaned. The downside of these formulations was that all of them blistered in two years or less of testing, indicating the coating had some sort of application defect or the barrier properties of it need to be improved and is not providing corrosion protection. A minimum service life of 15 years would be desired for any foul-release coatings used on Reclamation structures. Coating failure in the form of blistering after less than two years indicates these formulations need to be greatly improved to achieve the desired served life.

For Reclamation infrastructure where performance is directly and negatively impacted by mussel fouling, e.g., trashracks, commercially-available foul-release coatings can be used. For specific coating system recommendations, reach out to Reclamation Technical Service Center, Materials and Corrosion Laboratory. None of the experimental formulations evaluated during this research project are recommended for use on Reclamation infrastructure. Further development of the formulations is needed to improve the foul-release properties and barrier properties of the coatings before they can be approved.

1. Background/ Introduction

Quagga and zebra mussels are invasive freshwater mussels that have fouled Reclamation infrastructure. Mussels were first detected in the west at Lake Mead in 2007. Since then, they have spread throughout waters of the Western United States. The mussels adhere themselves on submerged surfaces such as gates, trashracks, small diameter pipes, and intake structures. The buildup of mussels interferes with the operation of hydraulic and hydroelectric equipment. In 2008, Reclamation staff at the Materials Engineering Research Laboratory began evaluating foul release coatings (FRCs) to prevent the attachment of mussels to Reclamation infrastructure. Parker Dam, on the Colorado River, was selected as the field test site for these coatings due to its mussel infestation, high mussel reproductive rates, and easy access to both flowing and quasi-static water conditions for testing.

The majority of commercially available FRCs are designed for marine application such as ship hulls, and were designed to be recoated regularly, with service life not exceeding six years. Due to Reclamation's operation requirements, accessibility to its infrastructure, and limited scheduled outage periods, the desired service life is 15-25 years. More durable FRCs are required to provide foul release properties for this increased service life. In addition, Reclamation's varied service environments, such as varying water quality, cyclic wet-dry immersion, high sediment loading, and variety of debris, require increased durability compared to the FRCs currently on the market.

Since the start of testing FRCs in 2008, over 20 commercial products and over 80 experimental coatings have been evaluated. Products have been installed at different times; the longest tested product was installed in 2009 and the newest tested product was installed in January 2022. Products remain in testing until failure. Failure is defined as the loss of foul-release properties or appearance of coating defects such as blisters. Reclamation has partnered with universities, national labs, and private companies to further develop and test more durable FRCs. Material transfer agreements (MTAs) between Reclamation and other organizations have been signed to test experimental formulations. Experimental formulations were applied to 3x 6x1/8th inches steel coupons and zip-tied to a test rack to place in flowing water or zip-tied to suspension ropes to place in quasi-static water.

In addition to evaluating both commercial products and experimental formulations, this research included a nine-year visual inspection of a trashrack coated with FRCs. A previous research project, Science and Technology project 5270 "Foul Release Coatings Scale up Testing – Parker Dam Trashrack," performed a scale-up study to evaluate the durability of four FRCs that had good foul release results in initial testing. This scale up was completed on a single trashrack panel at Parker Dam. The coatings on the trashrack were exposed to debris that collects on the trashrack, as well as scraping and abrasion from the trash rake. The scaled-up trashrack was installed in 2013. A GoPro camera was attached to the trash rake and used to record video of the trashrack panel during an inspection in 2015. This same method was used during the January 2022 inspection to collect new video footage of the coatings on the trashrack.

A list of all previous research projects investigating mussels and solutions to mitigate them are outlined in Table 1. This research project focused on improving the mechanical properties of experimental formulations to obtain a more durable FRC. In addition to this, the research continued evaluation of commercially available products from previous research projects.

Table 1: Previous mussel research projects by USBR.

Project Title	Year(s)	Report Number
Mussel Adhesion Mechanism	2011	MERL-2011-21
Investigation of Molybdenum and Tungsten Disulfide for Mussel Control	2011	MERL-2011-37
Overcoating Coal Tar Enamel using FRC	2011	MERL-2011-41
Natural Biocides for Zebra and Quagga Mussel Control	2011	MERL-2011-46
Advanced Review of Mussel Adhesion	2013	MERL-2013-43
Durable FRC	2012-2013	MERL-2014-57
FRC Scale-up Testing – Parker Dam Trashrack	2008-2015	ST-2015-7095-01
Durable Silicone FRC CRADA	2014-2016	ST-2016-0809-01 / 8540-2016-02
Continuation of Field Evaluations on Advance Coatings for Mussel Control	2015-2018	ST-2018-7089-01

2. Experimental Procedure

2.1 Preparation of Test Samples

In this research, twelve commercially-available coatings were tested and two commercially-available products were installed. Experimental formulations were also tested from NDSU, PNNL, and Adaptive Surface Technologies. These products were tested through material transfer agreements (MTA).

2.1.1 Surface Preparation and Application of Commercially-Available Products

Products were applied to an 18 in. x 30 in. steel floor grate and three 12 in. x 12 in. x 1/8 in. steel plates. Surface preparation of the samples consisted of removing oil and contaminants by detergent cleaning following SSPC-SP1. Once panels were cleaned, they were abrasive blast cleaned to SSPC-SP 5/NACE 1 with an angular profile of 3.5 mils. Coatings were applied in accordance with coating manufacturers' instructions by Reclamation staff. If the coating systems could not be applied by Reclamation staff, cleaned and abrasive blasted steel samples were provided to the manufacturer or researching organization to apply the coating. The only exception of this was Propspeed who supplied Reclamation with coated 3 in. x 6 in. aluminum. coupons.

2.1.2 Surface Preparation and Application of MTA Experimental Formulations

Experimental formulations tested under MTAs were applied and tested on 3 in. x 6 in. x 1/8 in. steel coupons. Surface preparation of the coupons consisted of removing oil and contaminants by detergent cleaning following SSPC-SP1. Once panels were cleaned, they were abrasive blast cleaned to SSPC-SP 5/NACE 1 with an angular profile of 3.5 mils. The clean steel was shipped to the research partnering organization who applied the coatings. The coated coupons were returned to Reclamation for testing.

2.1.3 Surface Preparation and Application of Scale-up Trashrack

A single trashrack grate designed for the trashrack pier at Parker Dam was fabricated and shipped to the Materials Engineering Research Laboratory in Reclamation. Staff prepared the steel trashrack by solvent cleaning following SSPC-SP1 and then abrasive blast cleaned it to SSPC-SP5/NACE 1 with an angular profile of 3.5 mils. The four products were applied in accordance to manufacturer recommendations. A further detail procedure of the surface preparation and coating application of the scale-up trashrack can be found in report *ST-2015-7095-01: FRC Scale-up Testing – Parker Dam Trashrack*.

2.2 Coating Performance Evaluation

Commercially available products and experimental formulations were evaluated using three rating criteria. The first was the coating's ability to prevent mussel attachment. This was done by approximating the percentage of the test sample covered by mussels. The second criterion was the cleanability of the coating, i.e., how easily the mussels could be removed. A force gauge was used to measure the force required to remove a single mussel. If the test specimen was too fouled, then the researcher cleaning the sample recorded qualitatively how easy it was to clean. The scale consisted of, easily cleaned, light force to clean, moderate force to clean, and heavy force to clean. The third criterion for rating was the overall condition of the coating sample. The coatings were evaluated for any defects such as abrasion, erosion, blistering, or delamination and any indication of corrosion product on the substrate was noted.

The scale-up trashrack was evaluated for its ability to prevent mussel attachment and the condition of the coating. These two rating criteria were done by reviewing video footage that was taken of the trashrack since it is too large and difficult to easily remove for testing.

2.3 Testing Facility

All field testing took place at Parker Dam on the Colorado River, at Lake Havasu Reservoir on the Arizona and California border. Parker Dam facility contains a large forebay area with a trashrack bridge structure that spans the entire forebay opening, Figure 1. This study tested panels in flowing water conditions (dynamic) suspended from the downstream side of this trashrack structure, as well as quasi-static conditions at the upstream face of the dam. During the July 2022 inspection, large growths of Cordylophora Caspia (colonial hydroid) were present on several of the panels. These have a similar appearance to algae.

Figure 1: Ariel view of Parker Dam. Yellow line is the flowing water test location downstream of the trashracks. Red line is location of quasi-static water flow testing on the side of the dam.

3. Results and Discussion

3.1 Commercially Available Products

Testing of commercially available foul-release and anti-fouling coatings from various manufacturers began in 2008. A total of fourteen products were tested. Two of the products were installed during this research project, 2019-2022, and twelve of the products were installed during previous research projects. Table 2 is a list of the current commercially available coatings in testing for all manufacturers, the year they were installed, and their results from the July 2022 inspection.

Table 2: All commercially available products in testing at Parker Dam during the July 2022 inspection.

Manufacturer	Coating System	Type of Coating	Installation	Years in Service	% Fouled: Dynamic	% Fouled: Quasi-Static	Cleanability	Coating Condition
Propspeed	Propspeed	Soft Silicone Biocide Free	January 2022	0.5	0%	0%	N/A	Coating in good condition
Jotun	SeaLion Repulse	Soft Silicone Nano Technology Biocide Free	May 2013	9.5	0%	0%	Easily cleaned	Covered with hydroid Areas of small damage of missing coating on grate
Jotun	SeaLion Resilient	Epoxy-silicone Hybrid Biocide Free	May 2013	9.5	90%	60%	Light force to clean	Top coat delaminating on dynamic grate.
Silicone Solutions	F23	Biocide-Free Soft Silicone	December 2014	8	<5%	0%	Easily cleaned	Coating in good condition
Silicone Solutions	5000	Clear Rubber Polydimethylsiloxane Biocide Free	December 2014	8	0%	100%	Light force to clean	Coating in good condition
Silicone Solutions	SS-3000	Silicone Rubber Biocide Free	December 2014	8	25%	95%	Light force to clean	Coating in good condition
Nusil Technologies	NuSil 9707	Silicone Biocide Free	May 2012	10.5	0%	0%	Easily cleaned	Grate covered in hydroid
PPG Industries	Sigmaglide 890	Silicone Biocide Free	October 2009	13	0%	0%	Easily cleaned	Grate covered in hydroid Corrosion present on side of grate

Manufacturer	Coating System	Type of Coating	Installation	Years in Service	% Fouled: Dynamic	% Fouled: Quasi-Static	Cleanability	Coating Condition
								Damage to topcoat of grate
PPG Industries	Sigmaglide 1290	100% Silicone Biocide Free	January 2019	3.5	0%	0%	N/A	Coating in good condition
International Paints	Intersleek 970	Fluorinated Silicone Biocide Free	May 2008	14	0%	0%	N/A	Damaged and missing coating on grate Blisters on static plates
International Paints	Intersleek 1425	Silicone Biocide Free	December 2012	10	0%	0%	N/A	Coating in good condition
CMP BioClean	Bioclean	High Solids Silicone Biocide Free	October 2009	13	0%	0%	Easily cleaned	Grate covered with hydroid Blisters on static plates
Hempel	Hempasil X3	Soft Silicone Hydrogel Micro-layer Biocide Free	December 2012	10	0%	0%	Easily cleaned	Small spots missing coating on grate Abrasion damage from rope on one static plate
Z-Alloy, Inc.	Z-Alloy	Copper Alloy fish screen	May 2015	7.5	0%	0%	N/A	Coating in good condition

3.1.1 Popspeed

Propspeed is a biocide-free foul-release coating system designed to be used on running gear for marine craft. This system is compatible with and can be applied to most metal surfaces including steel, aluminum, and bronze. Testing for this system began in January 2022. After six months of testing, all panels were in good condition with no fouling occurring in both dynamic and quasi-static water conditions, shown in Figure 2 and Figure 3. No defects such as blisters, delamination, or missing coating were observed.

Figure 2: Propspeed panels on experimental rack for dynamic testing prior to January 2022 installation.

Figure 3: Propspeed after six months in dynamic testing condition. Some accumulation of the colonial hydroid on surface. Mussels are attached to zip ties and not adhered to coated surface.

3.1.2 Jotun

Jotun has two products in testing. Product one, Sealion Repulse, is a soft-silicone coating that is biocide free. The coating system utilizes nanotechnology to create the surface properties that provide foul release. This system was installed in 2013 and remains effective in preventing mussel attachment with zero mussel fouling in both flowing and static water conditions shown in Figure 4 and Figure 5. The test grate in flowing water did have an accumulation of the colonial hydroid on the surface during the July 2022 inspection, shown in Figure 6, but was easily cleaned. During the January 2022 inspection, it was observed that minor damaged had occurred to the coating on the flowing test grate shown in Figure 7 and Figure 8. The damage was primarily on the upstream side of the grate. During the 2022 inspections it was observed that the static test panels had light fouling on the bottom edge of the panels where the coating had become damaged and/or missing. This damage was likely caused by the scrapping of the panels on the dam as they were pulled and reinstalled during inspections for data collection. Damage could also be caused by nearby flowing water causing the panels to move and rub against the dam during testing. Figure 5 shows the light fouling on the damaged areas of the static test panels.

Figure 4: Jotun Sealion Repulse flowing water test grate during January 2022 inspection. No fouling except for areas of damaged coating.

Figure 5: Quasi-static test plates for Jotun Sealion Repulse. Fouling only on edges due to damaged coating.

Figure 6: Jotun Repulse during July 2022 inspection with accumulation of colonial hydroid on surface of grate.

Figure 7: Damage on upstream side of Jotun Sealion Repulse test grate.

Figure 8: Abrasion style damage of Jotun Sealion Repulse test grate.

The second coating system, Sealion Resilient, is an epoxy-silicone hybrid coating and is classified as a durable foul-release coating. This system was also installed in 2013. Since 2019 the test grate in flowing water has been completely fouled during all inspections as shown in Figure 9. The mussels are easily cleaned off the surface and the grate was cleaned during each inspection before being placed back into testing. Between the January 2022 and July 2022 inspection, the test grate in flowing water lost some of its foul-release properties. The grate was slightly less fouled in July, as seen in Figure 10, but required a light force to clean. Results were similar for the test plates in static water testing. Panels were approximately 60% fouled, shown in Figure 11 and Figure 12, and required a light force to clean.

During an inspection in 2014 it was observed that the topcoat was delaminating on the dynamic test grate. Figure 13 and Figure 14 which were taken during the January 2022 inspections, but no corrosion was present. This defect only seemed to affect the topcoat of the coating system until the inspection in July 2022 when some of the primer had become exposed shown in Figure 15. No corrosion was present at any of the damaged areas during the July 2022 inspection.

Figure 9: Jotun Sealion Resilient During 2019 inspection. 100% fouled before cleaning (left) and partially cleaned (right).

Figure 10: Jotun Sealion Resilient during July 2022 inspection with large amounts of colonial hydroid and mussel fouling.

Figure 11: Jotun Sealion Resilient quasi-static test plates with mussel and sponge organism fouling during January 2022 inspection.

Figure 12: Jotun Sealion Resilient static test plates during July 2022 inspection with the surface partially fouled with mussels.

Figure 13: Damage to *Jotun* Sealion Resilient with topcoat flaking off.

Figure 14: Piece of topcoat of *Jotun* Sealion Resilient that has flaked off.

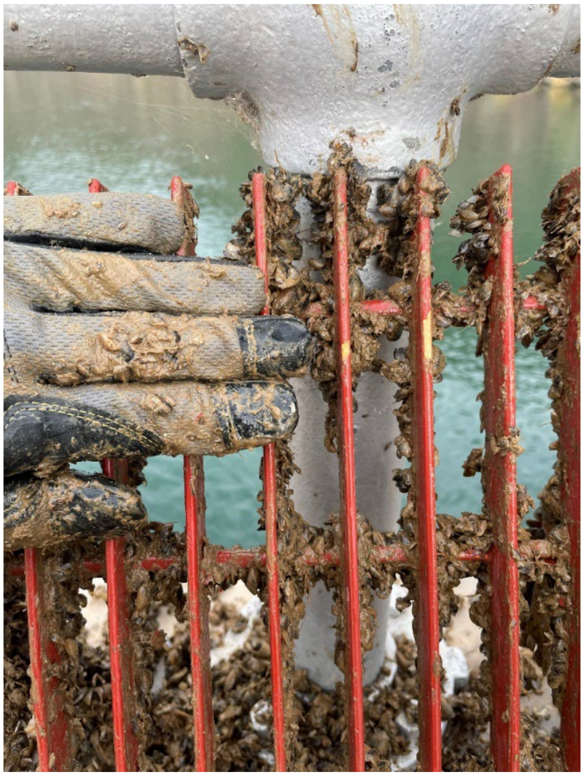

Figure 15: Damage in the upstream side of the Jotun Resilient exposing primer during July 2022 inspection.

3.1.3 Silicone Solutions

Silicone Solutions provided three products for evaluation and all three were installed in 2014. The first product, F-23, is a biocide-free soft silicone and has had the best performance of the three products from Silicone Solutions. During the 2019 site visit the dynamic test grate was approximately 50-55% fouled but easily cleaned; and during the January 2022 inspection the grate was less than 5% fouled on the surface as seen in Figure 16. During the July 2022 inspection the grate was covered with the colonial hydroid and had less than 5% mussel fouling, shown in Figure 17. In static testing F-23 had zero fouling during both the January and July 2022 inspection, shown in Figure 18.

Figure 16: Top and side view of Silicone Solutions F-23 during January 2022 inspection.

Figure 17: Top and side view of Silicone Solutions F-23 during July 2022 inspection. Minimal fouling of mussels but covered with

Figure 18: Silicone Solutions static test plates: F-23 (left), SS3000 (middle), and 5000A (right).

During the January 2022 inspection the second product from Silicone Solutions, 5000A was approximately 85% fouled, seen in Figure 19, and required a light force to clean. In static testing product 5000A also had similar results with 95% of the surface fouled and a light force was required to remove the mussels. This suggests the coating is beginning to lose some of its foul release properties. The dynamic test grate was approximately 25% fouled with mussels and 100% covered with the colonial hydroid during the July 2022 inspection, Figure 20. The grate did require a light force to remove the mussels, further supporting the claim that the coating is losing its foul-release properties. In static testing the plate was 95% fouled with mussels and required a light force to clean.

Figure 19: 5000A dynamic test grate during heavily fouled with mussels during January 2022 inspection.

Figure 20: Silicone Solutions 5000A dynamic test grate during July 2022 inspection. Part of the grate is densely fouled with mussels and the remainder of the grate is fouled with mussels and the colonial hydroids.

Product SS3000 is a silicone rubber and was only tested in static conditions. The test plate was 90% fouled during both 2022 inspections. However, the surface was easily cleaned displaying the coating still retained good foul-release properties.

3.1.4 NuSil 9707

NuSil 9707 is a product form NuSil Technologies that was installed for testing in 2012. This product has retained its foul-release properties and during both the January and July 2022 inspections the coating was free of mussel fouling for both flowing and static test samples. During the January inspection both the test grate and plates were fouled with a sponge organism. This was not present during the July 2022 inspection, but the test grate was completely covered in the colonial hydroid. All of the fouled material was easily cleaned from the surface. Figure 21 through Figure 24 show the samples during the 2022 inspections. During the July 2022 inspection corrosion was observed on one side of the test grate, as shown in Figure 25. This is likely from the coating becoming damage during testing and making contact with the concrete structure of the trashrack pier.

Figure 21: NuSil 9707 test grate during January 2022 inspection. Grate is fouled with sponge organism but no mussels.

Figure 22: NuSil 9707 static plates during January 2022 inspection. Surface is fouled with sponge organism and mussel fouling is only at edges where coating is damaged.

Figure 23: NuSil 9707 test grate during July 2022 inspection. Surface is 100% covered with colonial hydroid but no mussel fouling.

Figure 24: NuSil 9707 static plates during July 2022 inspection. Surface is free of fouling except for edges where coating is damaged.

Figure 25: Corrosion present on edge of NuSil 9707 test grate, likely from damage.

3.1.5 PPG Industries

Both coating products from PPG are silicone-based coatings that are biocide-free. Sigmaglide 890 was installed in testing in 2009 and is one of the coating systems that has been in testing the longest. Even as one of the longest exposed samples, it has retained its foul release properties with only 5% mussel fouling on the dynamic test grate and prevented fouling on the static test plates for the duration of testing as shown in Figure 26 and Figure 27. Figure 28 shows the static test plate during the July 2022 inspection which had no mussel fouling and the majority of the sponge organism fouling observed during the January 2022 inspection was gone. The dynamic test grate was completely covered with the colonial hydroid at the July 2022 inspection but no mussel fouling was observed and the hydroid was easily cleaned. Figure 29 shows the Sigmaglide 890 grate before and after cleaning. During the July 2022 inspection, missing and coating damage was observed on the dynamic test grate, shown in Figure 30.

Sigmaglide 1290, installed in July 2019, had good results through to the July 2022 inspection. The dynamic test grate did not have any fouling during the January and July 2022 inspections as Figure 31 and Figure 32 show. The static test plates also had the same results with no fouling present during both 2022 inspections. Figure 33 and Figure 34 show the static test plates and some early-stage damage to the coating can be observed at the edges.

Figure 26: Sigmaglide 890 during January 2022 inspection. Surface is lightly fouled with mostly a sponge organism and minimal mussel fouling.

Figure 27: Static test plates Sigmaglide 890. Fouled with sponge organism over most of the surface and one plate is stained with a dark color from an unknown source.

Figure 28: Static test plates Sigmaglide 890. Little fouling from sponge organism and no mussel attachment.

Figure 29: Before and after cleaning photos of Sigmaglide 890 dynamic test grate during July 2022 inspection. No mussel fouling but surface covered in colonial hydroid.

Figure 30: Damage and missing coating observed on edge of Sigmaglide 890 grate during July 2022 inspection.

Figure 31: Sigmaglide 1290 after 1.5 years in flowing water during January 2022 inspection.

Figure 32: Sigmaglide 1290 dynamic test grate after 2 years in field testing during July 2022 inspection.

Figure 33: Sigmaglide 1290 after 1.5 years in quasi-static water conditions.

Figure 34: Sigmaglide 1290 static plates after 2 years of testing. There is no mussel fouling.

3.1.6 International Paints

Two products were tested by International Paints, Intersleek 970 and Intersleek 1425. Intersleek 970 was installed in 2008 and is currently the oldest coating still in testing. This is a three-component fluorinated silicone. Intersleek 970 has continued to display foul release properties in both dynamic and static testing. All International Paint samples had no fouling for all inspections during this project as shown in Figure 35 through Figure 40. These results indicate that Intesleek

970 continues to retain its foul release properties. During the January 2022 inspection, small areas of chipped and missing coating were observed on the upstream side of the dynamic test grate seen in Figure 38 and Figure 39. It was also observed that the coating at the edges on the static test plates were damaged as well. These areas of damaged or missing coatings allowed for mussel attachment. At the July 2022 inspection, blisters were observed along the top edge of both static test plates which are shown in Figure 40 and Figure 41.

Figure 35: Intersleek 970 after 14 years of testing and no fouling.

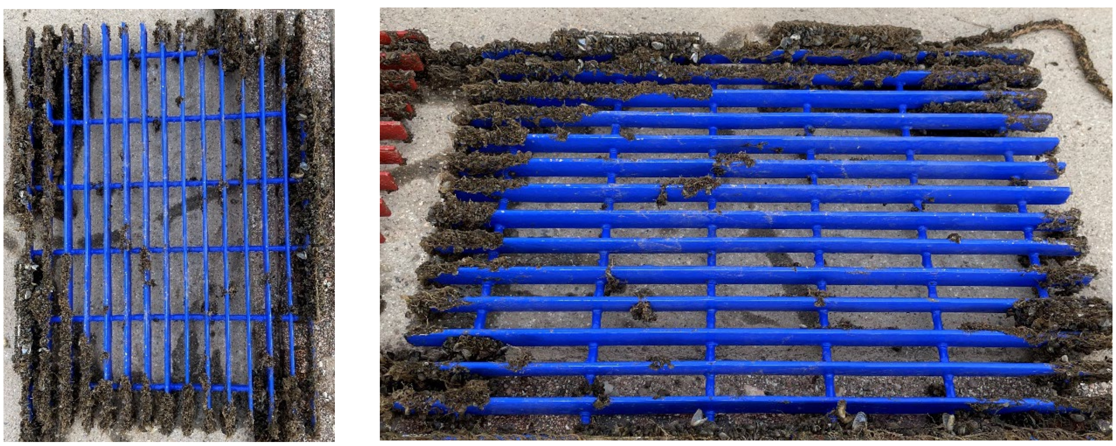

Figure 36: Intersleek 970 test grate during July 2022 inspection. Mussels have attached to around the edge where the coating has become damaged or is missing. Where the coating is intact there is no damage to the coating.

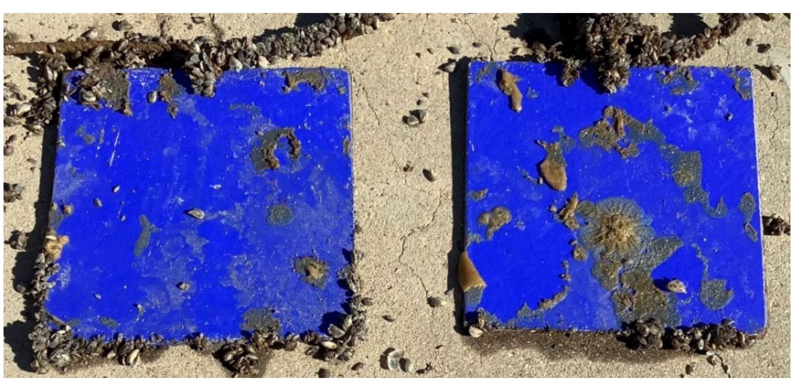

Figure 37: Intersleek 970 test plates lightly fouled with sponge organism and around edges due to damage during 2019.

Figure 38: Damage to flowing water Intersleek 970 test grate in the form of small chips.

Figure 39: Damage to Intersleek 970 test grate on the edge of the grate, observed during January 2022 inspection.

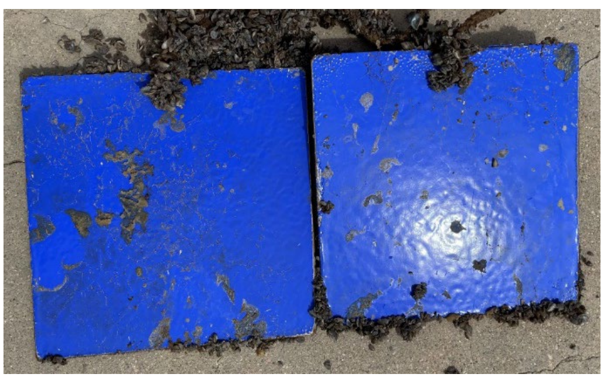

Figure 40: Intersleek 970 during July 2022 inspection. Static plates had no fouling of mussels.

Figure 41: Intersleek 970 static plates during the July 2022 inspection with blistering observed around the edges.

Intersleek 1425, is International Paints' second product, and was installed in 2012. This product was only tested in static conditions during this project due to the dynamic test grate being lost during a previous inspection. The results have continued to be good for Intersleek 1425 with no mussel fouling during the January 2022 and July 2022 inspection as seen in Figure 42 and Figure 43.

Figure 42: Intersleek 1425 quasi-static test panels with two panels being slightly fouled with sponge organism during January 2022 inspection.

Figure 43: Intersleek 1425 quasi-static test plates. No mussel fouling and small amounts of sponge and hydroid present during July 2022 inspection.

3.1.7 BioClean

Chugoku Marine Paint (CMP) Bioclean was installed in 2009 and has continued to retain foul release properties. During the January 2022 inspection the both the dynamic and static test grates were less than 5% fouled as shown in Figure 44 and Figure 45. All fouling was easily cleaned from the surface. The dynamic test grate and static plates had the same results during July 2022 inspection. Note the sponge was removed by slight water flow on the static test plates between January and July inspections. However, the dynamic test grate which was 100% covered with the colonial hydroid, was easily cleaned as shown in Figure 47. No damage was observed on the dynamic test grate but blisters were observed at the bottom of one of the static test plates during the July 2022 inspection which is shown in Figure 48.

Figure 44: BioClean flowing water test grate during January 2022 inspection. Light fouling of sponge organism and mussels.

Figure 45: BioClean quasi-static test panels that are slightly fouled with both mussels and sponge organism during January 2022 inspection.

Figure 46: BioClean static test plates during July 2022 inspection.

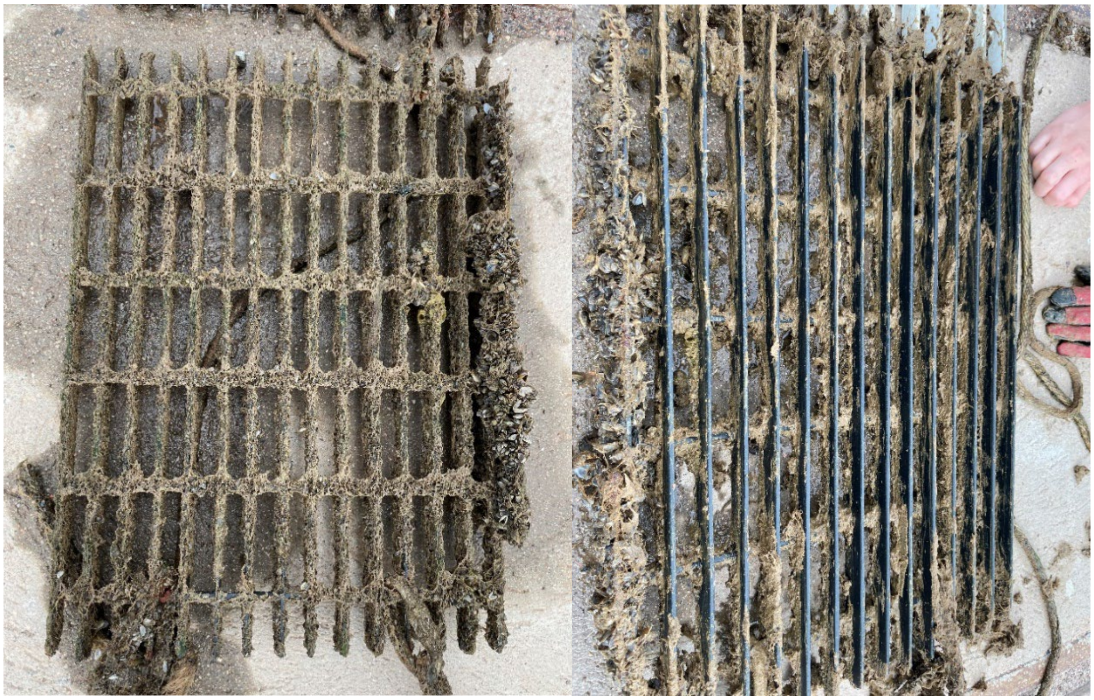

Figure 47: BioClean test grates before and after cleaning during July 2022 inspection.

Figure 48: Blister on bottom of BioClean static plate which were observed during July 2022 inspection.

3.1.8 Hempel

Hempel has one product in testing which was installed in 2012. Hempasil X3 has continued to retain its foul release properties over the duration of testing. Both the static and dynamic test samples had 5% or less fouling during the January inspection shown in Figure 49 and Figure 50. . Both the test grate and plates had similar results during the following inspection during July 2022 with the exception of the dynamic test grate being covered in the colonial hydroid as seen in Figure 51 and Figure 52. Any fouling that occurred was easily cleaned for all inspections. During the January 2022 inspection, damage was observed on the upstream side of the dynamic test grate as shown in Figure 53. This damage did not appear to worsen when inspected at the following inspection. The static test plates also had coating damage around the edges of the plates caused by abrasion from rubbing on the dam. During the July 2022 inspection, new rope damage to one of the static plates was evident. The damage presented itself as missing coating down the middle of one plate that likely caused by abrasion from the rope, shown in Figure 52.

Figure 49: Hempel X3 test grate that is fouled with some mussels and sponge organism during January 2022 inspection.

Figure 50: Hempel X3 Quasi-static test plates with fouling around damaged edges and fouled with sponge organism during January 2022 inspection.

Figure 51: Hempel X3 dynamic test grate, covered in colonial hydroid, before and after cleaning during July 2022 inspection.

Figure 52: Hempel X3 static test plates during July 2022 inspection. One plate appears to have abrasion damage in the center of the plate caused by the rope it suspends from.

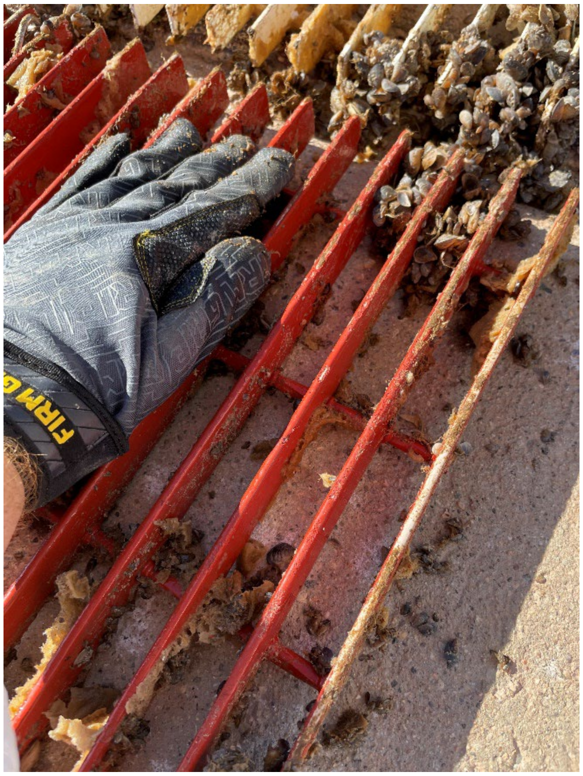

Figure 53: Damage to Hempel X3 flowing water test grate taken during July 2022 inspection.

3.1.9 Z Alloy

Z Alloy is a fish screen made from a copper alloy. This was the only antifouling system that was evaluated. It was installed in 2015. This product was only evaluated in dynamic water conditions. All fouling appeared to be localized to the zip-ties that were securing the test screen to a larger test grate and there was no fouling on the Z-alloy fish screen during both 2022 inspections. Figure 54 and Figure 60 show the test sample and the fouling on the zip-ties.

Figure 54: Z-Alloy fish screen during January 2022 inspection. All fouling appeared to be attached to zip-ties securing screen to larger test grate.

Figure 55: Z-Alloy fish screen at July 2022 inspection. All fouling is on zip-tie securing the sample.

3.2 Experimental Formulations

Reclamation has signed material transfer agreements for testing experimental products from both universities and private companies. Three MTAs were signed or continued during this research project.

3.2.1 North Dakota State University

Reclamation and North Dakota State University entered a MTA in 2012 with the purpose of developing a more durable silicone foul release coating. A total of nineteen formulations have been tested during this MTA. Table 3 lists the thirteen formulations that were tested during this research project. During the January 2022 inspection all NDSU formulations were removed from testing and sent back to NDSU for internal evaluation at the request of NDSU.

Table 3: List of formulations provided by NDSU and tested at Parker Dam.

Coating System	Installation	Years in Service	% Fouled: Dynamic	% Fouled: Quasi-Static	Cleanability	Coating Condition
C10	December 2012	9	0%	70%	Light to moderate force	Coating in good condition
C20	December 2012	9	<5%	80%	Light force	Coating in good condition
C4-20%	August 2014	7.5	15%	0%	Easily cleaned	Coating in good condition
SO-PMM-0021	August 2014	7.5	50%	0%	Easily cleaned	Coating in good condition
NDSU 1	July 2017	4.5	60%	80%	Light force to moderate force	Coating in good condition
NDSU 2	July 2017	4.5	65%	70%	Light Force	Panel bent, coating cracked at bend (Quasi-static)
NDSU 3	July 2017	4.5	55%	80%	Light Force	Topcoat delaminated (Dynamic)
NDSU 4	July 2017	4.5	80%	50%	Light Force	Coating in good condition
NDSU 5	July 2017	4.5	75%	60%	Light Force	Blistered (Quasi-static)
NDSU 6	July 2017	4.5	Missing	80%	Light force	Coating in good condition
NDSU 7	July 2017	4.5	80%	50%	Easily to light force	Coating in good condition

Coating System	Installation	Years in Service	% Fouled: Dynamic	% Fouled: Quasi-Static	Cleanability	Coating Condition
NDSU 8 IS970	July 2017	4.5	0%	0%	Easily cleaned	Fouled with a sponge organism
NDSU 9 BRA 640	July 2017	4.5	70%	0%	Easily cleaned	Top coat is damaged. Spots of missing coating (Dynamic)

NDSU 8, C20, and C4-20% had the best results in flowing water testing. These formulations had little to no fouling and were easily cleaned. Figure 56 through Figure 59 show the dynamic panels for NDSU 8 and NDSU 9 formulations. NDSU 8 had blisters form and NDSU 9 is damaged with some of the topcoat missing. The other noticeable observation during the January 2022 inspection was a large section of topcoat on NDSU 3 had delaminated in as a single piece shown in Figure 60 through Figure 62.

NDSU 1 through NDSU 7 had different degrees of fouling in flowing water tests which are listed in Table 3 and are shown in Figure 63 and Figure 64. NDSU 1 through NDSU7 formulations required a light force to clean. It is important to note that NDSU 6 was lost during the test duration between July 2019 and January 2022 and was unable to be evaluated. When the panels were removed during the July 2022 inspection, formulations SO-PMM-0021 and C4-20% still displayed foul-release properties. The coatings did allow for some mussel fouling but were easily cleaned. Formulation C20, shown in Figure 65, had lost some of its release properties and required a light force to remove attached mussel.

NDSU 9 was the only formulation to prevent fouling in static testing. The back side of the panel had become damaged with part of the topcoat missing, allowing for mussel attachment as shown in Figure 66. All other formulations did not prevent mussels from adhering to the surface and 50% to 80% of the surfaces were fouled; requiring a light force to clean the surfaces. Figures 67 through Figure 71 show NDSU formulations during testing. Blisters were observed on the surface of NDSU 5 in static testing.

Figure 56: NDSU 8 (left) NDSU 9 (right) test panels in dynamic conditions. NDSU 8 remained free of fouling since the January inspection. NDSU 9 was fouled but easily cleaned. NDSU 9 also had some damage to the topcoat.

Figure 57: NDSU 8 in flowing conditions during January 2022 covered in sponge organism.

Figure 58: Blisters on NDSU 8 flowing water panel during January 2022 inspection.

Figure 59: Close up of damage on NDSU 9 dynamic panel after cleaning during January 2022 inspection.

Figure 60: NDSU 3 (left) and NDSU 2 (right) in dynamic testing conditions January 2022 inspection.

Figure 61: NDSU 3 panel where large portion of topcoat has delaminated in one piece.

Figure 62: Delaminated topcoat from NDSU 3. Blisters can be seen in the film.

Figure 63: NDSU 1 dynamic testing results January 2022 inspection.

Figure 64: NDSU 7 (left), NDSU 5 (middle), and NDSU 4 (right) in dynamic testing conditions. NDSU 6 was lost during testing and one panel of NDSU 7 was lost also.

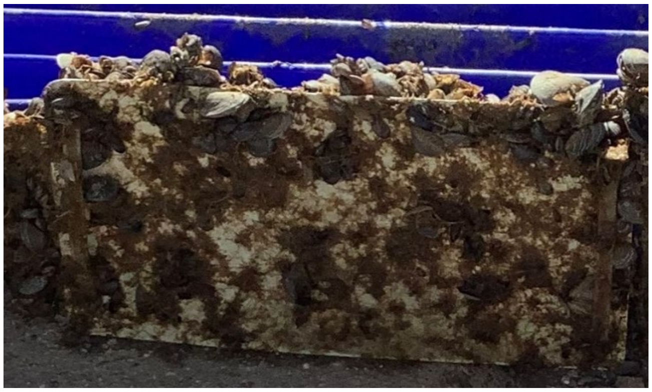

Figure 65: NDSU C20 dynamic conditions.

Figure 66: NDSU 9 quasi-static plate with damaged backside allowing for mussel fouling.

Figure 67: NDSU 1 static panels.

Figure 68: NDSU 1 static panels after being cleaned.

Figure 69: NDSU 3 static test panel completely fouled January 2022 inspection.

Figure 70: NDSU 4 (left two panels) and NDSU 5 (right two panels) in static testing conditions January 2022 inspection.

Figure 71: NDSU 6 (left two panels) and NDSU 7 (right two panels) in static conditions January 2022 inspection.

3.2.2 Adaptive Surface Technologies

Adaptive Surface Technologies and Reclamation entered into an MTA in 2019. A total of seven formulations were provided for testing which are listed in Table 4 below.

Table 4: Adaptive Surface Technologies formulations in testing results from July 2022 inspection.

Coating System	Panel Number	% Fouled: Dynamic	% Fouled: Quasi-Static	Cleanability	Coating Condition
Adaptive Surface A	1	80	N/A	Light force to clean	Blistering around edges
Adaptive Surface A	2	80	N/A	Light force to clean	Blistering around edges. Some corrosion present around edges
Adaptive Surface A	3	35	N/A	Light force to clean	Blistering around edges. Some corrosion present around edges
Adaptive Surface A	4	30	N/A	Light force to clean	Blistering around edges
Adaptive Surface A	5	30	N/A	Light force to clean	Blistering around edges
Adaptive Surface B		15	N/A	Easily cleaned	Blistering around edges
Adaptive Surface B	2	15	N/A	Easily cleaned	Blistering around edges
Adaptive Surface B	3	15	N/A	Easily cleaned	Blistering around edges
Adaptive Surface B	4	15	N/A	Easily cleaned	Blistering around edges
Adaptive Surface B	5	15	N/A	Easily cleaned	Blistering around edges
Adaptive Surface C	1	40	N/A	Light force to clean	Blistering around edges

Coating System	Panel Number	% Fouled: Dynamic	% Fouled: Quasi-Static	Cleanability	Coating Condition
Adaptive Surface C	2	80	N/A	Light force to clean	Blistering around edges
Adaptive Surface C	3	40	N/A	Light force to clean	Blistering around edges
Adaptive Surface C	4	85	N/A	Light force to clean	Blistering around edges
Adaptive Surface C	5	55	N/A	Light force to clean	Blistering around edges
Adaptive Surface D	1	85	N/A	Light force to clean	Blistering around edges
Adaptive Surface D	2	20	N/A	Light force to clean	Blistering around edges
Adaptive Surface D	3	30	N/A	Light force to clean	Blistering around edges
Adaptive Surface D	4	15	N/A	Light force to clean	Blistering around edges
Adaptive Surface D	5	30	N/A	Light force to clean	Blistering around edges
Adaptive Surface E	1	<5	N/A	Light force to clean	Blistering around edges
Adaptive Surface E	2	<5	N/A	Light force to clean	Blistering around edges
Adaptive Surface E	3	<5	N/A	Light force to clean	Blistering around edges
Adaptive Surface E	4	<5	N/A	Light force to clean	Blistering around edges

Coating System	Panel Number	% Fouled: Dynamic	% Fouled: Quasi-Static	Cleanability	Coating Condition
Adaptive Surface E	5	<5	N/A	Light force to clean	Blistering around edges
Adaptive Surface F	1	100	N/A	Light force to clean	Blistering around edges
Adaptive Surface F	2	100	N/A	Light force to clean	Blistering around edges
Adaptive Surface F	3	100	N/A	Light force to clean	Blistering around edges. Some corrosion present around edges
Adaptive Surface F	4	100	N/A	Light force to clean	Blistering around edges. Some corrosion present around edges
Adaptive Surface F	5	100	N/A	Light force to clean	Blistering around edges.
Adaptive Surface G	1	10	N/A	Light force to clean	Blistering around edges
Adaptive Surface G	2	15	N/A	Light force to clean	Blistering around edges
Adaptive Surface G	3	10	N/A	Light force to clean	Blistering around edges
Adaptive Surface G	4	10	N/A	Light force to clean	Blistering around edges
Adaptive Surface G	5	15	N/A	Light force to clean	Blistering around edges

Adaptive Surface Technologies' formulations were only tested in dynamic water conditions. The January 2022 inspection was the first time the test panels were inspected since they were installed in July 2019. During that inspection it was observed that six out of the seven formulations had some degree of blistering around the edges of the panels. Formulations A, B, C, D, F, and G were blistered and had some degree of fouling ranging from 5 percent fouled up to 70 percent fouled. Formulation E was the only set of panels that was not blistered and was not fouled.

During the July 2022 inspection, Formulation E continued to have the best performance out of the experimental systems from Adaptive Surface Technologies. This formulation prevented most fouling, and any fouling present was easily cleaned. Formulation E and all other formulations had blisters form around the edges indicating application defects or the coating has poor barrier properties and corrosion prevention. All formulations, except Formulation E, allowed for mussel fouling to occur to varying degrees ranging from 15% up to 100% of the surface being fouled. System B was the only other formulation that was easily cleaned. The other systems, A, C, D, G, and F, all lost some of their foul release properties from the previous inspection and did require a light force to remove the mussels. Two panels from each system were removed from testing and were shipped back to Adaptive Surface Technologies for internal evaluation. Three panels from each set remained in testing for another data point collection. Figure 72 through Figure 87 show the formulations in and after removal from testing.

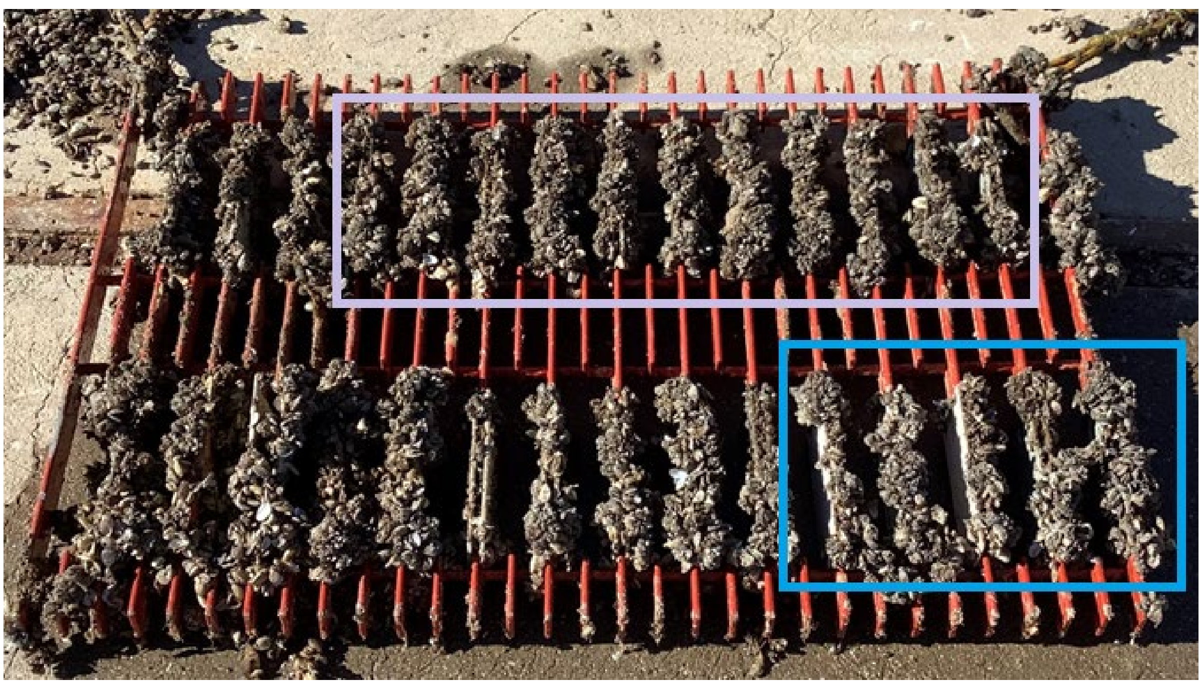

Figure 72: Experimental Test Rack during January 2022 inspection. Adaptive Surface Technologies' panels are outlined in the colored boxes. Formulation A, B, C, and D are on the top row and formulations E, and G are on the bottom row.

Figure 73: From left to right Formulation A, B, and C with various degrees of fouling during July 2022 inspection.

Figure 74: From left to right formulations B, C, and D with different degrees of fouling during July 2022 inspection.

Figure 75: Formulation E (left) and formulation G (right) prior to cleaning of mussels during July 2022 inspection.

Figure 76: From left to right Formulation A, B, and C with various degrees of fouling during July 2022 inspection.

Figure 77: Formulation E after cleaning during July 2022 inspection.

Figure 78: Formulation E and G after cleaning during July 2022 inspection.

Figure 79: Formulation F during July 2022 inspection.

Figure 80: Formulation F panels after cleaning during July 2022 inspection.


Figure 81: Adaptive Surface Technologies' Formulation A after removal from testing.


Figure 82: Adaptive Surface Technologies' Formulation B after removal from testing.


Figure 83: Adaptive Surface Technologies' Formulation C after removal from testing.


Figure 84: Adaptive Surface Technologies' Formulation D after removal from testing.


Figure 85: Adaptive Surface Technologies' Formulation E after removal from testing.


Figure 86: Adaptive Surface Technologies' Formulation F after removal from testing.


Figure 87: Adaptive Surface Technologies' Formulation G after removal from testing.

3.2.3 Pacific Northwest National Laboratories

Pacific Northwest National Laboratories (PNNL) signed an MTA with Reclamation in 2019. Test panels were supplied to Reclamation in 2020 but were unable to be installed until January 2022 due to COVID-19. A total of five panels were supplied for each formulation; two were installed on the test rack in flowing water and three were installed on the lines in quasi-static conditions. Table 5 is a list of all the formulations and panels that were supplied by PNNL. Table 5 also includes the results from the July 2022 inspection which was the first data point collection for these samples.

All panels in both dynamic and static water conditions exhibited good foul release properties. Formulation 1 had the most fouling with about 15% of the dynamic panels' surface covered with mussels. All other formulations had 10% or less of the surface fouled with mussels. All fouling was easily cleaned. However, all the panels did have blisters that formed on the surface of the panel. In addition to the blisters, some of the panels did have spots of black staining. It is unknown what the cause was, but it was removable from the surface of the panels. One panel for each formulation was removed from dynamic and static testing. These panels were returned to PNNL for internal evaluation; the other panels remained in testing. Figure 88 through Figure 101 show the PNNL panels.

Table 5: PNNL list of formulations and panels in testing and results from July 2022 inspection.

Formulation Code Name	Panel Number	% Fouled: Dynamic	% Fouled: Quasi-Static	Cleanability	Coating Condition
1	1 - 2	15	0%	Easily Cleaned	Blistering
1	3 - 5	0%	<5	Easily Cleaned	Blistering
2	6 - 7	<10	-0%	Easily Cleaned	Blistering, black discoloration spot
2	8 - 10	0%	0%	Easily Cleaned	Blistering
3	11 – 12	<5	0%	Easily Cleaned	Blistering
3	13 - 15	0%	0%	Easily Cleaned	Blistering
4	16 - 17	5 - 10	0%	Easily Cleaned	Blistering, black discoloration spot
4	18 - 20	-	0%	Easily Cleaned	Blistering
5	21 - 22	10	0%	Easily Cleaned	Blistering
5	23 - 25	0%	0%	Easily Cleaned	Blistering
6	26 - 27	5	0%	Easily Cleaned	Blistering
6	28 - 30	0%	0%	Easily Cleaned	Blistering
7	31 - 32	5	0%	Easily Cleaned	Blistering, black spot
7	33 - 35	0%	0%	Easily Cleaned	Blistering
8	36 – 37	5	0%	Easily Cleaned	Blistering
8	38 – 40	0%	<5	Easily Cleaned	Blistering
9	41 – 42	5	0%	Easily Cleaned	Blistering, black discoloration spot
9	43 - 45	0%	<5	Easily Cleaned	Blistering

Formulation Code Name	Panel Number	% Fouled: Dynamic	% Fouled: Quasi-Static	Cleanability	Coating Condition
10	46 - 47	5	0%	Easily Cleaned	Blistering
10	48 - 50	0%	0%	Easily Cleaned	Blistering

Figure 88: PNNL panels prior to install for testing during January 2022 inspection.

Figure 89: PNNL panels on experimental rack after approximately 6 months of testing. Minor mussel fouling and some buildup of colonial hydroid.

Figure 90: PNNL panels on experimental rack after approximately 6 months of testing. Minor mussel fouling and some buildup of colonial hydroid. Formulations 3 through 10 (left to right).


Figure 91: Panels after cleaning. Some of the black spots can be seen on the two right panels, 40 and 42.


Figure 92: Close up view of PNNL formulation 2 showing blisters on panels.


Figure 93: Closeup view of black spot on panel 42 from PNNL.


Figure 94: Close up view of panel 40 with black spots.


Figure 95: Formulation 1 panels in static testing. Less than 5% fouled with mussels and some sponge organism build up.


Figure 96: Formulation 2 in static testing with no fouling but blisters on surface.

Figure 97: Formulation 3 in static testing with no fouling.

Figure 98: Closeup of formulation 3 surface showing blistering and air bubbles in coating.

Figure 99: PNNL Formulations 1 (coupon 1), 2 (coupon 6), and 3 (coupon 10 and 12) coupons that were removed from testing.

Figure 100: PNNL formulations 4 (coupon 16), 5 (coupon 20 and 21), and 6 (coupon 26) coupons that were removed from testing.

Figure 101: PNNL formulations 7 (coupon 31), 8 (coupon 36), 9 (coupon 41) and 10 (coupon 45 and 46) couponsthat were removed from testing.

3.3 Scale-up Trashrack

The scale up trashrack tested four foul release products, three soft silicone and one durable hybrid silicone FRCs. Table 6 is a summary of the products used to coat the trashrack including what type of coating they are. Figure 102 shows the trashrack during its installation at the end of 2013 and Figure 103 shows the trashrack during the 2015 inspection.

Table 6: List of products used to coat the trashrack for scale up project.

Product	Type of coating	Color	Note
International Intersleek 970	Fluorinated silicone foul-release	White	• No mussel fouling • No damage observed • Slight algae build accumulations
Sherwin-Williams Sher-release	Silicone foul-release	Light Grey	• No mussel fouling • Missing coating and corrosion observed • Slight algae build accumulations • Discontinued in 2015
PPG Sigmaglide 890	Silicone foul-release	Red	• No mussel fouling • Small amounts of missing coating and corrosion observed • Slight algae build accumulations
Seacoat Seaspeed V5	Epoxy silicone hybrid	Blue	• No mussel fouling • Missing coating and corrosion observed • Complete coverage of algae

Figure 102: Trashrack during installation in 2013.

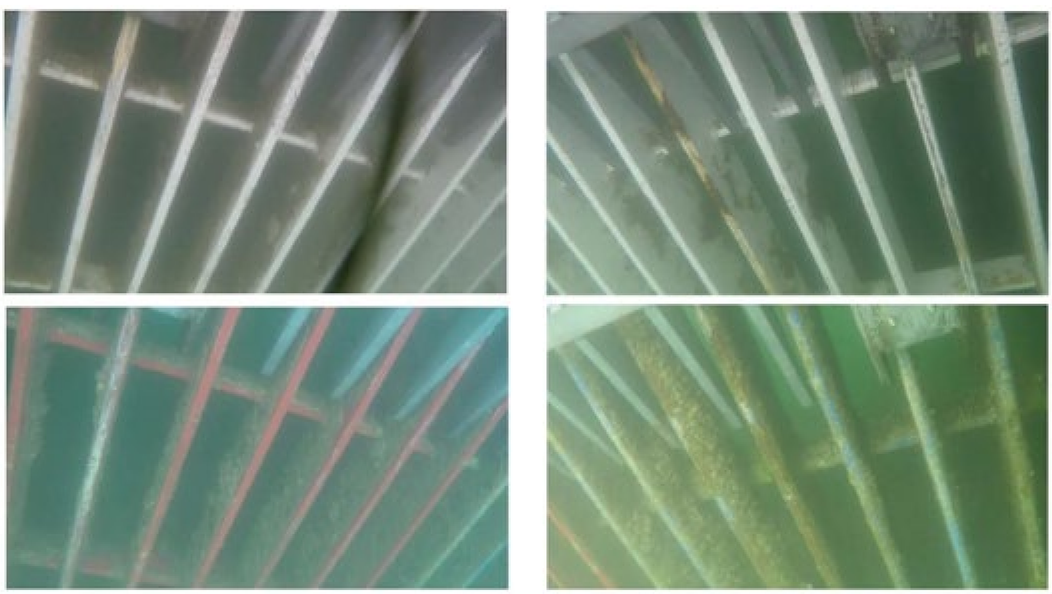

Figure 103: Still captures of video from 2015 inspection of trashrack.

After nine years of service, all four coatings appeared to have lost a small amount of their foul-release properties and allowing the accumulation of hydroids. However, all four coatings are still preventing the fouling of mussels to the trashrack. Sigmaglide 890 appears to have retained its foul release properties the best, compared to the other coatings on the scale-up project, with no mussel fouling and minimal accumulation of algae which Figure 104 shows. The bottom of the trashrack was damaged were the Sigmaglide 890 was once located and corrosion is occurring as shown in Figure 105. Both Sher-release and Intersleek 970 appeared to have the same performance with no mussel fouling and some hydroid accumulation. Intersleek 970 did not appear to have any damage as seen in Figure 106. Sher-release had damage on one of the grates bearing bars, seen in Figure 107, where the coating was completely missing due to abrasion. The Intersleek 970 damage was only observed on one of the bearing bars which may be experiencing an excess of abrasion due to how the rake moves along this grate as it cleans. If the weight primarily sits on this bearing bar the force of the rake isn't evenly distributed and is unable to be absorbed by the coating. Seaspeed V5 is the epoxy-silicone hybrid coatings and had the worst performance of the four coatings. Seaspeed V5 had the most accumulation of hydroids, approximately 90% of the surface covered, but still prevented the fouling of mussels. Seaspeed V5 had the most damage or missing coating which was cause by the trash rake cleaning system. Figure 108 through Figure 110 show the Seaspeed V5 coated section of the trashrack.


Figure 104: Sigmaglide 890 on trashrack. Coating is in good condition.

Figure 105: Bottom section of trashrack coated with Sigmaglide 890. Some missing coating at the bottom of the grate likely damaged by the rake system.

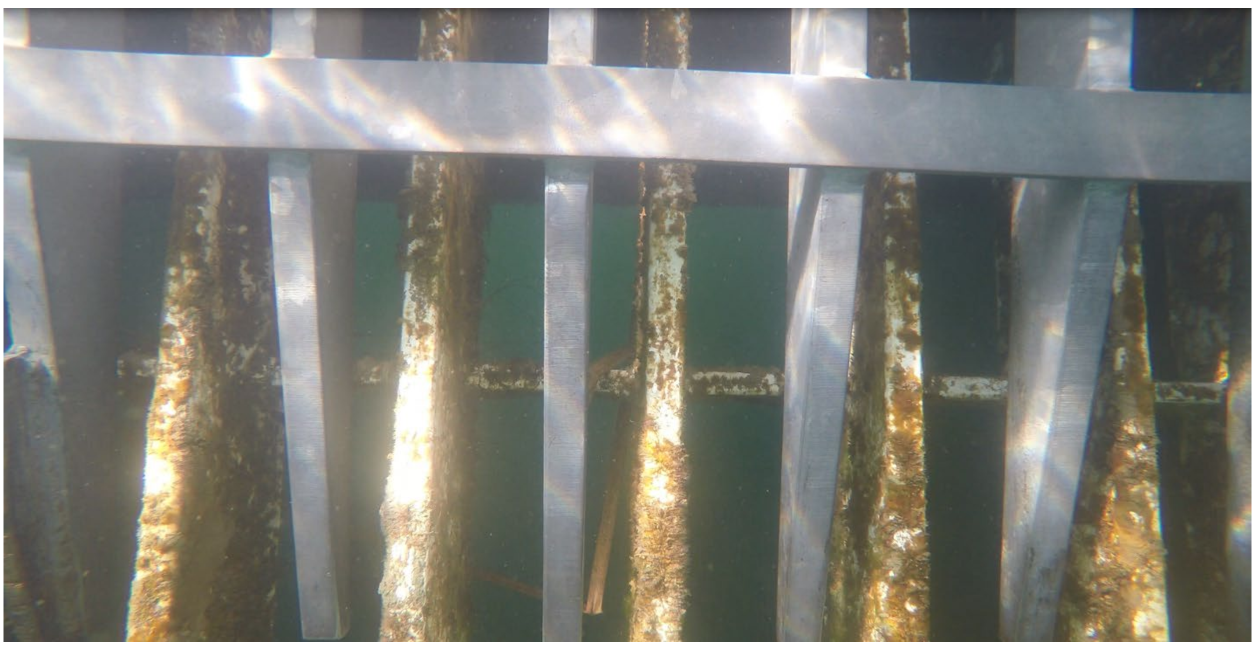

Figure 106: Intersleek 970 on scale up trashrack. Coating in good condition.

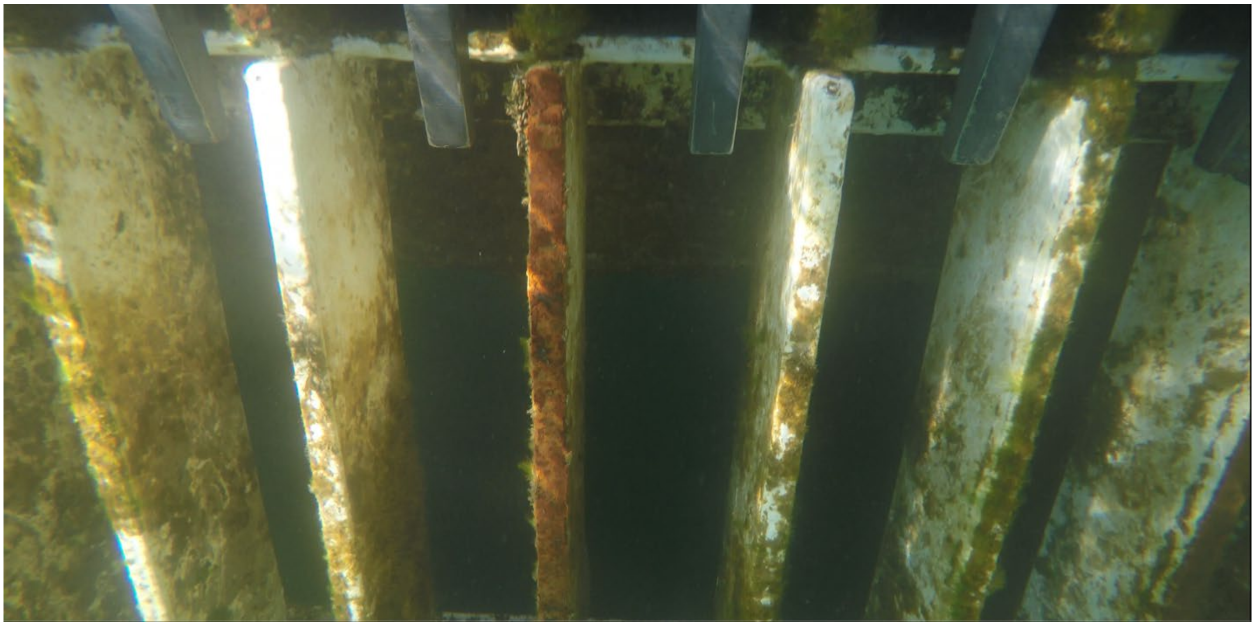

Figure 107: Sher-release coated section of trashrack. Can see one of the bearing bars is damaged caused by wear from abrasion forces caused by the rake cleaning system.

Figure 108: Sher-release and Seaspeed V5 interface. The bearing bars for the Seaspeed have abrasion damage and the coating has allowed for more accumulation of algae.

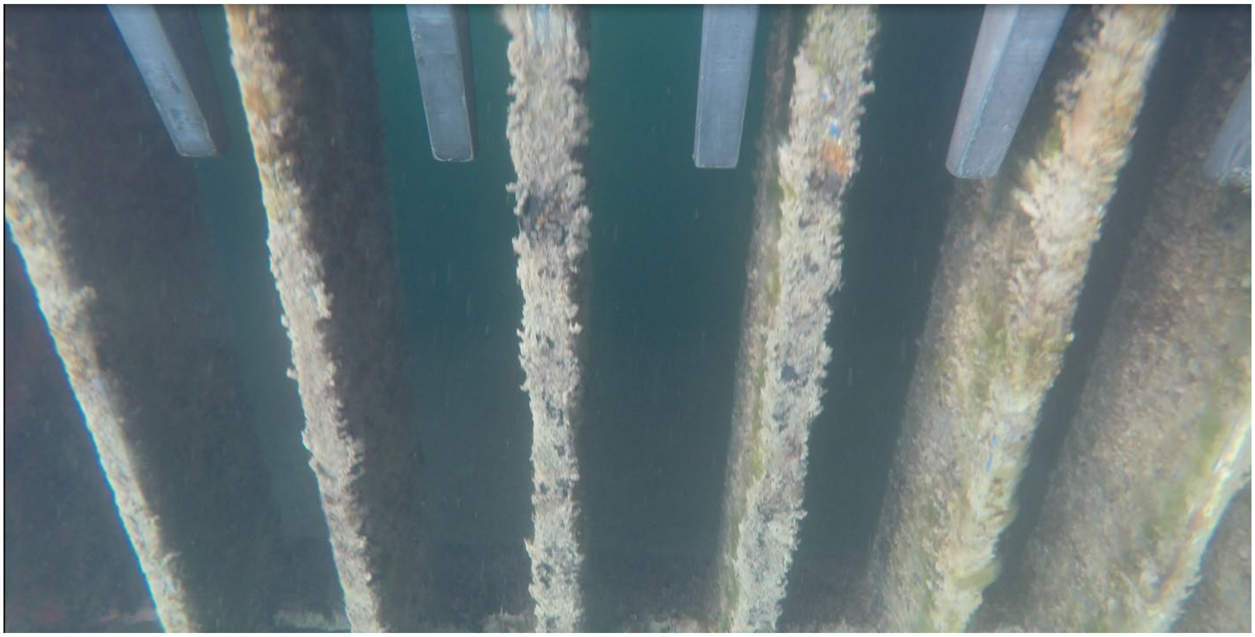

Figure 109: Seaspeed V5 which has become covered in algae but still prevents mussel attachment. The coating is damaged with missing spots of coating and corrosion present.

Figure 110: Section of trashrack not coated with FRC that is 100% fouled with mussels.

4. Conclusion

Testing has shown that foul release coatings can be used as a viable means to prevent the fouling of quagga and zebra mussels on Reclamation infrastructure. Several of the commercial products tested in this study had prevented fouling in both flowing water and quasi-static conditions. The 2013 trashrack scale-up study showed that some commercial products can hold up to the forces applied by the automated rake cleaning system. However, several of the products had observable damage on both flowing water and quasi-static samples due to abrasion from the panels rubbing against the concrete dam or the trashrack structure. Improving the durability of FRC is still a main concern for Reclamation. Experimental formulations have increased durability with no erosion or abrasion damage observed. However, some experimental products had defects such as blisters and top-coat delamination indicating application defects or the formulations need to be modified to improve barrier properties. These defects indicate that the formulations still need to be improved on in order to prevent premature coating failure and reach the desired service life of 15 years for Reclamation. Listed below are the conclusions drawn from this research.

- Commercial products Jotun Sealion Repulse, International Intersleek 970 and 1425, Hempel Hempasil X3, CMP BioClean, NuSil 9707, PPG Sigmaglide 890, and Silicone Solutions F23 prevented fouling or were easily cleaned.
- Jotun Sealion Resilient is a good option for a hard foul-release coating system but would need periodic cleaning. This coating would perform well on a fish screen with a brush cleaning system.
- Propspeed and PPG Sigmaglide 1290 have prevented fouling in initial testing but require long-term field exposure to determine if the products will retain their foul-release properties.
- International Intersleek 970 and CMP BioClean have been in testing for 14 and 13 years respectively. Both systems had blisters form between the January 2022 and July 2022 inspections. Although blisters are unsightly, the coatings will still prevent mussels from attaching, but they are a sign that the coating is starting to fail. This indicates that achieving Reclamation's desired service life of 15 years might not be possible with these commercially available products.
- The trashrack scale-up test showed the soft silicone FRC coatings have better performance on structures with automated rake cleaning systems than hard epoxy silicone hybrid FRCs. The soft silicone coatings had minimal damage after 9 years of service.
- NDSU experimental formulations increased the durability but some had blister formation or topcoat delamination. Many NDSU formulations also lost their foul-release properties over time allowing for increased mussel attachment. NDSU C4-20% provided the best fouling prevention. NDSU formulations still need to be modified to address these issues.
- All formulations from Adaptive Surface Technologies and PNNL formed blisters in under two years of testing. Formulations need to be modified to address these issues.

5. Recommendations

In cases where mussel fouling is the limiting factor on infrastructure performance, e.g., for trashracks in mussel-infested water, commercially available foul-release coatings can be used despite their poor durability under abrasion and impact conditions. For specific system recommendations, please reach out to the Reclamation Technical Service Center Materials and Corrosion Laboratory.

6. References

SSPC-SP 1, 2015 (2016), "Surface Preparation Standard No. 1 Solvent Cleaning," The Society for Protective Coatings, Pittsburgh, PA, 2016

SSPC-SP 5, 2007," Surface Preparation Standard No. 5 White Metal Blast Cleaning (NACE 1)," The Society for Protective Coatings, Pittsburgh, PA, 2007

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