APPENDIX I

Evaluation of Environmentally Acceptable Lubricants (EALs) Non-Hydropower Uses for Dams Affected by the 2014 Riverkeeper's Settlement

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EVALUATION OF ENVIRONMENTALLY ACCEPTABLE LUBRICANTS (EALS) NON-HYDROPOWER USES FOR NWD AND NWW DAMS

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Background

This report focuses on two questions:

1. Are EAL greases available for use at multipurpose facilities (dams) for non-hydropower application? And,
2. Do these EALs meet performance needs?

A separate study was conducted evaluating candidate greases for hydropower applications (HDR 2015). Although applicable to all US Army Corps of Engineers (USACE) dams, this project particularly focused on dams in the Columbia and Snake Rivers, under the management of the Portland and Walla Walla Districts (NWP and NWW respectively), both of which are part of the Northwest Division of the US Army Corps of Engineers.

EAL Assessment

The EAL assessment focused on Section 4 of EPA-R-11-002 (USEPA 2011), lubricants that have been demonstrated to meet standards for biodegradability, toxicity and bioaccumulation potential that minimize their likely adverse consequences in the aquatic environment compared to conventional lubricants. This includes, but was not limited to products following one of the following labeling programs: Blue Angel; Swedish Standard(s); Nordic Swan; European Eco-label; and OSPAR (Convention for the

Protection of the Marine Environment of the North-East Atlantic). This definition was interpreted as broad as possible.

An initial assessment indicated that EAL-candidate greases were already being used at some projects. The Dalles and John Day Dams use an environmentally friendly grease, Mobil SHC EAL 100 series[1]. Subsequent review indicated that Bonneville Dam currently uses Huskey lubricants, which are purported to be environmentally friendly greases. Dworshak, a NWW dam, uses VSG grease, a canola oil based environmental friendly grease. (The use of the term environmentally friendly is to differentiate from the assessment of Environmentally Acceptable, which is defined below).

Non-hydropower uses

Non-hydropower lubrication needs are wide and demanding. Some key non-hydropower activities requiring in water lubrication, include (but are not limited to):

- Navigation locks,
- Spillway gates,
- Fishways, and
- Cranes (wire cables and ropes) and lifting beams.

Although the focus was on in water non-hydropower applications, many of the literature and data sources did not discriminate between hydropower and non-hydropower uses. Therefore, some of the data and analyses presented crosses over to hydropower applications (particularly wicket gates).

[1] Reference to trade names does not infer endorsement by ERDC or the US Army Corps of Engineers.

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Environmentally Acceptable Lubricants

The definition of an EAL in the settlement is specified in section 4 of EPA 800-R-11-002: the lubricant has to be biodegradable, minimally toxic and non-bioaccumulative (USEPA, 2011).

There are three ways that a grease could pass each criteria:

1. Testing. EPA 800-R-11-002 has defined several tests for each criteria. By presenting test results as a report or in a spec sheet, a grease can conclusively state that it passes the criteria.
2. Vendor's statements. This is not as conclusive as actual test results, but a vendor's statement does indicate that they stand behind their product and is a strong endorsement for meeting a given criteria.
3. Base oil composition. The EPA indicates that greases of specific compositions generally meet the criteria (Tables 3, 5, 6 and 7 in EPA 800-R-11-002). For example, vegetable oil grease would generally be readily biodegradable, have no potential for bioaccumulation, and low toxicity, even without supporting testing. The EPA also indicated that synthetic ester and PAG based greases also generally meet EAL criteria. Although this is the weakest of the supporting data, it is acceptable based on EPA 800 R11-002.

Labeling

The definition also indicates that specific labeled products are considered as EALs. Several are cited in the settlement, including: Blue Angel; Swedish Standard(s); Nordic Swan; European Eco-label; and OSPAR, and these labeling programs are also identified in Section 5 of EPA 800-R11-002. In addition, some greases are certified as

Vessel General Permit (VGP) compliant (USEPA, 2013). ERDC has determined this to be an equivalent label and all greases defined as VGP compliant are determined to be EALs.

Tiered Definition

Acknowledging that some of the candidate greases have more complete data than others and that the EPA definition can be interpreted either tightly or more broadly, ERDC has developed a tiered definition, which might be helpful for dam owners and to make more environmentally friendly grease choices (As proposed in the latest draft of EM 1424). A Tier 1 USACE EAL is one that conforms to a strict interpretation of the EPA definition and will either:

A. Be a product labeled by European Eco-label, and/or Ospar. Other product labeling could be considered by an Environmental Officer.
B. Be a product classified as Vessel General Permit (VSG) Appendix A compliant, or
C. Have test data as specified in USEPA 800-R-2-001 or in USEPA Vessel General Permit document Appendix A, indicating that it meets requirements for bioaccumulation, toxicity, and biodegradability. Such data may be presented as test reports or reported on product specification sheets.

A Tier 2 USACE EAL is a product that does not meet the criteria of a Tier 1 EAL, but:

A. Is labeled by one or more of the following: Blue Angel, Nordic Swan, or Swedish Standard and/or,
B. Contains a manufacturer's statement that it meets one or more of the test criteria (bioaccumulation, toxicity, and biodegradability) as discussed in part C of the Confirmed USACE EAL definition, with appropriate test data to confirm the other criteria; and/or
C. Its base oil indicates that it meets one or more of the test criteria (see USEPA 800-R-2-011, section 4, table 3 for biodegradability, table 5 for toxicity, and table 6 for bioaccumulation), with test data to support the other criteria. USACE would prefer products with data on lubricant composition, including toxic or RCRA metals and certification that additives do not affect toxicity or accumulation.

The preference would be to use Tier 1 EALs, but Tier 2 EALs can be used if deemed a safer choice for equipment. In a recent analysis conducted by HDR for the USACE Hydropower Design Center (HDR 2015), a strict interpretation of EALs was used, equivalent to the Tier 1 definition used in this document. However, there are many

excellent candidate greases that do not, as of now, have complete test data, including many of those that are currently being used by the USACE and by other organizations that operate hydropower dams. Allowing a broader set of greases (i.e. Tier 2 greases) allows the transition to EAL greases to be much easier and with a much higher degreeof confidence. Since Tier 2 greases have base oil compositions that are more environmentally benign, they do represent a better alternative from an environmental perspective than mineral oil lubricants.

Approach

Nineteen lubricants were evaluated. These were identified as environmentally friendly greases already used in USACE dams or as potentially applicable environmentally friendly greases from other sources. Each grease was checked against the EPA criteria for bioaccumulation, biodegradation, and toxicity. ERDC considered the composition of the greases where direct data was not available. ERDC also checked for labels that indicated EAL acceptability.

Results

The results are summarized in Table 1. Six of the greases were Tier 1 EALs based on testing, VGP compliance (we did not identify any other labels), or both. The remaining 12 greases met the Tier 2 standard. Of the Tier 2 greases, it should be pointed out that there were also variations in the quality of data available. Five of these had test data for two of the criteria and the third passing due to composition or vendor statement. However, the remaining 6 greases had weaker data sets, with more than one of the criteria based on either composition or vendor statement.

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The USACE currently reported using six products that were included in the assessment, and all four were Tier 2 EALs. The Mobil SHC EAL 100 Series, the VSG Wicket Grease, Huskey LVI-50, and Dynagard Blue and Dynagard E all had test results available for two of the criteria (biodegradability and toxicity) and one criteria being filled based on base oil composition or vendor's statement (bioaccumulation). Huskey Hydrolube, on the other hand, had a weaker data set, with all three criteria lacking actual test data, being based on either vendor statement or on base oil composition.

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Table 1. Assessments of greases for EAL suitability.

Lubricant	Composition	Label	Bioaccumulation	Toxicity	Biodegradability	EAL
Dynagard Blue	Solvent Refined Mineral Oil	None	Yes, Vendor's statement	Yes, Test results	Yes, Test results	Tier 2
Dynagard E	Seed Oil	None	Yes, Vendor's statement	Yes, Test results	Yes, Test results	Tier 2
Huskey Lube O Seal	Synthetic Ester	None	Yes, Composition	Yes, Composition	Yes, Vendor's statement	Tier 2
Huskey Ecolube EP2	Vegetable Oil	None	Yes, Composition	Yes, Composition	Yes, Vendor's statement	Tier 2
Huskey Hydrolube	Synthetic Ester	None	Yes, Composition	Yes, Vendor's statement	Yes, Composition	Tier 2
Huskey LVI-50	Synthetic oil	None	Yes, Composition	Yes, Test results	Yes, Test results	Tier 2
ROCOL Biogen Wireshield	Vegetable/Synthetic Ester Mix	None	Yes, Test results	Yes, Test results	Yes, Test results	Tier 1
Mobil SHC Aware Grease EP 2	Synthetic Ester	VGP Compliant	Yes, Test results	Yes, Test results	Yes, Test results	Tier 1
Mobil SHC Grease 100 EAL Series	Synthetic Ester	None	Yes, Composition	Yes, Test results	Yes, Test results	Tier 2
Renewable Lubricants Bio-EP Wire Rope Lubricant	Vegetable Oil	None	Yes, Composition	Yes, Test results	Yes, Test results	Tier 2
Vickers Oil Product Biogrease EP 2	Synthetic Ester	VGP Compliant	Yes, Composition	Yes, Test results	Yes, Test results	Tier 1
Lubriplate ATB Biobased EP-2 Grease	Vegetable Oil	VGP Compliant	Yes, Test results	Yes, Test results	Yes, Test results	Tier 1
VSG Wicket Gate Grease	Canola Oil	None	Yes, Composition	Yes, Test results	Yes, Test results	Tier 2
Envirologic 802 Grease	"Natural" esters	VGP Compliant	Yes, Vendor's statement	Yes, Composition	Yes, Vendor's statement	Tier 1
Envirologic 268 Wire Rope Lubricant	"Natural" esters	VGP Compliant	Yes, Composition	Yes, Testing	Yes, Testing	Tier 1
Lanopro EP Grease 53	Synthetic esters	None	Yes, Composition	Yes, Composition	Yes, Vendor's Statement	Tier 2
Shell Naturelle Grease S5 V120P 2	Synthetic esters	None	Yes, Composition	Yes, Composition	Yes, Vendor's Statement	Tier 2
Shell Naturelle S2 Wire Rope Grease A	Synthetic esters	VGP Compliant	Yes, Composition	Yes, Composition	Yes, Vendor's Statement	Tier 1
Panolin Biogrease EP 2		VGP Compliant	Yes, Test results	Yes, Test results	Yes, Test results	Tier 1

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Performance

ASTM tests and measurements provide well defined, quantifiable results of grease performance. However, correspondence and interviews with NWP and NWW engineers and operators suggest that choosing an appropriate grease is as much of an art as a science. Therefore, a final answer on performance is not really feasible until the new grease is actually used. That said, ERDC used a 3 pronged approach for assessing performance:

1. Comparison of EAL performance specifications to greases already being used by the NWP/NWW.
2. Comparison of EAL performance specs to any published performance requirements for non-hydropower equipment.
3. Interviews of engineers, mechanics and operators who have already used EAL greases.

Comparison of EAL performance specifications to greases already being used by the NWP/NWW

Engineer Research Development Center – Environmental Laboratory, ERDC-EL identified 9 test specifications based on review of various literature and reports. These are identified in the first column of Table 2. ERDC then examined a grease survey conducted by NWP and NWW. From the survey, ERDC focused on non-hydropower uses and identified 8 greases that were widely used and/or used in high quantities. These were:

- Chevron EP NGLI 0
- Chevron EP NGLI 1

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- Chevron EP NGLI 2
- Omega 65
- Purplex with Omnistal
- Super GL6 High Core, and
- Mobil SHC 100 EAL Series.

The first 7 of these greases are conventional greases, while Mobil SHC 100 EAL is a Tier 2 EAL. The range of performance of these greases was recorded, as shown in the last column of Table 2.

Data for the existing greases was limited to the first 6 tests. Some of the products had incomplete data sets, however, some of the mineral oil greases did not have data for all of the specifications either. Four of the EAL candidates did have complete data sets, and for these, all of the performance requirements were within the required ranges, or exceeded the range. For the cumulative data available, only one was below the range of the existing greases and several exceeded the existing range. We were not able to find specifications for Panolin Biogrease EP 2 on line, so it is not included on the table; however, it was tested as part of the HDR study, and was found to be suitable for hydropower applications (HDR 2012). These results suggest that the EAL greases can meet specifications of greases currently being used at USACE dams.

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Table 2. Evaluation of Performance Properties Compared to Existing Greases. Green indicates performance is within the range of existing greases, dark green indicates performance exceeds the range of existing greases, and yellow indicates performance is below the lowest performance value for that category. Purple means no data for the EAL and no color means no data was available for the existing greases.

	Greases currently used at USACE Dams					Other candidates											
	VSG Wicket Gate Grease	Huskey: Lubolube EP 2	Huskey: Hydrolube (0 NLGI Grade)	Huskey LVI-50	Mobil SHC™ Grease 100 EAL Series	Mobil SHC Aware Grease EP 2 (VGP)	Huskey: Lube O Seal Grease	Dynagard Blue	Dynagard E	Renewable Lubricants Bio-EP Wire Rope Lubricant (extreme heavy 20W 50)	Vickers Oil Product (Biogrease EP 2) (VGP)	Lanopro EP Grease 50	Environtologic 802 Grease (VGP)	Shell Naturelle Grease S5 V129P 2	Shell Naturelle S2 Wire Rope Grease A (VGP)	Lubriplate AIB Biobased EP 2	**Range: ECB 2006-11 and existing greases**
D217 Penetration of Lubricating Grease (mm)	325	265-295	355-385	280	290	280	280	305	301	-----	295	265-295	265-295	-----	-----	265-295	267-430
D566 Dropping Point of Lubricating Grease (°C)	260	-----	+500	-----	255	>160	-----	177	Over 200	-----	178	>140	+550	180	120	385	172-286
D1092 Viscosity of Lubricating Greases (cSt) @ 40°C	429	*95.8 D 445	*[illegible] D 445	*[illegible] D 445	100	150	200	-----	-----	212	150	-----	-----	120	>550	100	*180-460
D1264 Water Washout Characteristic of Lubricating Greases (wt %)	5	-----	0.5	1.9	5	7	0.01	-----	-----	-----	1.8 @ 38°C 6.1 @79°C	<5	1	-----	-----	1	0.2-15
D2596 Extreme-Pressure Properties of Lubricating Greases, Four Ball Method [weld point] (kgf)	400	-----	160	-----	250	400	-----	250	-----	450	>480	-----	400	-----	-----	250 (D-2783)	140-500
D2509 Extreme-Pressure Properties of Lubricating Greases, Timken Method (lb)	55	-----	60	35	-----	-----	40	-----	-----	70 D-2792	40	-----	55	-----	-----	40 (D-2783)	25-70
D4048 Corrosion Preventive Properties of Lubricating Greases	1B	-----	-----	-----	1A	1B	-----	-----	-----	1B	1B	-----	1A	-----	-----	1A	-----
D942 Oxidation Stability of Lubricating Greases by the Oxygen Bomb Method (psi)	10 (100 hours)	-----	-----	-----	-----	-----	-----	-----	-----	-----	24h @60 degrees C 6.0 psi	-----	@ 100 hrs (0 Psi Typical) @ 500 hrs. (-2 Psi Typical)	-----	-----	3 psi/100 hours	-----
Rust prevention D1743			PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS			PASS				

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Comparison of EAL performance specs to published performance requirements

ERDC-EL pursued several tracks to find published performance requirements for greases in non-hydropower roles. One document was found, USACE Engineering and Construction Bulletin (ECB) 2001-11 (USACE 2006), which focused on Tainter Gate Trunnion Lubrication. The following tests and criteria are in Table 3, which compares how the EALs performed in comparison. Although the data is spotty, at least one EAL grease met each requirement (although separation was not evaluated). For viscosity, only two of the EAL greases met this (Huskey Hydrolube and Huskey LVI-50, both Tier 2 EALs), but none of the existing non-EAL greases met the target value. (Huskey Hydrolube has an unusually large viscosity. We double checked the value based on specification sheets provided by Huskey).

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Table 3. Comparison of EAL performance to Target Performance Values given in ECB 2006-11.

Test	Purpose	Requirement	EAL performance
ASTM D-1743	Rust Prevention	Pass	9 of the EAL greases have this data and all pass
ASTM D-1264	Water washout	Max. 1.9%	9 of the EAL greases have this data, 4 meet the criteria. Most of the mineral oil greases evaluated did not meet this criteria.
ASTM D-217	Worked Penetration	NGLI 1	The EAL greases have a range of NGLI numbers. In particular, VSG and Mobil EAL 101 are NGLI 1 greases.
ASTM D-445	Viscosity	Minimum 700 cSt at 40C	Only two of the EALs meet this. However, none of the existing mineral oil greases had this level either.
ASTM D-2596	Antiwear/scuffing	Wear load index 40 kgf Weld point 140 kgf	All the EAL greases exceeded the weld point.
ASTM D-4048	Prevention of Copper Corrosion	1B	Four of the greases are listed as 1B
ASTM D-1742	Non-separation in storage	0.5 to 1%	Not evaluated

Interviews of engineers and operators who are already using EALs

ERDC-EL interviewed (via phone, email, or face to face discussion) the following people who have used EALs at Dams. The following testimonials discuss the implementation and use of EALs in numerous environments:

- Bob McKeown, Orillia Power District. Orillia Power is located in Canada and is subject to sub zero weather. They use VSG grease (a Tier 2 EAL) for wicket gates and for other purposes.

  "We have not had any operating difficulties with the *(VSG)* grease at our plants that I am aware of. We use it to lubricate our wicket gates, and it was adopted to mitigate concerns with its contact with water i.e.

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pollution. Our staff also use *(sic)* it on the vertical screw arrangement on our two sluice gates at our Matthias plant in Bracebridge. I have not heard of any issues in regards to the screw application, and this application is outdoors in severe weather (-30 C in winter, +30 C max in summer)."

In terms of a new application,

"I was not with the company when the changeover was carried out, but I think they would have just started to pump in the new grease without removing the old. The manufacturer would likely have some input on this. I don't have any idea of what was used previous to this product. We do use the grease on some sluice gate screws - these stand about 20 feet in the air on top of a dam with no wind break or shade, and we have found that it seems to adhere to the steel fairly well, and have *(sic)* not heard of any issues with the grease itself."

- Kelly LaCoste, U.S. Bureau of Reclamation. Reliability Program Analyst. Power Resources Office. Parker Dam.

"Yes we used 'VSG' wicket gate grease (http://vsggrease.com/) at Parker Dam (you will see a pic of Parker Dam when you open up their website). It performed well at Parker, we had approx. 80 ft of hydraulic head and ~28 psi at the gate.

I would recommend this as a 'Green Grease', the only draw back (*sic*) is if you use it outside of water i.e.on the fixed wheel gates, it would separate (oil/wax) in the heat for those wheels above the waterline (Parker see's in excess of 120 degF in summer), but performs well on the Wicket Gates."

- Frank Salber, USACE. The Dalles. Mobil EAL 101 and Huskey LVI 50 are both Tier 2 EALs.

"The trunnion bearings on the NL upstream gate and spillway all use Mobil SHC EAL 101 and it works. For fish weirs, we use Huskey LVI 50. All wire ropes use Omega #65."

In a meeting with engineers and operators from The Dalles on 10 February 2015, we discussed the implementation of the use of the Mobil SHC EAL 101 grease. Unfortunately, no one on staff remembered the process of implementation of the

grease, but they confirmed that they had not undergone any significant grease removal or overhaul, or it is doubtful the grease would have been implemented.

- William Lewis, Tennessee Valley Authority, (TVA) stated that VSG actually performed better than mineral oil greases.

"TVA started using the VSG product about 14-15 years ago on one of the units at Fontana dam. This was just following a discovery of some problems with greaseless wicket gate bushings. Fontana was chosen because it had 3 units, one with greaseless bushings, one using grease from mineral oil and one the VSG was used on. All three units had a differential pressure transmitter across the servo motors. The trends over the first 5 years showed the VSG was better than the mineral oil grease by a consistent 10 psi.

The greaseless bushings also performed just as well, but due to greaseless bushing issues at other TVA a decision was made to continue using the greased bushings.

Over the following years, almost all of our units have been changed to the VSG grease for greasing wicket gate bushings. The grease has what appears to be an infinite shelf life (over 5 years), while the mineral oil grease would separate after 2-3 years."

Mr. Isaac Allen, a Mechanical Engineer at TVA.

"Mobil - EAL 101 and 102 Spillway gate wheels, radial gate chains, Howell-Bunger Valve drive screws. Approved for TVA use in submerged service. This is a mineral oil *(it is actually a synthetic ester)* lubricant that is bound very well to the thickeners. Release of oil into water is nearly insignificant."

- We contacted Dr. Alex Qiang of Exxon/Mobil regarding Mobil SHC Environmental Aware EP2 grease, which is a Tier 1 grease with promising characteristics.

"I don't have any experience of applying Aware Grease EP 2 into any hydropower dams, so I can't guarantee it would work properly. The base oil of Mobil SHC Aware Grease EP 2 is only 150 cSt and I guess it might be a little bit lower in terms of dams."

This should not rule out the use of this grease, but it does suggest that its application should be conducted cautiously.

HDR (2015) also sought user information primarily by the use of questionnaires. One of their results indicated that a user of Shell Naturelle grease found its performance was not satisfactory, and they returned to the previously used mineral oil grease.

These testimonials suggest that several types of Tier 2 EALs, particularly VSG and Mobil EAL 100 series, can be used in dam projects with no adverse affect on performance and that their implementation should not be an insurmountable obstacle. However, the HDR report did find an unfavorable review of the Shell Naturelle product. As best as we can determine at this time, there are no Tier 1 EALs that have significant usage in dams.

Literature

The literature contains numerous studies comparing mineral oil lubricants to environmentally friendly lubricants. Various survey reports indicate that although each formulation of lubricants has its respective advantages and disadvantages, there is no inherent advantage to mineral oil lubricants and that bio-based lubricants and synthetic esters can perform as well, and in some cases far superior (Bartz 1998, Pai and Hargreaves, 2002). Pearson and Spagnoli (2000) documented on the order of a dozen applications ranging from pump applications, hydraulic oil applications, sewage outfall applications, maintenance of golf course equipment, and construction equipment maintenance – all with successful long term performance.

Regarding application to a dam, the U.S. Bureau of Reclamation (Hanna and Pugh, 1994) conducted a comparison study of various lubricants. They defined a lithium based mineral oil grease lubricant as providing 100% lubrication and the friction torque was measured at 401 in-lb. A synthetic ester grease reached 93% lubrication (437 in-lb), and this was deemed acceptable performance. Better still, a canola based lubricant (which has been revealed to be VSG, a Tier 2 EAL) outperformed all of the greases, providing 105% percent lubrication and the lowest friction torque at 377 in-lb.

Conclusions

A two tiered definition was developed for EALs. Tier 1 EALs either are certified by an acceptable labeling program, or have test data for all three criteria (biodegradation, bioaccumulation, and toxicity). Tier 2 EALs are not labeled and lack data for at least one of the criteria, but are classified based on vendor statement and/or base oil composition.

1. ERDC found 18 greases that qualify as EALs, 6 as Tier 1 and 12 as Tier 2. Four of these greases are already being used at USACE dams (Mobil SHC 100 series, VSG, Huskey Hydrolube, and Huskey LVI 50), and each of these are Tier 2 greases.
2. EAL greases (both Tier 1 and 2) have similar performance requirements for non-hydropower uses of the dams compared to greases currently being used.
3. At least two EAL greases meet each of the performance requirements given by ECB 2006-11.
4. Testimonials from longtime users of EAL qualifying greases indicate that they are satisfied with their performance, and in some cases indicate even better performance than previously used mineral oil greases. Although there were not

a lot of details on the implementation, it appears that the process was relatively easy and did not involve complete removal of the previous grease.

5. There is long experience for hydropower use for some of the greases, but the only greases we have identified with experience in hydropower dams are Tier 2 greases. Care should be taken in applying grease without any hydropower experience, even if the specifications are in range.
6. Studies documented in the literature also indicate EALs can perform as well as mineral oil greases for a wide range of applications.

All of these suggest that EALs can meet the performance requirements needed for non-hydropower uses. The best options appear to be greases that are already being used by USACE. All of these particular greases are Tier 2 greases.

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