ROOT CAUSE FAILURE ANALYSIS (RCFA)

Recurring Gearbox Failure: Line 3 Filler Main Drive (GR-305)

Three seizures in 13 months on the plant's constraint line. This report covers cause, cost of unreliability, and a corrective action package for capital approval.

SAMPLE — FICTIONAL DAT

CLIENT	Larkspur Valley Foods, Inc. — Plant 2 (cultured dairy)
ASSET	GR-305 filler main drive gear reducer · Line 3 · 12-lane cup filler
REPORT NO.	RCA-2026-014 · Revision 0 · Issued November 6, 2026
ANALYSIS WINDOW	July 1, 2025 – October 31, 2026 (16 months)
TRIGGER	Repeat failure on a constraint asset (two or more corrective work orders in 12 months)
METHOD	Evidence-verified cause-and-effect logic tree (physical, human, and latent roots), change analysis, and cost of unreliability valued at contribution margin
RCA TEAM	Apex Reliability Engineering (facilitator) · Maintenance Supervisor · Line 3 Lead Mechanic · Sanitation Supervisor · Line 3 Production Supervisor · Food Safety & QA Manager · Plant Controller (financial validation)
DISTRIBUTION	Plant Manager · Maintenance & Engineering Manager · Plant Controller · Sanitation Manager · QA Manager

Demonstration document. Sample report. All company names, people, data, and financial figures are fictional and shown for demonstration only. The structure, methods, and level of detail match Apex Reliability Engineering client deliverables.

Executive Summary

Decision brief for the Plant Manager and Plant Controller. Sections 1–7 contain the supporting detail.

BOTTOM LINE

GR-305 has failed three times in 13 months because **washdown water and cleaning solution enter the gearbox during sanitation**, not because of a defective gearbox. The unit installed today shows the same contamination after six weeks, so its next failure is expected around March 2027. A **$36.9K package** (a washdown-duty gearbox, a critical spare, and procedure changes) removes the cause. It pays back in **4.5 months** in the expected case and has a positive NPV in all three scenarios.

COST OF UNRELIABILITY, 16 MONTHS	UNPLANNED DOWNTIME	CASH OUTLAY REQUESTED	PAYBACK, EXPECTED CASE	5-YEAR NPV AT 10%
$225.4K	**62.0 h**	**$36.9K**	**4.5 mo**	**$335K**
Only $28.4K (13%) appeared in maintenance spend	On the plant constraint across three events	CAPEX $13.6K · Inventory $11.9K · OPEX $11.4K	Range 2.7–20.2 months	Range $46K–$583K; positive in all cases

DECISIONS REQUESTED

1. **Approve $13.6K CAPEX** for a sealed, washdown-duty reducer (CA-1) and **$11.9K in inventory** for a matching critical spare (CA-6).
2. **Endorse the sanitation procedure revision** (CA-3) and management-of-change coverage for sanitation changes (CA-11), with Sanitation and QA sign-off.
3. **Authorize the survey** of 14 other washdown-zone reducers (CA-10; $630 plus internal labor).

WHAT THE EVIDENCE SHOWS

- CONFIRMED The failed unit's oil held **4,850 ppm water** (57× new oil). Its sodium content points to cleaning solution.
- CONFIRMED **Life fell from 73 months to about 6.6 months** after the May 2025 sanitation program change.
- RULED OUT The working assumption of a **defective gearbox or batch**. Restocking the same model resets the clock to about 200 days.
- CONFIRMED The 41-hour event was a **spares failure**. It cost $137.1K more than an average event with a spare on hand.

FINANCIAL SUMMARY (PRE-TAX)

	CONSERV.	EXPECTED	HIGH
Annual loss avoided	$26.5K	$102.6K	$168.1K
Net annual benefit	$21.9K	$98.0K	$163.5K
Payback (months)	20.2	4.5	2.7
5-yr NPV at 10%	**$46K**	**$335K**	**$583K**

Break-even: the package pays for itself if it prevents one spare-on-hand failure every 2.1 years. Since the sanitation change, GR-305 has failed every 6.6 months.

CONFIDENCE

HIGH for Event 3, from physical, oil, and thermal evidence and the same ingress measured on a new unit. MODERATE for Events 1–2, whose units were scrapped without teardown. The corrective actions do not depend on Events 1–2.

SAMPLE — FICTIONAL DATA

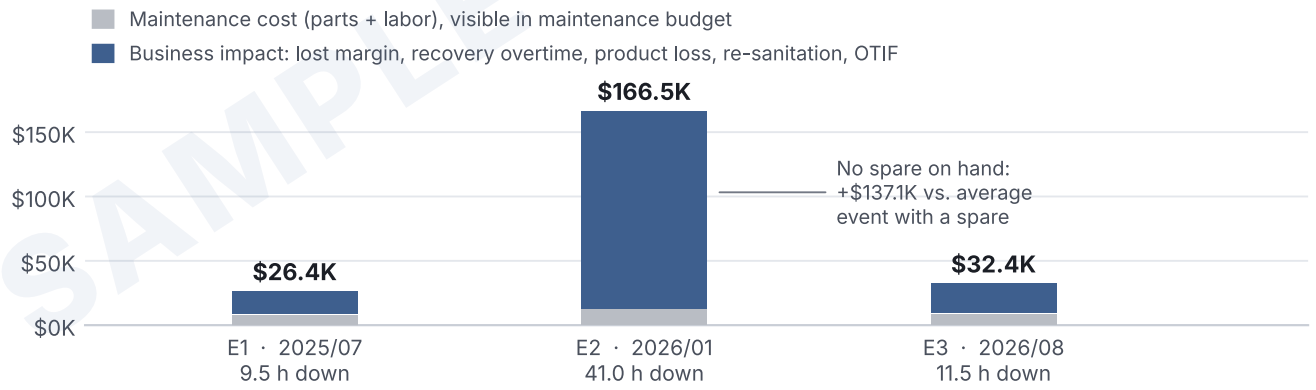
1 Event and Financial Impact

Three unplanned seizures cost $225.4K over 16 months, or $169.0K annualized. The maintenance budget recorded $28.4K of that total. The rest fell on margin, customer penalties, and product loss.

TABLE 1.1 — COST OF UNRELIABILITY BY EVENT (USD, PRE-TAX)

COST ELEMENT	E1 · JUL 18, 2025	E2 · JAN 27, 2026	E3 · AUG 21, 2026	TOTAL
Unplanned downtime (h)	9.5	41.0	11.5	62.0
of which recovered on overtime (h)	7.1 (75%)	16.4 (40%)	8.1 (70%)	31.6
Lost contribution margin (unrecovered h × $4,620)	$10,972	$113,652	$15,939	$140,563
Recovery cost (recovered h × $610)	$4,346	$10,004	$4,910	$19,260
Customer OTIF deductions	$0	$18,400	$0	$18,400
Product and WIP loss (standard cost)	$1,334	$8,568	$1,472	$11,374
Re-sanitation cycles	$1,850	$3,700	$1,850	$7,400
Subtotal: business impact	**$18,502**	**$154,324**	**$24,171**	**$196,997**
Parts, including expedite premium	$6,450	$9,300	$6,450	$22,200
Maintenance labor (fully burdened)	$1,482	$2,912	$1,794	$6,188
Subtotal: maintenance cost	**$7,932**	**$12,212**	**$8,244**	**$28,388**
Total cost of unreliability	**$26,434**	**$166,536**	**$32,415**	**$225,385**

FIGURE 1.1 — MAINTENANCE COST VS. BUSINESS IMPACT, BY EVENT



FINANCIAL METHODOLOGY (VALIDATED BY THE PLANT CONTROLLER)

- **Downtime is valued at lost contribution margin, not revenue:** 1,200 cases/h × $3.85 contribution margin per case = $4,620 per line-hour (FY2026 standard).
- **Recovered volume is charged at recovery cost, not lost margin.** Recovery cost covers the overtime crew at the burdened overtime rate, incremental utilities, and the added sanitation cycle. Recovery percentages come from production records.
- **Idle direct labor during downtime is excluded.** It is a period cost, not incremental cash, and it already appears as under-absorbed conversion cost. Counting it here would double count.
- Parts are valued at replacement cost. Sunk costs are excluded. All historical figures are pre-tax and undiscounted.

SAMPLE — FICTIONAL D

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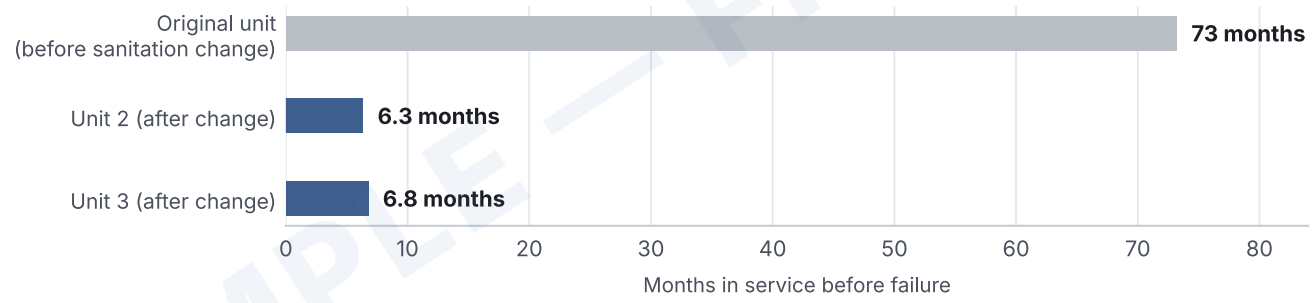
2 Asset Context and Change Analysis

GR-305 drives the 12-lane cup filler on Line 3, the plant constraint, and has no redundancy. It is a standard-duty, vented, painted reducer with NBR seals and H1 PAO VG 220 oil, installed in a washdown zone. It was ranked criticality B in 2019 and never re-ranked. Its life fell by a factor of eleven after the May 2025 sanitation change.

TABLE 2.1 — SEQUENCE OF EVENTS

DATE	EVENT AND SIGNIFICANCE
Jun 2019	GR-305 installed; OEM-standard reducer accepted for a washdown zone
Mar 2024	SKU rationalization makes Line 3 the plant constraint; criticality not re-ranked
May 2025	**Sanitation program revised** (SSOP-L3-07 Rev C): chlorinated alkaline foam, high-volume rinse, ambient final rinse. No equipment review.
Jul 18, 2025	**E1**: original unit seizes after 6.1 years. The stocked spare is installed and never reordered.
Jan 27, 2026	**E2**: seizes after 193 days. No spare on hand, so a unit is expedited: **41 h down**. WO note: “oil milky.”
Aug 21, 2026	**E3**: seizes after 206 days. Unit retained for teardown; RCA chartered Aug 24.
Oct 2, 2026	Oil from the unit installed at E3 shows **1,900 ppm water after 6 weeks**. Mechanism still active.

FIGURE 2.1 — CHANGE ANALYSIS: TIME IN SERVICE BEFORE FAILURE



Post-change mean life is 199.5 days, about 1.83 failures per year if nothing changes. The next failure of the current unit is expected around March 2027.

SAMPLE — FICTIONAL D

3 Evidence and Hypotheses

Every finding is graded by how it is known. Six hypotheses were tested against the evidence: one is confirmed, and the rest are ruled out, including the one the plant had been acting on.

TABLE 3.1 — KEY EVIDENCE

ID	EVIDENCE (METHOD)	RESULT	STATUS
EV-01	Oil, failed E3 unit (lab: KF ASTM D6304, ICP, ISO 4406)	Water **4,850 ppm** (new oil 85 ppm), milky; **Na 58 ppm** (new < 2); Fe 312 ppm; ISO 22/20/17	CONFIRMED
EV-02	Oil, unit installed at E3, after 6 weeks	Water **1,900 ppm**, Na 21 ppm: **ingress active on a new unit**	CONFIRMED
EV-04	Teardown, witnessed (ISO 15243:2017)	Corrosion etching at roller spacing; spalling starts at corrosion sites; rust above oil line; no tooth fracture	CONFIRMED
EV-06	Output-shaft NBR lip seal	Hardened (+14 Shore A), radially cracked; chemical attack inferred from compatibility data	SUPPORTED
EV-08	IR thermography, 2 sanitation cycles	Housing 67 °C → 23 °C in 8 min of ambient rinse (**−44 °C**); open vent, no desiccant	CONFIRMED
EV-09	Sanitation observation, 2 shifts	Foam and rinse applied directly to the drive; SSOP silent on drive protection	CONFIRMED
EV-10	CMMS work orders and PMs	No failure or cause codes; spare coded non-stock; “cloudy oil” noted twice and topped off	CONFIRMED
EV-12	VFD fault log, 30 days before E3	No overcurrent trips; motor current 62–71% of FLA	CONFIRMED
EV-13	E1 and E2 physical evidence	Units scrapped without teardown; E2 note: “oil milky”	INFERENCE

TABLE 3.2 — HYPOTHESES TESTED

HYPOTHESIS	DECIDING EVIDENCE	RESULT
H1 · Water and cleaner ingress → moisture corrosion	EV-01, 02, 04, 08, 09: water 57× baseline, sodium signature, corrosion-initiated spalling, active ingress on a new unit	CONFIRMED
H2 · Defective unit or batch (working assumption)	Three units, two bearing lots, identical environmental damage; original unit lasted 6.1 years until the sanitation change	RULED OUT
H3 · Overload from filler jams	No overcurrent trips (EV-12); no tooth fracture or plastic deformation	RULED OUT
H4 · Misalignment	Normal bearing load zone; torque arm serviceable; no fretting	RULED OUT
H5 · Wrong lubricant	H1 PAO VG 220 matches OEM spec; viscosity about 4% below new oil	RULED OUT
H6 · Particulate contamination	Silicon 4 ppm; particle load tracks iron wear debris, so it is an effect, not a cause	RULED OUT

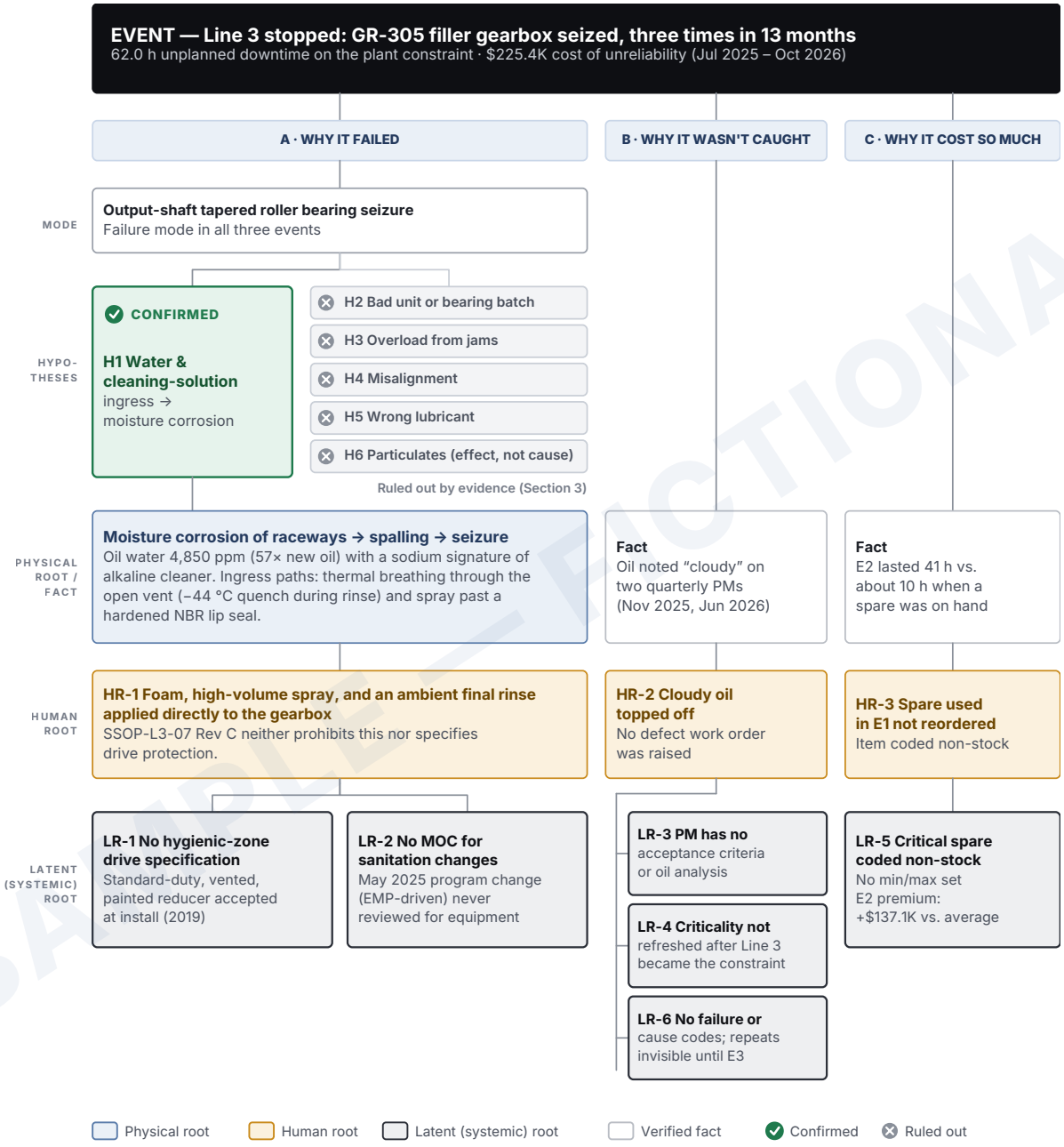
ASSUMPTION CHALLENGED

After E2, the working explanation was a defective gearbox, so the plant restocked the same model. Like-for-like replacement would have reset the clock to roughly 200 days at about $29.4K per event. **What would reopen this analysis:** dry oil at a future failure, or bearing damage that does not start at corrosion sites.

SAMPLE — FICTIONAL DATA

4 Cause-and-Effect Logic Tree and Root Causes

The tree has three branches: why the gearbox failed, why the plant did not catch it, and why one event cost more than five times the others. Every latent root has a corrective action in Section 5.



Each level answers "how could the level above occur?" Human roots are decisions made inside the system; latent roots explain why those decisions were reasonable at the time. No individual blame is assigned.

ROOT CAUSE STATEMENT

Physical: water and alkaline cleaner in the oil caused moisture corrosion of the output-shaft bearing, which progressed to spalling and seizure (ISO 15243:2017). **Human:** sanitation sprays the drive, cloudy oil was topped off without escalation, and the used spare was never reordered. **Latent:** no hygienic-zone drive specification, no MOC for sanitation changes, PMs without acceptance criteria, an outdated criticality ranking, a non-stock critical spare, and no CMMS failure coding. Three of these are plant-wide.

SAMPLE — FICTIONAL D

5 Corrective and Preventive Action Plan

Eleven actions, each traced to a root. The plan favors engineering controls that remove the ingress path over procedures that depend on daily compliance.

ID	ACTION	CLOSES	CONTROL	OWNER	DAYS	COST	CLASS
CA-1	**Replace GR-305 with a sealed, washdown-duty reducer**: stainless housing, FKM double-lip seals, no open vent, IP69K rating, NSF H1 factory fill	Physical, LR-1	Engineering (removes path)	Maint. & Eng. Mgr	30	$13,600	CAPEX
CA-2	**Interim protection until CA-1**: desiccant breather, cleanable stainless splash shield, oil change, monthly oil sample	Physical	Engineering (interim)	Maint. Supervisor	7	$1,150	OPEX
CA-3	**Revise SSOP-L3-07**: no direct foam or spray on drives; cover drives during foaming; revised final-rinse sequence; joint Sanitation and Maintenance sign-off; train all crews	HR-1, LR-2	Admin.	Sanitation Mgr + QA	21	$1,400	OPEX
CA-4	**Quarterly oil-analysis route** for the 12 highest-criticality reducers, including all Line 3 units: KF water, elemental with sodium, ISO 4406, with alarm limits (Figure 7.1)	LR-3, LR-4	Detection	Reliability Engineer	30	$2,160/ yr	OPEX
CA-5	**Rewrite the PM**: replace “check and top off” with inspect and sample; set acceptance criteria; cloudy or milky oil automatically raises a defect WO	HR-2, LR-3	Admin. / detection	Planner	30	6 h	OPEX
CA-6	**Stock one washdown-duty spare**; set min 1 / max 1; flag it as a critical spare in the CMMS	HR-3, LR-5	Admin.	Storeroom / Purchasing	45	$11,900	INVENTORY
CA-7	**Re-rank criticality** for Line 3 and every asset whose duty changed in the 2024 volume shift; update PdM routes	LR-4	Admin.	Reliability Engineer	60	24 h	OPEX
CA-8	**Add failure mode, cause, and action codes** to the CMMS (adapted from ISO 14224); flag any asset with two or more corrective WOs in 12 months for RCA screening	LR-6	Detection	Maint. Mgr / CMMS admin	60	32 h	OPEX
CA-9	**Issue a hygienic-zone drive specification** for capital projects and MRO purchasing: sealed reducers, FKM seals, washdown-rated motors, NSF H1 lubricants	LR-1	Design standard	Engineering	90	16 h	OPEX
CA-10	**Extent of condition**: oil-sample and inspect 14 reducers in washdown zones; rank them and request replacements separately	Physical (fleet)	Detection	Reliability Engineer	30	$630 + 20 h	OPEX
CA-11	**Extend MOC to sanitation program and SSOP changes**, with a mandatory Maintenance and Engineering review step	LR-2	Admin.	Plant Manager	60	8 h	OPEX

Days: due date counted from approval. Internal labor costed at $78/h fully burdened. **Food-safety guardrail:** CA-2 and CA-3 require QA approval. Shields must be cleanable and must not create harborage; cleaning thoroughness does not change (21 CFR 117.35, 117.40).

SAMPLE — FICTIONAL D

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6 Financial Justification

A $36.9K outlay, two-thirds of it CAPEX and balance-sheet inventory, produces a positive 5-year NPV in every scenario tested. The expected case pays back in 4.5 months.

TABLE 6.1 — INVESTMENT AND ACCOUNTING TREATMENT

ITEM	CLASS	AMOUNT	ACCOUNTING TREATMENT
CA-1 washdown-duty reducer, installed	CAPEX	$13,600	Betterment (upgraded design), not like-for-like repair. Capitalization subject to Controller review under plant policy.
CA-6 critical spare (matching unit)	INVENTORY	$11,900	MRO inventory on the balance sheet. P&L impact is carrying cost until the spare is issued.
CA-2 interim guards, breather, oil change	OPEX	$1,150	Expensed as incurred
CA-3 SSOP revision and crew training	OPEX	$1,400	Expensed as incurred
Internal labor, 106 h at $78/h (CA-5, 7–11)	OPEX	$8,268	Mostly non-incremental; included so cost is not understated
CA-10 oil samples, 14 reducers	OPEX	$630	Expensed as incurred
Total cash outlay (year 0)		**$36,948**	
Recurring: oil-analysis route (CA-4)	OPEX/YR	$2,160	12 reducers × 4 samples × $45
Recurring: spare carrying cost (CA-6)	OPEX/YR	$2,380	20% of inventory value per year

TABLE 6.2 — SCENARIO ANALYSIS (PRE-TAX, 5-YEAR HORIZON, 10% HURDLE RATE)

	CONSERVATIVE	EXPECTED	HIGH IMPACT
Failures per year without action	1.20	1.83	2.25
Cost per failure without action	$29,424	$56,846	$75,128
Annual loss exposure without action	**$35,309**	**$104,028**	**$169,038**
Residual failures per year with action	0.30	0.15	0.10
Residual cost per failure	$29,424	$9,800	$9,800
Residual annual loss	($8,827)	($1,470)	($980)
Recurring OPEX added	($4,540)	($4,540)	($4,540)
Net annual benefit	**$21,942**	**$98,018**	**$163,518**
Payback (months, undiscounted)	20.2	4.5	2.7
5-year NPV at 10%	**$46,229**	**$334,617**	**$582,914**
IRR	52%	> 100%	> 100%
PV benefit ÷ outlay	2.3×	10.1×	16.8×

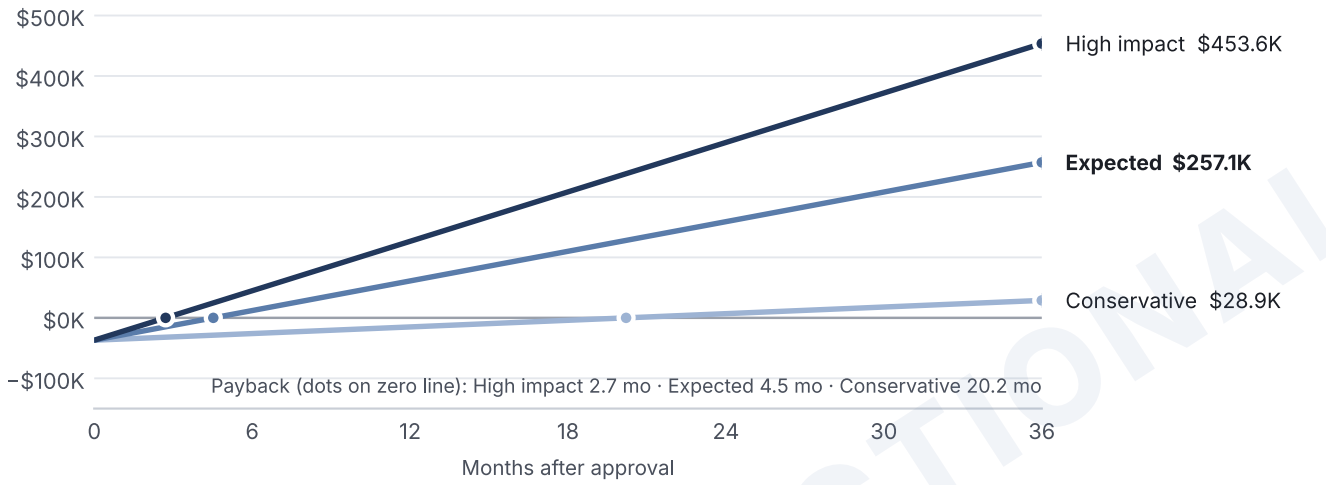
Conservative: 1.2 failures/yr, every one with a spare on hand; residual 0.30/yr at full event cost.
Expected: 1.83 failures/yr implied by post-change life (200 days); 20% of events without a spare; residual 0.15/yr, detected early.
High impact: 2.25 failures/yr (observed rate) at the observed average cost; residual 0.10/yr, detected early.
Cost per failure: $29,424 is the average of E1 and E3 (spare on hand); $166,536 is E2 (no spare); $75,128 is the observed average; $9,800 is a condition-detected, planned replacement in a sanitation window.

SAMPLE — FICTIONAL D

6 Financial Justification (continued)

The cash curve, the stress tests, and the break-even point all lead to the same conclusion: the decision holds even under pessimistic assumptions.

FIGURE 6.1 — CUMULATIVE NET CASH POSITION BY SCENARIO (UNDISCOUNTED)



Line ends show the cumulative cash position at 36 months.

TABLE 6.3 — STRESS TESTS ON THE CONSERVATIVE CASE

STRESS APPLIED	5-YEAR NPV
Base case (Conservative)	**$46,229**
Contribution margin −15%	$39,342
Cash outlay +25%	$36,991
Residual failure rate doubled (0.6/yr)	$12,766
Discount rate 15%	$36,604

NPV stays positive under every single stress. The largest sensitivity is the residual failure rate, which is why verification (Section 7) tracks it directly.

BREAK-EVEN

NPV reaches zero if the package avoids $14,287 of loss per year. That equals about **one spare-on-hand failure every 2.1 years**. Since May 2025, GR-305 has failed every 6.6 months.

CONSERVATISM IN THESE FIGURES

Figures are pre-tax and unlevered. They exclude the CA-1 depreciation tax shield, spare salvage value at year 5, and any benefit from the 14 other reducers (Section 7). Internal labor is included even though most of it is not incremental cash.

SAMPLE — FICTIONAL D

7 Extent of Condition and Verification of Effectiveness

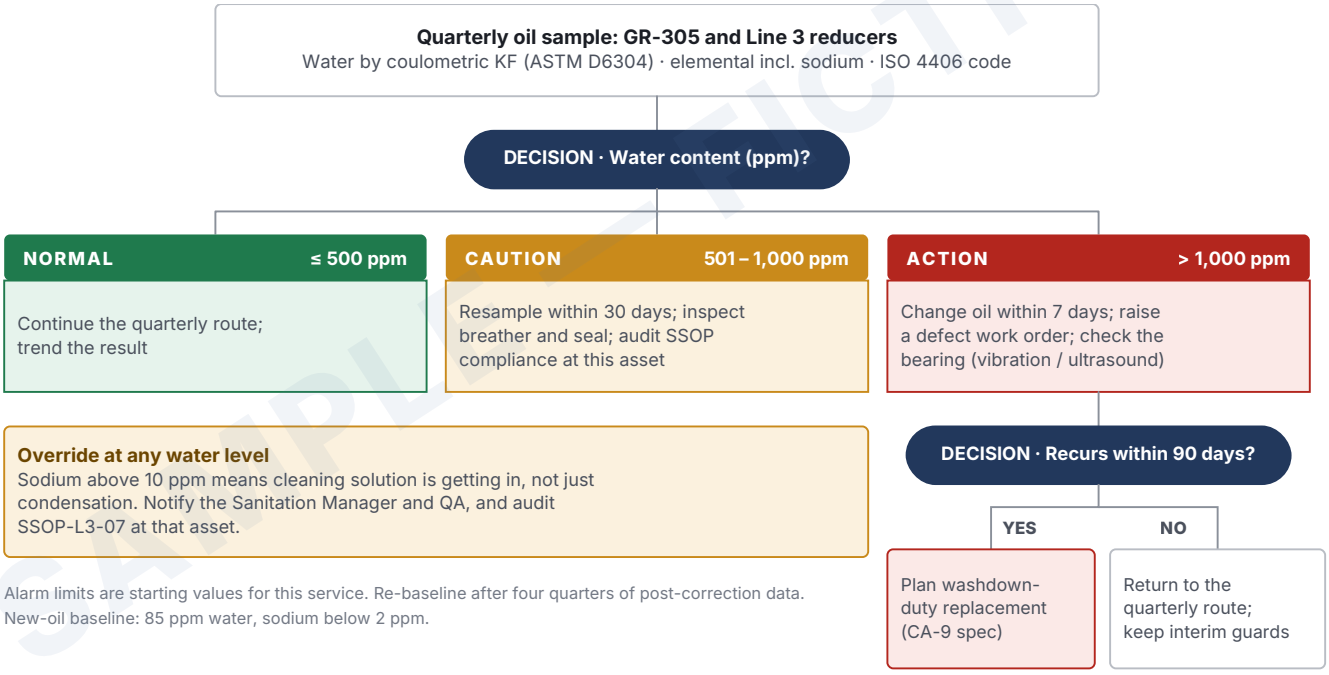
The same sanitation practice reaches 14 other reducers in washdown zones, five of them criticality A. All 14 will be oil-sampled within 30 days (CA-10). That exposure is not included in Section 6 INFERENCE: it may exceed this single-asset case.

TABLE 7.1 — VERIFICATION OF EFFECTIVENESS

MEASURE	TARGET	OWNER · CADENCE
Unplanned GR-305 failures	Zero for 18 months after CA-1	Reliability · monthly
Oil water, Line 3 reducers	≤ 500 ppm and sodium < 10 ppm, 4 consecutive quarters	Reliability · quarterly
SSOP drive-protection compliance	≥ 95% of audited cycles, 3 consecutive months	QA · monthly audit
Corrective WOs with mode and cause coded	100% within 5 days of close	Maint. Mgr · monthly

Why 18 months: at an unchanged 1.83 failures per year, the chance of 18 failure-free months by luck is 6.4%, so 18 clean months gives about 94% confidence that the rate has dropped.

FIGURE 7.1 — DECISION TREE: RESPONSE TO OIL-ANALYSIS RESULTS (CA-4, CA-5)



Alarm limits are starting values for this service. Re-baseline after four quarters of post-correction data. New-oil baseline: 85 ppm water, sodium below 2 ppm.

SAMPLE — FICTIONAL D

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A Limitations, References, and Approval

TABLE A.1 — LIMITATIONS AND THEIR EFFECT ON CONCLUSIONS

GAP	EFFECT
E1 and E2 units scrapped without teardown	E1–E2 attribution is MODERATE. Actions do not change; the mechanism is confirmed on E3 and on the active unit.
Sanitation observed on 2 of about 12 weekly cycles	Variation between crews is unknown; CA-3 audits will measure it.
Recovery percentages from production records	Lost margin uncertain by about ±15%; the conservative NPV stays positive (Table 6.3).
Seal hardening attributed from compatibility data, not lab-tested	Graded SUPPORTED; no effect, because CA-1 specifies FKM seals.

TABLE A.2 — STANDARDS AND REFERENCES

REFERENCE	TITLE AND USE
ISO 15243:2017	Rolling bearings — Damage and failures — Terms, characteristics and causes. Classification of the bearing damage mode (EV-04)
ISO 14224:2016	Petroleum, petrochemical and natural gas industries — Collection and exchange of reliability and maintenance data for equipment. Failure taxonomy adapted for CMMS coding (CA-8). The standard's scope is petroleum industries, but its taxonomy is widely adapted elsewhere.
ASTM D6304-25	Standard Test Method for Determination of Water in Petroleum Products, Lubricating Oils, and Additives by Coulometric Karl Fischer Titration. Water content (EV-01 to EV-03); CA-4 alarm limits
ISO 4406:2021	Hydraulic fluid power — Fluids — Method for coding the level of contamination by solid particles. Particle cleanliness code reported by the laboratory (applied to gear oil by convention)
21 CFR 178.3570	Lubricants with incidental food contact. Basis for the NSF H1 lubricant requirement (CA-1, CA-9)
21 CFR 117.35, 117.40	Current Good Manufacturing Practice — Sanitary operations; Equipment and utensils. Food-safety guardrail for CA-2 and CA-3: equipment must be designed and used to avoid adulterating food with lubricants or contaminated water
ISO 21469:2006	Safety of machinery — Lubricants with incidental product contact — Hygiene requirements. Preferred lubricant certification in the CA-9 specification
Client documents	SSOP-L3-07 Rev C · PM-L3-GR-Q · MOC procedure ADM-012 · Asset criticality register (2019). Internal procedures and records reviewed

REVIEW AND APPROVAL

Prepared by
Lead Reliability Engineer, Apex Reliability Engineering
Signature _____ Date _____

Financials validated by
Plant Controller
Signature _____ Date _____

Approved by
Plant Manager
Signature _____ Date _____

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