Quantifying Antiquity

Integrated Constructibility Model

Working White Paper Draft v1.8

Based on QA_Integrated_Model_v0_64_source_hardening_20260711.xlsx

July 11, 2026

Field	Current working status
Status	Working draft based on a partial integrated model and diagnostic-governance layer. Final findings remain pending full integration decisions for food method, sanitation, processing, river/harbor, administration, and security modules.
Purpose	Construction-management constructibility and logistics analysis. This draft does not propose an alternative construction method.
Core question	Does the conventional construction explanation close as a resource-loaded system when labor, materials, replacement, logistics, human support, and state capacity are loaded together?
Current result	The current partial model does not close as a sustainable state-capacity scenario under the stated assumptions. Shaping/setting (Wave 1), timber labor (Wave 3), ramp construction/maintenance/removal (Wave 4), the Aswan granite expedition (Wave 5, bodies only), and the river/harbor corridor (Wave 6, bodies only; v0.63, Finding F26) are now integrated into M3; sanitation/ medical and processing/fuel/containers remain quantified diagnostics outside M3 until integration-readiness gates are satisfied. Test 1 of the national closure test reports the ex-farmer labor share per the v0.60 numerator ruling (Finding F24), and the food method is ruled: the direct-cropland lower-bound is the headline; the feedback-solved farmer-household loop is published as the named ceiling. The demographic closure test (Section 9.4, Finding F25) finds sustained project mobilization at or above the largest levy the Old Kingdom ever documented, held continuously for the full build. v0.62 adds two hardening levers - imported-labor share (DEFAULT 0) and plank service-life (STEELMAN 2.0x) - that close narrative escape routes by construction; neither moves either verdict. v0.64 page-pins the load-bearing source register with all sight-checks cleared; no model value changes.

Working Table of Contents

1. Executive Summary

This working paper summarizes the current Quantifying Antiquity integrated constructibility model for the conventional Great Pyramid construction explanation. The model treats the construction explanation as a resource-loaded program rather than as a series of isolated demonstrations. It asks whether the claimed system closes when labor, materials, replacement cycles, logistics, human support, and state capacity are loaded together.

The model is deliberately complex, and that complexity is a feature of the method rather than a defect. Prior treatments achieve apparent simplicity by isolating one constraint at a time - moving a block, cutting a stone, floating a beam - and solving each alone. The construction claim only appears to close because its constraints are never loaded simultaneously against a single labor pool, a single food supply, a single landscape, and a single state. This model prices those interactions; its size reflects the size of the real problem.

The current workbook version is v0.64. Its main integrated result remains a partial M3 population burden, not a final full-build maximum. New sheets and updates since v0.39 primarily strengthen control and diagnostic governance. They identify required functions, first-order exposure, source-control gaps, and integration-readiness gates. They do not silently reduce or inflate the main M3 result unless the associated burden has been accepted into Model_04.

Primary finding (labor)	**Value**	**Interpretation**
Test 1 labor (ex-farmer numerator)	54,142	All priced departments minus annual-yield farmers; farmers are priced in Test 2 (Finding F24).
Non-farm able-bodied labor pool (1.6M)	76,800	The real pool for all non-farming functions.
Project share of pool	70.5%	2.8x the 25% single-project mobilization ceiling.
Inclusive share (transparency line)	130.8%	All rostered labor including project farmers; retained for transparency, not the reported Test 1 share.
Robustness across the defensible range	>= 32.2% at every defensible OK population	Below the ceiling only at implausible NK-era corners; Sec 9.1.
Sustained mobilization vs documented max	1.08x the Weni levy (rostered)	The kingdom's largest recorded army, read at maximum, held continuously for 20-30 years; Sec 9.4 (F25).

Primary finding (labor)	Value	Interpretation
Cohort intake	12.3% of every maturing male cohort	2,707 fresh prime-age males required every year of the build, for one monument's non-farm departments.
Population footprint (secondary)	483,769	SECONDARY: includes dependents existing independently of project.
Population share 1.6M	30.24%	Secondary context only.
Secondary ratio vs 150k screen	3.23x	Reference ratio only; the model does not rely on a single hard cutoff.
Diagnostic governance status	v0.56 matrix added	Open diagnostic modules are now rolled up in DiagnosticIntegration_35 and are not additive headline totals.

The principal finding remains restrained: the conventional explanation does not currently close as an integrated, resource-loaded system under the stated assumptions. This is not a claim that the Great Pyramid was impossible. It is a claim that the conventional construction narrative still lacks a closed labor/material/support model.

2. Purpose and Scope

The purpose of the model is to test constructibility. It does not attempt to identify who built the Great Pyramid, and it does not propose a replacement construction method. It tests whether the conventional explanation can satisfy its own required functions without double-spending labor, grain, water, timber, rope, copper, land output, transport capacity, or administrative support.

The model is deliberately framed as a construction-management audit. In modern program controls, a project is not considered constructible merely because an isolated task can be demonstrated. The full work breakdown structure must be resource-loaded, sequenced, supported, and sustained.

The scope of the current draft includes hauled-stone cadence, water logistics, route capacity, quarrying, rope/fiber, copper/tools, food, kingdom capacity, universal human requirements, water feedback, youth light support, water-infrastructure alternatives, food feedback, sanitation/medical control, processing/fuel/container control, timber-system control, ramp-system control, and shaping/setting/casing control. Shaping/setting/casing, timber labor, and ramp systems are integrated into the headline M3 total (Waves 1, 3, and 4); the remaining diagnostic layers are not.

3. Methodology and Definitions

Why a Resource-Loaded Program Model Is Required

The conventional construction explanation commonly invokes ramps, sledges, ropes, corvee labor, skilled organization, and state capacity. Those are not complete models. They are components of a model. The constructibility question is whether all required components can operate together at the required production cadence without exceeding the available labor, material, replacement, logistics, and support capacity.

In program-controls terms, the pyramid build must be treated as a resource-loaded WBS. Direct work crews create indirect work. Indirect work creates households, water, food, replacement, sanitation, containers, storage, tools, supervisors, and administration. A burden cannot be deleted unless the function it performs is reassigned to another mechanism and cost-loaded.

System Closure

System closure means that every necessary function is assigned a feasible mechanism, and every mechanism is assigned its labor, material, replacement, support, and feedback burden. A system does not close if it satisfies the visible construction task while leaving required support functions unpriced.

Material Balance

Material balance means the same output cannot be spent twice. Grain assigned to project workers cannot simultaneously feed the non-project economy. Timber assigned to fuel cannot simultaneously serve as sled runners, planking, levers, cribbing, anchors, or boats. Rope assigned to active hauling cannot simultaneously satisfy replacement, handling, anchor, and staging demands unless those demands are separately loaded.

Required-Function Audit

The model uses a required-function audit. If a critic reduces a burden, the associated function remains. The model therefore asks what replacement mechanism, productivity change, schedule change, scope reduction, or source-supported assumption carries that function instead.

4. Model Architecture

The workbook is organized as an integrated model plus control layers, diagnostic modules, source-control tracking, and an integration-decision roll-up. Model_04 carries the current headline partial M3 result. Later sheets identify open functions, feedback risks, source gaps, and future integration gates. This prevents open diagnostic burdens from being mistaken for accepted totals.

Workbook layer	Status in v0.63	Purpose
Model_04	Integrated partial M3	Main live calculation engine for current headline population and key operating assumptions.
WorkforceLedger_05	Integrated	Active labor, rostered labor, and household/ population separation.
RouteCapacity_12	Integrated / partial	Route, lane, cadence, and track-wetting support checks.
FoodSystem_13	Integrated / lower-bound partial	Grain, cropland, food production, and food-processing capacity checks.
HumanRequirements_20 / WaterFeedback_21	Integrated for water when toggle is YES	Algebraic domestic/process water feedback and carrier-village population loop.
YouthLightSupport_26	Integrated as bounded credit	5% intermittent youth light-support credit against adult-carried village domestic/process water only.
WaterInfrastructureAlternatives_27	Control only	Replacement-system gate for canals, depots, wells, animals, storage, boats, or other water-delivery claims.
FoodFeedback_28	Method ruled / named ceiling	Direct-cropland lower-bound remains the M3 headline; the feedback-solved farmer-household loop is published as the named ceiling (Section 7.3).
SanitationMedical_29	First-order diagnostic	Waste handling, cleaning, and basic medical support diagnostic.
ProcessingFuelContainers_30	First-order diagnostic / non-additive risk	Processing labor, fuel handling, container circulation, reserve, and replacement diagnostic.

Workbook layer	Status in v0.63	Purpose
ShapingSetting_33	Integrated (Wave 1)	Final shaping, setting, casing, copper-tool wear, timber support, and rework exposure with readiness gate.
TimberSystem_31	Material screen control-only; labor integrated via TimberLabor_40 (Wave 3)	Structural timber active stock, replacement, gross timber, and service-life sensitivity screens.
RampSystem_32	Integrated (Wave 4)	Ramp body material, construction, maintenance, traffic/staging, and removal/rework screens.
CitationControl_34	Source-control layer	Flags load-bearing source gaps, page/table tasks, and internal model-control rules.
DiagnosticIntegration_35	Governance / roll-up layer	Summarizes diagnostic modules, first-order exposure, M3 readiness, and non-additive controls.
GraniteAswan_42 / BargeTimber_43	Integrated (Wave 5, bodies only)	Aswan expedition corps, barge-fleet sizing, and felled-acacia feed into the timber labor chain.
DemographicClosure_46	Verdict layer (v0.61)	Sustained-mobilization test against the kingdom's maximum documented capacity; adds no burden to M3.
RiverHarbor_47	Integrated (Wave 6, bodies only)	Barge crews, harbor gangs, and pilotage for the Aswan granite corridor, Merer-anchored.

5. Current Partial Model Results

Metric	Current value	Notes
Hauling rostered labor vs adjusted effective labor pool	8,761	Case C hauling alone remains above the adjusted effective labor pool.
On-site rostered labor, six priced departments	47,316	Haulage + water + rope plant + quarry + shaping/setting + ramp.
Implied on-site village population	281,643	Village ratio applied to on-site rostered burden.
Current partial project-dedicated population	483,769	Includes implied village and off-site support households.
Share of 1.6M Old Kingdom population (standard anchor)	30.24%	Standard scholarly anchor (Butzer); higher-estimate sensitivity in workbook.
Copper demand multiple of Bir Nasib all-time average	7.76x	Supply-chain burden check.
Share of Bir Nasib all-time output consumed by one build	11.93%	Supply-chain burden check.

The current headline result should be read with two cautions. First, it falls between the 300,000 and 500,000 mobilization-capacity bands before several major functions are integrated. Second, some open sheets may add burden if accepted into the main model, while possible alternatives can reduce specific burdens only if their replacement functions are cost-loaded.

Reporting convention: headline values are live workbook outputs. In prose they are reported to three significant figures; exact values remain in the tables and the workbook to preserve traceability without implying false precision.

The model also fails in layers rather than only after burdens are stacked:

Model level	Result	Status
M1 - Hauling only	8,761 rostered vs 4,200 effective pool	Does not close.
M2 - Construction core	47,316 on-site rostered and 281,643 implied village vs 25,000 excavated capacity	Does not close on labor or on settlement capacity.

Model level	Result	Status
M3 - Integrated (partial)	483,769 project-dedicated population	Does not close against mobilization-capacity bands.

The 25,000 settlement ceiling in M2 is set generously and is now re-badged as such (v0.64): it sits at the top of the mainstream workforce range, well above the published excavated-capacity arithmetic for the worker town itself (Lehner 2002; Lehner 2015). A smaller, excavation-honest ceiling only worsens the M2 failure. The number is a steelman by construction.

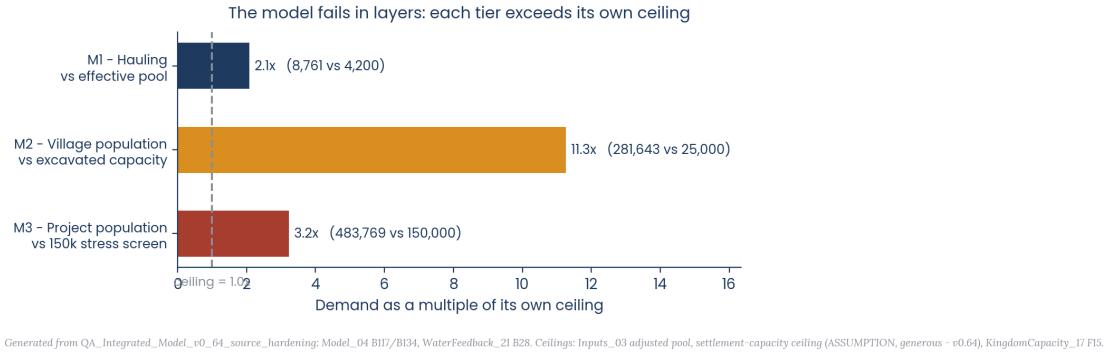

Figure 1. Layered failure: each model tier exceeds its own ceiling before the next tier is stacked. All values live from the v0.63 workbook.

6. Model Mode, Integration Rules, and Burden Maturity

The current workbook is best treated as a feedback-solved integrated partial model, not a final full integrated release candidate. Water has been moved beyond a first-order diagnostic by solving the carrier-village feedback loop. Food is now a ruled method pair: the main M3 direct-cropland lower-bound is the headline, and the feedback-solved farmer-household loop is published as the named ceiling (Section 7.3). Sanitation/medical support and processing/fuel/containers remain controlled/open unless and until their integration gates are satisfied; shaping/setting/casing (Wave 1), timber labor (Wave 3), ramp systems (Wave 4), the Aswan granite expedition (Wave 5, bodies only), and the river/harbor corridor (Wave 6, bodies only) are integrated.

Rule	Application
No silent burden deletion	A reduction in carriers, labor, timber, water, food, or material requires a replacement mechanism or changed productivity/ schedule/scope assumption.
No double-spending	Fuel wood, structural timber, labor, rope, grain, containers, and land output cannot satisfy two independent burdens unless separately sized.
No direct-labor-only additions	Future operations must be human-loaded and feedback-checked before entering M3.
Diagnostics are not headline totals	Control sheets may show first-order impact, but the main result does not change until the burden is accepted into Model_04.
Diagnostic roll-up is not additive	DiagnosticIntegration_35 prevents first-order diagnostic burdens from being stacked into a new headline total before readiness gates, double-count controls, and feedback treatment are resolved.

7. Operation Modules and Support Layers

7.1 Cadence and Haulage

The Case C desert-honest scenario requires a 205.7-block/day cadence, approximately 63 simultaneous haul teams, and approximately 55 blocks in tow simultaneously. These values set a traffic and route-capacity burden that any ramp or route solution must support.

Haulage metric	Case C value
Blocks per 24 hours	205.7
Teams required to hold cadence	63
Blocks in tow simultaneously	55.0
Track-wetting water already priced	144,000 L/day

7.2 Water Feedback, Youth Light Support, and Water Alternatives

Water is the most mature feedback layer in the current workbook. Domestic/process water was integrated because the previous model could not simply add village water as a one-step load. More village water requires more carriers; more carriers increase rostered workers; more rostered workers increase implied village population; and that larger village requires more water. WaterFeedback_21 solves this loop algebraically.

Water metric	Current value	Treatment
Integrated Giza-delivered water	3,388,287 L/day	Loaded in current M3 water treatment.
Domestic/process water dispatched incl. loss	2,964,662 L/day	Volume remains required even if delivery method changes.
Base active carriers before domestic/process feedback	1,471	Pre-feedback baseline.
Current active adult water carriers	19,960	After water feedback and 5% youth light-support credit.
Incremental active carriers from domestic/process water	18,489	Main reducible burden if a replacement water-delivery system is cost-loaded.

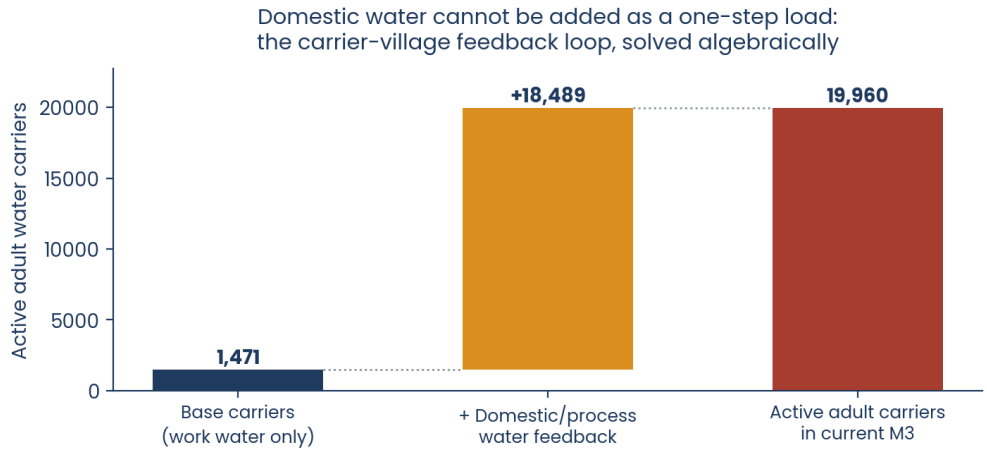

Figure 2. The carrier-village feedback loop: adding domestic/process water multiplies the carrier department roughly thirteenfold once the loop is solved rather than stacked.

YouthLightSupport_26 applies a bounded 5% intermittent youth light-support credit only to adult-carried village domestic/process water burden. This recognizes that older children likely helped with light tasks at times, but it does not turn children into a continuous adult-equivalent labor department and does not reduce the water volume required.

WaterInfrastructureAlternatives_27 preserves the fair criticism that water may not have been entirely hand-carried. The model does not reject that possibility. It requires the replacement system to be quantified: depots, canals, wells, cisterns, animals, sled tanks, boats, or permanent water infrastructure must carry their own labor, material, maintenance, feedback, and evidence burden before they reduce the main M3 carrier total.

7.3 Food System and Food Feedback

The food method is now ruled rather than forked. FoodSystem_13 remains integrated as the direct-cropland lower-bound, and that lower-bound stays the headline M3 method. FoodFeedback_28's feedback-solved farmer-household loop is no longer an unresolved sensitivity fork: it is published as the named ceiling of the food system. The two methods bracket the food burden. The headline is the least the food system can cost; the named ceiling is what it costs once producer households are solved through the surplus loop. v0.38 corrected grain and fiber farmers to a roster factor of 1.0 because annual crop yield already embeds the agricultural calendar. Standing facility, transport, retting, fiber prep, water, quarry, copper, rope, ramp, and other continuous project-service crews retain the full roster/replacement multiplier.

Food-feedback diagnostic	Current value	Result
Gross grain output per active farmer	1.80 t/yr	Current input.

Food-feedback diagnostic	Current value	Result
Gross food required per active farmer household	1.21 t/yr	Corrected farmer-household requirement; no construction-crew roster multiplier.
Net surplus per active farmer after own household support	+0.59 t/yr	Positive under corrected annual-yield treatment.
Implied net surplus share	32.53%	Net surplus divided by gross output.
Food feedback status	PASS / CONTROL	Annual-yield farmer loop generates surplus; full project food-method choice remains open.
Feedback-solved total, FoodFeedback_28 basis	869,946 people	Sheet value; its off-site basis predates Waves 3-6 (DERIVED).
Named ceiling, reconciled for Waves 3-6	~880,300 people	880,308 at current levers: sheet value + timber households (6,836) + granite corps (2,783) + river/harbor crews (743, bodies only) (DERIVED).
Named ceiling as share of the 1.6M kingdom	55.0%	Ceiling method only; the headline M3 remains the direct-cropland lower-bound (DERIVED).

The food diagnostic is still important because off-site production is not free. If the pyramid requires the output, that production capacity is project-dedicated. The same grain cannot feed the pyramid workforce, feed farm households, serve as seed/storage reserve, and remain fully available to the non-project economy.

7.4 Sanitation, Waste, and Basic Medical Support

SanitationMedical_29 is a first-order control layer. It does not add a new water demand, because the current water model already includes a hygiene/sanitation water allowance. It exposes the missing labor/function side: latrines, waste handling, cleaning, refuse control, and basic injury care.

Sanitation / medical diagnostic	Current first-order result	Integration status
Combined support workers	1,128 active / 1,961 rostered	Diagnostic only.

Sanitation / medical diagnostic	Current first-order result	Integration status
Population if integrated before feedback	7,843	Not accepted into M3. Full feedback would be required first.
Treatment	Control layer	Labor, materials, and support feedback remain open.

7.5 Processing, Fuel, and Containers

ProcessingFuelContainers_30 exposes the fact that grain, water, and fuel are not useful merely because they exist. They must be milled, baked, brewed, stored, distributed, carried, contained, cleaned, repaired, and replaced. FoodSystem_13 already had some food-processing math, but the new control layer isolates container circulation and replacement logic.

Processing/fuel/ container diagnostic	Current value	Integration note
Food-processing labor total	24,171 active	Capacity check/control layer, not added as a new department.
Processing share of current on-site rostered workers	51.08%	High share; must not be double-counted as both background household labor and standing department.
First-order M3 if processing labor were added as new department	648,285 people	Diagnostic only; not accepted into Model_04.
Integrated Giza water needing containers	3,388,287 L/day	Container circulation must be compatible with water system.
Minimum daily utility containers in circulation	79,089	One full annual turnover implies 79,089 replacements/year.

7.6 Timber System

TimberSystem_31 is now a quantified structural-stock and replacement diagnostic. It screens active structural timber stock, annual replacement, gross timber before conversion/reject/handling losses, and cumulative 20-year gross timber demand. The material-stock screen remains control-only, but the labor it implies is converted and integrated into M3 off-site via TimberLabor_40 (Wave 3). Species/grade/dimensions, service life by use class, boat/harbor recursion, and feedback effects remain open levers on the screen.

Timber diagnostic item	Base result
Base active structural timber stock screen	292.7 m3
Usable replacement timber per year	292.7 m3/yr
Gross timber before losses	667.2 m3/yr
Cumulative gross over 20-year build	13,343.7 m3
Multiple of 2,745 m3 cedar comparator	4.86x
M3 readiness	Material screen control-only; labor integrated (Wave 3)

7.7 Ramp System

RampSystem_32 is now an expanded material, traffic, maintenance, and removal diagnostic. It screens ramp body volume, material mass, construction man-days, annual maintenance, removal/rework, traffic/staging crew, and diagnostic population. The construction, maintenance, and removal crew is integrated into M3 (Wave 4) at the restored base parameters; surface-replacement treatment, traffic-model detail, and final-access/removal phasing remain open levers.

Ramp-system diagnostic	Base value	Status
Ramp body volume	250,000 m3	Diagnostic screen only.
Ramp body material mass	450,000 t	Material burden screen.
Construction man-days	125,000	Productivity/source basis remains open.
Annual maintenance volume	25,000 m3/yr	Surface/route maintenance screen.
Removal/rework volume	62,500 m3	Final-access/removal/rework screen.
Traffic/staging active crew proxy	12.6 active workers	Traffic-control proxy only.
Base diagnostic active crew	108.1 active workers	Integrated (Wave 4): 188 rostered in M3.
Diagnostic population (integrated)	1,118 people	Enters M3 through the village ratio.
Total material handled over build	1,062,500 m3 / 1,912,500 t	Construction + maintenance + removal/rework screen.
M3 readiness	INTEGRATED (Wave 4)	Surface replacement, traffic detail, and removal phasing remain open levers.

7.8 Quarrying, Rope/Fiber, Copper/Tools, and Route Capacity

Quarrying, rope/fiber, copper/tool support, and route capacity remain part of the integrated or partially integrated model. Their treatment is not final. They already show that the visible block-hauling task imports off-site land, fiber, copper, wood/fuel, and transport burdens that cannot be treated as free background economy once their output is assigned to the pyramid.

One reading note on the copper comparator, recorded once (v0.64): the Bir Nasib all-time output ceiling of roughly 5,000-5,500 tonnes is dominated by Late Bronze Age and New Kingdom smelting, roughly a millennium after Khufu (Abdel-Motelib et al. 2012; Bachmann's calculation for the metallic total). The Old Kingdom-era ceiling is therefore lower than the all-time figure the model grants, and the 7.76x and 11.93% comparisons are computed against the inflated denominator - generous to the conventional scenario as used.

7.9 Shaping, Fitting, Setting, Casing, and Rework

ShapingSetting_33 is now a quantified shaping/setting/casing/rework diagnostic with an explicit M3 integration-readiness gate. Model_04 B48 remains quarry-only copper-tool demand. Final shaping, fitting, trimming, setting, alignment, casing, copper-tool wear, timber support, and rework are priced at the base screen and integrated into M2/M3 (Wave 1); productivity, tool wear, casing scope, and support materials remain open levers.

Shaping/setting diagnostic	**Base result**
Final shaping/trim active labor	25.7 active workers
Setting/alignment support active labor	82.3 active workers
Casing active labor	0 in base screen
Rework/correction active labor	5.4 active workers
Base diagnostic total	113.4 active / 197.1 rostered
Diagnostic population if integrated	1,173 people
Copper/tool diagnostic	1.38 t/yr gross copper incl. supply-chain loss
M3 readiness	INTEGRATED INTO M2/M3 (Wave 1)

7.10 Diagnostic Integration Matrix

DiagnosticIntegration_35 is the current governance layer for open diagnostic modules. It records M3 readiness and prevents first-order diagnostic burdens from being treated as additive headline totals. This is a control layer, not a new burden total.

Module	Diagnostic status	M3 ready?	Why outside M3
Food feedback	Ruled: named ceiling	No	Headline M3 uses the direct-cropland lower-bound; feedback-solved ceiling ~880,300 published (Sec 7.3).
Sanitation/ medical	Support diagnostic	No	Rates, materials, and feedback remain open.
Processing/ fuel/ containers	Handling diagnostic	No	Non-additive risk; household vs standing labor unresolved.
Shaping/ setting	Quantified diagnostic	Yes (Wave 1)	Integrated; casing scope and tool-wear levers remain open.
Timber	Stock/replacement diagnostic	Labor: Yes (Wave 3)	Material screen control-only; labor integrated via TimberLabor_40.
Ramp	Material/traffic/ removal diagnostic	Yes (Wave 4)	Integrated; surface and phasing levers remain open.

The diagnostic modules are not additive headline totals. They identify required construction and support functions, first-order exposure, and readiness gaps. A diagnostic burden enters M3 only after productivity, material basis, person-category treatment, food/water feedback, and double-count controls are resolved.

7.11 Sourced-Chassis Audit: The Integrated Edge-Ramp (IER) Model

In 2026, a peer-reviewed computational study proposed an Integrated Edge-Ramp (IER) construction model for the Great Pyramid (Rosell Roig, npj Heritage Science 14:142). The study couples parametric geometry, discrete-event logistics, and staged finite-element analysis, and concludes that an adaptive multi-ramp schedule can sustain the required block cadence within the reign window. The author published the complete code and datasets openly; that reproducibility standard is what makes the audit in this section possible, and this module is offered in the spirit of extension that the study's open framework explicitly invites.[1]

This model adopts the IER chassis in full: its geometry, its friction basis, its lane dimensions, its corner architecture, and its traffic log. Two of its parameters independently corroborate choices made elsewhere in this model: the IER work calendar is a 10-hour day, six days per week - the same modern-practice availability floor adopted in Section 3 - and its block mass and team sizes sit near this model's steelman values. On its own terms, the IER study prices the mechanics and the schedule. It does not price the support system, and its running surface is specified as wetted adobe or short planking with corner bays planked per experimental calibration, at a friction value purchased with approximately 5% water saturation.

The author's own simulation log supplies the wear driver: 670,264 loaded sledge-kilometers on ramp surfaces across 2,236,463 blocks - 670 million lane-meter passes before any empty return. Priced at a 2,000-pass plank service life, 30% planked share, and 70 mm decking, the replacement stream is approximately 26,700 cubic meters of planking over the build - about 1,340 cubic meters per year, 156 times the peak standing stock, and 9.7 times the cedar-import comparator carried in the Timber System module. The study's zero-footprint recycling claim is true of the standing stock, which is the denominator of that ratio; wear is the numerator, and abraded planking does not return to service. Sensitivity is reported in the workbook: at a 5,000-pass service life the stream remains roughly four times the cedar comparator.

As of v0.62 the reuse claim is priced as a lever rather than argued. The workbook carries a plank service-life multiplier for flipping and down-grading worn decking (DEFAULT 1.0), so the 26,700 cubic meters is now the DEFAULT of a levered quantity, not a fixed number. At the STEELMAN setting of 2.0 - every plank flipped and run to a second full life - the replacement stream halves to roughly 13,350 cubic meters per build and the conventional scenario is granted 714 rostered timber men in full, propagated through the timber labor chain into M3. The verdict does not move. Fuel down-cycling is credited separately in the wood-fuel ledger (Section 9.3), capped at actual fuel demand, so the lever cannot spend the same wood twice.

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[1] Workbook module IERRampTimber_38 uses the author's latest data deposit (GitHub viroroi-pub/Egypt v1.0.14, mirrored at Zenodo DOI 10.5281/zenodo.16732345), whose adaptive ramp schedule (12/6/3 channels) differs from the schedule printed in the published paper (16/8/4/2/1, dataset v1.0.10). All figures in this section derive from the v1.0.14 deposit and are pinned to named files on the module sheet.

Two further burdens are logged as open items on the module sheet. First, lane wetting at the study's own saturation specification adds a modest volume (roughly 23,000 liters per day on average) but every liter climbs to the active course, and the carriers ascend the same 3.8-meter lanes that the study's queuing model fills with block traffic at 4-6 minute headways; the study acknowledges counterflow in single-ramp phases and does not model support traffic. Second, between-pull holdback: sledges on a 7-degree grade must be blocked behind during team repositioning or they run back - standard dunnage practice in modern haulage - adding timber consumables, chock crews, and cycle time that a continuous-speed model does not carry.

The finding, in this model's terms: the IER study closes the schedule and does not close the system. Its feasibility conclusion rests on the support burden it excludes, and this section prices that burden from the author's own published geometry and traffic data. The module is control-only and does not enter the M3 headline pending its integration gates.

8. Workforce Ledger and Population Burden

The model separates active labor from rostered labor and separates both from household/dependent population. This is a critical distinction. A headcount of people physically present in a settlement is not the same as an effective continuous labor pool. Rostered labor accounts for availability, replacement, rest, rotation, and attrition assumptions. Household/dependent population accounts for the wider support footprint implied by standing labor departments.

Population category	Current value	Notes
On-site rostered workers	47,316	Current M3 on-site rostered construction/support total.
Implied on-site village population	281,643	On-site rostered burden converted to settlement population footprint.
Off-site project-dedicated population	202,126	Rope/fiber, copper/tools, food, timber, and other off-site project-support households after farmer roster correction, plus the granite and river/harbor corps carried as bodies only.
Total project-dedicated population	483,769	Current partial M3 headline.

8.4 Village Sufficiency Test (Wave 2)

Several support functions - food processing, sanitation, basic medical care, and container circulation - describe people who live inside the worker village rather than additional off-site labor. The excavated settlement ratio (approximately 5.95 villagers per rostered worker) already contains such people implicitly. Adding their head-counts to the project-dedicated total would double-count the ratio.

This model therefore does not stack them. Instead it runs a sufficiency test: it sums the village-internal support headcount the model's own modules require and compares that to the non-worker population the settlement ratio actually supplies. At current assumptions the required village-internal support is approximately 24,700 against roughly 234,300 non-worker villagers supplied - about 10.5% - so the ratio is sufficient to staff its own support functions, and the test returns WITHIN RATIO.

The finding is reported honestly: at default assumptions this test does not break the settlement ratio. Its value is structural. The model publishes the excavated ratio (5.95) as a floor and a bottom-up derived village multiplier (5.52 at current levers: one worker, plus dependents, plus required internal support) as an audit of it. The derived multiplier tracks the support burden directly, so any tightening of the support assumptions - caregiver-to-population ratio, milling rate, sanitation coverage - raises required support and moves the test toward RATIO INSUFFICIENT without any change to the headline method. The sufficiency test is a standing diagnostic, not a one-time claim, and it is immune to the double-counting objection that headcount stacking would invite.

9. Kingdom Capacity and Mobilization-Capacity Bands

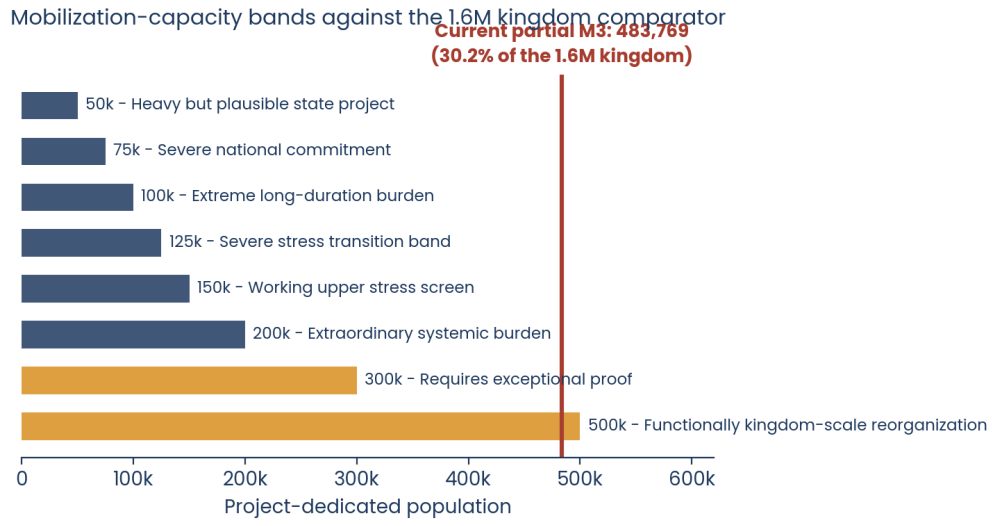
The kingdom-capacity sheet compares the total project-dedicated population footprint against the standard scholarly anchor for the Old Kingdom population comparator of 1.6 million. This is intentionally generous and is treated as a stress-test denominator, not a literal census figure. The workbook cites Karl W. Butzer, Early Hydraulic Civilization in Egypt, Table 4, 2500 B.C., as the source basis for this comparator.

The model now uses mobilization-capacity bands rather than a single hard cutoff. The 150,000 line is retained only as a working upper stress screen inside the band table. It is not a sourced historical ceiling, and the 9.375% figure is arithmetic only: 150,000 divided by 1,600,000.

Capacity metric	Current value	Interpretation
Old Kingdom population denominator	1,600,000	Standard scholarly anchor comparator.
Current partial project-dedicated population	483,769	Live M3 population footprint.
Share of kingdom	30.24%	Primary population-share metric.
Capacity-band position	Between 300,000 and 500,000 bands	Primary framing.
150k working upper stress screen	150,000	Reference screen only, not a hard historical ceiling.
Current model / 150k screen	3.23x	Secondary reference only.
Excess above 150k screen	333,769	Secondary reference only.

Project-dedicated population	Share of 1.6M	Capacity-band label
50,000	3.13%	Heavy but plausible state project
75,000	4.69%	Severe national commitment
100,000	6.25%	Extreme long-duration burden
125,000	7.81%	Severe stress transition band
150,000	9.38%	Working upper stress screen
200,000	12.50%	Extraordinary systemic burden
300,000	18.75%	Requires exceptional proof

Project-dedicated population	Share of 1.6M	Capacity-band label
500,000	31.25%	Functionally kingdom-scale reorganization



Generated from QA_Integrated_Model_v0_64_source_hardening: KingdomCapacity_17 B15 and band table A23:C30. Partial model - pending burdens push the line right, not left.

Figure 3. Capacity-band position: the current partial M3 population sits between the 300,000 and 500,000 bands before pending burdens are integrated.

The evidentiary support for this framework does not come from a single sourced percentage. It comes from several lanes: the Old Kingdom population comparator provides the denominator; the archaeology of Heit el-Ghurab shows organized provisioning; published mainstream workforce estimates provide scale comparison; Old Kingdom provisioning networks support treating required off-site output as economically project-dedicated; and preindustrial agrarian surplus logic supports testing large output and labor diversions against available surplus.

The mainstream's own subsistence work points the same direction. Modeling the Old Kingdom provisioning network from the faunal record at both of its ends - the Kom el-Hisn production site and the Giza worker town - Redding concludes that "labour, not land, must have been the limiting factor" (Redding 2013). Labor is precisely the resource the closure tests in this section price.

The model therefore does not ask the reader to accept one magic number. It reports the current burden across bands. At approximately 483,000 (live workbook value 483,769) project-dedicated people, the current partial model falls between the 300,000 and 500,000 bands before multiple open burdens are integrated.

9.1 National Closure Test: Able-Bodied Labor and Agricultural Surplus

The population-share metric, while striking, understates the problem. A construction project does not draw on a national population in the abstract. It draws on two specific and far scarcer resources: able-bodied labor, and agricultural surplus. The national closure test evaluates the project against both, and it is the point at which the integrated model returns a definite verdict.

Consider able-bodied labor first. In a high-mortality preindustrial agrarian population, the working-age, physically-fit share is on the order of one in four or fewer; the model takes 24% - a generous figure. Against the 1.6 million anchor, that is approximately 384,000 able-bodied people for the entire kingdom. But most of them cannot leave the land: preindustrial societies require the large majority of their labor simply to feed themselves, and the model takes 80% as agrarian, which is low and therefore generous. That leaves roughly 76,800 non-farm able-bodied people to supply everything the state does that is not farming - the army, the priesthood, trade, administration, every other monument, and the pyramid.

The project's own rostered labor demand, integrated across all priced departments, is approximately 100,492 people. That total includes 46,350 rostered annual-yield farmers - the grain and fiber growers on project-dedicated land. Test 1 does not count them. The reason is structural, and it answers the strongest objection this test faces. A critic can argue that counting project farmers against the non-farm pool charges the same people twice: once as labor drawn from a pool defined to exclude farmers, and once as agricultural burden in Test 2. The objection is fair, and the model concedes it in full (Finding F24, ruling 2026-07-09). Annual-yield farmers are farm-side labor. Their entire burden - land, households, surplus draw - is priced in Test 2, the agricultural surplus ceiling. They are removed from the Test 1 numerator.

What remains is the ex-farmer numerator: 54,142 rostered people who are not farmers and must come from the non-farm pool. As a share of all able-bodied labor that is 14.1%. As a share of the non-farm able-bodied pool - the honest denominator and now the honest numerator - it is 70.5%. The single-project mobilization ceiling is 25%: no pre-modern state assigns more than a quarter of its non-farm labor to one monument and still funds its army, temples, administration, trade, and other construction. The ex-farmer demand is 2.8 times that ceiling. The inclusive figure of 130.8% - all rostered labor including project farmers against the same pool - is retained as a transparency line so the pre-ruling framing remains visible, but it is not the reported Test 1 share.

National closure metric	Value	Reading
Able-bodied population (24% of 1.6M)	384,000	Generous high share
Non-farm able-bodied (after 80% farm)	76,800	The real labor pool for all state functions
Test 1 labor (ex-farmer numerator, F24)	54,142	All priced departments minus annual-yield farmers

National closure metric	Value	Reading
Share of all able-bodied	14.1%	One project, one metric
Share of non-farm able-bodied	70.5%	2.8x the 25% single-project mobilization ceiling
Inclusive share (transparency line)	130.8%	Pre-ruling framing, retained; not the Test 1 share

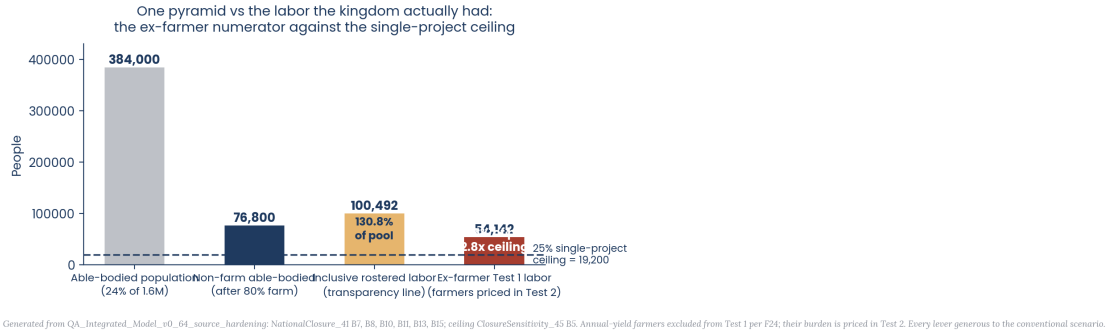


Figure 4. The national closure test on the ex-farmer numerator: Test 1 labor against the non-farm pool and the 25% single-project mobilization ceiling, with the inclusive rostered total retained as the transparency line.

This result does not depend on the demographic assumptions. The non-farm pool is the product of three levers - population, able-bodied share, and agrarian share - and a critic can widen it by pushing all three. The closure sensitivity grid (workbook sheet ClosureSensitivity_45) rebuilds the test on the ex-farmer numerator across the full range: able-bodied share from 20% to 30%, agrarian share from 85% down to 65%, and population from 1.6 million to an implausibly high 2.5 million. The claim is stated precisely, because the ruling changed what the grid shows. The finding holds at every defensible Old Kingdom population: at the 1.6 million Butzer anchor, no cell in the grid brings one pyramid under the 25% single-project ceiling, and the minimum anywhere in that grid is 32.2%. At the 2.0 million high case, every cell still exceeds the ceiling. Shares dip below the ceiling only at 2.5 million - a New-Kingdom-era population no one claims for the reign of Khufu - and even at that grid's most generous corner one pyramid still takes 20.6% of the entire non-farm workforce. The verdict is robust across the defensible range and is no longer exposed to the farm/non-farm double-jeopardy objection.

One escape route is closed by construction rather than by argument. As of v0.62 the model carries an imported-labor share lever (DEFAULT 0, because the mainstream model itself claims an Egyptian workforce). Moving it does not rescue the test. Imported labor shifts only the pool draw; the food, water, housing, and population burdens are nationality-invariant - a foreign hauler eats, drinks, and lives in the same village as a domestic one. The documented record points the same

way: the Weni inscription shows foreign auxiliaries raised episodically for single campaigns, never sustained for decades.

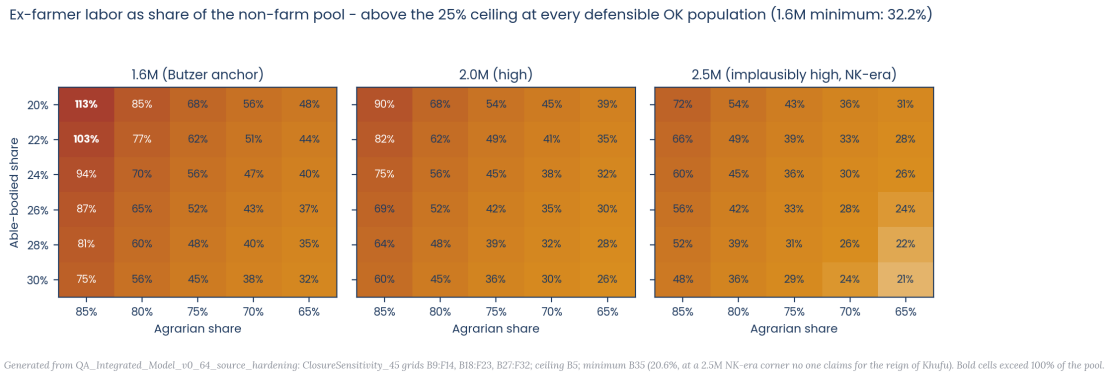


Figure 5. Closure sensitivity on the ex-farmer numerator. Above the 25% single-project ceiling at every defensible Old Kingdom population (1.6M minimum: 32.2%); below the ceiling only at implausible NK-era corners. Bold cells exceed the entire pool.

The result should be read for what it is. The model has just handed the conventional scenario its strongest available correction - every farmer removed from the labor numerator, their whole burden shifted to the surplus test where it belongs - and one pyramid still demands 70.5% of the entire non-farm workforce, 2.8 times the ceiling any pre-modern state could assign to a single monument. That pool must simultaneously sustain the military, the administration, the temple economy, trade, and the other monumental works of the period, including the three preceding pyramids of the same dynasty built within living memory. The test returns EXCEEDS SINGLE-PROJECT MOBILIZATION CEILING, and the national closure verdict is DOES NOT CLOSE - MOBILIZATION CEILING EXCEEDED. This result holds with every lever set generously to the conventional scenario, and it holds for the partial model - before granite mechanisms, casing, administration, and the remaining open burdens are integrated, all of which raise the labor share further.

One rebuttal must be addressed directly, because it is the strongest one available to the conventional scenario: seasonal corvee. The annual inundation idles a large share of agricultural labor for roughly three to four months, and it is often argued that this labor was therefore “free” for construction. The model’s own cadence answers it. The required placement rate is approximately 206 blocks per day, sustained every working day for twenty years. A workforce available for only one season per year must either triple the flood-season cadence - which the work-front density of the shrinking pyramid platform physically forbids - or triple the construction timeline, which the conventional twenty-year reign window itself forbids. The labor ceiling this test measures is an annual ceiling, and seasonality does not relieve it. The model assumes peak concurrency across the support departments (water, food, timber, ramp) and treats granite as sequential; both are stated simplifications rather than outputs of a construction schedule, disclosed here as assumptions. The flood season is also precisely when the delivery basins are

navigable, so peak labor, peak stone movement, and peak water transport would compete for the same months and the same settlement capacity.

This is the finding the integrated model was built to test. The conventional scenario's own workforce framework, its own population anchor, and its own construction timeline cannot be simultaneously satisfied once the full support system is loaded and priced against the labor and surplus the kingdom actually had.

9.2 Peak-Load Operations: Aswan Granite, Barges, and Timber

The national closure test in Section 9.1 uses the sustained-rate burden. The granite operation adds a second, independent class of problem: not a rate, but a set of peak-load transitions for which the conventional literature offers no agreed mechanism. The King's Chamber and its relieving chambers are roofed with roughly forty to fifty granite beams in the fifty-to-eighty-tonne class, quarried at Aswan and moved some 900 kilometers. The mainstream record itself concedes the point: the sled method is accepted for the 2.5-tonne blocks, but there is no agreed method for the seventy-to-eighty-tonne granite.

The model prices each transition in the chain and, where no mechanism is attested, prices the physical requirement rather than inventing a device. The results are reported as required capabilities:

Granite transition	Requirement	Status
Overland haul, one beam	~1,067 haulers on one rope	Rope train >425 m on unimproved ground
Mid-route sled repair	Re-lift the beam	Same unattested 80 t lift
Shore lift, ground bearing pressure	8x pressure concentration	Exceeds saturated bank capacity
Barge ground-out and refloat	~90 t laden vessel	No attested mechanism
Mobile expedition, one campaign	~1,601 people	Priced and integrated (Wave 5), no families
River/harbor standing organization	743 rostered	Priced and integrated (Wave 6), bodies only

The shore transfer is the decisive point. A beam resting flat imposes a modest ground pressure; a lifting device concentrates that same load onto a handful of point contacts, multiplying the pressure roughly eightfold, and it must do so on the saturated riverbank - the weakest ground on the route. No attested Old Kingdom lifting device is rated for these loads, and the requirement

exceeds the bearing capacity of soft saturated alluvium. The float is the easy part; the transitions on and off the water are not.

The barge itself is a further burden the conventional account does not enter. A vessel that floats an eighty-tonne beam together with its cradle, crew, and provisions - and its own hull mass - must displace on the order of 220 tonnes, requiring roughly fifty-five tonnes of worked acacia per hull. Herodotus records that Egyptian cargo hulls were built of acacia: the same species the copper furnaces, bread ovens, mortar kilns, and now the barge fleet all draw on, in a country whose structural timber was imported. The excavated Khufu ship, at roughly 44 meters and over 1,200 planks, anchors the scale of large Egyptian hull construction as physical fact rather than extrapolation.

The granite operation is conceded on generous terms - as a special mobile expedition with no resident families, priced as sequential rather than concurrent, and understated in beam count. As of Wave 5 the expedition corps enters M3 as 2,783 rostered bodies with no family multiplier, and the barge fleet's felled acacia feeds the timber labor chain (felling, sawing, and overhead only; the cedar-import voyage and Giza overland haul lines are excluded because the hulls are native acacia built at riverside yards - a generous exclusion). Integration prices the bodies; it does not resolve the mechanisms. The operation still returns a chain of transitions with no demonstrated mechanism, each of which must succeed for a single beam to arrive, roughly forty to fifty times, early in the build when the limestone haul is already at peak.

As of Wave 6 the river corridor itself is priced (workbook sheet RiverHarbor_47). The anchor is the mainstream's own best document: the Diary of Merer records 40-man phyles organized into roughly 200-man gangs running two to three round trips per ten-day week between Tura and Giza, and names the harbor basin (Ro-She Khufu) and its director (Ankh-haf). The model scales that documented operation to the 890-kilometer Aswan corridor, now a workbook lever: a laden round trip takes roughly 46 days, a barge completes about 3.3 trips per 150-day navigable season, and the 30 large pieces require about 1.14 barge-seasons of fleet time. The schedule is feasible on paper. That is the finding, not a concession: the burden is not the voyage count, it is the standing organization the voyages require - 557 rostered barge crew, 140 harbor and dock gang at both ends, 46 pilotage including the cataract detail, 743 rostered in total, entering M3 as bodies only with no family multiplier. Transit water is conceded Nile-direct at zero carrier burden, and en-route provisioning is conceded small: about 55 tonnes of grain over the campaign against roughly 300 tonnes of fleet capacity. Corridor support is now priced; Gates 1 through 4 - the shore lift, the ground-out and refloat, the mid-route repair, and the overland rope train - remain unresolved capability findings, not corridor findings (Finding F26). One sourcing argument is pre-answered on the sheet: crewing the barges with soldiers changes nothing, because soldiers are drawn from the same prime-age cohort and the closure numerator counts bodies regardless of which state department supplies them.

9.3 Timber Waste and the Wood-Fuel Ledger

Timber enters the model as three streams: structural stock (sledges, levers, cribbing, planking), the edge-ramp planking of Section 7.11, and the granite barge fleet. Each is loaded with the same waste stack - conversion loss, unsuitable stock, handling loss, and water damage - so that the felled volume, not the installed volume, drives the labor and land burden. Under this treatment the felled timber is roughly 4,200 tonnes per year.

Timber waste is not discarded; cutoffs, sawdust, and spoiled stock are fuel. The model credits a generous three-quarters of all timber waste against the fuel-wood demand already carried by the smelting, baking, and mortar operations, capped so the credit can never exceed actual demand. This pre-empts a double-counting objection: the waste is explicitly burned. But the credit covers only about 3.7% of a fuel-wood demand approaching 53,000 tonnes per year. Netting every burnable scrap, the total acacia felled - structural timber plus net fuel wood - is on the order of 55,000 tonnes per year, implying roughly 2,200 square kilometers of managed woodland. The waste credit closes the loophole without closing the woodland gap, on the one sacred, imported-scarce species every wood-consuming department competes for.

9.4 Demographic Closure: Sustained Mobilization vs Documented Capacity

The closure test in Section 9.1 prices one year of the project against one year of the kingdom. The demographic closure test prices the duration. It asks a question no annual snapshot can answer: can a kingdom of 1.6 million hold this commitment for twenty to thirty years and remain a functioning state? The test runs on workbook sheet DemographicClosure_46, is a verdict layer only - it adds no burden to M3 - and uses no new demographic levers. The prime-age male cohort is the same 384,000-person pool already carried in Section 9.1, and the working span and mortality replacement are the model's own values, derived from the Giza worker cemetery.

Three tests. First, the standing extraction: the ex-farmer roster of 54,142 decomposes into a concurrent standing force of 47,374 men - 12.3% of every prime-age male in the kingdom, continuously absent from the general economy for the full build (14.1% on the rostered basis). Second, the cumulative drain: over a 20-year build, 54,142 distinct men pass through the roster; over 30 years, 81,213, of whom 33,839 are mortality replacements. The steady-state statement is the sharpest form: the project must recruit approximately 2,707 fresh prime-age males every year of the build, against a national maturing cohort of roughly 21,943 per year. One in eight of every year's maturing males, nationally, every year, for decades - for one monument's non-farm departments alone. The standing share and the intake share are the same finding stated two ways, not two findings; the sheet says so to pre-empt the double-count objection.

Third, the comparator that anchors the verdict to the kingdom's own record. The largest military mobilization the Old Kingdom ever documented is Weni's levy: "an army of many tens of thousands," raised from all of Upper Egypt, all of Lower Egypt, five named Nubian groups, and Libya - the entire kingdom plus foreign auxiliaries - and raised and disbanded five separate times,

campaign by campaign. The figure is read at its maximum, 50,000, in the mainstream's favor: a higher Weni makes the pyramid look easier. Two caveats, stated once, and both also cut in the mainstream's favor: the inscription is 6th Dynasty, roughly two centuries after Khufu, so a later and larger state sets the ceiling high; and the figure is rhetorical, read high. The Palermo Stone's Snefru registers - 7,000 Nubian captives, 200,000 cattle - confirm the expeditionary character of the Old Kingdom military: temporary levies for targeted campaigns, no professional standing army.

Against that record, the project's standing mobilization is 0.95 times the maximum documented levy on the leaner concurrent basis, and 1.08 times it on the rostered basis. The comparison is not merely of size but of posture: Weni's levy was episodic - raised, marched, sent home. The project's is continuous for twenty to thirty years, drawn from the domestic non-farm pool alone, while the actual army, the temples, the administration, and every other monument of the dynasty must still be staffed on top of it.

Demographic closure metric	**Value**	**Reading**
Prime-age male cohort (24% of 1.6M)	384,000	Same pool as Section 9.1; no new lever
Concurrent standing force (ex-farmer)	47,374	12.3% of the cohort, continuously absent
Cumulative distinct men, 20-yr / 30-yr	54,142 / 81,213	Mortality-only replacement - generous
Annual intake of fresh prime-age males	2,707	12.3% of every maturing cohort, duration-invariant
Weni levy, maximum documented mobilization	50,000	Read at maximum; episodic, kingdom-wide + auxiliaries
Project vs Weni, concurrent / rostered	0.95x / 1.08x	The emergency posture, held as a permanent baseline

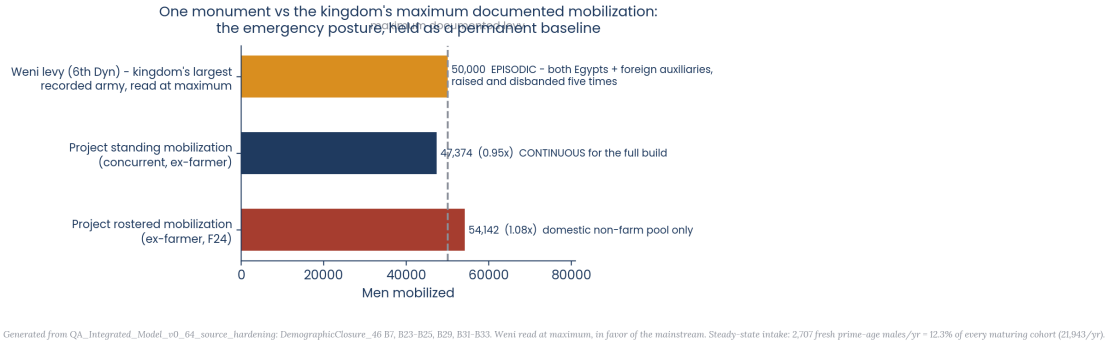


Figure 6. The demographic closure comparator: sustained project mobilization against the largest levy the Old Kingdom ever documented, read at its most generous.

The test returns AT OR ABOVE THE KINGDOM'S MAXIMUM DOCUMENTED MOBILIZATION - HELD CONTINUOUSLY, and the demographic closure verdict is DOES NOT CLOSE - SUSTAINED MOBILIZATION EXCEEDS MAXIMUM DOCUMENTED CAPACITY. The conventional model requires the kingdom to hold its maximum documented emergency mobilization as a permanent baseline for decades, consuming one-eighth of every maturing male cohort, before the army, the temples, trade, administration, or any other monument employs anyone. One adaptation argument dies on arithmetic alone: a state cannot breed its way out of a project shorter than a generation - a child born in year one enters the workforce at fifteen, in year sixteen of a twenty-year build.

10. Material Balance and Off-site Production

Off-site production may be geographically dispersed, but it is not economically free if its output is required by the pyramid. The model therefore treats project-dedicated output as committed capacity. Grain, fiber, copper, timber, rope, fuel, pottery, containers, boats, animals, and labor all remain subject to material-balance logic.

This point is central to the critique. Moving a burden off-site does not remove the burden. It changes where the burden is paid. The model asks whether the total kingdom-level system can absorb that payment while still feeding, watering, equipping, defending, administering, and operating the rest of the economy.

11. Concessions to the Conventional Scenario

The model is not designed to maximize failure. It already grants several favorable assumptions, including the standard scholarly population anchor with sensitivity to higher estimates (2.0M and 2.5M, which lower the share and favor the conventional scenario), an adjusted effective labor pool, a bounded youth light-support credit, and control layers that allow future alternatives to reduce burdens if they are cost-loaded. v0.38 also corrected annual-yield farmers to roster factor 1.0,

lowering the headline M3 burden in favor of the conventional model. Several pending operations are not yet integrated into M3, which means the current headline burden is not a maximum.

The full concession set is broader than the population denominator, and several concessions were paid in both directions. Workforce entry at age 15 grants full adult output and simultaneously widens the effective labor pool from 3,000 to 4,200. Worker replacement is derived from cemetery mortality only, with disabling injury excluded despite a documented 67% healed-fracture rate. All calories are priced as grain, the cheapest calorie; the documented cattle and fish diet would cost more land and labor. Track-wetting water is charged to loaded lanes only, with return lanes run dry. Water carriers receive a 0.75 work-rest factor against the haulers' 0.20 duty cycle. Copper recycling is assumed complete except unrecoverable filings. Workforce availability is floored at modern regional labor practice - a floor the IER study (Section 7.11) independently adopts with its 10-hour, 6-day calendar. And the v0.38 farmer-roster correction was applied specifically because the prior treatment overstated the burden.

The purpose of these concessions is methodological. The conventional model should be allowed every reasonable opportunity to close. If it still does not close under favorable conditions, the finding is stronger.

12. Closure Requirements and Adversarial Tests

The closure requirement is simple: a construction explanation must preserve all required functions. If a reviewer objects to an input, the model invites that objection. But the reviewer must show how the changed input affects the full system.

Adversarial move	Model response
Reduce water carriers	Identify the replacement delivery system and cost-load labor, materials, maintenance, containers, feedback, and evidence.
Use youth help	Apply bounded intermittent credit unless youth are modeled as a standing labor department with productivity, supervision, work water, fatigue, and household opportunity cost.
Use canals, wells, boats, animals, or depots	Treat as replacement systems, not free deletions.
Use ramps	Define geometry, material volume, route capacity, maintenance, phasing, and removal/rework.

Adversarial move	Model response
Move production off-site	Keep the output project-dedicated and prevent double-spending in the non-project economy.
Increase productivity or extend schedule	Update direct cadence and support loops; verify whether food, water, replacement, and state capacity improve or simply shift.
Dismiss the 150k screen	Use the full capacity-band table. The current partial result still falls between the 300k and 500k bands.
Import foreign labor	Lever exists (v0.62, DEFAULT 0 - the mainstream model itself claims an Egyptian workforce). Imported labor shifts only the pool draw; food, water, housing, and population burdens are nationality-invariant. The documented record (Weni) shows episodic auxiliaries, never decades of sustained foreign labor.
Flip, down-grade, and reuse worn planks	Lever exists (v0.62, STEELMAN 2.0x effective service life). Fuel down-cycling is already credited at 75% and capped at actual fuel demand. The binding constraint is structural-grade extraction rate, which the multiplier prices directly - and the woodland gap survives it.
Crew the barges and harbors with the army	Changes nothing. Soldiers are drawn from the same prime-age cohort; the closure numerator counts bodies regardless of which state department supplies them. An army standing crew duty on a monument corridor for decades is not garrisoning borders or fielding campaigns, and the Weni comparator already prices what the kingdom could mobilize and for how long.

13. Pending Operations, Diagnostic Matrix, and Exclusions

The following functions remain pending, partial, controlled/open, or diagnostic-only in v0.63. Their absence from the main M3 total should not be misread as evidence that they are unnecessary. DiagnosticIntegration_35 now governs whether these first-order diagnostic burdens can enter M3.

Function	Current status	Why it matters
Food method selection	RULED (v0.60 / v1.5)	Direct-cropland lower-bound is the headline; the feedback-solved loop is published as the named ceiling (~880,300, 55.0% of kingdom; Section 7.3). The method decision is closed.
Sanitation/ medical support	First-order diagnostic / not M3-ready	Waste, cleaning, injury care, and support labor scale with village population; rates, materials, and feedback remain open.
Processing/fuel/ containers	First-order diagnostic / non-additive risk	Water, grain, and fuel require handling, storage, containers, breakage reserve, and labor; double-count control remains essential.
Shaping/setting/ casing/rework	Integrated (Wave 1)	Final shaping, setting, casing, rework, copper-tool wear, and timber support are priced at the base screen and integrated.
Structural timber	Material screen control-only; labor integrated (Wave 3)	Sledges, planks, anchors, levers, cribbing, boats, and repair stock have a stock/ replacement screen; the implied labor enters M3 via TimberLabor_40.
Ramp construction/ maintenance/ removal	Integrated (Wave 4)	Route system construction, maintenance, and removal crews are priced and integrated; surface and phasing levers remain open.
Aswan granite expedition	Integrated (Wave 5, bodies only)	Expedition corps and barge-timber feed are priced and loaded; shore-lift, refloat, and mid-route repair capability gaps remain findings; corridor support is priced separately (Wave 6).

Function	Current status	Why it matters
River / harbor leg	Integrated (Wave 6, bodies only)	Barge crews, harbor gangs, and pilotage over the 890 km corridor are priced and loaded (RiverHarbor_47, Merer-anchored); en-route provisioning conceded small; Gates 1-4 remain capability findings.
Administration/ security	Pending	Large system requires measurement, accounting, supervision, storage control, guards, and conflict management.
Lighting/night work	Pending	Night operations require lamps, fuel, wicks, safety, supervision, and rest-cycle effects.

14. Working Findings

The current partial integrated model does not close as a sustainable state-capacity scenario under the stated assumptions.

The model does not fail because every possible burden is maximized. It fails despite favorable assumptions, despite the v0.38 farmer roster correction in favor of the conventional model, and despite several significant systems remaining open or diagnostic only.

Water feedback is now the most mature universal-support loop. The current M3 result includes algebraic domestic/process water feedback and a bounded 5% youth light-support credit.

Food feedback is now corrected and the method is ruled. Under annual-yield farmer treatment, the active farmer household loop generates surplus. The direct-cropland lower-bound remains the headline M3 method; the feedback-solved loop is published as the named ceiling - approximately 880,300 project-dedicated people once reconciled for the Waves 3-6 off-site additions, 55.0% of the 1.6 million kingdom. The two methods bracket the food burden; neither closes the system.

Test 1 of the national closure test now reports the ex-farmer labor share (Finding F24). Annual-yield farmers are excluded from the labor numerator because their entire burden is priced in Test 2, removing the farm/non-farm double-jeopardy objection. The ex-farmer share of the non-farm pool is 70.5% - 2.8 times the 25% single-project mobilization ceiling. The inclusive 130.8% figure is retained as a labeled transparency line.

The demographic closure test is added as Finding F25 (v0.61, sheet DemographicClosure_46). The ex-farmer standing force holds 12.3% of the national prime-age cohort continuously absent and conscripts one-eighth of every maturing male cohort every year of the build. On the rostered basis

the project exceeds, at 1.08 times, the largest mobilization the Old Kingdom ever recorded - Weni's episodic national emergency levy, read at its most generous - and holds that posture for 20-30 years from the domestic non-farm pool alone. Verdict layer only; no change to M3.

The river/harbor corridor is priced and integrated as Finding F26 (v0.63, sheet RiverHarbor_47). Barge crews, harbor gangs at both ends, and pilotage enter M3 as bodies only, anchored to the Diary of Merer - the mainstream's own document. The voyage schedule is feasible on paper, roughly 1.14 barge-seasons for the 30 large pieces; the burden is the standing organization, 743 rostered. Gates 1 through 4 in the granite chain remain unresolved capability findings. The army-sourcing objection is pre-answered: soldiers come from the same prime-age cohort, and the numerator counts bodies.

Two hardening levers added in v0.62 close narrative escape routes by construction rather than by argument: imported-labor share (DEFAULT 0; the burdens are nationality-invariant) and plank service life (STEELMAN 2.0x; the conventional scenario is granted 714 rostered timber men in full). Neither moves either verdict.

Shaping/setting/casing (Wave 1), timber labor (Wave 3), ramp construction/maintenance/removal (Wave 4), the Aswan granite expedition (Wave 5, bodies only), and the river/harbor corridor (Wave 6, bodies only) are now integrated into M3. Sanitation/medical and processing/fuel/containers remain quantified diagnostics with readiness gates; they represent visible required-function exposure, not solved assumptions and not additive headline totals.

DiagnosticIntegration_35 now provides the governance layer for open diagnostic modules. It records whether each module is M3-ready, why it remains outside the headline total, and what integration requirements must be resolved before adoption.

A burden cannot be deleted by narrative. If a proposed reduction removes adult carriers, timber, ramps, rope, food, water, labor, shaping, setting, casing, or rework, the replacement system must be specified and resource-loaded.

15. Limitations, Open Items, and Next Draft Tasks

This draft remains a working paper. It is suitable for internal review and model development, not final public release. The next model work should move open control layers toward either accepted integration or documented exclusion.

Next task	Reason
Extend the figure set	Six workbook-generated figures regenerated against v0.64 in v1.8; all values identical to v0.63 (register-only bump), footers re-cite the baseline. Granite transition chain and the wood-fuel ledger may warrant figures in later drafts.
Food-method ruling recorded (closed)	Ruled in v0.60/v1.5: direct-cropland lower-bound is the headline; feedback-solved loop is the named ceiling. Remaining food work is source-hardening of yield/surplus levers, not method selection.
Source hardening recorded (largely closed)	v0.64: Butzer pinned to p. 83, Table 4 (sight-verified); Merer pinned to MIFAO 136 internal pages; Lake Khufu pinned (Equinox 2020, DOI); Redding pinned (ANE X, pp. 307-322); Bir Nasib pinned with OK-era caveat; worker-town capacity re-badged ASSUMPTION (generous). Remaining page tasks: Lichtheim (Weni), Wilkinson (Palermo), rope/fiber, food productivity.
Resolve diagnostic integration criteria	Diagnostics should enter M3 only after productivity, material basis, person-category treatment, feedback, and double-count controls are stabilized.
River/harbor sheet recorded (closed)	Built and integrated in v0.63 (Wave 6, bodies only): barge crews, harbor gangs, and pilotage over the 890 km corridor, Merer-anchored (RiverHarbor_47, Finding F26). Remaining granite work is the Gates 1-4 capability findings, not corridor support.
Prepare external-review package	Baseline, assumptions, source register, known limitations, and change log must be clear before outside review.

Appendix A. Current Model Tables

Metric	Value
Current partial project-dedicated population	483,769
Current share of 1.6M comparator	30.24%
Capacity-band position	Between 300k and 500k bands
Secondary ratio vs 150k screen	3.23x
On-site rostered workers	47,316
Implied on-site village population	281,643
Off-site project-dedicated population	202,126
Integrated Giza-delivered water	3.39M L/day
Current active adult water carriers	19,960
Project rostered labor, all priced departments (inclusive)	100,492
Test 1 labor, ex-farmer numerator (F24)	54,142
Ex-farmer share of non-farm able-bodied pool	70.5% (2.8x the 25% single-project ceiling)
Inclusive share of pool (transparency line)	130.8%
Feedback-solved food ceiling, reconciled for Waves 3-6	~880,300 people (55.0% of 1.6M); headline stays lower-bound
ShapingSetting_33 diagnostic population (integrated, Wave 1)	1,173 people
TimberSystem_31 base 20-year gross timber screen	13,343.7 m3
RampSystem_32 diagnostic population (integrated, Wave 4)	1,118 people
RampSystem_32 total material handled over build	1,062,500 m3 / 1,912,500 t
DiagnosticIntegration_35 status	Roll-up added; diagnostics are not additive headline totals

Metric	Value
Concurrent standing force, ex-farmer (F24/F25)	47,374 (12.3% of the prime-age cohort)
Annual intake of fresh prime-age males	2,707/yr = 12.3% of every maturing male cohort
Cumulative distinct men, 20-yr / 30-yr build	54,142 / 81,213
Project vs Weni maximum levy, concurrent / rostered	0.95x / 1.08x - continuous vs episodic

Appendix B. Source Register and Citation Tasks

The workbook includes SourceRegister_01 and sheet-level source notes. The working white paper should eventually convert these references into formal footnotes or endnotes. Current known citation tasks include source-page cleanup for selected Old Kingdom population, worker village capacity, copper/Bir Nasib, rope/fiber assumptions, food/agricultural productivity, timber availability, ramp/route assumptions, Heit el-Ghurab provisioning context, and food-system surplus logic.

Current population comparator source in workbook: Karl W. Butzer, Early Hydraulic Civilization in Egypt (University of Chicago Press, 1976), p. 83, Table 4, 2500 B.C. row: 1.6 million (sight-verified 2026-07-11 against the open-access ISAC/Oriental Institute edition). Butzer's own table title is "Hypothetical demographic development in ancient Egypt," and the register quotes that framing: the model treats the figure as a stress-test denominator, not a census. Sensitivity runs at 2.0 and 2.5 million are available in the workbook and are more favorable to the conventional scenario.

v0.64 source-hardening pass (all sight-checks cleared 2026-07-11): Merer operational metrics pinned to Tallet, Les papyrus de la mer Rouge I (MIFAO 136, 2017) - phyle and gang structure pp. 15-17 with log validation pp. 40-41; transport cadence pp. 23-25; load estimation pp. 25-26; English secondary Tallet & Lehner, The Red Sea Scrolls (2022); harbor geography Lehner, "Merer and the Sphinx," Guardian of Ancient Egypt II (2020), pp. 895-925. Lake Khufu pinned to Lehner, "Lake Khufu: On the Waterfront at Giza," in Profane Landscapes, Sacred Spaces (Equinox, 2020), pp. 191-292, DOI 10.1558/equinox.29191, open access, independently corroborated by Sheisha et al., PNAS 119 (2022). Bir Nasib pinned to Abdel-Motelib et al., Metalla 19.1/2 (2012) for the ~100,000 t slag mass and Bachmann's ~5,000 t metallic calculation, with the OK-era caveat recorded. Redding pinned to Archaeozoology of the Near East X (Peeters, 2013), pp. 307-322. Worker-town capacity re-badged ASSUMPTION (generous) against Lehner 2002 (JARCE 39:27-74) and Lehner 2015 (Labor in the Ancient World, pp. 397-522).

Newly verified sources (full citation, open access): Rosell Roig, V. L. (2026). A computational framework for evaluating an edge-integrated, multi-ramp construction model of the Great Pyramid of Giza. npj Heritage Science 14:142, DOI 10.1038/s40494-026-02405-x. Dataset and code: Zenodo DOI 10.5281/zenodo.16732345; GitHub viroroi-pub/Egypt, v1.0.14. These are the source register's first entries verified to DOI and open data, recorded as SRC-ROSELLROIG-IER and SRC-IER-DATASET in CitationControl_34.

Source lane	**Current use**
Butzer / Old Kingdom population comparator	Provides 1.6M denominator for population-share stress testing; PAGE-PINNED to p. 83, Table 4, sight-verified (v0.64).
AERA / Heit el-Ghurab	Worker settlement and provisioning context; capacity ceiling re-badged ASSUMPTION (generous) with publications pinned (v0.64).
PBS NOVA / Lehner-Hawass workforce context	Mainstream workforce-scale comparison.
Redding / A Tale of Two Sites	Old Kingdom production-consumption model, PINNED (ANE X, Peeters 2013, pp. 307-322); author concludes labor, not land, was the limiting factor.
Boserup / agrarian surplus logic	General support for testing large diverted-output burdens against surplus, seasonality, and labor availability.
Internal model-control rules	Material balance, required-function audit, annual-yield farmer roster correction, capacity bands, citation control, and diagnostic-integration readiness.
Weni autobiography (Lichtheim AEL I)	Maximum documented OK mobilization comparator (SRC-WENI-LEVY); read at maximum in the mainstream's favor; Lichtheim page verification remains open.
Palermo Stone, Snefru registers	Expeditionary character of the OK military - temporary levies, no standing army (SRC-PALERMO-SNEFRU); register/page verification remains open.
CitationControl_34	Maintains source-control and page/table verification tasks.
DiagnosticIntegration_35	Maintains integration-readiness status for diagnostic modules and prevents additive misuse.

Appendix C. Version History Since v0.2

Workbook version	Major addition	White-paper treatment
v0.31	WaterInfrastructureAlternatives_27	Replacement-system gate for water-delivery alternatives.
v0.32	FoodFeedback_28	Originally exposed agricultural/farmer-household feedback as fail/open under then-current assumptions.
v0.33	SanitationMedical_29	Adds first-order sanitation, waste, cleaning, and basic medical diagnostic.
v0.34	ProcessingFuelContainers_30	Adds processing, fuel-handling, container circulation, reserve, and replacement diagnostic.
v0.35	TimberSystem_31	Adds structural timber dependency and fuel/structural double-spend control.
v0.36	RampSystem_32	Adds ramp construction, maintenance, traffic, phasing, and removal/rework control.
v0.46	ModelAnchors_36, CompatibilityControl_37	Anchor-layer references, basis-tag governance, and Excel/Numbers round-trip integrity rules.
v0.47	Integrity repair + survivable QA	Fourteen corrupted formulas rebuilt in anchor-routed style; canary tripwire added for round-trip detection.
v0.48	IERRampTimber_38	Sourced-chassis audit of the IER model on author-published data (Section 7.11); control-only.
v0.49	ShapingSetting_33 integrated; VillageSufficiency_39	Wave 1: shaping/fitting/setting enters M2/M3 and the copper chain. Wave 2: village-internal support tested for sufficiency rather than stacked; derived village multiplier published alongside the Ep 2 floor.
v0.50	TimberLabor_40	Wave 3: structural + IER ramp timber (m3/yr) converted to felling, sawing, cedar-shipping, and haul labor; integrated into M3 off-site.
v0.51	NationalClosure_41	National closure test: able-bodied labor and agricultural-surplus ceilings (Section 9.1). Verdict: does not close. Seasonal-corvee rebuttal addressed.

Workbook version	Major addition	White-paper treatment
v0.52	GraniteAswan_42	Aswan granite transition-chain diagnostic; capability gaps priced as physical requirements (Section 9.2).
v0.53	BargeTimber_43	Granite barge displacement sizing and acacia hull timber (Section 9.2).
v0.54	Ramp integrated (Wave 4)	Ramp construction/maintenance/removal moved from diagnostic into M3 using the conventional model's own required structure.
v0.55	WoodFuelCredit_44	Unified timber waste stack across all streams; timber waste credited to fuel, capped; net woodland reported (Section 9.3).
v0.37	QA repair after formula-error debris	Repaired corruption/check formulas and restored core QA checks.
v0.38	Agricultural roster correction and ShapingSetting_33 scope gate	Corrected annual-yield grain/fiber farmer roster factor to 1.0; added shaping/setting control.
v0.39	Mobilization-capacity bands	Replaced single-cutoff framing with capacity-band framework.
v0.40	CitationControl_34	Added source-control/citation-governance sheet and load-bearing citation gap tracking.
v0.41	ShapingSetting_33 quantified diagnostic	Quantified shaping/setting/casing/rework exposure while holding it outside M3.
v0.42	ShapingSetting readiness gate	Marked shaping/setting diagnostic not M3-ready and listed integration requirements.
v0.43	TimberSystem_31 quantified stock/ replacement diagnostic	Added structural timber stock, replacement, gross timber, and service-life screens.
v0.44	RampSystem_32 expanded diagnostic	Added ramp material, traffic, maintenance, and removal/rework screens.
v0.56	DiagnosticIntegration_35	Added roll-up and integration-decision matrix for open diagnostic modules.

Workbook version	Major addition	White-paper treatment
v0.57	Ramp-parameter repair	Restored overwritten ramp parameters and corrected the associated ramp-labor inflation; headline M3 revised from 531,793 to 480,231. Verdict unchanged: does not close.
v0.58	Granite integrated (Wave 5); barge-timber feed	Aswan expedition enters M3 bodies-only (2,783 rostered); barge felled acacia feeds TimberLabor_40 felling/sawing/overhead. Headline M3 483,026; inclusive non-farm labor share 129.9%. Verdict unchanged: does not close.
v0.59	Tab reorder	Sheet order rationalized for review flow. No model change; all live values identical to v0.58.
v0.60	Test 1 numerator ruling (F24)	Annual-yield farmers (46,350 rostered) excluded from the Test 1 numerator; their burden is priced in Test 2, removing the double-jeopardy objection. Ex-farmer share 69.5% vs the 25% ceiling (2.8x); inclusive 129.9% retained as transparency line. ClosureSensitivity_45 rebuilt on the ex-farmer numerator. Verdict: DOES NOT CLOSE - MOBILIZATION CEILING EXCEEDED.
v0.61	DemographicClosure_46 (F25)	Demographic closure test added as a verdict layer, no M3 change. Standing extraction 12.2% of the prime-age cohort; annual intake one-eighth of every maturing male cohort; sustained mobilization 0.93x/1.07x (concurrent/rostered) the Weni maximum documented levy, read at its most generous. New lever: Weni comparator reading (DEFAULT 50,000). Sources SRC-WENI-LEVY, SRC-PALERMO-SNEFRU. Verdict: DOES NOT CLOSE - SUSTAINED MOBILIZATION EXCEEDS MAXIMUM DOCUMENTED CAPACITY.

Workbook version	Major addition	White-paper treatment
v0.62	Hardening levers: imported labor, plank reuse	Two levers added, both DEFAULT-neutral to the headline. Imported-labor share (DEFAULT 0 - the mainstream model itself claims an Egyptian workforce): moving it shifts only the pool draw; food, water, housing, and population burdens are nationality-invariant. Plank service-life multiplier (STEELMAN 2.0x flip/downgrade): propagates through TimberLabor_40 into M3; at the steelman setting the ~26,700 m3 planking stream halves and the conventional scenario is granted 714 rostered timber men in full. Objections rows 19-20 pre-answered. Verdicts unchanged.
v0.63	RiverHarbor_47 integrated (Wave 6, F26)	River/harbor corridor priced bodies-only, no families: barge crews 557 + harbor gangs 140 + pilotage 46 = 743 rostered, Merer-anchored (SRC-MERER, Tallet 2017); new 890 km corridor lever. Schedule feasible on paper (~1.14 barge-seasons for 30 pieces); the burden is the standing organization. Headline M3 483,769 (30.24% of the 1.6M kingdom); ex-farmer Test 1 share 70.5% (2.8x the 25% ceiling); inclusive transparency 130.8%; demographic closure 0.95x/1.08x the Weni maximum. Army-sourcing objection pre-answered (Objections row 21). Both verdicts unchanged: does not close.
v0.64	Source hardening (register-only)	No model value changes; verdicts unchanged by construction. Load-bearing rows page-pinned, all sight-checks cleared 2026-07-11: Butzer p. 83 Table 4 (1.6M at 2500 BC); Merer MIFAO 136 pp. 15-17/23-26/40-41; Lake Khufu Equinox 2020 pp. 191-292 (DOI 10.1558/equinox.29191); Redding ANE X pp. 307-322; Bir Nasib Metalla 2012 + Bachmann ~5,000 t with OK-era caveat (generous as used); worker-town 25,000 re-badged ASSUMPTION (generous - smaller ceiling worsens M2). CitationControl_34 public-release source blocker downgraded.