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RIVER REFUGIUM PROJECT Cernunnos Foundation Bright Meadow Group	**Appendix E — Agricultural Feed Production Pathway** Document No: RRP0002-AppE │ Version: 1.0 │ 04 AUG 2026 0003 Status: Published — New document, issued against Series Version 2.0 │ Supersedes: None *Contact: robert@brightmeadowgroup.com │ www.cernunnosfoundation.com*

Abstract

Appendix E defines the agricultural feed production pathway — an RRP deployment mode in which captured nitrogen and phosphorus are converted into livestock and aquaculture feed rather than fiber, fuel, or char. Its purpose is to give agricultural operators a participation route into the RRP framework that produces an input they already purchase, rather than a compliance cost they must absorb. The appendix specifies three feed crop classes, a six-stage farm-scale process train built around a mandatory refugium conditioning stage, a three-tier source-water eligibility system, a five-step biomass disposition hierarchy, and a feed qualification protocol. It states the pathway's central technical tension plainly: the bioaccumulation behavior that makes duckweed and algae effective nutrient remediators is the same behavior that creates feed-safety risk — and, at sufficient concentration, the same behavior that creates a trace metal recovery opportunity. The tier system and disposition hierarchy manage that tension; Section 8 defines when it becomes an asset. All yield, protein, uptake, and recovery figures in this document are provisional academic proxies pending RRP pilot data per RRP8.

1. Position Within the RRP Framework

1.1 What This Pathway Is

The agricultural feed production pathway is a deployment mode of the River Refugium Project, not a separate system. It isolates one economically useful function of the full RRP architecture — biological nutrient capture — and directs the resulting biomass toward animal feed rather than toward fiber, structural material, or thermochemical conversion.

The engineering is not new. RRP3 documents the conditioning and biofiltration train that prepares raw river water for biological capture; RRP4 documents shallow algae and duckweed beds operating as the polishing house, the final stage before clean-water return. This pathway compresses the first and promotes the second: the conditioning stage becomes a farm-scale refugium, and the polishing species are promoted from residual interception to primary production.

The intended operator is not a node developer. It is a farmer, a cooperative, a conservation district, a tribal agriculture program, or an aquaculture operation with access to nutrient-bearing water and existing livestock demand.

1.2 What This Pathway Is Not

- It is not a substitute for a full RRP node. It carries no thermochemical plant, no evaporation greenhouse, and no routing grid.
- It is not a permit to grow feed in polluted water. Section 6 defines which waters qualify and which categorically do not.
- It is not a claim that duckweed and algae are proven feed ingredients under all conditions. Regulatory ingredient status is addressed in Section 10.6 and is a real gate, not a formality.

- It is not a set of raceways on a ditch. The refugium stage in Section 5 is mandatory, and the reasons are structural rather than optional.

1.3 Relationship to Existing Series Documents

Document	Relationship to Appendix E
RRP1	Establishes nutrient pollution as a structural, diffuse problem unsuited to conventional treatment. This pathway is the smallest-capital response to that finding.
RRP3	Forebay, cistern, and six-tank biofiltration train. The Section 5 refugium is the farm-scale analog, with one deliberate inversion: the feed pathway suppresses denitrification rather than performing it. See §5.4.
RRP4 §3.10	Polishing house architecture. Species selection, bed depth, and harvest-at-coverage logic are inherited directly.
RRP5	HTC/HTL feedstock routing. Receives all off-spec biomass under disposition tier D-4, and is the concentration step in the metal recovery pathway of Section 8.
RRP6 §5	Modular slot framework. Section 13.3 proposes Slot Type F (feed production) as an amendment.
RRP7	Governance and regulatory positioning. This pathway introduces FDA/AAFCO feed jurisdiction and, under Section 8, residue and ash classification questions not present elsewhere in the series.
RRP8	Governing document for all measurement standards. Axis 2 and Axis 3 protocols apply unmodified. Feed qualification testing in Section 10 is additive.
RRP12	Revenue stack. This pathway monetizes Layer 1 and Layer 5 primarily; Layers 2, 3, and 7 remain available through hub routing of off-spec material and recovered mineral fractions.
Appendix A	Site Selection Matrix. Section 8.5 proposes a supplementary metal recovery review for feed pathway sites without altering the published ten-criterion scoring.
Field Kit	Forms A, B, and C apply as written. Section 10.5 proposes Form D — Feed Qualification & Disposition Record.

2. The Agricultural Argument

Agriculture is routinely named as the source of riverine nutrient pollution. The framing is accurate in aggregate and useless in practice, because it offers the individual operator nothing but blame and restriction.

Most conservation programs approach a farm with some version of the same proposition: change your operation, accept new constraints, retire acreage, document everything, and receive a payment that expires before the practice does. The operator is asked to absorb a permanent cost in exchange for a temporary transfer.

This pathway inverts the proposition. It offers a nutrient stream and asks the operator to grow something already appearing as a line item on the feed bill.

The fertilizer escaping American farms does not cease to be fertilizer when it reaches a river. It merely becomes fertilizer in the wrong place.

The operator-facing form of the argument is shorter: grow part of your feed bill out of the nutrients your watershed is currently paying to lose.

This is not a moral appeal. It is a change in the direction of cash flow. Nutrient reduction currently functions as an expenditure with no productive return — public money spent to destroy or dilute a resource. Nutrient harvesting converts the same environmental objective into a commodity production system, and commodity production systems attract operators without needing to be mandated.

3. Feed Crop Classes

Three crop classes are specified. They are not interchangeable. Each occupies a different position in the nutrient gradient, targets a different livestock category, and carries a different risk profile.

3.1 Class F-1 — Floating Aquatic Macrophytes

Primary species: Lemna minor, Lemna gibba, Spirodela polyrhiza, Wolffia spp. Duckweed is among the fastest-growing flowering plants known, doubling biomass in roughly two to four days under warm conditions, and reported protein content ranges from approximately 20 to 45 percent of dry weight depending on species, nitrogen availability, and harvest interval. ⚑ PROVISIONAL

Role in the train: bulk nitrogen and phosphorus removal. F-1 does the heaviest lifting on the highest-concentration conditioned water and produces the largest tonnage per unit area.

Known limitations: high ash content, variable mineral composition, calcium oxalate in some species, sensitivity to free ammonia at elevated concentration, and — critically — a documented capacity to concentrate trace metals from the water column. Duckweed is used as a phytoremediation species precisely because it accumulates cadmium, lead, arsenic, chromium, copper, and zinc. This property is treated as a hazard in Section 7 and as a potential asset in Section 8.

3.2 Class F-2 — Hydroponic Forage Mats

Primary species: barley, wheat, oats, ryegrass, sorghum-sudangrass, and locally adapted forage grasses grown as dense tray or floating mat cultures on a five- to eight-day cycle.

Role in the train: mid-gradient polishing and fresh green forage production, particularly valuable during periods when pasture growth is poor — late summer dormancy, drought, and winter.

An honest note on dry matter: sprouted fodder systems are frequently criticized on the grounds that total dry matter declines between seed and harvest, because germination respires stored carbohydrate. That criticism is correct and is not contested here. The RRP case for F-2 does not rest on dry matter gain. It rests on two other outputs — dissolved nutrient uptake per unit area, and the conversion of a low-value dry input into a high-moisture, highly digestible fresh forage at a time of year when fresh forage is scarce. Any operator evaluating F-2 purely as a feed-tonnage multiplier will be disappointed. ⚑ PROVISIONAL

Known limitation specific to this class: forage grown on high-nitrate water can accumulate nitrate in plant tissue. This is a livestock toxicity hazard, not a quality issue. See Section 7.4.

3.3 Class F-3 — Protein-Dense Microalgae

Primary species: Chlorella vulgaris, Scenedesmus spp., Arthrospira (Spirulina) where climate and water chemistry permit. Reported crude protein content for these genera commonly falls between 40 and 60 percent of dry weight under controlled cultivation. ⚑ PROVISIONAL

Role in the train: residual phosphorus capture and production of a protein-dense concentrate suitable for aquaculture and poultry rations, where the value per unit mass is highest and the inclusion rate is lowest.

Known limitations: harvesting and dewatering microalgae is the most energy- and capital-intensive step in the entire pathway. Open cultivation is also subject to colonization by unintended species, including cyanobacteria capable of producing microcystin and other toxins. F-3 is the class least suited to independent single-operator deployment and the class most improved by hub processing.

3.4 Crop Class Reference Table

Class	Representative Species	Cycle	Protein (% DW)	Nutrient Role	Primary Livestock Target	HTC/HTL Fallback
F-1 Duckweed	Lemna, Spirodela, Wolffia	2–4 day doubling; continuous skim	20–45 ⚑	Bulk N and P	Poultry, swine, tilapia, carp	Good — HTL preferred
F-2 Forage Mats	Barley, wheat, ryegrass, sorghum-sudan	5–8 day tray cycle	10–18 ⚑	Mid-gradient N polish	Cattle, sheep, goats, rabbits	Good — HTC preferred
F-3 Microalgae	Chlorella, Scenedesmus, Arthrospira	Days; semi-continuous	40–60 ⚑	Residual P and N	Aquaculture, poultry, high-value rations	Excellent — HTL preferred
⚑ **PROVISIONAL:** *All protein, cycle, and uptake values are derived from published academic literature for individual species under controlled conditions. They are placeholders. Field-scale values from RRP feed pathway operation will replace them per the RRP8 data protocol. Routing preferences follow RRP5 §2 — lipid-rich material to HTL, lignocellulosic material to HTC.*						

Table E-1. *Feed crop class reference. All figures provisional pending pilot data per RRP8.*

4. Farm-Scale Process Train

The train below is the reference configuration. It is deliberately sequential — each stage receives water that the previous stage has already partially stripped, which places each crop class at the nutrient concentration it handles best and prevents the highest-value crop from being grown on the dirtiest water.

Stage 2, the refugium, is not optional. Its function and the consequences of omitting it are the subject of Section 5.

Stage	Function	Configuration	Output
0	Intake and screening	Low-head gravity diversion or low-lift pump from ditch, tile outlet, retention pond, lagoon supernatant, or tributary. Coarse screen. Flow metered.	Metered raw water; intake flow record for Form B
1	Solids settling	Settling chamber, forebay, or baffled basin. Residence time sized to site turbidity.	Clarified water; captured solids routed to the refugium or to D-4
2	**REFUGIUM — biological conditioning**	Fixed-film media bed, vegetated cell, and detritivore zone in series. Aerobic-dominant. Farm-scale analog of the RRP3 six-tank train. See Section 5.	Nitrate-dominant, ammonia-reduced, alkalinity-stabilized, biologically inoculated feedwater

3	F-1 duckweed raceways	Shallow raceways or basins, 6–18 in. depth, wind-sheltered, baffled to prevent mat rafting. Harvest at 70–90% surface coverage.	Bulk N and P removal; largest biomass tonnage
4	F-2 forage channels	Tray racks, floating mats, or shallow NFT-style channels. Covered or greenhouse-protected in cold season.	Fresh green forage; mid-gradient nutrient polish
5	F-3 algae stage	Shallow raceway or covered tank. Optional at single-operator scale; standard at cooperative scale.	Residual P capture; protein concentrate
6	Return	Discharge to source water body or to downstream use. Sampled at OUT per Field Kit Form B.	Treated water; SRC-to-OUT delta as performance evidence

Table E-2. *Reference farm-scale process train. Stages 4 and 5 are optional at the smallest deployment scale. Stages 0, 1, 2, 3, and 6 are the minimum viable configuration — the refugium is inside the minimum, not outside it.*

Operators should note the ordering rule: F-3 is placed last not because algae tolerate clean water better, but because the highest-value, highest-inclusion-risk crop should see the water that has already passed conditioning and two biological stages. If site constraints require reordering, the feed qualification panel in Section 10 must be expanded accordingly.

5. The Refugium Stage — Conditioning and Competitive Control

5.1 Why the Raceways Cannot Come First

Nutrient-bearing agricultural water does not arrive as fertilizer. It arrives as a mixture of nutrient forms in various stages of biological availability: particulate organic nitrogen, dissolved organic nitrogen, ammonia and ammonium, nitrite, nitrate, orthophosphate, and phosphorus bound to suspended sediment. Only a fraction of that is directly available to a planted crop.

The rest is available to whatever organism can process it fastest. Bacterial films, filamentous algae, cyanobacteria, and opportunistic wild vegetation all have shorter generation times and lower resource thresholds than a managed duckweed or forage crop. Delivered raw water, they win.

Without conditioning, the nutrients are taken up by anything. The raceway still removes nutrients — the environmental result occurs regardless — but the harvest is not the crop that was planted.

The practical consequences are specific and all bear directly on feed eligibility: species composition drift away from the intended crop, unpredictable protein content, elevated turbidity and shading that suppress the planted stand, competitive displacement by filamentous algae, and — the outcome the feed pathway can least afford — colonization by cyanobacteria, with the cyanotoxin exposure described in Section 7.2.

The refugium is the stage that decides who eats.

5.2 Functions of the Refugium

- Mineralization — heterotrophic bacteria and detritivores break particulate and dissolved organic nitrogen down into ammonium, releasing nutrients bound in material the crop cannot use directly.

- Nitrification — fixed-film bacterial communities convert ammonium to nitrite to nitrate, delivering nitrogen in the stable, plant-available form the crop stages are sized around.
- Ammonia reduction — free ammonia is inhibitory to duckweed and to several algal species at elevated concentration. The refugium brings it below the inhibitory threshold before the crop encounters it. ⚑ PROVISIONAL — threshold is species- and pH-dependent and must be established per site.
- Fine solids polishing — removes the residual organic fraction carrying turbidity, BOD, and light attenuation that the settling stage did not capture.
- Alkalinity and pH stabilization — nitrification consumes alkalinity. Buffering that consumption in the refugium rather than in the crop bed keeps the growing stages within a stable pH band.
- Biological inoculation — the refugium maintains a persistent, diverse microbial and detritivore community that continuously seeds the downstream stages, so recovery from a disturbance is reseeding rather than restarting.
- Shock absorption — first-flush storm events, lagoon pumping events, and seasonal application peaks arrive as concentration spikes. The refugium buffers them before they reach a crop that cannot move.

5.3 Configuration Options

The refugium is the farm-scale analog of the RRP3 six-tank biofiltration train: the same nitrogen chemistry, with substantially less instrumentation and no requirement for tank vessels. Three components are specified, deployed in series where space permits and combined where it does not.

If You Have Run a Four-Barrel System, You Already Know This

Everything in Section 5 is the biofilter barrel from a backyard aquaponics rig, scaled up and instrumented. Source and settling are the fish tank and the solids barrel. R-1 is the biofilter. Stage 3 is the grow bed. R-3 is the worms and snails that colonize the media whether anyone invited them or not — built on purpose this time.

Anyone who has cycled a system knows what happens when you skip it: you do not get a crop, you get an algae bloom and a fish kill. The RRP is making the same argument at watershed scale. You have to cycle it first.

Component	Configuration	Primary Function
R-1 Fixed-Film Media Bed	Biochar, lava rock, expanded shale, or equivalent high-surface-area media in a flow-through bed. Aerated passively by cascade or actively by low-power blower. The minimum viable refugium.	Nitrification; ammonia reduction; BOD oxidation
R-2 Vegetated Cell	Constructed wetland cell planted with cattail, bulrush, sedge, or locally adapted emergent macrophytes. Not harvested for feed.	Nutrient buffering; solids capture; root-zone microbial habitat; the wild species do their work here rather than contaminating the crop stages
R-3 Detritivore Zone	Quiescent zone supporting worms, snails, amphipods, and benthic invertebrates. Settled organics from Stage 1 may be routed here rather than to disposal.	Mineralization of settled organic solids; conversion of a waste stream into available nutrient

Table E-3. *Refugium components. R-1 is mandatory at all scales. R-2 and R-3 are strongly recommended and become standard at cooperative scale.*

5.4 A Deliberate Inversion of RRP3

RRP3's six-tank train includes two anaerobic tanks performing denitrification — converting nitrate to nitrogen gas and stripping nitrate load before the greenhouse stage. The feed pathway inverts that objective.

Denitrification destroys the crop's feedstock. In the feed pathway, nitrate is the product being delivered to the growing stages, not a load being eliminated. The farm-scale refugium is therefore aerobic-dominant, and anoxic zones are included only where a site has nitrate loading in excess of what the crop stages can absorb, or where the operation is running through a dormant season with the crop stages offline.

This is a genuine divergence from the main series architecture and is stated here so it is not read as an omission. An operator who builds a denitrifying refugium will produce clean water and a poor harvest.

5.5 Sizing and Residence Time

Refugium sizing is a function of influent ammonia and organic nitrogen concentration, target effluent ammonia, temperature, and media surface area. RRP3 provides the industrial-scale design basis and carries the same research disclaimer that applies here. No farm-scale sizing standard is proposed in this version.

⚑ **TBD —** Refugium sizing ratios, hydraulic retention time, and media surface area requirements for the farm-scale configuration are unestablished and are a primary target of field data collection per Section 14.

5.6 The Namesake Stage

A refugium is a protected place where a biological community persists through conditions it could not survive in the open, and from which the surrounding system is reseeded. That is the origin of the project's name, and this stage is where the term is doing literal rather than metaphorical work.

Everything downstream of Stage 2 is production. The refugium is the part that keeps the biology alive, stable, and yours.

6. Source-Water Eligibility Tiers

This section is the safety spine of the pathway. Feed eligibility is determined by the water source, not by the appearance of the harvest.

Tier	Typical Sources	Required Characterization	Feed Eligibility
Tier I — Controlled Agricultural	Own-operation retention pond, livestock lagoon supernatant, tile drainage from known cropland, aquaculture pond effluent	Baseline full panel once; routine core panel each batch; pathogen panel where animal waste is present	Eligible with routine batch testing
Tier II — Mixed Rural Surface Water	Drainage ditches with multiple contributors, small tributaries, shared irrigation returns, watershed reaches with unknown upstream operations	Baseline full panel plus seasonal re-characterization; expanded contaminant panel every batch; hold-and-test mandatory	Eligible only under hold-and-test discipline
Tier III — Urban, Industrial, or Unknown	Municipal stormwater, water downstream of a WWTP outfall, industrial corridors, legacy-contaminated watersheds, mine-	Full panel for documentation, credit, and Section 8 recovery screening	NOT feed-eligible. Route to D-4 thermochemical, fiber, or non-feed use only

	influenced water, any source that cannot be characterized		

Table E-4. *Source-water eligibility tiers. Tier assignment governs the entire disposition decision.*

6.1 The Tier Rule

Tier is a property of the water source, not of the harvest. A clean laboratory result on a single batch does not upgrade a Tier III source. Tier downgrade is immediate on discovery of an uncharacterized upstream input; tier upgrade requires a full re-characterization cycle and is never retroactive.

This rule exists because contaminant loading in surface water is episodic. A spill, a seasonal application, an industrial upset, or a single failed septic system can produce a contaminated window that a routine sampling schedule will miss entirely. Source tiering protects against the events that were not sampled. Batch testing protects against the events that were.

6.2 Non-Feed Deployment Is Not a Failure Mode

Tier III sites remain fully valid RRP participants. They operate under the fiber, fuel, and char logic already documented in RRP4 and RRP5, they still generate nutrient removal documentation eligible under RRP12 Layer 5, and they are the sites most likely to qualify for the metal recovery review in Section 8. The feed pathway is one disposition option among several, and excluding it does not reduce the environmental performance of the installation by any amount.

7. Contaminant and Hazard Profile

The pathway's central technical tension must be stated without softening: the species selected for this pathway are effective nutrient remediators because they are aggressive accumulators, and aggressive accumulators do not distinguish between nutrients and contaminants. Every hazard below follows from that single fact. Section 8 addresses the circumstances under which the same fact becomes an asset.

7.1 Trace Metal Bioaccumulation

Duckweed and microalgae are established phytoremediation organisms for cadmium, lead, arsenic, chromium, mercury, copper, and zinc, concentrating these elements substantially above ambient water concentrations. The enrichment factor is species-, metal-, and condition-dependent and cannot be assumed from water chemistry alone.

Mitigation: source tiering per Section 6; metals panel on baseline characterization for all tiers and on every batch for Tier II; disposition to D-4 on exceedance. Where concentrations are high enough to matter economically, the recovery review in Section 8 applies — but recovery interest never overrides feed disqualification.

7.2 Cyanotoxins

Open aquatic cultivation invites colonization by cyanobacteria. Microcystins, anatoxin-a, and cylindrospermopsin are hepatotoxic or neurotoxic and are not eliminated by drying or pelleting. Nutrient-rich, warm, low-flow water — exactly the condition this pathway creates — is also the condition that favors cyanobacterial dominance. A properly functioning refugium reduces but does not eliminate this risk, because it lowers the free nutrient concentration the opportunists are competing for.

Mitigation: microcystin screening on every feed-destined batch during warm-season operation; visual and microscopic species monitoring; immediate D-4 routing on detection above threshold; no exception for visually clean material.

7.3 Pathogens

Lagoon- and manure-influenced water carries Escherichia coli, Salmonella, Campylobacter, and Listeria risk, with the additional concern of recirculating a pathogen back into the herd or flock that produced it.

Mitigation: pathogen panel mandatory for all animal-waste-influenced sources; species-of-origin separation where practical — biomass grown on swine lagoon water should not be returned to swine without clearance; drying and heat treatment reduce but do not guarantee elimination.

7.4 Nitrate Accumulation in Forage

This hazard is specific to Class F-2 and is the one most likely to be overlooked, because it is a property of a healthy-looking crop rather than a contaminated one. Grasses grown on high-nitrate water accumulate nitrate in stem tissue. Ruminants convert nitrate to nitrite in the rumen, and nitrite binds hemoglobin. Acute nitrate poisoning is fast and fatal.

This hazard is intensified rather than reduced by a well-run refugium, because effective nitrification is precisely what raises nitrate concentration in the conditioned water. The benefit and the hazard have the same source.

Mitigation: forage nitrate testing on every F-2 batch destined for ruminants, evaluated against established forage nitrate feeding thresholds; dilution into a total mixed ration rather than free-choice feeding; F-2 placement at Stage 4 downstream of the duckweed raceways specifically to reduce nitrate exposure; preferential routing of F-2 to non-ruminant species where nitrate levels are elevated.

7.5 Pesticide, Pharmaceutical, and PFAS Residues

Agricultural drainage carries herbicide and pesticide residues. Livestock lagoon water may carry veterinary pharmaceutical residues, including antibiotics with withdrawal implications. PFAS is present in some watersheds at concentrations relevant to bioaccumulating organisms and is not removed by conventional treatment.

Mitigation: baseline screening informed by known upstream land use; PFAS screening required for any source within a documented affected watershed; antibiotic residue screening for lagoon-sourced Tier I operations feeding animals destined for the food supply.

7.6 Unintended Species and Composition Drift

Open cultivation is not monoculture. Wild-type duckweed populations shift species composition seasonally; algae cultures drift; forage mats develop mold under poor airflow. Composition drift affects protein content, palatability, and hazard profile simultaneously. Refugium conditioning is the primary structural control on drift; testing is the secondary control.

Mitigation: species identification recorded at each harvest event on Field Kit Form C; visible mold or off-odor is an automatic D-4 disposition without further testing.

8. Trace Metal Concentration as a Recovery Pathway

8.1 Dispersal Is the Damage

Nutrients, solids, and trace metals are not harmful because they exist. They are harmful because they were spread thin across a watershed where nothing can recover them and everything is exposed to them.

That is the operating principle of the entire system, and every stage of the RRP runs in the opposite direction — gathering what an industry scattered back into defined, assayed, handleable streams. The nutrient work does it for nitrogen and phosphorus. The same machinery does it for metals, because the organisms doing the gathering do not distinguish between them.

A concentrated stream can be sold, stockpiled against a future price, or controlled at a cost that can at least be calculated. A dispersed one can only be suffered. That difference is the product, and it exists before any buyer does.

Section 7.1 treats metal accumulation as a feed disqualifier. That treatment is correct and is not modified here — but disqualification from feed is not absence of value. A site with elevated metal loading is not a lost site. It is a site where the recovery question is worth asking, and the remainder of Section 8 is how it gets answered.

8.2 The Mechanism

Recovery depends on two concentration steps operating in series, both of which already exist in the RRP architecture.

- Biological concentration — the crop accumulates metals from dilute water into tissue at an enrichment factor determined by species, metal, pH, and competing ion load.
- Thermochemical concentration — biomass routed to HTC or HTL per RRP5 loses its organic mass to char, oil, and gas fractions while the inorganic fraction largely remains, partitioning into hydrochar and ash. The metal that entered as parts per billion in water leaves as a substantially concentrated fraction in a small solid volume.

Disposition tier D-5 — mineral recovery and fertilizer return — is where this material already terminates. Section 8 does not add a new process step. It adds an assay and a decision to a stream the system already produces.

This is the same logic as agromining and phytomining, where hyperaccumulating plants are grown on mineralized or contaminated ground and the harvested biomass is ashed to produce a metal-bearing concentrate. The precedent is established for nickel in particular; its transfer to aquatic species on agricultural and mine-influenced water is not. ⚑ PROVISIONAL

8.3 Review Criteria

Metal recovery is worth pursuing at a given site only where the following hold together. Any one of them failing is usually sufficient to make the answer no.

- Metal identity — recovery-interest metals carry market value per unit mass; liability metals carry disposal cost. A stream can contain both.
- Enrichment factor — the measured ratio between water concentration and tissue concentration for the species actually grown, not a literature value.
- Throughput — grams recovered per tonne of ash multiplied by tonnes of ash per year. Small operations rarely clear the threshold regardless of concentration.
- Co-occurrence — a zinc stream carrying cadmium may cost more to handle than the zinc returns.
- Ash classification — high-metal ash may be classified as a regulated waste. If so, the recovery question becomes a disposal-cost question, and the correct answer may be to avoid the site rather than to mine it.
- Buyer access — a metal-bearing ash with no smelter, refiner, or reprocessor willing to take it has no realized value.

8.4 Metal Categories

Category	Representative Elements	Typical Source Association	Review Position
Recovery Interest	Nickel, cobalt, copper, zinc, manganese; rare earth elements where present	Mine-influenced water, industrial corridors, mineralized geology, some legacy agricultural soils	Assay ash fraction. Evaluate against §8.3 criteria. Potential Layer 7 side-stream.
Liability	Cadmium, lead, arsenic, mercury, hexavalent chromium	Legacy industrial, smelter fallout, some phosphate-derived agricultural inputs, urban stormwater	Feed-disqualifying without exception. Ash classification governs cost. Recovery value rarely offsets handling.
Mixed	Any combination of the above	Most real sites	Case-by-case assay required. Do not assume separability. Default position is D-4 with no recovery claim until assayed.
⚑ **PROVISIONAL:** *No RRP metal recovery data exists. Enrichment factors, thermochemical partitioning behavior, ash grade, and recovery economics are all unmeasured for this pathway. This table is a review framework, not a performance claim, and no site should be sited or financed on the basis of anticipated metal recovery.*			

Table E-5. *Trace metal review categories for feed pathway sites. Review outcome never overrides the feed disqualification rules in Section 7.*

8.5 Site Selection Implication

Appendix A scores prospective sites across ten weighted criteria, of which Criterion 1 addresses nutrient load and water quality. Metal loading is not currently a scored variable anywhere in that matrix — a site with high metal concentration may score well on nutrient density with no indication that its biomass will be feed-ineligible or that it carries a recovery opportunity.

This appendix proposes a supplementary review rather than a matrix change. Altering the ten-criterion weighting would require rescoring every site published in Appendix C, and the case for that is not yet made.

Proposed: a Trace Metal Review is completed for any site being evaluated for the feed pathway. It produces two outputs — a feed eligibility determination feeding Section 6 tier assignment, and a recovery interest determination feeding Section 8.3. It attaches to the Appendix A score sheet as a supplement and does not alter the composite score.

8.6 The Honest Constraint

A metal recovery stream is an attractive idea and a poor foundation. The concentration factors are unmeasured, the ash grades are unknown, the regulatory classification of high-metal ash may convert the entire proposition into a cost center, and the buyer relationships do not exist yet.

The correct posture is review, not projection. Assay the ash where the water chemistry suggests it is worth assaying, publish the numbers under the open data doctrine in RRP8, and let the recovery case be made by data rather than by the appeal of the idea. The nutrient work stands on its own and does not require this to succeed.

9. Biomass Disposition Hierarchy

A failed feed batch is not a failed harvest. It is a reclassified harvest.

This is the structural feature that makes the pathway economically survivable. Feed production demands strict control over contaminants, pathogens, nutrient composition, and species purity — a standard no biological system meets one hundred percent of the time. In most agricultural contexts, failing a feed specification converts a crop back into a disposal cost. Inside the RRP architecture, it converts the crop into a different product.

Tier	Disposition	Trigger	Notes
D-1	Fresh feed, on-farm	Batch clears full qualification panel; consumed on the operation that produced it	Highest net value — avoids drying energy entirely. Shortest hold time. Preferred first target for new operators.
D-2	Dried ingredient	Batch clears panel; surplus beyond fresh demand, or seasonal storage requirement	Drying is the dominant energy cost in the pathway. Solar and waste-heat drying materially change the economics.
D-3	Cooperative pellet blend	Batch clears panel and meets hub formulation specification	Requires hub infrastructure and, for sale into commerce, ingredient status per Section 10.6.
D-4	Thermochemical feedstock	Any panel exceedance, visible spoilage, Tier III source, or composition outside specification	Routed to HTC or HTL per RRP5 §2. Nutrient removal credit is unaffected — the nutrient left the water regardless of end use.
D-5	Mineral recovery and fertilizer return	Post-thermochemical ash and recovered mineral fraction	Closes the loop. Recovered phosphorus has direct agronomic value on the originating operation. This is also the assay point for the trace metal recovery review in Section 8.

Table E-6. *Biomass disposition hierarchy. Movement down the hierarchy is a routing decision, not a loss event.*

The operator therefore is not betting the season on producing premium feed every week. The system has a graceful degradation path, and the environmental performance — the nutrient removed from the water column — is identical at every tier.

10. Feed Qualification Protocol

This protocol is additive to RRP8. It does not replace any Axis 2 or Axis 3 requirement. Where a parameter appears in both, RRP8 governs the method and this section governs the acceptance decision.

10.1 Baseline Source Characterization

Performed once before any feed use, and repeated annually or on any change in upstream land use. Full panel: total nitrogen, total phosphorus, nitrate-N, ammonia-N, metals screen, pathogen screen where animal waste is present, pesticide screen informed by upstream cropping, PFAS screen where the watershed is affected, and cyanotoxin screen. Results establish tier assignment under Section 6 and feed the Trace Metal Review under Section 8.5.

10.2 Refugium Performance Verification

Because the refugium governs which organism captures the nutrient, its performance is a feed quality control point rather than a water treatment detail. Sampling at refugium inlet and outlet establishes whether conditioning is actually occurring.

- Ammonia-N reduction across the refugium — the primary indicator of nitrification function.
- Nitrate-N increase across the refugium — confirms conversion rather than loss.
- pH and alkalinity at outlet — confirms buffering capacity has not been exhausted.
- Turbidity and BOD reduction — confirms solids and organic polishing.

A refugium showing ammonia passing through unconverted is not conditioning the water, and the crop stages downstream should be treated as unqualified until it is corrected.

10.3 Batch Testing at Harvest

A batch is defined as the material removed in a single harvest event from a single stage, held together, and dispositioned together. Batch testing is performed on the biomass, not the water — water quality data does not substitute for tissue analysis, because the accumulation factor is exactly what is in question.

- Core panel, every feed-destined batch: dry matter, crude protein, ash, nitrate (F-2 mandatory), visible species composition.
- Hazard panel, frequency by tier: metals screen, microcystin (warm season), pathogen screen (animal-waste sources).
- Full panel: at baseline, mid-season, and season-end at minimum, per Field Kit lab submission guidance.

10.4 Hold-and-Test Discipline

Feed-destined biomass is held pending panel results. Material is not released forward on the assumption that it will clear. This is a discipline, not a formality — the entire feed-safety case rests on it, and it is the single easiest point at which an operator under time pressure will compromise the system.

Where hold capacity is unavailable, the correct answer is D-4 routing, not release-on-assumption.

10.5 Records and Proposed Form D

Every batch carries a record from harvest through disposition: site ID, stage, harvest date, wet and dry mass, species composition, panel results, disposition tier, and destination. Records are retained for a minimum of three years or the retention period required by the operator's state feed control official, whichever is longer.

The RRP Field Documentation Kit currently contains Form A (System Configuration), Form B (Water Quality Monitoring), and Form C (Biomass Harvest and Disposition). Form C captures harvest and disposition but not the qualification decision. This appendix proposes Form D — Feed Qualification & Disposition Record — capturing batch definition, panel results, the accept/reject decision, the decision-maker, and the destination. Form A will also require a refugium configuration block. Both are Field Kit amendments and are not published with this appendix.

10.6 Regulatory Ingredient Status — A Real Gate

This section exists because it is the point at which an otherwise sound project most commonly fails.

In the United States, animal food ingredients are regulated by the FDA Center for Veterinary Medicine, with ingredient definitions maintained through the Association of American Feed Control Officials and enforced by state feed control officials. Not every species and production method in this pathway has an established ingredient definition, and definitions that exist may not cover material produced on a non-potable water source.

Two situations must be distinguished clearly:

- Feeding one's own animals from one's own production is generally the lower-friction case and is the recommended entry point for a first-season operator.
- Selling feed or feed ingredients into commerce triggers ingredient definition requirements, labeling requirements, state registration, and facility obligations that must be confirmed before the first sale, not after it.

Bright Meadow Group does not provide regulatory or legal counsel, and nothing in this appendix constitutes a determination of ingredient status for any operator. Operators intending to sell should engage their state feed control official early. Cooperative and hub operators should treat ingredient status as a gating condition on the D-3 disposition tier.

11. Cooperative Architecture

The cooperative model is stronger than the individual-farm model for the same reason the RRP node architecture uses hub-and-spoke: the biologically productive functions are cheap and distributable, and the quality-control and processing functions are expensive and centralizable.

Spoke — Operator Level	Hub — Regional Level
• Intake, settling, and refugium operation • Growing and harvest • Field-level water quality monitoring (Form B) • Refugium inlet/outlet verification (§10.2) • Harvest and disposition logging (Form C) • Fresh feed use on-site (D-1) • Basic dewatering	• Laboratory testing and panel interpretation • Dewatering and drying at scale • Formulation and pelleting • Storage and inventory • Feed ingredient status and labeling compliance • Off-spec routing to HTC/HTL (D-4) • Ash assay, mineral recovery, and Section 8 metal review (D-5) • Aggregate nutrient credit documentation

Table E-7. *Function allocation between operator spokes and regional hub. Mirrors the RRP Model A / Model B distinction — the hub performs the capital-intensive processing role a Model A node performs for its satellites.*

One operator grows duckweed. Another runs forage mats. A third operates algae raceways sized to a shared drying line. Each operator does the portion matching their land, climate, equipment, and livestock. The hub does the portion that requires a laboratory relationship, a dryer, a pellet mill, and a regulatory file.

12. Economics

12.1 Offset Before Sale

The first economic case for most operators is not feed sales. It is feed offset. Displacing a purchased input avoids the supplier's margin, the freight, the market volatility, and the entire regulatory apparatus of selling into commerce. An operator who replaces a portion of a protein supplement or winter forage purchase captures value immediately and at the lowest possible compliance burden.

Feed sale is a second-phase objective and should be treated as a hub function rather than an operator function.

12.2 Revenue Stack Mapping

Within the RRP12 eight-layer revenue stack, this pathway monetizes primarily:

- Layer 1 — Biomass Production, realized as feed offset or feed sale rather than fiber sale.
- Layer 5 — Nutrient Trading and Water-Quality Credits, realized on documented removal regardless of biomass end use.
- Layers 2 and 3 — Hydrochar and Bio-Oil, available on D-4 material where a hub with thermochemical access exists.
- Layer 7 — Productized Side-Streams, the layer under which recovered mineral and any Section 8 metal fraction would be reported. ⚑ PROVISIONAL — no valuation basis exists.
- Layer 8 — Environmental Data, available at cooperative scale where a hub aggregates multi-site datasets.

12.3 Credit Accounting Integrity

One removal event, one credit.

Nitrogen and phosphorus removed from the water column and sold as feed cannot also be claimed by a downstream party as a separate reduction. Credit protocols must be written to a specific claim, and the claim this pathway supports is removal from the water column at the point of harvest.

An honest complication must be stated: nitrogen embodied in feed re-enters the agricultural nutrient cycle as manure. A regulator or credit protocol administrator will ask whether this is removal or relocation. The RRP position is that harvest constitutes removal from the water body — the environmental harm being addressed is aquatic hypoxia, and the nutrient has left the aquatic system — but that this position must be stated in the credit instrument rather than assumed. Protocols requiring permanent sequestration should route to D-4 and claim on hydrochar permanence instead, which is the pathway RRP12 Layer 4 already documents. ⚑ PROVISIONAL — pending credit protocol negotiation.

12.4 Cost Drivers

- Harvest labor — dominant cost at small scale; the primary target for mechanization.
- Dewatering and drying energy — dominant cost at any scale where D-2 or D-3 is the target disposition. This is the single strongest argument for D-1 fresh use and for hub aggregation of drying capacity.
- Drying air conditioning — where covered drying is used, a covered water tower of the type described in RRP3 §2 functions as a condensing surface, dropping moisture out of circulated air as recoverable water rather than venting it and the heat with it. Condensing surface area rather than tower volume is the governing constraint. ⚑ PROVISIONAL — unsized for this application.
- Laboratory testing — a fixed cost per batch that scales badly for small operators and well for cooperatives. A significant driver of the hub model.
- Refugium construction — a real capital line that the raceway-only mental model omits. It is nonetheless the cheapest insurance in the system relative to the harvest failures it prevents.
- Cold-season protection — greenhouse or tunnel capital where year-round operation is intended.

13. Deployment Scales

13.1 Scale E-1 — Single Operator

A pond, a ditch diversion, or a lagoon; a settling basin; an R-1 media bed refugium; duckweed raceways; fresh feed to the operator's own poultry, swine, or fish. Minimal capital. Tier I water. D-1 disposition only. Documentation via Field Kit Forms A, B, and C. This is the entry configuration and the one most likely to generate the first real field data for the pathway.

13.2 Scale E-2 — Cooperative with Hub

Multiple operator spokes feeding a shared processing hub as described in Section 11. Adds full R-1/R-2/R-3 refugium configurations, D-2 and D-3 dispositions, laboratory relationship, formulation capability, ash assay capacity, and aggregate credit documentation. This is the configuration at which the pathway becomes a regional industry rather than a farm practice.

13.3 Scale E-3 — Integrated Node Module

Feed production operated as a dedicated greenhouse assignment within a full RRP node, drawing conditioned water from the node's existing six-tank biofiltration train rather than from a separate refugium. This requires an amendment to the RRP6 modular slot framework, which currently defines Slot Types A through E by growth profile and HTC suitability. A proposed Slot Type F — feed-grade aquatic and forage production — would carry an additional characteristic absent from the existing slot definitions: a feed qualification status field governing whether the slot's output is eligible for D-1 through D-3 disposition or restricted to D-4.

Downstream dependency: Scale E-3 cannot be modeled financially until RRP6 §5 is amended to include Slot Type F and the financial model is updated with a feed-value output stream. A node routing water to Slot Type F must also confirm that its anaerobic denitrification tanks are bypassed or throttled for that stream, per the inversion in §5.4. This appendix does not make either amendment.

14. What the Pilot Must Prove

No field-validated RRP feed pathway data exists as of this version. The following are the open questions, in priority order, that a first-season operator or pilot must answer before any figure in this appendix should be treated as anything other than a literature proxy.

- Refugium sizing — hydraulic retention time and media surface area required to bring a given influent ammonia load below the crop inhibition threshold.
- Refugium effect on harvest purity — the measurable difference in species composition, protein consistency, and cyanobacterial incidence between conditioned and unconditioned raceways run in parallel. This is the single most valuable A/B comparison available in the pathway.
- Field-scale nutrient uptake per unit area per crop class, measured as SRC-to-OUT delta rather than inferred from biomass.
- Contaminant enrichment factors under real farm conditions — the ratio between water concentration and tissue concentration for the metals of concern, by species and season.
- Batch failure rate by source tier. This single number determines whether the pathway is a feed business with a fallback or a fuel business with an occasional feed premium.
- Ash metal grade after HTC/HTL and its regulatory classification — the gating question for Section 8.
- Harvest labor hours per wet kilogram, and the effect of the simplest available mechanization.

- Dewatering and drying energy per dry kilogram, with and without solar or waste-heat integration.
- Animal performance: palatability, intake, feed conversion, and health outcomes on defined inclusion rates, by species.
- Seasonal composition drift in wild-type duckweed populations and its effect on protein consistency.

15. Provisional Status

⚑ **PROVISIONAL —** All yield, protein content, cycle time, nutrient uptake, refugium sizing, and metal recovery figures in this appendix are derived from published academic literature or are unestablished. They are the closest available proxies and are placeholders only. Actual pathway performance data will be generated by field operators and pilot deployment and will replace these proxies per the RRP8 data collection protocol. No figure in this document should be used as the basis for a capital commitment, a feed formulation, a metal recovery projection, or a credit claim without site-specific validation.

Closing Note

The rest of the RRP series argues that nutrient pollution should be treated as feedstock rather than waste. Appendix E is the version of that argument aimed at the people already standing in the watershed with the equipment, the land, and the livestock — and who have, until now, been offered only restriction.

The pathway is not offered as easy. Sections 6, 7, and 10 exist because the biology that makes it work is the same biology that makes it risky, and pretending otherwise would fail the operator, the animal, and the open-data standard the rest of this series is built on. Section 5 exists because a raceway on a ditch is not a system, and the difference between a crop and a colonization event is a stage most people would skip.

It is offered as available. The water is already carrying the nutrients. The species already grow on them. What is missing is the conditioning that decides who gets them, and the documentation discipline that turns a good idea into evidence.

Notes

Citations follow Chicago Notes-Bibliography style. Internal Bright Meadow Group / Cernunnos Foundation documents are cited by document title and year. Figures marked ⚑ are provisional academic proxies pending replacement by RRP pilot data per RRP8. Regulatory references are provided for orientation and do not constitute legal or regulatory advice.

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