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EGLE A Level Exam Prep

Nutrient Removal

This free preview gives away the nutrient heart of the Class A book: the nutrient removal study information, the process cartoon, the nitrogen flow sheet, and the first 10 questions — with their answers — from the book's 139-question Nutrient Removal Practice Exam. Read the overview, study the two sheets, work the questions, then check yourself against the answer key. The other 129 questions are waiting in the book.

Inside this free preview:

- **Nutrient Information** — the study overview: nitrification, denitrification, and biological phosphorus removal, with the numbers an operator has to know
- **The Nutrient Removal Story** — the process cartoon from the book
- **Follow the Nitrogen** — the process flow sheet, tracking one load of nitrogen from influent to effluent
- **Questions 1–10** of the 139-question Nutrient Removal Practice Exam
- **Answer Key 1–10** — correct answers with full explanations

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S T U D Y O V E R V I E W

Nutrient Information

Nutrient removal is where the Class A exam lives. This overview is the study core of the nutrient section of the book: how nitrogen and phosphorus move through a plant, which organisms do the work, what each step costs, and where operators lose control. It is built around how nutrient removal actually fails in a working plant, and what an operator does about it — in the five biological phosphorus removal systems (A/O, A2/O, SBR, concentric ring oxidation ditch, and Modified Bardenpho) and across the plant as a whole, including clarifier solids floating from denitrification, return flows, toxicity, temperature, alkalinity and pH crashes, dissolved oxygen control, SRT, RAS, foaming, and bulking as they bear on nutrient removal.

Start with the nitrogen: TKN

Total Kjeldahl Nitrogen (TKN) is the nitrogen that enters with the wastewater. It has two parts:

> **TKN = Organic N + Ammonia N (NH_3-N)**

Bacteria first break the organic nitrogen down and release it as ammonia — ammonification. The total nitrogen does not change; only its form changes. Which form the ammonia takes matters: at high pH and high temperature, more of it is unionized ammonia gas (NH_3), the form most toxic to aquatic life; below pH 7 and at low temperature it sits mostly as the ammonium ion (NH_4+). Ammonia left in an effluent also exerts a nitrogenous oxygen demand in the receiving stream — stream microbes nitrify it there, consuming dissolved oxygen as they do.

Nitrification — two steps, two organisms

Nitrification is a two-step oxidation carried out by slow-growing autotrophic bacteria — organisms that get their energy from oxidizing ammonia and nitrite, and their carbon from inorganic carbon (carbon dioxide and bicarbonate), not from BOD. That is why they grow so much more slowly than the ordinary carbon-removing bacteria, and why everything about nitrification control comes back to keeping them in the system.

Step 1 — *Nitrosomonas* (ammonia-oxidizing bacteria) oxidize ammonia to nitrite: $NH_3 \rightarrow NO_2^-$.

Step 2 — *Nitrobacter* (nitrite-oxidizing bacteria) oxidize nitrite to nitrate: $NO_2^- \rightarrow NO_3^-$. The second step cannot proceed until the first supplies nitrite.

Nitrification changes the *form* of the nitrogen — it does not remove it. The nitrate is still in the water. And nitrification is expensive:

What nitrification costs	Per 1 lb of NH_3-N nitrified
Oxygen	4.57 lb of O_2 (about 3.43 lb to nitrite, plus 1.14 lb to nitrate)
Alkalinity	7.14 lb of alkalinity as $CaCO_3$ consumed

Control points. Hold dissolved oxygen up in the aeration basin. Hold the solids retention time long enough that the slow growers are not washed out — a high cell residence time, at least about 8 days

under typical conditions, favors nitrification. Watch alkalinity and pH, because nitrification consumes alkalinity and produces acid, and alkalinity is also the nitrifiers' carbon source. Cold temperatures slow the nitrifiers down. A high organic load lets fast-growing carbon-removing bacteria compete for oxygen and space and crowd the nitrifiers out, even when aeration capacity looks adequate. And wasting is the classic self-inflicted wound: a plant that loses nitrification every time the wasting rate goes up is wasting its nitrifiers out of the system faster than they can regrow.

Denitrification — the step that actually removes nitrogen

In an anoxic zone — no free dissolved oxygen — bacteria use the oxygen bound in nitrate and release the nitrogen as N_2 gas, which bubbles out into the air: $NO_3^- \rightarrow N_2 \uparrow$. This is the step that removes nitrogen from the water. It needs a carbon source — influent BOD, or added methanol where BOD runs short.

Denitrification also gives something back: about half of the alkalinity nitrification consumed — **3.57 lb of alkalinity returned for every 1 lb of NO_3-N denitrified**.

Run it in the wrong place, though, and it runs anyway: denitrification in the clarifier floats solids on rising nitrogen gas — a symptom every operator should be able to diagnose on sight.

Biological phosphorus removal — a different track

Phosphorus rides a different track from nitrogen. In an anaerobic zone, phosphorus-accumulating organisms (PAOs) release phosphorus and take up volatile fatty acids (VFAs). In the aerobic zone they take up more phosphorus than they released — "luxury uptake" — and store it in their cells. The phosphorus then leaves the plant in the waste activated sludge. In the flow-sheet example on the pages that follow, influent total phosphorus of 6.0 mg/L leaves the plant at 0.5 mg/L.

The exam works across the five biological phosphorus removal systems: **A/O, A2/O, SBR, concentric ring oxidation ditch, and Modified Bardenpho**.

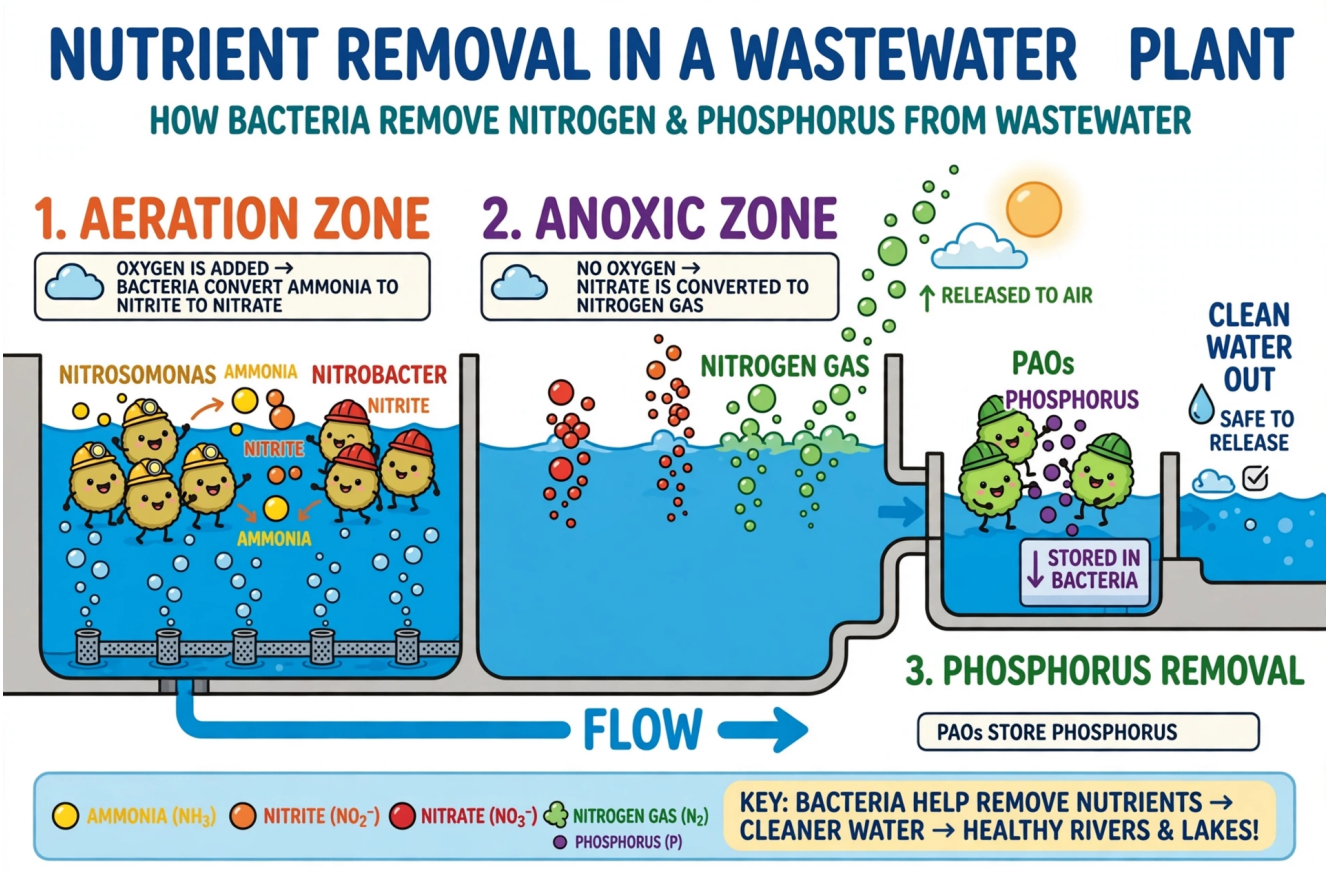
Numbers to know cold

Figure	Value
TKN	Organic N + Ammonia N (NH_3-N)
Oxygen for complete nitrification	4.57 lb O_2 per lb NH_3-N
Alkalinity consumed by nitrification	7.14 lb as $CaCO_3$ per lb NH_3-N
Alkalinity returned by denitrification	3.57 lb per lb NO_3-N denitrified
SRT that favors nitrification	High — at least about 8 days under typical conditions

Now study the cartoon and the flow sheet that follow — they tell this same story in pictures — then work Questions 1–10 and check yourself against the key.

VISUAL SHEET 1

The Nutrient Removal Story



How to read the cartoon. In the **aeration zone**, bacteria do the converting: **Nitrosomonas** turn **ammonia** into **nitrite**, and **Nitrobacter** turn **nitrite** into **nitrate**. In the **anoxic zone** — no oxygen — other bacteria turn **nitrate** into **nitrogen gas**, which bubbles up and out into the air. Down the line, **PAOs** grab **phosphorus** and store it inside themselves, so the phosphorus leaves the plant with the waste sludge. What flows out at the end is clean water.

VISUAL SHEET 2

Follow the Nitrogen — Process Flow Sheet

One example load of nitrogen, tracked through every step of the plant. All values are mg/L as N unless noted. Watch the **tracker line** in each box: the form of the nitrogen changes at every step, and the total only drops where nitrogen gas leaves.

1 INFLUENT — THE NITROGEN ARRIVES

Total Kjeldahl Nitrogen (TKN) is the nitrogen that enters with the wastewater. It has two parts:
TKN = Organic N + Ammonia N (NH_3-N)

Worked example used on this sheet: **TKN 40 mg/L = Organic N 12 mg/L + NH_3-N 28 mg/L**.

TRACKER: Organic N **12** · NH_3-N **28** · NO_2-N **0** · NO_3-N **0** · Total **40**

▼

2 AMMONIFICATION — ORGANIC N BECOMES AMMONIA

Bacteria break down the organic nitrogen (proteins, urea) and release it as ammonia. The total nitrogen does not change — only its form changes.

TRACKER: Organic N **~0** · NH_3-N **40** · NO_2-N **0** · NO_3-N **0** · Total **40**

▼

3 NITRIFICATION, STEP 1 — *NITROSOMONAS* (AEROBIC)

Nitrosomonas bacteria oxidize ammonia to **nitrite**: $NH_3 \rightarrow NO_2^-$. This step needs dissolved oxygen — it happens in the aeration basin.

TRACKER: NH_3-N **0** · NO_2-N **40** · NO_3-N **0** · Total **40**

▼

4 NITRIFICATION, STEP 2 — *NITROBACTER* (AEROBIC)

Nitrobacter bacteria oxidize nitrite to **nitrate**: $NO_2^- \rightarrow NO_3^-$. The nitrogen is still all in the water — nitrification changes its form, it does not remove it.

TRACKER: NH_3-N **0** · NO_2-N **0** · NO_3-N **40** · Total **40**

▼

WHAT NITRIFICATION COSTS (STEPS 3–4 TOGETHER)

Oxygen: 4.57 lb of O_2 for every 1 lb of NH_3-N nitrified. Example: 40 mg/L × 4.57 ≈ **183 mg/L of O_2** that the blowers must supply.

Alkalinity: 7.14 lb of alkalinity (as $CaCO_3$) is consumed for every 1 lb of NH_3-N nitrified. Example: 40 mg/L × 7.14 ≈ **286 mg/L of alkalinity consumed** — watch the pH.

5 DENITRIFICATION — NITRATE BECOMES NITROGEN GAS (ANOXIC)

In an **anoxic zone** (no free dissolved oxygen), bacteria use the oxygen in nitrate and release the nitrogen as **N_2 gas**, which bubbles out into the air: $NO_3^- \rightarrow N_2 \uparrow$. This is the step that actually **removes** nitrogen from the water. It needs a **carbon source** — influent BOD, or added methanol. In the example, **32 of the 40 mg/L** leaves as N_2 gas.

TRACKER: NO_3-N **8** · N_2 gas released **32** · Total accounted **40**

WHAT DENITRIFICATION GIVES BACK

Alkalinity returned: about half of what nitrification consumed — 3.57 lb for every 1 lb of NO_3-N denitrified. Example: 32 mg/L × 3.57 ≈ **114 mg/L returned**. Net alkalinity cost of the example: 286 − 114 ≈ **171 mg/L**.

6 EFFLUENT — WHAT LEAVES THE PLANT

The ammonia is gone, the nitrate is low, and the nitrogen that was removed is harmless N_2 in the air. Mass check on the example: **40 in = 32 out as N_2 gas + 8 out in the effluent** (a small additional share always leaves in the waste sludge, as nitrogen built into new bacteria cells).

EFFLUENT: NH_3-N **< 1** · NO_2-N **~0** · NO_3-N **8** · Total N **≈ 8–9**

ALONGSIDE: BIOLOGICAL PHOSPHORUS REMOVAL

Phosphorus rides a different track. In an **anaerobic zone**, phosphorus-accumulating organisms (PAOs) release phosphorus and take up volatile fatty acids (VFAs). In the **aerobic zone** they take up **more phosphorus than they released** ("luxury uptake") and store it. The phosphorus then leaves the plant in the **waste activated sludge**. Example: influent total phosphorus **6.0 mg/L** → effluent total phosphorus **0.5 mg/L**.

F R O M T H E B O O K

Nutrient Removal Practice Exam — Questions 1–10 (of 139)

1. Nitrification in Depth

Requirements, dependencies, inhibitors - and what goes wrong, and why. Work in pencil or on separate paper; short-answer questions have writing lines.

1. Which form of ammonia is most toxic to aquatic life, and under what conditions does it dominate?

A. Ammonium ion (NH4+), at low pH and low temperature
B. Ammonia gas (NH3), at high pH and high temperature
C. Nitrite, at low pH and low temperature
D. Nitrate, at high pH and high temperature

2. As pH falls below 7 and temperature drops, most ammonia in wastewater is present as:

A. Free ammonia gas
B. Nitrite
C. The ammonium ion (NH4+)
D. Nitrogen gas

3. Nitrification is carried out in two steps. Which pairing is correct?

A. Ammonia to nitrite by Nitrobacter, then nitrite to nitrate by Nitrosomonas
B. Ammonia to nitrite by Nitrosomonas, then nitrite to nitrate by Nitrobacter
C. Ammonia directly to nitrogen gas by Nitrosomonas
D. Nitrate to ammonia by Nitrobacter

4. [Short answer] Name, by genus, the two groups of organisms responsible for nitrification and state what each group produces, in order.

5. Why do nitrifying bacteria grow so much more slowly than the ordinary carbon-removing bacteria in activated sludge?

A. They get little energy from oxidizing ammonia and nitrite and fix inorganic carbon
B. They need no oxygen
C. They only grow in the clarifier
D. They reproduce only in winter

6. Nitrification is carried out by autotrophic bacteria. What does that mean, and why does it matter in a plant?

A. They get energy from oxidizing ammonia and nitrite and get their carbon from inorganic carbon (carbon dioxide and bicarbonate), so they grow slowly and need adequate alkalinity

B. They get both energy and carbon from influent BOD, so they grow as fast as carbon-removing bacteria

C. They need no oxygen and no alkalinity

D. They live only on phosphorus

7. Why does ammonia left in an effluent exert an oxygen demand in the receiving stream?

A. Microbes in the stream oxidize the ammonia to nitrite and then to nitrate, consuming dissolved oxygen as they do - a nitrogenous oxygen demand that can deplete stream oxygen and harm fish

B. Ammonia evaporates from the stream and takes dissolved oxygen with it

C. Ammonia reacts instantly with sunlight to consume oxygen

D. It does not - ammonia is a toxicity problem only and never affects stream oxygen

8. For complete nitrification, about how much dissolved oxygen is required for each milligram of ammonia-nitrogen oxidized to nitrate?

A. About 1.0 mg

B. About 4.57 mg

C. About 7.14 mg

D. About 0.2 mg

9. A plant keeps losing nitrification every time the wasting rate is increased. The most likely cause is:

A. The solids retention time (cell residence time) has fallen below what slow-growing nitrifiers need to stay in the system

B. Dissolved oxygen is too high

C. Alkalinity is too high

D. The RAS rate is too low

10. [True/False] A high cell residence time - at least about 8 days under typical conditions - favors nitrification because nitrifiers are not washed out.

A. True

B. False

A N S W E R K E Y

Answer Key — Questions 1–10

Correct answers and explanations for Questions 1–10 of the Nutrient Removal Practice Exam, numbered identically to the exam. The full key covers all 139 questions in the book.

1. Nitrification in Depth

1. Which form of ammonia is most toxic to aquatic life, and under what conditions does it dominate?

Answer: B - Ammonia gas (NH3), at high pH and high temperature.

Unionized ammonia (NH3) crosses fish gills readily and is the toxic form. As pH and temperature rise, the NH4+ / NH3 equilibrium shifts toward NH3, so the same total ammonia becomes more toxic. Option A reverses the conditions; nitrite and nitrate (C, D) are far less acutely toxic in this comparison.

2. As pH falls below 7 and temperature drops, most ammonia in wastewater is present as:

Answer: C - The ammonium ion (NH4+).

Below pH 7 and at lower temperature the equilibrium favors the ionized, comparatively non-toxic ammonium form. It is not free ammonia gas (A), and ammonia is not converted to nitrite or nitrogen gas simply by cold, low-pH conditions (B, D).

3. Nitrification is carried out in two steps. Which pairing is correct?

Answer: B - Ammonia to nitrite by Nitrosomonas, then nitrite to nitrate by Nitrobacter.

Nitrification is a two-step oxidation. Option A swaps the two genera; ammonia is never converted directly to nitrogen gas by nitrifiers (C - that is denitrification, by different organisms), and Nitrobacter does not run the reaction backward (D).

4. Name, by genus, the two groups of organisms responsible for nitrification and state what each group produces, in order.

Answer: Model answer: Nitrosomonas first, then Nitrobacter.

Step 1: Nitrosomonas (ammonia-oxidizing bacteria) oxidize ammonia (NH3/NH4+) to nitrite (NO2-). Step 2: Nitrobacter (nitrite-oxidizing bacteria) oxidize nitrite to nitrate (NO3-). Both groups are autotrophs, and the second step cannot proceed until the first supplies nitrite.

5. Why do nitrifying bacteria grow so much more slowly than the ordinary carbon-removing bacteria in activated sludge?

Answer: A - They get little energy from oxidizing ammonia and nitrite and fix inorganic carbon.

Nitrifiers obtain very little energy per unit of ammonia or nitrite oxidized, and they must build cell carbon from CO2/bicarbonate rather than ready-made organic carbon. The result is a low yield and slow growth. They absolutely require oxygen (B is wrong), they live in the aerated mixed liquor, not only the clarifier (C), and they grow year-round, only slower in the cold (D).

6. Nitrification is carried out by autotrophic bacteria. What does that mean, and why does it matter in a plant?

Answer: A - Energy from oxidizing ammonia/nitrite; carbon from inorganic carbon, so they grow slowly and need adequate alkalinity.

Autotrophic means carbon comes from inorganic sources (CO2, bicarbonate), not from BOD. That slow, low-energy lifestyle is why nitrifiers need a long SRT and why alkalinity - their carbon source and the buffer against the acid nitrification produces - must not run out. Option B describes heterotrophic carbon-removing bacteria.

7. Why does ammonia left in an effluent exert an oxygen demand in the receiving stream?

Answer: A - Stream microbes oxidize the ammonia, consuming dissolved oxygen (nitrogenous oxygen demand).

Ammonia discharged to a stream is nitrified there by stream organisms, drawing down DO - about 4.57 mg of oxygen per mg of ammonia-nitrogen fully oxidized. That sag can stress or kill fish, on top of ammonia's direct toxicity. Evaporation and sunlight (B, C) are not the mechanism, and D denies a real, well-documented demand.

8. For complete nitrification, about how much dissolved oxygen is required for each milligram of ammonia-nitrogen oxidized to nitrate?

Answer: B - About 4.57 mg of oxygen per mg of ammonia-nitrogen.

Complete oxidation of ammonia-nitrogen to nitrate requires about 4.57 mg O2 per mg NH3-N (about 3.43 for the nitrite step and 1.14 for the nitrate step). 7.14 mg (C) is the alkalinity figure, not oxygen; 1.0 and 0.2 mg (A, D) are far too low - which is why nitrification is such a heavy aeration load.

9. A plant keeps losing nitrification every time the wasting rate is increased. The most likely cause is:

Answer: A - SRT (cell residence time) has fallen below the nitrifiers' minimum.

Wasting removes nitrifiers along with all other solids. Because nitrifiers reproduce slowly, wasting faster than they can regrow washes them out and ammonia breaks through. High DO or high alkalinity (B, C) would help, not hurt, nitrification, and RAS rate (D) returns solids rather than removing them from the system inventory the way wasting does.

10. A high cell residence time - at least about 8 days under typical conditions - favors nitrification because nitrifiers are not washed out.

Answer: A - True.

A high cell residence time - at least about 8 days under typical conditions, per the owner's review and standard practice - keeps slow-growing nitrifiers in the system long enough to maintain a working population. Short SRT is a classic cause of nitrifier washout.

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