NUTRIENT REMOVAL WASTEWATER TREATMENT

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The Impacts of Excess Nutrients

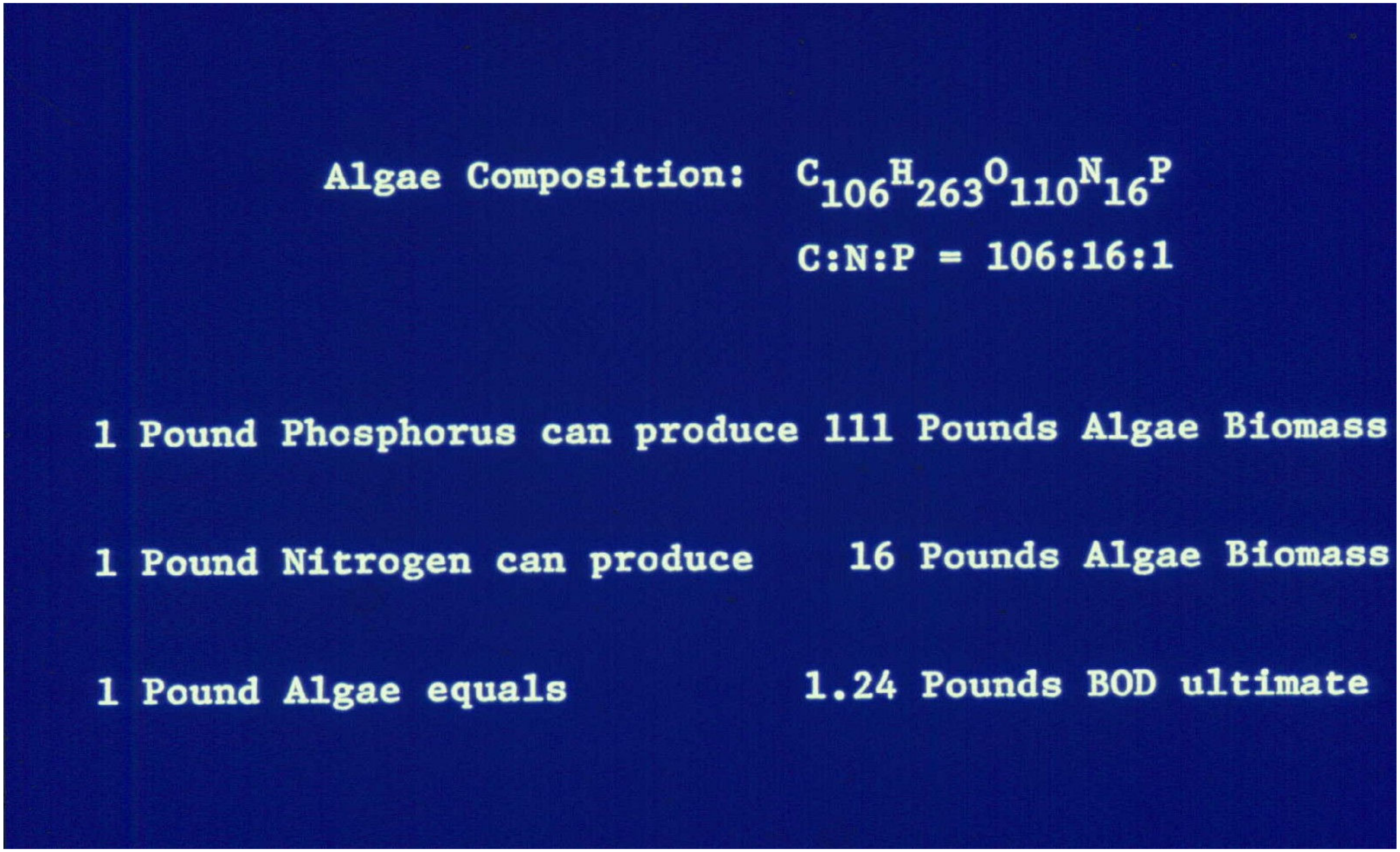
Nitrogen

and

Phosphorus

**Are the nutrients that cause
over fertilization of water bodies,
stimulate excessive growth of algae,
and result in loss of dissolved oxygen
and loss of habitat for living resources.**

WHY DOES IT HAPPEN?



Algae Composition: $C_{106}H_{263}O_{110}N_{16}P$

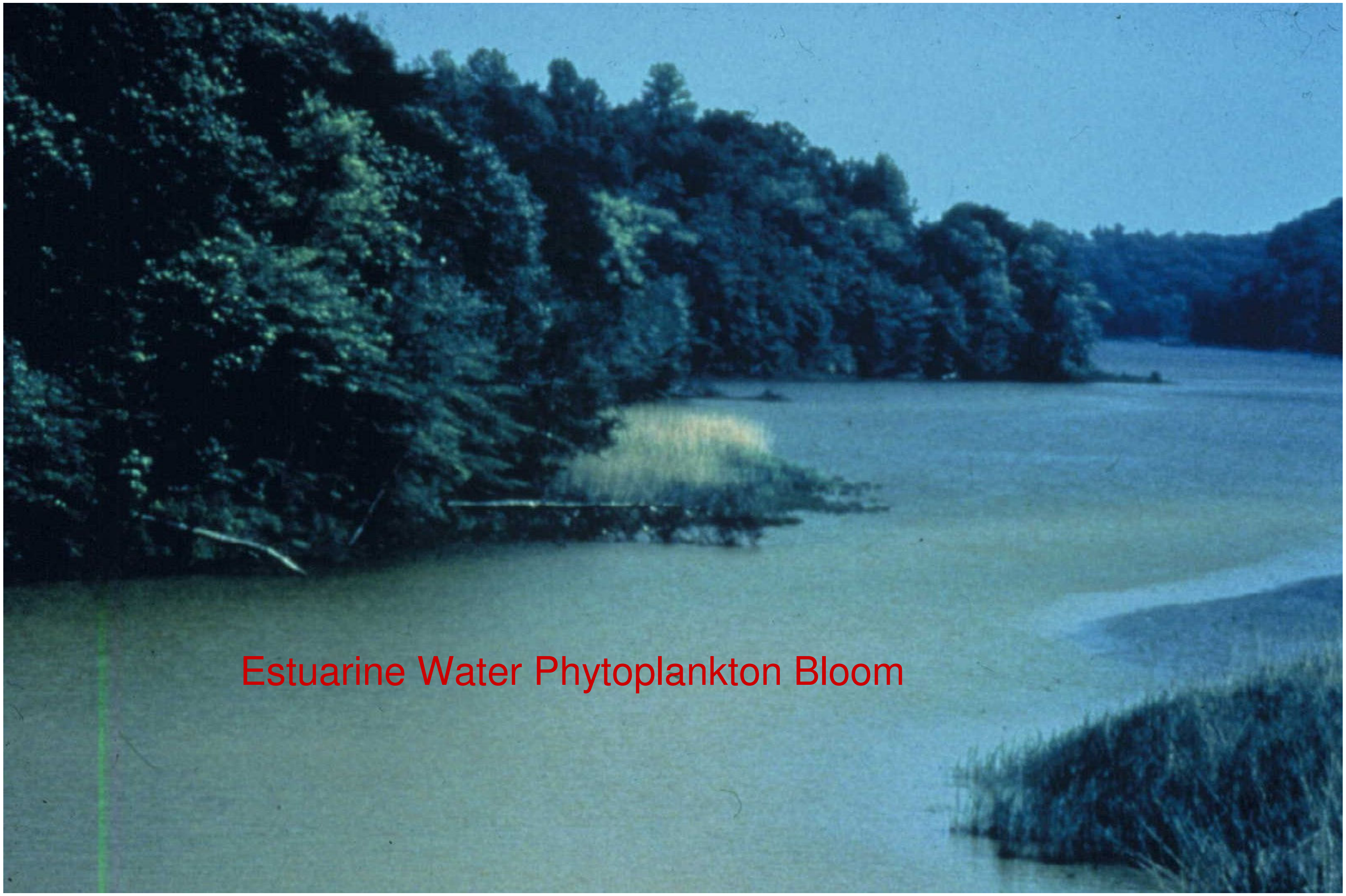
$C:N:P = 106:16:1$

1 Pound Phosphorus can produce	111 Pounds Algae Biomass
1 Pound Nitrogen can produce	16 Pounds Algae Biomass
1 Pound Algae equals	1.24 Pounds BOD ultimate

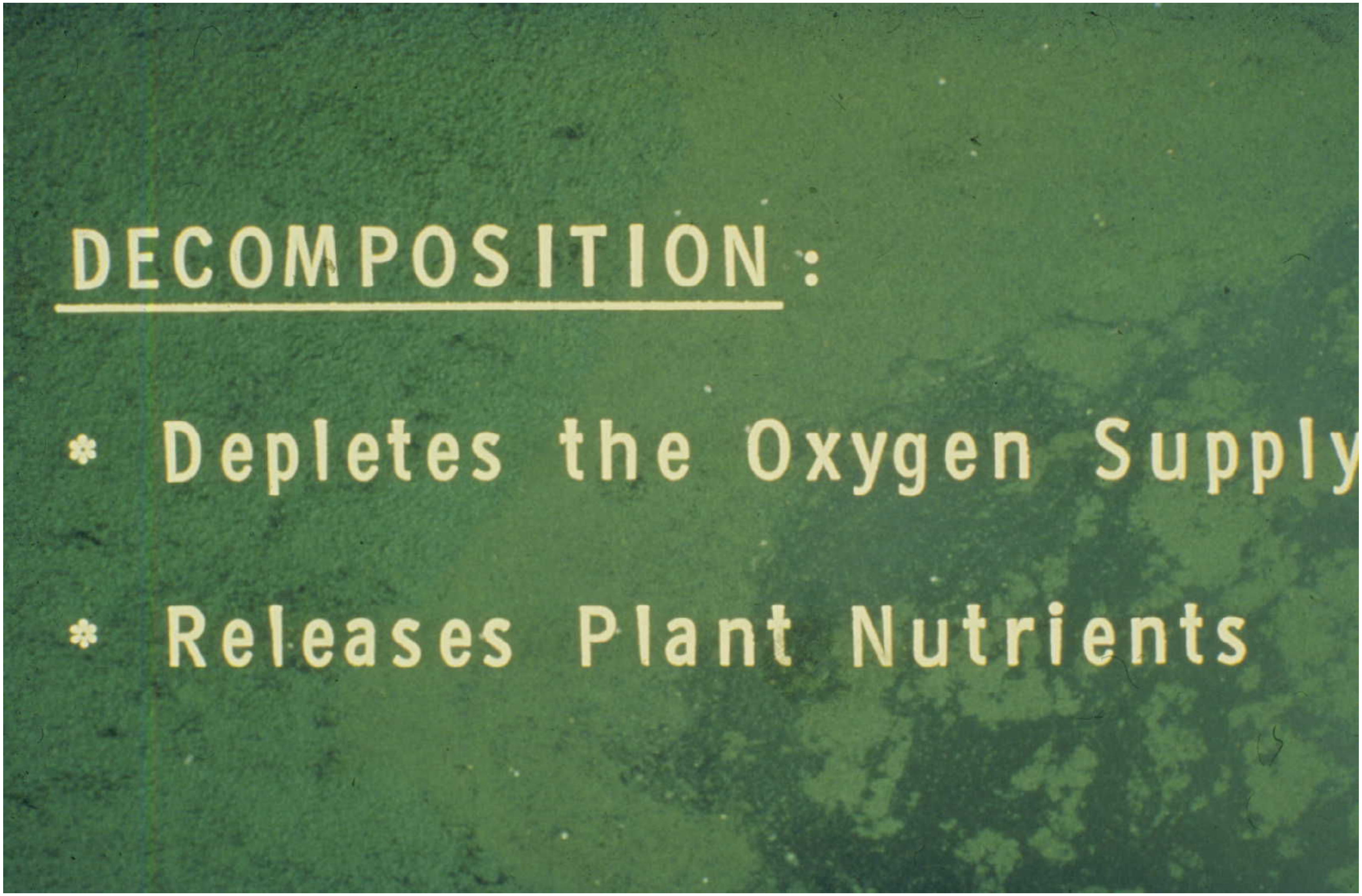
- THEREFORE, 1 KG OF P CAN GENERATE 138 KG OF COD & 5 MG/L OF EFFLUENT P CAN GENERATE 690 MG/L OF COD, AND
- 1 KG OF N CAN GENERATE 19.8 KG OF COD, & 20 MG/L OF EFFLUENT N CAN GENERATE 397 MG/L OF COD IF IT IS THE LIMITING NUTRIENT.

Potential COD Production from Nutrients > COD of Untreated Sewage

THE RESULT OF PHOSPHORUS OVER FERTILIZATION OF A LAKE,
OCCOQUAN RESERVOIR, NORTHERN VIRGINIA, 1972



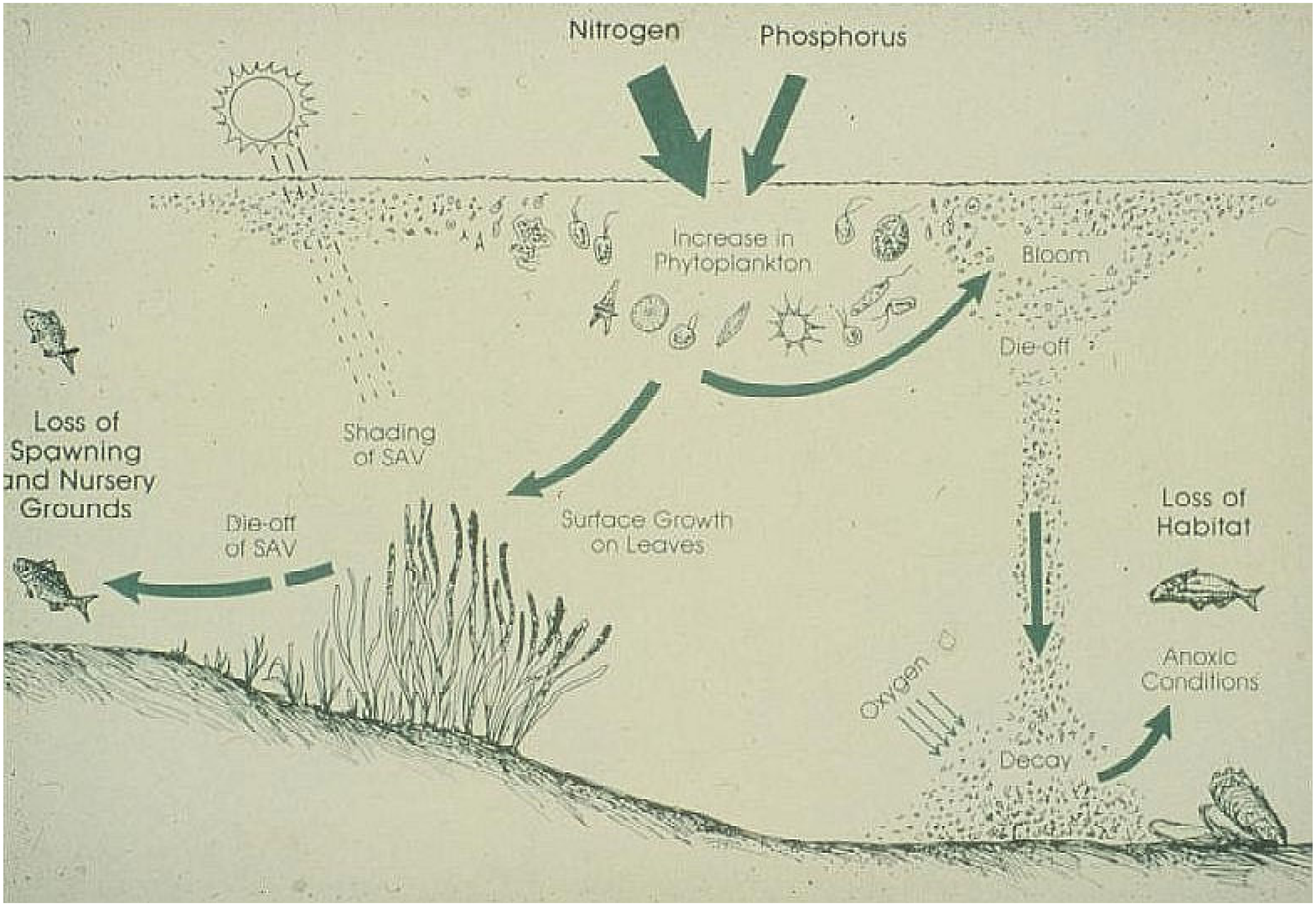
THE RESULT OF NITROGEN OVER FERTILIZATION OF AN ESTUARY, EASTERN SHORE TRIBUTARY, CHESAPEAKE BAY



DECOMPOSITION:

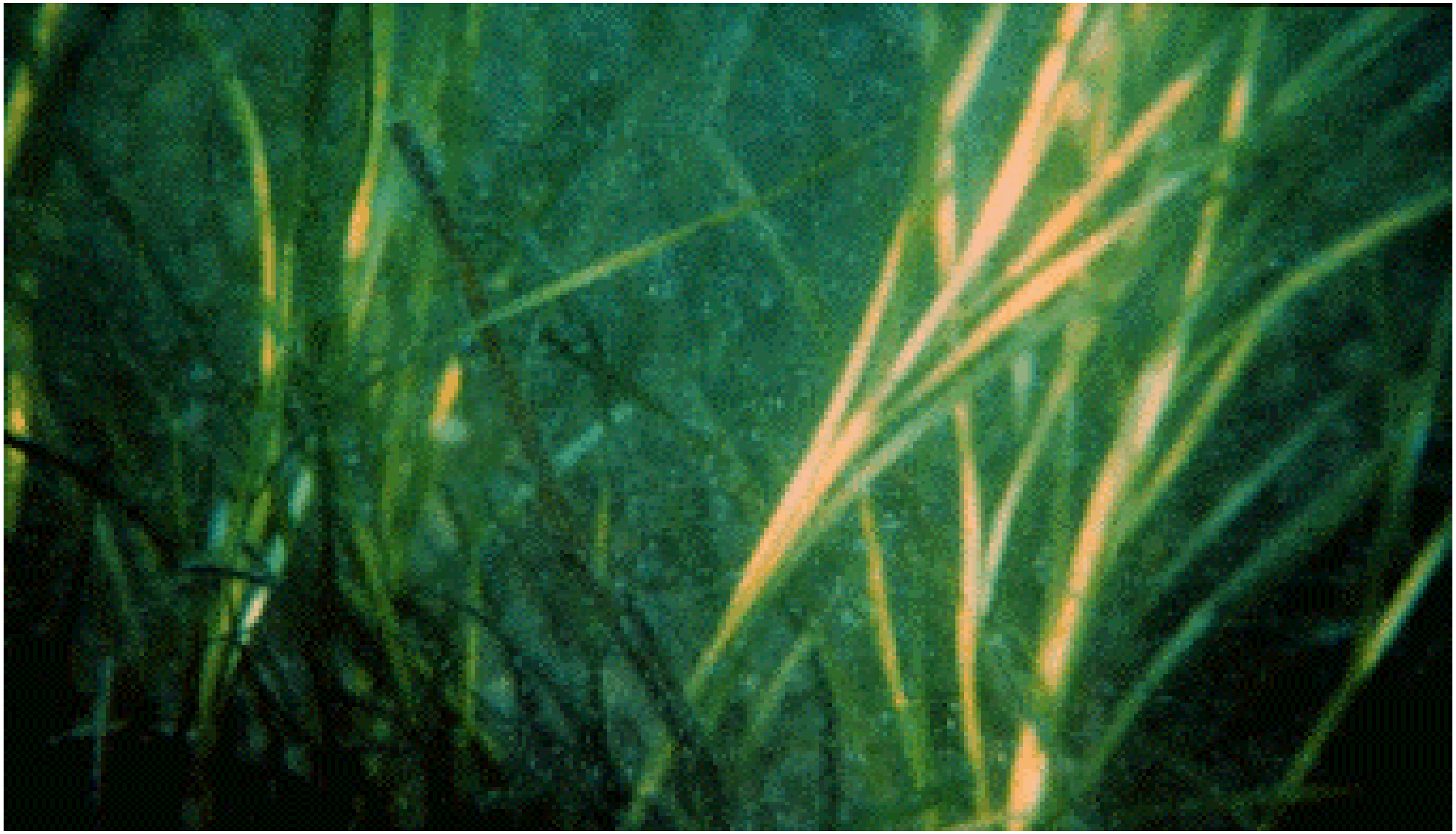
- Depletes the Oxygen Supply
- Releases Plant Nutrients

THE ALGAE DIE, SETTLE TO THE BOTTOM, AND ARE DECOMPOSED BY MICROORGANISMS, WHICH CONSUME THE DISSOLVED OXYGEN



IMPACTS OF NUTRIENTS ON WATER QUALITY AND AQUATIC LIFE
COASTAL AND ESTUARINE WATERS

What are the effects of excess nutrients?
Aquatic grasses die.



EXCESSIVE ALGAL GROWTH & DECOMPOSITION CAUSES DESTRUCTION OF ESSENTIAL HABITAT

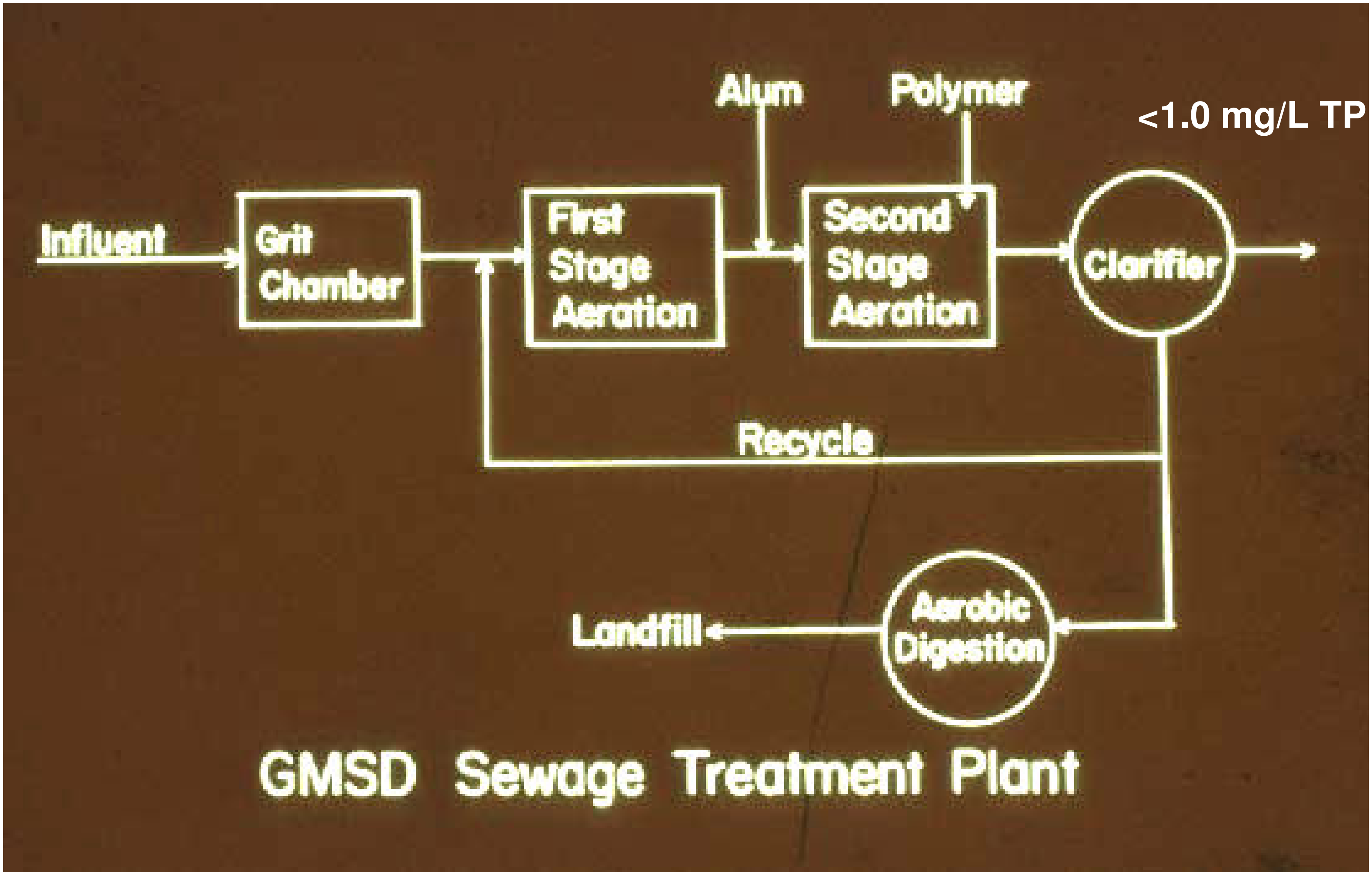
What are the effects of excess nutrients?
Low oxygen levels in water.

FISH DIE!

PHOSPHORUS REMOVAL FROM WASTEWATER

- CHEMICAL: Precipitation with Fe, Al or Ca
- BIOLOGICAL: Incorporation into Biomass

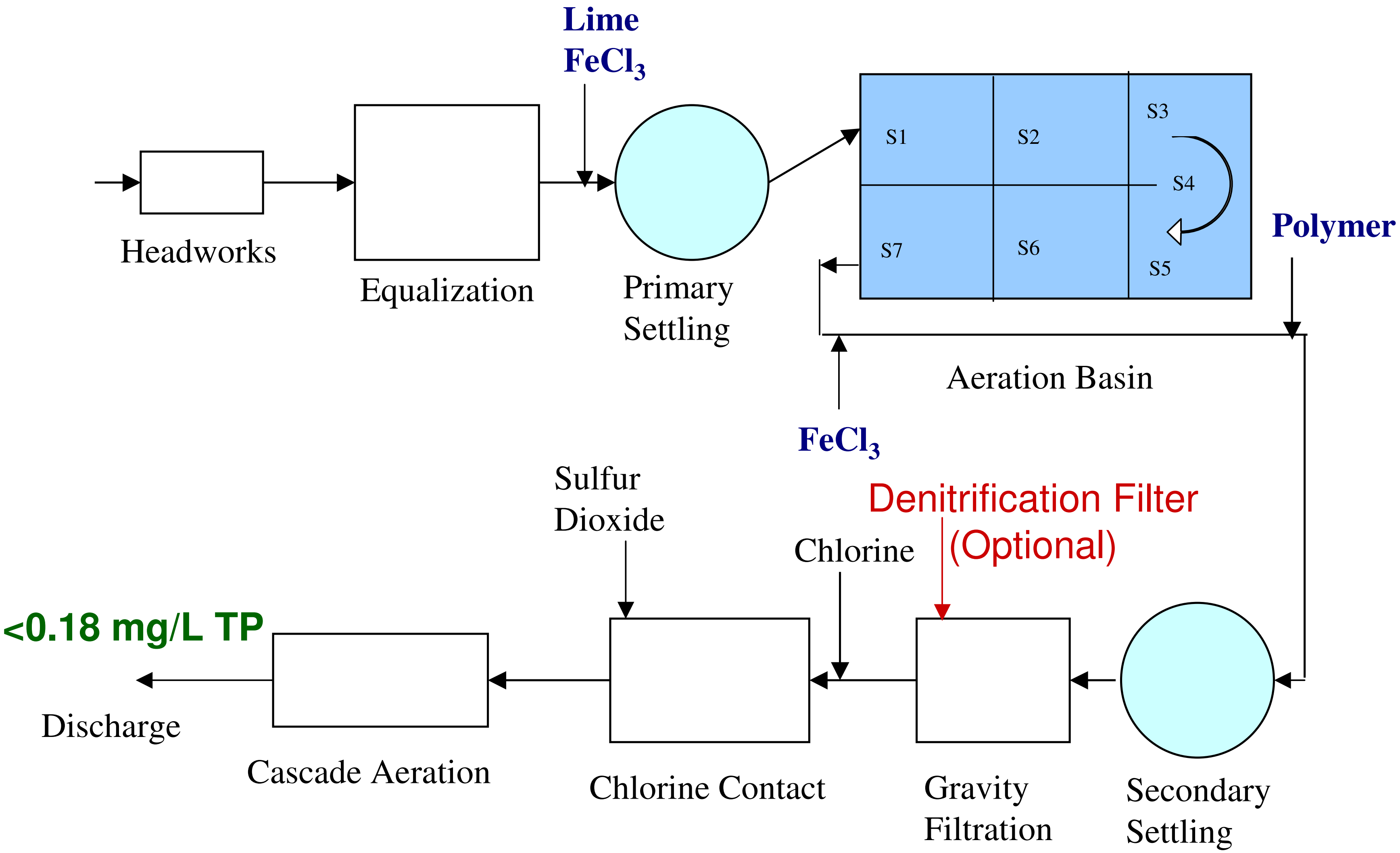
  -requires alternating exposure of biomass to anaerobic and aerobic conditions with VFAs available in anaerobic zone



<1.0 mg/L TP

GMSD Sewage Treatment Plant

Flow Schematic of the H.L. Mooney WWTP



S1-S7 : Sampling points in the aeration basin of the HL Mooney WWTP
Prince William County, VA, Sanitation Authority

Chemical Removal

- ADVANTAGES

  1. Modification of Biological Process not required

  2. Optional Points of Application
     -Primary -Secondary -Tertiary

  3. Rapid Reaction, effluent SP concentration determined by amount of chemical added, therefore can be selected

  4. Effluent TP concentrations <0.1 mg/L are possible

  5. Not affected by biological toxicity

  6. Secondary addition improves Activated Sludge Settleability

  7. Primary addition reduces required aeration basin volume and oxygen transfer requirements.

  8. Operation relatively insensitive to changes

Chemical Removal

- DISADVANTAGES

  1. Cost of Chemicals

  2. May require polymer addition

  3. Increases waste sludge production

  4. Increases inorganic content of waste sludge

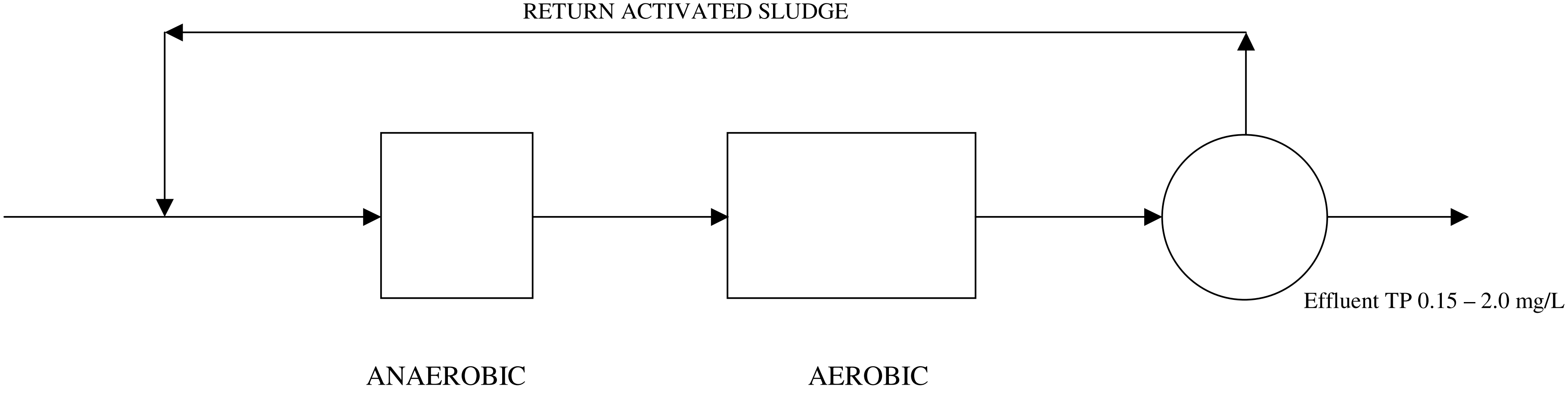
  5. Primary addition may result in nutrient deficiency in the secondary process

  6. Secondary addition increases MLSS concentration, AS mixing requirements and clarifier solids loading

  7. Tertiary addition requires additional construction and separate sludge processing

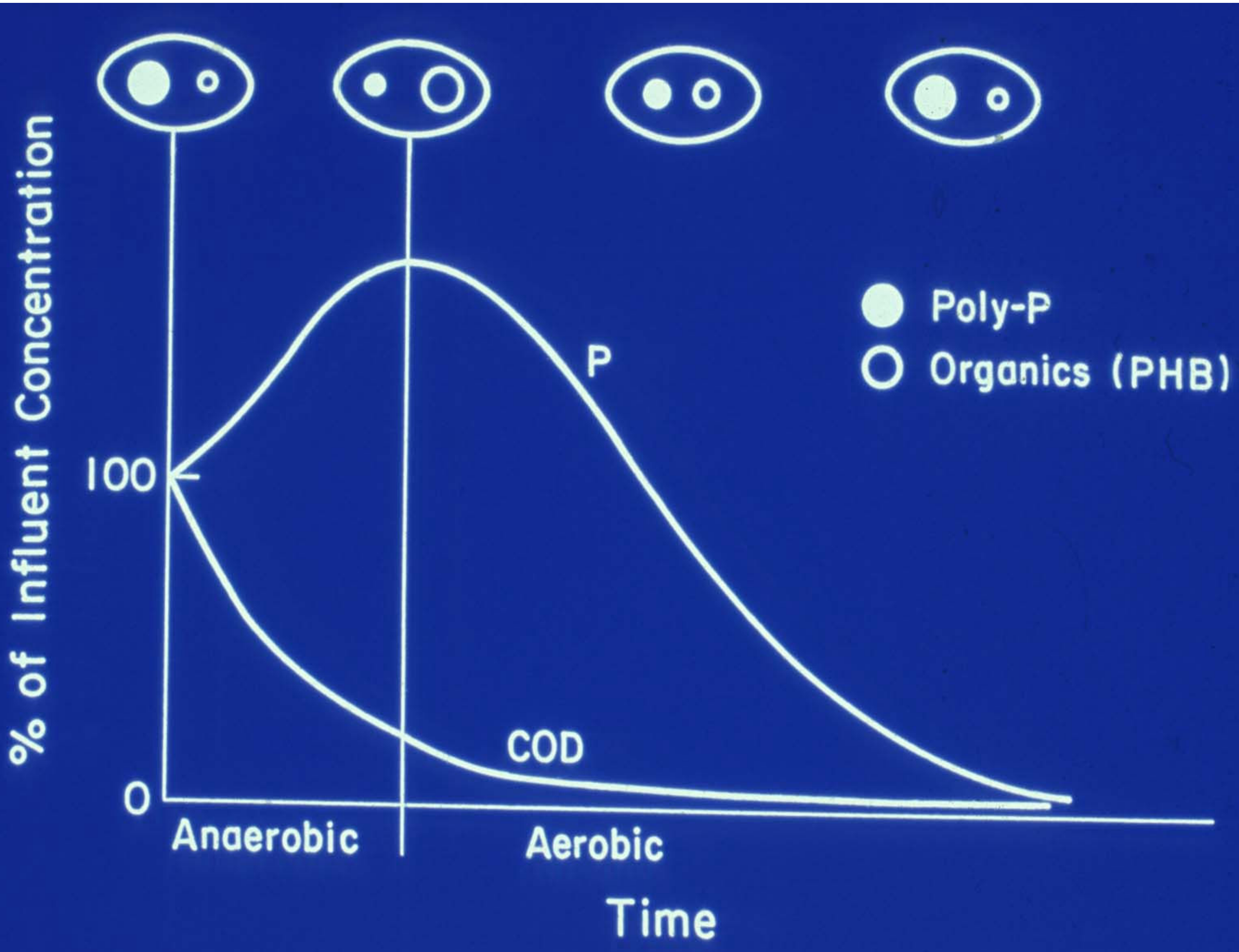
CONDITIONS REQUIRED FOR BIOLOGICAL PHOSPHORUS REMOVAL

1. Anaerobic-Aerobic Sequencing of Activated Sludge, i.e. Anaerobic zone followed by an Aerobic zone.
2. Short Chain Volatile Fatty Acids available in the Anaerobic zone (acetic, propionic, etc.)
3. No electron acceptors available in the Anaerobic zone.



Effluent TP is a function of influent bioavailable COD:TP ratio i.e., the VFA to TP ratio, and the quantity of electron acceptors that enter the Anaerobic zone.

PHOREDOX CONFIGURATION
A/O CONFIGURATION IN USA
BASIC BIOLOGICAL PHOSPHORUS REMOVAL CONFIGURATION


● Poly-P
○ Organics (PHB)
P
COD
% of Influent Concentration
100
0
Anaerobic
Aerobic
Time

Enhanced Biological Phosphorus Removal (EBPR)

- **ADVANTAGES**

  1. Elimination or reduction of chemical costs

  2. Effluent SP concentrations <0.2 mg/L are possible

  3. No increase in waste sludge production

  4. Provides better control of filamentous growth

  5. Improves Activated Sludge settleability

  6. Reduces oxygen transfer requirement in aeration basin for BOD removal; improves oxygen transfer rate in aeration basin

  7. Improves nitrification rate in aeration basin

  8. Provides better control of struvite formation during anaerobic digestion

Enhanced Biological Phosphorus Removal (EBPR)

- DISADVANTAGES

1. Requires modification of biological process, i.e. anaerobic-aerobic sequencing and modest additional capital expense.

2. Effluent SP concentration determined by VFA:TP ratio in influent to anaerobic zone; supplementation of VFAs may be required

3. Could be affected by biological toxicity, but toxicity is very rare

4. Design and operation requirements are more sensitive, therefore requires more rigorous biological process control

5. WAS processing requirements are more complex

NO_X MUST BE PREVENTED FROM ENTERING THE ANAEROBIC ZONE IN SIGNIFICANT AMOUNTS

- Will promote VFA metabolism rather than storage.
- Will result in wash-out of phosphorus storing organisms (PAOs).
- Configurations have been developed to minimize NO_x recycle to the anaerobic zone.

QUESTIONS TO BE ANSWERED

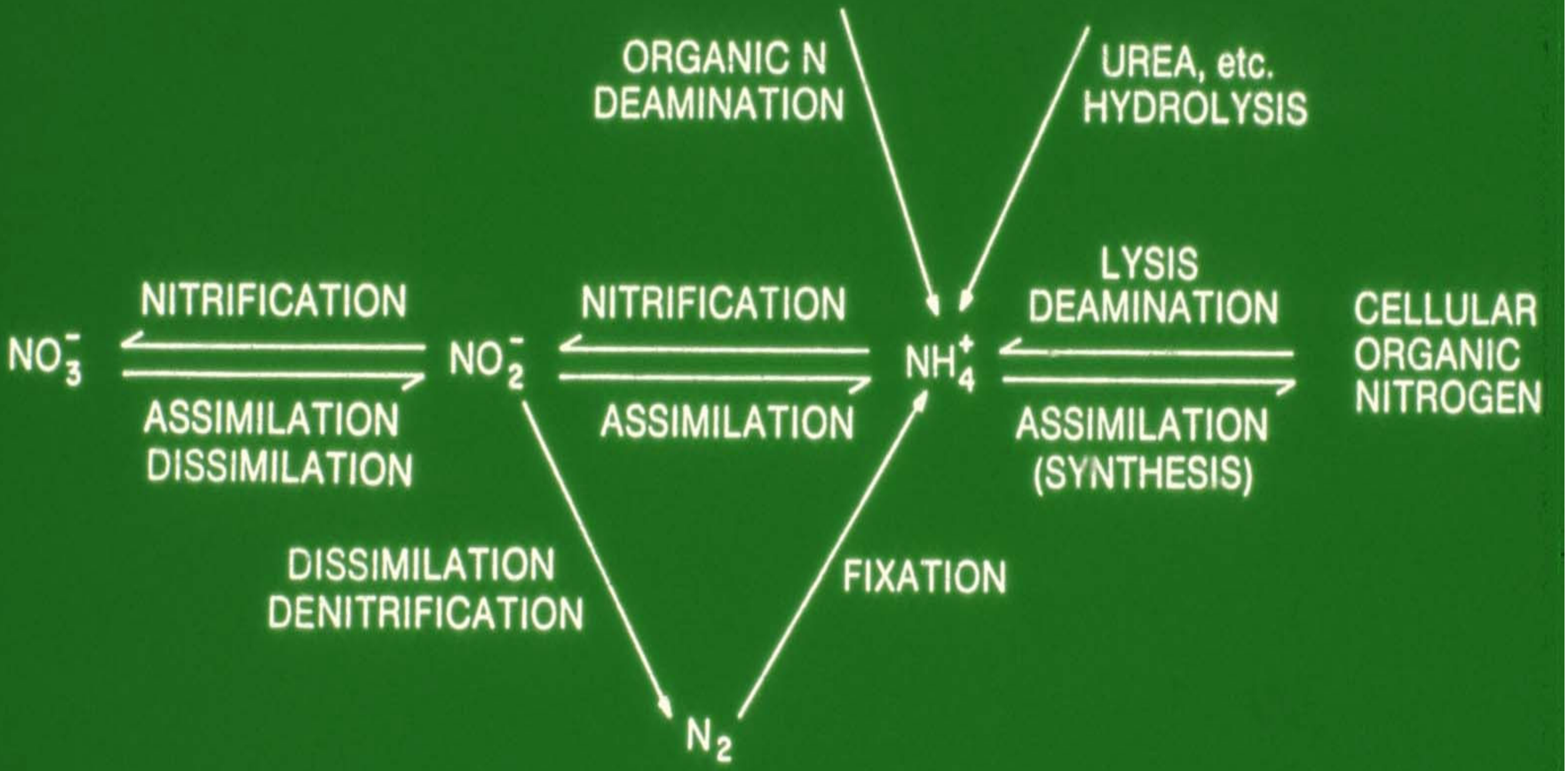
- How low can we go with chemical removal? With enhanced biological phosphorus removal (EBPR)?
- How are cost breakpoints related to effluent concentrations? To the sample averaging period, i.e. weekly, monthly, seasonally and yearly?
- Can water conservation be a significant factor for compliance?

QUESTIONS?

PANEL DISCUSSION

NITROGEN REMOVAL WASTEWATER TREATMENT

NITROGEN CYCLE



ORGANIC N
DEAMINATION

UREA, etc.
HYDROLYSIS

NO_3^-

NITRIFICATION

ASSIMILATION
DISSIMILATION

NO_2^-

NITRIFICATION

ASSIMILATION

NH_4^+

LYSIS
DEAMINATION

ASSIMILATION
(SYNTHESIS)

CELLULAR
ORGANIC
NITROGEN

DISSIMILATION
DENITRIFICATION

FIXATION

N_2

BIOLOGICAL PROCESSES INVOLVING INORGANIC NITROGEN.
AFTER PAINTER, REFERENCE(7).

Three Steps for Total N Removal

1. Hydrolysis & Ammonification of Complex N
   - Urea & Organic Nitrogen → NH_4-N
2. Nitrification to NO_2^- & NO_3^-
   - NH_4-N + O_2 → NO_3-N
3. Denitrification
   - NO_3-N → $N_2\uparrow$

Nitrification

Destroys Alkalinity, Lowers pH

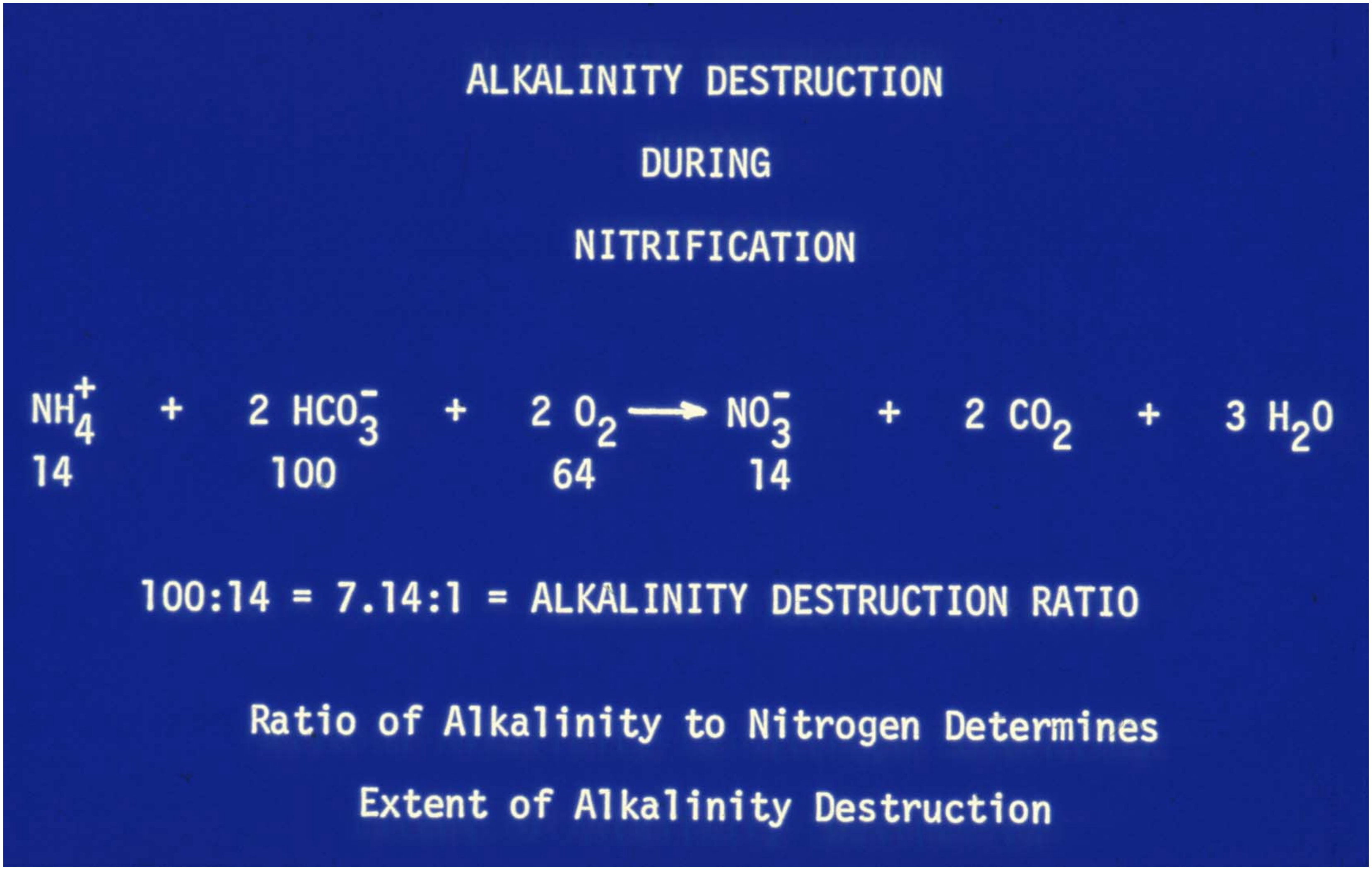
$$NH_3 + {}^3/_2\, O_2 \xrightarrow{\text{nitrosomonas}} NO_2^- + H_2O + H^+$$

ΔF = -66,500 calories (79%)

$$NO_2^- + {}^1/_2\, O_2 \xrightarrow{\text{nitrobacter}} NO_3^-$$

ΔF = -17,500 calories (21%)

Total ΔF = -84,000 calories (100%)



ALKALINITY DESTRUCTION

DURING

NITRIFICATION

$$\underset{14}{NH_4^+} + \underset{100}{2\ HCO_3^-} + \underset{64}{2\ O_2} \longrightarrow \underset{14}{NO_3^-} + 2\ CO_2 + 3\ H_2O$$

100:14 = 7.14:1 = ALKALINITY DESTRUCTION RATIO

Ratio of Alkalinity to Nitrogen Determines

Extent of Alkalinity Destruction

ALKALINITY DESTRUCTION DURING NITRIFICATION FREQUENTLY RESULTS IN THE NEED TO ADD CHEMICALS FOR pH ADJUSTMENT

DENITRIFICATION

NITRATE IS USED AS THE ELECTRON ACCEPTOR FOR BOD METABOLISM INSTEAD OF DISSOLVED OXYGEN

Aerobic reaction:

$$\text{BOD} + \text{DO} \xrightarrow[\text{sludge}]{\text{activated}} CO_2 + H_2O + \text{cells} + \text{energy}$$

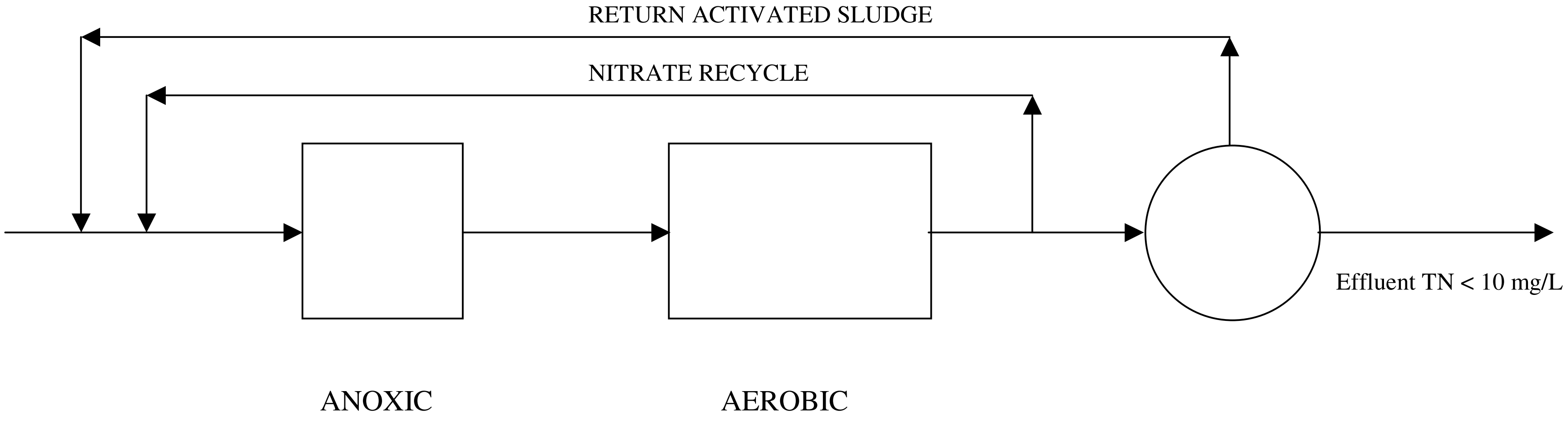
Anoxic reaction (no DO present):

$$\text{BOD} + NO_3 \xrightarrow[\text{sludge}]{\text{activated}} CO_2 + H_2O + N_2 + 0.75\ \text{cells} + \approx 0.8\ \text{energy}$$

Alkalinity is recovered: 3.57 mg/L $CaCO_3$ per 1 mg/L NO_3-N fully denitrified

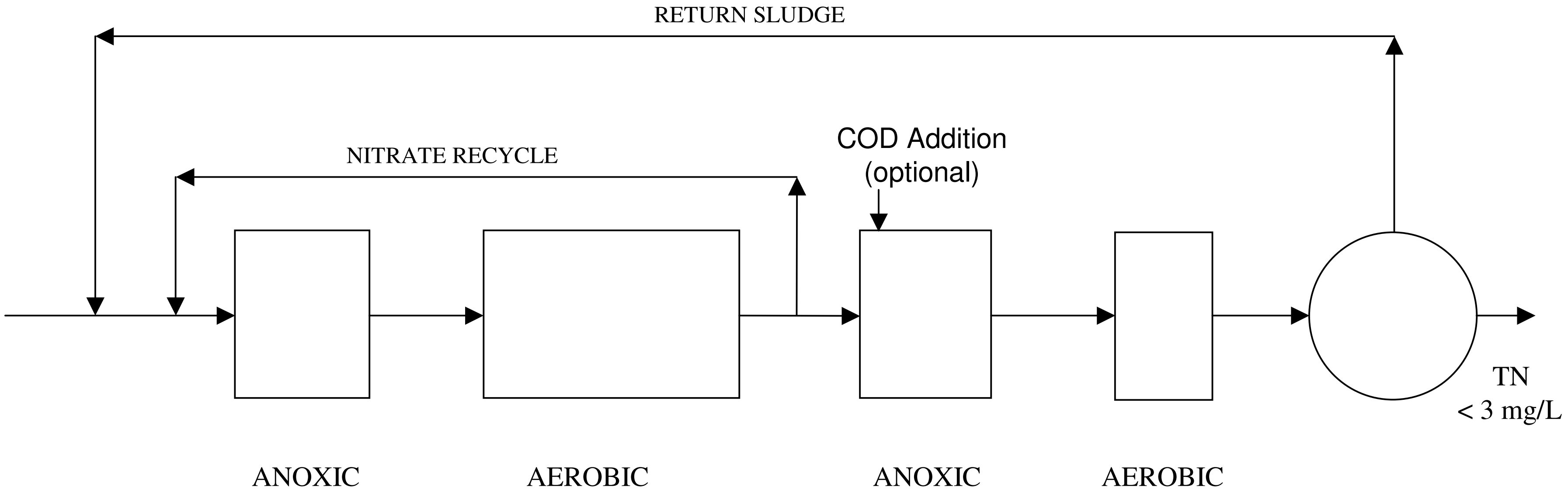
Conditions required for Nitrogen Removal Wastewater Treatment

1. Nitrification followed by denitrification
2. Nitrification requires Aerobic Conditions (DO as an electron acceptor)
3. Denitrification requires Anoxic Conditions (NO_X as electron acceptor), and biodegradable organic carbon (COD)
4. Biological approach uses wastewater COD for organic carbon source



MODIFIED LUDZAK-ETTINGER (MLE) CONFIGURATION

BASIC BIOLOGICAL NITROGEN REMOVAL CONFIGURATION



Effluent TP varies with influent bioavailable COD:TN ratio

FOUR-STAGE BIOLOGICAL NITROGEN REMOVAL (BARDENPHO) CONFIGURATION

BIOLOGICAL NITROGEN REMOVAL

Advantages of Biological Nitrogen Removal Wastewater Treatment

1. Reduced oxygen requirements because BOD is removed by denitrification, therefore, reduced energy requirements. Approximately 20 % reduction is possible.
2. Reduced Waste Activated Sludge production because Bacteria obtain less energy from using oxidized nitrogen as an electron acceptor compared to dissolved oxygen. Approximately 25% reduction is possible.

OTHER METHODS OF NITROGEN REMOVAL

- DENITRIFICATION FILTERS
  - REMOVES NITRITES & NITRATES (NO_X)
  - REQUIRES COD ADDITION
- AMMONIA STRIPPING
  - REMOVES AMMONIA (NH_3)
- ION EXCHANGE
  - REMOVES EITHER NH_4 OR NO_X
- REVERSE OSMOSIS
  - REMOVES ALL NITROGEN FORMS

QUESTIONS TO BE ANSWERED

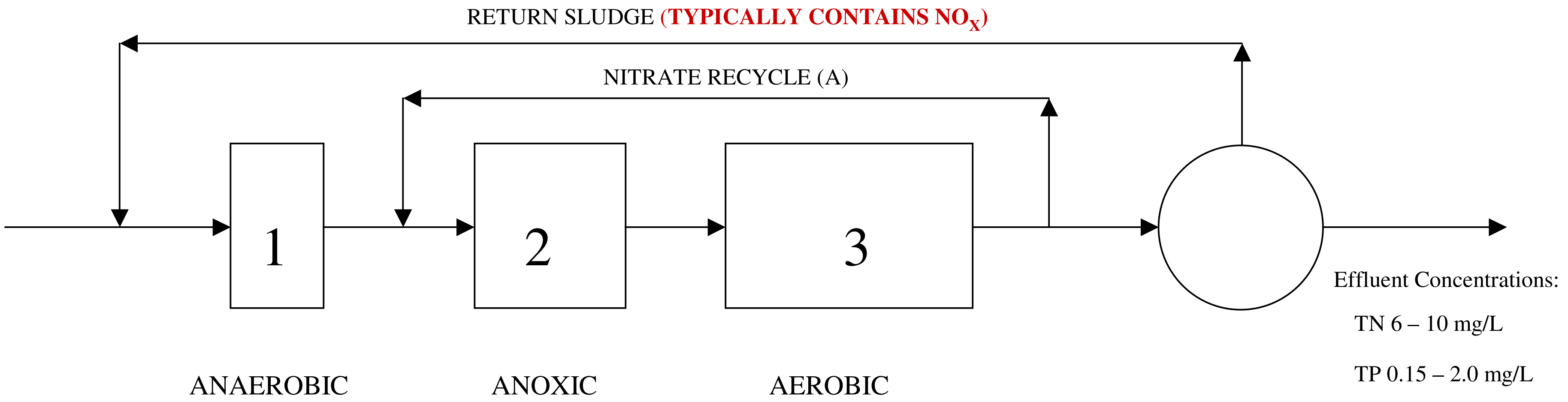
- How low can we go without membrane separation? What are the likely impacts of rDON on compliance?
- How are cost breakpoints related to effluent concentrations? To sample averaging period, i.e. weekly, monthly, seasonally and yearly?
- Can water conservation be a significant factor for compliance?

QUESTIONS?

PANEL DISCUSSION

COMBINED N & P REMOVAL WASTEWATER TREATMENT

BIOLOGICAL NUTRIENT
REMOVAL (BNR)



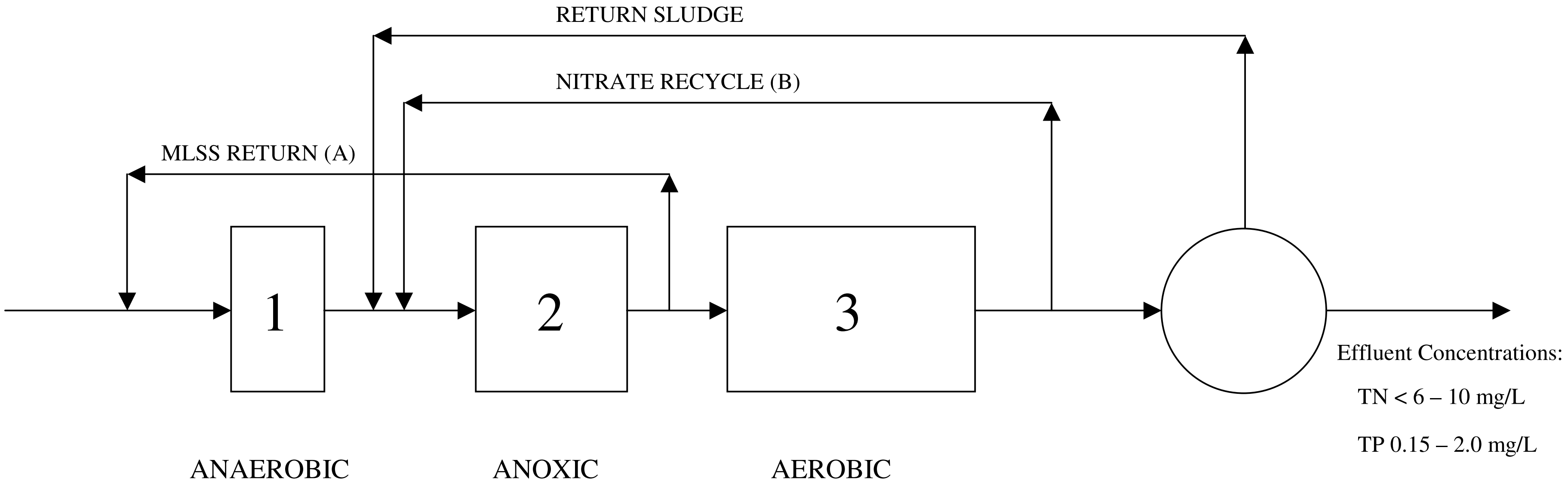
A^2/O CONFIGURATION
COMBINED MLE AND PHOREDOX

COMBINED BIOLOGICAL NITROGEN AND PHOSPHORUS REMOVAL

CONFIGURATIONS HAVE BEEN DEVELOPED TO MINIMIZE NO_X ENTERING THE ANAEROBIC ZONE

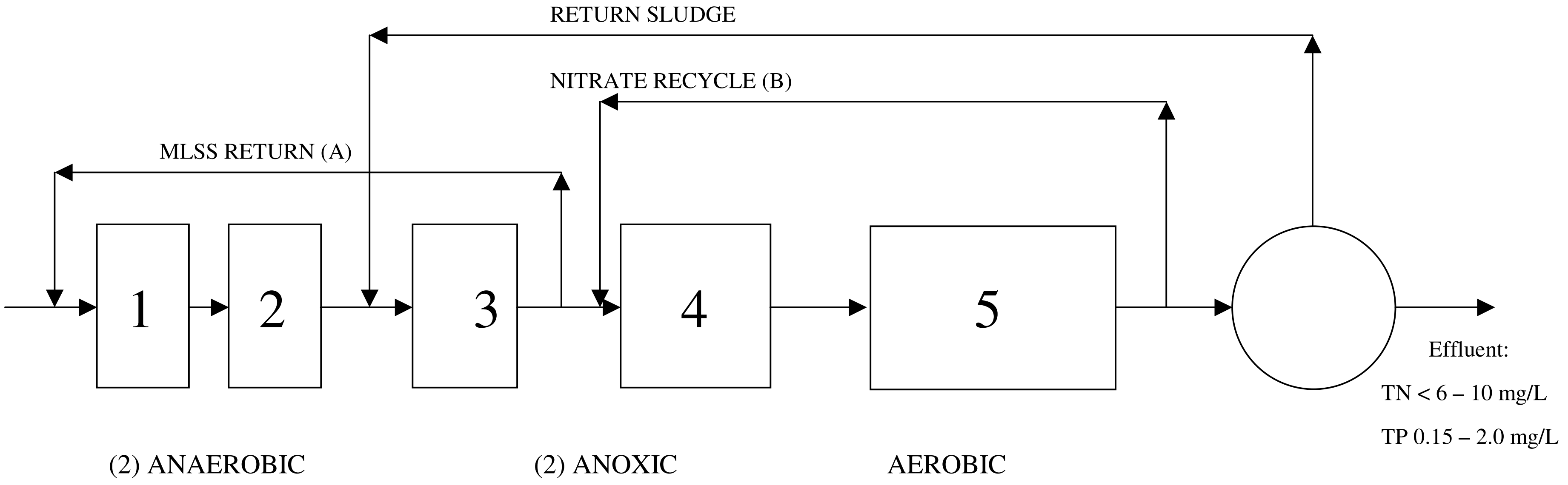
- UCT/VIP PROCESS
- MODIFIED UCT PROCESS
- JOHANNESBURG PROCESS

They all are designed to accomplish combined N & P removal.



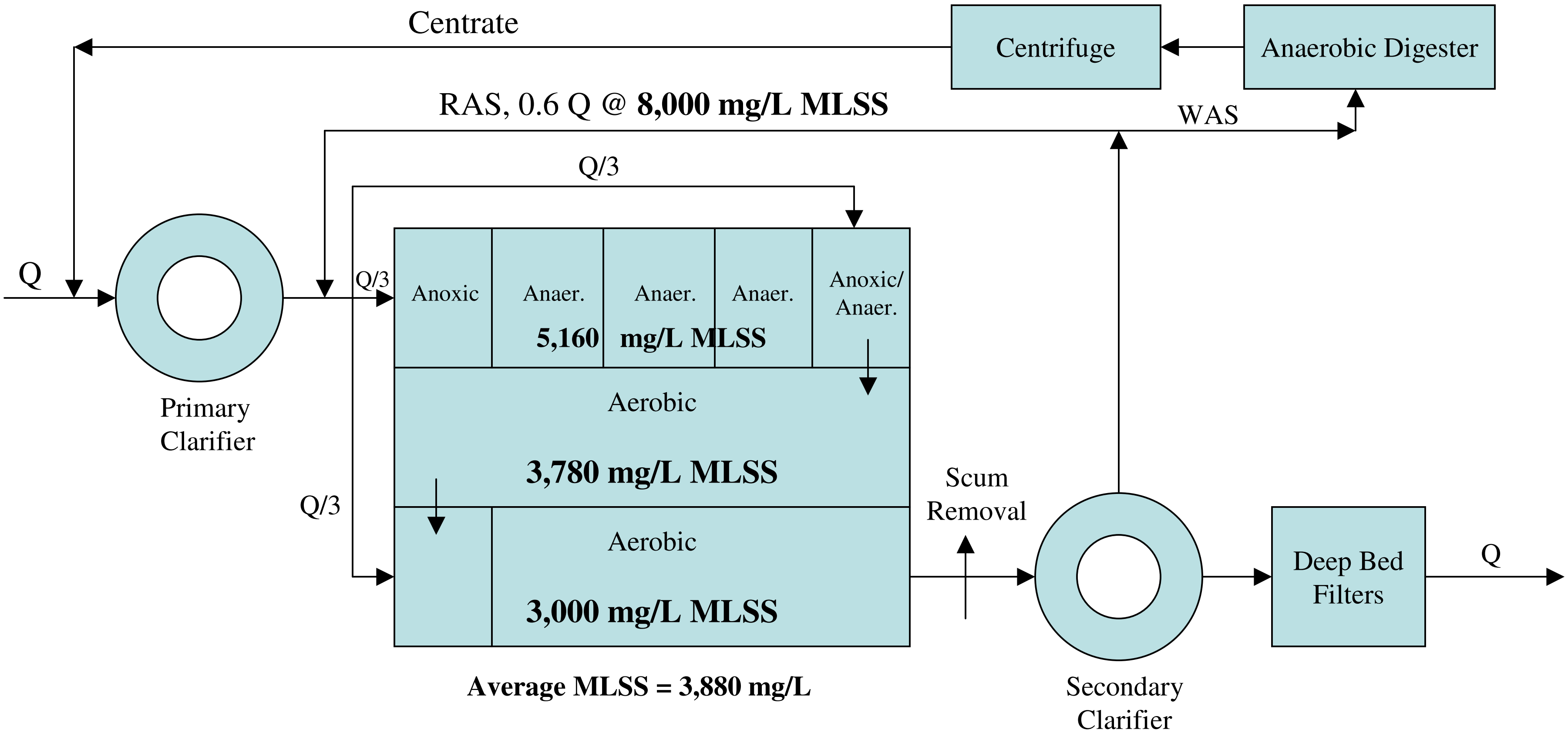
Designed to protect the anaerobic zone from excess nitrates

UCT PROCESS CONFIGURATION
aka VIP PROCESS CONFIGURATION
BIOLOGICAL NITROGEN AND
PHOSPHORUS REMOVAL



Designed to provide further protection of the anaerobic zone from excess nitrates

MULTISTAGE MODIFIED UCT/VIP CONFIGURATION **BIOLOGICAL NITROGEN AND PHOSPHORUS REMOVAL**



STEP-FEED/JOHANNESBURG BNR DESIGN

South River WRC, Atlanta, GA.

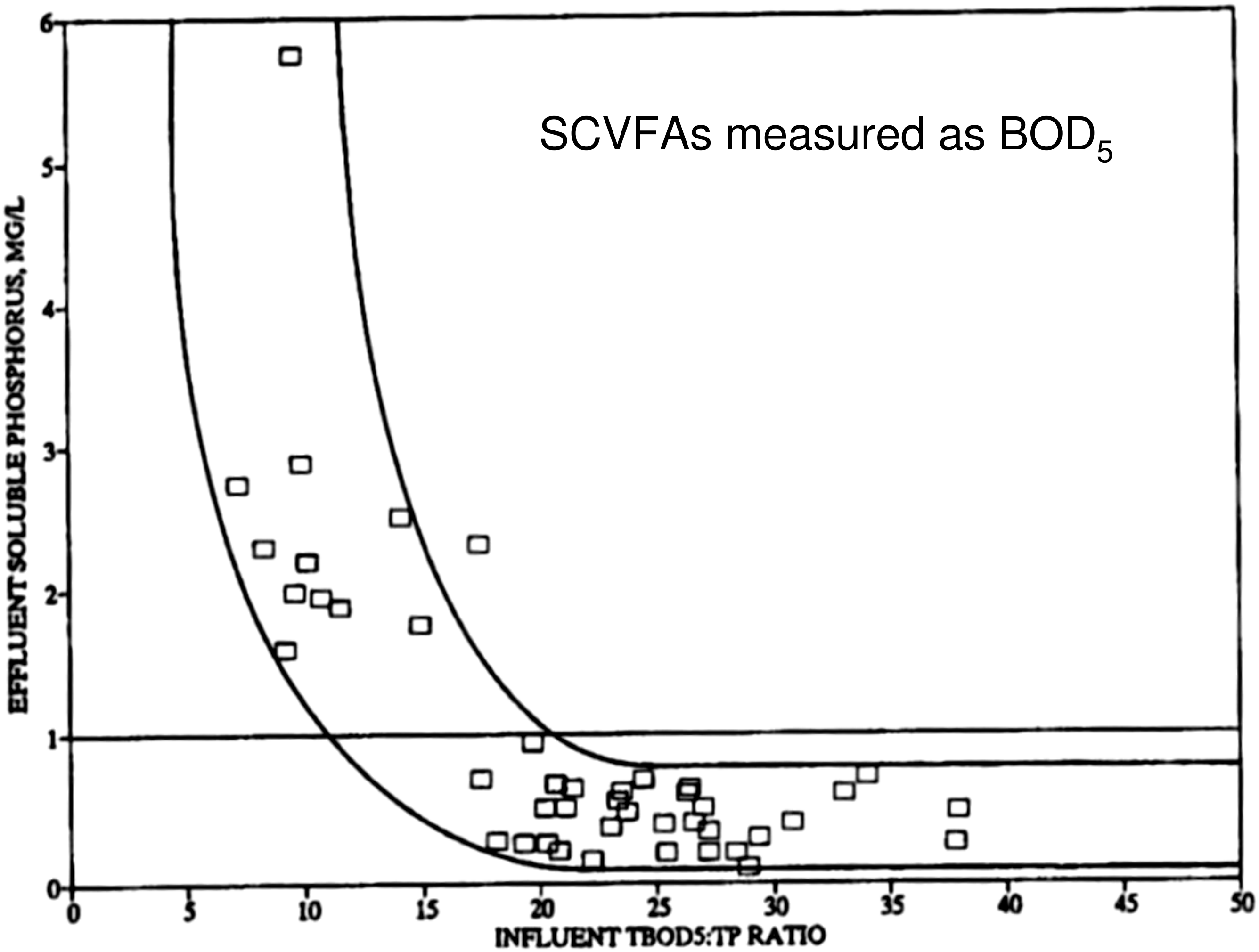
O & M Reduction with BNR

- Ways BNR processes reduce O&M Costs:

1. Reduce O_2 Transfer Energy Costs ≈ 20%
2. Reduce WAS Production by 20-30%
3. Reduce or Eliminate Chemical Costs for Nutrient Removal and pH Adjustment.
4. Improve Sludge Settleability, therefore, reduce clarification requirement and improve sludge dewatering.

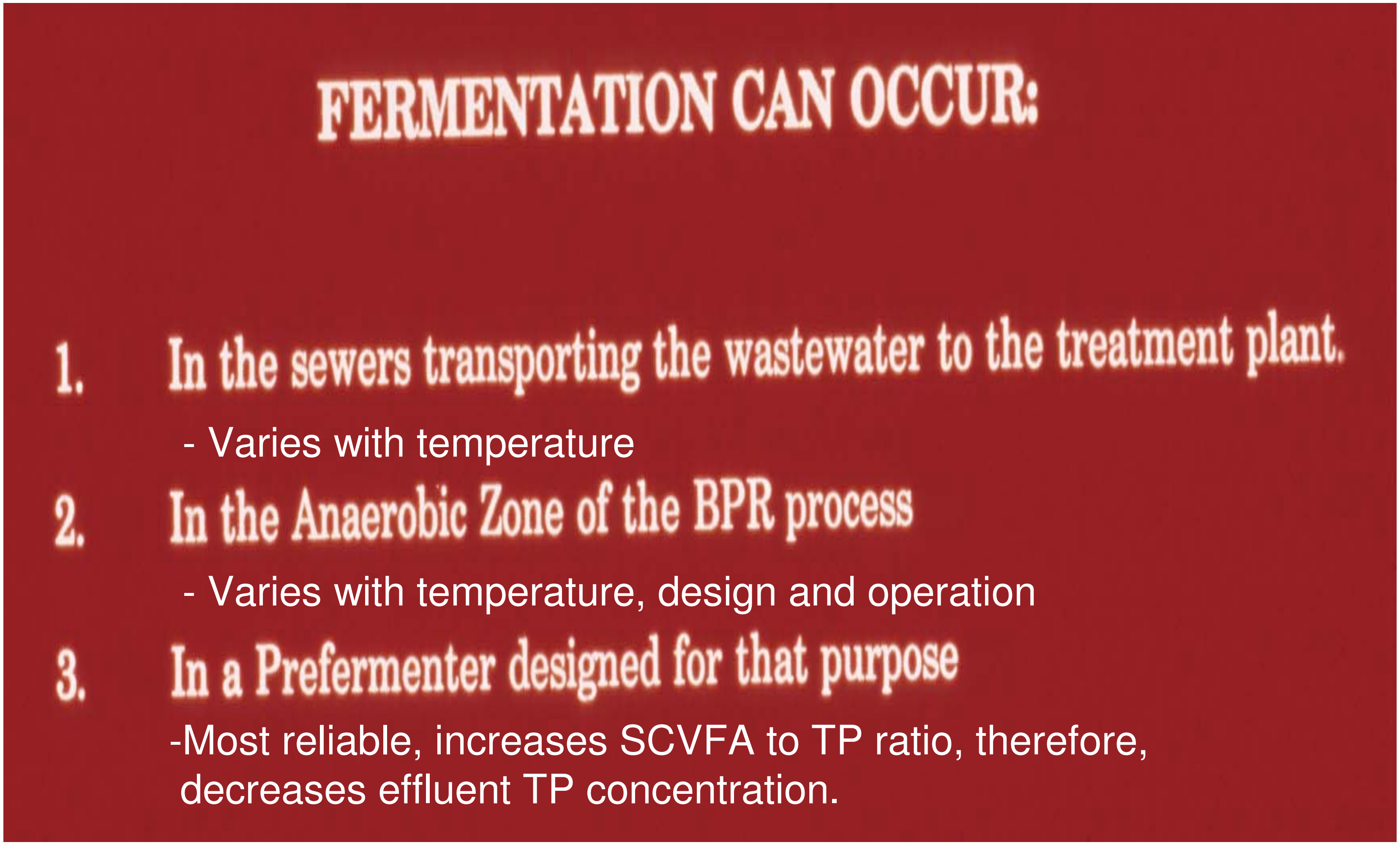
HOW LOW CAN WE GO WITH EBPR?

THE PROCESS INFLUENT SHORT-CHAIN VOLATILE FATTY ACID (SCVFA) TO TOTAL PHOSPHORUS RATIO IS THE PRIMARY DESIGN FACTOR THAT DETERMINES THE CONFIGURATION THAT SHOULD BE USED FOR BIOLOGICAL NUTRIENT REMOVAL WASTEWATER TREATMENT



SCVFAs measured as BOD_5

Effect of influent TBOD5:TP ratio on effluent soluble phosphorus



FERMENTATION CAN OCCUR:

1. In the sewers transporting the wastewater to the treatment plant.
   - Varies with temperature
2. In the Anaerobic Zone of the BPR process
   - Varies with temperature, design and operation
3. In a Prefermenter designed for that purpose
   - Most reliable, increases SCVFA to TP ratio, therefore, decreases effluent TP concentration.

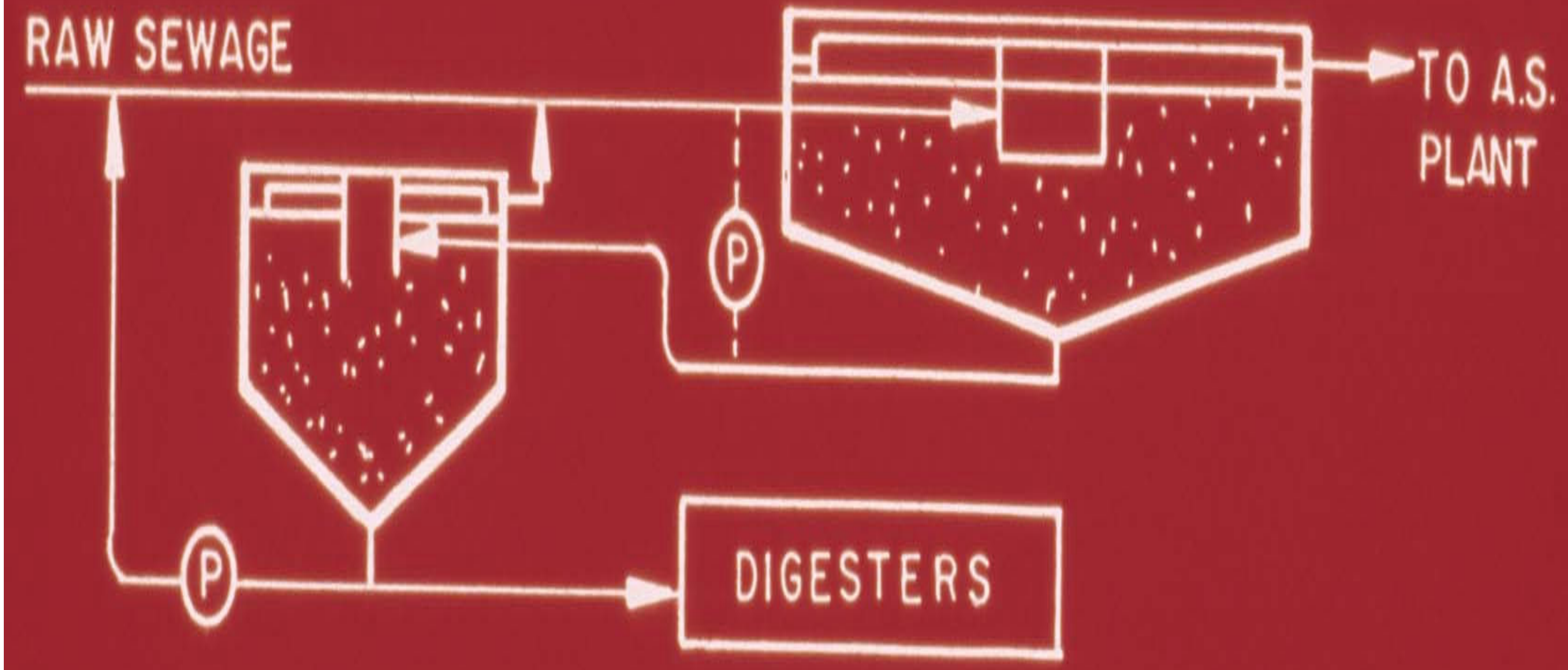


Figure 5
The activated primary sedimentation tank

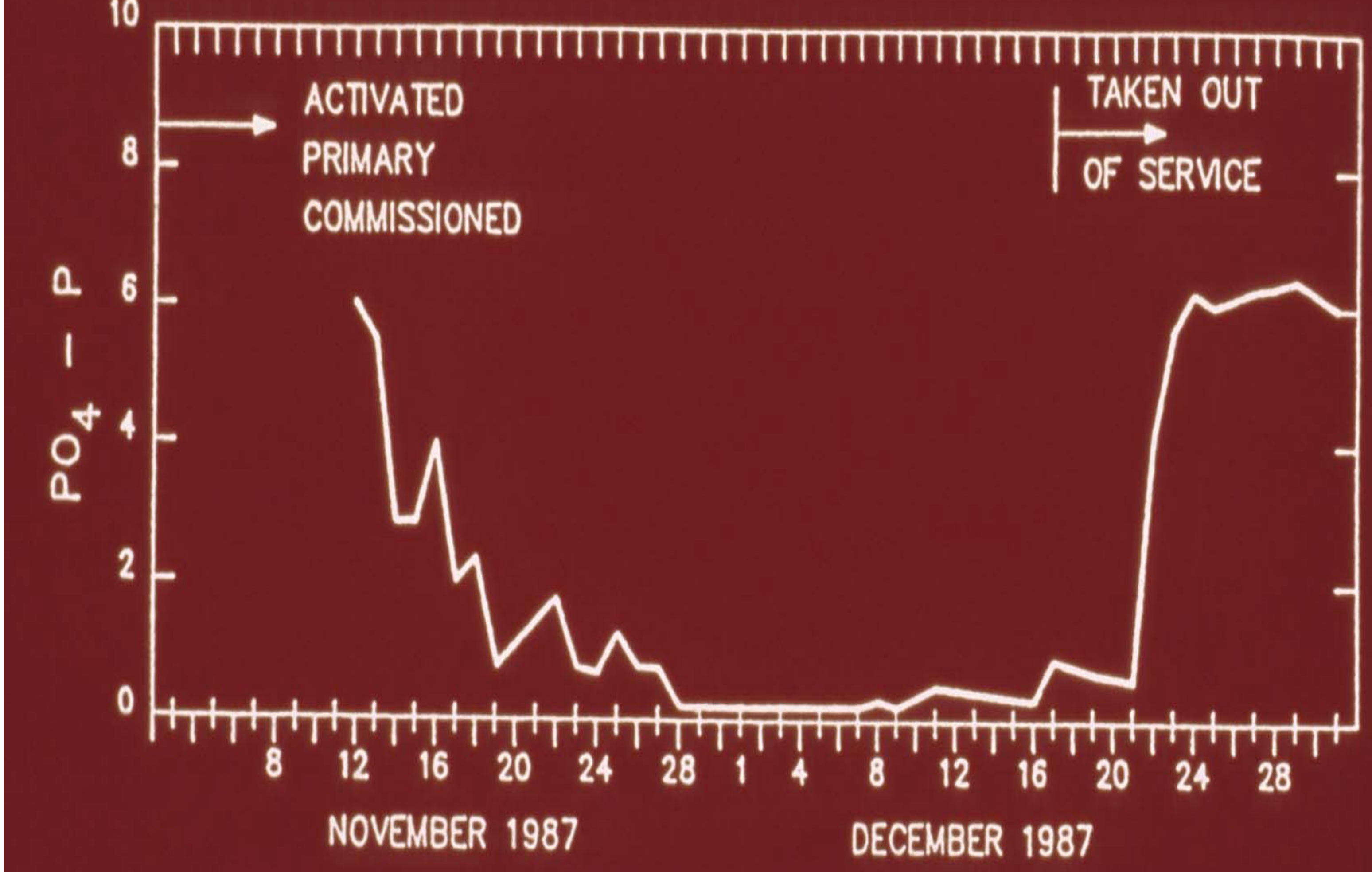
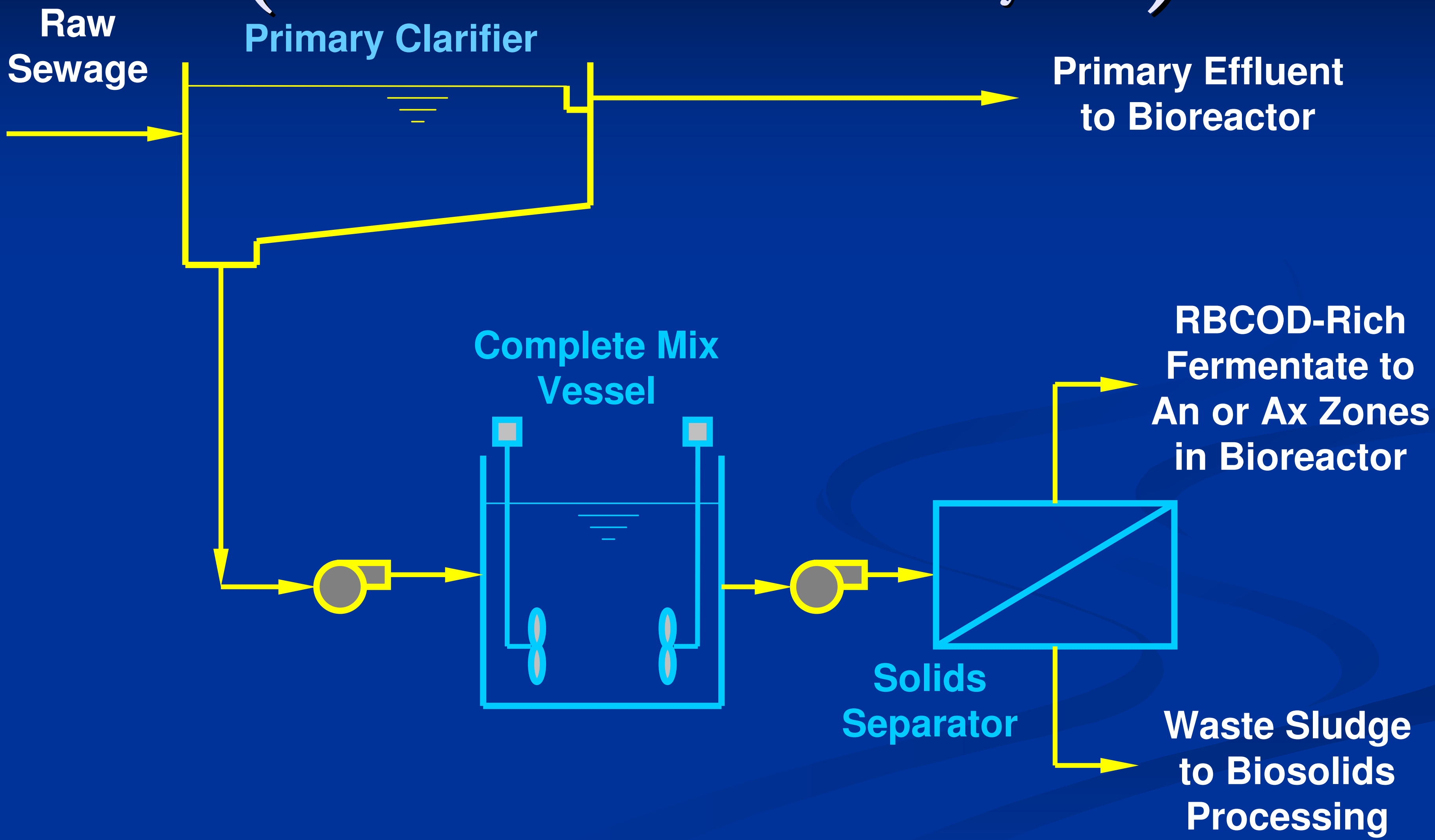


Figure 6.21 Effect of activated PST at Olifantsfontein.

Complete Mix Fermenter

(A Sidestream Fermentation System)



Raw Sewage

Primary Clarifier

Primary Effluent to Bioreactor

Complete Mix Vessel

RBCOD-Rich Fermentate to An or Ax Zones in Bioreactor

Solids Separator

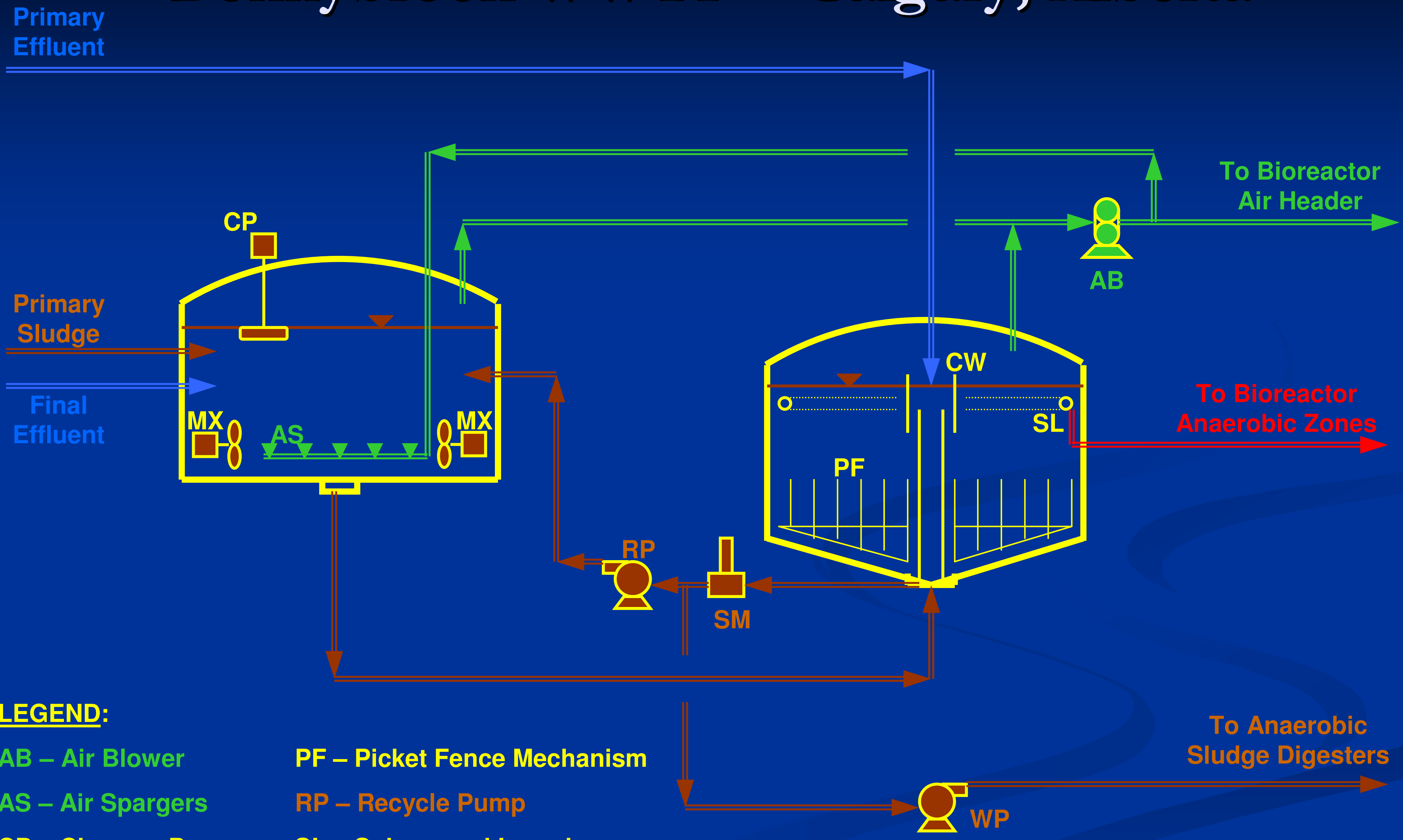
Waste Sludge to Biosolids Processing

Bonnybrook WWTP
Calgary, Alberta

Bonnybrook Secondary C

Fermenter System

Schematic of Fermenter-Thickener System
Bonnybrook WWTP – Calgary, Alberta



LEGEND:

AB – Air Blower

AS – Air Spargers

CP – Chopper Pump

CW – Centerwell

MX – Mixer

PF – Picket Fence Mechanism

RP – Recycle Pump

SL – Submerged Launder

SM – Sludge Macerator

WP – Waste Pump

Complete Mix Fermenter Design & Operating Features

- Primary Sludge Flowrate = ~0.5% to ~1% of $Q_{RAW\ SEW}$
- Primary Sludge Conc'n = ~2% to ~4%
- Complete Mix Vessel HRT = ~3 to ~6 days
- Solids SRT = ~3 to ~6 days
- Primary Sludge Flowrate is the Main Controlling Variable

Advantages of Complete Mix Fermenter

- Good SRT Control

- Better Ability to Control SRT and Reduce Potential for Odours and Methane Formation
  than with APT Technology

- No Adverse Impact on Primary Clarifier Performance

HOW MUCH WILL IT COST?

Cost Factors

1. Effluent Requirements
   - 4 mg/L TN versus 3 mg/L TN
   - Non-biodegradable Nitrogen

2. Mandated Averaging Period
   - Yearly vs Seasonally vs Monthly vs Weekly

3. Mandated Design Requirements
   - Innovative vs Standard Technology

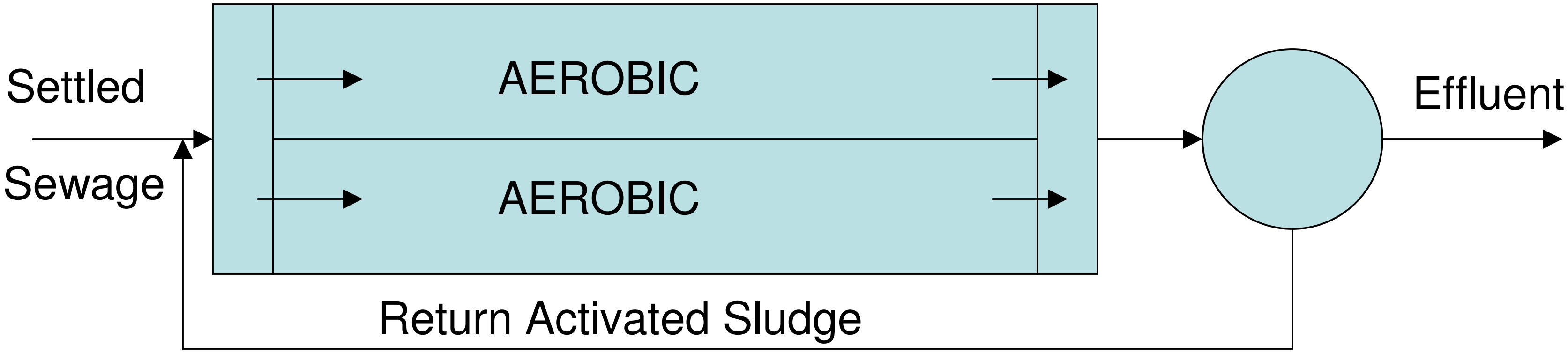
4. Permissible Construction Period

QUESTIONS?

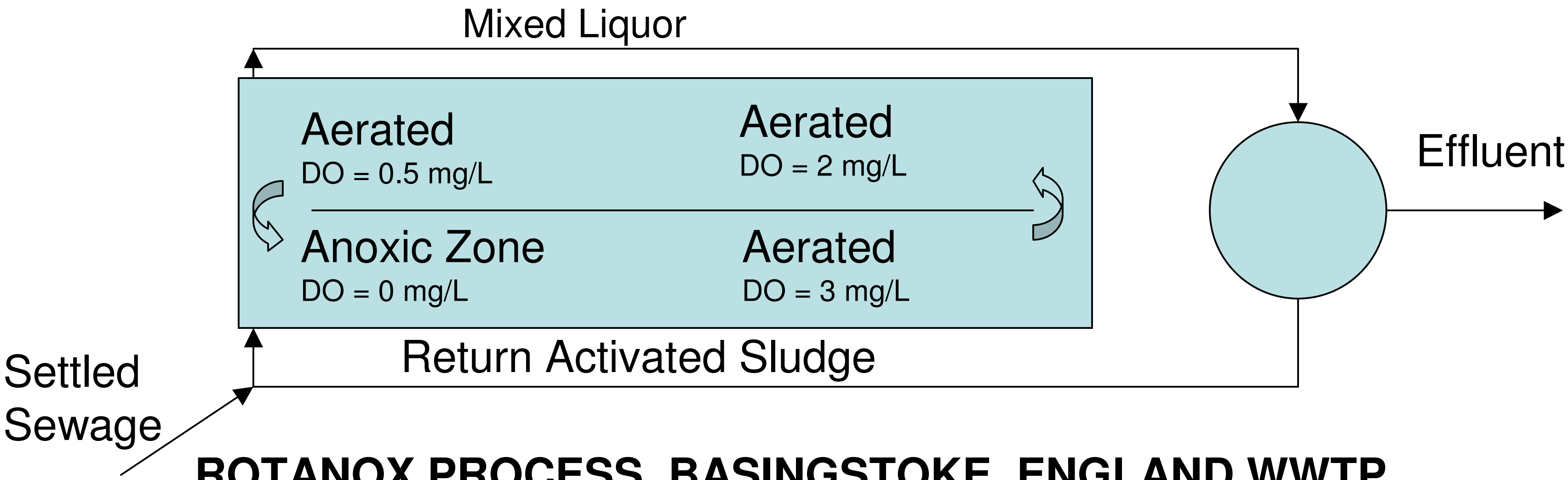
PANEL DISCUSSION

CASE HISTORIES

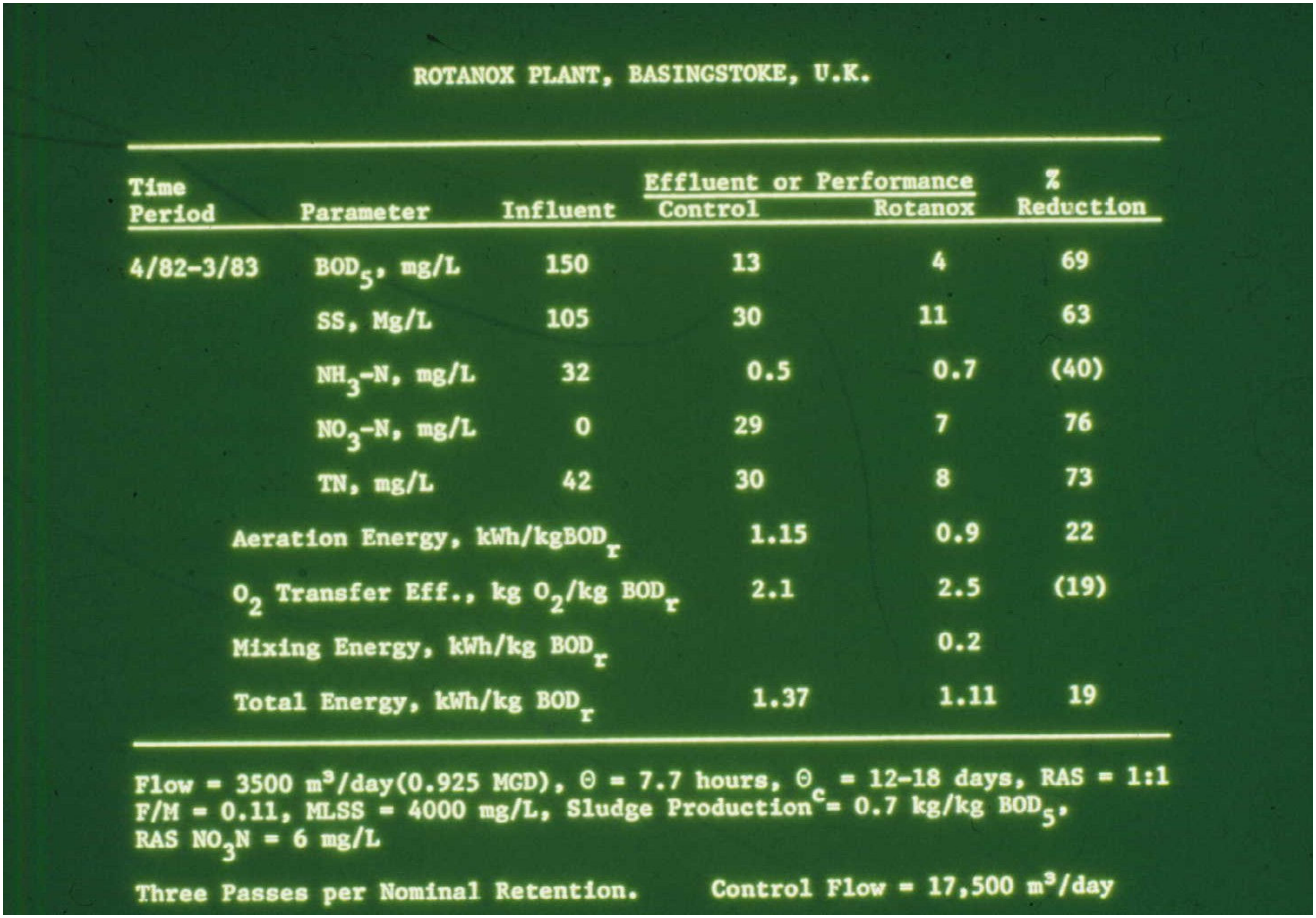
BEFORE MODIFICATION



AFTER MODIFICATION



ROTANOX PROCESS, BASINGSTOKE, ENGLAND WWTP



ROTANOX PLANT, BASINGSTOKE, U.K.

Time Period	Parameter	Influent	Effluent or Performance		% Reduction
			Control	Rotanox	
4/82-3/83	BOD_5, mg/L	150	13	4	69
	SS, Mg/L	105	30	11	63
	NH_3-N, mg/L	32	0.5	0.7	(40)
	NO_3-N, mg/L	0	29	7	76
	TN, mg/L	42	30	8	73
	Aeration Energy, kWh/kgBOD_r		1.15	0.9	22
	O_2 Transfer Eff., kg O_2/kg BOD_r		2.1	2.5	(19)
	Mixing Energy, kWh/kg BOD_r			0.2	
	Total Energy, kWh/kg BOD_r		1.37	1.11	19

Flow = 3500 m^3/day(0.925 MGD), Θ = 7.7 hours, Θ_c = 12-18 days, RAS = 1:1
F/M = 0.11, MLSS = 4000 mg/L, Sludge Production = 0.7 kg/kg BOD_5,
RAS NO_3N = 6 mg/L

Three Passes per Nominal Retention. Control Flow = 17,500 m^3/day

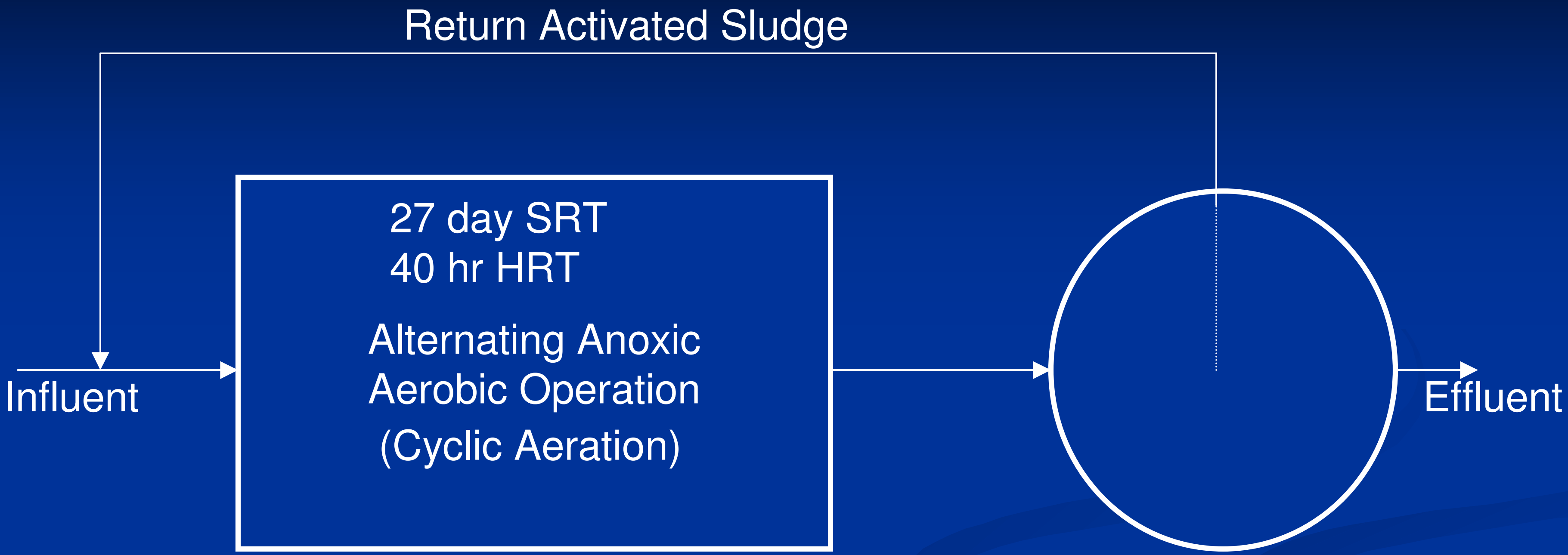
NITRATE IS USED AS THE ELECTRON ACCEPTOR FOR BOD METABOLISM INSTEAD OF DISSOLVED OXYGEN

<u>Aerobic reaction</u>:

$$\text{BOD} + \text{DO} \xrightarrow[\text{sludge}]{\text{activated}} CO_2 + H_2O + \text{cells} + \text{energy}$$

<u>Anoxic reaction</u>:

$$\text{BOD} + NO_3 \xrightarrow[\text{sludge}]{\text{activated}} CO_2 + H_2O + N_2 + 0.75\ \text{cells} + 0.8\ \text{energy}$$



YARRA GLEN WWTP, MELBOURNE, AUSTRALIA

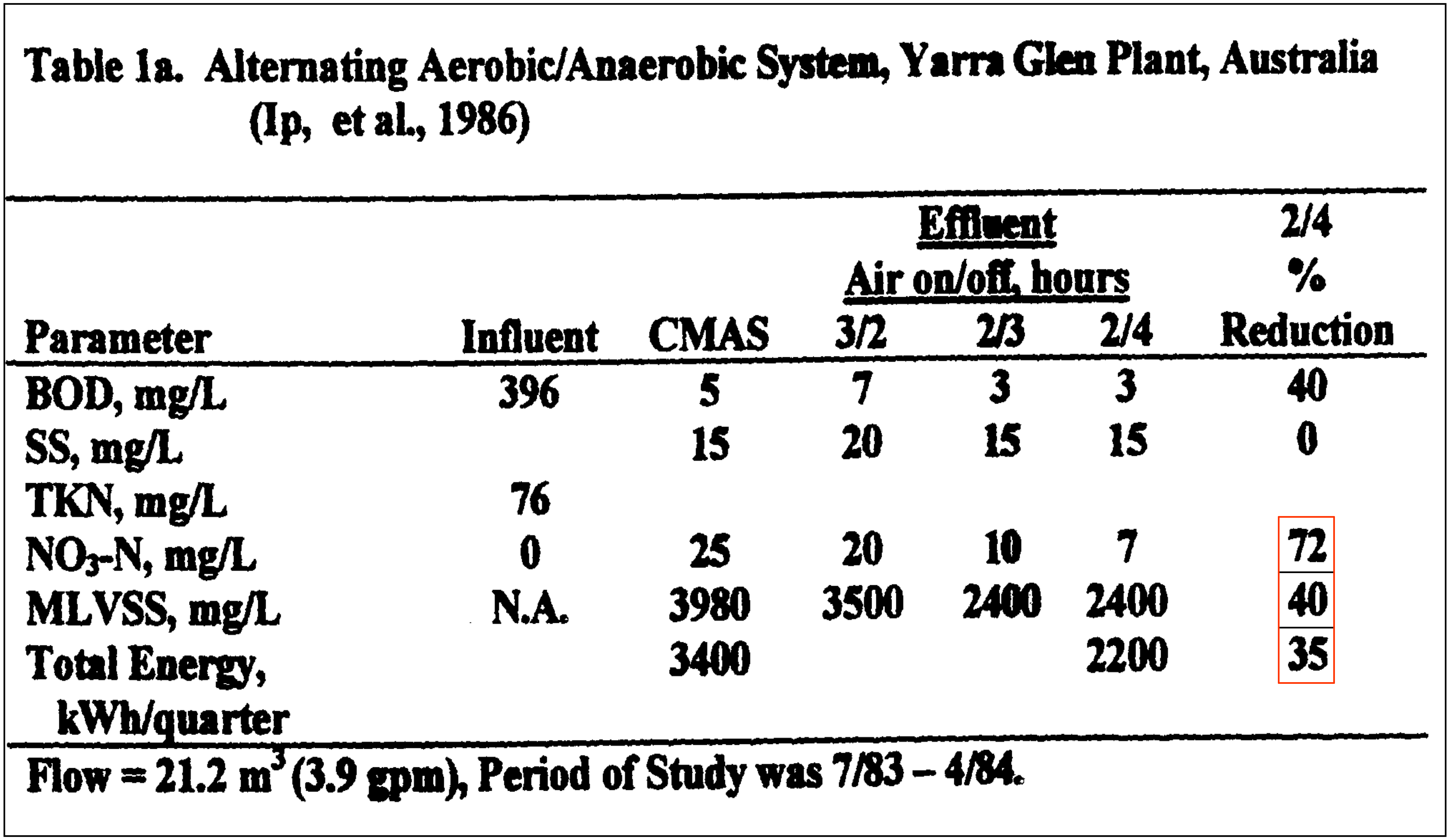


Table 1a. Alternating Aerobic/Anaerobic System, Yarra Glen Plant, Australia (Ip, et al., 1986)

			Effluent			2/4
			Air on/off, hours			%
Parameter	Influent	CMAS	3/2	2/3	2/4	Reduction
BOD, mg/L	396	5	7	3	3	40
SS, mg/L		15	20	15	15	0
TKN, mg/L	76					
NO_3-N, mg/L	0	25	20	10	7	72
MLVSS, mg/L	N.A.	3980	3500	2400	2400	40
Total Energy, kWh/quarter		3400			2200	35

Flow = 21.2 m^3 (3.9 gpm), Period of Study was 7/83 – 4/84.

REDUCTIONS OF WASTE SLUDGE PRODUCTION AND AERATION ENERGY REQUIREMENT BY ANOXIC RESPIRATION


BOWIE WASTEWATER
TREATMENT PLANT
TOYOTA
89 8 3

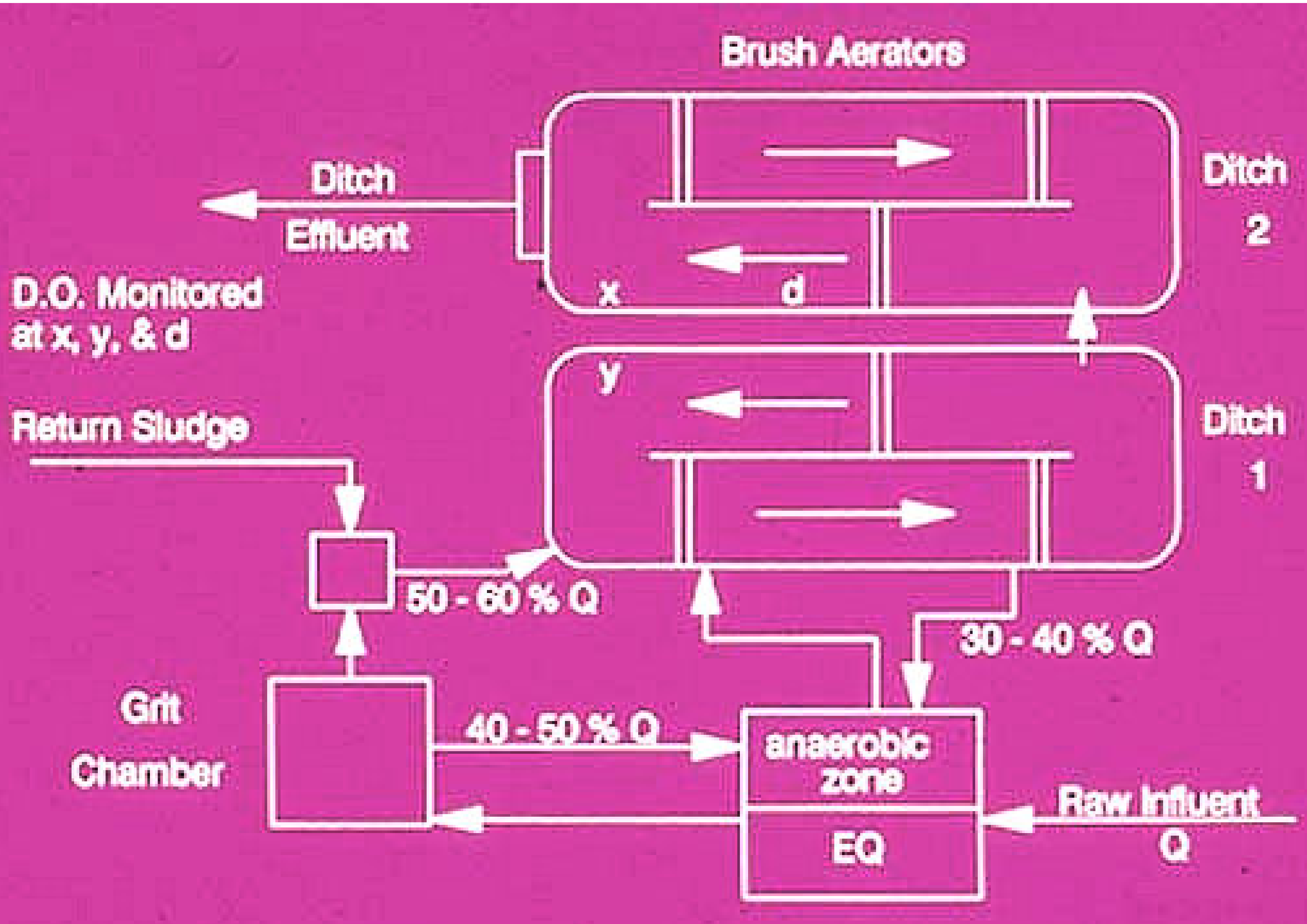
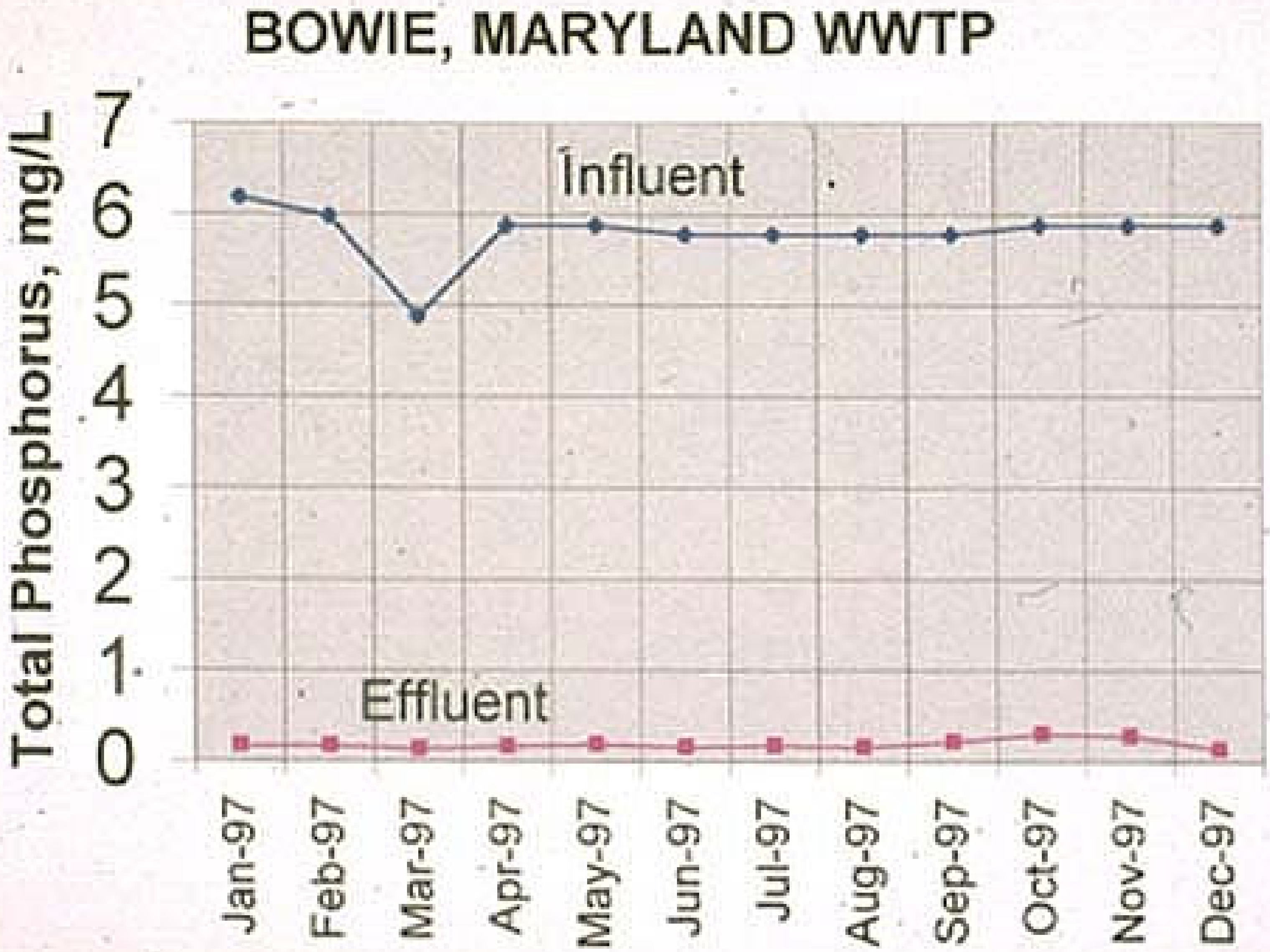
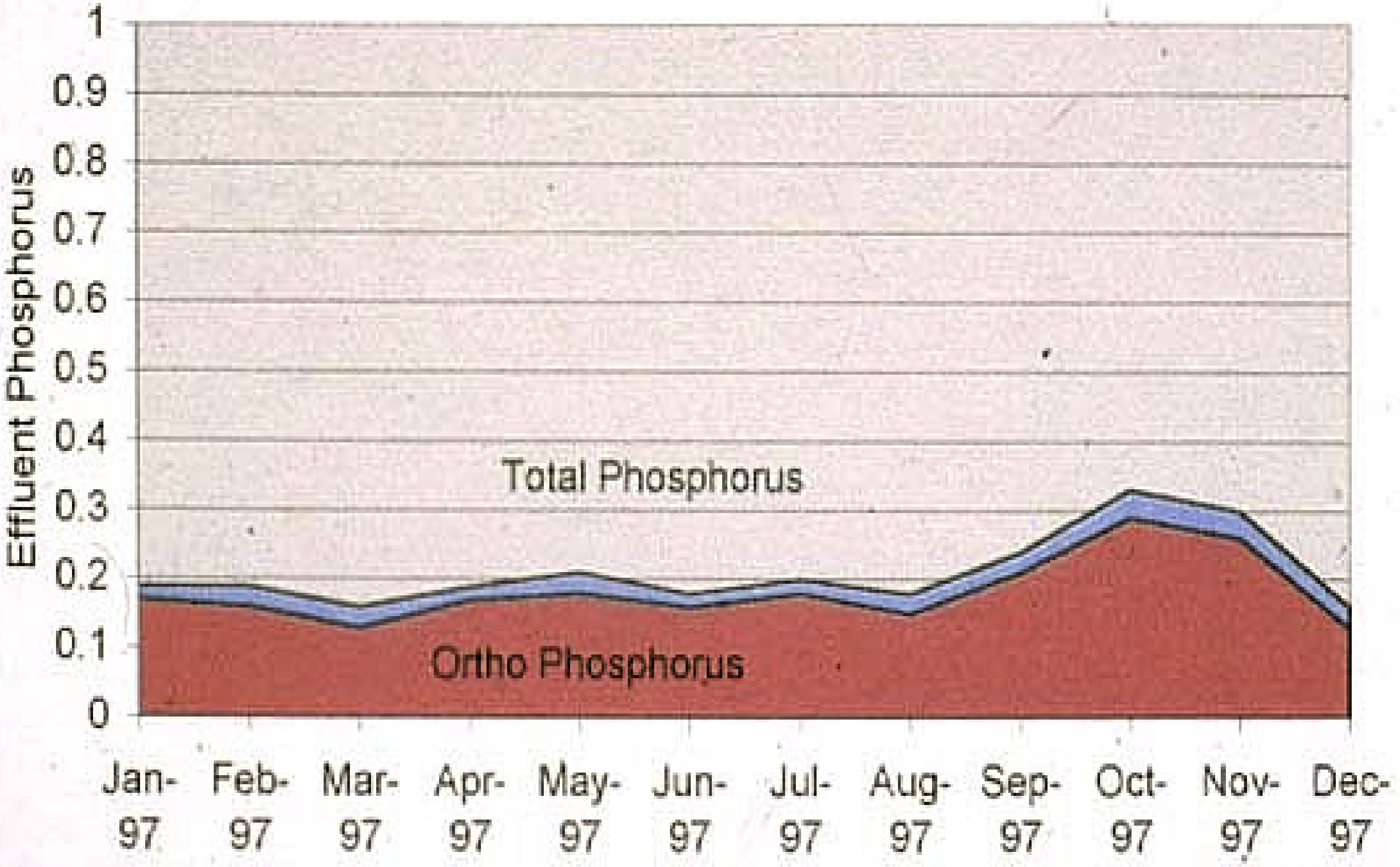
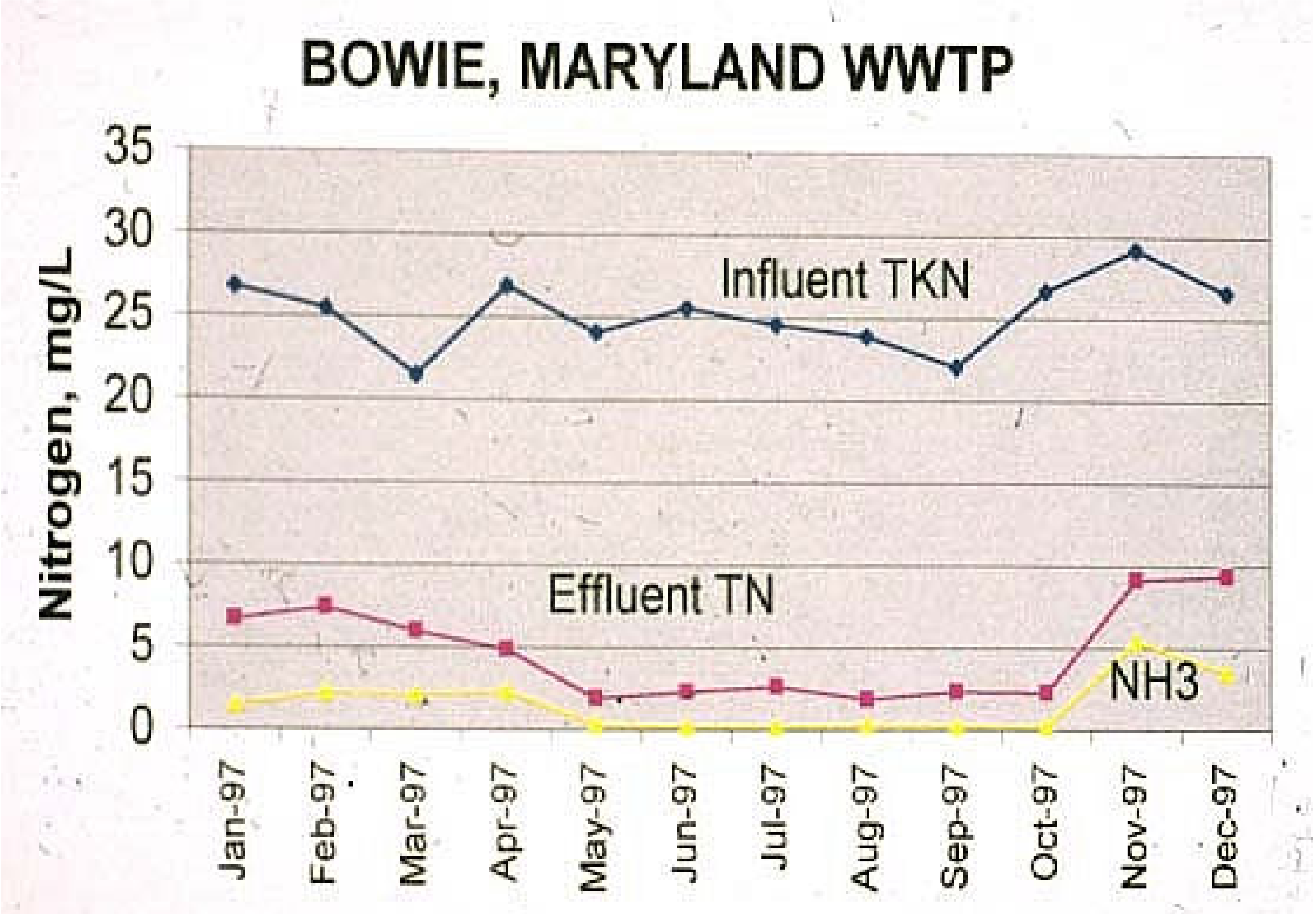


Figure 11. VT2 Process Diagram, Bowie, Maryland WWTP


BOWIE, MARYLAND WWTP
Total Phosphorus, mg/L
7
6
5
4
3
2
1
0
Influent
Effluent
Jan-97
Feb-97
Mar-97
Apr-97
May-97
Jun-97
Jul-97
Aug-97
Sep-97
Oct-97
Nov-97
Dec-97

BOWIE MARYLAND WWTP





BOWIE, MARYLAND WWTP

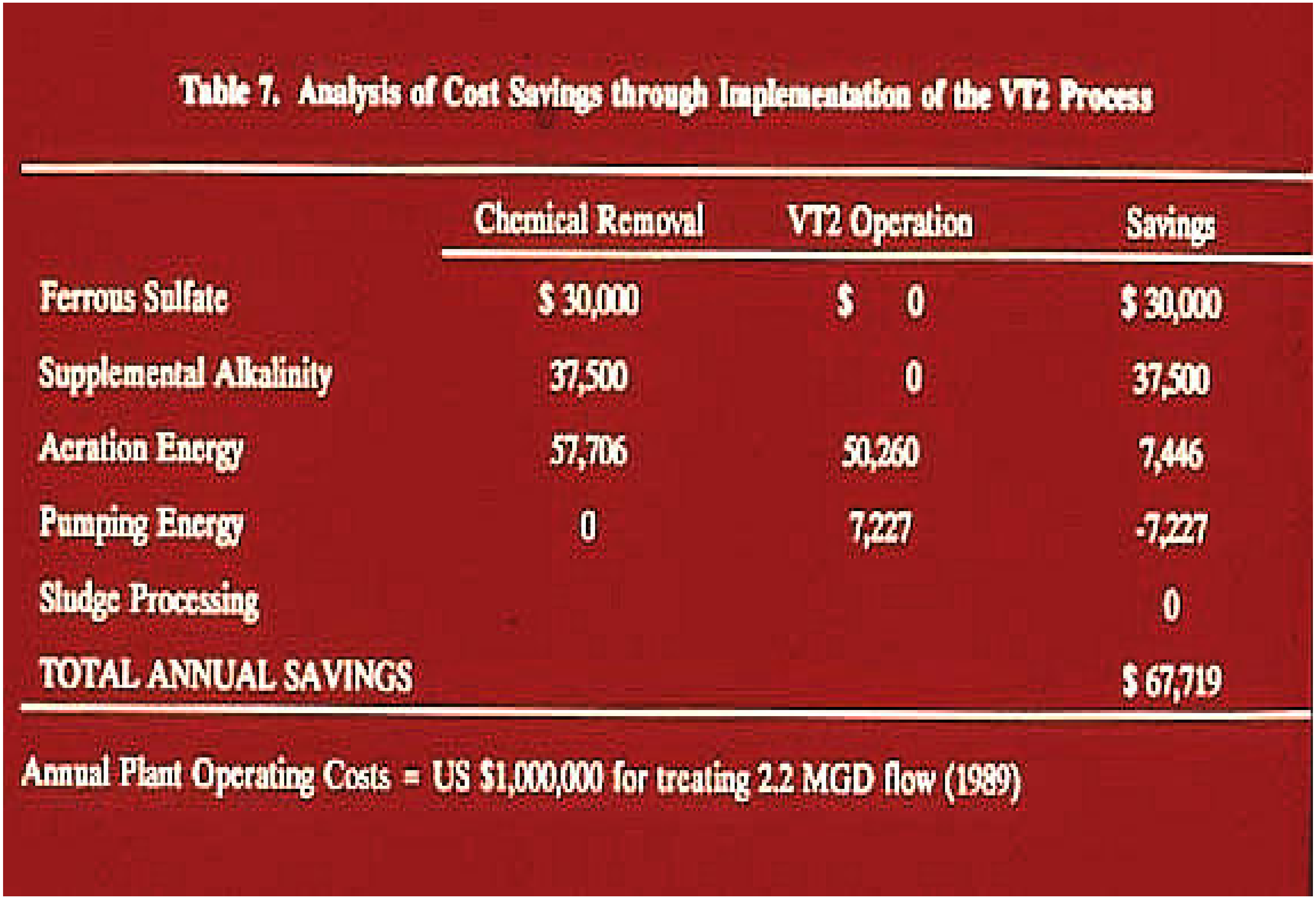


Table 7. Analysis of Cost Savings through Implementation of the VT2 Process

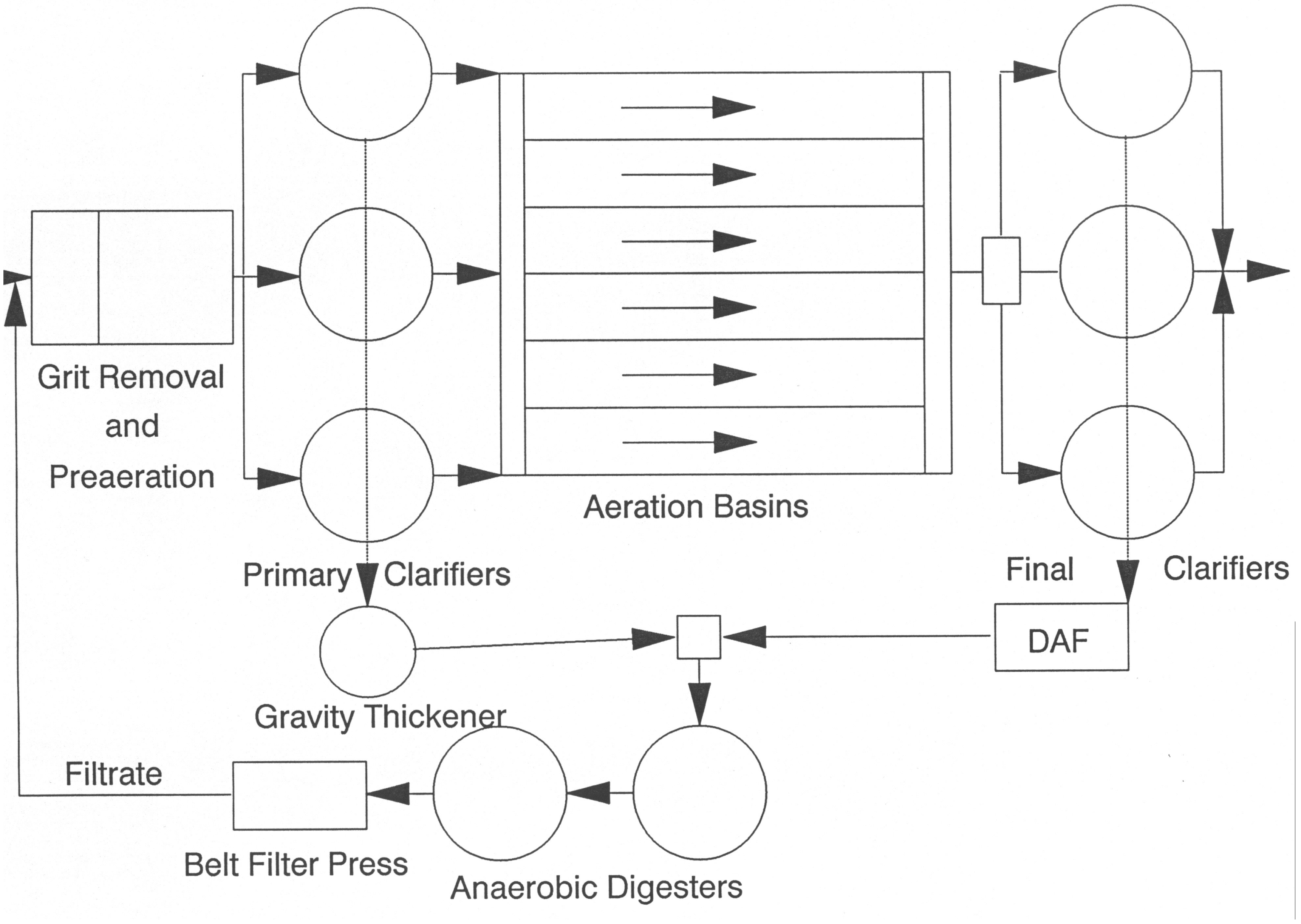
	Chemical Removal	VT2 Operation	Savings
Ferrous Sulfate	$ 30,000	$ 0	$ 30,000
Supplemental Alkalinity	37,500	0	37,500
Aeration Energy	57,706	50,260	7,446
Pumping Energy	0	7,227	-7,227
Sludge Processing			0
TOTAL ANNUAL SAVINGS			$ 67,719

Annual Plant Operating Costs = US $1,000,000 for treating 2.2 MGD flow (1989)

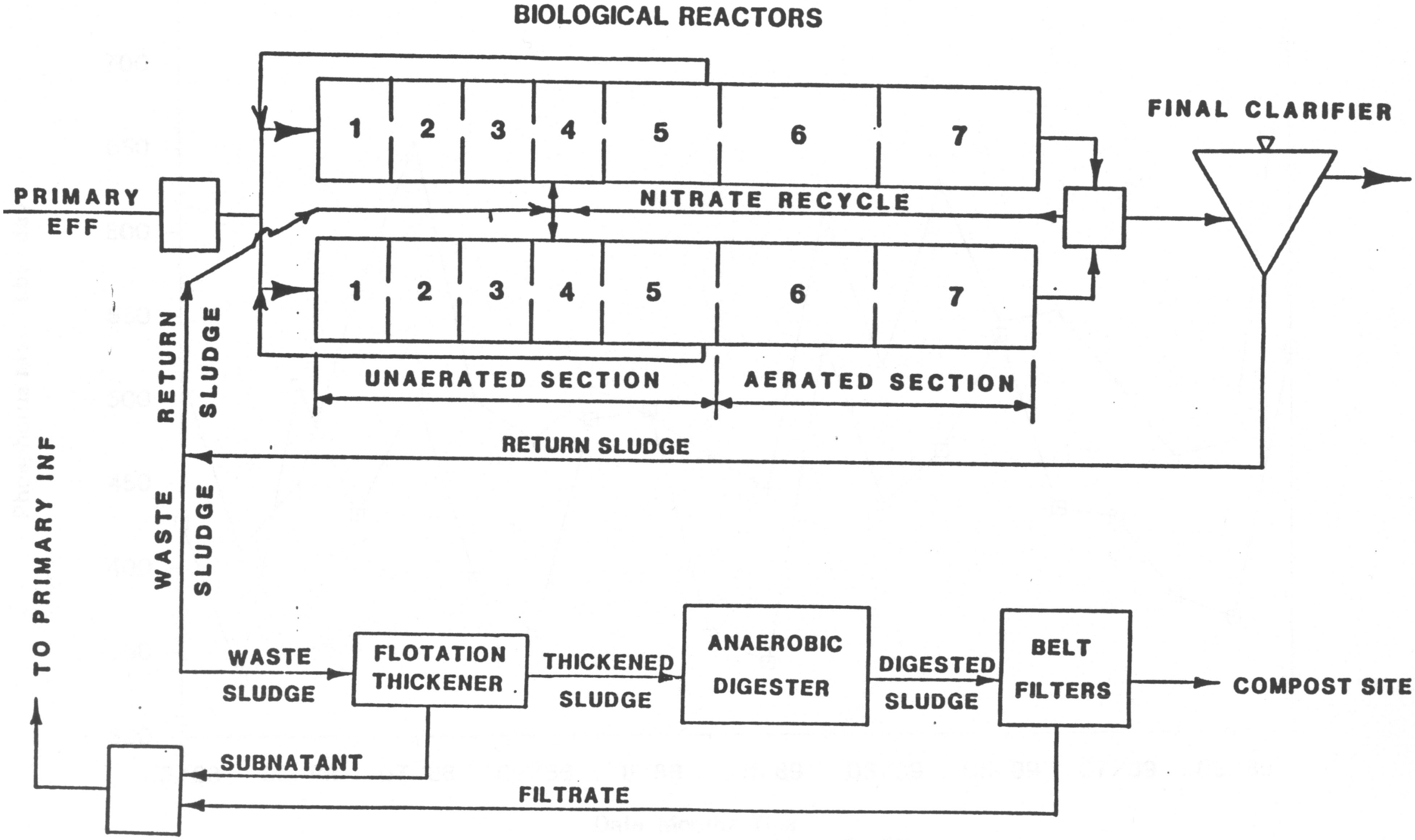
BOWIE, MARYLAND

- Cost of Modification for N & P BNR:
  - $230,000 for a 2.2 mgd Oxidation Ditch
- Reduction in O&M of $68,000 per year:
  - Cost recovery time of 3.4 years

York River 15 mgd Conventional Activated Sludge WWTP

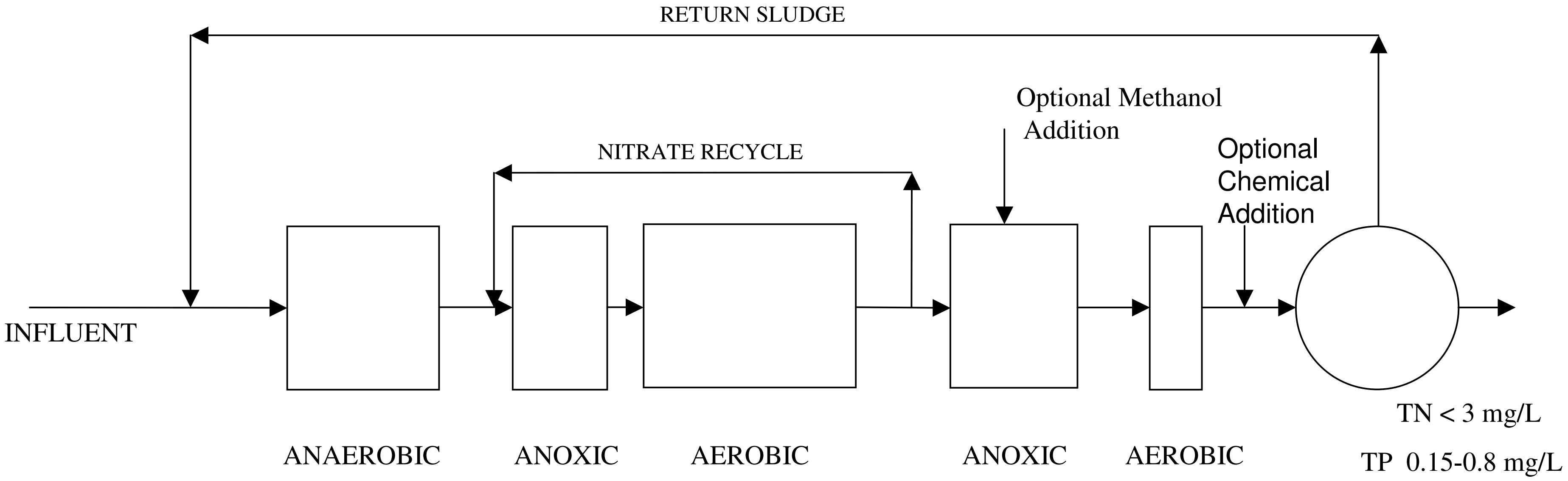


Hampton Roads Sanitation District, Tidewater, Virginia



15 mgd York River WWTP: Modified 1/3rd of Aeration Volume for 6.5 mgd Flow
Potential Aeration Basin Capacity of 19.5 mgd, but limited by Clarification
1986 Modification Cost of $155,000 w/in-house engineering & labor
Equipment & Installation considered to be temporary

FOR LOT COMBINED BIOLOGICAL NITROGEN and PHOSPHORUS REMOVAL, Additional Zones could have been added within the then existing aeration tank volume



Typically Requires 15-25% Volume increase

York River down rating of 7% to 13.95 MGD
2003 Flow = 12.93 MGD

FIVE-STAGE BIOLOGICAL NITROGEN REMOVAL (MODIFIED BARDENPHO) CONFIGURATION
BIOLOGICAL NITROGEN AND PHOSPHORUS REMOVAL

A Potential 17+ years of Operation before Expansion

HOW MUCH WILL IT COST?

Cost Factors

1. Effluent Requirements
   - 4 mg/L TN versus 3 mg/L TN
   - Non-biodegradable Nitrogen

2. Mandated Averaging Period
   - Yearly vs Seasonally vs Monthly vs Weekly

3. Mandated Design Requirements
   - Innovative vs Standard Technology

4. Permissible Construction Period

QUESTIONS?

PANEL DISCUSSION

HOW SHOULD WASTEWATERS BE MANAGED TO REDUCE THE ECOLOGICAL, ECONOMICAL AND SOCIETAL IMPACTS OF NUTRIENT POLLUTION?

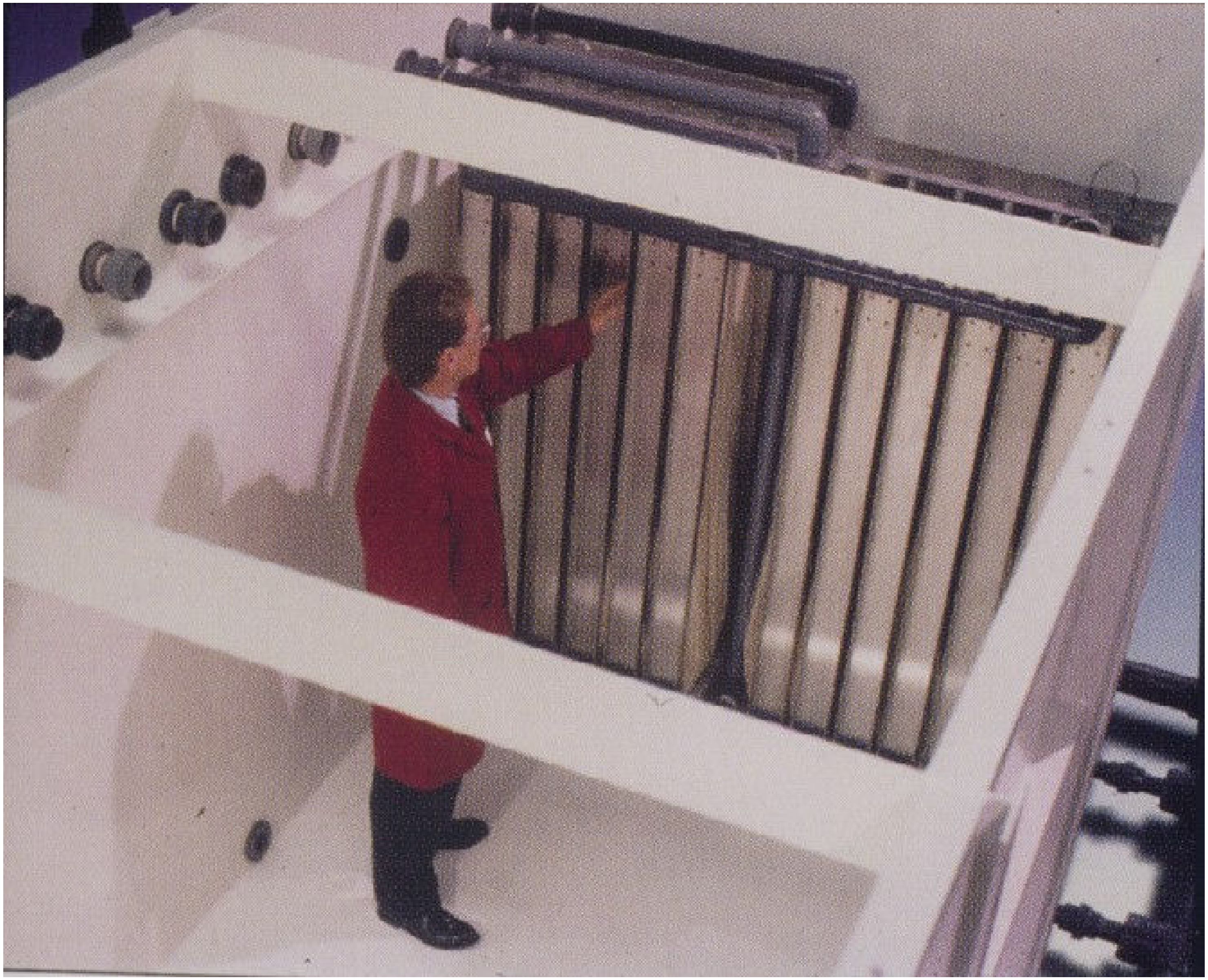
REDUCE, RECYCLE,
RECOVERY
& REUSE

WASTEWATERS CONTAIN LIMITED RESOURCES THAT SHOULD BE RECOVERED AND REUSED

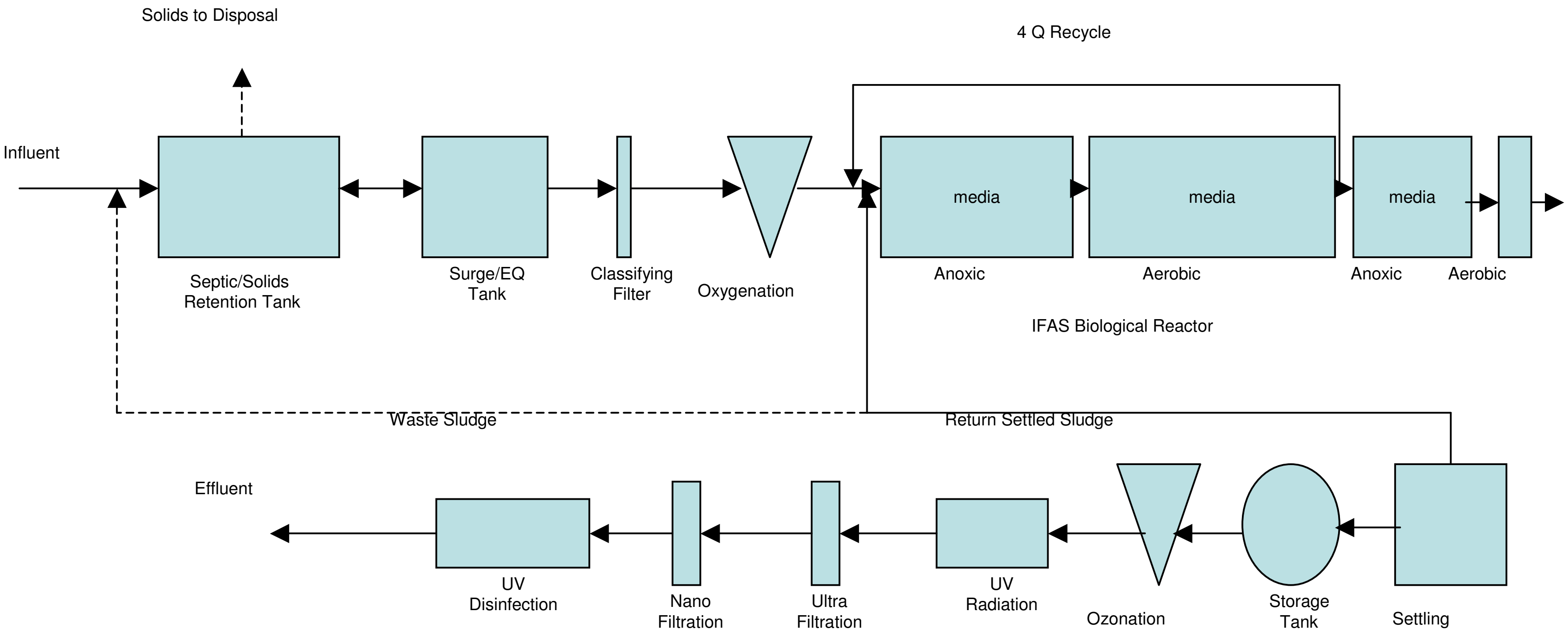
- Water
- Nutrients
  - Phosphorus
  - Nitrogen
- Commercial By-Products

The Need to Recover and Reuse Water from Wastewaters

- Water is a Limiting Resource in many Land Areas of the World.
- Wastewaters can be renovated more economically than seawater can be desalinated.
- Recovery of Water reduces Flows and makes it more Economical to treat Wastewater Flows



MEMBRANE SEPARATION FOR PRODUCTION OF WATER



Schematic Flow Diagram of the Wastewater Conversion Technologies, Inc. On-Site Wastewater Treatment System

RECOMMENDED STRATEGY TO REDUCE COSTS AND ACCELERATE IMPLEMENTATION OF BNR AND LOT.

1. Utilize Existing Excess Capacities of the Significant WWTPs to:

    a. Reduce the costs and accelerate implementation of BNR and LOT at the Significant WWTPs in the Bay Watershed.

    b. Enable Point-to-Point nutrient removal trading.

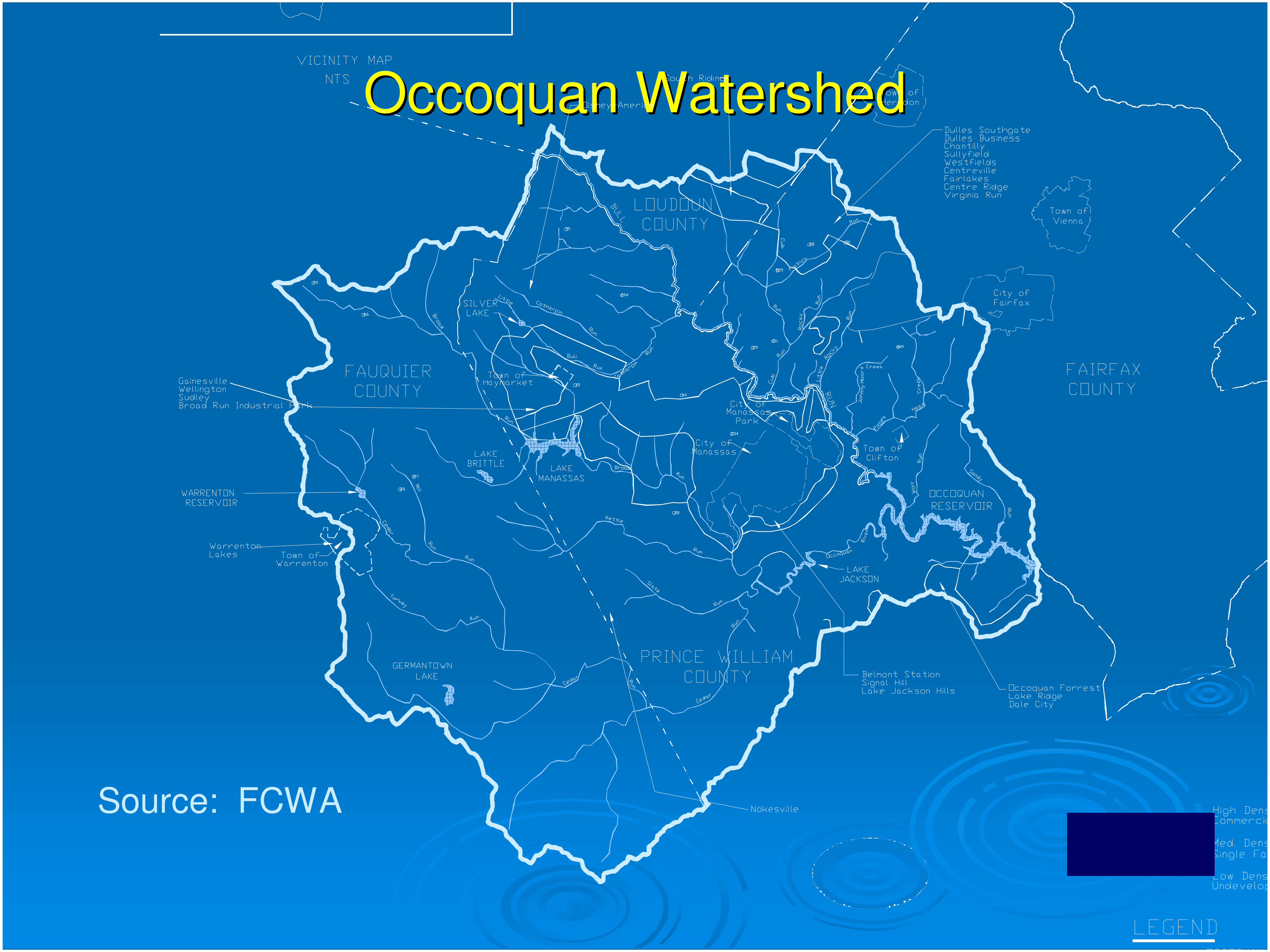
2. Inaugurate a Water Savings Program to further Increase Excess Capacity.

3. Supplement Excess Capacities w/ Innovative Treatment Technologies.

4. Utilize Centralized Sludge Processing wherever feasible.

5. Incorporate Recycle, Reuse and Recovery methodologies.

Occoquan Watershed



Source: FCWA

Bowie WWTP: Final Effluent Total N