POTW
PHOSPHORUS REMOVAL PROCESSES

Ohio Lake Erie Phosphorus Task Force - December 20, 2007

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OUTLINE

- SOURCES AND FORMS IN WASTEWATER
- TYPICAL POTW PROCESSES
- PHOSPHORUS REMOVAL PROCESSES
  - PHYSICAL SETTLING
  - BIOLOGICAL ASSIMILATION
  - CHEMICAL ADDITION
- NEORSD PLANTS, CONCENTRATIONS / LIMITS
- PROCESSES FOR FURTHER REDUCTIONS
  - ENHANCED BIOLOGICAL PHOSPHORUS REMOVAL
  - FILTERS / MEMBRANES

SOURCES OF PHOSPHORUS IN WASTEWATER

- FECAL & WASTE MATERIALS
- INDUSTRIAL & COMMERCIAL USES
- DRINKING WATER - ORTHOPHOSPHATES
- SYNTHETIC DETERGENTS

FORMS OF PHOSPORUS IN WASTEWATER

- DISSOLVED (SOLUBLE)
- SOLID

- ORTHOPHOSPHATES
- CONDENSED PHOSPHATES
- ORGANIC PHOSPHATES

TYPICAL POTW PROCESSES

- SECONDARY TREATMENT-WET STREAM
  - PRELIMINARY
    - BAR SCREENS & GRIT CHANNELS
  - PRIMARY
    - SEDIMENTATION w/ & w/o chemical addition
  - SECONDARY – AEROBIC PROCESSES
    - BIOLOGICAL C, N and P REMOVAL
      - ACTIVATED SLUDGE, TRICKLING FILTERS
    - SEDIMENTATION w/ & w/o chemical addition
  - DISINFECTION
    - CHLORINATION / DECHLORINATION

ACTIVATED SLUDGE

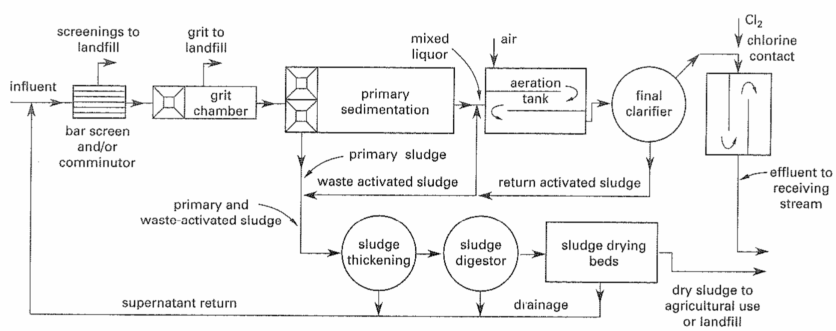

Figure 30.1 *Typical Activated Sludge Plant*

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BIOLOGICAL PRINCIPLES

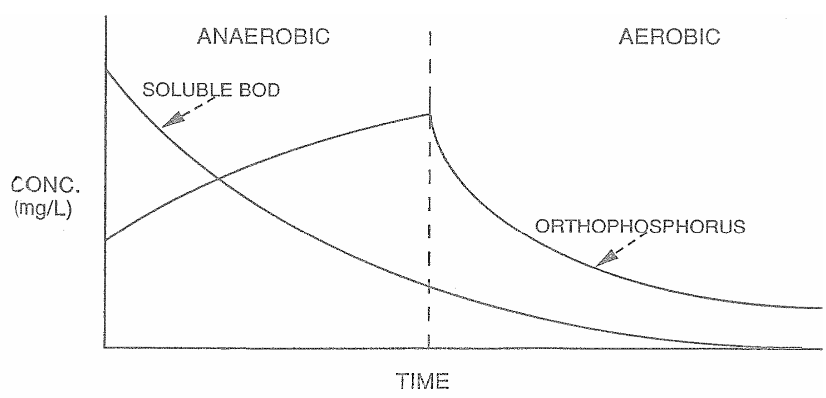
- Normal cellular uptake in aerobic respiration

  C : N : P ratios 100 : 5 : 1

  BOD : Total N : Total P

- Certain facultative microorganisms, when subjected to anaerobic conditions, can survive by assimilating and storing fermentation products (measured as soluble BOD). In the process, energy in the form of ATP (Adenosine Triphosphate) is used and dissolved (ortho) phosphorus is released from the cells.
- When these microorganisms ("stressed" under anaerobic conditions) come in contact with dissolved phosphorus under aerobic conditions, they "take up" excess phosphorus beyond normal amounts required for cell growth. Phosphate Accumulating Organisms (PAO).

BOD & PHOSPHORUS UPTAKE



Fate of soluble BOD and phosphorus.

CHEMICAL ADDITION

- ADDED BEFORE SEDIMENTATION
- COAGULATION – one or more chemicals are added to the wastewater and their reactions with the chemicals already in the water form a precipitate.
- FLOCCULATION – usually anionic polymers - added after coagulation chemicals to "attach" the particles together for improved settling.

COAGULATION CHEMICALS

- Ferrous (+2) and Ferric (+3) Sulfate
  - $FeSO_4$, $Fe_2(SO_4)_3$
- Ferrous (+2) and Ferric (+3) Chloride
  - $FeCl_2$ $FeCl_3$
- Alum $Al_2(SO_4)_3$ Al^{+3}
- Lime $Ca(OH)_2$ Ca^{+2}

CHEMICAL REACTIONS

- Alum
  - $Al^{+3} + PO_4^{-3} \rightarrow ALPO_4$ precipitate
- Lime
  - $5Ca^{+2} + 3PO_4^{-3} + OH^- \rightarrow Ca_5OH(PO_4)_3$ ppt
- Ferric Chloride
  - $FeCl_3 + PO_4^{-3} \rightarrow FePO_4$ precipitate
  - $FeCl_3 + 3OH^- \rightarrow Fe(OH)_3$ precipitate

PRECIPITATES

Table 4-3. Precipitates formed during phosphate precipitation.

Phosphate Precipitant	Precipitates That May Form
Ca(II)	Various calcium phosphates eg. ß-tricalcium phosphate: $Ca_3(PO_4)_2(s)$ hydroxyapatite: $Ca_5(OH)(PO_4)_3(s)$ dicalcium phosphate: $CaHPO_4(s)$ calcium carbonate: $CaCO_3(s)$
Fe(II)	ferrous phosphate: $Fe_3(PO_4)_2(s)$ ferric phosphate: $Fe_x(OH)_y(PO_4)_3(s)^a$ ferrous hydroxide: $Fe(OH)_2(s)$ ferric hydroxide: $Fe(OH)_3(s)^a$
Fe(III)	ferric phosphate: $Fe_x(OH)_y(PO_4)_z(s)$ ferric hydroxide: $Fe(OH)_3(s)$
Al(III)	aluminum phosphate: $Al_x(OH)_y(PO_4)_3(s)$ aluminum hydroxide: $Al(OH)_3(s)$

[a]Formed by oxidation of Fe(II) to Fe(III) during the treatment process

SOLUBILITY DIAGRAMS

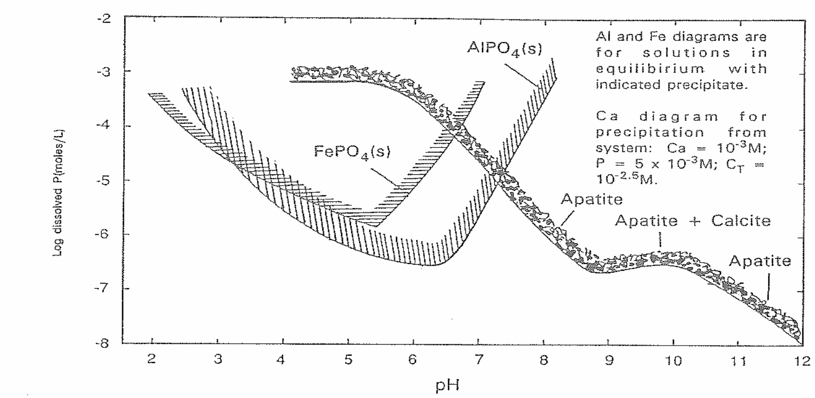


Figure 4-2. Equilibrium solubility diagrams for Fe, Al, and Ca phosphates(7).

FERRIC HYDROXIDE SOLUBILITY DIAGRAM

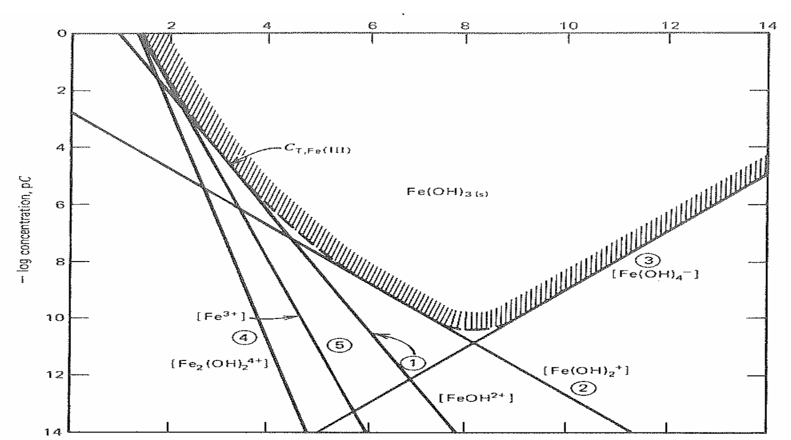


Fig. 6-7. Equilibrium concentrations of hydroxo iron(III) complexes in a solution in contact with freshly precipitated $Fe(OH)_{3(s)}$ at 25°C.

NEORSD $FeCl_3$ CONTRACT

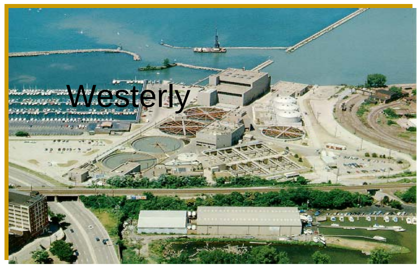
- COMPETITIVELY BID 2–YR DURATION
- SPECIFIED CONCENTRATION RANGE

  28 % – 40 %

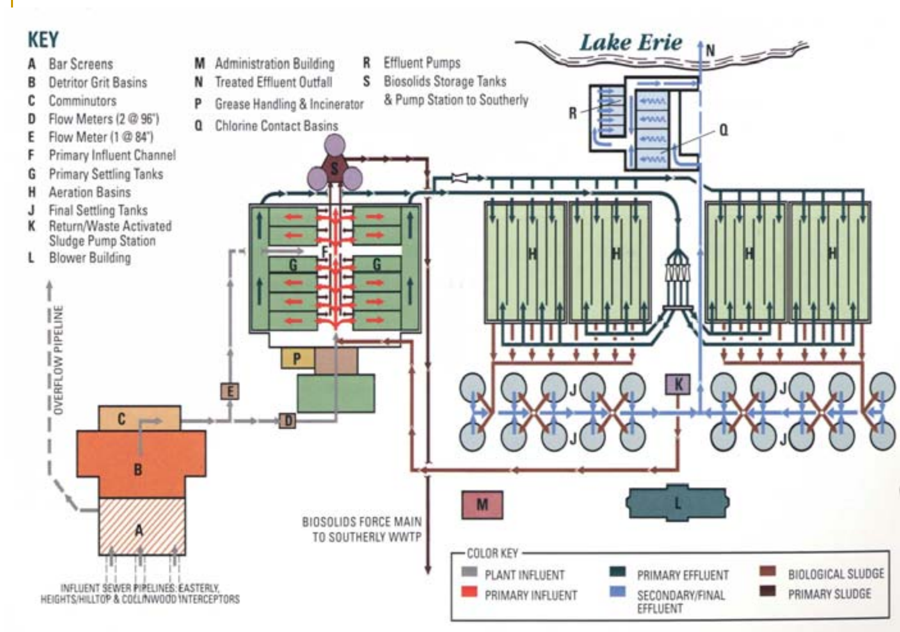
- PRESENT CONTRACT 33 %
  - $0.155 / dry lb
  - Annual Cost = $290,000.00
  - 21% of the total chemical costs

NEORSD TREATMENT PLANTS

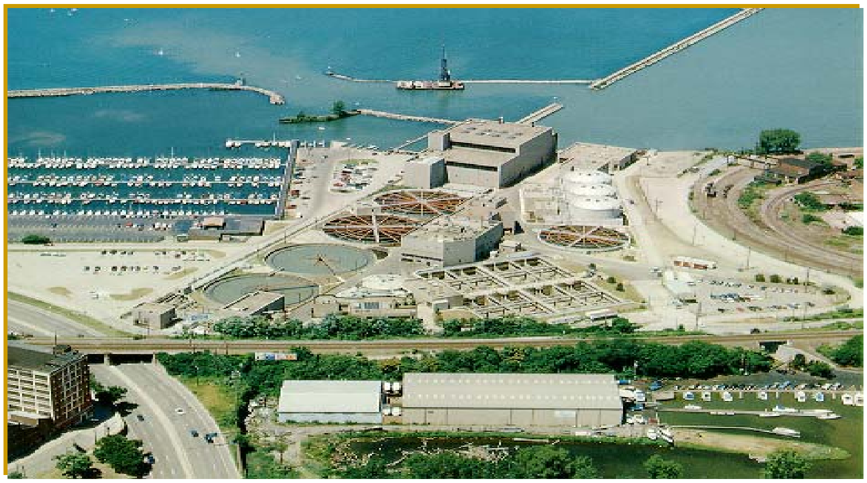
- EASTERLY WWTP
  - AVERAGE 100 MGD FLOW
  - ACTIVATED SLUDGE PROCESS
- WESTERLY WWTP
  - AVERAGE 25 MGD FLOW
  - TRICKLING FILTER/SOLIDS CONTACT PROCESS
- SOUTHERLY WWTP
  - AVERAGE 100 MGD FLOW
  - TWO STAGE ACTIVATED SLUDGE PROCESS
  - NITROGEN (Ammonia) LIMIT

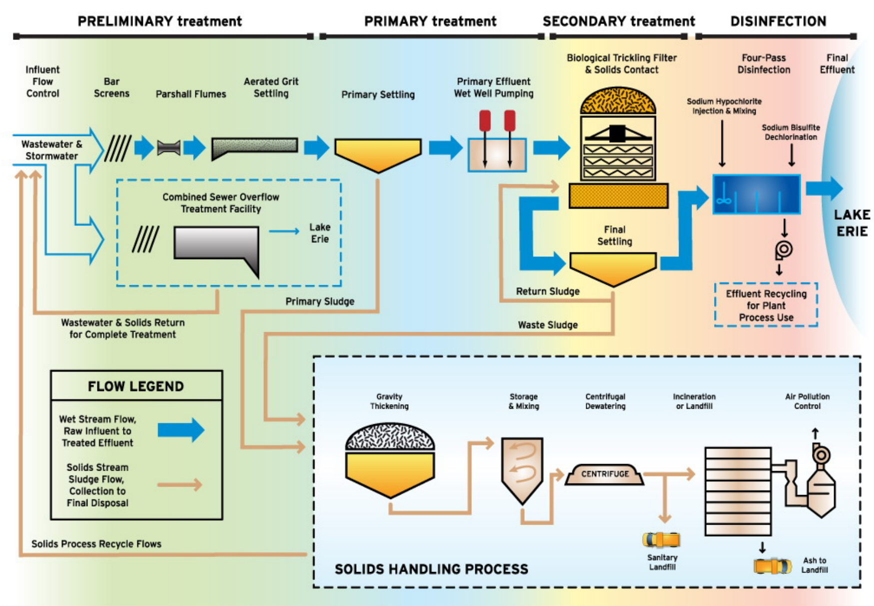


EASTERLY WWTP


KEY
A Bar Screens
B Detritor Grit Basins
C Comminutors
D Flow Meters (2 @ 96")
E Flow Meter (1 @ 84")
F Primary Influent Channel
G Primary Settling Tanks
H Aeration Basins
J Final Settling Tanks
K Return/Waste Activated Sludge Pump Station
L Blower Building
M Administration Building
N Treated Effluent Outfall
P Grease Handling & Incinerator
Q Chlorine Contact Basins
R Effluent Pumps
S Biosolids Storage Tanks & Pump Station to Southerly
Lake Erie
OVERFLOW PIPELINE
INFLUENT SEWER PIPELINES: EASTERLY, HEIGHTS/HILLTOP & COLLINWOOD INTERCEPTORS
BIOSOLIDS FORCE MAIN TO SOUTHERLY WWTP
COLOR KEY
PLANT INFLUENT
PRIMARY INFLUENT
PRIMARY EFFLUENT
SECONDARY/FINAL EFFLUENT
BIOLOGICAL SLUDGE
PRIMARY SLUDGE

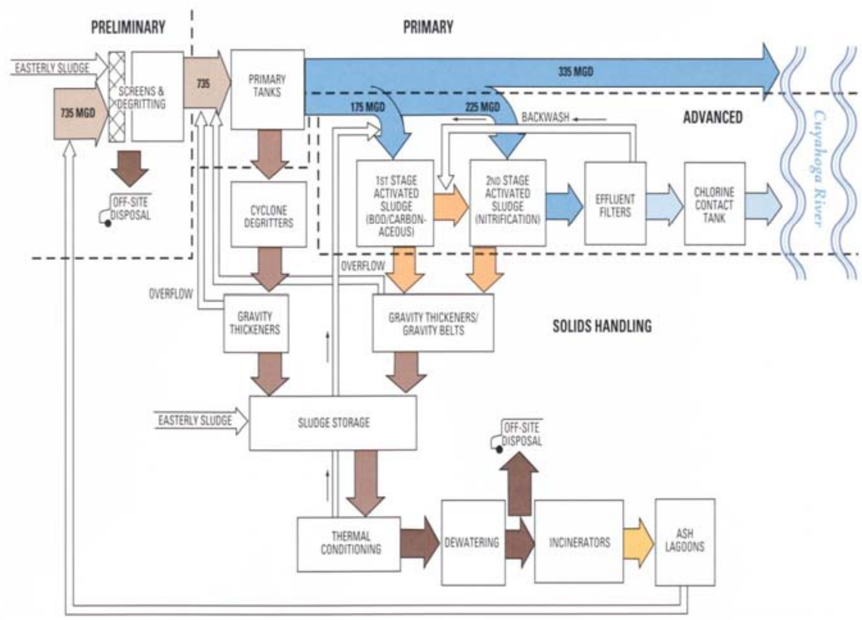
WESTERLY WWTP





SOUTHERLY WWTP

Process Flow Diagram



2006 AVERAGE TOTAL PHOSPHORUS CONCENTRATIONS (mg/l)

POTW	RAW INF	PRI EFF	SEC EFF	FINAL EFF	Monthly LIMIT
E	2.6	1.5	-	0.5	1.0
W	2.5	2.0	-	0.7	1.0
S	3.0	2.1	0.6	0.5	1.0

PROCESSES FOR FURTHER PHOSPHORUS REDUCTIONS

- ENHANCED BIOLOGICAL P REMOVAL
  - PATENTED PROCESSES
  - ANAEROBIC ZONE
    - DISSOLVED (ORTHO) PHOSPHORUS RELEASE
  - AEROBIC ZONE
    - AFTER “STRESS” - EXCESS P UPTAKE OCCURS
- FILTERS / MEMBRANES
  - PILOT PLANTS

ENHANCED BIOLOGICAL PHOSPHORUS REMOVAL

- EXAMPLE PROCESSES
  - A/O PROCESS
  - PHOSTRIP PROCESS – first commercial
- SOME DESIGNS REMOVE P & N (EBNR)
  - BARDENPHO PROCESS
  - PHOREDOX PROCESS
- INVOLVE ANAEROBIC P RELEASE STEP AND AEROBIC P UPTAKE STEP

A/O PROCESS

- DEFINITION: ANAEROBIC / OXIC
- MODIFIED ACTIVATED SLUDGE PROCESS
- PATENTED - AIR PRODUCTS & CHEMICALS
- INFLUENT WW AND RETURN SLUDGE FLOW INTO AN ANAEROBIC PROCESS ZONE
  - PHOSPHORUS IS RELEASED IN THE ANAEROBIC ZONE
- PHOSPHORUS UPTAKE OCCURS IN THE AERATION TANK (AEROBIC ZONE)

A/O PROCESS

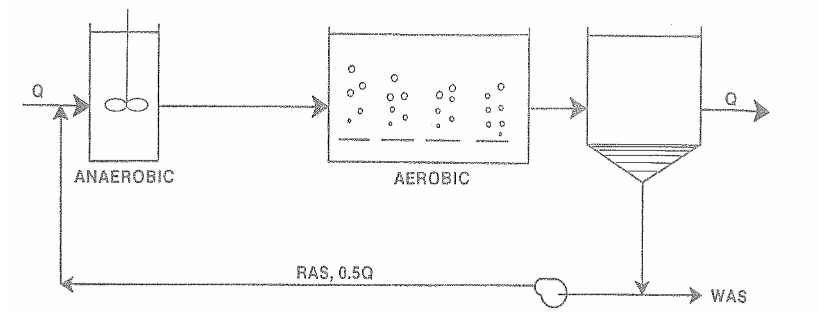


Figure 7-1. A/O Process.

PHOSTRIP PROCESS

- MODIFIED ACTIVATED SLUDGE PROCESS
- INCLUDES BOTH BIOLOGICAL AND CHEMICAL PHOSPHORUS REMOVAL
- SIDESTREAM DIVERTED FROM RAS INTO AN ANAEROBIC STRIPPER TANK (8-12 HR)
  - "PHOS. STRIPPED" SLUDGE IS RETURNED TO THE AERATION TANK AND GREATER P UPTAKE OCCURS
  - HIGH PHOS. SUPERNATANT IS CHEMICALLY TREATED AND REMOVED WITH LIME

PHOSTRIP PROCESS

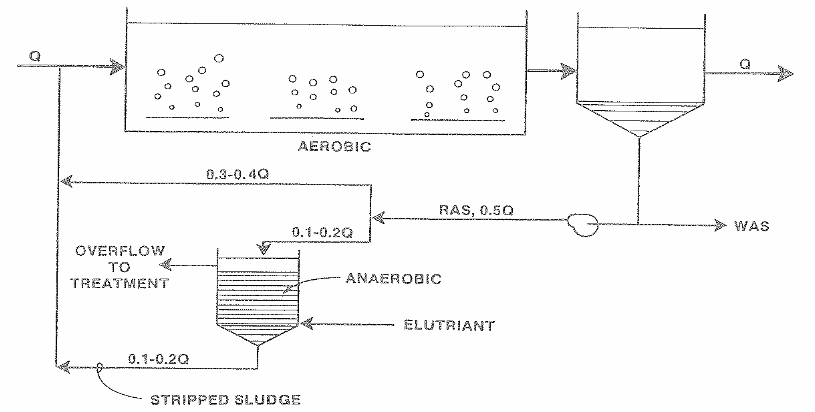


Figure 7-2. Phostrip Process.

FILTERS / MEMBRANES FOR PHOSPHORUS REMOVAL

- PILOT PLANT – IDAHO (SPOKANE RIVER)
  - DRAFT DISCHARGE LIMIT 0.05 mg/l P
  - PROCESSES
    - BLUE WATER BLUE PRO™
    - PARKSON DYNASAND
    - US FILTER TRIDENT HS-1
    - ZEEWEED™ 500
  - RESULTS
    - 0.015 – 0.035 mg/l Total P

PILOT PLANT FOR PHOSPHORUS REMOVAL

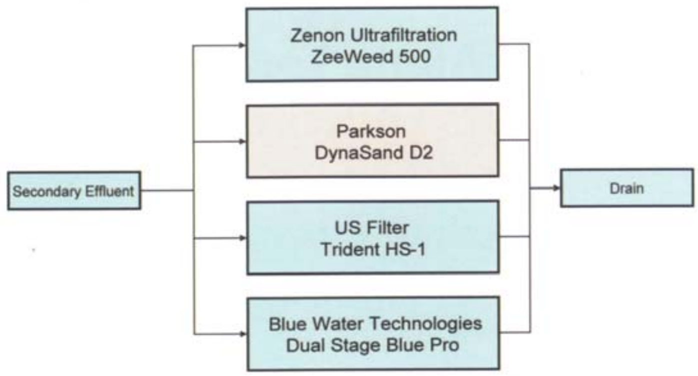


Figure 1 - *City of Coeur d'Alene Tertiary Phosphorus Removal Pilot Schematic*

BLUE WATER BLUE PRO™

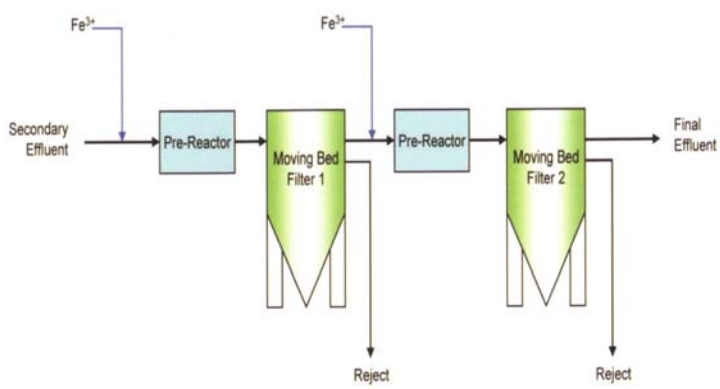


Figure 2 - *Dual Stage Blue PRO™ (DSBP) Process Schematic*

PARKSON DYNASAND

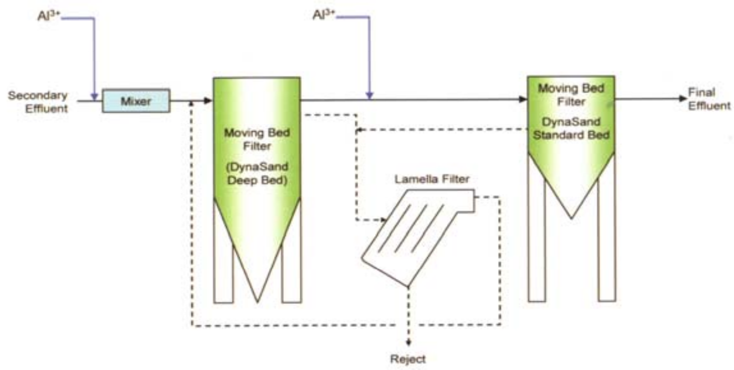


Figure 3 *- Parkson DSD2 Advanced Filtration System Schematic*

US FILTER TRIDENT HS-1

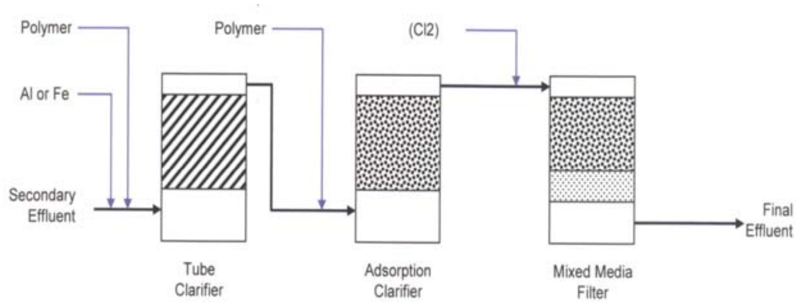


Figure 4 *- THS-1 Schematic*

ZEEWEED™ 500

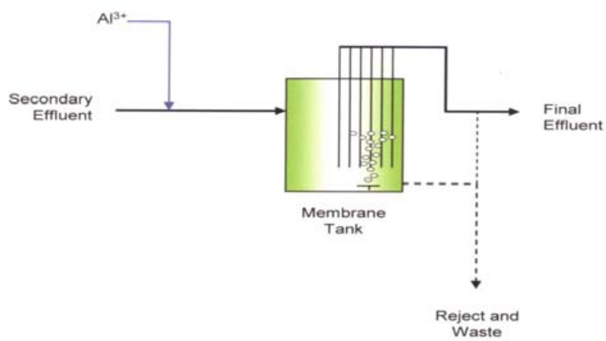


***Figure 5** - Schematic of Zenon ZeeWeed™ 500 Ultrafiltration Process*

CONCLUSIONS

- CONVENTIONAL SETTLING AND BIOLOGICAL PROCESS DESIGNS ARE TYPICALLY NOT ADEQUATE (AND NON-FLEXIBLE) TO CONSISTENTLY REMOVE TOTAL PHOSPHORUS CONC. LESS THAN 1.0 mg/l
- NEORSD PLANTS UTILIZE FERRIC CHLORIDE ADDITION TO THE PRIMARY OR SECONDARY CLARIFIERS TO MEET PERMIT LIMITS
  - CONSISTENT PHOSPHORUS REMOVAL LESS THAN 1.0 mg/l IS ACHIEVED AT WIDELY RANGING FLOWRATES
  - PRESENT ANNUAL CHEMICAL COST $300,000.00/YR
  - COSTS FOR CAPITAL EXPENDITURES, O & M

QUESTIONS - PHOSPHORUS REMOVAL PROCESSES

- FULL SCALE TERTIARY TREATMENT PERFORMANCE CONSISTENCY
  - FULL SCALE PLANT FLOWRATES FLUCTUATE WIDELY DUE TO COMBINED SYSTEMS
- INNOVATIVE TECHNOLOGY
  - TRIED AND TRUE 100 + MGD?
- ADDITIONAL PROCESSES REQUIRE DESIGN, CONSTRUCTION, LAND, O & M
  - COST FUNDED BY RATEPAYERS

REFERENCES

- “Biological Wastewater Treatment”, Grady & Lim, 1980.
- “Coeur d’Alene Tertiary Phosphorus Removal Tests Limits of Technology”, HDR Waterscapes Publication, Fall 2007.
- “Civil Engineering Reference Manual, Tenth Edition”, Lindeberg, 2006.
- Phosphorus and Nitrogen Removal From Municipal Wastewater”, Richard Sedlak, 1991.