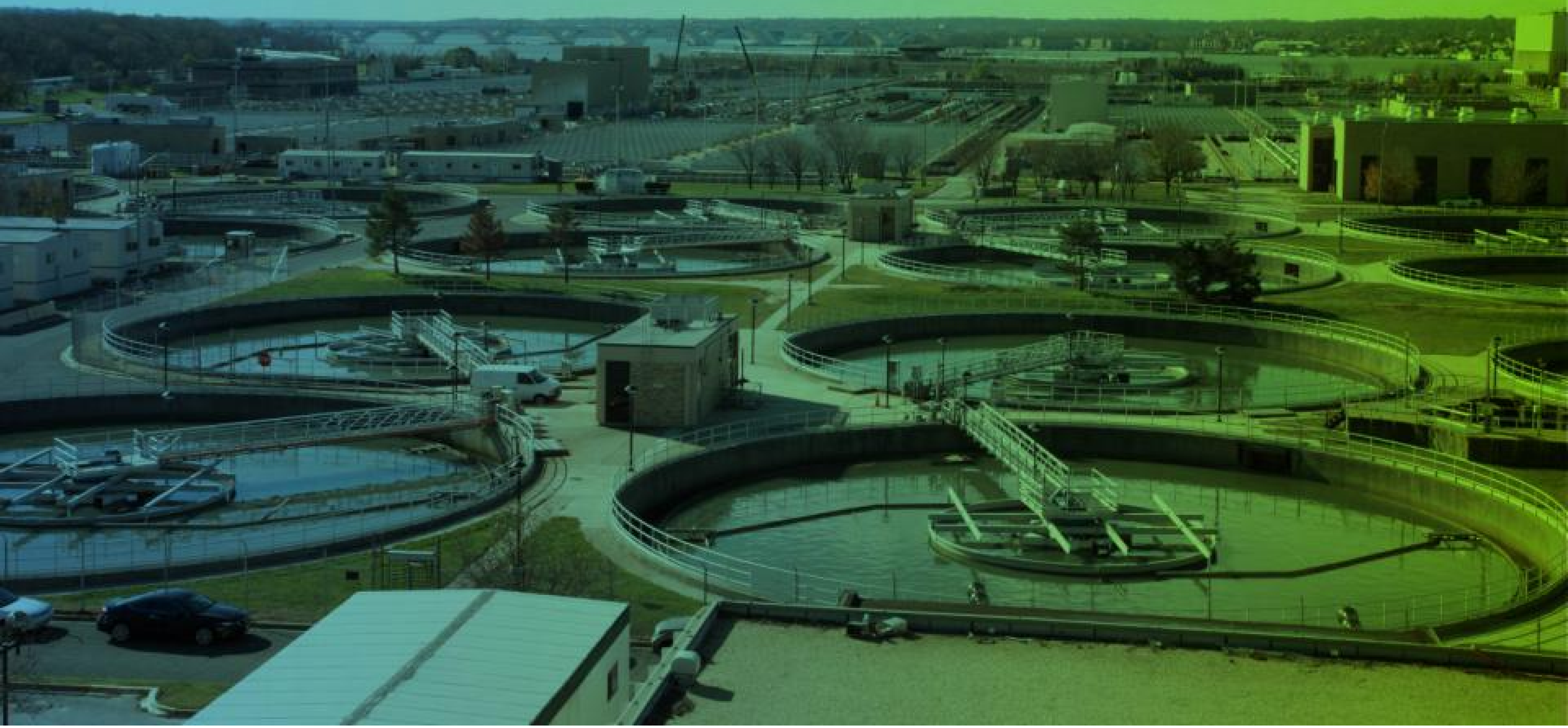
Nitrogen Removal Technology: Past, Present and Future- Blue Plains Advanced Wastewater Treatment Plant's Current Nutrient Regulation and Nitrogen Removal Processes

May 20th, 2011



Sudhir N. Murthy, PhD, PE

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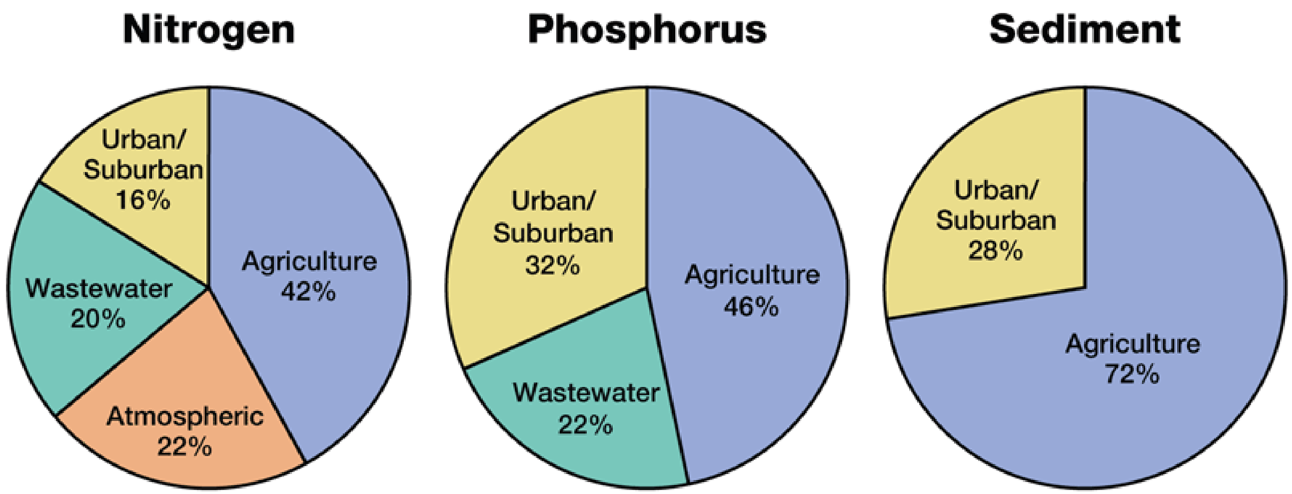
Discussion Topics

- History and Basis of Nitrogen Removal at Blue Plains
- Nitrogen Removal Program Elements
  - Integration of evolving science within the nitrogen program
- New Frontiers

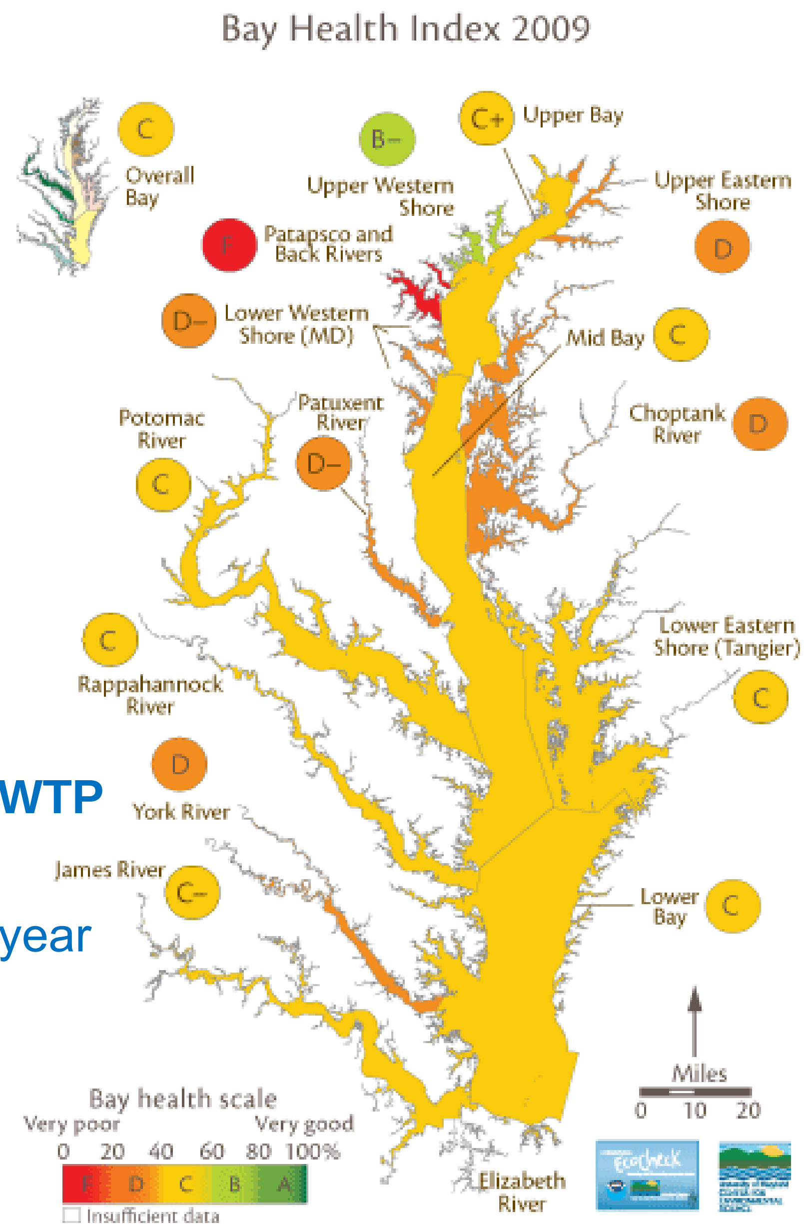
Relative Responsibility for Pollution Loads to the Bay (2007)



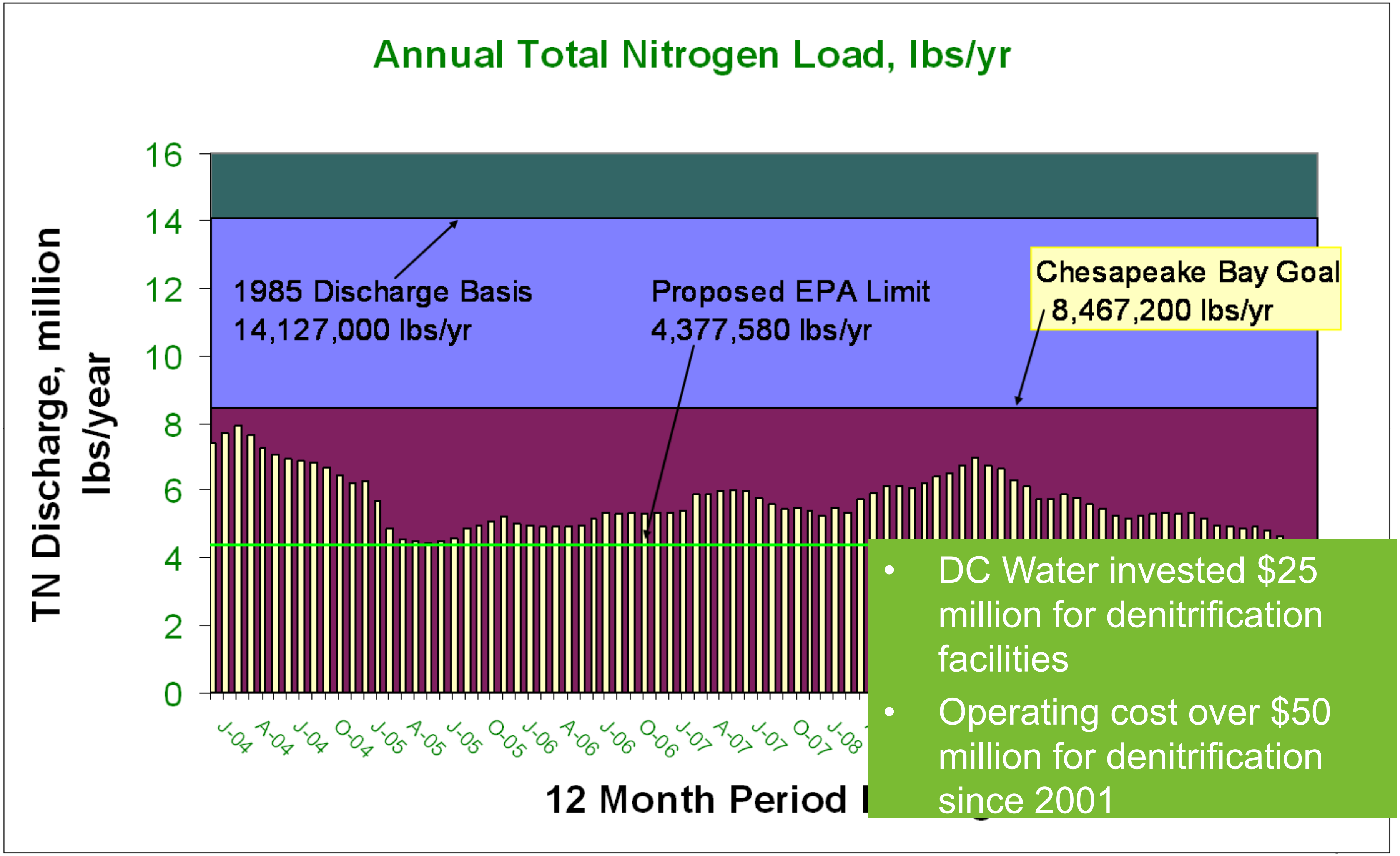
Wastewater loads based on measured discharges; the rest are based on an average-hydrology year.
Does not include loads from direct deposition to tidal waters, tidal shoreline erosion or the ocean.
Data and Methods: www.chesapeakebay.net/status_reducingpollution.aspx

History of Nitrogen Removal at Blue Plains

- 1999 – Full scale operation of denitrification in same basins as nitrification
  - Met Chesapeake Bay goal of 40% reduction by 2000 from 1985 levels
  - Goal is 8.4672 million lbs/yr or 7.5 mg/L at 370 mgd
- Chesapeake 2000 - Tributary Strategies to lower TN load to the Bay by 2010. EPA and states agree to include annual cap load in NPDES permits
- **2011 TMDL requirements for Blue Plains AWTP**
  - 4.689 million lb TN limit for 001 and 002
    - **3.87** mg/L at 370 mgd – average climatic year
    - **3.44** mg/l at 435 mgd – wet climatic year



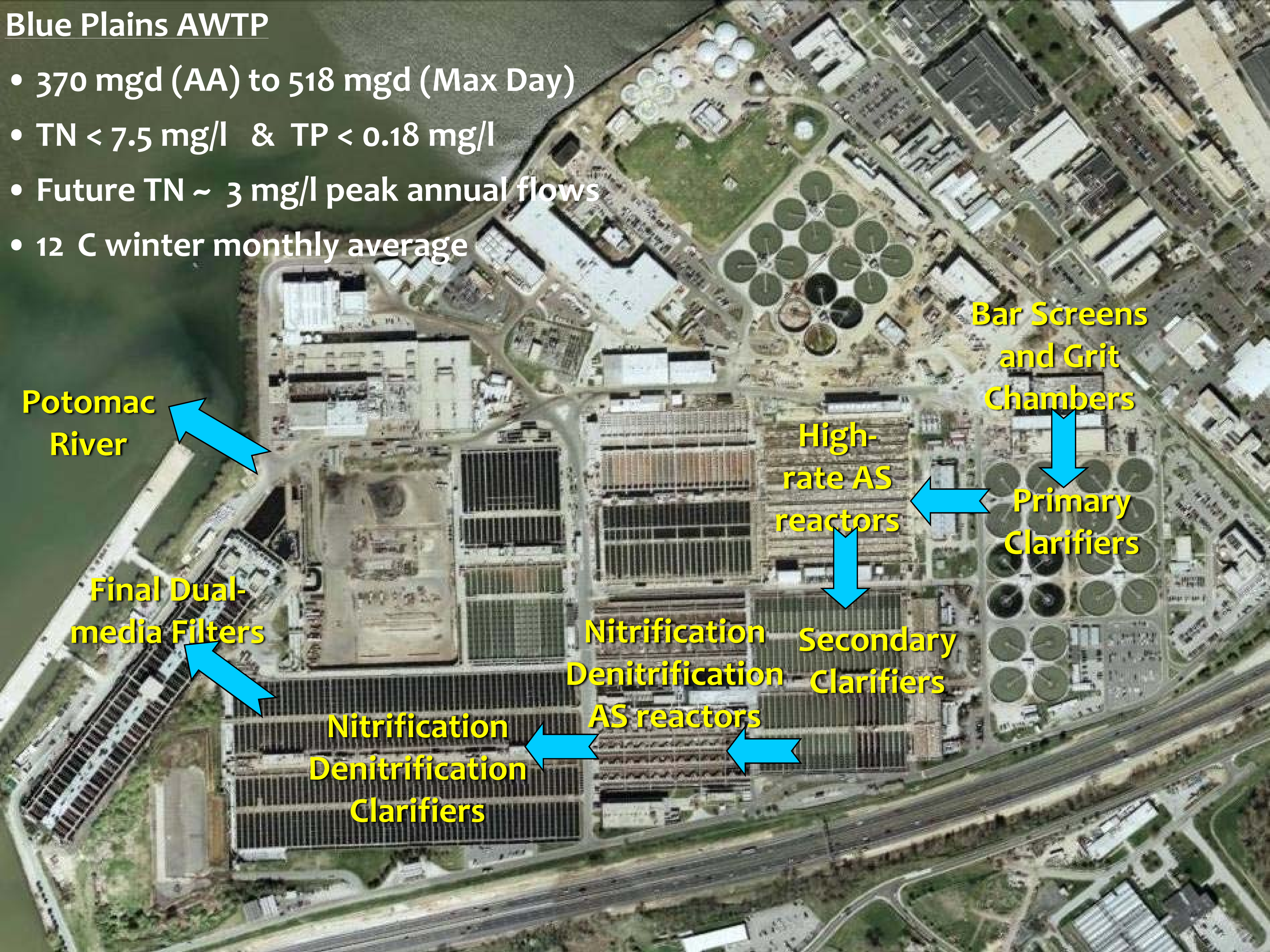
Exceeding Chesapeake Bay Nitrogen Reduction Goal



- DC Water invested $25 million for denitrification facilities
- Operating cost over $50 million for denitrification since 2001

Blue Plains AWTP

- 370 mgd (AA) to 518 mgd (Max Day)
- TN < 7.5 mg/l & TP < 0.18 mg/l
- Future TN ~ 3 mg/l peak annual flows
- 12 C winter monthly average



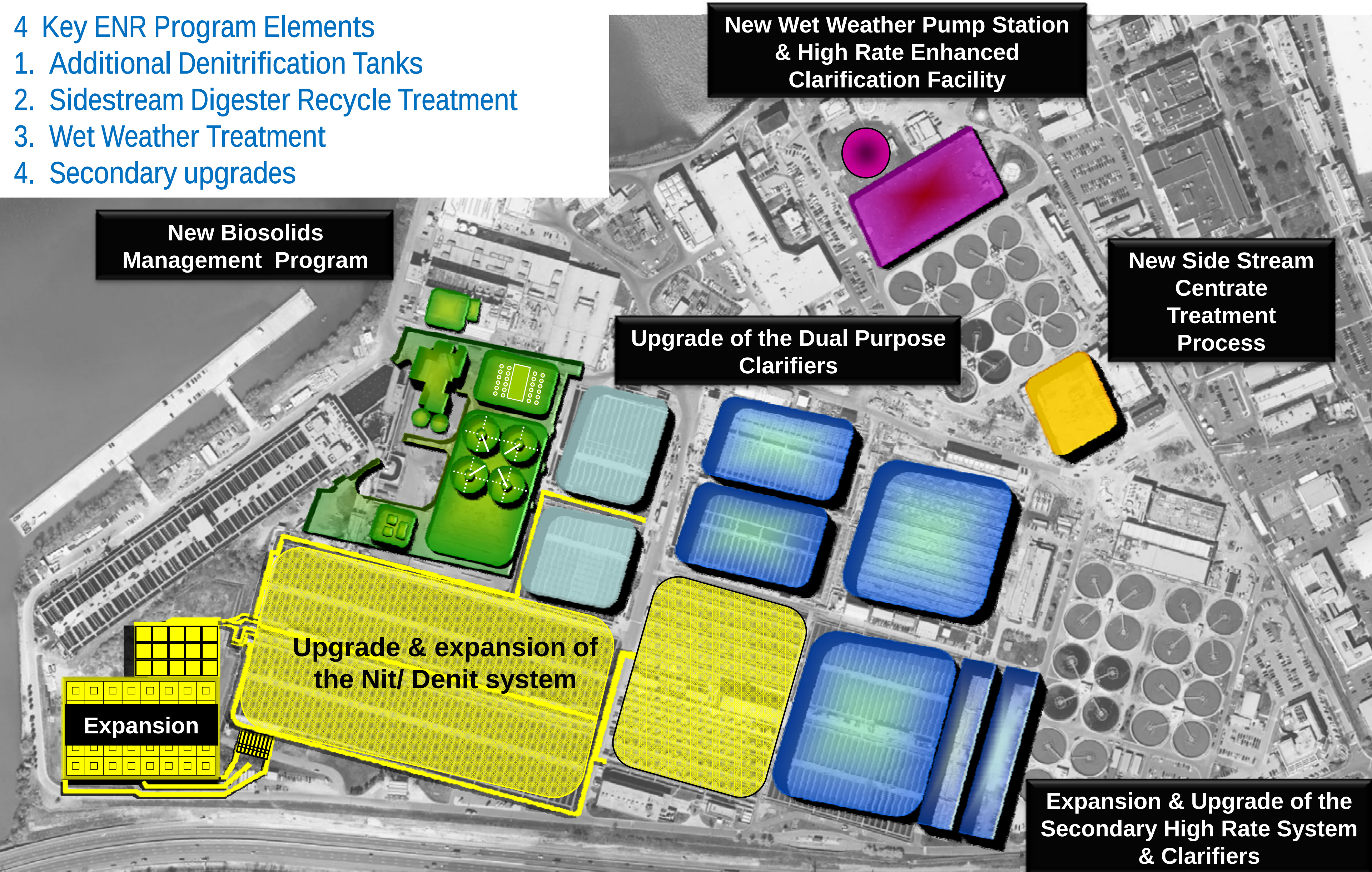
Discussion Topics

- Nitrogen Removal Program Elements
  - Integration of evolving science within the nitrogen program

Several Major Capital Programs Currently in Design

4 Key ENR Program Elements

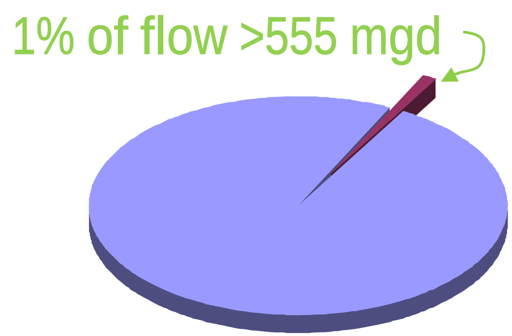
1. Additional Denitrification Tanks
2. Sidestream Digester Recycle Treatment
3. Wet Weather Treatment
4. Secondary upgrades



Wet Weather Management Plan

Challenges to Blue Plains in Meeting TN Requirements

- Storm flows impact entire plant operation
  - Primary tanks are overloaded
  - Secondary and BNR sedimentation basins overloaded
  - Operators intervene to protect bio-processes
    - Reduced biological treatment capacity
    - Return to normal mode takes up to 5 days
  - 1% of annual BNR flow volume (flows > 555 mgd) causes ENR problems

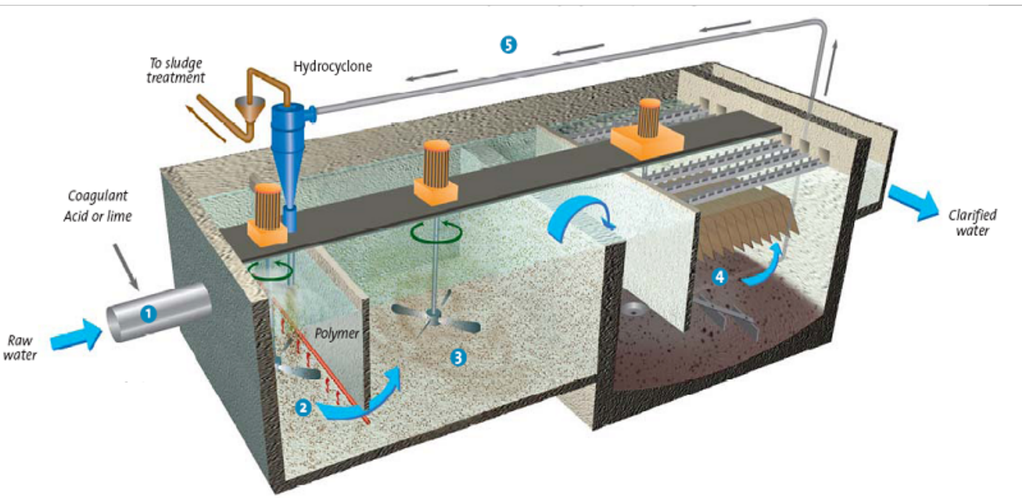


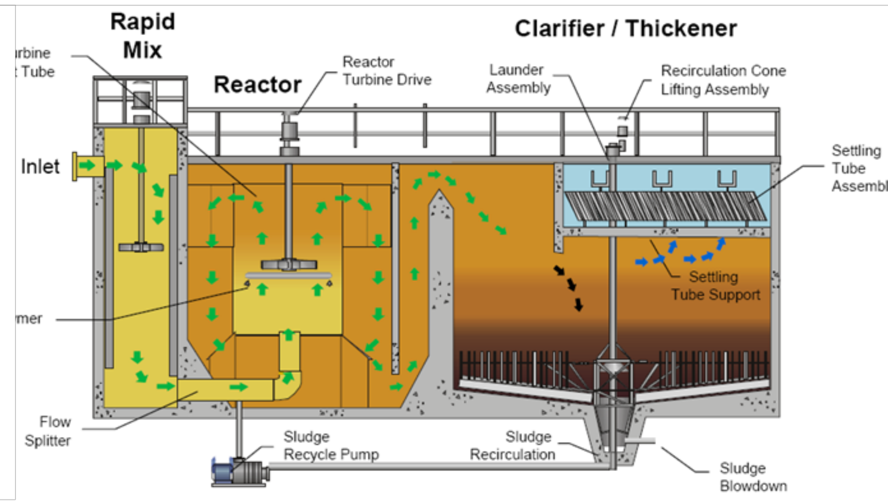
- Site constraints
  - Land area is limited
  - Most of land is built-out
  - Limited space for new process trains

- **Must continue permit compliance while construction is underway**

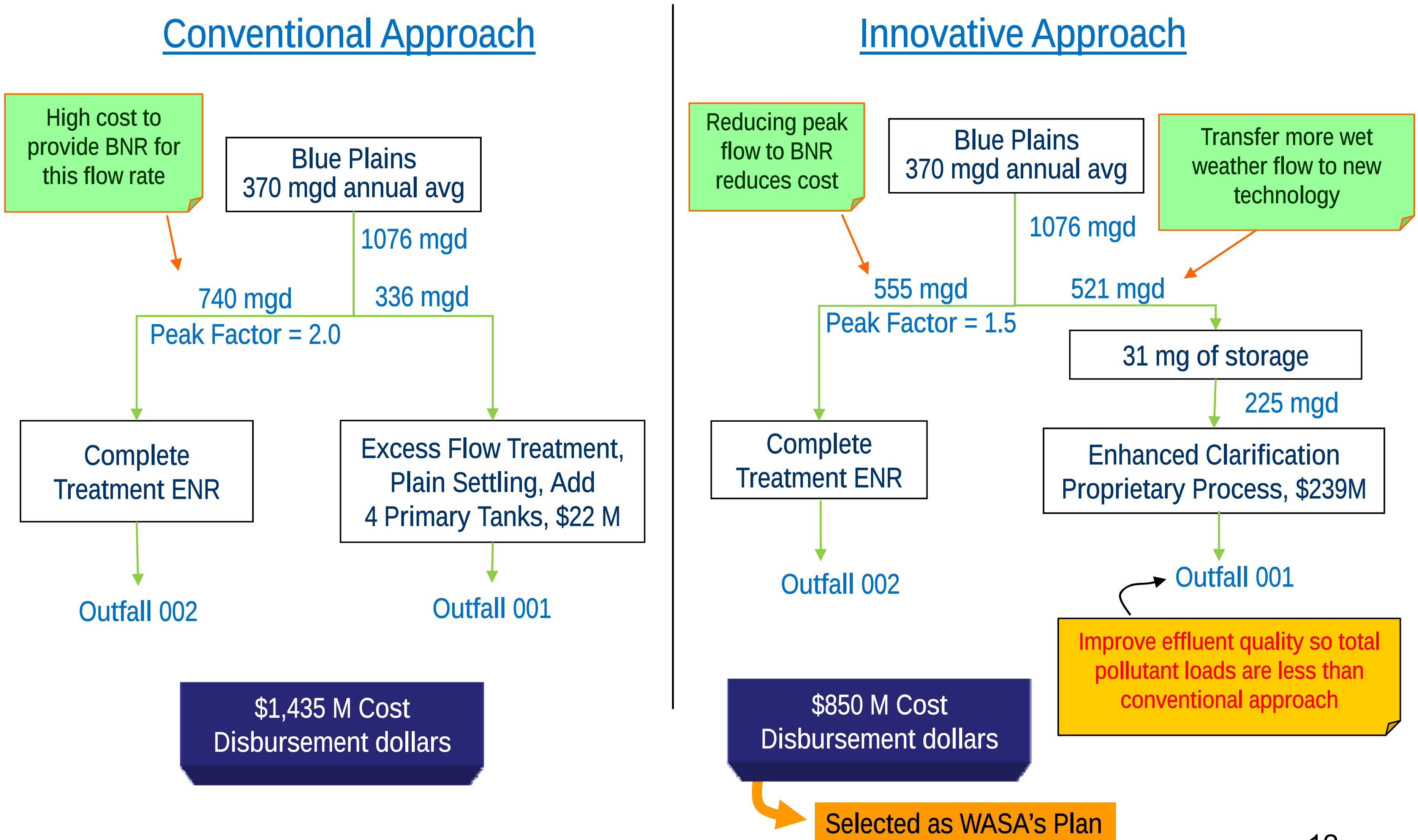
Coordinated & Comprehensive ENR / Wet Weather Planning

- By Coordinating the Nitrogen Removal and Wet Weather Treatment planning, WASA could:
  - Provide better water quality performance than original CSO plan (LTCP), as required by EPA
  - Increase reliability of both TN & CSO controls
  - Achieve TN and CSO reductions earlier
  - Less impact on rate payers than conventional approach





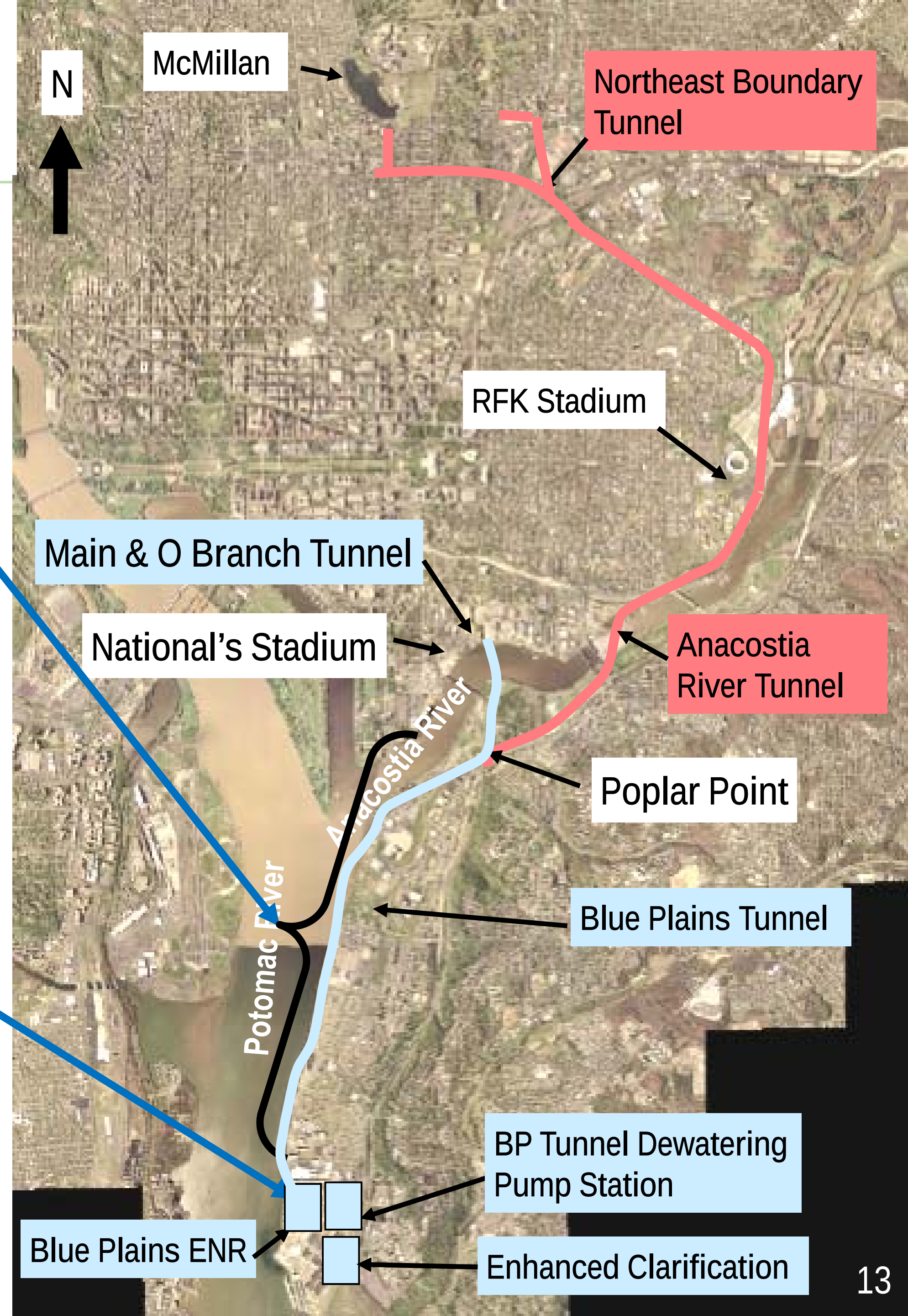
Total Nitrogen Removal: Nitrogen Removal Options



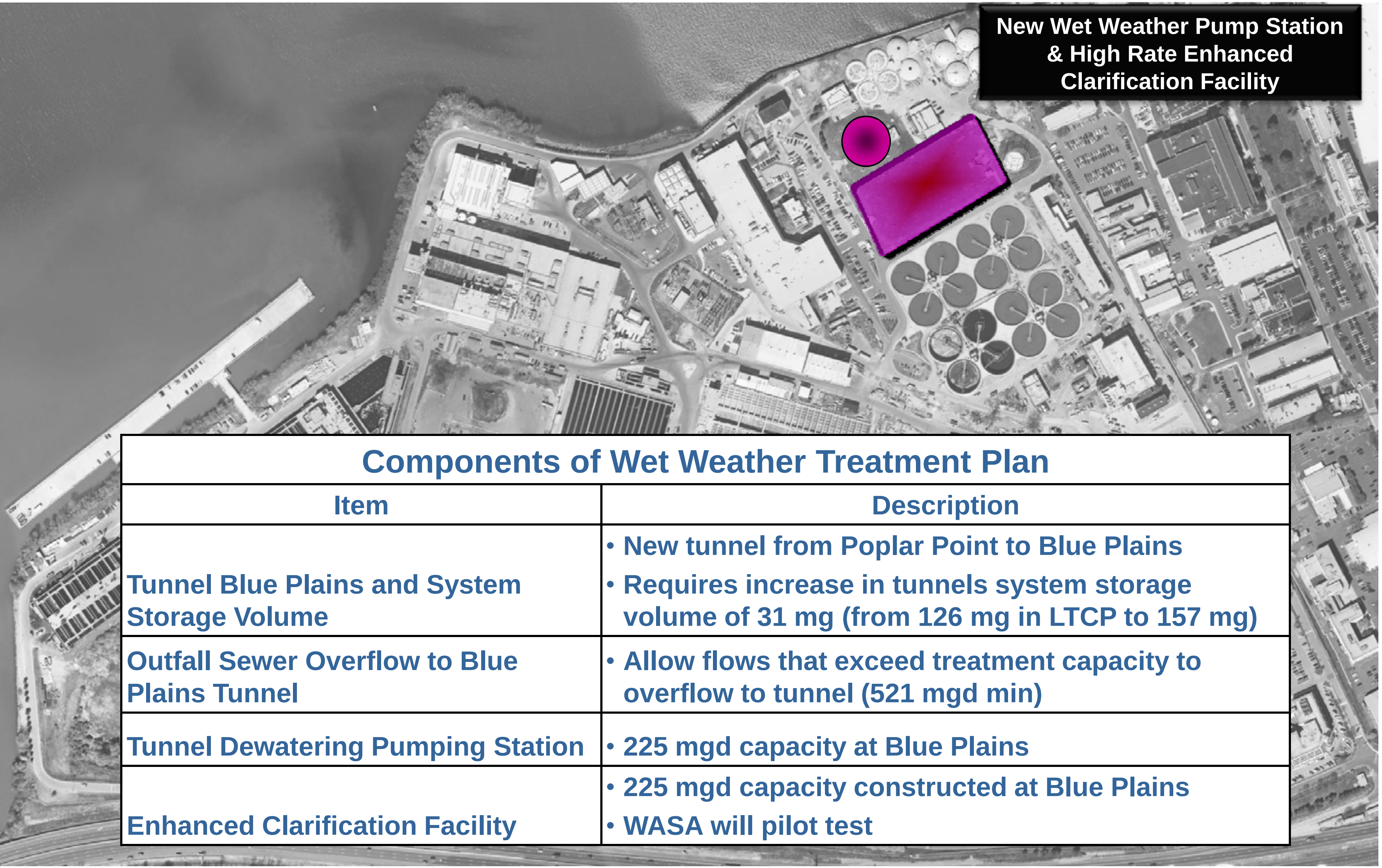
Wet Weather Plan: Submitted 2007

Extend tunnel by 3.5 miles:
- 23 feet diameter
- Added 31 million gallons to 126 million gallons of LTCP tunnels for total of 157 million gallons
- Increases storage capacity by about 25%

Construct at Blue Plains:
- Nitrogen removal facilities
- Enhanced Clarification Facility (ECF)
- Tunnel Dewatering pumping station



Wet Weather Management Plan



Components of Wet Weather Treatment Plan	
Item	**Description**
Tunnel Blue Plains and System Storage Volume	• New tunnel from Poplar Point to Blue Plains • Requires increase in tunnels system storage volume of 31 mg (from 126 mg in LTCP to 157 mg)
Outfall Sewer Overflow to Blue Plains Tunnel	• Allow flows that exceed treatment capacity to overflow to tunnel (521 mgd min)
Tunnel Dewatering Pumping Station	• 225 mgd capacity at Blue Plains
Enhanced Clarification Facility	• 225 mgd capacity constructed at Blue Plains • WASA will pilot test

Meeting the New Chesapeake Bay Nitrogen Load Reduction Challenge

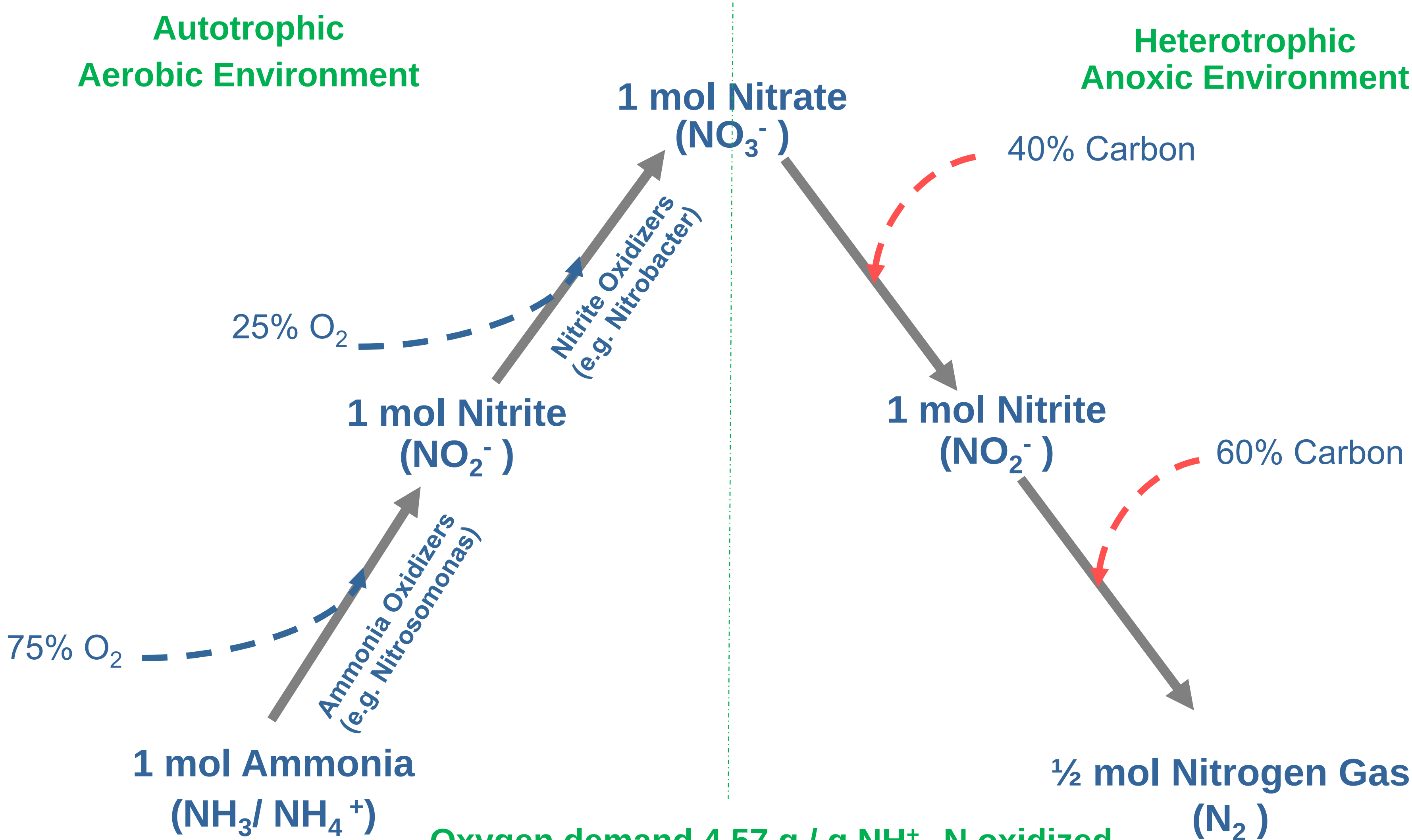
No	Item	Average Climatic Year	Wet Climatic Year (2003)	Notes
1	Rainfall (in)	40.97	59.3	
2	Base 002 Discharge in avg year (mgd)	370	370	
3	Est. 002 increment for wet weather (mgd)	0	65	From experience in 2003
4	Total 002 Flow (mgd)	370	435	(2) + (3)
5	001 Discharge (mgd)	7.3	17	From model
6	Bubble Permit (EPA Approach)			001 + 002 must meet permit
7	TN Permit Limit (lbs/yr)	4,689,000		Per permit
8	001 Effluent TN Allowance (lbs/yr)	311,420		Est. ECF performance
9	TN left for 002 (lbs/yr)	4,377,580		(7) – (8)
10	Effluent TN required at 002 (mg/L)	3.87	3.44	(10)/(4) x conversions factors

New Effluent TN Limit is very challenging especially in a wet year when the plant is most vulnerable to process upsets

Discussion Topics

- Nitrogen Removal Program Elements
  - Integration of evolving science within the nitrogen program

Fundamentals of Nitrification - Denitrification



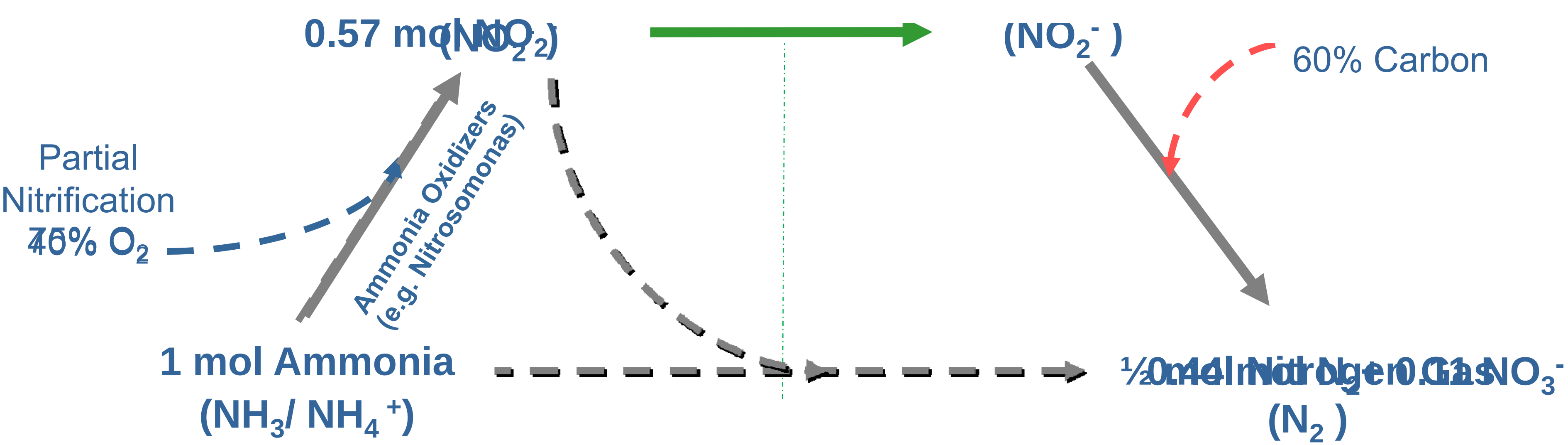
Oxygen demand 4.57 g / g NH^+_4-N oxidized
Carbon demand 4.77 g COD / g NO^-_3-N reduced

Fundamentals of Deammonification

Autotrophic
Aerobic Environment

ANAMMOX
Heterotrophic
Anoxic Environment
Anaerobic Ammonium Oxidation
Autotrophic Nitrite Reduction
(New Planctomycete, Strous et. al. 1999)

$$NH_4^+ + 1.32\ NO_2^- + 0.066\ HCO_3^- + 0.13\ H^+ \rightarrow 0.26\ NO_3^- + 1.02 N_2 + 0.066\ CH_2O_{0.5}N_{0.15} + 2.03\ H_2O$$



Oxygen demand 1.9 g / g NH^+_4-N oxidized

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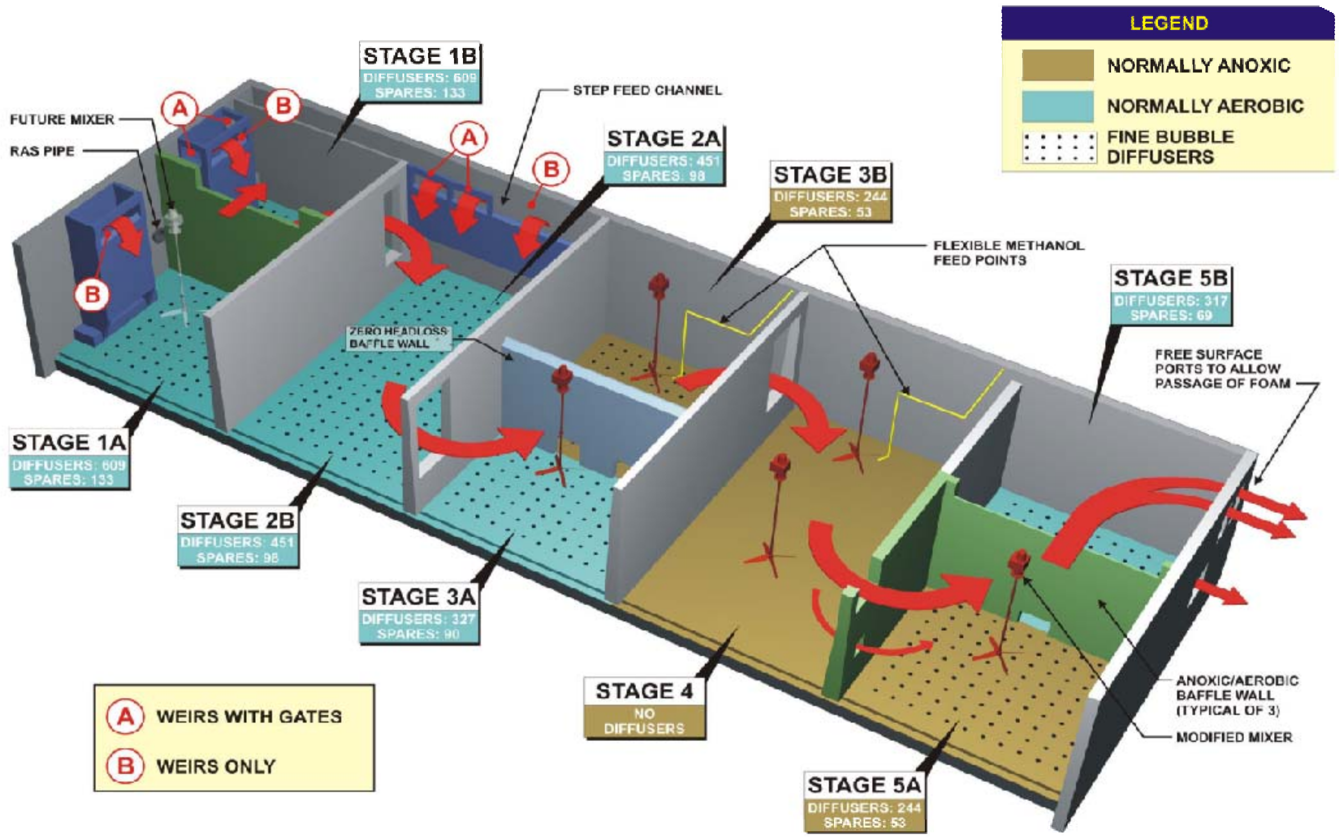
ENR Upgrade and Expansion – Research & Planning

The Nitrification/Denitrification Process

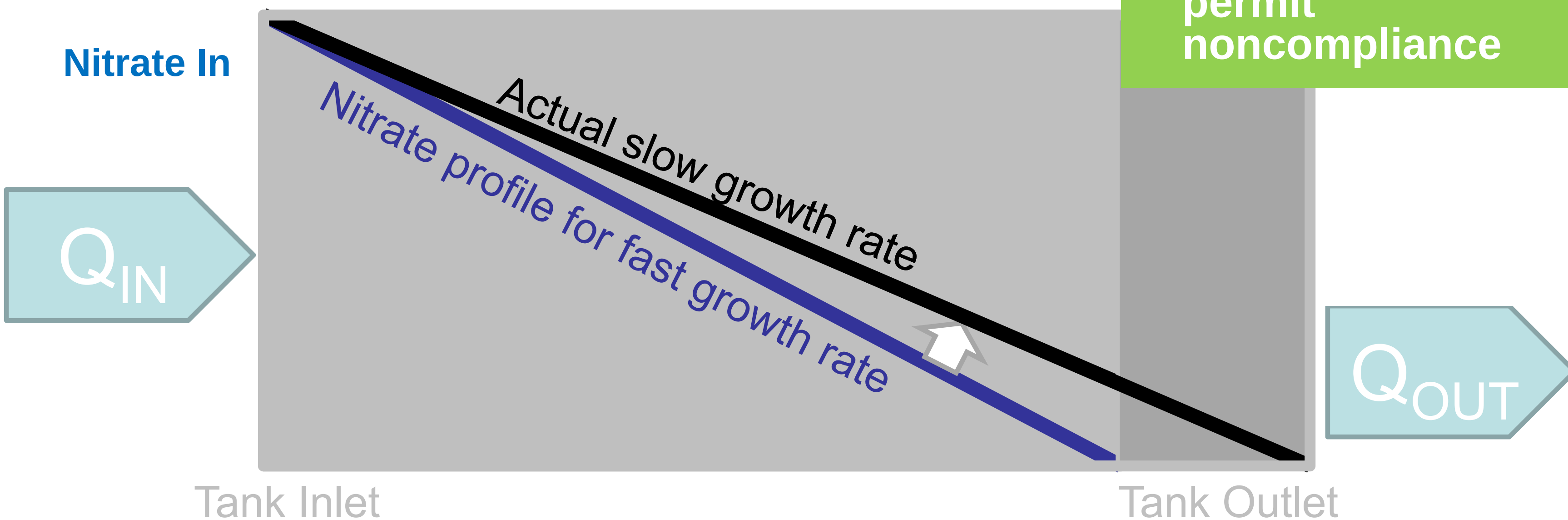
- Only 370 mgd facility in the world removing nitrogen and phosphorus to low levels
- Deep tank (33 ft) nit/denit system
- Twelve reactors were designed and optimized for equal flow split.



Defined Denitrification Kinetics

- Rate of Nitrogen removal defined by bacterial growth rates
- Industry standard denitrification rates assumed to be very fast
- Only small tank volumes required
- Blue Plains observed much slower rates

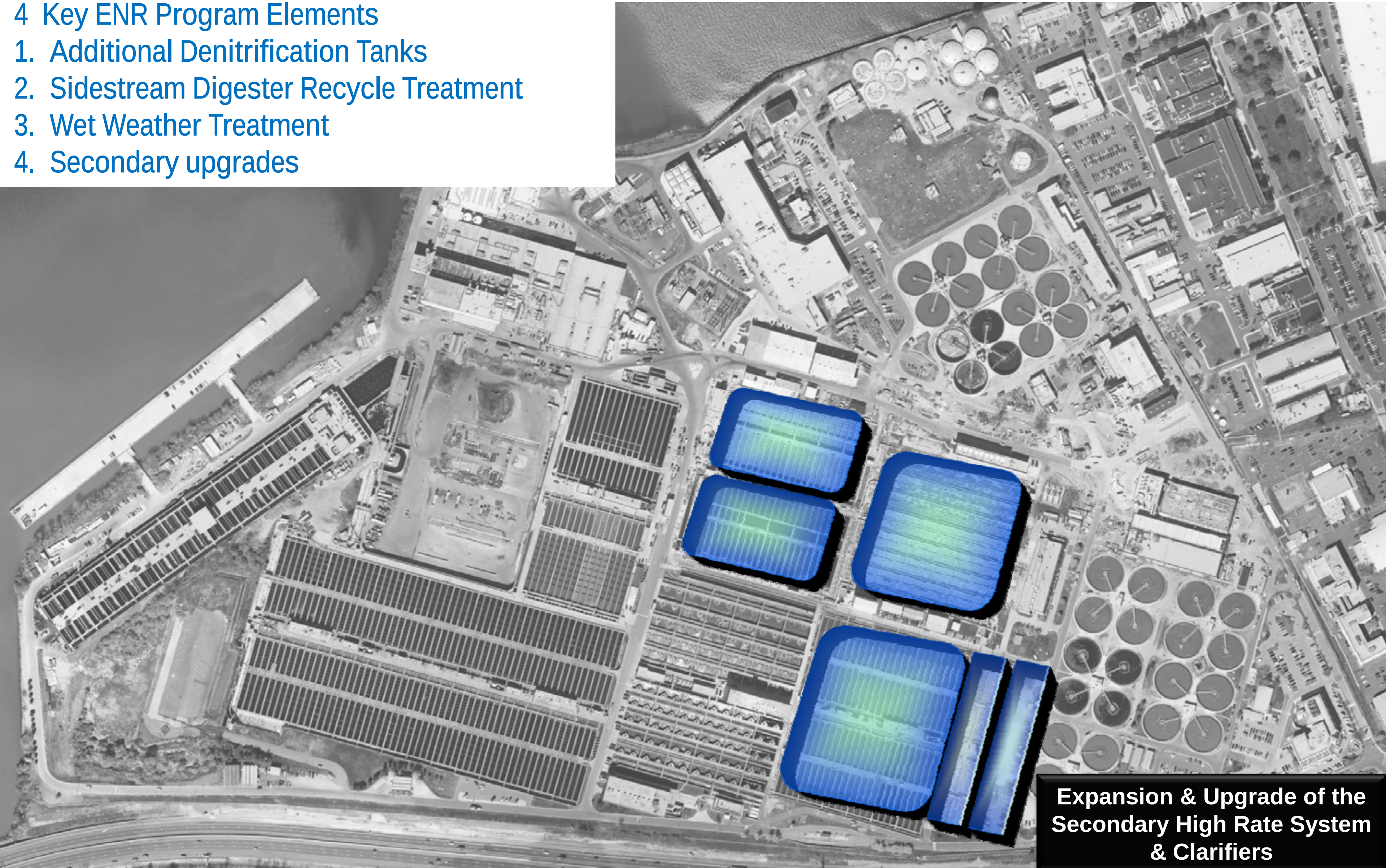
✓ **Required tank expansion, but reduced risk of permit noncompliance**



Secondary Upgrade – Research & Planning

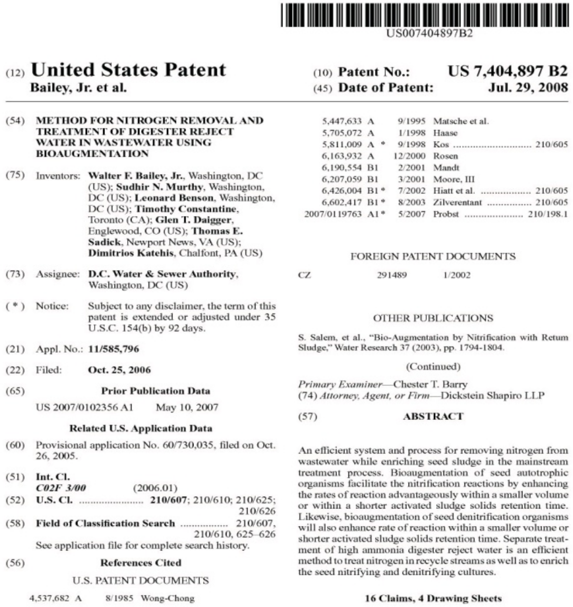
4 Key ENR Program Elements

1. Additional Denitrification Tanks
2. Sidestream Digester Recycle Treatment
3. Wet Weather Treatment
4. Secondary upgrades



ENR Research & Planning Program
Bioaugmentation Patent

- Bioaugmentation
  - Maximizes use of free wastewater carbon
  - 1/3 less methanol
  - Reduces size of new tanks
- Process is currently in operation



US007404897B2

(12) **United States Patent**
Bailey, Jr. et al.

(10) **Patent No.: US 7,404,897 B2**
(45) **Date of Patent: Jul. 29, 2008**

(54) **METHOD FOR NITROGEN REMOVAL AND TREATMENT OF DIGESTER REJECT WATER IN WASTEWATER USING BIOAUGMENTATION**

(75) Inventors: **Walter F. Bailey, Jr.**, Washington, DC (US); **Sudhir N. Murthy**, Washington, DC (US); **Leonard Benson**, Washington, DC (US); **Timothy Constantine**, Toronto (CA); **Glen T. Daigger**, Englewood, CO (US); **Thomas E. Sadick**, Newport News, VA (US); **Dimitrios Katehis**, Chalfont, PA (US)

(73) Assignee: **D.C. Water & Sewer Authority**, Washington, DC (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 92 days.

(21) Appl. No.: **11/585,796**

(22) Filed: **Oct. 25, 2006**

(65) **Prior Publication Data**

US 2007/0102356 A1 May 10, 2007

Related U.S. Application Data

(60) Provisional application No. 60/730,035, filed on Oct. 26, 2005.

(51) **Int. Cl.**
C02F 3/00 (2006.01)

(52) **U.S. Cl.** **210/607**; 210/610; 210/625; 210/626

(58) **Field of Classification Search** 210/607, 210/610, 625–626
See application file for complete search history.

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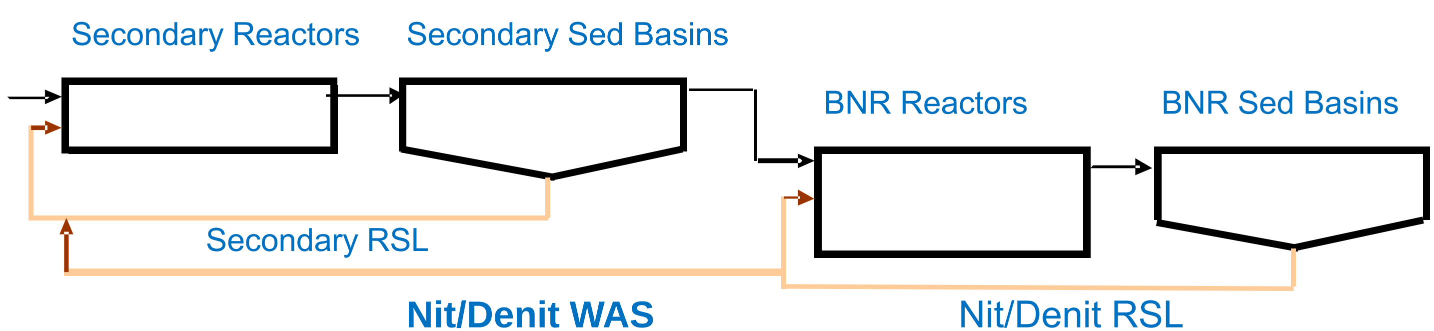
(Continued)

Primary Examiner—Chester T. Barry
(74) *Attorney, Agent, or Firm*—Dickstein Shapiro LLP

(57) **ABSTRACT**

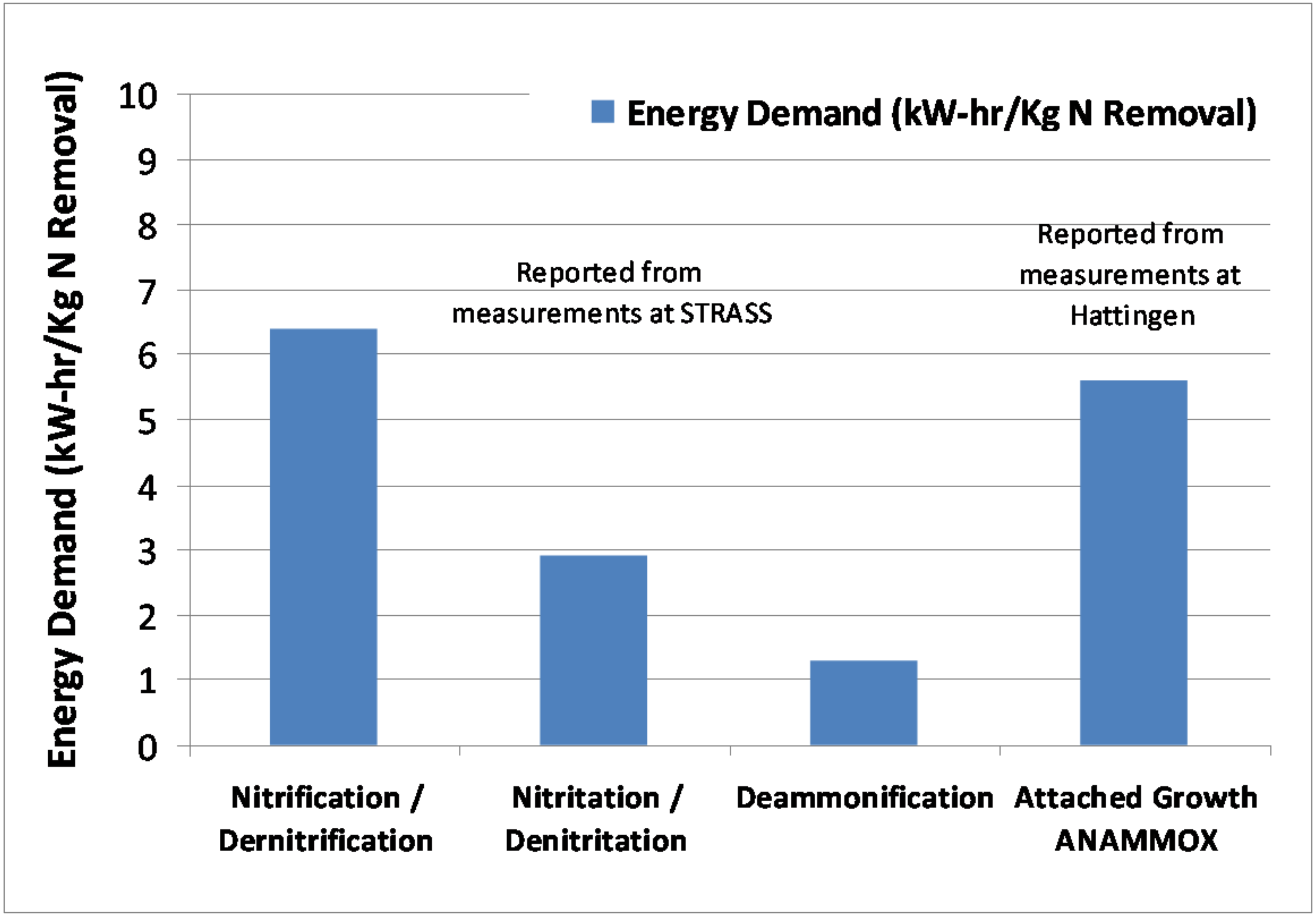
An efficient system and process for removing nitrogen from wastewater while enriching seed sludge in the mainstream treatment process. Bioaugmentation of seed autotrophic organisms facilitate the nitrification reactions by enhancing the rates of reaction advantageously within a smaller volume or within a shorter activated sludge solids retention time. Likewise, bioaugmentation of seed denitrification organisms will also enhance rate of reaction within a smaller volume or shorter activated sludge solids retention time. Separate treatment of high ammonia digester reject water is an efficient method to treat nitrogen in recycle streams as well as to enrich the seed nitrifying and denitrifying cultures.

16 Claims, 4 Drawing Sheets



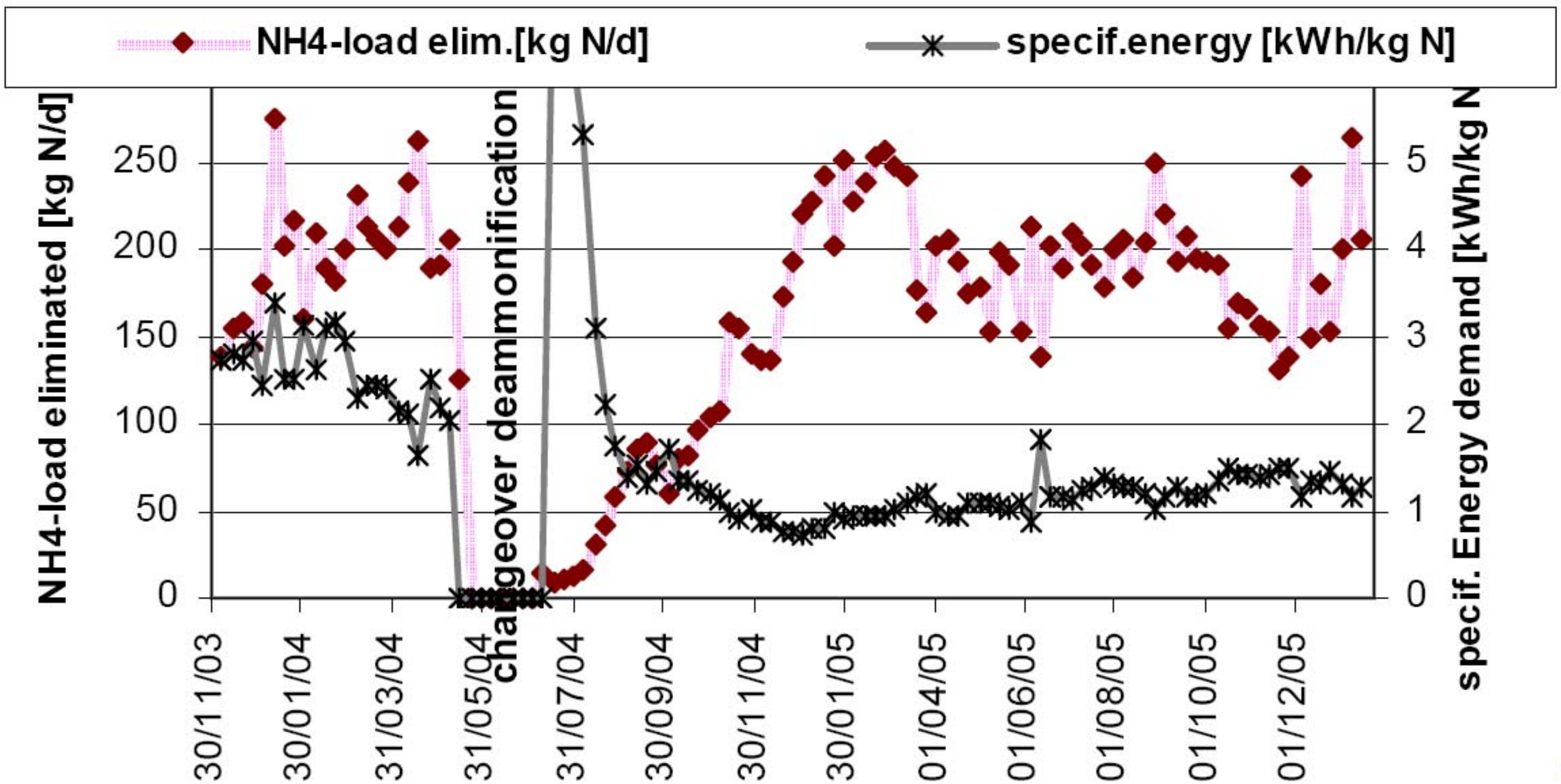
Side Stream Centrate Research & Planning

Energy Demand



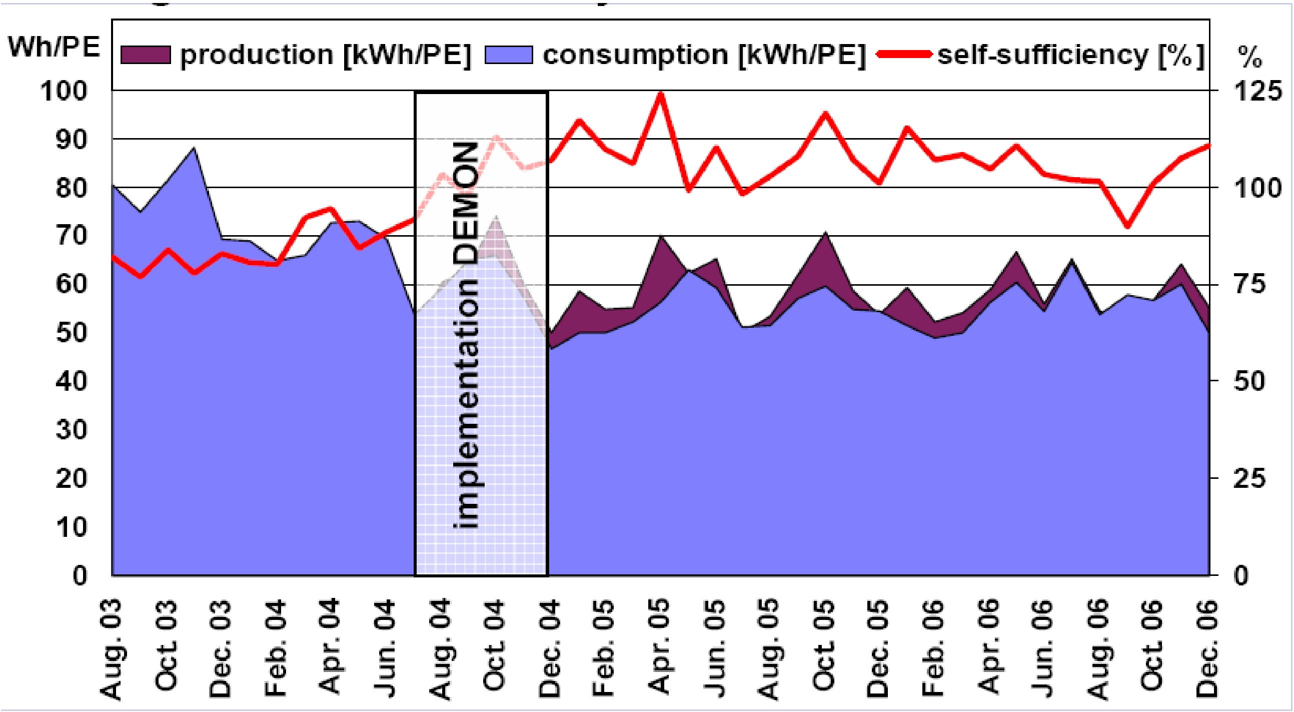
DEMON® Sequencing Batch Reactor – Energy Demand

- 84% TN Removal at design loading rate of 0.7 kg/ m^3 / day
- 1.3 kW hr / kg N removed
- However more sensitive to NO_2-N accumulation < 5 mg/l



DEMON® Sequencing Batch Reactor

- Plant undertook many energy efficiency activities
- With the introduction of DEMON it became a net energy producer



Bernhard Wett, March 2007

Suspended Growth Deammonification Experience: DEMON® Process

Suspended growth SBR systems:

- Strass, Austria
- Glarnerland, Switzerland
- Thun, Switzerland
- Plettenberg, Germany
- Heidelberg, Germany
- Apeldoorn, Netherlands
- Zalaegerszeg WWTP, Hungary

Several under construction;

- Croatia
- Austria
- Germany

- By 2012 project > 20 Demon facilities on-line


Strass (A)


Apeldoorn (NL)


Heidelberg (D)

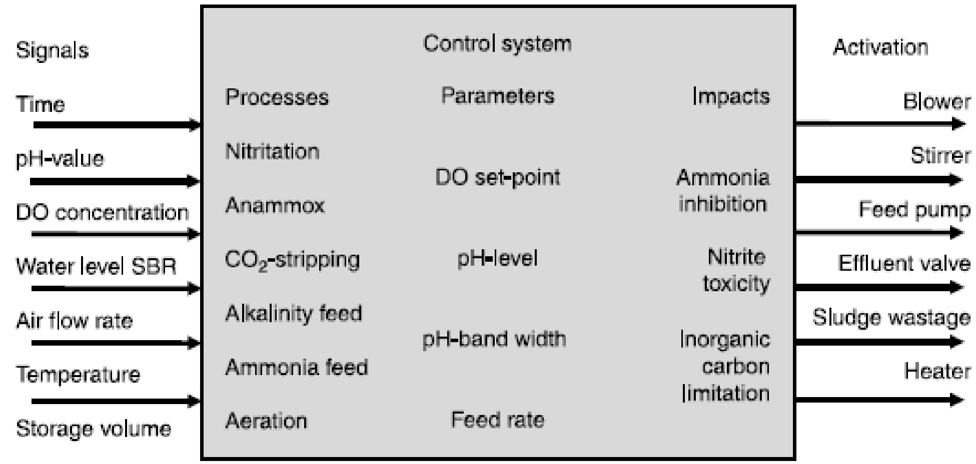

Thun (CH)

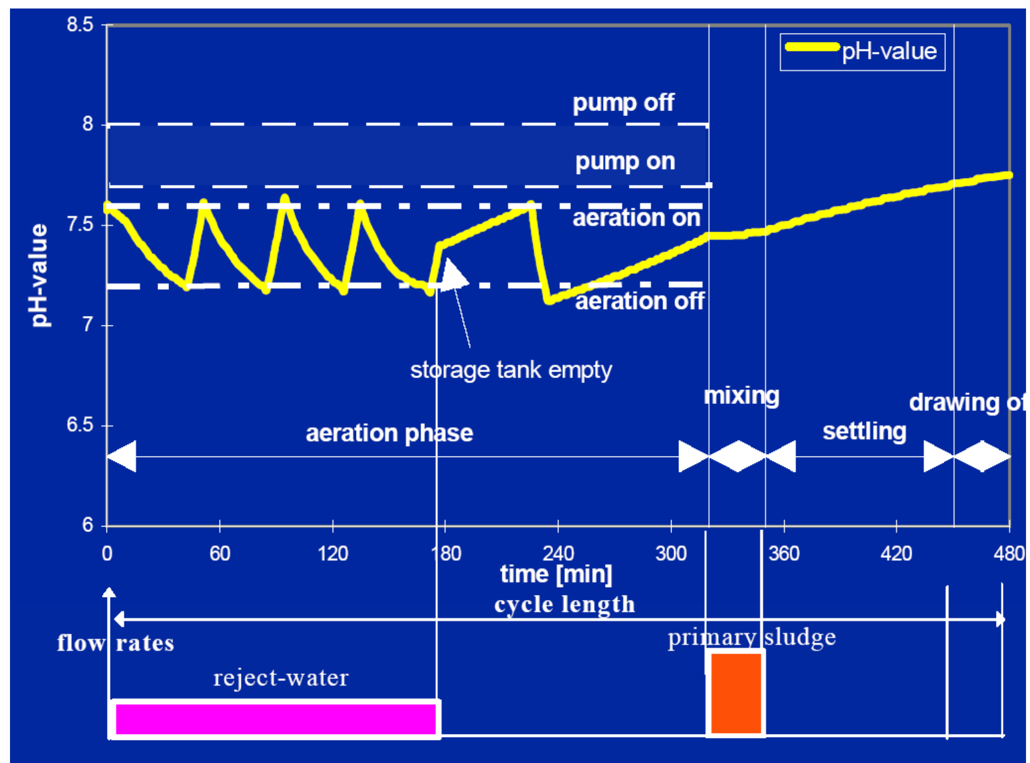
Process Control

Need Long Solids Residence Time

Need to control nitrite toxicity

Need to inhibit competing NOB





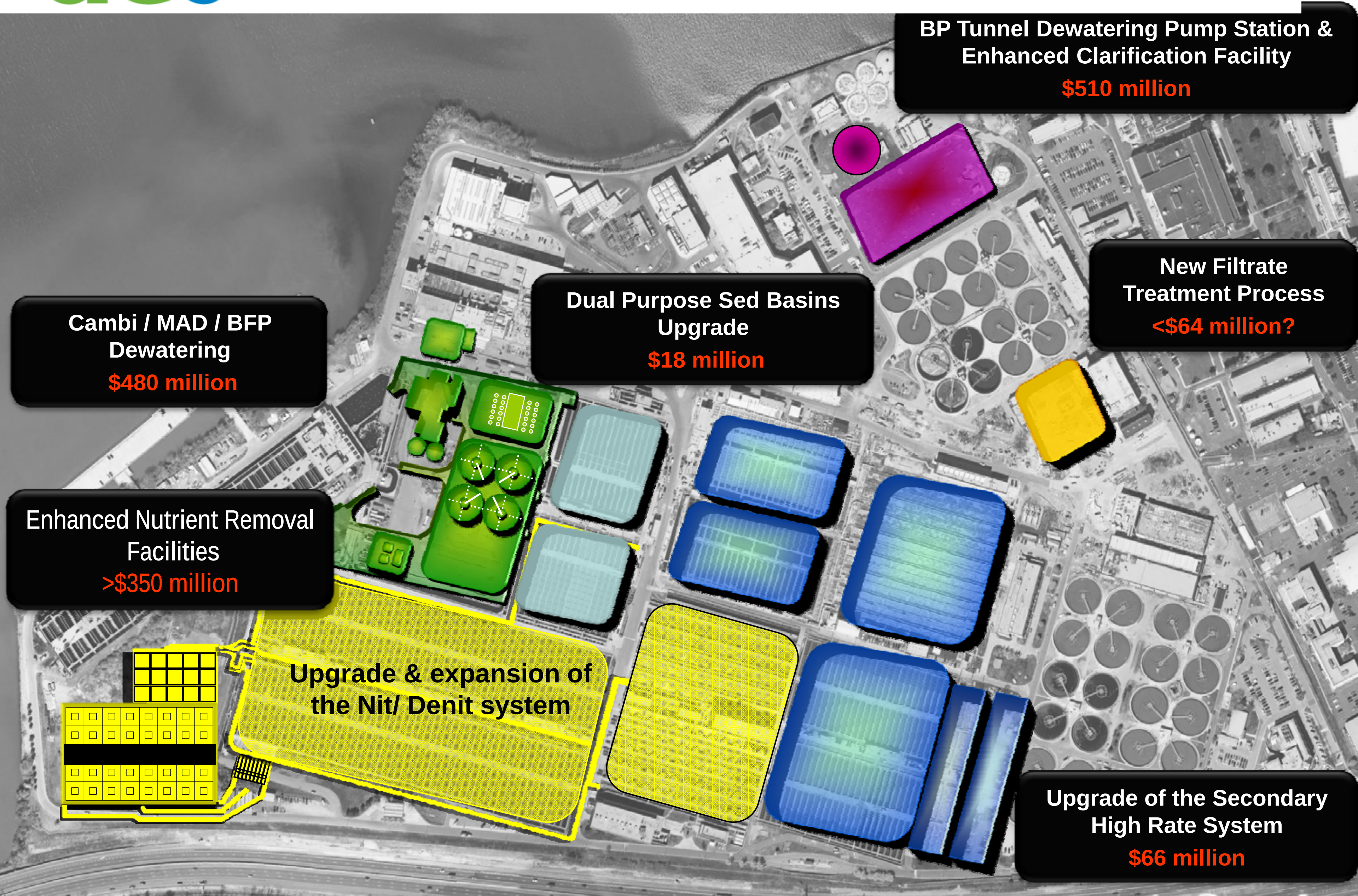
Bernhard Wett, Water Science & Technology Vol 56 No 7 pp 81–88 Q IWA Publishing 2007

General Overview of DEMON the Site Visits & Design Criteria

Facility	Load (lbs/day)	Tank Vol. (MG)	Design Loading Rate (Kg N / m^3 / d	Performance % TN Removal % NH_3-N Removal
Apeldoorn	4,180	0.77	0.66	> 80% TN > 90% NH_3-N
Thun	880	0.16	0.67	> 90% TN > 90% NH_3-N
Glarnerland	550	0.1	0.69	> 90% TN (80 mg/l) > 90% NH_3-N (40mg/l)
Strass	1320	0.13	1.2	> 80% TN > 90% NH_3-N
Blue Plains	20,000	5.8	0.58	>80% NH_3-N
Alexandria	2831	0.8	0.42	> 90% TN

- Typical Volumetric Design Criteria = 0.7 Kg / m^3 / day
- Typically > 80% TN
- Effluent NO_3-N < 10% or less if biodegradable COD available

Ongoing



BP Tunnel Dewatering Pump Station & Enhanced Clarification Facility
$510 million
Cambi / MAD / BFP Dewatering
$480 million
Dual Purpose Sed Basins Upgrade
$18 million
New Filtrate Treatment Process
<$64 million?
Enhanced Nutrient Removal Facilities
>$350 million
Upgrade & expansion of the Nit/ Denit system
Upgrade of the Secondary High Rate System
$66 million

New Frontiers for Nutrient Removal

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What's Next? – Research & Planning

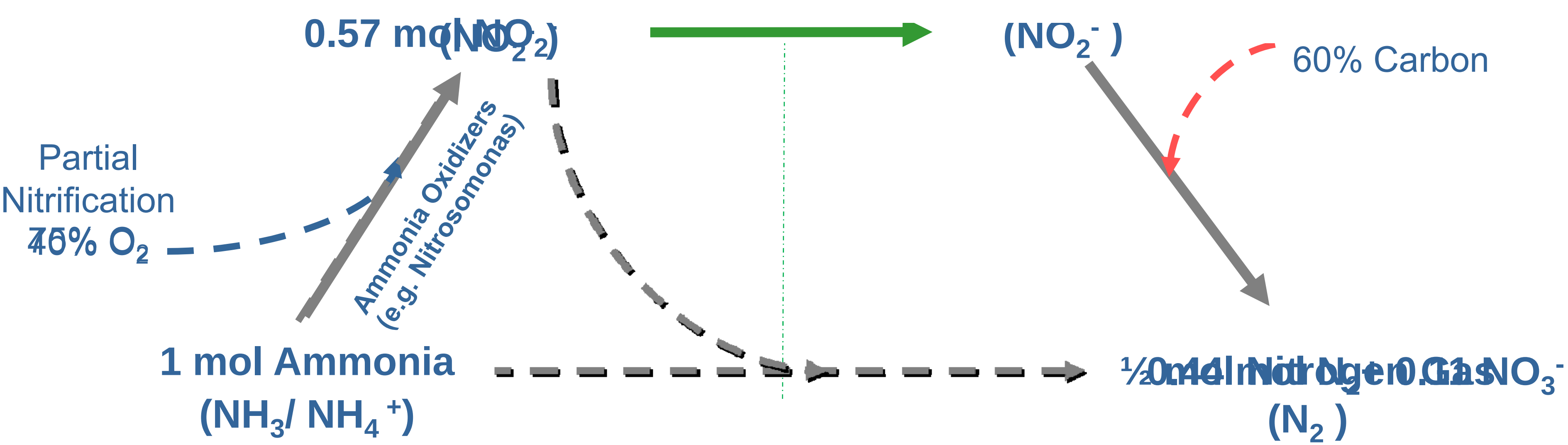
Fundamentals of Deammonification

Autotrophic
Aerobic Environment

ANAMMOX
Anaerobic Ammonium Oxidation
Autotrophic Nitrite Reduction
(New Planctomycete, Strous et. al. 1999)

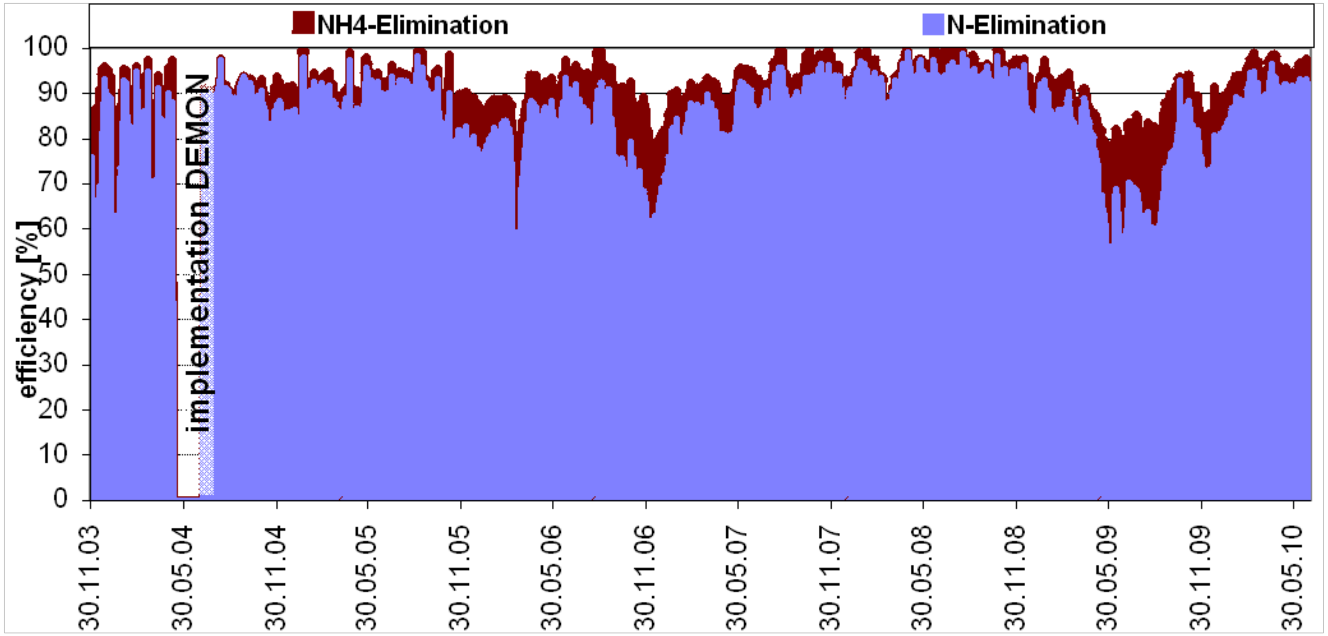
Heterotrophic
Anoxic Environment

$$NH_4^+ + 1.32\ NO_2^- + 0.066\ HCO_3^- + 0.13\ H^+ \rightarrow 0.26\ NO_3^- + 1.02 N_2 + 0.066\ CH_2O_{0.5}N_{0.15} + 2.03\ H_2O$$



Oxygen demand 1.9 g / g NH^+_4-N oxidized

Can we apply Deammonification to Mainstream TN removal?

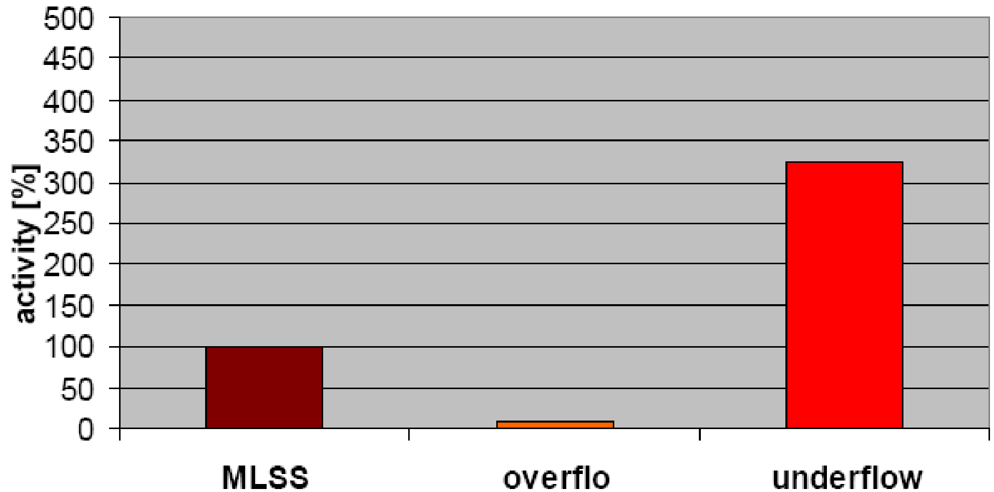


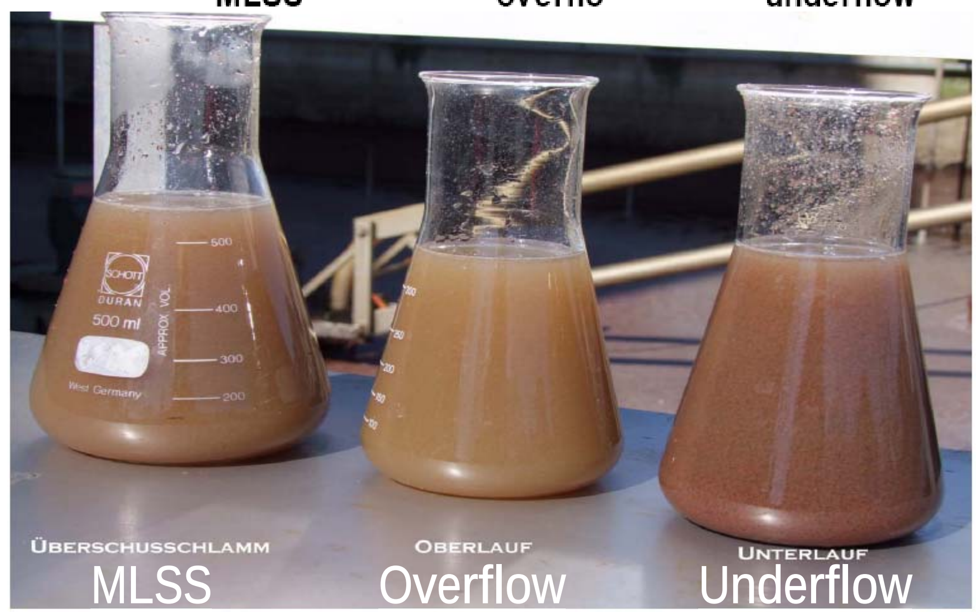
Strass, Austria
Source: Bernhard Wett

Sidestream characteristics – high temperature, higher NH_4^+ and N/C ratio and adequate SRT

What about mainstream??
– lower temperature, low N/C ratio and limited SRT

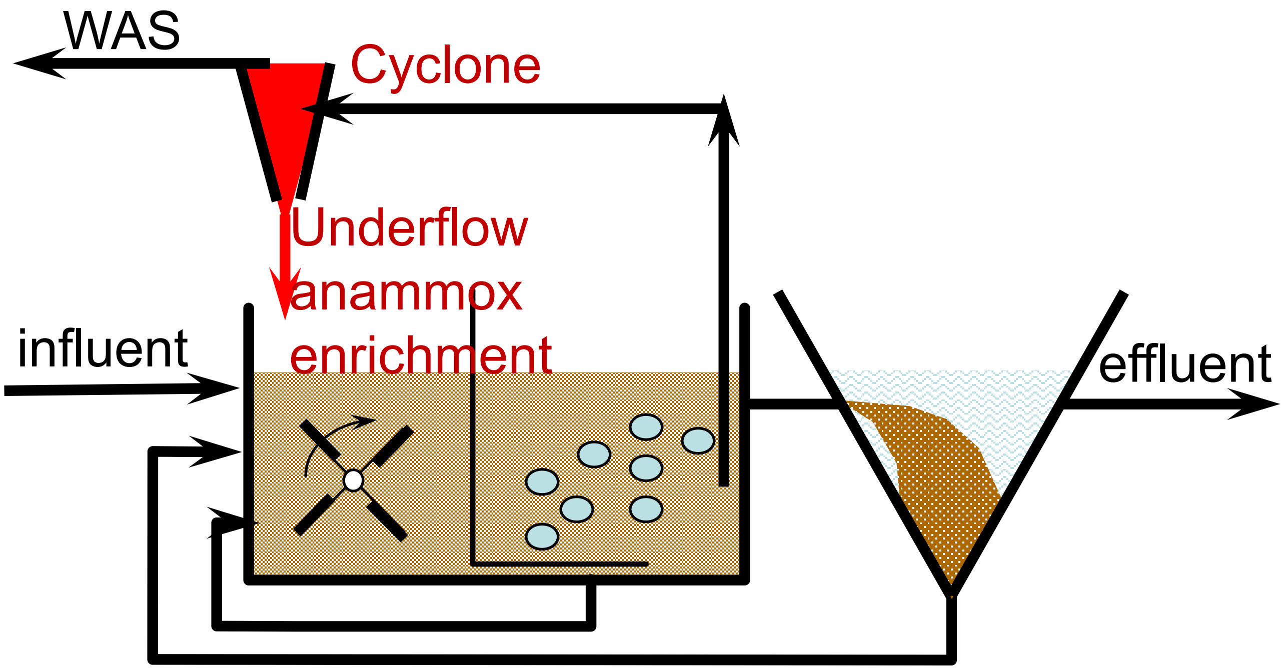
SRT Control –
Cyclone for selecting for DEMON® Granules





water is life

Selector



Source: Bernhard Wett, ARA Consult

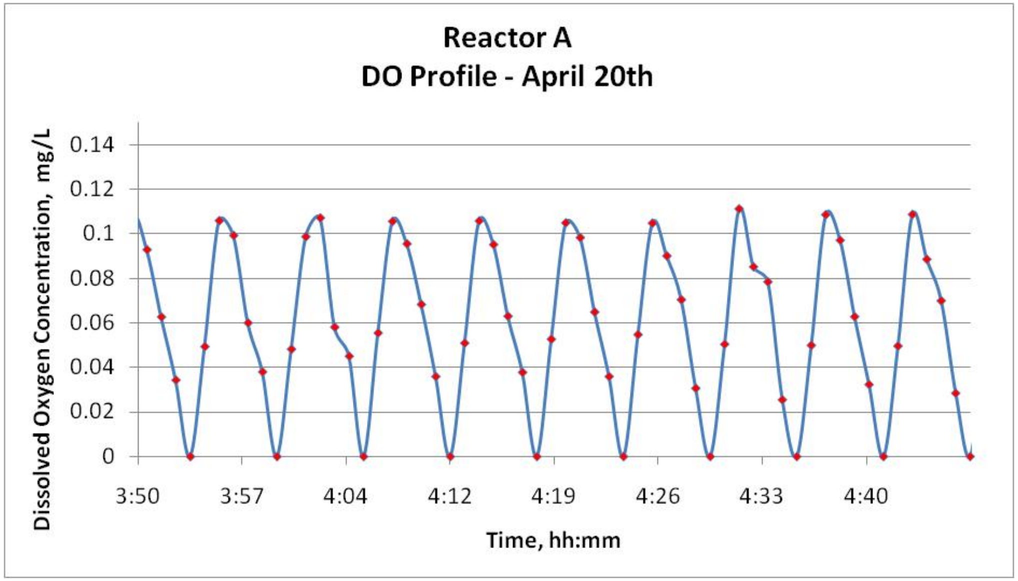
- **WERF Project: INFR6R11**
- **Full-Plant Deammonification For Energy-Positive Nitrogen Removal**
  - **Principal Investigators: Maureen O'Shaughnessy and Bernhard Wett**
  - **Several utilities jointly investigating in Europe & USA**
  - **Full-scale, pilot-scale, bench-scale**
  - **Kartik Chandran, Columbia University**

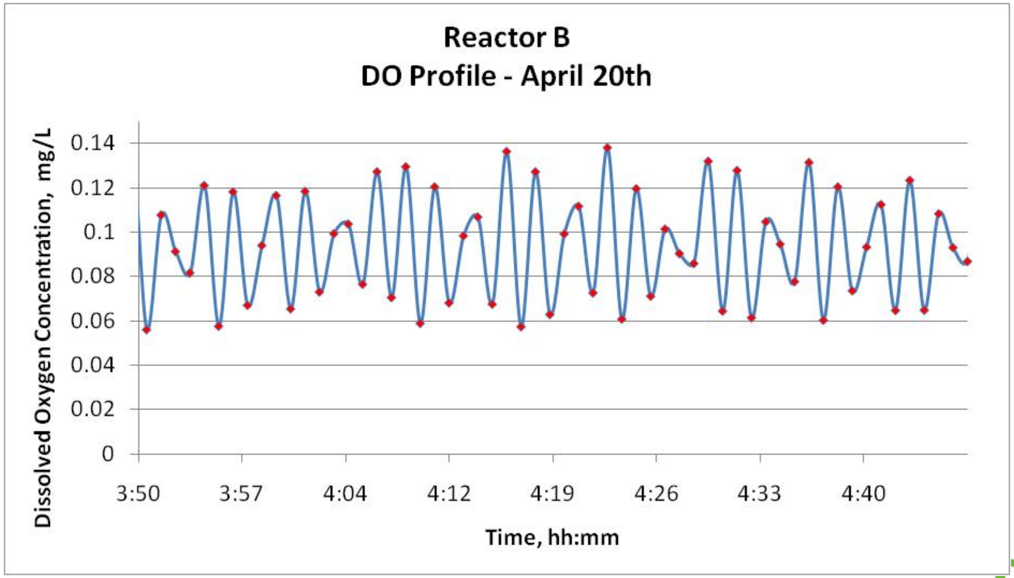
Can we apply Deammonification to Mainstream TN removal?

- International Collaboration
  - Maureen O’Shaughnessy & Bernhard Wett / WERF & EPA
  - **Blue Plains** bench scale SBRs started January 2011
  - **HRSD Chez-Liz** pilot starting Summer 2011
  - **Strass WWTP**, Austria started April 2011
  - **Glarnerland WWTP**, Austria started to look at this 2010
  - Initial concept:
    - Operate low C/N ratio
    - Optimize ammonia oxidizing autotrophs
    - Bioaugment and retain anammox
    - Out-compete nitrite oxidizing bacteria

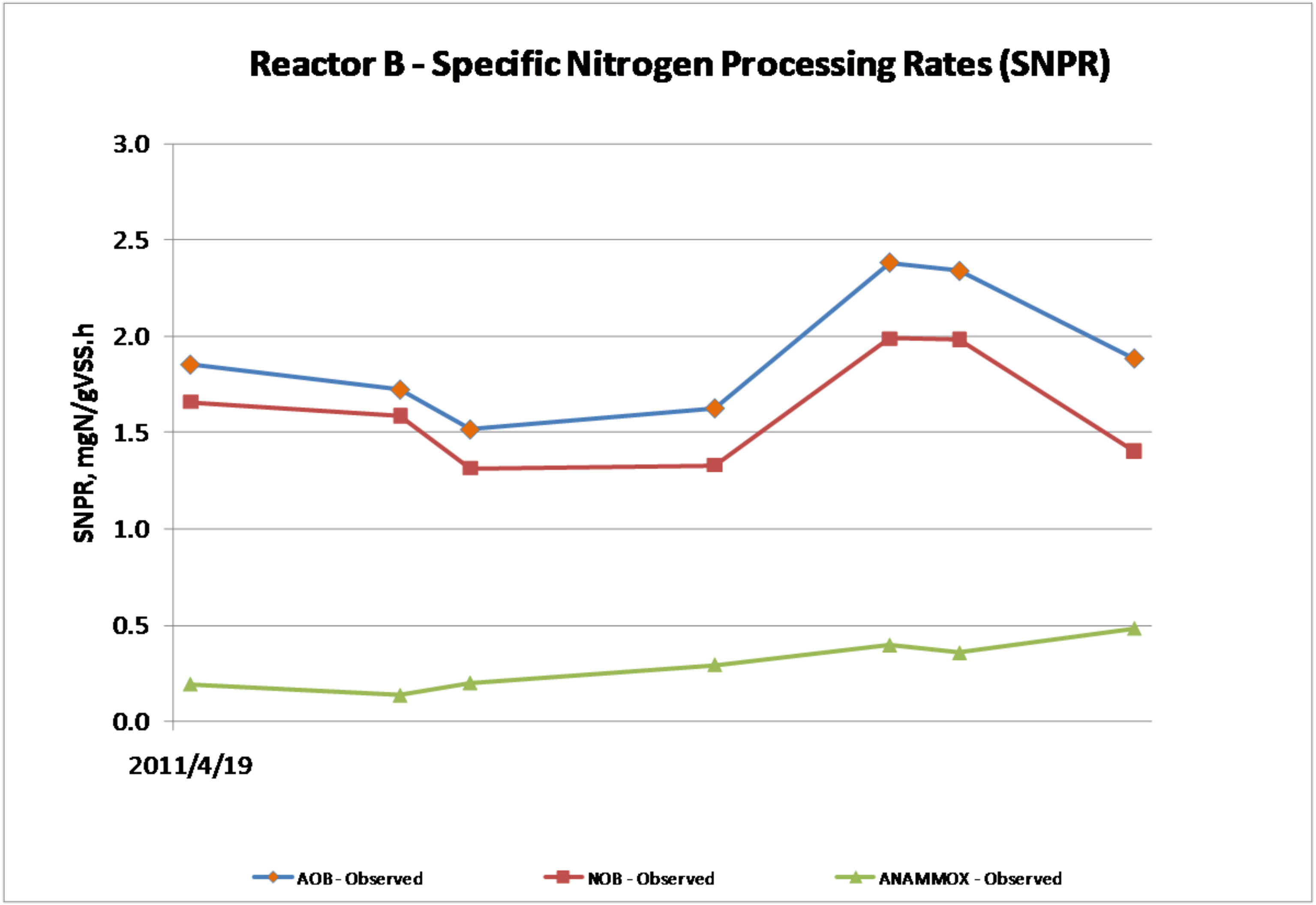
Glarnarland WWTP, Austria

Deammonification pilot at Blue Plains





Reactor B – Profiling Specific Nitrogen Processing Rate



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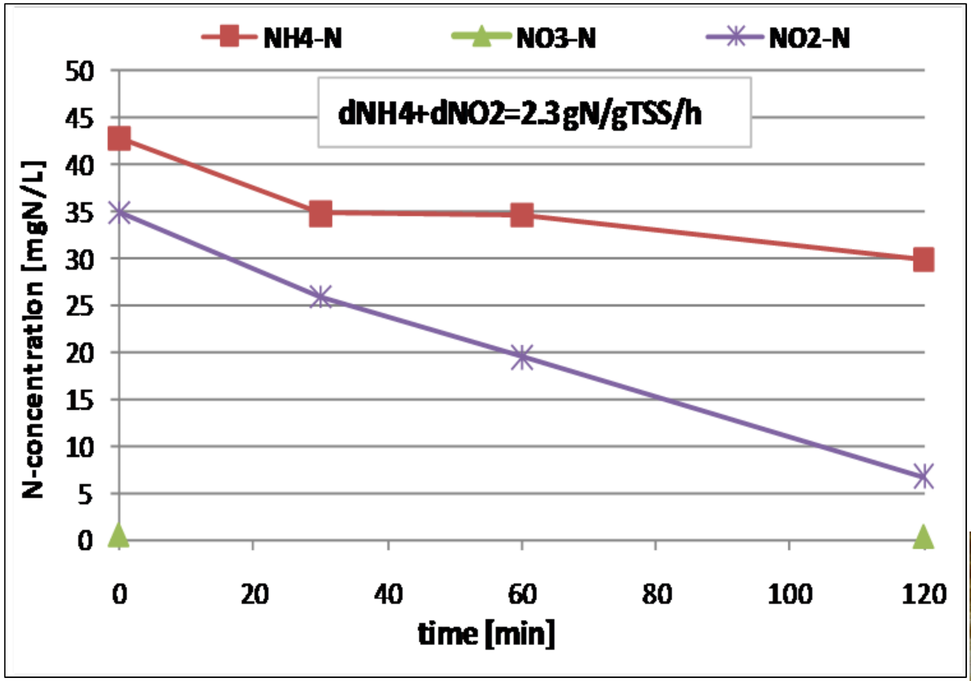

Anammox-granules visible in mainstream activated sludge

- Preliminary and promising data
- Three months of seeding
- Could take a year for steady state
- Nitrate concentration is significantly lower in deammonification lane

DEMON-cyclone installed for mainstream (left) and sidestream process (right)

The Benefits…

Potential Operating Cost Savings		
Wastewater Plant	**Annual Energy Savings***	**Annual External Carbon Savings**
Blue Plains (DC Water) (330 mgd)	\$4.0 - \$6.0 million	\$7.0 million
8 WWTPs (HRSD) (125 mgd)	\$2.0 - \$4.0 million	\$2.0 million
* Assumes 50% - 75% Anammox nitrogen removal.		

Summary

- New technologies for nitrogen removal are in development
  - Could considerably help reduce energy and carbon requirements for nitrogen removal
  - Could go a long way towards energy positive wastewater treatment
  - Compatible with existing infrastructure

How does the *Program* work?

- Collaboration (Teams)
  - Within DC Water (DWT, Program Management)
  - Other Utilities (ASA, WSSC, Fairfax County, HRSD)
  - Universities
  - Modeling Experts
  - External Research Agencies (primarily WERF)

Approximately 200 publications and presentations in the past 8 years

How does this *Program* work?

- Example Universities
  - Howard University
  - George Washington University
  - University of Maryland

  - Virginia Tech
  - Virginia Military Institute
  - Bucknell University

  - University of Innsbruck
  - University of Waterloo
  - Laurier University

Approximately 30 MS and PhDs in 8 years


Contact: Sudhir N. Murthy, PhD, PE
DC Water

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