Process Requirements for Disinfection of Recirculating Water Using Ozonation & UV Irradiation

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  - ✓Bacteria inactivation in RAS vs O_3 dose
  - ✓O_3 dose & RAS Water Quality
  - ✓Process control for full-flow ozonation
- Conclusions

Introduction

- Obligate and opportunistic fish pathogens can accumulate in RAS
  - ✓ during a disease outbreak when pathogens propagate and shed from their host
  - ✓ when no internal water disinfection process is used

Introduction

- Ozonation (O_3) and ultra violet (UV) irradiation can be used separately or in combination to treat water in RAS before it returns to the fish culture tanks.
  - ✓Proactively prevent the accumulation of fish pathogens

O_3 Doses for Disinfection

- Must maintain a residual concentration (C) for a given time (t):

	C*t, mg*min/L
✓ ISAV	0.3
✓ Aeromonas salmonicida	1.6
✓ Yersinia ruckeri	0.45-0.6
✓ Flavobacterium sp.	2.8
✓ Flexibacter sp.	1.6
✓ Streptococcus sp.	0.015
✓ Vibrio salmonicidia	0.45-0.6

UV Doses for Disinfection

- Dose to inactivate 99.9% of BACTERIA from Wedemeyer (1996) and Liltved (2001):

	$mW\text{-}sec/cm^2$
✓ *Aeromonas salmonicida*	4
✓ *Aeromonas hydrophila*	5
✓ *Vibrio anguillarum*	4
✓ *Yersinia ruckeri*	3
✓ *Pseudomonas fluorescens*	5

UV Doses for Disinfection

- Dose to inactivate 99.9% of VIRUSES from Wedemeyer (1996) and Liltved (2001):

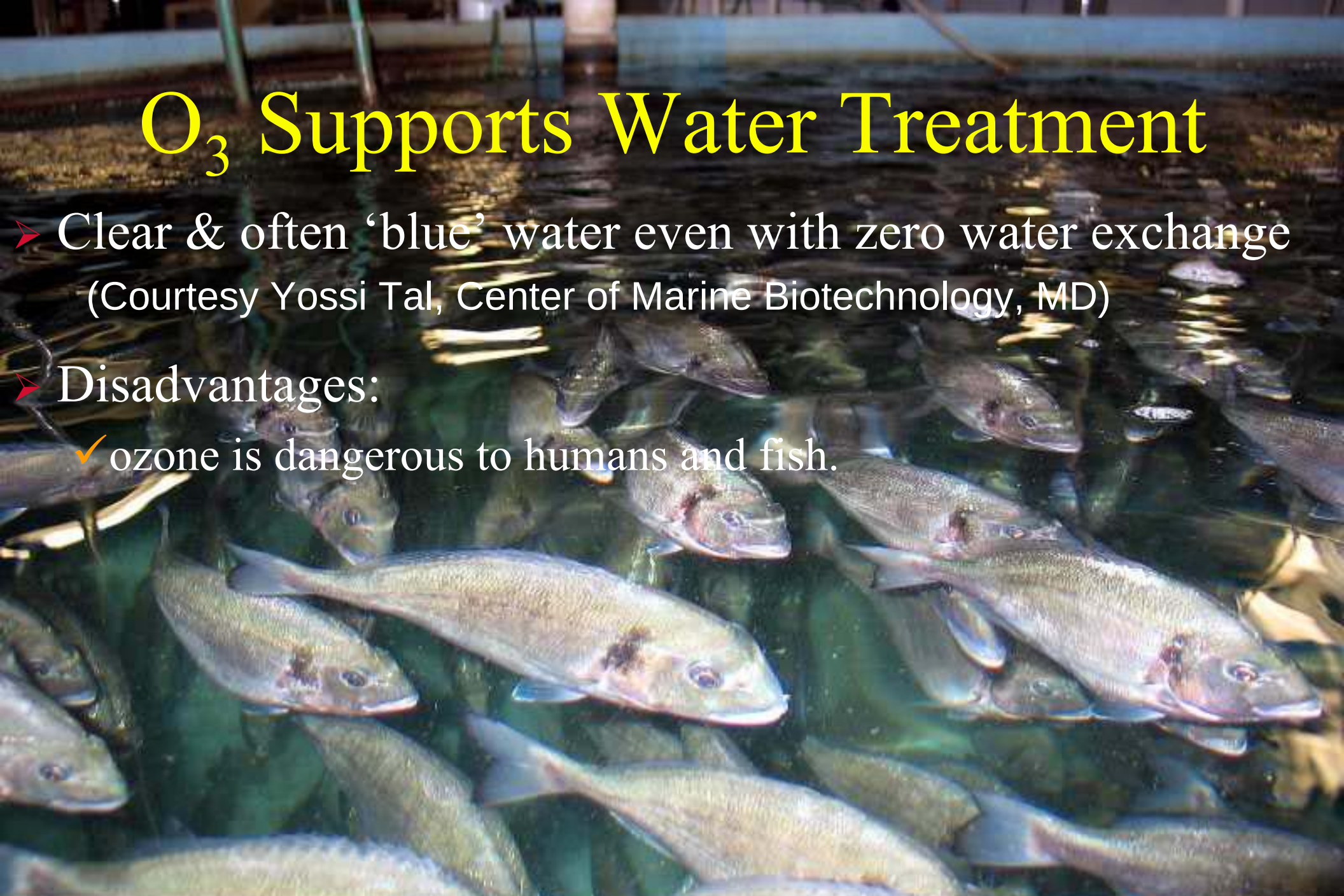
	mW-sec/cm^2
✓ *ISA*	4-10*
✓ *IHN*	1-3
✓ *IPN*	100-200
✓ *Channel catfish virus*	2
✓ *Herpesvirus salmonis*	2
✓ *White spot syndrome baculovirus*	900*

*loss of infectivity

UV Doses for Disinfection

- Wedemeyer (1996):

	mW-sec/cm^2
✓Dose to inhibit growth of *Saprolignia*	230
✓Dose to decrease infectivity of *myxobolus cerebralis*	28
✓Recommended dose for recirculated water	50*
✓Recommended dose for hatchery wastewater	30



O_3 Supports Water Treatment

- Clear & often 'blue' water even with zero water exchange
  (Courtesy Yossi Tal, Center of Marine Biotechnology, MD)
- Disadvantages:
  - ozone is dangerous to humans and fish.

UV Removes Dissolved O_3

- 50 mW-s/cm^2 removed 100% of the dissolved O_3 @ inlet O_3 concentration ≤ 0.10 mg/L
  - ✓36 mW-s/cm^2 could not remove 100% of the O_3 @ inlet O_3 concentration of ≤ 0.10 mg/L.

Summerfelt et al. 2004. Aquacultural Engineering

Methods: Full-Flow O_3 + UV Treatment

- Freshwater Institute's Grow-out System.
  - ✓4700 L/min recycle flow
  - ✓O_3 added w/ O_2 feed gas in LHO
  - ✓1.5 min O_3 contact time in LHO sump
  - ✓UV irradiation at 90 MJ/cm^2
  - ✓O_3 + UV before flow enters culture tank
    - 150 m^3 culture tank
    - 30 min HRT
    - 7.3-8.6 mg/L ΔDO across tank
    - 73-93 kg/day mean feed rate

Methods: Full-Flow O_3 + UV Treatment

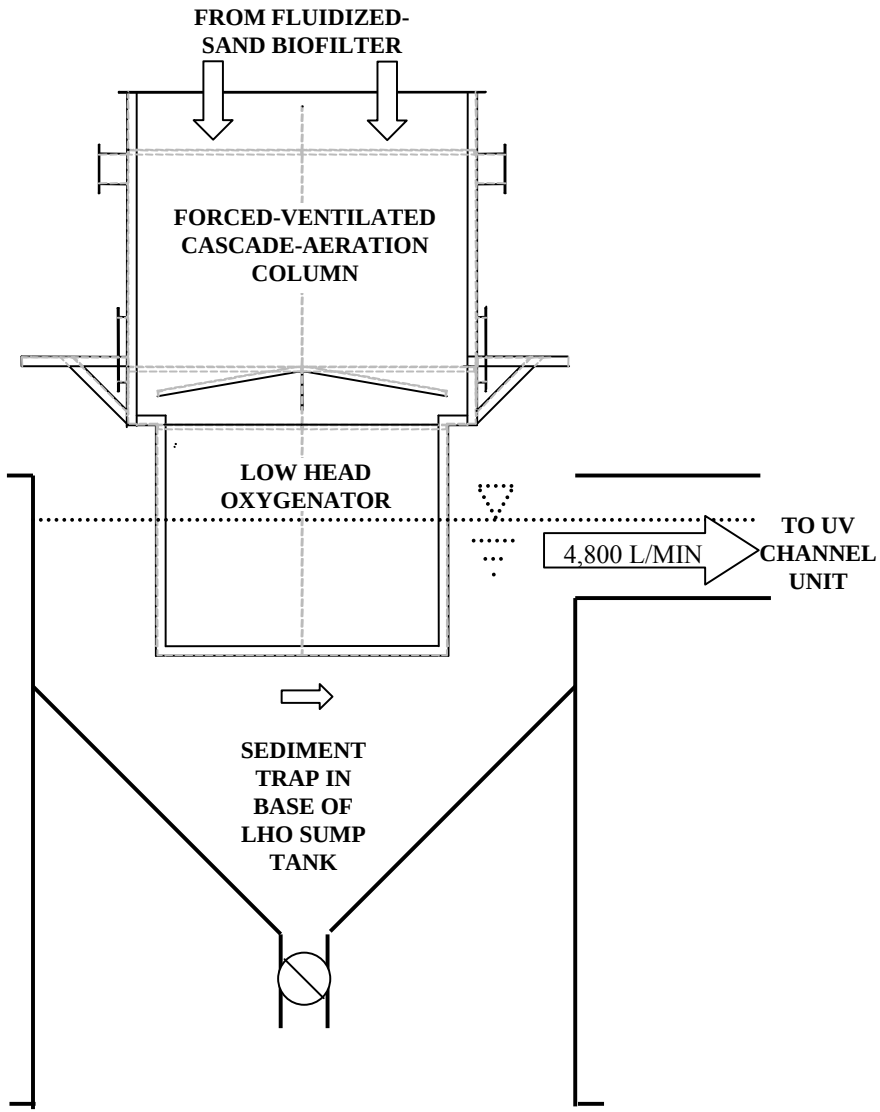
- O_3 Control Processes:
  - ✓ A proportional-integral-derivative (PID) feed-back control loop automatically adjusted the O_3 generated in the O_2 feed gas to maintain the O_3 residual or ORP at a pre-selected set-point at end of O_3 contact chamber.
    - 20 ppb O_3
    - 375, 450, & 525 mv ORP

Methods: Full-Flow O_3 + UV Treatment

- O_3 concentration generated in the O_2 feed gas was automatically & remotely adjusted at the PCI-Wedeco model GSO40 ozone generator.

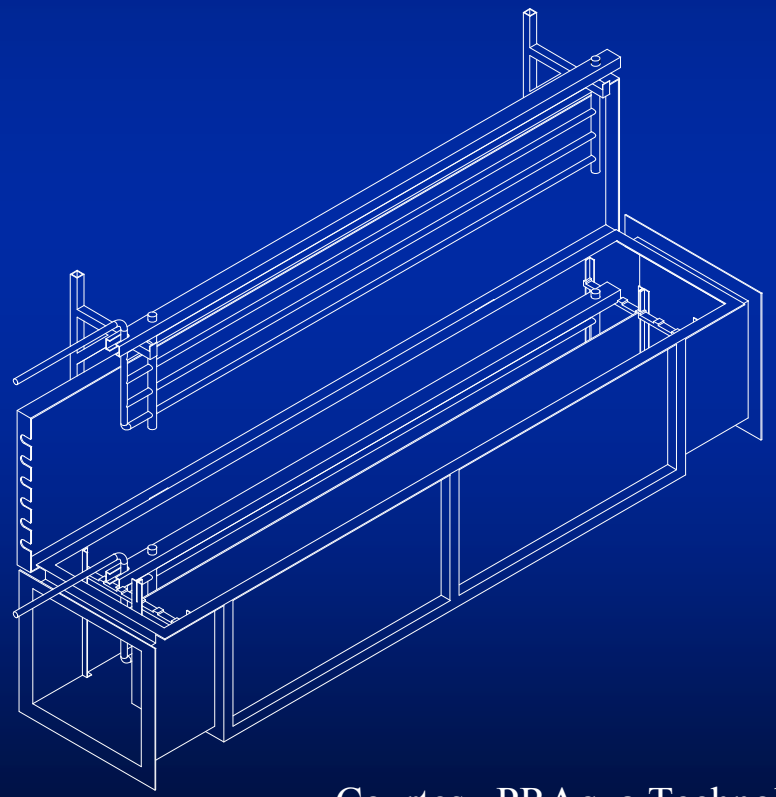
Methods: Full-Flow O_3 + UV Treatment

- O_3 transfers in LHO
- O_3 contacting in:
  - ✓LHO
  - ✓LHO sump
  - ✓Channel to UV unit
  - ✓HRT of 1.5 min



Methods: Full-Flow O_3 + UV Treatment

- UV irradiation channel unit delivered 90 MJ/cm^2



Courtesy PRAqua Technologies (BC)

RESULTS: Bacteria Inactivation

Results: O_3 Followed by UV

- Total Heterotrophic Plate Counts, cfu/ml

	Before Ozone	After Ozone	**After UV**	**% Removal**
No Ozone & No UV	466 ± 147	509 ± 139	**530 ± 145**	**NA**
Ozone @ 375 mv & No UV	48 ± 9	22 ± 5	**21 ± 3**	**56.3**
Ozone @ 375 mv + UV	124 ± 27	81 ± 18	**3 ± 1**	**97.6**
Ozone @ 450 mv + UV	50 ± 12	22 ± 4	**0 ± 0**	**100**
Ozone @ 525 mv + UV	386 ± 348	225 ±209	**0.4 ± 0.3**	**99.9**
Ozone @ 20 ppb + UV	47 ± 11	8 ± 2	**0 ± 0**	**100**

FULL-FLOW STUDY: Summerfelt et al. (In Prep.)

Results: O_3 Followed by UV

- Total Coliform Plate Counts, cfu/100ml

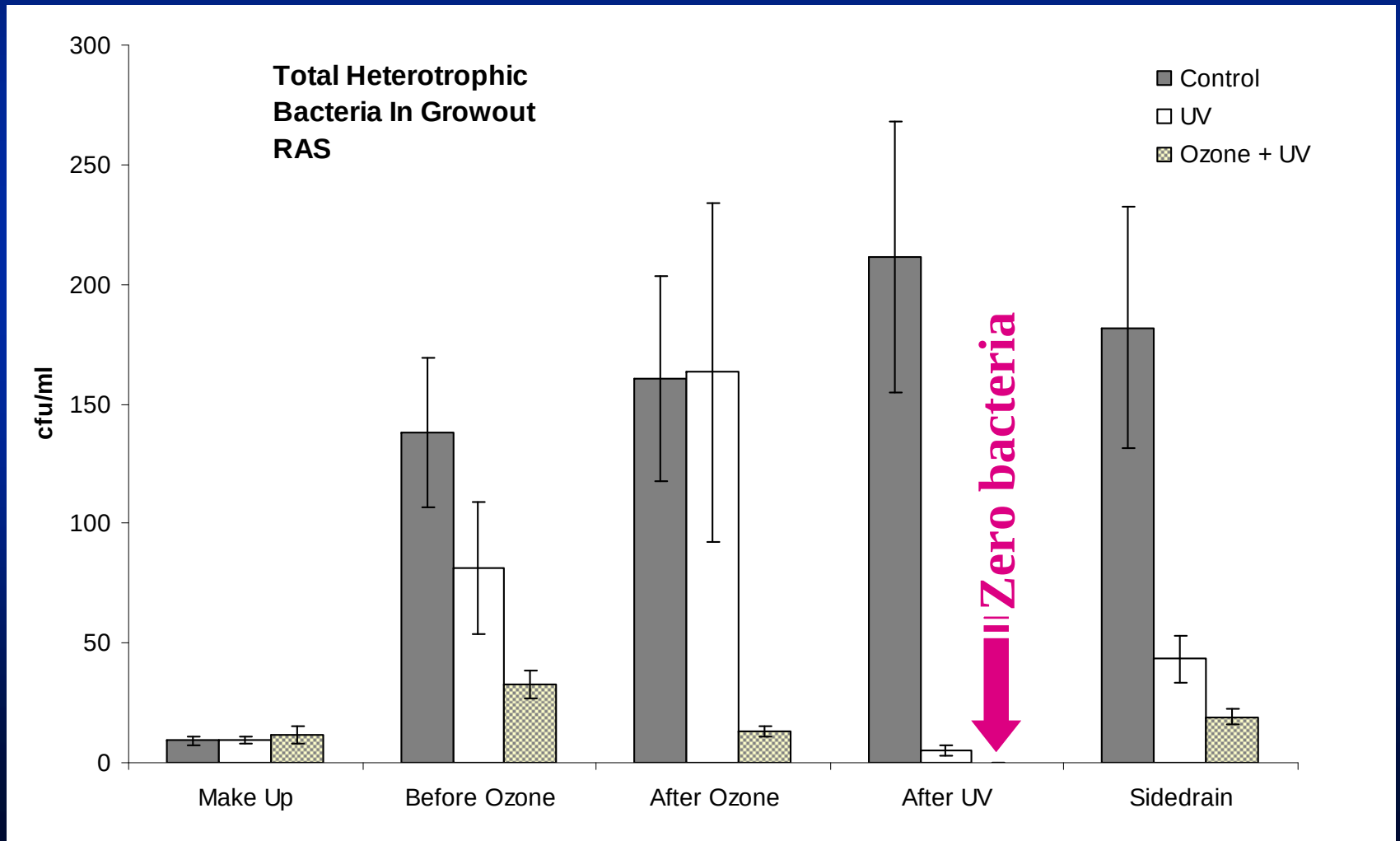
	Before Ozone	After Ozone	**After UV**	**% Removal**
No Ozone & No UV	27203 ± 7458	30065 ± 8209	**31123 ± 8327**	**NA**
Ozone @ 375 mv & No UV	1293 ± 326	571 ± 229	**636 ± 304**	**55.8**
Ozone @ 375 mv + UV	2800 ± 665	2293 ± 763	**26 ± 15**	**99.1**
Ozone @ 450 mv + UV	2702 ± 1054	864 ± 236	**5 ± 2**	**99.8**
Ozone @ 525 mv + UV	1418 ± 505	439 ± 107	**3 ± 2**	**99.8**
Ozone @ 20 ppb + UV	3195 ± 939	498 ± 272	**3 ± 1**	**99.9**

FULL-FLOW STUDY: Summerfelt et al. (In Prep.)

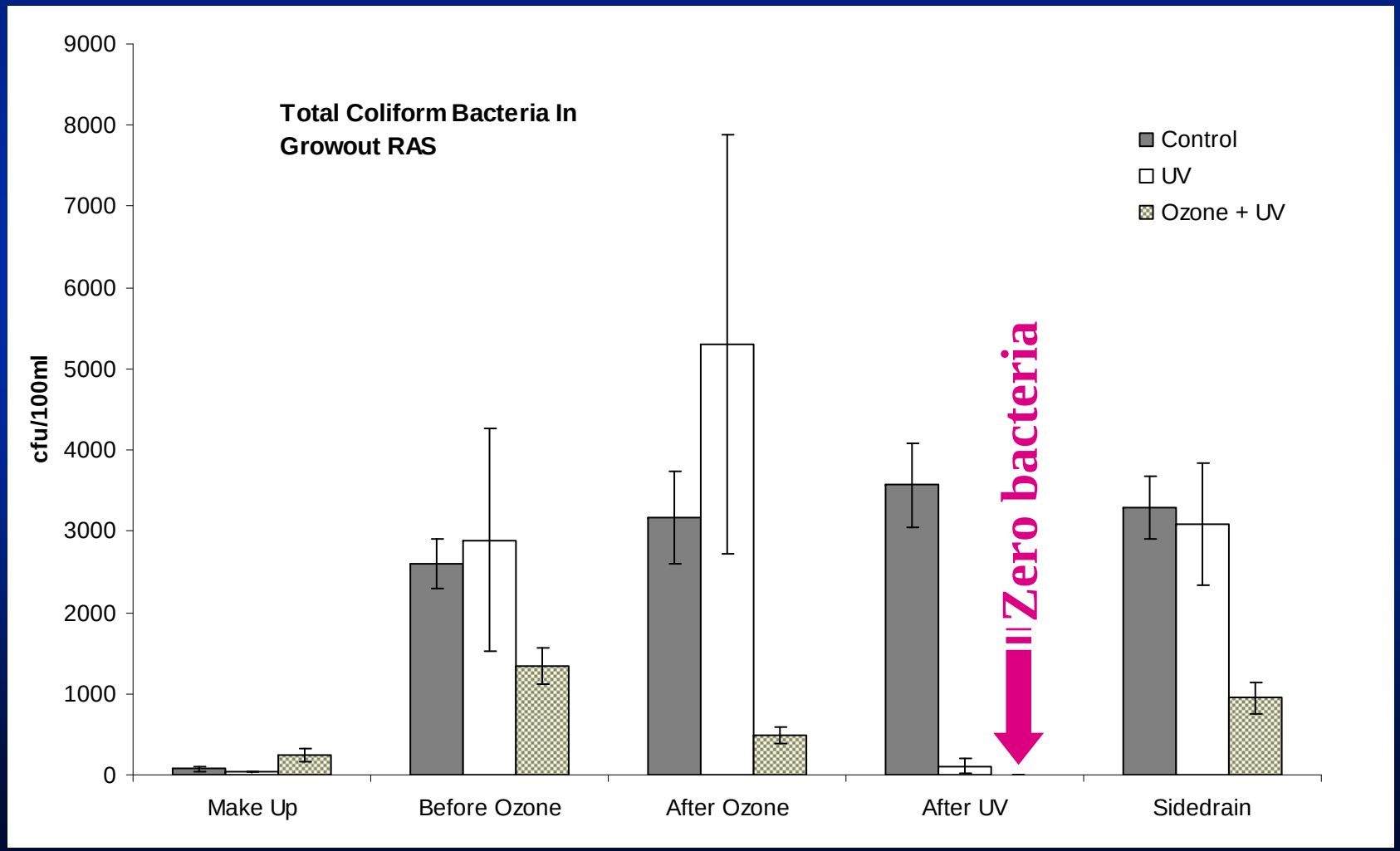
O_3 Followed by UV Irradiation

- Total Heterotrophic Bacteria Plate Count
  - ✓< 1 cfu/ml @ ORP of 450 mv & 525 mv & O_3 of 20 ppb
    - 3+ LOG_{10} reduction
- Total Coliform Bacteria Plate Count
  - ✓3-5 cfu/100ml @ ORP of 450 mv & 525 mv & O_3 of 20 ppb
    - 3 LOG_{10} reduction

Follow-up Study: UV Alone vs. O_3 + UV



Follow-up Study: UV Alone vs. O_3 + UV



Results: O_3/UV & Water Quality

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- Water quality after O_3 & UV treatment (flow entering fish tank)

	TAN (mg/L)	NO_2-N (mg/L)	TSS (mg/L)	Color (Pt-Co)	UV Trans. (%)
No Ozone & No UV	0.11 ± 0.01	0.06 ± 0.03	4.0 ± 0.9	9.5 ± 2.2	90.2 ± 1.5
Ozone @ 375 mv & No UV	0.10 ± 0.01	0.02 ± 0.01	3.0 ± 1.2	0.3 ± 0.3	95.7 ± 0.3
Ozone @ 375 mv + UV	0.13 ± 0.02	0.01 ± 0.01	2.1 ± 0.4	1.7 ± 0.3	94.9 ± 0.2
Ozone @ 450 mv + UV	0.11 ± 0.01	0.01 ± 0.01	2.5 ± 0.5	0.7 ± 0.3	95.3 ± 0.2
Ozone @ 525 mv + UV	0.14 ± 0.02	0.01 ± 0.01	2.4 ± 0.6	1.0 ± 0.6	95.9 ± 0.3
Ozone @ 20 ppb + UV	0.10 ± 0.02	0.01 ± 0.01	2.2 ± 0.2	1.7 ± 0.3	96.8 ± 1.0

Results: O_3/UV & Water Quality

- Water quality after O_3 & UV treatment (flow entering fish tank)
  - ✓Mean NO2-N dropped from 0.06 mg/L to 0.01-0.02 mg/L
  - ✓Mean TSS dropped from 4.0 mg/L to 2.1-2.5 mg/L
  - ✓Mean True Color dropped from 9.5 Pt-Co to 0.7-1.7 Pt-Co
  - ✓Mean UV Transmittance rose from 90.2% to 94.9-96.8%

RESULTS: How much O_3 dose must be added to overcome the O_3 demand of the RAS water?

Results: O_3 Dose Required

- Mean O_3 concentration & dose applied per kg feed with only 1.5 min HRT for O_3 contacting

Treatment	ORP (mv)	Dissolved Ozone, Probe (ppb)	Dissolved Ozone, Ampoule (ppb)	**Ozone Applied per Feed (g/kg)**	**Ozone Dose Applied (mg/L)**
375 mV + UV	375 ± 0	3 ± 0	0 ± 0	**28 ± 4**	**0.38 ± 0.04**
450 mV + UV	450 ± 0	7 ± 2	2 ± 1	**29 ± 3**	**0.39 ± 0.06**
525 mV + UV	525 ± 0	12 ± 3	7 ± 2	**29 ± 2**	**0.34 ± 0.04**
20 ppb + UV	607 ± 32	20 ± 0	22 ± 3	**27 ± 3**	**0.34 ± 0.05**

FULL-FLOW STUDY: Summerfelt et al. (In Prep.)

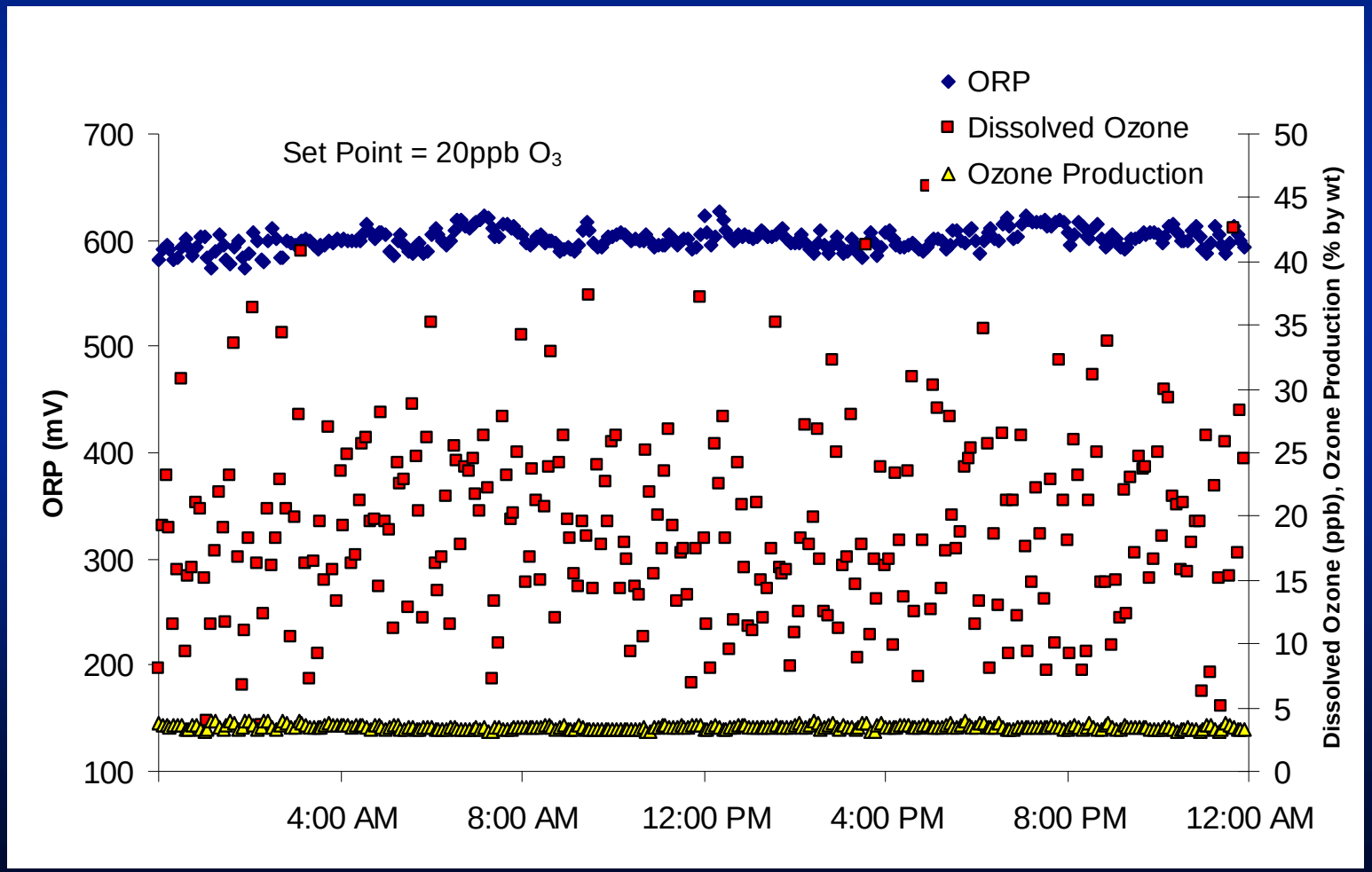
Previous Research: O_3 Dosing Rate
O_3 Prevents BGD Outbreaks

- Bullock et al. (1997); Summerfelt et al. (1997)
  - ✓25 g O_3 per kg feed input
    - improved water quality and microscreen filter performance
    - reduced mortalities associated with Bacterial Gill Disease (BGD)
    - eliminated chemical treatments required to control BGD
    - did not reduce bacteria counts by even 1 $\log_{10}$
  - ✓36-39 g O_3 per kg feed input
    - same type and magnitude of benefits of lower ozone dose
    - much more likely to kill fish

Results: Process Control for Full-Flow Ozonation

Results: Process Control for Full-Flow O_3

- ORP & dissolved O_3 probe measurements



Results: Process Control for Full-Flow O_3

- ORP probe vs dissolved O_3 probe
  - ✓ORP was easier to calibrate & maintain
  - ✓ORP & dissolved O_3 similar to tune for PID control
  - ✓ORP was just as effective to monitor and automatically control O_3 dose
  - ✓Dissolved O3 probe was quick to respond to changes
  - ✓ORP was slow to respond to sudden drop in dissolved O_3

Conclusions

- ORP can be used to reliably monitor and automatically control O_3 dose
- ORP of 450, 525, & 600 mv followed by UV of 90 mJ/cm^2 inactivates total heterotrophic bacteria plate counts
  - ✓< 1 cfu/ml
  - ✓3+ LOG_{10} reduction

Conclusions

- O_3 + UV was more efficient at inactivating bacteria than
  - ✓UV irradiation w/o O_3
  - ✓O_3 w/o UV irradiation

Conclusions

- Dose of O_3 that must be added to produce UV disinfection:
  - ✓27-29 g O_3 per kilogram feed
  - ✓0.34-0.39 mg/L ozone addition
- O_3 improves water quality in intensive RAS's:
  - ✓TSS
  - ✓NO_2-N
  - ✓color
  - ✓% UVT

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- All experimental protocols involving live animals were in compliance with Animal Welfare Act (9CFR) and have been approved by the Freshwater Institute Animal Care and Use Committee.