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Electrocoagulation for cost-effective wastewater treatment

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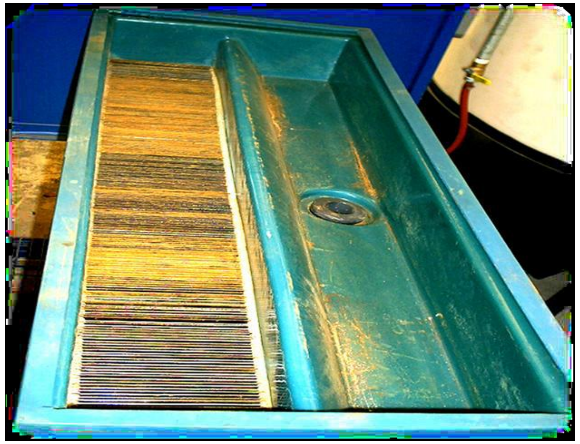
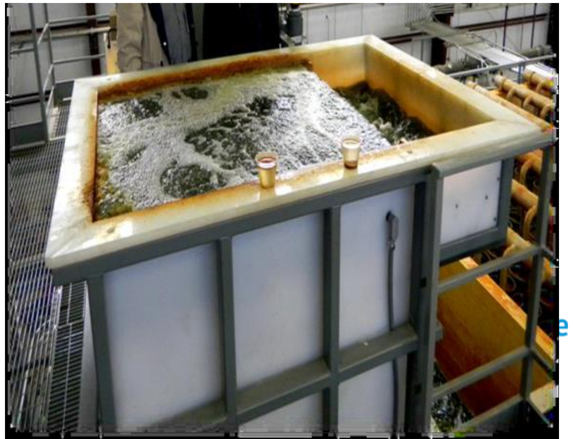
Outline

- Electrocoagulation (EC) for wastewater treatment
- Laboratory experiments
- Full-scale system costs
- Conclusions





What is Electrocoagulation (EC)?

- EC is a water/wastewater treatment technology for the removal of TSS, dissolved organic matter, nutrients, *E. coli* as well as heavy metals, oils and other organic contaminants.
- EC has been widely used for the treatment of domestic & industrial wastewaters, including textile, oil, paper, and dye wastewaters.

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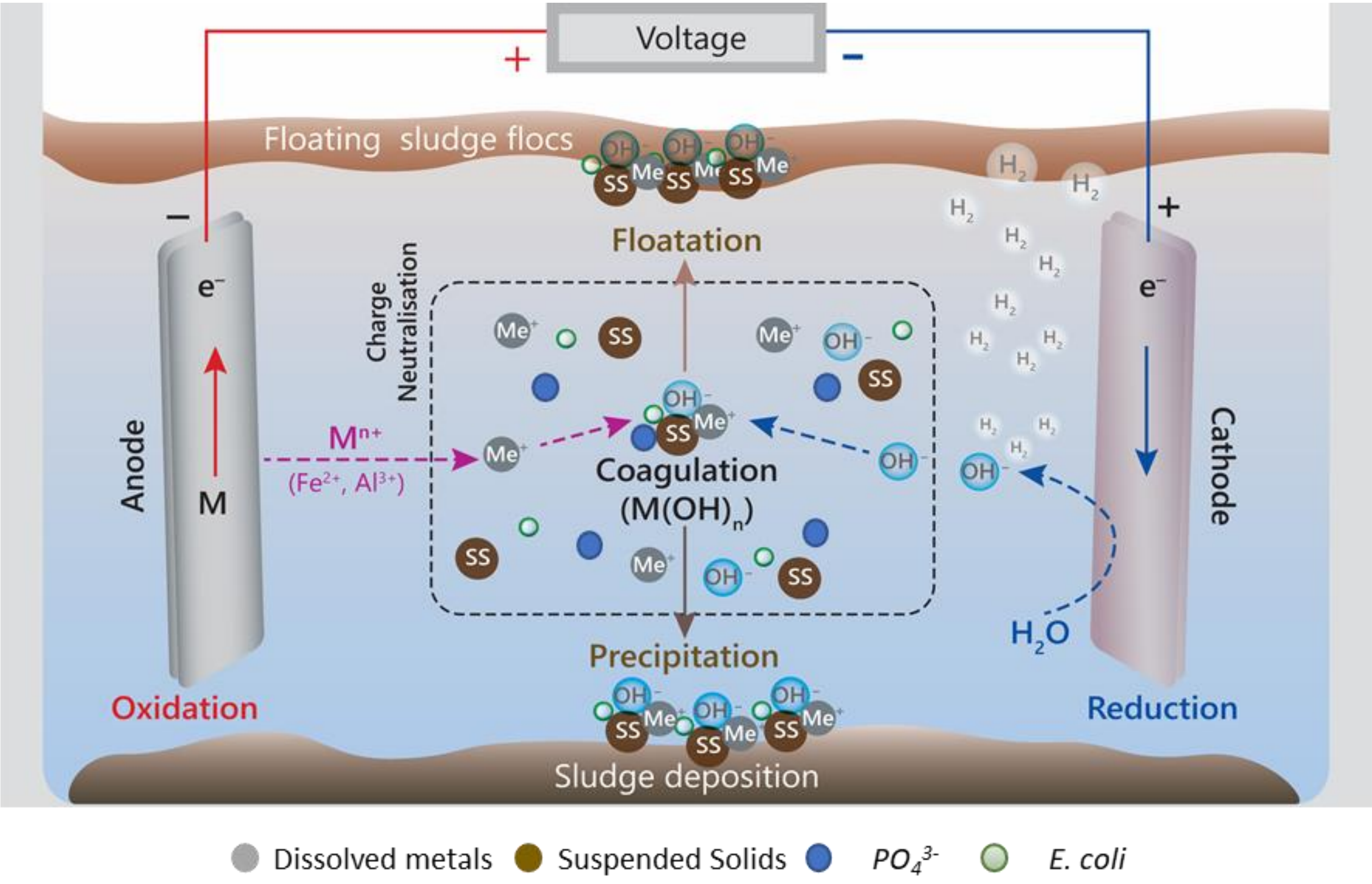
Principle of EC process

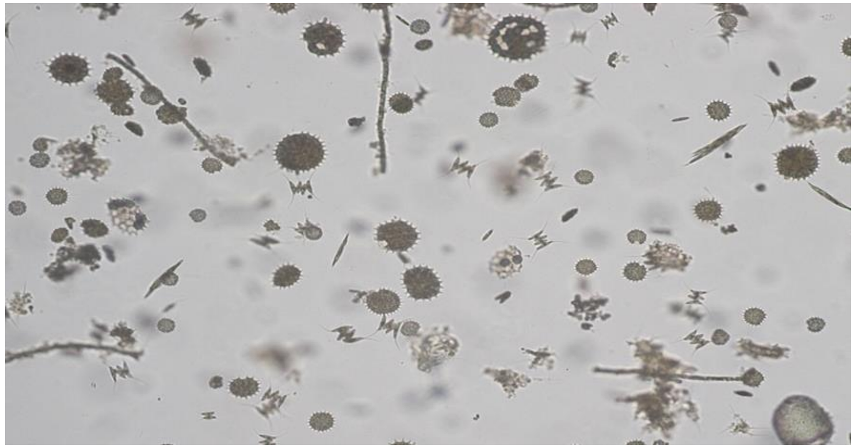


- EC generate coagulants in-situ by electrolytic oxidation of metal anode.
- Anode (Fe or Al plates) release metal ions, which hydrolyze to polymeric hydroxides
- Cathode hydrolyzes H_2O to OH^- ions and produces H_2 gas bubbles
- Coagulation involves charge neutralization of negatively charged contaminants
- Aggregation of destabilized phases to form large flocs
- Settling or floating

Critical EC operational parameters

- EC efficiency can be improved by optimizing operational parameters including:
  - Current density (A/m^2),
  - Electrode spacing,
  - Electrode orientation,
  - Periodic electrode polarity reversal, and
  - Contact time.
- Greater organic matter removal can normally be achieved at higher current density/contact time, as the removal is mainly dependent on the amount of Fe^{2+} or Al^{3+} ions.
- However, there is a critical current density/contact time, above which no further improvement in EC performance as power is wasted by heating.

Research objectives



- To investigate the treatment of wastewater pond effluent using a laboratory-scale electrocoagulation (EC) unit
- Removal of wastewater contaminants including:
    - TSS (mainly algal solids)
    - Organic matter (BOD_5)
    - Nutrients (N and P)
    - *E. coli*

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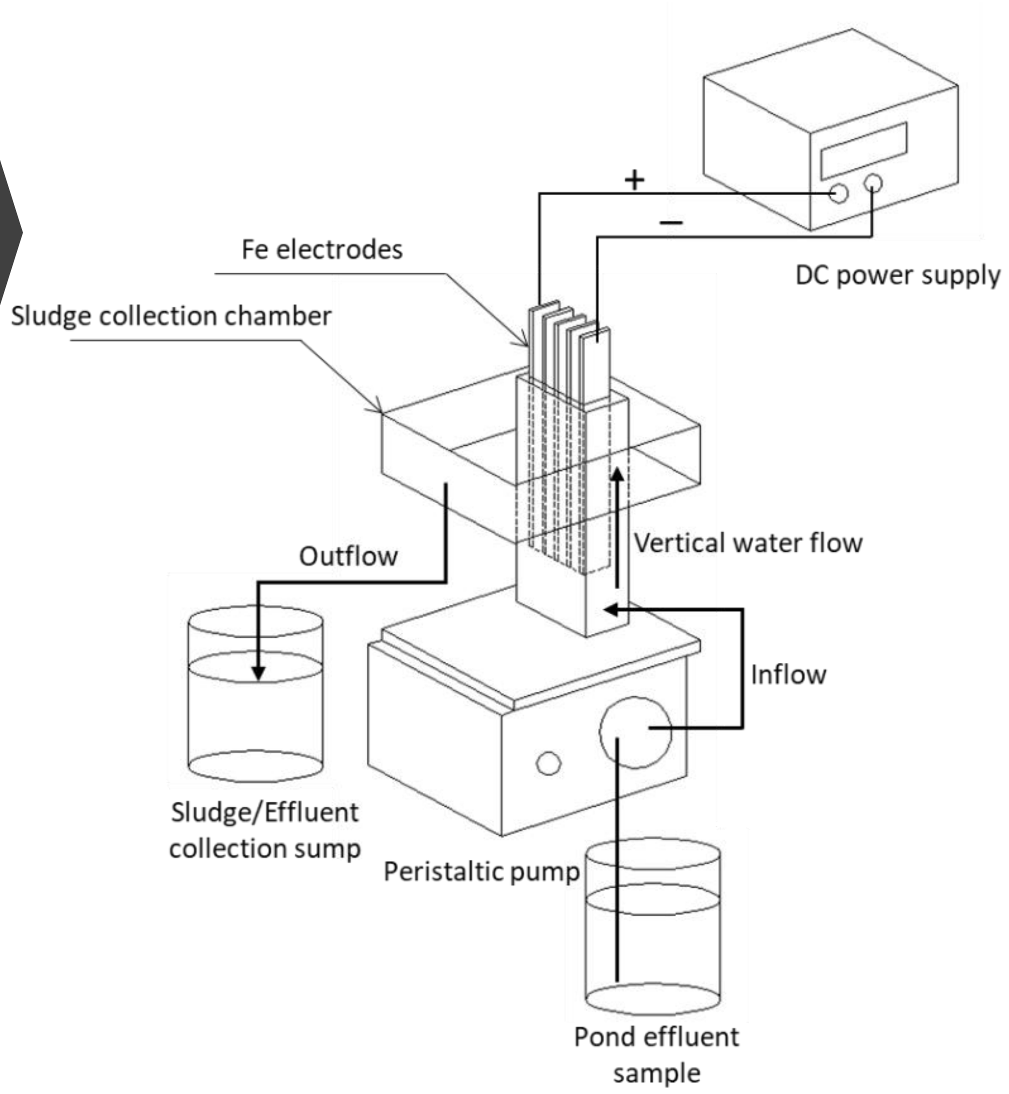
Lab-scale EC unit



Provided by Powell Water Systems (PWS)

Laboratory EC trials

- Collected 20 L wastewater pond samples
- Investigated the effect of different EC currents (between 0.4A and 3A) on the water quality of the wastewater pond effluent
- Treated and untreated samples analysed for:
  - Organic matter (TSS and BOD_5)
  - Nutrients (nitrogen and phosphorus)
  - Faecal indicator bacteria (*E. coli*)
  - Temperature, pH, dissolved oxygen (D.O.), conductivity
  - Turbidity and %UV transmittance (UVT)

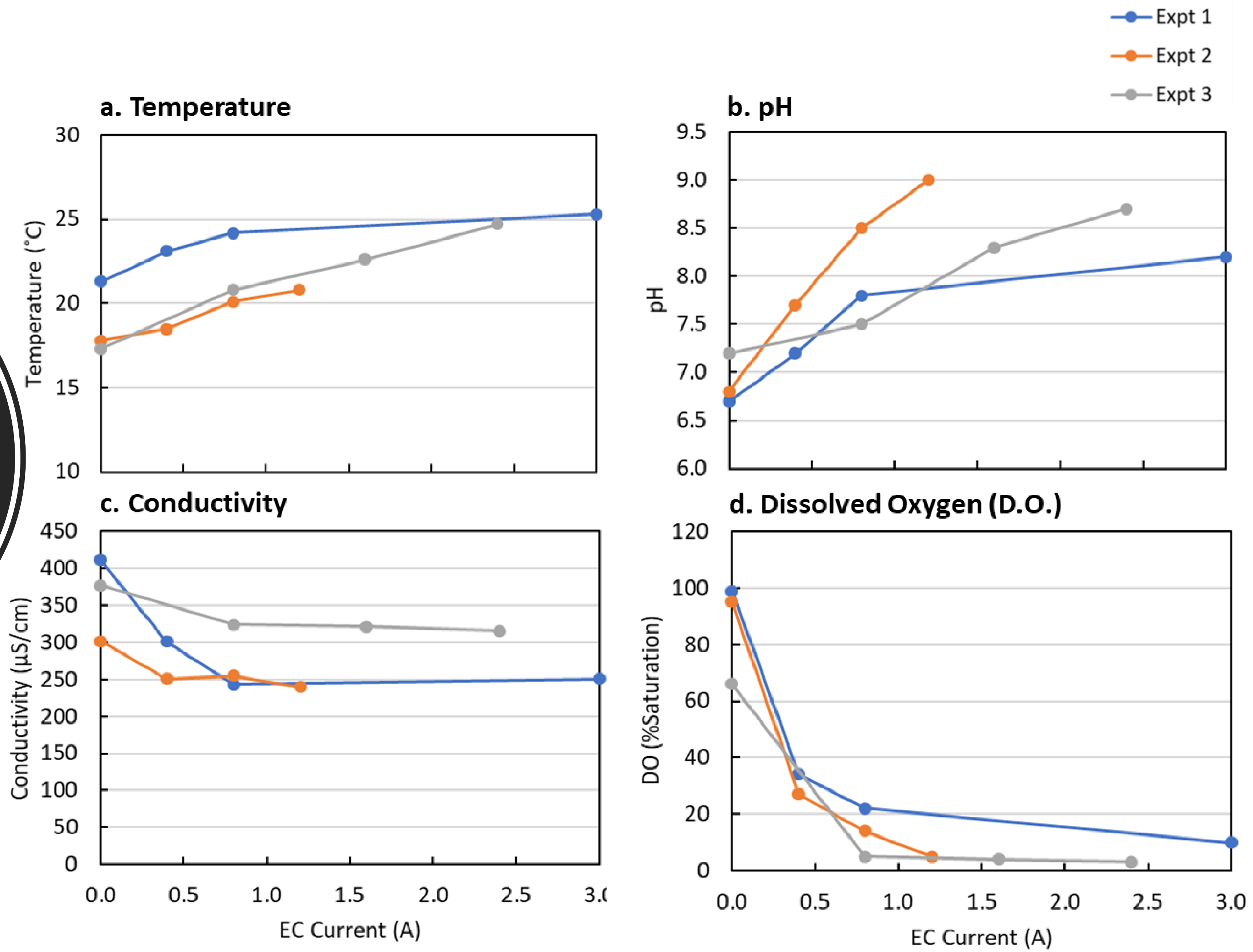
Operational parameters for the lab-scale EC

Operation Variables	Expt 1			Expt 2			Expt 3		
Flow rate	1 L/min (1.4 m^3/d)								
EC Current (A)	0.4	0.8	3	0.4	0.8	1.2	0.8	1.6	2.4
Current density (A per L/min)	0.2	0.4	1.0	0.4	0.4	0.6	0.4	0.8	1.2
Voltage (V)	96	106	88	210	115	130	78	108	150
Interelectrode voltage (V)	2.7	2.9	1.6	11.7	3.2	3.6	2.2	3.0	4.2
Total power (kW)	0.04	0.08	0.26	0.08	0.09	0.16	0.06	0.17	0.36
Lab power use (kWh/m^3)	0.6	1.4	4.4	1.4	1.5	2.6	1.0	2.9	6.0

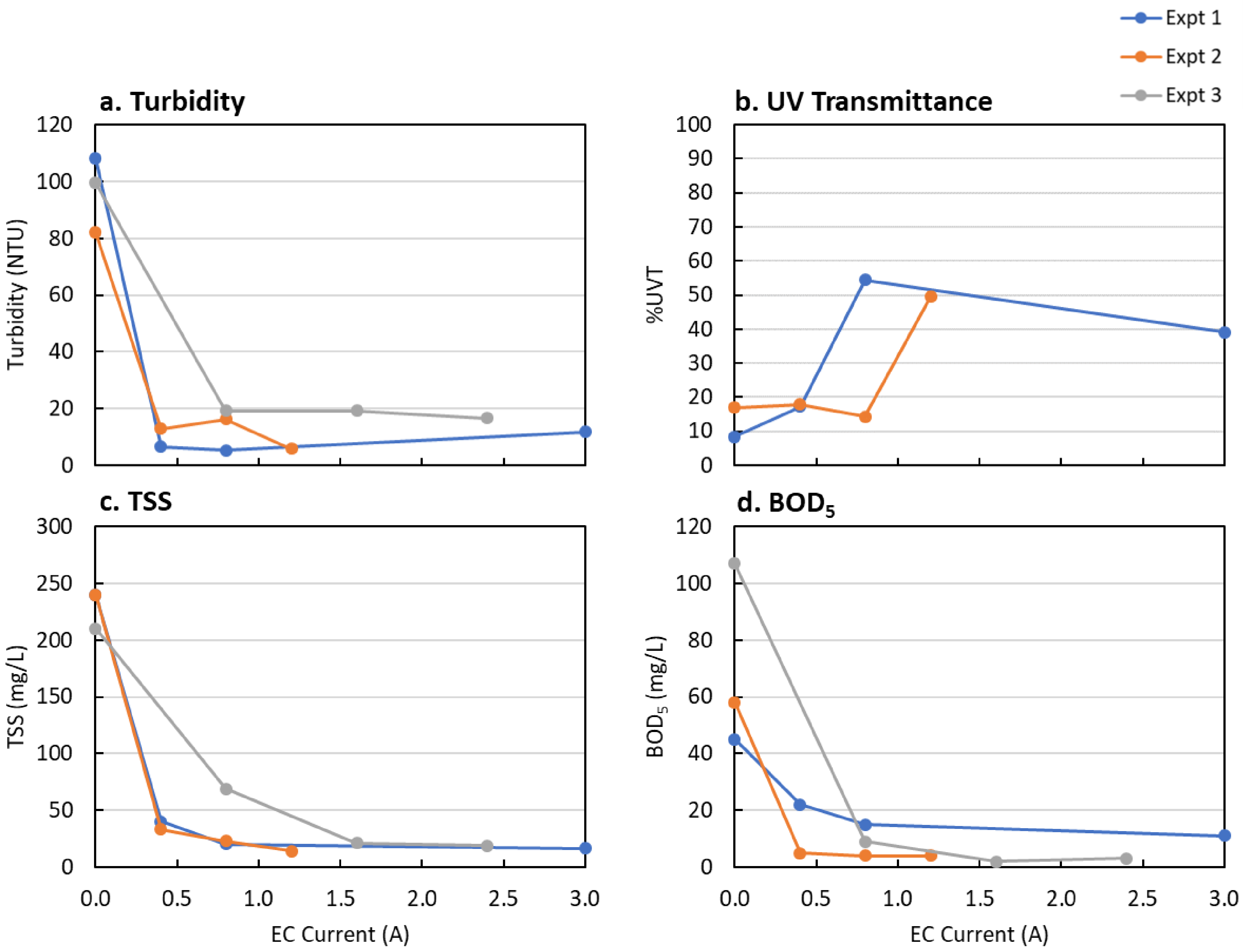
Initial pond water characteristics

	Expt 1	Expt 2	Expt 3
pH	6.7	6.8	7.2
TSS (mg/L)	240	240	210
BOD_5 (mg/L)	45	58	107
Soluble BOD_5 (mg/L)	4	5	5
TKN (mg/L)	40	24	44
NH_4-N (mg/L)	13	0.01	22
NO_x-N (mg/L)	0.1	0.1	0.09
TP (mg/L)	2.8	2.4	3.2
DRP (mg/L)	0.86	0.02	1.1
E. coli (MPN/100ml)	7.9×10^4	5.4×10^4	1.6×10^5

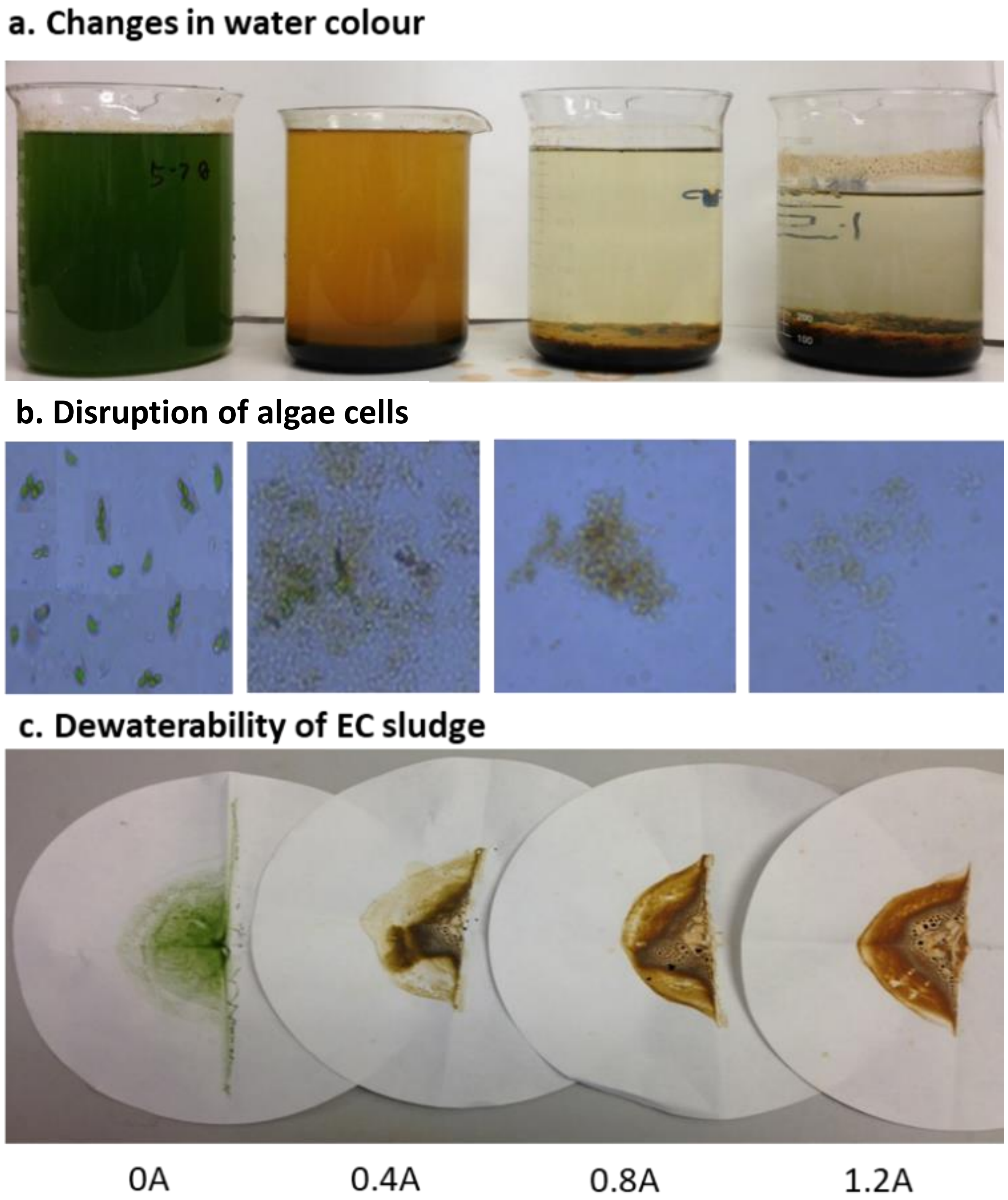
EC increased Temp & pH, and decreased conductivity & D.O.



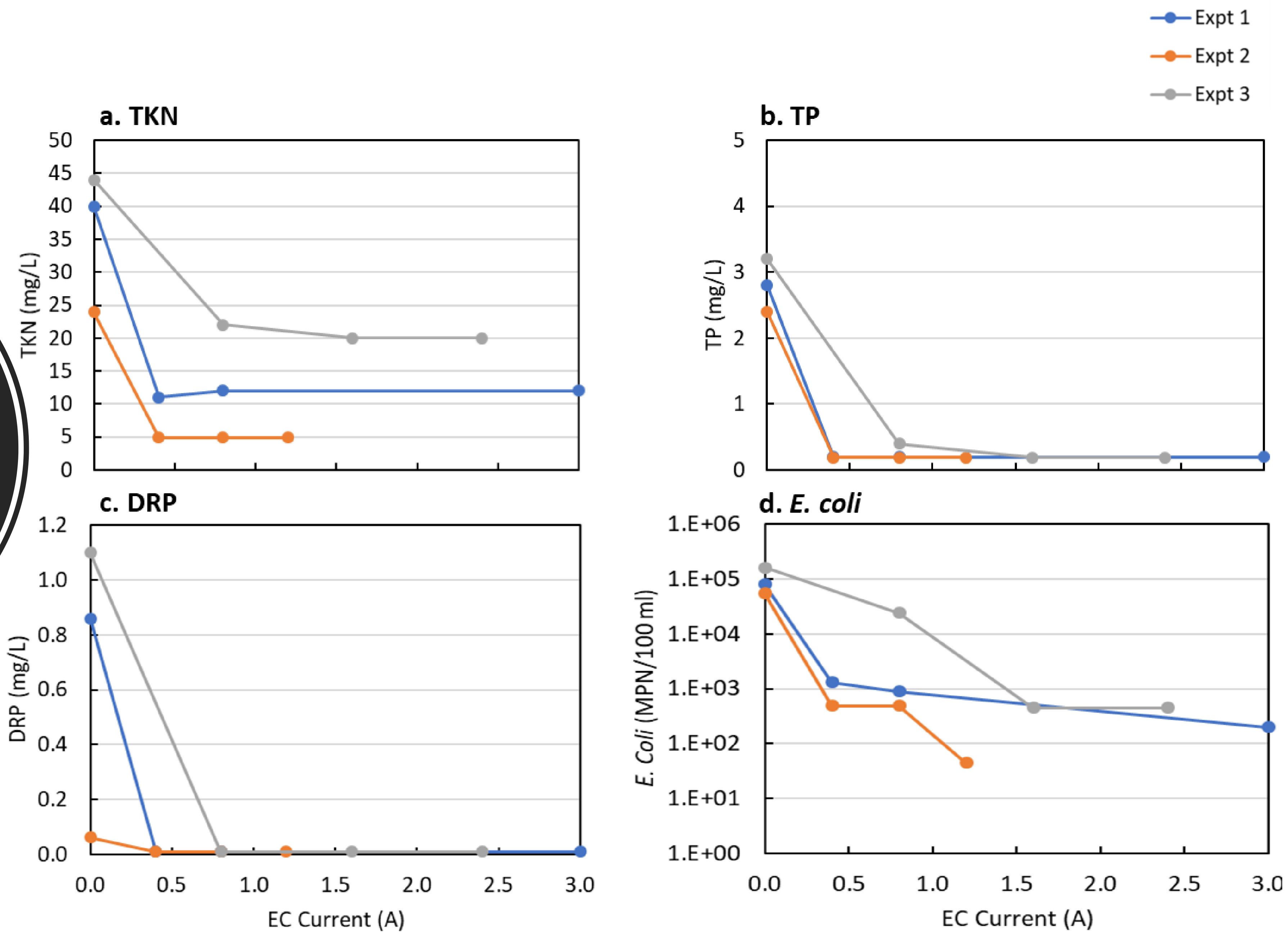
TSS and BOD_5 removal



Changes with increasing EC current



Nutrient and *E. coli* removal



EC removal efficiencies of TKN, TP DRP and *E. coli*

- The lab-scale EC (at a EC current of 0.8-1.6A) achieved;
    - >90% removal of TSS, BOD_5 and TP,
    - >95% removal of DRP,
    - 50-80% removal of TKN, and
    - 2-3 log removal of faecal coliforms.

Electric power consumption and costs

Water quality variables	% Removal	Full-scale power consumption (kWh/m^3)	Full-scale power cost ($\$/m^3$)[1]
TSS	>90	~0.4-0.7	~0.06-0.15
$cBOD_5$ (g/m^3)	>90	~0.3-0.4	~0.14-0.15
TKN (g/m^3)	50-80	~0.2-0.4	~0.06-0.15
TP (g/m^3)	>90	~0.2-0.7	~0.06-0.15
DRP (g/m^3)	>99	~0.2-0.4	~0.06-0.15
E. coli (MPN/100 ml)	3-log	~0.7-1.1	~0.15-0.26

1) The current average power cost of ~$0.30/kWh (April 2018)

Chemical flocculation vs EC treatment

- The cost of chemical flocculation (using cationic polyacrylamide, PAM): ~$0.05 /$m^3$ to achieve >50% TSS and about 1-log *E. coli* removal (Park et al, 2019).
- The operation cost of the EC unit (excl. plate costs): ~2.5-fold more expensive than that of the chemical flocculation.
  - However, EC provides combined removal of organic matter, phosphorus as well as disinfection, and the EC sludge is highly dewaterable.

Capital costs for EC

- Limited information available on the capital costs of full-scale EC systems
- Poelman et al. (1997) estimates for pond effluent treatment (mainly TSS):
  - Capital cost of \$70 USD/m^3/d in 1997; currently ~\$140 USD/m^3/d or \$210 NZD/m^3/d
  - Similar to chemical flocculation with sedimentation tanks (US\$33k),
  - Substantially cheaper than centrifugation (US\$125k) or chemical flocculation with flotation (US\$180k).

Cost estimates for EC installation in NZ

- Powell Water Inc. Electrocoagulation Systems
- Electricity and metal blade consumption is per volume of water processed
- HRT: 20-60 seconds, can accommodate wide flow fluctuations.
- Higher flows and reduced residence time can be offset by higher power (same power use per volume treated)
- Metal blades: low cost un-machined mill run iron plate.

Cost estimates for EC installation in NZ

Large-scale WWTP following secondary treatment

- **Flow:** 20,000 m^3/d
- **HRT:** 36 s
- **Capital Cost:** NZ$10 M (~NZ$500/m^3/d)
- **Additional Cost:** Clarifier (upflow sludge blanket / Vacuum clarifier tower) +50%
- **Operating Costs:**
  - **Electricity:** 1.1 kWh/m^3 x 20,000 m^3/d x NZ$0.16/kWh = ~NZ$3000/d
  - **Iron blades:** 24 g/m^3 x 20,000 m^3/d = 480 kg x NZ$2/kg = ~NZ$800/d
  - **Blade cleaning (acid):** NZ$0.0035/$m^3$ x 20,000 m^3/d = ~NZ$70/d
  - **Total operation cost (including 5% contingency) = ~NZ$4300/d (NZ$0.21/m^3)**

    = ~NZ$1.5 M/year
  - **Unskilled operator labour:** 7 h/d

Cost estimates for EC installation in NZ

Small-scale WWTP following oxidation pond system

- **Flow:** ~550 m^3/d
- **HRT:** 50 s
- **Capital Cost EC:** ~NZ$900k
- **Rotary self-cleaning screens (on** EC inflow): ~NZ$94k
- **Total:** **~NZ$ 1M**
- **Additional Cost: Clarifier (upflow sludge blanket / Vacuum clarifier tower) +50%**
- **Operating Costs:**
  - **Electricity:** 0.75 kWh/m^3 x 548 m^3/d x NZ$0.35/kWh = NZ$144/d
  - **Iron blades:** 24 g/m^3 x 548 m^3/d = 13 kg x NZ$2/kg = NZ$27/d
  - **Blade cleaning (acid):** NZ$0.0035/$m^3$ x 548 m^3/d = NZ$1.92/d
  - **Total operation cost (included 5% contingency) = NZ$182/d (NZ$0.33/m^3)**

    = NZ$64k/year
  - **Unskilled operator labour:** 0.5 h/d

Conclusions

- Laboratory EC experiments (tested at 0.8-1.6A EC current) provided efficient pond effluent treatment:
  - >90% removal of organic matter (TSS, BOD_5) and TP,
  - >95% removal of DRP,
  - 50-80% removal of TKN and,
  - Disinfection (2-3 log removal of *E. coli*)
- Full-scale EC system power consumption based on the lab-trial would be:
  - ~0.4 kWh/m^3 and NZ$0.12/$m^3$ (0.75-1.1 kWh/m^3; $0.20-0.30/$m^3$)
  - ~2.5-fold more expensive than chemical flocculation
- However, EC not only removes organic matter and TP, but provides partial disinfection, as well as producing a readily dewaterable sludge.

Thank you

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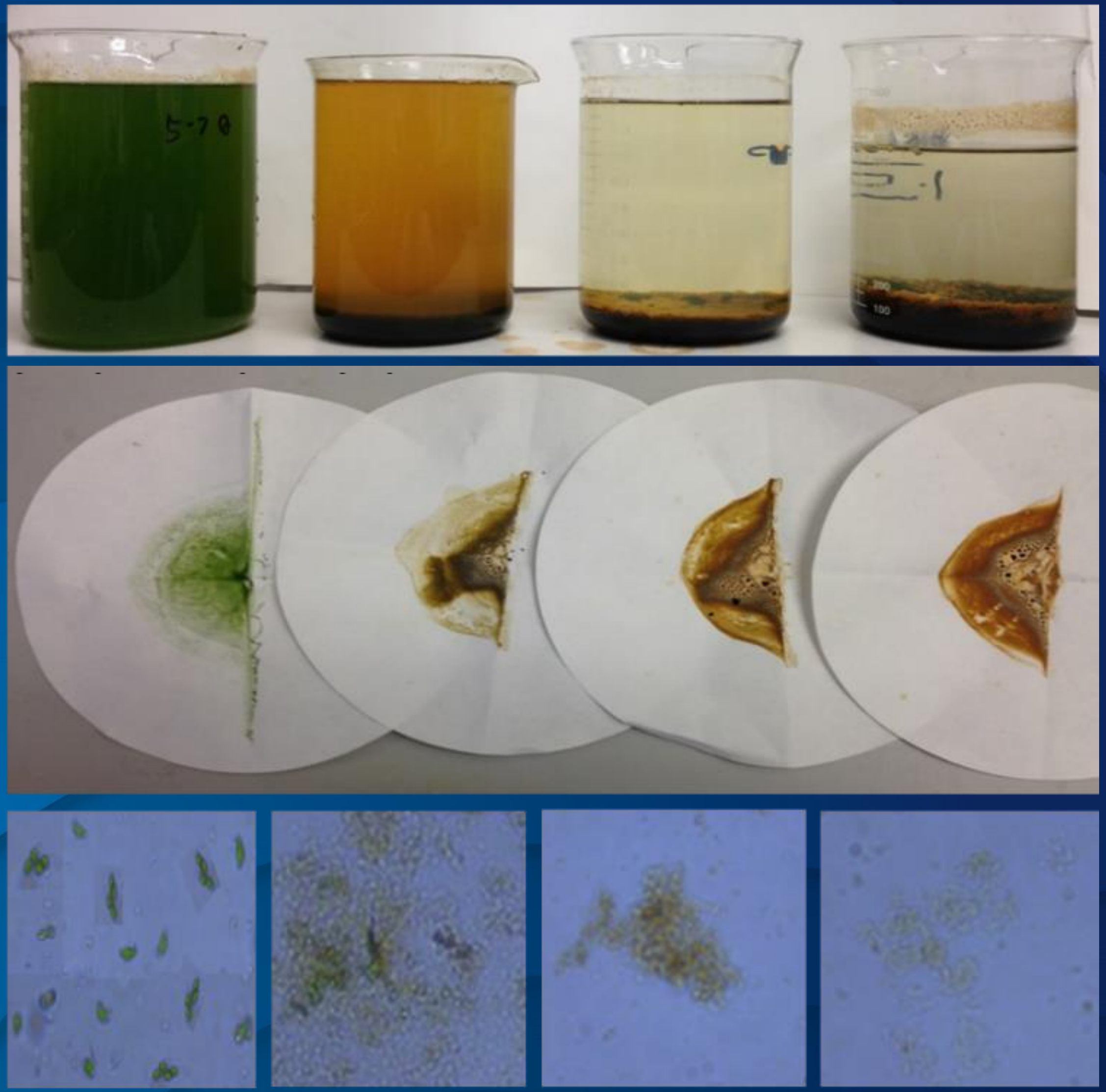

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