ADVANCING CANADIAN WASTEWATER ASSETS (ACWA) 
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TECHNOLOGIES AND EFFECTS ON RECEIVING 
ENVIRONMENTS

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ADVANCING CANADIAN WASTEWATER ASSETS (ACWA) BRIDGES LABORATORY-SCALE TESTING OF WASTEWATER TECHNOLOGIES AND EFFECTS ON RECEIVING ENVIRONMENTS

by

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Abstract

Laboratory assessments of organism responses to wastewater are inexpensive, easily replicated and offer control and precision, yet are often so reduced in temporal and spatial scale that results are difficult to apply to receiving environments. Whole-system experiments are expensive, lack true replication and can be logistically challenging, yet offer the best insight as to how ecosystems will respond to effluent inputs. Advancing Canadian Wastewater Assets (ACWA), which includes a wastewater treatment plant, analytical labs and research streams, provides unique infrastructure to test new wastewater treatment technologies, demonstrate technology benefits by direct analytical chemistry and determine receiving environment effects. The ability to measure temperature, conservative ions and dissolved oxygen in 12 replicated, naturalized streams allows physical modelling and biological monitoring consistent with larger, natural rivers. Assessments of receiving environment data could guide policy development for safe discharge of emerging contaminants and develop strategies to reduce development and persistence of antimicrobial resistance.

Key Words:
Wastewater, wastewater treatment, advanced oxidation, filtration, environmental effects, replication, diagnostic tools, receiving environments, environmental performance, antimicrobial resistance
Society derives numerous ecosystem services provided by natural environmental capital. As the global population and urban centres grow, and natural landscapes continue to be converted to agriculture, it is important to conserve remaining natural areas in watersheds and to protect source waters that provide resilient water supplies. It is also clear that part of ecosystem conservation involves reducing pollutant loads to receiving waters. As changing climate alters water availability patterns and amounts, development and evaluation of water treatment technologies to enable water reuse options has become a research focus to attempt to get more water use with limited, or even declining, water supplies (Casani et al. 2005).

Despite knowledge that phosphorus is the nutrient most often responsible for eutrophication of freshwater globally (Oliveira and Machado, 2013), eutrophication remains one of the largest threats to global water quality and aquatic system degradation. On top of this decades old problem, many biologically active compounds (BACs), including pharmaceuticals, personal care products, chemical residues from industrial processes, pesticides and herbicides, plus bacteria and viruses, are present in water that receives agricultural run-off or treated industrial or municipal effluent (Kolpin et al. (2002); Jiang et al. (2014)). Studies on wildlife provide abundant evidence that organisms in receiving waters are exposed to, and affected by, a wide range of compounds (Sumpter and Jobling (1995); Jobling and Tyler (2003); Jeffries et al. (2008); Evans et al. (2012)). Scientists are also very interested in possible links between environmental contaminants and human disease (Levine and Swan (2015); Iida and Takemoto (2018)); therefore, there is need to determine the best technologies available to reduce, remove or inactivate the broad suite of BACs present in domestic water to protect the health of downstream consumers and receiving environments.
There is an ever-increasing number of chemicals that find their way into water systems, generating concern regarding the impact and risk to downstream users and receiving environments. To understand and predict the response of ecosystems, processes should be measured at the scale of ecosystems (Macek et al. (2016); Carpenter et al. (1998)). There are examples where this has successfully been done, such as at the Experimental Lakes Area (ELA) in northwest Ontario (Johnson and Vallentyne, 1971) or the University of Notre Dame Environmental Research Center (UNDERC; Carpenter and Kitchell, 1993), yet whole-system manipulations remain relatively rare and not always possible due to financial, logistic or political reasons. Ecologists have identified (Levin (1992); Chave (2013)), and debated (Schindler (1998); Srivastava et al. (2004)), the consequences and trade-offs between the scale of measurement (time, space, container size) and the scale of processes they are trying to understand (Figure 1). It is beyond the scope of this paper to review that debate, yet it is also important to acknowledge scale trade-offs because a key question from that debate is whether or not it is possible to conduct experiments that are of sufficient intermediate scale to have controls and replication (the foundation of modern biology), yet also be of sufficient size to contain relevant ecological processes that will allow the results of experiments to be translated to natural ecosystems, which is often the object of environmental monitoring and management.

Small-scale (micro- and mesocosm; Figure 1) studies are advantageous because they can provide high replication, low cost, precision and control of the experimental environment and the variables manipulated, yet small-scale studies are difficult to translate to whole ecosystems because small-scale studies are necessarily abstractions of ecosystems (Carpenter 1996). Large-scale, whole system studies, such as those at ELA or UNDERC, include the full suite of processes and complex interactions present, even if they are unknown or not measured, and because whole systems are studied or manipulated, there are no abstractions of processes or interactions. However, because whole ecosystem experiments
are typically large, they are expensive and lack the controls and replication that make the same statistical
assessment of effects used in small, replicated experiments inappropriate or certainly problematic. There
are statistical analysis solutions to this problem (Payne (2006); Davies and Gray (2015); Smokorowski and
Randall (2017)), but they may involve an understanding of context that is only provided by comparing
current results of a manipulation to long term data, other comparable systems, or if available, other
whole system manipulations.

“Is it possible to build experimental systems that are: i) sufficiently similar to be experimental replicates,
ii) large enough to contain processes at scales of natural ecosystems, and, iii) be relevant to natural
ecosystem management?”. I describe below select components of Advancing Canadian Wastewater
Assets (ACWA), a facility conceived and constructed to develop and test tertiary wastewater treatment
technologies to remove a growing array of chemicals present in municipal wastewaters, yet also
sufficiently flexible to address emerging issues, such as the development, transmission, evolution and
persistence of antimicrobial resistance in wastewater treatment plants and environmental reservoirs –
an emerging global concern (Berglund (2015); Sanderson et al. (2016); Larsson et al. (2018); Manaia et al.
(2018)).

ACWA’s infrastructure consists of advanced tertiary wastewater treatment modules, experimental
research streams, and analytical, aquatic, microbiology and stable isotope laboratories. Table 1
summarizes selected design features and components of ACWA’s river intake, tertiary treatment
modules and research streams. Data from the streams illustrate the similarities among the 12 streams
for water temperature, and between two pools in one stream for temperature and dissolved oxygen,
two widely used water quality measurements. Chemical data highlight changes in conservative and non-
conservative ions and elements along the streams’ 320 m length and macrophyte data illustrate the
biomass of rooted plants in 10 sequential stream pools. These data collectively show that the
engineering and construction of the experimental streams and associated infrastructure has led to low
variability in the measured data and that the streams function in a similar manner after stream
commissioning.

ACWA's Experimental Wastewater Treatment Plant (WWTP)
ACWA's Research WWTP draws effluent from a post-BNR secondary clarifier, following which the
effluent is passed through a GE Model Z-Box S-18 ultra-filtration system (0.02 μm pore size membranes).
Permeate is stored in a 3785 L tank, following which it is directed to a GE Muni-100 reverse osmosis
(0.001 μm pore size membranes) module, or to modules that can dose the permeate with either H₂O₂ or
O₃, with the option to apply UV (Trojan Technologies Model UVFit 04AL20 UV-PhOX system). Chemical
quantification of effluent chemistry can be performed on secondary clarifier effluent, UF permeate, or
effluent from the oxidation processes as one measure of module performance. ACWA’s experimental
wastewater treatment plant processes ~510,000 L/day – a volume equivalent to a community of about
5,000 people in a water use efficient country.

ACWA's Analytical Laboratory
Pharmaceuticals in municipal wastewater are typically present at μg/L to ng/L (Vidal-Dorsch et al.
(2012)). ACWA’s analytical laboratory contains ICP/MS, LC/MS/QqQ and QToF, and GC with MS, NPD,
FID, or ECD detectors to measure a broad suite of metals and non-volatile and volatile compounds,
respectively. The fate of emerging contaminants can also be quantified in the research streams’ water as
the water flows from the first pool along the subsequent 300 m of alternating pools and riffles as
illustrated in the schematic Figure 2. Following digestion and/or extraction, the same compounds can be
measured in plant and animal tissues to understand transport and fate in receiving systems. Diagnostic
markers (e.g., vitellogenin transcripts or circulating plasma vitellogenin) can also be developed, tested
and measured following whole effluent dosing.

ACWA's Research Streams

Stream Construction and Colonization

The ACWA research streams were built to function like a small, headwater prairie stream exiting the
foothills of the Rocky Mountains. Jumpingpound Creek, at approximately 51° 02' 00.51'' N; 114° 51'
37.34'' W, was the model system. Construction of ACWA's research streams began with the placement of
a clay pad approximately 200 m x 400 m x 2-4 m thick. Porosity tests indicated negligible exchange
between the clay layer and underlying aquifer, which was important given that a desired option was to
dose streams with individual emerging contaminants. Streams were constructed by removing clay in the
desired configuration to create 12 replicated channels, then backfilling the excavated channels with
locally sourced pit-run gravel to produce the riffle/pool patterns in the dimensions listed in Table 1. To
create habitat for benthic invertebrates and periphyton, rocks were placed in the riffles to generate
water movement patterns, micro-habitats and aeration characteristic of Jumpingpound Creek. By
constructing the research streams in this manner, naturalized, replicate streams were created in which
environmental variation has been reduced by eliminating variation in channel morphology. Stream flow
is also controlled to ensure that all streams receive similar flow rates. These design features effectively
increase the signal:noise by eliminating differences in stream morphology and flow velocity, which are
two primary differences among natural streams and rivers. A 5.6 x 10⁶ L head pond was built on the clay
pad and provides ~8 hr water supply in the event of a disruption at the intake building (Figure 2), or extra
water to generate spring flushing flows, which are simulated by increasing flow from 14 L/s (typical base
flow) to 140 L/s. Adjacent to the streams, the most common plants to have colonized the new landscape
include poplar (Populus balsamifera), trembling aspen (P. tremuloides), sand bar willow (Salix exigua)
and yellow sweet clover (*Melilotus officinalis*). In the streams, cattails (*Typha latifolia*) have colonized the shallow margins and Sago pondweed (*Stuckenia pectinatus*) dominate the pools.

Because the streams are supplied from a common source (head pond), temperature would be expected to be nearly identical in each stream. The water temperature of pool 1 of each stream, measured every 10 minutes from July 28 to August 11, \( n = 2048 \) averaged 18.51°C with a very small standard deviation (0.31) and therefore provides a very consistent water source to each stream, based on temperature and flow. To enable the streams to operate year round, which is necessary to allow winter survival of stream biota, three heat exchangers use water heated by Pine Creek effluent to heat incoming Bow River water, which prevents frazzle ice formation on the intake louvre during winter and raises river water temperature from near freezing to about 4°C.

**Similarity to Natural Systems**

Figure 3 illustrates temporal patterns in dissolved oxygen saturation from October 27 to November 16, 2016 in pool 1 and pool 9 of stream 7, chosen by random draw. In pool 1 (top panel), diel variation in oxygen saturation (mean = 90.36 (4.54)%) was largely driven by the diel change in water temperature \( r = 0.75 \), which averaged 6.18 (0.62)°C and decreased by 0.002 °C/day over the two week period, and oxygen’s temperature-dependent solubility. The average temperature in pool 9 (mean of 6.17 (1.08)°C) was similar to pool 1 and the higher standard deviation reflects the cumulative heating during the day and cooling during the night as water flowed from pool 1 to pool 9. In pool 9 water temperature and oxygen saturation were less correlated \( r = 0.43 \) due to added oxygen from photosynthesis during day (maximum oxygen saturation 151.67 %) and oxygen removal by respiration during night (minimum oxygen saturation 63.51 %) that accumulated as water flowed along the streams. The daily component of the detrended time series, labelled ‘seasonal’ (Figure 3), is dominated by the temperature-oxygen
solubility relationship in pool 1, while in pool 9 is driven by that relationship plus accumulated depletion due to respiration at night, which generates additional oxygen removal at night. Respiration and organic matter decay during night leads to a similar minimum diel dissolved oxygen saturation in both pools. By the time water reaches pool 9, highly variable daily rates of photosynthesis, which would depend heavily on daily variation in solar radiation, led to a much wider range in maximum dissolved oxygen saturation (note the change in scale for the observed series of pools 1 and 9) relative to the diel minimum. Water is drawn from the Bow River and pumped approximately 1.3 km uphill to the head pond, where it is temporarily stored before flowing through the 12 experimental streams. Residence time in the head pond is approximately 8 hours, so there is insufficient time for much phytoplankton growth to occur. The water in pool 1 is on average, about 8 hours removed from the Bow River. As water flows along the research streams, it alternates time spent flowing through the shallow riffles (10 m long x 5-10 cm deep) and deeper pools (20 m long and 1.5 m deep) and provides an opportunity to measure cumulative impacts of physical, chemical and biological processes, as reflected in dissolved oxygen time series. The patterns observed in ACWA’s research streams are very similar to the diel pattern of $O_2$ saturation and impact of macrophytes as those in the much larger, adjacent Bow River (Chung (2013); Singer (2018)).

Rooted aquatic macrophytes provide important physical, chemical and biological structure (Chung (2013); Jackson et al. (2007); Jackson (2003); Jeppesen et al. (1993)) in rivers and shallow lakes. Macrophyte biomass, which was nearly mono-specific \textit{Stukenia pectinatus}, was measured in the centre of each of the 120 pools to determine variation in plant biomass and community composition along and among streams in late August, 2017, when the plants were at their maximum seasonal biomass. Macrophyte biomass reached a maximum value in pool 4 and in general, variation in biomass increased with distance downstream from the stream beginning (Figure 4). The biomass measured, per m$^2$, is high compared to typical values determined in the adjacent Bow River (Chung (2013)) and also when compared
to southern Alberta shallow lakes (Jackson 2013) where the water column is 2-3 m deeper than the
ACWA stream pools. From June to October, when macrophytes are growing and accruing biomass, the
streams are fully exposed to sunlight, have stabilized flow and are downstream of numerous stormwater
inputs and two wastewater treatment plants within Calgary’s urban footprint; therefore, the water that
is drawn from the Bow River is enriched with nutrients compared to the Bow River upstream of Calgary
(Chung 2013) and growing conditions in the streams are ideal, as reflected in the high macrophyte
biomasses measured.

Non-conservative elements, such as nutrients, and other water quality measures that are affected by
biological processes, such as dissolved oxygen and pH (Table 2), display patterns in ACWA’s experimental
streams that are similar to highly productive natural rivers. During daylight (pH in Table 4 was measured
between 10 am and 3 pm), pH rises when there are high rates of photosynthesis as the plants draw
HCO\textsubscript{3}\textsuperscript{-} from the water. The removal of HCO\textsubscript{3}\textsuperscript{-} also leads to H\textsuperscript{+} removal, which increased pH on average by
0.31 (0.11) pH units as water flows along the streams; the effect leads to significant differences in pH
between riffles 1 and 6 (F=56.99; p < 0.0001) that is independent of effluent dosing (F=0.96; p=0.41). In
addition to the significant differences for pH, TP (F = 8.40; p=0.0043), N:P (F=7.48; p=0.0070) and DIN
(F=10.01; p=0.0019) also varied significantly between riffles 1 and 6, with TP and N:P decreasing from
riffle 1 to 6, and DIN increasing. The most readily bioavailable forms of N and P for periphyton and
macrophytes are NO\textsubscript{2}\textsuperscript{-}, NO\textsubscript{3}\textsuperscript{-}, NH\textsubscript{4}\textsuperscript{+} and PO\textsubscript{4}\textsuperscript{3-} (NO\textsubscript{2}\textsuperscript{-} was exceedingly low compared to NO\textsubscript{3}\textsuperscript{-} and NH\textsubscript{4}\textsuperscript{+} - the
latter two were summed and considered dissolved inorganic N (DIN) in Table 3). The significant increase
in DIN in riffle 6 relative to riffle 1 is largely driven by an increase in NO\textsubscript{3}\textsuperscript{-} (data not shown), which is
hypothesized to be due to ammonification of organic-N, followed by nitrification.
For all water chemistry measurements presented in Table 2 there were no significant effects associated with effluent dosing on their concentrations, indicating that at the levels of dosing and the element concentrations in the effluent, and the element concentrations in Bow River water, dosing the streams with tertiary treated final effluent, or, \(O_3\) or reverse osmosis module effluent does not significantly increase or decrease each element’s concentration. Conservative ions such as Ti and F (Table 2), which are common additives to personal care products such as sunscreen or toothpaste (Ti) or are added to drinking water supplies (F) to supplement naturally occurring F to reduce the incidence of dental caries, show variable patterns. Ti did not differ between riffles 1 and 6 (\(F=0.06; p=0.81\)) while F did (\(F=14.46; p=0.0002\)). Thus, the water chemistry data provide direct evidence that ACWA’s constructed, naturalized research streams mimic real-world systems.

### Additional Research Laboratories

Three off-site laboratories provide research support for the main ACWA site. The isotope science laboratory contains two Delta V Plus IR/MS for carbon and nitrogen stable isotope signature measurements to allow compound tracing. To understand the response of model aquatic species to exposure to contaminants, individually or in mixtures, an aquatic laboratory houses static and flow-through aquaria in which to conduct exposure experiments. Finally, ACWA’s microbiology laboratory provides sequencing capacity (Nextseq 500) to allow assessment of genomes and transcriptomes and their changes in model organisms following exposure to differently treated effluent.

### Summary

ACWA was constructed to develop and test engineered technologies to remove a growing array of contaminants from municipal wastewater and demonstrate technology performance through analytical chemistry and environmental assessments of effluent quality. The facility is globally unique due to the
combination of analytical laboratory, experimental research wastewater plant and constructed,
replicated, naturalized streams in which to measure environmental effects co-located in an operating
wastewater treatment facility. Key design elements that provide experimental flexibility include: i) heat
exchangers in the water intake structure to allow year-round operation of research streams, ii) valves in
distribution galleries to allow dosing streams with individual or mixtures of emerging contaminants of
concern, iii) optional stream discharge to either the Bow River (Bow River water or tertiary treated final
effluent) or to further treatment (any streams dosed with effluent from ACWA’s experimental
wastewater treatment plant tertiary modules), and, iv) sequential pools and riffles in experimental
streams to measure transport and fate of effluent chemicals. ACWA’s infrastructure provides
opportunities for researchers and industry, from Canada and abroad, to pursue collaborative research,
proof-of-concept testing and de-risking of new technologies.

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References


Chave, J. 2013. The problem of pattern and scale in ecology: what have we learned in 20 years? Ecology Letters 16: 4-16.

Chung, C.W.Y. 2013. Diel oxygen cycles in the Bow River: relationships to Calgary’s urban nutrient footprint and periphyton and macrophyte biomass. M.Sc. thesis, Department of Biological Sciences, University of Calgary, Calgary, AB.


Table 1. Dimensions and operating conditions of selected research infrastructure components presented in Figure 2, designed to assess the environmental performance of advanced wastewater treatment of clarified BNR-treated effluent.

<table>
<thead>
<tr>
<th>Facility</th>
<th>Component</th>
<th>Dimensions</th>
<th>Note(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Intake Structure</td>
<td>Intake Chamber</td>
<td>1550 cm H x 3022 cm W</td>
<td>Hollow stainless steel allows water heated by final effluent to heat incoming Bow River water</td>
</tr>
<tr>
<td></td>
<td>Louvres</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Heat Exchangers</td>
<td>#1: heat transfer capacity - 1.4 MW; 56 L/s flow; #2: heat transfer capacity - 2.35 MW; 93 L/s flow.</td>
<td>Adds additional heat to incoming water - uses Pine Creek final effluent as the heat source</td>
</tr>
<tr>
<td></td>
<td>(2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Raw Water Transfer Pumps (2 duty; 1 spare)</td>
<td>97-145 L/s capacity; 40.2 kW power</td>
<td>1.8 x 10^7 L/day are pumped to the research streams’ head pond</td>
</tr>
<tr>
<td></td>
<td>Barrel Screens</td>
<td>2, 900 cm diameter x 2000 cm length, in sequence</td>
<td>Screen mesh (6 mm x 25 mm openings) based on DFO regulations are designed to restrict fish and macrophytes from being pumped to the head pond.</td>
</tr>
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<td>------------</td>
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<td>------------------------</td>
<td>----------------------------------------------</td>
</tr>
<tr>
<td>Head Pond</td>
<td></td>
<td>5.7 x 10^6 L</td>
<td>Layered locally sourced clay,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>landscape fabric, bentonite liner,</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>landscape fabric and local pit-run gravel</td>
</tr>
<tr>
<td>Research Streams</td>
<td>Total length (each)</td>
<td>320 m</td>
<td>First pool is not a research pool.</td>
</tr>
<tr>
<td>Riffles</td>
<td></td>
<td>10 m x 1 m x 10 cm</td>
<td>L x W x D</td>
</tr>
<tr>
<td>Pools</td>
<td></td>
<td>20 m x 2 m x 1.5 m</td>
<td>L x W x D</td>
</tr>
<tr>
<td>Base flow</td>
<td></td>
<td>14 L/s</td>
<td>Typical base flow</td>
</tr>
<tr>
<td>Flushing flow</td>
<td></td>
<td>140 L/s</td>
<td>Used to simulate spring flood, flush fines</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>and accumulated organic debris</td>
</tr>
</tbody>
</table>
Table 2. Summary of mean and one standard deviation (in parentheses) of select water quality, nutrient and ion values for riffles 1 and 6 from ACWA’s 12 replicate, naturalized experimental research streams, collected during May – October, 2017, a period that overlaps the macrophyte growing season (Figure 4). TN, TP and the N:P is by atoms. DIN is the sum of NO\textsubscript{3}\textsuperscript{-} and NH\textsubscript{4}\textsuperscript{+}. All elements are reported as mg/L, with exception of F and Ti, which are reported as µg/L. TTFE: Tertiary Treated Final Effluent. The Bow River treatment is Bow River water only (14 L/s); the other three treatments and Bow River water (13.6 L/s) plus the treatment effluent (0.4 L/s).
<table>
<thead>
<tr>
<th>Treatment</th>
<th>Stream</th>
<th>Riffle</th>
<th>pH</th>
<th>TOC</th>
<th>TN</th>
<th>TP</th>
<th>N:P</th>
<th>DIN</th>
<th>PO₃⁻</th>
<th>F</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bow River</td>
<td>1</td>
<td>8.31 (0.15)</td>
<td>1.69 (0.73)</td>
<td>1.87 (0.21)</td>
<td>13.74 (9.90)</td>
<td>76.06 (39.52)</td>
<td>4.30 (3.93)</td>
<td>0.14 (0.17)</td>
<td>0.16 (0.07)</td>
<td>3.81 (0.81)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>8.58 (0.17)</td>
<td>1.76 (0.15)</td>
<td>0.86 (0.44)</td>
<td>12.80 (2.24)</td>
<td>58.20 (36.80)</td>
<td>6.00 (3.63)</td>
<td>0.18 (0.18)</td>
<td>0.19 (0.07)</td>
<td>3.63 (0.76)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>8.32 (0.12)</td>
<td>1.84 (0.48)</td>
<td>1.04 (0.74)</td>
<td>13.07 (6.23)</td>
<td>53.75 (23.83)</td>
<td>4.33 (4.08)</td>
<td>0.13 (0.17)</td>
<td>0.16 (0.06)</td>
<td>3.98 (0.59)</td>
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<td>6</td>
<td>8.59 (0.15)</td>
<td>1.87 (0.04)</td>
<td>0.72 (0.25)</td>
<td>16.43 (0.69)</td>
<td>41.40 (9.35)</td>
<td>6.49 (4.12)</td>
<td>0.15 (0.13)</td>
<td>0.19 (0.07)</td>
<td>4.01 (0.48)</td>
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<tr>
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<td>7</td>
<td>8.38 (0.22)</td>
<td>1.83 (0.42)</td>
<td>1.01 (0.48)</td>
<td>12.57 (6.54)</td>
<td>92.31 (56.86)</td>
<td>4.18 (3.77)</td>
<td>0.17 (0.21)</td>
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<td>8.74 (0.23)</td>
<td>1.76 (0.05)</td>
<td>0.96 (0.82)</td>
<td>18.47 (5.19)</td>
<td>39.06 (35.64)</td>
<td>6.49 (4.10)</td>
<td>0.17 (0.13)</td>
<td>0.13 (0.12)</td>
<td>3.44 (0.62)</td>
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<tr>
<td>TTFE</td>
<td>2</td>
<td>8.20 (0.11)</td>
<td>1.92 (0.49)</td>
<td>1.87 (0.34)</td>
<td>14.24 (7.52)</td>
<td>73.33 (34.61)</td>
<td>4.52 (3.85)</td>
<td>0.22 (0.29)</td>
<td>0.16 (0.06)</td>
<td>3.94 (0.41)</td>
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<tr>
<td></td>
<td>6</td>
<td>8.40 (0.14)</td>
<td>1.76 (0.14)</td>
<td>0.69 (0.45)</td>
<td>17.60 (1.10)</td>
<td>27.59 (12.30)</td>
<td>6.47 (3.74)</td>
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Figure 1. Experimental size gradient used to measure ecological processes. ACWA’s 12 experimental streams were engineered to provide true experimental replication and contain many of the components, features and processes of natural southern Alberta rivers.

Figure 2. Schematic arrangement of Advancing Canadian Wastewater Assets’ engineered infrastructure to test the efficacy of membrane and oxidation wastewater treatment modules. Select design criteria are summarized in Table 1. Water is drawn from the adjacent Bow River through a side bank intake structure (A) that has a screen that allows water to enter a wet well and fish and macrophytes to return to the river. Wastewater effluent is drawn from a secondary clarifier and enters the experimental wastewater treatment plant (B), where it is then treated with an ultra-filtration (UF) system. UF permeate is routed to reverse osmosis, $\text{H}_2\text{O}_2$, or $\text{O}_3$ treatment modules. The $\text{H}_2\text{O}_2$ and $\text{O}_3$ modules have optional UV radiation. Two of the four modules direct effluent to the research streams (C) or return effluent back to a secondary clarifiers for additional treatment. Research streams dosed with effluent from ACWA’s tertiary treatment modules are routed to headworks for additional treatment. Initial operations use Bow River water (river reference), tertiary treated final effluent (WWTP reference) and two experimental treatments (reverse osmosis and $\text{O}_3$) to dose three streams each (E). Each stream was constructed to mimic a small prairie stream and has 10 riffle/pool combinations in sequence to allow assessment of cumulative impacts and fate and transformation of contaminants by receiving environments.

Figure 3. Decomposition of dissolved oxygen time series from pools 1 and 9 of stream 7, measured from October 27 (hour 0 of data logging) to November 16, 2016. Data were logged every 10 minutes.
For each pool the top panel is the observed dissolved oxygen saturation (percent) from data loggers. The trend panel illustrates the change in oxygen saturation once the daily (seasonal) and random variations have been removed. Water travels 240 m through alternating pools and riffles between the centre of pools 1 and 9, where data loggers were placed.

Figure 4. Mean biomass (+/- 1 SE of the mean) of macrophytes sampled in ACWA research stream pools on August 30, 2017 when the plants were at their maximum seasonal biomass. The values reported are fresh mass (excluding roots) per 1000 cm$^2$, averaged for the 12 research streams. Quadrats were placed in the centre of each 20 m long pool, mid way between the bank edges.
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