Summary report

January 2021

Workshop:
Indicators for assessing cumulative effects of nutrients on *Cladophora*
(December 7, 2020)

Elaine Ho, Denise Ding,
and Navjot Dhaliwal

INTRODUCTION

This study was undertaken as a collaboration between Elaine Ho (for PhD research) and Denise Ding (for undergraduate honors research). There were eight attendees during the workshop, in addition to nine contributors outside the workshop (i.e., via email or collaborating with workshop attendees). Attendees represented agencies/departments in the federal, provincial, and municipal governments, the Grand River Conservation Authority, academia, a non-profit organization, and industry (i.e., independent scientist/consultant).

Our collective research strives to:

1. Further develop a new approach for indicator selection and prioritization (Criteria-Based Ranking, initially developed during exploratory work in Muskoka in 2016)
2. Provide a concrete example for application of theoretical principles of cumulative effects assessment from the literature
3. Demonstrate how existing frameworks may be adapted for cumulative effects assessment

This workshop had three goals:

1. Develop a metadatabase of indicators related to *Cladophora*, N, P currently being measured in the area – achieved through pre-workshop contributions
2. Assess indicators for use in cumulative effects assessment of nutrients – achieved through workshop discussion and an activity submitted before, during, or after the workshop
3. Contribute to a proposed estuary working group framework that helps connecting monitoring and management – achieved by publishing this summary report, which will inform the PhD research described here

The study area (Figure 1) is the lowest portion of the lower Grand River and nearshore Lake Erie (i.e., the estuary).

Figure 1. Study focus area on the north shore of Lake Erie's eastern basin. Map created using Grand River Conservation Authority's GIS tool.

SECTION 1: PRE-WORKSHOP CONTRIBUTIONS

Before the workshop, we asked participants to respond to two questions. The results are described below.

Question 1

How would you assess whether an indicator is a good choice for cumulative effects assessment (i.e., criteria for indicator selection)? Describe qualities indicators should have to contribute to cumulative effects assessment (e.g., the indicator is known to influence at least one other indicator).

What it measures

- Measures the status of the aquatic environment
- Is ordinal (have magnitude and defined units of measurement) or binary
- Reflects impacts at higher or lower levels of biological organization/ecosystem function
- Can measure multiple effects coinciding in the same space or time (i.e., multivariate interactive effects)
- Measures the endpoint of concern directly or, if no direct measurement is possible, influences the direct endpoint (i.e., exposure to stressor or effect of interest/responsive to change)
- Accurate enough to confidently discriminate stressor-specific effects (i.e., precise, power/replication)

Related data or information

- Is measured with other parameters to incorporate stressor (physical/chemical) and effect-based (biological) indicators
- Processes that determine the condition of the indicator (i.e., influence change in the indicator) are understood
- Discernible significance to multiple environments (e.g., land, air, water) and/or trophic levels for species of interest (i.e., tied to the health of other organisms or measurable parameters)
- We have knowledge of normal or desired conditions and variability of the endpoint
- We have baseline data in the study area: Grand River estuary and/or nearshore of Erie's eastern basin (north shore)
- Can be used with other indicators to build evidence re: environmental impacts

Other qualities

- Responds predictably (for modeling)
- Is related to one or more valued ecosystem component (VEC) or priority (i.e., is relevant) and is backed by research to be a good indicator of each VEC/priority
- Conceptually simple enough for broad dissemination (i.e., interpretable by non-technical audience)
- Dataset that is meaningful (i.e., enough data) and useful (for calculating) is not too onerous/costly to assemble

- Analyses for cumulative effects assessment using this indicator are known/established/feasible
- Influences at least one other indicator
- Specific, measurable, achievable
- Measurable responses and/or mitigation measures are in place
- Timely - can demonstrate change within a management timeframe
- A systems diagram or model, which illustrates cumulative effects throughout the system (from initial drivers to endpoints), has been created or is possible to create with data we have

Question 2

What nutrient-related issue(s) do you manage, and how do you measure it? In other words, what do you currently monitor related to nutrients and eutrophication?

Participants collectively provided us with 18 indicators they currently measure:

- Total phosphorus (TP)
- Soluble reactive phosphorus (SRP)
- Oxygen Isotope Ratios of Phosphate
- Total ammonia nitrogen (TAN)
- Nitrate (NO_3)
- Total suspended solids (TSS)
- *Cladophora* (remote sensing)
- *Cladophora* (biomass)
- Chlorophyl a (Chl-a)
- Dissolved oxygen (DO)
- pH
- Conductivity
- Turbidity
- phyto/zooplankton
- Benthic invertebrates
- Stable isotopes
- Fish condition
- Temperature

SECTION 2: WORKSHOP DISCUSSION SUMMARY

Discussion 1

Question 1: What is currently being measured to understand the issue of nutrients? What do these indicators tell us? What do we still need to learn?

Agencies at the federal, provincial, and local levels monitor indicators relevant to this study. For example, Environment and Climate Change Canada (ECCC) currently measures phosphorus (P) concentrations at the mouth of the Grand River and transects in the

Eastern basin of Lake Erie. Both federal and provincial agencies monitor *Cladophora* biomass via air and water analyses. The Grand River Conservation Authority (GRCA) also attempts to identify the level of nutrients within the Grand River. Originally, it was theorized that managing P would limit *Cladophora* outbreaks, as with Cyanobacteria. More recently, it was discovered that *Cladophora* is influenced by complex interactions between multiple factors – e.g., water temperature, light, zebra mussels, and nutrients. Identifying the nature of these interactions is vital information that could improve *Cladophora* and nutrient management, primarily by the GRCA.

Cladophora is a stressor that changes nutrient availability of a lake, altering ecosystem services (i.e., different endpoints – from biomass to socioeconomic impacts – are of interest). This requires a host of different variables to be measured at appropriate scales, which would then provide accurate analysis. While data from many monitoring indicators (perhaps the right indicators) are being accumulated, whether these data are being collected in the right way for the questions being asked is an ongoing discussion since at least the 1950s. Variables and indicators measured without relating context is ineffective, limiting the value of certain collected datasets. Government silos further exacerbate this issue, resulting in minimal knowledge transfer on the integration of these relationships. We must focus on developing capacity that connects interdisciplinary researchers; integration of their work may allow us to correctly interpret the information.

Agriculture is a main source of Grand River nutrients. Unfortunately, it is difficult to measure the practices of farmers as they are not required to reveal their operations. Remote sensing and census data contain low temporal frequency and low spatial designation, resulting in inaccurate farming data. The data that are available (e.g., from fertilizer and soil studies) cannot be used for monitoring and management purposes because farmers have not explicitly permitted this use of their data (i.e., they were not asked). Obtaining this data via independent studies is difficult, and calculating an accurate nutrient budget is challenging since nutrient removal/uptake is not well-documented outside limited research in Norfolk County wetlands.

Quantification of each nutrient has its own challenges as well. For example, Nitrogen (N) is water soluble. Current research on P sinks via crop harvest and wetlands contain significant uncertainties and cannot be applied reliably in the Grand River watershed. While there is interest in P recovery and reuse from sediment, the global price for P makes the cost of P recovery prohibitive. Other strategies – e.g., via stormwater management and wastewater treatment plants – are still under study and each have their own challenges that need to be addressed. One established practice is GRCA's voluntary program that urges farmers to reduce the level of sediment received by Haldimand County's stormwater infrastructure.

Question 2: If someone were to tell you they are assessing cumulative effects of nutrients and algae in the area, what does this mean to you? (Are we all on the same page?)

Cumulative effects (CE) assessments require researchers to analyze the final effect of a stressor collectively with other sources. Current compliance requirements and environmental assessment (EA) practices do not assess the condition of the endpoint (i.e., what levels of a given contaminant are found in the receiving waters?); additionally, an EA is not required to identify the effect size. CE assessments incorporate multiple endpoints collectively to safeguard against misrepresentation of data. These assessments require researchers to design conceptual models (systems diagram) of all pathways that affect the endpoint. In some cases, pathways are well-established, so little work is needed, but others are quite dynamic, requiring deeper analysis. Analysts must identify the subject of the assessment and then correlate appropriate valued ecosystem components to be studied.

Adequate comprehension of singular and combined effects of nutrients on Grand River ecology is required when developing a well-informed strategy. In addition, understanding the models, features and other stresses that might modify the relationship(s) between nutrients and algae further develops researchers' ability to improve the preservation of ecological functions. Amalgamation of relationship analysis, monitoring on substantial geographic scopes and modeling would be ideal but would result in a lengthy exercise. Disentangling different stressors and their cumulative impacts of time, including variable impact over time would be key.

Workshop participants indicated a potential connection to planning/regulatory process for managing the way nutrients accrue; however, these studies often attempt to find solutions to problems that do not have a process in place yet. A third participant stressed the need to identify an endpoint (e.g., a lake ecosystem objective), and linking it back to biomass density. This could include establishing a level of acceptable algae biomass based on what level impacts our most sensitive endpoint. Further research could determine which link or influence is most limiting or has a detrimental impact at the lowest level of biomass density. These data could then be tracked back to establish biomass thresholds at or below the set level. Subsequent research may then develop techniques and technologies that limit nutrient contamination to ensure biomass remains within a desired zone. Implementation of the process would require determination of sources that impact nutrients or *Cladophora* so managers may disentangle and control these practices at the source, thereby limiting CE.

As municipalities are often tasked with remediation of local symptoms, e.g., *Cladophora* fouling beaches, the tools developed at higher level management agencies should be usable by municipalities as well. Systems diagrams – which require significant capacity to develop – should be used to visually characterize CE; unfortunately, an exceedingly complex representation may only exacerbate layman confusion and therefore would be ineffective. Increasing understanding and the transfer of knowledge is vital to promote pre-emptive rational urban planning. Current end-of-pipeline limits are set in terms of concentration; unfortunately, this only regulates discharge on a facility level. A loading approach would more aptly assess the contamination of downstream discharge, better determining the current levels of a contaminant watershed wide. GRCA's recent monitoring demonstrates the efficacy of nutrient reduction using a loading approach, as total phosphorus was reduced by about 25% since reporting began in 2012. Management based on only concentration ignores the endpoint condition and undermines legislation. This must be amended for us to adequately address CE of nutrients in the Grand River and Eastern Lake Erie areas.

Discussion 2

What indicator or set of indicators should be monitored for understanding cumulative effects related to nutrients and/or *Cladophora*?

Our participants pointed out that *Cladophora* is more complex than we previously thought, and so a systems mapping/network diagram exercise would be needed to most accurately pinpoint the indicators to measure and manage. Rather than look at which indicators should or should not be measured, a recommendation was to start by considering which could be grouped together (– and several examples were suggested). Essentially, the goal would be to understand how changes in one indicator would influence or represent changes in other indicators and our endpoint(s) – which, in theory, would reduce the number of indicators we need to assess. This kind of an exercise should be done with experts who know the organism (*Cladophora*) and the system well, in collaboration with end users of the information (e.g., managers).

Without an ecosystem analysis as described above, participants did not feel it would be possible to look at the list of potential indicators and make an informed decision regarding what should be measured. A model for analyzing indicator data and limiting uncertainties (likely developed after the above exercise is carried out) was recommended to assist decision-making. Recognizing where uncertainties exist and managing them is critical for cumulative assessment. Managing uncertainties includes understanding the systems diagram well enough to determine how a change in measurement protocol, for example, will influence changes in the information that results from monitoring. Still, even by measuring indicators using consistent, known protocols, models would be needed to achieve explanatory power of how phosphorus and nitrogen contribute to *Cladophora* biomass (i.e., beyond correlations). The challenge is existing models still contain uncertainty levels that are too large to determine how much of each nutrient should be reduced, to what degree (i.e., managing uncertainty as described above is not done as well as we would like due to capacity limitations).

A final question in this discussion was whether Chlorophyl-a is an appropriate proxy for monitoring trends in *Cladophora* biomass. Although Chl-a is often used to assess phytoplankton abundance, it is not recommended for algae like *Cladophora*. Participants suggested Chl-a is likely not a good way to address this monitoring question, and that getting as close to the endpoint as possible (e.g., measuring *Cladophora* biomass directly) is ideal.

Discussion 3

How would you use these indicators in cumulative effects assessment? How would you analyze the data? What challenges do you foresee?

The relative uncertainty in cumulative effects assessment (CEA) was highlighted as an important consideration in response to this question. The relative magnitude of uncertainty in relation to its effect should be considered. To manage the issue and apply monitoring data, a precursor (some threshold) may need to be determined to measure stressors before *Cladophora* proliferation occurs. This approach would provide managers with a way to assess whether known uncertainty in their data is acceptable. In this approach, if the precursor determines a decision must be made because we know the current trend will cause *Cladophora* proliferation, a manager can compare the risk (knowing its potential magnitude) against the level of uncertainty to determine whether the uncertainty exceeds or is within the effect threshold. If the level of uncertainty exceeds the effect threshold, the uncertainty is too big to make a decision from the information at hand. Another method described by a participant is to run models using a control dataset alongside a manipulated dataset to assess the changes that occur when one or more parameters were altered in the model. This approach may help build an understanding of uncertainty in the system being managed. Overall, understanding the natural variability of parameters being assessed is critical knowledge for CEA.

Identifying the amount of P from a particular source is a challenge due to the lack of resources for implementing CEA techniques. Therefore, it is difficult for organizations to target regulations to limit P loading. Moreover, CEA in agriculture (one of the main stressors) in the Grand River watershed focuses on the upper section, as the lower section consists of a high-order stream (Strahler classification 7) that presents immense logistical challenges for downstream measurements. Upper watershed information includes soil management and farming practices as well as weather impacts; however, these datasets have yet to be pulled together for CEA. Two questions arose as we considered how to potentially utilize these data: what happens from the time a farmer applies nutrients to the time P enters the lake, and how do we translate known pathways into an answer regarding CEA? Watershed modelling is likely useful for estimating the consequences of nutrient data while recognizing uncertainty.

Participants reiterated that the basic variability of endpoints should be assessed to fine-tune models before forecasting outcomes. Still, models were reiterated numerous times as a critical tool for supporting decisions in our study context. In an example from Ajax, Ontario, models were used for developing a formal position on nutrients from York's wastewater outflow affecting *Cladophora* in Lake Ontario. This decision on nutrients and *Cladophora* may be the most recent and geographically near to our study area. Therefore, it is likely a valuable case study to observe how models were used and how they considered measurement uncertainty (if at all). ECCC has recently explored the use of other systems tools, including fuzzy cognitive mapping, to identify pathways between stressors and effects and facilitate decision-making. Currently, ECCC is developing a plan to use Ensemble as a modeling tool. Past models used data from 11 watersheds to determine soil-nutrient dynamics and water flows in the Lake Erie basin. However, due to the use of lots of parameters, there is great uncertainty to answer the management ideas. Although limitations exist – e.g., we do not always have all the data needed and time lags impact decision-making – modelling is the most-used and best-informed approach for decision-making.

Much of the data and information related to nutrients and *Cladophora* are still being collected or pulled together. The most recent systems mapping exercise (March 2019), which describes processes that influence algae (including *Cladophora*) across Lake Erie, is still being compiled. The Great Lakes Nutrient Initiative is a promising program that integrates biotic and abiotic indicators in nearshore areas, though data are largely still being analyzed. The Nearshore Monitoring Framework, developed under Annex 2 of the Great Lakes Water Quality Agreement, has been collecting data directly and through spin-off programs that have yet to be disseminated publicly. One recent program born from the Nearshore Monitoring Framework is a weekly citizen science initiative housed by Swim Drink Fish. In this initiative, qualitative *Cladophora* biomass assessments have been recorded weekly (during set seasons) by the Niagara Coastal Community Collaborative for the past three years, and the data are fed directly to ECCC. A supporting mobile/web application is under development to make the data more easily applied to future decision-making, and there are plans to compare beach observations to drone data starting in 2021. Data from the Nearshore Monitoring Framework are being developed into an online visualization tool that is also likely to incorporate other monitoring and research (e.g., current LiDAR work). Despite numerous complementary and promising initiatives, published information remains sparse pending further data collection, analysis, and discussion on applications for decision-making.

Closing discussion ('open floor')

The idea of alternative hypotheses – as opposed to common practice of focusing only on the hypothesis and null hypothesis – is relevant to looking at the effects of multiple stressors. Literature by Chamberlin was recommended. Chamberlin's first paper, printed in *Science* in 1890, is linked here; however, a reprint of this paper, printed in the *Journal of Geology* in 1897, is the more commonly-referred to 'original work' that many are familiar with (which was revised to include more geology-specific language).

In addition, we posed a final question on potential implications of the proposed (now passed) changes to the *Conservation Authorities Act* on monitoring activities. Although actual implications will be observed over time, it was thought that member municipalities would continue to support ongoing monitoring activities already provided by Conservation Authorities, and so this knowledge capacity should be generally maintained.

SECTION 3: WORKSHOP ACTIVITY

Background

In August 2016, we tested a criteria-based ranking approach for selecting or short-listing (i.e., reducing) monitoring indicators during a workshop in the Muskoka River Watershed. We developed this approach using elements from two environmental assessment tools: simple weighted and Leopold matrices.

To further develop this approach and explore its potential application, we requested workshop participants complete a criteria-based ranking activity. The 22 criteria and 18 indicators listed in Section 1 were incorporated into a table, in which scoring on a 1-5 scale was completed in the intersecting cells. A score of "1" meant the indicator did not meet the criterion at all, while a score of "5" meant the indicator fully met the criterion. Participants were asked to complete the activity individually and were instructed to only score those indicators and criteria they felt were relevant to the cumulative effects assessment of nutrients and/or algae. In addition, participants were asked to provide a "yes/no" answer to the statement "I would (or do) use this indicator."

Seven activities were returned, with varying degrees of completion (i.e., some were completed in their entirety, while others were partially completed due to time constraints – one had only the first column, total phosphorus, scored). Scores were averaged then summed for each indicator. Then, a weighted average score was calculated by multiplying the average by the percentage of people who responded for each indicator/criterion. Individuals were only asked to score the indicators/criteria they would use, and so a weighted average was necessary to reflect indicator preferences. This approach also supports the process of collaborative indicator selection, even without the persons in the room together. Total phosphorus was calculated out of a total of seven respondents, while the other indicators were calculated using a denominator of six.

Results

Figure 2 illustrates the indicators in order of highest to lowest calculated score (e.g., weighted average) shown in green, with unweighted averages shown in blue. As you can see, the top five indicators our responding participants recommend are total phosphorus, dissolved oxygen, water temperature, *Cladophora* biomass, and nitrate.

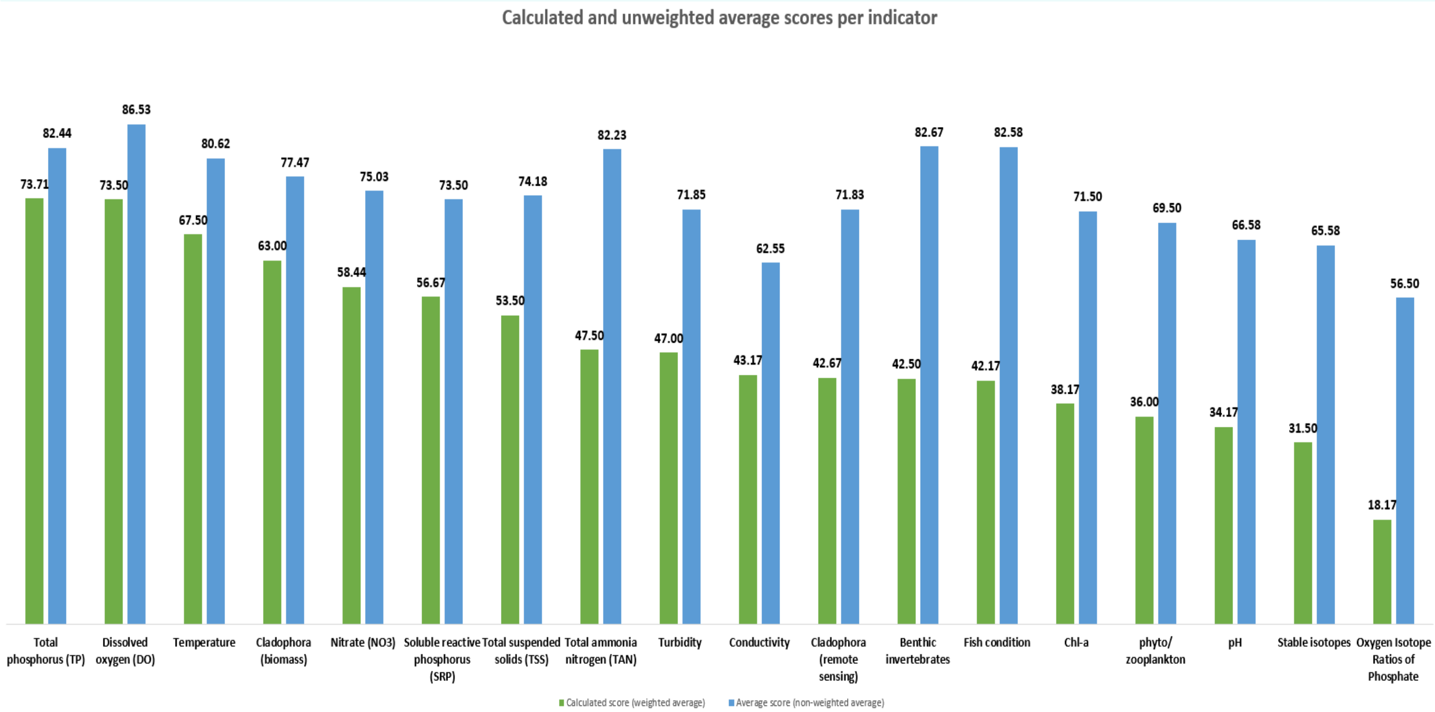

Figure 2. Calculated (weighted) and unweighted average scores per indicator, from highest to lowest calculated score.

Table 1 provides a comparison of three different approaches for selecting indicators used in this study: calculated (weighted) score, average (unweighted) score, and "yes/no" responses. We propose using the calculated (weighted averaged) scores for determining the top indicators, as these scores most reflect the collective preferences of participants based on consideration of the criteria; however, the other two approaches are included to demonstrate the differences in potential indicator lists based on which approach is applied. It is important to note that, due to the broadly interpretable question asked (i.e., with no single endpoint specified – by design, as we were interested in how participants would interpret algae-nutrient relationships), unweighted average scores may more closely reflect individual interpretations of the endpoint being measured than other approaches do.

Four of the top five indicators are identical (ordered differently) between the calculated scores and yes/no frequency counts; nitrate and soluble reactive phosphorus are fifth indicators unique between the two columns. Eight of the top 10 indicators are common to all three columns, shown in Table 1 as white-colored cells. The two indicators that are not common to all three columns (but may be shared between two columns) are shaded in grey cells in each column.

Temperature and *Cladophora* biomass in the top five indicators of the first and third columns are replaced by benthic invertebrates and fish condition in the unweighted averages column. Benthic invertebrates were unique to the unweighted averages, while fish condition also appeared in the yes/no frequency counts. *Cladophora* by remote sensing was unique to yes/no frequency counts, while turbidity and conductivity were both unique to the calculated averages.

Table 1. Comparison of top 10 indicators from each of three approaches used in this study. The red line separates the top five indicators.

Top 10 indicators according to three approaches, ordered from highest to lowest counts		
CALCULATED (weighted average)	**AVERAGE (unweighted average)**	**YES/NO (frequency counts)**
Total phosphorus (TP)	Dissolved oxygen (DO)	*Cladophora* (biomass)
Dissolved oxygen (DO)	Benthic invertebrates	Total phosphorus (TP)
Temperature	Fish condition	Temperature
Cladophora (biomass)	Total phosphorus (TP)	Soluble reactive phosphorus (SRP)
Nitrate (NO_3)	Total ammonia nitrogen (TAN)	Dissolved oxygen (DO)
Soluble reactive phosphorus (SRP)	Temperature	Nitrate (NO_3)
Total suspended solids (TSS)	*Cladophora* (biomass)	Total suspended solids (TSS)
Total ammonia nitrogen (TAN)	Nitrate (NO_3)	*Cladophora* (remote sensing)
Turbidity	Total suspended solids (TSS)	Fish condition
Conductivity	Soluble reactive phosphorus (SRP)	Total ammonia nitrogen (TAN)

Further reading and follow-up

This summary report is available online (at least until the end of 2021) via our study website, below. All other study resources – summaries from other phases, publications, presentations, etc. – are also found on the resources page of our website.

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee (ORE #42584). If you have questions for the Committee contact the Office of Research Ethics, at 1-519-888-4567 ext. 36005 or ore-ceo@uwaterloo.ca.

For more information visit **www.GrandErieStudy.ca** or email us:

Elaine Ho e23ho@uwaterloo.ca
Denise Ding z59ding@uwaterloo.ca

We thank our participants for their contributions!