Analyzing and Comparing Different Data Driven Methods for Hydrological Forecasting to Understand Dam Construction Requirements

Walter P Moore

Henry Hughes

4A Civil Engineering

May 2023

534 Crimson Court

Oshawa ON L1J 8E2

May 16, 2023

Dr. Brush

Associate Chair, Undergraduate Studies

Department of Civil and Environmental Engineering

University of Waterloo

Waterloo, ON, N2L 3G1

Dear Dr. Brush:

This report, entitled "Analyzing and Comparing Different Data Driven Methods for Hydrological Forecasting to Understand Dam Construction Requirements" was prepared as my 3A work term report. During my work term, I worked on projects dam reinforcement projects. These dams needed to be reinforced due to higher levels of discharge that initially expected. The purpose of this report is to gain additional understanding into how levels of hydrological discharge can be forecasted by using data driven methods.

This report was prepared during my Co-op at Walter P Moore. I would like to thank the team at Walter P Moore, as they allowed me to work on several dam projects which inspired me to write a report that is focused on how data driven methods for hydrological forecasting can be used to create more resilient infrastructure.

This report focuses on the numerical methods that are multiple linear regression (MLR), and extreme learning machines (ELM). While not being the most complicated mathematical tools that can be utilized for this type of analysis, these methods are not too challenging to apply, and allow for standard datasets to be used without much difficulty.

This report was written entirely by me and has not received any previous academic credit at this or any other academic institution. I received no outside help with the report.

Sincerely,

Text, letter

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Henry Hughes  
ID# 20792437

Analyzing and Comparing Different Data Driven Methods for Hydrological Forecasting to Understand Dam Construction Requirements

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# Summary

The aim of the Summary is to convey the main points of a report to senior management personnel who are not usually involved in technical details. For this reason, it is sometimes labeled Executive Summary. It should be written last and must be written in full sentence form while avoiding too much jargon or heavy details. The Summary may be thought of as a mini report of about 250 words (3-4 paragraphs) that must be able to be read and understood in isolation from the main body of the report. It must not exceed one page and should include the scope and purpose of the report (including background/rationale); the technical approach taken, which might include a discussion of the alternatives considered and the major technical findings; and the principal conclusions and recommendations. It must not include tables and figures or a direct reference to tables, figures, and sections contained in the main report.

# Acknowledgements

I wish to thank Professor John Quilty for allowing me to be a part of his research team, which has inspired me to write about this topic. The work his team does is fascinating, and the reason I am focused on learning more about the topic of applied machine learning and statistical analysis in hydrology.

**Table of Contents**

[Summary v](#_Toc131876751)

[Acknowledgements vi](#_Toc131876752)

[List of Figures viii](#_Toc131876753)

[List of Tables ix](#_Toc131876754)

[List of Appendices ix](#_Toc131876755)

[1.0 Introduction 1](#_Toc131876756)

[1.1. General 1](#_Toc131876757)

[1.2. Background 1](#_Toc131876758)

[1.3. Scope and Objectives 1](#_Toc131876759)

[2.0 Multiple Linear Regression 2](#_Toc131876760)

[2.1. Multiple Linear Regression Formulas 2](#_Toc131876761)

[2.2. Variable Dependency 3](#_Toc131876762)

[3.0 Extreme Learning Machine 3](#_Toc131876763)

[3.1. Length of report 3](#_Toc131876764)

[3.2. Structure 3](#_Toc131876765)

[3.3. Formatting and Styling 4](#_Toc131876766)

[3.3.1. Font and Spacing 5](#_Toc131876767)

[3.3.2. Margins and Page Numbers 5](#_Toc131876768)

[3.3.3. Units (SI) 6](#_Toc131876769)

[3.3.4. Figures 6](#_Toc131876770)

[3.3.5. Tables 9](#_Toc131876771)

[3.3.6. Equations 10](#_Toc131876772)

[3.3.7. Software and Spellcheck 11](#_Toc131876773)

[3.4. Citations and References 11](#_Toc131876774)

[3.4.1. Journal Papers 12](#_Toc131876775)

[3.4.2. Books 12](#_Toc131876776)

[3.4.3. Technical Reports 13](#_Toc131876777)

[3.4.4. Electronic Sources 13](#_Toc131876778)

[3.4.5. Referencing for Figures and Tables 14](#_Toc131876779)

[4.0 Additional Resources 16](#_Toc131876780)

[5.0 Conclusion 16](#_Toc131876781)

[6.0 Recommendation (optional) 17](#_Toc131876782)

[References 18](#_Toc131876783)

# List of Figures

[**Figure 1:** Sample summary page 6](https://uofwaterloo-my.sharepoint.com/personal/dlacroix_uwaterloo_ca/Documents/Work%20Reports%20-%20CEE%20UW/CEE%20WKRPT/Work%20Report%20Guidelines/Technical%20Report/Template%20for%20technical%20report%20draft%202.docx#_Toc69472653)

[**Figure 2:** Sample of a Table of Contents with more than three appendices and lengthy lists of tables and figures 7](https://uofwaterloo-my.sharepoint.com/personal/dlacroix_uwaterloo_ca/Documents/Work%20Reports%20-%20CEE%20UW/CEE%20WKRPT/Work%20Report%20Guidelines/Technical%20Report/Template%20for%20technical%20report%20draft%202.docx#_Toc69472654)

[**Figure 3**: Example of a table included in a work report. It should be noted that the table is presented immediately after it is first introduced in the text. 8](https://uofwaterloo-my.sharepoint.com/personal/dlacroix_uwaterloo_ca/Documents/Work%20Reports%20-%20CEE%20UW/CEE%20WKRPT/Work%20Report%20Guidelines/Technical%20Report/Template%20for%20technical%20report%20draft%202.docx#_Toc69472655)

[**Figure 4:**Example of an equation layout in a work report 9](https://uofwaterloo-my.sharepoint.com/personal/dlacroix_uwaterloo_ca/Documents/Work%20Reports%20-%20CEE%20UW/CEE%20WKRPT/Work%20Report%20Guidelines/Technical%20Report/Template%20for%20technical%20report%20draft%202.docx#_Toc69472656)

[**Figure 5:** Example of a citation for a table taken from a published source 14](https://uofwaterloo-my.sharepoint.com/personal/dlacroix_uwaterloo_ca/Documents/Work%20Reports%20-%20CEE%20UW/CEE%20WKRPT/Work%20Report%20Guidelines/Technical%20Report/Template%20for%20technical%20report%20draft%202.docx#_Toc69472657)

[**Figure 6:** Example of a citation for a figure and data taken from a published source 14](https://uofwaterloo-my.sharepoint.com/personal/dlacroix_uwaterloo_ca/Documents/Work%20Reports%20-%20CEE%20UW/CEE%20WKRPT/Work%20Report%20Guidelines/Technical%20Report/Template%20for%20technical%20report%20draft%202.docx#_Toc69472658)

# List of Tables

[**Table 1:** Sample Table 9](#_Toc69472344)

# List of Appendices

[**Appendix A**: Explanation of Symbols Used for Marking Work Report Grammar. 18](#_Toc69472458)

[**Appendix B:** Avoiding Common Grammar Errors 19](#_Toc69472459)

[**Appendix C:** Proofreading Checklist 20](#_Toc69472460)

[**Appendix D:** Writing Tips 21](#_Toc69472461)

Please note that these sections are only required if you are including many (greater than 10) figures, or tables.

# Introduction

## General

There are many benefits to understanding how water moves and, and how the movement of that water changes over time. It allows cities to be constructed in the right locations, and with the correct water resources asset, ensures proper flood protection measures can be put in place to protect critical infrastructure, and will allow society to function in a way that allows people to utilize the benefits of water, without the drawbacks. This is a challenge that engineers must face, and use technology to better understand, so that moving forward, infrastructure can be created in the most effective way possible to serve individuals around the world.

## Background

Water resources assets are critical for any society to function. This primarily includes the rivers, lakes, and groundwater from which we obtain all our potable water. It also includes physical assets such as dams, water and wastewater treatment plants, desalination plants, and water distribution networks. To ensure these physical assets will be able to last into the future, their owners must be able to forecast their future demand. For dams, the demand is how much upstream discharge will pass through the dam. Accurately forecasting this discharge will allow dams of the correct size to be constructed, increasing their longevity.

## Scope and Objectives

There are several ways that discharge through a dam can be forecasted. Historically, physical methods have been used. These were primarily a function of historical precipitation, and the geography of a specific river basin. This would allow engineers to forecast discharge through dams so their size could be determined. Recently, data driven methods have been used to forecast hydrological discharge. These methods are more efficient, since they can be done with basic data, and physical methods that require lots of empirical data are difficult to come up with, particularly in a short amount of time. This report will detail and apply two data driven methods; 1. Multiple Linear Regression, and 2. Extreme Learning Machines. The results will then be analyzed, and future methods will be explored.

# Multiple Linear Regression

Multiple linear regression is a simple statistical tool that is used to create forecasts for a specific variable of interest, based on a variable number of explanatory variables. In essence, it identifies the linear relationship between a set of input explanatory variables and an output variable. The mathematical model allows the output variable to be forecasted into the future by utilizing a linear equation that projects the dependent variable.

## Multiple Linear Regression Formulas

The general equation for MLR is as follows:

In the above equation, y is the dependent variable, or the output. This variable can be linked to the n independent variables, which are represented by xi. Each of these independent variables are weighted by their coefficients ai. The coefficient ao is a correction term, which allows the curve to be properly fitted. All the other coefficients are what define the relationship between each independent variable xi and the dependent variable y.

To determine whether an independent variable is correlated to the dependent variable in a significant way, a p-value can be used. In linear regression, a p-value of one means that the independent variable in question is perfectly correlated with the dependent variable. A p-value of zero means there is no correlation between the independent and dependent variables. The p-value is calculated based on a t-test of the estimated coefficient, which compares the estimated coefficient to the standard error of the estimate.

The goal of MLR is to determine the values for the coefficients ai such that the function in equation one above best fits the data, which is typically done by minimizing the sum of the squared errors between the actual values of the dependent variable and the predicted values of the dependent variable. This can all be done using basic tools such as Microsoft Excel or Python.

## Variable Dependency

A benefit to MLR is that there isn’t any connection between the independent variables in the equation. However, it is important to analyze the variables in a way that results in a model that is statistically efficient. This means that multicollinear variables should not be included in the model, and all variables should be statistically significant.

# Extreme Learning Machine

An ELM is a type of machine learning algorithm that is used

## Length of report

The text of the main section of work term reports, from the beginning of the Introduction to the Conclusions, should be within the range of 3000 to 5000 words, excluding tables and figures. Reports that are shorter or longer than this size may be rejected

## Structure

Work term reports should be organized in the following sequence.

Front cover – no page number

Letter of Submittal – no page number

Title Page – considered to bei, but not indicated

Summary (or Executive Summary) – page ii

Acknowledgments (optional) – page iii if included

Table of Contents – page iii or iv, depending on whether acknowledgements are included

List of Tables – page iv or v, depending on the length of the list and whether acknowledgments are included

List of Figures – page iv or v, depending on the length of the list and whether   acknowledgments are included

List of Appendices (if appropriate) – page iv or v, depending on the length of the list and whether acknowledgments are included

Main Section – beginning with the Introduction, page 1

Conclusions

Recommendations (optional)

References

Glossary (optional)

Appendices (optional)

## Formatting and Styling

Tables and Figures should be numbered consecutively throughout the report (1, 2, 3, 4, etc.). Headings or captions for tables are placed above the table while those for figures are placed below the figure. Additionally, make sure that you are introducing the figure or graph using a sentence or two before the actual graph.

### Font and Spacing

Reports should be typed using double (2X) line spacing, using 12-point Times New Roman. Bold type font should not be used to emphasize words within the text, although bold headings are acceptable.

Except for the Summary, Table of Contents, Lists of Tables and Figures, References, and Acknowledgements, you should not start each section on a new page. That is, beginning with the Introduction, each section should follow immediately after the previous one. Large blank spaces should not be left between sections of the main body. However, if the text is block formatted with no indentation of the first lines of the paragraphs, as these guidelines are, an extra space should be inserted between paragraphs.

### Margins and Page Numbers

A minimum width of 25 mm should be used for the top, bottom, and right margins. All text should be aligned with the left margin and justified, except for indented quotes.

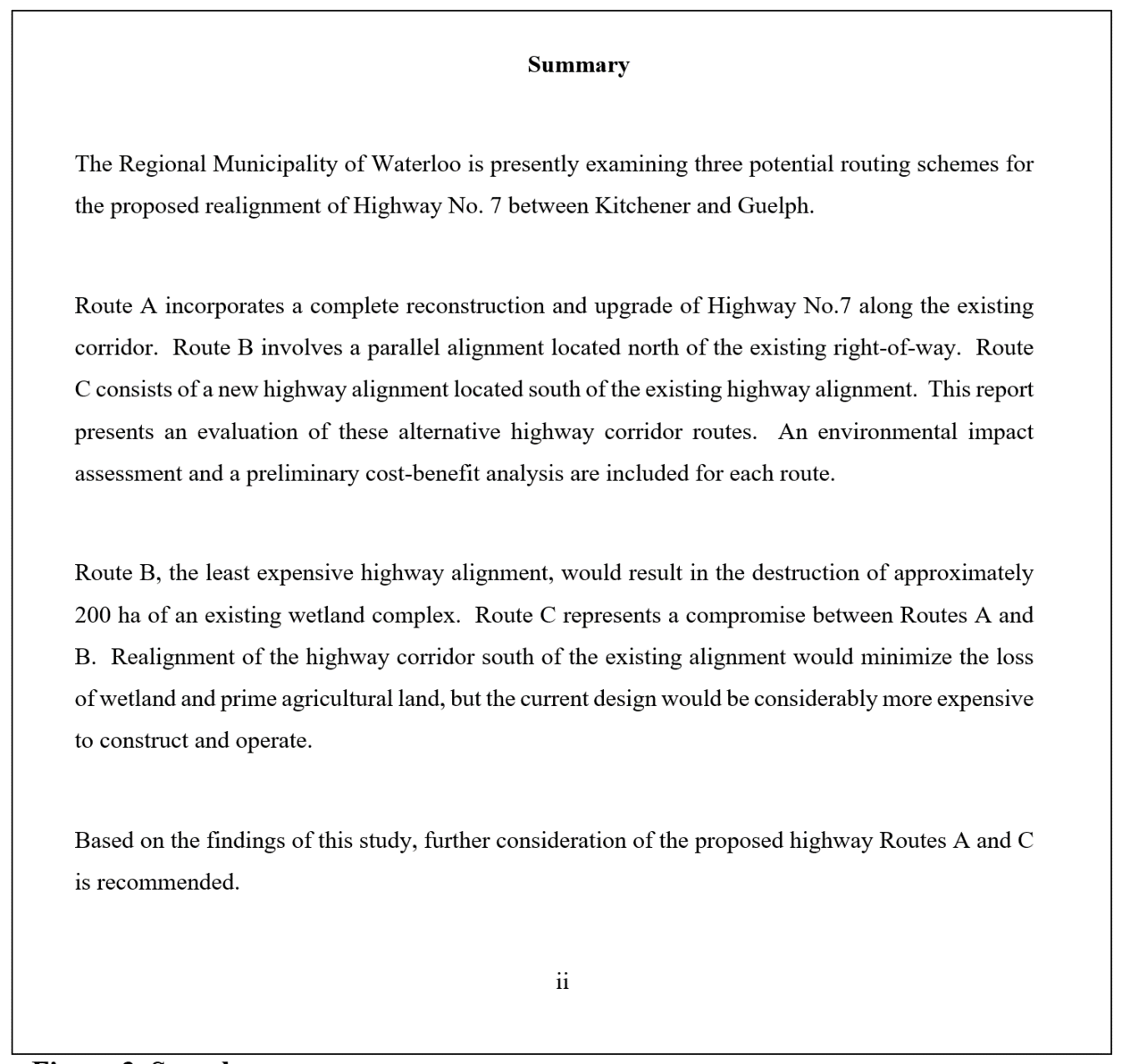
Pages must be numbered. The numbers are to be located at the bottom of the page and can be placed in the middle of the page or in the right-hand corner. The numbering must be consistent throughout the report. Pages for the introductory sections of a report should be numbered using lower-case Roman numerals. The first page to be numbered with an Arabic numeral is the first page of the Introduction section.

### Units (SI)

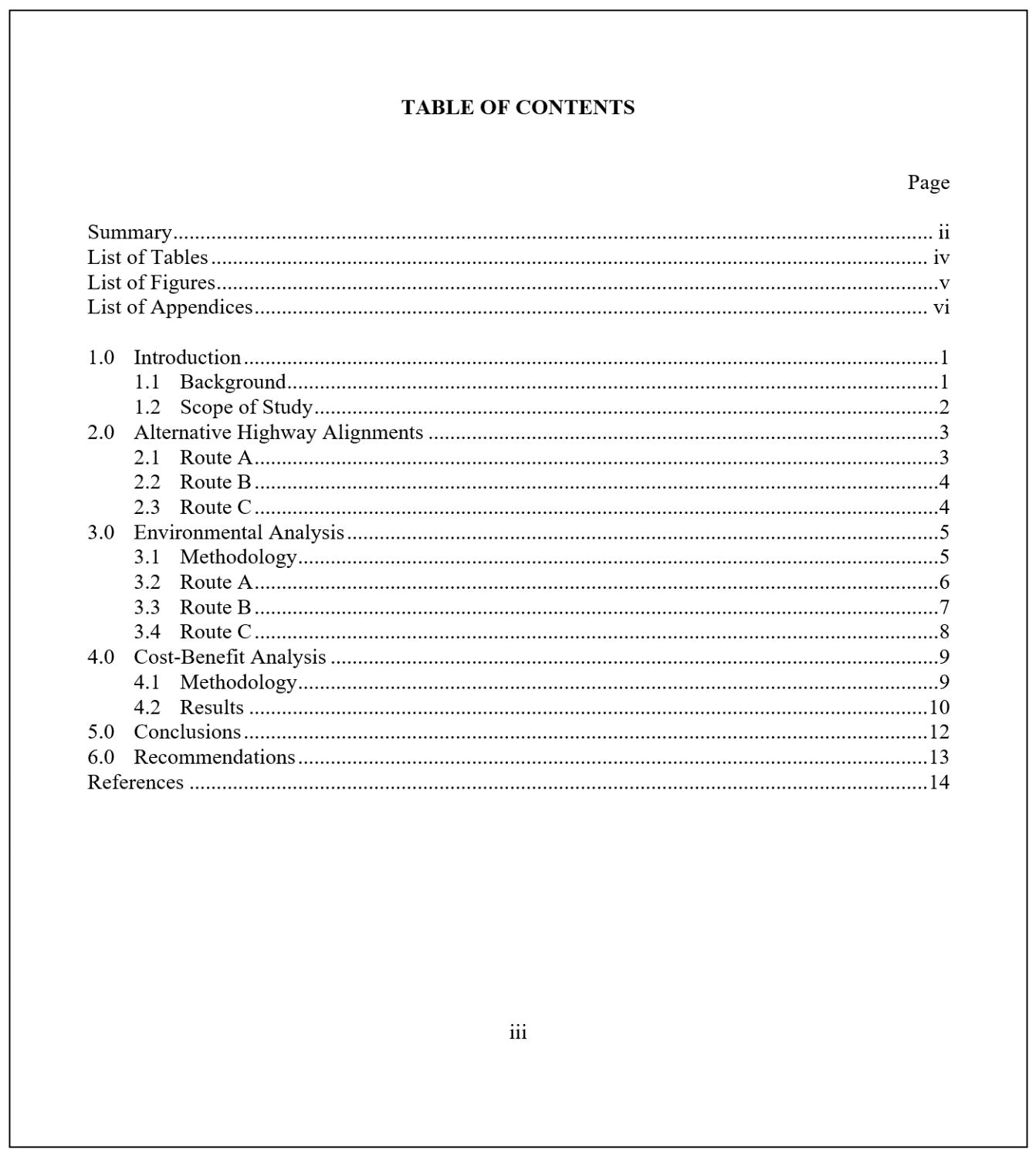
The International System (SI) of units should be used throughout the report. If the British (or Imperial) system of units is used during the work term, then SI equivalents must be quoted in parentheses immediately following the Imperial units.

### Figures

The current section serves two purposes: 1) to demonstrate how a figure should be referenced, and 2) to demonstrate the expected, or similar, formatting of key components comprising the report. Figure 1 shows a representative Summary with its key elements.

Figure 2 shows a representative table of content with all of its key elements. Note that separate list of tables, figures, and appendices are required.

**Figure 1:** Sample summary page



**Figure 2:** Sample of a Table of Contents with more than three appendices and lengthy lists of tables and figures

When presenting tables, or figures, it is always required to first introduce the table by providing a short description of what it presents while also referencing it. Figure 3 shows a screen capture of how tables should be introduced and formatted. Note that tables should never be presented as figures (e.g., Fig. 3), even if reproduced from another report, and is only presented in the current form to illustrate formatting expectations.

### Tables

**Figure 3**: Example of a table included in a work report. It should be noted that the table is presented immediately after it is first introduced in the text.

Table 1 is an example of a possible table that you might include in your report. Note that this table is for illustration purposes only. Table 1 is a decision matrix, not all successful reports require a decision matrix. Do not generate alternatives for the sake of generating alternatives. Furthermore, note how Table 1 was reproduced into a table and properly referenced.

**Table 1**: Sample Table

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Proposed Alternative | All Design Objectives Achieved | Suitable for Site | Impacts on Environment | Cost Effectiveness | Recommended for Conceptual Design |
| No Action | No |  |  |  | No |
| Replacement in Kind | No |  |  |  | No |
| Multiple Culverts | No |  |  |  | No |
| Bottomless Culverts | Yes | Moderate | Moderate | Moderate | Yes |
| Embedded Culverts | Yes | High | Low | Moderate | Yes |
| \*Reproduced from “Mckillop 2020” | | | | | | |

### Equations

Equations that are referred to later in the text should be numbered with right-justified Arabic numerals in parentheses. Number equations consecutively throughout the report (1, 2, 3, 4, etc.). Figure 4 illustrates the typical placement of an equation within a report. If the equation is referred to after it has been introduced, refer to it using the same notation used for figures and tables (e.g. “Equation 1”).Text, letter

Description automatically generated

**Figure 4:**Example of an equation layout in a work report

### Software and Spellcheck

Work term reports should be prepared on computer software that is accessible to the author during an academic term so that corrections may be readily undertaken. The use of an electronic spell-checker is expected. Note, however, that the Canadian version is expected if it differs from the U.S. version.

## Citations and References

Citations and references are meant to give authority to the contents of the report and to direct the reader to more details. General references not cited in the report should not be included in the reference list.

An important principle in citing published literature is that an individual reading a report should readily be able to obtain the reference materials. As much as possible, avoid citing obscure papers, course notes and personal communications, for example, as these may not be accessible to a reader of a report. You can give credit to these sources of information in your letter of submittal or the acknowledgments.

There are several alternative styles of documentation. This work report follows the American Psychological Association (APA) style, which is summarized in both Hacker (1996) and Buckley (2003). These books also include discussions of citations and references. These books are available in the University of Waterloo Bookstore or the library. Other references are available in section PE 1408 of the Dana Porter Library.

The following report excerpts (in italics) demonstrate common examples that show how references to literature should be cited in the text and incorporated in the reference list.

### Journal Papers

*Lafontaine (1988) has measured wind loads on very tall exhaust stacks in the mining areas of the Sudbury region.*

or

*Several authors have measured wind loads on tall exhaust stacks in the mining areas of the Sudbury region (Lafontaine, 1988; Yung, 1982), and these measurements have been used to establish design wind loads.*

The reference list would then contain the following:

Lafontaine, P.W. (1988). Wind load measurements on smelter exhaust stack in the Sudbury region. *Journal of Wind Engineering*, 17(5), 171–183.

Yung, F. S. (1982). Drag coefficients for large structures. *Journal of Structural Engineering*, 21(3), 99-103.

Italics are used to emphasize the document title used in a library search because authors of individual papers published in journals are not listed in library catalogues.

### Books

*McCarthy (1988) describes the analytical method that is most commonly used for slope stability analysis of the marine clays in the St. Lawrence Valley.*

The reference list would then contain the following:

McCarthy, D.F. (1988). *Essentials of Soil Mechanics and Foundations: Basic Geotechnics*. Prentice Hall, Englewood Cliffs, NJ.

### Technical Reports

*Geometric design standards for major arterial roads are specified by the Ontario Ministry of Transportation (Highway Design Branch, 1992).*

The reference list would then contain the following:

Highway Design Branch. (1992). *Geometric Design Standards for Ontario*. Ministry of Transportation of Ontario, Downsview, ON.

### Electronic Sources

Electronic sources are relatively new, and many suggestions for methods of referencing them are available. The department has selected the following guidelines. The important consideration is that the reader needs to be able to access your sources. Items are to be cited in the text with the author and date as usual. For example,

*Nutall (1999) has published a different opinion of MP3.*

This item would appear in the list of references as follows:

Nutall, C. (25 September 1999). It's on MP3 but I like it. http://news.bbc.co.uk/hi/english/sci/tech/newsid\_443000/443086.stm (retrieved 9April 2000).

The objective of referencing is to direct the reader to the original source. The URL and the search engine with key words are used to locate the new reference. If the author is not identified, use the name of the company or organization that posted the web site. Use the date last updated as the date of publication. If there is no date listed, use the date you accessed the site. The date of access is important to include in any case because the web page may have changed since you used it, and the reader may not be able to find the information without knowing the date.

### Referencing for Figures and Tables

All data, figures, diagrams, photographs and tables that are not your own must be cited. Even figures, diagrams and tables that you modify or adapt from another source must be cited accordingly. Failure to properly cite material that is not your own may result in a violation of academic integrity for plagiarism.

The reference or citation for the figure, photograph or table should be placed within the figure or table caption. Examples are shown in Figure 5 and Figure 6. The references cited in your figure/table captions must be included in your list of references and should formatted in the same manner as described in Sections 7.1 through 7.4 depending on the reference type.

It should be noted that formal publication of your work, for example in a book, journal paper or conference proceedings, may also require you to obtain copyright permission from the original publisher or author of the source material, even when that material is properly cited. Guidelines for copyright requirements will be specified by the book, journal or conference publisher.

Table

Description automatically generatedChart, line chart

Description automatically generated

**Figure 6:** Example of a citation for a table taken from a published source

**Figure 5:** Example of a citation for a figure and data taken from a published source

# Additional Resources

To aid in your writing many additional resources have been prepared. Please use these documents available on Piazza, and Learn, to avoid common mistakes and improve your communication to achieve the best possible mark.

**Appendix A** contains an explanation of symbols that may be used when marking grammar. This document goes over many grammar mistakes that are made when writing a report. Additionally, it showcases incorrect and than the corrected mistakes.

**Appendix B**, common grammar mistakes. This document goes over many different grammar mistakes and provides several strategies on how to avoid these mistakes. There is also more advice for proper punctuation, word choice, and correcting awkward sentences.

**Appendix C**, proof reading checklist. This document contains a list of 15 things that are simple to check to help with your grammar. This checklist is recommended to be apart of your proofreading.

**Appendix D**, writing tips. Contains several tips, including which tense to use, and formatting. Contains more information on referencing, tables, figure and letter of submittal.

**Appendix E**, sample literature review. Appendix E contains two sample literature reviews, they are to serve as a reference as to what a literature review of the ten credible sources be. While they may not follow the guidelines recommended in this document, please use them to help form your understanding of literature reviews.

# Conclusion

Conclude the report with a short summary of the current state-of-the-art on the topic, conclusions from your application problem, and provide recommendations for future study based on questions or issues that remain and any flaws that exist in the literature.

The conclusions should only contain statements that follow logically from the content of the report. The aim is to reinforce the findings of the report. New information should not be presented in the conclusions section, and it should not refer directly to components of the main body of the report, nor contain tables, figures, or references. For example, "The temperature effects, analyzed on page 6 showed that ......." is unacceptable. Bulleted or numbered lists should be avoided.

# Recommendation (optional)

The Recommendations contain statements about additional work that might be required. For example, "Insufficient data were available for this study to establish conclusively the temperature effects, and a sequence of laboratory strength tests is recommended." Conclusions are required for your Work Report; however, the recommendations are not always necessary. Conclusions and Recommendations can be combined into one section.

# References

Andrews, G.C. and Ratz, H.C. (1996).  *Introduction to Professional Engineering* (5th ed.). University of Waterloo, Waterloo, ON.

Buckley, J. (2003). *Checkmate: A Writing Reference for Canadians*. Nelson Canada, Scarborough, ON.

Mckillop, B. (2020, December). *ENVE 100* *Alternative design solutions.* [PowerPoint slides]

Trotter, B. (2020). *Guidelines for Writing Work Term Reports.* (Version 3.4). University of Waterloo, Waterloo, ON.

(2020). *Guidelines for Writing a Self Study Work Term Report.* University of Waterloo, Waterloo, ON.

**Appendix A:** Explanation of Symbols Used for Marking Work Report Grammar.

Please see separate document on Learn/Piazza.

Appendix B: Avoiding Common Grammar Errors

Please see separate document on Learn/Piazza.

Appendix C: Proofreading Checklist

Please see separate document on Learn/Piazza.

Appendix D: Writing Tips

Please see separate document on Learn/Piazza.