PNNL-15197

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

Preparing PNNL Reports with LaTeX

S. R. Waichler

June 2005

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
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Executive Summary

LaTeX is a mature document preparation system that is the standard in many scientific and academic workplaces. It has been used extensively by scattered individuals and research groups within Pacific Northwest National Laboratory (PNNL) for years, but until now there have been no centralized or laboratory-focused resources to help authors and editors. PNNL staff can use the LaTeX document preparation system and the template files presented here to efficiently produce correctly formatted PNNL or Battelle – Pacific Northwest Division (PNWD) reports. Please visit the PNNL-LaTeX Project[(a)] (inside the PNNL firewall) for additional information and files.

In LaTeX, document *content* is maintained separately from document *stucture* for the most part. This means that the author can easily produce the same content in different formats and, more importantly, can focus on the content and write it in a plain text file that does not go awry, is easily transferable, and will not become obsolete due to software changes. LaTeX produces the finest print quality output; its typesetting is noticeably better than that of Microsoft (MS) Word. This is particularly true for mathematics, tables, and other types of special text. Other benefits of LaTeX include:

- easy handling of large numbers of figures and tables
- automatic and error-free captioning, citation, cross-referencing, hyperlinking, and indexing
- excellent published and online documentation
- free or low-cost distributions for Windows/Linux/Unix/Mac OS X.

This document serves two purposes: 1) it provides instructions to produce reports formatted to PNNL requirements using LaTeX, and 2) it provides examples of many solved formatting challenges, and the document itself is in the form of a PNNL report. Authors can use this document or its skeleton version (with formatting examples removed) as the starting point for their own reports. The pnnreport.cls class file and pnnl.bst bibliography style file contain the required formatting specifications for reports to the U.S. Department of Energy. Options are also provided for formatting PNWD (non-1830) reports. This documentation and the referenced files are meant to provide a complete package of particulars for laboratory authors and editors who wish to prepare technical reports using LaTeX.

The Portable Document Format (PDF) version of this report contains hyperlinks to facilitate navigation. Hyperlinks are provided for all cross-referenced material, including section headings, figures, tables, and references. Not all hyperlinks are colored but will be obvious when you move your mouse over them. This document is available at the PNNL-LaTeX[(a)] website inside the PNNL firewall, or at the PNNL Publications external website.[(b)]

(a) http://latex.pnl.gov/
(b) http://www.pnl.gov/main/publications/

Acknowledgments

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(Example) Abbreviations and Acronyms

ALE	Arid Lands Ecology Reserve
CFEST	Coupled Fluid, Energy, and Solute Transport model
DEM	Digital Elevation Model
ET	evapotranspiration
HMS	Hanford Meteorological Station
Mm^3	millions of cubic meters
PNNL	Pacific Northwest National Laboratory
PNWD	Battelle Pacific Northwest Division
SGM	Sitewide Groundwater Model
USGS	United States Geological Survey
WY	water year: the year ending September 30 (10/1–9/30)
YTC	Yakima Training Center

(Example) Notation

D	flow duration
f	factor limiting maximum infiltration
H	heat flux from upper soil layer
i	infiltration rate
$i_{\max}$	maximum infiltration rate
P	precipitation
Q	flow rate
Q_p	peak flow rate

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1.0 Introduction

This guidance document and the files at PNNL-LaTeX Project[(a)] are provided for Pacific Northwest National Laboratory (PNNL) authors and editors who wish to produce laboratory reports with the LaTeX document preparation system. Currently, the PNNL-LaTeX Project is aimed primarily at users who are already familiar with LaTeX and mainly need help with meeting PNNL document requirements.

LaTeX (pronounced Luh-tek, Lah-tek, or Lay-tek) is a structured typesetting system that can produce technical reports that are better looking than output from what-you-see-is-what-you-get (WYSIWYG) word processors such as Microsoft Word—with less effort. LaTeX[(b)] is a mature system that is the standard in many scientific and academic workplaces and has been used extensively by scattered individuals and research groups within PNNL for years. In LaTeX, document *content* is, for the most part, maintained separately from document *stucture*. This means that the author can easily produce the same content in different formats and, more importantly, can focus on the content and write it in a plain text file that never goes awry, is portable, and is not subject to obsolescence through software changes. In contrast, word processors mix content and formatting commands together in a binary file that can do strange and unexpected things, especially when elements like equations, figures, and tables are involved. Technical reports such as those we write at PNNL typically have many of these elements, and they often change during the course of writing the manuscript. LaTeX makes updates easy because figures, tables, and any other report elements that exist in separate files are included in the report document only when the author runs the formatting engine to produce the finished report. The following are some other benefits of LaTeX for PNNL authors and editors:

- Typography is highest quality, especially for mathematics, tables, and other kinds of specialized text.
- Large numbers of figures and tables are handled easily.
- Captioning, citation, cross-referencing, hyperlinking, and indexing are automated and error-free.
- LaTeX has a wide base of users and developers, both in the United States and internationally.
- Excellent published and online documentation is available.
- LaTeX is available in free or low-cost distributions for Windows/Linux/Unix/Mac OS X.

The final product is a file in Portable Document Format (PDF) or Postscript (PS). The PDF file can include hyperlinks, allowing the online reader to easily navigate in your document among all elements that are cross-referenced, including headings, figures, tables, and references.

(a) http://latex.pnl.gov/
(b) http://www.tug.org/

The main drawback of LaTeX is the investment of time to learn how to use it. This document and the associated files should greatly reduce the time needed to learn how to produce a PNNL report. Another drawback for some is the lack of ability to track changes in drafts involving multiple authors. However, many authors and editors prefer to work from marked-up paper copies when revising a document. The ASCII text file that contains the report content can of course be readily shared and revised with any text editor. Also, comments can be written in the PDF file using Adobe Acrobat.

Section 2 of this document contains advice and instructions on producing reports using the tools provided here. Section 3 contains examples of figures, tables, footnotes, and other material that demonstrate some ways to format these elements. Many "tricks" are provided. Appendix A provides more examples of figure and table formats and shows how these are captioned in an appendix. Appendix B provides more examples of mathematics. Appendixes A and B also have their own reference lists, which are produced independently from the reference list for the main text. Appendix C provides an example of nomenclature definitions in two-column format and gives additional examples of mathematical symbols. Finally, an example distribution list is provided at the end.

Training in LaTeX for "newbies" is available on a per-project basis and may be offered to groups if sufficient demand arises. If you have questions or are interested in LaTeX assistance or training, please contact Scott Waichler/Hydrology (509-372-4423, scott.waichler@pnl.gov), Courtenay Turner/Publication Design (509-375-2702, courtenay.turner@pnl.gov), or Sheila Bennett/Editing (509-375-6679, sheila.bennett@pnl.gov). We hope to add examples to this document in the future and continually improve the project offerings, so please contact us with your questions, comments and implementations. For general guidance on Laboratory standards, users should consult the PNNL Author's Guide[a].

NOTE: The *example* material in this document was borrowed from real reports and edited for demonstration purposes. The subject matter content of the example material is not relevant here and generally does not make literal sense in the context of this document. Brackets "[]" are used to denote large blocks of example text.

(a) http://www.pnl.gov/ag/

2.0 Instructions

This document is aimed primarily at users already familiar with LaTeX. Some introductory information about the software and related tools is provided, followed by the PNNL-specific advice that is the main emphasis of this document.

2.1 LaTeX Software and Documentation

For a great deal of advice on getting started and using LaTeX, please visit the TeX Users Group (TUG).[a] Some of their advice on obtaining LaTeX follows:

> "If you are looking to install a complete system, we recommend TeX Live: you either can download the ISO images from the Comprehensive TeX Archive Network (CTAN) to burn your own discs, or join TUG or another user group and have them sent to you, or you can buy TeX Live without joining. If you want to download a smaller distribution, we recommend teTeX for Unix, fpTeX for Windows, and gwTeX for Mac OS X. (These form the basis of TeX Live.) There are many other TeX implementations, some free, some shareware, some commercial."

A summary of distributions and their websites is given in Table 2.1. All of these versions of LaTeX are free or low-cost. For Mac OS X users, TeXShop provides a combined editor and previewer. The TeXShop page also has links to obtain an OS X-specific teTeX distribution, a Bibtex bibliography manager application, a LaTeX-aware spell checker, and other useful extras. More advice on selecting and setting up LaTeX distributions will be provided in the future if sufficient interest exists.

Table 2.1. Recommended LaTeX distributions

Operating system	Distribution	Website
Linux/Unix	TeTeX	`http://www.tug.org/teTeX`
Mac OS X	TexShop	`http://www.uoregon.edu/~koch/texshop/texshop.html`
Windows	MikTeX	`http://www.miktex.org`
Windows	PCTeX	`http://www.pctex.com`

Two must-have book references for LaTeX users are *LaTeX: A Document Preparation System* by (Lamport 1994) that covers the basics and *The LaTeX Companion* by Mittelbach et al. (2004) that provides additional and essential information for frequent users. The first edition of *The LaTeX Companion* by Goosens et al. (1994) is still useful but covers less ground. Additional advice for working with graphics is provided in *The LaTeX Graphics Companion* (Goosens et al. 1997).

(a) http://www.tug.org/

Additional advice for working with web content (PDF, HMTL, XML) is provided in *The LaTeX Web Companion* (Goosens and Rahtz 1999).

Finally, the Usenet newsgroup comp.text.tex is the best place to go for advice on problems the books do not cover. Anyone can search this newsgroup using the appropriate Google Groups webpage.(a) To post queries, users just join the group with a username and password. Although PNNL does not have a newsgroup server, you can post queries and read the responses by interactively browsing the Google page.

2.2 Strategies for Producing PNNL Reports with LaTeX

At present, PNNL editors and design specialists are unfamiliar with LaTeX details, and authors need to submit work to them as paper or electronic PDF drafts. However, there is hope that this situation will change in the near future, and one editor and one document design specialist are currently learning LaTeX. LaTeX processing is very good, and you can count on producing a correctly formatted report with little formatting intervention if you use the provided class and bibilography style files and the full or skeletal version of this document as your starting point. Only a few minor format changes will typically be necessary for the final document, as prompted by inspection of the output ("visual formatting"). Your main concern as an author will be getting the content right, as it should be.

If a co-author or editor who does not know LaTeX is involved in producing your report, you can provide them a hard copy to mark up and then keyboard the changes yourself in the *.tex file. Alternatively, you can give them the *.tex file and let them keyboard the word and punctuation changes using a text editor such as Emacs, TexShop, or TextPad (or even Word, so long as the file is saved as plain text), returning the *.tex file to you for changes involving LaTeX coding. The other people involved can work around the coding and make most of the content changes themselves, saving some of your time and keeping the overall process as efficient as possible. If you don't already have a favorite text editor, Emacs and the AUCTEX package, or TexShop, are both recommended and will give you syntax color highlighting and full menus for executing all sorts of LaTeX tasks and macros.

In almost all cases you will want the final, deliverable product to be a PDF file and/or hard copy. Making a PDF document is a snap with LaTeX. If your client desires an electronic copy in a different format (e.g., Word), there are three notable solutions:

- If your client just wants pieces from your report, they can copy and paste text and figures from the PDF file using Acrobat Reader.

- If your client needs the whole document, make your PDF file using LaTeX, then convert it to Word using a program such as Scansoft's PDF Converter.(b) This program has worked very well in limited testing by the author and costs around $50.

(a) http://groups-beta.google.com/group/comp.text.tex/
(b) http://www.scansoft.com/pdfconverter/

- Use the converter program latex2rtf[a] to make a Word-friendly Rich Text Format (*.rtf) file directly from your *.tex file. After running the conversion, many things in the resulting file will probably need fixing, but running latex2rtf will still have saved significant time. This program is free.

2.3 PNNL-LaTeX Style Files and Example Documents

Files provided by the PNNL-LaTeX Project are listed in Table 2.2 and described below.

2.3.1 The Format Templates or "Style Files"

Most of the formatting requirements for PNNL reports are defined in the document class file `pnnlreport.cls`. This class uses the LaTeX base report class as the starting point and revises format settings to satisfy PNNL requirements. Some of the required formatting is implemented the report document itself, and it is recommended that you use the source files for either the full or skeleton version of this document as the starting point for your report.

The PNNL style bibliography is implemented with the bibliography style file `pnnl.bst`. This is an author-year format based on the package apalike. The most significant differences from apalike are in the punctuation. For example, periods are not used after author initials.

Almost any format specification can be met with the use of LaTeX packages, add-on style sheets and documentation written by the LaTeX community and made available through CTAN. The following packages are required by the pnnlreport class: ifthen, geometry, times, mathptm, setspace, graphicx, longtable, caption, natbib, fancyheadings, fancybox, booktabs, tocloft, tocvsec2, ragged2e, url, hyperref, html, chappg, footmisc.

The following additional packages were used to produce this document: bibunits, rotating, multicol, calc, needspace, ulem, paralist, color, epsfig, pstcol, pstricks, pst-node, overpic, amssymb, amsmath, bm, textcomp, dcolumn, threeparttable, array, appendix, afterpage, flafter, placeins, moreverb, fancyvrb, enumitem, textcomp.

2.3.2 Format Options

The default formatting is for 1830 reports with a Standard Disclaimer with No Limits on Distribution, but options are provided for non-1830 clients and the other three PNNL disclaimers currently in use. A complete listing of available options for the **`pnnlreport`** class is given in Table 2.3. Please see the PNNL Author's Guide[b] and the Disclaimers Exhibit in SBMS[c] for further information on correct usage. To double space (as for a draft), use the `\doublespacing` setting (provided by package setspace) in the preamble. If you create any new options (or otherwise improve on the class file), please consider sharing them with the author so they can be made available to others. If you need assistance in creating a new report format, you may contact the author.

(a) http://latex2rtf.sourceforge.net/
(b) http://www.pnl.gov/ag/
(c) http://sbms.pnl.gov/standard/85/8504e010.htm

Table 2.2. Components of the PNNL-LaTeX package. All of these files except `*.pdf` are plain text (ASCII).

Filename	Purpose
"Style" files—most of the formatting specifications	
`pnnlreport.cls`	PNNL report class file, which contains the formatting specifications
`pnnl.bst`	PNNL bibliography style file, which defines how entries in the reference list appear
Source files—what the author writes (Full version of this document)	
`pnnlreport.tex`	report preamble and front matter
`pnnlreport_instructions.tex`	Introduction, Instructions chapters
`pnnlreport_examples.tex`	Examples
`pnnlreport_appA.tex`, `pnnlreport_appB.tex`, `pnnlreport_appC.tex`	Appendixes A, B, C
`pnnlreport_distrlist.tex`	distribution list
`reference_database.bib`	bibliography database
`misc_macros.tex`	miscellaneous macros for cross-referencing and units
`graphics/*`	graphics files included as figures in this document
Source files—what the author writes (skeleton version of this document)	
`main.tex`	preamble and front matter
`chap1.tex`, `chap2.tex`	first and second chapters
`appA.tex`, `appB.tex`	Appendixes A and B
`dist.tex`	distribution list
Finished reports	
`pnnlreport.pdf`	this document
`skeleton.pdf`	skeleton version of this document
`PNNL-15125.pdf`	an example DOE report
`PNNL-14820-2.pdf`	an example DOE report that is a software user guide
`PNNL-14779.pdf`	an example DOE report with lots of math

Table 2.3. Options for the **`pnnlreport`** class. Options are set in the document preamble. Incompatible options should not be invoked together. If none of **`private`**, **`corps`**, **`limits`**, **`markdraft`** are used, the report will contain the standard disclaimer with no limits on distribution. Other options recognized by the base LaTeX class **`report`** may also be invoked; e.g., `12pt`.

Option	Purpose	Incompatible
`cover`	Include the teal gradient cover page that is to be printed on heavy stock paper	
`limits`	Standard disclaimer with limited distribution	`markdraft`, `private`, `corps`
`markdraft`	Limited distribution disclaimer for drafts	`limits`
`private`	Non-1830 disclaimer	`limits`, `private`, `corps`
`corps`	Construct a special title page for Army Corps of Engineers	
`colorhyper`	Create colored hyperlinks in the PDF file	`invisiblehyper`
`invisiblehyper`	Create hyperlinks in the PDF file, but do not color them	`colorhyper`
`rightjustify`	Justify the right text margin	
`chapterpagenumbering`	Use the chapter or section in the page numbering; e.g., "2.3" for the third page of Chapter 2	
`draftstamp`	Place gray background "DRAFT" on pages, and omit teal gradient on cover	

The hyperref package provides hyperlinks within your document for easy navigation during onscreen viewing of the PDF file, as well as hyperlinks to external URLs. Choose the **`colorhyper`** option if you want to use hyperref and have colored links. For most purposes, you'll want to skip the color (especially for a printed copy); in that case, use the **`invisiblehyper`** option. With either option, hyperlinks will be in effect, allowing you jump around from the table of contents, list of figures, etc., to the respective locations in the text.

2.3.3 Justification

By default `pnnlreport.cls` will produce a ragged right margin. LaTeX is capable of producing high-quality fully-justified text, but many authors and editors prefer otherwise. Also, using a ragged right margin (via the ragged2e package) reduces the number of bad line breaks and orphaned lines that have to be manually corrected. The amount of allowed whitespace at the end of the line can be adjusted by changing the value of `\RaggedRightRightskip` in the class file.

2.4 Tips on Tables and Figures

If you are creating a table whose contents are output from some kind of software, consider using that software to generate a text file with the table rows. In your main file you can then use `\input` to include the table file, making it a snap to update the report if your data change—just re-LaTeX your main file. The same principle of seamless updating applies to figures. Just use the graphicx package and `\includegraphics` inside your figure environment.

If you want to include EPS files, they must not contain a thumbnail (preview) image, which is binary. Turn off generation of the preview image in your graphics software.

If you have bitmapped images you want to include (as opposed to Postscript files), you will need to use **`pdflatex`** instead of the command sequence **`latex-dvips-ps2pdf`** to produce a PDF file. **`pdflatex`** can handle JPG, PNG, and PDF file formats for figures. If your figure files have a different format, convert them to one of the recognized formats first.

2.5 Tips on Including Tables and Figures from Excel and Other Windows Programs

To include an Excel table in your document, there are two ways to go: 1) convert the Excel table to a *.tex file that you can insert into your main document or 2) make a graphics file out of the Excel table and insert that into your main document using `\includegraphics` inside a table environment. You can also use the second method to include a figure produced with any Windows or Mac OS X program. Both methods are described below.

2.5.1 Converting an Excel Table to LaTeX

To convert an Excel table into LaTeX code, Windows and Mac OS X users can use the wonderful utility Excel2Latex.[a] This method is very fast and can help you maintain a consistent appearance for your tables. You download a *.xla file and can either open it from within Excel to activate the functionality or copy the *.xla file to your AddIns directory, then add it by checking the box under Tools→AddIns (e.g., c:\Documents and Settings\username\Application Data\Microsoft\AddIns in Windows). Either way, an additional item is added under the Tools menu, and there is an additional button added in a new toolbar. Just highlight the cells you'd like to convert and press the button. Excel2Latex will prompt you for a filename to export to and give you a chance to edit the LaTeX code before exporting it. At least some of the formatting in your Excel table will be translated correctly to LaTeX; see the Excel2Latex readme file for details. Hidden *columns* in Excel are included in the output either whole (as if they were not hidden) or as blank columns. Hidden *rows* in Excel are included whole. To get rid of columns and rows you don't wish to include, make minor changes in the Excel2Latex window or use your text editor for heavy lifting. For example, Emacs has rectangle editing that allows you easily remove columns (Excel2Latex outputs aligned columns, making rectangle editing straightforward).

(a) http://www.jam-software.com/freeware/index.shtml

2.5.2 Including a Table or File as a Graphic in LaTeX

If you want a table to appear in your document exactly as it does in Excel, you'll need to convert the table to a graphics file that you can then include inside a table environment. If you have many hidden cells, this method may also be faster than the above method. Figures produced in Windows can be treated the same way. The key to this method is getting the bounding box right so that your included graphic file doesn't have extra white space around it or take up a whole page in your document. The following method uses Powerpoint and the utility program WMF2EPS,[a] which is free or inexpensive shareware. WMF2EPS is easy to set up and use:

1. Copy and paste your table selection or graphic into a blank Powerpoint slide using Paste Special→Picture (Windows or Enhanced Metafile).
2. Save the slide as a Windows Metafile (*.wmf) or Enhanced Metafile (*.emf) file. Don't worry for now about the extra white space you'll likely have around the graphic.
3. Open the *.wmf or *.emf file in WMF2EPS and use the Graphics Properties button to open the file dialog. Use your mouse to adjust the bounding box around the graphic.
4. Hit the WMF2EPS convert button to convert the file to *.eps. The final file will have the correct bounding box and can be included in your document using the `\includegraphics` command.

WMF is scalable like Postscript, so the fonts in the final *.eps graphic will look good at any size. If you want to use pdflatex, just convert the *.eps file to *.png, *.jpg, or *.pdf, or produce the graphic with correct bounding box as a *.pdf file in the first place. You can do this using Adobe Acrobat, Mac OS X Preview, or a free utility for Windows called PDFreDirect.[b] When this utility is installed, you can "print" to PDFreDirect from Excel or Word and it will make a PDF file. It will likely have white space around it that you don't want. Under Unix/Linux, you can fix this by using the utility pdfcrop available at the Comprehensive TeX Archive Network (CTAN).[c]

2.6 If You Have Appendixes

PNNL format requires the following for appendix material in a report:

1. Only the title of an Appendix is usually listed in the Contents. Lower level headings are usually not listed.
2. Figures and tables in the appendixes may or may not be included in the (List of) Figures and (List of) Tables.
3. Each appendix containing cited references must have its own reference section, and the references section in the main report must include only references cited in the main report.

(a) http://520060481190-0001.bei.t-online.de/WMF2EPS/index.htm
(b) http://www.exp-systems.com/PDFreDirect/
(c) http://www.ctan.org/

4. Each appendix starts with an unnumbered title page (which is blank on the reverse side if doing two-sided printing), followed by the title again on the first page of appendix text.

5. Each appendix has its own page, figure and table numbering, such as B.1 for the first page of the second appendix.

6. The appendix letter is followed by an en dash in the header on the first text page of the appendix and in the Contents (e.g., “Appendix A – The First Appendectomy”).

To satisfy all of these requirements while maintaining compatibility with hyperref, the bibunits, appendix, and tocvsec2 packages are used. The report body (Introduction through References) and each appendix are created as separate files and included in the top-level file. The top-level file contains all of the front matter and inputs or includes to the subsidiary files. Each of the subsidiary files contains a `\putbib` bibliography call (from bibunits) to generate the References for that part of the report. To prevent the listing of headings below the chapter level from appearing in the table of contents, the following line is added at the beginning of each appendix file:

```
\settocdepth{chapter}
```

and at the end:

```
\settocdepth{subsection}.
```

To prevent appendix figures and tables from appearing in the front matter lists, the user can have their captions are written to a dummy file during LaTeX processing. Uncomment the following lines in `pnnlreport.cls` so they are exercised when the appendixes begin, sending the appendix figure and table captions to the dummy files `*.alof` and `*.alot`, respectively:

```
\renewcommand{\ext@figure}{alof}
\renewcommand{\ext@table}{alot}
```

Capability to generate lists of contents, figures, and tables that appear within each appendix will be developed in the future. All other format changes for appendixes are accomplished in the class file.

See the next chapter for formatting examples. Happy LaTeXing!

3.0 Examples of Tables, Figures, and Other Components

This chapter contains examples of simple and complex ways to include tables, figures, lists, and footnotes in a report. Further examples are given in the appendixes. Section 3.6 contains an example bibliography produced from the citations in this document and the references database file reference_database.bib. An example distribution list is included at the end of the document.

NOTE: The examples are culled from several different reports, and their subject matter content is unrelated and irrelevant. Some of the original text has been retained as filler to invoke more citations for the bibliography and to help show how floating objects such as figures and tables are placed with text. Such filler is generally noted with brackets "[]."

3.1 Lists

This is an example of a bulleted list:

- Head-dependent, areally distributed leakage through the basalt confining layer
- Increased leakage at an erosional window near Gable Mountain/Gable Butte
- Increased leakage along two fault zones: the Cold Creek Fault zone west of 200 West area and May Junction Fault east of 200 East Area.

For examples of custom list environments, see the distribution list at the end of the document.

3.2 Tables

Examples of basic tables can be found in Section 2. Some variations are shown here. Table 3.1 uses the package threeparttable to produce a table with its own footnotes. Table 3.2 uses the package dcolumn to align numbers on the decimal point.

[Some authors have conceptualized recharge as only a vertical process and did not consider lateral movement away from the source area. Others have included lateral movement in their conceptual model for recharge but did not distinguish between streamflow and lateral subsurface flow and tended to call both of these "runoff." Infiltration of streamflow away from the source area is rapid in the arid setting of Hanford; therefore, characterizing the surface or subsurface nature of runoff depends on location and one's particular objectives.]

[Newcomb et al. (1972) examined water level records from wells and gathered anecdotal information about runoff events in Cold Creek as part of the first comprehensive study of Hanford Site hydrogeology. They estimated surface runoff from Cold Creek as 0.376 million cubic meters per year (Mm^3y^{-1}) (=300 ac-ft y^{-1}), and from Dry Creek and Rattlesnake Spring as 0.185 Mm^3y^{-1} (150 ac-ft y^{-1}).]

[Jacobson and Freshley (1990) estimated natural recharge by inversing (calibrating) an early version of the Coupled Fluid, Energy, and Solute Transport (CFEST) site-wide groundwater

Table 3.1. A table with footnotes. This table also uses the package booktabs to provide better vertical spacing and nicer looking horizontal rules.

Recharge Source Area	Recharge mm y^{-1}	Recharge Mm^3y^{-1}	Study
Cold Creek, runoff only (Basins 1 and 2)		0.376$^{(a)}$	Newcomb et al. (1972)
Cold Creek (Basins 1 and 2)	33$^{(b)}$	3.298$^{(c)}$	Bauer and Vaccaro (1990)
Cold Creek (Basins 1 and 2)	32$^{(d)}$	3.218$^{(c)}$	Jacobson and Freshley (1990)
Cold Creek, runoff only (Basins 1 and 2)		0.530$^{(e)}$	Dinicola (1997)
Dry Creek, runoff only (Basins 3 and 4)		0.185$^{(a)}$	Newcomb et al. (1972)
Upper Dry Creek (Basin 3)	10$^{(b)}$		Bauer and Vaccaro (1990)

(a) From runoff estimate reported in ac-ft y^{-1}.
(b) From recharge simulation of WY1956-77 using the Deep Percolation Model.
(c) Computed from recharge in mm y^{-1} and watershed areas in Table 3.2.
(d) From calibration of early CFEST groundwater flow model.
(e) From runoff simulation of WY1958-93 using HSPF.

Table 3.2. A table that uses package dcolumn to align numbers.

Location	Min. Elev. (m)	Mean Elev. (m)	Max. Elev. (m)	Mean Annual Temperature (°C)	Mean Annual Precipitation (mm)	Area (km^2)	Number of Grid Cells in DEM
Basin 1	442	773	1217	10.5	214	73.5	1837
Basin 2	289	508	850	11.3	192	27.0	676
Basin 3	347	649	1255	10.8	190	150	3740
Basin 4	208	510	1080	11.3	188	167	4185
Basin 5	131	282	1082	11.9	168	431	10765
Basins 1–4	208	606	1255	11.0	194	417	10438
Basins 1–5	131	442	1255	11.4	181	848	21203
HMS		220		12.1	167		

model. They estimated total recharge from Cold Creek Valley as 3.218 Mm^3y^{-1} of groundwater inflow and 17.31 Mm^3y^{-1}as direct recharge within the SGM area.]

[Bauer and Vaccaro (1990) conducted the first detailed modeling of the upper vadose zone in a study of recharge over the entire mid-Columbia basin. They applied the one-dimensional Deep Percolation Model to 1-km^2 cells in the Hanford region and explicitly accounted for soil type, land use/land cover, and local climate effects. They did not explicitly account for streamflow generation or lateral subsurface flow between grid cells.]

[Fayer and Walters (1995) used a combination of lysimeter, tracer, and neutron probe soil moisture data from Hanford Site locations together with the one-dimensional Unsaturated Soil Water and Heat Flow (UNSAT-H) model to estimate direct recharge over a range of combined soil and vegetation conditions. Their study area included the entire area owned by the Department of Energy south and west of the Columbia River, including lower Cold Creek and Dry Creek Valleys and Rattlesnake Mountain. Estimated rates ranged from zero in areas with loamy soils and significant vegetation to more than 100 mm y^{-1} in areas with rocky soils and no vegetation.]

[In the early 1990s, Dinicola (1997) conducted a study of recharge originating from high-elevation areas. Field data and the semi-distributed Hydrological Simulation Program-Fortran (HSPF) watershed model were used to estimate long-term recharge from Cold and Dry Creek runoff. This study noted that most runoff events in the region occur during winter, typically under conditions involving a combination of rainfall, snowmelt, and frozen soil. Unfortunately, only data through 1993 were considered in that report, and very little runoff occurred during that time, limiting the effectiveness of the modeling.]

Table 3.3 uses indentation for subordinate rows and the • symbol. Table 3.4 is an example of a sideways (landscape orientation) table. Table 3.5 is an example of a multi-page table.

Table 3.3. A table that uses indentation and the • symbol. [Values from Vermeul et al. (2003).]

Recharge Source	**Flux (Mm^3y^{-1})**	**Calibrated**
Recharge from GCC		
Cold Creek Valley	11.72	•
Dry Creek Valley	7.122	•
Rattlesnake Mountain	1.023	•
Total from GCC	19.87	
Direct recharge	8.583	
Leakage from basalt faults	0.354	•
Areally distributed basalt leakage	0.325	
Leakage from basalt erosional window	0.080	

Table 3.4. A sideways table. [Simulated fluxes for regions in GCC.[(a)] For extent of regions, see Figure 3.1.]

Region	Area	P		ET	P−ET		Streamflow		ACM-2
	(km^2)	($mm\ y^{-1}$)	($Mm^3 y^{-1}$)	($mm\ y^{-1}$)	($mm\ y^{-1}$)	($Mm^3 y^{-1}$)	($Mm^3 y^{-1}$)	RR	($Mm^3 y^{-1}$)
Basins 1 and 2 (Cold Cr.)	101	207	20.81	178	29	2.915	2.118	0.14	11.72
Basins 3 and 4 (Dry Cr.)	317	188	59.61	168	20	6.235	0.829	0.10	7.122
Rattlesnake Mountain	164	177	28.96	160	17	2.780		0.09	1.023
SGM portion of GCC	182	157	28.53	147	10	1.874		0.06	
non-SGM portion of GCC	666	187	124.6	166	20	13.33		0.10	
SGM Domain[(b)]	810	167	135.3	156	11	8.470		0.07	8.583

(a) P = precipitation, ET = evapotranspiration, RR = recharge ratio, (P−ET)/P.

(b) Recharge estimate for "future Hanford Site" from Fayer and Walters (1995); ET calculated as difference between HMS P and recharge.

Table 3.5. A multipage table using the **`longtable`** environment.

Record	Field	Type	Description
1			Line read and discarded.
2		string	Title of simulation (entire line read).
3	1	integer	Number of computational mesh blocks.
4	1	integer	Number of transported variables. A value is always required and must be greater than zero, but it is only used when scalar transport is enabled in record 7.
5	1	string	Name of the file containing a single grid block. If the filename contains spaces or a "/," the entire name must be in enclosed in double quotes. One line in the file is used for each grid file name. The number of grid files expected is the number of blocks specified in record 3.
6	1	flag	If true, hydrodynamics are simulated.
7	1	flag	If true, scalar transport is simulated, and the files `scalar_source.dat` and `scalar_bcspecs.dat` are expected to exist in the current directory.
8	1	flag	not used
	2	flag	not used
	3	string	The name of the file from which meteorologic data is to be read. This file is required to exist if atmospheric exchange is enabled for total dissolved gas or temperature.
9	1	flag	If true, a lot of extra, and usually unintelligible, output is put into `status.out` and `output.out`.
10	1	flag	If true, bed resistance is computed using Manning's equation; otherwise, the Chezy equation is used.
11	1	flag	If true, hot-start files are written at regular intervals.
	2	integer	The number of simulation time steps between which hot-start files are written.
12	1	flag	If true, initial conditions are read from a hot-start file named `hotstart.bin` created in a previous simulation.
13	1	flag	If true, gage location output is enabled and gage location information is read from a file named `gage_control.dat`. This also enables the output of mass source error.
14	1	flag	If true, and initial conditions are not read from a hot-start (record 12, the value supplied elsewhere will be used as the initial water surface elevation over the entire domain; otherwise, the value is used as the initial depth.
	2	flag	If true, initial hydrodynamic conditions are estimated from a precomputed water surface profile. The profile data are read from `initial_specs.dat`.
15	1	date	Simulation start date in the format described.
	2	time	Simulation start time in the format described.
16	1	real	Longitudinal wind speed, ft/sec. This should always be zero.

Table 3.5. (continued)

Record	Field	Type	Description
17	1	real	Lateral wind speed, ft/sec. This should always be zero.
18	1	flag	Enable wetting and drying (Theory Manual). Enabling wetting and drying will allow cells to dry. Any negative depths simulated will be corrected. Without wetting and drying, cells are not allowed to dry, and MASS2 will abort a simulation in which a negative depth is encountered.
	2	real	The depth below which a cell is considered dry, ft (dry depth).
	3	real	The depth above which a cell is allowed to rewet, ft. This is equal to or greater than the dry depth.
	4	real	The initial depth assigned to dry cells, ft (zero depth). If at initialization, the cell depth is less than the zero depth, the cell depth is assigned the zero depth. When a negative depth is simulated, the depth is reset to the zero depth. This should be less than the dry depth.
19	1	real	The bed porosity to be used over the entire domain.
	2	real	The initial bed depth, ft. If no other information is supplied using a hotstart or initial bed files, the bed is set to this depth, and its composition is assumed to be equally divided among the number of sediment fractions specified in the `scalar_source.dat` file.
	3	flag	If true, read the initial bed depth and composition from initial bed files.
	4	integer	Number of sub-time-steps used in the simulation of contaminant bed sources moving through the bed (see the Theory Manual).

3.3 Figures

Figure 3.1 uses a narrow caption to better fit the small size of the graphic. Figure 3.2 uses a table to lay out multiple figures and letter labels.[a]

An example of a sideways (landscape) figure is given in Figure 3.3. Note that the caption is also sideways. This example also shows how to overlay text on an existing Postscript figure, a handy solution when you need to add labels but can't revise the graphic.

Figure 3.4 is a graphic that is created entirely within LaTeX using the PSTricks package. Figure 3.5 displays the contents of a computer script. Figure 3.6 presents the final product along with the code that created it.

(a) Notice how the normal footnote rule is used here again after changing the default setting for the previous long table.

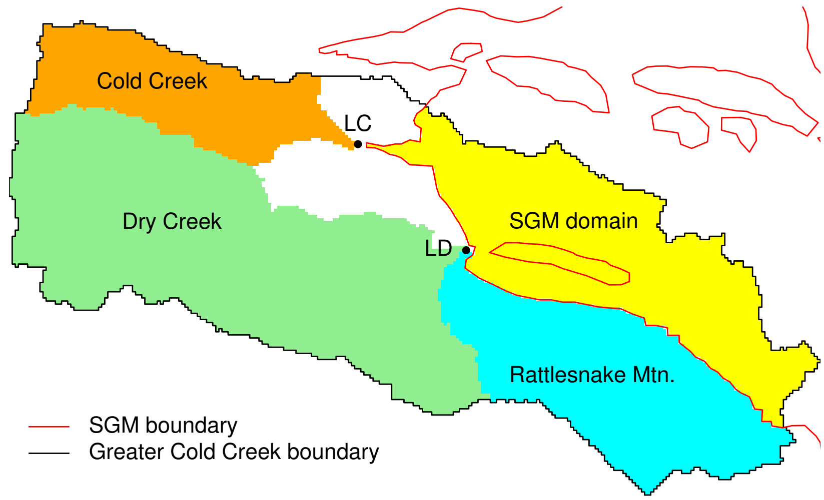


Figure 3.1. A small figure with a narrowed caption. Notice how this text wraps. Graphic was created with R, an open source enironment for interactive data analysis, statistics, and graphics.

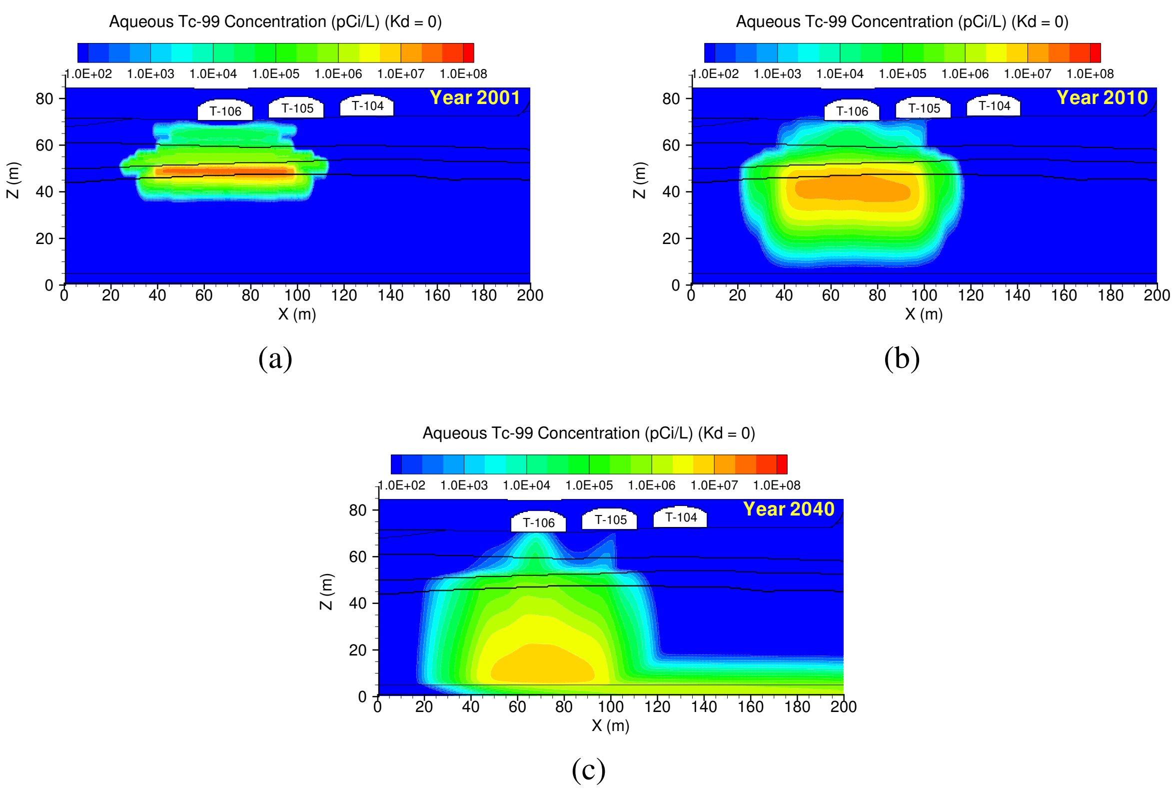


Figure 3.2. Multiple graphics organized with a table to make a figure. Graphics were created with Tecplot.

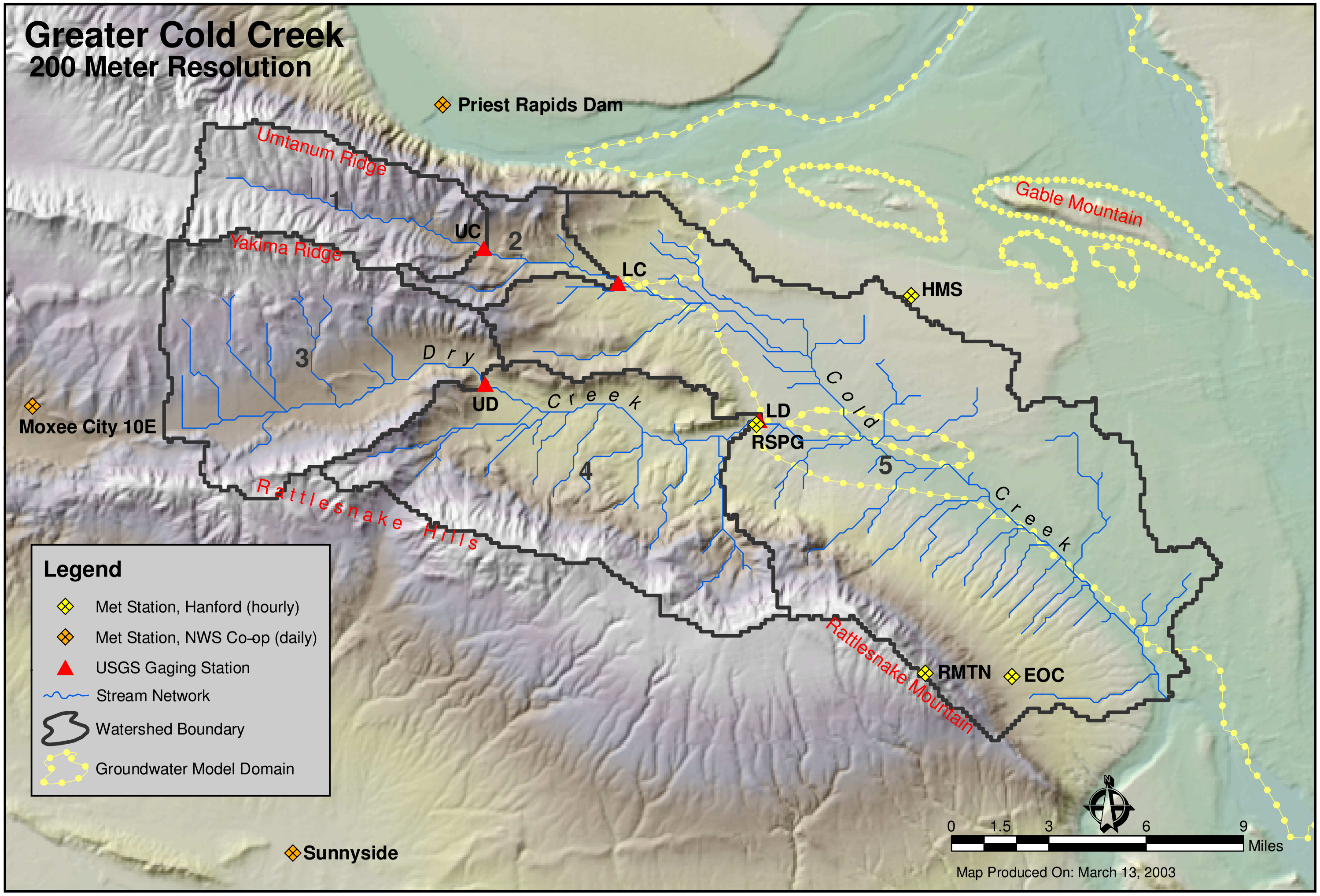


Figure 3.3. Text placed over a sideways (landscape) graphic using the overpic package. Graphic was created with ArcView.

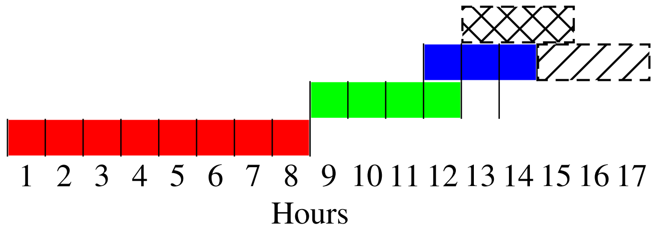
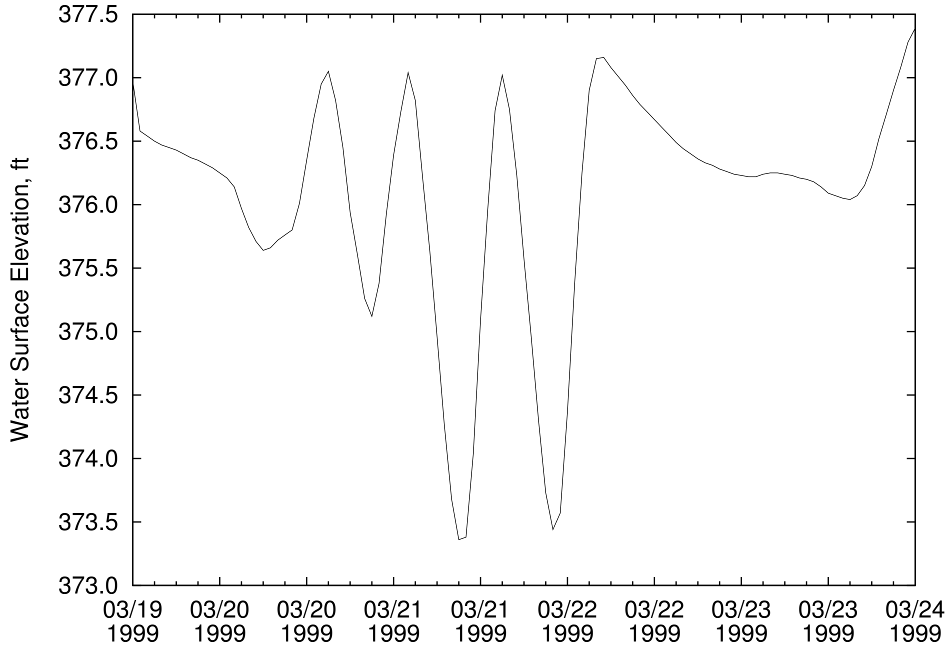


Figure 3.4. Figure created within LaTeX using the PSTricks package.

```
#!MC 800

$!EXPORTSETUP
   EXPORTFNAME = "looper.avi"
   EXPORTFORMAT = AVI

$!LOOP |Nloop|

$!VARSET |B1| = ((|Loop| - 1)*|Blocks| + 1)
$!VARSET |BN| = (|B1| + |Blocks| - 1)
$!VARSET |MYFRAME| = |Loop|

$!LOOP |NUMFRAMES|
$!FRAMECONTROL PUSHTOP
$!ACTIVEFIELDZONES=[ |B1|-|BN| ]
$!REDRAWALL
$!ENDLOOP

$!IF |MYFRAME| == 1
   $!EXPORT
   APPEND = NO
$!ENDIF

$!IF |MYFRAME| != 1
   $!EXPORT
   APPEND = YES
$!ENDIF

$!ENDLOOP

$!EXPORTFINISH
```

Figure 3.5. Display of programming code. Environment **`boxlisting`** from the fancyvrb package lists text in a box with line numbers. Use the **`boxtt`** for listing without line numbers.




```
set xdata time
set timefmt '%m-%d-%Y %H:%M:%S'

set format x "%m/%d\n%Y"
set format y "%.1f"
set ylabel "Water Surface Elevation, ft"
set nokey

plot " <perl mass2gage.pl -v wsel -g 10 gage.nc" using 1:3 with lines
```

Figure 3.6. A graphic and the Gnuplot code that produced it. LaTeX has many tools for literate programming, the practice of showing code and output together.

3.4 Footnotes

PNNL style specifies alpha characters for footnote symbols, enclosed in parentheses, with the sequence starting over on each page where footnotes appear. For examples of footnotes in tables, see Tables 3.1 and 3.4.

[Initial efforts of this study used the USGS streamflow data set to derive runoff curve numbers (SCS 1972), and estimate potential extreme-storm runoff from the Cold and Dry Creek basins under two hypothetical precipitation events.[a] Wigmosta and Guensch derived curve numbers ranging from 78 to 92 for several storm events during January 1995.

In subsequent efforts the SCS runoff approach was extended to estimate location of the recharge from runoff by accounting for infiltration in the streambed.[b] Weather and the runoff data from the January 1995 storm events were analyzed in greater detail to support a simple runoff/recharge model constructed from SCS methods and an exponential-decay channel infiltration equation proposed by Lane et al. (1985).]

3.5 Mathematics

Mathematics is an area where LaTeX is truly peerless for desktop publishing. Check out the examples here and in the following section.

[The snow water content method was developed as a way to implicitly link the formation of snow and its insulating effect with frozen soil. In this method, infiltration i was a function of snow water content:

$$i = f i_{\mathrm{max}} \tag{3.1}$$

$$f = \begin{cases} 0 & \text{if } s \geq s_{\mathrm{T}} \\ 1 - s/s_{\mathrm{T}} & \text{if } s < s_{\mathrm{T}} \end{cases} \tag{3.2}$$

where f is the limiting factor, i_{max} is maximum infiltration rate, s is snow water equivalent, and s_{T} is a threshhold value of snow water equivalent above which there is no infiltration. If the cumulative heat flux H from the soil was greater than or equal to -20 W m^{-2}, maximum infiltration was not reduced; otherwise, the combined method was invoked and Equations 3.1, 3.3–3.5 were used to define f and reduce maximum infiltration:

$$f = f_{\mathrm{hf}} f_{\mathrm{mc}} \tag{3.3}$$

(a) Wigmosta MS and GR Guensch. 2000. *Progress Report: Potential Groundwater Recharge from the Infiltration of Surface Runoff in Cold and Dry Creeks*. Unpublished report. Pacific Northwest National Laboratory, Richland, Washington.
(b) Waichler SR. 2002. *Progress Report: Potential Groundwater Recharge from the Infiltration of Surface Runoff in Cold and Dry Creeks*. Unpublished report. Pacific Northwest National Laboratory, Richland, Washington.

where f_{hf} is the heat flux factor and f_{mc} is the moisture content factor.

$$f_{\text{hf}} = \begin{cases} 0 & \text{if } H \leq H_{\text{L}} \\ 1 & \text{if } H \geq H_{\text{U}} \\ \frac{H - H_{\text{L}}}{H_{\text{U}} - H_{\text{L}}} & \text{otherwise} \end{cases} \tag{3.4}$$

where H_{L} is a lower bound on heat flux, and H_{U} is an upper bound on heat flux. For this application the calibrated values were $H_{\text{L}} = -33.6$ W m^{-2} and $H_{\text{U}} = -20$ W m^{-2}. The soil moisture factor was

$$f_{\text{mc}} = \begin{cases} 1 & \text{if } \theta \leq \theta_{\text{L}} \\ 0 & \text{if } \theta \geq \theta_{\text{U}} \\ 1 - \frac{\theta - \theta_{\text{L}}}{\theta_{\text{U}} - \theta_{\text{L}}} & \text{otherwise} \end{cases} \tag{3.5}$$

where θ_{L} is a lower bound on soil moisture content, and θ_{U} is an upper bound on moisture content. For this application θ_{L} was set to 0.325, the mean of field capacity and porosity of the upper soil layer, and θ_{U} was set equal to porosity, 0.45.]

3.6 More Mathematics

And now for some really involved mathematics kindly provided by Daniel Deng. Isn't the typography gorgeous?

[For the equations of a rigid-body motion in a water flow field, the total forces and moments are

$$\begin{aligned} \sum \mathbf{F} &= \mathbf{F_{HS}} + \mathbf{F_L} + \mathbf{F_D} + \mathbf{F_A} + \mathbf{F_P} \\ \sum \mathbf{M} &= \mathbf{M_{HS}} + \mathbf{M_L} + \mathbf{M_D} + \mathbf{M_A} + \mathbf{M_P} \end{aligned} \tag{3.6}$$

where $\mathbf{F_{HS}}$ and $\mathbf{M_{HS}}$ are hydrostatic forces and moments, $\mathbf{F_L}$ and $\mathbf{M_L}$ are body lift forces and moments, $\mathbf{F_D}$ and $\mathbf{M_D}$ are body hydrodynamic drag forces and moments, $\mathbf{F_A}$ and $\mathbf{M_A}$ are the corresponding forces and moments of added mass, and $\mathbf{F_P}$ and $\mathbf{M_P}$ are propulsion forces and moments.

In the current investigation, no propulsion is assumed, i.e., $\mathbf{M_P} = \mathbf{0}$, $\mathbf{F_P} = \mathbf{0}$, so Equation (3.6) becomes

$$\begin{aligned} \sum \mathbf{F} &= \mathbf{F_{HS}} + \mathbf{F_L} + \mathbf{F_D} + \mathbf{F_A} \\ \sum \mathbf{M} &= \mathbf{M_{HS}} + \mathbf{M_L} + \mathbf{M_D} + \mathbf{M_A} \end{aligned} \tag{3.7}$$

Suppose the ambient flow field has velocity (V_x, V_y, V_z) in the inertial frame; then the angular velocity is defined as

$$\begin{aligned} \omega_x &= \frac{1}{2}\left(\frac{\partial V_z}{\partial y} - \frac{\partial V_y}{\partial z}\right) \\ \omega_y &= \frac{1}{2}\left(\frac{\partial V_x}{\partial z} - \frac{\partial V_z}{\partial x}\right) \\ \omega_z &= \frac{1}{2}\left(\frac{\partial V_y}{\partial x} - \frac{\partial V_x}{\partial y}\right) \end{aligned} \tag{3.8}$$

In the body-fixed frame they are transformed to

$$
\begin{aligned}
\begin{pmatrix} V_1(\varepsilon) \\ V_2(\varepsilon) \\ V_3(\varepsilon) \end{pmatrix} &= \mathbf{Q}(\varepsilon) \cdot \begin{pmatrix} V_x \\ V_y \\ V_z \end{pmatrix} \\
&= \begin{pmatrix} V_x Q_{1,1}(\varepsilon) + V_y Q_{1,2}(\varepsilon) + V_z Q_{1,3}(\varepsilon) \\ V_x Q_{2,1}(\varepsilon) + V_y Q_{2,2}(\varepsilon) + V_z Q_{2,3}(\varepsilon) \\ V_x Q_{3,1}(\varepsilon) + V_y Q_{3,2}(\varepsilon) + V_z Q_{3,3}(\varepsilon) \end{pmatrix} \qquad (3.9)
\end{aligned}
$$

$$
\begin{aligned}
\begin{pmatrix} \omega_1(\varepsilon) \\ \omega_2(\varepsilon) \\ \omega_3(\varepsilon) \end{pmatrix} &= \mathbf{Q}(\varepsilon) \cdot \begin{pmatrix} \omega_x \\ \omega_y \\ \omega_z \end{pmatrix} \\
&= \begin{pmatrix} \omega_x Q_{1,1}(\varepsilon) + \omega_y Q_{1,2}(\varepsilon) + \omega_z Q_{1,3}(\varepsilon) \\ \omega_x Q_{2,1}(\varepsilon) + \omega_y Q_{2,2}(\varepsilon) + \omega_z Q_{2,3}(\varepsilon) \\ \omega_x Q_{3,1}(\varepsilon) + \omega_y Q_{3,2}(\varepsilon) + \omega_z Q_{3,3}(\varepsilon) \end{pmatrix} \qquad (3.10)
\end{aligned}
$$

where $\begin{pmatrix} V_1(\varepsilon) \\ V_2(\varepsilon) \\ V_3(\varepsilon) \end{pmatrix}$ and $\begin{pmatrix} \omega_1(\varepsilon) \\ \omega_2(\varepsilon) \\ \omega_3(\varepsilon) \end{pmatrix}$ are the translational velocity and angular velocity of the ambient flow field in the body-fixed frame.

Define gradient tensor of the ambient velocity in the inertial frame:

$$
\nabla \mathbf{V_e} = \begin{pmatrix} \frac{\partial Vx}{\partial x} & \frac{\partial Vx}{\partial y} & \frac{\partial Vx}{\partial z} \\ \frac{\partial Vy}{\partial x} & \frac{\partial Vy}{\partial y} & \frac{\partial Vy}{\partial z} \\ \frac{\partial Vz}{\partial x} & \frac{\partial Vz}{\partial y} & \frac{\partial Vz}{\partial z} \end{pmatrix} \qquad (3.11)
$$

and in the body-fixed frame it becomes

$$
\nabla \mathbf{V_b} = \mathbf{Q} \cdot (\nabla \mathbf{V_e}) \cdot \mathbf{Q^{-1}} \qquad (3.12)
$$

where the subscripts b and e relate to the body-fixed frame and the earth-fixed (inertial) frame, respectively.

The time derivative of the transformation matrix $\mathbf{Q}$ is

$$
\dot{Q}_{i,j} = \frac{\partial Q_{i,j}}{\partial \varepsilon_1} \dot{\varepsilon}_1 + \frac{\partial Q_{i,j}}{\partial \varepsilon_2} \dot{\varepsilon}_2 + \frac{\partial Q_{i,j}}{\partial \varepsilon_3} \dot{\varepsilon}_3 + \frac{\partial Q_{i,j}}{\partial \varepsilon_4} \dot{\varepsilon}_4, \quad i,j = 1,2,3 \qquad (3.13)
$$

where

$$
\begin{pmatrix} \dot{\varepsilon}_1 \\ \dot{\varepsilon}_2 \\ \dot{\varepsilon}_3 \\ \dot{\varepsilon}_4 \end{pmatrix} = \frac{1}{2} \begin{pmatrix} 0 & r & -q & p \\ -r & 0 & p & q \\ q & -p & 0 & r \\ -p & -q & -r & 0 \end{pmatrix} \begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \varepsilon_4 \end{pmatrix}. \qquad (3.14)
$$

4.0 References

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Appendix A

An Example Appendix

Appendix A – An Example Appendix

[The HMS hourly dataset was relatively complete. There was only one extended period of missing data at HMS—wind speed over the last six months of 1974. In the case of wind, month/hour means were computed from the entire period of record and used for the large gap in 1974. Missing precipitation records from the NWS stations occurred in whole-month blocks (Table A.1).]

A.1 A Section Within the Appendix

[The methods used for distributing precipitation in Cold and Dry Creeks were modified from Dinicola (1997).]

A.2 Another Section Within the Appendix

[The third approach is described below for the sake of completeness and background for future studies. Stone et al. (1983) reported the final precipitation results including mean monthly values at the 27 stations from 1969-80. The data in Table A.V-2 of Stone et al. (1983) was used to explore relationships between local mean monthly precipitation, HMS mean monthly precipitation, and elevation difference between the local station and HMS.

The most general regression model and one that is useful for deriving a method for predicting precipitation at the short time steps of DHSVM includes precipitation at HMS and elevation as regressor variables:]

$$A = a_0 H + a_1 E + a_2 HE + a_3 HE^2 \tag{A.1}$$

where

A = local mean monthly precipitation (cm)
H = HMS mean monthly precipitation (cm)
E = elevation difference between local station and HMS (m)
a_i = regression coefficients.

Although stations on Rattlesnake Mountain commonly have precipitation when HMS does not,

Table A.1. A table in the appendix.

Station	Missing months
Moxie City 10 E	3/81, 5/81, 2/96, 3/96, 12/97, 4/98, 4/99, 2/00, 6/81-10/83
Priest Rapids Dam	3/97-11/97, 10/98, 10/00
Sunnyside	4/91-4/91, 12/96-2/97, 11/98-5/99, 9/99

for process-based modeling at short time steps it would not be appropriate to have precipitation occuring all the time. Also, to scale correctly at different timescales, all terms in the regression need to include HMS precipitation. Therefore, only models that met this constraint were selected for further consideration and of these, the four best models are summarized in Table A.2. The possible justification for the a_0 model term is that precipitation may be greater near Rattlesnake Mountain, independent of elevation. The a_1 and a_2 interaction terms account for elevation difference between HMS and the ALE sites, and the squaring of elevation difference E with term a_2 is used to explain the decrease in precipitation near the summit. Of these, model 7 was considered to be the best choice, because of acceptable R^2 value (0.88) and because it predicts ALE precipitation will be the same as HMS if the elevations are the same, a desirable result for grid cells near Highway 240:

$$A = H + a_1 HE + a_2 HE^2 \tag{A.2}$$

where A = ALE precipitation, H = HMS precipitation and E = elevation difference between ALE and HMS. Rearranging Equation A.2 to make a single factor to HMS yields

$$A = H(1 + a_1 E + a_2 E^2) \tag{A.3}$$

For application of Equation A.3 it would be desirable to enforce a minimum value of 1.0 for the factor $F = 1 + a_1 E + a_2 E^2$.]

Table A.2. A table with equations.

#	Model	R^2	a_0	a_1	a_2
3	$A = H + a_1 HE$	0.77		7.623×10^{-4} m^{-1}	
4	$A = a_0 H + a_1 HE$	0.84	1.304	7.623×10^{-4} m^{-1}	
6	$A = a_0 H + a_1 HE + a_2 HE^2$	0.90	1.180	2.495×10^{-3} m^{-1}	-2.784×10^{-6} m^{-2}
7	$A = H + a_1 HE + a_2 HE^2$	0.88		3.265×10^{-3} m^{-1}	-3.469×10^{-6} m^{-2}

A figure produced with the R language is shown in Figure A.1.

A.3 References

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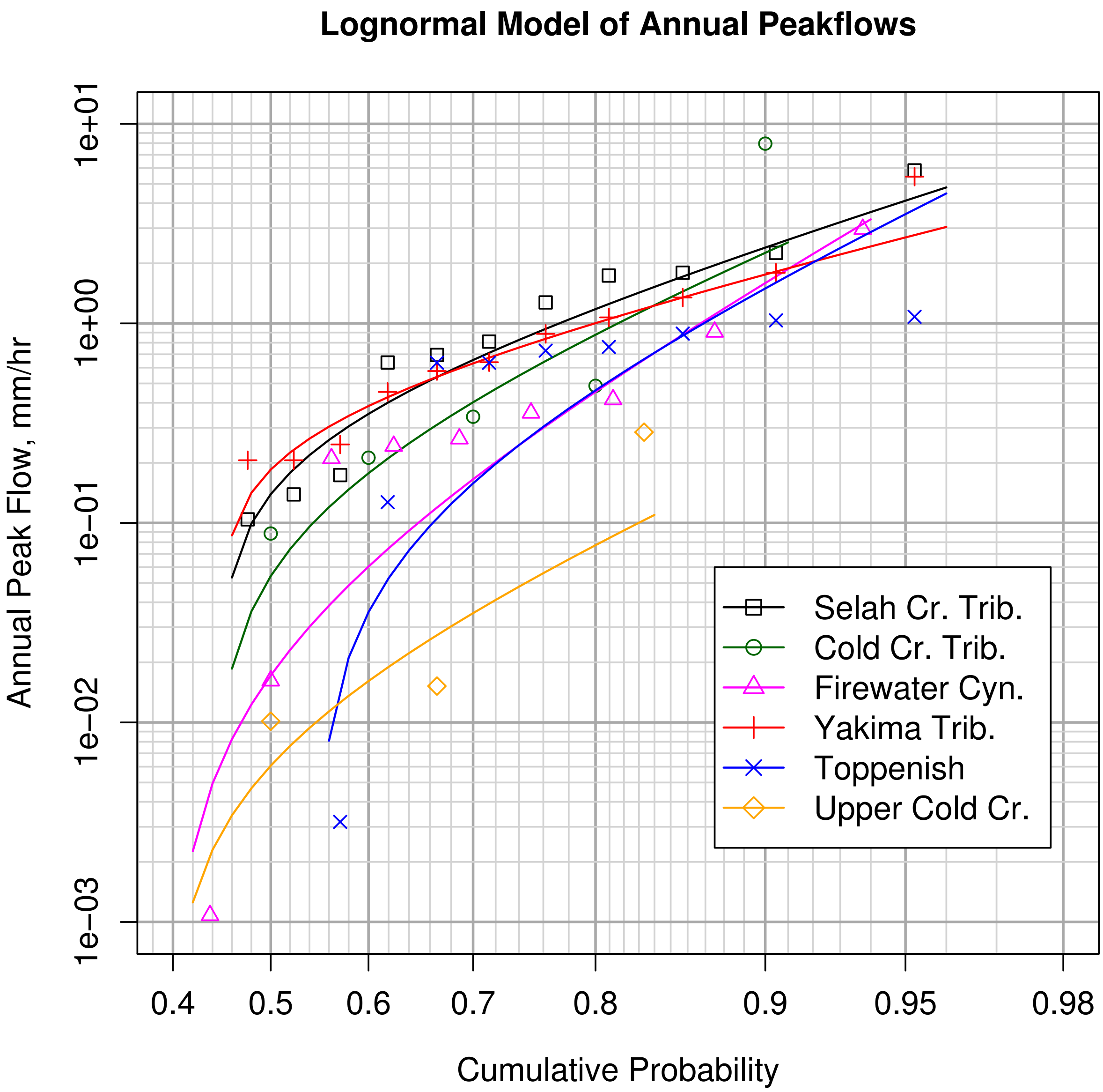

Figure A.1. A figure in the appendix. Graphic was created with R. [Cumulative probability of annual peak flow data (points) and lognormal distribution model (lines) from regional USGS crest height gauge data. Probability of zero flow in any year was $>$ 0.40 at all locations. The Weibull method was used for plotting position (Haan 1977).]

Appendix B

An Appendix with More Math

Appendix B – An Appendix with More Math

This appendix contains more math examples.

[Bias and several goodness-of-fit measures were the primary statistics used to evaluate model skill at reproducing climate variables and streamflow. The overall approach and certain definitions are taken from Legates and McCabe (1999), an excellent reference on goodness-of-fit measures.]

B.1 Equations

[Bias was defined as the ratio of predicted (simulated) mean to observed mean

$$bias = \frac{\bar{P}}{\bar{O}} \tag{B.1}$$

where

$$\begin{aligned} \bar{P} &= \text{mean of the predictions} \\ \bar{O} &= \text{mean of the observations.} \end{aligned}$$

The traditional R^2, or square of Pearson's product-moment correlation coefficient, describes the portion of total variance in the observed data that can be explained by the model and ranges from 0.0 to 1.0:

$$R^2 = \left\{ \frac{\sum_{i=1}^{N} (O_i - \bar{O})(P_i - \bar{P})}{\left[\sum_{i=1}^{N} (O_i - \bar{O})^2\right]^{0.5} \left[\sum_{i=1}^{N} (P_i - \bar{P})^2\right]^{0.5}} \right\}^2 \tag{B.2}$$

where

$$\begin{aligned} N &= \text{number of timesteps} \\ O_i &= \text{observed value at timestep i} \\ \bar{O} &= \text{mean of the observations} \\ P_i &= \text{the predicted value at timestep i} \\ \bar{P} &= \text{mean of the predictions.} \end{aligned}$$

There are two disadvantages of R^2 for describing model skill: 1) any linear relationship between the observations and the predictions, not necessarily a 1:1 relationship, results in a high value of R^2; and 2) the squaring of terms gives too much weight to large values. In the case of streamflow, a high R^2 value may indicate good fit of peak flows but may mask poor model skill during baseflow periods.

Efficiency E (Nash and Sutcliffe 1970) is a tougher test than R^2 and casts the mean of the observations as a benchmark for the model:

$$E = 1.0 - \frac{\sum_{i=1}^{N} (O_i - P_i)^2}{\sum_{i=1}^{N} (O_i - \bar{O})^2} \tag{B.3}$$

Values of E tend to be slightly less than R-squared in the case of streamflow.

Three first-degree goodness-of-fit measures from Legates and McCabe (1999) use absolute values of differences instead of squares. The first-degree efficiency is defined as

$$E_1 = 1.0 - \frac{\sum_{i=1}^{N} \mid O_i - P_i \mid}{\sum_{i=1}^{N} \mid O_i - \bar{O} \mid} \tag{B.4}$$

E_1 is an improvement over E when evaluating model skill at low and moderate streamflow levels is important, but the grand mean is still the basis of comparison. A further discrimination can be gained by using a baseline mean involving some kind of seasonal or other categorical variation inherent in the data. Here, the the baseline mean was defined as the mean for each month of the year where the mean is taken across all years in the simulation. Avoidance of squaring and use of baseline mean instead of the grand mean provides tougher, more revealing tests of model skill.]

B.2 References

Legates DR and GJ McCabe. 1999. "Evaluating the use of "goodness-of-fit" measures in hydrologic and hydroclimatic model validation." *Water Resources Research* 35(1):233–241.

Nash JE and JV Sutcliffe. 1970. "River flow forecasting through conceptual models, Part 1—A discussion of principles." *Journal of Hydrology* 10:282–290.

Appendix C

An Appendix for Nomenclature

Appendix C – An Appendix for Nomenclature

The following example of a two-column section for definitions was provided by Daniel Deng. Nomenclature may also be placed in the front section before the table of contents.

[The following is a list of the symbols and their definitions used in this document. As a common practice, symbols in bold face are defined as vectors or tensors, and symbols dotted above are time derivative in their own coordinate systems.]

A Homogeneous transform matrix given a set of roll, pitch, and yaw angles

$A_{i,j}$ components of transform matrix **A**, $i, j = 1, 2, 3$

A_f Frontal area of Sensor Fish, $\pi(d/2)^2$

A_p Projected area of Sensor Fish, πdL

B Magnitude of buoyancy

C 6×6 matrix of coefficient on the left side of 6DOF motion equations

C_D axial drag coefficient

$\mathbf{F_A}$ Resultant of forces due to added mass in body-fixed frame

$\mathbf{F_D}$ Resultant of drag forces in body-fixed frame

$\mathbf{F_{HS}}$ Resultant of hydrostatic forces in body-fixed frame

$\mathbf{F_L}$ Resultant of lift forces in body-fixed frame

H Inverse of coefficient matrix C, C^{-1}

I Inertial tensor of a rigid body

I_{ij} Components of inertial tensor in body-fixed frame, $i, j = x, y, z$

$\mathbf{I}'$ Normalized inertial tensor of a rigid body, I/m

I'_{ij} Components of normalized inertial tensor in body-fixed frame, $I'_{ij} = I_{ij}/m, \quad i, j = x, y, z$

J Transform matrix for rotational velocities given a set of roll, pitch, and yaw angles

K_A Resultant of moments due to added mass along body-fixed X-axis

$K_{A\dot{p}}$ Coefficients of moments due to added mass in body-fixed frame

K_D Resultant of drag moments along body-fixed X-axis

K_{Dww} Drag moment coefficient in body-fixed frame

K_{HS} Resultant of hydrostatic moments along body-fixed X-axis

K_L Resultant of lift moments along body-fixed X-axis

L Length of Sensor Fish

$\mathbf{M_A}$ Resultant of moments due to added mass in body-fixed frame

M_A Resultant of moments due to added mass along body-fixed Y-axis

M_{Ai} Coefficients of moments due to added mass in body-fixed frame, $i = \dot{w}, \dot{q}, uw, vp, rp, uq$

$\mathbf{M_D}$ Resultant of drag moments in body-fixed frame

M_D Resultant of drag moments along body-fixed Y-axis

M_{Dww} Drag moment coefficient in body-fixed frame

M_{Dqq} Drag moment coefficient in body-fixed frame

y_g Spanwise position of center of mass in body-fixed frame

z Vertical position of Sensor Fish with respect to inertial frame

$\dot{z}$ Vertical velocity of Sensor Fish in inertial frame, $\frac{dz}{dt}$

z_b Vertical position of center of buoyancy in body-fixed frame

z_g Vertical position of center of mass in body-fixed frame

ε Quaternion, $(\varepsilon_1, \varepsilon_2, \varepsilon_3, \varepsilon_4)^T$

ε_1 First component of quaternion ε

ε_2 Second component of quaternion ε

ε_3 Third component of quaternion ε

ε_4 Fourth component of quaternion ε

θ Pitch angle of Sensor Fish with respect to inertial frame

$\dot{\theta}$ Angular velocity of Sensor Fish with respect to inertial y-axis, $\frac{d\theta}{dt}$

ν Kinematic viscosity of water

ρ Density of water

ρ_o Density of Sensor Fish or the underwater rigid-body

ϕ Roll angle of Sensor Fish with respect to inertial frame

$\dot{\phi}$ Angular velocity of Sensor Fish with respect to inertial x-axis, $\frac{d\phi}{dt}$

ψ Yaw angle of Sensor Fish with respect to inertial frame

$\dot{\psi}$ Angular velocity of Sensor Fish with respect to inertial z-axis, $\frac{d\psi}{dt}$

Ω Angular velocity vector of Sensor Fish with respect to body-fixed frame, $(p,\ q,\ r)^T$

ω_x Angular velocity of ambient flow with respect to inertial x-axis

$\dot{\omega}_x$ Rate of change of ambient flow angular velocity with respect to inertial x-axis, $\frac{d\omega_x}{dt}$

ω_y Angular velocity of ambient flow with respect to inertial y-axis

$\dot{\omega}_y$ Rate of change of ambient flow angular velocity with respect to inertial y-axis, $\frac{d\omega_y}{dt}$

ω_z Angular velocity of ambient flow with respect to inertial z-axis

$\dot{\omega}_z$ Rate of change of ambient flow angular velocity with respect to inertial z-axis, $\frac{d\omega_z}{dt}$

$\nabla\mathbf{V_b}$ Gradient tensor of ambient flow velocity in body-fixed frame

$\nabla\mathbf{V_e}$ Gradient tensor of ambient flow velocity in inertial frame

$\sum\mathbf{F}$ Resultant of external forces in body-fixed frame

$\sum F_X$ Resultant of external forces along body-fixed X-axis

$\sum F'_X$ Normalized resultant of external forces along body-fixed X-axis, $\sum F_X/m$

$\sum F_Y$ Resultant of external forces along body-fixed Y-axis

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