Appendix B.
Watershed and Open Boundary Condition Updates

This appendix includes:

- Appendix B1: Updates to Watershed Delineations as well as Freshwater Flows, Water Quality Data, and Regressions
- Appendix B2: Changes to Watershed Loading due to Updates
- Appendix B3: Time Series Plots of Flow and Water Quality for Watersheds
- Appendix B4: Evaluation of Inorganic Nitrogen Watershed Regressions on Continuous Data
- Appendix B5: Open Boundary Tides and Water Quality

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[1] https://ecology.wa.gov/about-us/accessibility-equity/accessibility

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Appendix B1. Updates to Watershed Delineations, Freshwater Flows, Water Quality Data, and Regressions

Updates to watershed delineations

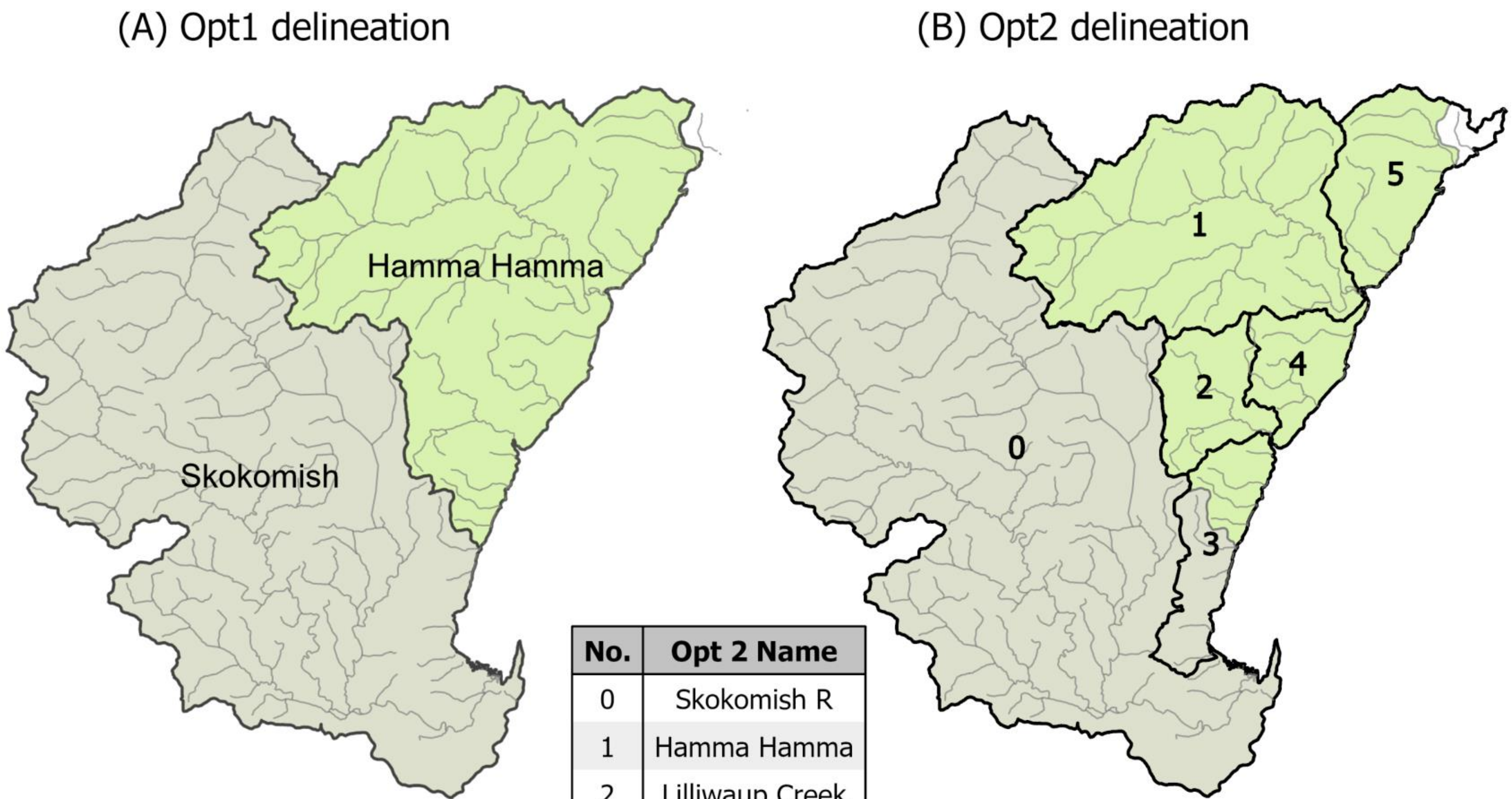
Since the Optimization Phase 1 (Opt1) Technical Memo (Ahmed et al. 2021), various updates were made to watershed inputs to the Salish Sea Model for this phase of the study, defined as Optimization Phase 2 (Opt2). These included updates to watershed delineations, flows, and the water quality data used to estimate daily inputs for rivers and streams entering the model domain.

Several watershed delineations used in the Optimization Phase 1 (Opt1) scenario runs included hydrologically disconnected regions as a portion of the drainage area. Since the excess drainage area assigned to these watersheds could impact the stream nutrient inputs to the Salish Sea Model, we refined watershed delineations so that most hydrologic units within a given watershed are connected.

Where needed, to improve watershed delineations, we aggregated hydrologically connected sub-watersheds within Hydrologic Unit Code (HUC 12) delineations. Watersheds in the South Sound, as well as Main Basin islands, however, were already delineated at a finer resolution than HUC 12, and therefore, we did not make delineation changes in those areas. Callam Bay and North Olympic watersheds do not have enough water quality data available to derive freshwater water quality regressions for these regions at finer HUC resolution, so no changes were made in those areas either. Additionally, we did not make any changes to the delineations of Canadian watersheds in the Salish Sea Model domain, as these watersheds are not a primary focus of our analysis.

National Hydrography Dataset (NHD) medium resolution (1:100,000 scale) flowlines were used to determine which HUC 12 sub-watersheds should be combined. If an NHD reach crossed several HUC 12 watersheds, then each of the intersected watersheds would be combined. Using the Skokomish and Hamma Hamma watersheds as an example (Figure B1-1A), we can see several changes from the Opt1 delineations. Most notably, we see in Figure B1-1B that the Hamma Hamma watershed was divided into five HUC 12 watersheds and that a portion of the previously delineated Skokomish watershed was reallocated to one of the five Hamma Hamma watersheds. The separation of larger, hydrologically disconnected watersheds into hydrologically distinct watersheds resulted in an increase in the number of Washington watersheds in our domain from 135 in Opt1 to 162 in Opt2.

Resolution at HUC 12, however, was not always sufficient, and as a result, 44 of the 162 Washington SSM watersheds still contain portions of hydrologically disconnected drainage area. All areas are used to represent inflows, whether connected or not. This is particularly the case for island watersheds in the Strait of Georgia, Strait of Juan de Fuca, and even in some locations within the Puget Sound Main Basin and Whidbey Basin, where watershed resolution is finer than HUC-12.



No.	Opt 2 Name
0	Skokomish R
1	Hamma Hamma
2	Lilliwaup Creek
3	Finch Creek
4	Eagle Creek
5	Fulton Creek

Figure B1-1. (A) Opt1 delineations of Skokomish and Hamma Hamma watersheds. (B) Differences between Opt1 delineations of Skokomish and Hamma Hamma watersheds and aggregated HUC-12 watersheds that are hydrologically connected (Opt2 delineations).

(B) shows that Hamma Hamma was split into 5 watersheds, that a portion of Skokomish was reallocated to Hamma Hamma (3), and that an additional drainage area was added to the Opt1 delineation of Hamma Hamma (5).

Updated watershed delineations are shown in Figure B1-2. The most frequent update consists of dividing Opt1 watersheds into two or more hydrologically distinct sub-watersheds (Figure B1-2 and Table B1-1). About half of the delineation changes occurred in the Olympic region. In that region, aside from the Hamma Hamma example mentioned above, Discovery Bay now contains 3 watersheds, Quilcene was split into two watersheds (Little and Big Quilcene), Sequim Bay was divided into 3 watersheds, and the Port Townsend watershed became two watersheds (Port Townsend East and Port Townsend West). As a result of the refinements to Opt1 watersheds, we increased the number of Washington watershed inputs into the model. Including the Canadian watersheds, which were not changed, we now have a total of 193 watersheds.. The Northern Bays are another region with a large number of changes in delineations. A list of all major changes between Opt1 and Opt2 watersheds can be found in Table B1-2.

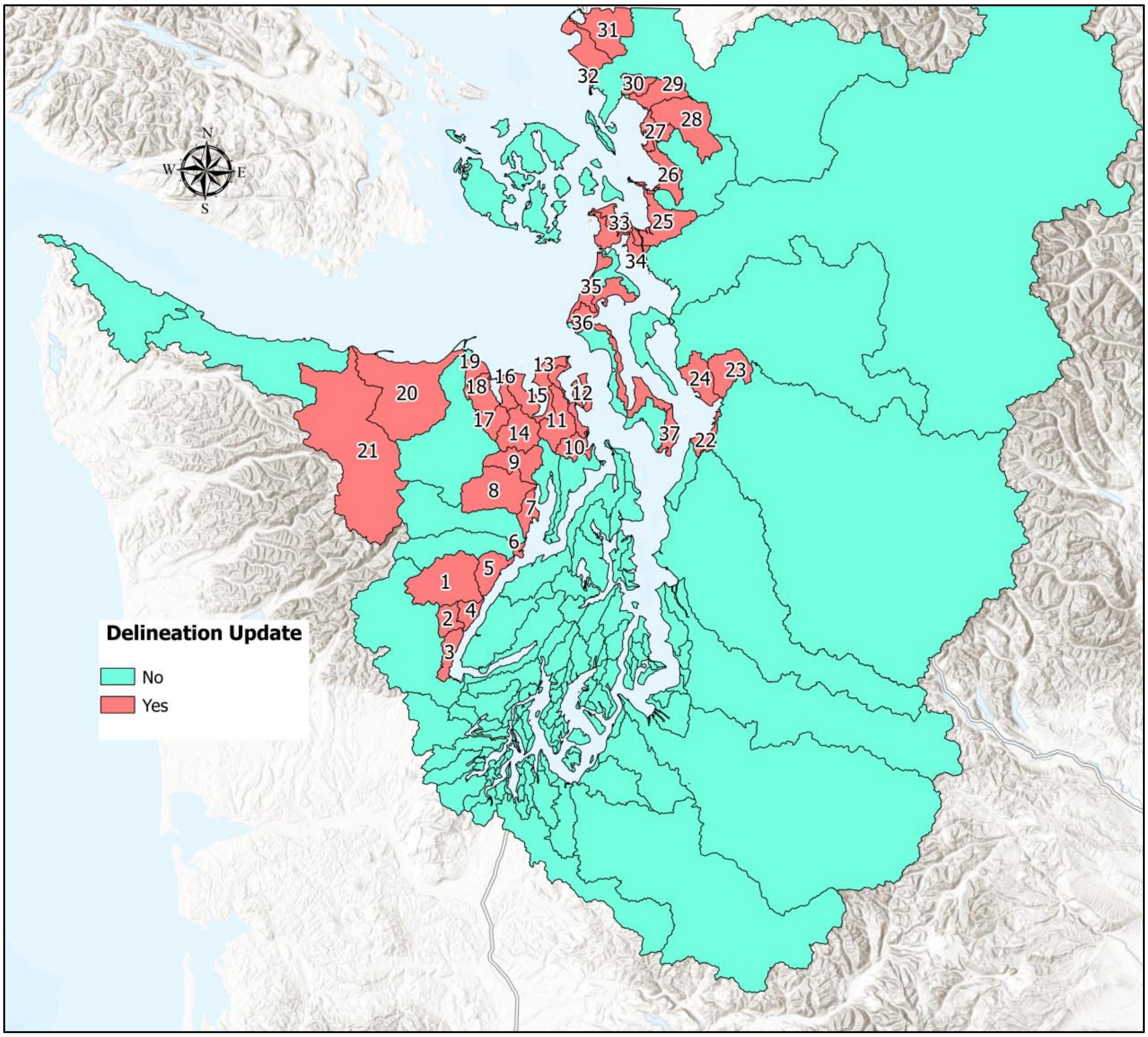


Figure B1-2. Watershed delineations that were updated since the Optimization Scenarios Phase 1 (Opt1) Report.

Areas shown in green indicate that no changes were made to the delineation, and red means that delineations were updated according to HUC12 watersheds shapefiles.

Table B1-1. Changes between Opt1 and Opt2 watersheds.

Watershed Number (as labeled in Figure B1-2)	Opt1 Name	Opt2 Name
1	Hamma Hamma	Hamma Hamma
2	Hamma Hamma	Lilliwaup Creek
3	Hamma Hamma /Skokomish	Finch Creek
4	Hamma Hamma	Eagle Creek
5	Hamma Hamma	Fulton Creek
6	Dosewallips	Lower Dosewallips[1]
7	Dabob Bay	Spencer Creek
8	Quilcene	Big Quilcene
9	Quilcene	Little Quilcene
10	NW Hood	Chimacum Valley
11	Port Townsend	Port Townsend W
12	Port Townsend	Port Townsend E
13	Discovery Bay	Discovery Bay 3
14	Discovery Bay	Discovery Bay 1
15	Discovery Bay	Discovery Bay 2
16	Sequim Bay	Sequim Bay E
17	Sequim Bay	Sequim Bay S
18	Sequim Bay	Sequim Bay W
19	Dungeness	Cassalery Creek
20	Port Angeles	Port Angeles
21	Elwha R	Elwha R
22	Snohomish	Possession Sound
23	Snohomish	Quilceda Creek
24	Snohomish	Tulalip Creek
25	Samish/Bell South	Joe Leary
26	Whatcom/Bell North	Colony Creek
27	Whatcom/Bell North	Chuckanut/Padden Creek
28	Whatcom/Bell North	Whatcom Creek
29	Whatcom/Bell North	Squalicum Creek
30	Nooksack R	Silver Creek
31	Birch Bay	Drayton Harbor
32	Birch Bay	Birch Bay
33	Samish/Bell South	Fidalgo Island N
34	Samish/Bell South	Fidalgo Island S
35	Whidbey E	Whidbey NE
36	Whidbey W	Whidbey NW
37	Whidbey E	Whidbey E
38	Whidbey E	Whidbey S

Watershed Number corresponds to values shown in Figure B1-3.

[1] Dosewallips still exists in Opt2 but was split into Dosewallips and Lower Dosewallips.

Table B1-2. Major changes made from Opt1 to Opt2 Watersheds.

Opt1 Name	Opt2 Change
Birch Bay	Split into Drayton Harbor and Birch Bay
Discovery Bay	Split into Discovery Bay 1-3
Dosewallips	A portion of the mouth of Opt1 Dosewallips watershed was reallocated to Dabob Bay
Dungeness R.	Cassalery Creek removed and made into its own watershed.
Hamma Hamma	Divided into 5 watersheds
Nooksack R.	Silver Creek removed and made into its own watershed.
Port Townsend	Split into Port Townsend East and West
Quilcene	Split into Little and Big Quilcene
Samish/Bell South	Divided into Samish Bell/South (smaller subsection), Joe Leary Slough, Fidalgo Island North, and South
Sequim Bay	Divided into 3 watersheds
Stillaguamish R.	Camano Island removed and made into its own watershed.
Whatcom/Bell North	Divided into 4 watersheds.

Updates to watershed regression & data sources

In this section, we present updates to the watershed regressions used in Opt1. We focus on new data sources that were used to build the watershed regressions and assess the performance of Opt2 watershed regressions using recently available data to get an indication of the differences between our current and previous watershed regression models. An outline of the regression update process is shown in Figure B1-3.

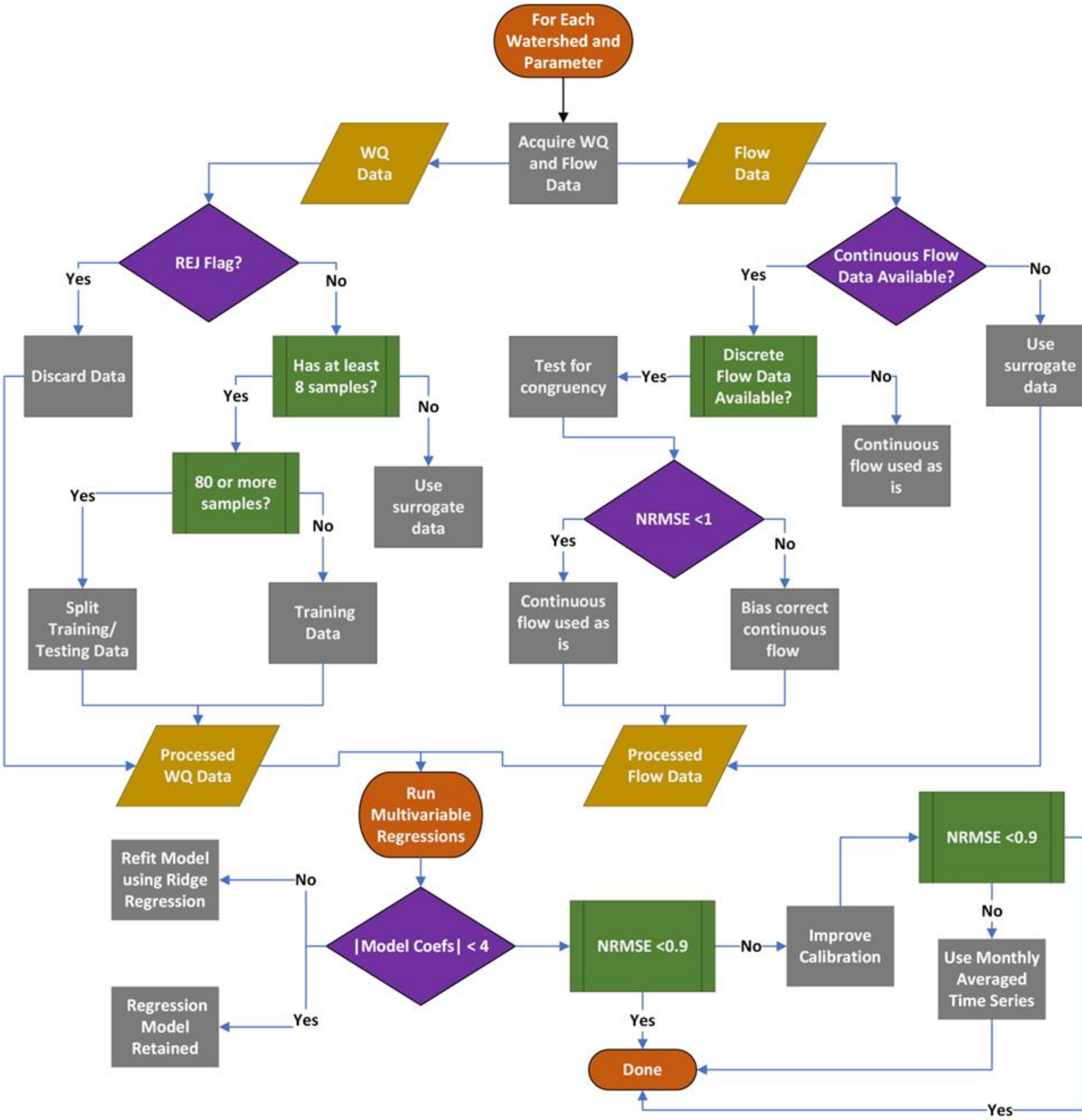


Figure B1-3. Flow diagram of all major tasks and decisions for freshwater water quality regressions.

Data sources

In the Opt1 technical memorandum (Ahmed et al. 2021), we identified several watersheds that were lacking sufficient data required for a watershed regression. For these watersheds, we used the regression of a neighboring watershed (Ahmed et al. 2021; Figure A-1) when data were insufficient. Using the terminology from the Opt1 report, watersheds with enough data for regression are referred to as “site-specific regressions,” while watersheds that borrow regressions from another are called “neighboring watershed regressions.” For Opt2, we reduced the number of neighboring watershed regressions as much as possible. Previously, we only considered Ecology's Freshwater Monitoring Unit's long-term ambient water quality data and the 2006 South Puget Sound Dissolved Oxygen Study's (SPSDO) water quality data as potential inputs to our watershed regressions. We expanded freshwater data sources for Opt2 scenarios to include all freshwater water quality sites in Ecology's Environmental Information Management Database (EIM) from 1999 to 2021, and additionally to include quality-assured data from cities, counties, and Tribes. Data sources for Opt2 watershed regressions includes: EIM, King County, Pierce County, Thurston County, Jefferson County, Squaxin Island Tribe, City of Bellingham, US EPA Water Quality Exchange (WQX) data, which includes tribal water quality data, USGS National Water Information System (NWIS) data and Environment Canada (Table B1-3).

Table B1-3. Data sources used to build or test Opt2 watershed regressions.

Data Source	Data URL	Entities
EIM	https://ecyeim/search/Default.aspx	Ecology
WQX/NWIS	Water Quality Data[2]	EPA, Local Tribes, USGS
King County	https://catalog.data.gov/dataset/water-quality	King County
Pierce County	https://waterquality.piercecountywa.org/	Pierce County
Thurston County	https://www.co.thurston.wa.us/health_fpforms/ehswat/swdata.html	Thurston County
Jefferson County	https://www.co.jefferson.wa.us/1580/Water-Quality-Monitoring	Jefferson County
Environment Canada	https://data-donnees.az.ec.gc.ca/data/substances/monitor/national-long-term-water-quality-monitoring-data/	Environment Canada

We improved the flow and water quality coverage for watersheds in the U.S portion of the SSM domain following Opt1. In Opt1, 22% of the total watershed area was ungauged and borrowed flow data from neighboring watersheds (Figure B1-4). Currently, in Opt2, 18% of the total watershed area is ungauged, and 55% of the ungauged watershed drainage area (10% of total

[2] https://www.waterqualitydata.us/#countrycode=US&statecode=US%3A53&siteType=Stream&siteType=Aggregate%20surface-water-use&startDateLo=01-01-2005&startDateHi=01-01-2022&sampleMedia=Water&characteristicType=Nutrient&characteristicType=Organics%2C%20Other&mimeType=csv&sorted=no&providers=NWIS&providers=STORET

watersheds) now use National Oceanic and Atmospheric Administration (NOAA) Weather Research Forecast (WRF) Hydro (Gochis et al. 2020) streamflow predictions. Accordingly, the percentage of total watershed area borrowing flow data from neighboring watersheds has dropped from 22% to 8%. Most of the usage of WRF-Hydro by drainage area is in Hood Canal (34%), Strait of Georgia (24%), and Strait of Juan de Fuca (18%) (Figure B1-5A). Island watersheds that exclusively borrowed flow from neighboring watersheds in Opt1 account for approximately 33% of WRF-Hydro usage.

The increase in gauged watershed coverage was more subtle, with 76% of total watershed area now being gauged compared to previous gauge coverage of 72% in Opt1. In total, gauge data were made available to 18 additional watersheds since Opt1. These watersheds, however, were on average considerably smaller (59 Km^2) than the domain-wide average watershed size (229 Km^2) and therefore, had minor impacts on gauged watershed coverage with respect to the total drainage area of all U.S Salish Sea watersheds.

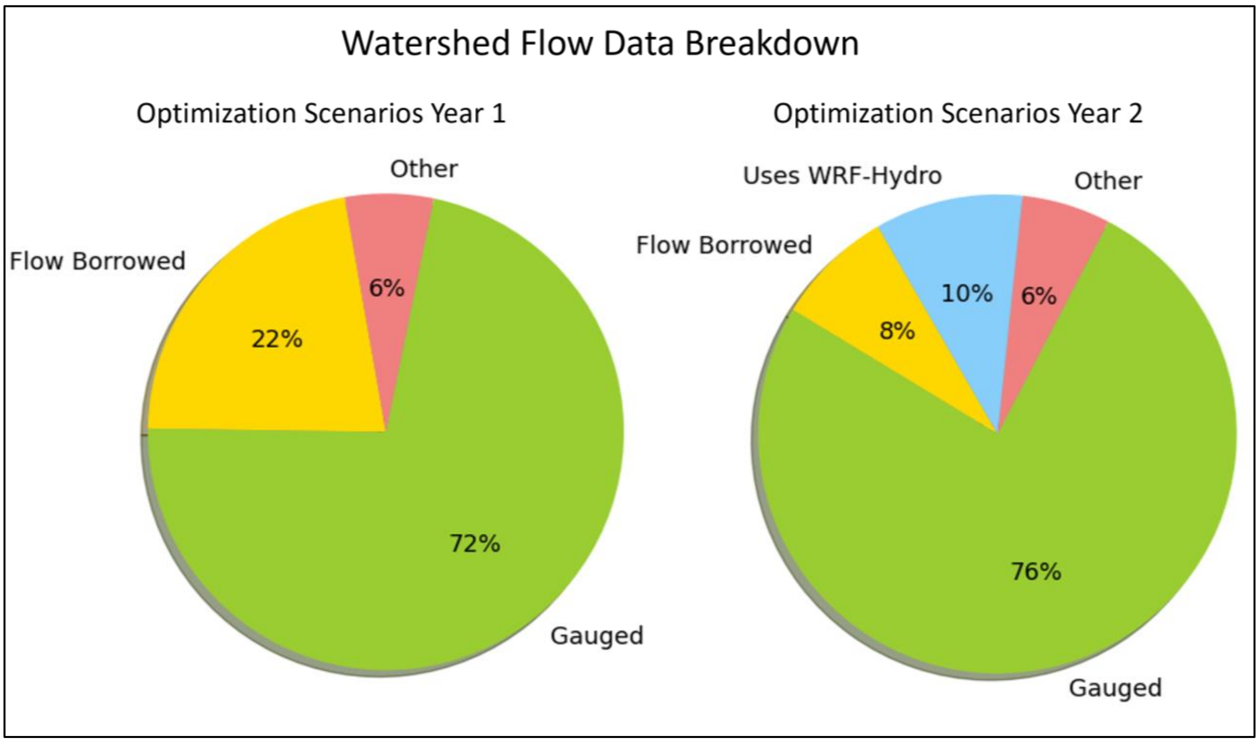


Figure B1-4. Differences in the proportions of flow data sources used for SSM watersheds between Opt1 and Opt2.
'Other' refers to flow-controlled watersheds such as Lake Washington and Deschutes/Capitol Lake.

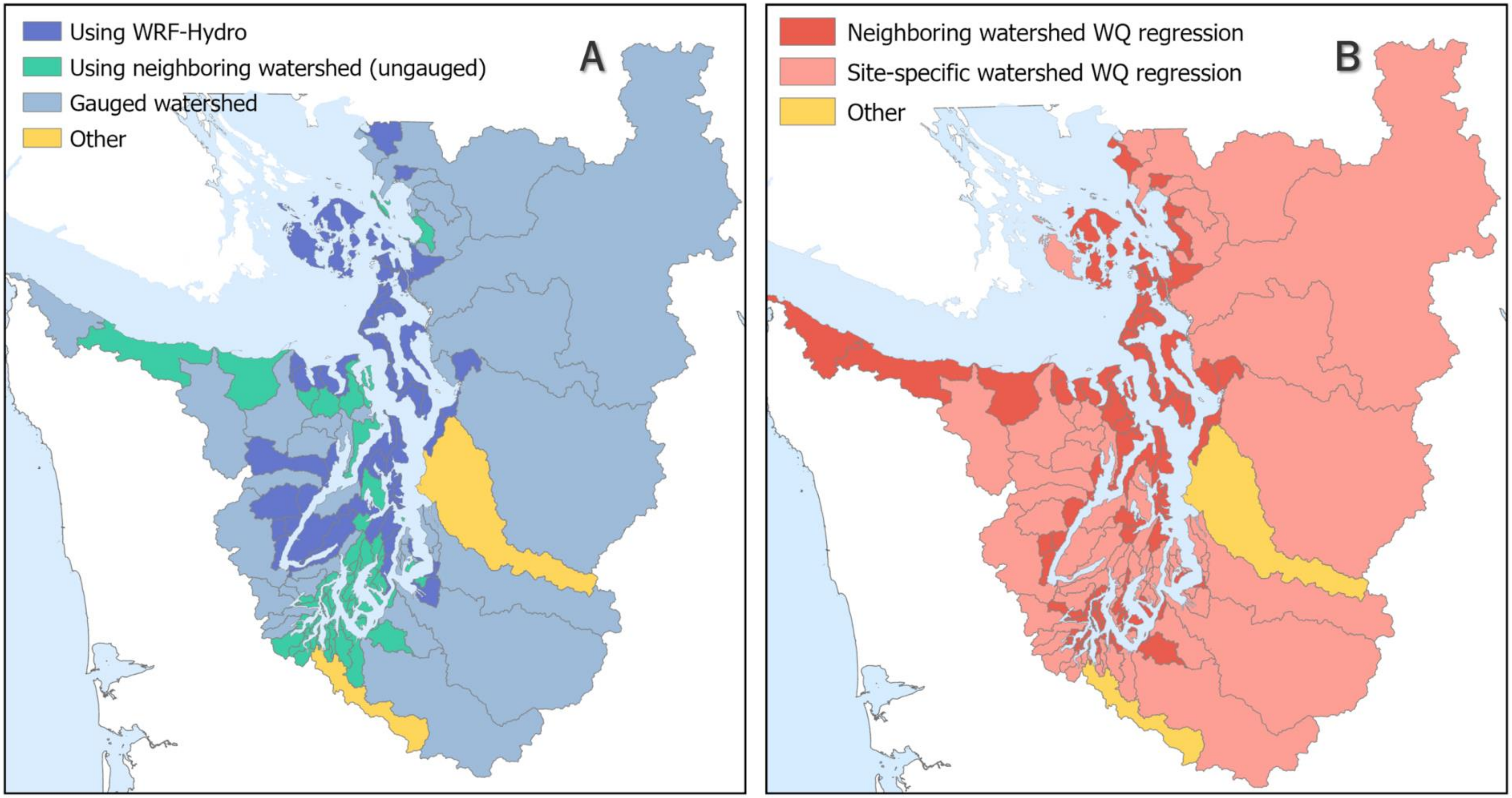


Figure B1-5. (A) Current status of flow data availability for Opt2 watersheds.
Additional flow data has been acquired since (Ahmed et al. 2021), which includes more gauged watersheds and the use of National Oceanic and Atmospheric Administration (NOAA) Weather Research Forecast (WRF) Hydro data (green). (B) Current status of water quality availability for Opt2 watersheds. The “Other” category refers to flow-controlled watersheds such as Lake Washington and Deschutes/Capitol Lake.

Site-specific watershed water quality coverage increased from 72% of the total watershed area in Opt1 to 81% in Opt2 (Figure B1-6). A majority of the new site-specific water quality data were found within small watersheds, which had a lower drainage area than the average size of 229 Km^2.

The total number of watersheds with site-specific water quality data increased. Of the 162 Opt2 Washington watersheds, 39 have new site-specific water quality data and are primarily located in South Puget Sound (38%), Main Basin (28%), and Hood Canal (18%). We used additional data for most of the Opt1 Washington watersheds. We obtained supplementary data for all but 5 of 33 watersheds from Opt1. The 5 watersheds that are using the same data as Opt1 were all part of 2006/2007 SPSDO Study and include Burley Creek, Chambers Creek, Minter Creek, McLane Creek, and Kennedy Creek. A complete overview of changes in data availability from Opt1 and Opt2 can be found in Table B1-4.

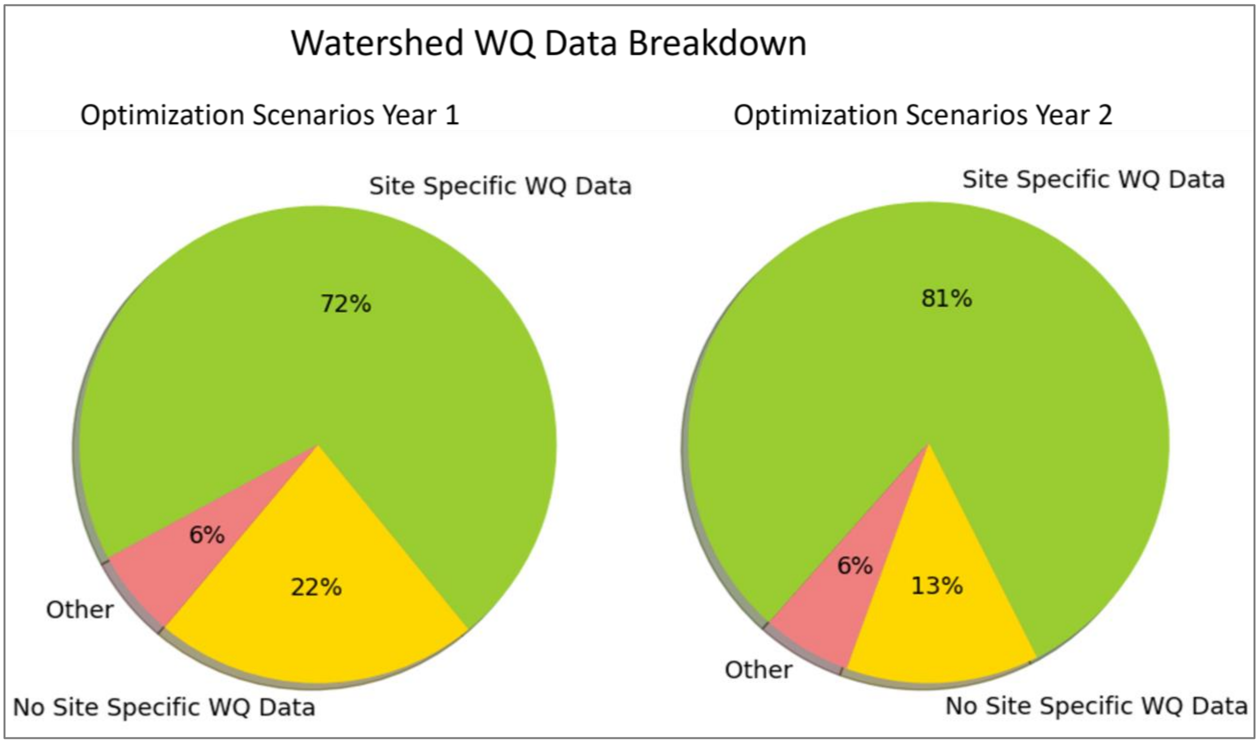


Figure B1-6. Differences in the proportions of water quality data sources used for SSM watersheds between Opt1 and Opt2.

Table B1-4. Differences in data availability between Opt1 and Opt2.

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Anderson West	NH_4	ND	ND	02/2017–06/2021	49	ND
Anderson West	TOC	ND	ND	10/2017–06/2021	44	ND
Anderson West	DO	ND	ND	11/2016–07/2021	57	ND
Anderson West	Temp	ND	ND	11/2016–03/2020	37	ND
Anderson West	pH	ND	ND	11/2016–07/2021	57	ND
Anderson West	NO_3-NO_2	ND	ND	11/2016–06/2021	51	ND
Anderson West	OP	ND	ND	11/2016–06/2021	54	ND
Anderson West	TP	ND	ND	11/2016–06/2021	54	ND
Anderson West	TPN	ND	ND	02/2017–06/2021	49	ND
Artondale Creek	NH_4	ND	ND	01/2017–06/2021	47	ND
Artondale Creek	TOC	ND	ND	10/2017–06/2021	45	ND
Artondale Creek	DO	ND	ND	01/2016–07/2021	69	ND
Artondale Creek	Temp	ND	ND	01/2016–09/2019	45	ND
Artondale Creek	pH	ND	ND	01/2016–07/2021	68	ND
Artondale Creek	NO_3-NO_2	ND	ND	01/2016–06/2021	60	ND
Artondale Creek	OP	ND	ND	02/2016–06/2021	62	ND
Artondale Creek	TP	ND	ND	01/2016–06/2021	62	ND
Artondale Creek	TPN	ND	ND	01/2017–06/2021	46	ND
Big Beef Creek	NH_4	08/2006 –9/2011	62	11/2000–09/2011	97	20
Big Beef Creek	DOC	ND	ND	04/2007–06/2015	9	ND
Big Beef Creek	TOC	ND	ND	10/2004–02/2011	16	ND

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Big Beef Creek	DO	08/2006–9/2011	62	01/2006–09/2011	69	ND
Big Beef Creek	Temp	08/2006–9/2011	60	01/2006–09/2011	67	ND
Big Beef Creek	pH	08/2006–9/2011	59	01/2006–09/2011	66	ND
Big Beef Creek	NO_3-NO_2	08/2006–9/2011	62	10/2000–06/2015	104	21
Big Beef Creek	OP	08/2006–9/2011	62	10/2000–06/2015	97	27
Big Beef Creek	TP	08/2006–9/2011	62	10/2000–06/2015	102	22
Big Beef Creek	TPN	08/2006–9/2011	62	11/2000–09/2011	88	29
Big Quilcene	NH_4	ND	ND	01/1999–09/2010	44	ND
Big Quilcene	DO	ND	ND	01/1999–12/2015	58	ND
Big Quilcene	Temp	ND	ND	01/1999–12/2015	58	ND
Big Quilcene	pH	ND	ND	01/1999–12/2015	58	ND
Big Quilcene	NO_3-NO_2	ND	ND	01/1999–09/2010	45	ND
Big Quilcene	OP	ND	ND	01/1999–09/2010	44	ND
Big Quilcene	TP	ND	ND	01/1999–09/2010	44	ND
Big Quilcene	TPN	ND	ND	01/1999–09/2010	44	ND
Blackjack Cr	NH_4	ND	ND	01/2015–12/2015	12	ND
Blackjack Cr	DOC	ND	ND	05/2008–12/2015	14	ND
Blackjack Cr	DO	ND	ND	01/2015–12/2015	12	ND
Blackjack Cr	Temp	ND	ND	01/2015–12/2015	12	ND
Blackjack Cr	pH	ND	ND	01/2015–12/2015	12	ND
Blackjack Cr	NO_3-NO_2	ND	ND	05/2008–12/2015	14	ND
Blackjack Cr	OP	ND	ND	05/2008–12/2015	14	ND

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Blackjack Cr	TP	ND	ND	05/2008–12/2015	14	ND
Blackjack Cr	TPN	ND	ND	01/2015–12/2015	12	ND
Burley Creek	NH_4	08/2006–10/2007	14	08/2006–10/2007	14	ND
Burley Creek	DOC	08/2006–10/2007	14	08/2006–10/2007	14	ND
Burley Creek	TOC	08/2006–10/2007	14	08/2006–10/2007	14	ND
Burley Creek	DO	08/2006–10/2007	14	08/2006–10/2007	14	ND
Burley Creek	Temp	08/2006–10/2007	14	08/2006–10/2007	14	ND
Burley Creek	pH	08/2006–10/2007	14	08/2006–10/2007	14	ND
Burley Creek	NO_3-NO_2	08/2006–10/2007	14	08/2006–10/2007	14	ND
Burley Creek	OP	08/2006–10/2007	14	08/2006–10/2007	14	ND
Burley Creek	DTP	08/2006–10/2007	14	08/2006–10/2007	14	ND
Burley Creek	TP	08/2006–10/2007	14	08/2006–10/2007	14	ND
Burley Creek	DTPN	08/2006–10/2007	14	08/2006–10/2007	14	ND
Burley Creek	TPN	08/2006–10/2007	14	08/2006–10/2007	14	ND
Butler Creek	NH_4	ND	ND	01/1996–10/2007	25	ND
Butler Creek	DOC	ND	ND	10/2004–10/2007	8	ND
Butler Creek	TOC	ND	ND	10/2004–10/2007	8	ND
Butler Creek	DO	ND	ND	01/1996–10/2007	22	ND
Butler Creek	Temp	ND	ND	01/1996–10/2007	35	ND
Butler Creek	pH	ND	ND	01/1996–10/2007	56	ND
Butler Creek	NO_3-NO_2	ND	ND	01/1996–10/2007	25	ND
Butler Creek	OP	ND	ND	10/2004–10/2007	8	ND

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Butler Creek	TP	ND	ND	01/1996–10/2007	25	ND
Butler Creek	TPN	ND	ND	10/2004–10/2007	8	ND
Chambers Creek	NH_4	08/2006–10/2007	14	08/2006–10/2007	14	ND
Chambers Creek	DOC	08/2006–10/2007	14	08/2006–10/2007	14	ND
Chambers Creek	TOC	08/2006–10/2007	14	08/2006–10/2007	14	ND
Chambers Creek	DO	08/2006–10/2007	14	08/2006–10/2007	14	ND
Chambers Creek	Temp	08/2006–10/2007	14	08/2006–10/2007	14	ND
Chambers Creek	pH	08/2006–10/2007	14	08/2006–10/2007	14	ND
Chambers Creek	NO_3-NO_2	08/2006–10/2007	14	08/2006–10/2007	14	ND
Chambers Creek	OP	08/2006–10/2007	14	08/2006–10/2007	14	ND
Chambers Creek	DTP	08/2006–10/2007	14	08/2006–10/2007	14	ND
Chambers Creek	TP	08/2006–10/2007	14	08/2006–10/2007	14	ND
Chambers Creek	DTPN	08/2006–10/2007	14	08/2006–10/2007	14	ND
Chambers Creek	TPN	08/2006–10/2007	14	08/2006–10/2007	14	ND
Coulter Creek	NH_4	08/2006–10/2007	14	08/2006–10/2007	14	ND
Coulter Creek	DOC	08/2006–10/2007	14	08/2006–06/2015	22	ND
Coulter Creek	TOC	08/2006–10/2007	14	08/2006–10/2007	18	ND
Coulter Creek	DO	08/2006–10/2007	14	08/2006–10/2007	14	ND
Coulter Creek	Temp	08/2006–10/2007	14	08/2006–10/2007	14	ND
Coulter Creek	pH	08/2006–10/2007	14	08/2006–10/2007	14	ND
Coulter Creek	NO_3-NO_2	08/2006–10/2007	14	08/2006–06/2015	22	ND
Coulter Creek	OP	08/2006–10/2007	14	08/2006–06/2015	22	ND

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Coulter Creek	DTP	08/2006–10/2007	14	08/2006–10/2007	14	ND
Coulter Creek	TP	08/2006–10/2007	14	08/2006–06/2015	22	ND
Coulter Creek	DTPN	08/2006–10/2007	14	08/2006–10/2007	14	ND
Coulter Creek	TPN	08/2006–10/2007	14	08/2006–10/2007	14	ND
Cranberry Creek	NH_4	ND	ND	03/1999–10/2007	11	ND
Cranberry Creek	DOC	ND	ND	03/1999–10/2007	11	ND
Cranberry Creek	TOC	ND	ND	03/1999–10/2007	11	ND
Cranberry Creek	DO	ND	ND	03/1999–10/2007	11	ND
Cranberry Creek	Temp	ND	ND	03/1999–10/2007	11	ND
Cranberry Creek	NO_3-NO_2	ND	ND	03/1999–10/2007	11	ND
Cranberry Creek	OP	ND	ND	03/1999–10/2007	11	ND
Cranberry Creek	TP	ND	ND	03/1999–10/2007	11	ND
Cranberry Creek	TPN	ND	ND	03/1999–10/2007	11	ND
Dabob Bay	NH_4	ND	ND	10/2006–08/2021	38	ND
Dabob Bay	DOC	ND	ND	10/2019–08/2021	14	ND
Dabob Bay	TOC	ND	ND	10/2020–08/2021	10	ND
Dabob Bay	DO	ND	ND	10/2006–08/2021	28	ND
Dabob Bay	Temp	ND	ND	10/2006–08/2021	28	ND
Dabob Bay	pH	ND	ND	11/2006–08/2021	25	ND
Dabob Bay	NO_3-NO_2	ND	ND	10/2006–08/2021	38	ND
Dabob Bay	OP	ND	ND	10/2006–08/2021	26	ND
Dabob Bay	TP	ND	ND	10/2006–08/2021	38	ND

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Dabob Bay	TPN	ND	ND	10/2006–08/2021	27	ND
Des Moines Cr	NH_4	ND	ND	10/2003–09/2021	35	ND
Des Moines Cr	DO	ND	ND	10/2003–09/2021	35	ND
Des Moines Cr	Temp	ND	ND	10/2003–09/2021	36	ND
Des Moines Cr	pH	ND	ND	10/2003–09/2021	36	ND
Des Moines Cr	NO_3-NO_2	ND	ND	10/2003–09/2021	35	ND
Des Moines Cr	OP	ND	ND	10/2003–09/2021	35	ND
Des Moines Cr	TP	ND	ND	10/2003–09/2021	35	ND
Des Moines Cr	TPN	ND	ND	10/2003–09/2021	35	ND
Deschutes R.	NH_4	08/2006–12/2018	149	01/1999–08/2021	208	49
Deschutes R.	DOC	08/2006–10/2007, 2010 (2 mo), 2011 (4mo), 10/2017–12/2018	36	03/1999–08/2021	67	ND
Deschutes R.	TOC	08/2006–10/2007, 2010 (2 mo), 2011 (4 mo), 10/2017–12/2018	34	03/1999–08/2021	53	ND
Deschutes R.	DO	08/2006–12/2018	150	01/2006–02/2019	127	32
Deschutes R.	Temp	08/2006–12/2018	148	01/2006–01/2019	131	26
Deschutes R.	pH	08/2006–12/2018	147	01/2006–02/2019	124	31
Deschutes R.	NO_3-NO_2	08/2006–12/2018	475	02/1999–08/2021	356	83
Deschutes R.	OP	08/2006–12/2018	148	01/1999–08/2021	216	41
Deschutes R.	DTP	08/2006–10/2007	15	07/2006–10/2007	16	ND
Deschutes R.	TP	08/2006–12/2018	149	03/1999–08/2021	205	52
Deschutes R.	DTPN	08/2006–10/2007, 07/2009–10/2009	19	ND	ND	ND

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Deschutes R.	TPN	08/2006–12/2018	150	01/1999–07/2021	199	64
Discovery Bay 1	NH_4	ND	ND	01/2015–12/2015	12	ND
Discovery Bay 1	DOC	ND	ND	01/2015–12/2015	12	ND
Discovery Bay 1	DO	ND	ND	01/2015–12/2015	12	ND
Discovery Bay 1	Temp	ND	ND	01/2015–12/2015	12	ND
Discovery Bay 1	pH	ND	ND	01/2015–12/2015	12	ND
Discovery Bay 1	NO_3-NO_2	ND	ND	01/2015–12/2015	12	ND
Discovery Bay 1	OP	ND	ND	01/2015–12/2015	12	ND
Discovery Bay 1	TP	ND	ND	01/2015–12/2015	12	ND
Discovery Bay 1	TPN	ND	ND	01/2015–12/2015	12	ND
Dosewallips	NH_4	ND	ND	11/2017–10/2018	21	ND
Dosewallips	NO_3-NO_2	ND	ND	11/2017–10/2018	21	ND
Dosewallips	TP	ND	ND	11/2017–10/2018	21	ND
Dosewallips	TPN	ND	ND	11/2017–10/2018	21	ND
Drayton Harbor	NH_4	ND	ND	01/2004–07/2006	26	ND
Drayton Harbor	DO	ND	ND	06/2002–12/2008	92	ND
Drayton Harbor	Temp	ND	ND	06/2002–12/2008	91	ND
Drayton Harbor	pH	ND	ND	01/2004–12/2008	48	ND
Drayton Harbor	NO_3-NO_2	ND	ND	01/2004–07/2006	26	ND
Drayton Harbor	OP	ND	ND	01/2004–07/2006	26	ND
Drayton Harbor	TP	ND	ND	01/2004–07/2006	26	ND
Drayton Harbor	TPN	ND	ND	01/2004–07/2006	26	ND

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Duckabush	NH_4	08/2006–12/2018	147	01/1999–08/2021	204	54
Duckabush	DOC	2010 (2 mo), 2011 (4 mo), 10/2017–12/2018	22	08/2010–09/2019	31	ND
Duckabush	TOC	2010 (2 mo), 2011 (4 mo), 10/2017–12/2018	21	07/2010–09/2018	21	ND
Duckabush	DO	08/2006–12/2018	146	01/2006–02/2019	124	31
Duckabush	Temp	08/2006–12/2018	143	01/2006–02/2019	124	28
Duckabush	pH	08/2006–12/2018	143	01/2006–02/2019	120	31
Duckabush	NO_3-NO_2	08/2006–12/2018	146	02/1999–07/2021	205	54
Duckabush	OP	08/2006–12/2018	145	01/1999–08/2021	205	51
Duckabush	TP	08/2006–12/2018	145	01/1999–08/2021	205	52
Duckabush	TPN	08/2006–12/2018	144	01/1999–08/2021	212	45
Dungeness	NH_4	ND	ND	11/1999–03/2014	105	29
Dungeness	DOC	ND	ND	01/2015–12/2015	12	ND
Dungeness	TOC	ND	ND	11/2021–03/2022	5	ND
Dungeness	DO	ND	ND	10/2000–09/2006	72	ND
Dungeness	Temp	ND	ND	10/2000–09/2006	72	ND
Dungeness	pH	ND	ND	10/2000–09/2006	72	ND
Dungeness	NO_3-NO_2	ND	ND	11/1999–03/2014	112	27
Dungeness	OP	ND	ND	11/1999–03/2014	91	23
Dungeness	TP	ND	ND	11/1999–03/2014	117	23
Dungeness	TPN	ND	ND	11/1999–03/2014	98	19
Dutcher Creek	NH_4	ND	ND	01/2017–06/2021	51	ND

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Dutcher Creek	TOC	ND	ND	10/2017–06/2021	45	ND
Dutcher Creek	DO	ND	ND	01/2016–07/2021	68	ND
Dutcher Creek	Temp	ND	ND	01/2016–09/2019	44	ND
Dutcher Creek	pH	ND	ND	01/2016–07/2021	67	ND
Dutcher Creek	NO_3-NO_2	ND	ND	01/2016–06/2021	63	ND
Dutcher Creek	OP	ND	ND	02/2016–06/2021	63	ND
Dutcher Creek	TP	ND	ND	01/2016–06/2021	64	ND
Dutcher Creek	TPN	ND	ND	01/2017–06/2021	50	ND
Dyes Inlet	NH_4	ND	ND	10/2007–02/2020	17	ND
Dyes Inlet	DO	ND	ND	10/2007–06/2020	18	ND
Dyes Inlet	Temp	ND	ND	10/2007–06/2020	17	ND
Dyes Inlet	pH	ND	ND	10/2007–06/2020	18	ND
Dyes Inlet	NO_3-NO_2	ND	ND	10/2007–02/2020	17	ND
Dyes Inlet	OP	ND	ND	10/2007–02/2020	17	ND
Dyes Inlet	TP	ND	ND	10/2007–02/2020	17	ND
Dyes Inlet	TPN	ND	ND	10/2007–02/2020	17	ND
Ellis Creek	NH_4	ND	ND	10/2004–10/2007	8	ND
Ellis Creek	DOC	ND	ND	10/2004–10/2007	8	ND
Ellis Creek	TOC	ND	ND	10/2004–10/2007	8	ND
Ellis Creek	DO	ND	ND	12/2002–09/2012	79	ND
Ellis Creek	Temp	ND	ND	12/2002–09/2012	73	21
Ellis Creek	pH	ND	ND	12/2002–09/2012	80	35

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Ellis Creek	NO_3-NO_2	ND	ND	01/2003–08/2012	67	16
Ellis Creek	OP	ND	ND	10/2004–10/2007	8	ND
Ellis Creek	TP	ND	ND	12/2002–08/2012	66	17
Ellis Creek	TPN	ND	ND	10/2004–10/2007	8	ND
Ellisport	NH_4	ND	ND	02/2007–12/2017	79	19
Ellisport	DO	ND	ND	12/2006–11/2017	69	28
Ellisport	Temp	ND	ND	12/2006–11/2017	78	20
Ellisport	pH	ND	ND	12/2006–11/2017	83	15
Ellisport	NO_3-NO_2	ND	ND	12/2006–12/2017	78	20
Ellisport	OP	ND	ND	12/2006–12/2017	77	21
Ellisport	TP	ND	ND	12/2006–12/2017	84	14
Ellisport	TPN	ND	ND	12/2006–12/2017	81	17
Elwha	NH_4	08/2006–12/2018	147	01/1999–08/2021	211	51
Elwha	DOC	2010 (2 mo), 2011 (4 mo), 10/2017–12/2018	22	07/2010–08/2021	46	ND
Elwha	TOC	2010 (2 mo), 2011 (4 mo), 10/2017–12/2018	22	07/2010–08/2021	31	ND
Elwha	DO	08/2006–12/2018	147	01/2006–02/2019	137	19
Elwha	Temp	08/2006–12/2018	145	01/2006–02/2019	124	30
Elwha	pH	08/2006–12/2018	143	01/2006–02/2019	139	13
Elwha	NO_3-NO_2	08/2006–12/2018	146	01/1999–07/2021	209	52
Elwha	OP	08/2006–12/2018	146	01/1999–08/2021	199	61
Elwha	TP	08/2006–12/2018	145	01/1999–08/2021	213	47

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Elwha	TPN	08/2006–12/2018	147	01/1999–08/2021	212	50
False Bay Creek	NH_4	ND	ND	01/2015–12/2015	12	ND
False Bay Creek	DOC	ND	ND	01/2015–12/2015	12	ND
False Bay Creek	DO	ND	ND	01/2015–12/2015	13	ND
False Bay Creek	Temp	ND	ND	01/2015–12/2015	13	ND
False Bay Creek	pH	ND	ND	01/2015–12/2015	13	ND
False Bay Creek	NO_3-NO_2	ND	ND	01/2015–12/2015	12	ND
False Bay Creek	OP	ND	ND	01/2015–12/2015	12	ND
False Bay Creek	TP	ND	ND	01/2015–12/2015	12	ND
False Bay Creek	TPN	ND	ND	01/2015–12/2015	12	ND
Federal Way	NH_4	ND	ND	10/2010–12/2015	24	ND
Federal Way	DOC	ND	ND	01/2015–12/2015	12	ND
Federal Way	DO	ND	ND	10/2010–12/2015	25	ND
Federal Way	Temp	ND	ND	10/2010–12/2015	25	ND
Federal Way	pH	ND	ND	10/2010–12/2015	25	ND
Federal Way	NO_3-NO_2	ND	ND	10/2010–12/2015	24	ND
Federal Way	OP	ND	ND	10/2010–12/2015	24	ND
Federal Way	TP	ND	ND	10/2010–12/2015	24	ND
Federal Way	TPN	ND	ND	10/2010–12/2015	24	ND
Fraser[3]	NH_4	ND	ND	05/2011–10/2018	92	22
Fraser[3]	DOC	08/2006–12/2018	258	09/2008–11/2018	122	25
Fraser[3]	DO	08/2006–12/2018	235	09/2008–08/2018	73	ND

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Fraser[3]	Temp	08/2006–05/2015	193	09/2008–05/2015	76	ND
Fraser[3]	pH	08/2006–12/2018	261	09/2008–11/2018	123	24
Fraser[3]	NO_3-NO_2	09/2006–12/2018	235	09/2008–11/2018	122	25
Fraser[3]	DTP	08/2006–12/2018	257	09/2008–11/2018	122	ND
Fraser[3]	TP	08/2006–12/2018	251	09/2008–11/2018	115	25
Fraser[3]	DTPN	09/2006–12/2018	253	10/2008–10/2018	118	27
Fraser[3]	TPN	09/2006–12/2018	211	05/2009–11/2018	110	26
Gig Harbor	NH_4	ND	ND	01/2017–12/2020	40	ND
Gig Harbor	DOC	ND	ND	04/2015–06/2015	10	ND
Gig Harbor	TOC	ND	ND	10/2017–12/2020	39	ND
Gig Harbor	DO	ND	ND	01/2016–12/2020	62	ND
Gig Harbor	Temp	ND	ND	01/2016–09/2019	46	ND
Gig Harbor	pH	ND	ND	01/2016–12/2020	61	ND
Gig Harbor	NO_3-NO_2	ND	ND	12/2013–12/2020	63	ND
Gig Harbor	OP	ND	ND	04/2015–12/2020	67	ND
Gig Harbor	TP	ND	ND	08/2012–12/2020	70	15
Gig Harbor	TPN	ND	ND	01/2017–12/2020	39	ND
Goldsborough Creek	NH_4	08/2006–10/2007	14	01/1999–12/2015	35	ND
Goldsborough Creek	DOC	08/2006–10/2007	14	08/2006–12/2015	26	ND
Goldsborough Creek	TOC	08/2006–10/2007	14	08/2006–10/2007	14	ND
Goldsborough Creek	DO	08/2006–10/2007	14	08/2006–10/2007	14	ND
Goldsborough Creek	Temp	08/2006–10/2007	14	08/2006–10/2007	14	ND

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Goldsborough Creek	pH	08/2006–10/2007	14	08/2006–10/2007	14	ND
Goldsborough Creek	NO_3-NO_2	08/2006–10/2007	14	01/1999–12/2015	35	ND
Goldsborough Creek	OP	08/2006–10/2007	14	01/1999–12/2015	35	ND
Goldsborough Creek	DTP	08/2006–10/2007	14	08/2006–10/2007	14	ND
Goldsborough Creek	TP	08/2006–10/2007	14	01/1999–12/2015	35	ND
Goldsborough Creek	DTPN	08/2006–10/2007	14	08/2006–10/2007	14	ND
Goldsborough Creek	TPN	08/2006–10/2007	14	01/1999–12/2015	35	ND
Green Cove	DO	ND	ND	01/1999–09/2012	96	34
Green Cove	Temp	ND	ND	01/1999–09/2012	95	39
Green Cove	pH	ND	ND	01/1999–08/2012	108	26
Green Cove	NO_3-NO_2	ND	ND	02/1999–08/2012	109	25
Green Cove	TP	ND	ND	01/1999–09/2012	105	29
Green River	NH_4	08/2006–12/2018	147	01/1999–09/2021	207	55
Green River	DOC	2010 (3 mo), 2011 (4 mo), 10/2017–12/2018	37	07/2006–10/2021	62	ND
Green River	TOC	2010 (3 mo), 2011 (4 mo), 10/2017–12/2018	34	07/2006–10/2021	46	ND
Green River	DO	08/2006–12/2018	148	01/2006–02/2019	121	36
Green River	Temp	08/2006–12/2018	147	01/2006–11/2018	128	28
Green River	pH	08/2006–12/2018	146	01/2006–02/2019	121	34
Green River	NO_3-NO_2	08/2006–12/2018	149	01/1999–10/2021	210	56
Green River	OP	08/2006–12/2018	147	02/1999–09/2021	205	54
Green River	DTP	08/2006–10/2007	15	11/2001–10/2007	17	ND

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Green River	TP	08/2006–12/2018	148	01/1999–10/2021	202	62
Green River	DTPN	08/2006–09/2009	19	11/2001–10/2009	5	ND
Green River	TPN	08/2006–12/2018	149	03/1999–09/2021	217	47
Green Valley Cr	NH_4	ND	ND	11/2006–12/2007	14	ND
Green Valley Cr	DO	ND	ND	11/2006–12/2007	14	ND
Green Valley Cr	Temp	ND	ND	11/2006–12/2007	14	ND
Green Valley Cr	pH	ND	ND	11/2006–12/2007	14	ND
Green Valley Cr	NO_3-NO_2	ND	ND	11/2006–12/2007	14	ND
Green Valley Cr	OP	ND	ND	11/2006–12/2007	14	ND
Green Valley Cr	TP	ND	ND	11/2006–12/2007	14	ND
Green Valley Cr	TPN	ND	ND	11/2006–12/2007	14	ND
Hamma Hamma	NH_4	ND	ND	11/2010–09/2019	80	21
Hamma Hamma	DOC	ND	ND	10/2010–09/2019	29	ND
Hamma Hamma	TOC	ND	ND	10/2010–08/2018	18	ND
Hamma Hamma	DO	ND	ND	10/2010–02/2019	77	19
Hamma Hamma	Temp	ND	ND	10/2010–02/2019	68	24
Hamma Hamma	pH	ND	ND	10/2010–02/2019	73	19
Hamma Hamma	NO_3-NO_2	ND	ND	10/2010–09/2019	77	22
Hamma Hamma	OP	ND	ND	10/2010–09/2019	86	16
Hamma Hamma	TP	ND	ND	10/2010–08/2019	84	15
Hamma Hamma	TPN	ND	ND	10/2010–09/2019	77	22
Herron Creek	NH_4	ND	ND	01/2017–08/2017	8	ND

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Herron Creek	DO	ND	ND	01/2016–09/2017	22	ND
Herron Creek	Temp	ND	ND	01/2016–09/2017	22	ND
Herron Creek	pH	ND	ND	01/2016–09/2017	22	ND
Herron Creek	NO_3-NO_2	ND	ND	01/2016–08/2017	20	ND
Herron Creek	OP	ND	ND	02/2016–09/2017	16	ND
Herron Creek	TP	ND	ND	01/2016–09/2017	17	ND
Herron Creek	TPN	ND	ND	01/2017–08/2017	8	ND
Hylebos Cr	NH_4	ND	ND	07/2007–12/2015	28	ND
Hylebos Cr	DOC	ND	ND	07/2007–12/2015	16	ND
Hylebos Cr	DO	ND	ND	07/2007–12/2015	29	ND
Hylebos Cr	Temp	ND	ND	07/2007–12/2015	29	ND
Hylebos Cr	pH	ND	ND	07/2007–12/2015	29	ND
Hylebos Cr	NO_3-NO_2	ND	ND	07/2007–12/2015	28	ND
Hylebos Cr	OP	ND	ND	07/2007–12/2015	28	ND
Hylebos Cr	TP	ND	ND	07/2007–12/2015	28	ND
Hylebos Cr	TPN	ND	ND	07/2007–12/2015	28	ND
Hylebos Cr	NH_4	ND	ND	03/2016–04/2017	18	ND
Hylebos Cr	DOC	ND	ND	03/2016–04/2017	18	ND
Hylebos Cr	TOC	ND	ND	03/2016–04/2017	18	ND
Hylebos Cr	pH	ND	ND	03/2016–04/2017	18	ND
Hylebos Cr	NO_3-NO_2	ND	ND	03/2016–04/2017	18	ND
Hylebos Cr	OP	ND	ND	03/2016–04/2017	18	ND

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Hylebos Cr	TP	ND	ND	03/2016–04/2017	18	ND
Hylebos Cr	TPN	ND	ND	03/2016–04/2017	18	ND
Judd Cr	NH_4	ND	ND	11/2006–11/2017	98	34
Judd Cr	DOC	ND	ND	07/2007–09/2012	37	ND
Judd Cr	TOC	ND	ND	07/2007–09/2012	37	ND
Judd Cr	DO	ND	ND	12/2006–12/2017	110	23
Judd Cr	Temp	ND	ND	11/2006–12/2017	117	16
Judd Cr	pH	ND	ND	11/2006–12/2017	109	24
Judd Cr	NO_3-NO_2	ND	ND	11/2006–12/2017	101	32
Judd Cr	OP	ND	ND	11/2006–12/2017	94	39
Judd Cr	TP	ND	ND	12/2006–12/2017	108	25
Judd Cr	TPN	ND	ND	11/2006–12/2017	110	23
Kennedy Creek	NH_4	08/2006–10/2007	14	08/2006–10/2007	14	ND
Kennedy Creek	DOC	08/2006–10/2007	14	08/2006–10/2007	14	ND
Kennedy Creek	TOC	08/2006–10/2007	14	08/2006–10/2007	14	ND
Kennedy Creek	DO	08/2006–10/2007	14	08/2006–10/2007	14	ND
Kennedy Creek	Temp	08/2006–10/2007	14	08/2006–10/2007	14	ND
Kennedy Creek	pH	08/2006–10/2007	14	08/2006–10/2007	14	ND
Kennedy Creek	NO_3-NO_2	08/2006–10/2007	14	08/2006–10/2007	14	ND
Kennedy Creek	OP	08/2006–10/2007	14	08/2006–10/2007	14	ND
Kennedy Creek	DTP	08/2006–10/2007	14	08/2006–10/2007	14	ND
Kennedy Creek	TP	08/2006–10/2007	14	08/2006–10/2007	14	ND

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Kennedy Creek	DTPN	08/2006–10/2007	14	08/2006–10/2007	14	ND
Kennedy Creek	TPN	08/2006–10/2007	14	08/2006–10/2007	14	ND
Liberty Bay	NH_4	ND	ND	12/2006–06/2015	14	ND
Liberty Bay	DOC	ND	ND	12/2006–06/2015	15	ND
Liberty Bay	DO	ND	ND	10/2002–09/2006	41	ND
Liberty Bay	Temp	ND	ND	10/2002–09/2006	42	ND
Liberty Bay	pH	ND	ND	10/2002–09/2006	39	ND
Liberty Bay	NO_3-NO_2	ND	ND	12/2006–06/2015	14	ND
Liberty Bay	OP	ND	ND	12/2006–06/2015	14	ND
Liberty Bay	TP	ND	ND	12/2006–06/2015	14	ND
Liberty Bay	TPN	ND	ND	12/2006–06/2015	14	ND
Little Quilcene	NH_4	ND	ND	11/2016–10/2017	36	ND
Little Quilcene	DO	ND	ND	10/2012–12/2015	25	ND
Little Quilcene	Temp	ND	ND	10/2012–12/2015	25	ND
Little Quilcene	pH	ND	ND	10/2012–12/2015	25	ND
Little Quilcene	NO_3-NO_2	ND	ND	11/2016–10/2017	36	ND
Little Quilcene	TP	ND	ND	11/2016–10/2017	36	ND
Lynch Cove	NH_4	ND	ND	01/1999–09/2003	24	ND
Lynch Cove	DO	ND	ND	01/1999–09/2003	24	ND
Lynch Cove	Temp	ND	ND	01/1999–09/2003	24	ND
Lynch Cove	pH	ND	ND	01/1999–09/2003	23	ND
Lynch Cove	NO_3-NO_2	ND	ND	01/1999–09/2003	24	ND

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Lynch Cove	OP	ND	ND	01/1999–09/2003	24	ND
Lynch Cove	TP	ND	ND	01/1999–09/2003	24	ND
Lynch Cove	TPN	ND	ND	01/1999–09/2003	24	ND
Magnolia Bch	NH_4	ND	ND	01/2007–12/2015	69	22
Magnolia Bch	DOC	ND	ND	01/2010–09/2012	33	ND
Magnolia Bch	TOC	ND	ND	01/2010–09/2012	33	ND
Magnolia Bch	DO	ND	ND	11/2006–12/2015	73	18
Magnolia Bch	Temp	ND	ND	11/2006–12/2015	74	17
Magnolia Bch	pH	ND	ND	12/2006–10/2015	69	22
Magnolia Bch	NO_3-NO_2	ND	ND	11/2006–12/2015	68	23
Magnolia Bch	OP	ND	ND	11/2006–12/2015	70	21
Magnolia Bch	TP	ND	ND	12/2006–12/2015	71	20
Magnolia Bch	TPN	ND	ND	11/2006–12/2015	75	16
McAllister Creek	NH_4	08/2006–10/2007	14	04/2001–10/2007	25	ND
McAllister Creek	DOC	08/2006–10/2007	14	08/2006–10/2007	14	ND
McAllister Creek	TOC	08/2006–10/2007	14	08/2006–10/2007	14	ND
McAllister Creek	DO	08/2006–10/2007	14	08/2006–10/2007	14	ND
McAllister Creek	Temp	08/2006–10/2007	14	08/2006–10/2007	14	ND
McAllister Creek	pH	08/2006–10/2007	14	08/2006–10/2007	14	ND
McAllister Creek	NO_3-NO_2	08/2006–10/2007	14	04/2001–10/2007	25	ND
McAllister Creek	OP	08/2006–10/2007	14	07/2002–10/2007	22	ND
McAllister Creek	DTP	08/2006–10/2007	14	08/2006–10/2007	14	ND

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
McAllister Creek	TP	08/2006–10/2007	14	04/2001–10/2007	25	ND
McAllister Creek	DTPN	08/2006–10/2007	14	08/2006–10/2007	14	ND
McAllister Creek	TPN	08/2006–10/2007	14	04/2001–10/2007	25	ND
McCorkmick Creek	NH_4	ND	ND	01/2017–06/2021	51	ND
McCorkmick Creek	TOC	ND	ND	10/2017–06/2021	45	ND
McCorkmick Creek	DO	ND	ND	01/2016–07/2021	70	ND
McCorkmick Creek	Temp	ND	ND	01/2016–09/2019	46	ND
McCorkmick Creek	pH	ND	ND	01/2016–07/2021	69	ND
McCorkmick Creek	NO_3-NO_2	ND	ND	01/2016–06/2021	63	ND
McCorkmick Creek	OP	ND	ND	02/2016–06/2021	63	ND
McCorkmick Creek	TP	ND	ND	01/2016–06/2021	63	ND
McCorkmick Creek	TPN	ND	ND	01/2017–06/2021	50	ND
McLane Creek	NH_4	08/2006–10/2007	14	08/2006–10/2007	14	ND
McLane Creek	DOC	08/2006–10/2007	14	08/2006–10/2007	14	ND
McLane Creek	TOC	08/2006–10/2007	14	08/2006–10/2007	14	ND
McLane Creek	DO	08/2006–10/2007	14	08/2006–10/2007	14	ND
McLane Creek	Temp	08/2006–10/2007	14	08/2006–10/2007	14	ND
McLane Creek	pH	08/2006–10/2007	14	08/2006–10/2007	14	ND
McLane Creek	NO_3-NO_2	08/2006–10/2007	14	08/2006–10/2007	14	ND
McLane Creek	OP	08/2006–10/2007	14	08/2006–10/2007	14	ND
McLane Creek	DTP	08/2006–10/2007	14	08/2006–10/2007	14	ND
McLane Creek	TP	08/2006–10/2007	14	08/2006–10/2007	14	ND

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
McLane Creek	DTPN	08/2006–10/2007	14	08/2006–10/2007	14	ND
McLane Creek	TPN	08/2006–10/2007	14	08/2006–10/2007	14	ND
Mill Creek	NH_4	ND	ND	03/1999–12/2015	19	ND
Mill Creek	DOC	ND	ND	03/1999–12/2015	19	ND
Mill Creek	DO	ND	ND	03/1999–12/2015	20	ND
Mill Creek	Temp	ND	ND	03/1999–12/2015	20	ND
Mill Creek	pH	ND	ND	01/2015–12/2015	13	ND
Mill Creek	NO_3-NO_2	ND	ND	03/1999–12/2015	19	ND
Mill Creek	OP	ND	ND	03/1999–12/2015	19	ND
Mill Creek	TP	ND	ND	03/1999–12/2015	19	ND
Mill Creek	TPN	ND	ND	03/1999–12/2015	19	ND
Miller Ck	NH_4	ND	ND	10/2003–09/2019	40	ND
Miller Ck	DOC	ND	ND	07/2006–09/2019	19	ND
Miller Ck	DO	ND	ND	10/2003–09/2019	40	ND
Miller Ck	Temp	ND	ND	10/2003–09/2019	40	ND
Miller Ck	pH	ND	ND	10/2003–09/2019	40	ND
Miller Ck	NO_3-NO_2	ND	ND	10/2003–09/2019	40	ND
Miller Ck	OP	ND	ND	10/2003–09/2019	40	ND
Miller Ck	TP	ND	ND	10/2003–09/2019	40	ND
Miller Ck	TPN	ND	ND	10/2003–09/2019	40	ND
Minter Creek	NH_4	08/2006–10/2007	14	08/2006–10/2007	14	ND
Minter Creek	DOC	08/2006–10/2007	14	08/2006–10/2007	14	ND

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Minter Creek	TOC	08/2006–10/2007	14	08/2006–10/2007	14	ND
Minter Creek	DO	08/2006–10/2007	14	08/2006–10/2007	14	ND
Minter Creek	Temp	08/2006–10/2007	14	08/2006–10/2007	14	ND
Minter Creek	pH	08/2006–10/2007	14	08/2006–10/2007	14	ND
Minter Creek	NO_3-NO_2	08/2006–10/2007	14	08/2006–10/2007	14	ND
Minter Creek	OP	08/2006–10/2007	14	08/2006–10/2007	14	ND
Minter Creek	DTP	08/2006–10/2007	14	08/2006–10/2007	14	ND
Minter Creek	TP	08/2006–10/2007	14	08/2006–10/2007	14	ND
Minter Creek	DTPN	08/2006–10/2007	14	08/2006–10/2007	14	ND
Minter Creek	TPN	08/2006–10/2007	14	08/2006–10/2007	14	ND
Moxlie Creek	NH_4	ND	ND	10/2004–10/2007	8	ND
Moxlie Creek	DOC	ND	ND	10/2004–10/2007	8	ND
Moxlie Creek	TOC	ND	ND	10/2004–10/2007	8	ND
Moxlie Creek	DO	ND	ND	11/1996–09/2012	34	ND
Moxlie Creek	Temp	ND	ND	11/1996–09/2012	36	ND
Moxlie Creek	pH	ND	ND	07/2003–09/2012	19	ND
Moxlie Creek	NO_3-NO_2	ND	ND	10/2004–10/2007	8	ND
Moxlie Creek	OP	ND	ND	10/2004–10/2007	8	ND
Moxlie Creek	TP	ND	ND	10/2004–10/2007	8	ND
Moxlie Creek	TPN	ND	ND	10/2004–10/2007	8	ND
Nisqually River	NH_4	08/2006–12/2018	147	01/1999–10/2021	225	39
Nisqually River	DOC	2010 (2 mo), 2011 (4 mo), 10/2017–12/2018	35	03/1999–10/2021	68	ND

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Nisqually River	TOC	2010 (2 mo), 2011 (4 mo), 10/2017–12/2018	37	03/1999–10/2021	71	ND
Nisqually River	DO	08/2006–12/2018	147	01/2006–02/2019	122	34
Nisqually River	Temp	08/2006–12/2018	145	01/2006–01/2019	125	29
Nisqually River	pH	08/2006–12/2018	141	03/2006–02/2019	122	27
Nisqually River	NO_3-NO_2	08/2006–12/2018	147	02/1999–10/2021	217	44
Nisqually River	OP	08/2006–12/2018	145	02/1999–10/2021	203	57
Nisqually River	DTP	08/2006–10/2007	15	07/2006–10/2007	15	ND
Nisqually River	TP	08/2006–12/2018	146	02/1999–08/2021	215	48
Nisqually River	DTPN	08/2006–10/2009	19	ND	ND	ND
Nisqually River	TPN	08/2006–12/2018	148	01/1999–10/2021	213	52
Nooksack River	NH_4	08/2006–12/2018	147	02/1999–10/2021	198	64
Nooksack River	DOC	2010 (3 mo), 2011 (4 mo), 10/2017–12/2018	22	08/2010–10/2021	48	ND
Nooksack River	TOC	2010 (3 mo), 2011 (4 mo), 10/2017–12/2018	22	08/2010–08/2021	47	ND
Nooksack River	DO	08/2006–12/2018	146	01/2006–02/2019	133	21
Nooksack River	Temp	08/2006–12/2018	147	01/2006–02/2019	129	27
Nooksack River	pH	08/2006–12/2018	146	01/2006–02/2019	121	33
Nooksack River	NO_3-NO_2	09/2006–12/2018	147	01/1999–10/2021	219	45
Nooksack River	OP	09/2006–12/2018	146	01/1999–09/2021	197	64
Nooksack River	TP	09/2006–12/2018	141	01/1999–10/2021	209	46
Nooksack River	TPN	09/2006–12/2018	147	02/1999–10/2021	207	58
Olalla Cr	NH_4	ND	ND	10/2002–10/2007	16	ND

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Olalla Cr	DOC	ND	ND	03/2007–06/2015	18	ND
Olalla Cr	TOC	ND	ND	03/2007–10/2007	8	ND
Olalla Cr	DO	ND	ND	10/2002–10/2007	16	ND
Olalla Cr	Temp	ND	ND	10/2002–10/2007	16	ND
Olalla Cr	pH	ND	ND	10/2002–10/2007	16	ND
Olalla Cr	NO_3-NO_2	ND	ND	10/2002–06/2015	30	ND
Olalla Cr	OP	ND	ND	10/2002–06/2015	30	ND
Olalla Cr	TP	ND	ND	10/2002–06/2015	30	ND
Olalla Cr	TPN	ND	ND	10/2002–10/2007	16	ND
Perry Creek	NH_4	08/2006–10/2007	14	01/1999–10/2007	24	ND
Perry Creek	DOC	08/2006–10/2007	14	03/1999–10/2007	22	ND
Perry Creek	TOC	08/2006–10/2007	14	01/1999–10/2007	24	ND
Perry Creek	DO	08/2006–10/2007	14	08/2006–10/2007	14	ND
Perry Creek	Temp	08/2006–10/2007	14	08/2006–10/2007	14	ND
Perry Creek	pH	08/2006–10/2007	14	08/2006–10/2007	14	ND
Perry Creek	NO_3-NO_2	08/2006–10/2007	14	01/1999–10/2007	24	ND
Perry Creek	OP	08/2006–10/2007	14	01/1999–10/2007	23	ND
Perry Creek	DTP	08/2006–10/2007	14	08/2006–10/2007	14	ND
Perry Creek	TP	08/2006–10/2007	14	01/1999–10/2007	24	ND
Perry Creek	DTPN	08/2006–10/2007	14	08/2006–10/2007	14	ND
Perry Creek	TPN	08/2006–10/2007	14	01/1999–10/2007	24	ND
Purdy Creek	NH_4	ND	ND	01/2017–06/2021	50	ND

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Purdy Creek	TOC	ND	ND	10/2017–06/2021	45	ND
Purdy Creek	DO	ND	ND	01/2016–07/2021	70	ND
Purdy Creek	Temp	ND	ND	01/2016–09/2019	46	ND
Purdy Creek	pH	ND	ND	01/2016–07/2021	70	ND
Purdy Creek	NO_3-NO_2	ND	ND	01/2016–06/2021	62	ND
Purdy Creek	OP	ND	ND	02/2016–06/2021	63	ND
Purdy Creek	TP	ND	ND	01/2016–06/2021	63	ND
Purdy Creek	TPN	ND	ND	01/2017–06/2021	49	ND
Puyallup River	NH_4	08/2006–12/2018	149	01/1999–09/2021	216	47
Puyallup River	DOC	2010 (2 mo), 2011 (4 mo), 10/2017–12/2018	36	03/1999–10/2021	70	ND
Puyallup River	TOC	2010 (2 mo), 2011 (4 mo), 10/2017–12/2018	37	03/1999–10/2021	64	ND
Puyallup River	DO	08/2006–12/2018	149	01/2006–02/2019	126	32
Puyallup River	Temp	08/2006–12/2018	148	01/2006–02/2019	121	36
Puyallup River	pH	08/2006–12/2018	144	01/2006–02/2019	120	31
Puyallup River	NO_3-NO_2	08/2006–12/2018	148	02/1999–10/2021	206	59
Puyallup River	OP	08/2006–12/2018	148	01/1999–10/2021	212	52
Puyallup River	DTP	08/2006–10/2007	15	12/2001–10/2007	17	0
Puyallup River	TP	08/2006–12/2018	148	02/1999–10/2021	202	57
Puyallup River	DTPN	08/2006–10/2009	19	12/2001–10/2009	6	ND
Puyallup River	TPN	08/2006–12/2018	148	01/1999–10/2021	208	56
Ray Nash Creek	NH_4	ND	ND	01/2017–06/2021	49	ND

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Ray Nash Creek	TOC	ND	ND	10/2017–06/2021	45	ND
Ray Nash Creek	DO	ND	ND	01/2016–07/2021	69	ND
Ray Nash Creek	Temp	ND	ND	01/2016–09/2019	45	ND
Ray Nash Creek	pH	ND	ND	01/2016–07/2021	68	ND
Ray Nash Creek	NO_3-NO_2	ND	ND	01/2016–06/2021	61	ND
Ray Nash Creek	OP	ND	ND	02/2016–06/2021	64	ND
Ray Nash Creek	TP	ND	ND	01/2016–06/2021	64	ND
Ray Nash Creek	TPN	ND	ND	01/2017–06/2021	48	ND
Rocky Creek	NH_4	08/2006–10/2007	14	03/1999–06/2021	46	ND
Rocky Creek	DOC	08/2006–10/2007	14	03/1999–10/2007	21	ND
Rocky Creek	TOC	08/2006–10/2007	14	03/1999–06/2021	54	ND
Rocky Creek	DO	08/2006–10/2007	14	08/2006–07/2021	48	ND
Rocky Creek	Temp	08/2006–10/2007	14	08/2006–09/2019	26	ND
Rocky Creek	pH	08/2006–10/2007	14	08/2006–07/2021	48	ND
Rocky Creek	NO_3-NO_2	08/2006–10/2007	14	03/1999–06/2021	46	ND
Rocky Creek	OP	08/2006–10/2007	14	03/1999–06/2021	48	ND
Rocky Creek	DTP	08/2006–10/2007	14	08/2006–10/2007	14	ND
Rocky Creek	TP	08/2006–10/2007	14	03/1999–06/2021	48	ND
Rocky Creek	DTPN	08/2006–10/2007	14	08/2006–10/2007	14	ND
Rocky Creek	TPN	08/2006–10/2007	14	03/1999–06/2021	46	ND
Saltwater St Pk	NH_4	ND	ND	01/2015–12/2015	12	ND
Saltwater St Pk	DOC	ND	ND	01/2015–12/2015	12	ND

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Saltwater St Pk	DO	ND	ND	01/2015–12/2015	13	ND
Saltwater St Pk	Temp	ND	ND	01/2015–12/2015	13	ND
Saltwater St Pk	pH	ND	ND	01/2015–12/2015	13	ND
Saltwater St Pk	NO_3-NO_2	ND	ND	01/2015–12/2015	12	ND
Saltwater St Pk	OP	ND	ND	01/2015–12/2015	12	ND
Saltwater St Pk	TP	ND	ND	01/2015–12/2015	12	ND
Saltwater St Pk	TPN	ND	ND	01/2015–12/2015	12	ND
Samish River	NH_4	08/2006–12/2018	148	02/1999–10/2021	216	51
Samish River	DOC	2010 (3 mo), 2011 (4 mo), 10/2017–12/2018	22	08/2010–10/2021	50	ND
Samish River	TOC	2010 (3 mo), 2011 (4 mo), 10/2017–12/2018	22	08/2010–08/2021	38	ND
Samish River	DO	08/2006–12/2018	146	01/2006–02/2019	113	42
Samish River	Temp	08/2006–12/2018	148	01/2006–02/2019	130	27
Samish River	pH	08/2006–12/2018	146	01/2006–02/2019	125	30
Samish River	NO_3-NO_2	08/2006–12/2018	148	01/1999–09/2021	213	54
Samish River	OP	08/2006–12/2018	147	01/1999–08/2021	207	59
Samish River	TP	08/2006–12/2018	148	01/1999–09/2021	207	59
Samish River	TPN	08/2006–12/2018	147	01/1999–10/2021	211	55
Sequim Bay S	NH_4	ND	ND	11/1999–09/2001	23	ND
Sequim Bay S	DO	ND	ND	11/1999–09/2001	23	ND
Sequim Bay S	Temp	ND	ND	11/1999–09/2001	23	ND
Sequim Bay S	pH	ND	ND	11/1999–09/2001	23	ND

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Sequim Bay S	NO_3-NO_2	ND	ND	11/1999–09/2001	23	ND
Sequim Bay S	OP	ND	ND	11/1999–09/2001	23	ND
Sequim Bay S	TP	ND	ND	11/1999–09/2001	23	ND
Sequim Bay S	TPN	ND	ND	11/1999–09/2001	23	ND
Sherwood Creek	NH_4	08/2006–10/2007	14	03/1999–09/2013	33	ND
Sherwood Creek	DOC	08/2006–10/2007	15	03/1999–10/2007	21	ND
Sherwood Creek	TOC	08/2006–10/2007	15	03/1999–10/2007	21	ND
Sherwood Creek	DO	08/2006–10/2007	14	08/2006–09/2013	26	ND
Sherwood Creek	Temp	08/2006–10/2007	14	08/2006–09/2013	26	ND
Sherwood Creek	pH	08/2006–10/2007	14	08/2006–09/2013	26	ND
Sherwood Creek	NO_3-NO_2	08/2006–10/2007	14	03/1999–09/2013	33	ND
Sherwood Creek	OP	08/2006–10/2007	14	03/1999–09/2013	33	ND
Sherwood Creek	DTP	08/2006–10/2007	14	08/2006–10/2007	14	ND
Sherwood Creek	TP	08/2006–10/2007	14	03/1999–09/2013	33	ND
Sherwood Creek	DTPN	08/2006–10/2007	14	08/2006–10/2007	14	ND
Sherwood Creek	TPN	08/2006–10/2007	14	03/1999–09/2013	33	ND
Shingle Mill Cr	NH_4	ND	ND	12/2006–09/2015	74	21
Shingle Mill Cr	DOC	ND	ND	07/2007–09/2012	37	ND
Shingle Mill Cr	TOC	ND	ND	07/2007–09/2012	37	ND
Shingle Mill Cr	DO	ND	ND	11/2006–12/2015	80	15
Shingle Mill Cr	Temp	ND	ND	11/2006–12/2015	81	14
Shingle Mill Cr	pH	ND	ND	11/2006–12/2015	80	15

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Shingle Mill Cr	NO_3-NO_2	ND	ND	12/2006–12/2015	77	18
Shingle Mill Cr	OP	ND	ND	11/2006–12/2015	73	22
Shingle Mill Cr	TP	ND	ND	11/2006–12/2015	76	19
Shingle Mill Cr	TPN	ND	ND	12/2006–12/2015	81	14
Skagit	NH_4	08/2006–12/2018	145	01/1999–09/2021	199	57
Skagit	DOC	2010 (3 mo), 2011 (4 mo), 10/2017–12/2018	22	08/2010–10/2021	47	ND
Skagit	TOC	2010 (3 mo), 2011 (4 mo), 10/2017–12/2018	22	08/2010–08/2021	46	ND
Skagit	DO	08/2006–12/2018	146	01/2006–02/2019	127	28
Skagit	Temp	08/2006–12/2018	148	01/2006–02/2019	132	25
Skagit	pH	08/2006–12/2018	146	01/2006–02/2019	128	25
Skagit	NO_3-NO_2	08/2006–12/2018	148	01/1999–10/2021	206	60
Skagit	OP	08/2006–12/2018	147	02/1999–10/2021	216	50
Skagit	TP	08/2006–12/2018	145	01/1999–10/2021	201	63
Skagit	TPN	08/2006–12/2018	148	01/1999–10/2021	207	59
Skokomish	NH_4	08/2006–10/2018	140	01/1999–07/2021	214	45
Skokomish	DOC	2010 (3 mo), 2011 (4 mo), 10/2017–10/2018	19	02/1996–09/2019	68	ND
Skokomish	TOC	2010 (3 mo), 2011 (4 mo), 10/2017–10/2018	20	02/1996–09/2018	51	ND
Skokomish	DO	08/2006–10/2018	141	01/2006–02/2019	136	19
Skokomish	Temp	08/2006–10/2018	137	01/2006–02/2019	132	19
Skokomish	pH	08/2006–10/2018	136	01/2006–02/2019	134	16

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Skokomish	NO_3-NO_2	08/2006–10/2018	139	03/1999–07/2021	195	62
Skokomish	OP	08/2006–10/2018	140	01/1999–08/2021	204	54
Skokomish	TP	08/2006–10/2018	140	02/1999–08/2021	208	51
Skokomish	TPN	08/2006–10/2018	140	01/1999–08/2021	203	56
Skookum Creek	NH_4	08/2006–10/2007	14	03/1999–10/2007	21	ND
Skookum Creek	DOC	08/2006–10/2007	14	03/1999–10/2007	21	ND
Skookum Creek	TOC	08/2006–10/2007	14	03/1999–10/2007	21	ND
Skookum Creek	DO	08/2006–10/2007	14	08/2006–10/2007	14	ND
Skookum Creek	Temp	08/2006–10/2007	14	08/2006–10/2007	14	ND
Skookum Creek	pH	08/2006–10/2007	14	08/2006–10/2007	14	ND
Skookum Creek	NO_3-NO_2	08/2006–10/2007	14	03/1999–10/2007	21	ND
Skookum Creek	OP	08/2006–10/2007	14	03/1999–10/2007	21	ND
Skookum Creek	DTP	08/2006–10/2007	14	08/2006–10/2007	14	ND
Skookum Creek	TP	08/2006–10/2007	14	03/1999–10/2007	21	ND
Skookum Creek	DTPN	08/2006–10/2007	14	08/2006–10/2007	14	ND
Skookum Creek	TPN	08/2006–10/2007	14	03/1999–10/2007	21	ND
Snohomish	NH_4	08/2006–12/2018	148	01/1999–10/2021	217	49
Snohomish	DOC	2010 (3 mo), 2011 (4 mo), 10/2017–12/2018	22	08/2010–10/2021	46	ND
Snohomish	TOC	2010 (3 mo), 2011 (4 mo), 10/2017–12/2018	22	08/2010–10/2021	45	ND
Snohomish	DO	08/2006–12/2018	145	01/2006–02/2019	125	29
Snohomish	Temp	08/2006–12/2018	148	01/2006–02/2019	130	27

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Snohomish	pH	08/2006–12/2018	146	01/2006–02/2019	134	21
Snohomish	NO_3-NO_2	08/2006–12/2018	148	01/1999–10/2021	213	52
Snohomish	OP	08/2006–12/2018	145	01/1999–10/2021	216	47
Snohomish	TP	08/2006–12/2018	146	03/1999–10/2021	201	63
Snohomish	TPN	08/2006–12/2018	148	01/1999–10/2021	199	66
Squalicum Creek	NH_4	ND	ND	03/2015–09/2015	14	ND
Squalicum Creek	DOC	ND	ND	04/2015–09/2015	13	ND
Squalicum Creek	NO_3-NO_2	ND	ND	03/2015–09/2015	14	ND
Squalicum Creek	OP	ND	ND	03/2015–09/2015	14	ND
Squalicum Creek	TP	ND	ND	03/2015–09/2015	14	ND
Squalicum Creek	TPN	ND	ND	03/2015–09/2015	14	ND
Stillaguamish	NH_4	08/2006–12/2018	148	01/1999–10/2021	223	46
Stillaguamish	DOC	2010 (3 mo), 2011 (4 mo), 10/2017–12/2018	22	08/2010–10/2021	50	ND
Stillaguamish	TOC	2010 (3 mo), 2011 (4 mo), 10/2017–12/2018	22	08/2010–08/2021	49	ND
Stillaguamish	DO	08/2006–12/2018	143	01/2006–02/2019	118	34
Stillaguamish	Temp	08/2006–12/2018	147	01/2006–02/2019	122	34
Stillaguamish	pH	08/2006–12/2018	147	01/2006–02/2019	123	33
Stillaguamish	NO_3-NO_2	08/2006–12/2018	149	01/1999–10/2021	226	43
Stillaguamish	OP	08/2006–12/2018	148	01/1999–10/2021	214	55
Stillaguamish	TP	08/2006–12/2018	146	03/1999–10/2021	209	57
Stillaguamish	TPN	08/2006–12/2018	149	01/1999–10/2021	231	37

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Tahlequah	NH_4	ND	ND	11/2006–12/2015	35	ND
Tahlequah	DO	ND	ND	11/2006–12/2015	35	ND
Tahlequah	Temp	ND	ND	11/2006–12/2015	35	ND
Tahlequah	pH	ND	ND	11/2006–12/2015	35	ND
Tahlequah	NO_3-NO_2	ND	ND	11/2006–12/2015	35	ND
Tahlequah	OP	ND	ND	11/2006–12/2015	35	ND
Tahlequah	TP	ND	ND	11/2006–12/2015	35	ND
Tahlequah	TPN	ND	ND	11/2006–12/2015	35	ND
Tahuya	NH_4	ND	ND	10/2007–09/2008	12	ND
Tahuya	DO	ND	ND	10/2007–09/2008	12	ND
Tahuya	Temp	ND	ND	10/2007–09/2008	12	ND
Tahuya	pH	ND	ND	10/2007–09/2008	12	ND
Tahuya	NO_3-NO_2	ND	ND	03/2004–09/2008	20	ND
Tahuya	OP	ND	ND	10/2007–09/2008	12	ND
Tahuya	TP	ND	ND	03/2004–09/2008	20	ND
Tahuya	TPN	ND	ND	10/2007–09/2008	12	ND
Vaughn Creek	NH_4	ND	ND	01/2017–06/2021	55	ND
Vaughn Creek	TOC	ND	ND	10/2017–06/2021	45	ND
Vaughn Creek	DO	ND	ND	01/2016–07/2021	68	ND
Vaughn Creek	Temp	ND	ND	01/2016–09/2019	44	ND
Vaughn Creek	pH	ND	ND	01/2016–07/2021	67	ND
Vaughn Creek	NO_3-NO_2	ND	ND	01/2016–06/2021	67	ND

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Vaughn Creek	OP	ND	ND	02/2016–06/2021	61	ND
Vaughn Creek	TP	ND	ND	01/2016–06/2021	63	ND
Vaughn Creek	TPN	ND	ND	01/2017–06/2021	54	ND
Whatcom Creek	NH_4	ND	ND	01/2015–12/2015	12	ND
Whatcom Creek	DOC	ND	ND	01/2015–12/2015	12	ND
Whatcom Creek	DO	ND	ND	01/2015–12/2015	13	ND
Whatcom Creek	Temp	ND	ND	01/2015–12/2015	13	ND
Whatcom Creek	pH	ND	ND	01/2015–12/2015	13	ND
Whatcom Creek	NO_3-NO_2	ND	ND	01/2015–12/2015	12	ND
Whatcom Creek	OP	ND	ND	01/2015–12/2015	12	ND
Whatcom Creek	TP	ND	ND	01/2015–12/2015	12	ND
Whatcom Creek	TPN	ND	ND	01/2015–12/2015	12	ND
Whitman Creek	NH_4	ND	ND	01/2017–06/2021	51	ND
Whitman Creek	DOC	ND	ND	08/2018–12/2018	5	ND
Whitman Creek	TOC	ND	ND	10/2017–06/2021	45	ND
Whitman Creek	DO	ND	ND	01/2016–07/2021	69	ND
Whitman Creek	Temp	ND	ND	01/2016–09/2019	46	ND
Whitman Creek	pH	ND	ND	01/2016–07/2021	68	ND
Whitman Creek	NO_3-NO_2	ND	ND	01/2016–06/2021	63	ND
Whitman Creek	OP	ND	ND	02/2016–06/2021	65	ND
Whitman Creek	TP	ND	ND	01/2016–06/2021	66	ND
Whitman Creek	TPN	ND	ND	01/2017–06/2021	50	ND

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Woodard Creek	NH_4	08/2006–10/2007	14	06/2003–10/2007	20	ND
Woodard Creek	DOC	08/2006–10/2007	14	08/2006–10/2007	14	ND
Woodard Creek	TOC	08/2006–10/2007	15	08/2006–05/2010	15	ND
Woodard Creek	DO	08/2006–10/2007	14	08/2006–10/2007	14	ND
Woodard Creek	Temp	08/2006–10/2007	14	08/2006–10/2007	14	ND
Woodard Creek	pH	08/2006–10/2007	14	08/2006–10/2007	14	ND
Woodard Creek	NO_3-NO_2	08/2006–10/2007	14	06/2003–10/2007	20	ND
Woodard Creek	OP	08/2006–10/2007	14	06/2003–10/2007	18	ND
Woodard Creek	DTP	08/2006–10/2007	14	08/2006–10/2007	14	ND
Woodard Creek	TP	08/2006–10/2007	14	06/2003–10/2007	18	ND
Woodard Creek	DTPN	08/2006–10/2007	14	08/2006–10/2007	14	ND
Woodard Creek	TPN	08/2006–10/2007	14	06/2003–10/2007	20	ND
Woodland Creek	NH_4	08/2006–10/2007	14	06/2003–10/2007	28	ND
Woodland Creek	DOC	08/2006–10/2007	14	08/2006–06/2015	28	ND
Woodland Creek	TOC	08/2006–10/2007	14	08/2006–06/2014	19	ND
Woodland Creek	DO	08/2006–10/2007	14	08/2006–10/2007	14	ND
Woodland Creek	Temp	08/2006–10/2007	14	08/2006–10/2007	14	ND
Woodland Creek	pH	08/2006–10/2007	14	08/2006–10/2007	14	ND
Woodland Creek	NO_3-NO_2	08/2006–10/2007	14	06/2003–06/2015	42	ND
Woodland Creek	OP	08/2006–10/2007	14	06/2003–06/2015	40	ND
Woodland Creek	DTP	08/2006–10/2007	14	08/2006–10/2007	14	ND
Woodland Creek	TP	08/2006–10/2007	14	06/2003–06/2015	40	ND

River Regression	Variable	Opt 1 Regression—Date Range	Opt 1 N[1]	Opt 2 Regression—Date Range	Opt 2—Train N[2]	Opt 2—Test N[2]
Woodland Creek	DTPN	08/2006–10/2007	14	08/2006–10/2007	14	ND
Woodland Creek	TPN	08/2006–10/2007	14	06/2003–10/2007	28	ND

Note. In Opt2, parameters with at least 80 samples were split into testing (Test N) and training (Train N) sets, while in Opt1, regressions were fit using the entire data set.

[1] Hourly averaged samples.

[2] Daily averaged samples.

[3] Switched from Fraser at Hope (Opt 1) to Fraser at Gravesend Reach (Opt 2) to account for tidal influence.

ND=no data; NH_4=ammonium; DOC=dissolved organic carbon; TOC=total organic carbon; DO=dissolved oxygen; Temp= temperature; NO_3-NO_2=nitrate + nitrite; DTP= dissolved total phosphorus; TP=total phosphorus; OP=Orthophosphate; DTPN=dissolved total persulfate nitrogen; TPN=total persulfate nitrogen.

Sample site selection

Water quality site selection for each watershed followed a general set of criteria for establishing how representative the water quality data would be for the given watershed. Ideal candidate sites were those that were closest to the mouth of the watershed but did not exhibit saltwater influence (salinity of less than 0.5 parts per thousand), had a streamflow gauge nearby, and had at least 8 or more samples available for each water quality parameter. An example of this scenario can be seen in (Figure B1-7A). As shown in (Figure B1-7A), one of the sites selected was near the mouth (including a coincident streamflow gauge). The site is an Ecology long-term monitoring station (18A050) and had plenty of data for all variables except for Dissolved Organic Carbon (DOC).

DOC data are limited for many watersheds. As a result, even if DOC data came from a site greater than 2 miles upstream of the primary site, the data were considered as more representative than borrowing DOC data from a neighboring watershed. In the example mentioned above, blue colored sites shown in Figure B1-7A were not used, as none of them had any DOC data. Since a sufficient amount of data for other parameters was obtained from 18A050, and because no other sites within 2 miles of it had DOC data, we used the closest site to it with available data. In this case, DOC data were available at the confluence of Caraco Creek and Dungeness, 5 miles upstream of the Ecology gauge and water quality station 18A050 (Figure B1-7A).

Matching all the criteria listed above for an ideal candidate water quality site was not usually possible. For watersheds with limited or less frequent water quality monitoring, locations with the most data were generally prioritized over sites with closer proximity to the mouth of the watershed, with the condition that the site occurs on a reach of the same stream order as the watershed and downstream of all confluences. These criteria were met with only a few exceptions, including Hylebos Creek and Whatcom Creek, which used DOC from an upstream location of a lower stream order, and McAllister Creek, which only had sufficient data for all parameters on the 2nd-order portion of the 3rd-order stream. McAllister Creek sites were additionally the only locations that we used where brackish conditions were observed (salinity of around 2 parts per thousand), which introduces limitations with regard to our representation of river inputs to the Salish Sea Model for this watershed.

For Goldsborough Creek (Figure B1-7B), all three of the available water quality sites were selected. The sites were all within 2 miles of each other, and all occurred on a reach of the same order. Three sites were needed for Goldsborough due to the low number of data points in each one (Table B1-4). The most upstream site near the confluence of Coffee Creek with Goldsborough was also included as it contained as much data as the two downstream sites combined, including DOC data.

In general, upstream sites from a lower order reach were not used unless DOC data were only available at these locations. Except for McAllister Creek, if a lower-order reach were used, it would only be used for DOC, with data for other parameters coming from downstream locations in the watershed. Big Beef Creek (Figure B1-7C) had an adequate number of samples for most parameters but had the bare minimum number of samples to build a regression model for DOC. Upstream sites for Big Beef Creek (in blue) were not selected as they were on a lower order reach, and none of the parameters collected for either of these sites were for DOC (Figure B1-7C).

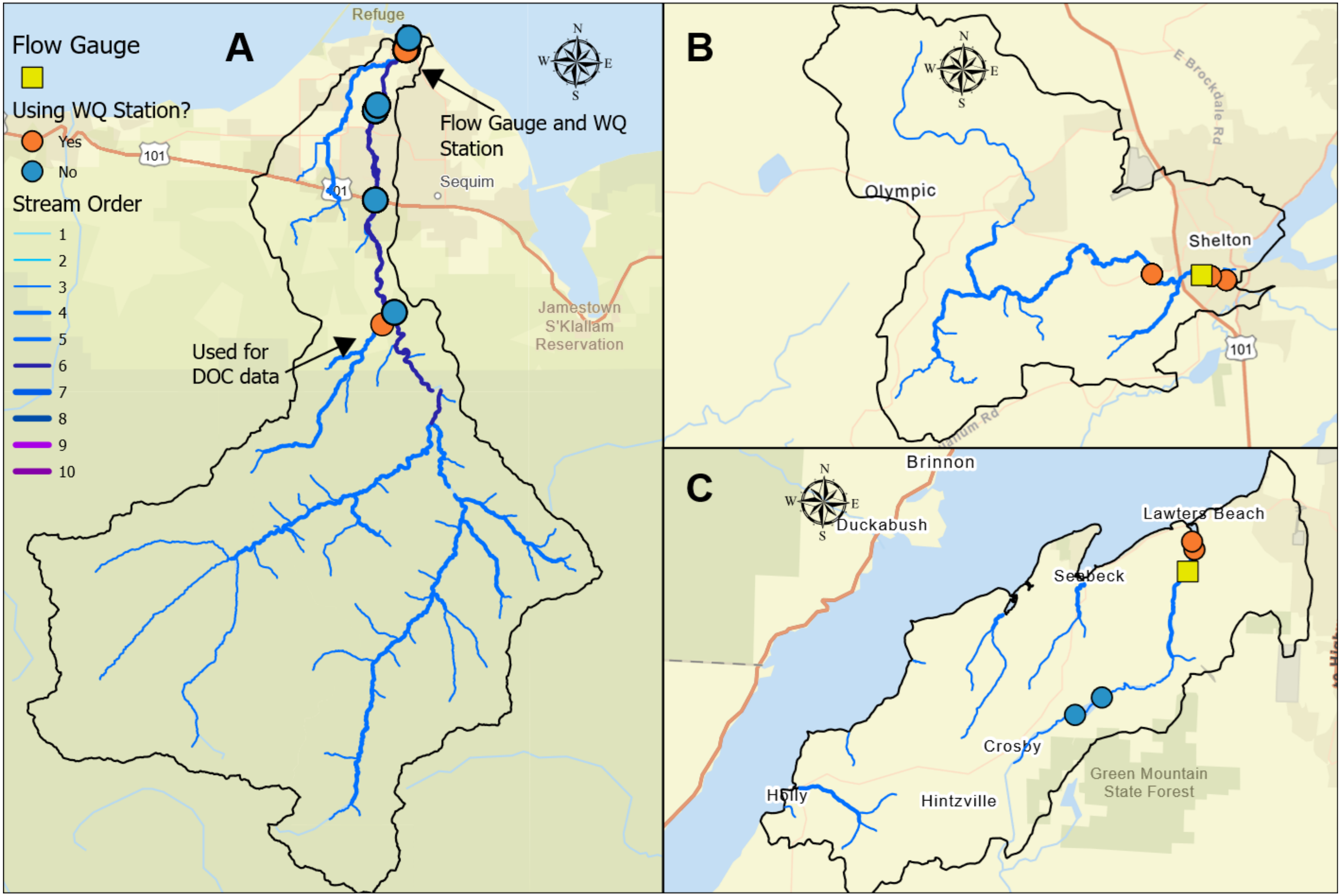


Figure B1-7. Examples of WQ site selection criteria applied to (A) Dungeness River, (B) Goldsborough Creek, and (C) Big Beef Creek.

Flow updates

Flow data were obtained using continuous gauge data (Ecology, USGS, County, City, or Tribe) when possible. When gauge data were unavailable for watersheds, WRF-Hydro modeled streamflow data were used if no dams or significant diversions were present. If such modifications were present, we did not use WRF-Hydro flow hindcast predictions because hydrologic modifications are currently not accounted for in the WRF-Hydro version we used (2.1) (B. Cosgrove, Pers. Comm., 2021). If WRF-Hydro was considered unsuitable for use in an ungauged watershed, then flow was borrowed from a neighboring watershed.

If discrete flow measurements were available, then they were compared with the continuous flow data used for the watershed (gauge, WRF-Hydro, or neighboring watershed gauge) and tested for congruency. When comparing discrete and continuous flow measurements, both data sets were first normalized by their respective drainage area to ensure that flows that were not co-located could be compared on a similar scale. We considered discrete and continuous flow pairs to be incongruent if there was a normalized root mean square error (NRMSE) of 1 or greater. An NRMSE of 1 or greater signals a less representative estimate than the mean of observations (Jolliff et al. 2009; USECos Team 2008).

Discrete and continuous flow pairs were assessed visually using Taylor (2001) and target diagrams (Jolliff et al. 2009; Pederzoli et al. 2012). Target diagrams consist of centered normalized root mean square difference (CNRMSD) (eq. B1-1) on the x-axis and normalized bias (eq. B1-2) on the y-axis. Negative values for CNRMSD are assigned when predictions have lower variance than observations. In target plots, the NRMSE is the radius (eq. B1-3) of the diagram, and therefore, values that fall outside of the unit circle have an NRMSE greater than 1. For Taylor diagrams, centered and normalized centered RMSE (same as CNRMSD) and correlation statistics are plotted. Values close to the bottom center of the Taylor diagram indicate low CNRMSE and high correlation.

For the 13 watersheds with NRMSE greater than 1, we bias adjusted, which resulted in achieving an NRMSE for all cases below 1. WRF-Hydro or neighboring watershed continuous streamflow that had an NRMSE of 1 or more was bias adjusted to discrete measurements using the monthly average ratio between the two. As shown in Figure B1-8, 13 out of 50 of the watersheds tested were outside the unit circle in the target diagram (NRMSE>1). However, with the exception of Sequim Bay S, Sherwood Creek, and Hamma Hamma, which had low correlation, the plurality of correlations was around 0.9.

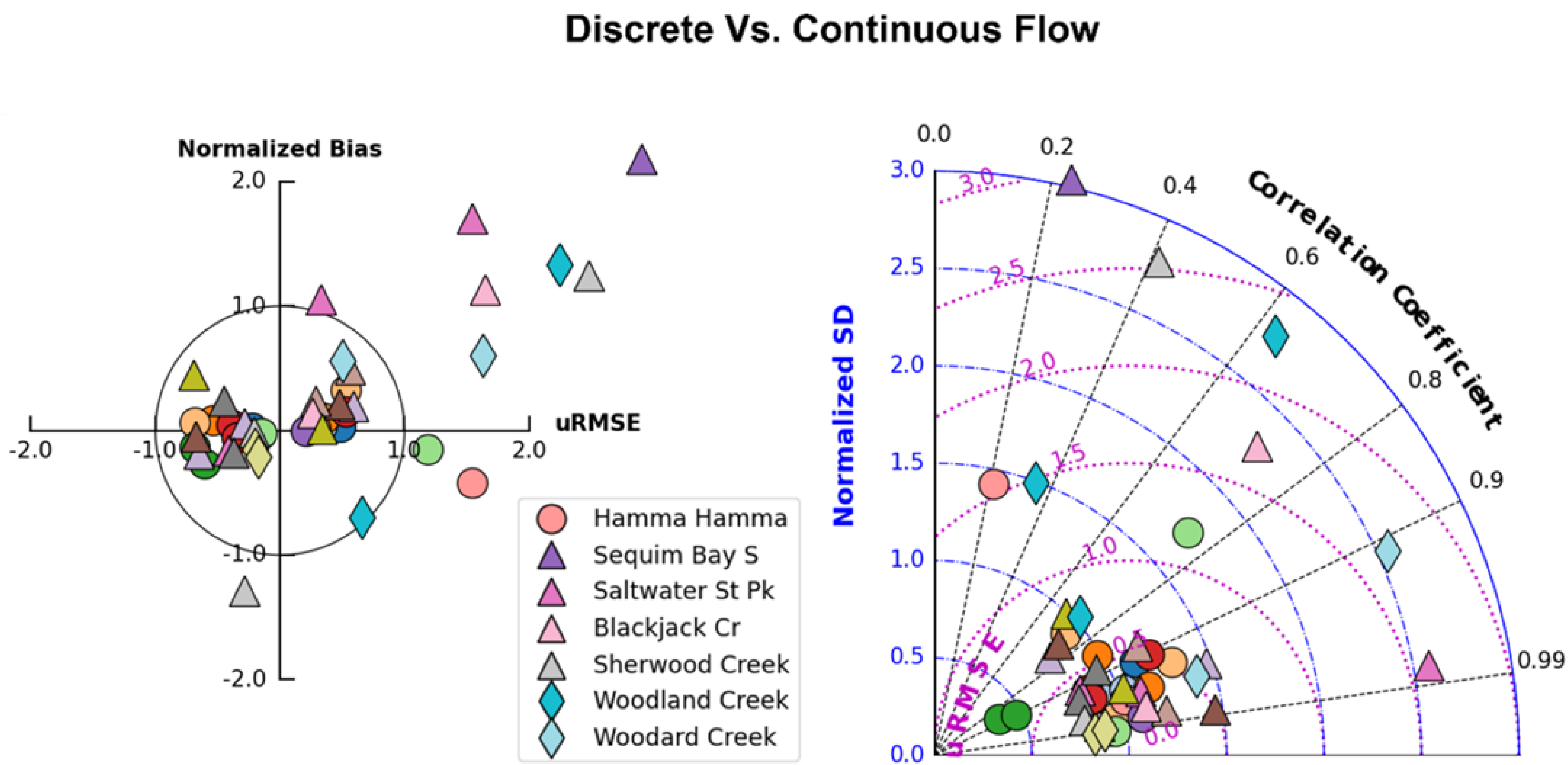


Figure B1-8. Taylor and target diagram of discrete vs. continuous flow measurements.
Values that are outside of the unit circle in the target diagram (on the left) reveal that a simple average would match better than the continuous flow used. In these cases, we bias-corrected the flows. Values within the Taylor diagram (on the right) are considered in good agreement if they have high correlation, low RMSD, and low normalized standard deviation.

$$\text{CNRMSD (eq. 1)} = \frac{\sqrt{\frac{1}{N}\sum\left((\text{Predicted} - \overline{\text{Predicted}}) - (\text{Observed} - \overline{\text{Observed}})\right)^2}}{\text{standard deviation}_{\text{observed}}}$$

$$\text{NBias (eq. 2)} = \frac{\text{Mean(Predicted)} - \text{Mean(Observed)}}{\text{standard deviation}_{\text{observed}}}$$

$$\text{NRMSE (eq. 3)} = \frac{\sqrt{\frac{1}{N}\sum(\text{Predicted} - \text{Observed})^2}}{\text{standard deviation}_{\text{observed}}} = \sqrt{\text{NBias}^2 + \text{CNRMSD}^2}$$

Table B1-5. Monthly Bias-adjusted watershed flows.

Watershed Name	Discrete Flow N	Continuous Flow Station Location	Continuous Flow Source	NRMSE	Bias Adjusted NRMSE
Burley Creek	13	Adjacent WS	Gauge	1.31	0.1
Butler Creek	57	Adjacent WS	Gauge	1.01	0.49
Blackjack Creek	12	Inside WS	WRF-Hydro	1.99	0.17
Federal Way	13	Inside WS	WRF-Hydro	4.38	0.004
Hamma Hamma	51	Inside WS	WRF-Hydro	1.60	0.90
Hylebos Creek	17	Inside WS	WRF-Hydro	4.90	0.41
Moxlie Creek	430	Adjacent WS	Gauge	1.19	0.70
Rocky Creek	20	Adjacent WS	Gauge	1.10	0.16
Saltwater St Pk	13	Inside WS	WRF-Hydro	2.30	0.008
Sequim Bay S	23	Adjacent WS	Gauge	3.63	0.43
Sherwood Creek	21	Inside WS	Gauge	2.77	—
Woodard Creek	13	Adjacent WS	Gauge	1.73	0.006
Woodland Creek	36	Adjacent WS	Gauge	2.61	0.79

For the flow comparison, an example of good performance for WRF-Hydro was False Bay Creek, while an example of bad performance was Hamma Hamma (Figure B1-9). Hamma Hamma had poor performance initially with an NRMSE of 1.6 and an R-square of 0.05. Following monthly bias adjustment, however, performance improved with NRMSE dropping to 0.9 and R-squared increasing to 0.4. Hamma Hamma WRF-Hydro predictions tended to perform well during baseflow periods and performed poorly during peak flow events, where it exclusively overpredicted flow.

Watersheds borrowing flow generally require bias adjustment. However, Green Cove is an example where no bias adjustment was needed (Figure B1-10). On the other hand, Moxlie Creek required bias adjustment, which greatly reduced NRMSE from 1.19 to 0.7 but had minimal impact on R-squared (Figure B1-10).

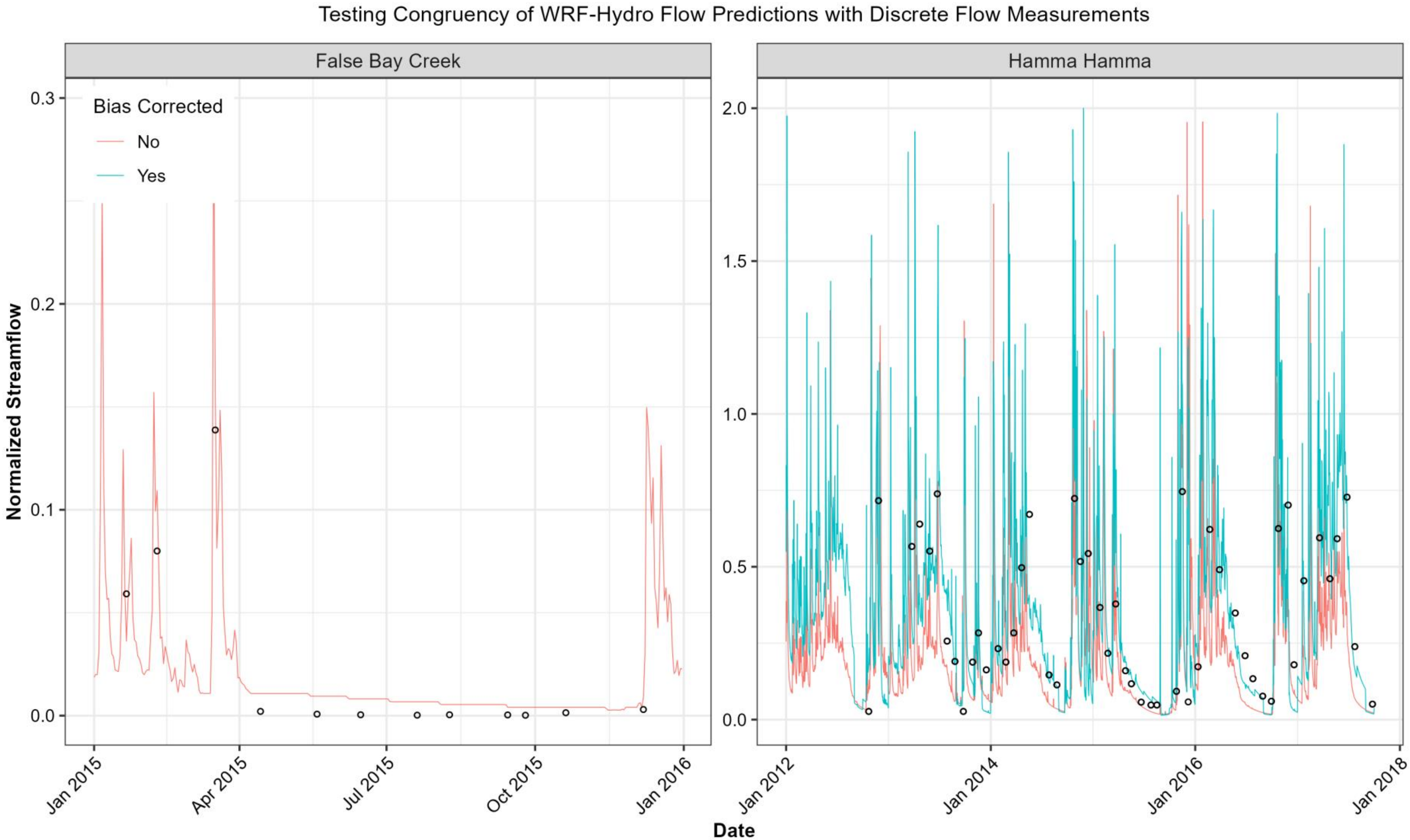


Figure B1-9. Comparison of discrete flow measurements (from ungauged watershed) with WRF-Hydro continuous flow predictions for the ungauged watershed.

Flow measurements were normalized by the drainage area at the given flow location of interest. WRF-Hydro flow in the above comparison was compared against discrete flow from matching locations, and as a result, both WRF-Hydro and discrete flow measurements were normalized by the same drainage area. False Bay Creek (N=12) performed very well (NRMSE=0.29, $R2=0.95$). Hamma Hamma (N=51) had very poor performance initially (NRMSE= 1.6, $R2=0.05$), and adequate performance following bias correction (NRMSE =0.9, $R2=0.4$).

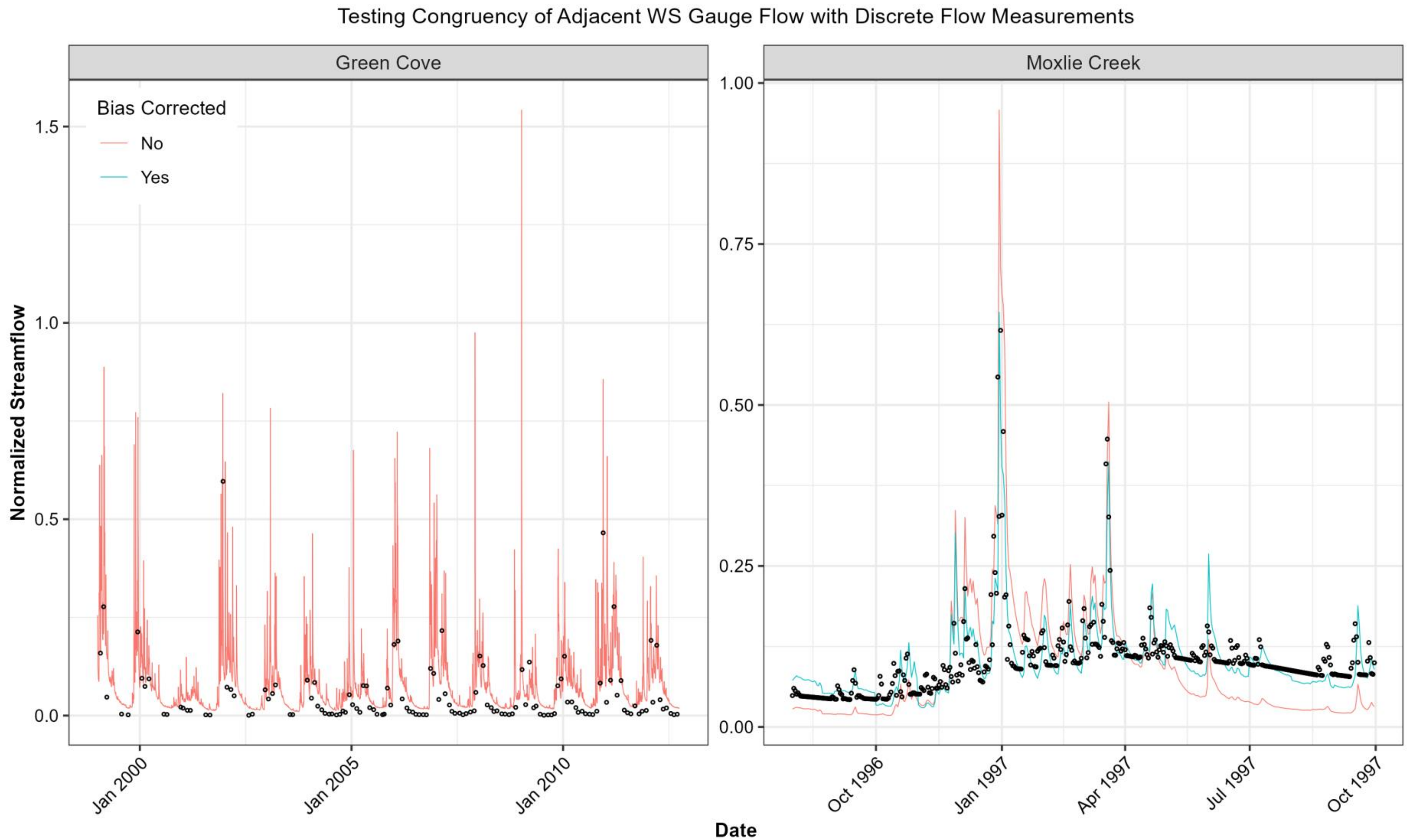


Figure B1-10. Comparison of discrete flow measurements (from an ungauged watershed) with continuous flow borrowed from an adjacent watershed.

Flow measurements were normalized to the drainage area at the given flow location of interest. Using Green Cove as an example, discrete flow measurements were normalized by their corresponding drainage area (8.5 Km^2), and continuous flow borrowed from an adjacent watershed (Goldborough) was normalized by the drainage area of the gauge (142 Km^2). Green Cove (N=134) performed fairly well (NMRSE=0.74, R2=0.77) but showed signs of over-predicting peak flow events. Moxlie Creek (N=430) initially performed poorly (NRMSE=1.19, R2=0.56) but showed adequate improvement following bias correction (NRMSE=0.7, R2=0.57).

Gauged flow data were sometimes missing for the period of interest and required either interpolation or another method of approximation. Excluding flow interpolations previously performed in Opt1 (Ahmed et al. 2021), four gauges required some level of interpolation. Of these four gauges, three were only missing 5 – 18 days for the years 1999 – 2022. For these three gauges, linear interpolation was used to impute missing values. The King County gauge 42a at Miller Creek, however, was missing flow data from November of 2010 until December of 2012 and thus required a more sophisticated interpolation scheme. Missing flow at Miller Creek was imputed using the R imputeTS package function na.seasplit, which splits the flow time series into seasons and performs linear interpolation for each season (Chandrasekaran et al. 2016). The interpolated values appear to follow the general characteristics of other years in the hydrograph (Figure B1-11) with the caveat of potentially underpredicting peak flow events.

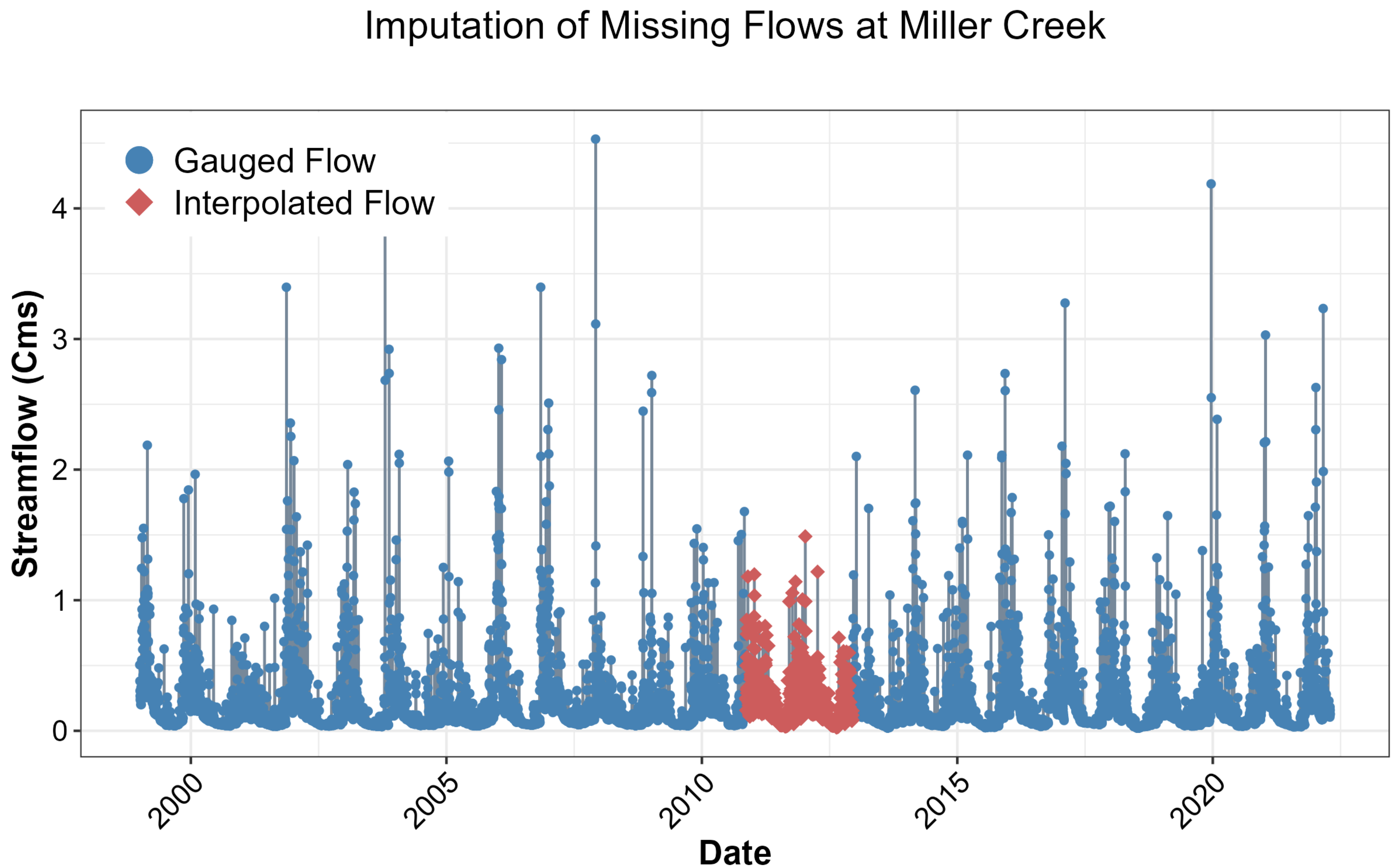


Figure B1-11. Imputation of Missing Flows at Miller Creek.
Flow missing from 11/13/2010 to 12/13/2012 was imputed using the “imputeTS” R package function na.seasplit, which splits the hydrograph into seasons and performs linear interpolation for each season.

Water quality updates

We updated our water quality regressions used to estimate daily concentrations for water quality parameters using data from cities, counties, tribes, USGS, and Ecology's EIM database (Table B1-3) for the years 1999 – 2022. Water quality data that was flagged as poor quality was not included in our updated regressions (Figure B1-3). This had an impact primarily on dissolved total persulfate nitrogen (DTPN) data for Deschutes River, Green River, Nisqually River, and Puyallup River (Table B1-4). Pierce County data collected prior to 2016 was additionally discarded as there were no formal measurement quality objectives in place until 2015 (S. Groce, Pers. Comm., 2022). Water quality data were limited for DOC, DTPN, and dissolved total phosphorus (DTP). As a result, some assumptions had to be made to extrapolate missing data for these parameters.

It was very common for a given watershed to only have data for TOC or DOC, but not both. To extrapolate data for the missing organic carbon parameter, we used the average ratio of TOC to DOC from the nearest watershed (Table B1-6). In calculating TOC/DOC ratios, we did not include cases where both TOC and DOC were non-detects. Further, we did not include cases where DOC concentrations were reported as greater than TOC, as this makes no physical sense and is likely either a measurement or reporting error. TOC/DOC ratios were usually borrowed from adjacent watersheds, but in some circumstances, they were instead derived using data from the watershed of interest. Dungeness, for example, had 5 TOC samples. That was an insufficient amount to build a regression, but it was adequate for determining the TOC/DOC ratio for the watershed. The TOC/DOC ratio could then be applied to the available parameter to extrapolate data for the missing parameter. Using Dungeness as an example, we approximated TOC data by multiplying the available DOC data by the determined TOC/DOC ratio (Table B1-6). The TOC/DOC ratios shown in Table B1-6 did not vary significantly and had a range of 1.03 to 1.27 (TOC 3%–27% greater than DOC).

Table B1-6. Extrapolation of DOC and TOC using the TOC/DOC ratio from the nearest watershed.

River Regression Name	SSM Watershed Basin	Organic Carbon Variable Available	Missing Organic Carbon Variable	Adjacent Watershed TOC/DOC Ratio	Watershed Used	Comment
Anderson West	South Sound	TOC	DOC	1.2	McAllister Creek	DOC= (1/1.2) *TOC
Artondale Creek	South Sound	TOC	DOC	1.27	Goodnough Creek	DOC= (1/1.27) *TOC
Blackjack Creek	Main Basin	DOC	TOC	1.08	Minter Creek	TOC= 1.08 * DOC
Des Moines Creek	Main Basin	DOC	TOC	1.07	Green River	TOC = 1.07 * DOC
Discovery Bay 1	Strait of Juan de Fuca	DOC	TOC	1.03	Dabob Bay	TOC = 1.03 * DOC
Dungeness	Strait of Juan de Fuca	DOC	TOC	1.02	Dungeness	TOC= 1.02 * DOC. Dungeness had Insufficient DOC data for regression. Data were used to determine TOC/DOC ratio.
Dutcher Creek	South Sound	TOC	DOC	1.13	Rocky Creek	DOC = (1/1.13) * TOC
False Bay Creek	Strait of Georgia	DOC	TOC	1.03	North Olympic	TOC = 1.03 * DOC
Federal Way	Main Basin	DOC	TOC	1.15	Liberty Bay	TOC = 1.15 * DOC
Herron Creek	South Sound	TOC	DOC	1.13	Rocky Creek	DOC = (1/1.13) * TOC
Liberty Bay	Main Basin	DOC	POC	1.15	Liberty Bay	TOC = 1.15 * DOC POC was used to calculate TOC (DOC +POC at coincident times). Liberty Bay had Insufficient TOC data for regression. Data were used to determine TOC/DOC ratio.
McCormick Creek	South Sound	TOC	DOC	1.27	Goodnough Creek	DOC= (1/1.27) *TOC
Mill Creek	South Sound	DOC	TOC	1.08	Mill Creek	TOC=1.08*DOC. Mill Creek had Insufficient TOC data for regression. Data were used to determine TOC/DOC ratio.
Miller Creek	Main Basin	DOC	TOC	1.07	Green River	TOC = 1.07 * DOC
Purdy Creek	South Sound	TOC	DOC	1.08	Burley Creek	DOC= (1/1.08) *TOC
Ray Nash Creek	South Sound	TOC	DOC	1.08	Minter Creek	DOC= (1/1.08) *TOC
Saltwater St Pk	Main Basin	DOC	TOC	1.07	Green River	TOC=1.07 * DOC

River Regression Name	SSM Watershed Basin	Organic Carbon Variable Available	Missing Organic Carbon Variable	Adjacent Watershed TOC/DOC Ratio	Watershed Used	Comment
Sequim Bay S	Strait of Juan de Fuca	DOC	TOC	1.02	Dungeness	TOC=1.02 * DOC
Squalicum Creek	Strait of Georgia	DOC	TOC	1.1	Lake Whatcom	TOC=1.1 * DOC
Vaughn Creek	South Sound	TOC	DOC	1.13	Rocky Creek	DOC= (1/1.13) * TOC
Whatcom Creek	South Sound	DOC	TOC	1.1	Lake Whatcom	TOC=1.1 * DOC
Whitman Creek	Strait of Georgia	TOC	DOC	1.05	Whitman Creek	DOC= (1/1.05) * TOC Whitman Creek had Insufficient DOC data for regression. Data were used to determine TOC/DOC ratio.

Note. DTPN and DTP data were only available for 18 of the 63 Washington SSM watersheds for which regressions were built (Table B1-7). DTPN and DTP are required for calculating particulate organic nitrogen (PON), dissolved organic nitrogen (DON), or particulate organic phosphorus (POP), and dissolved organic phosphorus (DOP) data, respectively. Due to a lack of DTPN and DTP data for a majority of SSM watersheds, we assumed equal fractions. Total organic nitrogen was split equally between PON and DON if DTPN data were not available. Total organic phosphorus was split equally between POP and DOP if DTP was unavailable (Table B1-7).

Table B1-7. Watershed inventory of DTP and DTPN data.

River Regression Name	SSM Watershed Basin	DTPN and TPN Data?	TP and DTP Data?	Comment
Burley Creek	South Sound	Yes	Yes	—
Chambers Creek	South Sound	Yes	Yes	—
Coulter Creek	South Sound	Yes	Yes	—
Deschutes River	South Sound	No	Yes	Has TPN data. DTPN data are also available, but were flagged as REJ.
Fraser	Strait of Georgia	Yes	Yes	—
Goldsborough Creek	South Sound	Yes	Yes	—
Green River	Main Basin	Yes	Yes	Only has 5 DTPN samples.
Kennedy Creek	South Sound	Yes	Yes	—
McAllister Creek	South Sound	Yes	Yes	—
McLane Creek	South Sound	Yes	Yes	—
Minter Creek	South Sound	Yes	Yes	—
Nisqually River	South Sound	No	Yes	Has TPN data. DTPN data are also available, but were flagged as REJ.
Perry Creek	South Sound	Yes	Yes	—
Puyallup River	Main Basin	Yes	Yes	Only has 6 DTPN samples.
Rocky Creek	South Sound	Yes	Yes	—
Sherwood Creek	South Sound	Yes	Yes	DON regression NRMSE >0.894, so monthly time series used.
Skookum Creek	South Sound	Yes	Yes	—
Woodard Creek	South Sound	Yes	Yes	—
Woodland Creek	South Sound	Yes	Yes	—

"—"=No comment

[1] If TP and DTP available: POP = TP - DTP and DOP = DTP - PO4

[2] If DTP is unavailable: POP = DOP = 0.5*(TP - PO4)

[3] If TPN and DTPN available: PON = TPN - DTPN and DON = DTPN - (NO_3-NO_2 + NH_4)

[4] If DTPN is unavailable: PON = DON = 0.5*(TPN - NO_3-NO_2 - NH_4)

Water quality regressions

Data preprocessing and regression formulation

To prepare for building regression models, continuous daily flows were matched with corresponding water quality samples. Daily averages were calculated for water quality parameters to match the temporal scale of flow data. This differs from Opt1, where coincident discrete flow data were used, when possible, and averages were only calculated for duplicates rather than for an entire day. In Opt2, we decided not to build regressions using discrete flow data and instead use only continuous flow data to be consistent with our application of the regressions to loading scenarios, which use continuous flow data.

Even after an exhaustive search for additional data, limitations still exist. Water quality parameters that had fewer than 8 samples for a given watershed were not used to build regressions, and instead, regressions were built using data borrowed from a neighboring watershed (Figure B1-3). When borrowing water quality data from another watershed, we examined not only the proximity of the watersheds but also looked for similar land use and stream order. There are 90 small or very small (54 Km^2) watersheds that have no water quality data. Excluding watersheds that completely lacked data, those that borrowed almost exclusively did so specifically for DOC. The only exceptions are Dosewallips, Moxlie Creek, and Squalicum Creek, which all borrowed data for Dissolved Oxygen (DO), Temperature, and pH, and for Green Cove, which borrowed data for pH, ammonium-ammonia, and TPN.

We split the data into training and testing sets for parameters with 80 or more samples for a given watershed. Data that met this criterion were grouped into a single aggregated data set. Testing data were randomly assigned using 20 percent of the data for a given parameter from the aggregated data set, with the remaining 80 percent reserved for training. This resulted in, on average, approximately 20 percent (generally within 3 percent) of the data being allocated to the testing set for each parameter and watershed. There were, however, extreme cases, including Judd Creek and Elwha River, where as little as 12 percent and as much as 32 percent of temperature data, respectively, were allocated to the testing set. If there were fewer than 80 samples available for a parameter in a watershed, then we did not set aside any data for testing performance and used all available data for training the model (Figure B1-3).

We fit regression models for 12 distinct water quality parameters (Table B1-4), including temperature, DO, pH, ammonium-ammonia, nitrate-nitrite, TPN, DTPN, orthophosphate, total phosphorus, DTP, DOC, and TOC. Sufficient data were available to establish regressions for 76 SSM watersheds, with most of these watersheds having data for 9 or 10 of the 12 water quality parameters. Regressions were fit for water quality parameters using (eq. B1-4), which is a statistical approach that relates concentrations to flow patterns and time of year based on the sediment discharge relationship found by Cohn et al. (1989, 1992) and adapted by Mohamedali et al. (2011).

$$log_{10}C = b_1 + b_2 log_{10}(Q/A) + b_3 log_{10}(Q/A)^2 + b_4 \sin 2\pi f_y + b_5 \cos 2\pi f_y + b_6 \sin 4\pi f_y + b_7 \cos 4\pi f_y \quad \text{(eq. B1-4)}$$

(Mohamedali et al. 2011, based on Cohn et al. 1989, 1992).

Where:

C is the observed parameter concentration (mg/L).

Q is the daily averaged streamflow (cubic meters per second).

A is the watershed drainage area at the sampling location of water quality data (Km^2)

f_y is the year fraction (dimensionless, varies from 0 to 1).

b_i are the best-fit regression coefficients.

Limitations

The regression approach based on Cohn et al. (1989, 1992) and Mohamedali et al. (2011) provides a practical framework for estimating constituent concentrations (generally sediment or nutrients), but it has limitations. Cohn et al. (1992) found that these regression models often had substantial serial correlation in the residuals (model error), which violates the assumptions of independence and constant variance of residuals for linear and log-linear regression models.

Serial correlation suggests that certain dynamics affecting the system are not being represented in the model. In this case, the serial correlation likely reflects the absence of representation of lag effects (Cohn et al. 1992) inherent in freshwater systems such as storage, travel time, and constituent remobilization. Despite these limitations, Cohn et al. (1992) found that the regression-based constituent estimates generally aligned well with observed data, and that nutrient estimates were less affected by the omission of lag effects compared to sediment. The application of these regression models to discrete monthly data, as in this study, is unlikely to capture fine-scale daily variability but has been found to reflect general seasonal trends when fit with monthly data (Cohn et al. 1992). Although our data has both spatial and temporal limitations (discussed in Sample Site Selection and in Data Preprocessing and Regression Formulation), these regressions offer a reasonable method of estimating water quality for watersheds in our domain.

Regression fitting process

The process of fitting regressions was an iterative process, and models were run several times using different schemes to optimize performance. Major decisions that were made prior to achieving the final fit for regressions included determining how to treat variable non-detects, if outliers should be removed, how outliers should be handled, and whether or not regressions should use ridge regression over ordinary multivariable linear regression.

Regressions were initially run using the ordinary least squares approach. The fitted model was assessed using a stepwise reduction approach as was done by Mohamedali et al. 2011. If the p-value of the model was less than 0.05, then no model terms were dropped. A maximum of two model coefficients were dropped iteratively until the model p-value was less than 0.05. If the model was unable to attain a p-value less than 0.05 after dropping two terms, then the full model was retained, and no terms were dropped. Once initial regression models were fit, we assessed the magnitude of each coefficient. We found in general that coefficients greater than 4 and less than -4 resulted in unrealistic spikes in regression predictions. Any watershed regression models with coefficients outside the range (-4,4) were refit using ridge regression to minimize the magnitude of the coefficients.

In Opt1, we did not analyze the influence of non-detect values. In Opt2, we explored different approaches for handling non-detects. Detection limits were found to slightly differ for any given parameter among the agencies from which we obtained data. Further, we found that detection limits changed over time, with lower limits becoming available in more recent years. Regression performance was assessed with and without standardizing non-detect values, and it was found that regressions actually performed worse when non-detect values were standardized by using the lowest reporting limit of all data sets. In light of this result, we did not make any changes to how non-detects were handled between Opt1 and Opt2.

Regression performance

Regression performance was determined primarily using NRMSE, R-squared, and, to a lesser extent, normalized bias. We employed a conservative NRMSE threshold of 0.894, instead of 1, to segregate between acceptable and unacceptable model performance. This threshold was based on an internal review of an extensive number of time series performance plots, which indicated a breakdown in performance above an NRMSE of 0.894. Models with unacceptable performance (NRMSE>0.894) were substituted with average monthly time series based on observational data.

In total, we fit 750 regression models for SSM watersheds, with 11% exhibiting an NRMSE exceeding 0.894. After a lot of trial and error, we decided that watersheds not meeting the NRMSE criteria would be fit following the removal of outliers, where outliers were considered to be values three standard deviations above or below the mean. This approach tended to only modestly improve performance for most watersheds but had a sizeable impact on the TPN regression model for Green River, where R-squared increased from 0.36 to 0.46.

For most variables, with the exception of ammonium-ammonia, pH, and total phosphorus, regressions exhibited good performance with R-squared values ranging from 0.6 (total organic carbon) to 0.87 (temperature). NRMSE statistics followed an almost identical trend to R-squared, with ammonium-ammonia, pH, and total phosphorus regressions performing adequately, though with lower skill (NRMSE ranged from 0.67 to 0.61). DOC, dissolved total phosphorus, DO, DTPN, and temperature regressions performed really well with NRMSE ranging from 0.53 to 0.35, respectively (Figure B1-12).

Ammonium-ammonia tended to perform the worst relative to other parameters, with an average NRMSE of 0.672 and average R-squared of 0.52 (Figure B1-12). Approximately a third of the 76 watersheds had an NRMSE greater than 0.894 for ammonium-ammonia (Figure B1-13). In these cases, regressions were substituted for monthly average values. The high prevalence of non-detects for ammonium-ammonia likely hampered the nutrient discharge regression relationship for most watersheds.

Nitrate-nitrite regression performance was found to be generally good. As shown in Figure B1-14, only 5 watersheds with an NRMSE greater than 0.894 were tabulated for that parameter. In addition, we found that regressions exhibited desired performance with respect to bias, normalized bias for nitrate-nitrite, and all other variables, with the exception of temperature for a couple of watersheds that were very close to zero. Correlations for nitrate-nitrite were high, with values ranging from 0.7 to 1 (Figure B1-14).

In several instances, orthophosphate and total persulfate nitrogen regressions (Figure B1-12) had NRMSE greater than 0.894. As in all other instances where this criterion was not met, we substituted these regressions with monthly averages.

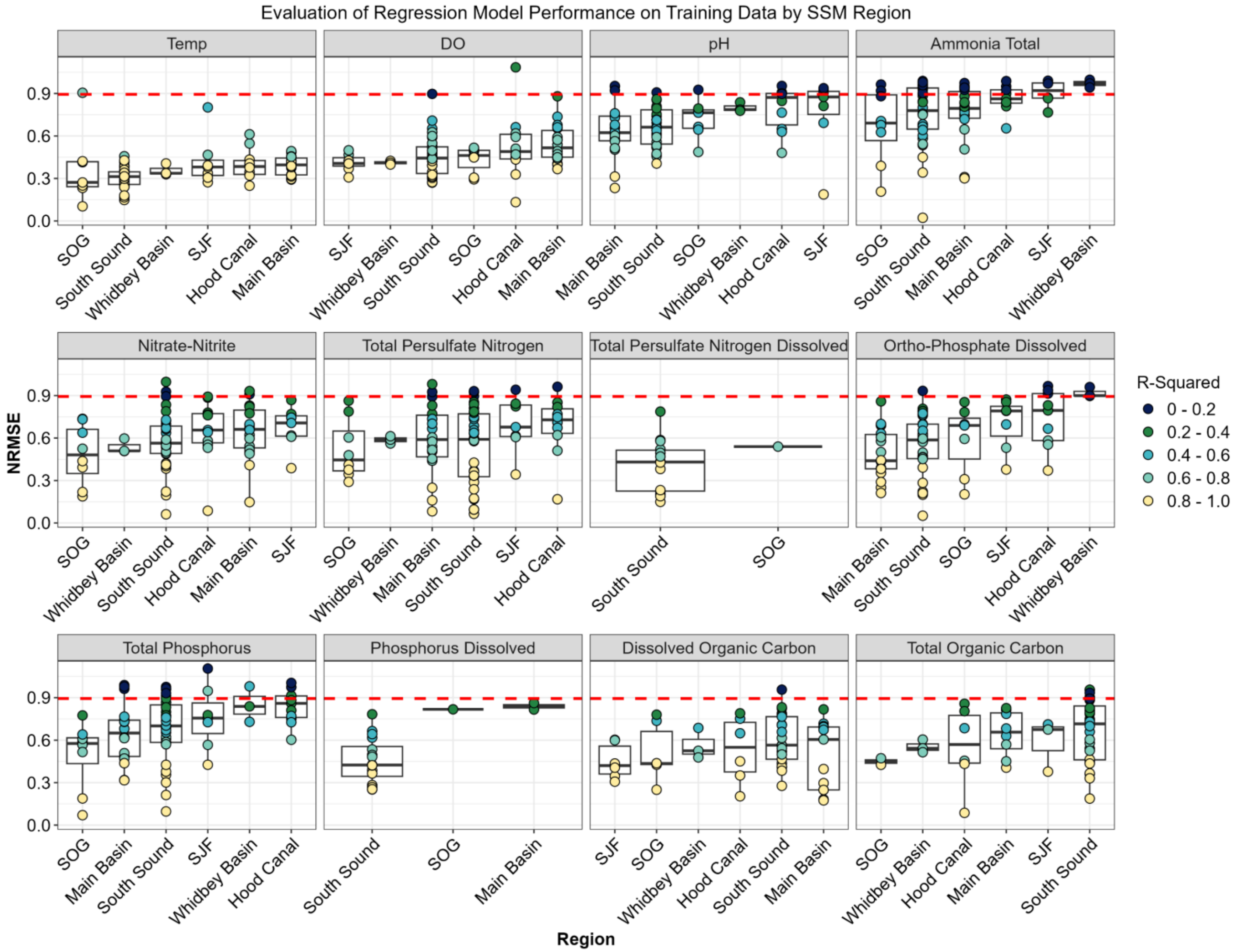


Figure B1-12. Diagnostic plots of model performance on the training data set for all variables and SSM basins.
Boxplots, which are arranged from best to worst performance, show the median NRMSE for each variable and SSM basin, while the jitter plot shows the distribution of NRMSE and R-squared for all watersheds within a given basin. The red dashed line represents an NRMSE of 0.894. Models with an NRMSE at or above this threshold were considered to have inadequate performance and were substituted with monthly time series based on observations.

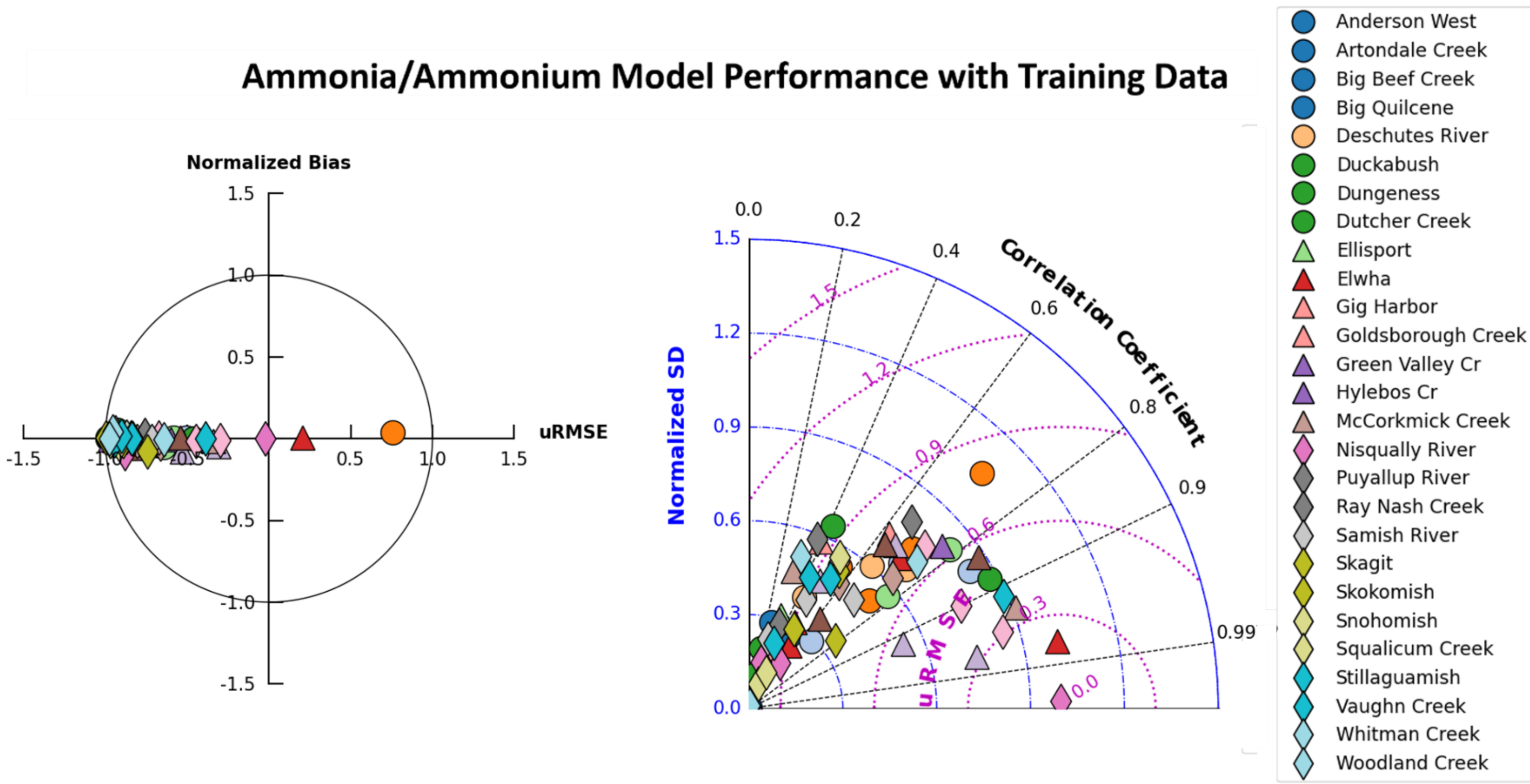


Figure B1-13. Taylor and target diagram assessing model performance on the training data set for ammonium-ammonia. We used a more conservative NRMSE threshold of 0.894 rather than 1 to distinguish good and poor performance. The legend consists of all watersheds for which regressions were not used because they had an NRMSE of 0.894 or greater (considered poor performance).

Nitrate-Nitrite Model Performance with Training Data

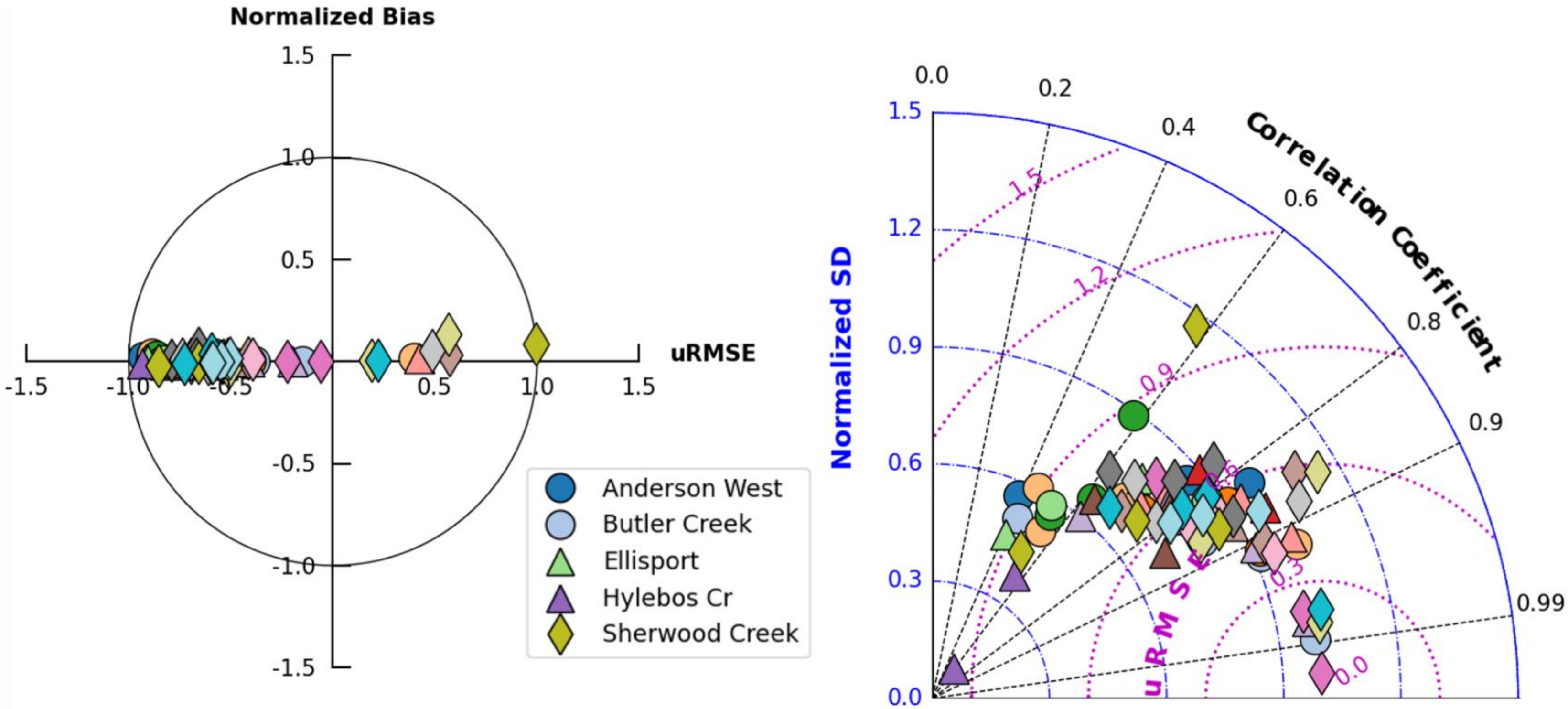


Figure B1-14. Taylor and target diagram assessing model performance on the training data set for nitrate-nitrite.
We used a more conservative NRMSE threshold of 0.894 rather than 1 to distinguish good and poor performance. The legend consists of all watersheds for which regressions were not used because they had an NRMSE of 0.894 or greater (considered poor performance).

Watersheds that had 80 or more samples for a given parameter were assessed for how well the regression model generalizes by comparing performance on the training and testing sets, respectively. Dissolved oxygen and temperature, in particular, both behaved very similarly in the training and testing sets, indicating that the regression models for these parameters are near optimal (Figure B1-15). Other parameters were, for the most part, similar between the training and testing data sets; however, performance tended to be slightly worse on the testing set.

In certain cases, NRMSE values exceeded 0.894 for the testing set but not for the training set. Notable watersheds that exhibited this behavior for more than one variable include: Big Beef Creek, Dungeness, Ellisport, Hamma Hamma, and Nisqually River (Figure B1-15) and (Figure B1-16). With the exception of Nisqually River, the other 3 watersheds listed all had a relatively low testing data set size of around 20 samples. We tested the impact of testing data set sample size on model performance and found that, with the exception of pH and orthophosphate, which had essentially no relationship, other variables displayed a negative correlation between NRMSE and testing data set sample size (Figure B1-17). These findings indicate that testing sets with smaller sample sizes may have less adequate error statistics, which is likely due to differences in the distribution of values between testing and training data sets. Overall, the general agreement between training and testing data set model performance, coupled with the relatively few regression models surpassing an NRMSE of 0.894, underscores the robustness of the models.

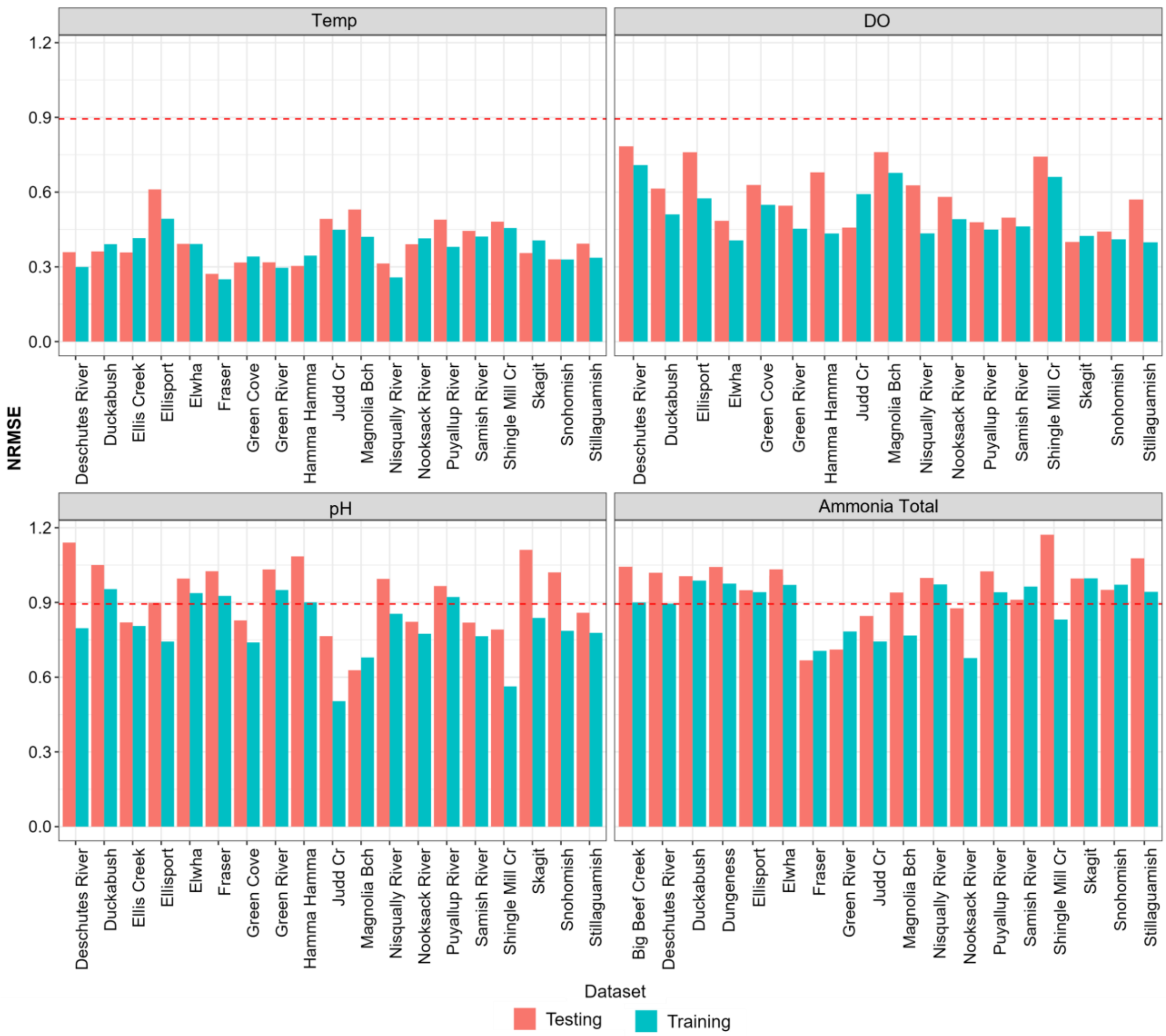


Figure B1-15. Comparison of model performance (NRMSE) on training and testing data sets for temperature, dissolved oxygen, pH, and ammonia.

Only watersheds that had sufficient data for both training and testing data sets are plotted above. The red dashed line represents an NRMSE of 0.894, which is the threshold that we used to distinguish good from poor performance.

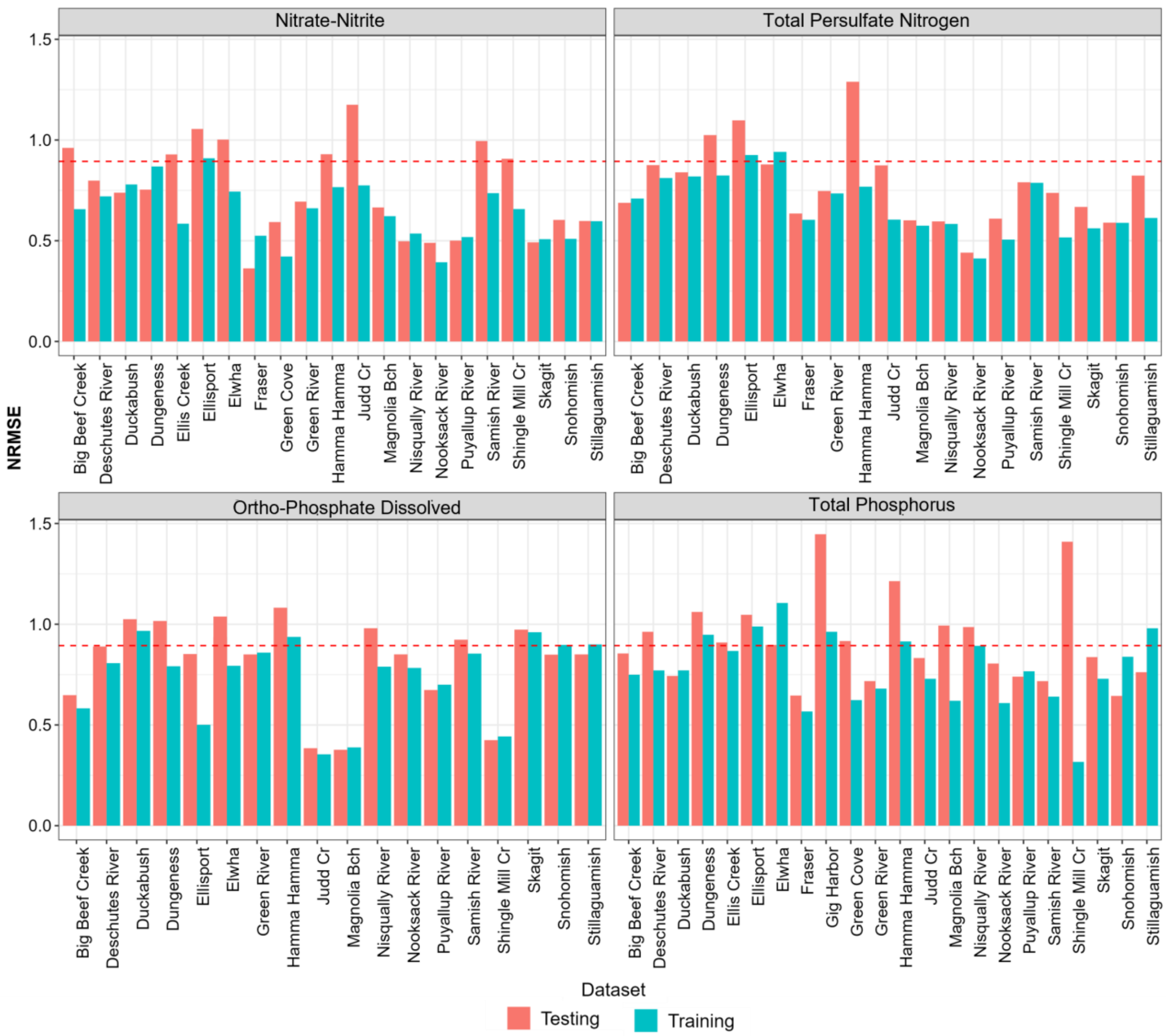


Figure B1-16. Comparison of model performance (NRMSE) on training and testing data sets for nitrate-nitrite, total persulfate nitrogen, orthophosphate, and total phosphorus. Only watersheds that had sufficient data for both training and testing data sets are plotted above. The red dashed line represents an NRMSE of 0.894, which is the threshold that we used to distinguish good from poor performance. Fraser River (not plotted above) is the only watershed that had enough DOC data for training and testing. NRMSE for Fraser DOC was nearly identical for training (0.737) and testing (0.733).

Figure B1-17. Relationship between testing data set performance and sample size. Testing data set evaluation was only assessed for regression models that met performance criteria (NRMSE<0.894) for training data. Results are qualitative but show that there is a negative relationship between model performance on the testing set and the sample size. These findings indicate that testing sets with smaller sample sizes may have less adequate error statistics. Additionally, we examined if there was a noticeable difference in performance when regressions were evaluated on data with a greater range than they were trained on. This is represented in the legend where “No” means that regressions were evaluated on data within a similar range to the data that they were trained on, and “Yes” means that they were evaluated on data with a greater range than they were trained on.

Association changes

Regression associations used in Opt1 for unmonitored watersheds were updated in Opt2 for 32 out of the 162 Washington SSM watersheds (Table B1-8). Due to refinements in watershed delineations since Opt1, several new watersheds have had changes in the water quality regressions that they are associated with. Out of the 32 watersheds with regression association changes, 18 of them were new watersheds resulting from the disaggregation of non-hydrologically connected watersheds in Opt1. For example, as previously mentioned, Hamma Hamma in Opt2 was split into 5 watersheds consisting of Hamma Hamma, Finch Creek, Lilliwaup Creek, Fulton Creek, and Eagle Creek. These watersheds were previously using regressions from Skokomish River to represent water quality; however, now that Hamma Hamma has water quality data, Finch Creek, Lilliwaup Creek, Fulton Creek, and Eagle Creek are all associated with the Hamma Hamma regression instead of Skokomish River (Table B1-8).

Water quality regression associations for unmonitored watersheds were changed in Opt2 based on similarities in the 2019 National Land Cover Database land use and, to a lesser extent, drainage area between the unmonitored watershed of interest and the monitored watershed that it is associated with for water quality. A complete overview of changes in regression association changes from Opt1 to Opt2 can be found in Table B1-8.

Table B1-8. Summary of changes made to regression associations used to estimate water quality concentrations at select unmonitored watersheds.

Watershed Name	SSM Watershed Basin	Original WQ regression association	Updated WQ regression association	Reason for change	Flow Association Change	Comment
Agate East	South_Sound	Skookum Creek	Mill Cr	Mill Cr land use (urban, Forested, and agricultural) has greater similarity to Agate East, despite Skookum being closer in drainage area.	No	—
Agate West	South_Sound	Skookum Creek	Mill Cr	Mill Cr land use (urban, forested, and agricultural) has greater similarity to Agate West, despite Skookum being closer in drainage area.	No	—
Anderson east	South_Sound	Woodland Creek	Anderson West	Anderson West is more representative of Anderson East due to similarity in drainage area and land use (mostly forested) compared to Woodland Creek, which is heavily urbanized.	No	—
Birch Bay	SOG	Nooksack River	Drayton Harbor	Drayton Harbor and Birch Bay have similar land use distributions and drainage areas compared to Nooksack River	Yes	In Opt1, it was included in Drayton Harbor drainage area despite not being hydrologically connected.
Cassalery Creek	SJF	Elwha River	Dungeness	Dungeness WQ sites are in a region with primarily agricultural and urban land use, which matches the land use in Cassalery Creek. Elwha is primarily forested.	No	In Opt1, it was included in Dungeness River drainage area despite not being hydrologically connected.

Watershed Name	SSM Watershed Basin	Original WQ regression association	Updated WQ regression association	Reason for change	Flow Association Change	Comment
Chuckanut_Padden Creek	Bellingham_Bay	Samish River	Whatcom Creek	Whatcom Creek and Chucknut_Padden Creek have similar land use distribution (urban and forested), while Samish River is mixed land use.	Yes	In Opt1, it was included in Whatcom Creek drainage area despite not being hydrologically connected.
Cypress_Guemes Is	SOG	Samish River	False Bay Creek	False Bay Creek (forested and agricultural) is closer in size to Cypress_Guemes Is (forested and agricultural) and has slightly more representative land use distribution than Samish River (mixed land use).	Yes	—
Discovery Bay 2	SJF	Elwha River	Discovery Bay 1	Similar land use, drainage area, and close in proximity.	Yes	Discovery Bay was split into 3 watersheds in Opt2
Discovery Bay 3	SJF	Elwha River	Discovery Bay 1	Has more urban and agricultural land use than Discovery Bay 1, but Discovery Bay 1 is a better option than Elwha, as it has a similar drainage area to Discovery Bay 3 and does not have a dam.	Yes	Discovery Bay was split into 3 watersheds in Opt2
Eagle Creek	Hood_Canal	Skokomish River (Duckabush River for DOC/POC)	Hamma Hamma	Similar land use (forest and shrubland), drainage area, and close in proximity.	Yes	Was part of Hamma Hamma in Opt1, but was separated in Opt2 as it is not hydrologically connected.

Watershed Name	SSM Watershed Basin	Original WQ regression association	Updated WQ regression association	Reason for change	Flow Association Change	Comment
Finch Creek	Hood_Canal	Skokomish River (Duckabush River for DOC/POC)	Hamma Hamma	Similar land use (forest and shrubland), drainage area, and close in proximity.		Was part of Hamma Hamma in Opt1, but was separated in Opt2 as it is not hydrologically connected.
Fox Island	South_Sound	Burley Creek	Artondale Creek	Similar land use (primarily urban, compared to Burley, which is mixed land use), drainage area, and close in proximity.	No	—
Fulton Creek	Hood_Canal	Skokomish River (Duckabush River for DOC/POC)	Hamma Hamma	Similar land use (forest and shrubland), drainage area, and close in proximity.	Yes	Was part of Hamma Hamma in Opt1, but was separated in Opt2 as it is not hydrologically connected.
Hale Passage	South_Sound	Burley Creek	Artondale Creek	Similar land use (primarily urban, compared to Burley, which is mixed land use), drainage area, and close in proximity.	No	—
Jarrel Cove	South_Sound	Sherwood Creek	Cranberry Creek	Both have similar land use, but Cranberry Creek is slightly closer in size to Jarrel Cove.	Yes	—
Johns Cr	South_Sound	Sherwood Creek	Goldsborough Cr	Goldsborough land use (mixed) is more representative of Johns Cr than Sherwood Creek, despite Goldsborough being around 5 times larger.	Yes	—

Watershed Name	SSM Watershed Basin	Original WQ regression association	Updated WQ regression association	Reason for change	Flow Association Change	Comment
Lilliwaup Creek	Hood_Canal	Skokomish River (Duckabush River for DOC/POC)	Hamma Hamma	Similar land use, drainage area, and close in proximity.	Yes	Was part of Hamma Hamma in Opt1, but was separated in Opt2 as it is not hydrologically connected.
Lopez Island	SOG	Samish River	False Bay Creek	Similar land use (agriculture), drainage area, and close in proximity.	Yes	—
Lower Dosewallips	Hood_Canal	Duckabush	Dosewallips	Similar land use despite Lower Dosewallips being much smaller (10 Km^2) than Dosewallips (301 Km^2)	Yes	Was part of Dosewallips in Opt1, but was separated in Opt2 as it is not hydrologically connected.
Lummi Island E	Bellingham_Bay	Samish River	False Bay Creek	Lummi Island E is primarily forested with a little agricultural land use. False Bay Creek (forested and agricultural) is more representative than Samish (mixed land use).	Yes	Was part of Whatcom Creek in Opt1, but was separated in Opt2 as it is not hydrologically connected.
Lummi Island W	SOG	Samish River	False Bay Creek	Lummi Island W is primarily forested, with a little agriculture and urban land use. False Bay Creek (forested and agricultural) is more representative than Samish (mixed land use).	Yes	Was part of Whatcom Creek in Opt1, but was separated in Opt2 as it is not hydrologically connected.

Watershed Name	SSM Watershed Basin	Original WQ regression association	Updated WQ regression association	Reason for change	Flow Association Change	Comment
Mayo Cove	South_Sound	Minter Creek	Whitman Creek	Similar land use, drainage area, and close in proximity. Minter Creek has much more urban land use than both Mayo Cove and Whitman Creek.	No	—
McNeil Isl	South_Sound	Woodland Creek	Whitman Creek	Whitman Creek and McNeil Island are in close proximity, have almost identical drainage areas, and similar land use.	No	—
Orcas Island	SOG	Samish River	False Bay Creek	False Bay Creek and Orcas Island are in close proximity, have almost identical drainage areas, and similar land use.	Yes	—
Port Angeles	SJF	Elwha River	Dungeness	Elwha is primarily forested, while Dungeness and Port Angeles have significant urban land use near the mouth of both watersheds.	Yes	—
Port Gamble	Hood_Canal	Big Beef Creek (Sinclair-Dyes for DOC/POC)	Liberty Bay	Big Beef Creek is primarily forested, while Port Gamble and Liberty Bay have a lot of urban land use in addition to forest land.	Yes	—
Port Townsend E	Admiralty	Elwha River	Discovery Bay 1	Elwha is primarily forested land use, while Discovery Bay 1 is forested and agricultural. Port Townsend E, however, does have urban land use, which is not represented by either selection. Due to data limitations, however, Discovery Bay 1 is the best option.	Yes	Port Townsend was one watershed in Opt1, but was separated in Opt2 as it is not hydrologically connected.

Watershed Name	SSM Watershed Basin	Original WQ regression association	Updated WQ regression association	Reason for change	Flow Association Change	Comment
Port Townsend W	Admiralty	Elwha River	Discovery Bay 1	Elwha is primarily forested land use, while Discovery Bay 1 is forested and agricultural. Port Townsend W, however, does have urban land use, which is not represented by either selection. Due to data limitations, however, Discovery Bay 1 is the best option.	Yes	Port Townsend was one watershed in Opt1, but was separated in Opt2 as it is not hydrologically connected.
Sequim Bay E	SJF	Elwha River	Sequim Bay S	Similar land use, drainage area, and close in proximity.	Yes	Sequim Bay was one watershed in Opt1 but was separated in Opt2 as it is not hydrologically connected.
Silver Creek	Bellingham_Bay	Nooksack River	Squalicum Creek	Silver Creek and Squalicum Creek are primarily urban and agricultural land use, while Nooksack is mostly forested.	Yes	Was part of Nooksack River in Opt1 but was separated in Opt2 as it is not hydrologically connected.
Spencer Creek	Hood_Canal	Duckabush	Big Quilcene	Spencer Creek, Duckabush, and Big Quilcene are all forested watersheds. Big Quilcene was selected because it has a similar drainage area to Spencer Creek and is in closer proximity than Duckabush.	Yes	Was part of Dabob Bay in Opt1, but was separated in Opt2 as it is not hydrologically connected.
Thorndyke Creek	Hood_Canal	Big Beef Creek (Duckabush for DOC/POC)	Duckabush	Duckabush and Thorndyke Creek are both primarily forest and shrubland.	No	—

Watershed Name	SSM Watershed Basin	Original WQ regression association	Updated WQ regression association	Reason for change	Flow Association Change	Comment
Whidbey West	Admiralty	Samish River	Stillaguamish	Stillaguamish and Whidbey West both have a significant amount of agricultural land use, while Samish River does have agricultural land use, all of the water quality stations are near shrubland.	Yes	—

"—"=No comment

Watershed associations that were updated in Opt 2 were changed for all parameters other than temperature. Watershed associations for temperature in Opt 2 were either updated to native data if available or the association from Opt 1 was retained.

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Appendix B2. Changes to Watershed Loadings

This section presents changes in watershed flows and nutrient loading between Optimization Phase 1 (Opt1) and Optimization Phase 2 (Opt2) due to the updates made to watershed delineations and watershed regressions described in Appendix B1.

Flow changes

Table B2-1 below compares annual average flows between Optimization Phase 1 (Opt1) and Optimization Phase 2 (Opt2) for years 2006 and 2014, aggregated to different basins of the Salish Sea. The total flow magnitude between Opt1 and Opt2 across all of Washington. Watersheds decreased by about 3%. At the basin level, SOG had the largest percent changes in flows (where flows decreased by 43.7% and 37.6% for 2006 and 2014 in Opt2). This big decrease in flows is primarily due to a change in how flow from creeks in the San Juan Islands is estimated — previously, flow from the San Juan Islands was estimated by scaling down flow from the Samish River. For Opt2, these flows are now estimated using WRF-Hydro hindcast flow predictions.

The second largest percent change in flows were in Admiralty Inlet (where flows decreased by 14.6% and 16.0% for 2006 and 2014 in Opt2), but this basin also had the smallest magnitude of change in flow (0.68 and 0.82 cms for 2006 and 2014, respectively) — this basin only has a few small creeks so small changes to flow estimates resulted in a larger percent change.

Whidbey Basin had the largest magnitude of change in flow, where flow decreased by 64.2 and 77.8 cms in 2006 and 2014 in Opt2. This decrease in flow estimated to Whidbey Basin was primarily because of changes to Skagit River flow data, which was likely provisional when it was downloaded for Opt1. Main Basin had the smallest change in percent flows (where flows increased by 1.5% and 0.3% respectively, for the years 2006 and 2014 for Opt2). These results show that the combination of updating watershed delineations as well as using WRF flows for some ungauged locations does not appear to have heavily changed our flow estimates at the scale of the Salish Sea (for US rivers), even though flow estimates from individual basins did change.

Table B2-1. Comparison of annual daily average watershed flows for years 2006 and 2014, existing conditions between Optimization Phase 1 (Opt1) and Optimization Phase 2 (Opt2) in different basins in the Salish Sea.

Basin	2006 Opt1 flow (cms)	2006 Opt2 flow (cms)	2006 Diff. in flow (cms)	2006 Diff. in flow (%)	2014 Opt1 flow (cms)	2014 Opt2 flow (cms)	2014 Diff. in flow (cms)	2014 Diff. in flow (%)
South Sound	150	160	5.27	3.5%	120	130	4.30	3.4%
Main Basin	230	230	3.35	1.5%	240	240	0.66	0.3%
Hood Canal	190	200	7.9	4.1%	150	170	17.8	11.6%
Whidbey Basin	990	930	-63.4	-6.4%	1180	1100	-76.8	-6.5%
Admiralty	4.68	4.00	-0.68	-14.6%	5.13	4.31	-0.82	-16.0%
Northern Bays[1]	140	130	-3.68	-2.7%	160	160	-4.51	-2.8%
SOG - US	12.4	6.97	-5.40	-43.7%	14.7	9.14	-5.52	-37.6%
SJF - US	150	150	-2.83	-1.8%	150	150	-1.15	-0.8%
Salish Sea US Total	**1867**	**1811**	**-56.1**	**-3.0%**	**2020**	**1963**	**-56.4**	**-2.8%**

[1] Includes Bellingham, Samish, and Padilla Bays.

SOG = Strait of Georgia

SJF = Strait of Juan de Fuca

Total nitrogen load changes

Figure B2-1 and Table B2-2 compare total nitrogen (TN) load estimates between Opt1 and Opt2 for the years 2006 and 2014. Across all of Washington watersheds, existing TN load estimates between Opt1 and Opt2 increased by under 4.7%, reference TN loads decreased by 4.3% and 6.2%, while anthropogenic TN load estimates increased by about 15.8% and 19.5% for 2006 and 2014, respectively. As in other sections of the report and Appendices, “anthropogenic” refers to local and regional human loads or influence.

The largest differences in the magnitude of estimated anthropogenic loads between Opt2 and Opt1 are in Main Basin and Hood Canal. In Main Basin, estimated anthropogenic TN loads increased by 1,750 kg/day and 1,710 kg/day in 2006 and 2014, respectively, while in Hood Canal, they increased by 772 kg/day and 670 kg/day in 2006 and 2014, respectively. The increases in Main Basin TN loads between Opt 1 and Opt 2 were primarily due to regression changes for Dyes Inlet and Green River. Dyes Inlet previously used the median concentrations of water quality data from Puyallup, Nisqually, Deschutes, Green, and Cedar Lake to build regressions. In Opt 2, we acquired native data for Dyes Inlet to build regressions. For Green River, the data set used was expanded from 2006 to 2018 in Opt 1 to 1999 to 2022 in Opt 2. The new regression fit for Green River resulted in higher TN loads than in Opt 1. The changes in TN loads in Hood Canal were the result of acquiring data for watersheds that did not previously have data. In Opt 1, 25% of the watersheds in Hood Canal had native data for TN. This number increased to 60% in Opt 2. In terms of percent changes, we see that SJF, SOG, and Hood Canal have the largest percentage increases in existing and anthropogenic TN loads.

We now have more spatial and temporal coverage in terms of freshwater nitrogen data, which allowed the development of site-specific regressions for more watersheds. For example, previously, several rivers SJF used the Elwha River regression, but now use site-specific regressions, or regressions from a different, closer watershed. Nitrogen loading estimates for rivers draining to Hood Canal are now also based on more site-specific data. This indicates that our previous estimates in Opt1 likely underestimated existing and anthropogenic TN loads for watersheds draining to Hood Canal. However, these higher loads are still much lower than those estimated for watersheds in more developed regions. For example, South Sound which has annual average freshwater inflows of 150 cms, has an estimated anthropogenic TN load in Opt2 of 4,070 kg/day in 2006, while SJF, which also has about 150 cms of freshwater flow has an estimated anthropogenic TN load in Opt2 that is 83% below that of South Sound, at 673 kg/day. Hood Canal flows are greater than those in South Sound, at 190 cms, but its estimated anthropogenic TN loads are 1,400 kg/day, which is 66% below that of South Sound.

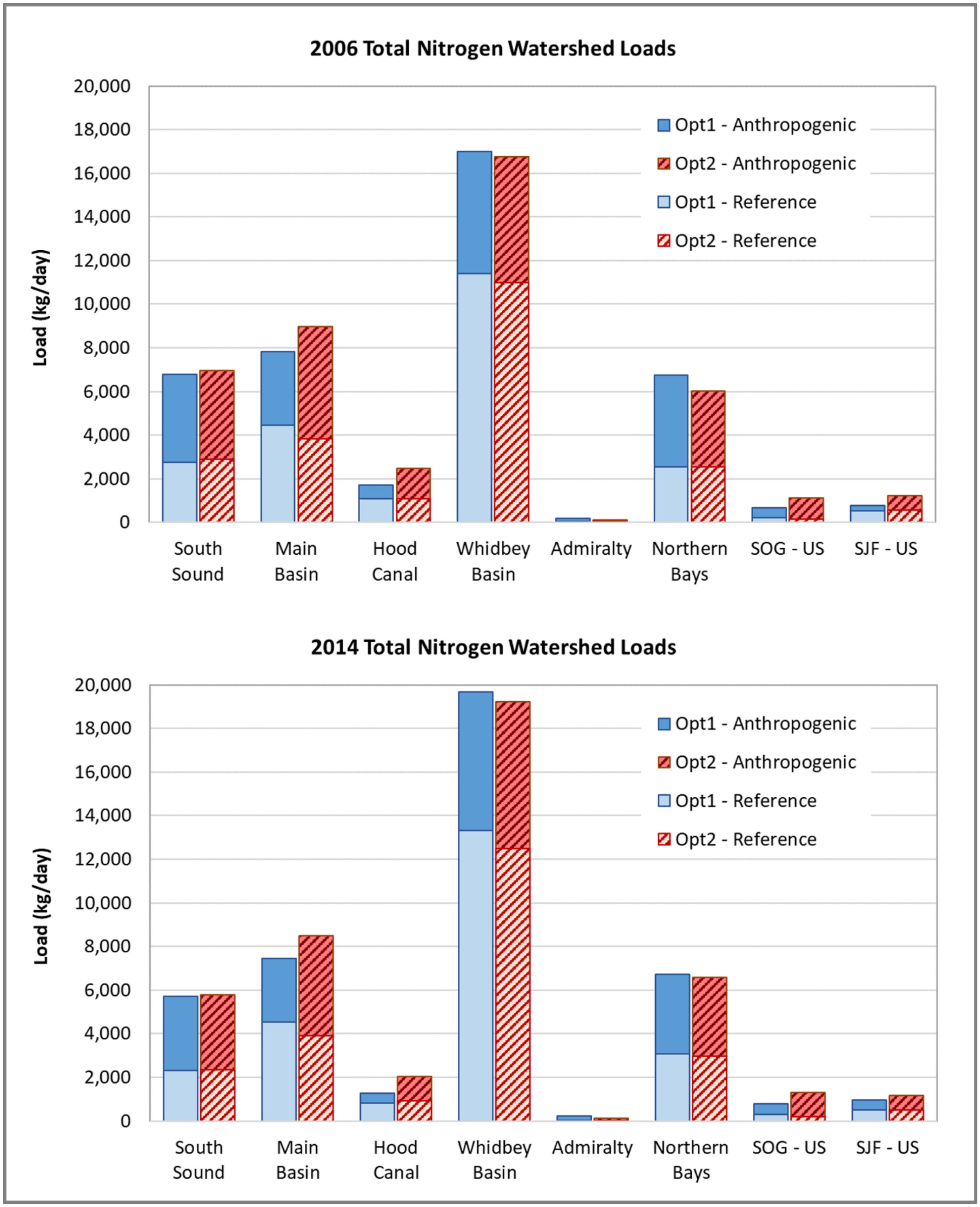

Figure B2-1. Comparison of annual daily average reference and anthropogenic total nitrogen (TN) watershed loads entering different basins in the Salish Sea in Optimization Phase 1 (Opt1) and Optimization Phase 2 (Opt2) during 2006 (top plot) and 2014 (bottom plot).

Table B2-2. Comparison of annual daily average existing, reference, and anthropogenic total nitrogen (TN) watershed loads entering different basins in the Salish Sea in Optimization Phase 1 (Opt1) and Optimization Phase 2 (Opt2) during 2006 and 2014.

Total Nitrogen: Existing loads by Basin	2006 Opt1 load (kg/day)	2006 Opt2 load (kg/day)	2006 Diff. in load (kg/day)	2006 Diff. in load (%)	2014 Opt1 load (kg/day)	2014 Opt2 load (kg/day)	2014 Diff. in load (kg/day)	2014 Diff. in load (%)
South Sound	6,800	6,950	150	2.2%	5,710	5,800	90.0	1.6%
Main Basin	7,840	8,970	1,130	14.4%	7,440	8,510	1,070	14.4%
Hood Canal	1,700	2,470	770	45.3%	1,260	2,020	760	60.3%
Whidbey Basin	16,990	16,760	-230	-1.4%	19,690	19,220	-470	-2.4%
Admiralty	169	124	-45.0	-26.6%	216	116	-100	-46.3%
Northern Bays1	6,750	6,020	-730	-10.8%	6,720	6,600	-120	-1.8%
SOG – US	669	1,110	441	65.9%	777	1,320	543	69.9%
SJF – US	774	1,230	456	58.9%	955	1,150	195	20.4%
Salish Sea US Total	**41,692**	**43,634**	**1,942**	**4.7%**	**42,768**	**44,736**	**1,968**	**4.6%**
Total Nitrogen: Reference loads by Basin	**2006 Opt1 load (kg/day)**	**2006 Opt2 load (kg/day)**	**2006 Diff. in load (kg/day)**	**2006 Diff. in load (%)**	**2014 Opt1 load (kg/day)**	**2014 Opt2 load (kg/day)**	**2014 Diff. in load (kg/day)**	**2014 Diff. in load (%)**
South Sound	2,770	2,880	110	3.9%	2,310	2,360	50.0	2.2%
Main Basin	4,440	3,820	-620	-13.9%	4,550	3,910	-640	-14.1%
Hood Canal	1,070	1,070	0.0	0.2%	818	907	89.0	10.9%
Whidbey Basin	11,410	11,000	-410	-3.6%	13,330	12,500	-830	-6.2%
Admiralty	16.3	15.4	-0.90	-5.7%	16.8	14.6	-2.20	-13.1%
Northern Bays1	2,560	2,540	-20.0	-0.8%	3,060	2,960	-100.0	-3.3%
SOG – US	232	136	-96.0	-41.3%	287	178	-109	-38.0%
SJF – US	521	557	36.0	6.9%	491	501	10.0	2.0%
Salish Sea US Total	**23,019**	**22,018**	**-1,001**	**-4.3%**	**24,863**	**23,331**	**-1,532**	**-6.2%**
Total Nitrogen: Anthropogenic loads by Basin	**2006 Opt1 load (kg/day)**	**2006 Opt2 load (kg/day)**	**2006 Diff. in load (kg/day)**	**2006 Diff. in load (%)**	**2014 Opt1 load (kg/day)**	**2014 Opt2 load (kg/day)**	**2014 Diff. in load (kg/day)**	**2014 Diff. in load (%)**
South Sound	4,030	4,070	40.0	1.0%	3,410	3,440	30.0	0.9%
Main Basin	3,400	5,150	1,750	51.4%	2,890	4,600	1,710	59.2%
Hood Canal	628	1,400	772	123%	440	1,110	670	152%
Whidbey Basin	5,580	5,760	180	3.2%	6,360	6,720	360	5.7%
Admiralty	152	108	-44.0	-28.8%	199	102	-97.0	-48.7%
Northern Bays1	4,190	3,480	-710	-16.9%	3,660	3,640	-20.0	-0.5%
SOG – US	438	978	540	123%	490	1,140	650	133%
SJF – US	254	673	419	165%	464	650	186	40.1%
Salish Sea US Total	**18,672**	**21,619**	**2,947**	**15.8%**	**17,913**	**21,402**	**3,489**	**19.5%**

Total organic carbon load changes

Figure B2-2 and Table B2-3 compare total organic carbon (TOC) load estimates between Opt1 and Opt2 for the years 2006 and 2014. Across all of Washington watersheds, existing TOC load estimates decreased by 14.3% in 2006 and increased by 3.3% in 2014 for Opt2 relative to Opt1. Estimates of reference TOC loads increased by 5.0% in 2006 and decreased by 4.6% in 2014, while estimates of anthropogenic TOC loads decreased by 34.2% in 2006 and increased by 19.3% in 2014 for Opt2 relative to Opt1.

The largest magnitudes of changes in estimated existing and anthropogenic TOC loads were in Whidbey Basin, SJF, and Hood Canal. In Whidbey Basin, existing load estimates decreased for both years. In SJF, they decreased in 2006 and increased in 2014, while in Hood Canal, they increased for both years. The largest percent change in estimated existing and anthropogenic TOC loads between Opt1 and Opt2 was in Hood Canal (existing loads increased by 94.4% and 56.2% in 2006 and 2014, respectively, and anthropogenic loads increased by 123% in 2006, but decreased by 21.4% in 2014). Existing TOC loads in Hood Canal for Opt2 were 36.3% less in 2014 than in 2006 (25,600 kg/day vs. 40,200 kg/day), and anthropogenic loads were 66.8% less in 2014 than in 2006 (13,100 kg/day vs. 4,340 kg/day in 2006 and 2014).

Existing TOC loads for 2006 and 2014 increased from Opt 1 due to greater data coverage for Hood Canal in Opt 2. In Opt 1, many of the watersheds without TOC data were borrowing from watersheds with much lower TOC concentrations than what would be supported by our current data. The decrease in anthropogenic TOC loads in 2014, however, was primarily due to changes in Skokomish River TOC data used and due to changes in the regression. In Opt 1, we used TOC data from 2011 to 2018 to fit a regression for Skokomish, as this was the only data that we were aware of. In Opt 2, we found additional data that included the years 1996 – 2004. The data from 1996 to 2004 had TOC concentrations that were on average 2.5 times greater than the data from 2011 to 2018. The stark differences between 2014 and 2006 TOC loads in Opt 2 are due to the use of two regressions, one for 1996 – 2009 using data from 1996 to 2004 and the other for 2010 – present using the data from 2011 to 2018. The decision to split Skokomish regressions into two temporal periods was also influenced by noticeable changes in the hydrograph from 2009 onwards. The Skokomish River channel at the Potlach USGS gauge has been gradually filling in over the years, resulting in greater occurrences of overbank flow losses during high flow events (Collins et al. 2019).

The change in TOC loads between Opt1 and Opt2 is not consistent between the two years, i.e., in some basins, like in SJF, where existing and anthropogenic TOC loads decreased in 2006 and increased in 2014. This is because in Opt1, we used an expanded freshwater TOC data set for regressions to estimate concentrations for model year 2014, but an older set of regressions using a smaller TOC data set was used for model year 2006. For Opt2, we are now using a consistent and expanded freshwater database for both modeled years. As a result, the magnitude of estimated anthropogenic TOC loads is now more similar for the two years. For example, in SJF, in Opt1, existing TOC loads were estimated at 60,800 kg/day and 13,100 kg/day in 2006 and 2014, respectively. In Opt2, these TOC loads in Opt2 are now 26,800 kg/day and 22,800 kg/day for 2006 and 2014, respectively.

Since our method of estimating reference TOC concentrations is based on calculating the 10th or 50th percentile of existing TOC concentrations, any increase or decrease in the existing TOC load estimates also resulted in analogous increases or decreases in the reference TOC load estimates.

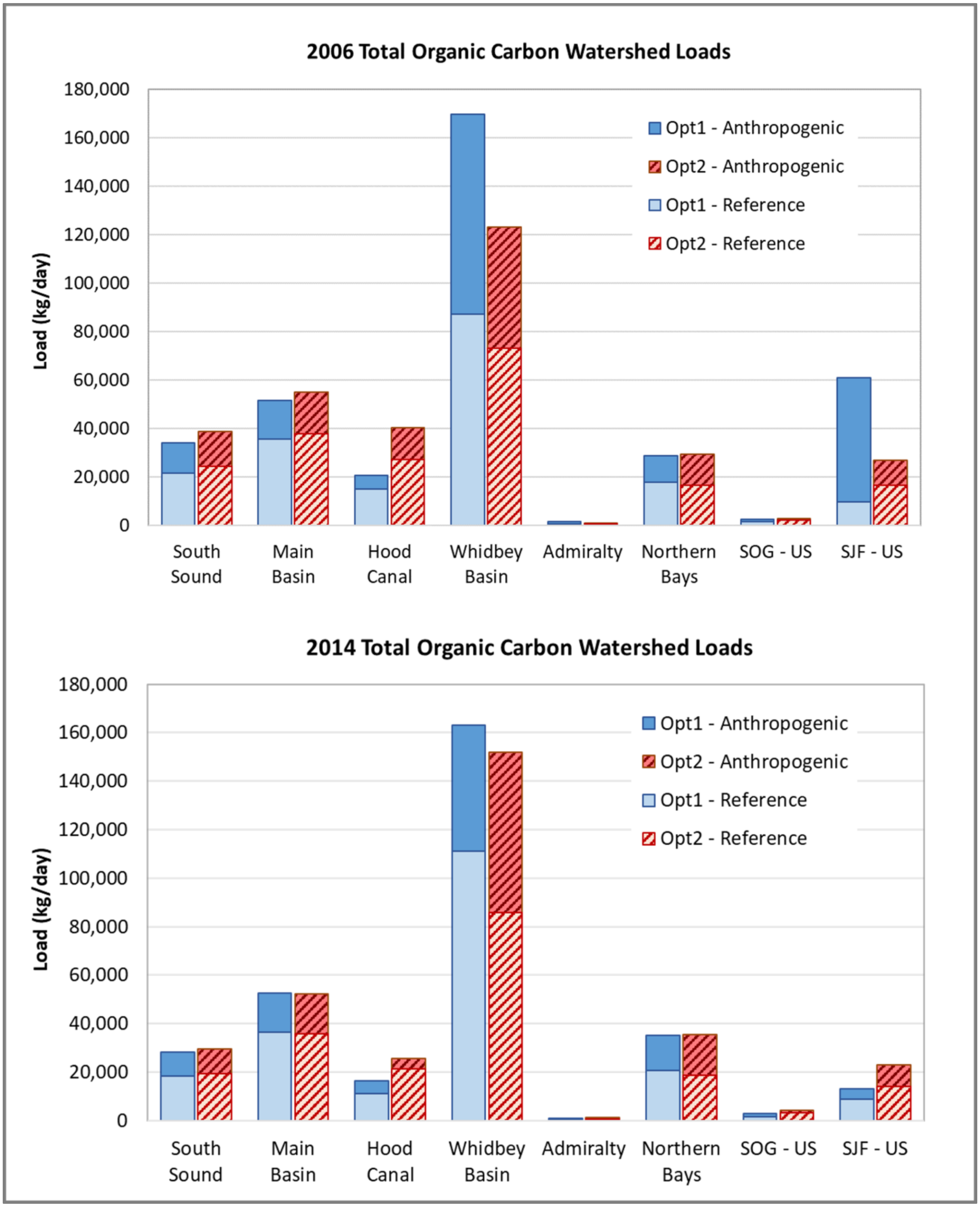

Figure B2-2. Comparison of annual daily average reference and anthropogenic total organic carbon (TOC) watershed loads entering different basins in the Salish Sea in Optimization Phase 1 (Opt1) and Optimization Phase 2 (Opt2) during 2006 (top plot) and 2014 (bottom plot).

Table B2-3. Comparison of annual daily average existing, reference, and anthropogenic total organic carbon (TOC) watershed loads entering different basins in the Salish Sea in Optimization Phase 1 (Opt1) and Optimization Phase 2 (Opt2) during 2006 and 2014.

Total Organic Carbon: Existing Loads by Basin	2006 Opt1 load (kg/day)	2006 Opt2 load (kg/day)	2006 Diff. in load (kg/day)	2006 Diff. in load (%)	2014 Opt1 load (kg/day)	2014 Opt2 load (kg/day)	2014 Diff. in load (kg/day)	2014 Diff. in load (%)
South Sound	34,200	38,800	4,600	13.5%	28,300	29,400	1,100	3.8%
Main Basin	51,500	54,900	3,400	6.7%	52,400	52,100	-300	-0.50%
Hood Canal	20,700	40,200	19,500	94.4%	16,400	25,600	9,200	56.2%
Whidbey Basin	170,000	123,000	-47,000	-27.5%	163,000	152,000	-11,000	-6.7%
Admiralty	1,500	979	-521	-34.9%	830	1,110	280	33.6%
Northern Bays1	28,600	29,200	600	2.4%	35,200	35,300	100	0.50%
SOG – US	2,410	2,880	470	19.4%	2,960	4,070	1,110	37.2%
SJF – US	60,800	26,800	-34,000	-55.9%	13,100	22,800	9,700	73.5%
Salish Sea US Total	**369,710**	**316,759**	**-52,951**	**-14.3%**	**312,190**	**322,380**	**10,190**	**3.3%**
Total Organic Carbon: Reference Loads by Basin	**2006 Opt1 load (kg/day)**	**2006 Opt2 load (kg/day)**	**2006 Diff. in load (kg/day)**	**2006 Diff. in load (%)**	**2014 Opt1 load (kg/day)**	**2014 Opt2 load (kg/day)**	**2014 Diff. in load (kg/day)**	**2014 Diff. in load (%)**
South Sound	21,400	24,200	2,800	13.2%	18,200	19,300	1,100	6.3%
Main Basin	35,500	37,500	2,000	5.6%	36,300	35,800	-500	-1.3%
Hood Canal	14,800	27,100	12,300	83.2%	10,900	21,300	10,400	95.5%
Whidbey Basin	87,200	73,200	-14,000	-16.0%	111,000	85,800	-25,200	-22.8%
Admiralty	405	518	113	27.8%	441	536	95.0	21.5%
Northern Bays1	17,900	16,500	-1,400	-7.8%	20,600	18,500	-2,100	-10.1%
SOG – US	1,400	2,090	690	49.4%	1,580	3,060	1,480	93.3%
SJF – US	9,560	16,400	6,840	71.5%	8,840	14,000	5,160	58.3%
Salish Sea US Total	**188,165**	**197,508**	**9,343**	**5.0%**	**207,861**	**198,296**	**-9,565**	**-4.6%**

Total Organic Carbon: Anthropogenic Loads by Basin	2006 Opt1 load (kg/day)	2006 Opt2 load (kg/day)	2006 Diff. in load (kg/day)	2006 Diff. in load (%)	2014 Opt1 load (kg/day)	2014 Opt2 load (kg/day)	2014 Diff. in load (kg/day)	2014 Diff. in load (%)
South Sound	12,800	14,600	1,800	14.0%	10,100	10,100	0.00	-0.80%
Main Basin	16,000	17,400	1,400	9.0%	16,100	16,300	200	1.2%
Hood Canal	5,870	13,100	7,230	123%	5,520	4,340	-1,180	-21.4%
Whidbey Basin	82,300	49,700	-32,600	-39.6%	51,600	66,100	14,500	28.2%
Admiralty	1,097	461	-636	-58.0%	388	571	183	47.3%
Northern Bays1	10,700	12,700	2,000	19.5%	14,600	16,800	2,200	15.4%
SOG – US	1,010	790	-220	-22.0%	1,380	1,010	-370	-27.1%
SJF – US	51,200	10,400	-40,800	-79.6%	4,300	8,800	4,500	105%
Salish Sea US Total	**180,977**	**119,151**	**-61,826**	**-34.2%**	**103,988**	**124,021**	**20,033**	**19.3%**

References (Appendix B2)

Collins, B.D., Dickerson-Lange, S.E., Schanz, S. and Harrington, S., 2019. Differentiating the effects of logging, river engineering, and hydropower dams on flooding in the Skokomish River, Washington, USA. Geomorphology, 332:138 – 156. https://doi.org/10.1016/j.geomorph.2019.01.021

Appendix B3. Time Series Plots of Flow and Water Quality for Watersheds

Appendix B3 is available as a separate document at
https://apps.ecology.wa.gov/publications/SummaryPages/2503003.html.

This appendix includes:

- Appendix B3A. Flow time series for watersheds: 2000, 2006, 2008, and 2014
- Appendix B3B. Exist and reference water quality time series for watersheds: 2000
- Appendix B3C. Exist and reference water quality time series for watersheds: 2008
- Appendix B3D. Exist and reference water quality time series for watersheds: 2006
- Appendix B3E. Exist and reference water quality time series for watersheds: 2014

For definitions of terms, refer to the glossary in the main report.

Appendix B4. Evaluation of Inorganic Nitrogen Watershed Regressions on Continuous Data

This section presents an evaluation of watershed regressions developed for Inorganic nitrogen with continuous observed data.

Background

To meet the data needs of the Salish Sea model, Ecology's Freshwater Monitoring Unit (FMU) installed Submersible Ultraviolet Nitrate Analyzers (SUNA) in 2023 in several major watersheds in the Puget Sound, including Puyallup, Duwamish, Skagit, Snohomish, Cedar, Stillaguamish, Nooksack, and the Nisqually. The continuous SUNA inorganic nitrogen data provided by these sensors presented us with the opportunity to thoroughly evaluate the performance of our regressions on a comprehensive and independent data set from the data used to fit the regressions. For our evaluation, we identified SUNA nitrate-nitrite monitoring locations that were coincident with discrete monthly monitoring locations used to fit the regressions. Coincident locations used for the evaluation include Nooksack, Puyallup, Skagit, and Snohomish (Figure B4-1). With the exception of Snohomish, the regressions for these locations were fit with water quality sampling data that corresponded with USGS gauge locations.

The FMU discrete monitoring location in Snohomish used to fit the regressions was collocated with a stage only USGS gauge, 12155500. Flow was approximated at 12155500 by taking an area weighted sum of the Snohomish Monroe USGS gauge (1215800) and the Pilchuck River gauge near Snohomish (12155300) (Figure B4-1) and scaling the resulting flow to 12155500 using the drainage ratio method. The USGS recently developed rating curves for 12155500 with continuous discharge dating available from September 2022 to April 2024. A comparison of our flow estimates for 12155500 with the recently available gauge flow data for 12155500 will be discussed in the Flow Conditions section below.

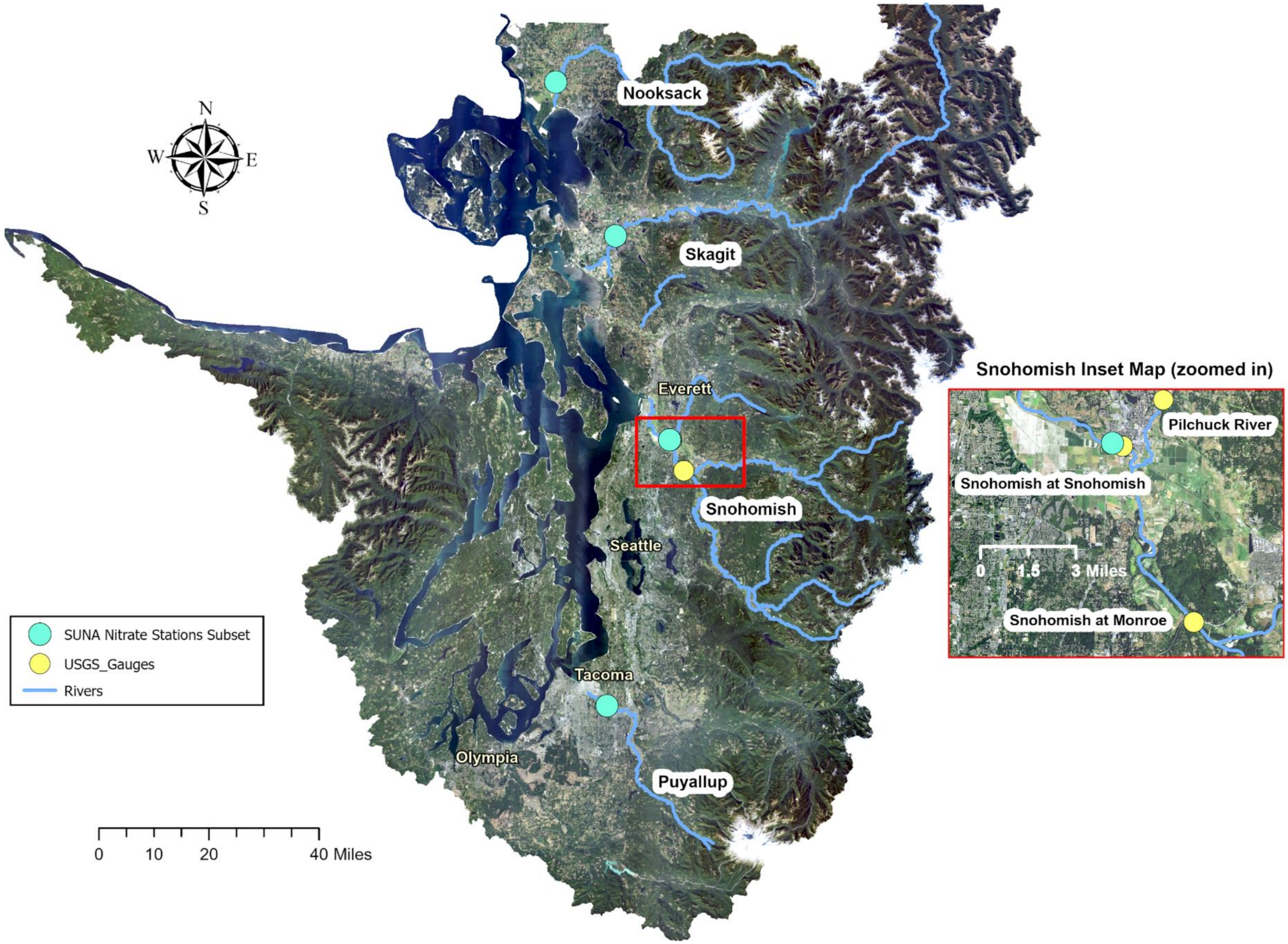

Figure B4-1. Map of SUNA nitrate-nitrite stations in four major Puget Sound Watersheds used to evaluate regressions. USGS gauges were coincident with all four of the SUNA evaluation locations. The Snohomish inset map shows the Snohomish at Snohomish USGS gauge and the gauges used to estimate it, including Snohomish at Monroe at the Pilchuck River USGS gauge.

Flow Conditions

Flow conditions for the four watersheds were assessed from July 2023 to October 2024, to match the period of currently available SUNA nitrate-nitrite data. Hydrologic conditions in these watersheds are driven by snowmelt, which is the dominant influence for Nooksack and Skagit (Sobocinski 2021), and a mix of rain and snow for the Puyallup and Snohomish watersheds (Kerwin 1999; Mauger et al. 2005). Nooksack and Puyallup had moderate baseflow from July to October in both 2023 and 2024 (Figure B4-2), with Nooksack having a shorter recession period in 2024. Baseflow conditions for Skagit were relatively high at around 6,460 cfs (Table B4-1) compared to the relatively stable baseflow conditions (Figure B4-2) at Snohomish of around 2,570 cfs (Table B4-1). The Nooksack River had the greatest seasonal fluctuations of any of the watersheds, with peak discharge in February (Figure B4-2). The other three watersheds were less flashy and had peak discharge in December.

Table B4-1. Statistics and Flow Record for USGS gauges used for regression evaluation.

Watershed	USGS Gauge	Dates Assessed	Low Flow (cfs)	Median Flow (cfs)	High Flow
Nooksack	12213100	07/01/2023–10/01/2024	1,068	2,464	4,704
Puyallup	12101500	07/01/2023–10/01/2024	1,232	2,340	4,365
Skagit	12200500	07/01/2023–10/01/2024	6,460	10,364	16,328
Snohomish	12155500	07/13/2023–03/30/2024	2,570	6,880	16,540
Snohomish	12155500 (Estimated)	07/13/2023–10/01/2024	1,608	6,099	13,711

Low Flows = 10^{th} percentile flow values calculated using data from Figure B4-2.
High Flows = 90^{th} percentile flow values calculated using data from Figure B4-2.

Flow ranges for Nooksack and Puyallup were nearly identical for low flow, median flow, and high flow conditions (Table B4-1). Snohomish and Skagit had very similar high flow conditions of around 16,000 cfs (Table B4-1) and peak flows greater than 60,000 cfs (Figure B4-2), however, Skagit River had nearly 3 times more flow during baseflow conditions than Snohomish and had a greater overall median across all flow conditions (Table B4-1).

Snohomish River flow estimates of 12155500, which were used for the regressions in Appendix B1, were compared against gauge flow data at 12155500 from July 13^{th}, 2023, to October 1^{st}, 2024. Flow estimates had good agreement with observed flow, with the estimates capturing 99% of the variance in the actual data (R^2=0.99), and an NRMSE of 0.22, which is much lower than the threshold for poor performance of 1 (Figure B4-2). Flow estimates were generally slightly lower than actual flow at 1215500 (Table B4-1), with a Mean Absolute Error (MAE) of 1,084 cfs, and a Maximum Absolute Error (MaxAE) of 11,866 cfs (Figure B4-2). On a daily average time scale these estimates appear to be a good approximation of actual flow conditions, however, because the Snohomish River is tidally influenced (Hall et al. 2018) this approximation would likely not work as well for finer time scales (15 minute, hourly, etc.) as flow at the Monroe USGS gauge was typically greater than at 12155500 during high tide.

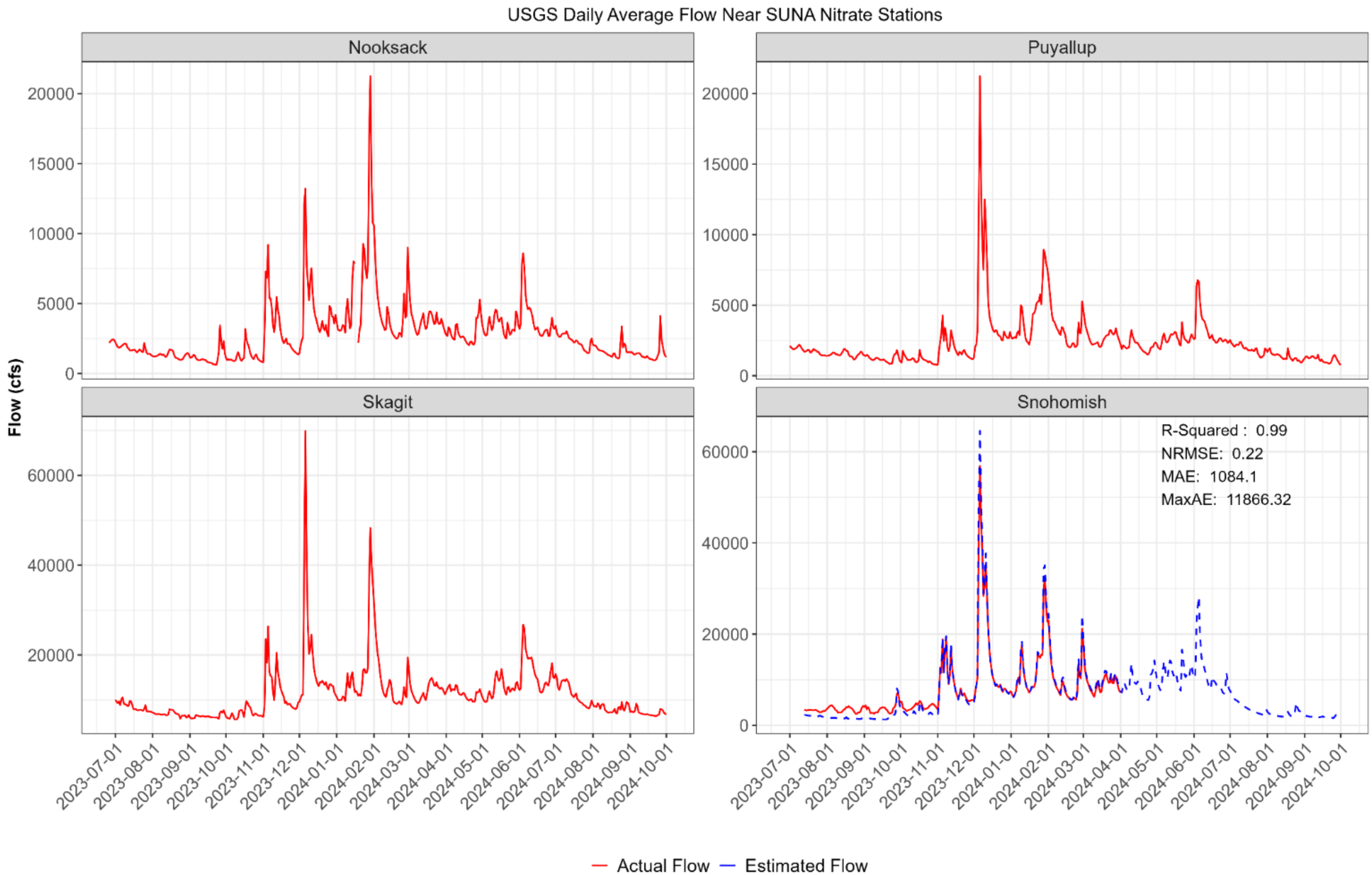

Figure B4-2. Hydrographs of SUNA regression evaluation sites.
The Snohomish estimated flow used for fitting the regression was compared to actual gauge flow data, which has discharge data available from September 2022 to April 2024.

Nitrate-Nitrite Regression Evaluation

In addition to the discrete data used for regression validation discussed in Appendix B1, regression performance for nitrate-nitrite was also evaluated using Ecology's FMU's continuous SUNA observations near the mouth of major Puget Sound watersheds, Nooksack, Puyallup, Skagit, and Snohomish. As mentioned previously, these SUNA locations are the same locations where the discrete monthly monitoring data used to fit the regressions were collected.

For these four rivers, we compared regression-predicted nitrate-nitrite concentrations and loads with SUNA observations. Continuous flow data and SUNA nitrate-nitrite data at these rivers spanned from either July or August 2023 to October 2024, with the exception of the Puyallup, where data spanned from November 2023 to October 2024.

Nitrate-nitrite regression performance was good for all four of the watersheds assessed. Regression predictions in all four watersheds are less variable on a daily time scale than SUNA measurements. This is likely due to the resolution of the data used to fit the regressions, which consisted of discrete monthly observations and daily average flows corresponding to the day of measurement. Nitrate-nitrite regression predictions explained 72% (Snohomish) to 86% (Nooksack) of the variance in the observed data based on R-Squared and had NRMSE values ranging from 0.4 (Nooksack) to 0.55 (Snohomish) (Figure B4-3). An NRMSE of 1 or greater signals a less representative estimate than the mean of observations (Jolliff et al. 2009; USECos Team 2008). The combination of low NRMSE values and high R-squared values indicates that the regressions are adequately representing nitrate-nitrite in these four watersheds. Overall, the regressions appear to be capturing general seasonal trends well but struggle with short-term sporadic events.

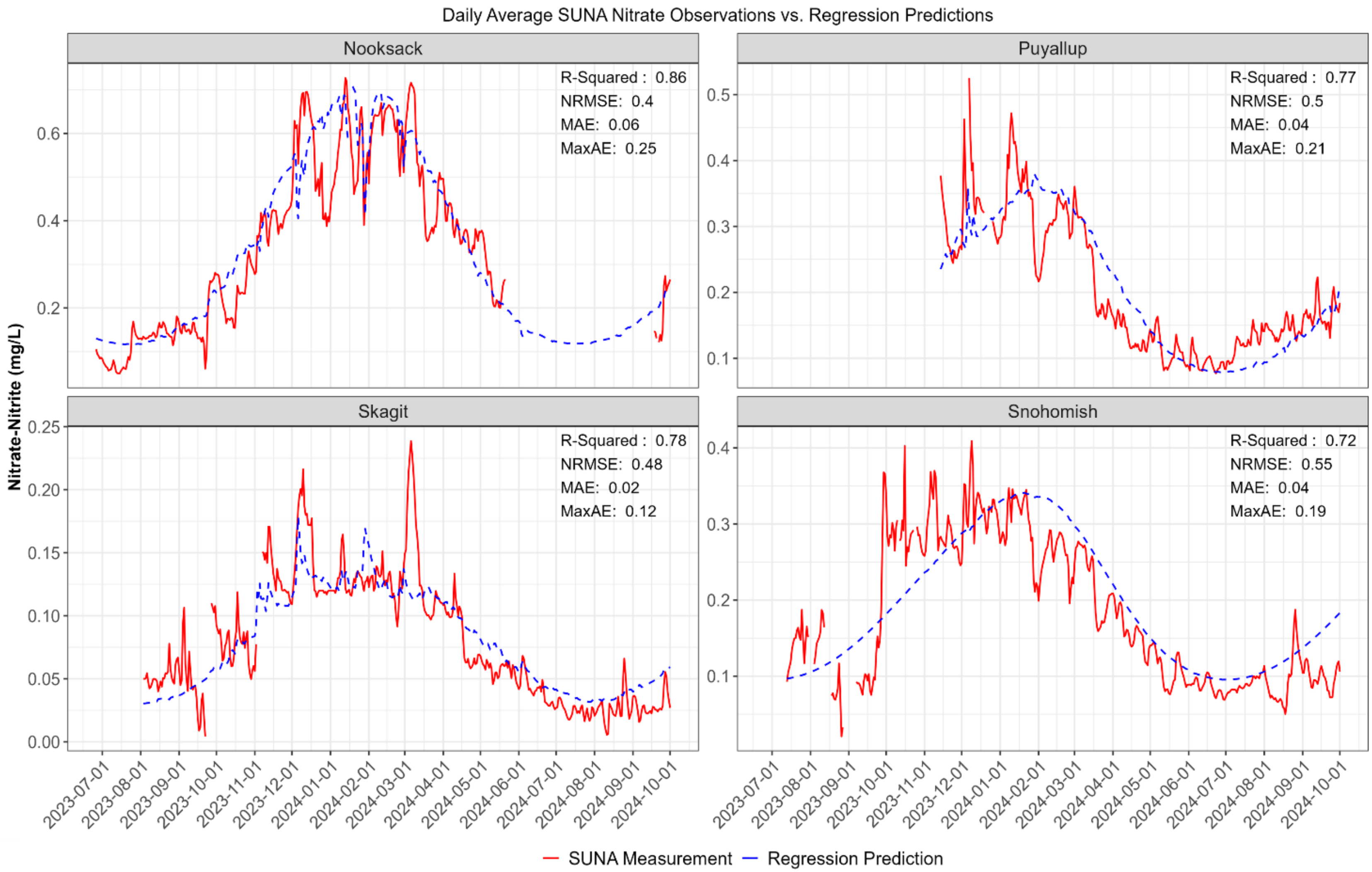

Figure B4-3. Comparison of continuous SUNA nitrate-nitrite data with regression predictions at four major Puget Sound Watersheds.

Regression performance was also assessed for different flow conditions using 24 years of gauge data (1999 – 2023) (Figure B4-4) for each of the four watersheds. We evaluated performance for high flow conditions (90th percentile or greater flows), low flow conditions (10th percentile or lower flows), and normal flow conditions (everything else).

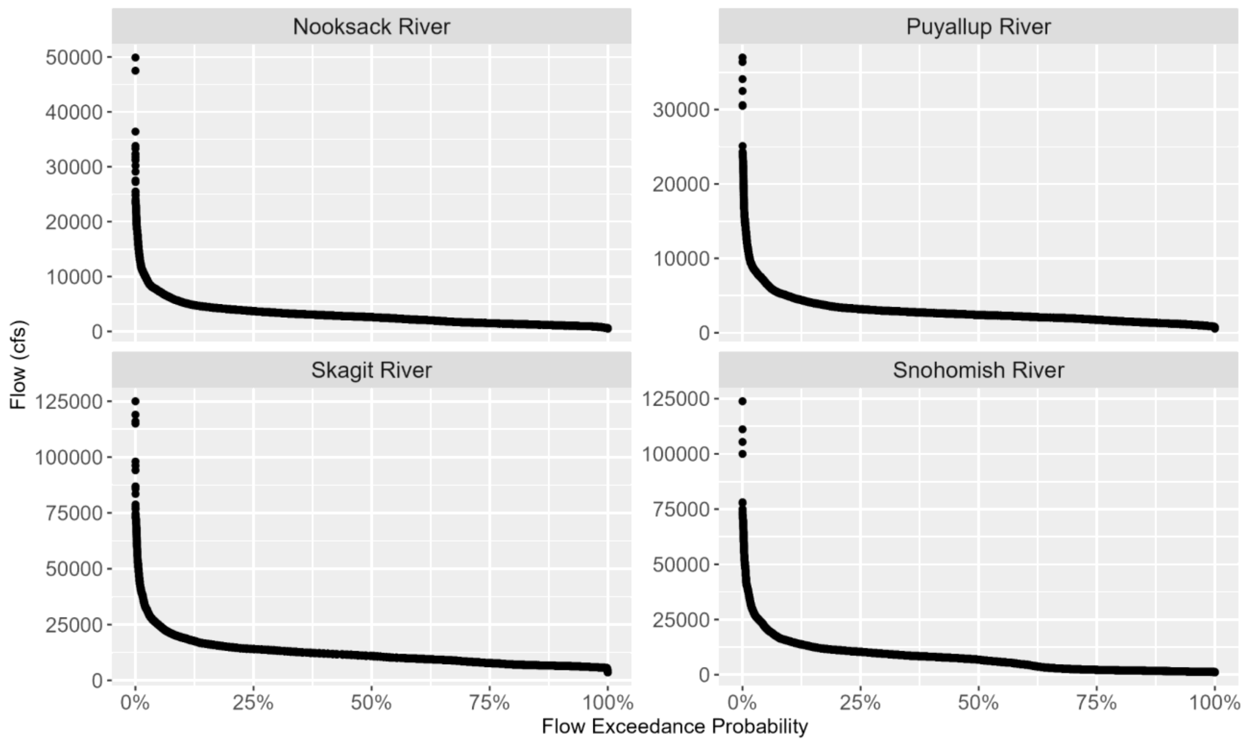

Figure B4-4. Flow Duration Curves for four SUNA evaluation watersheds constructed from 24 years of USGS gauge data.

Regression performance was found to be good for all flow conditions at all locations except low flow conditions at Snohomish and Skagit. As shown in the target plot in Figure B4-5, both Snohomish and Skagit at low flow are outside of the target plot, meaning that the NRMSE for these two watersheds during low flow conditions is greater than 1. Nooksack and Puyallup performed well for all flow regimes; however, there was greater residual error during high flow for Puyallup and during low flow for Nooksack, with both of these watersheds tending to overestimate (positive bias, Figure B4-5) SUNA measurements for each of these flow regimes. Regression performance was best during normal flow conditions for all of the watersheds. As shown in the Taylor plot (Figure B4-5), the correlation between SUNA measurements and predictions was generally between 0.6 and 0.93, with most values around 0.8. Skagit and Snohomish during low flow conditions had the lowest correlations, with Skagit exhibiting a correlation of 0.2 and Snohomish a correlation of -0.28, which indicates a complete breakdown of performance (Figure B4-5)

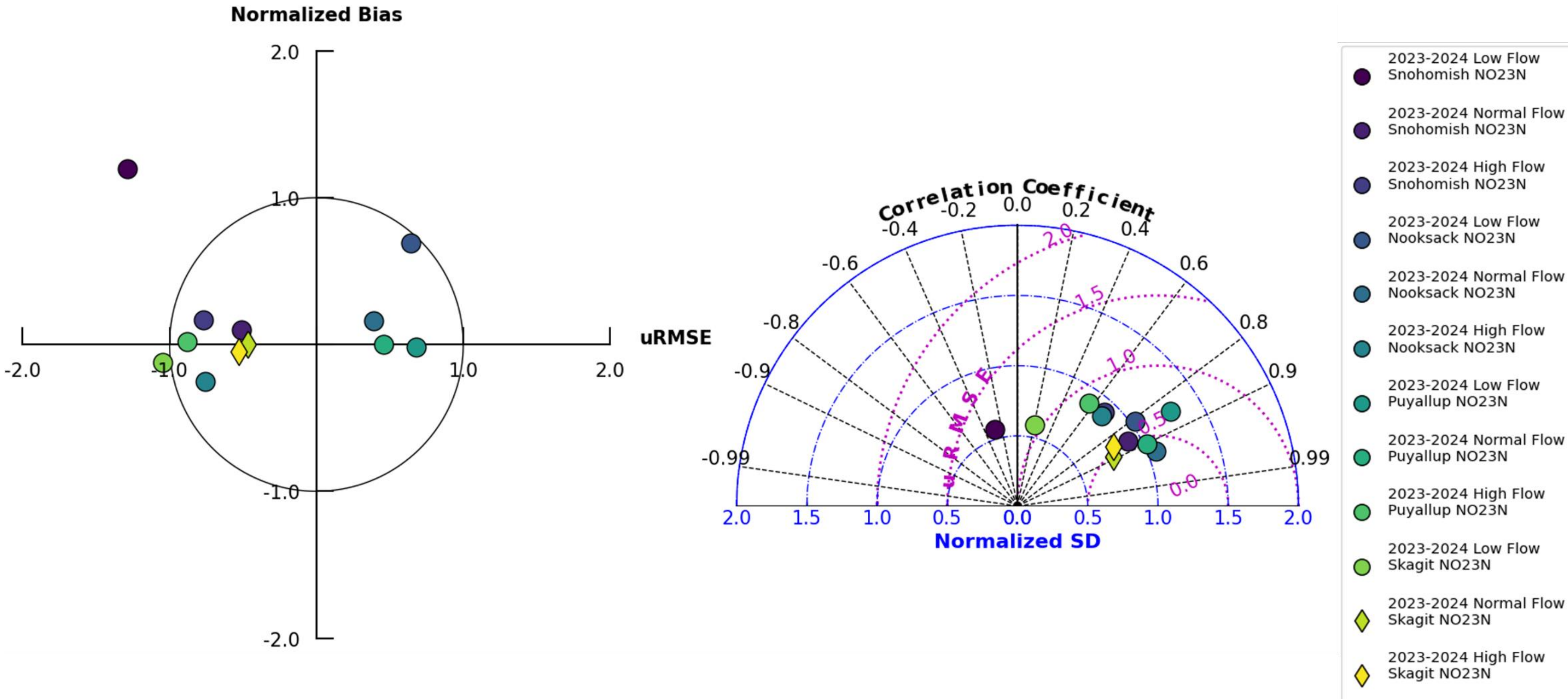

Figure B4-5 Taylor and target diagram performance of nitrate-nitrite regressions for different flow regimes in SUNA evaluation watersheds.

We found that the Snohomish nitrate-nitrite regression was fit on monthly data that, on average, had higher values and a greater range (min to max) of values than the continuous SUNA data during low flow conditions. (Figure B4-6) This seems to explain the overpredictions occurring during low flow in Snohomish from September 1st to October 1st in 2023 and 2024 (Figure B4-3). Similarly, the regression for Skagit was trained on data with a much higher minimum value than the continuous SUNA data, but had a lower average and maximum (Figure B4-6) and had little to no overlap between training and testing data sets during low flow. This is consistent with Skagit's predictions in Figure B4-3, which alternate from overpredicting to underpredicting during low flow conditions from September 1st to November 1st, 2023, and mid-September to October 1st, 2024. Except for low flow conditions, both Snohomish and Skagit had a high degree of overlap between the training and testing data sets.

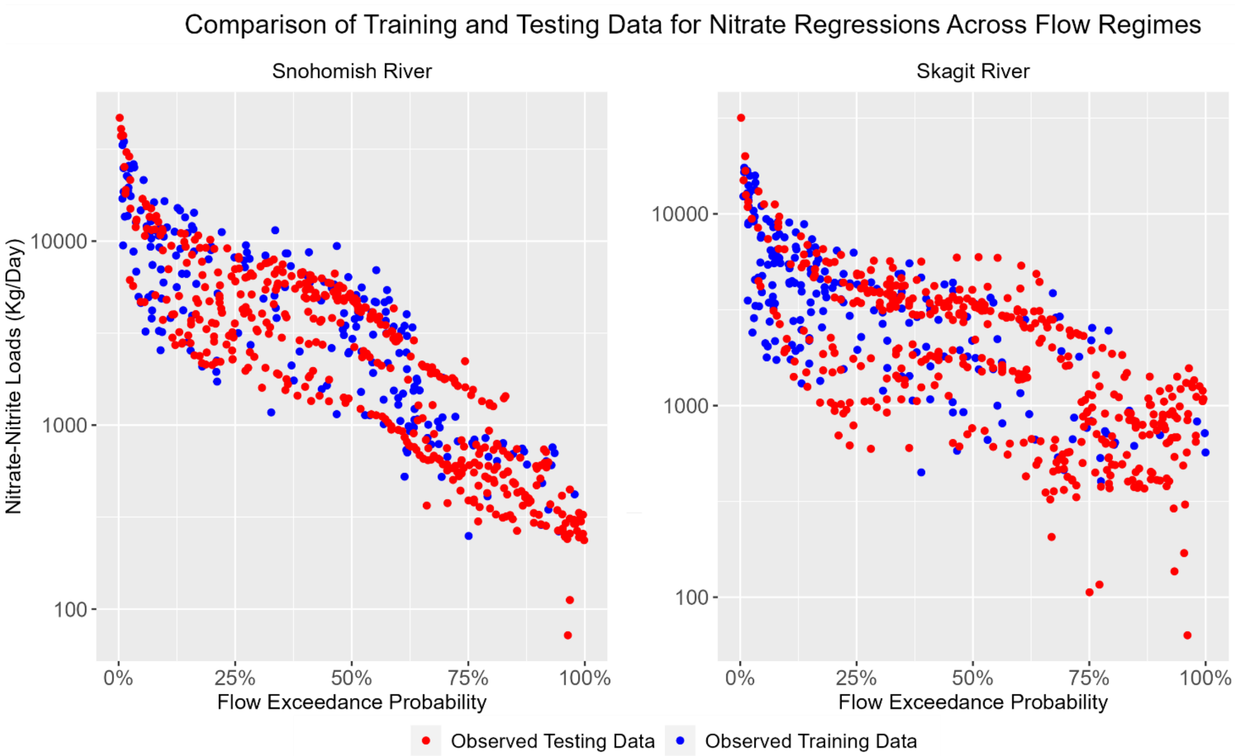

Figure B4-6. Plots show the distribution of nitrate-nitrite data used to train and test the regression across different flow regimes for the Snohomish and Skagit Rivers. Overlap between training and testing data is an indicator of regression performance on the evaluation data for a given flow regime.

Nooksack and Puyallup rivers showed similar distributions between training and testing data across flow regimes. The most notable differences between training and testing data distributions occurred during low flow for Nooksack and during high flow for Puyallup (Figure B4-7). The Nooksack nitrate-nitrite regression was fit on monthly data that, on average, had higher values than the continuous SUNA data (Figure B4-7). This may explain the slight overpredictions occurring during low flow conditions in Nooksack in October 2023 (Figure B4-

3). Similarly, the regression for Puyallup was trained on data with greater average and maximum values than the continuous SUNA data during low and high flow conditions, but had a higher degree of overlap between training and testing data than Nooksack (Figure B4-7). Puyallup performed slightly worse during high flow conditions, with most of the error being related to random error (NRMSE), while the average error (normalized centered bias) is near zero (0.02). This is most apparent for Puyallup from December through January 2024 (Figure B4-3), where we can see that the regression has minimum average error but is missing peak spikes in concentrations in December and sharp declines in concentrations in January.

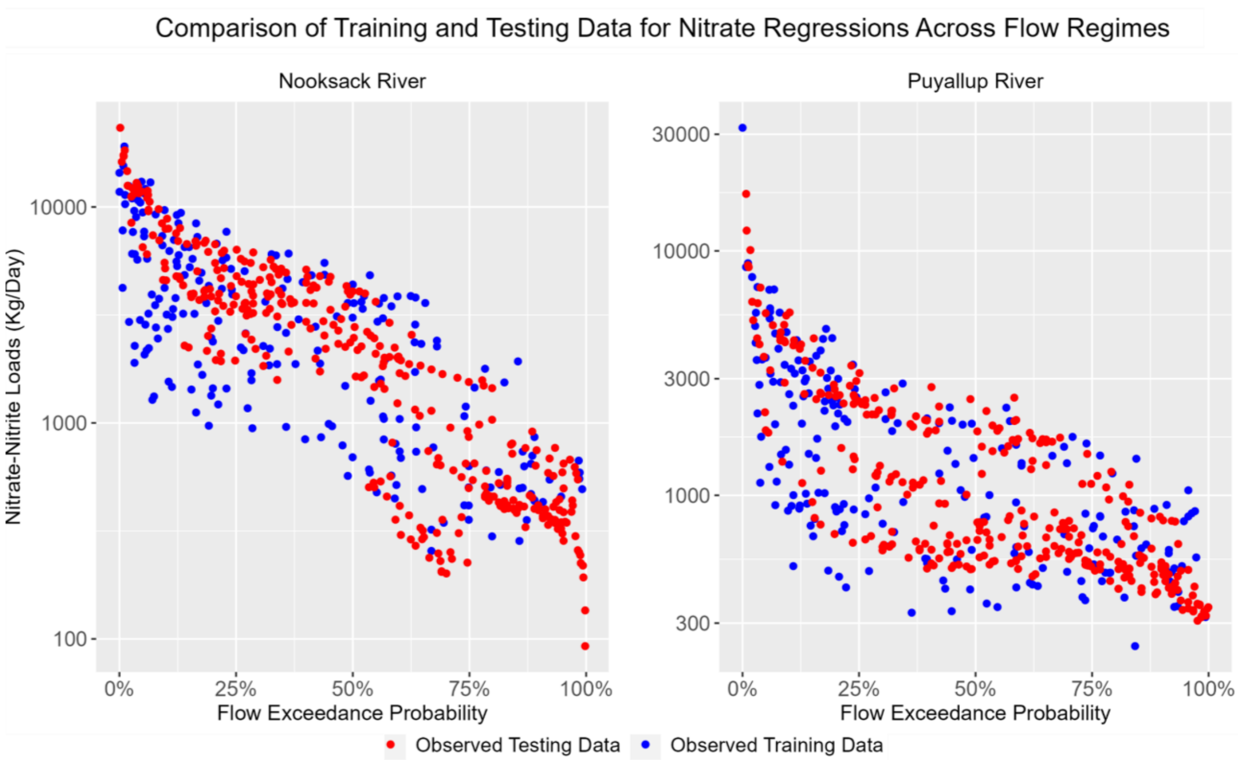

Figure B4-7. Plots show the distribution of nitrate-nitrite data used to train and test the regression across different flow regimes for the Nooksack and Puyallup Rivers. Overlap between training and testing data is an indicator of regression performance on the evaluation data for a given flow regime.

We also compared regression-predicted and SUNA observed monthly average nitrate-nitrite loads to determine how well predicted values captured seasonal patterns. Snohomish River gauge flow for 12200500 was available from July 13th, 2023, to April 1st, 2024, and was used for observed loads, while estimated flow for 12200500 (used for the regression) was used for predicted loads. For all watersheds, except for Snohomish, the same gauge flow data were used for both predicted and observed loads. Predicted and observed loads were similar for most months, with notable discrepancies in June – July for Nooksack, February, April, and July for Puyallup, July for Skagit, and September to October for Snohomish (Figure B4-8).

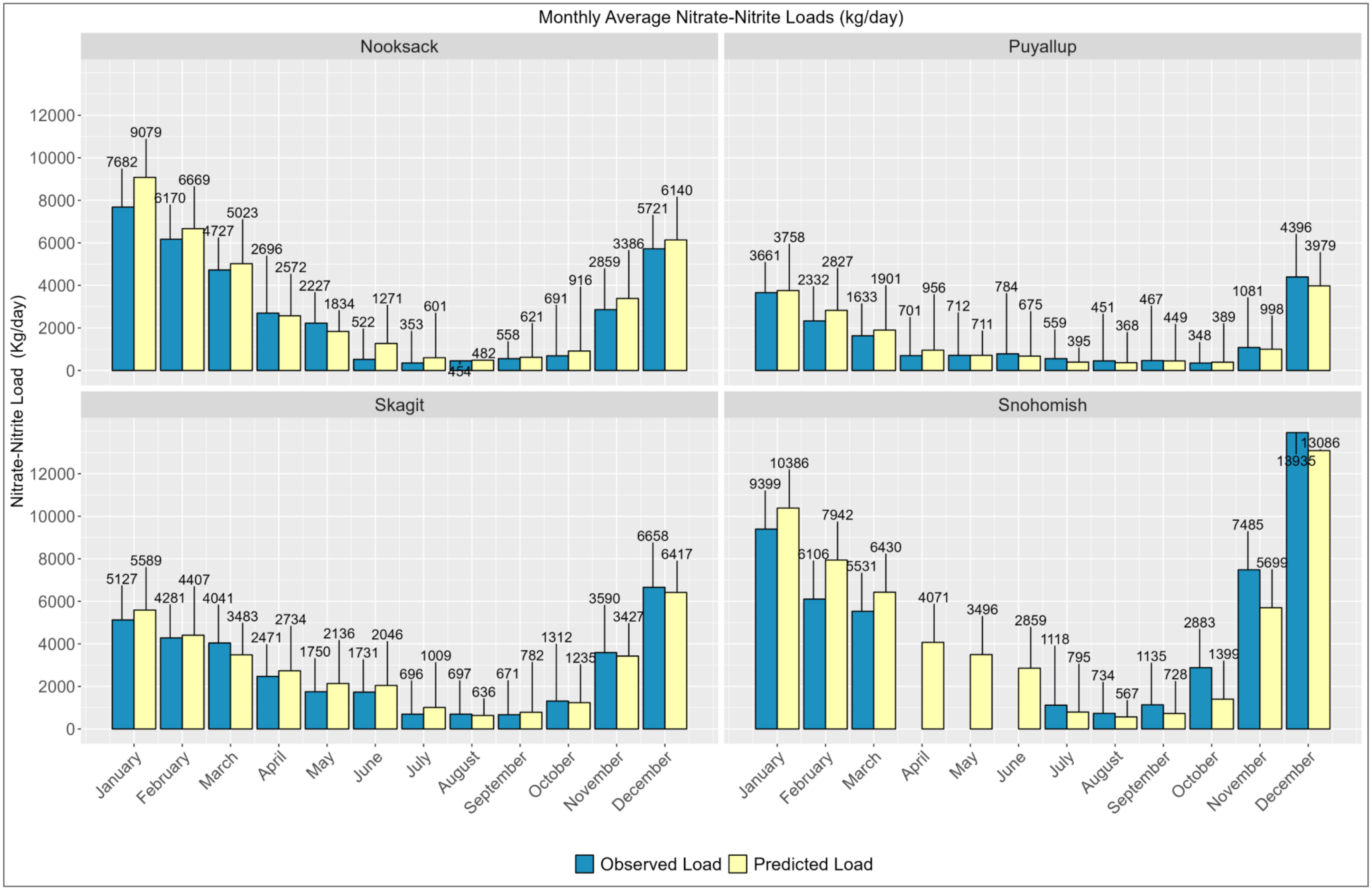

Figure B4-8. Comparison of 2023 to 2024 monthly average nitrate-nitrite regression-predicted and SUNA observed loads and at four major Puget Sound watersheds.
Observed flow data at Snohomish was missing for April – June 2024.

References (Appendix B4)

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Appendix B5. Open Boundary Tides and Water Quality

This appendix describes how the tidal moments (magnitudes and phases) and water quality at the open boundary were developed. For definitions of terms, refer to the glossary in the main report.

Estimation of Tidal harmonics (Magnitudes and Phase)

When specifying tidal forcing at the SSM open boundary, a set of 10 major tidal constituents (magnitude and phase) is specified for each of the 87 nodes at the open boundary of SSM. These constituents include S2 (principal solar semidiurnal), M2 (principal lunar semidiurnal), N2 (larger lunar elliptic semidiurnal), K2 (lunisolar semidiurnal), K1 (lunisolar declinational diurnal), P1 (solar diurnal), O1 (lunar declinational diurnal), Q1 (larger lunar elliptic diurnal), M4 (shallow water over tides of principal lunar), and M6 (shallow water sixth diurnal constituent). Ahmed et al. (2019) derived the harmonics (magnitude and phase) for the years 2006, 2008, and 2014 for the open boundary along the continental shelf from the ENPAC-2003 database (Spargo et al. 2003). In this study, the same harmonics for the 10 tidal constituents were derived from an updated ENPAC-2015 database (Szpilka et al. 2018) for years 2000, 2006, 2008, and 2014. The procedure to create the harmonics for all the tidal constituents was developed by the Salish Sea Modeling Center (T. Khangaonkar, pers. comm, 2023).

Table B5-1 shows a key to understanding the tidal harmonics input file. This table shows the tidal constituent harmonics for the first of the 87 nodes at the open boundary of SSM. The first row is the total number of nodes. The numbers in the second row represent the node number followed by the mean sea level for that node. The 3rd and 4th rows represent the magnitude and phase for each of the 10 tidal constituents.

Table B5-1. Key to understanding the tidal harmonics input file.

Key	Tidal harmonics (amplitudes are in cm) !2000									
	S2	M2	N2	K2	K1	P1	O1	Q1	M4	M6
Total number of nodes	87									
Node, mean sea level	1	1.18								
Harmonic amplitude	24.8	92.3	19.1	6.1	42.7	14.1	26.5	4.6	0.1	0.2
Harmonic phase	9.9	217	-35	179	113	121	-31	94.4	265	8.6

An input file for the 10 tidal constituents for the open boundary model nodes was generated for years 2000, 2006, 2008, 2014 and included in Tables B5-2 and B5-3.

Table B5-2. Tidal harmonics for the years 2000 and 2006.

Tidal harmonics (amplitudes are in cm) !2000										Tidal harmonics (amplitudes are in cm) !2006									
S2	M2	N2	K2	K1	P1	O1	Q1	M4	M6	S2	M2	N2	K2	K1	P1	O1	Q1	M4	M6
87	—	—	—	—	—	—	—	—	—	87	—	—	—	—	—	—	—	—	—
1	1.18	—	—	—	—	—	—	—	—	1	1.18	—	—	—	—	—	—	—	—
24.8	92.3	19.1	6.1	42.7	14.1	26.5	4.6	0.1	0.2	24.8	87.5	18.1	9	49.4	14.1	33.3	5.8	0.1	0.2
9.9	217	-35	179	113	121	-31	94.4	265	8.6	9.9	19.7	-34	161	104	121	145	108	265	8.6
2	1.18	—	—	—	—	—	—	—	—	2	1.18	—	—	—	—	—	—	—	—
24.6	91.4	18.9	6	42.5	14	26.3	4.6	0.1	0.2	24.6	86.6	18	8.9	49.1	14	33.1	5.8	0.1	0.2
10.3	218	-35	179	113	121	-30	94.9	265	9	10.3	20	-34	161	104	122	145	109	265	9
3	1.18	—	—	—	—	—	—	—	—	3	1.18	—	—	—	—	—	—	—	—
24.3	90.7	18.8	6	42.3	14	26.2	4.6	0.1	0.2	24.3	86	17.8	8.8	48.9	14	32.9	5.8	0.1	0.2
10.6	218	-35	179	113	121	-30	95.2	264	9.4	10.6	20.2	-34	161	104	122	146	109	264	9.4
4	1.18	—	—	—	—	—	—	—	—	4	1.18	—	—	—	—	—	—	—	—
24.1	90.1	18.7	5.9	42.2	13.9	26.1	4.6	0.1	0.2	24.1	85.4	17.7	8.7	48.8	13.9	32.8	5.7	0.1	0.2
11	218	-34	180	113	121	-30	95.5	265	9.8	11	20.5	-34	162	104	122	146	110	265	9.8
5	1.18	—	—	—	—	—	—	—	—	5	1.18	—	—	—	—	—	—	—	—
24.1	89.9	18.6	5.9	42.2	13.9	26	4.5	0.1	0.2	24.1	85.3	17.7	8.7	48.8	13.9	32.8	5.7	0.1	0.2
11.5	219	-34	180	114	122	-30	95.8	266	10.2	11.5	20.9	-33	162	104	122	146	110	266	10.2
6	1.18	—	—	—	—	—	—	—	—	6	1.18	—	—	—	—	—	—	—	—
24.2	90	18.6	5.9	42.2	13.9	26	4.5	0.1	0.2	24.2	85.3	17.6	8.7	48.8	13.9	32.7	5.7	0.1	0.2
12	219	-34	181	114	122	-29	96.1	266	10.7	12	21.3	-33	163	105	122	146	110	266	10.7
7	1.18	—	—	—	—	—	—	—	—	7	1.18	—	—	—	—	—	—	—	—
24.3	90.4	18.7	6	42.2	13.9	26	4.5	0.1	0.2	24.3	85.7	17.7	8.8	48.8	13.9	32.8	5.7	0.1	0.2
12.6	220	-33	181	114	122	-29	96.2	267	11.2	12.6	21.8	-32	164	105	123	147	110	267	11.2
8	1.18	—	—	—	—	—	—	—	—	8	1.18	—	—	—	—	—	—	—	—

Tidal harmonics (amplitudes are in cm) !2000										Tidal harmonics (amplitudes are in cm) !2006									
24.5	90.8	18.8	6	42.2	13.9	26	4.5	0.1	0.2	24.5	86	17.8	8.8	48.8	13.9	32.8	5.7	0.1	0.2
13.1	220	-33	182	114	122	-29	96.3	268	11.7	13.1	22.2	-32	164	105	123	147	110	268	11.7
9	1.18	—	—	—	—	—	—	—	—	9	1.18	—	—	—	—	—	—	—	—
24.6	91.1	18.8	6	42.3	14	26.1	4.5	0.1	0.2	24.6	86.3	17.9	8.9	48.9	14	32.8	5.7	0.1	0.2
13.6	220	-32	182	114	123	-29	96.4	268	12.2	13.6	22.6	-31	165	105	123	147	111	268	12.2
10	1.18	—	—	—	—	—	—	—	—	10	1.18	—	—	—	—	—	—	—	—
24.7	91.4	18.9	6	42.3	14	26.1	4.5	0.1	0.2	24.7	86.6	17.9	8.9	48.9	14	32.9	5.7	0.1	0.2
14.1	221	-32	183	115	123	-29	96.6	268	12.6	14.1	23	-31	165	105	123	147	111	268	12.6
11	1.18	—	—	—	—	—	—	—	—	11	1.18	—	—	—	—	—	—	—	—
24.8	91.7	19	6.1	42.4	14	26.2	4.6	0.1	0.2	24.8	86.9	18	8.9	49	14	32.9	5.7	0.1	0.2
14.5	221	-31	183	115	123	-28	96.7	268	13.1	14.5	23.4	-31	165	106	123	147	111	268	13.1
12	1.18	—	—	—	—	—	—	—	—	12	1.18	—	—	—	—	—	—	—	—
24.9	92	19	6.1	42.5	14	26.2	4.6	0.1	0.2	24.9	87.2	18	9	49.1	14	33	5.7	0.1	0.2
15	221	-31	184	115	123	-28	96.8	268	13.6	15	23.7	-30	166	106	124	147	111	268	13.6
13	1.18	—	—	—	—	—	—	—	—	13	1.18	—	—	—	—	—	—	—	—
25.1	92.3	19.1	6.1	42.5	14	26.3	4.6	0.1	0.2	25.1	87.5	18.1	9	49.2	14	33.1	5.8	0.1	0.2
15.4	222	-31	184	115	123	-28	96.9	268	14.1	15.4	24	-30	166	106	124	148	111	268	14.1
14	1.18	—	—	—	—	—	—	—	—	14	1.18	—	—	—	—	—	—	—	—
25.2	92.6	19.1	6.2	42.6	14.1	26.4	4.6	0.1	0.2	25.2	87.8	18.1	9.1	49.2	14.1	33.2	5.8	0.1	0.2
15.7	222	-30	185	115	124	-28	97.1	268	14.6	15.7	24.4	-30	167	106	124	148	111	268	14.6
15	1.18	—	—	—	—	—	—	—	—	15	1.18	—	—	—	—	—	—	—	—
25.3	92.8	19.2	6.2	42.7	14.1	26.4	4.6	0.1	0.2	25.3	88	18.2	9.1	49.3	14.1	33.3	5.8	0.1	0.2
16.1	222	-30	185	116	124	-28	97.2	267	15	16.1	24.6	-29	167	106	124	148	111	267	15
16	1.18	—	—	—	—	—	—	—	—	16	1.18	—	—	—	—	—	—	—	—
25.4	93.1	19.2	6.2	42.7	14.1	26.5	4.6	0.1	0.2	25.4	88.3	18.2	9.1	49.3	14.1	33.4	5.8	0.1	0.2

Tidal harmonics (amplitudes are in cm) !2000										Tidal harmonics (amplitudes are in cm) !2006									
16.4	223	-30	185	116	124	-27	97.5	267	15.5	16.4	24.9	-29	167	107	125	148	112	267	15.5
17	1.18	—	—	—	—	—	—	—	—	17	1.18	—	—	—	—	—	—	—	—
25.5	93.4	19.3	6.2	42.7	14.1	26.5	4.6	0.1	0.2	25.5	88.6	18.3	9.2	49.3	14.1	33.4	5.9	0.1	0.2
16.8	223	-29	186	116	124	-27	97.9	267	16.1	16.8	25.3	-29	168	107	125	149	112	267	16.1
18	1.18	—	—	—	—	—	—	—	—	18	1.18	—	—	—	—	—	—	—	—
25.6	93.8	19.4	6.3	42.7	14.1	26.4	4.7	0.1	0.2	25.6	88.9	18.4	9.2	49.3	14.1	33.3	5.9	0.1	0.2
17.2	223	-29	186	116	124	-26	98.4	266	16.6	17.2	25.6	-28	168	107	125	149	113	266	16.6
19	1.18	—	—	—	—	—	—	—	—	19	1.18	—	—	—	—	—	—	—	—
25.8	94.1	19.4	6.3	42.6	14.1	26.3	4.6	0.1	0.2	25.8	89.2	18.4	9.3	49.3	14.1	33.1	5.8	0.1	0.2
17.6	224	-29	186	116	125	-26	98.9	266	17.2	17.6	25.9	-28	169	107	125	149	113	266	17.2
20	1.18	—	—	—	—	—	—	—	—	20	1.18	—	—	—	—	—	—	—	—
25.9	94.4	19.5	6.3	42.6	14.1	26.1	4.6	0.1	0.2	25.9	89.4	18.5	9.3	49.2	14.1	32.9	5.8	0.1	0.2
17.9	224	-28	187	116	125	-26	99.2	267	17.6	17.9	26.2	-28	169	107	125	149	113	267	17.6
21	1.18	—	—	—	—	—	—	—	—	21	1.18	—	—	—	—	—	—	—	—
26	94.6	19.5	6.3	42.6	14.1	26	4.6	0.1	0.2	26	89.6	18.5	9.3	49.2	14.1	32.7	5.7	0.1	0.2
18.4	224	-28	187	116	125	-27	99.4	267	18	18.4	26.6	-27	169	107	125	149	114	267	18
22	1.18	—	—	—	—	—	—	—	—	22	1.18	—	—	—	—	—	—	—	—
26	94.7	19.5	6.4	42.6	14.1	26	4.5	0.1	0.2	26	89.7	18.5	9.4	49.3	14.1	32.8	5.7	0.1	0.2
18.6	225	-28	187	116	125	-27	99.2	266	18.2	18.6	26.8	-27	170	107	125	149	113	266	18.2
23	1.18	—	—	—	—	—	—	—	—	23	1.18	—	—	—	—	—	—	—	—
26.1	94.8	19.6	6.4	42.7	14.1	26.1	4.5	0.1	0.2	26.1	89.9	18.5	9.4	49.4	14.1	32.9	5.7	0.1	0.2
18.9	225	-28	188	116	125	-27	99	266	18.6	18.9	27	-27	170	107	125	149	113	266	18.6
24	1.18	—	—	—	—	—	—	—	—	24	1.18	—	—	—	—	—	—	—	—
26.1	94.9	19.6	6.4	42.8	14.1	26.2	4.6	0.1	0.2	26.1	90	18.6	9.4	49.5	14.1	33	5.7	0.1	0.2
19.1	225	-27	188	116	125	-27	98.8	266	19	19.1	27.2	-27	170	107	125	149	113	266	19

Tidal harmonics (amplitudes are in cm) !2000										Tidal harmonics (amplitudes are in cm) !2006									
25	1.18	—	—	—	—	—	—	—	—	25	1.18	—	—	—	—	—	—	—	—
26.2	95.1	19.6	6.4	43	14.2	26.4	4.6	0.1	0.2	26.2	90.1	18.6	9.4	49.7	14.2	33.2	5.8	0.1	0.2
19.4	225	-27	188	117	125	-27	98.7	265	19.4	19.4	27.4	-26	170	107	125	149	113	265	19.4
26	1.18	—	—	—	—	—	—	—	—	26	1.18	—	—	—	—	—	—	—	—
26.3	95.3	19.7	6.4	43.2	14.3	26.5	4.6	0.1	0.2	26.3	90.3	18.6	9.4	49.9	14.3	33.4	5.8	0.1	0.2
19.8	226	-27	189	117	125	-26	98.9	265	20.1	19.8	27.7	-26	171	108	126	149	113	265	20.1
27	1.18	—	—	—	—	—	—	—	—	27	1.18	—	—	—	—	—	—	—	—
26.4	95.6	19.7	6.4	43.3	14.3	26.6	4.6	0.1	0.2	26.4	90.6	18.7	9.5	50	14.3	33.5	5.8	0.1	0.2
20.1	226	-27	189	117	126	-26	99.3	265	20.6	20.1	28.1	-26	171	108	126	150	113	265	20.6
28	1.18	—	—	—	—	—	—	—	—	28	1.18	—	—	—	—	—	—	—	—
26.5	95.8	19.8	6.5	43.3	14.3	26.7	4.6	0.1	0.2	26.5	90.8	18.7	9.5	50	14.3	33.6	5.8	0.1	0.2
20.5	226	-26	189	118	126	-26	99.5	266	20.9	20.5	28.4	-25	172	109	126	150	114	266	20.9
29	1.18	—	—	—	—	—	—	—	—	29	1.18	—	—	—	—	—	—	—	—
26.6	96.2	19.8	6.5	43.1	14.3	26.7	4.6	0.1	0.2	26.6	91.1	18.8	9.6	49.9	14.3	33.6	5.8	0.1	0.2
21.1	227	-26	190	118	126	-25	99.7	268	21.5	21.1	28.8	-25	172	109	127	150	114	268	21.5
30	1.18	—	—	—	—	—	—	—	—	30	1.18	—	—	—	—	—	—	—	—
26.7	96.4	19.9	6.5	43	14.2	26.7	4.7	0.1	0.2	26.7	91.4	18.8	9.6	49.7	14.2	33.7	5.9	0.1	0.2
21.5	227	-25	190	118	126	-25	99.8	270	21.3	21.5	29.2	-25	173	109	127	151	114	270	21.3
31	1.18	—	—	—	—	—	—	—	—	31	1.18	—	—	—	—	—	—	—	—
26.8	96.6	19.9	6.5	42.8	14.2	26.6	4.6	0.1	0.2	26.8	91.5	18.9	9.6	49.5	14.2	33.5	5.9	0.1	0.2
22	227	-25	191	118	126	-25	100	272	21.3	22	29.6	-24	173	109	127	151	114	272	21.3
32	1.18	—	—	—	—	—	—	—	—	32	1.18	—	—	—	—	—	—	—	—
27	96.9	20	6.6	43.1	14.2	26.5	4.6	0.1	0.1	27	91.8	18.9	9.7	49.8	14.2	33.4	5.8	0.1	0.1
22.6	228	-24	192	118	126	-25	101	274	21.6	22.6	30.2	-24	174	109	127	151	115	274	21.6
33	1.18	—	—	—	—	—	—	—	—	33	1.18	—	—	—	—	—	—	—	—

Tidal harmonics (amplitudes are in cm) !2000										Tidal harmonics (amplitudes are in cm) !2006									
27	97.1	20	6.6	43.3	14.3	26.6	4.6	0.1	0.1	27	92	19	9.7	50	14.3	33.5	5.8	0.1	0.1
23.1	228	-24	192	118	127	-25	101	275	21.5	23.1	30.6	-23	174	109	127	151	115	275	21.5
34	1.18	—	—	—	—	—	—	—	—	34	1.18	—	—	—	—	—	—	—	—
27.1	97.2	20	6.6	43.4	14.3	26.7	4.6	0.1	0.1	27.1	92.1	19	9.7	50.1	14.3	33.6	5.8	0.1	0.1
23.5	229	-24	192	118	127	-25	101	277	21.3	23.5	30.9	-23	174	109	127	151	115	277	21.3
35	1.18	—	—	—	—	—	—	—	—	35	1.18	—	—	—	—	—	—	—	—
27.2	97.3	20.1	6.6	43.6	14.4	26.8	4.7	0.1	0.1	27.2	92.3	19	9.8	50.3	14.4	33.8	5.9	0.1	0.1
23.9	229	-23	193	119	127	-25	101	278	20.2	23.9	31.3	-22	175	110	128	151	115	278	20.2
36	1.18	—	—	—	—	—	—	—	—	36	1.18	—	—	—	—	—	—	—	—
27.3	97.4	20.1	6.6	43.7	14.4	27	4.7	0.1	0.1	27.3	92.3	19	9.8	50.5	14.4	33.9	5.9	0.1	0.1
24.4	230	-23	193	119	127	-24	101	280	15.8	24.4	31.8	-22	175	110	128	151	115	280	15.8
37	1.18	—	—	—	—	—	—	—	—	37	1.18	—	—	—	—	—	—	—	—
27.3	97.3	20.1	6.6	43.7	14.5	27	4.7	0.1	0.1	27.3	92.2	19	9.8	50.6	14.5	34.1	5.9	0.1	0.1
24.8	230	-22	194	119	128	-24	101	282	9.3	24.8	32.1	-22	176	110	128	152	115	282	9.3
38	1.18	—	—	—	—	—	—	—	—	38	1.18	—	—	—	—	—	—	—	—
27.4	97.4	20.1	6.7	43.8	14.5	27.2	4.7	0.1	0.1	27.4	92.3	19	9.8	50.6	14.5	34.2	6	0.1	0.1
25.1	230	-22	194	120	128	-23	102	282	7.2	25.1	32.3	-21	176	110	128	152	116	282	7.2
39	1.18	—	—	—	—	—	—	—	—	39	1.18	—	—	—	—	—	—	—	—
27.4	97.4	20.1	6.7	43.8	14.5	27	4.7	0.1	0.1	27.4	92.3	19	9.8	50.6	14.5	34	5.9	0.1	0.1
25.4	230	-22	194	120	128	-23	102	284	1.6	25.4	32.6	-21	176	111	129	153	116	284	1.6
40	1.18	—	—	—	—	—	—	—	—	40	1.18	—	—	—	—	—	—	—	—
27.4	97.4	20.1	6.7	43.7	14.5	27	4.7	0.1	0.1	27.4	92.3	19	9.8	50.5	14.5	34	5.9	0.1	0.1
25.6	230	-22	194	120	128	-23	102	285	359	25.6	32.7	-21	176	111	129	153	116	285	359
41	1.18	—	—	—	—	—	—	—	—	41	1.18	—	—	—	—	—	—	—	—
27.6	97.7	20.1	6.7	43.8	14.5	26.9	4.7	0.1	0.1	27.6	92.6	19.1	9.9	50.6	14.5	33.8	5.9	0.1	0.1

Tidal harmonics (amplitudes are in cm) !2000										Tidal harmonics (amplitudes are in cm) !2006									
25.9	231	-22	195	120	128	-23	103	285	0.2	25.9	32.9	-21	177	111	129	153	117	285	0.2
42	1.18	—	—	—	—	—	—	—	—	42	1.18	—	—	—	—	—	—	—	—
27.7	98	20.2	6.8	44	14.5	26.9	4.7	0.1	0.1	27.7	92.9	19.1	9.9	50.8	14.5	33.9	5.9	0.1	0.1
26.2	231	-21	195	120	129	-23	103	287	359	26.2	33.2	-20	177	111	129	153	117	287	359
43	1.18	—	—	—	—	—	—	—	—	43	1.18	—	—	—	—	—	—	—	—
27.8	98.4	20.2	6.8	44.3	14.6	27.2	4.7	0.1	0.1	27.8	93.2	19.2	10	51.2	14.6	34.2	5.9	0.1	0.1
26.7	231	-21	195	121	129	-22	103	287	5.4	26.7	33.5	-20	178	112	130	153	117	287	5.4
44	1.18	—	—	—	—	—	—	—	—	44	1.18	—	—	—	—	—	—	—	—
28	98.7	20.3	6.8	44.1	14.5	27.3	4.7	0.1	0.1	28	93.6	19.2	10.1	51	14.5	34.3	6	0.1	0.1
27	232	-21	196	122	130	-22	103	286	6.7	27	33.8	-20	178	113	131	154	117	286	6.7
45	1.18	—	—	—	—	—	—	—	—	45	1.18	—	—	—	—	—	—	—	—
28.1	99.1	20.4	6.9	43.9	14.5	27.1	4.7	0.1	0.1	28.1	93.9	19.3	10.1	50.7	14.5	34.2	6	0.1	0.1
27.4	232	-20	196	122	130	-21	104	285	7.7	27.4	34.2	-19	178	113	131	155	118	285	7.7
46	1.18	—	—	—	—	—	—	—	—	46	1.18	—	—	—	—	—	—	—	—
28.2	99.3	20.4	6.9	43.5	14.4	26.9	4.7	0.1	0.1	28.2	94.1	19.3	10.2	50.3	14.4	33.9	5.9	0.1	0.1
27.8	232	-20	197	122	130	-21	104	284	9.7	27.8	34.5	-19	179	113	131	155	118	284	9.7
47	1.18	—	—	—	—	—	—	—	—	47	1.18	—	—	—	—	—	—	—	—
28.3	99.5	20.4	6.9	43.6	14.4	26.9	4.7	0.1	0.1	28.3	94.3	19.4	10.2	50.4	14.4	33.8	5.9	0.1	0.1
28.2	233	-20	197	122	130	-21	104	284	10.9	28.2	34.9	-19	179	113	131	155	118	284	10.9
48	1.18	—	—	—	—	—	—	—	—	48	1.18	—	—	—	—	—	—	—	—
28.4	99.8	20.5	6.9	43.5	14.4	26.9	4.7	0.1	0.1	28.4	94.6	19.4	10.2	50.3	14.4	33.8	5.9	0.1	0.1
28.5	233	-19	197	122	131	-21	104	284	11.9	28.5	35.2	-18	179	113	131	155	118	284	11.9
49	1.18	—	—	—	—	—	—	—	—	49	1.18	—	—	—	—	—	—	—	—
28.6	100	20.5	7	43.2	14.3	27	4.7	0.1	0.1	28.6	94.8	19.5	10.3	50	14.3	34	5.9	0.1	0.1
29.1	233	-19	198	123	131	-21	104	285	13.8	29.1	35.7	-18	180	113	131	155	118	285	13.8

Tidal harmonics (amplitudes are in cm) !2000										Tidal harmonics (amplitudes are in cm) !2006									
50	1.18	—	—	—	—	—	—	—	—	50	1.18	—	—	—	—	—	—	—	—
28.7	100	20.6	7	43.1	14.3	27	4.7	0.1	0.1	28.7	95	19.5	10.3	49.8	14.3	34	5.9	0.1	0.1
29.6	234	-18	198	123	131	-20	104	286	14.8	29.6	36.1	-18	181	113	131	155	118	286	14.8
51	1.18	—	—	—	—	—	—	—	—	51	1.18	—	—	—	—	—	—	—	—
28.8	100	20.6	7	43	14.3	26.9	4.7	0.1	0.1	28.8	95.2	19.5	10.3	49.7	14.3	33.9	5.9	0.1	0.1
29.9	234	-18	199	122	131	-20	105	288	15.4	29.9	36.4	-17	181	113	131	156	119	288	15.4
52	1.18	—	—	—	—	—	—	—	—	52	1.18	—	—	—	—	—	—	—	—
28.8	101	20.7	7	43	14.3	26.6	4.7	0.1	0.1	28.8	95.3	19.6	10.4	49.7	14.3	33.5	5.9	0.1	0.1
30.2	234	-18	199	122	130	-20	105	287	16	30.2	36.7	-17	181	113	131	156	119	287	16
53	1.18	—	—	—	—	—	—	—	—	53	1.18	—	—	—	—	—	—	—	—
28.9	101	20.7	7.1	43.4	14.4	26.5	4.6	0.1	0.1	28.9	95.4	19.6	10.4	50.1	14.4	33.4	5.8	0.1	0.1
30.6	235	-17	199	122	130	-21	105	285	16.6	30.6	37	-17	182	112	131	155	119	285	16.6
54	1.18	—	—	—	—	—	—	—	—	54	1.18	—	—	—	—	—	—	—	—
29	101	20.7	7.1	43.8	14.5	26.8	4.7	0.1	0.1	29	95.5	19.6	10.4	50.6	14.5	33.7	5.9	0.1	0.1
30.8	235	-17	200	122	130	-21	104	285	16.9	30.8	37.2	-16	182	113	131	155	118	285	16.9
55	1.18	—	—	—	—	—	—	—	—	55	1.18	—	—	—	—	—	—	—	—
29.1	101	20.7	7.1	44	14.5	27	4.7	0.1	0.1	29.1	95.7	19.6	10.5	50.8	14.5	34.1	5.9	0.1	0.1
31.2	235	-17	200	122	131	-20	104	285	17.3	31.2	37.5	-16	182	113	131	155	119	285	17.3
56	1.18	—	—	—	—	—	—	—	—	56	1.18	—	—	—	—	—	—	—	—
29.1	101	20.8	7.1	44.1	14.6	27	4.7	0.1	0.1	29.1	95.8	19.7	10.5	51	14.6	34	5.9	0.1	0.1
31.5	236	-16	200	123	131	-20	105	285	17.7	31.5	37.8	-16	182	114	132	156	119	285	17.7
57	1.18	—	—	—	—	—	—	—	—	57	1.18	—	—	—	—	—	—	—	—
29.2	101	20.8	7.1	44.1	14.6	27	4.7	0.1	0.1	29.2	96	19.7	10.5	51	14.6	34.1	5.9	0.1	0.1
31.8	236	-16	201	123	132	-20	105	286	18	31.8	38.1	-15	183	114	132	156	119	286	18
58	1.18	—	—	—	—	—	—	—	—	58	1.18	—	—	—	—	—	—	—	—

Tidal harmonics (amplitudes are in cm) !2000										Tidal harmonics (amplitudes are in cm) !2006									
29.3	102	20.8	7.2	43.9	14.5	27.3	4.7	0.1	0.1	29.3	96.2	19.7	10.6	50.7	14.5	34.3	6	0.1	0.1
32.2	236	-16	201	124	132	-20	105	286	18.2	32.2	38.4	-15	183	115	133	156	119	286	18.2
59	1.18	—	—	—	—	—	—	—	—	59	1.18	—	—	—	—	—	—	—	—
29.4	102	20.9	7.2	43.7	14.5	27.2	4.8	0.1	0.1	29.4	96.3	19.8	10.6	50.5	14.5	34.3	6	0.1	0.1
32.5	236	-16	201	124	132	-19	106	286	18.4	32.5	38.7	-15	184	115	133	156	120	286	18.4
60	1.18	—	—	—	—	—	—	—	—	60	1.18	—	—	—	—	—	—	—	—
29.5	102	20.9	7.2	43.8	14.5	27.1	4.7	0.1	0.1	29.5	96.5	19.8	10.6	50.7	14.5	34.2	6	0.1	0.1
32.8	237	-15	202	124	132	-19	106	285	18.5	32.8	39	-15	184	114	133	157	120	285	18.5
61	1.18	—	—	—	—	—	—	—	—	61	1.18	—	—	—	—	—	—	—	—
29.6	102	20.9	7.2	43.9	14.5	27.2	4.7	0.1	0.1	29.6	96.7	19.8	10.6	50.8	14.5	34.2	6	0.1	0.1
32.9	237	-15	202	124	132	-19	106	285	18.5	32.9	39.1	-14	184	115	133	157	120	285	18.5
62	1.18	—	—	—	—	—	—	—	—	62	1.18	—	—	—	—	—	—	—	—
29.7	102	21	7.2	43.9	14.5	27.2	4.7	0.1	0.1	29.7	96.8	19.9	10.7	50.8	14.5	34.3	6	0.1	0.1
33.1	237	-15	202	124	132	-19	106	285	18.4	33.1	39.3	-14	184	115	133	157	120	285	18.4
63	1.18	—	—	—	—	—	—	—	—	63	1.18	—	—	—	—	—	—	—	—
29.7	102	21	7.3	43.9	14.5	27.2	4.8	0.1	0.1	29.7	97	19.9	10.7	50.7	14.5	34.3	6	0.1	0.1
33.3	237	-15	202	124	132	-19	106	284	18.3	33.3	39.4	-14	184	115	133	157	120	284	18.3
64	1.18	—	—	—	—	—	—	—	—	64	1.18	—	—	—	—	—	—	—	—
29.8	102	21	7.3	43.9	14.5	27.2	4.7	0.1	0.1	29.8	97.1	19.9	10.7	50.8	14.5	34.2	6	0.1	0.1
33.5	237	-15	202	124	132	-19	106	284	18.1	33.5	39.6	-14	185	115	133	157	120	284	18.1
65	1.18	—	—	—	—	—	—	—	—	65	1.18	—	—	—	—	—	—	—	—
29.8	103	21	7.3	44	14.6	27.3	4.7	0.1	0.1	29.8	97.1	19.9	10.7	50.9	14.6	34.3	6	0.1	0.1
33.6	237	-15	203	124	132	-19	106	284	17.9	33.6	39.7	-14	185	115	133	157	120	284	17.9
66	1.18	—	—	—	—	—	—	—	—	66	1.18	—	—	—	—	—	—	—	—
29.9	103	21	7.3	44	14.6	27.4	4.8	0.1	0.1	29.9	97.2	19.9	10.7	50.9	14.6	34.4	6	0.1	0.1

Tidal harmonics (amplitudes are in cm) !2000										Tidal harmonics (amplitudes are in cm) !2006									
33.7	238	-14	203	124	133	-19	106	284	17.8	33.7	39.8	-14	185	115	133	157	120	284	17.8
67	1.18	—	—	—	—	—	—	—	—	67	1.18	—	—	—	—	—	—	—	—
29.9	103	21.1	7.3	44	14.6	27.3	4.8	0.1	0.1	29.9	97.3	20	10.8	50.9	14.6	34.4	6	0.1	0.1
33.9	238	-14	203	124	133	-18	107	284	17.5	33.9	39.9	-14	185	115	133	157	121	284	17.5
68	1.18	—	—	—	—	—	—	—	—	68	1.18	—	—	—	—	—	—	—	—
30	103	21.1	7.3	44	14.6	27.3	4.8	0.1	0.1	30	97.5	20	10.8	50.8	14.6	34.3	6	0.1	0.1
34	238	-14	203	124	133	-18	107	284	16.9	34	40.1	-13	185	115	133	158	121	284	16.9
69	1.18	—	—	—	—	—	—	—	—	69	1.18	—	—	—	—	—	—	—	—
30.1	103	21.1	7.3	43.9	14.6	27.1	4.7	0.1	0.1	30.1	97.6	20	10.8	50.8	14.6	34.2	6	0.1	0.1
34.2	238	-14	203	124	133	-18	107	284	16	34.2	40.2	-13	185	115	133	158	121	284	16
70	1.18	—	—	—	—	—	—	—	—	70	1.18	—	—	—	—	—	—	—	—
30.1	103	21.1	7.4	43.9	14.6	27.1	4.7	0.1	0.1	30.1	97.7	20	10.8	50.8	14.6	34.1	5.9	0.1	0.1
34.3	238	-14	203	124	133	-18	107	283	14.8	34.3	40.3	-13	185	115	133	157	121	283	14.8
71	1.18	—	—	—	—	—	—	—	—	71	1.18	—	—	—	—	—	—	—	—
30.2	103	21.2	7.4	44	14.6	27.1	4.7	0.1	0.1	30.2	97.8	20.1	10.9	50.8	14.6	34.1	5.9	0.1	0.1
34.4	238	-14	203	124	133	-18	107	281	13.6	34.4	40.4	-13	185	115	133	157	121	281	13.6
72	1.18	—	—	—	—	—	—	—	—	72	1.18	—	—	—	—	—	—	—	—
30.3	103	21.2	7.4	44	14.6	27.2	4.7	0.1	0.1	30.3	98	20.1	10.9	50.9	14.6	34.2	5.9	0.1	0.1
34.5	238	-14	203	124	133	-19	107	279	12.1	34.5	40.5	-13	186	115	133	157	121	279	12.1
73	1.18	—	—	—	—	—	—	—	—	73	1.18	—	—	—	—	—	—	—	—
30.4	104	21.2	7.4	44.1	14.6	27.3	4.7	0.1	0.1	30.4	98.3	20.1	10.9	50.9	14.6	34.4	6	0.1	0.1
34.6	238	-14	204	125	133	-18	107	275	10.9	34.6	40.6	-13	186	115	134	157	121	275	10.9
74	1.18	—	—	—	—	—	—	—	—	74	1.18	—	—	—	—	—	—	—	—
30.5	104	21.3	7.5	44.1	14.6	27.4	4.8	0	0.1	30.5	98.7	20.2	11	50.9	14.6	34.4	6	0	0.1
34.8	239	-13	204	125	133	-18	107	266	9.4	34.8	40.8	-13	186	116	134	158	121	266	9.4

Tidal harmonics (amplitudes are in cm) !2000										Tidal harmonics (amplitudes are in cm) !2006									
75	1.18	—	—	—	—	—	—	—	—	75	1.18	—	—	—	—	—	—	—	—
30.7	105	21.4	7.5	44	14.6	27.3	4.8	0	0.1	30.7	99.1	20.3	11	50.9	14.6	34.4	6	0	0.1
34.9	239	-13	204	125	133	-18	107	253	7.2	34.9	40.9	-13	186	116	134	158	121	253	7.2
76	1.18	—	—	—	—	—	—	—	—	76	1.18	—	—	—	—	—	—	—	—
31	105	21.6	7.6	44.1	14.6	27.3	4.8	0	0.1	31	99.7	20.4	11.1	50.9	14.6	34.3	6	0	0.1
35	239	-13	204	125	133	-18	107	238	6.1	35	41.1	-12	186	116	134	158	121	238	6.1
77	1.18	—	—	—	—	—	—	—	—	77	1.18	—	—	—	—	—	—	—	—
31.8	108	22	7.8	44.2	14.7	27.3	4.8	0.1	0.2	31.8	102	20.9	11.5	51.1	14.7	34.4	6	0.1	0.2
36.1	240	-12	205	126	134	-17	108	218	354	36.1	42	-11	187	116	135	159	122	218	354
78	1.18	—	—	—	—	—	—	—	—	78	1.18	—	—	—	—	—	—	—	—
32.9	110	22.6	8	44.4	14.8	27.6	4.8	0.1	0.2	32.9	105	21.4	11.8	51.3	14.8	34.8	6.1	0.1	0.2
36.6	240	-11	205	126	135	-16	108	198	341	36.6	42.4	-11	188	117	135	159	122	198	341
79	1.18	—	—	—	—	—	—	—	—	79	1.18	—	—	—	—	—	—	—	—
33.6	112	23	8.2	44.4	14.8	27.5	4.8	0.2	0.2	33.6	106	21.8	12.1	51.3	14.8	34.7	6.1	0.2	0.2
37.1	241	-11	206	127	135	-16	109	193	336	37.1	42.9	-10	188	117	136	160	123	193	336
80	1.18	—	—	—	—	—	—	—	—	80	1.18	—	—	—	—	—	—	—	—
34.4	114	23.4	8.4	44.3	14.7	27.4	4.8	0.2	0.3	34.4	108	22.1	12.4	51.2	14.7	34.6	6.1	0.2	0.3
37.5	241	-11	206	127	136	-15	110	189	334	37.5	43.2	-9.8	188	118	136	160	124	189	334
81	1.18	—	—	—	—	—	—	—	—	81	1.18	—	—	—	—	—	—	—	—
34.9	116	23.7	8.5	44.2	14.7	27.4	4.8	0.2	0.4	34.9	110	22.4	12.6	51.1	14.7	34.5	6.1	0.2	0.4
37.9	241	-10	207	128	136	-15	110	188	334	37.9	43.5	-9.4	189	119	137	161	124	188	334
82	1.18	—	—	—	—	—	—	—	—	82	1.18	—	—	—	—	—	—	—	—
35.3	117	23.9	8.6	44.2	14.7	27.4	4.8	0.2	0.4	35.3	111	22.6	12.7	51.1	14.7	34.5	6.1	0.2	0.4
38.1	241	-10	207	128	137	-14	110	187	334	38.1	43.7	-9.2	189	119	137	161	124	187	334
83	1.18	—	—	—	—	—	—	—	—	83	1.18	—	—	—	—	—	—	—	—

Tidal harmonics (amplitudes are in cm) !2000										Tidal harmonics (amplitudes are in cm) !2006									
35.7	118	24.1	8.8	44.4	14.8	27.5	4.8	0.3	0.5	35.7	112	22.9	12.9	51.3	14.8	34.6	6.1	0.3	0.5
38.3	242	-9.8	207	129	137	-14	111	187	334	38.3	43.8	-9	189	119	138	162	125	187	334
84	1.18	—	—	—	—	—	—	—	—	84	1.18	—	—	—	—	—	—	—	—
36.1	119	24.3	8.8	44.5	14.8	27.6	4.8	0.3	0.5	36.1	113	23.1	13	51.5	14.8	34.8	6.1	0.3	0.5
38.3	242	-9.7	207	129	137	-14	111	185	335	38.3	43.9	-9	189	120	138	162	125	185	335
85	1.18	—	—	—	—	—	—	—	—	85	1.18	—	—	—	—	—	—	—	—
36.4	120	24.5	8.9	44.6	14.8	27.7	4.8	0.3	0.6	36.4	114	23.2	13.1	51.6	14.8	34.8	6.1	0.3	0.6
38.3	242	-9.7	207	129	137	-14	111	183	338	38.3	43.8	-9	189	120	138	162	125	183	338
86	1.18	—	—	—	—	—	—	—	—	86	1.18	—	—	—	—	—	—	—	—
36.6	121	24.6	8.9	44.7	14.8	27.7	4.8	0.3	0.6	36.6	114	23.3	13.2	51.6	14.8	34.8	6.1	0.3	0.6
38.1	241	-9.9	207	129	138	-14	111	181	340	38.1	43.7	-9.1	189	120	138	162	125	181	340
87	1.18	—	—	—	—	—	—	—	—	87	1.18	—	—	—	—	—	—	—	—
36.7	121	24.7	9	44.6	14.8	27.7	4.8	0.3	0.6	36.7	115	23.4	13.2	51.6	14.8	34.8	6.1	0.3	0.6
37.8	241	-10	206	129	138	-14	111	178	343	37.8	43.4	-9.4	188	120	138	162	125	178	343

Table B5-3. Tidal harmonics for year 2008 and 2014.

Tidal harmonics (amplitudes are in cm) !2008										Tidal harmonics (amplitudes are in cm) !2014									
S2	M2	N2	K2	K1	P1	O1	Q1	M4	M6	S2	M2	N2	K2	K1	P1	O1	Q1	M4	M6
87	—	—	—	—	—	—	—	—	—	87	—	—	—	—	—	—	—	—	—
1	1.18	—	—	—	—	—	—	—	—	1	1.18	—	—	—	—	—	—	—	—
24.8	88.2	18.3	8.5	48.5	14.1	32.4	5.7	0.1	0.2	24.8	93.9	19.5	5.2	39.7	14.1	23.4	4.1	0.1	0.2
9.9	177	-60	151	99.2	121	-51	89.5	265	8.6	9.9	-18	-57	153	99.4	121	114	92.8	265	8.6
2	1.18	—	—	—	—	—	—	—	—	2	1.18	—	—	—	—	—	—	—	—
24.6	87.4	18.1	8.4	48.2	14	32.2	5.6	0.1	0.2	24.6	93	19.3	5.2	39.5	14	23.2	4.1	0.1	0.2
10.3	177	-59	152	99.4	121	-51	90	265	9	10.3	-18	-56	153	99.6	122	114	93.3	265	9
3	1.18	—	—	—	—	—	—	—	—	3	1.18	—	—	—	—	—	—	—	—
24.3	86.7	18	8.3	48	14	32	5.6	0.1	0.2	24.3	92.3	19.1	5.1	39.4	14	23.1	4	0.1	0.2
10.6	177	-59	152	99.6	121	-51	90.3	264	9.4	10.6	-18	-56	154	99.8	122	114	93.6	264	9.4
4	1.18	—	—	—	—	—	—	—	—	4	1.18	—	—	—	—	—	—	—	—
24.1	86.1	17.8	8.2	47.9	13.9	31.9	5.6	0.1	0.2	24.1	91.7	19	5.1	39.3	13.9	23	4	0.1	0.2
11	178	-59	152	99.7	122	-51	90.6	265	9.8	11	-18	-56	154	99.9	122	114	93.9	265	9.8
5	1.18	—	—	—	—	—	—	—	—	5	1.18	—	—	—	—	—	—	—	—
24.1	86	17.8	8.2	47.9	13.9	31.9	5.6	0.1	0.2	24.1	91.6	19	5.1	39.2	13.9	23	4	0.1	0.2
11.5	178	-59	153	99.9	122	-50	90.9	266	10.2	11.5	-17	-55	155	100	122	115	94.2	266	10.2
6	1.18	—	—	—	—	—	—	—	—	6	1.18	—	—	—	—	—	—	—	—
24.2	86	17.8	8.3	47.9	13.9	31.8	5.6	0.1	0.2	24.2	91.6	19	5.1	39.2	13.9	22.9	4	0.1	0.2
12	179	-58	154	100	122	-50	91.2	266	10.7	12	-17	-55	155	100	123	115	94.5	266	10.7
7	1.18	—	—	—	—	—	—	—	—	7	1.18	—	—	—	—	—	—	—	—
24.3	86.4	17.9	8.3	47.9	13.9	31.9	5.6	0.1	0.2	24.3	92	19	5.1	39.3	13.9	23	4	0.1	0.2
12.6	179	-58	154	100	122	-50	91.3	267	11.2	12.6	-16	-54	156	101	123	115	94.6	267	11.2
8	1.18	—	—	—	—	—	—	—	—	8	1.18	—	—	—	—	—	—	—	—
24.5	86.8	17.9	8.4	48	13.9	31.9	5.6	0.1	0.2	24.5	92.4	19.1	5.1	39.3	13.9	23	4	0.1	0.2

Tidal harmonics (amplitudes are in cm) !2008										Tidal harmonics (amplitudes are in cm) !2014									
13.1	179	-57	155	101	122	-50	91.4	268	11.7	13.1	-16	-54	156	101	123	115	94.7	268	11.7
9	1.18	—	—	—	—	—	—	—	—	9	1.18	—	—	—	—	—	—	—	—
24.6	87.1	18	8.4	48	14	31.9	5.6	0.1	0.2	24.6	92.7	19.2	5.2	39.3	14	23	4	0.1	0.2
13.6	180	-57	155	101	123	-50	91.5	268	12.2	13.6	-16	-54	157	101	123	115	94.8	268	12.2
10	1.18	—	—	—	—	—	—	—	—	10	1.18	—	—	—	—	—	—	—	—
24.7	87.4	18.1	8.4	48.1	14	32	5.6	0.1	0.2	24.7	93	19.2	5.2	39.4	14	23	4	0.1	0.2
14.1	180	-56	156	101	123	-49	91.7	268	12.6	14.1	-15	-53	157	101	123	115	95	268	12.6
11	1.18	—	—	—	—	—	—	—	—	11	1.18	—	—	—	—	—	—	—	—
24.8	87.6	18.1	8.5	48.1	14	32	5.6	0.1	0.2	24.8	93.3	19.3	5.2	39.4	14	23.1	4	0.1	0.2
14.5	181	-56	156	101	123	-49	91.8	268	13.1	14.5	-15	-53	158	101	124	116	95.1	268	13.1
12	1.18	—	—	—	—	—	—	—	—	12	1.18	—	—	—	—	—	—	—	—
24.9	87.9	18.2	8.5	48.2	14	32.1	5.6	0.1	0.2	24.9	93.6	19.4	5.2	39.5	14	23.1	4	0.1	0.2
15	181	-56	157	101	123	-49	91.9	268	13.6	15	-14	-53	158	102	124	116	95.2	268	13.6
13	1.18	—	—	—	—	—	—	—	—	13	1.18	—	—	—	—	—	—	—	—
25.1	88.3	18.2	8.6	48.3	14	32.2	5.6	0.1	0.2	25.1	94	19.4	5.3	39.6	14	23.2	4	0.1	0.2
15.4	181	-55	157	102	123	-49	92	268	14.1	15.4	-14	-52	159	102	124	116	95.3	268	14.1
14	1.18	—	—	—	—	—	—	—	—	14	1.18	—	—	—	—	—	—	—	—
25.2	88.5	18.3	8.6	48.4	14.1	32.3	5.6	0.1	0.2	25.2	94.3	19.5	5.3	39.6	14.1	23.3	4.1	0.1	0.2
15.7	182	-55	157	102	124	-49	92.2	268	14.6	15.7	-14	-52	159	102	124	116	95.5	268	14.6
15	1.18	—	—	—	—	—	—	—	—	15	1.18	—	—	—	—	—	—	—	—
25.3	88.8	18.3	8.6	48.4	14.1	32.4	5.6	0.1	0.2	25.3	94.5	19.5	5.3	39.7	14.1	23.3	4.1	0.1	0.2
16.1	182	-55	158	102	124	-48	92.3	267	15	16.1	-14	-52	159	102	124	117	95.6	267	15
16	1.18	—	—	—	—	—	—	—	—	16	1.18	—	—	—	—	—	—	—	—
25.4	89	18.4	8.7	48.5	14.1	32.5	5.7	0.1	0.2	25.4	94.8	19.6	5.3	39.7	14.1	23.4	4.1	0.1	0.2
16.4	182	-54	158	102	124	-48	92.6	267	15.5	16.4	-13	-51	160	102	125	117	95.9	267	15.5

Tidal harmonics (amplitudes are in cm) !2008										Tidal harmonics (amplitudes are in cm) !2014									
17	1.18	—	—	—	—	—	—	—	—	17	1.18	—	—	—	—	—	—	—	—
25.5	89.3	18.4	8.7	48.5	14.1	32.4	5.7	0.1	0.2	25.5	95.1	19.6	5.4	39.7	14.1	23.4	4.1	0.1	0.2
16.8	182	-54	158	102	124	-48	93	267	16.1	16.8	-13	-51	160	103	125	117	96.3	267	16.1
18	1.18	—	—	—	—	—	—	—	—	18	1.18	—	—	—	—	—	—	—	—
25.6	89.7	18.5	8.7	48.4	14.1	32.3	5.7	0.1	0.2	25.6	95.5	19.7	5.4	39.7	14.1	23.3	4.1	0.1	0.2
17.2	183	-54	159	103	124	-47	93.5	266	16.6	17.2	-13	-51	160	103	125	118	96.8	266	16.6
19	1.18	—	—	—	—	—	—	—	—	19	1.18	—	—	—	—	—	—	—	—
25.8	90	18.6	8.8	48.4	14.1	32.2	5.7	0.1	0.2	25.8	95.8	19.8	5.4	39.6	14.1	23.2	4.1	0.1	0.2
17.6	183	-53	159	103	125	-47	94	266	17.2	17.6	-12	-50	161	103	125	118	97.3	266	17.2
20	1.18	—	—	—	—	—	—	—	—	20	1.18	—	—	—	—	—	—	—	—
25.9	90.2	18.6	8.8	48.4	14.1	32	5.6	0.1	0.2	25.9	96	19.8	5.4	39.6	14.1	23.1	4.1	0.1	0.2
17.9	183	-53	160	103	125	-47	94.3	267	17.6	17.9	-12	-50	161	103	125	118	97.6	267	17.6
21	1.18	—	—	—	—	—	—	—	—	21	1.18	—	—	—	—	—	—	—	—
26	90.4	18.7	8.9	48.3	14.1	31.8	5.6	0.1	0.2	26	96.3	19.9	5.5	39.6	14.1	22.9	4	0.1	0.2
18.4	184	-53	160	103	125	-47	94.5	267	18	18.4	-12	-50	162	103	125	118	97.8	267	18
22	1.18	—	—	—	—	—	—	—	—	22	1.18	—	—	—	—	—	—	—	—
26	90.5	18.7	8.9	48.4	14.1	31.9	5.6	0.1	0.2	26	96.3	19.9	5.5	39.7	14.1	23	4	0.1	0.2
18.6	184	-53	160	103	125	-48	94.3	266	18.2	18.6	-11	-49	162	103	125	117	97.6	266	18.2
23	1.18	—	—	—	—	—	—	—	—	23	1.18	—	—	—	—	—	—	—	—
26.1	90.6	18.7	8.9	48.5	14.1	32	5.6	0.1	0.2	26.1	96.5	19.9	5.5	39.8	14.1	23.1	4	0.1	0.2
18.9	184	-52	160	103	125	-48	94.1	266	18.6	18.9	-11	-49	162	103	125	117	97.4	266	18.6
24	1.18	—	—	—	—	—	—	—	—	24	1.18	—	—	—	—	—	—	—	—
26.1	90.7	18.7	8.9	48.6	14.1	32.1	5.6	0.1	0.2	26.1	96.6	19.9	5.5	39.8	14.1	23.1	4	0.1	0.2
19.1	184	-52	161	103	125	-48	93.9	266	19	19.1	-11	-49	162	103	125	117	97.2	266	19
25	1.18	—	—	—	—	—	—	—	—	25	1.18	—	—	—	—	—	—	—	—

Tidal harmonics (amplitudes are in cm) !2008										Tidal harmonics (amplitudes are in cm) !2014									
26.2	90.9	18.8	8.9	48.8	14.2	32.3	5.6	0.1	0.2	26.2	96.8	20	5.5	40	14.2	23.3	4	0.1	0.2
19.4	185	-52	161	103	125	-47	93.8	265	19.4	19.4	-11	-49	163	103	125	117	97.1	265	19.4
26	1.18	—	—	—	—	—	—	—	—	26	1.18	—	—	—	—	—	—	—	—
26.3	91.1	18.8	9	49	14.3	32.5	5.6	0.1	0.2	26.3	97	20	5.5	40.1	14.3	23.4	4.1	0.1	0.2
19.8	185	-52	161	103	125	-47	94	265	20.1	19.8	-10	-48	163	104	126	118	97.3	265	20.1
27	1.18	—	—	—	—	—	—	—	—	27	1.18	—	—	—	—	—	—	—	—
26.4	91.4	18.8	9	49.1	14.3	32.6	5.7	0.1	0.2	26.4	97.3	20.1	5.5	40.3	14.3	23.5	4.1	0.1	0.2
20.1	185	-51	162	104	126	-47	94.4	265	20.6	20.1	-10	-48	163	104	126	118	97.7	265	20.6
28	1.18	—	—	—	—	—	—	—	—	28	1.18	—	—	—	—	—	—	—	—
26.5	91.6	18.9	9	49.1	14.3	32.6	5.7	0.1	0.2	26.5	97.5	20.1	5.6	40.2	14.3	23.5	4.1	0.1	0.2
20.5	186	-51	162	104	126	-47	94.6	266	20.9	20.5	-9.8	-48	164	104	126	118	97.9	266	20.9
29	1.18	—	—	—	—	—	—	—	—	29	1.18	—	—	—	—	—	—	—	—
26.6	91.9	19	9.1	49	14.3	32.7	5.7	0.1	0.2	26.6	97.9	20.2	5.6	40.1	14.3	23.6	4.1	0.1	0.2
21.1	186	-50	163	104	126	-46	94.8	268	21.5	21.1	-9.3	-47	164	105	127	119	98.1	268	21.5
30	1.18	—	—	—	—	—	—	—	—	30	1.18	—	—	—	—	—	—	—	—
26.7	92.1	19	9.1	48.8	14.2	32.7	5.7	0.1	0.2	26.7	98.1	20.2	5.6	40	14.2	23.6	4.1	0.1	0.2
21.5	186	-50	163	105	127	-46	94.9	270	21.3	21.5	-8.9	-47	165	105	127	119	98.2	270	21.3
31	1.18	—	—	—	—	—	—	—	—	31	1.18	—	—	—	—	—	—	—	—
26.8	92.3	19	9.1	48.6	14.2	32.6	5.7	0.1	0.2	26.8	98.3	20.3	5.6	39.8	14.2	23.5	4.1	0.1	0.2
22	187	-50	164	105	127	-45	95.5	272	21.3	22	-8.5	-46	165	105	127	120	98.8	272	21.3
32	1.18	—	—	—	—	—	—	—	—	32	1.18	—	—	—	—	—	—	—	—
27	92.6	19.1	9.2	48.9	14.2	32.5	5.7	0.1	0.1	27	98.6	20.3	5.7	40.1	14.2	23.4	4.1	0.1	0.1
22.6	187	-49	164	105	126	-45	95.6	274	21.6	22.6	-7.9	-46	166	105	127	119	98.9	274	21.6
33	1.18	—	—	—	—	—	—	—	—	33	1.18	—	—	—	—	—	—	—	—
27	92.8	19.1	9.2	49.1	14.3	32.5	5.7	0.1	0.1	27	98.8	20.4	5.7	40.3	14.3	23.4	4.1	0.1	0.1

Tidal harmonics (amplitudes are in cm) !2008										Tidal harmonics (amplitudes are in cm) !2014									
23.1	188	-49	165	105	127	-46	95.6	275	21.5	23.1	-7.5	-45	166	105	127	119	98.9	275	21.5
34	1.18	—	—	—	—	—	—	—	—	34	1.18	—	—	—	—	—	—	—	—
27.1	92.9	19.2	9.2	49.3	14.3	32.6	5.7	0.1	0.1	27.1	99	20.4	5.7	40.4	14.3	23.5	4.1	0.1	0.1
23.5	188	-48	165	105	127	-46	95.7	277	21.3	23.5	-7.2	-45	167	105	127	119	99	277	21.3
35	1.18	—	—	—	—	—	—	—	—	35	1.18	—	—	—	—	—	—	—	—
27.2	93.1	19.2	9.2	49.4	14.4	32.8	5.7	0.1	0.1	27.2	99.1	20.4	5.7	40.5	14.4	23.7	4.1	0.1	0.1
23.9	189	-48	165	105	127	-45	95.8	278	20.2	23.9	-6.8	-45	167	105	128	120	99.1	278	20.2
36	1.18	—	—	—	—	—	—	—	—	36	1.18	—	—	—	—	—	—	—	—
27.3	93.1	19.2	9.3	49.6	14.4	33	5.7	0.1	0.1	27.3	99.1	20.4	5.7	40.6	14.4	23.8	4.1	0.1	0.1
24.4	189	-47	166	105	127	-45	96	280	15.8	24.4	-6.4	-44	168	106	128	120	99.3	280	15.8
37	1.18	—	—	—	—	—	—	—	—	37	1.18	—	—	—	—	—	—	—	—
27.3	93	19.2	9.3	49.7	14.5	33.1	5.8	0.1	0.1	27.3	99.1	20.4	5.7	40.7	14.5	23.9	4.2	0.1	0.1
24.8	189	-47	166	106	128	-45	96.3	282	9.3	24.8	-6	-44	168	106	128	120	99.6	282	9.3
38	1.18	—	—	—	—	—	—	—	—	38	1.18	—	—	—	—	—	—	—	—
27.4	93.1	19.2	9.3	49.7	14.5	33.3	5.8	0.1	0.1	27.4	99.1	20.4	5.7	40.8	14.5	24	4.2	0.1	0.1
25.1	190	-47	167	106	128	-44	96.7	282	7.2	25.1	-5.8	-44	168	106	129	121	100	282	7.2
39	1.18	—	—	—	—	—	—	—	—	39	1.18	—	—	—	—	—	—	—	—
27.4	93.1	19.2	9.3	49.7	14.5	33.1	5.8	0.1	0.1	27.4	99.1	20.4	5.7	40.7	14.5	23.9	4.2	0.1	0.1
25.4	190	-47	167	106	128	-44	97.3	284	1.6	25.4	-5.6	-43	168	107	129	121	101	284	1.6
40	1.18	—	—	—	—	—	—	—	—	40	1.18	—	—	—	—	—	—	—	—
27.4	93.1	19.2	9.3	49.6	14.5	33	5.8	0.1	0.1	27.4	99.2	20.4	5.7	40.7	14.5	23.8	4.2	0.1	0.1
25.6	190	-46	167	106	128	-44	97.4	285	359	25.6	-5.5	-43	169	106	129	121	101	285	359
41	1.18	—	—	—	—	—	—	—	—	41	1.18	—	—	—	—	—	—	—	—
27.6	93.4	19.2	9.4	49.7	14.5	32.9	5.7	0.1	0.1	27.6	99.4	20.5	5.8	40.8	14.5	23.7	4.1	0.1	0.1
25.9	190	-46	167	106	129	-43	97.7	285	0.2	25.9	-5.2	-43	169	107	129	121	101	285	0.2

Tidal harmonics (amplitudes are in cm) !2008										Tidal harmonics (amplitudes are in cm) !2014									
42	1.18	—	—	—	—	—	—	—	—	42	1.18	—	—	—	—	—	—	—	—
27.7	93.7	19.3	9.4	49.9	14.5	33	5.7	0.1	0.1	27.7	99.8	20.5	5.8	40.9	14.5	23.8	4.1	0.1	0.1
26.2	190	-46	168	107	129	-43	97.6	287	359	26.2	-5	-43	169	107	129	121	101	287	359
43	1.18	—	—	—	—	—	—	—	—	43	1.18	—	—	—	—	—	—	—	—
27.8	94	19.3	9.5	50.3	14.6	33.3	5.8	0.1	0.1	27.8	100	20.6	5.8	41.2	14.6	24	4.1	0.1	0.1
26.7	191	-46	168	108	130	-43	97.6	287	5.4	26.7	-4.6	-42	170	108	130	122	101	287	5.4
44	1.18	—	—	—	—	—	—	—	—	44	1.18	—	—	—	—	—	—	—	—
28	94.4	19.4	9.5	50.1	14.5	33.4	5.8	0.1	0.1	28	101	20.7	5.9	41	14.5	24.1	4.2	0.1	0.1
27	191	-45	168	108	130	-43	98.1	286	6.7	27	-4.3	-42	170	108	131	122	101	286	6.7
45	1.18	—	—	—	—	—	—	—	—	45	1.18	—	—	—	—	—	—	—	—
28.1	94.7	19.5	9.6	49.8	14.5	33.2	5.8	0.1	0.1	28.1	101	20.7	5.9	40.8	14.5	24	4.2	0.1	0.1
27.4	191	-45	169	108	130	-42	98.7	285	7.7	27.4	-3.9	-42	171	109	131	123	102	285	7.7
46	1.18	—	—	—	—	—	—	—	—	46	1.18	—	—	—	—	—	—	—	—
28.2	94.9	19.5	9.6	49.4	14.4	32.9	5.8	0.1	0.1	28.2	101	20.8	5.9	40.5	14.4	23.7	4.1	0.1	0.1
27.8	192	-45	169	109	130	-42	99.2	284	9.7	27.8	-3.6	-41	171	109	131	123	103	284	9.7
47	1.18	—	—	—	—	—	—	—	—	47	1.18	—	—	—	—	—	—	—	—
28.3	95.1	19.6	9.6	49.5	14.4	32.9	5.7	0.1	0.1	28.3	101	20.8	5.9	40.5	14.4	23.7	4.1	0.1	0.1
28.2	192	-44	170	109	130	-42	99.2	284	10.9	28.2	-3.3	-41	171	109	131	123	103	284	10.9
48	1.18	—	—	—	—	—	—	—	—	48	1.18	—	—	—	—	—	—	—	—
28.4	95.4	19.6	9.7	49.4	14.4	32.9	5.7	0.1	0.1	28.4	102	20.9	6	40.5	14.4	23.7	4.1	0.1	0.1
28.5	192	-44	170	109	131	-42	99.2	284	11.9	28.5	-3	-41	172	109	131	123	103	284	11.9
49	1.18	—	—	—	—	—	—	—	—	49	1.18	—	—	—	—	—	—	—	—
28.6	95.6	19.6	9.7	49.1	14.3	33	5.7	0.1	0.1	28.6	102	20.9	6	40.2	14.3	23.8	4.1	0.1	0.1
29.1	193	-43	171	109	131	-42	99	285	13.8	29.1	-2.4	-40	172	109	131	123	102	285	13.8
50	1.18	—	—	—	—	—	—	—	—	50	1.18	—	—	—	—	—	—	—	—

Tidal harmonics (amplitudes are in cm) !2008										Tidal harmonics (amplitudes are in cm) !2014									
28.7	95.8	19.7	9.8	48.9	14.3	33.1	5.8	0.1	0.1	28.7	102	21	6	40.1	14.3	23.9	4.2	0.1	0.1
29.6	193	-43	171	109	131	-41	99.3	286	14.8	29.6	-2	-40	173	109	131	124	103	286	14.8
51	1.18	—	—	—	—	—	—	—	—	51	1.18	—	—	—	—	—	—	—	—
28.8	96	19.7	9.8	48.8	14.3	32.9	5.8	0.1	0.1	28.8	102	21	6	40	14.3	23.7	4.2	0.1	0.1
29.9	194	-43	171	109	131	-41	99.8	288	15.4	29.9	-1.7	-39	173	109	131	124	103	288	15.4
52	1.18	—	—	—	—	—	—	—	—	52	1.18	—	—	—	—	—	—	—	—
28.8	96.1	19.7	9.8	48.9	14.3	32.6	5.7	0.1	0.1	28.8	102	21	6.1	40	14.3	23.5	4.1	0.1	0.1
30.2	194	-42	172	108	130	-41	100	287	16	30.2	-1.5	-39	173	109	131	124	104	287	16
53	1.18	—	—	—	—	—	—	—	—	53	1.18	—	—	—	—	—	—	—	—
28.9	96.2	19.8	9.9	49.3	14.4	32.5	5.6	0.1	0.1	28.9	103	21	6.1	40.4	14.4	23.4	4.1	0.1	0.1
30.6	194	-42	172	108	130	-42	99.7	285	16.6	30.6	-1.1	-39	174	108	131	123	103	285	16.6
54	1.18	—	—	—	—	—	—	—	—	54	1.18	—	—	—	—	—	—	—	—
29	96.3	19.8	9.9	49.7	14.5	32.8	5.7	0.1	0.1	29	103	21.1	6.1	40.7	14.5	23.6	4.1	0.1	0.1
30.8	194	-42	172	108	130	-42	99.2	285	16.9	30.8	-0.9	-39	174	108	131	123	103	285	16.9
55	1.18	—	—	—	—	—	—	—	—	55	1.18	—	—	—	—	—	—	—	—
29.1	96.5	19.8	9.9	49.9	14.5	33.1	5.8	0.1	0.1	29.1	103	21.1	6.1	40.9	14.5	23.9	4.2	0.1	0.1
31.2	195	-41	173	109	131	-41	99.5	285	17.3	31.2	-0.6	-38	174	109	131	124	103	285	17.3
56	1.18	—	—	—	—	—	—	—	—	56	1.18	—	—	—	—	—	—	—	—
29.1	96.7	19.8	9.9	50.1	14.6	33.1	5.8	0.1	0.1	29.1	103	21.1	6.1	41	14.6	23.9	4.2	0.1	0.1
31.5	195	-41	173	109	131	-41	100	285	17.7	31.5	-0.3	-38	175	109	132	124	103	285	17.7
57	1.18	—	—	—	—	—	—	—	—	57	1.18	—	—	—	—	—	—	—	—
29.2	96.8	19.9	10	50.1	14.6	33.1	5.7	0.1	0.1	29.2	103	21.2	6.1	41	14.6	23.9	4.1	0.1	0.1
31.8	195	-41	173	110	132	-41	100	286	18	31.8	0	-38	175	110	132	124	103	286	18
58	1.18	—	—	—	—	—	—	—	—	58	1.18	—	—	—	—	—	—	—	—
29.3	97	19.9	10	49.8	14.5	33.4	5.8	0.1	0.1	29.3	103	21.2	6.2	40.8	14.5	24.1	4.2	0.1	0.1

Tidal harmonics (amplitudes are in cm) !2008										Tidal harmonics (amplitudes are in cm) !2014									
32.2	196	-41	174	110	132	-41	100	286	18.2	32.2	0.3	-37	175	110	133	124	103	286	18.2
59	1.18	—	—	—	—	—	—	—	—	59	1.18	—	—	—	—	—	—	—	—
29.4	97.2	19.9	10	49.6	14.5	33.3	5.8	0.1	0.1	29.4	104	21.2	6.2	40.7	14.5	24	4.2	0.1	0.1
32.5	196	-40	174	110	132	-40	101	286	18.4	32.5	0.6	-37	176	110	133	125	104	286	18.4
60	1.18	—	—	—	—	—	—	—	—	60	1.18	—	—	—	—	—	—	—	—
29.5	97.4	20	10.1	49.8	14.5	33.2	5.8	0.1	0.1	29.5	104	21.3	6.2	40.8	14.5	23.9	4.2	0.1	0.1
32.8	196	-40	174	110	132	-40	101	285	18.5	32.8	0.9	-37	176	110	133	125	104	285	18.5
61	1.18	—	—	—	—	—	—	—	—	61	1.18	—	—	—	—	—	—	—	—
29.6	97.5	20	10.1	49.8	14.5	33.3	5.8	0.1	0.1	29.6	104	21.3	6.2	40.8	14.5	24	4.2	0.1	0.1
32.9	196	-40	175	110	132	-40	101	285	18.5	32.9	1	-37	176	110	133	125	104	285	18.5
62	1.18	—	—	—	—	—	—	—	—	62	1.18	—	—	—	—	—	—	—	—
29.7	97.7	20	10.1	49.9	14.5	33.4	5.8	0.1	0.1	29.7	104	21.3	6.2	40.9	14.5	24	4.2	0.1	0.1
33.1	196	-40	175	110	132	-40	101	285	18.4	33.1	1.1	-36	176	110	133	125	104	285	18.4
63	1.18	—	—	—	—	—	—	—	—	63	1.18	—	—	—	—	—	—	—	—
29.7	97.8	20.1	10.1	49.8	14.5	33.3	5.8	0.1	0.1	29.7	104	21.4	6.2	40.8	14.5	24	4.2	0.1	0.1
33.3	197	-39	175	110	132	-40	101	284	18.3	33.3	1.3	-36	177	111	133	125	105	284	18.3
64	1.18	—	—	—	—	—	—	—	—	64	1.18	—	—	—	—	—	—	—	—
29.8	97.9	20.1	10.2	49.9	14.5	33.2	5.8	0.1	0.1	29.8	104	21.4	6.3	40.9	14.5	24	4.2	0.1	0.1
33.5	197	-39	175	110	132	-40	101	284	18.1	33.5	1.5	-36	177	110	133	125	104	284	18.1
65	1.18	—	—	—	—	—	—	—	—	65	1.18	—	—	—	—	—	—	—	—
29.8	98	20.1	10.2	50	14.6	33.4	5.8	0.1	0.1	29.8	104	21.4	6.3	40.9	14.6	24.1	4.2	0.1	0.1
33.6	197	-39	175	110	132	-40	101	284	17.9	33.6	1.6	-36	177	111	133	125	104	284	17.9
66	1.18	—	—	—	—	—	—	—	—	66	1.18	—	—	—	—	—	—	—	—
29.9	98	20.1	10.2	50	14.6	33.5	5.8	0.1	0.1	29.9	104	21.4	6.3	41	14.6	24.1	4.2	0.1	0.1
33.7	197	-39	175	111	133	-39	101	284	17.8	33.7	1.7	-36	177	111	133	125	105	284	17.8

Tidal harmonics (amplitudes are in cm) !2008										Tidal harmonics (amplitudes are in cm) !2014									
67	1.18	—	—	—	—	—	—	—	—	67	1.18	—	—	—	—	—	—	—	—
29.9	98.2	20.1	10.2	50	14.6	33.5	5.9	0.1	0.1	29.9	105	21.4	6.3	40.9	14.6	24.1	4.2	0.1	0.1
33.9	197	-39	175	111	133	-39	102	284	17.5	33.9	1.8	-36	177	111	133	126	105	284	17.5
68	1.18	—	—	—	—	—	—	—	—	68	1.18	—	—	—	—	—	—	—	—
30	98.3	20.2	10.2	49.9	14.6	33.4	5.8	0.1	0.1	30	105	21.5	6.3	40.9	14.6	24.1	4.2	0.1	0.1
34	197	-39	176	111	133	-39	102	284	16.9	34	2	-36	177	111	134	126	105	284	16.9
69	1.18	—	—	—	—	—	—	—	—	69	1.18	—	—	—	—	—	—	—	—
30.1	98.4	20.2	10.2	49.9	14.6	33.2	5.8	0.1	0.1	30.1	105	21.5	6.3	40.9	14.6	23.9	4.2	0.1	0.1
34.2	197	-39	176	111	133	-39	102	284	16	34.2	2.1	-35	177	111	133	126	105	284	16
70	1.18	—	—	—	—	—	—	—	—	70	1.18	—	—	—	—	—	—	—	—
30.1	98.6	20.2	10.3	49.9	14.6	33.2	5.8	0.1	0.1	30.1	105	21.5	6.3	40.9	14.6	23.9	4.2	0.1	0.1
34.3	198	-39	176	111	133	-39	102	283	14.8	34.3	2.2	-35	178	111	133	126	105	283	14.8
71	1.18	—	—	—	—	—	—	—	—	71	1.18	—	—	—	—	—	—	—	—
30.2	98.7	20.2	10.3	49.9	14.6	33.2	5.8	0.1	0.1	30.2	105	21.5	6.3	40.9	14.6	23.9	4.2	0.1	0.1
34.4	198	-38	176	111	133	-39	102	281	13.6	34.4	2.3	-35	178	111	133	126	105	281	13.6
72	1.18	—	—	—	—	—	—	—	—	72	1.18	—	—	—	—	—	—	—	—
30.3	98.9	20.3	10.3	50	14.6	33.3	5.8	0.1	0.1	30.3	105	21.6	6.4	41	14.6	24	4.2	0.1	0.1
34.5	198	-38	176	111	133	-39	102	279	12.1	34.5	2.4	-35	178	111	133	126	105	279	12.1
73	1.18	—	—	—	—	—	—	—	—	73	1.18	—	—	—	—	—	—	—	—
30.4	99.1	20.3	10.4	50	14.6	33.5	5.8	0.1	0.1	30.4	106	21.6	6.4	41	14.6	24.1	4.2	0.1	0.1
34.6	198	-38	176	111	133	-39	102	275	10.9	34.6	2.5	-35	178	111	134	126	105	275	10.9
74	1.18	—	—	—	—	—	—	—	—	74	1.18	—	—	—	—	—	—	—	—
30.5	99.5	20.4	10.4	50	14.6	33.5	5.8	0	0.1	30.5	106	21.7	6.4	41	14.6	24.1	4.2	0	0.1
34.8	198	-38	176	111	133	-39	102	266	9.4	34.8	2.7	-35	178	111	134	126	105	266	9.4
75	1.18	—	—	—	—	—	—	—	—	75	1.18	—	—	—	—	—	—	—	—

Tidal harmonics (amplitudes are in cm) !2008										Tidal harmonics (amplitudes are in cm) !2014									
30.7	100	20.5	10.5	50	14.6	33.4	5.8	0	0.1	30.7	106	21.8	6.5	40.9	14.6	24.1	4.2	0	0.1
34.9	198	-38	177	111	133	-39	102	253	7.2	34.9	2.8	-35	178	111	134	126	105	253	7.2
76	1.18	—	—	—	—	—	—	—	—	76	1.18	—	—	—	—	—	—	—	—
31	101	20.6	10.6	50	14.6	33.4	5.8	0	0.1	31	107	21.9	6.5	41	14.6	24.1	4.2	0	0.1
35	198	-38	177	111	133	-39	102	238	6.1	35	2.9	-35	178	111	134	126	106	238	6.1
77	1.18	—	—	—	—	—	—	—	—	77	1.18	—	—	—	—	—	—	—	—
31.8	103	21	10.9	50.1	14.7	33.5	5.9	0.1	0.2	31.8	109	22.4	6.7	41.1	14.7	24.1	4.2	0.1	0.2
36.1	199	-37	178	112	134	-38	103	218	354	36.1	3.9	-34	179	112	135	127	106	218	354
78	1.18	—	—	—	—	—	—	—	—	78	1.18	—	—	—	—	—	—	—	—
32.9	105	21.6	11.2	50.4	14.8	33.8	5.9	0.1	0.2	32.9	112	23	6.9	41.3	14.8	24.4	4.3	0.1	0.2
36.6	200	-36	178	113	135	-37	103	198	341	36.6	4.3	-33	180	113	135	128	107	198	341
79	1.18	—	—	—	—	—	—	—	—	79	1.18	—	—	—	—	—	—	—	—
33.6	107	22	11.5	50.4	14.8	33.7	5.9	0.2	0.2	33.6	114	23.4	7.1	41.3	14.8	24.3	4.3	0.2	0.2
37.1	200	-36	179	113	135	-37	104	193	336	37.1	4.7	-32	180	113	136	128	107	193	336
80	1.18	—	—	—	—	—	—	—	—	80	1.18	—	—	—	—	—	—	—	—
34.4	109	22.3	11.7	50.3	14.7	33.6	5.9	0.2	0.3	34.4	116	23.8	7.2	41.2	14.7	24.2	4.3	0.2	0.3
37.5	200	-35	179	114	136	-36	105	189	334	37.5	5.1	-32	181	114	136	129	108	189	334
81	1.18	—	—	—	—	—	—	—	—	81	1.18	—	—	—	—	—	—	—	—
34.9	111	22.6	11.9	50.2	14.7	33.6	5.9	0.2	0.4	34.9	118	24.1	7.3	41.1	14.7	24.2	4.2	0.2	0.4
37.9	201	-35	179	114	136	-36	105	188	334	37.9	5.4	-32	181	114	137	129	108	188	334
82	1.18	—	—	—	—	—	—	—	—	82	1.18	—	—	—	—	—	—	—	—
35.3	112	22.8	12	50.2	14.7	33.6	5.9	0.2	0.4	35.3	119	24.3	7.4	41.1	14.7	24.2	4.2	0.2	0.4
38.1	201	-35	179	114	137	-35	105	187	334	38.1	5.6	-31	181	115	137	130	109	187	334
83	1.18	—	—	—	—	—	—	—	—	83	1.18	—	—	—	—	—	—	—	—
35.7	113	23.1	12.2	50.4	14.8	33.7	5.9	0.3	0.5	35.7	121	24.6	7.5	41.3	14.8	24.3	4.3	0.3	0.5

Tidal harmonics (amplitudes are in cm) !2008										Tidal harmonics (amplitudes are in cm) !2014									
38.3	201	-34	180	115	137	-35	106	187	334	38.3	5.7	-31	181	115	138	130	109	187	334
84	1.18	—	—	—	—	—	—	—	—	84	1.18	—	—	—	—	—	—	—	—
36.1	114	23.3	12.3	50.6	14.8	33.8	5.9	0.3	0.5	36.1	122	24.8	7.6	41.4	14.8	24.4	4.3	0.3	0.5
38.3	201	-34	180	115	137	-35	106	185	335	38.3	5.7	-31	181	115	138	130	109	185	335
85	1.18	—	—	—	—	—	—	—	—	85	1.18	—	—	—	—	—	—	—	—
36.4	115	23.4	12.4	50.7	14.8	33.9	5.9	0.3	0.6	36.4	122	24.9	7.7	41.5	14.8	24.4	4.3	0.3	0.6
38.3	201	-34	179	116	138	-35	106	183	338	38.3	5.7	-31	181	116	138	130	109	183	338
86	1.18	—	—	—	—	—	—	—	—	86	1.18	—	—	—	—	—	—	—	—
36.6	115	23.5	12.5	50.7	14.8	33.9	5.9	0.3	0.6	36.6	123	25	7.7	41.5	14.8	24.4	4.3	0.3	0.6
38.1	201	-35	179	116	138	-34	106	181	340	38.1	5.5	-31	181	116	138	131	109	181	340
87	1.18	—	—	—	—	—	—	—	—	87	1.18	—	—	—	—	—	—	—	—
36.7	116	23.6	12.5	50.7	14.8	33.9	5.9	0.3	0.6	36.7	123	25.1	7.7	41.5	14.8	24.4	4.3	0.3	0.6
37.8	201	-35	179	116	138	-34	106	178	343	37.8	5.3	-32	181	116	138	131	110	178	343

“—”=Nothing to report

Water Quality at the SSM Open Boundary

Water quality at the open boundary was established using data from the Department of Fisheries and Oceans (DFO) and outputs from the Hybrid Coordinate Ocean Model (HYCOM). The open boundary conditions were set up similarly to those in our Optimization Scenarios Phase 1 report (Ahmed et al. 2021). As in Ahmed et al. (2021), we reduced the temporal resolution of HYCOM outputs from a 3-hour to a daily interval. Temperature and salinity variations were gradual, showing noticeable changes over longer periods but minimal fluctuations within a given day. Except for 2008, we used HYCOM outputs for temperature and salinity, and applied piecewise regressions based on salinity to predict dissolved oxygen (DO), dissolved inorganic carbon (DIC), alkalinity, and nitrate (Ahmed et al. 2021).

The remaining variables, including inorganic solids, algal and zooplankton groups, organic carbon fractions, ammonium, organic nitrogen and organic phosphorus fractions, and inorganic phosphorus, were developed using DFO data. These variables were interpolated to the model ocean boundary over space and time using the procedure developed by Pacific Northwest National Laboratory (Khangaonkar et al. 2018). For variables without data, we used default values to represent them. Default values were primarily used for nutrient variables, including organic nitrogen, organic phosphorus, organic carbon, and algal groups. Apart from algal groups 1 and 2 (default: 0.06 gC/m^3), labile dissolved organic carbon (default: 0.48 gC/m^3), and labile particulate organic carbon (POC) (default: 0.06 gC/m^3), all other nutrient variables were assigned a default value of zero.

Open boundary data limitations were present for the years 2000 and 2008. DFO algal data were limited to September and October for the year 2000. Algal data were interpolated between September and October. For the remainder of the year, we used default values of 0.06 gC/m^3 for the photic zone and 0 gC/m^3 below the photic zone. We approximated the photic zone for each SSM open boundary node using depths of zero algal biomass from the 2014 model open boundary conditions.

For model year 2008, we did not use HYCOM outputs for open boundary conditions due to several days of model instability near the Washington coast. We found a number of issues with the 2008 HYCOM model output, including days with temperatures of up to 52 °C in the bottom layers as well as near-zero salinity. Further, for the days with temperature and salinity anomalies, we also found layers below the typical bottom layer to be active. Communication with Allan Wallcraft (May 22, 2024) from the HYCOM consortium confirmed that these irregularities were caused by corrupted GOFS 3.1 Reanalysis files on HYCOM.org. As a result, for 2008, we used the same open boundary conditions as in the 2019 Bounding Scenarios report (Ahmed et al. 2019), which consisted of interpolated DFO data.

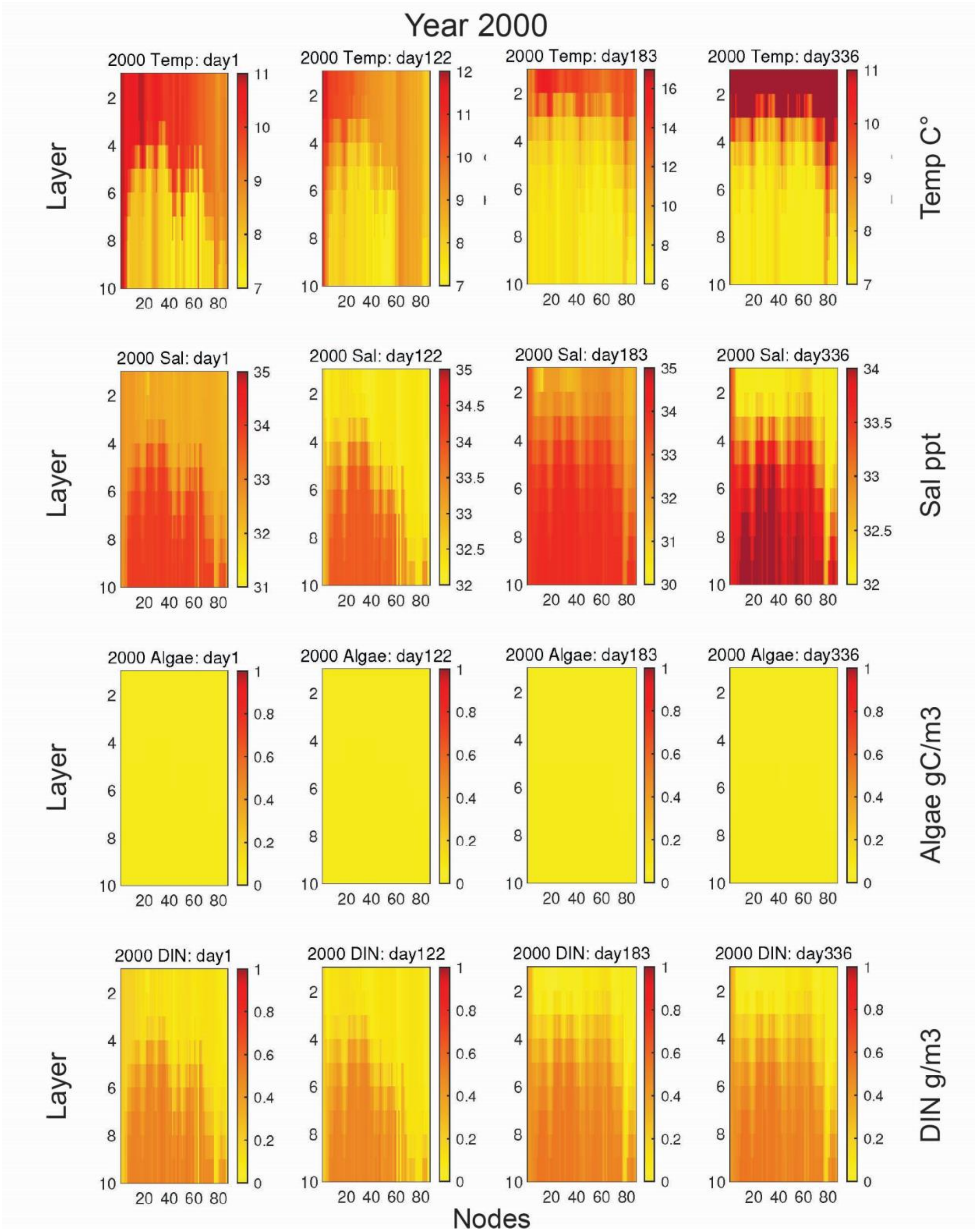

Figure B5-9. Year 2000 open boundary water quality data for select days (Jan 1, May 1, July 1, and Dec 1) for temperature, salinity, algae, and dissolved inorganic nitrogen (DIN).

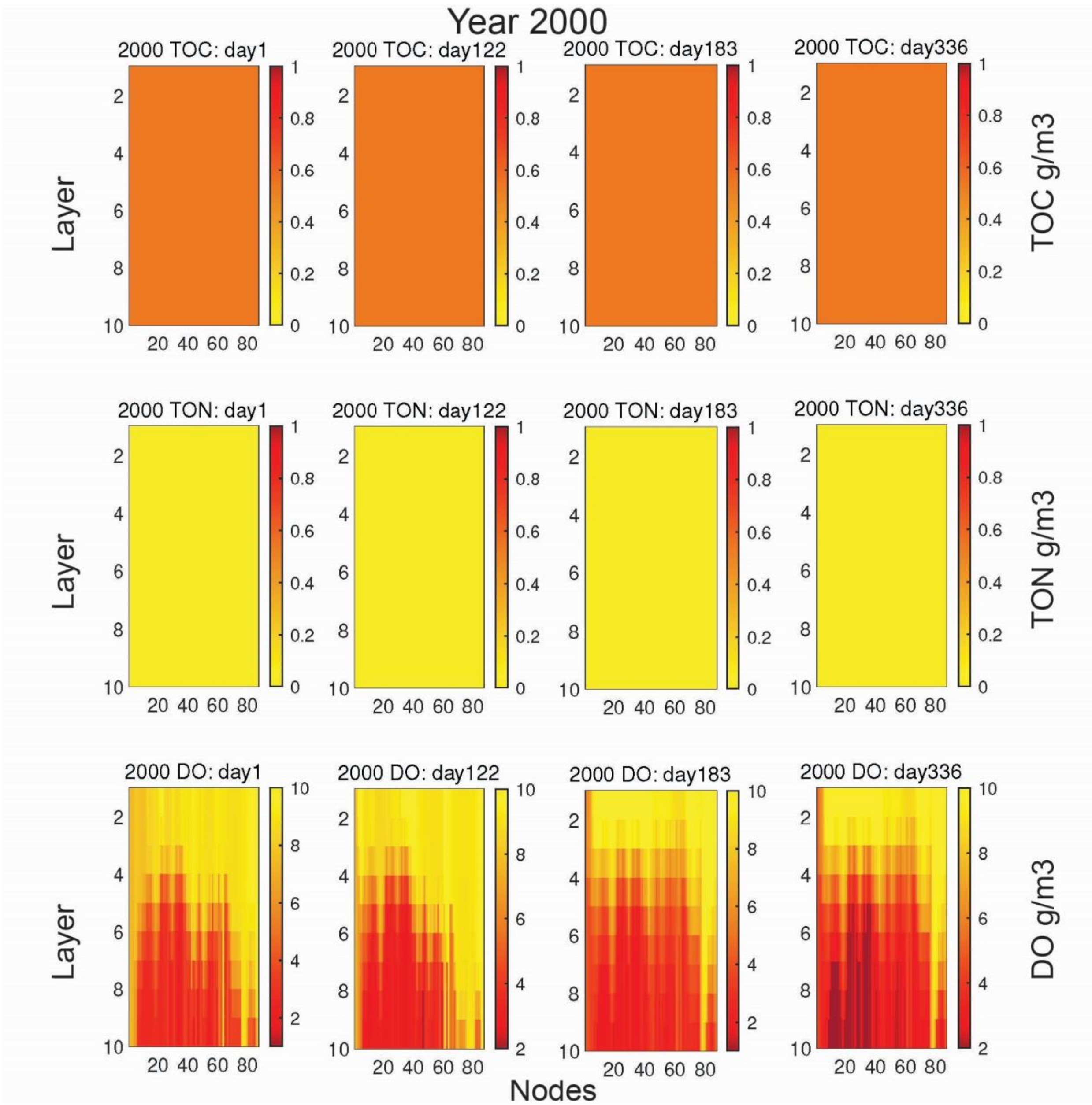

Figure B5-10. Year 2000 open boundary water quality data for select days (Jan 1, May 1, July 1, and Dec 1) for total organic carbon (TOC), total organic nitrogen (TON), and dissolved oxygen (DO).

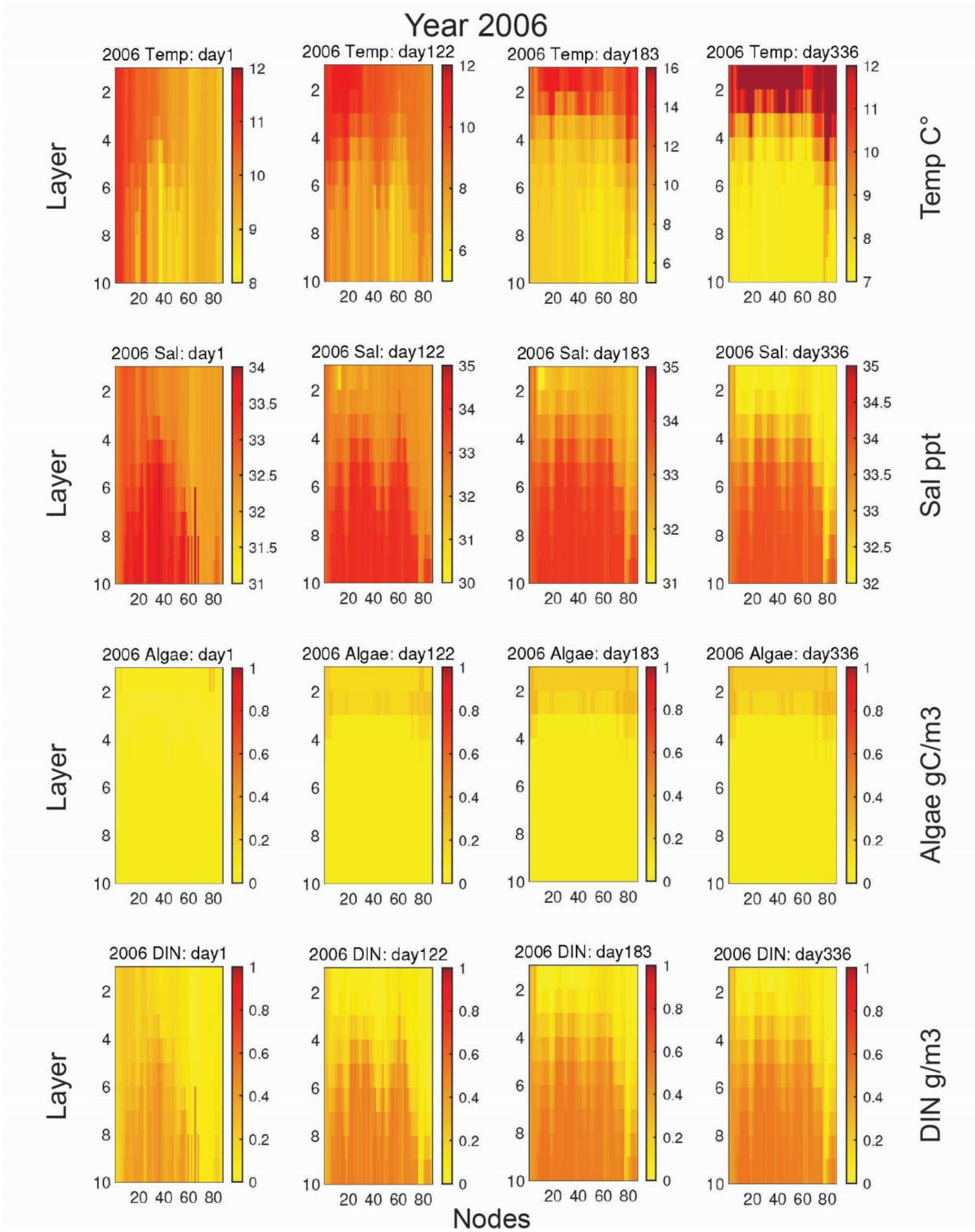

Figure B5-11. Year 2006 open boundary water quality data for select days (Jan 1, May 2, July 2, and Dec 2) for temperature, salinity, algae, and dissolved inorganic nitrogen (DIN).

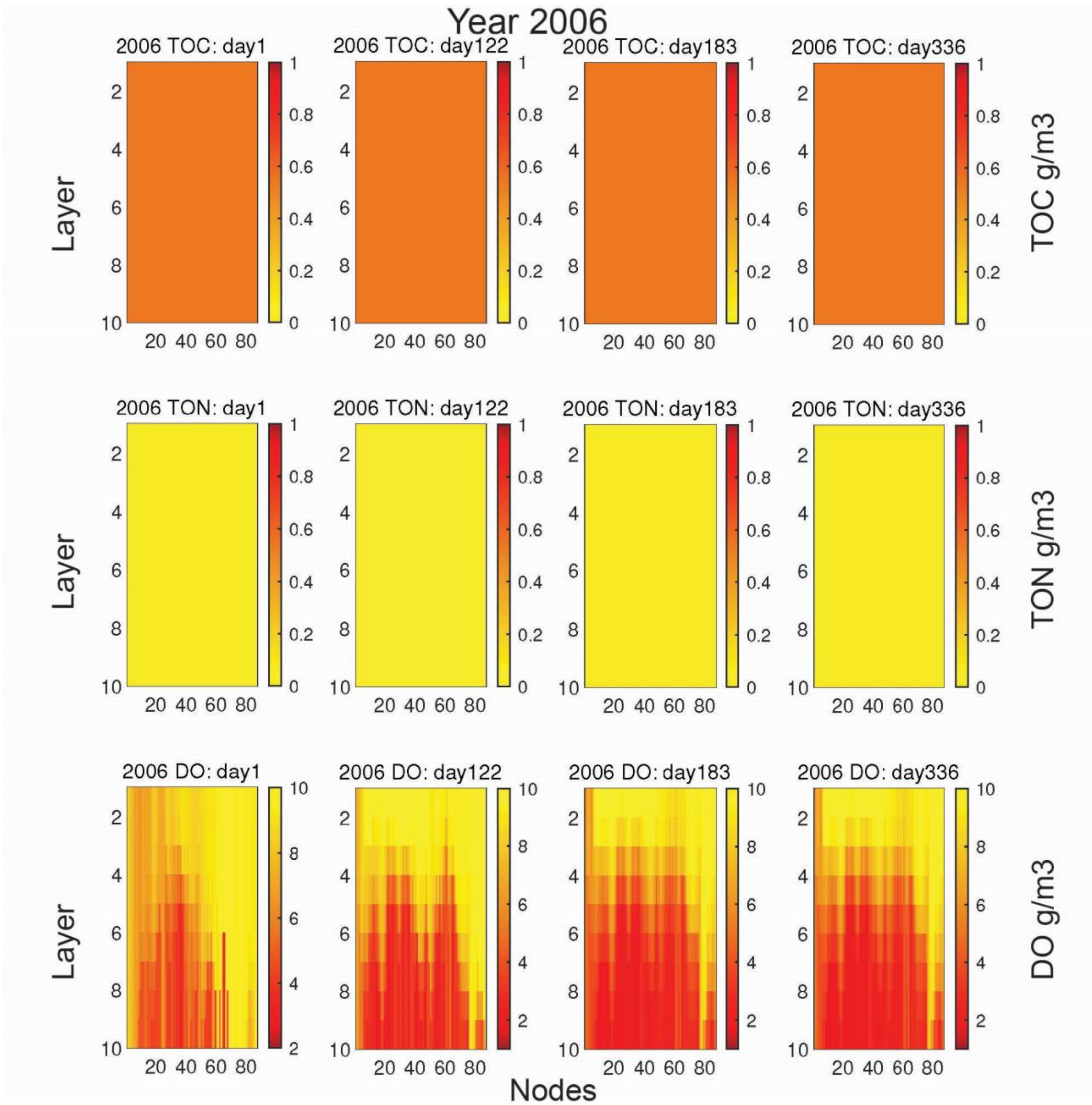

Figure B5-12. Year 2006 open boundary water quality data for select days (Jan 1, May 2, July 2, and Dec 2) for total organic carbon (TOC), total organic nitrogen (TON), and dissolved oxygen (DO).

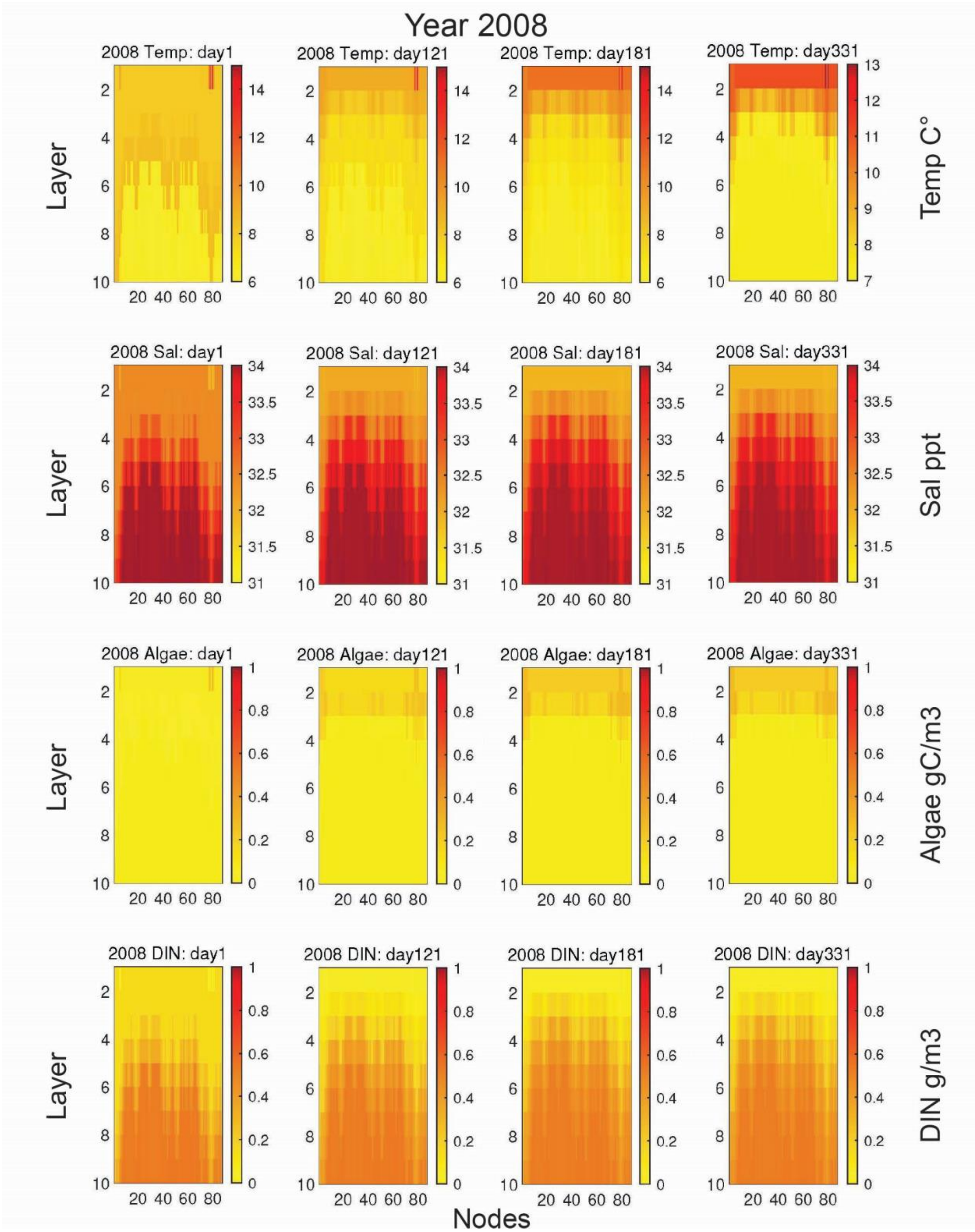

Figure B5-13. Year 2008 open boundary water quality data for select days (Jan 1, April 30, June 29, and Nov 26) for temperature, salinity, algae, and dissolved inorganic nitrogen (DIN).

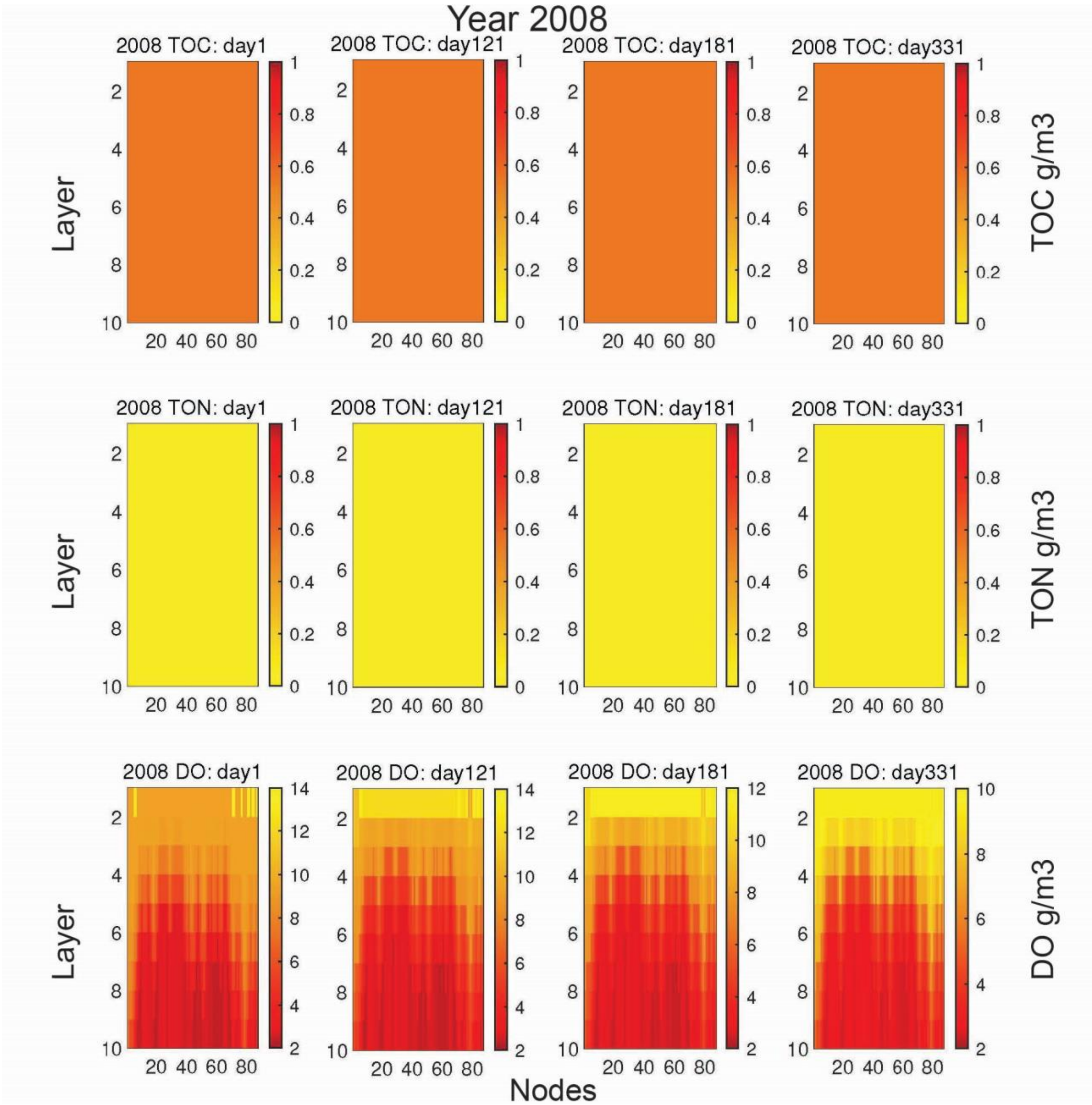

Figure B5-14. Year 2008 open boundary water quality data for select days (Jan 1, April 30, June 29, and Nov 26) for total organic carbon (TOC), total organic nitrogen (TON), and dissolved oxygen (DO).

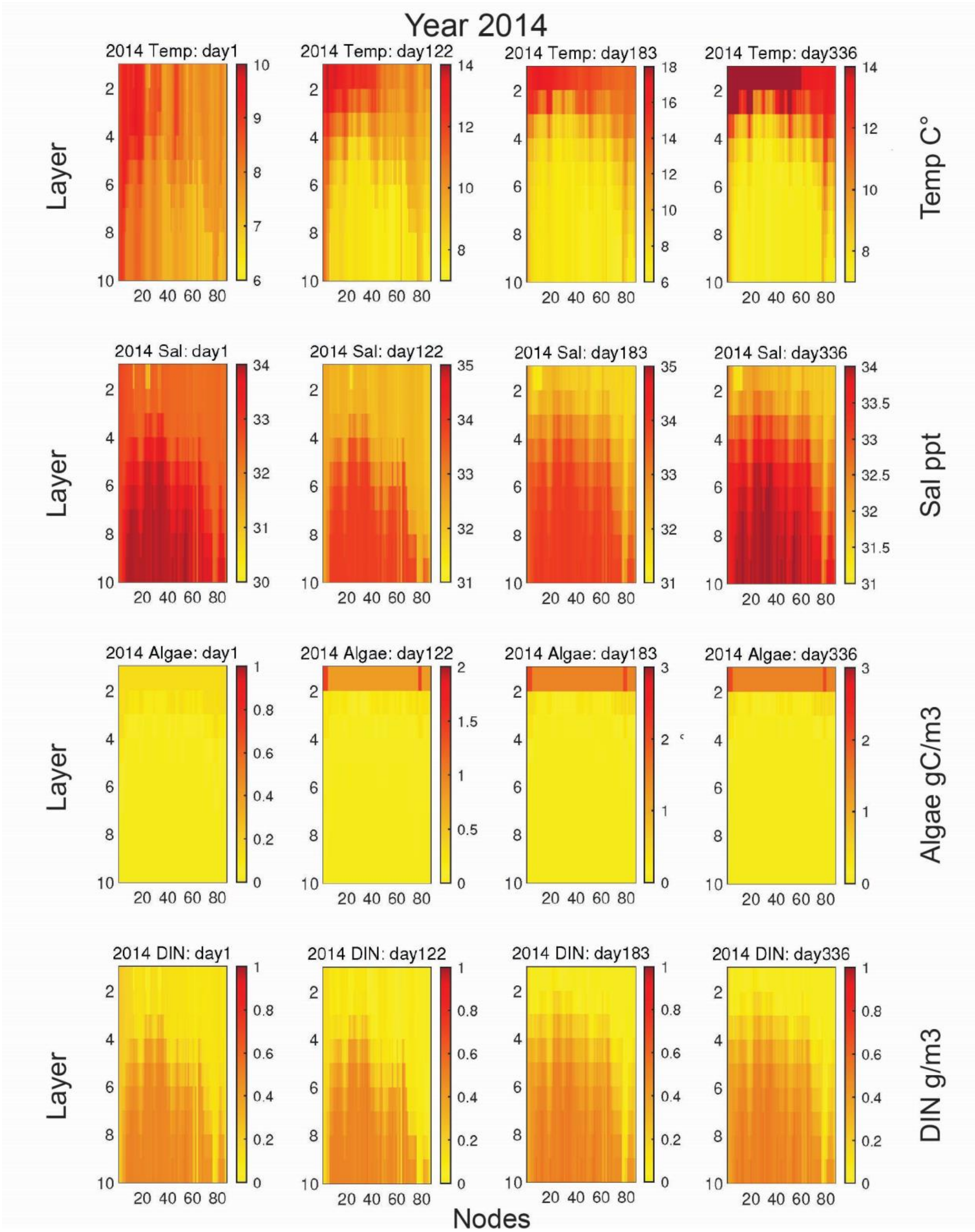

Figure B5-15. Year 2014 open boundary water quality data for select days (Jan 1, May 2, July 2, and Dec 2) for temperature, salinity, algae, and dissolved inorganic nitrogen (DIN).

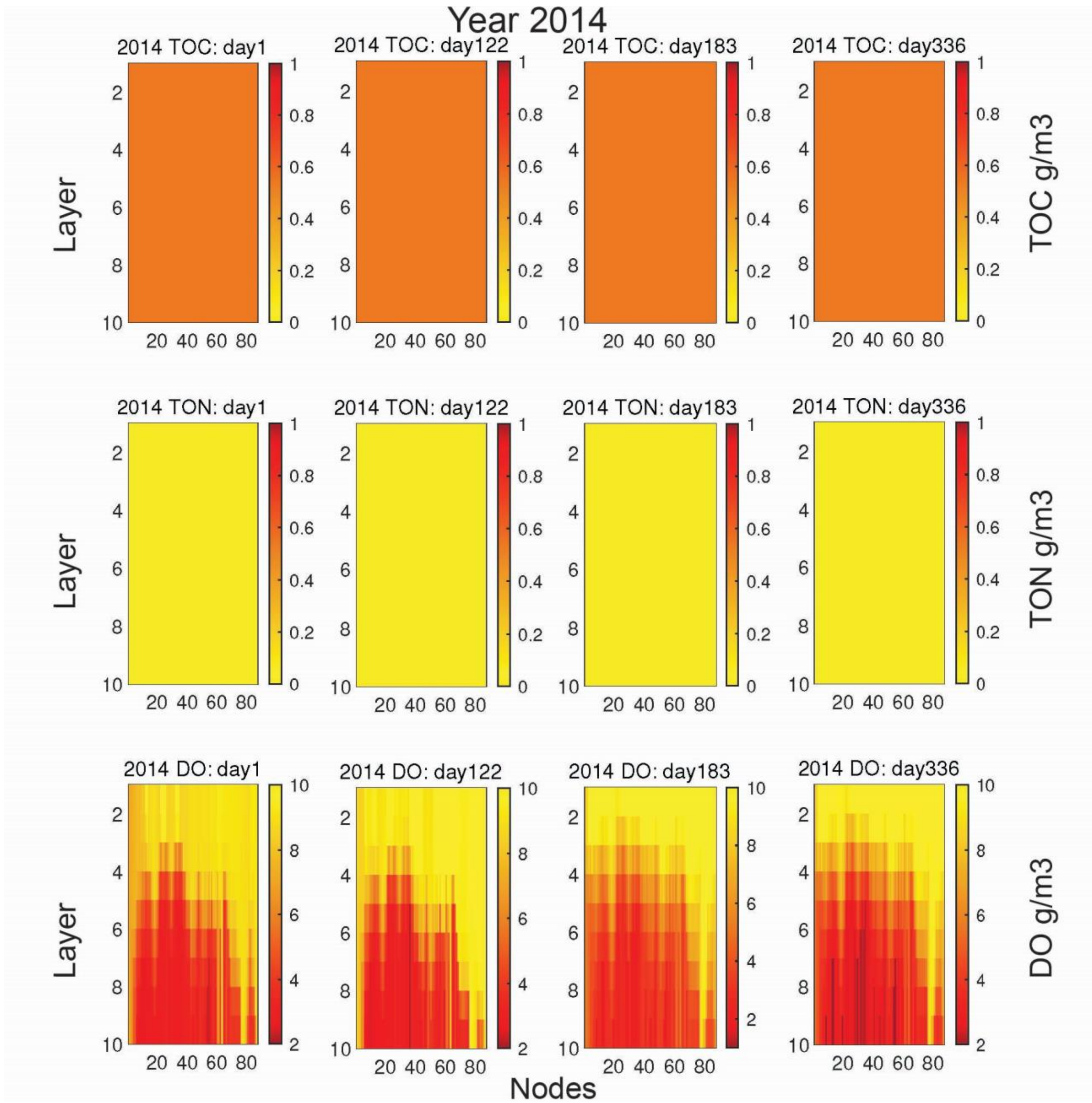

Figure B5-16. Year 2014 open boundary water quality data for select days (Jan 1, May 2, July 2, and Dec 2) for total organic carbon (TOC), total organic nitrogen (TON), and dissolved oxygen (DO).

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