Hydrodynamic and Water Quality Model of the North Saskatchewan River

May 2009

Prepared for:

North Saskatchewan Watershed Alliance
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Executive Summary

The North Saskatchewan River (NSR) in Alberta, Canada, begins at the Saskatchewan Glacier in Banff National Park and continues to the Alberta–Saskatchewan border. The NSR subsequently joins the South Saskatchewan River and eventually flows into Lake Winnipeg. This report documents the configuration, calibration, and validation of an in-stream hydrodynamic and water quality model for a portion of the NSR from 30 kilometers below Abraham Lake to 38 kilometers downstream of the Alberta-Saskatchewan border. Flow, water temperature, dissolved oxygen, organic carbon, nutrients, and algae interactions were modeled under the influence of tributaries, municipal wastewater treatment plants (WWTPs), industrial facilities, combined sewer overflows (CSOs), and stormwater.

The Environmental Fluid Dynamics Code (EFDC) was selected to model both hydrodynamics and water quality for the NSR in this study. EFDC is a public domain general purpose modeling package for simulating one-dimensional (1-D), two-dimensional (2-D), and three-dimensional (3-D) flow, transport, and biogeochemical processes in surface water systems including rivers, lakes, estuaries, reservoirs, wetlands, and coastal regions. Enhancements were made to the EFDC model to simulate ice cover in the river.

Configuration of the NSR EFDC model involved setting up the model computational grid using available geometric data, designating the model's state variables, setting boundary conditions, and setting initial conditions. The 1-D NSR model was represented by 778 segments of approximately 1,000 meter (m) lengths. Widths of the segments vary from approximately 50 m to 450 m. External forcing factors, or boundary conditions, specified for the model include upstream boundary conditions (i.e., upstream inflows, temperature, and constituent boundary conditions); tributary inflows (i.e., tributary inflows, temperature, and constituent boundary conditions); loadings from point sources including industrial sources, WWTPs, CSOs, and stormwater; surface boundary conditions (i.e., atmospheric conditions); and downstream boundary conditions (i.e., outflow). Initial conditions were set to ensure stable running of the model, especially the hydrodynamics. This was done by setting the initial water surface elevation, which was assumed to be parallel to the bottom elevation.

Once the NSR model was configured, calibration was performed. Calibration refers to the adjustment or fine-tuning of modeling parameters to produce an adequate fit of the simulated output to the field observations. The NSR model simulates all conditions from September 2000 to December 2007. Hydrodynamics and heat transport were calibrated first, and then water quality was calibrated using available monitoring data. Available in-stream data used for calibration included water surface elevation, continuous water temperature, continuous dissolved oxygen, and grab sample results of water quality constituents. The water surface elevation and continuous water temperature data were used to calibrate the hydrodynamics and heat transport simulation. The continuous dissolved oxygen and other discrete water quality data were used for water quality calibration.

Water surface elevations were calibrated to ensure flow balance at two flow stations in the modeling domain (Edmonton and Deer Creek stations). The modeled elevations agree well with the observed elevations during non-frozen seasons. Water temperature was evaluated to ensure correct heat transport in the NSR. Modeled water temperatures were compared to observed temperature data at eight datasonde stations. Overall, the modeled water temperature results agree well with observed data.

Water quality calibration involved examining the major reaction parameters and adjusting the parameters until model results agreed with the data. The major parameters adjusted include the ammonia nitrification rate; organic carbon dissolution rates; organic phosphorus hydrolysis rates; and algae growth, death, and respiration rates. Calibration focused primarily on a comparison of modeled and observed dissolved

oxygen. Dissolved oxygen is a key water quality indicator and is affected by various processes such as water temperature, reaeration, organic carbon decay, nitrification, and algae growth and death. The model was able to generally capture the trends and magnitudes seen in the dissolved oxygen observations. During ice cover, modeled dissolved oxygen results show a stable level because of the very low algae metabolism rates in low water temperature, no reaeration, and low bacteria activities to decay organic carbon or nitrifying ammonia. In warm weather, phytoplankton or benthic algae grow quickly and dissolved oxygen in the water column varies significantly. The model accurately reproduced such growing patterns for most NSR locations. The other modeled water quality constituents also agree well with observed data. Seasonal variations of nutrients are captured, and the modeled water quality constituents are in reasonable ranges. The model also captures the levels of the dissolved and total organic carbon.

The NSR EFDC model provides a sound basis for conducting scenario simulations. Boundary conditions can be readily changed to evaluate effects on conditions throughout the system. The model can be further improved through refinement of tributary boundary conditions, perhaps through watershed model simulation.

1 INTRODUCTION

The North Saskatchewan River (NSR) watershed in Alberta, Canada drains 57,000 square kilometers (km^2) (NSWA 2005). The sparsely populated NSR headwaters are at the Saskatchewan Glacier in Banff National Park and are mostly pristine. The river flows more than 1,000 kilometers (km) from its headwaters to the Alberta–Saskatchewan border (NSWA 2005) with an annual outflow of 7.2 billion cubic meters (m^3). The NSR joins the South Saskatchewan River and eventually flows into Lake Winnipeg.

Water use along the NSR and its tributaries includes human consumption, waste assimilation, hydroelectric power generation, thermal power plant cooling, oil and gas extraction, mining, and agriculture (NSWA 2005). Major dams in the watershed include two hydropeaking facilities: the Brazeau on the Brazeau River and the Bighorn on the mainstem of the NSR, which forms Abraham Lake. Land uses in the watershed include agriculture, resource exploration and extraction, forestry, recreation, urban centers and country residential development (NSWA 2005). The largest urban area is the Capital Region, which includes Edmonton and surrounding municipalities. Along, the mainstem of the NSR, the Devon to Pakan reach supports a population of about 1 million people, and a large segment of Alberta's resource processing industry. The heavy industrial area is called the *Industrial Heartland* and is the focus of the Water Management Framework for the Industrial Heartland and Capital Region.

This report documents the configuration, calibration, and validation of a one-dimensional, dynamic, in-stream water quality model for the NSR. The model was developed to support water resource management in the basin and simulates the impacts of point and nonpoint sources on conditions throughout the NSR. Flow, water temperature, dissolved oxygen, organic carbon, nutrients, and algae are included in the modeling framework. Specific sources considered include municipal wastewater treatment plants (WWTPs), industrial facilities, combined sewer overflows (CSOs), and stormwater. The portion of the river included in the model extends from approximately 30 kilometers below Abraham Lake to 38 kilometers below the Alberta–Saskatchewan border (Figure 1-1)—hereafter referred to as the *North Saskatchewan Watershed Alliance (NSWA) model domain*.

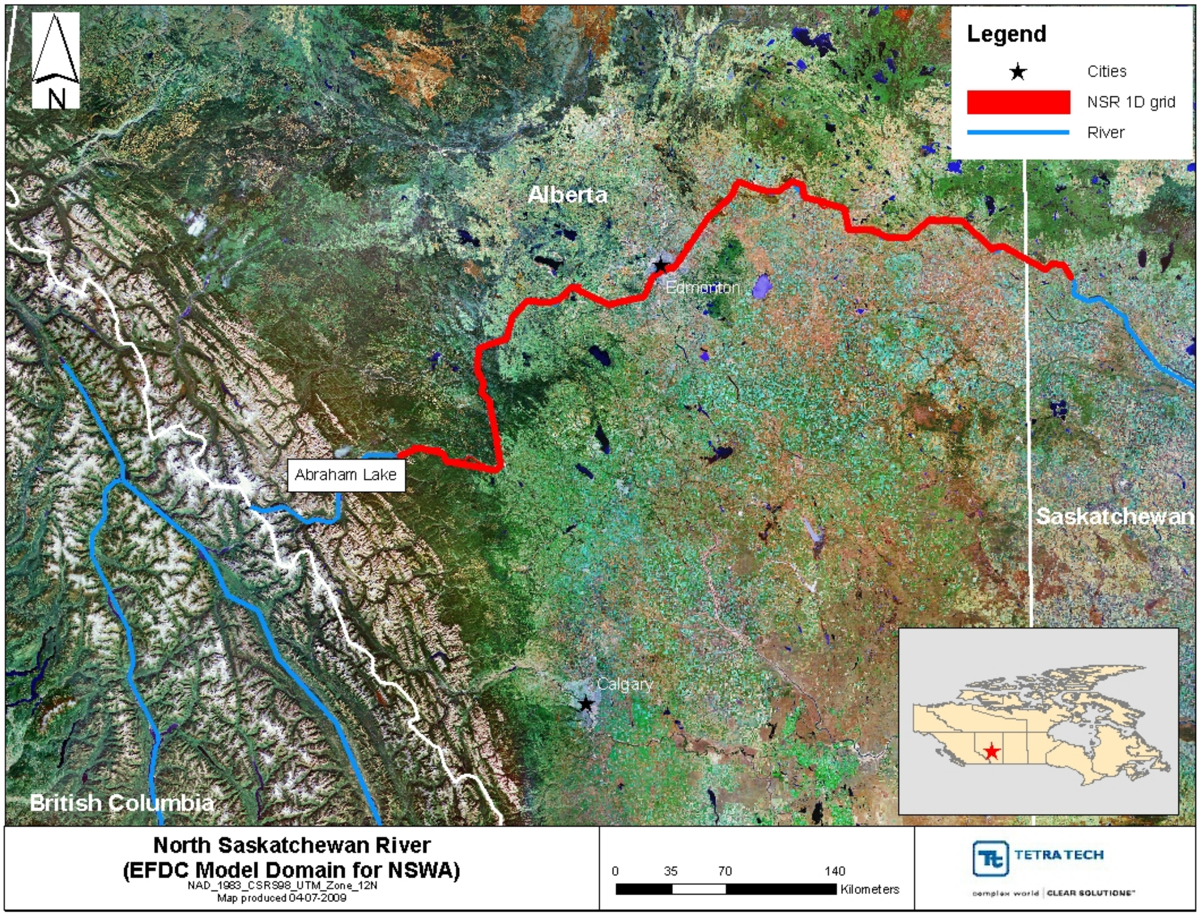

Figure 1-1. Extent of the modeled area of the NSR.

2 MODELING APPROACH

2.1 Model Selection

The Environmental Fluid Dynamics Code (EFDC) was selected as the system to model both hydrodynamics and water quality in the NSR Basin. Details of EFDC's hydrodynamic and eutrophication components are provided in Hamrick (1992) and Tetra Tech (2002, 2006a, 2006b, 2006c, 2006d). EFDC is a public domain, general purpose modeling package for simulating one-dimensional (1-D), two-dimensional (2-D), and three-dimensional (3-D) flow, transport, and biogeochemical processes in surface water systems including rivers, lakes, estuaries, reservoirs, wetlands, and coastal regions. The EFDC model was originally developed at the Virginia Institute of Marine Science for estuarine and coastal applications. This model is now being supported by the U.S. Environmental Protection Agency (EPA) and has been used extensively to support Total Maximum Daily Load (TMDL) development throughout the United States. In addition to hydrodynamic, salinity, and temperature transport simulation capabilities, EFDC is capable of simulating cohesive and noncohesive sediment transport, near-field and far-field discharge dilution from multiple sources, eutrophication processes, the transport and fate of toxic contaminants in the water and sediment phases, and the transport and fate of various life stages of finfish and shellfish. Cohesive sediment refers to silt and clay particles, while noncohesive refers to anything larger than silt (e.g., sand, gravel). The model has been extensively tested, documented, and applied to environmental studies worldwide by universities, governmental agencies, and environmental consulting firms.

EFDC includes four primary models: (1) a hydrodynamic model, (2) a water quality model, (3) a sediment transport model, and (4) a toxics model. The hydrodynamic model predicts water depth, velocities, and water temperature. The water quality portion of the model uses the results from the hydrodynamic model to compute the transport of the water quality variables. The water quality model then computes the fate of up to 22 water quality parameters including dissolved oxygen, phytoplankton (three groups), benthic algae, various components of carbon, nitrogen, phosphorus and silica cycles, and fecal coliform bacteria (Cerco and Cole 1994). The sediment transport and toxics models use the hydrodynamic model results to calculate the settling of suspended sediment and toxics, resuspension of bottom sediments and toxics, and bed load movement of noncohesive sediments and associated toxics.

2.2 Model Enhancements

The NSR is covered with ice for a long period each year. The original EFDC model code did not include the functionality to simulate hydrodynamic and water quality under ice-cover conditions. The hydrodynamic and water quality components of the EFDC model have been modified to account for the effect of ice cover on flow resistance, heat transport, and water quality simulation using externally supplied ice-cover information. Time varying fractional ice cover for a number of river regions is input to the model. Because of limited available data for ice cover thickness, the input is either *no cover* or *full cover*. Fractional ice cover information is used to block surface wind stress and define an under-ice-flow resistance in the hydrodynamic component of the model. In the heat transport model, fractional ice cover information is used to modify surface heat transfer changing from open water transfer to ice-covered transfer. Water surface reaeration is correspondingly reduced in response to fractional surface ice cover.

2.3 Model Configuration

Model configuration involved setting up the model computational grid using available geometric data, designating the model's state variables, setting boundary conditions, and setting initial conditions. This section describes briefly the configuration process and key components of the model in greater detail.

2.3.1 Segmentation/Computational Grid Setup

This section describes the process of segmenting the NSR into smaller computational segments for applying the model. A 1-D model grid was configured for the NSWA model domain. Figure 2-1 shows the portion of the NSR in the NSWA model along with flow stations. Because of the narrow nature of the river, it is difficult to view the 1-D grid in detail from Figure 2-1. Therefore, Figure 2-2 is a supplemental map with a clear view of a portion of the 1-D grid.

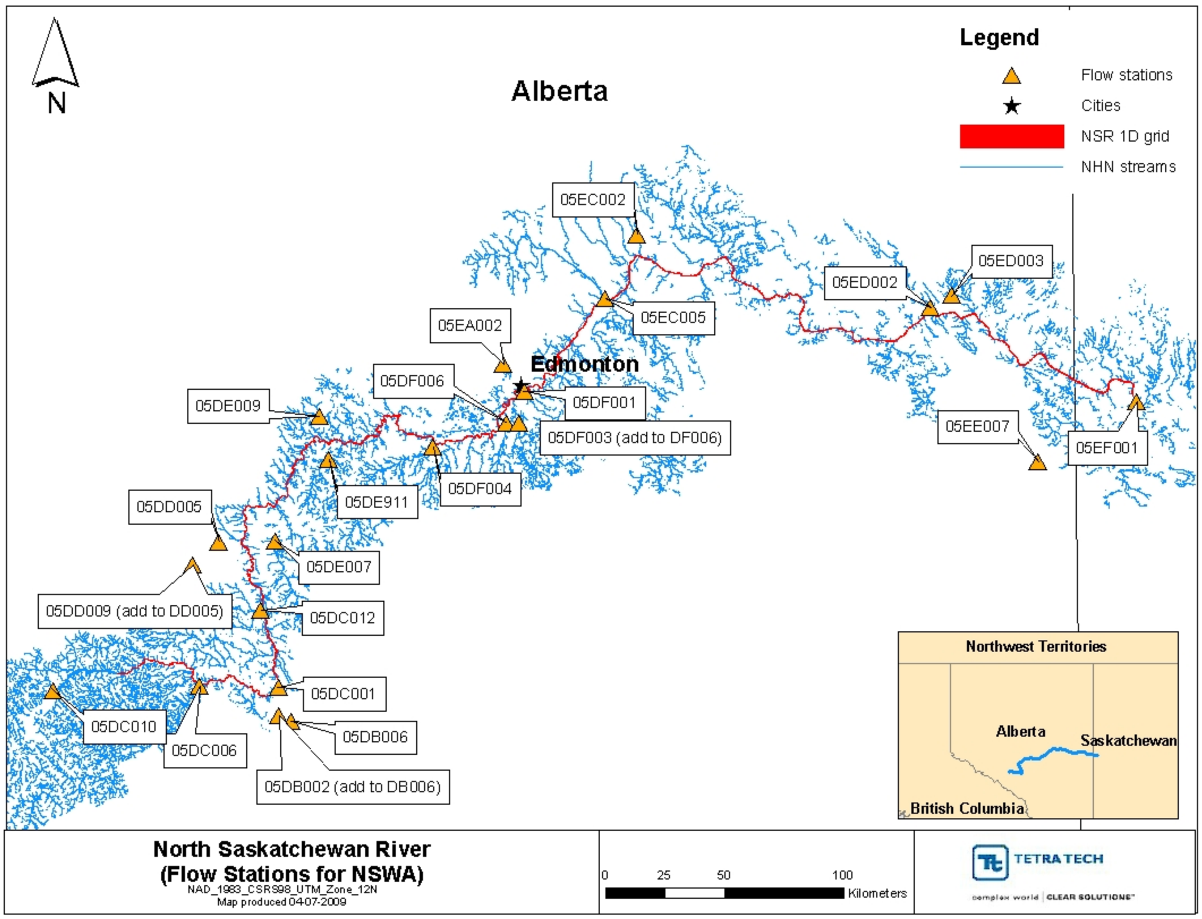

Figure 2-1. The NSWA model grid and flow stations on major tributaries and on the NSR.

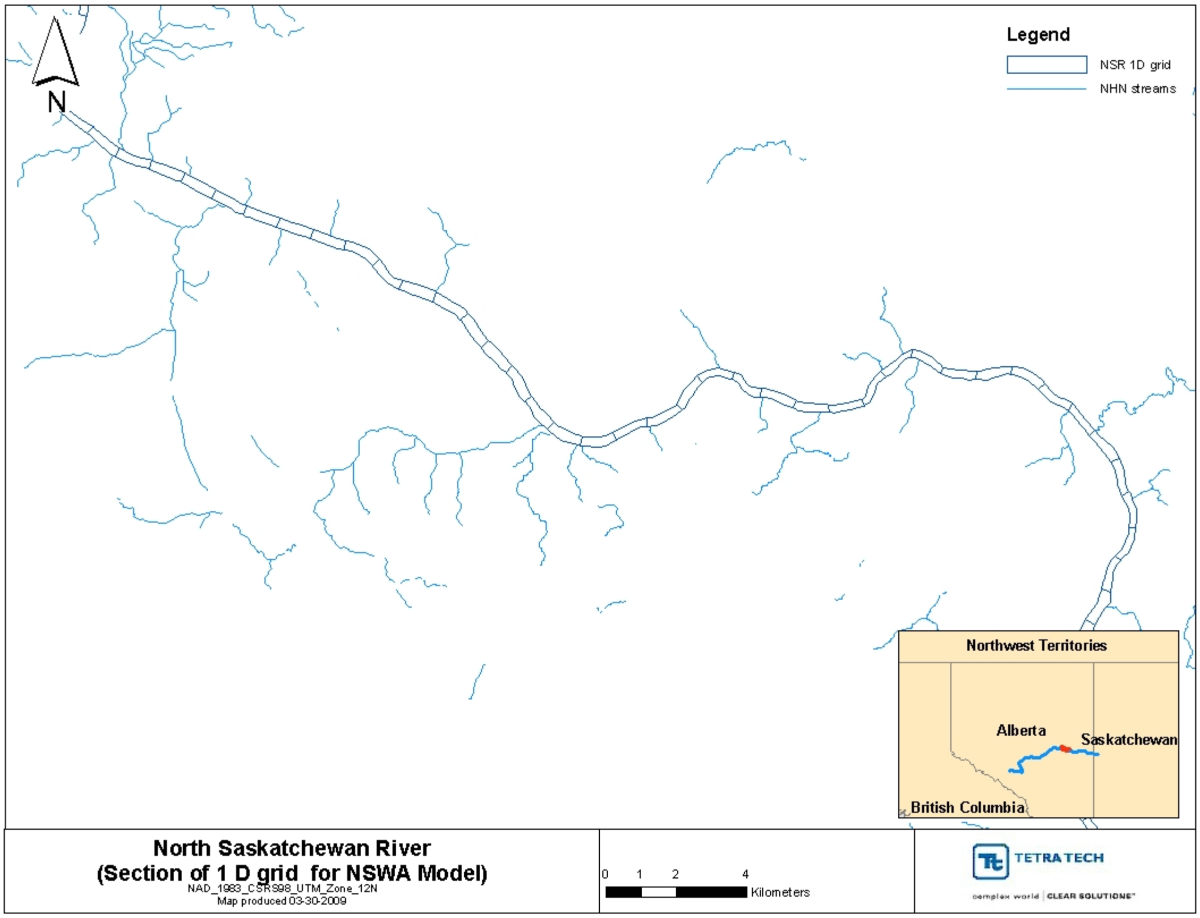

Figure 2-2. A portion of the 1-D grid for the NSR model.

To generate the grid, the original NSR geographic information system (GIS) files were first cleaned. The NSR was then divided into segments of approximately 1,000 meter (m) lengths, based longitudinally on the channel mid-line. The average width was calculated using GIS for each segment. A total of 778 segments were generated for the entire length of the 1-D model. Widths of the segments vary from approximately 50 m to 450 m. The width was adjusted to include only the waterway width for the river sections with islands. Corresponding files were generated using the EFDC grid generator.

The depth of each segment was determined to complete grid development. Three sources of depth information were used, including the 2007 HEC-RAS model cross-section data (that cover the 100-km reach from Devon to near Fort Saskatchewan), the 1990 cross-section data for the portion downstream of Fort Saskatchewan to flow station 05EF001, and a 1972 bottom and water surface profile map for the entire NSR. The locations of the cross-sections were estimated using maps because specific location data were not readily available.

Depth data were in different formats and were accordingly processed for incorporation into the model. The 2007 HEC-RAS cross-sections are in HEC-RAS input file format. Excel spreadsheets were used to calculate the average depth of each cross-section. The locations of the cross-sections were identified and digitized into Arcmap. Only hard copies of the 1990 cross-section data were available. The average depths were estimated directly from the plots of the cross-sections on the hard copies. Locations of the 1990 cross-sections were positioned by comparing maps and satellite images and digitized into Arcmap.

The 1972 bottom and water surface profiles were also provided as hard copies. Depth information was extracted from the map by visual inspection according to the site name and river kilometers. Depth info from the 1972 profiles was directly applied in a spreadsheet for generating depth data for EFDC. Linear interpolation was applied for the segments without any depth data. The 1972 profile data were used to conduct the interpolation for the segments without data from the upstream boundary to Devon. The segments without depth data from Devon to Fort Saskatchewan were interpolated using the 2007 HEC-RAS model cross section data. The segments without depth data from Fort Saskatchewan to station 05EF001 were interpolated using the 1990 data. In addition, the 1972 profiles were used as supplemental information to confirm or adjust the depths for each EFDC segment.

2.3.2 State Variables

Selection of appropriate model state variables to represent water quality processes of concern is a critical factor in model configuration. For this study, state variables were selected to most accurately predict dissolved oxygen, organic carbon, and nutrients under the influence of tributaries, WWTPs, industrial facilities, CSOs, and stormwater. The following state variables were configured for the NSR EFDC model:

1. Phytoplankton (one group)
2. Refractory particulate organic carbon (RPOC)
3. Labile particulate organic carbon (LPOC)
4. Dissolved organic carbon (DOC)
5. Refractory particulate organic phosphorus (RPOP)
6. Labile particulate organic phosphorous (LPOP)
7. Dissolved organic phosphorous (DOP)
8. Orthophosphate (PO_4)
9. Refractory particulate organic nitrogen (RPON)
10. Labile particulate organic nitrogen (LPON)
11. Dissolved organic nitrogen (DON)
12. Ammonia (NH_4)
13. Nitrate (NO_2/NO_3)
14. Dissolved oxygen (DO)
15. Periphyton (benthic algae)

2.3.3 Boundary Conditions

To run the NSR model, external forcing factors known as boundary conditions must be specified for the system. These forcing factors are a critical component in the modeling process and have direct implications on the quality of the model's predictions. External forcing factors include a wide range of dynamic information:

- Upstream Boundary Conditions: Upstream inflows, temperature, and constituent boundary conditions
- Tributary (or Lateral) Inflow Boundary Conditions: Tributary inflows, temperature, and constituent boundary conditions
- Loadings from point sources
- Surface Boundary Conditions: Atmospheric conditions (including wind, air temperature, solar radiation)
- Downstream Boundary Conditions.

These boundary conditions are discussed in more detail in the following sections.

2.3.3.1 Upstream Boundary Conditions

Upstream inflow represents the model's *starting* point. Inflow data for the model include flow, water temperature, and water quality. Flow measured at the Bighorn station (05DC010) was used as the upstream inflow for the model. Water temperature was not measured at this station; therefore, water temperatures from all other stations were combined and provided as the upstream temperature boundary condition. To simulate water quality conditions, loadings for all state variables (except periphyton) are needed. Water quality information at the Bighorn station is very limited. Therefore, water quality data measured near Rocky Mountain House were used to derive the upstream boundary conditions for the NSR model.

The water quality data near Rocky Mountain House were not daily data. Thus, data were averaged on a monthly basis. The final water quality data include NH_3, DOC, TOC, NO_2/NO_3, chlorophyll *a*, total Kjeldahl nitrogen (TKN), DO, total phosphorus, and dissolved phosphorus. Some of the water quality data were below the detection limit; therefore, 50 percent of the detection limit was used as the concentration. Carbon and nutrient data needed to be converted to EFDC state variables. Therefore an Excel spreadsheet was developed to (1) calculate loadings from the water quality data using flow data measured at Bighorn, (2) convert carbon and nutrients to the EFDC state variables, and (3) output data in the EFDC water quality boundary file format. Because of the limited available data, the conversion to EFDC state variables was conducted through a trial-and-error process. The final conversions are presented in Table 2-1.

Table 2-1. Conversion of water quality data to EFDC state variables

EFDC state variables	Conversion from water quality data
Refractory particulate organic carbon (RPOC)	(TOC – DOC) × 0.5
Labile particulate organic carbon (LPOC)	(TOC – DOC) × 0.5
Dissolved organic carbon (DOC)	DOC
Refractory particulate organic phosphorus (RPOP)	(TP – TDP) × 0.5
Labile particulate organic phosphorous (LPOP)	(TP – TDP) × 0.5
Dissolved organic phosphorous (DOP)	TDP × 0.5
Orthophosphate (PO4)	TDP × 0.5
Refractory particulate organic nitrogen (RPON)	(TKN – Ammonia) × 0.3
Labile particulate organic nitrogen (LPON)	(TKN – Ammonia) × 0.3
Dissolved organic nitrogen (DON)	(TKN – Ammonia) × 0.4

2.3.3.2 Tributary Boundary Conditions

Tributary inflows represent the major tributaries that feed into the NSR. Flow, temperature, and water quality data were also required for these inputs to the river. Table 2-2 presents the 18 tributaries included in the model from upstream to downstream. The tributaries were divided into two groups. The first group includes the tributaries above the flow station at Edmonton on the mainstem of the NSR and streams from Ram River to Whitemud in Table 2-2. The second group includes the tributaries below the Edmonton flow station and above the Deer Creek flow station on the mainstem of the NSR where the downstream boundary is. The second group also includes streams from Sturgeon to Vermillion in Table 2-2.

Table 2-2. Tributaries included in the NSR model

ID	Tributary name	Flow station	Flow adjustment	EFDC grid ID
1	Ram River	05DC006	1.00	54
2	Clearwater River	05DB006	1.00	93
3	Prairie Creek	05DB002	1.00	93
4	Baptiste River	05DC012	1.00	138
5	Brazeau River	05DD005	1.00	178
6	Nordegg River	05DD009	1.00	178
7	Rose Creek	05DE007	1.00	208
8	Modeste Creek	05DE911	1.00	263
9	Tomahawk Creek	05DE009	1.00	271
10	Strawberry Creek	05DF004	1.00	338
11	Blackmud Creek	05DF003	1.00	394
12	Whitemud Creek	05DF006	1.00	394
13	Sturgeon River	05EA002	5.17	451
14	Redwater River	05EC005	5.17	471
15	Waskatenau Creek	05EC002	5.17	498
16	Atimoswe Creek	05ED002	5.17	661
17	Moose Hill Creek	05ED003	5.17	683
18	Vermilion River	05EE007	5.17	715

The total flow of all tributaries was calculated for the two groups. The upstream inflow and the total flow from the tributaries in the first group were compared with the flow measured at the Edmonton flow station. Flow for the period from 2000 to 2007 is balanced for the NSR above Edmonton and ensures that the drainage area is sufficiently represented. Flow at Edmonton and the total flow from the tributaries in the second group were compared with the flow measured at Deer Creek. The total flow from 2000 to 2007 at Deer Creek was higher than the total flow from Edmonton and the tributaries, implying that flow from the drainage area was not fully represented by the tributaries used in the model. To ensure flow balance, the total flow from the tributaries was increased 5.17 times to represent the tributaries not explicitly included between Edmonton and Deer Creek, as shown in Table 2-2. Note that Table 2-2 also lists the EFDC cell locations that receive the tributary inflows.

Water temperature is also required for the tributaries. Water temperature was not measured on the tributaries at consistent time intervals. Therefore, water temperature used for the tributaries is the same as the upstream boundary water temperature. This is a combination of all available observed temperature data.

Nutrients, organic carbon, and dissolved oxygen data from the tributaries were additionally needed for water quality simulation in the model. Monitoring data for the tributaries were compiled, cleaned, and re-organized to prepare for conversion to EFDC state variables. Data from the Strawberry, Tomahawk, and Nordegg stations were used to calculate monthly average concentrations for the water quality constituents. In other tributaries with data, averaged values over the entire sampling period were used. Averaged values from all the tributaries with data were used for the tributaries without observation data. The final water quality data include ammonia, DOC, TOC, nitrate, TKN, dissolved oxygen, total phosphorus and dissolved phosphorus. In some cases, DOC values were reported higher than the TOC values, and the TOC values were reset to the DOC values. Some of the data were below the detection limit; therefore 50 percent of the detection level was used as the concentration. Carbon and nutrient data were converted to EFDC state variables as discussed in the inflow boundary conditions section. The conversion is the same as the inflow boundary conditions shown in Table 2-1.

2.3.3.3 Point Sources

A significant number of point source dischargers are in the NSR watershed, especially around Edmonton. The point sources mainly include WWTPs, industrial facilities, CSOs, and storm sewers. Figure 2-3 shows the locations of all the point sources. Note that some dischargers have multiple facility locations and Figure 2-3 shows all these locations. Table 2-3 presents the names of the point sources included in the model as well as the available data. Two water treatment plants in the watershed, E.L. Smith and Rossdale, are included in the model with dummy loads and can be replaced when actual loading rates are available.

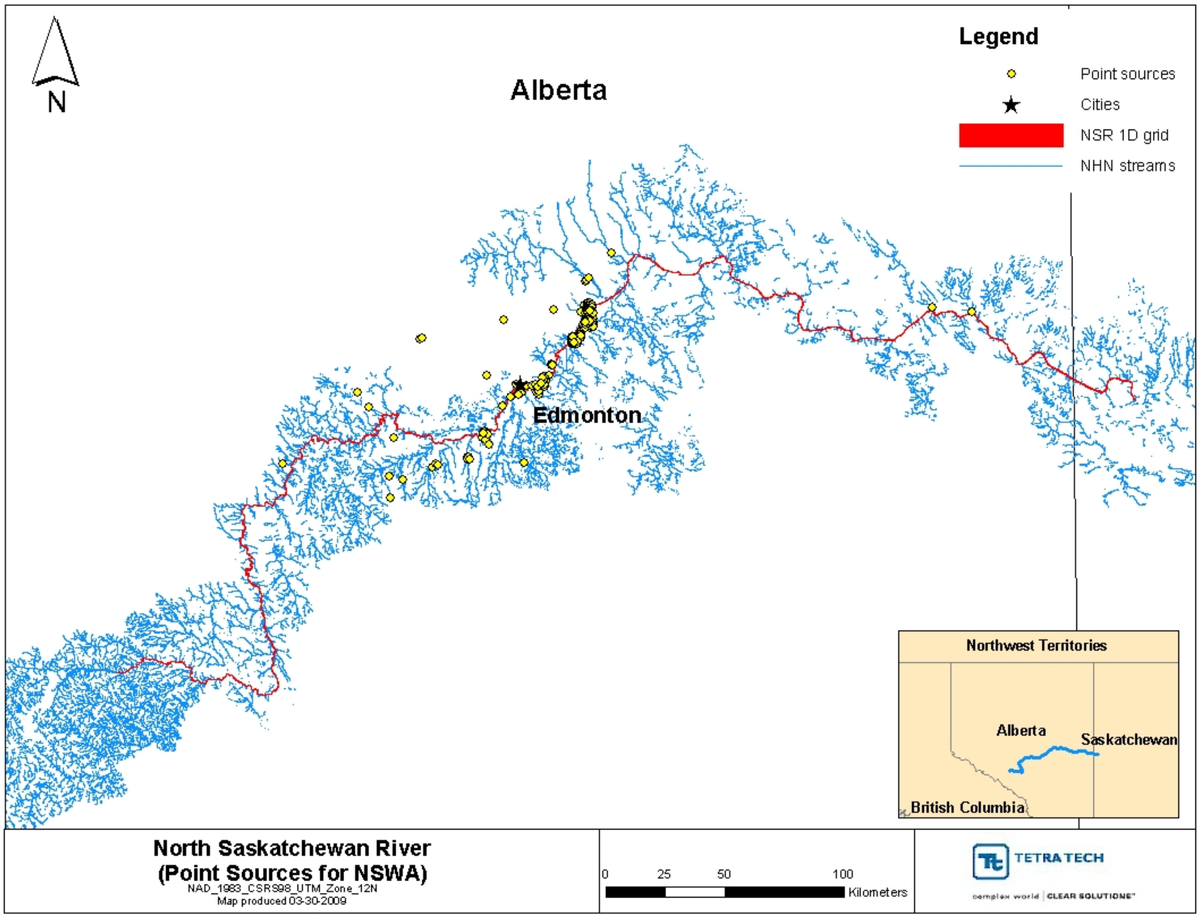

Figure 2-3. Locations of point sources included in the NSR model.

Table 2-3. Point sources included in the EFDC model for the NSR

Station no.	Facility name	Begin date	End date	Flow	NH3	NO23	Org N	TKN	PO4	TP	BOD	COD	DOC	TOC
AB05EB1391	ALTASTEEL LTD.	1/1/2000	4/30/2008	Y									Y	
AB05EB1650	PETRO-CANADA PRODUCTS	1/1/2000	4/29/2008	Y	Y					Y		Y		
AB05EB1740	OWENS-CORNING CANADA INC.	1/1/2000	2/29/2004	Y	Y				Y			Y		
AB05EB1741	OWENS-CORNING CANADA INC.	1/1/2000	2/29/2004	Y							Y			
AB05EB1990	VIRIDIAN FT SASK	1/1/2000	1/10/2000	Y	Y	Y	Y		Y		Y	Y		
AB05EB2580	GEON CANADA INC.-SCOTFORD	1/1/2000	3/30/2006	Y	Y				Y		Y			Y
AB05EB2630	SHELL CANADA PRODUCTS LIMITED SCOTFORD	1/4/2000	4/28/2008		Y							Y		
AB05EB2632	SHELL CANADA PRODUCTS LIMITED SCOTFORD REFINERY	1/5/2000	3/26/2008								Y			
AB05EB2930	DEGUSSA CANADA INC. GIBBONS	1/1/2000	4/30/2008	Y	Y		Y		Y		Y	Y	Y	Y
AB05EB2950	AGRIUM REDWATER	1/1/2000	5/31/2008	Y	Y	Y	Y		Y		Y	Y	Y	Y
AB05EB1410	AT PLASTICS INC.	4/6/2000	5/22/2008	Y	Y						Y	Y		Y
AB05EB1413	AT PLASTICS INC.	5/16/2000	5/8/2007	Y	Y							Y		
AB05EB1440	IMPERIAL OIL	1/1/2000	5/31/2008	Y	Y							Y		
AB05EB1760	RAYLO CHEMICALS INC.	1/1/2000	7/31/2000	Y								Y		
AB05EB1780	CELANESE CANADA INC.	1/1/2000	11/4/2003	Y							Y	Y	Y	Y
AB05EB1792	CELANESE CANADA INC.	1/1/2000	12/9/2002											Y
AB05EB2150	DOW CHEMICAL CANADA INC.	1/2/2000	4/30/2008	Y	Y			Y	Y		Y			Y
AB05EB2582	FORT SASKATCHEWAN/CHEMICAL PROCESSING/GULF CHEMICA	3/30/2007	10/1/2007	Y										Y
AB05EB2583	FORT SASKATCHEWAN/CHEMICAL PROCESSING/GULF CHEMICA	4/4/2007	10/1/2007	Y										
AB05EB2660	SHELL CANADA PRODUCTS LIMITED SCOTFORD	1/3/2000	12/28/2006					Y						Y
AB05EB2673	SHELL SCOTFORD ETHYLENE GLYCOL PLANT	7/2/2000	12/31/2006	Y				Y			Y	Y		Y
AB05EB4661	AIR LIQUIDE SCOTFORD	5/1/2000	5/31/2008	Y					Y			Y		Y
AB05EB4731	SCOTFORD UPGRADER EFFLUENT POND DISCHARGE	9/23/2002	4/30/2008	Y	Y						Y	Y		
AB05EB4732	SCOTFORD UPGRADER CLEAN STORMWATER POND RELEASES	10/3/2002	3/2/2003	Y	Y							Y		
	Devon WWTP	1/1/2000	5/31/2008	Y							Y			
	Capital Region WWTP	1/1/2000	6/30/2008	Y	Y					Y	Y			
	Gold Bar WWTP (From ANEV WASP7)	1/1/2000	12/31/2005		Y						Y			
	Rat Creek CSO (From ANEV WASP7)	1/1/2000	12/31/2005		Y						Y			

Station no.	Facility name	Begin date	End date	Flow	NH3	NO23	Org N	TKN	PO4	TP	BOD	COD	DOC	TOC
	Capilano/Hardisty CSO (From ANEV WASP7)	1/1/2000	12/31/2005		Y						Y			
	Highlands CSO (From ANEV WASP7)	1/1/2000	12/31/2005		Y						Y			
	30th Avenue Storm Sewer (From ANEV WASP7)	1/1/2000	12/31/2005		Y						Y			
	Kennedale Storm Sewer (From ANEV WASP7)	1/1/2000	12/31/2005		Y						Y			
	Quesnell Storm Sewer (From ANEV WASP7)	1/1/2000	12/31/2005		Y						Y			
	Groat Road Storm Sewer (From ANEV WASP7)	1/1/2000	12/31/2005		Y						Y			
	RAT CREEK CSO	1/1/2003	4/30/2007	Y	Y	Y		Y		Y	Y			
	HIGHLANDS CSO	1/1/2003	4/30/2007	Y	Y	Y		Y		Y	Y			
	CAPILANO CSO	1/1/2003	4/30/2007	Y	Y	Y		Y		Y	Y			
	REMAINING CSO	1/1/2003	4/30/2007	Y	Y	Y		Y		Y	Y			
	30TH AVE STORM	1/1/2003	4/30/2007	Y	Y	Y		Y		Y	Y			
	GROAT ROAD STORM	1/1/2003	4/30/2007	Y	Y	Y		Y		Y	Y			
	QUESNELL STORM	1/1/2003	4/30/2007	Y	Y	Y		Y		Y	Y			
	REMAINING STORM	1/1/2003	4/30/2007	Y	Y	Y		Y		Y	Y			
	Rocky Mountain House WWTP	1/1/2000	12/31/2008	Y							Y			
	Drayton Valley WWTP	1/1/2000	12/31/2008	Y										
	ELK Point WWTP	1/1/2000	12/31/2008	Y							Y			
	EL Smith WTP													
	Rossdale WTP													

Table 2-3 shows that point sources can discharge or report different pollutants. In addition, data for different point sources cover different time periods. The original data were compiled, cleaned, and processed, and this included interpolating missing data and averaging data reported for the same time. The available data did not exactly match the EFDC water quality state variables. Therefore, these data were converted to EFDC water quality state variables. Several assumptions were made to convert the point source data into the appropriate format. These assumptions include the following:

- Thirty percent of organic nitrogen is allocated to RPON, 30 percent of organic nitrogen is allocated to LPON, and 40 percent of organic nitrogen is allocated to DON.
- When no NH_3 data are available for a discharger, TKN is converted to NH3 and organic nitrogen using the NH_3/TKN ratio from other facilities.
- Total phosphorus is equally divided to PO_4 and organic phosphorus.
- Thirty percent of organic phosphorus is allocated to RPOP, 30 percent of organic phosphorus is allocated to LPOP, and 40 percent of organic phosphorus is allocated to DOP.
- POC is derived by subtracting DOC from TOC. POC is then evenly divided into LPOC and RPOC.
- When no DOC data are available, TOC is converted to DOC and POC using the TOC/DOC ratio from other facilities.
- When both BOD and COD are available, BOD is converted to DOC, and COD to TOC.
- When BOD, COD, DOC, and TOC are all available, only DOC and TOC are used.
- Monthly averages are used to fill the time periods without data.

2.3.3.4 Surface Boundary Conditions

The surface boundary conditions were determined by the meteorological or atmospheric conditions and include air temperature, dew point temperature, wind speed, wind direction, and cloud cover. Seven weather stations were used to determine surface boundary conditions for the EFDC model (Figure 2-4). Atmospheric data were processed and used to create atmosphere thermal interaction and wind forcing files. The wind file includes information on wind speed and direction. The atmosphere file includes air pressure, air temperature, relative humidity, precipitation, solar radiation, and cloud cover. The model segments were divided into sections to use the data from the different weather stations. The general rule to assign the model segments was to use the midpoint of two adjacent weather stations as the breaking point. Several assumptions were made to convert the observed data to EFDC input files:

- All missing flags *M* or blank fields were replaced using the previous hour observed for all parameters.
- Gaps in atmospheric pressure were filled using constant pressure values estimated from altitude.
- Gaps in weather descriptions were filled using the Edmonton station. Lloydminster or Rocky Mountain could be used, if necessary.
- The cloud cover description from the weather description was interpreted in the following way:
  Clear = 0.25
  Mainly Clear = 0.5
  Mostly Cloudy = 0.75
  Cloudy = 0.95
  All other descriptions (which seemed to be related to rainy conditions) = 0.9
- Solar Radiation was computed on the basis of the solar radiation algorithm of CE-QUAL-W2 for short wave solar radiation.

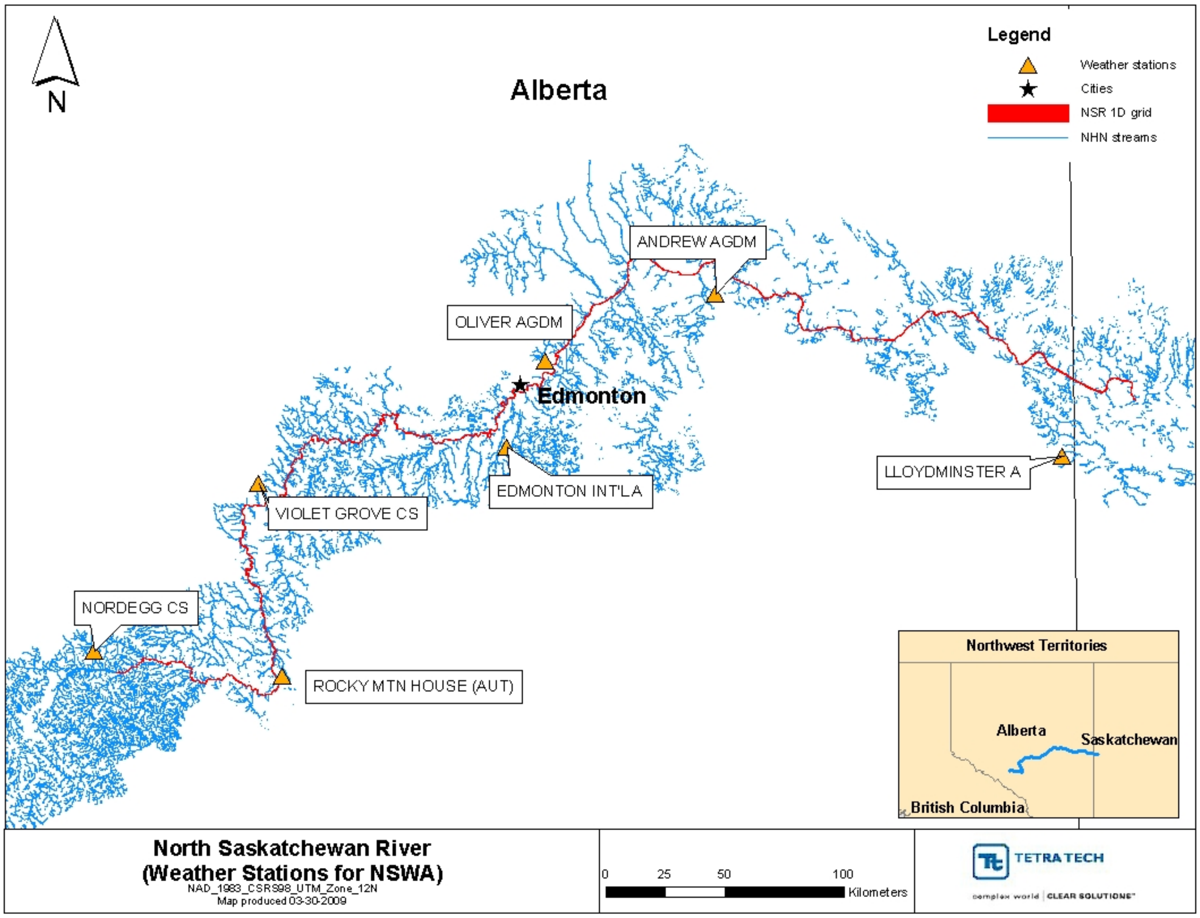

Figure 2-4. Weather station locations.

2.3.3.5 Downstream Boundary Conditions

In addition to the boundary conditions that specify the input of water, heat, and water quality constituents, the model needs to know how water, heat, and water quality constituents leave the model domain. The downstream water quality in river systems typically will not affect the upstream portion because water flows in one direction (assuming that backwater effects are localized and minimal). The only downstream boundary condition needed is related to outflow. Two approaches can be used for specifying the downstream outflow condition. One is to use observed flow data. The other is to use a stage-discharge curve. Both of these approaches were tested, and it was found that the stage-discharge approach generated better results. Therefore, the stage-discharge approach was used in the model. The observed water elevation and flow rates at the Deer Creek station was used to derive the stage-discharge curve. Only data from non-frozen conditions were used. The derived curve is shown in Figure 2-5.

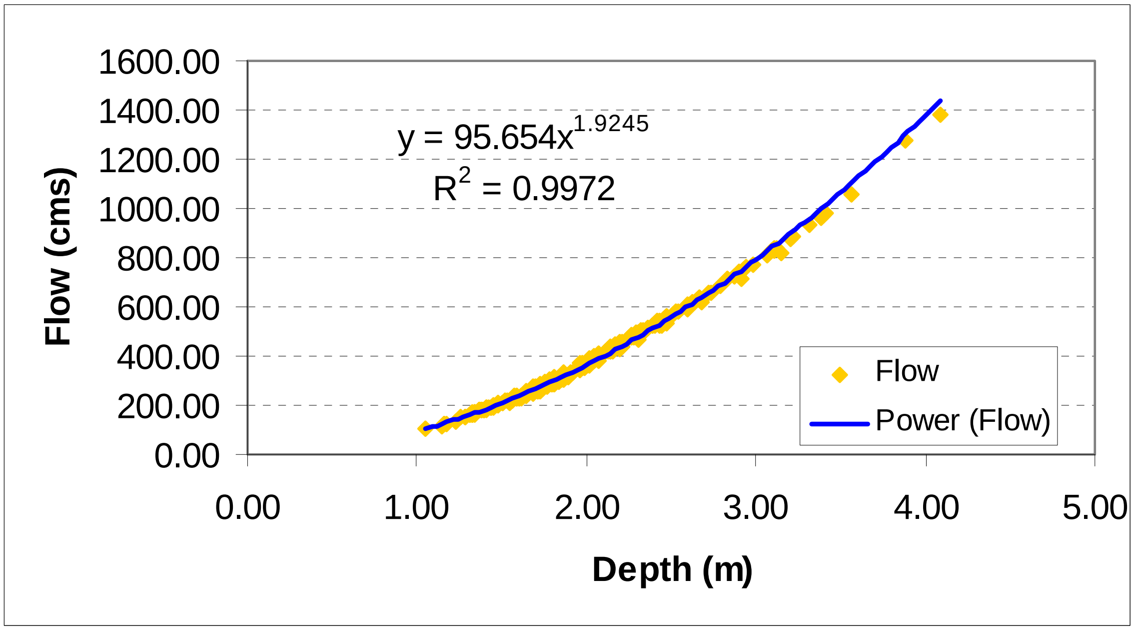

Figure 2-5. Stage-discharge curve derived from data measured at the Deer Creek station.

2.3.4 Initial Conditions

The NSR model required specifying initial conditions in the input files. The EFDC model allows constant or spatially varying initial conditions for all model state variables. The ideal initial conditions would be the measured water temperature, elevation, and water quality concentrations, which are not available for NSR. NSR's water residence time is short, and the impact of the initial conditions disappears quickly. When the model runs, the boundary conditions quickly change the values from the initial conditions. Therefore, the initial conditions were set to ensure stable running of the model, especially the hydrodynamics. The most important step was to set the initial water depths, which are approximately parallel to the bottom.

2.4 Model Assumptions, Limitations, and Sources of Uncertainty

This section describes the assumptions, limitations, and sources of uncertainty associated with the model. All mathematical water quality models are a simplified representation of the complex real world, and the NSR model is no exception. It is important to identify critical assumptions and limitations regarding the model's predictive capability and applicability.

2.4.1 Assumptions

The major underlying assumptions associated with NSR model development are as follows:

- Complete mixing is assumed for each model cell.
- The impact of sediment transport and siltation on channel geometry is not significant; therefore the same bathymetric configuration can be used for all model simulations.
- One phytoplankton species is sufficient for representing the overall primary production and nutrient interactions in the water column.
- All the organic matter in the water column has the same stochiometric ratio.

- The impact of zooplankton and other factors is lumped into a death rate for algal dynamics and nutrient recycling.
- One benthic algae species is able to represent the benthic conditions.
- Field data are reliable for calibration.

2.4.2 Limitations

Limitations of the model are generally associated with the model assumptions. The major model limitations are identified below:

- The EFDC model does not simulate multiple species of phytoplankton and benthic algae. Therefore, the model will not be suitable for evaluating competition among multiple species or evolution of the aquatic algal communities and their interaction with nutrients.
- Zooplankton is not simulated in the EFDC model; hence, there could be some uncertainty in the simulation of algal dynamics and nutrient cycling.
- Averaged depth across model cells limits the best simulation of benthic algae, which is highly related to bottom solar radiation.
- Ice conditions are specified externally. This is sufficient for diagnostic purposes but limited for scenario prediction.
- The spatial scale of the model is large. It is not suitable for detailed simulation for any localized phenomenon with spatial scale less than the cell length and width (including near-field analysis for dischargers). Finer scales are required for such modeling purposes.

2.4.3 Sources of Uncertainty

Boundary conditions are the major sources of uncertainty in the model. Because of the limited data available for tributaries, WWTPs, industrial dischargers, CSOs, and storm sewers, interpolation and averaging were applied to missing, incomplete, and repeated data. The temporal resolution of the simulation is higher than the boundary conditions. The weather data are on an hourly scale; flows from the tributaries are usually daily; loadings from tributaries used all available data to calculate monthly averages or multiple year averages; and loadings from point sources are on irregular periods. Additionally, the monitored water quality data were converted to EFDC state variables with constant conversion rates. All these factors contribute to model uncertainty.

3 MODEL CALIBRATION

Once the NSR model was configured, model testing was performed. Model testing is often carried out in two steps—calibration and validation. First, calibration is done for one period with adequate available field data. Calibration refers to adjusting or fine-tuning the modeling parameters to produce an adequate fit of the simulated output to the field observations. The calibrated model is then used to simulate an independent period for which field data under different environmental conditions are available for comparison. This is known as validation. For the validation run, most model process controlling parameters, except those for which field measurements are available, are held at values used during model calibration. Results of the validation run are then compared with field data for the same period, and a decision is made as to whether predictions and observations are close enough to consider the model valid for predictive purposes. If validation results are not adequately close, the model process controlling parameters are adjusted accordingly, and the calibration and validation process is repeated. This is done iteratively until the results are adequate to consider the model valid for predictive purposes.

The NSR model simulates conditions from 2000 to 2007. Because the model was run continuously for this period and because the period covers a range of conditions, it was deemed appropriate to combine calibration and validation. That is, instead of dividing the data into two separate periods, one for calibration and another for validation, all available data were used to support model calibration for the entire period. This approach inherently considers validation because the model is optimized for the entire range of available data.

The sequence of calibration for the NSR model involved calibrating hydrodynamic and heat transport first and then calibrating water quality using available monitoring data. The model simulated hydrodynamics and water quality for September 2000 to December 2007. The four months in 2000 are considered as a model spin-up period and were not included in the model calibration.

3.1 Supporting Data and Monitoring Locations

A significant amount of in-stream data was required to conduct the calibration. The available in-stream data included water surface elevation, continuous water temperature, continuous dissolved oxygen, and grab samples for water quality constituents. The water surface elevation and continuous water temperature data were used to calibrate the hydrodynamics and heat transport simulation. Continuous dissolved oxygen and other discrete water quality data were used for water quality calibration. Calibration was performed at multiple locations throughout the system. Table 3-1 lists the locations of the monitoring sites with continuous dissolved oxygen and temperature data as well as the EFDC grid IDs. Tables 3-2 and 3-3 list the years with temperature and dissolved oxygen data for the continuous monitoring sites. Table 3-4 lists the monitoring sites for the grab samples and the corresponding EFDC grid IDs. Figure 3-1 shows the monitoring locations on the NSR.

Table 3-1. Monitoring locations for continuous dissolved oxygen and temperature data

Site locations	EFDC grid ID
NSR at Devon	362
NSR u-s Capital region WWTP	429
NSR at Fort Saskatchewan Boat Launch	439
NSR at Hwy 15 Bridge	442
NSR u-s of Ft. Sask RR Trestle	449
NSR d-s of Ft. Sask RR Trestle	451
NSR at Vinca	471
NSR at Pakan	520
NSR at Lea Park	714

Table 3-2. Years with continuous temperature data at the monitoring locations

Site locations	2001	2002	2003	2004	2005	2006	2007
NSR at Devon	×	×	×	×	×	×	×
NSR u-s Capital region WWTP					×	×	×
NSR at Fort Saskatchewan Boat Launch					×	×	×
NSR at Hwy 15 Bridge			×	×			
NSR u-s of Ft. Sask RR Trestle	×						
NSR d-s of Ft. Sask RR Trestle	×						
NSR at Vinca				×	×		×
NSR at Pakan	×	×	×	×	×	×	×
NSR at Lea Park		×	×	×			

Table 3-3. Years with continuous dissolved oxygen data at the monitoring locations

Site locations	2001	2002	2003	2004	2005	2006	2007
NSR at Devon	×	×	×	×	×	×	×
NSR u-s Capital region WWTP					×	×	×
NSR at Fort Saskatchewan Boat Launch					×	×	×
NSR at Hwy 15 Bridge			×	×			
NSR u-s of Ft. Sask RR Trestle	×						
NSR d-s of Ft. Sask RR Trestle	×						
NSR at Vinca				×		×	×
NSR at Pakan	×	×	×	×	×	×	×
NSR at Lea Park		×	×	×			

Table 3-4. Monitoring locations for the grab samples used in water quality calibration

Site locations	EFDC grid ID
NSR at upstream of ROCKY MOUNTAIN HOUSE	99
NSR at DEVON	362
NSR at ANTHONY HENDAY	383
NSR at WALTERDALE	403
NSR at 50STREET	411
NSR at RUNDLE	416
NSR at upstream of FORT SASKATCHEWAN	442
NSR at VINCA	471
NSR at WASKATENAU	497
NSR at PAKAN	520
NSR at HWY17	742

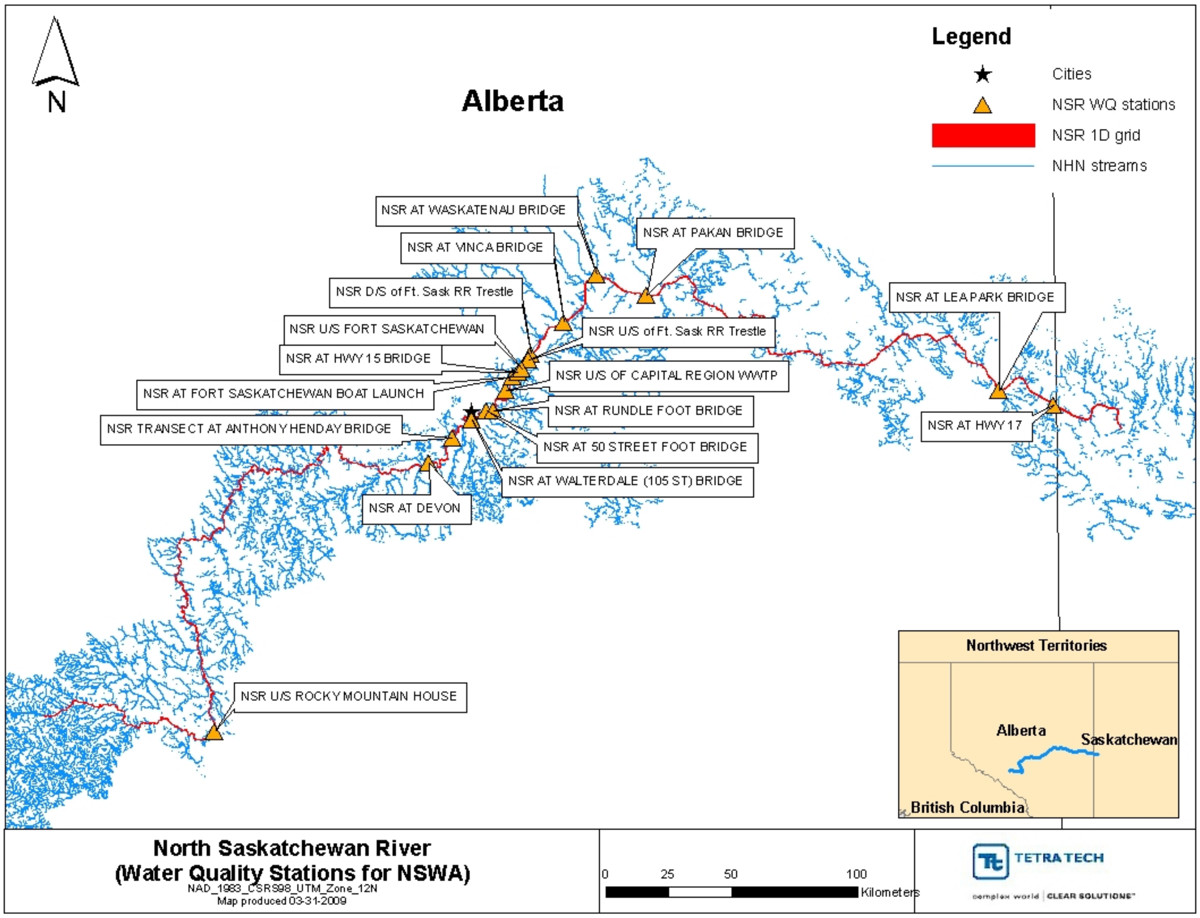

Figure 3-1. Water quality stations used for calibration.

3.2 Hydrodynamic Calibration and Validation

Water surface elevations were first examined to ensure correct configuration of slope, width, and roughness coefficients. Three flow stations are in the modeling domain (Rocky Mountain House, Edmonton, and Deer Creek) and have water surface elevation data from 2007 to 2008. The observed elevations were adjusted from the local datum to the sea level datum and then compared with modeled elevations. Figures 3-2 through 3-4 show the comparison of modeled and observed water surface elevations. In general, the modeled elevations agree well with the observed elevations during non-frozen seasons. Time series error measures for these three locations are shown in Table 3-5. The error measures are defined in Appendix A

Table 3-5. Water surface elevation error measures

Location	Mean of observations (meters)	Mean Error (meters)	Relative Mean Error	Mean Absolute Error (meters)	Relative Mean Absolute Error	Root Mean Square Error (meters)
Rocky MH	949.72	-0.079	-0.00008	0.083	0.00009	0.097
Edmonton	614.18	-0.080	-0.00013	0.145	0.00024	0.286
Deer Creek	489.81	-0.027	-0.00006	0.160	0.00033	0.287

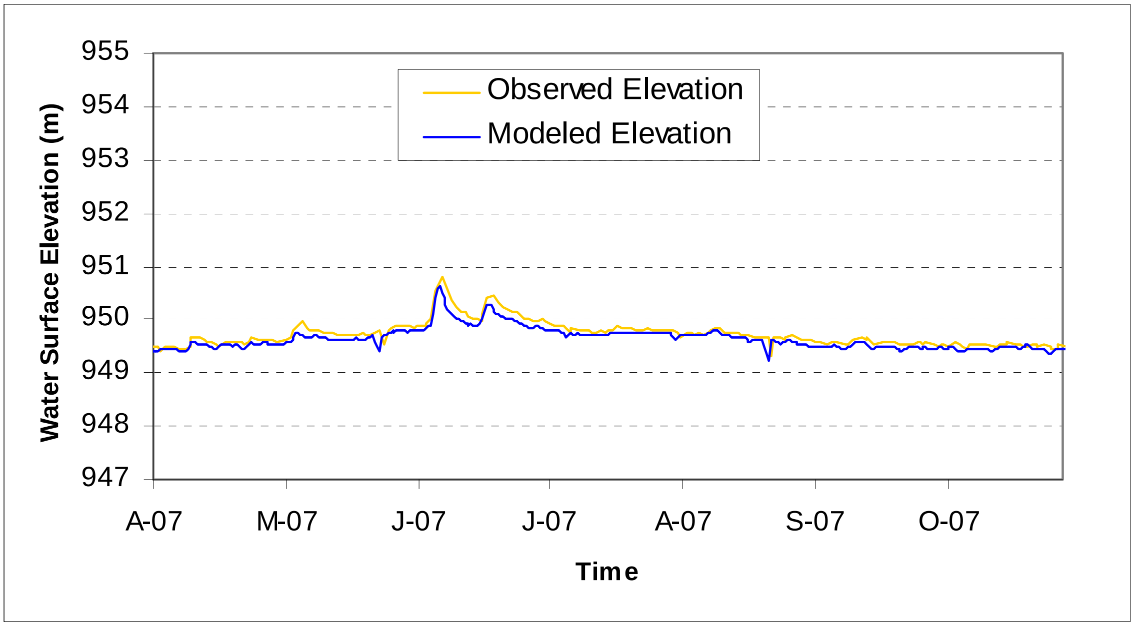

Figure 3-2. Modeled and observed water surface elevations at Rocky Mountain House.

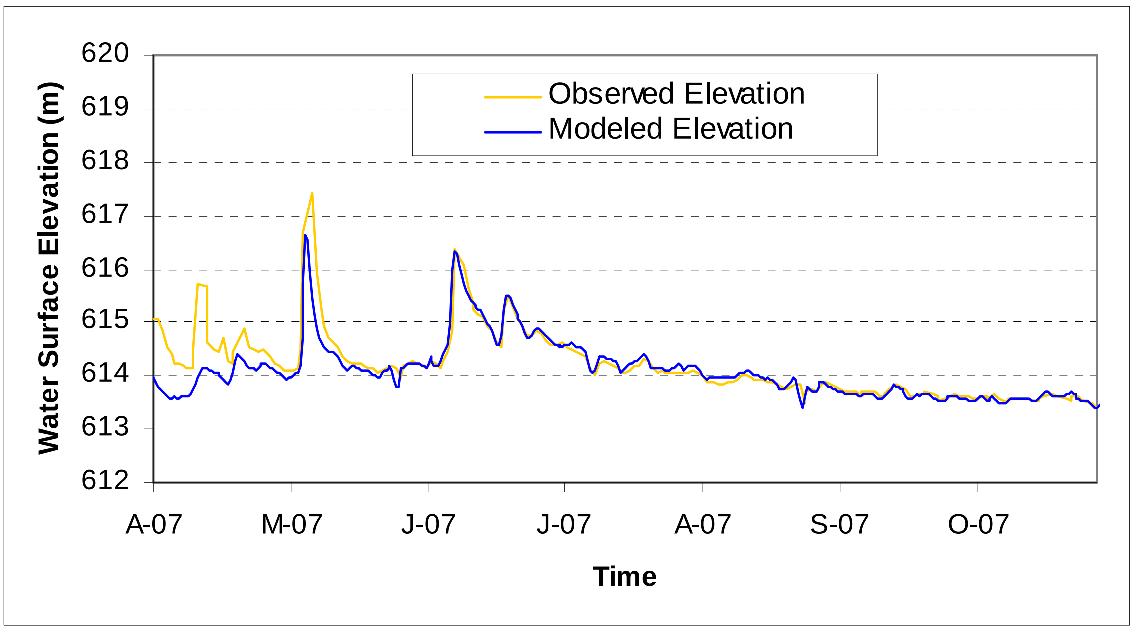

Figure 3-3. Modeled and observed water surface elevations at Edmonton.

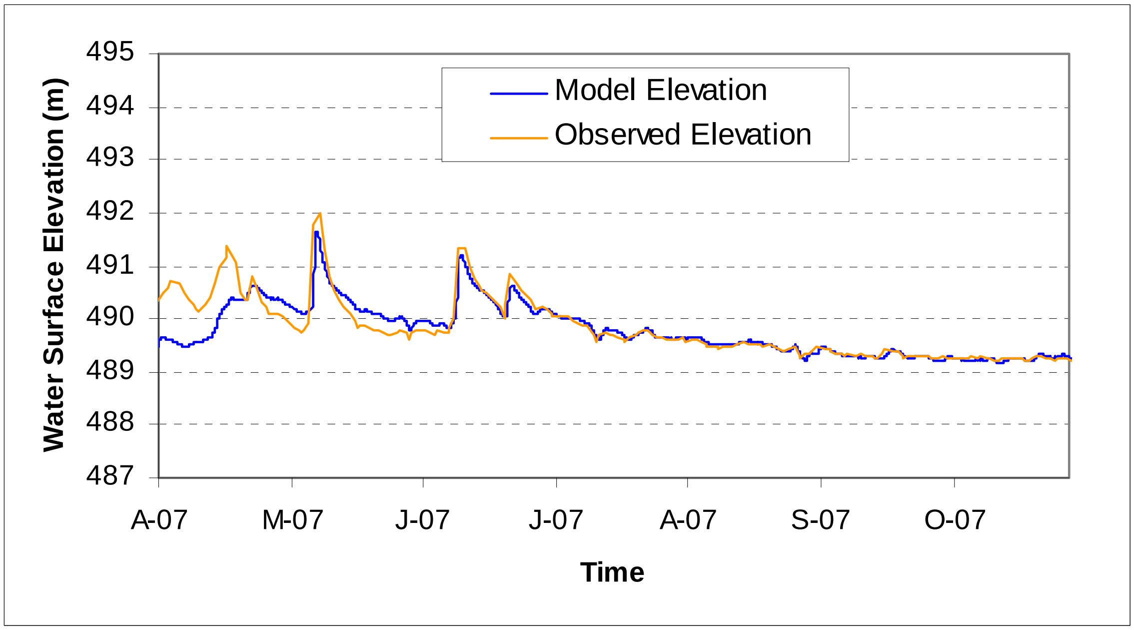

Figure 3-4. Modeled and observed water surface elevations at Deer Creek.

Water temperature strongly affects the chemical and biological reaction rates in the water column and is critical for accurate water quality simulation. Water temperature was evaluated to ensure correct heat transport in the NSR. Nine datasonde stations measured water temperature using a 15-minute recording interval from 2001 to 2007 as shown in Tables 3-1 and 3-2. Modeled water temperatures were compared to these data. Modeled water temperature is affected by the water temperature from the upstream and tributary inflows as well as weather conditions, including air temperature and solar radiation. Solar radiation reaching the water surface is strongly affected by the light attenuation in air, especially through cloud cover, which is highly variable in both space and time. The model was run with unadjusted solar radiation first and the results were compared with observed data. Solar radiation was adjusted to increase by 20 percent to achieve better temperature results.

Appendix B shows the comparison of modeled water temperature versus observed water temperature for eight datasonde stations. The 15 minute interval observational data was hourly averaged for comparison with the model predictions. Error measures are shown in Table 3-6. In general, the modeled water temperature results agree well with observed data. There are discrepancies between measured and modeled water temperature on some occasions, and these are primarily related to the boundary conditions for heat transport. The observed data have finer temporal resolution than the boundary conditions (e.g., for weather data and water temperature from upstream boundaries and tributaries). Given the highly spatial and temporal variable nature of weather, the weather stations are not able to capture all the local conditions.

Table 3-6. Datasonde station hourly averaged temperature error measures

Location	Mean of observations (°C)	Mean Error (°C)	Relative Mean Error	Mean Absolute Error (°C)	Relative Mean Absolute Error	Root Mean Square Error (°C)
Devon	10.782	0.885	0.082	0.995	0.092	1.377
Upstrm Capital Region WWTP	7.864	0.529	0.067	0.673	0.086	1.007
Ft. Saskatchewan	9.304	0.690	0.074	0.756	0.081	1.119
Upstrm HWY 15	11.649	0.767	0.066	0.957	0.082	1.430
Upstrm of RR Trestle	15.504	0.878	0.057	1.130	0.073	1.336
Downstrm of RR Trestle	15.589	0.672	0.043	0.840	0.054	0.990
Vinca	10.481	1.032	0.098	1.078	0.103	1.504
Pakan	11.508	0.585	0.051	0.794	0.069	1.114

3.3 Water Quality Calibration

Water quality was calibrated after hydrodynamics and heat transport. Water quality calibration involved examining the major reaction parameters and adjusting the parameters until model results agreed with the data. The model simulates phytoplankton, RPOC, LPOC, DOC, RPOP, LPOP, DOP, PO_4, RPON, LPON, DON, NH_3, NO_2/NO_3, DO, and benthic algae. The major parameters adjusted include the ammonia nitrification rate, organic carbon dissolution rates, organic phosphorus hydrolysis rates, and algae growth, death, and respiration rates.

Calibration focused on comparing modeled and observed DO. DO is a key water quality indicator and is affected by various processes such as water temperature, reaeration, organic carbon decay, nitrification, and algae growth and death. Strong swings of DO within a day usually imply that there is a high level of algae in the water column or on the river bottom. Calibration of the NSR model involved selecting the proper reaeration formula and specifying reasonable reaction rates, growth rates, and respiration rates of phytoplankton and benthic algae. These parameters were adjusted after comparing the model results to the observed data until the model results and observed data agreed well. Table 3-7 lists the mapping between EFDC output variables and the monitored water quality constituents. Table 3-8 lists the calibrated values for the major parameters for water quality simulation. Appendix C shows DO results at the continuous datasonde stations. The 15 minute interval dissolved oxygen observations where hourly averaged for comparison with model predictions, and calculation of error measures are shown in Table 3-9. Observed and model predicted daily dissolved oxygen ranges or fluctuations were determined and used to calculate the daily dissolved oxygen fluctuation error measures presented in Table 3-10. Appendix D presents time series plots and error measures for the modeled water quality constituents in Table 3-7 at locations in Table 3-4. Note that not all the stations have all the data in Table 3-7. Appendix D still includes the model results for such locations.

The figures in Appendix C show that the model is able to capture major trends, including DO swings due to high levels of phytoplankton or benthic algae. In cold weather, when water is covered with ice, modeled DO shows a stable level because of the very low algae metabolism rates at low water temperatures, no reaeration, and low bacteria activity that decays organic carbon or nitrifying ammonia. The observed data show slight fluctuation under ice-cover conditions. This could be because there are still algae impacts and water temperature changes within a small range. In warm weather, phytoplankton or benthic algae start growing fast, and DO in the water column responds strongly. The model accurately reproduced such growing patterns in most of the stations in the NSR. At some stations, observed data showed stronger swings of DO than what the model is capable of generating. This might be because the model uses average depth for each model grid, and benthic algae can be very sensitive to the depth of water.

The figures in Appendix D provide supplemental information on model performance. The figures show that the modeled water quality constituents agree well with the observed data. Seasonal variation of nutrients is captured, and the modeled water quality constituents are in reasonable ranges. The model also captures the levels of the dissolved and total organic carbon. Because of the uncertainties and limitations listed earlier, an exact match between model results and observed data is not expected.

Table 3-7. Mapping table between EFDC output variables and monitored water quality constituents

EFDC output variables	Monitored water quality constituents
NHX	AMMONIA
DOC	DOC
ROC + LOC	POC
DOC + ROC+LOC	TOC
MAC × 16.7	chla_epi
CHC × 22.0	Chla
NOX	NO23
RON + LON	PN
RON + LON + DON + NHX + NOX	TN
DOX	DO
P4D	PO4
ROP + LOP	PP
ROP + LOP + DOP	TP
P4D + DOP	TDP

Table 3-8. Major EFDC water quality parameters

EFDC parameters	Calibrated values
Minimum dissolution rate (1/day) of RPOC	0.002
Minimum dissolution rate (1/day) of LPOC	0.045
Minimum dissolution rate (1/day) of DOC	0.050
Maximum nitrification rate (gN/m^3/day)	0.500
Nitrogen half-saturation for phytoplankton (mg/L)	0.030
Nitrogen half-saturation for benthic algae (mg/L)	0.030
Phosphorus half-saturation for phytoplankton (mg/L)	0.003
Phosphorus half-saturation for benthic algae (mg/L)	0.003
Optimal depth (m) for benthic algae growth	0.250
Maximum growth rate for phytoplankton (1/day)	1.500
Maximum growth rate for benthic algae (1/day)	1.500
Basal metabolism rate for phytoplankton (1/day)	0.040
Basal metabolism rate for benthic algae (1/day)	0.040
Predation rate on phytoplankton (1/day)	0.215
Predation rate on benthic algae (1/day)	0.215
Settling velocity for phytoplankton (m/day)	0.150
Sediment oxygen demand at 20oC (g/m^2/d)	0.700

mg/L = milligrams per liter

Table 3-9. Datasonde station hourly averaged dissolved oxygen error measures

Location	Mean of observations (mg/l)	Mean Error (mg/l)	Relative Mean Error	Mean Absolute Error (mg/l)	Relative Mean Absolute Error	Root Mean Square Error (mg/l)
Devon	9.994	0.221	0.022	0.580	0.058	0.698
Upstrm Capital Region WWTP	11.138	0.229	0.021	1.109	0.100	1.466
Ft. Saskatchewan	10.787	0.259	0.024	0.970	0.090	1.310
Upstrm HWY 15	10.059	1.474	0.147	1.534	0.153	1.924
Upstrm of RR Trestle	9.619	3.551	0.369	3.795	0.395	4.147
Downstrm of RR Trestle	9.619	3.625	0.377	3.858	0.401	4.228
Vinca	10.140	1.030	0.102	1.627	0.160	2.036
Pakan	9.922	0.565	0.057	1.119	0.113	1.338
Lea Park	8.877	2.658	0.299	2.658	0.299	2.766

Table 3-10. Datasonde station daily dissolved oxygen fluctuation error measures

Location	Mean of observations (mg/l)	Mean Error (mg/l)	Relative Mean Error	Mean Absolute Error (mg/l)	Relative Mean Absolute Error	Root Mean Square Error (mg/l)
Devon	0.287	-0.192	-0.669	0.198	0.691	0.254
Upstrm Capital Region WWTP	2.699	-2.082	-0.771	2.163	0.802	2.739
Ft. Saskatchewan	1.849	-1.267	-0.685	1.383	0.748	1.783
Upstrm HWY 15	1.037	0.772	0.745	1.096	1.057	1.390
Upstrm of RR Trestle	6.194	-2.606	-0.421	2.635	0.425	3.269
Downstrm of RR Trestle	6.194	-3.002	-0.485	3.002	0.485	3.580
Vinca	1.832	-1.539	-0.840	1.656	0.904	2.380
Pakan	1.083	-0.900	-0.831	0.925	0.854	1.352
Lea Park	0.164	-0.132	-0.803	0.132	0.807	0.156

3.4 Recommendations for Model Performance Enhancement

Although the model generally simulates observed trends in the data well, model predictions could be improved through the following mechanisms:

- For a river system such as the NSR, loadings from the watershed tributaries play an important role in providing nutrients and organic carbon. In the NSR model, loadings from the major tributaries are based on either a constant, multiyear average or monthly average values because of data limitations. Because water quality monitoring is very time-consuming and costly, developing a watershed model is recommended to provide more reasonable time-variable loadings throughout the basin. A watershed model can also provide a better flow balance throughout the river system.
- As the NSR flows through the Capital Region, the point sources contribute significant amounts of organic carbon and nutrients. Point source discharges that are reported regularly can provide more consistent loading for model analysis.

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Appendix A. Time Series Error Measures

A variety of time series error measures have been used to quantify model performance (US EPA, 1990; Tetra Tech, 2006d). Three widely used error measures are defined here. Using O to denote observations and P to denote model predictions at the corresponding locations and times, the means of the observed and predicted variables for N observations at a single or multiple observation stations is given by:

$$\bar{O} = \frac{1}{N}\sum_{n=1}^{N} O_n \qquad \text{(A.1)}$$

$$\bar{P} = \frac{1}{N}\sum_{n=1}^{N} P_n \qquad \text{(A.2)}$$

The mean error of the model predictions is given by:

$$ME = \bar{P} - \bar{O} \qquad \text{(A.3)}$$

and is often referred to as the mean bias error and also written as observed minus predicted. Tabulation of the observed and predicted means is an alternate to eliminating confusion regarding the sign convention. The mean error is a measure of systematic model over or under prediction. It is noted that the *MBE* can be small in situations where there is large disagreement between predictions and observations. The mean absolute error:

$$MAE = \frac{1}{N}\sum_{n=1}^{N} \left| P_n - O_n \right| \qquad \text{(A.4)}$$

and the root mean square error:

$$RMSE = \sqrt{\frac{1}{N}\sum_{n=1}^{N} \left(P_n - O_n \right)^2} \qquad \text{(A.5)}$$

provide measures of the average differences between predictions and observations without regard to over or under prediction.

Normalization of the MBE, MAE and RMSE is often useful in facilitating the comparison of model performance between different application sites. The mean error may be normalized to define a fractional or relative mean error:

$$RME = \frac{\bar{P} - \bar{O}}{\bar{O}} \qquad \text{(A.6)}$$

with the choice of the denominator not being unique in the literature. The choice for normalization of the MAE is even less unique. Two possible choices are:

$$RMAE_O = \frac{MAE}{\bar{O}} \tag{A.7a}$$

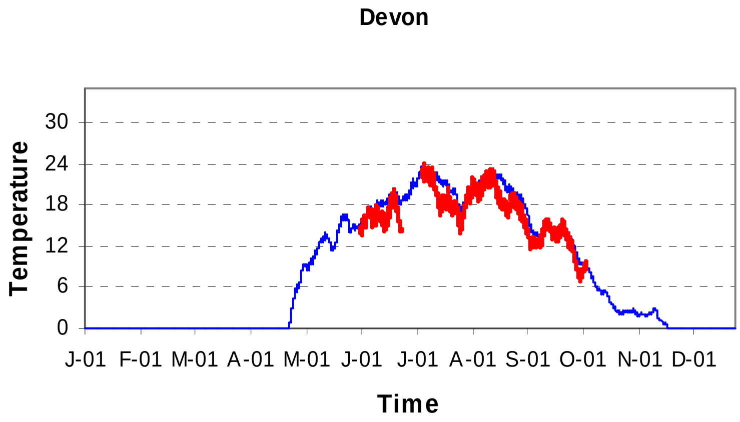
$$RMAE_{|O|} = \frac{MAE}{\frac{1}{N}\sum_{n=1}^{N}|O_n|} \tag{A.7b}$$

which are equivalent for positive observation variables. A logical choice for the fractional or relative RMSE is:

$$FRMSE = \frac{RMSE}{\sqrt{\frac{1}{N}\sum_{n=1}^{N}O_n^2}} \tag{A.8}$$

Additional error measures are summarized in Tetra Tech (2006d).

Appendix B. Water Temperature Plots


Devon
Temperature
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18
12
6
0
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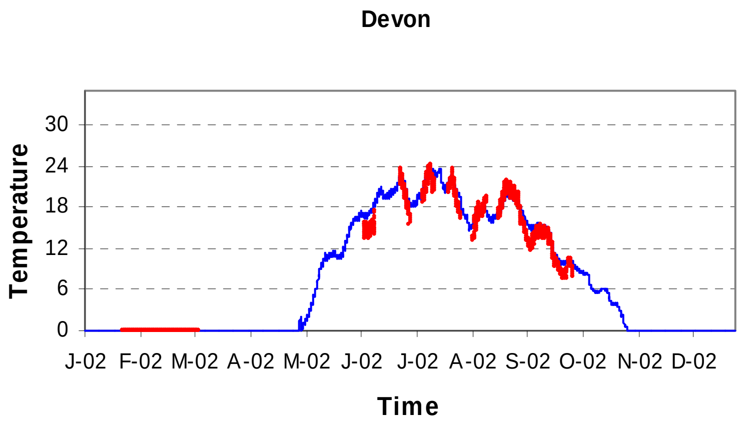
Time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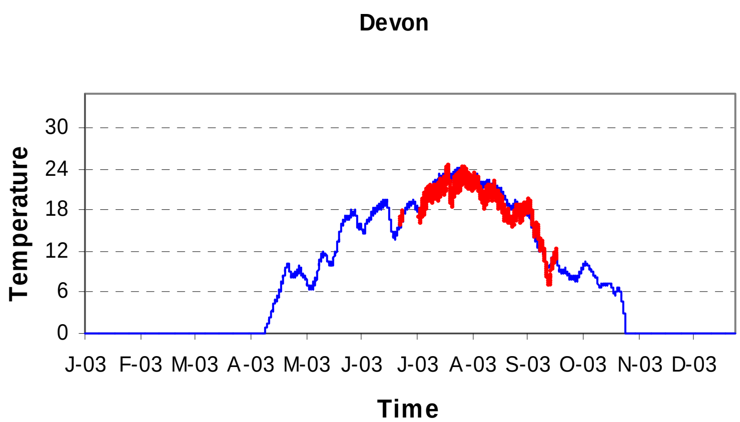
18
12
6
0
J-02 F-02 M-02 A-02 M-02 J-02 J-02 A-02 S-02 O-02 N-02 D-02
Time


Devon
Temperature
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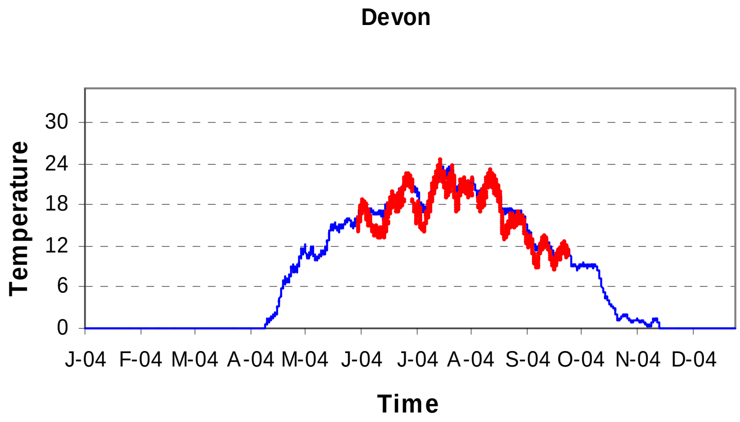
24
18
12
6
0
J-03 F-03 M-03 A-03 M-03 J-03 J-03 A-03 S-03 O-03 N-03 D-03
Time


Devon
Temperature
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24
18
12
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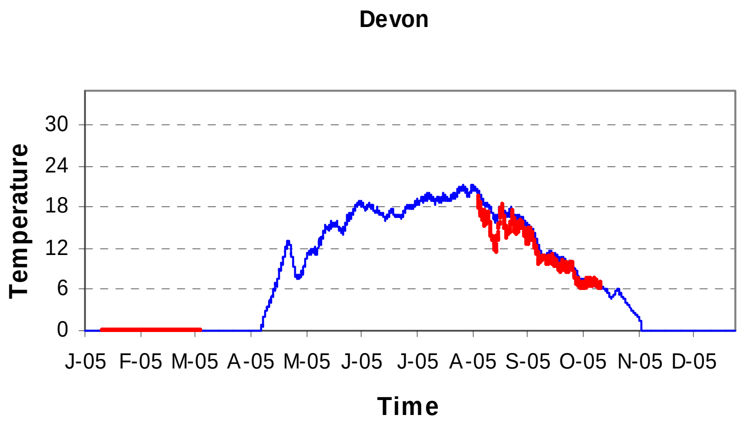
Time


Devon
Temperature
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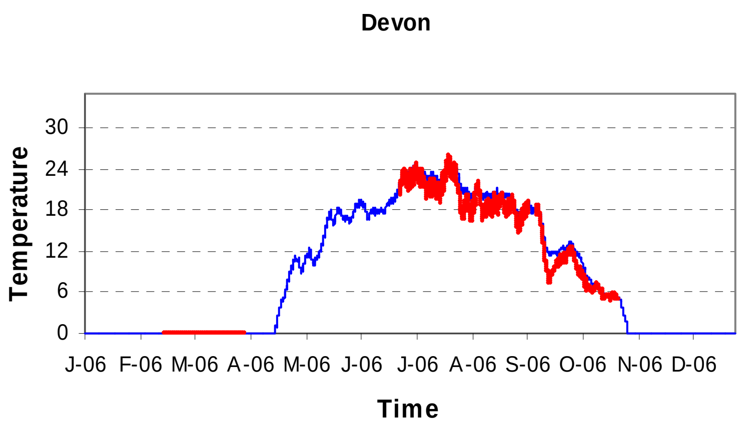
Time


Devon
Temperature
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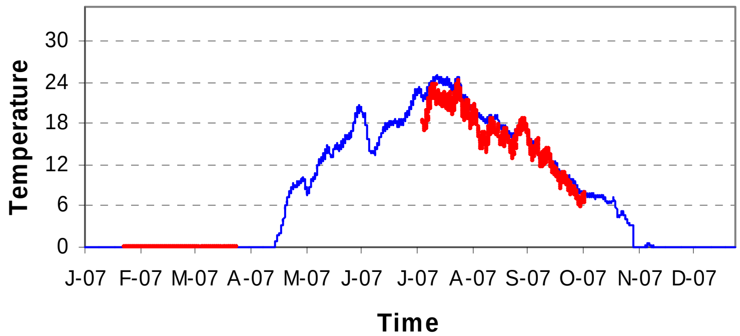
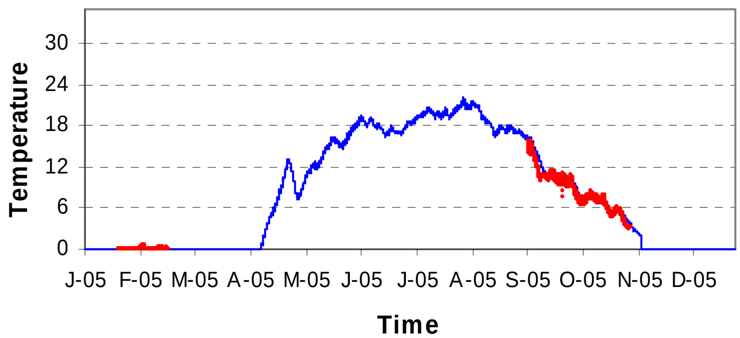
Time

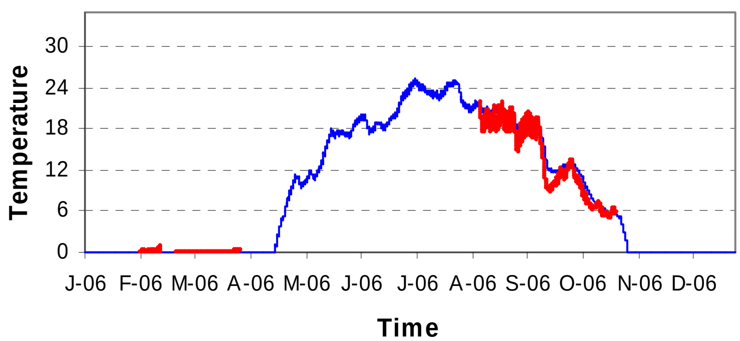
Devon

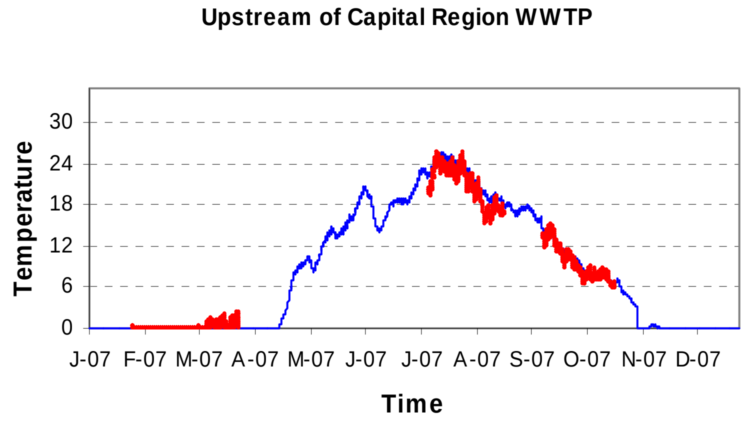


Upstream of Capital Region WWTP



Upstream of Capital Region WWTP




Upstream of Capital Region WWTP
Temperature
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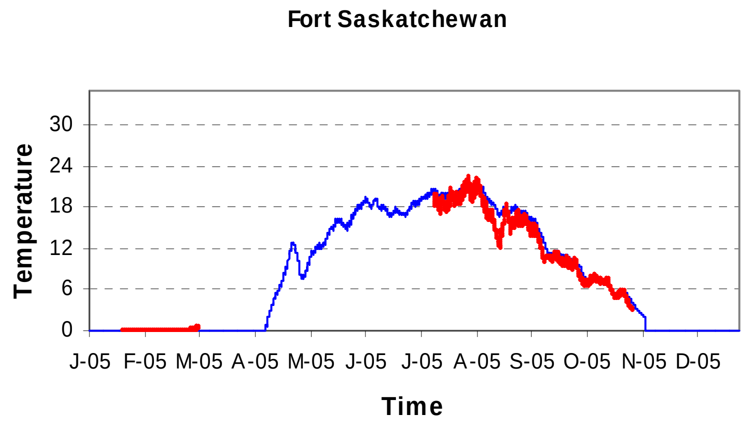
J-07 F-07 M-07 A-07 M-07 J-07 J-07 A-07 S-07 O-07 N-07 D-07
Time


Fort Saskatchewan
Temperature
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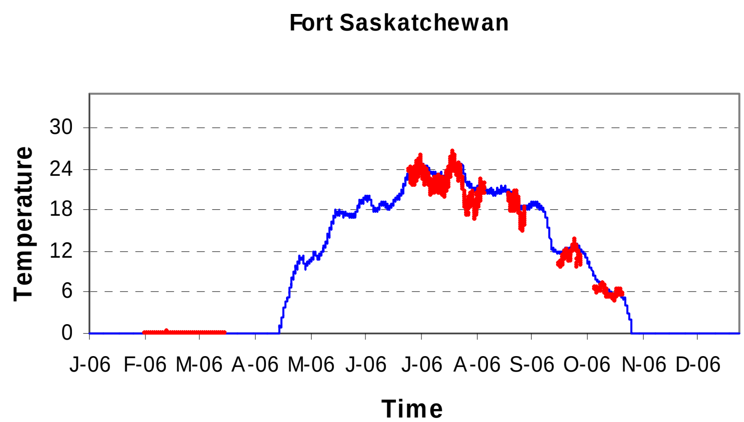
Time


Fort Saskatchewan
Temperature
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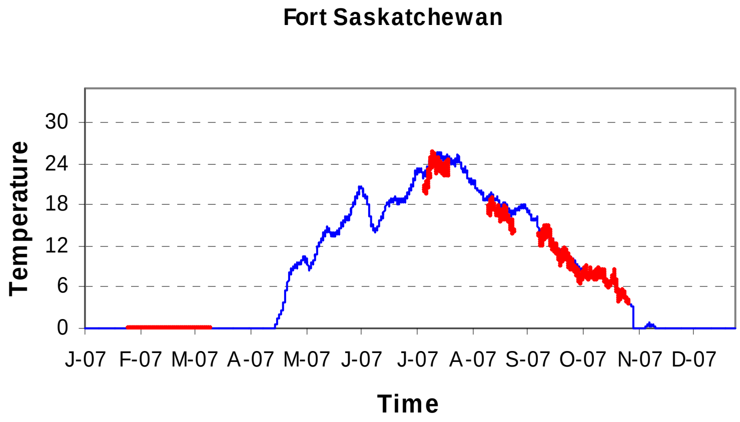
Time


Fort Saskatchewan
Temperature
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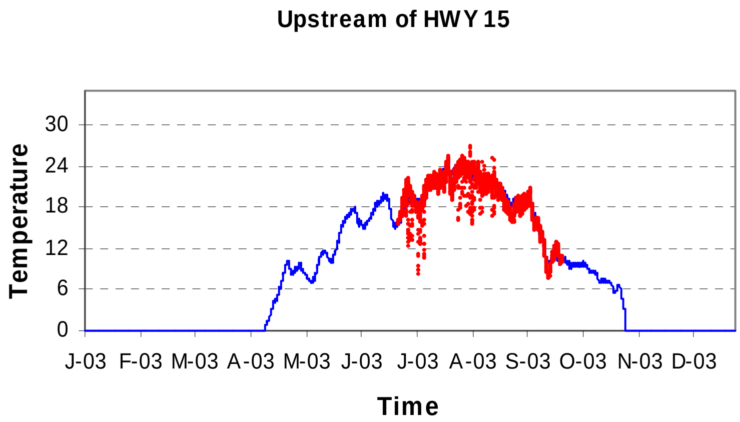
Time


Upstream of HWY 15
Temperature
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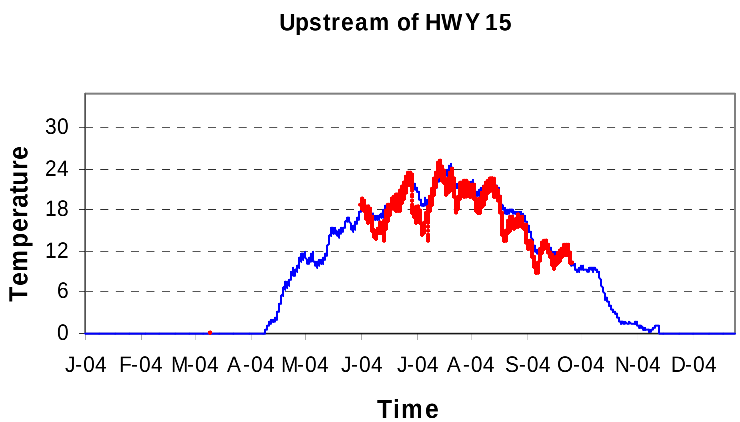
Time


Upstream of HWY 15
Temperature
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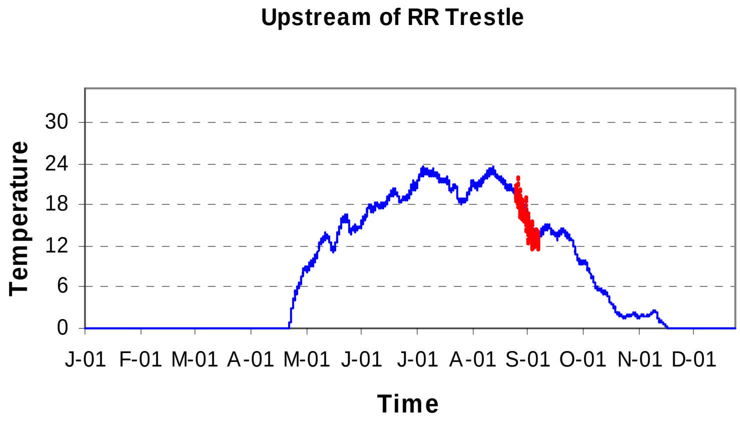
Time


Upstream of RR Trestle
Temperature
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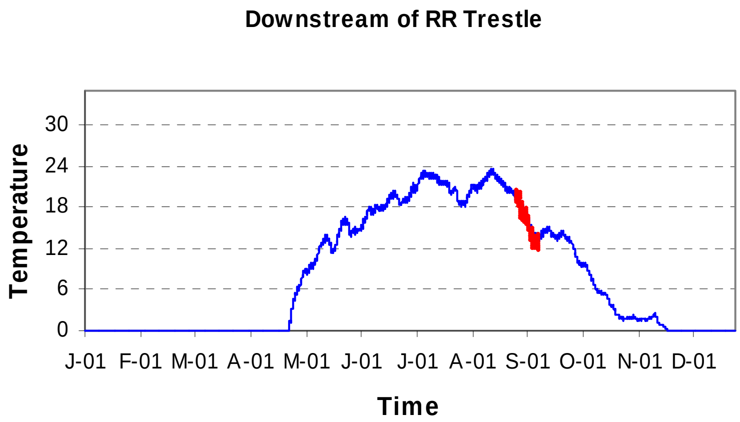
Time


Downstream of RR Trestle
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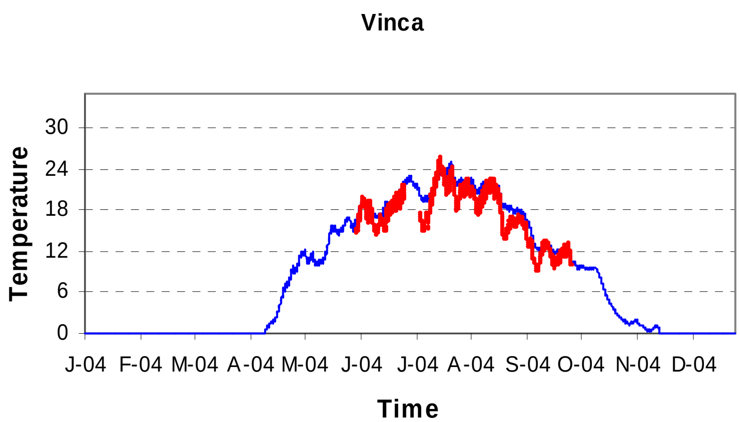
Time


Vinca
Temperature
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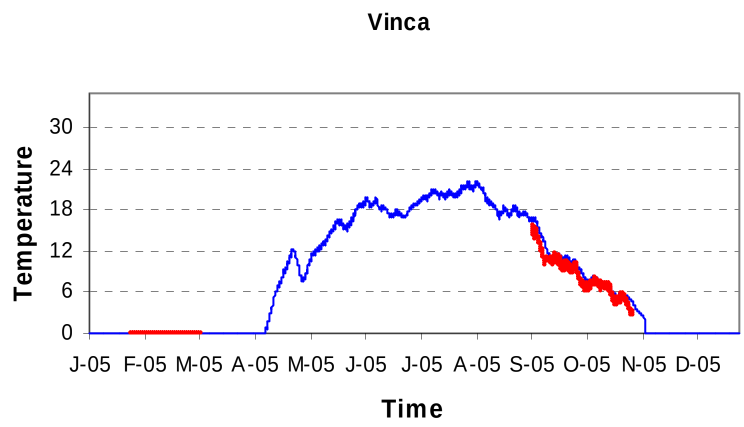
Time


Vinca
Temperature
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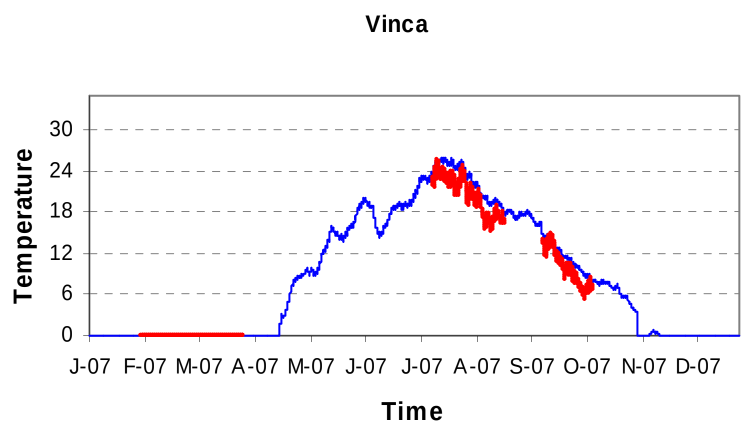
Time


Vinca
Temperature
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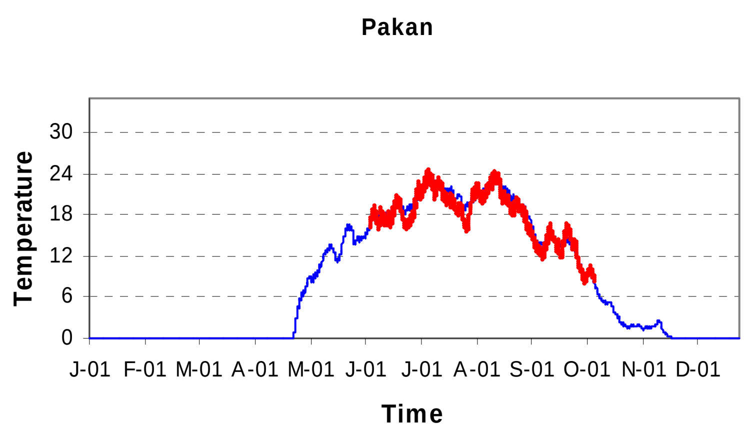
Time


Pakan
Temperature
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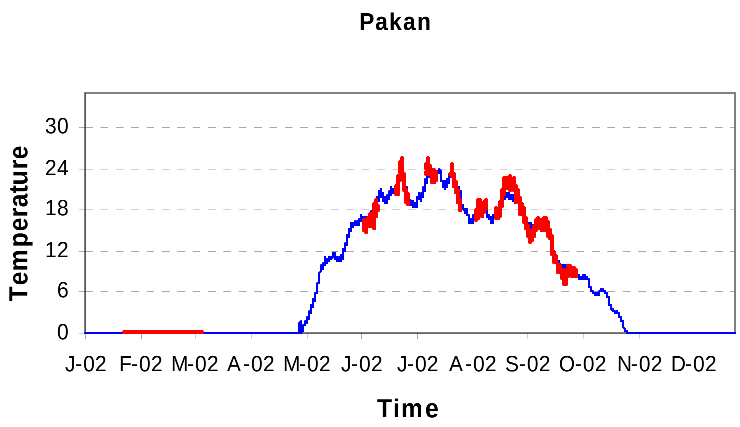
J-01 F-01 M-01 A-01 M-01 J-01 J-01 A-01 S-01 O-01 N-01 D-01
Time


Pakan
Temperature
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12
6
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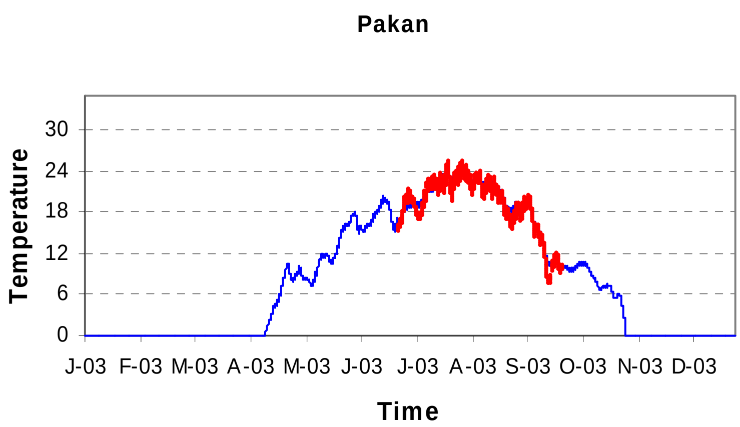
Time


Pakan
Temperature
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24
18
12
6
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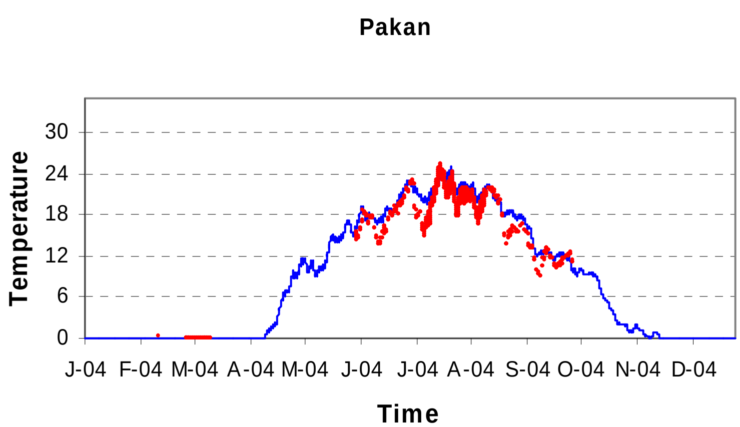
Time


Pakan
Temperature
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24
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12
6
0
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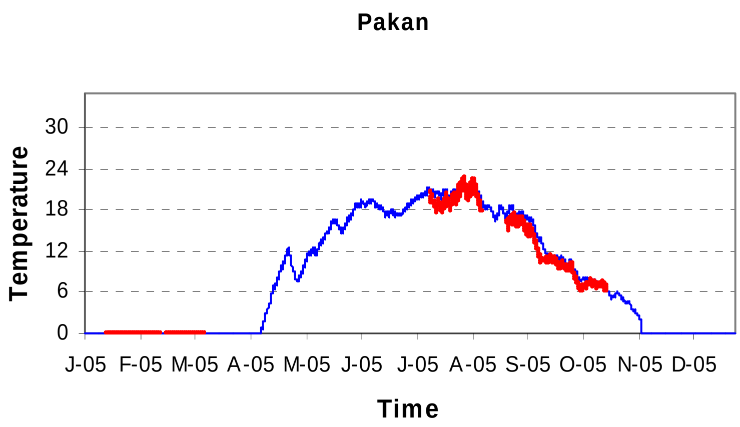
Time


Pakan
Temperature
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12
6
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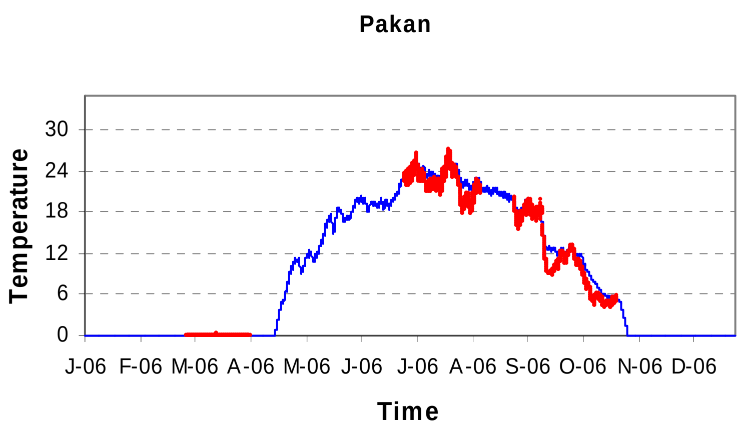
J-05 F-05 M-05 A-05 M-05 J-05 J-05 A-05 S-05 O-05 N-05 D-05
Time


Pakan
Temperature
30
24
18
12
6
0
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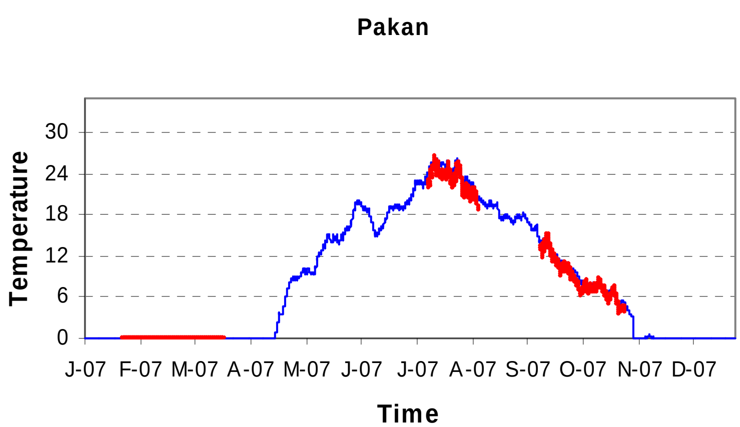
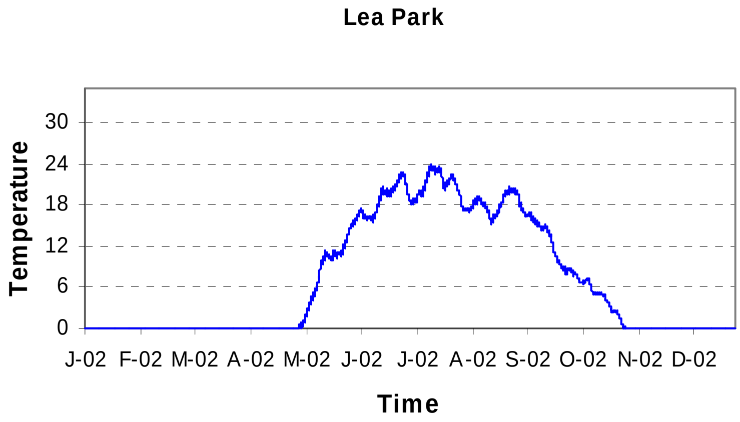
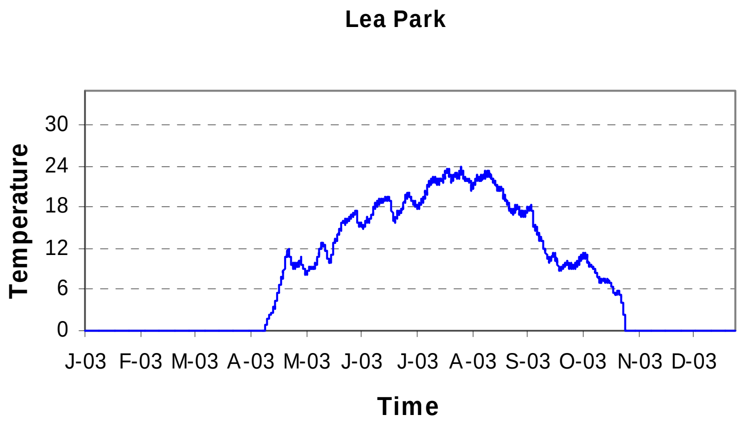
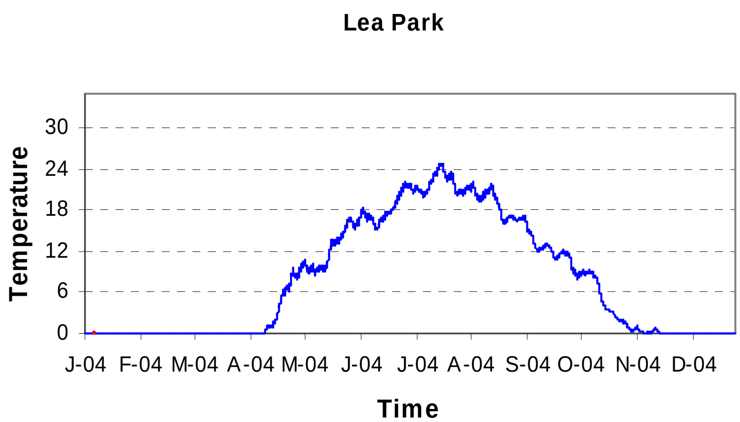
Time


Pakan
Temperature
30
24
18
12
6
0
J-07 F-07 M-07 A-07 M-07 J-07 J-07 A-07 S-07 O-07 N-07 D-07
Time


Lea Park
Temperature
30
24
18
12
6
0
J-02 F-02 M-02 A-02 M-02 J-02 J-02 A-02 S-02 O-02 N-02 D-02
Time


Lea Park
Temperature
30
24
18
12
6
0
J-03 F-03 M-03 A-03 M-03 J-03 J-03 A-03 S-03 O-03 N-03 D-03
Time


Lea Park
Temperature
30
24
18
12
6
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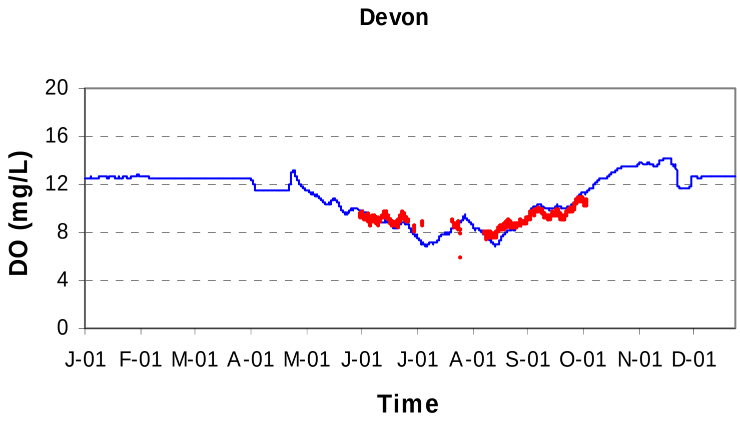
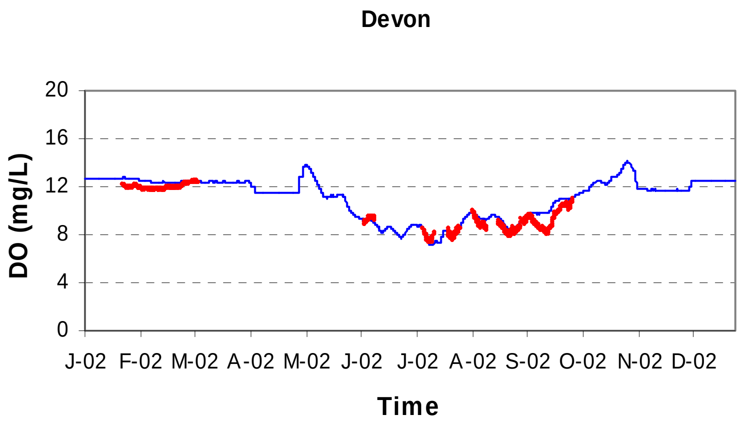
J-04 F-04 M-04 A-04 M-04 J-04 J-04 A-04 S-04 O-04 N-04 D-04
Time

Appendix C. Dissolved Oxygen Plots


Devon
DO (mg/L)
20
16
12
8
4
0
J-01 F-01 M-01 A-01 M-01 J-01 J-01 A-01 S-01 O-01 N-01 D-01
Time


Devon
DO (mg/L)
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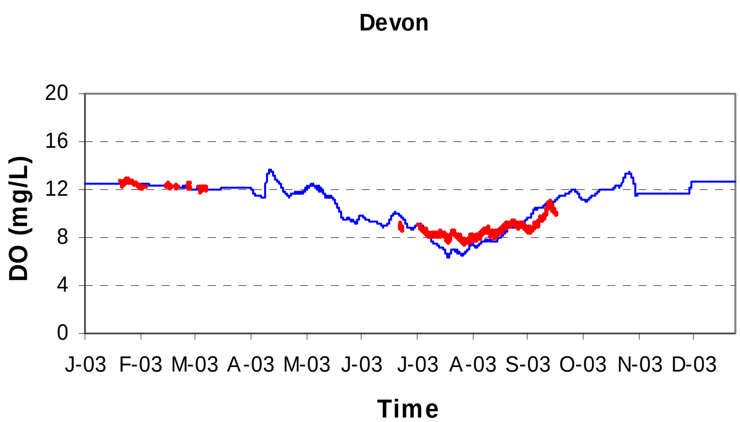
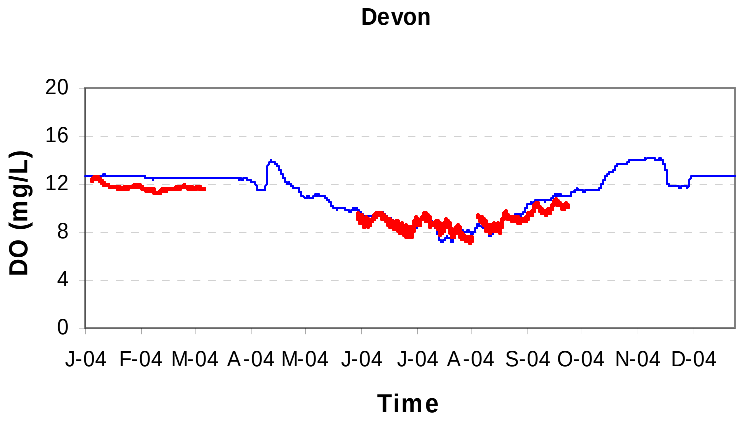
16
12
8
4
0
J-02 F-02 M-02 A-02 M-02 J-02 J-02 A-02 S-02 O-02 N-02 D-02
Time


Devon
DO (mg/L)
20
16
12
8
4
0
J-03 F-03 M-03 A-03 M-03 J-03 J-03 A-03 S-03 O-03 N-03 D-03
Time


Devon
DO (mg/L)
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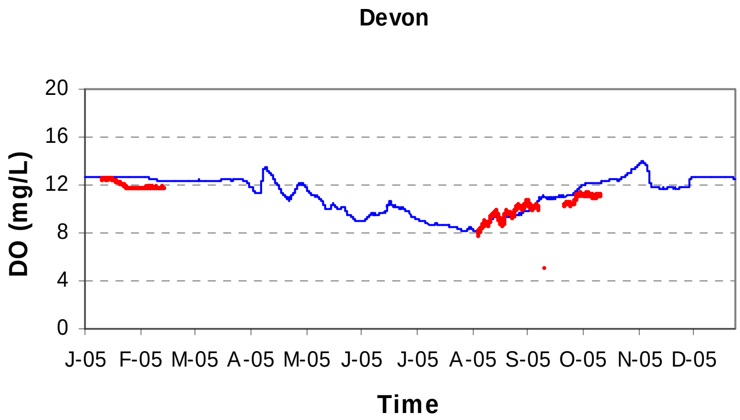
16
12
8
4
0
J-04 F-04 M-04 A-04 M-04 J-04 J-04 A-04 S-04 O-04 N-04 D-04
Time


Devon
DO (mg/L)
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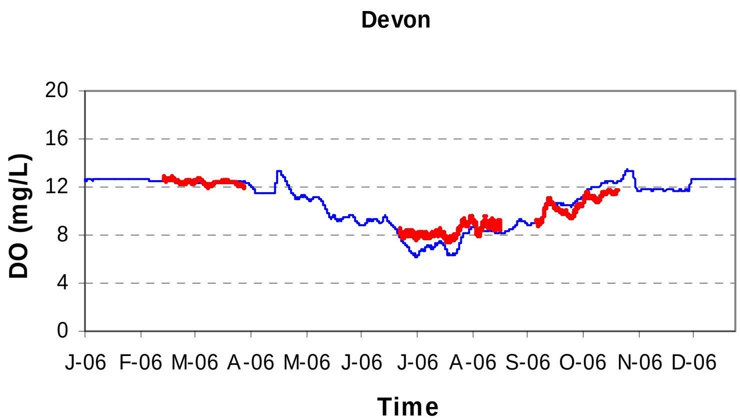
16
12
8
4
0
J-05 F-05 M-05 A-05 M-05 J-05 J-05 A-05 S-05 O-05 N-05 D-05
Time


Devon
DO (mg/L)
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16
12
8
4
0
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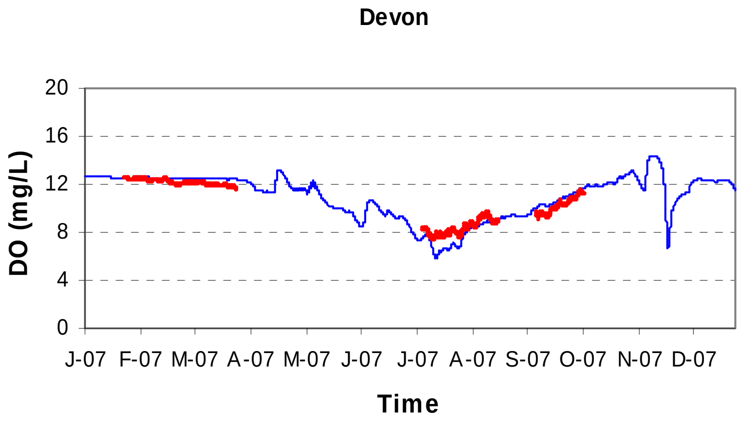
Time


Devon
20
16
12
8
4
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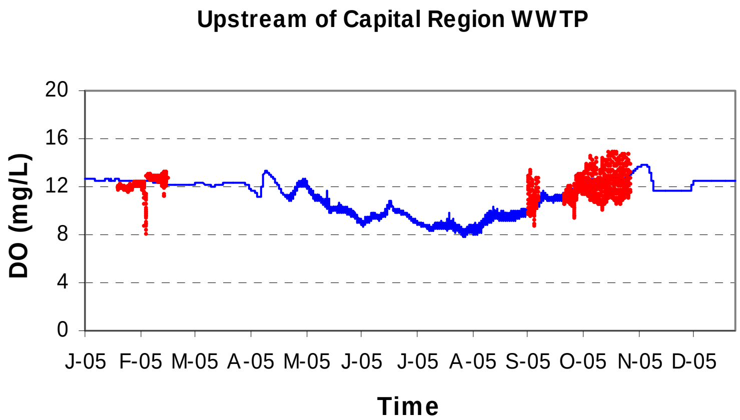
DO (mg/L)
J-07 F-07 M-07 A-07 M-07 J-07 J-07 A-07 S-07 O-07 N-07 D-07
Time


Upstream of Capital Region WWTP
20
16
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8
4
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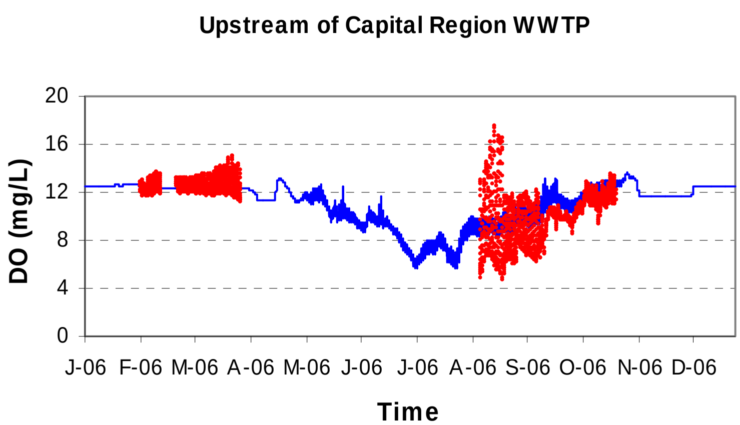
DO (mg/L)
J-05 F-05 M-05 A-05 M-05 J-05 J-05 A-05 S-05 O-05 N-05 D-05
Time


Upstream of Capital Region WWTP
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16
12
8
4
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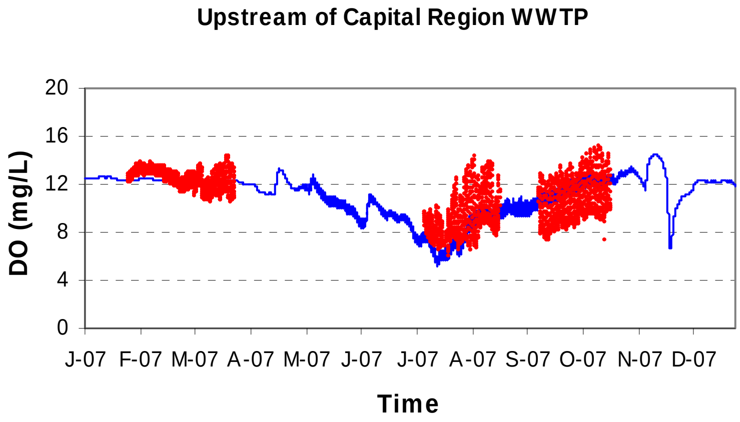
DO (mg/L)
J-06 F-06 M-06 A-06 M-06 J-06 J-06 A-06 S-06 O-06 N-06 D-06
Time


Upstream of Capital Region WWTP
DO (mg/L)
20
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4
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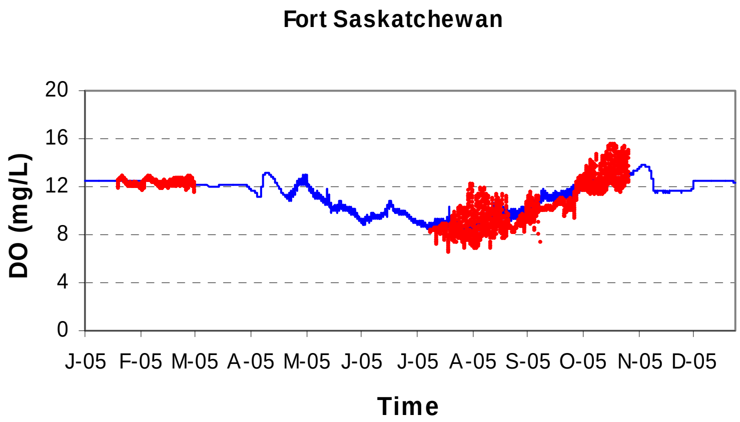
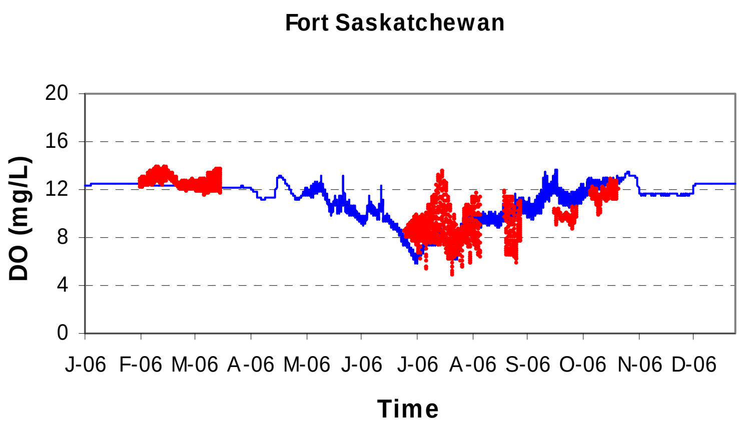
J-07 F-07 M-07 A-07 M-07 J-07 J-07 A-07 S-07 O-07 N-07 D-07
Time


Fort Saskatchewan
DO (mg/L)
20
16
12
8
4
0
J-05 F-05 M-05 A-05 M-05 J-05 J-05 A-05 S-05 O-05 N-05 D-05
Time


Fort Saskatchewan
DO (mg/L)
20
16
12
8
4
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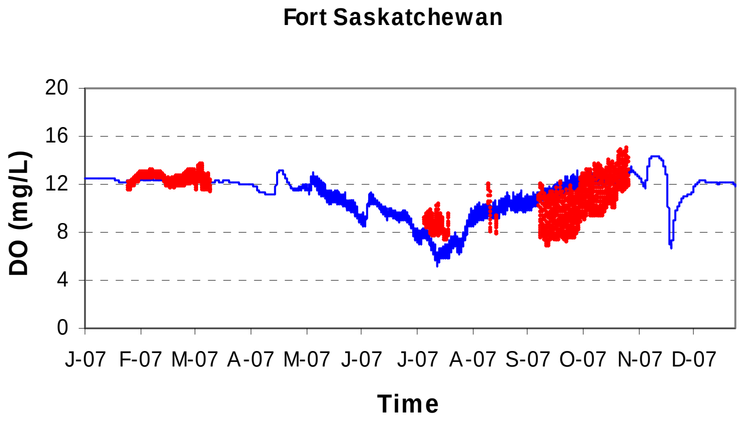
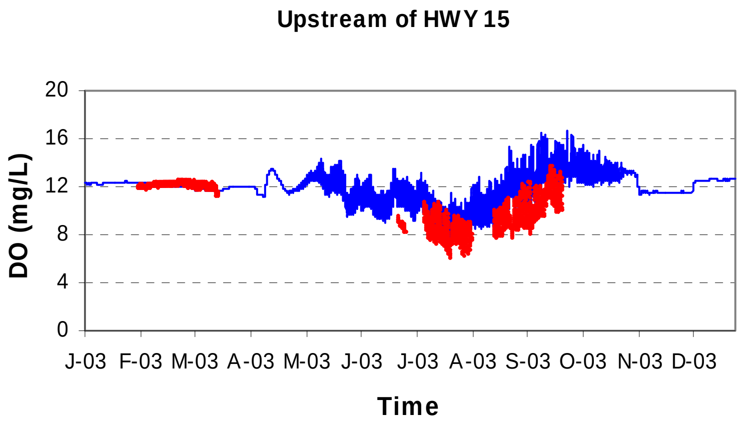
J-06 F-06 M-06 A-06 M-06 J-06 J-06 A-06 S-06 O-06 N-06 D-06
Time


Fort Saskatchewan
DO (mg/L)
20
16
12
8
4
0
J-07 F-07 M-07 A-07 M-07 J-07 J-07 A-07 S-07 O-07 N-07 D-07
Time


Upstream of HWY 15
DO (mg/L)
20
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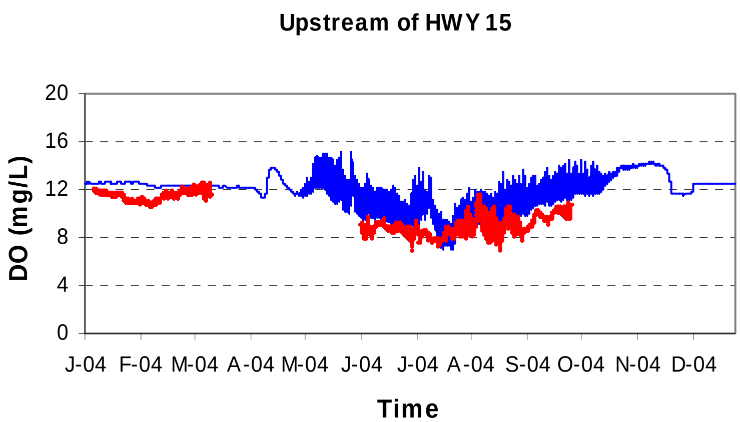
12
8
4
0
J-03 F-03 M-03 A-03 M-03 J-03 J-03 A-03 S-03 O-03 N-03 D-03
Time


Upstream of HWY 15
DO (mg/L)
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16
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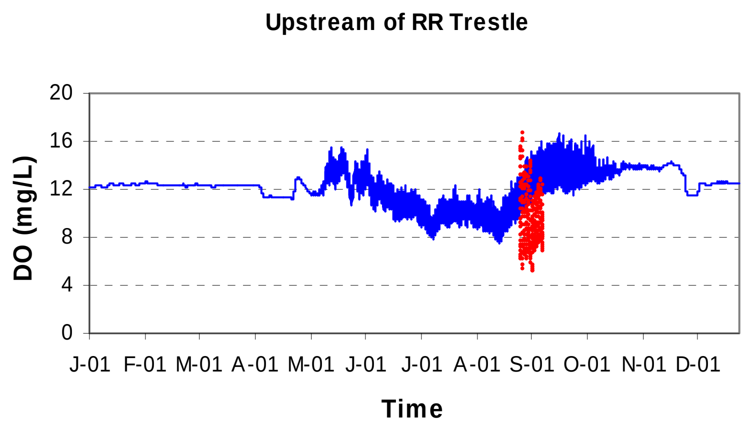
8
4
0
J-04 F-04 M-04 A-04 M-04 J-04 J-04 A-04 S-04 O-04 N-04 D-04
Time


Upstream of RR Trestle
DO (mg/L)
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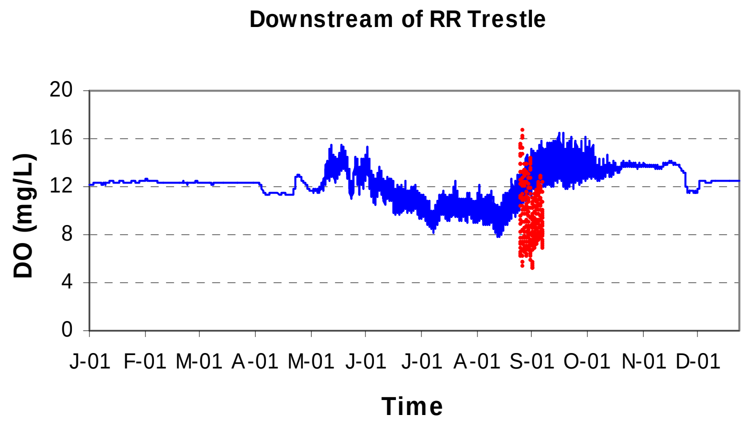
12
8
4
0
J-01 F-01 M-01 A-01 M-01 J-01 J-01 A-01 S-01 O-01 N-01 D-01
Time


Downstream of RR Trestle
DO (mg/L)
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8
4
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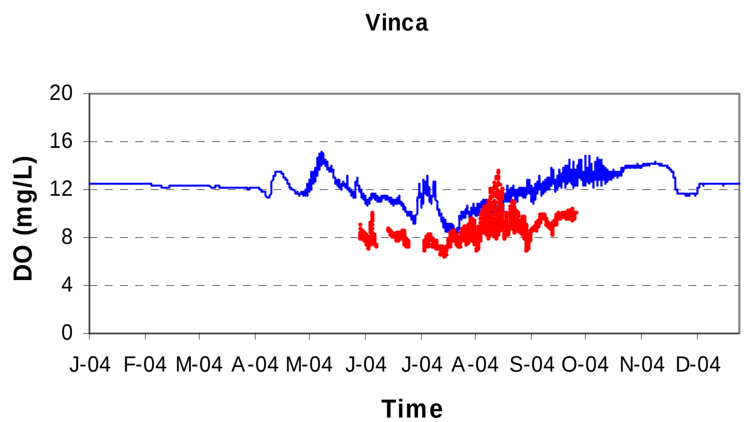
J-01 F-01 M-01 A-01 M-01 J-01 J-01 A-01 S-01 O-01 N-01 D-01
Time


Vinca
DO (mg/L)
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12
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4
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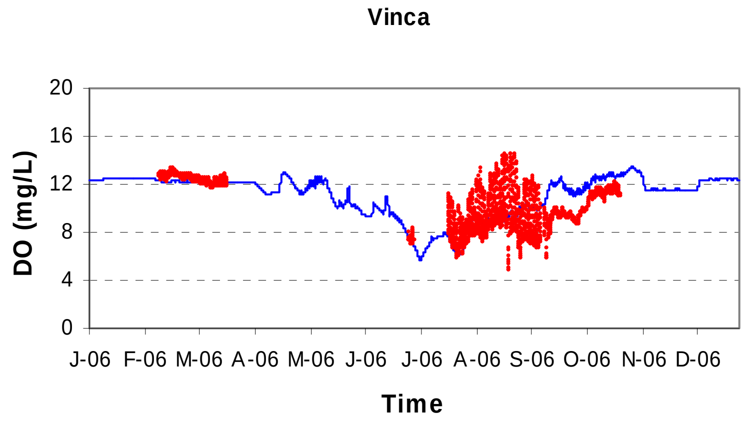
Time


Vinca
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DO (mg/L)
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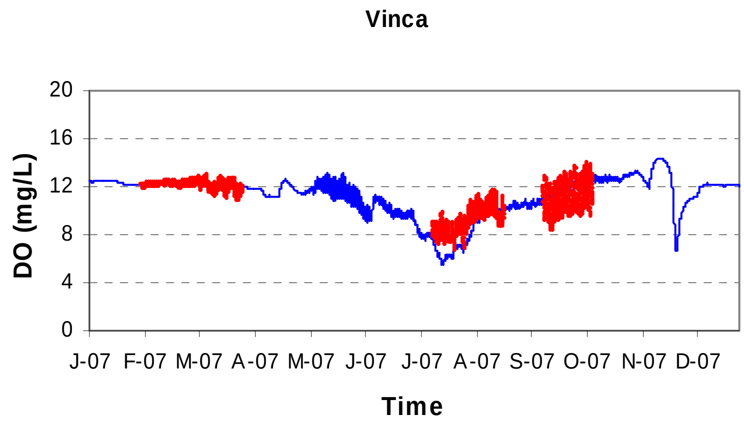
Time


Vinca
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4
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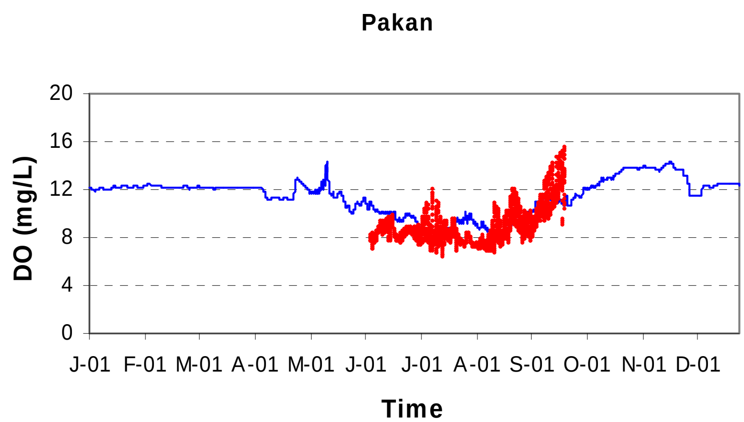
DO (mg/L)
J-07 F-07 M-07 A-07 M-07 J-07 J-07 A-07 S-07 O-07 N-07 D-07
Time


Pakan
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DO (mg/L)
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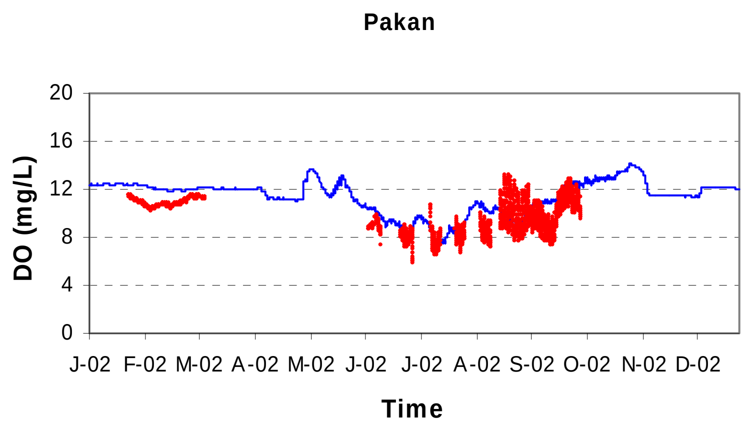
Time


Pakan
DO (mg/L)
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4
8
12
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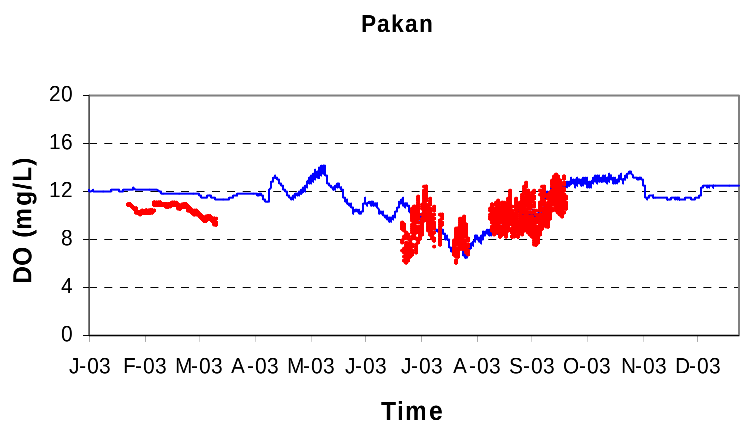
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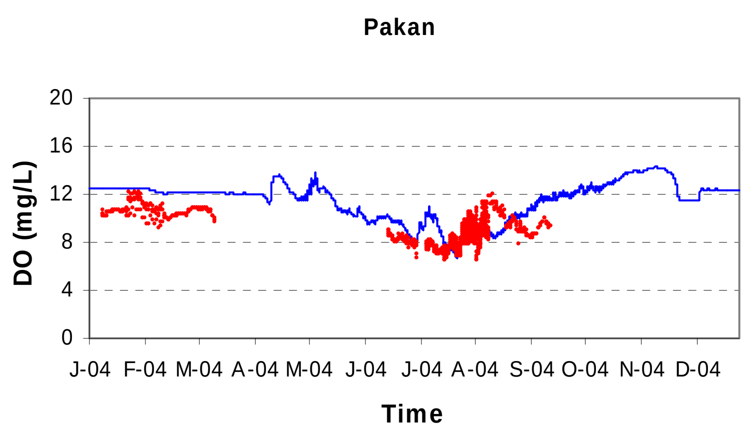
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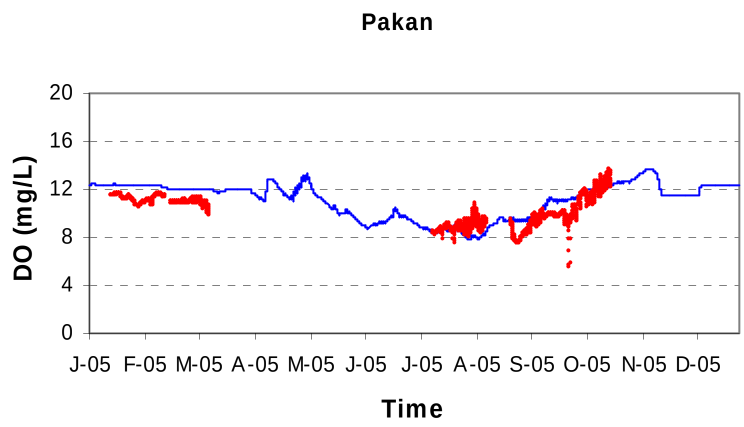
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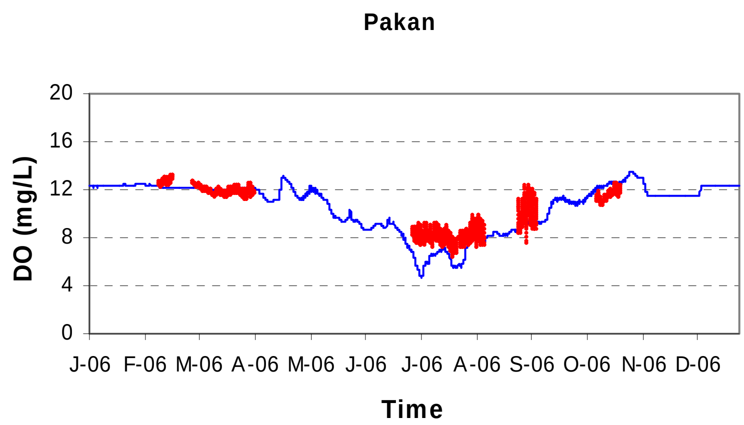
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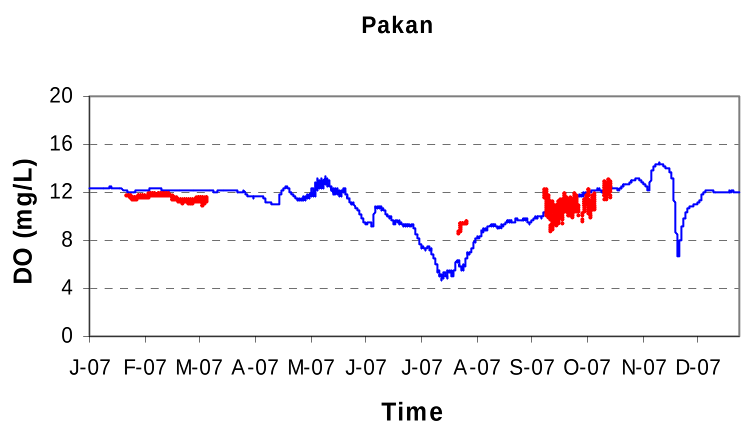
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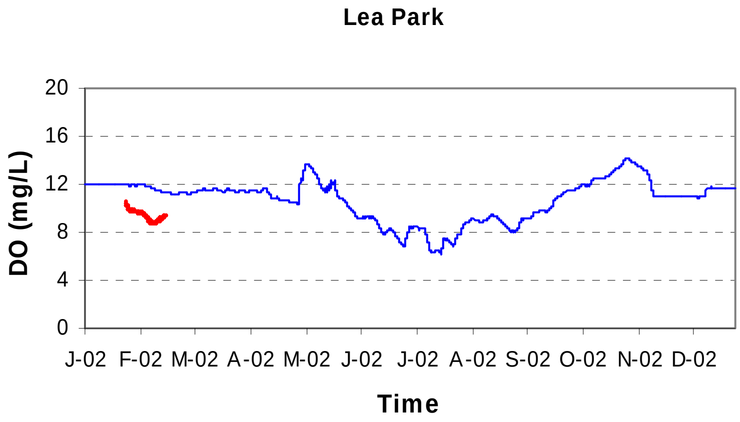
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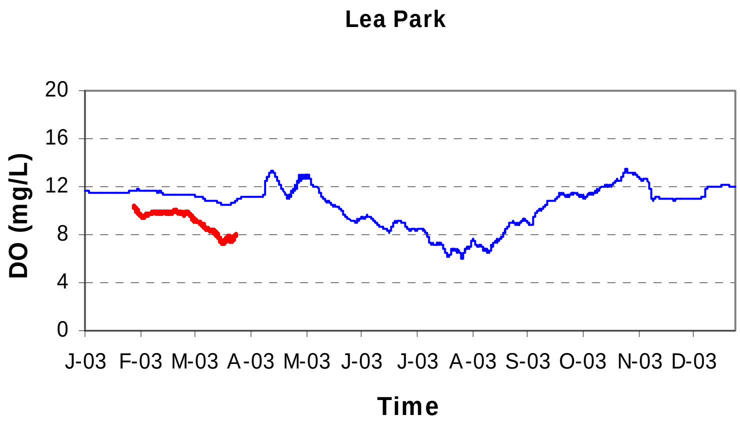
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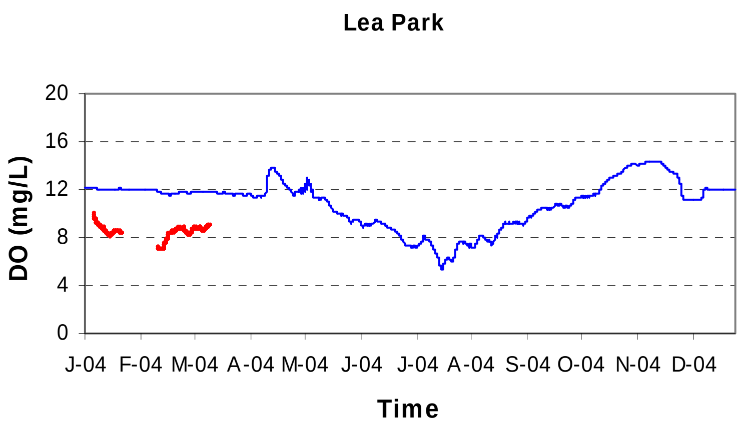
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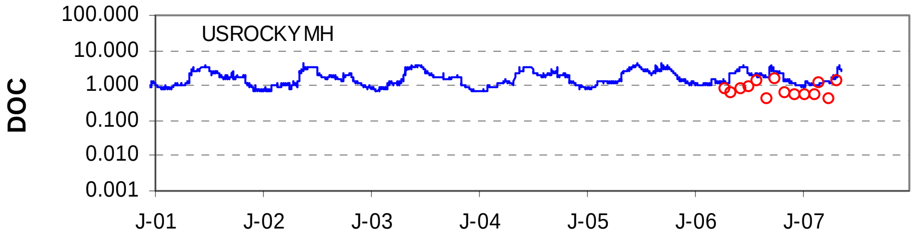
Appendix D. Water Quality Plots and Error Measures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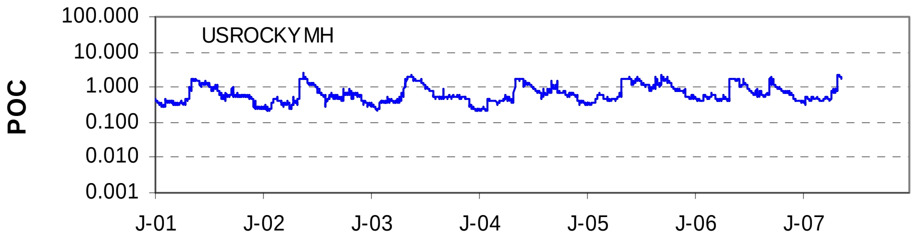
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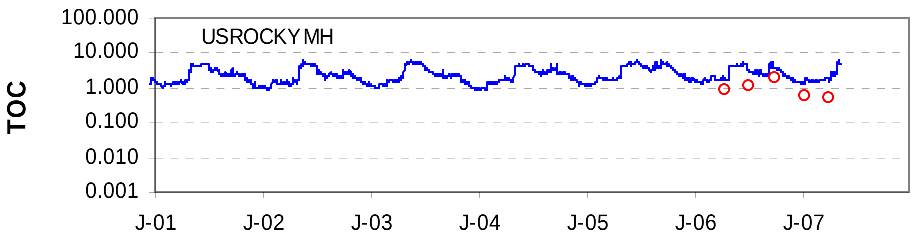
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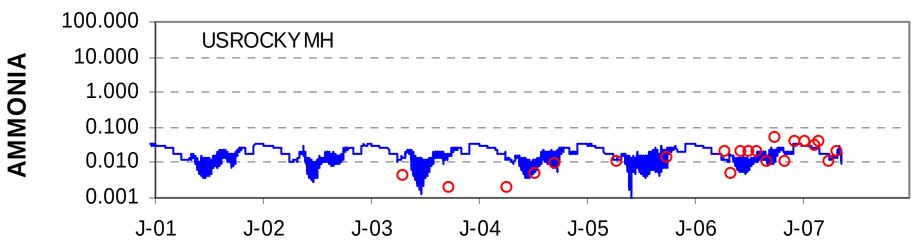
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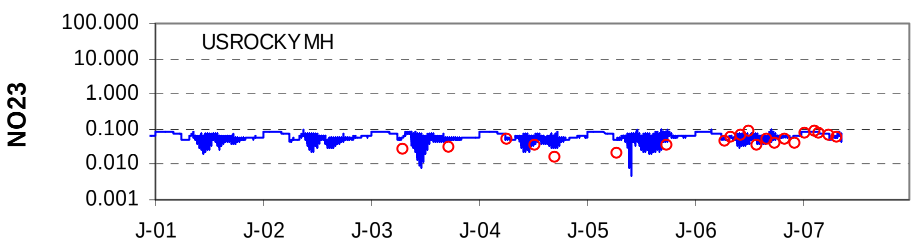
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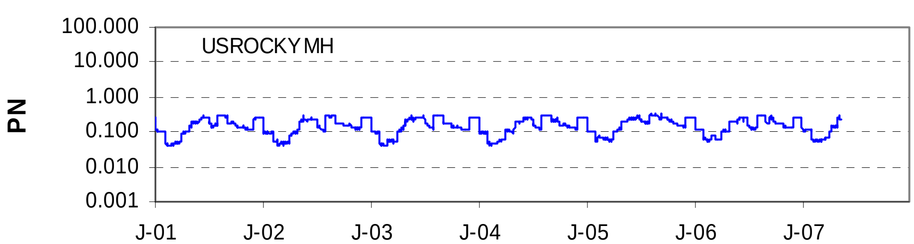
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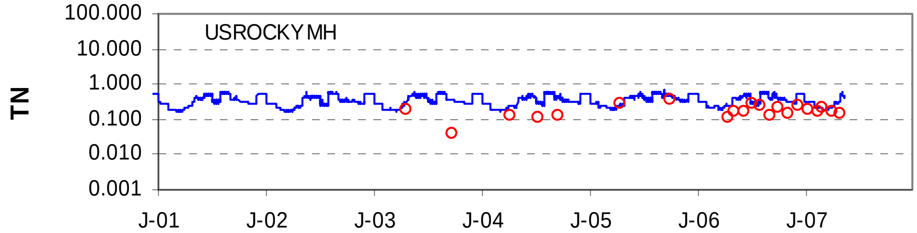
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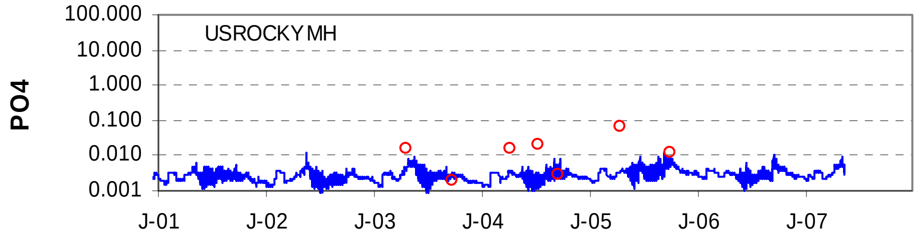
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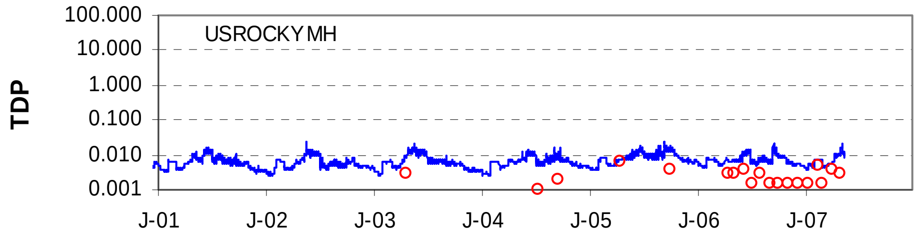
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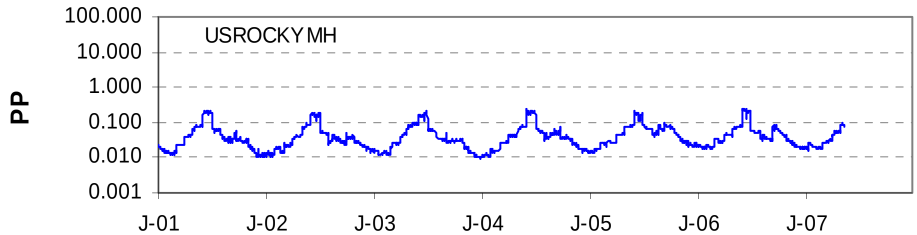
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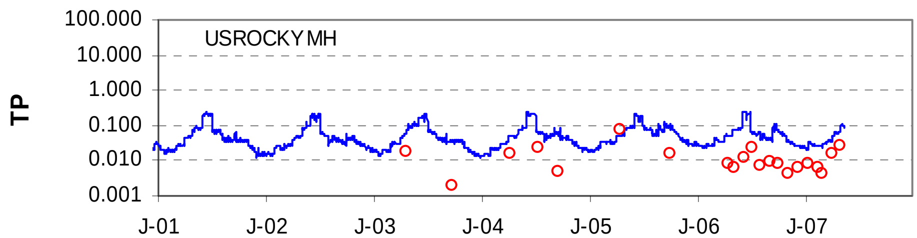
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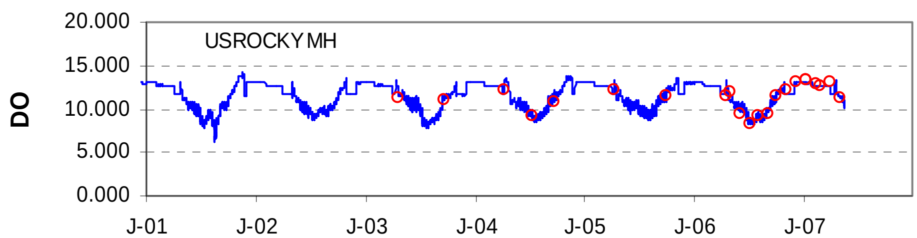
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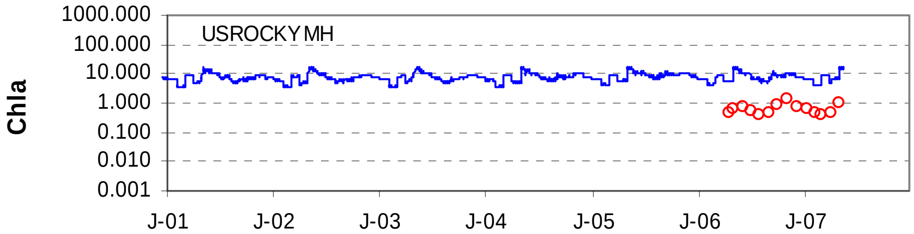
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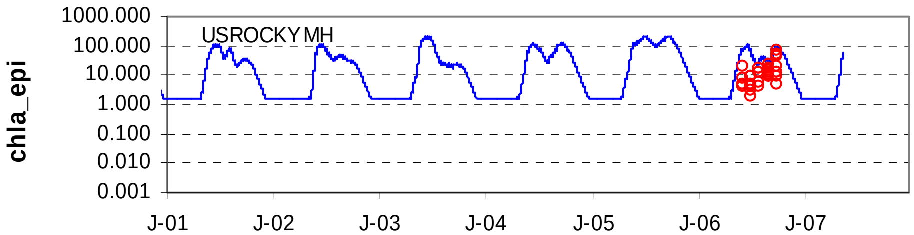
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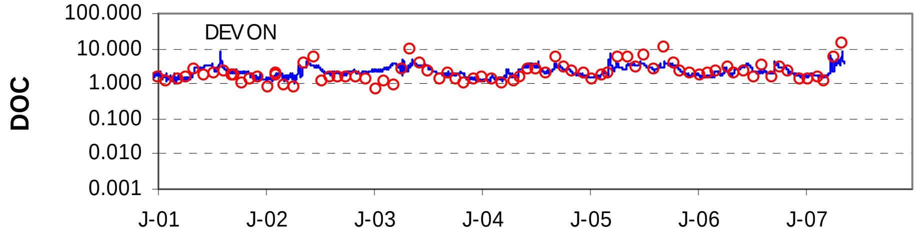
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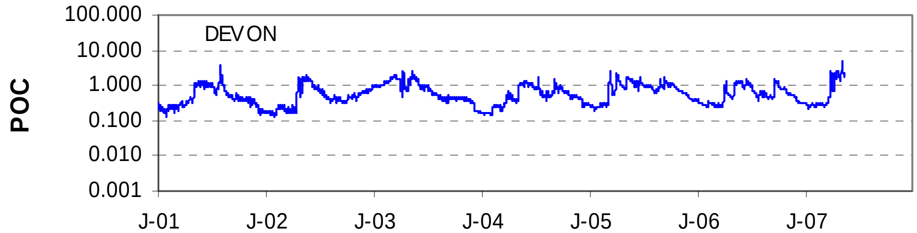
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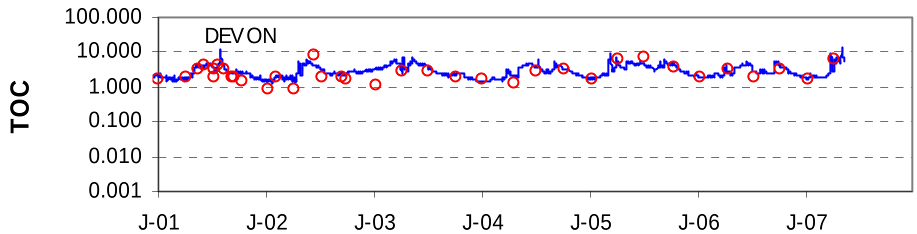
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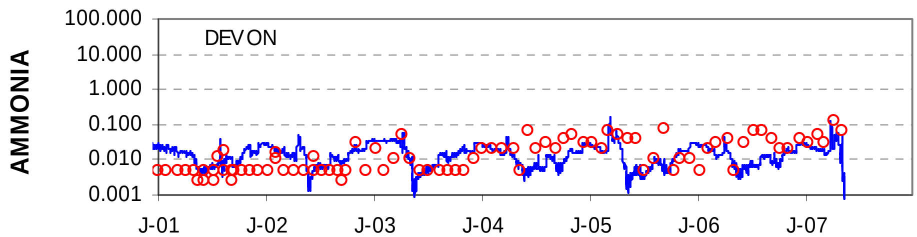
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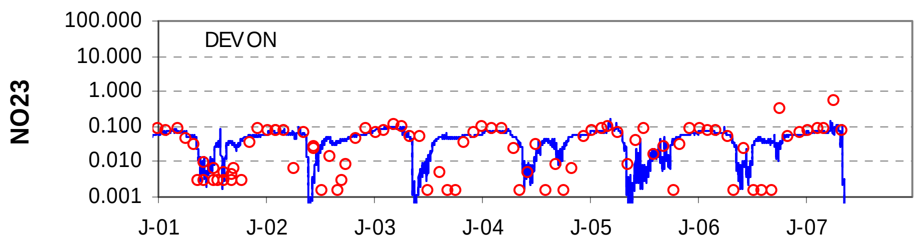
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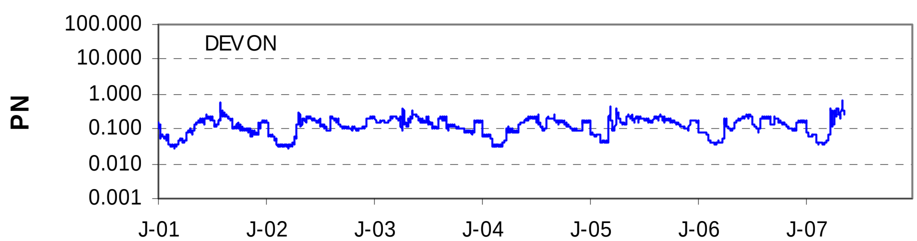
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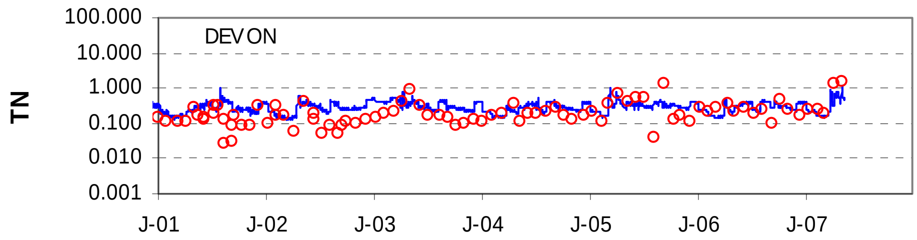
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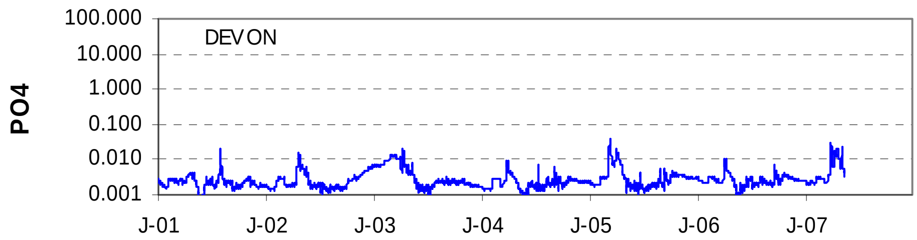
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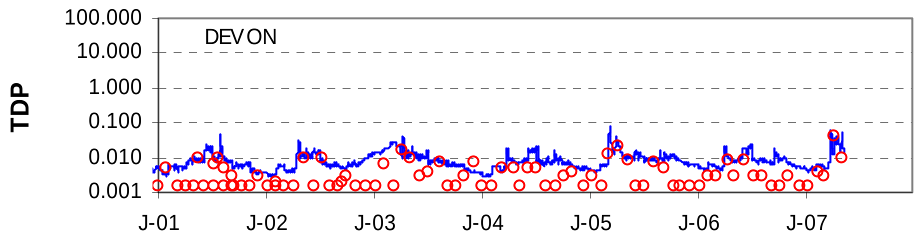
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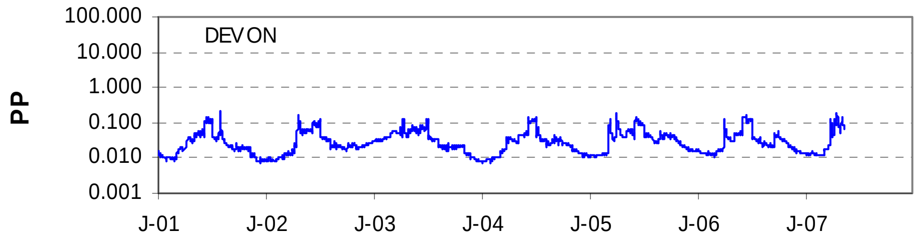
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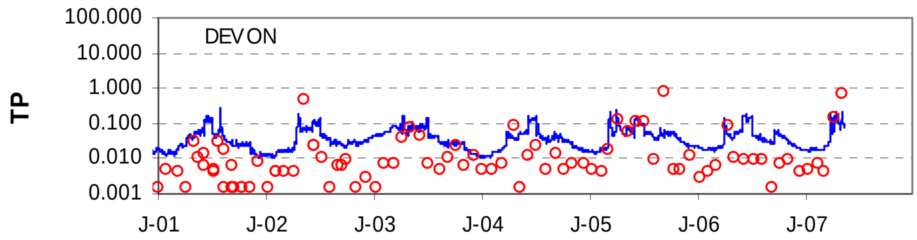
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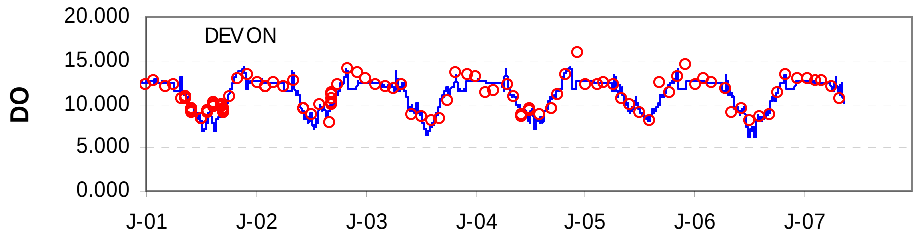
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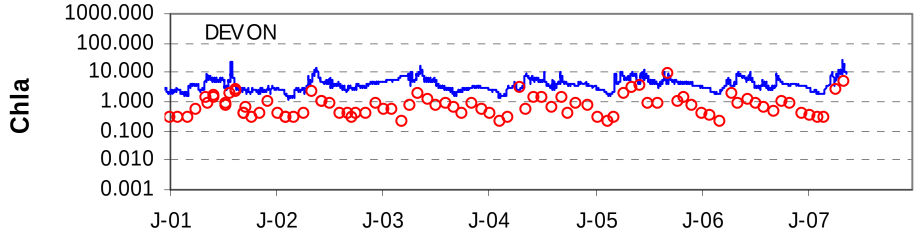
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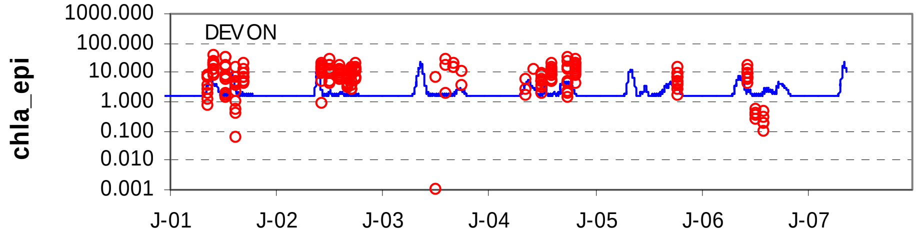
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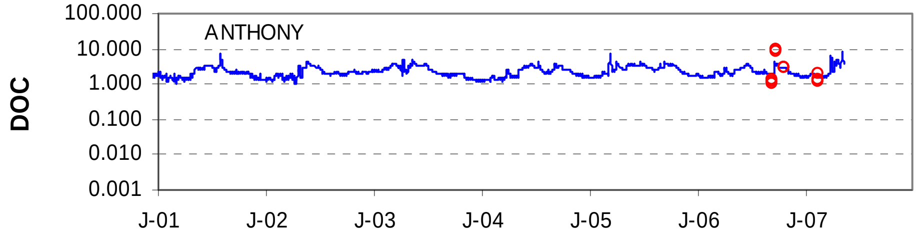
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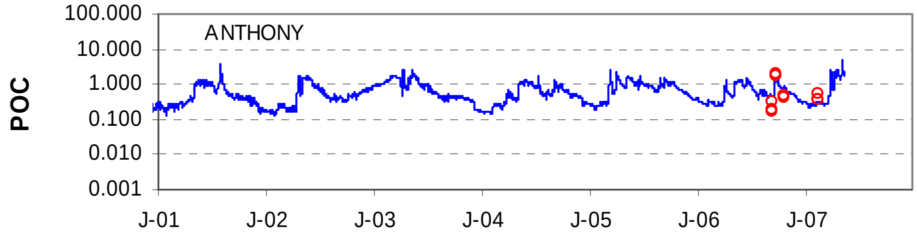
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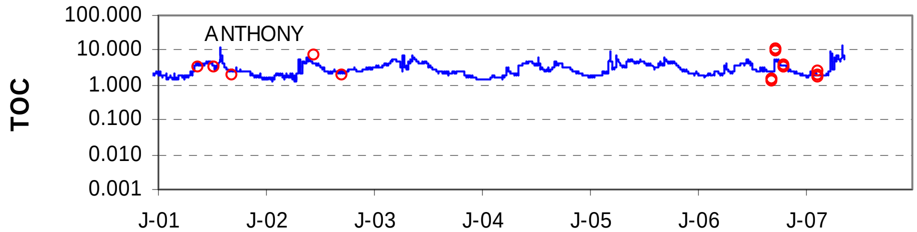
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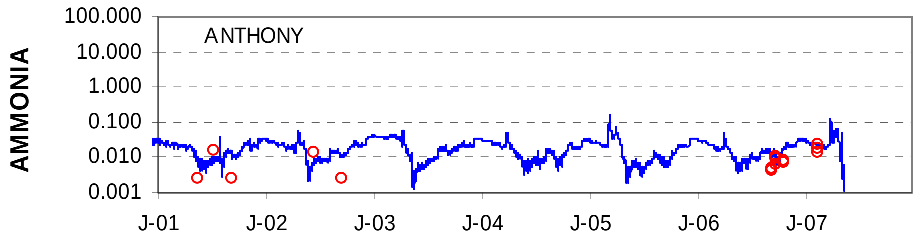
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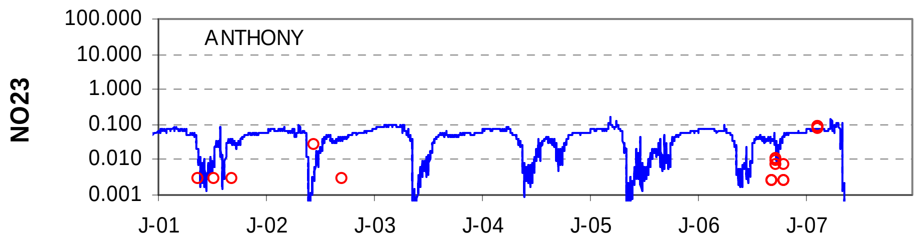
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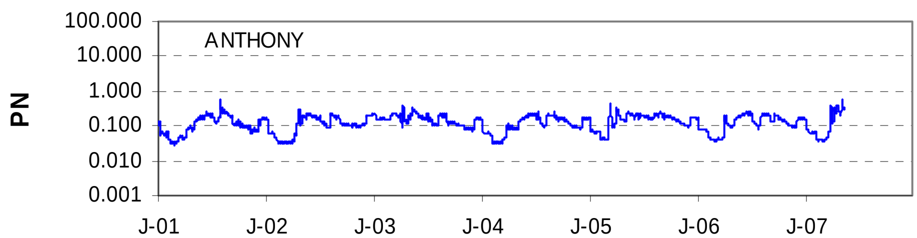
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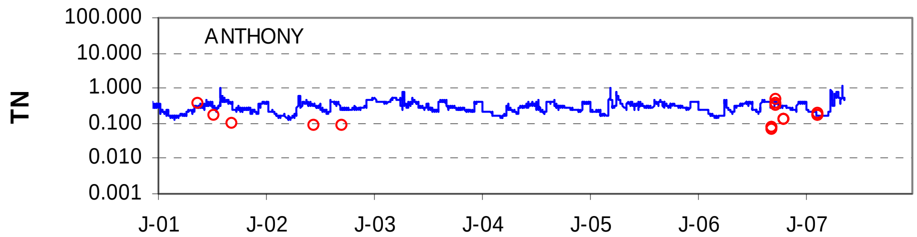
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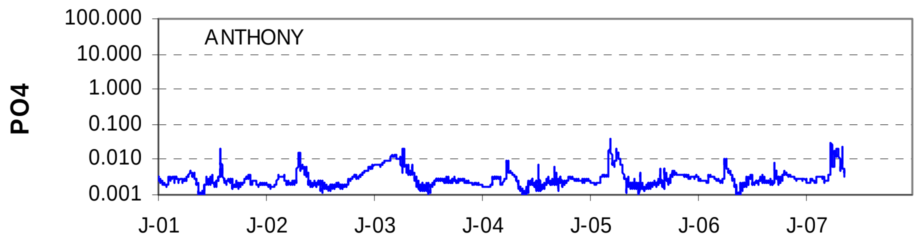
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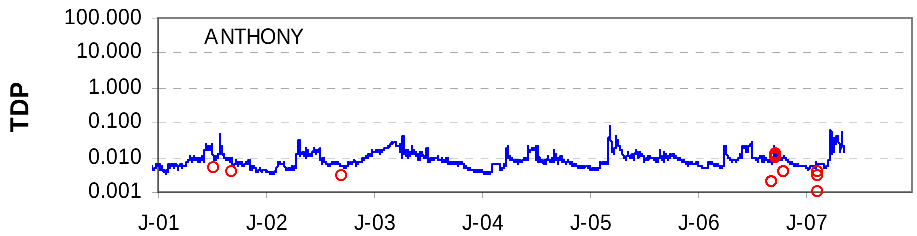
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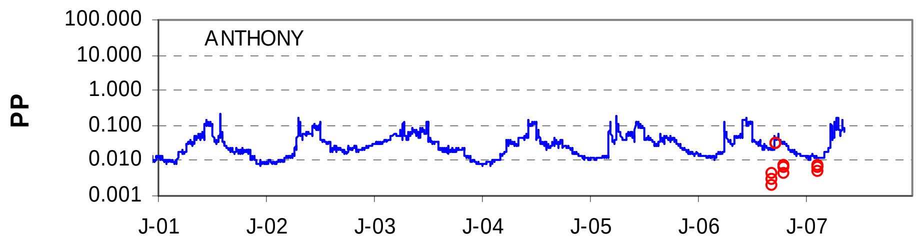
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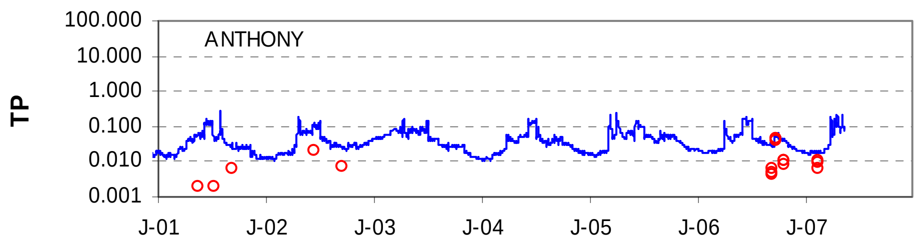
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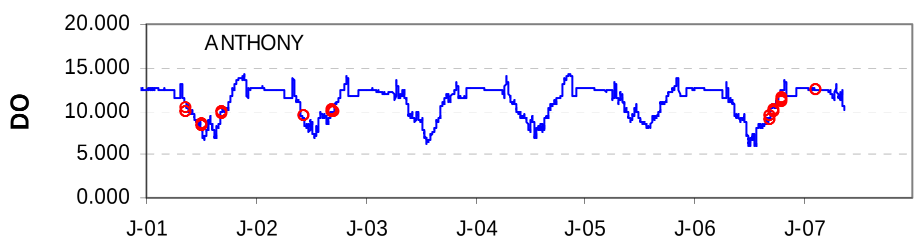
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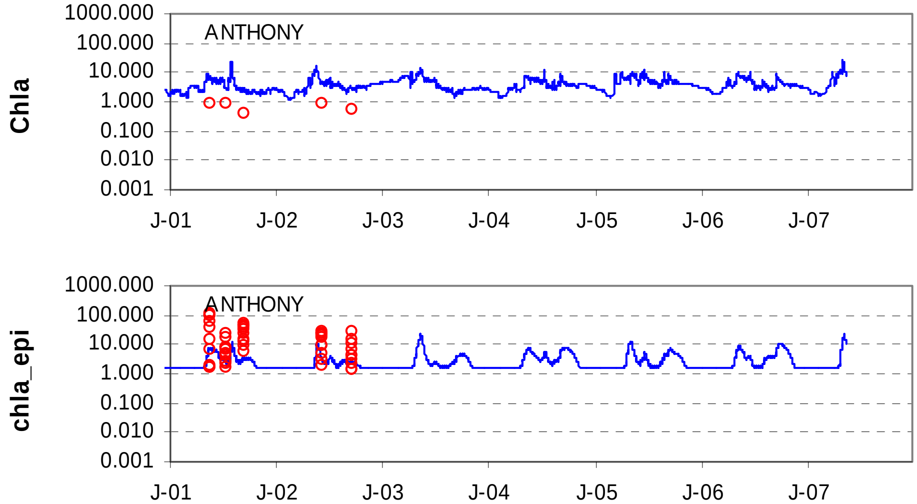
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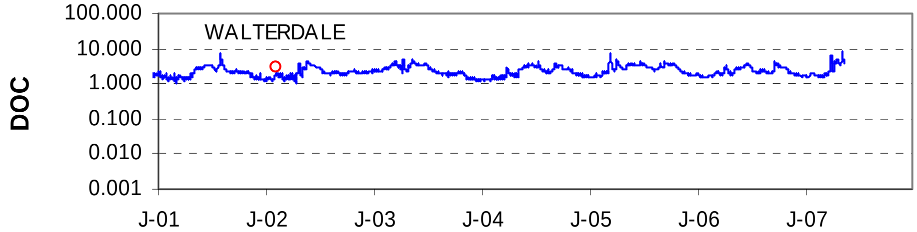
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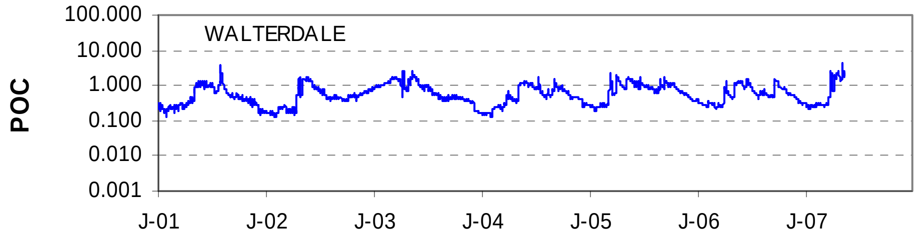
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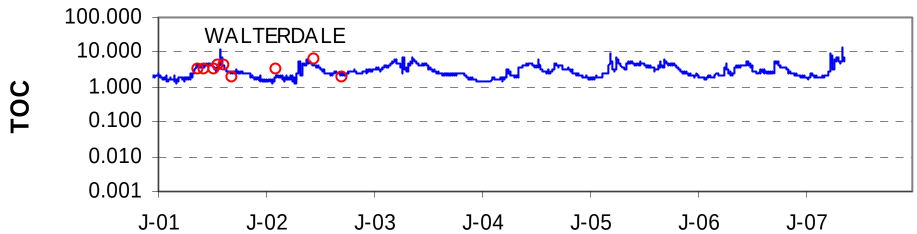
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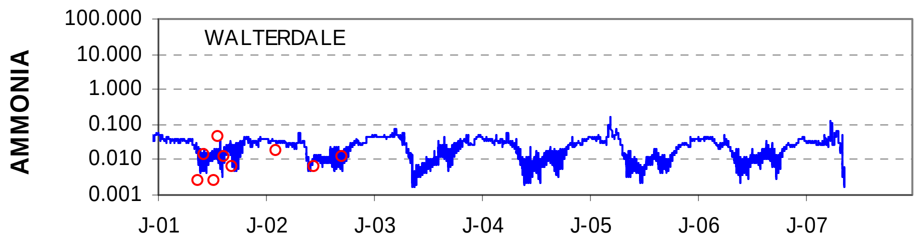
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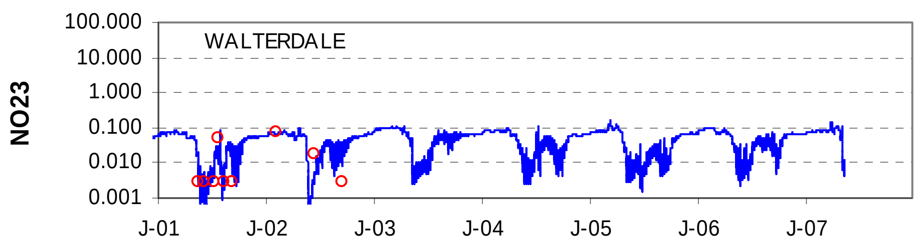
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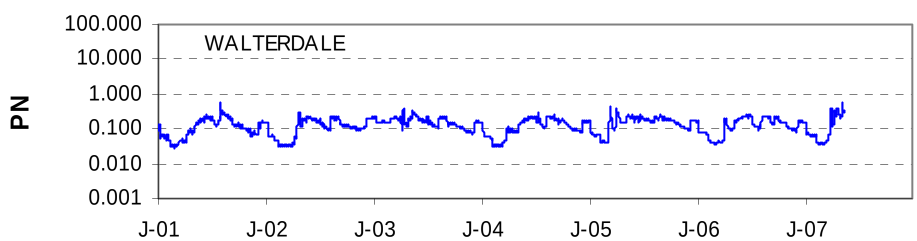
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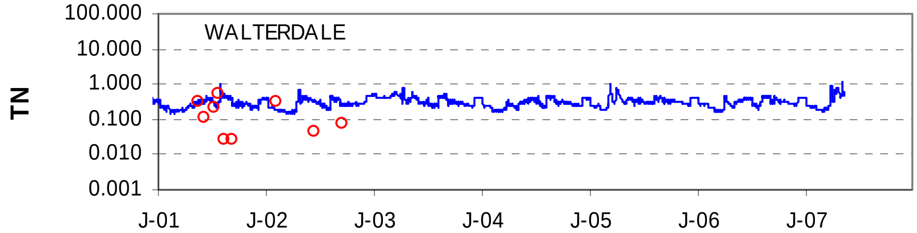
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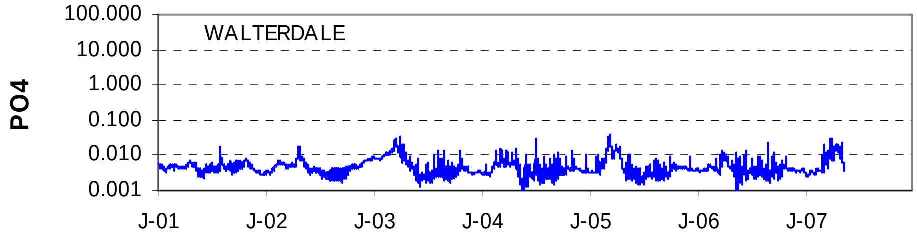
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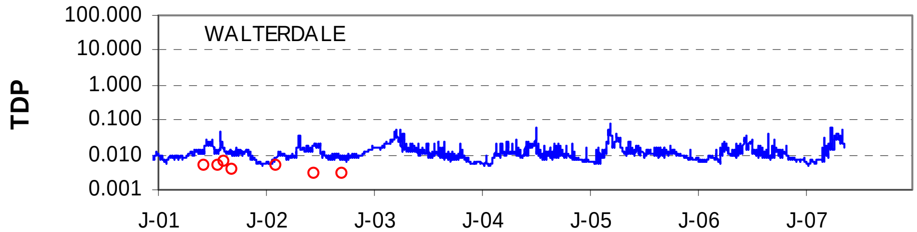
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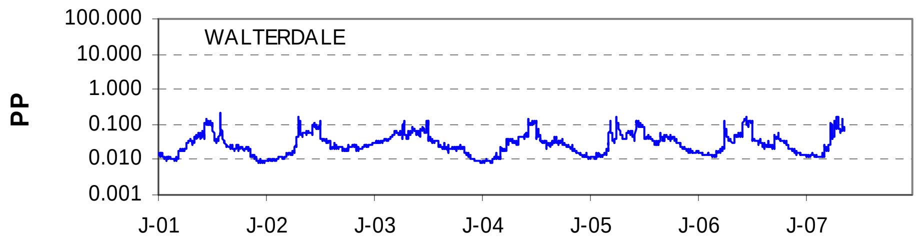
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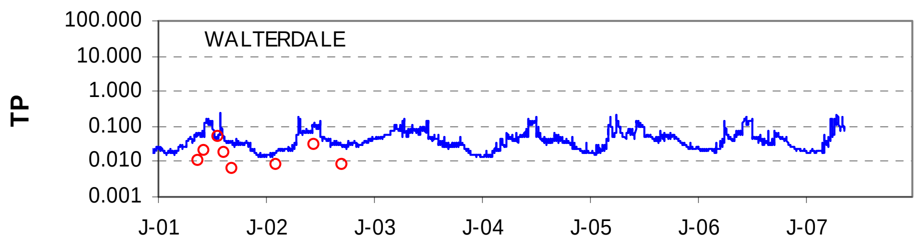
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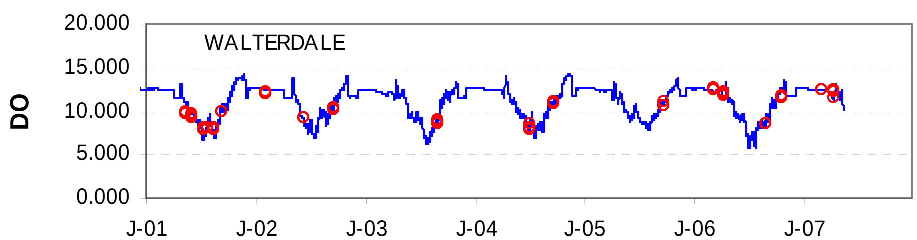
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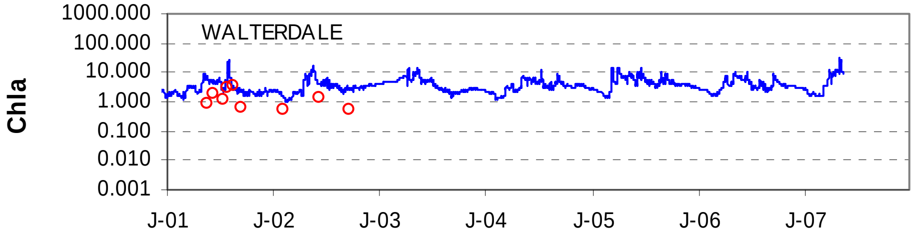
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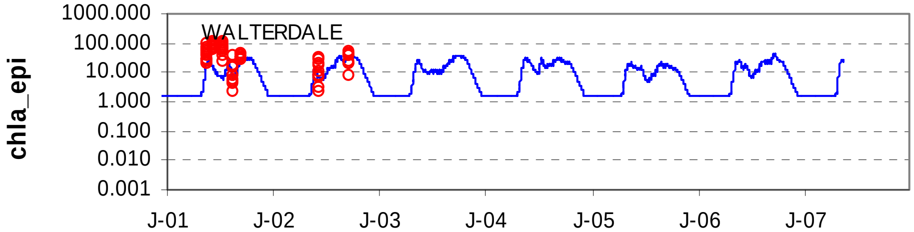
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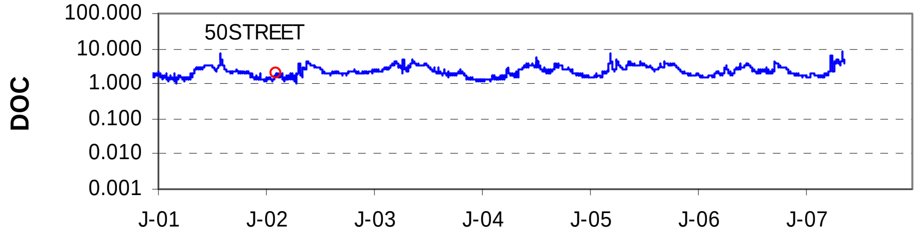
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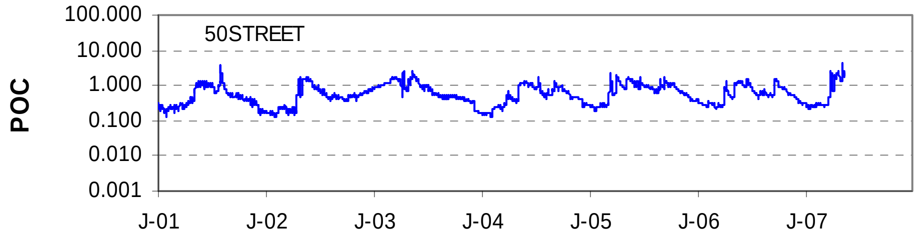
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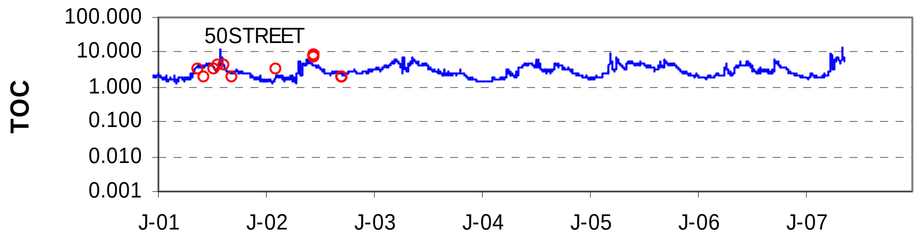
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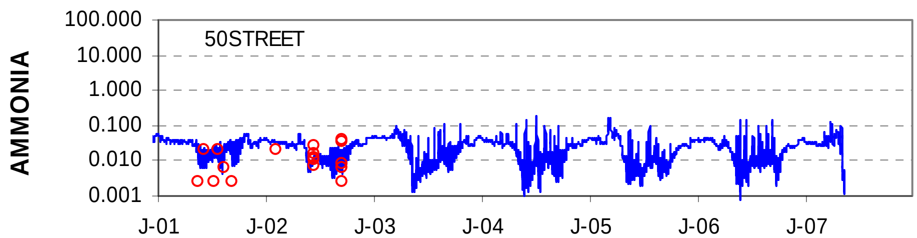
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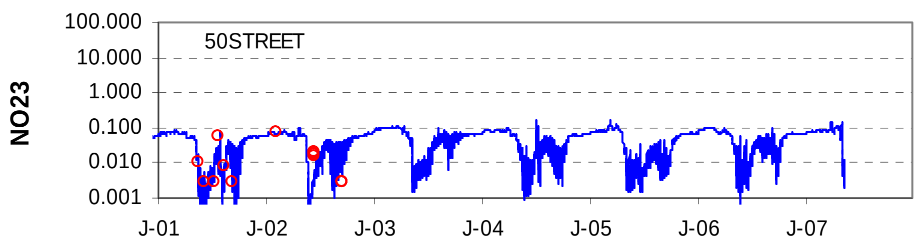
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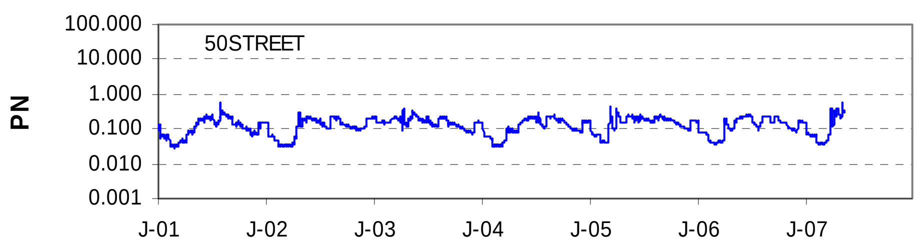
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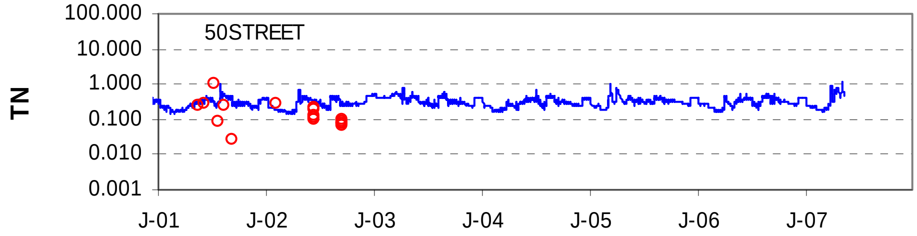
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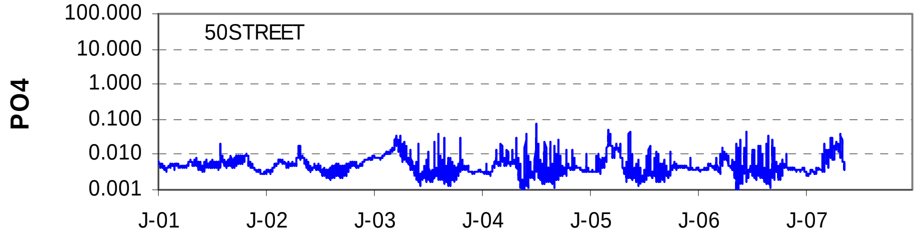
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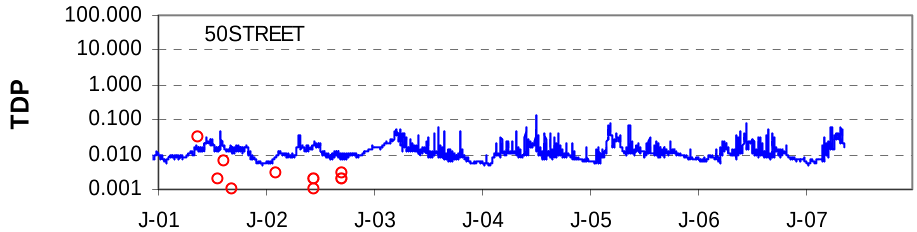
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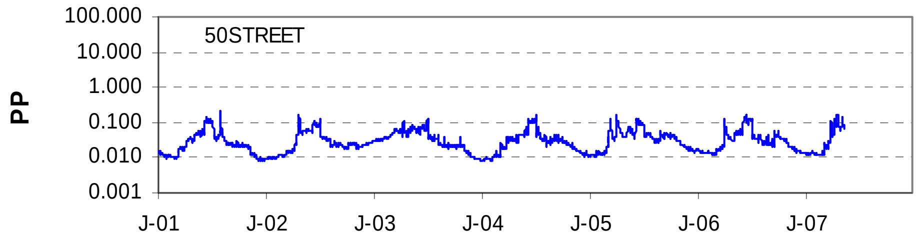
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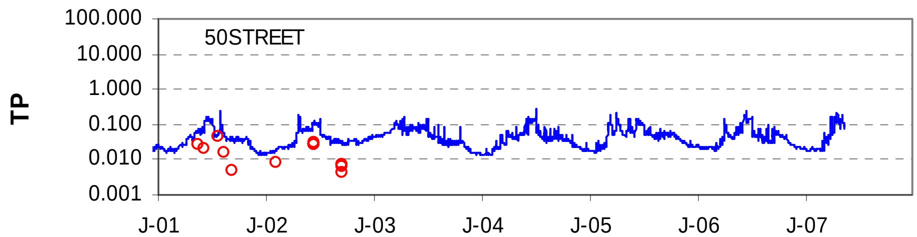
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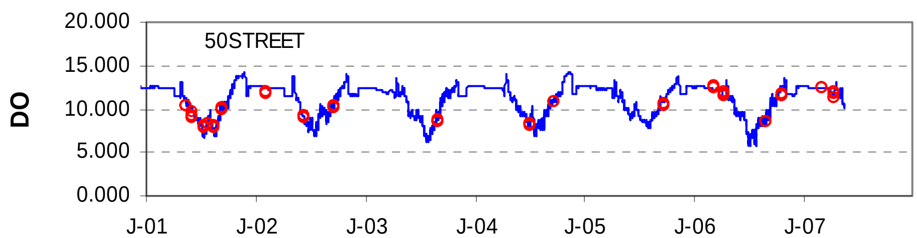
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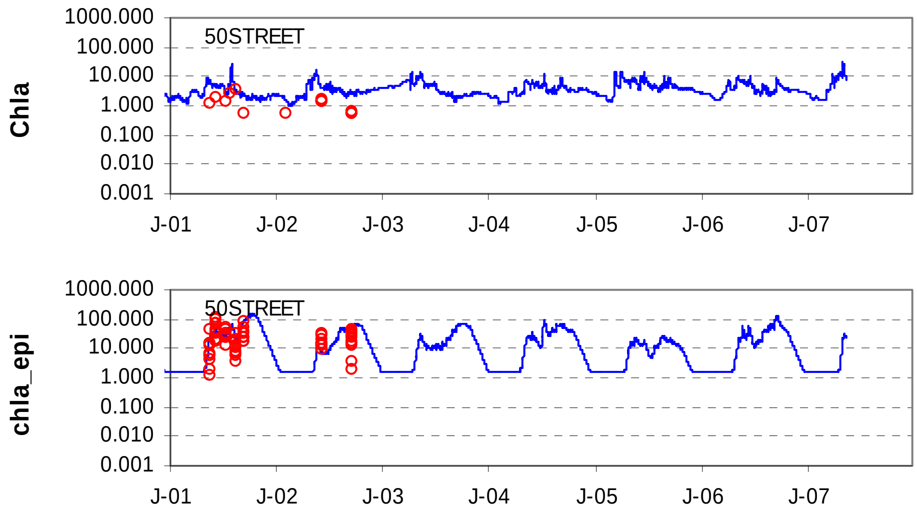
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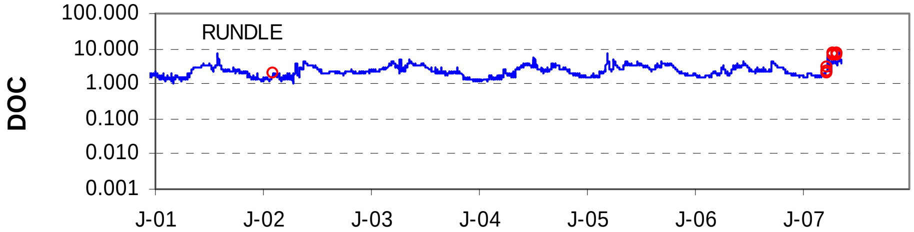
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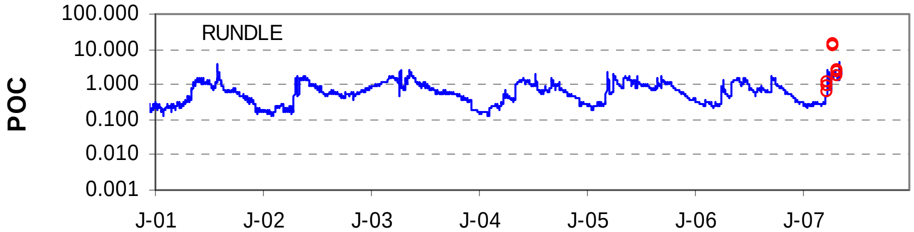
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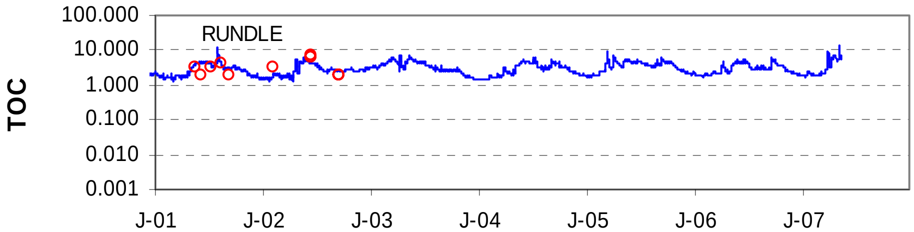
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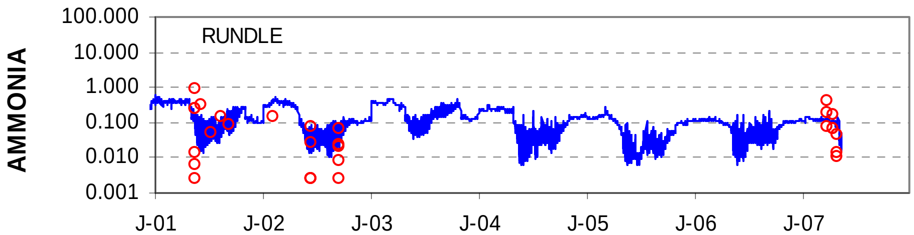
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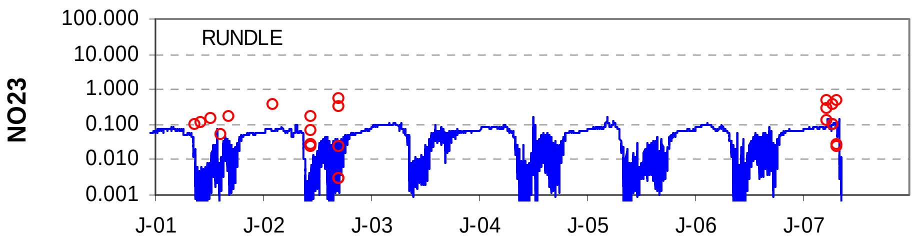
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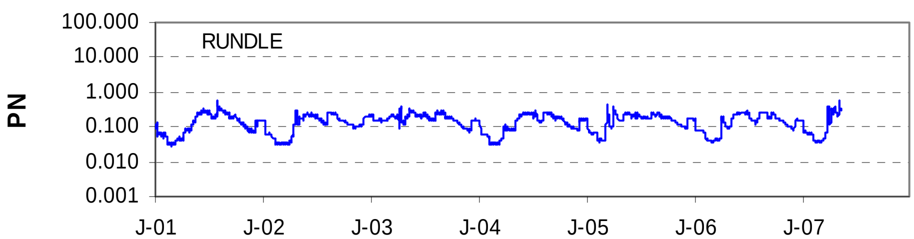
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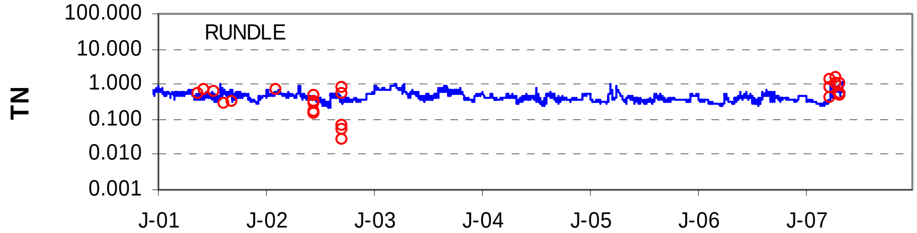
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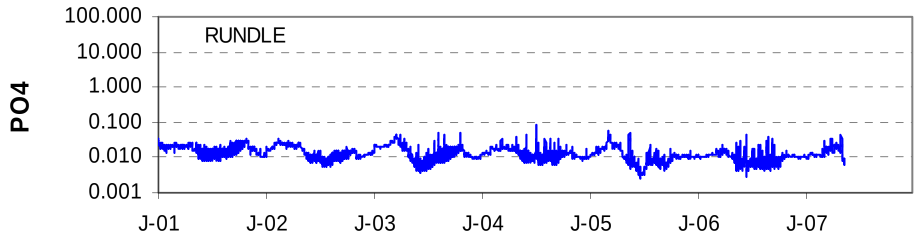
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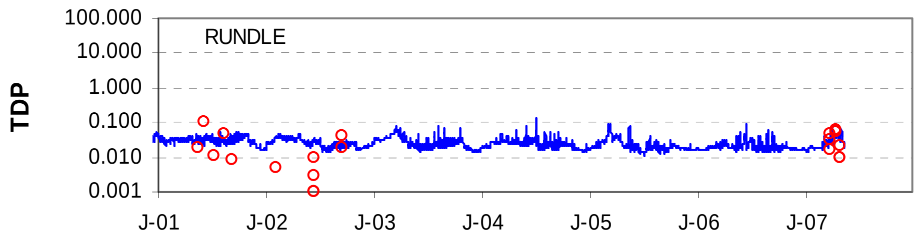
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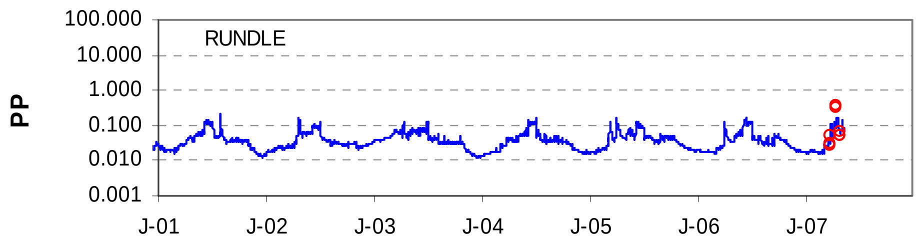
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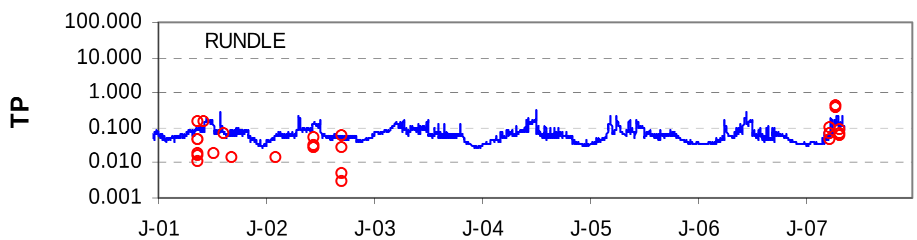
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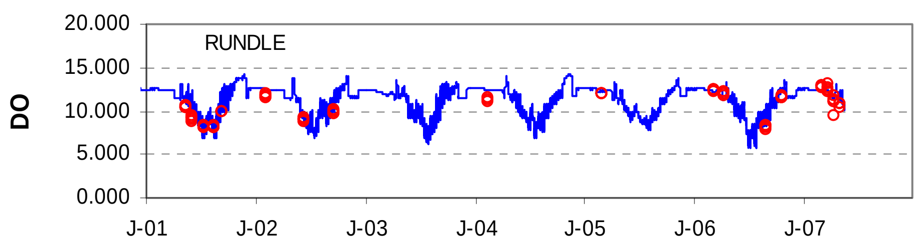
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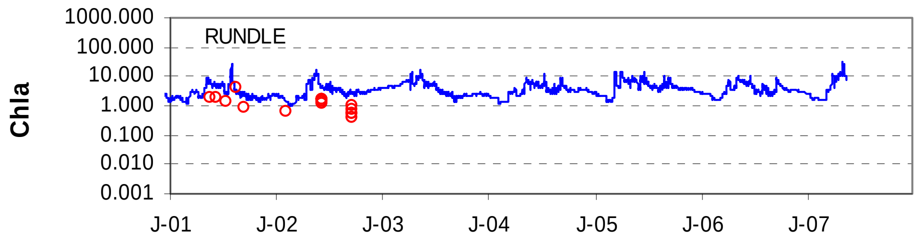
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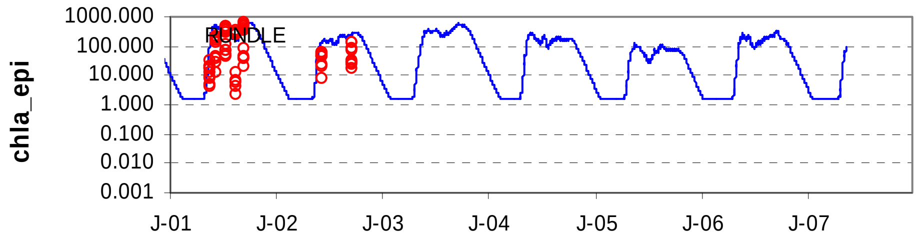
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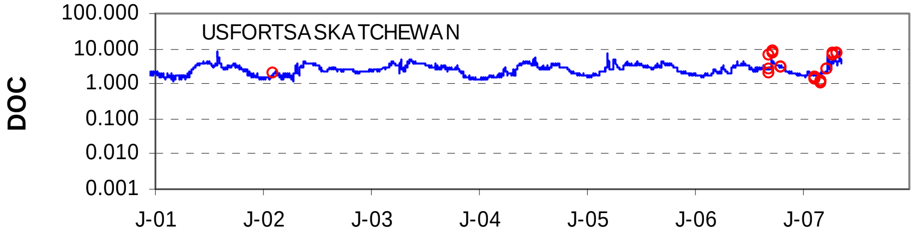
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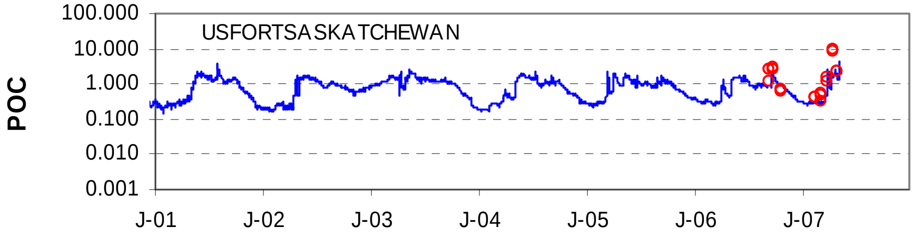
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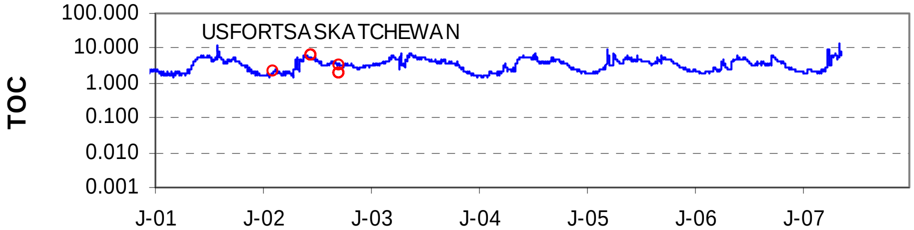
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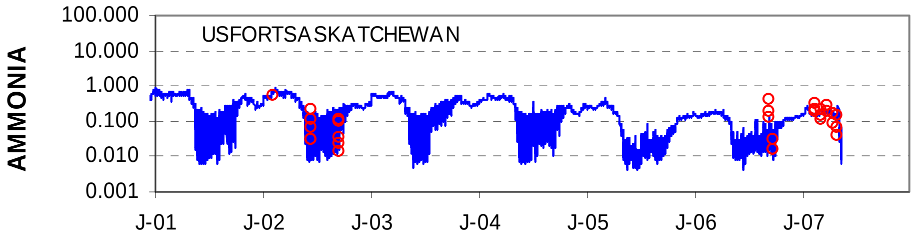
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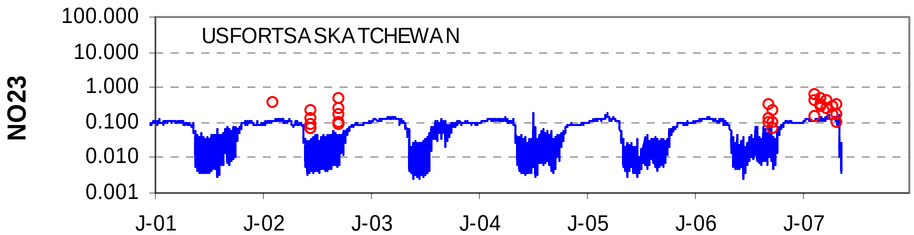
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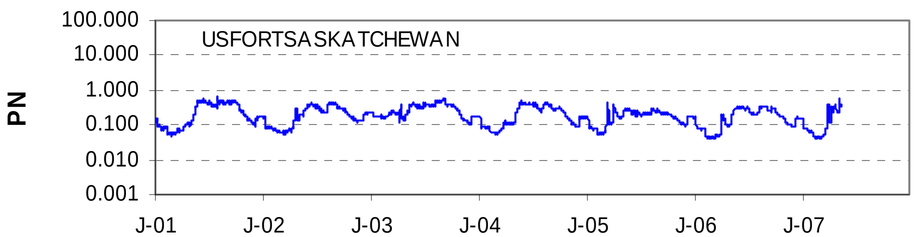
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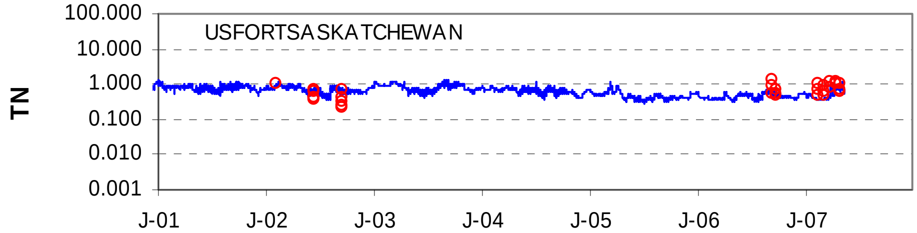
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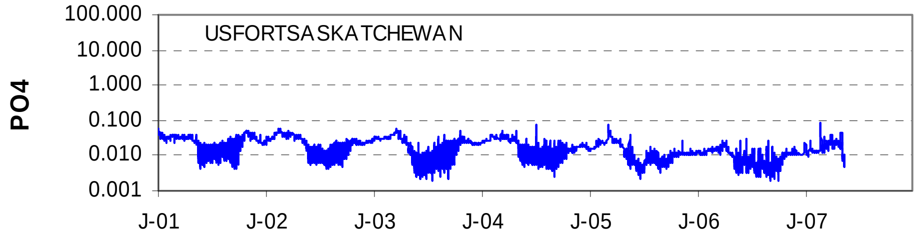
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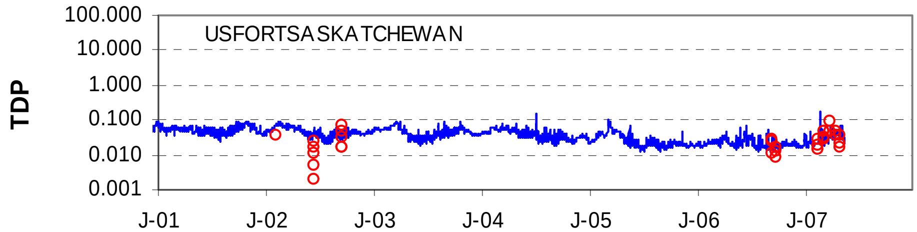
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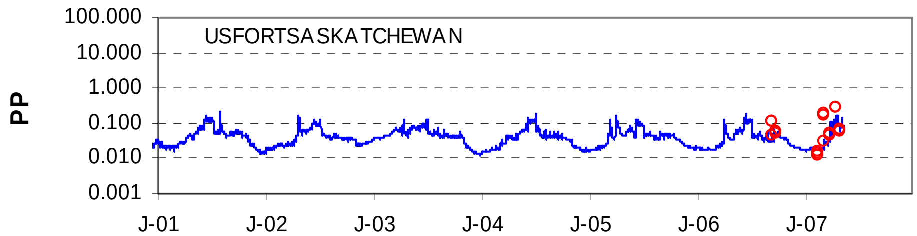
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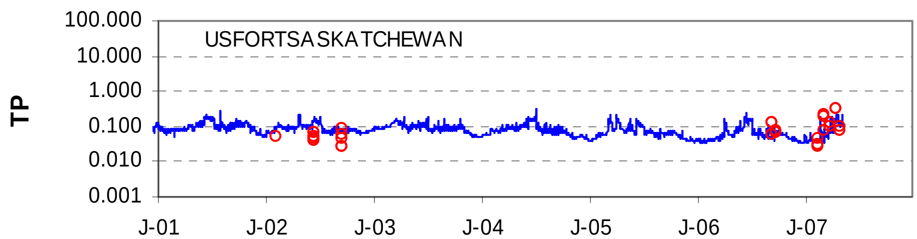
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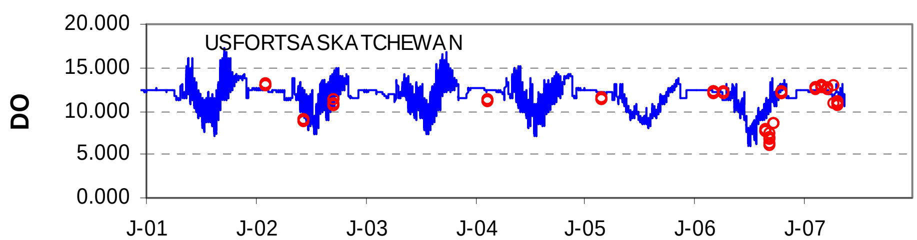
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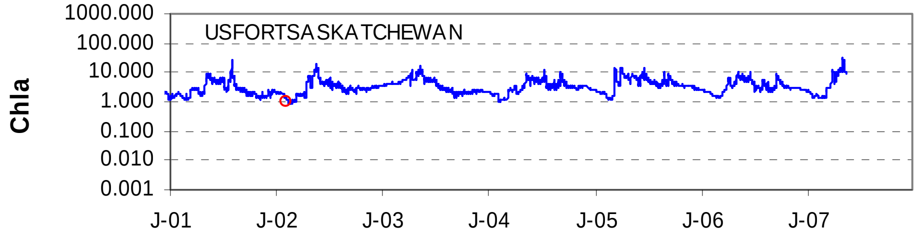
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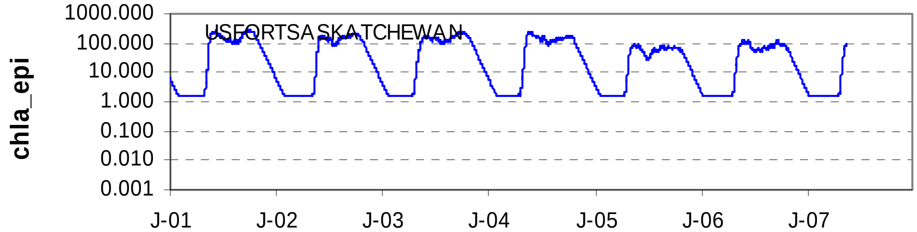
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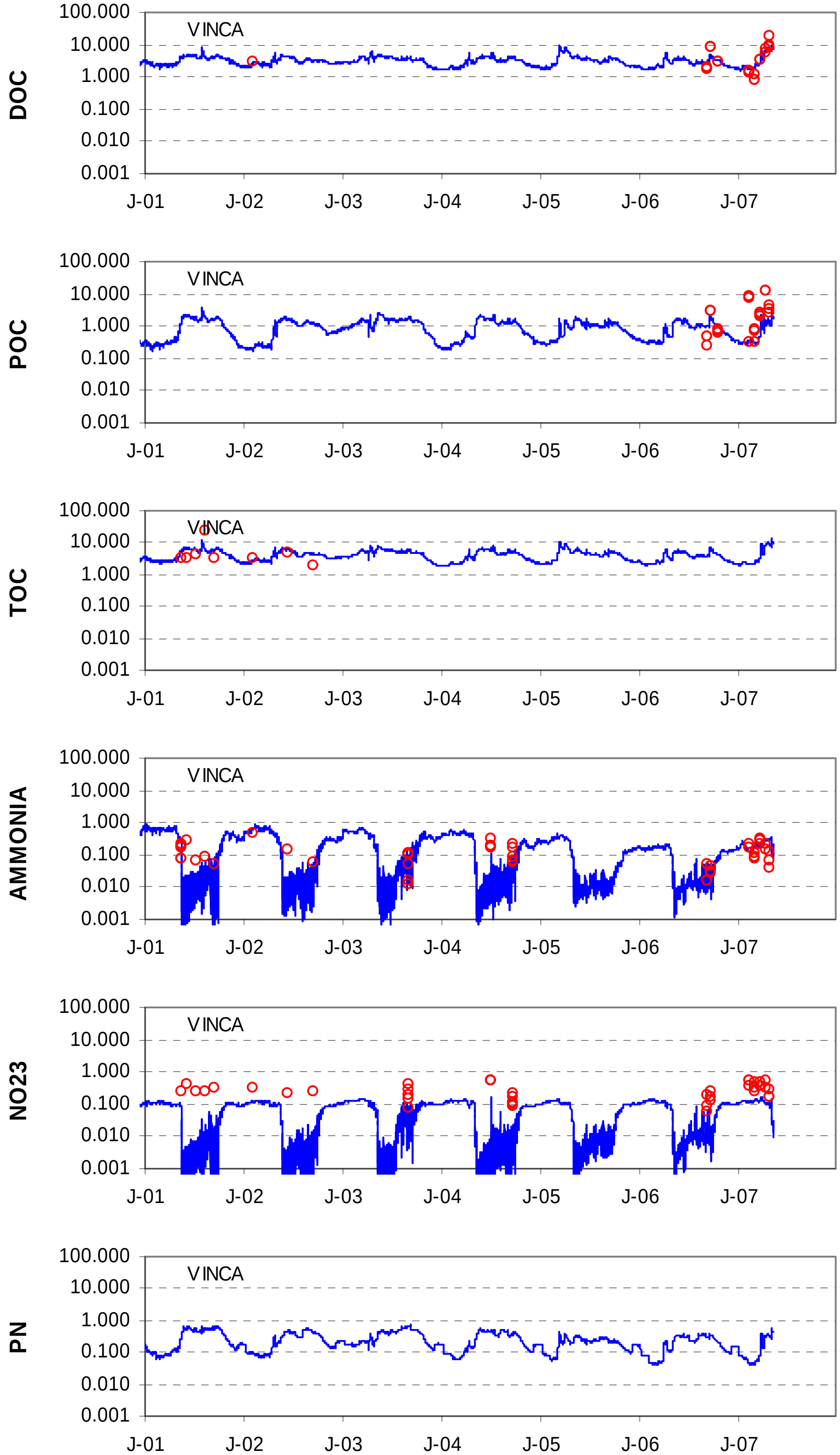
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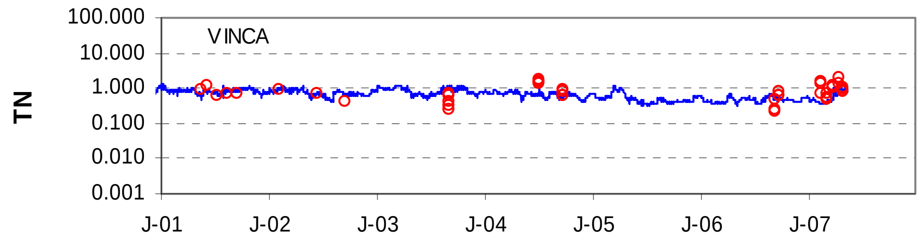
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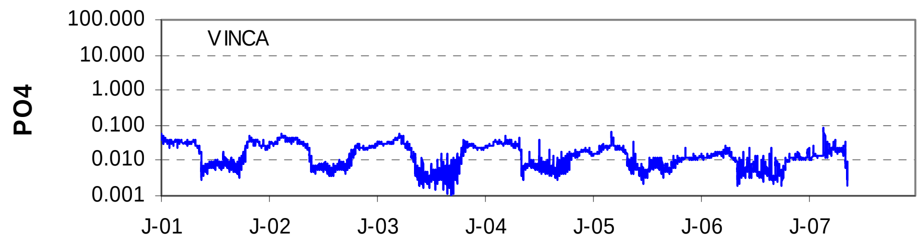
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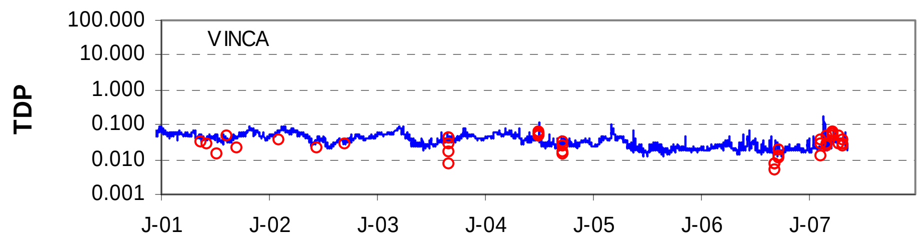
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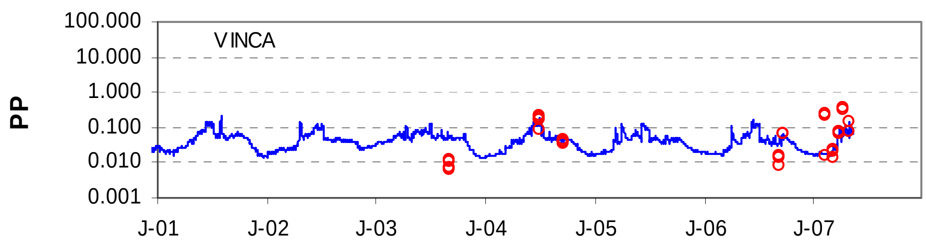
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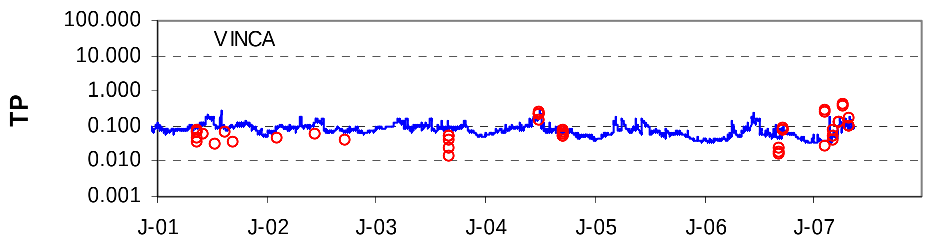
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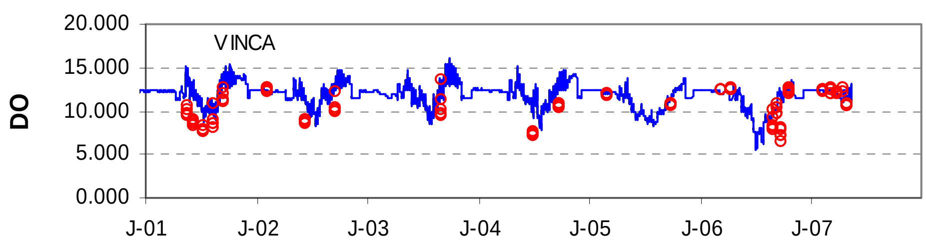
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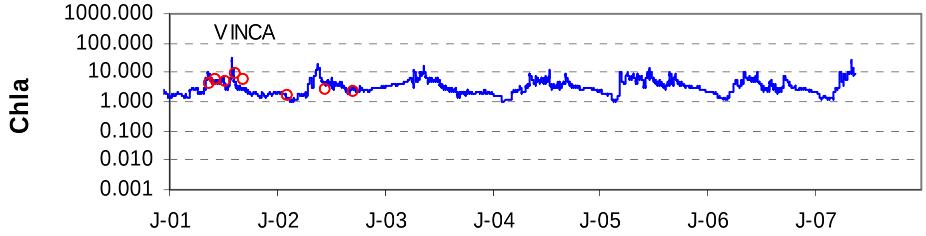
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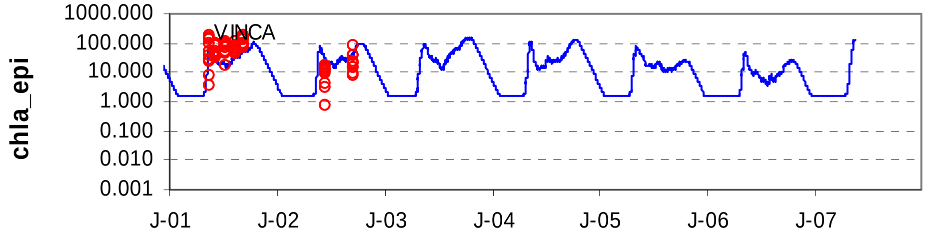
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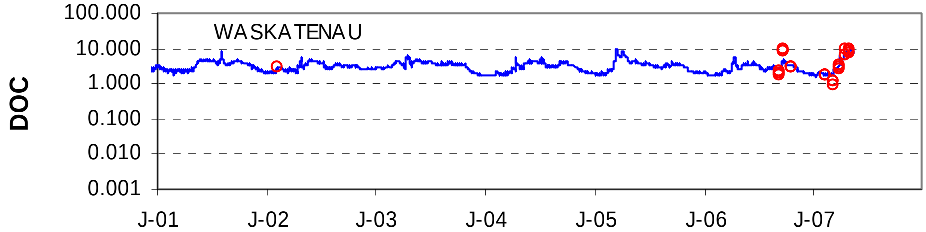
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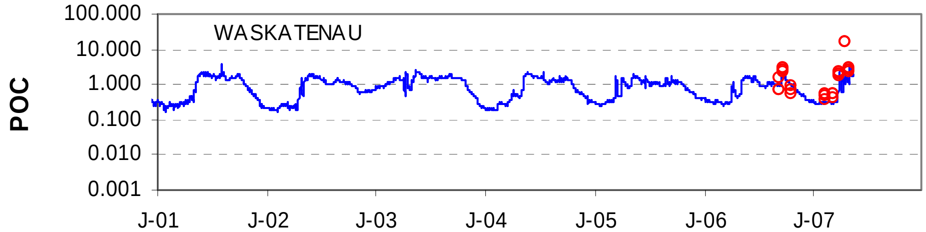
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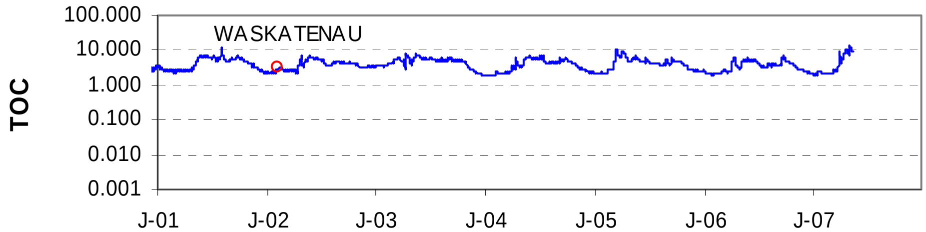
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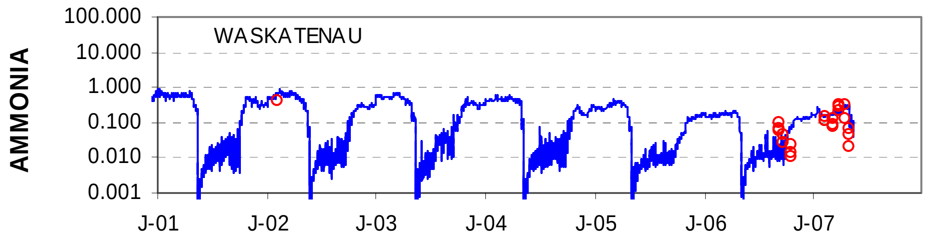
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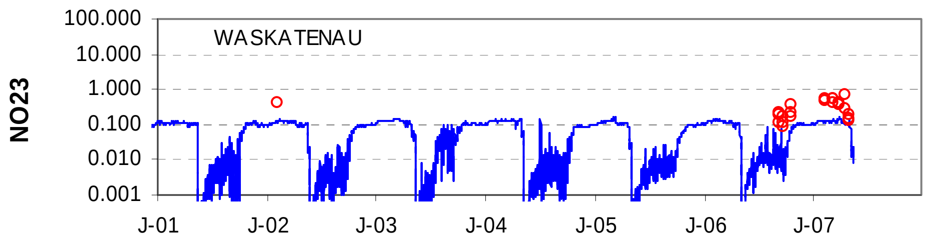
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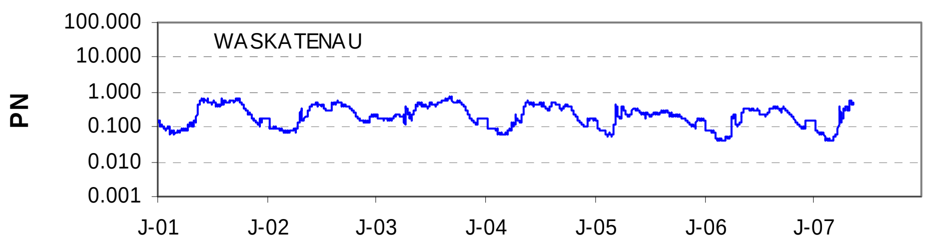
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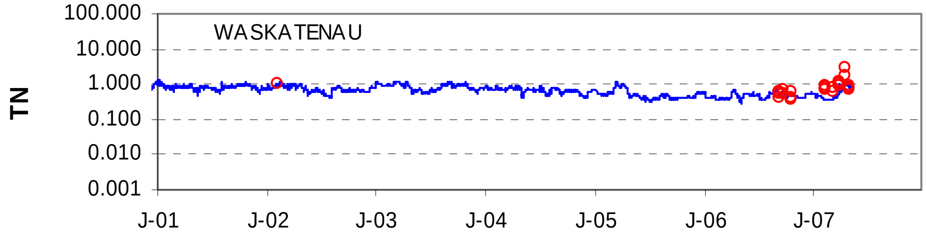
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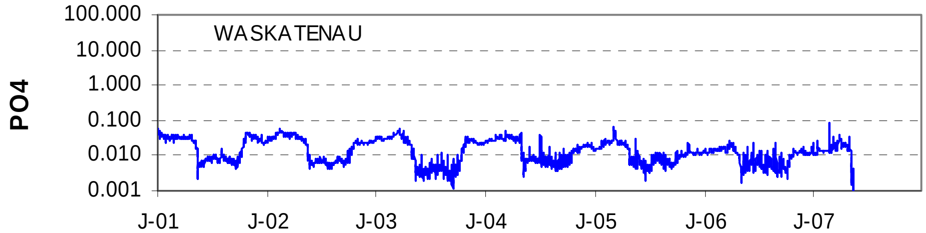
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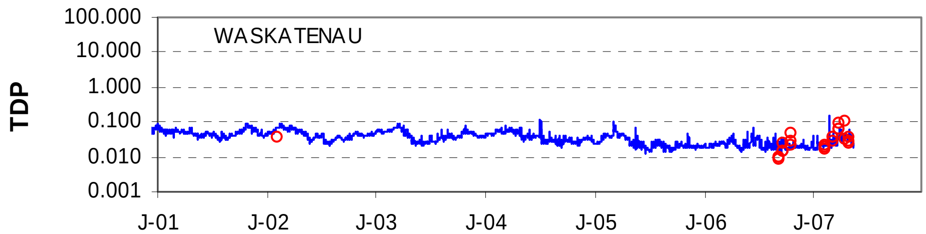
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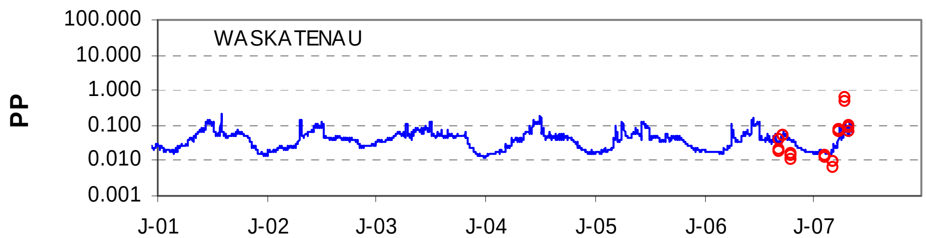
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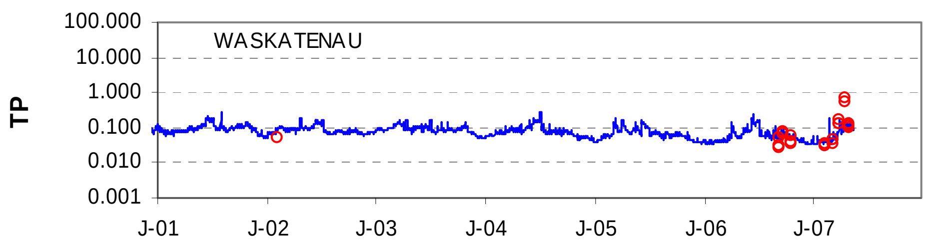
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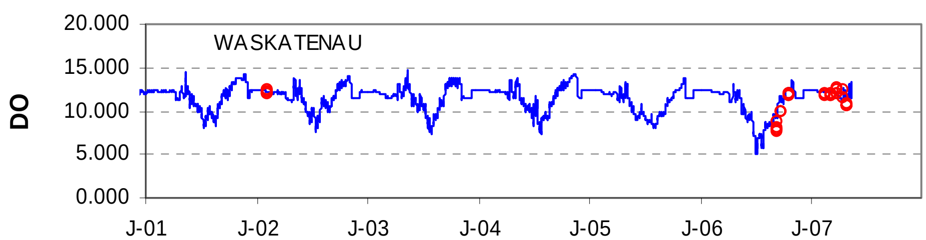
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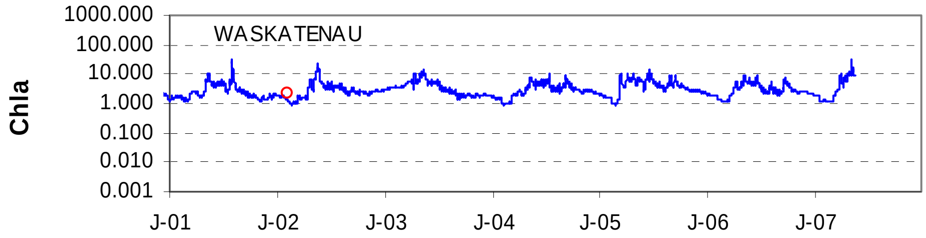
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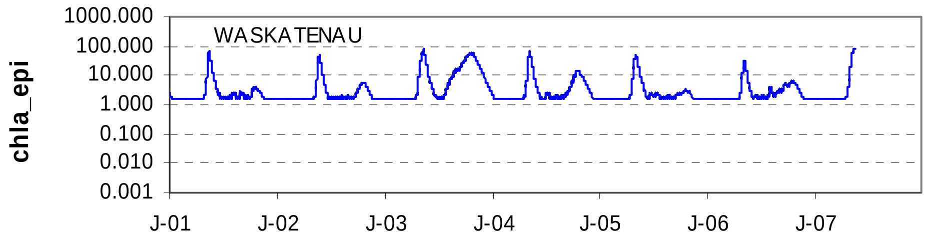
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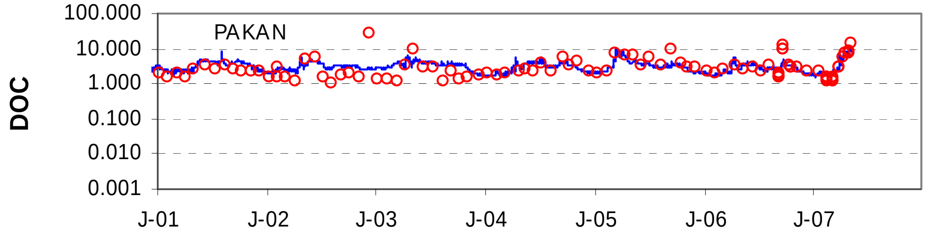
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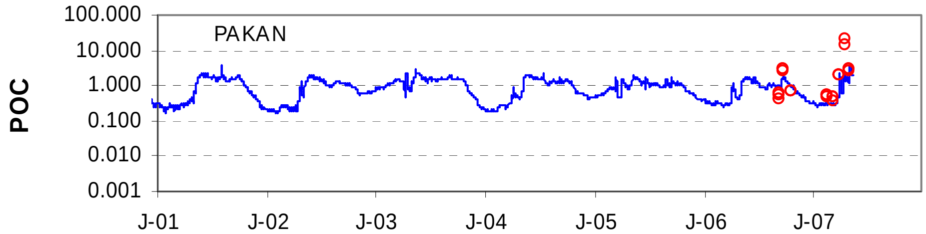
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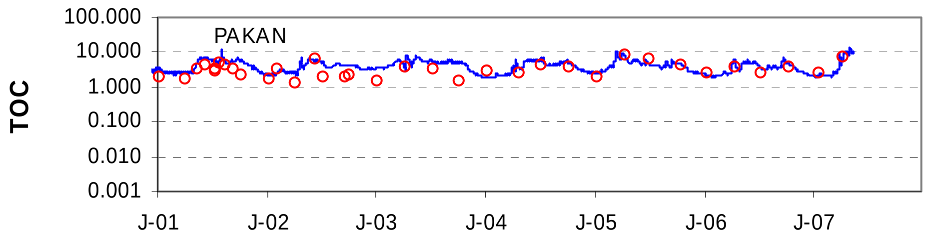
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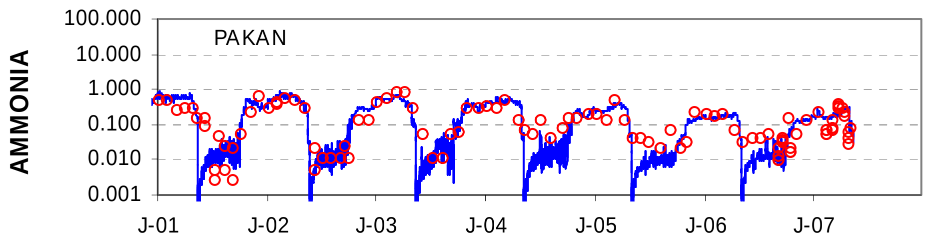
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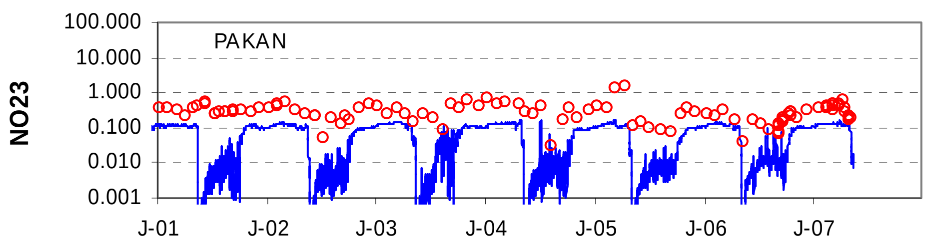
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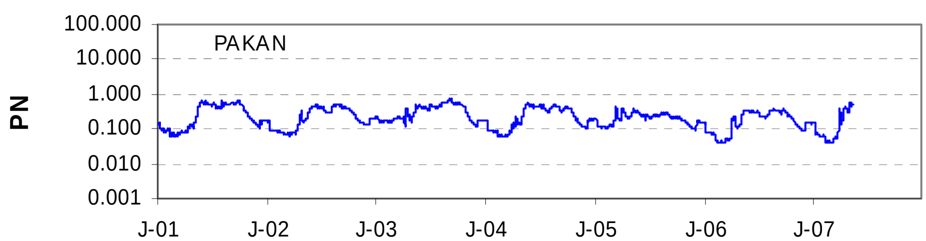
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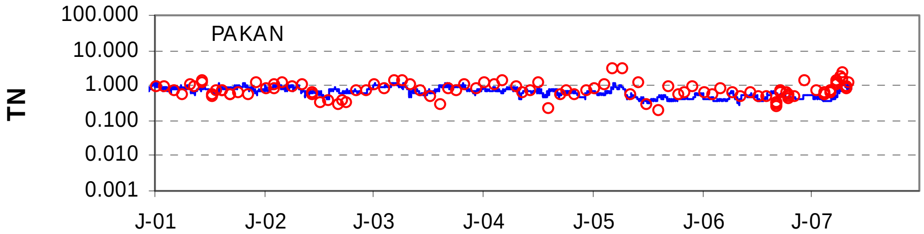
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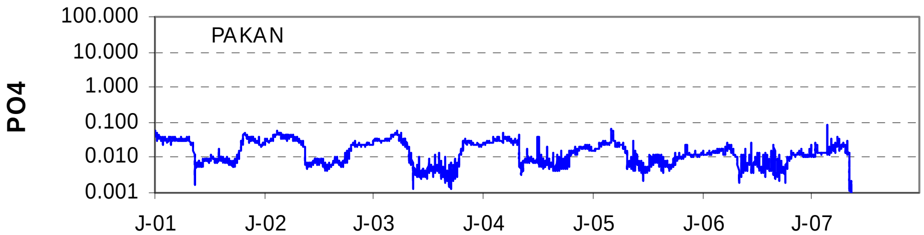
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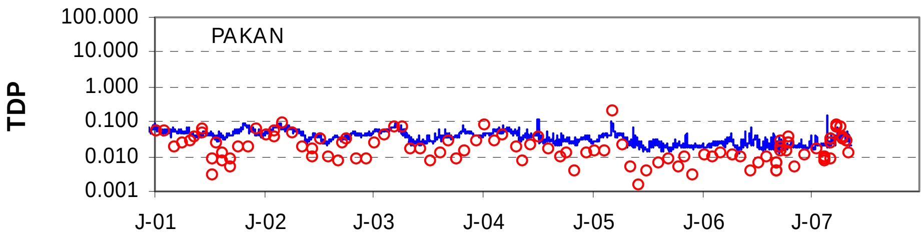
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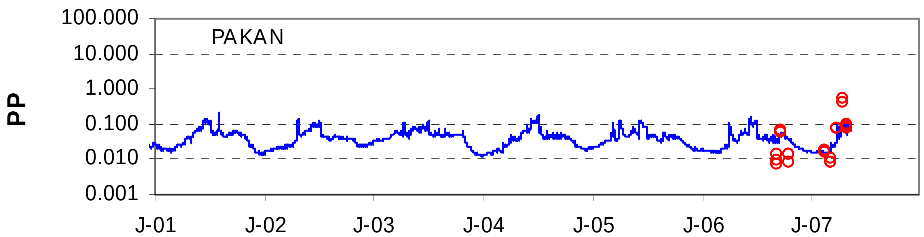
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J-02
J-03
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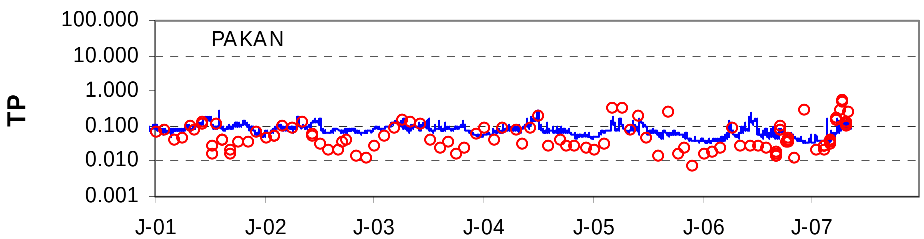
J-07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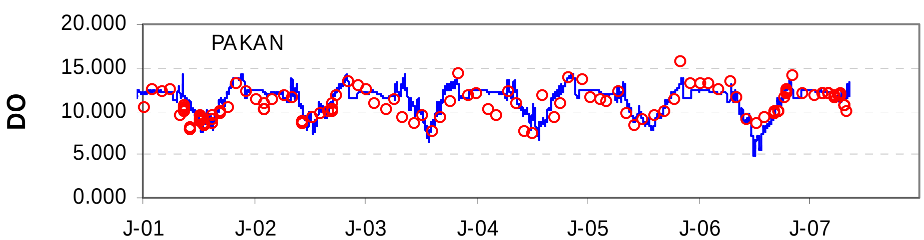
J-07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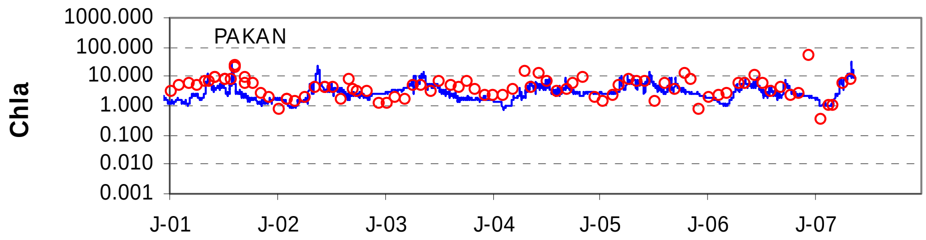
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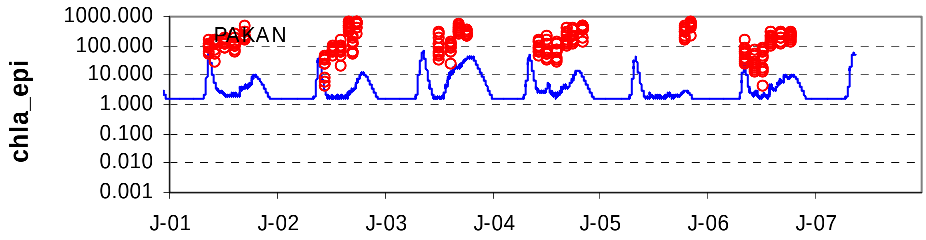
J-06
J-07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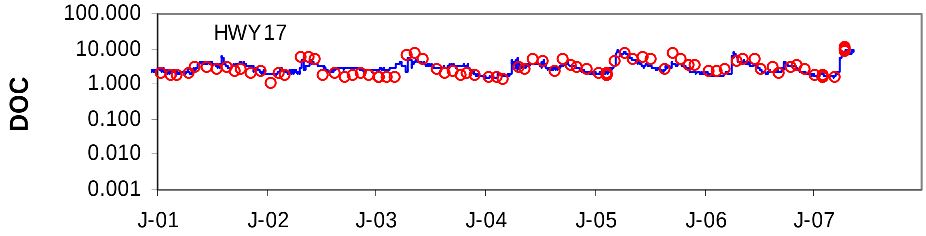
J-06
J-07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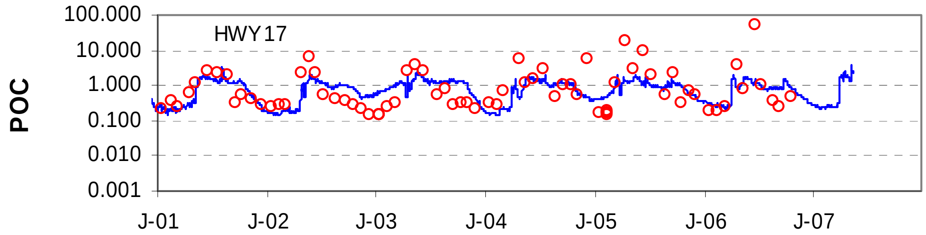
J-01 J-02 J-03 J-04 J-05 J-06 J-07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HWY17
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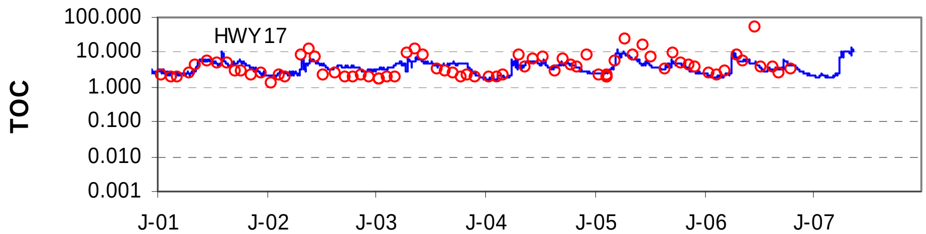
0.010
0.001
J-01 J-02 J-03 J-04 J-05 J-06 J-07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HWY17
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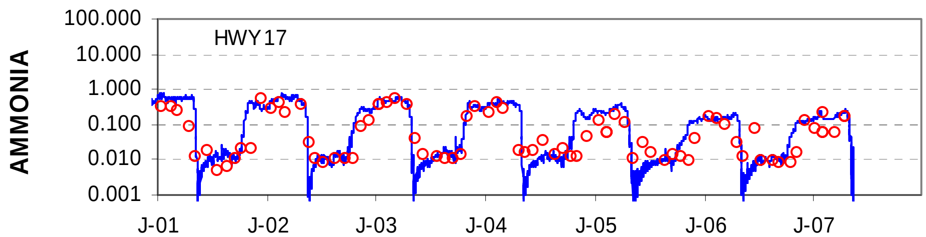
0.010
0.001
J-01 J-02 J-03 J-04 J-05 J-06 J-07


AMMONIA
HWY17
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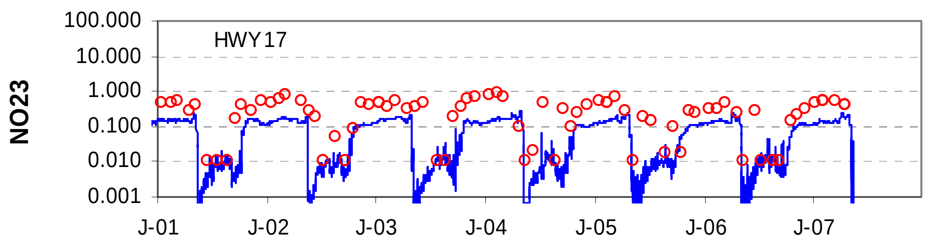
0.001
J-01 J-02 J-03 J-04 J-05 J-06 J-07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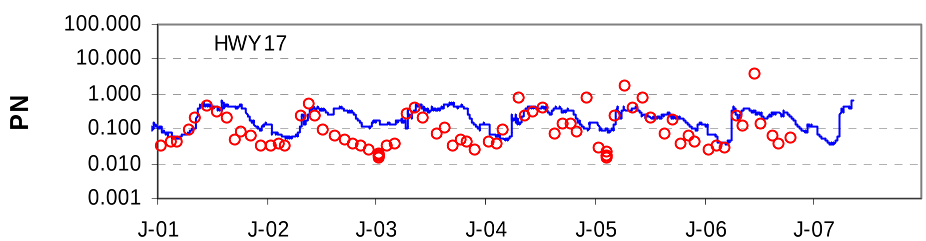
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HWY17
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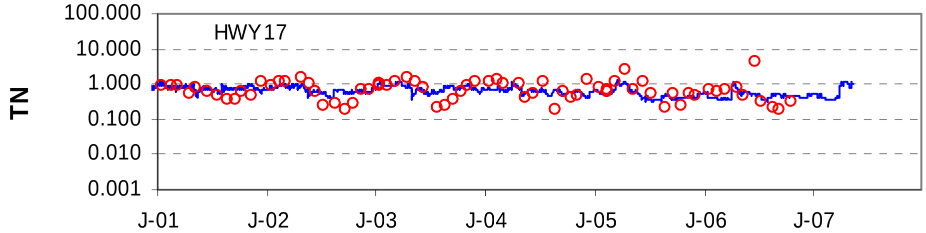
J-01 J-02 J-03 J-04 J-05 J-06 J-07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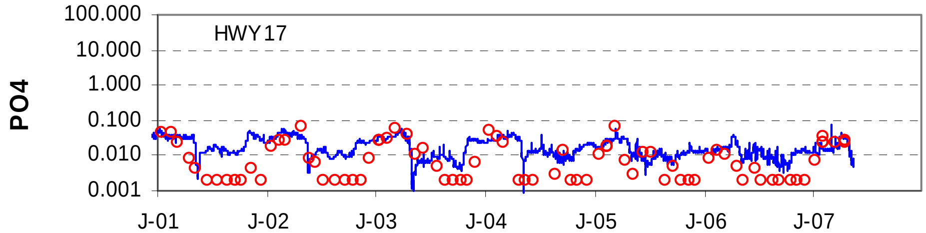
J-07


PO4
HWY17
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J-01
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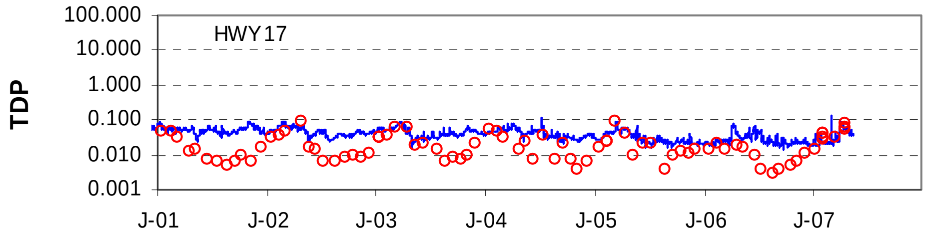
J-07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HWY17
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0.010
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J-01
J-02
J-03
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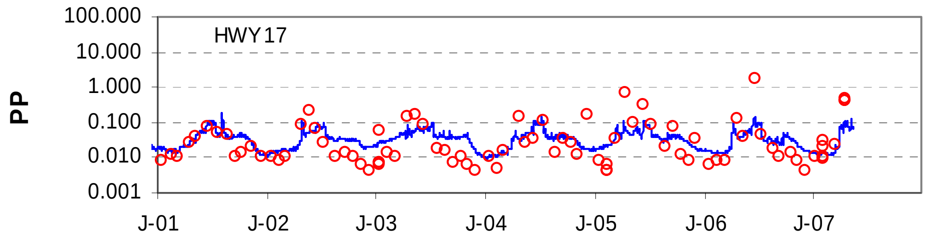
J-05
J-06
J-07


PP
HWY17
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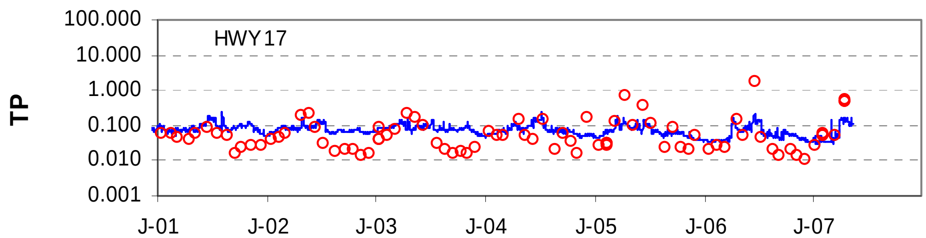
10.000
1.000
0.100
0.010
0.001
J-01
J-02
J-03
J-04
J-05
J-06
J-07


TP
HWY17
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10.000
1.000
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0.010
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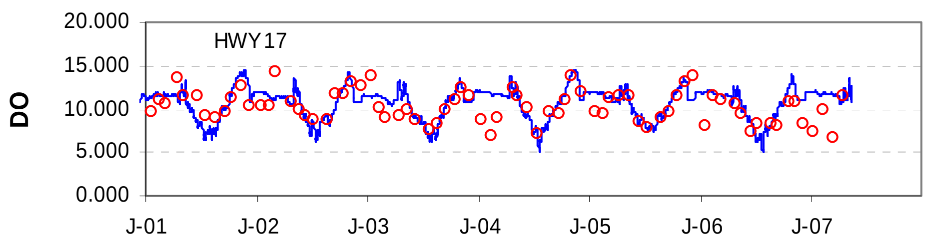
J-01
J-02
J-03
J-04
J-05
J-06
J-07


DO
HWY17
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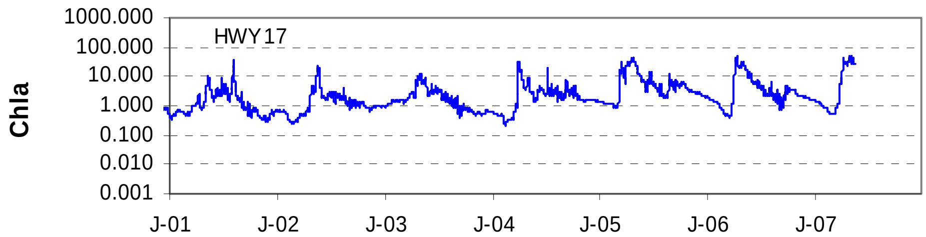
15.000
10.000
5.000
0.000
J-01
J-02
J-03
J-04
J-05
J-06
J-07


Chla
HWY17
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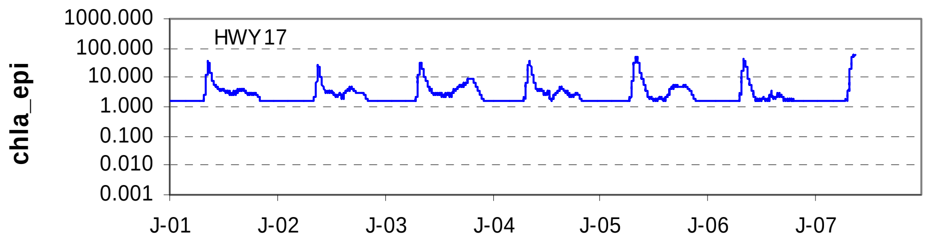
10.000
1.000
0.100
0.010
0.001
J-01
J-02
J-03
J-04
J-05
J-06
J-07


chla_epi
HWY17
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100.000
10.000
1.000
0.100
0.010
0.001
J-01
J-02
J-03
J-04
J-05
J-06
J-07

Units for the preceding plots and subsequent tables are as follows:

- For chla: ug/L
- For chla_epi: mg/m2
- For all the other parameters: mg/L

Statistics for Upstream of Rocky Mountain House

WQ Variables	Mean of Observations	Mean Error	Relative Mean Error	Mean Absolute Error	Relative Mean Absolute Error	Root Mean Square Error
DOC	0.81429	0.92821	1.13991	0.95625	1.17434	1.13324
POC						
TOC	0.98000	1.20195	1.22648	1.20195	1.22648	1.28905
AMMONIA	0.01819	-0.00080	-0.04393	0.00861	0.47319	0.01073
NO23	0.04981	0.01198	0.24054	0.01668	0.33485	0.02060
PN						
TN	0.18076	0.16902	0.93502	0.17345	0.95954	0.20714
PO4	0.01929	-0.01547	-0.80215	0.01622	0.84107	0.02593
TDP	0.00250	0.00504	2.01557	0.00504	2.01557	0.00554
PP						
TP	0.01405	0.04608	3.28017	0.04824	3.43378	0.06613
DO	11.33000	0.12119	0.01070	0.49738	0.04390	0.67464
Chla	0.66143	7.51904	11.36787	7.51904	11.36787	8.27703
Chla_epi	12.75568	45.88637	3.59733	45.88637	3.59733	50.00998

Statistics for Devon

WQ Variables	Mean of Observations	Mean Error	Relative Mean Error	Mean Absolute Error	Relative Mean Absolute Error	Root Mean Square Error
DOC	2.36013	-0.19988	-0.07945	0.90819	0.38480	1.66614
POC						
TOC	2.78571	0.14394	0.05167	0.82887	0.29754	1.15253
AMMONIA	0.02025	-0.00467	-0.22414	0.01615	0.79723	0.02322
NO23	0.05048	-0.00253	-0.04981	0.02889	0.57220	0.06002
PN	0.00000					
TN	0.23571	0.05678	0.22631	0.17310	0.73438	0.23373
PO4						
TDP	0.00416	0.00460	1.09046	0.00541	1.29908	0.00704
PP						
TP	0.03211	0.00390	0.09766	0.04722	1.47055	0.11264
DO	11.23390	0.03133	0.00279	0.71297	0.06347	0.92617
Chla	0.94098	3.28717	3.33621	3.32946	3.53831	3.99847
Chla_epi	6.89949	-4.46947	-0.64780	5.42897	0.78687	6.60217

Statistics for Anthony Henday

WQ Variables	Mean of Observations	Mean Error	Relative Mean Error	Mean Absolute Error	Relative Mean Absolute Error	Root Mean Square Error
DOC	3.55000	-1.01938	-0.28715	1.42688	0.40194	2.42013
POC	0.72167	0.02102	0.02913	0.28781	0.39882	0.31247
TOC	3.73352	-0.46477	-0.12449	1.30786	0.35030	2.03891
AMMONIA	0.00820	0.00430	0.52363	0.00700	0.85269	0.00754
NO23	0.01531	0.01611	1.05161	0.02300	1.50156	0.02659
PN						
TN	0.17050	0.11922	0.69927	0.12749	0.74776	0.15516
PO4						
TDP	0.00363	0.00576	1.58689	0.00576	1.58689	0.00693
PP	0.01150	0.01563	1.35946	0.01563	1.35946	0.01726
TP	0.01141	0.03505	3.07284	0.03505	3.07284	0.04365
DO	10.02650	0.10500	0.01047	0.49800	0.04967	0.67487
Chla	0.70000	3.33150	4.75929	3.33150	4.75929	3.69858
Chla_epi	19.46460	-15.85990	-0.81481	15.85990	0.81481	19.63767

Statistics for Walterdale

WQ Variables	Mean of Observations	Mean Error	Relative Mean Error	Mean Absolute Error	Relative Mean Absolute Error	Root Mean Square Error
DOC	3.00000	-1.14500	-0.38167	1.14500	0.38167	1.14500
POC						
TOC	3.33333	-0.06717	-0.02015	0.70250	0.21075	0.83292
AMMONIA	0.01267	0.00362	0.28561	0.01039	0.82004	0.01338
NO23	0.01822	-0.00101	-0.05540	0.01237	0.67900	0.01616
PN						
TN	0.18656	0.12247	0.65646	0.20819	1.11594	0.24568
PO4						
TDP	0.00356	0.00908	2.55438	0.00908	2.55438	0.00999
PP						
TP	0.01717	0.03544	2.06417	0.03581	2.08599	0.04443
DO	10.07603	0.10858	0.01078	0.47505	0.04715	0.56194
Chla	1.46667	2.21186	1.50808	2.28441	1.55755	2.73914
Chla_epi	39.53767	-23.12694	-0.58493	23.20430	0.58689	33.51582

Statistics for 50 Street

WQ Variables	Mean of Observations	Mean Error	Relative Mean Error	Mean Absolute Error	Relative Mean Absolute Error	Root Mean Square Error
DOC	2.00000	-0.13500	-0.06750	0.13500	0.06750	0.13500
POC						
TOC	3.42222	-0.13937	-0.04072	1.02765	0.30029	1.43576
AMMONIA	0.01178	0.00646	0.54858	0.01037	0.88047	0.01179
NO23	0.02051	-0.00560	-0.27315	0.01269	0.61876	0.01848
PN	0.00000					
TN	0.25651	0.05780	0.22532	0.22070	0.86038	0.28097
PO4						
TDP	0.00531	0.00882	1.66140	0.01261	2.37458	0.01331
PP						
TP	0.01700	0.03780	2.22381	0.03780	2.22381	0.04534
DO	10.05324	0.16505	0.01642	0.43700	0.04347	0.53914
Chla	1.48889	2.15871	1.44988	2.20027	1.47779	2.64299
Chla_epi	25.77069	11.64686	0.45194	19.67792	0.76358	25.70162

Statistics for Rundle

WQ Variables	Mean of Observations	Mean Error	Relative Mean Error	Mean Absolute Error	Relative Mean Absolute Error	Root Mean Square Error
DOC	4.58333	-1.41583	-0.30891	2.05167	0.44764	2.49618
POC	5.31556	-3.97422	-0.74766	4.05978	0.76375	6.55242
TOC	3.15000	0.27784	0.08820	1.03728	0.32930	1.20594
AMMONIA	0.12548	-0.00514	-0.04099	0.08125	0.64750	0.11338
NO23	0.16680	-0.13247	-0.79417	0.13247	0.79417	0.14789
PN						
TN	0.58650	-0.09403	-0.16032	0.21873	0.37294	0.26413
PO4						
TDP	0.02855	0.00359	0.12589	0.02352	0.82390	0.02875
PP	0.14289	-0.07190	-0.50317	0.09198	0.64372	0.14278
TP	0.07979	0.00856	0.10729	0.06564	0.82266	0.09497
DO	10.57414	0.54072	0.05114	0.78961	0.07467	0.94302
Chla	1.56500	2.00718	1.28254	2.19568	1.40299	2.60223
Chla_epi	121.78693	158.11701	1.29831	158.11701	1.29831	198.52183

Statistics for Upstream of Fort Saskatchewan

WQ Variables	Mean of Observations	Mean Error	Relative Mean Error	Mean Absolute Error	Relative Mean Absolute Error	Root Mean Square Error
DOC	3.99630	-1.16435	-0.29136	1.43194	0.35832	2.10383
POC	2.42729	-1.46826	-0.60490	1.52814	0.62956	2.85959
TOC	3.43333	0.14378	0.04188	0.68978	0.20091	0.82345
AMMONIA	0.18015	-0.01187	-0.06591	0.06441	0.35752	0.08782
NO23	0.24636	-0.16870	-0.68477	0.16870	0.68477	0.17959
PN						
TN	0.76212	-0.19103	-0.25066	0.27533	0.36127	0.31436
PO4						
TDP	0.03081	0.00561	0.18207	0.01404	0.45576	0.01855
PP	0.09626	-0.05089	-0.52863	0.05238	0.54413	0.08473
TP	0.10513	-0.01995	-0.18973	0.05753	0.54720	0.08058
DO	10.91678	0.91447	0.08377	1.28959	0.11813	1.76396
Chla	1.00000	0.15775	0.15775	0.15775	0.15775	0.15775
Chla_epi						

Statistics for Vinca

WQ Variables	Mean of Observations	Mean Error	Relative Mean Error	Mean Absolute Error	Relative Mean Absolute Error	Root Mean Square Error
DOC	4.47593	-0.55593	-0.12420	1.41870	0.31696	2.14756
POC	3.40792	-2.46976	-0.72471	2.67801	0.78582	4.28044
TOC	5.62500	-0.21381	-0.03801	3.85324	0.68502	6.16392
AMMONIA	0.14029	-0.02514	-0.17922	0.09543	0.68023	0.12307
NO23	0.29055	-0.23935	-0.82376	0.23935	0.82376	0.25722
PN						
TN	0.84233	-0.11440	-0.13582	0.29370	0.34867	0.38504
PO4						
TDP	0.02864	0.01218	0.42547	0.01378	0.48109	0.01873
PP	0.09869	-0.03951	-0.40037	0.05946	0.60251	0.10258
TP	0.09271	0.00875	0.09442	0.06328	0.68257	0.08925
DO	10.55558	1.35067	0.12796	1.62371	0.15382	2.18114
Chla	4.45000	-0.72354	-0.16259	2.18717	0.49150	2.76352
Chla_epi	60.13403	-16.46472	-0.27380	36.79695	0.61192	39.83007

Statistics for Waskatenau

WQ Variables	Mean of Observations	Mean Error	Relative Mean Error	Mean Absolute Error	Relative Mean Absolute Error	Root Mean Square Error
DOC	4.31852	-0.55046	-0.12747	1.00861	0.23355	1.69903
POC	3.21042	-2.32289	-0.72355	2.38305	0.74229	5.27129
TOC	3.00000	-0.04490	-0.01497	0.04490	0.01497	0.04490
AMMONIA	0.14206	0.06107	0.42990	0.09791	0.68926	0.12157
NO23	0.32333	-0.23576	-0.72915	0.23576	0.72915	0.26114
PN						
TN	0.91222	-0.31047	-0.34035	0.32074	0.35160	0.51254
PO4						
TDP	0.03419	-0.00209	-0.06100	0.01515	0.44331	0.01846
PP	0.09902	-0.05862	-0.59204	0.07096	0.71667	0.16181
TP	0.12409	-0.05371	-0.43285	0.07213	0.58122	0.16307
DO	11.16352	0.53065	0.04753	0.71209	0.06379	0.93272
Chla	2.20000	-1.06260	-0.48300	1.06260	0.48300	1.06260
Chla_epi						

Statistics for Pakan

WQ Variables	Mean of Observations	Mean Error	Relative Mean Error	Mean Absolute Error	Relative Mean Absolute Error	Root Mean Square Error
DOC	3.49177	-0.20959	-0.06002	1.36612	0.39124	3.11108
POC	3.37333	-2.41668	-0.71641	2.57484	0.76329	5.47223
TOC	3.24706	1.07856	0.33217	1.38442	0.42636	1.71946
AMMONIA	0.17104	0.04189	0.24494	0.09739	0.56943	0.14409
NO23	0.31803	-0.24743	-0.77802	0.24747	0.77814	0.31934
PN						
TN	0.81017	-0.11579	-0.14292	0.28903	0.35675	0.44053
PO4						
TDP	0.02504	0.01385	0.55310	0.02049	0.81836	0.02555
PP	0.09260	-0.05191	-0.56051	0.06638	0.71682	0.13738
TP	0.07444	0.00859	0.11540	0.05409	0.72670	0.07916
DO	10.92088	0.50714	0.04644	1.11051	0.10169	1.38752
Chla	5.18890	-1.92459	-0.37090	3.21796	0.62016	6.56667
Chla_epi	179.90145	-172.31346	-0.95782	172.31346	0.95782	218.39436

Statistics for HWY17

WQ Variables	Mean of Observations	Mean Error	Relative Mean Error	Mean Absolute Error	Relative Mean Absolute Error	Root Mean Square Error
DOC	3.09456	0.01418	0.00458	0.91013	0.29411	1.19282
POC	2.11448	-1.24254	-0.58764	1.71278	0.81003	6.09953
TOC	5.18410	-1.20299	-0.23205	2.45486	0.47354	6.47086
AMMONIA	0.10766	0.07500	0.69667	0.09211	0.85562	0.14385
NO23	0.30437	-0.21968	-0.72177	0.22466	0.73812	0.28906
PN	0.20940	0.03278	0.15654	0.21923	1.04696	0.46086
TN	0.77280	-0.10022	-0.12969	0.34562	0.44723	0.56460
PO4	0.01209	0.00710	0.58702	0.01176	0.97252	0.01460
TDP	0.02085	0.02017	0.96719	0.02329	1.11663	0.02726
PP	0.07307	-0.03587	-0.49091	0.05866	0.80278	0.19931
TP	0.09386	-0.01564	-0.16658	0.07579	0.80751	0.19785
DO	10.29570	0.53589	0.05205	1.36051	0.13214	1.78421
Chla						
Chla_epi						