



# **NEON USER GUIDE TO REAERATION (DP1.20190.001) AND SALT-BASED DISCHARGE SAMPLING (DP1.20193.001)**

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## CHANGE RECORD

REVISION	DATE	DESCRIPTION OF CHANGE
A	08/16/2017	Initial Release
B	06/24/2020	Included general statement about usage of neonUtilities R package and statement about possible location changes. Updated language in Analytical Facility Data Quality section
C	03/08/2022	Updated section 4.4 Data Revision with latest information regarding data release
C.1	08/27/2024	Updated for information on the dataframe table for conductivity logger data and sites which are changing expected injection types and experiment frequencies.
D	04/08/2025	Updated for protocol change to discontinue NaCl, NaBr, and model-CRI injections that use volatile gas (SF <sub>6</sub> ) tracer injections. Also template text changes included.



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# 1 DESCRIPTION

## 1.1 Purpose

This document provides an overview of the data included in this NEON Level 1 (L1) data product, the quality controlled product generated from raw Level 0 (L0) data, and associated metadata. In the NEON data products framework, the raw data collected in the field, the specific conductance of water for example, are considered the lowest level, L0. Raw data that have been quality checked via the steps detailed herein, as well as simple metrics that emerge from the raw data are considered L1 data products.

The text herein provides a discussion of measurement theory and implementation, data product provenance, quality assurance and control methods used, and approximations and/or assumptions made during L1 data creation.

## 1.2 Scope

This document describes the steps needed to generate the L1 data product and associated metadata from input data for Reaeration and Salt-based Discharge - which are components of a gas and salt tracer injection experiment. This document also provides details relevant to the publication of the data products via the NEON data portal, with additional detail available in the file, NEON Data Variables for Reaeration (DP1.20190.001) (AD[05]) and NEON Data Variables for Salt-based Discharge (DP1.20193.001) (AD[06]), provided in the download package for this data product.

This document describes the process for ingesting and performing automated quality assurance and control procedures on the data collected in the field pertaining to AOS Protocol and Procedure: Reaeration in Streams (AD[07]). The raw data that are processed in this document are detailed in the file, NEON Raw Data Validation for Reaeration and Salt-based Discharge (DP0.20190.001) (AD[04]), provided in the download package for this data product. Please note that raw data products (denoted by 'DP0') may not always have the same numbers (e.g., '20190') as the corresponding L1 data product.

## 2 RELATED DOCUMENTS AND ACRONYMS

### 2.1 Associated Documents

AD[01]	NEON.DOC.000001	NEON Observatory Design (NOD) Requirements
AD[02]	NEON.DOC.001152	Aquatic Sampling Strategy
AD[03]	NEON.DOC.002652	NEON Data Products Catalog
AD[04]	Available with data download	Validation csv
AD[05]	Available with data download	NEON Data Variables for Reaeration (DP1.20190.001)
AD[06]	Available with data download	NEON Data Variables for Salt-based Discharge (DP1.20193.001)
AD[07]	NEON.DOC.000693	AOS Protocol and Procedure: Reaeration in Streams
AD[08]	NEON.DOC.000008	NEON Acronym List
AD[09]	NEON.DOC.000243	NEON Glossary of Terms
AD[10]	NEON.DOC.004825	NEON Algorithm Theoretical Basis Document: OS Generic Transitions
AD[11]	Available on NEON data portal	NEON Ingest Conversion Language Function Library
AD[12]	Available on NEON data portal	NEON Ingest Conversion Language
AD[13]	Available with data download	Categorical Codes csv

### 2.2 Acronyms

Acronym	Definition
SF <sub>6</sub>	Sulfur hexafluoride



### 3 DATA PRODUCT DESCRIPTION

The Reaeration field and lab collection (DP1.20190.001) data product provides data for four different injection types: “NaCl” and “NaBr”, which are simultaneous inert gas (e.g. SF<sub>6</sub>) and conservative tracer (e.g. NaCl or NaBr) experiments and “model - slug” and “model - CRI”, which are conservative tracer (NaCl)-only slug or constant-rate injections, respectively. The data packages include tracer concentrations in stream water, conductivity time series, wetted width measurements, and related injection information (e.g. start and end times and rates of tracer injection) collected using AOS Protocol and Procedure: Reaeration in Streams (AD[07]). From the data provided in the Reaeration field and lab collection data package, users can calculate gas exchange velocities and rates (e.g., Aho et al., 2024a & Aho et al., 2024b). These gas exchange rates often have site-specific relationships with discharge (Aho et al., 2025) and may also be an important component of estimating stream metabolism.

The Salt-based Discharge (DP1.20193.001) data product provides data for the four reaeration injection types along with “Discharge only” slugs, where the associated data consists of only the field and external lab information related to the salt tracer. In some of the smaller NEON streams, discharge calculated from the data provided by the Salt-based stream discharge data product may provide more accurate discharge estimates than those determined using a handheld unit that are published as part of the Stream discharge field collection (DP1.20048.001) data product.

Reaeration and salt-based discharge injections are only performed in wadeable streams. There are five different types of experiments: NaCl constant rate injection (NaCl), NaBr constant rate injection plus an NaCl slug (NaBr), NaBr or NaCl constant rate injection without inert gas injection (model - CRI), NaCl slug (model - slug), or NaCl slug for discharge measurements only (wetted width measurements are not collected). An NaCl constant rate injection (conservative salt and inert, volatile gas) is the most common and takes place at streams with relatively low conductivity ( $\leq 500 \mu\text{S cm}^{-1}$ ) and low flows. At streams with high conductivity ( $> 500 \mu\text{S cm}^{-1}$ ) and/or higher flows, lower concentrations of NaBr are used for the constant rate injection (conservative salt and inert, volatile gas) along with an NaCl slug that will register changes in conductivity with the data loggers so that travel times can be calculated. For high flow wadeable streams ( $>2000 \text{ L/s}$ ; e.g., BLUE - Blue River) and low slope, low reaeration streams (e.g., ARIK - Arikaree River) an NaCl slug (without a gas or salt constant rate injection) will be performed to enable reaeration modeling without field measured reaeration rates. When field challenges impact the ability to complete a planned NaCl or NaBr injection with inert gas, a partial record may be entered with injection type model - CRI. Injection type “Discharge only” is only used at sites where capturing discharge with the wading surveys is (or has been) challenging.

#### 3.1 Spatial Sampling Design

Four stations downstream of the injection location (i.e. drip station) are sampled for analysis of salt tracer concentrations in the stream water (Figure 1) prior to tracer injection to capture background water concentrations. Once the injection is started and the tracers reach plateau, for NaCl and NaBr constant rate injections, samples are collected for gas and salt concentration at each of the 4 stations prior to ending the tracer injection. A salt sample is also collected from the injection solution. At the most upstream station, station #1, and the most downstream sampling station, station #4, submersible data loggers are deployed that record conductivity, temperature, and specific conductance in the stream water throughout



the injection experiments. A set of 30 (unless adverse conditions impacted data collection) wetted width measurements are also collected the same day as the tracer injection between station #1 and station #4.

As much as possible, sampling occurs in the same locations over the lifetime of the Observatory. However, over time some sampling locations may become impossible to sample, due to disturbance or other local changes. When this occurs, the location and its location ID are retired. A location may also shift to slightly different coordinates. Refer to the locations endpoint of the NEON API for details about locations that have been moved or retired: <https://data.neonscience.org/data-api/endpoints/locations/>

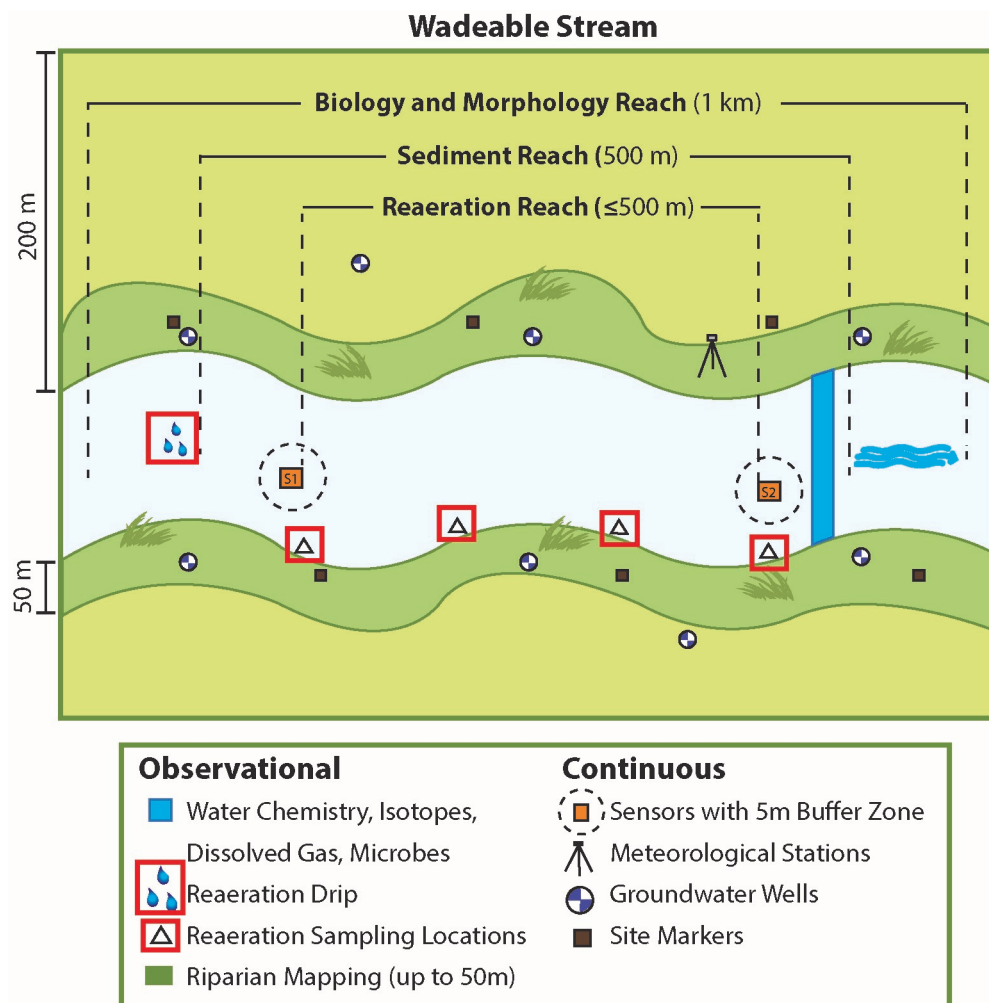


Figure 1: A generic wadeable stream site layout example with reaeration sampling stations.



### 3.2 Temporal Sampling Design

Reaeration measurements will be completed up to 10 times annually during NEON Site Characterization activities and up to 6 times annually during NEON Operations in wadeable stream locations until a relationship with discharge is developed (see section 3.3 Sampling Designs Changes). Sites that are high risk sites for flooding resulting in changes in stream morphology may be requested to continue to collect reaeration 10 times per year. Sampling events should be spread out throughout the year so as to collect a range of flows.

Timing of sampling is site specific and determined by rules developed using historical flow regime and environmental data. For example, streams with little or no flow during the summer dry-season are sampled more intensively during wet periods. Streams with snowmelt-dominated hydrographs are sampled more intensively during spring/summer-elevated flows than during winter snow-covered months.

### 3.3 Sampling Design Changes

**Note:** ARIK & BLUE have never successfully performed NaCl or NaBr **injectionType** experiments due to practical challenges related to large stream channels and high flows. Therefore, all published data for these two sites has been “model - slug” **injectionType**.

**Implemented 2021:** Permitting restrictions at the BLDE site prevented additional SF<sub>6</sub> releases and the site began collecting only “model - slug” injections types.

**Implemented 2022:** NEON discontinued release of sulfur hexafluoride (SF<sub>6</sub>) as part of reaeration experiments at 12 sites based on evaluation of the data quality by the Reaeration Technical Working Group (TWG, <https://www.neonscience.org/about/advisory-groups/twgs/reaeration-twg>). The 12 sites that discontinued SF<sub>6</sub> releases, denoted by NaCl, NaBr, and model - CRI **injectionType** are: LEWI, POSE, GUIL, WALK, LECO, PRIN, WLOU, COMO, REDB, BIGC, OKSR, CARI. The TWG recommended continuing SF<sub>6</sub> experiments at the remaining nine NEON sites, using targeted flow windows to better characterize the relationship between gas exchange and discharge within these sites. The 9 sites that continued SF<sub>6</sub> releases include: HOPB, CUPE, KING, MCDI, MAYF, SYCA, MART, MCRA, and TECR.

**Implemented 2025:** NEON discontinued the release of sulfur hexafluoride (SF<sub>6</sub>) at all NEON sites. Conservative salt slug experiments to measure stream travel time and calculate mean depth will continue at all sites, four times per year. This means that all sites will only perform the “model - slug” **injectionType** going forward. If these salt tracers indicate that major hydraulic changes that could influence gas exchange have occurred, gas release experiments may resume using an alternative gas (e.g., Argon).

### 3.4 Laboratory Quality Assurance and Uncertainty

NEON field procedures for collection of reaeration and salt-based discharge samples follow widely adopted community methods and all NEON technicians conducting this work receive proper training. For external laboratory analyses, facilities have been chosen for their use of analytical methods widely adopted by the aquatic chemistry community. Labs report the method detection limit, along with long-term analytical precision and uncertainty of standards analyzed as unknowns, for each gas or salt species in a summary file. This allows users to interpret and model the dissolved gas and salt data in the context of its uncertainty range. Contracted external facilities upload this summary file



(rea\_externalLabSummaryData) when they begin work for NEON, then again once per year or whenever their information changes (for example, a new instrument is acquired or a change is detected in analytical precision). Additionally, NEON's Calibration/Validation department has regular procedures for auditing the quality assurance of external laboratories and their reports are available to data users.

Occasionally, sample re-runs are requested following review of data returned from the external lab(s). For samples with salt concentrations less than the background concentrations measured for the same experiment, re-runs are requested. Another reason for salt or gas sample re-run requests is when a Dixon Q test flags a sample as an outlier compared to the other samples collected at the same station during plateau. In the case where the external lab re-runs a sample, the re-runs are ingested into the database and users can determine their preferred method for handling analytical duplicates.

**Note:** Following the discontinuation of SF<sub>6</sub> releases at all sites, i.e., the switch to only “model - slug” **injectionType**, samples are no longer collected or shipped to an external laboratory for analysis.

### 3.5 Variables Reported

All variables reported from the field or laboratory technician (L0 data) are listed in the file, NEON Raw Data Validation for Reaeration and Salt-based Discharge (DP0.20190.001) (AD[04]). All variables reported in the published data (L1 data) are also provided separately in the file, NEON Data Variables for Reaeration (DP1.20190.001) (AD[05]) and NEON Data Variables for Salt-based Discharge (DP1.20193.001) (AD[06]).

Field names have been standardized with Darwin Core terms (<http://rs.tdwg.org/dwc/>; accessed 16 February 2014), the Global Biodiversity Information Facility vocabularies (<http://rs.gbif.org/vocabulary/gbif/>; accessed 16 February 2014), the VegCore data dictionary (<https://projects.nceas.ucsb.edu/nceas/projects/bien/wiki/VegCore>; accessed 16 February 2014), where applicable. NEON AOS spatial data employs the World Geodetic System 1984 (WGS84) for its fundamental reference datum and Geoid12A geoid model for its vertical reference surface. Latitudes and longitudes are denoted in decimal notation to six decimal places, with longitudes indicated as negative west of the Greenwich meridian.

Some variables described in this document may be for NEON internal use only and will not appear in downloaded data.

### 3.6 Spatial Resolution and Extent

The finest resolution at which reaeration and salt-based discharge data are reported is a single water sample collected from a unique stationID. The namedLocation is the finest spatial resolution for the table and will be either stationID or siteID. All tables also contain a domainID and siteID field in addition to the namedLocation field. Overall, this results in a spatial hierarchy of:

**sampleID** (unique ID given to the individual sample) → **namedLocation** (ID of the sampling location) → **siteID** (ID of NEON site) → **domainID** (ID of a NEON domain).

The injection station (i.e. drip station) and four downstream sampling stations are predominantly stationary over time, and reaeration station #1 will always align with Sensor Set #1 while reaeration station #4 will always align with Sensor Set #2. However, differing flow conditions may necessitate shifting stations



2 or 3 either upstream or downstream. The exact geospatial location of these stations is less important for reaeration rate calculations than the distance the water flows between the stations. Users should use the downstream distances recorded in the data for each station as they could potentially be different for different dates (table: rea\_backgroundFieldSaltData or sbd\_backgroundFieldSaltData, field: stationToInjectionDistance).

Shapefiles related to the NEON Aquatic Observation System sampling locations can be found on the NEON science webpage at <https://www.neonscience.org/data-samples/data/spatial-data-maps>. If users are interested in the geospatial locations of the data relative to a global coordinate system, those can be retrieved using the NEON data API using the **namedLocation** and the following:

1. The `def.extr.geo.os.R` function from the `geoNEON` package, available here: <https://github.com/NEONScience/NEON-geolocation>
2. The NEON API: <http://data.neonscience.org/api>

### 3.7 Temporal Resolution and Extent

The finest resolution at which reaeration and salt-based discharge temporal data are reported is the time of day. For field measurements and sample collections this is recorded to the nearest minute. For in situ conductivity logger measurements data is recorded to the nearest second. One injection experiment takes place on a single date. The total number of injection experiments per year is expected to be 6 - 10 per wadeable stream per site.

The NEON Data Portal currently provides data in monthly files for query and download efficiency. Queries including any part of a month will return data from the entire month. All queries, regardless of the date range specified, will include a copy of `rea_externalLabSummaryData` which provides summary information from the external lab about the method detection limits, the equipment used, and precision and accuracy. Code to stack files across months is available here: <https://github.com/NEONScience/NEON-utilities>

### 3.8 Associated Data Streams

There are no directly associated data streams for Reaeration field and lab collection and Salt-based discharge. The protocol for these two data products is only performed on a day when other activities are not taking place in order to prevent disturbing the stream during the injection experiment.

### 3.9 Product Instances

The NEON Observatory contains 24 wadeable streams.

Reaeration and salt-based discharge sampling yields a set of background samples and a set of plateau samples per sampling event. There will be 6 complete sampling events per year in wadeable streams and may be some additional incomplete records for experiments that experience field challenges. The background set of samples consist of one sample collected from each of the four sampling stations and an injectate solution sample (5 total salt samples). It is assumed that the gas used for the injection, usually  $\text{SF}_6$ , is not present in the water naturally, and therefore background samples are not needed. The plateau



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samples consist of 5 replicates at each of the 4 sampling stations once the most downstream station, station #4, has reached a constant, maximum conductivity (20 total salt and 20 total gas). Observatory-wide, this will yield a total of 4320 to 7200 wetted width records and 3600 to 6000 salt concentration records and 2880 to 4800 gas concentration records for reaeration and salt-based discharge per year.

### 3.10 Data Relationships for Reaeration

The protocol dictates that the tracer injection will take place at each siteID per event (one record expected per siteID and collectDate combination in rea\_fieldData). A record from rea\_fieldData will usually have 4 child records in rea\_backgroundFieldSaltData and rea\_plateauMeasurementFieldData (one for each sampling station), two child records in rea\_backgroundFieldCondData (one for the upstream, station #1 and downstream, station #4 stations where conductivity loggers are deployed), many child records in rea\_conductivityFieldData (logger conductivity data is collected and a record is created every 10 seconds during the duration of the injection experiment). 30 records are created in rea\_widthFieldData (one for each wetted width measurement) for each injection experiment. Each record from rea\_plateauMeasurementFieldData is expected to have 5 child records in rea\_plateauSampleFieldData (one for each replicate collected at the station). Each record from rea\_backgroundFieldSaltData (background samples), rea\_plateauMeasurementFieldData (plateau samples), and rea\_fieldData (injectate sample) is expected to have one child record in rea\_externalLabDataSalt with the salt tracer concentration. Each record from rea\_plateauMeasurementFieldData is expected to have one child record in rea\_externalLabDataGas with the gas tracer concentration. However, duplicates and/or missing data may exist where protocol and/or data entry aberrations have occurred; *users should check data carefully for anomalies before joining tables*. Below, the data relationships are also summarized in a bulleted list. Records with an injection type of “model - slug” and “model - CRI” may contain fewer records and/or tables than described below.

- rea\_fieldData has one record per injection experiment (unique siteID and collectDate combination)
- rea\_backgroundFieldSaltData has one record per injection experiment per station (4 children of rea\_fieldData)
- rea\_plateauMeasurementFieldData has one record per injection experiment per station (4 children of rea\_fieldData)
- rea\_backgroundFieldCondData has one record per injection experiment per upstream, station #1, and downstream, station #4, station (2 children of rea\_fieldData)
- rea\_widthFieldData has 30 records per injection experiment (unique siteID and collectDate combination)
- rea\_plateauSampleFieldData has one record per sample collected per station per experiment (5 children of rea\_plateauMeasurementFieldData)
- rea\_externalLabDataSalt contains external lab records for background samples (4 **saltBackground-SampleID** samples in rea\_backgroundFieldSaltData per collectDate), tracer injectate samples (one **injectateSampleID** sample in rea\_fieldData per collectDate), and plateau samples (20 **saltTracer-SampleID** samples in rea\_plateauSampleFieldData per collectDate)



- `rea_externalLabDataGas` has one external lab record per sample in `rea_plateauSampleFieldData` **gasSampleID**
- `rea_externalLabSummaryData` has one record expected per `laboratoryName` x `analyte` x `method` x `labSpecificStartDate` combination. Can use corresponding variables in `externalLabData` tables to associate sample data with relevant uncertainty values and method detection limits

#### RELEASE-2023 and earlier

- `rea_conductivityFieldData` has one record per 10 second interval per injection experiment. The set of records that take place over time for a station and injection experiment date can be linked using the **hoboSampleID** which is a field in each record of both `rea_conductivityFieldData` and `rea_backgroundFieldCondData` tables.

#### RELEASE-2024 and later

- `rea_conductivityFieldData` will contain a single record for each `hoboSampleID`, of which there are usually two per sampling event. The 0.1 Hz conductivity data are in the expanded data package, stored in one file per `hoboSampleID`. The `neonUtilities` R package ( $\geq 2.4.0$ ), using either `stackByTable()` or `loadByProduct()`, stacks the conductivity data files and names the resulting table `rea_conductivityRawData`. To produce the equivalent of the previous `xxx_conductivityFieldData` table, join the `rea_conductivityFieldData` to the `rea_conductivityRawData`, joining on the `hoboSampleID`.

### 3.11 Data Relationships for Salt-based Discharge

The Salt-based Discharge (DP1.20193.001) data product is a subset of the tracer injection information that includes only the field and external lab information related to the salt tracer injection. This section describes the tables that are part of the salt-based discharge publication package. The protocol dictates that the tracer injection will take place at each `siteID` per event (one record expected per `siteID` and `collectDate` combination in `sbd_fieldData`). A record from `sbd_fieldData` will usually have 4 child records in `sbd_backgroundFieldSaltData` and `sbd_plateauMeasurementFieldData` (one for each sampling station), two child records in `sbd_backgroundFieldCondData` (one for the upstream, station #1 and downstream, station #4 stations where conductivity loggers are deployed), many child records in `sbd_conductivityFieldData` (logger conductivity data is collected and a record is created every 10 seconds during the duration of the injection experiment). Each record from `sbd_plateauMeasurementFieldData` is expected to have 5 child records in `sbd_plateauSampleFieldData` (one for each replicate collected at the station). Each record from `sbd_backgroundFieldSaltData` (background samples), `sbd_plateauMeasurementFieldData` (plateau samples), and `sbd_fieldData` (injectate sample) is expected to have one child record in `sbd_externalLabDataSalt` with the salt tracer concentration. However, duplicates and/or missing data may exist where protocol and/or data entry aberrations have occurred; *users should check data carefully for anomalies before joining tables*. Below, the data relationships are also summarized in a bulleted list. Records with an injection type of “model - slug”, “model - CRI”, or “Discharge only” may contain fewer records and/or tables than described below.

- `sbd_fieldData` has one record per injection experiment (unique `siteID` and `collectDate` combination)



- `sbd_backgroundFieldSaltData` has one record per injection experiment per station (4 children of `sbd_fieldData`)
- `sbd_plateauMeasurementFieldData` has one record per injection experiment per station (4 children of `sbd_fieldData`)
- `sbd_backgroundFieldCondData` has one record per injection experiment per upstream, station #1, and downstream, station #4, station (2 children of `sbd_fieldData`)
- `sbd_plateauSampleFieldData` has one record per sample collected per station per experiment (5 children of `sbd_plateauMeasurementFieldData`)
- `sbd_externalLabDataSalt` contains external lab records for background samples (4 **saltBackground-SampleID** samples in `sbd_backgroundFieldSaltData` per `collectDate`), tracer injectate samples (one **injectateSampleID** sample in `sbd_fieldData` per `collectDate`), and plateau samples (20 **saltTracer-SampleID** samples in `sbd_plateauSampleFieldData` per `collectDate`)
- `rea_externalLabSummaryData` has one record expected per laboratoryName x analyte x method x labSpecificStartDate combination. Can use corresponding variables in externalLabData tables to associate sample data with relevant uncertainty values and method detection limits

#### RELEASE-2023 and earlier

- `sbd_conductivityFieldData` has one record per 10 second interval per injection experiment, the set of records that take place over time for a station and injection experiment date can be linked using the **hoboSampleID** which is a field in each record of both `sbd_conductivityFieldData` and `sbd_backgroundFieldCondData` tables.

#### RELEASE-2024 and later

- `sbd_conductivityFieldData` will contain a single record for each `hoboSampleID`, of which there are usually two per sampling event. The 0.1 Hz conductivity data are in the expanded data package, stored in one file per `hoboSampleID`. The `neonUtilities` R package ( $\geq 2.4.0$ ), using either `stackByTable()` or `loadByProduct()`, stacks the conductivity data files and names the resulting table `sbd_conductivityRawData`. To produce the equivalent of the previous `xxx_conductivityFieldData` table, join the `sbd_conductivityFieldData` to the `sbd_conductivityRawData`, joining on the `hoboSampleID`.

### 3.12 Special Considerations

Data users are encouraged to search the relevant literature prior to using the NEON Reaeration data product (DP1.20190.001) for calculating gas exchange velocities ( $k_{600}$ ), gas exchange rates ( $K_{600}$ ), and hydraulic geometries at the NEON sites. Methods more sophisticated than those outlined in this appendix have been used (and new ones may be developed in the future) to calculate these metrics (Aho et al., 2025a & Aho et al., 2025b). Users are encouraged to review the literature and use appropriate calculated metrics derived from the NEON dataset in addition to or potentially in place of direct download and processing of the NEON dataset for this data product.

The equations needed to calculate reaeration rates and salt-based discharge from the data available in



this downloaded package are detailed and referenced in the appendix. The information provided there is outside of the scope of basic QA/QC of L0 data used to create this L1 data product. However, the field and laboratory methods chosen were designed to enable these calculations by data users, thus a discussion of them is provided. NEON does maintain the reaRate R package, that can be found in the NEON-reaeration GitHub repository (<https://github.com/NEONScience/NEON-reaeration>) that contains functions to make some of the calculations outlined in the appendix.

Data downloaded from the NEON Data Portal are provided in separate data files for each site and month requested. The neonUtilities package in R and the neonutilities package in Python contain functions to merge these files across sites and months into a single file for each table. The neonUtilities R package is available from the Comprehensive R Archive Network (CRAN; <https://cran.r-project.org/web/packages/neonUtilities/index.html>) and can be installed using the install.packages() function in R. The neonutilities package in Python is available on the Python Package Index (PyPi; <https://pypi.org/project/neonutilities/>) and can be installed using pip. For instructions on using the package in either language to merge NEON data files, see the Download and Explore NEON Data tutorial on the NEON website: <https://www.neonscience.org/download-explore-neon-data>.

## 4 DATA QUALITY

### 4.1 Data Entry Constraint and Validation

Many quality control measures are implemented at the point of data entry within a mobile data entry application or web user interface (UI). For example, data formats are constrained and data values controlled through the provision of drop-down options, which reduces the number of processing steps necessary to prepare the raw data for publication. An additional set of constraints are implemented during the process of ingest into the NEON database. The product-specific data constraint and validation requirements built into data entry applications and database ingest are described in the document NEON Raw Data Validation for Reaeration and Salt-based Discharge (DP0.20190.001), provided with every download of this data product. Contained within this file is a field named 'entryValidationRulesForm', which describes syntactically the validation rules for each field built into the data entry application. Data entry constraints are described in Nicl syntax in the validation file provided with every data download, and the Nicl language is described in NEON's Ingest Conversion Language (NICL) specifications ([AD[11]]).

A schematic of the data entry application design is depicted in Figure 2 located at the end of this document.

Data collected prior to 2017 were processed using a paper-based workflow that did not implement the full suite of quality control features associated with the interactive digital workflow.

### 4.2 Calculations made on data ingest

Specific conductance, conductivity normalized to 25 °C, is calculated during data ingest for **lowRangeHobo** and **fullRangeHobo** using Equation 1 specified by *Standard Methods for the Examination of Water and Wastewater*. **lowRangeSpCondLinear** and **fullRangeSpCondLinear** are calculated using an *r* value of 0.0191, which is the value for a pure potassium chloride solution. **lowRangeSpCondNonlinear** and **fullRangeSpCondNonlinear** are calculated using a non-linear *r* value calculated according to Equation 2 de-



rived from the Practical Salinity Scale 1978 (PSS-78) equations.  $S$  is assumed to be 0 for all NEON sites since conductivity has been measured below 1500 microSiemens.

$$SC = \frac{AC}{1 + r(T - 25)} \quad (1)$$

Where:

$SC$  is Specific Conductance at 25 degrees Celsius in microSiemens per cm

$AC$  is the measured conductivity of the sample in microSiemens per cm

$r$  is the temperature correction coefficient for the sample

$T$  is the temperature of the sample in Celsius

$$r = A + B \cdot T + C \cdot S + D \cdot T^2 + E \cdot S^2 + F \cdot T \cdot S \quad (2)$$

Where:

$r$  is the temperature correction coefficient for the sample

$S$  is the salinity of the sample

$T$  is the temperature of the sample in Celsius

$A = 1.86221444$

$B = 0.00799141780$

$C = -0.00204882760$

$D = -0.0000479386353$

$E = 0.0000167997158$

$F = -0.0000155721008$

### 4.3 Automated Data Processing Steps

Following data entry into a mobile application or web user interface, the steps used to process the data through to publication on the NEON Data Portal are detailed in the NEON Algorithm Theoretical Basis Document: OS Generic Transitions (AD[10]).

### 4.4 Data Revision

All data are provisional until a numbered version is released. Annually, NEON releases a static version of all or almost all data products, annotated with digital object identifiers (DOIs). The first data Release was made in 2021. During the provisional period, QA/QC is an active process, as opposed to a discrete





activity performed once, and records are updated on a rolling basis as a result of scheduled tests or feed-back from data users. The Issue Log section of the data product landing page contains a history of major known errors and revisions.

## 4.5 Quality Flagging

The **dataQF** field in each data record is a quality flag for known errors applying to the record. Please see the *Special Considerations* section of this document for a list of known errors that may be present in the data, and below for an explanation of **dataQF** codes specific to this product.

Table 1: Descriptions of the dataQF codes for quality flagging

fieldName	value	definition
dataQF	legacyData	Data recorded using a paper-based workflow that did not implement the full suite of quality control features associated with the interactive digital workflow

\end{table}

In the `rea_fieldData` table, the **incompleteExperimentQF** quality flag is used to indicate that a reaeration experiment is incomplete in some way, e.g. a field discharge measurement was not collected. Often this is a result of an unplanned mishap during data collection, i.e. an equipment malfunction. This flag is populated on a semi-annual basis following science review. An external lab data flag in this table indicates that there will not be any external lab data returned for any samples for the indicated type of analysis. For example, an `externalLabSaltDataNA` flag indicates that no salt concentrations will be returned from the external lab at all. If more than one flag is applicable, the appropriate flags will be concatenated with a pipe “|” delimiter.

Table 2: Descriptions of the dataQF codes for quality flagging field data

fieldName	value	definition
incompleteExperimentQF	HOBO_S1_dataNA	HOBO file for station 1 not available for reaeration experiment
incompleteExperimentQF	HOBO_S4_dataNA	HOBO file for station 4 not available for reaeration experiment
incompleteExperimentQF	fieldDischargeDataNA	Wading survey discharge data not available for reaeration experiment
incompleteExperimentQF	externalLabSaltDataNA	External lab salt data not available for reaeration experiment
incompleteExperimentQF	externalLabGasDataNA	External lab gas data not available for reaeration experiment

\end{table}



In the `rea_backgroundFieldSaltData_in` and `rea_plateauSampleFieldData_in` tables, the **incompleteExperimentQF** quality flag is used to indicate that External lab data will not be returned for one or more samples in the specific record. This flag is populated on a semi-annual basis following science review. For example, an `externalLabSaltSampleDataNA` flag indicates that no salt concentrations will be returned from the external lab for the `saltTracerSampleID`, but external lab gas data may be returned for the gas sample in the same record and external lab salt data may be returned for other salt samples collected during the respective reaeration experiment. If more than one flag is applicable, the appropriate flags will be concatenated with a pipe “|” delimiter.

Table 3: Descriptions of the dataQF codes for quality flagging external lab data

fieldName	value	definition
incompleteExperimentQF	externalLabSaltSampleDataNA	External lab salt data not available for sample
incompleteExperimentQF	externalLabGasSampleDataNA	External lab gas data not available for sample

\end{table}

Records of land management activities, disturbances, and other incidents of ecological note that may have a potential impact are found in the Site Management and Event Reporting data product (DP1.10111.001)

## 4.6 Analytical Facility Data Quality

Data analyses conducted for reaeration conform to the current data quality standards used by practitioners. On at least an annual basis a QAQC summary file is reported that contains a description of the method, method detection limit, precision, and measurement uncertainty associated with a specific time range and analyte. This is published in the `rea_externalLabSummaryData` or `sbd_externalLabSummaryFile` table in the expanded download package.

As of 07/01/20, analytical replicate values run in the lab as a process check are recorded in the appropriate `analyticalReplicate` column. Samples that were run multiple times by the lab are recorded as additional rows. Prior to 07/01/20, sample replicate values can be pulled from the remarks field. In all cases where NEON has asked for samples to be re-run following data return, sample data is submitted as a new row and all data published to allow user to evaluate data.

## 5 REFERENCES

Aho, K., Cawley, K., Hensley, R., Hall, R.O., Dodds, W., and Goodman, K. (2024a) Gas transfer velocities derived from the NEON reaeration field and lab collection data product (DP1.20190.001). *Earth System Science Data*, 16(12), 5563-5578. <https://doi.org/10.5194/essd-16-5563-2024>

Aho, K.S., K. Cawley, R. Hensley, R.O. Hall, W. Dodds, and K. Goodman. (2024b) Gas exchange velocities ( $k_{600}$ ), gas exchange rates ( $K_{600}$ ), and hydraulic geometries for streams and rivers derived from the NEON Reaeration field and lab collection data product (DP1.20190.001) ver 2. Environmental Data Initiative. <https://doi.org/10.6073/pasta/18dcc1871ee71cf0b69f2ee4082839d0>



Aho, K., Cawley, K., Hall, R.O., Hensley, R., Dodds, W., Harrison, N., and Goodman, K. (2025) Gas transfer velocity ( $k_{600}$ ) increases with discharge in steep streams but not in low-slope streams. *Limnology and Oceanography-Letters*, <https://doi.org/10.1002/lol2.70003>

Calkins, D. and Dunne, T. (1970) A salt tracing method for measuring channel velocities in small mountain streams. *Journal of Hydrology* 11(4), 379-392, [doi:10.1016/0022-1694\(70\)90003-X](https://doi.org/10.1016/0022-1694(70)90003-X)

Clesceri LS, Greenberg AE, Eaton AD (1996) *Standard Methods for the Examination of Water and Wastewater*. 20th edition, Portland, OR.

Jahne B, Munnich KO, Bosinger R, Dutzi A, Huber W, Libner P (1987) On parameters influencing air-water gas exchange. *J Geophys Res* 92:1937-1949

Kilpatrick, F.A. and Cobb, E.D. Measurement of discharge using tracers, *Techniques of Water Resources Investigations of the United States Geological Survey, Book 3 Applications of Hydraulics, Chapter A16*.

Rantz, S.E., and others. *Measurement and computation of streamflow*, U.S. Geological Survey, Water Supply Paper 2175.

Raymond, Peter A., Zappa, Christopher J., Butman, David, Bott, Thomas L., Potter, Jody, Mulholland, Patrick, Laursen, Andrew E., McDowell, William H., Newbold, Denis, (2012), Scaling the gas transfer velocity and hydraulic geometry in streams and small rivers. *Limnology and Oceanography: Fluids and Environments*, 2, 10.1215/21573689-1597669.

Waldon, M.G. (2004) Estimation of Average Stream Velocity, *Journal of Hydraulic Engineering*, 130(11), [doi:10.1061/\(ASCE\)0733-9429\(2004\)130:11\(1119\)](https://doi.org/10.1061/(ASCE)0733-9429(2004)130:11(1119))

Wanninkhof, R. (1992), Relationship between wind speed and gas exchange over the ocean, *J. Geophys. Res.*, 97(C5), 7373-7382, [doi:10.1029/92JC00188](https://doi.org/10.1029/92JC00188).

## 6 APPENDIX

### 6.1 Calculating salt-based discharge from a constant rate injection

$$Q = \left[ \frac{C_1 - C_b}{C_2 - C_b} \right] q$$

where

$Q$  is the discharge of the stream

$q$  is the rate of flow of the injected tracer solution (table: fieldData, fields: dripRateStart & dripRateEnd, there will be one pair of records per site per injection experiment date)

$C_b$  is the background concentration of the stream (table: externalLabDataSalt where saltSampleID = saltBackgroundSampleID, there will be one record for each station)

$C_1$  is the concentration of the tracer solution injected into the stream (table: externalLabDataSalt where saltSampleID = injectateSampleID, there will be one record per site per injection experiment date)



$C_2$  is the measured concentration of the plateau of the concentration-time curve (table: external-LabDataSalt where saltSampleID = saltTracerSampleID, there will be 5 replicates for each station)

Adapted from Rantz et al. U.S. Geological Survey, Water Supply Paper 2175, chapter 7.

## 6.2 Calculating salt-based discharge from a slug injection

$$Q = \frac{V_1 \cdot C_1}{\int_0^\infty (C - C_b) dt}$$

where

$Q$  is the discharge of the stream

$V_1$  is the volume of the tracer solution introduced into the stream (calculate as the difference between the dripEndTime and dripStartTime multiplied by dripRateStart and/or dripRateEnd, all found in fieldData table, there will be one set of records per site per injection experiment date)

$C_1$  is the concentration of the tracer solution injected into the stream (table: externalLabDataSalt where saltSampleID = injectateSampleID, there will be one record per site per injection experiment date)

$C$  is the measured concentration at a given time at the downstream sampling site (the conductivityFieldData table contains conductivity measurements recorded at stations #1 and #4 every 10 seconds during the tracer injection; users should not include data collected prior to the dripStartTime in their calculations)

$C_b$  is the background concentration of the stream (table: externalLabDataSalt where saltSampleID = saltBackgroundSampleID, there will be one record for each station)

The term  $\int_0^\infty (C - C_b) dt$  can be approximated by the term

$$\sum_{i=1}^N \frac{(C_i - C_b)(t_{i+1} - t_{i-1})}{2}$$

where

$i$  is the sequence number of a sample (table: conductivityFieldData, field: measurementNumber)

$N$  is the total number of samples (measurement number of the last measurementNumber used minus measurementNumber for dateTimeLogger ~ dripStartTime)

$t_i$  is time when sample,  $C_i$ , is obtained (table: conductivityFieldData, field: dateTimeLogger)

Adapted from Rantz et al. U.S. Geological Survey, Water Supply Paper 2175, chapter 7.

## 6.3 Calculating reaeration rates

### 6.3.1 Calculating Tracer Gas ( $\text{SF}_6$ ) Loss Rate

1. Background correct the salt (NaCl or NaBr) plateau samples.
2. Divide  $\text{SF}_6$  concentrations by the background corrected salt plateau samples for the site



3.  $LR_{SF_6}$  is the slope of the relationship between LN(salt corrected  $SF_6$  concentration)(y-axis) and distance downstream (x-axis)

### 6.3.2 Calculating travel times and velocity

$$V_r = \text{downstreamDistance} / \text{traveltime}$$

The time difference between the station #1 and #4 peak of the slug or time of arrival of 50 % of the relative concentration for a constant rate injection is the travel time. There are some other methods of estimating travel time using the initial rise, center of mass, or harmonic mean for a slug injection, which could also be used (Calkins and Dunne, 1970; Waldon, 2004).

### 6.3.3 Calculating Tracer Gas Reaeration Rate

$$k_{SF_6} = LR_{SF_6} \cdot V_r$$

where

$LR_{SF_6}$  is the  $SF_6$  loss rate

$V_r$  is the water velocity

### 6.3.4 Calculating Gas Transfer Velocity for $O_2$

$$k_2 = k_{SF_6} \cdot 1.34$$

where

$k_{SF_6}$  is the  $SF_6$  reaeration rate coefficient

1.34 is from Wanninkhof (1992)

$$k_{O_2} = k_2 \cdot z$$

where

$k_2$  is the  $O_2$  reaeration rate coefficient

$z$  is the mean depth (Q/Wavg/Vr) (table: conductivityFieldData, field: waterTemp)

### 6.3.5 Normalize $O_2$ Gas Transfer Velocity to schmidt number of 600 (Jahne et al. 1987, Wanninkhof 1992, Raymond et al. 2012)

$$k_{600} = \left( \frac{600}{S_{CO_2}} \right)^{-0.5} \cdot k_{O_2}$$

$$S_{CO_2} = A - BT + CT^2 - DT^3 = 1800.6 - 120.10 \cdot T + 3.7818 \cdot T^2 - 0.047608 \cdot T^3$$

where

$T$  is the mean temperature in degrees Celsius (table: conductivityFieldData, field: waterTemp)



**6.3.6**  $k_{600}$  can be used to calculate the  $k$  of any gas at any temperature using (Jahne et al. 1987, Wanninkhof 1992)

$$k = \left( \frac{S_{CO_2}}{600} \right)^{-0.5} \cdot k_{600}$$

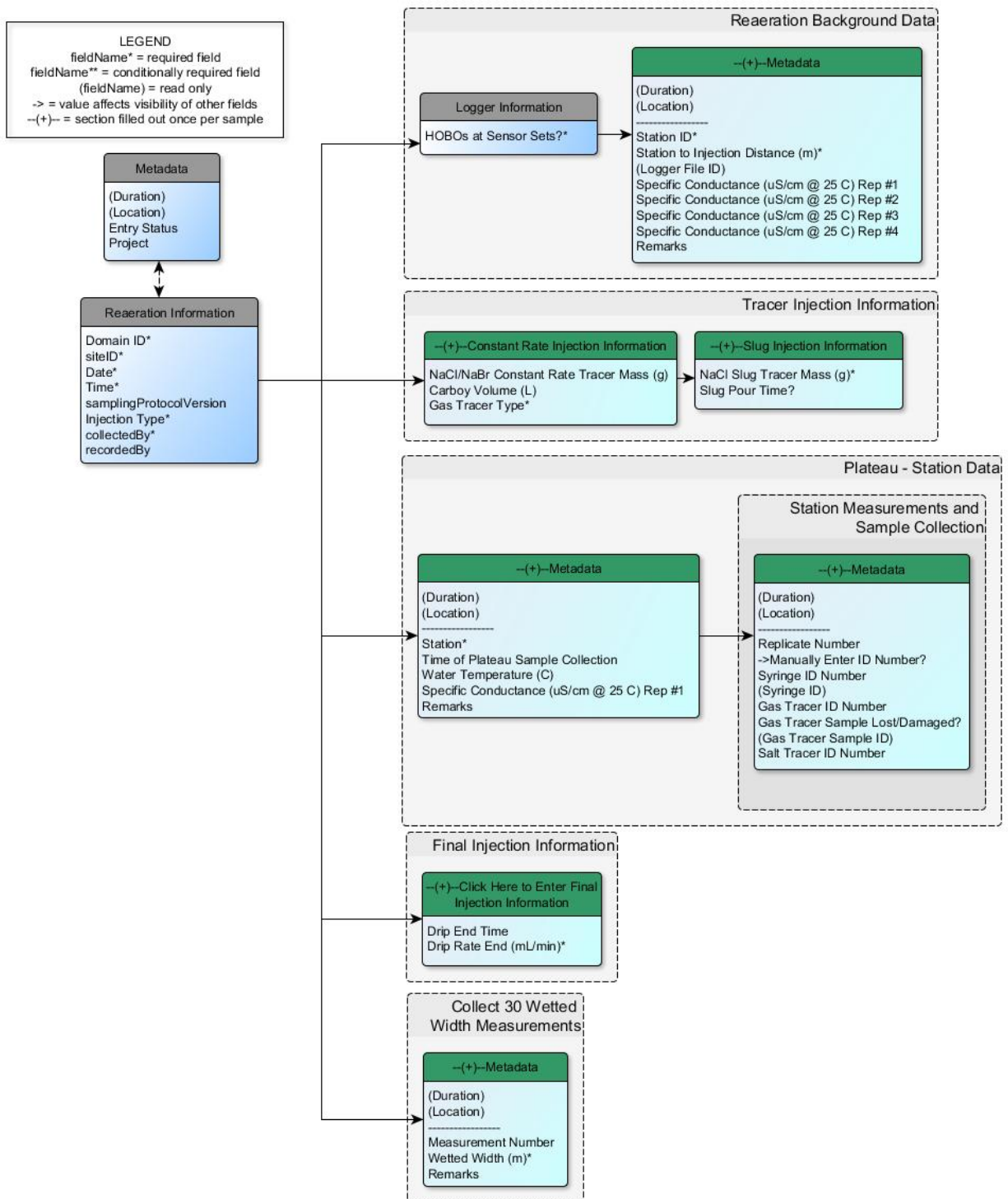


Figure 2: Schematic of the applications used by field technicians to enter reaeration and salt-based discharge data