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Prepared in cooperation with the Long Term Resource Monitoring element of the Upper Mississippi River Restoration Program, U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, Iowa Department of Natural Resources, Minnesota Department of Natural Resources, and Wisconsin Department of Natural Resources

Pocket Guide for Long Term Resource Monitoring Procedures—Aquatic Vegetation Monitoring

U.S. Department of the Interior
U.S. Geological Survey

Cover. Foreground photograph showing double-headed aquatic plant rake holding aquatic vegetation, taken by Alicia Carhart, U.S. Geological Survey. Background photograph showing submerged aquatic vegetation, taken by Eric Lund, Minnesota Department of Natural Resources.

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By Danelle M. Larson, Eric Lund, Alicia M. Carhart, Seth Fopma, and Stephanie Szura

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Contents

Figures

Tables

Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)
	Area	
square meter (m^2)	0.0002471	acre
square meter (m^2)	10.76	square foot (ft^2)
	Flow rate	
meter per second (m/s)	3.281	foot per second (ft/s)

Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Abbreviations

>	greater than
AVS	aquatic vegetation specialist
FOM	figure of merit
GPS	Global Positioning System
LTRM	Long Term Resource Monitoring
PDOP	percentage dilution of precision
SAV	submersed aquatic vegetation
SOP	standard operating procedure
USDA	U.S. Department of Agriculture
UTM	Universal Transverse Mercator

Pocket Guide for Long Term Resource Monitoring Procedures—Aquatic Vegetation Monitoring

By Danelle M. Larson,[1] Eric Lund,[2] Alicia M. Carhart,[3] Seth Fopma,[4] and Stephanie Szura[2]

Introduction

This standard operating procedure (SOP) manual is a condensed version of U.S. Geological Survey Techniques and Methods, book 2, chapter A22 (Larson and others, 2025; hereafter referred to as the "main report") and describes the collection of standardized, long-term data for aquatic vegetation communities in selected study pools of the Upper Mississippi River System in the United States. The primary intent of the data collection is to assess the status and trends that aid in understanding the unique river ecosystem and to guide large-scale ecological restoration of the river and its biological communities, like aquatic plants and their dependent wildlife. This SOP is an update to the version published in 2000 and reflects modifications to sample sizes and additions of new data collection procedures. All long-term monitoring programs and their SOPs must be adapted to changing conditions and be improved through learning, and this SOP clarifies procedures and adds new elements since the initial SOP was written more than 25 years ago. The SOP is intended for multiple audiences, including vegetation specialists through the Upper Mississippi River Restoration Program, data analysts using the publicly available data generated through this SOP, and natural resource managers and restoration practitioners who need data and science to guide some decisions. This SOP may be transferable and adaptable to other ecosystems when the aquatic plant community is the focus. Because this pocket guide version has been condensed, some mentions of figures, tables, and appendixes, as noted throughout, refer to the main report.

Sampling Effort and Schedule

In each study pool (fig. 1*A*, *B*), 450 sites are randomly selected annually using a stratified random sampling design. The sample sizes by pool and stratum are listed in table 1 in the main report only. Sampling is done between June 15 and August 15 to obtain the highest species richness detection probabilities. The aquatic vegetation specialists (AVS) attempt to sample all 450 sites, but a few sites may be inaccessible or unsafe to sample and are noted in the database as NOSMPL with the reason sampling was not completed. If the site is accessible but water depths are greater than (>) 3 meters (m) and preclude raking, please refer to the "Common Situations" section.

[1]U.S. Geological Survey.

[2]Minnesota Department of Natural Resources.

[3]Wisconsin Department of Natural Resources.

[4]Iowa Department of Natural Resources.

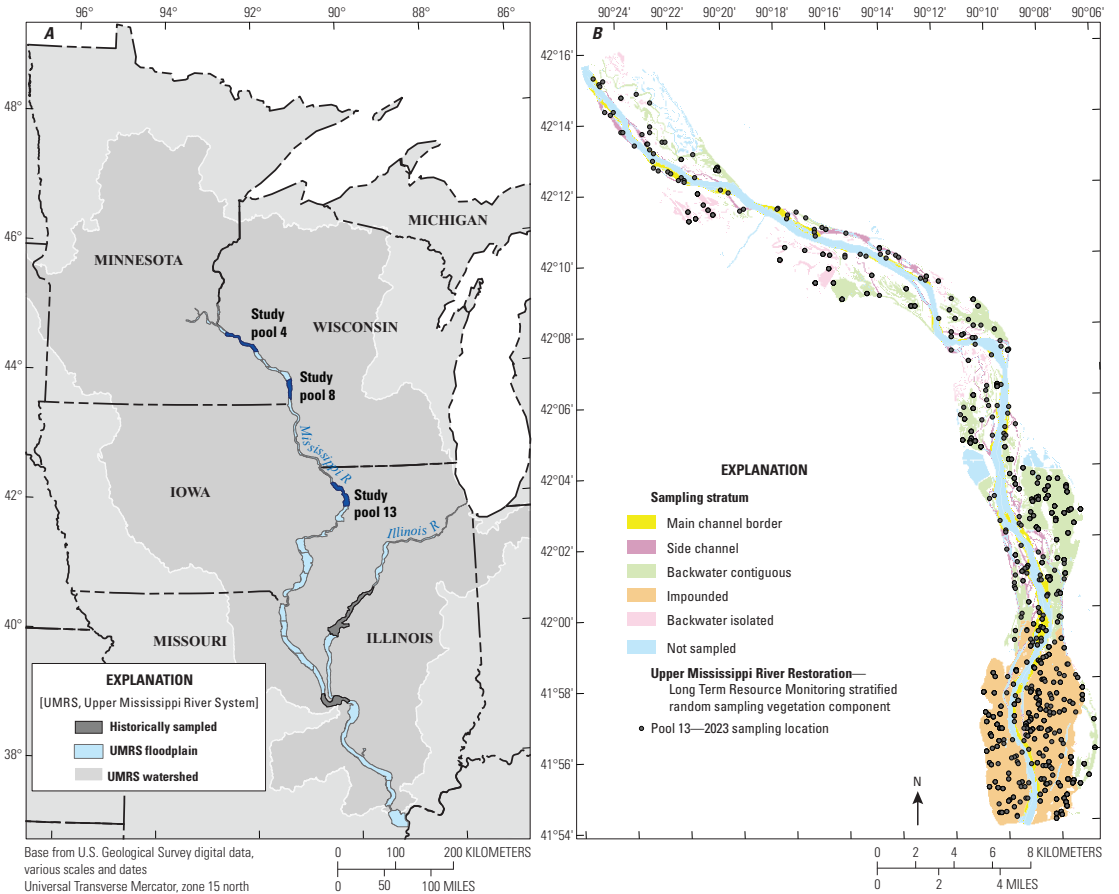

Figure 1. Maps showing (*A*) the Upper Mississippi River System Basin and the Long Term Resource Monitoring element's main study pools for aquatic plants, historical study pools, and the main stems of the Mississippi River and Illinois River and (*B*) an example from pool 13 showing the stratified random sampling design used for aquatic plant collection through the Upper Mississippi River Restoration's Long Term Resource Monitoring element.

Equipment and Definitions

Most sampling is done from a boat, and the type of boat depends on the habitats and weather conditions for sampling. The Long Term Resource Monitoring (LTRM) sampling is primarily done using airboats, jon boats, and mud motors, although paddle craft such as canoes or kayaks can be used to access and sample the site. Most boats are 5–6 m long and approximately 2 m wide. The sampling site is considered the 2-m ring extending out from the perimeter of the boat, which is about 44 square meters (m^2; fig. 2). Occasionally, sites are sampled on foot, and procedures mimic those of being in a boat to have the same sampling area (44 m^2). For sites requiring walk-in access, chest waders are recommended to avoid the mud, insects, and poisonous and prickly plants. Please refer to the "Common Situations" section for details of sampling on foot and (or) walk-in sites.

The sampling rake (fig. 3*A*, *B*) is used to estimate submersed aquatic vegetation (SAV) species composition and relative abundance. The rake is long handled and double headed, which is modified from the rake used by Jessen and Lound (1962) and Deppe and Lathrop (1992). The rake is 36 centimeters (cm) wide with 14 teeth, each 5 cm long, on each side. The double-headed rake is not commercially available but is made by welding

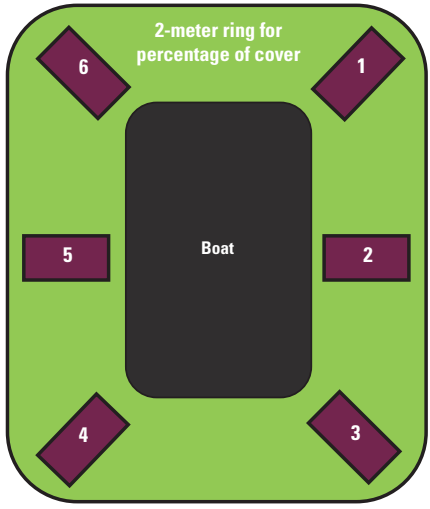

Figure 2. Diagram (not to scale) showing aquatic plant sampling around a boat.

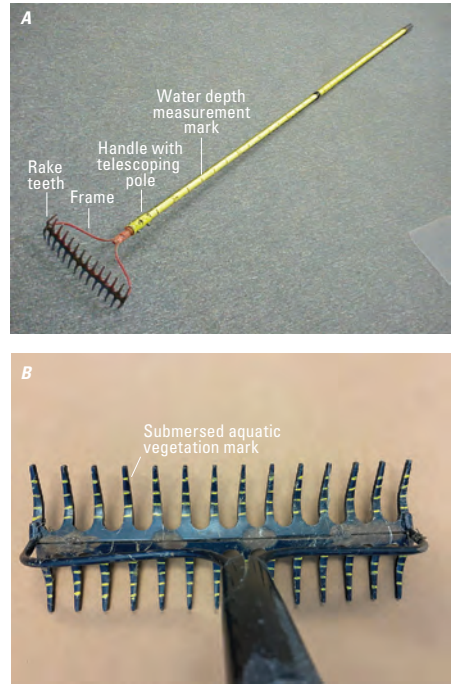

Figure 3. Photographs showing (*A*) the double-headed aquatic plant rake, including rake teeth, frame, and handle with a telescoping pole and water depth measurement markings along the pole, and (*B*) a closer view of the double-headed rake with yellow markings to indicate the submersed aquatic vegetation density ratings (refer to table 3).

two square-headed garden rakes together. The rake's telescoping handle is at least 3 m long. The rake handle is marked at 10-cm increments to also measure water depth. The rake teeth are painted with five equidistant horizontal lines to estimate relative plant abundance. SAV biomass can be estimated from rake scores using models developed by Drake and others (2022), which rely on separate density scores for branched and unbranched (that is, *Vallisneria americana* Michx.) species—refer to step 9 in the "Technique and Recording" section. The rake teeth can also capture substrate for classification of relative particle size.

The LTRM aquatic vegetation component uses a customized Microsoft Access data form and tables for all data entry. However, an equivalent paper data sheet for data collection is available in appendix 2 (fig. 2.1) and can be adapted for other projects. Additional sampling devices, such as a velocity meter and turbidity meter, are noted in the "Optional Measures" section.

Sampling Procedures

The field crew uses an enlarged field map to navigate to the general area of a site and a Global Positioning System (GPS) unit to find the predetermined and randomly selected site. The boat is anchored at each site when the coordinates shown on the GPS unit are within plus or minus 10 m of the target location (that is, the centroid of the selected sampling unit). The habitat type of the site at the time of sampling may or may not seem to match the map stratum indicated on the map. Site location should not be altered because of an apparent mismatch in stratum classification or for any other reason. If a site cannot be accessed within 10 m, record the reason in the comments field (refer to the "Common Situations" section).

The plant sampling techniques use a combination of visual examination of species, visual estimation of areal cover (that is, the percentage of surface water that is obscured by vegetation), rake samples, and subsampling to quantify the species composition and relative abundance of all aquatic plant species detected at each site (fig. 2). A detailed study on SAV sampling efficacy was provided by Yin and Kreiling (2011). Each site has six subsampling areas, each of which is a rectangle 1.5 m long (rake drag) and 0.36 m wide (width of the rake head). One subsampling area is off each corner of the boat, and the other two are off the left and right sides (fig. 2). The subsampling areas are numbered from 1 to 6 clockwise starting at the starboard-bow corner of the boat. The exact locations of the six subsampling areas may vary among the types of boats used (for example, canoe or airboat; also refer to the "Common Situations" section).

The data collection sheet (app. 2, fig. 2.1) and computer data collection application are divided into four sections: "Site Information," "Subsampling Area Information," "Species Information," and "Reminder Information." The "Reminder Information" section contains the choices of data to be entered in the data fields.

The data field names, and their respective options are detailed in this section and explained further in appendix 3. The sampling procedure consists of multiple steps, beginning with recording data in the "Site Information" section of the data sheet. Steps 1–4 are for collecting species information at the site level. Steps 5–12 are for collecting data for the "Subsampling Area Information" and "Species Information" sections of the data sheet, including SAV and water depth at each subsampling area. Steps 13–16 are for completing the remaining fields in the "Site Information" section of the data sheet, such as substrate and second Universal Transverse Mercator (UTM) coordinates.

Default values are set in the data application at the beginning of each field season. Default settings include the UTM zone, UTM method, AVS code, and assistant code. All AVS and assistants are given a unique three-digit code that is generated by the LTRM database manager. Defaults are changed if the AVS or assistant changes during the season.

Step 1. After navigating to within 10 m of a site, anchor the boat securely with two anchors. Select the site identifier (listed as site ID; typically, a number between 1 and 450) from the "Select Site Number" dropdown menu. The software automatically assigns a unique barcode to each site. Use a data sheet (app. 2, fig. 2.1) if the Microsoft Access

data entry application is not available. Click the "Get 1st coordinates" button and ensure UTM coordinates and GPS accuracy are automatically entered by the connected GPS in the 1st UTM coordinates fields. Record optional measures (refer to the "Optional Measures" section) as appropriate. Record all site information except the number of rows, substrate, detritus, and vegetation type, which will be recorded later. Record the habitat type on the data sheet (in the "Site Information" section).

Step 2. Begin a species list. The AVS walk around the boat and call out all aquatic plant species they detect at the site (fig. 2). The other field assistant records all species in the species code data field, thereby adding one new row (record) to the data sheet for each species detected. The vegetation type field(s) are automatically populated according to the species codes recorded at the site.

Step 3. Visually estimate the percentage of areal cover, in 10-percent increments, by life forms of nonrooted floating-leaved, rooted floating-leaved, and emergent life forms in the 2-m ring around the site (table 2). Record the estimated cover ratings for life forms in the appropriate cover field. If the nonrooted floating-leaved species are thought to be transient and not permanently at the site (less than 5-percent cover), record the nonrooted floating-leaved species as absent (score=0). When nonrooted floating-leaved species combined at a site are >5 percent of the assessment area, record the appropriate cover value of the life form. Cover ratings are in table 2. Note: Before 2025, percentage of cover was recorded categorically in 20-percent increments.

Step 4. Estimate the percentage of areal cover, in 10-percent increments, for each species observed in the 2-m ring of the site and record in the cover field (in the "Species Information" section). Do not estimate for submersed life form species as those are obscured by water clarity and light reflection. The data entry application has a quality assurance check to ensure that a percentage of cover is entered for every life form if a species categorized in that life form was detected. Cover ratings are in table 2. Note: Before 2025, percentage of cover was recorded in 20-percent increments.

Step 5. Visually search the first subsampling area for aquatic species. Record the species code in the species code field (if not already added in step 2) and a "1" in the visual field (V on the data sheet) for filamentous algae and all life forms except nonrooted floating-leaved species observed in the subsampling area (in the "Species Information" section of the data sheet). A value of 1 is automatically recorded in the additional species field for every nonrooted floating-leaved species observed (because we are ignoring nonrooted floating-leaved species in the visuals and rakes within the subsampling area). If the subsampling area is land or exposed rock, refer to the "Common Situations" section.

Table 2. Areal percentage of cover estimates for all species of nonrooted floating-leaved, rooted floating-leaved, and emergent life forms.

Percentage of cover rating	Percentage of cover range within 2-meter ring
0	0
1	1–10
2	11–20
3	21–30
4	31–40
5	41–50
6	51–60
7	61–70
8	71–80
9	81–90
10	91–100

Step 6. Extend the rake outward from the boat and lower it to the bottom of the river, thereby placing the rake at the top of the subsampling area. Drag the rake at a consistent speed with gently applied pressure along the bottom toward the boat for 1.5 m.

Step 7. Hold the rake handle vertically with the rake head resting on the bottom and read and record the water depth (to the nearest 0.1 m) in the corresponding "Subsampling Area Information" section of the data sheet.

Step 8. Twist the rake 180 degrees and pull the rake and vegetation into the boat. Note: Twisting minimizes the loss of plants from the rake teeth but twisting more than 180 degrees may cause the plants to fall off.

Step 9. Fold plants hanging on the left and right side of the metal frame over the top of the rake teeth once (refer to fig. 3*A* and *B*). If necessary, sweep the rake head through the water to rinse the vegetation of excessive sediment. Rate the total combined amount of SAV and macroalgae like *Chara* spp. (but exclude filamentous algae) according to table 3 and record this value in the plant density field. Also record the branched density score (that is, all submersed species except for *Vallisneria americana* Michx.) according to table 3. The branched density score is the same as the plant density score unless *Vallisneria americana* Michx. and branched species are both present and have unique density scores. Note: In 2019, the protocol changed to include the branched density field; refer to appendix 6 (table 6.1) in the main report.

Step 10. Estimate the plant density for each SAV species and filamentous algae detected in the rake sample. Rate the density according to table 3 and record the density rating in the rake field (R on the data sheet in the "Species Information" section). Record a "1" in the rake field for every rooted floating-leaved and emergent species to indicate that the species was detected in the rake sample. If a species is unknown (not fitting the app. 1, table 1.1, species list), then refer to the "Common Situations" section for collecting vouchers and verifying species identification.

Step 11. Repeat steps 5–10 for subsampling areas 2 through 6 (refer to fig. 2 for subsampling areas).

Step 12. Examine, by sight and touch, the sediment brought up from the bottom with the rake. Classify the sediment according to table 4 and record in the substrate field (in the "Site Information" section). If plant detritus was detected visually or on any rake, record a "1" in the detritus field. Plant detritus is defined as dead organic plant matter of any size. If mussel or snail shells were detected visually in the substrate, record a "1" in the shells field. Note: The optional shells field was added in 2024.

Table 3. Relative submersed aquatic vegetation density or relative abundance rating. The rating is determined by examining the markings on the rake teeth and assigning a density rating. The trace rating was added in 2021 to represent plant presence with low biomass (Drake and others, 2022).

[SAV, submersed aquatic vegetation]

SAV density rating	Approximate percentage of rake teeth filled
0	0
0.08 (trace)	1.5 (as many as 1 of 13 spaces between rake tines filled)
1	1.6–20
2	21–40
3	41–60
4	61–80
5	81–100

Table 4. Substrate types and data entry codes.

Substrate type	Substrate code	Description
Silt/clay	1	Typically clumps and adheres to the rake; no sand can be felt when pressed between fingers.
Mostly silt with sand	2	Typically clumps and adheres to the rake; sand can be felt when pressed between fingers.
Mostly sand with silt	3	Sand is often audible when the rake is dragged but does not adhere to the rake, and silt is released as a cloud in the water column when the rake is retrieved.
Hard clay	4	Clumps and adheres to rake; typically does not wash away when the rake is rinsed.
Gravel/rock	5	Larger than sand; no silt present.
Sand	6	Sand is audible when the rake is dragged but does not adhere to rake; little to no silt is released in the water column when the rake is retrieved.
Unobtainable	7	Substrate type is not obtainable (water is too deep, high in velocity, and so on).

Step 13. Collect or omit any optional measures (refer to "Optional Measures" section) such as turbidity, velocity, or the 31 map classes (details in app. 3) or voucher specimens (table 5).

Step 14. At the end of the sampling, but before boat anchors are retrieved, click "Get 2nd coordinates" to record the UTM coordinates in the 2nd UTM coordinates fields.

Step 15. Verify all required data have been entered correctly by clicking the quality assurance button (QA in the software). Fix any errors before leaving the site. Data are saved automatically. The AVS back up the local database at least weekly to the field station computer and data cloud resources.

Table 5. Species identification coding upon collection. For species with a quality evaluation other than blank, a voucher must be collected and processed according to instructions outlined in the "Voucher and Herbarium Specimens" section.

Species identification uncertainty	Quality evaluation code
Species code available and known	Blank
Likely hybrid	1
Genus certain, species suspected	2
Genus and species suspected	3
Genus and species unknown	4

Common Situations

No SAV.—If no SAV species are detected in a subsampling area, put "NOSAV" in the species code field and a "1" in the rake field(s), but leave the rest of the fields in the "Species Information" section (visual [V on the data sheet], additional species, cover, quality evaluation [QE on the data sheet], and voucher) blank. Put a "0" in the corresponding plant density field (in the "Subsampling Area Information" section). If other life forms are detected at the site, follow steps 1–15 in the "Techniques and Recording" section for the remaining subsampling areas.

Aquatic vegetation of any life form is absent at the site.—If filamentous algae and aquatic vegetation of all life forms are not observed anywhere within the 2-m site ring or in any of the six subsample areas, put a "U" in the VEG U field in the data app or on the data sheet (all other life form fields should be blank). Continue to measure all possible data fields, such as water depth and site information.

Nonaquatic subsampling area.—Leave the habitat quality assurance (habitat QA on the data sheet) field empty/blank if the subsampling has some water depth and is aquatic. If a subsampling area is on land or exposed rock, put a "T" in the habitat quality assurance field and "0" in the water depth and plant density fields. Land is defined as dry during most of the growing season and lacking wetland obligate plant species (refer to app. 1, table 1.1). Refer to the "No SAV" subsection for recording species information.

Nonaquatic site.—If a site is on an island or dewatered floodplain, put "LND" in the habitat type field, a "U" in the correct life form field, and "0" in all three cover fields (in the "Site Information" section). Refer to the "Nonaquatic subsampling area" subsection for recording subsampling area information. Refer to the "No SAV" subsection for guidance in recording species information. Treat temporarily dewatered aquatic sites the same as regular aquatic sites but put "0" for the water depth.

Inaccessible sites.—If a site cannot be accessed, put "NOSMPL" in the species code field and "1" in each of the six rake fields. Leave the rest of the fields in the "Subsampling Area Information" and "Species Information" sections blank. Record the UTM coordinates of the boat stop location and the reason for not sampling in the comments field.

Unable to rake.—If safety conditions (for example, blue-green algal blooms or wing dams) or physical conditions such as depth (>3 m) and current velocity preclude raking the river bottom for SAV, put "NORAKE" in the species code field and "1" in each of the rake fields that were not raked. Note: The "NORAKE" option was implemented in 2024. Record the reason for not raking in the comments field. Do not code the site as "NOSMPL" when the site was accessible but not raked (for example, during a high-water sampling event) because this can affect prevalence calculations in appendix 5 in the main report. Rather, collect as much data as safely possible for the site but use "NORAKE" in the species code field if accurate SAV subsampling is not possible.

Species identification is uncertain.—If a species code is available in the master species list (table 1.1 in app. 1), leave the quality evaluation field blank. If an existing species code is not available in table 1.1 in appendix 1, assign a quality evaluation code (table 5) in the quality evaluation field to flag an unknown species. Voucher specimens should be collected for any species that is not in the field station herbarium and when the identity is uncertain and has the quality evaluation flag from table 5. When a voucher is collected for a species, record a "1" (not sent for identification but retained at a field station) or a "2" (sent for external identification) in the voucher field (app. 3). If no voucher is collected, leave the voucher field blank.

Walk-in procedures.—If a site must be sampled on foot (or paddle craft), navigate to the site using a handheld GPS. Complete the sampling as if from a full-sized boat when determining the sampling area around a hypothetical boat and the placement of the six subsampling areas. If overly dense wetland vegetation or other circumstances preclude effective, straight-line raking (for example, tree species, debris, and so on), place a "1" in the visual and rake fields for all species within the subsampling area. Additionally, if the subsampling area is land or exposed rock, refer to

the information in the "Nonaquatic subsampling area" subsection. If the water depth is >0 m, follow steps 1–14 of the "Techniques and Recording" section, as appropriate. Label the site as "sampled on foot" or "paddle craft" in the vessel type field.

Optional Measures

Several additional metrics may be collected at sites as deemed relevant by the field crew. Commonly recorded metrics at sites include surface velocity and turbidity because of their known association with aquatic plant communities (Larson and others, 2023) and the likelihood that they directly drive species composition and overall suitability for aquatic vegetation.

Measurement of velocity should follow the methods described in the LTRM water quality procedures manual (Soballe and Fischer, 2004). Velocity measurements can be recorded at sites with depths >0.2 m. Velocity measurements should be made using an electromagnetic device following established manufacturer protocols. The sensor should be 20 cm below the surface of the water and oriented in a way that maximizes the observed velocity. Directional measurements of velocity are not necessary.

Measurements of turbidity will also follow the methods established in the LTRM water quality procedures manual (Soballe and Fischer, 2004). Measurements should be made using the nephelometric method (in nephelometric turbidity units; American Public Health Association, 1992). The water should be sampled before raking vegetation to avoid disturbing the sediment and potentially biasing the turbidity sample. Turbidity sampling depths should follow the same depth restrictions as established for velocity (that is, sampled when water depth is >20 cm).

Land cover classifications can be defined by physical characteristics and plant communities at each sampling location. Land cover is classified according to the 31 map classes (app. 3) in the General Wetland Vegetation Classification System (Dieck and others, 2015). We record a separate data field called habitat type, which is the AVS interpretations of the habitat type during the sampling event.

Taxonomy and Species Codes

The AVS are trained to recognize the nearly 70 species (app. 1, table 1.1). Some wetland-obligate species detected in shallow marsh perennial and wet meadow plant communities as described in Dieck and others (2015) are omitted because those species are not typically detected in the LTRM sampling frame. However, the 31 map classes field includes an option to collect wetland plant community information.

This SOP targets aquatic vegetation for multiple life forms. All species are categorized in the life type field (app. 3) according to options of either submergent (S), rooted floating leaved (F), nonrooted floating leaved (N), emergent (E), filamentous algae (A), or unvegetated (U). The nonrooted floating-leaved category consists of *Spirodela*, *Wolffia*, *Lemnaceae*, and *Azolla* spp. Filamentous algae are not speciated.

Whenever possible, identify aquatic plants to the species level using the following taxonomic keys: Fassett (1957), Winterringer and Lopinot (1966), Voss (1972, 1985), Crow and Hellquist (1982, 1983, 1985), Hellquist and Crow (1980, 1982, 1984), Gleason and Cronquist (1991), and Skawinski (2019). Most aquatic species detected are listed in table 1.1 in appendix 1. Species codes not available in table 1.1 are available in the U.S. Department of Agriculture (USDA) PLANTS Database (https://plants.usda.gov/). Our LTRM database retains the USDA coding convention from taxonomy of the early 1990s when LTRM started; however, the newest species codes and taxonomy can always be cross-referenced by searching these original USDA species codes in table 1.1.

If the genus of a plant is known and the species is unknown, create a new code with the first four letters of the genus name and a question mark inserted between the second and third letters; for example, "PO?TA" for *Potamogeton* spp. and "MY?RI" for *Myriophyllum* spp. Also note the quality evaluation code (table 5) for the uncertainty of identification. If the genus is unknown, create a unique code (for example, "UNKN01," "UNKN02," and so on) for each unknown taxon.

Collect two or more voucher specimens for each uncertainly identified or unknown aquatic plant for follow-up identification in the office or by external taxonomists (refer to procedures in the "Voucher and Herbarium Specimens" section). Upon positive identification, uncertain and unknown species codes will be confirmed or replaced with new codes. Do not create species codes or collect vouchers for terrestrial plant species, like those detected on dewatered islands. The AVS are obligated to confirm every new species code with the LTRM aquatic vegetation component leader.

Voucher and Herbarium Specimens

The AVS should collect at least one voucher specimen in the following scenarios:

1. Being uncertain about an aquatic species identification.
2. Detecting a new species, rare species, or one that is underrepresented in our existing collection. Underrepresented aquatic species include the following:
    a. Existing specimens that are poor in quality or missing key structures.
    b. A lack of specimens with flowers or fruiting bodies.
3. Detecting a notable, morphological variation within a species.
4. Detecting a species in a new study pool or that represents a substantial range extension.

Field collection procedures include the following steps:

1. Enter the appropriate status in the voucher and quality evaluation fields.
2. Collect two whole specimens where possible when uncertain about species identification or if the sample represents a novel species or location for the Upper Mississippi River System.
3. Retain the entire structure as much as possible (including roots, leaves, and flowers).
4. Contain loose seeds or fruiting bodies in a glassine envelope.
5. Initially place the aquatic specimens in sealable plastic bags.
6. Label the bags using the label template in appendix 7 (fig. 7.1) in the main report.
7. Keep specimens out of direct sunlight and cool until they are brought to the field station.
8. Press and dry specimens on the same day as collected. If same-day pressing and drying are not possible, most submersed species can be adequately stored for several days in a sealed plastic bag with water if kept in the refrigerator; exceptions include Charophytes, which should be pressed within 24 hours of collection because they degrade quickly.
9. Ship the pressed and dried specimens and their labels to the Bell Museum at the University of Minnesota in St. Paul, Minnesota.

All herbarium specimens are permanently preserved and archived at the Bell Museum Herbarium at the University of Minnesota using their SOP. Some voucher specimens are retained at the respective field stations of the AVS for training and outreach education.

Quality Assurance and Quality Control

The data are backed up locally on the field laptops during the sampling season each time the application is closed or manually saved. The AVS move data frequently from their field collection applications to a cloud-based server at their field stations as backup. At the end of the sampling season, the AVS review all data to make sure all required data fields were filled out and data values make logical sense. The data are then exported into comma-separated value (or .csv) files via the data collection application and sent to the LTRM database manager.

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Appendix 1. Species List

In this appendix, table 1.1 lists the aquatic macrophyte species detected throughout the Upper Mississippi River since sampling began in 1998. The aquatic vegetation specialists are trained to identify these species. Questions and voucher specimens related to species identification are advanced to the Long Term Resource Monitoring aquatic vegetation component leader and the Bell Museum of Minnesota. The taxonomy was updated as of 2024.

Table 1.1. Aquatic macrophyte species detected throughout the Upper Mississippi River. We list 71 aquatic macrophyte species over the period of record (1998–2024) in pools 4, 8, and 13 of the Upper Mississippi River. Species are listed in order from most commonly detected to least commonly detected as of 2024 and grouped by lifeform (modified from Larson and others [2025]).

[Species codes are from U.S. Department of Agriculture Natural Resources Conservation Service (2025), taxonomic authority is from ITIS Organization (2024), and species data are from U.S. Geological Survey (2010). * indicates that the genus *Ranunculus* was previously parsed into two species, *R. longirostris* and *R. tricophyllus*, but collapsed into one species as of 2023 according to the ITIS Organization]

Species code	Common name	Family	Scientific name
		Lifeform—Submersed	
CEDE4	Coontail	Ceratophyllaceae	*Ceratophyllum demersum* L.
ELCA7	Canadian waterweed	Hydrocharitaceae	*Elodea canadensis* Michx.
VAAM3	Watercelery, wild celery	Hydrocharitaceae	*Vallisneria americana* Michx.
ZODU	Water stargrass, grass-leaf mudplantain	Pontederiaceae	*Heteranthera dubia* (Jacq.) MacM.
NLPW	Narrow-leaf pondweed	Potamogetonaceae	*Potamogeton foliosus* Raf. and *Potamogeton pusillus* L.
POPE6	Sago pondweed	Potamogetonaceae	*Stuckenia pectinata* (L.) Börner
MYSP2	Eurasian watermilfoil	Haloragaceae	*Myriophyllum spicatum* L.
POCR3	Curly-leaved pondweed	Potamogetonaceae	*Potamogeton crispus* L.
POZO	Flatstem pondweed	Potamogetonaceae	*Potamogeton zosteriformis* Fern.
PONO2	Longleaf pondweed	Potamogetonaceae	*Potamogeton nodosus* Poir.
NAFL	Nodding waternymph	Najadaceae	*Najas flexilis* (Willd.) Rostk. & Schmidt
NAGU	Southern waternymph	Najadaceae	*Najas guadalupensis* (Spreng.) Magnus
UTMA	Common bladderwort	Lentibulariaceae	*Utricularia vulgaris* ssp. macrorhiza
RALO2 (formerly RATR)*	Longbeak buttercup	Ranunculaceae	*Ranunculus aquatilis* var. diffusus
MYSI	Northern watermilfoil	Haloragaceae	*Myriophyllum sibiricum* Komarov
CH?AR	Chara (macro-algae), muskgrass	Characeae	*Chara* spp.
NAMI	Brittle naiad	Hydrocharitaceae	Najas minor
ZAPA	Horned pondweed	Zannichelliaceae	*Zannichellia palustris* L.
PORI2	Richardson's pondweed	Potamogetonaceae	*Potamogeton richardsonii* (Benn.) Rydb.
ELNU2	Western waterweed	Hydrocharitaceae	*Elodea nuttallii (Planch) H. St. John*
NAGR	Slender waternymph	Najadaceae	*Najas gracillima* (A. Braun ex. Engelm.) Magnus

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[Species codes are from U.S. Department of Agriculture Natural Resources Conservation Service (2025), taxonomic authority is from ITIS Organization (2024), and species data are from U.S. Geological Survey (2010). * indicates that the genus *Ranunculus* was previously parsed into two species, *R. longirostris* and *R. tricophyllus*, but collapsed into one species as of 2023 according to the ITIS Organization]

Species code	Common name	Family	Scientific name
		Lifeform—Submersed—Continued	
POFO3	Leafy pondweed	Potamogetonaceae	*Potamogeton foliosus* Raf.
NI?TE	Nitella species	Characeae	*Nitella* spp.
POAM5	Largeleaf pondweed	Potamogetonaceae	*Potamogeton amplifolius* Tuck.
POAL8	Alpine pondweed	Potamogetonaceae	*Potamogeton alpinus* Balbis
POEP2	Ribbonleaf pondweed	Potamogetonaceae	*Potamogeton epihydrus* Raf.
STFI6	Fineleaf pondweed	Potamogetonaceae	*Stuckenia filiformis* (Pers.) Börner
POPU7	Small pondweed	Potamogetonaceae	*Potamogeton pusillus* L.
		Lifeform—Nonrooted floating leaf	
LEMI3	Small duckweed	Lemnaceae	*Lemna minor* L.
SPPO	Big duckweed	Lemnaceae	*Spirodela polyrrhiza* (L.) Schleid.
WOCO	Columbian watermeal	Lemnaceae	*Wolffia columbiana* Karst.
LETR	Star duckweed	Lemnaceae	*Lemna trisulca* L.
AZCA	Carolina mosquitofern	Azollaceae	*Azolla caroliniana* Willd.
RIFL4	Liverwort	Ricciaceae	*Riccia fluitans* L.
WOBO	Northern watermeal, dotted watermeal, watermeal	Lemnaceae	*Wolffia borealis* (Engelm. Ex Hegelm.) Landolt
		Lifeform—Filamentous algae	
ALGA	Filamentous algae (not speciated)	Algae, filamentous	Filamentous algae
		Lifeform—Rooted floating leaved	
NYTU	White waterlily	Nymphaeaceae	*Nymphaea odorata* Ait. spp. *tuberosa* (Paine) Wiersma & Hellquist
NELU	Lotus, American lotus	Nelumbonaceae	*Nelumbo lutea* Willd.
NULU	Yellow pond lily	Nymphaeaceae	*Nuphar lutea* (L.) Sm.

Table 1.1. Aquatic macrophyte species detected throughout the Upper Mississippi River. We list 71 aquatic macrophyte species over the period of record (1998–2024) in pools 4, 8, and 13 of the Upper Mississippi River. Species are listed in order from most commonly detected to least commonly detected as of 2024 and grouped by lifeform (modified from Larson and others [2025]).—Continued

[Species codes are from U.S. Department of Agriculture Natural Resources Conservation Service (2025), taxonomic authority is from ITIS Organization (2024), and species data are from U.S. Geological Survey (2010). * indicates that the genus *Ranunculus* was previously parsed into two species, *R. longirostris* and *R. tricophyllus*, but collapsed into one species as of 2023 according to the ITIS Organization]

Species code	Common name	Family	Scientific name
		Lifeform—Emersed	
SALA2	Broadleaf arrowhead	Alismataceae	*Sagittaria latifolia* Willd.
SARI	Sessilefruit arrowhead	Alismataceae	*Sagittaria rigida* Pursh.
ZIAQ	Southern wild rice	Poaceae	*Zizania aquatica* L.
ZI?ZA	Wild rice	Poaceae	*Zizania spp.* (genetics unknown as of 2024)
SPEU	Giant burreed	Sparganiaceae	*Sparganium eurycarpum* Engelm. ex-Gray
SCFL	River bulrush	Cyperaceae	*Bolboschoenus fluviatilis* Torr. Soják
PHAR3	Reed canarygrass	Poaceae	*Phalaris arundinacea* L.
LEOR	Rice cutgrass	Poaceae	*Leersia oryzoides* (L.) Sw.
SCVA	Softstem bulrush	Cyperaceae	*Schoenoplectus tabernaemontani* (K.C. Gmel.) Palla
POCO14	Pickerelweed	Pontederiaceae	*Pontederia cordata* L.
BUUM	Flowering rush	Butomaceae	*Butomus umbellatus*
TYAN	Narrowleaf cattail	Typhaceae	*Typha angustifolia L.*
POAM8	Water knotweed	Polygonaceae	*Persicaria amphibia L. Gray*
LYSA2	Purple loosestrife	Lythraceae	*Lythrum salicaria* L.
EL?EO	Spikerush species	Cyperaceae	*Eleocharis spp.*
TYLA	Broadleaf cattail	Typhaceae	*Typha latifolia* L.
SA?LI	Willow species	Salicaceae	*Salix spp.*
SANI	Black willow	Salicaceae	*Salix nigra* Marshall
SAIN3	Sandbar willow	Salicaceae	*Salix interior* Rowlee
LEVI2	Whitegrass	Poaceae	*Leersia virginica* Willd.
CA?RE	Sedge/carex species	Cyperaceae	*Carex spp.*
CY?PE	Flatsedge species	Cyperaceae	*Cyperus spp.*
CEOC2	Buttonbush	Rubiaceae Juss.	*Cephalanthus occidentalis* L.

Table 1.1. Aquatic macrophyte species detected throughout the Upper Mississippi River. We list 71 aquatic macrophyte species over the period of record (1998–2024) in pools 4, 8, and 13 of the Upper Mississippi River. Species are listed in order from most commonly detected to least commonly detected as of 2024 and grouped by lifeform (modified from Larson and others [2025]).—Continued

[Species codes are from U.S. Department of Agriculture Natural Resources Conservation Service (2025), taxonomic authority is from ITIS Organization (2024), and species data are from U.S. Geological Survey (2010). * indicates that the genus *Ranunculus* was previously parsed into two species, *R. longirostris* and *R. tricophyllus*, but collapsed into one species as of 2023 according to the ITIS Organization]

Species code	Common name	Family	Scientific name
Lifeform—Emersed—Continued			
ASIN	Swamp milkweed	Asclepiadaceae	*Asclepias incarnata* L.
AL?IS	Water plantain	Alismataceae Vent.	*Alisma spp.*
PHAUA6	American common reed	Poaceae Barnhart	*Phragmites australis* (Cav.) Trin. ex Steud. ssp. *americanus* Saltonst., P.M. Peterson & Soreng
PHAUA7	European common reed	Poaceae Barnhart	*Phragmites australis* (Cav.) Trin. ex Steud. ssp. *australis*
CIBU	Bulblet-bearing water hemlock	Apiaceae	*Cicuta bulbifera* L.
IRVE2	Harlequin blueflag	Iradaceae	*Iris versicolor* L.
IRPS	Paleyellow iris	Iridaceae	*Iris pseudacorus L.*
POHY2	Swamp smartweed	Polygonaceae	*Persicaria hydropiperoides* Michx.

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Appendix 2. Data Sheet

In this appendix, an aquatic vegetation stratified random sampling data sheet is shown in figure 2.1. A printable version of the data sheet is available for download at https://doi.org/10.3133/tm2A22.

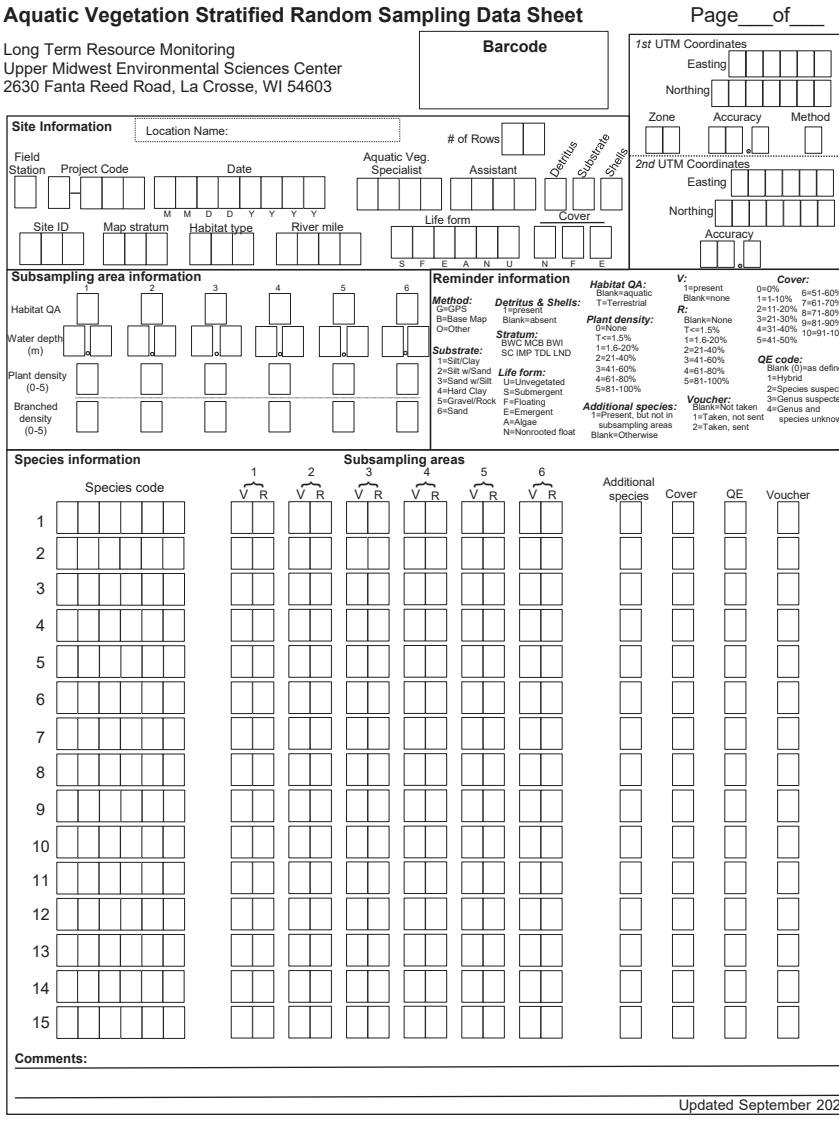

Figure 2.1. Aquatic vegetation stratified random sampling data sheet. [#, number; veg., vegetation; ID, identifier; UTM, Universal Transverse Mercator; QA, quality assurance; m, meter; V, presence or absence of a species; R, rake; QE, quality evaluation. Stratum options include BWC, backwater contiguous lake; MCB, main channel border; BWI, backwater isolated lake; SC, side channel tributary; IMP, impounded area; TDL, tributary Delta Lake (that is, Lake Pepin); LND, land]

Appendix 3. Explanations of Field Options

In this appendix, the fields of the aquatic vegetation stratified random sampling data sheet (app. 2, fig. 2.1) and electronic data application are explained.

- Barcode—Each data sheet requires a barcode number. The barcode uniquely identifies each sheet. In the data application, barcodes are automatically generated for each site.

Site information is recorded in the following fields:

- Location name—This information is not entered into the official LTRM database; the field applies to special projects only (not the stratified random sampling in LTRM).
- # of rows—The total number of detail records (rows) in the "Species Information" section of the data sheet that contain data.
- Field station—The number assigned to each field station within the LTRM.
  - 1 = pool 4
  - 2 = pool 8
  - 3 = pool 13
  - 4 = pool 26
  - 5 = open river
  - 6 = La Grange Pool
- Project code—The project code is M-98A (which identifies that the project is part of the LTRM). Additional project codes may be generated for special use projects outside of the LTRM.
- Date—The month, day, and year (in MMDDYYYY format) during which a site was sampled. All boxes must be filled, so zeros should be entered if a site was not sampled.
- Aquatic veg. specialist code—A number that uniquely identifies the aquatic vegetation specialist responsible for certifying that the samples and the data on the form were collected in compliance with current LTRM procedures and are, to the best of their knowledge, complete and free of errors. This code underscores the importance of LTRM methods and is one of the chain-of-custody procedures.
- Assistant—A number that uniquely identifies the individual assisting the aquatic vegetation specialist.
- Detritus—A "1" is used to identify the presence of coarse, dead aquatic plant organic material in the sediment on one or more rakes or anywhere at the site. The default is a blank space indicating no detritus present.
- Substrate—A qualitative code that is assigned to substrate type after tactile and visual examination of sediment at the six subsampling areas. Substrate is rated on a scale of 1–6 according to table 4.
- Shells—A "1" is used to identify the presence of invertebrate shells in the sediment on one or more rakes or anywhere at the site. The default is a blank space indicating no shells present.

- Site ID—A three-digit number assigned to uniquely identify each site. Accuracy of the site identifier (or ID) is critical because it links field data to be collected with data already available in the database (such as Universal Transverse Mercator [UTM] coordinates and map stratum).

- Map stratum—The habitat stratum of the site according to the aquatic area stratum geographic information system coverage. The letter codes are listed in table 1 in the main report.

- Habitat type—Record habitat type using this coding system:

  - BWC = backwater contiguous—shallow (pool 4)
  - BWI = backwater isolated—shallow
  - IMP = impounded—shallow
  - LND = land
  - MCB = main channel border
  - SC = side channel

- River mile—An alphanumeric code that approximates the location of the site in reference to the navigation river miles used by the U.S. Army Corps of Engineers. A prefix "M" indicates the Mississippi River, and an "I" indicates the Illinois River. Round down to the nearest whole number.

- Life form—This letter code is used to identify each type of life form detected at a site. *Nelumbo* and *Ludwigia* spp. are considered rooted floating-leaved species. *Chara* and *Nitella* are considered submersed species (app. 1, table 1.1).

  - S = submersed
  - F = rooted floating leaved
  - E = emergent
  - A = filamentous algae
  - N = nonrooted floating leaved
  - U = unvegetated

- Cover—This field is used to record the type and percentage of areal cover for each life form.

  - N = The percentage of areal cover of all nonrooted floating-leaved species combined at the site (a 2-meter- [m-] wide ring) using the cover ratings described in table 2.
  - F = The percentage of areal cover of all rooted floating-leaved species combined at the site (a 2-m-wide ring) using the cover ratings.
  - E = The percentage of areal cover of all emergent species combined at the site (a 2-m-wide ring) using the cover ratings.

- Percent (Areal) Cover Ratings are as follows:

  - 0 = 0 percent
  - 1 = 1–10 percent
  - 2 = 11–20 percent
  - 3 = 21–30 percent
  - 4 = 31–40 percent
  - 5 = 41–50 percent
  - 6 = 51–60 percent
  - 7 = 61–70 percent
  - 8 = 71–80 percent
  - 9 = 81–90 percent
  - 10 = 91–100 percent

- 1st UTM coordinates—This information is recorded when the AVS is anchored at the site.
  - Easting—The UTM easting coordinate for the site. The coordinate is recorded from the Global Positioning System (GPS) unit when the AVS first arrives at the site.
  - Northing—The UTM northing coordinate for the site. The coordinate is recorded from the GPS unit when the AVS first arrives at the site.
  - Zone—The number that identifies the correct grid from which the UTM coordinates were taken. All the coordinates provided by the U.S. Geological Survey Upper Midwest Environmental Sciences Center are zone 15 readings, even though part of the La Grange Pool is zone 16.
  - Accuracy—The GPS measure of possible error related to the geometry of satellites. This number value is recorded when the UTM coordinates are recorded. The method field indicates whether the scale is percentage dilution of precision (PDOP) or figure of merit (FOM).
  - Method—A code that identifies the method used to locate the site and the type of accuracy measurement used by the equipment.
    - B = base map,
    - D = GPS with differential corrections and PDOP,
    - G = GPS without differential corrections and PDOP,
    - F = GPS with differential corrections and FOM,
    - X = GPS without differential corrections and FOM, and
    - O= other (explain in the comments field).
- 2nd UTM coordinates—This information is recorded after samples are taken and before leaving the site.
  - Easting—The UTM easting coordinate for the site. The coordinate is recorded from the GPS unit after sampling is complete, before leaving the site.
  - Northing—The UTM northing coordinate for the site. The coordinate is recorded from the GPS unit after sampling is complete, before leaving the site.
  - Accuracy—The GPS measure of possible error related to the geometry of satellites. This number value is recorded when the UTM coordinates are recorded. The method field indicates whether the scale is PDOP or FOM.

Subsampling area information is recorded in the following fields:

- Habitat QA—A quality assurance code denoting whether a subsampling area was on land or water.
  - T = terrestrial or nonaquatic and
  - Blank (default) = water or aquatic habitat

If "T" is used, then the water depth (0.0) and plant density (0) should be zero.

- Water depth—The depth of each subsampling area recorded to a tenth of a meter.
- Plant density—A rating assigned to the total amount of submersed aquatic vegetation retrieved on a rake drag (table 3). The 0–5 rating scale is based on the percentage of the rake teeth covered (in 20-percent increments) by submersed plants and macroalgae. Plant density is recorded separately for the six subsampling areas.

- Branched density—A rating assigned to the total amount of submersed aquatic vegetation with a branching morphology that is retrieved on a rake drag. Branching species typically include all submersed species except for *Vallisneria americana* Michx. The branched density score is the same as the plant density score unless *Vallisneria americana* Michx. and branched species are both present and have unique density scores. The 0–5 rating scale is based on the percentage of the rake teeth covered (in 20-percent increments) by submersed, branching plants (table 3). Branched density is recorded separately for the six subsampling areas.

The "Reminder Information" section contains the abbreviated glossary of codes used in the data fields. Species information is recorded in the following fields:

- Species code—The alphanumeric code (as many as six digits) for a species based on the U.S. Department of Agriculture PLANTS Database (https://plants.usda.gov/; U.S. Department of Agriculture Natural Resources Conservation Service, 2025). Most of the species codes are available in table 1.1 in appendix 1. If the genus of a plant is known and the species is unknown, then a new code is created using the first four letters of the genus name and inserting a question mark between the second and third letters; for example, "PO?TA" for *Potamogeton* sp. and "MY?RI" for *Myriophyllum* sp. Using the species code of a suspected species is preferable, however, when based on the suggestion of the AVS. The confidence level of species identification will be reflected in the quality evaluation code.

- V—A code for the presence or absence information of species. A "1" is recorded for a species that was visually detected in the subsampling area before raking; otherwise, the box is left blank (default). For nonrooted floating-leaved species, the V box is always left blank.

- R—Plant density (a categorical index score), according to table 3, for each submersed species detected in the rake sample of vegetation. Plant density is reported separately for filamentous algae. A floating-leaved or emergent species receives a "1" regardless of its plant density as long as the species was collected in the rake sample of vegetation. The box is left blank (default) for species not sampled by the rake. For nonrooted floating-leaved species, the R box is always left blank.

- Additional species—A "1" is recorded for each species that is present at a site but not in any of the six subsampling areas. Otherwise, the box is left blank (default). A "1" is also used to indicate species of nonrooted floating-leaved plants that are at the site but not recorded by subsampling area.

- Cover—The visually estimated percentage of cover for each rooted floating-leaved and emergent species by site (not by subsampling area).

- QE—A number (1–4) used to flag the taxonomic identification uncertainty (table 5). A blank indicates a species code is available and known according to the U.S. Department of Agriculture PLANTS Database.

- Voucher—A code denoting whether a voucher specimen was taken of the species.
  - Blank = no voucher taken.
  - 1 = voucher taken and not sent out for identification.
  - 2 = voucher taken and sent out for identification.

- Comments—A field for recording any additional observations. Comments should be limited to 80 characters.

Optional data that may be recorded include the following:

- Velocity—Maximum water speed measured at sites with depths greater than 20 centimeters (cm) at 20 cm below surface. The value is reported in meters per second to the nearest centimeter (for example, 0.01 meter per second).
- Turbidity—Measured at sites with depths greater than 20 cm. Measured to the nearest whole number in nephelometric turbidity units at 20 cm below surface.
- Vessel type—A code defining how the sampling site was accessed.
  - 1 = airboat
  - 2 = outboard
  - 3 = mud motor and (or) shallow drive
  - 4 = nonmotorized and (or) paddle driven
  - 5 = sampled on foot
- 31 map classes—A code indicating land cover classification using Dieck and others (2015).
  - Open water (OW)
  - Submersed vegetation (SV)
  - Rooted floating aquatics (RFA)
  - Deep marsh annual (DMA)
  - Deep marsh perennial (DMP)
  - Shallow marsh annual (SMA)
  - Shallow marsh perennial (SMP)
  - Sedge meadow (SM)
  - Wet meadow (WM)
  - Deep marsh shrub (DMS)
  - Shallow marsh shrub (SMS)
  - Wet meadow shrub (WMS)
  - Scrub shrub (SS)
  - Wooded swamp (WS)
  - Floodplain forest (FF)
  - Populus community (PC)
  - Salix community (SC)
  - Lowland forest (LF)
  - Agriculture (AG)
  - Conifer (CN)
  - Plantation (PN)
  - Upland forest (UF)
  - Developed (DV)
  - Grassland (GR)
  - Levee (LV)
  - Pasture (PS)
  - Roadside (RD)
  - Mudflat (MUD)
  - Sand bar (SB)
  - Sand (SD)
  - No photographic coverage (NPC)

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