A5. Detailed Evaluations of the April 2013 Water-Quality Dataset

Detailed evaluations of the April 2013 samples collected at the 23 secondary sites associated with the 9 primary watershed sites are presented in this appendix. Each of the primary sites (SW-04, SW-05, SW-08, SW-13, SP-01, SP-04, SP-05, SP-09, and SP-11) included one to four secondary sites in upstream areas of the watersheds. Most of the secondary sites were located adjacent to or immediately downstream from swine concentrated animal feeding operations (CAFOs); four of the sites (SW-05B, SW-08D, SP-01A, and SP-04A) were at background locations receiving inputs only from agricultural fields with no CAFOs.

Initially, the water-quality data for these sites (appendix table A4-1) were examined by plotting different combinations of the results for individual nutrients and major ions (including summed concentrations and ratios) and the nitrate+nitrite stable isotopes to explore those pairings of constituent results that best reflected differences in water quality among the sites. On the basis of the initial examinations, it was decided to perform a more thorough evaluation using the nitrate+nitrite and sodium+potassium concentrations and the nitrate+nitrite delta nitrogen-15 ($\delta^{15}N$) values (provided in table 13 in the main report) for differentiating those sites with measurable CAFO manure influences on water quality. The $\delta^{15}N$ data for this evaluation included those samples having nitrate+nitrite concentrations greater than or equal to 0.100 milligram per liter (mg/L). A discussion of the results for each group of associated sites follows. Note that for a given group of sites, the secondary sites were located upstream from the primary site; however, they were not necessarily located along the same stream segment as each other.

Primary site SW-04 and secondary sites SW-04A and SW-04B (figs. A5-1 and A5-2)

Site SW-04A is located at the upgradient edge of a swine spray field, which is also downstream from a primarily wooded and residential area. Results for site SW04A are unclear where the low nitrate+nitrite (0.307 mg/L) and sodium+potassium (7.96 mg/L) for SW-04A do not suggest a manure influence, but the elevated $\delta^{15}N$ value (15.80 per mil [‰]) possibly reflects a manure signature or denitrification effects on nitrate derived from inorganic fertilizer or natural soil organic nitrogen (N). The increase in nitrate+nitrite (3.31 mg/L), sodium+potassium (16.10 mg/L), and $\delta^{15}N$ (19.37 ‰) downstream from the spray fields at site SW-04B located next to the swine facility indicates a waste-manure effect. The effect was still noticeable further downstream at primary site SW-04 (drainage area of 1.2 square miles [mi^2]) where, although there was lower nitrate+nitrite (1.09 mg/L), the sodium+potassium (16.66 mg/L) and $\delta^{15}N$ (22.16 ‰) remained elevated.

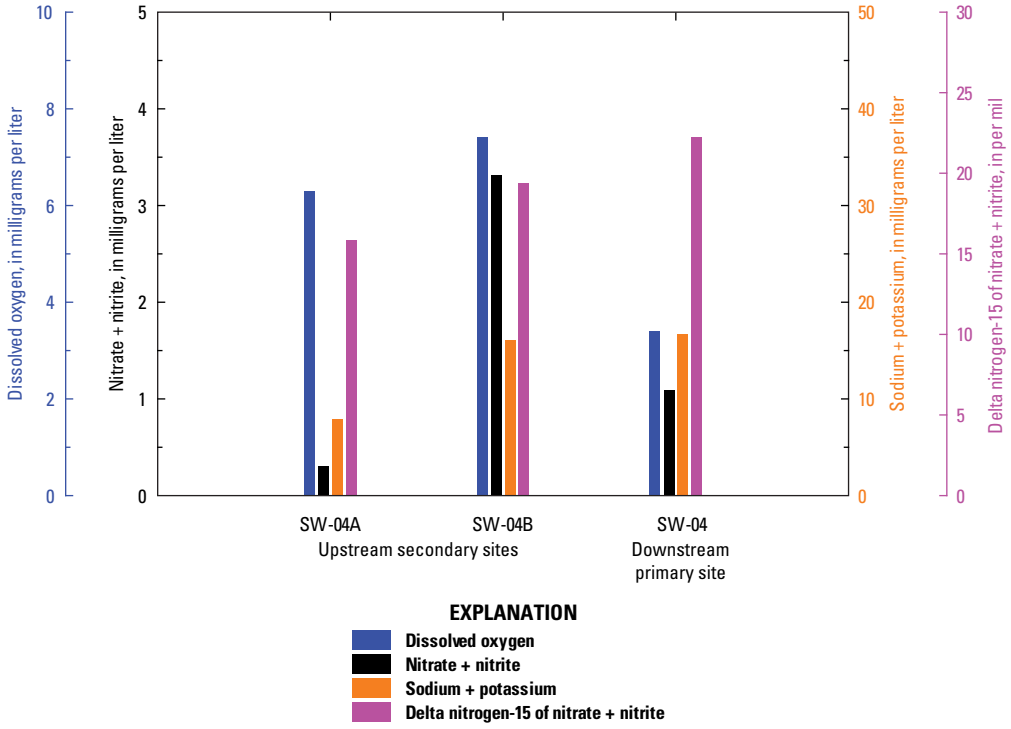

Figure A5-1. Dissolved oxygen, nitrate plus nitrite, sodium plus potassium, and delta nitrogen-15 results for April 2013 samples collected at sites SW-04, SW-04A, and SW-04B.

Figure A5-2. Locations of study sites SW-04, SW-04A, and SW-04B.

Primary site SW-05 and secondary sites SW-05A, SW-05B, and SW-05C (figs. A5-3 and A5-4)

The sample site for SW-05A, downstream from a swine CAFO and other agricultural fields, was in a backed-up wetland area with sluggish flow conditions. This site essentially had no dissolved oxygen (DO) (0.08 mg/L) or nitrate+nitrite (0.052 mg/L), likely as a result of denitrification. The relatively low sodium+potassium (10.01 mg/L) at SW-05A does not appear to suggest a manure influence. The results for nitrate+nitrite (1.70 mg/L), sodium+potassium (7.28 mg/L), and $\delta^{15}N$ (9.66 ‰) at site SW-05B, with more open flowing streamflow conditions, are indicative of inputs from background agricultural fields with no CAFOs, which is consistent with the watershed setting of this site. Waste-manure effects at site SW-05C located immediately downstream from a swine CAFO are indicated by the results for nitrate+nitrite (3.40 mg/L), sodium+potassium (19.16 mg/L), and $\delta^{15}N$ (21.68 ‰), which are at least two times higher than those for the SW-05B background location. Primary site SW-05, with a drainage area of 3.9 mi^2 and multiple tributaries, reflects a mixture of waters derived from CAFO and non-CAFO areas. Swine-manure effects are evident at downstream watershed site SW-05 on the basis of the values of sodium+potassium (12.42 mg/L) and $\delta^{15}N$ (17.05 ‰), which are intermediate to those observed for sites SW-05B and SW-05C.

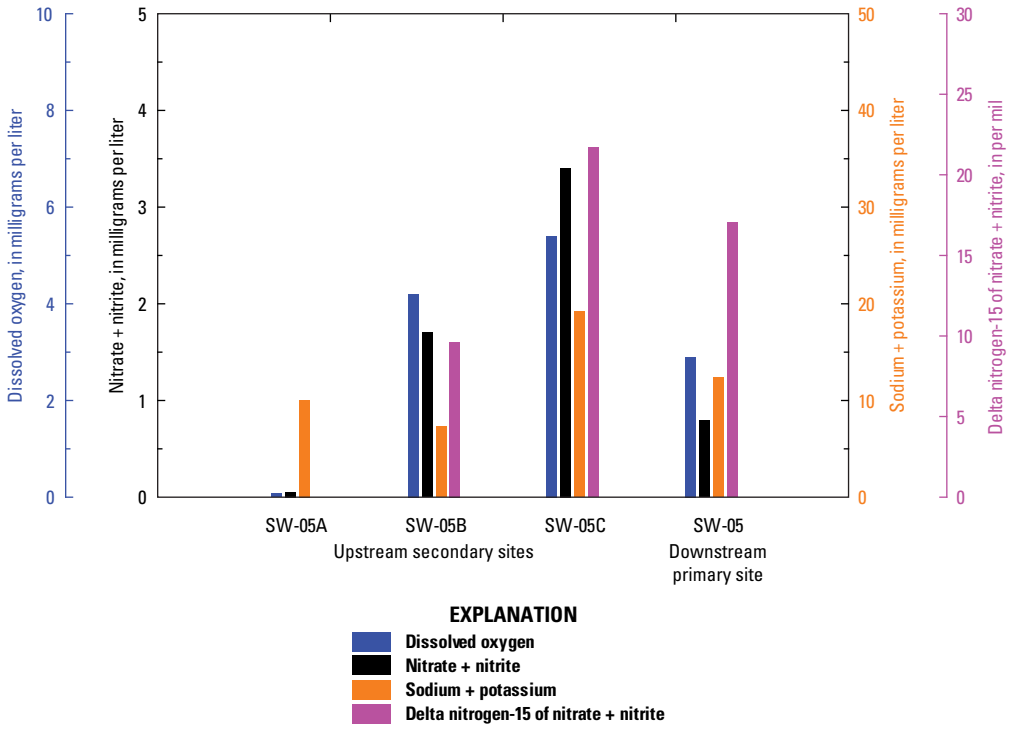

Figure A5-3. Dissolved oxygen, nitrate plus nitrite, sodium plus potassium, and delta nitrogen-15 results for April 2013 samples collected at sites SW-05, SW-05A, SW-05B, and SW-05C.

Figure A5-4. Locations of study sites SW-05, SW-05A, SW-05B, and SW-05C.

Primary site SW-08 and secondary sites SW-08A, SW-08B, SW-08C, and SW-08D (figs. A5-5 and A5-6)

Primary site SW-08 has multiple tributaries and represents one of the larger study watersheds (15.8 mi^2). The results for nitrate+nitrite (2.74 mg/L), sodium+potassium (9.95 mg/L), and $\delta^{15}N$ (5.44 ‰) at site SW-08D are indicative of inputs from background agricultural fields with no CAFOs, which is consistent with the watershed setting of this site. The results for nitrate+nitrite (0.681 mg/L), sodium+potassium (12.67 mg/L), and $\delta^{15}N$ (7.42 ‰) at site SW-08B on a tributary downstream from a swine CAFO and other agricultural fields appear to reflect background conditions rather than a CAFO effect. Higher values of nitrate+nitrite (1.22 mg/L), sodium+potassium (16.40 mg/L), and $\delta^{15}N$ (24.56 ‰) were noted at site SW-08C located further downstream from site SW-08B and just below another swine CAFO. Although SW-08C had less nitrate+nitrite than background site SW-08D, the higher values of sodium+potassium and $\delta^{15}N$ for SW-08C relative to SW-08D indicate a swine-manure effect. The two sites (upstream secondary site SW-08A and downstream primary site SW-08) on the main stream channel in the swampy riparian floodplain with sluggish flow conditions had essentially no DO (≤0.1 mg/L) nor detectable nitrate+nitrite (<0.04 mg/L), indicating the effects of reducing conditions at these locations. Although the somewhat elevated sodium+potassium concentrations of 16.41 and 16.70 mg/L at SW-08A and SW-08, respectively, were suggestive of swine manure influences, there were no available $\delta^{15}N$ data to examine so results for these sites were considered unclear.

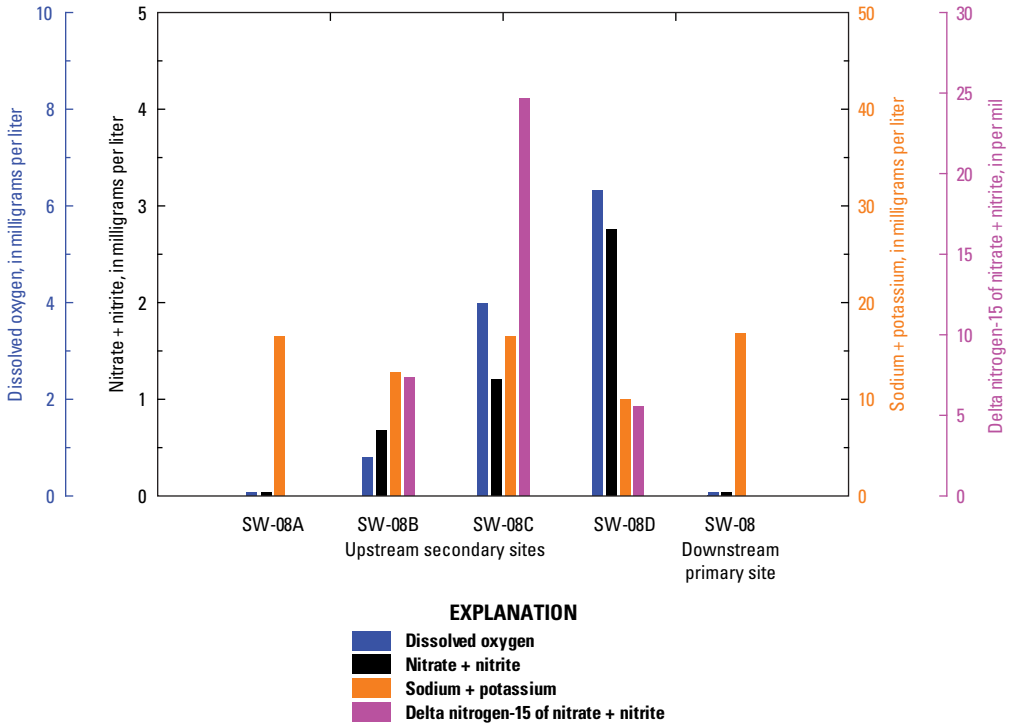

Figure A5-5. Dissolved oxygen, nitrate plus nitrite, sodium plus potassium, and delta nitrogen-15 results for April 2013 samples collected at sites SW-08, SW-08A, SW-08B, SW-08C, and SW-08D.

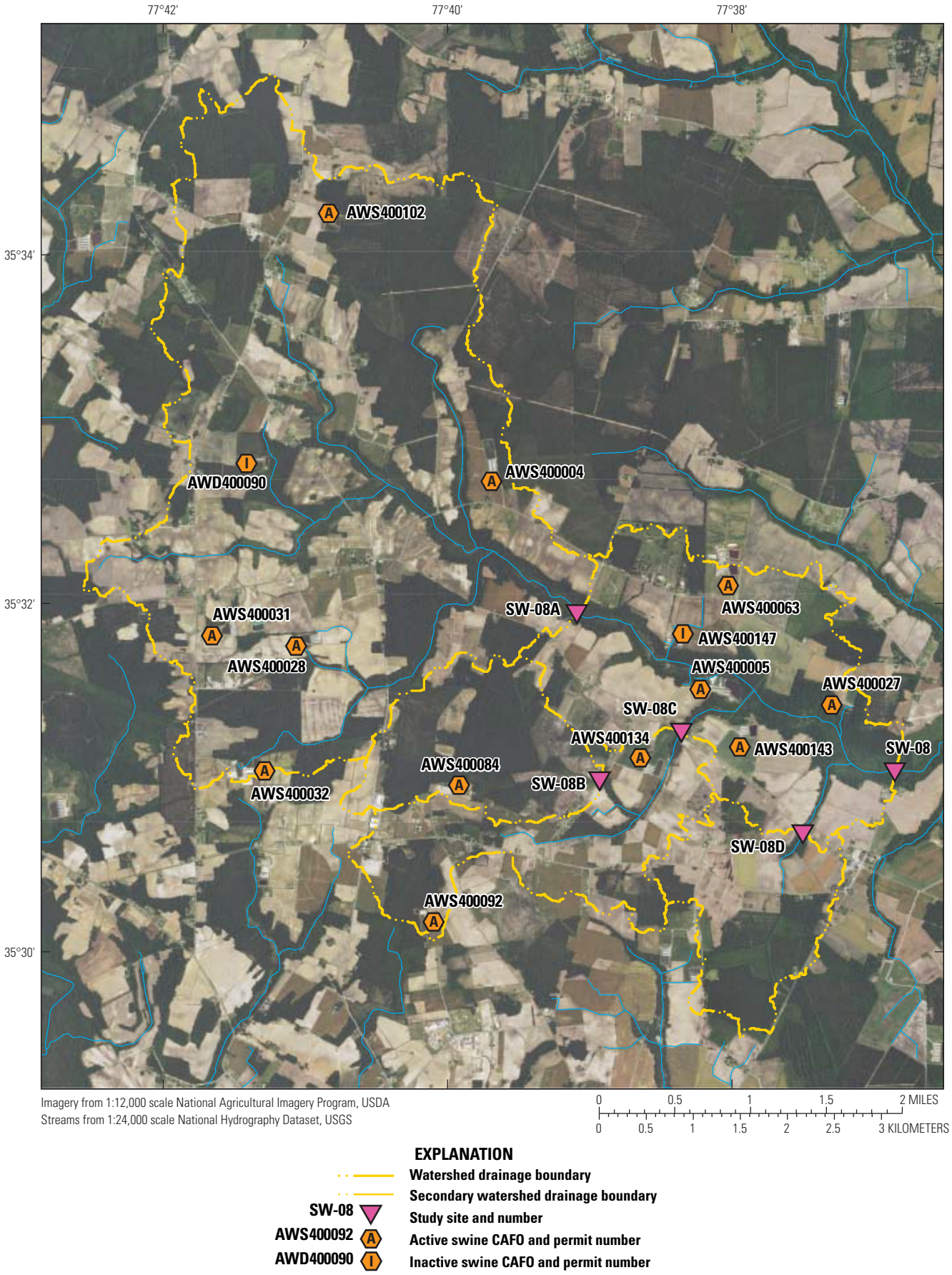

Figure A5-6. Locations of study sites SW-08, SW-08A, SW-08B, SW-08C, and SW-08D.

Primary site SW-13 and secondary sites SW-13A and SW-13B (figs. A5-7 and A5-8)

The results for all three sites in this small watershed (1.9 mi^2) were influenced by swine waste manure. Upstream site SW-13A and midstream site SW-13B next to swine CAFOs had high sodium+potassium concentrations (65.70 and 51.80 mg/L, respectively) and $\delta^{15}N$ values (18.92 and 19.98 ‰, respectively). A high sodium+potassium concentration of 33.10 mg/L and $\delta^{15}N$ value of 22.04 ‰ also were noted further downstream at watershed site SW-13. Very high nitrate+nitrite concentrations were measured at upstream sites SW-13A (35.4 mg/L) and SW-13B (27.5 mg/L), but downstream site SW-13 had minimal nitrate+nitrite (0.39 mg/L). It would be easy to conclude that site SW-13 was not influenced by swine manure if the interpretations were based only on examining nitrate+nitrite results; however, inclusion of the sodium+potassium and $\delta^{15}N$ results indicate this was not the case. Interestingly, the February sample collected at SW-13 had a much higher nitrate+nitrite concentration of 15.9 mg/L (appendix table A4-1). The difference in nitrate+nitrite at SW-13 between the February and April samples likely reflects the influence of two beaver ponds on flow conditions and subsequent N cycling in the stream reach between sites SW-13B and SW-13. There was likely less denitrification during the colder February sampling period with higher streamflows, which allowed nitrate+nitrite to be more quickly transported through the beaver ponds. Lower streamflow conditions likely increased surface-water residence times within the beaver ponds during the warmer April sampling period, thereby enhancing the potential for denitrification to lower the amount of nitrate+nitrite transported downstream from site SW-13B to site SW-13.

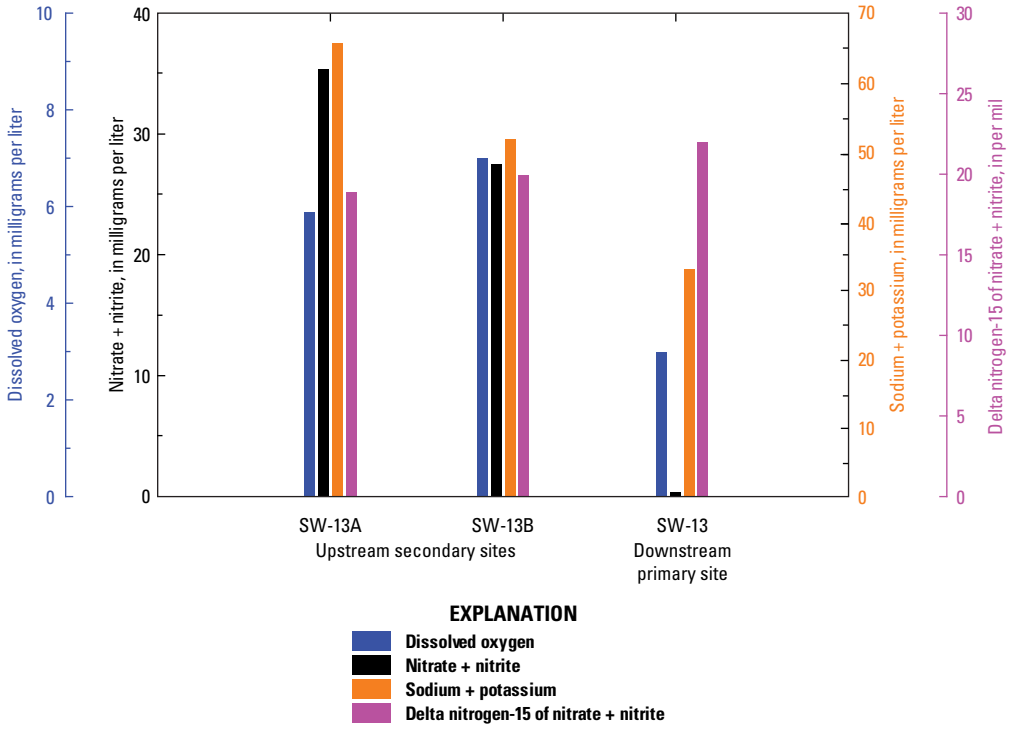

Figure A5-7. Dissolved oxygen, nitrate plus nitrite, sodium plus potassium, and delta nitrogen-15 results for April 2013 samples collected at sites SW-13, SW-13A, and SW-13B.

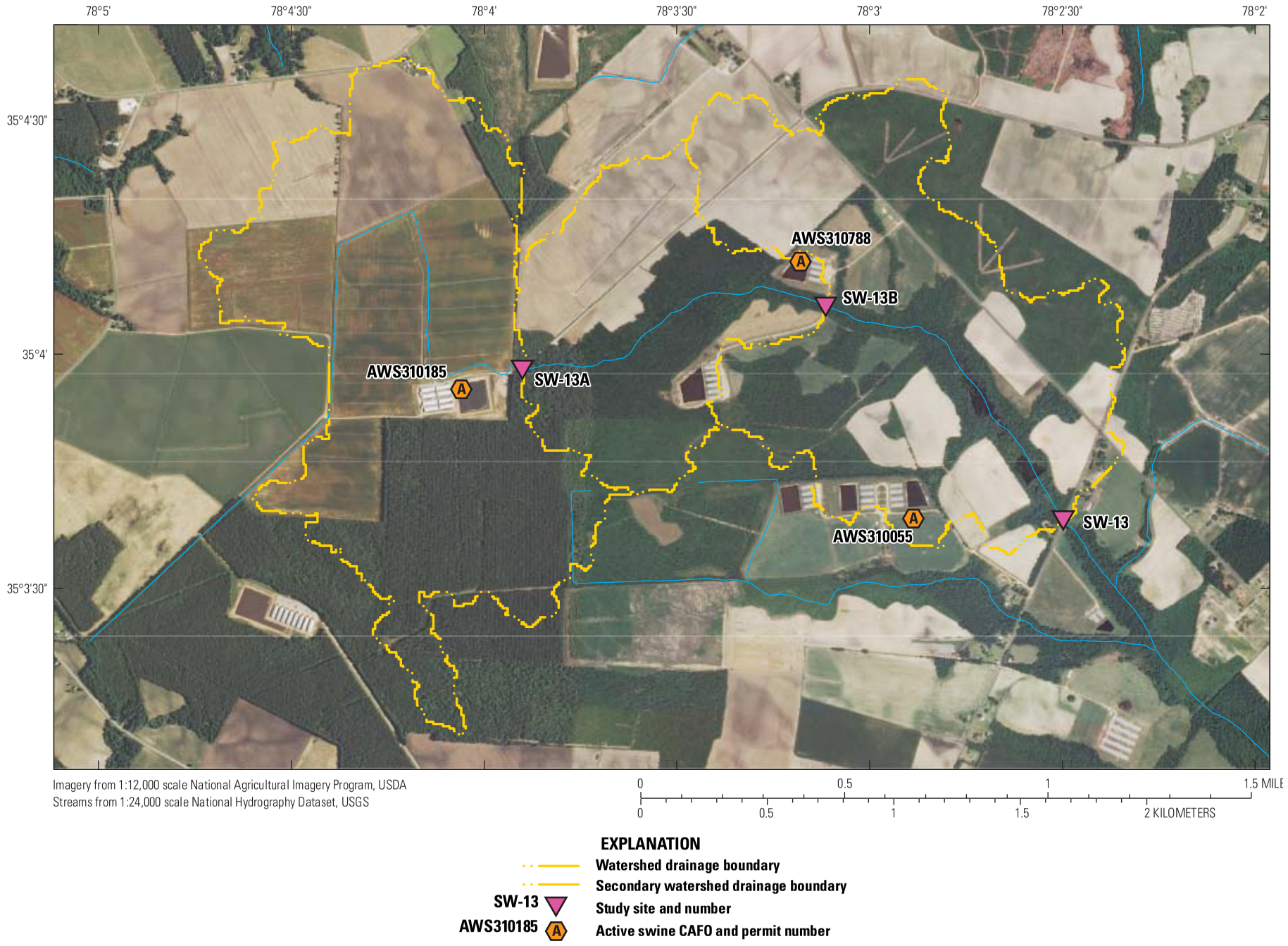

Figure A5-8. Locations of study sites SW-13, SW-13A, and SW-13B.

Primary site SP-01 and secondary sites SP-01A, SP-01B, and SP-01C (figs. A5-9 and A5-10)

Primary site SP-01 has multiple tributaries and is the largest study watershed (17.5 mi^2). Background site SP-01A, downstream from woodlands and agricultural fields with no CAFOs, had no detectable nitrate+nitrite (<0.040 mg/L) and low sodium+potassium (5.19 mg/L). Downstream on the same tributary is site SP-01B, which is located downstream from a poultry CAFO and next to a swine CAFO. The results for nitrate+nitrite (<0.040 mg/L) and sodium+potassium (5.93 mg/L) at site SP-01B are similar to upstream background site SP-01A and do not suggest a waste-manure effect. In contrast, site SP-01C, on a separate tributary, is downstream from two swine CAFOs where the influence of swine-waste manure is evident in the results for sodium+potassium (31.10 mg/L) and $\delta^{15}N$ (27.99 ‰). The two tributaries with sites SP-01B and SP-01C merge with the main watershed stream just upstream from primary site SP-01. The results at site SP-01 for nitrate+nitrite (0.103 mg/L), sodium+potassium (10.63 mg/L), and $\delta^{15}N$ (8.94 ‰) do not appear to exhibit the swine-manure effect noted at SP-01C, likely because most of the streamwater originates from upstream areas in the watershed draining predominantly forested and agricultural lands without CAFOs.

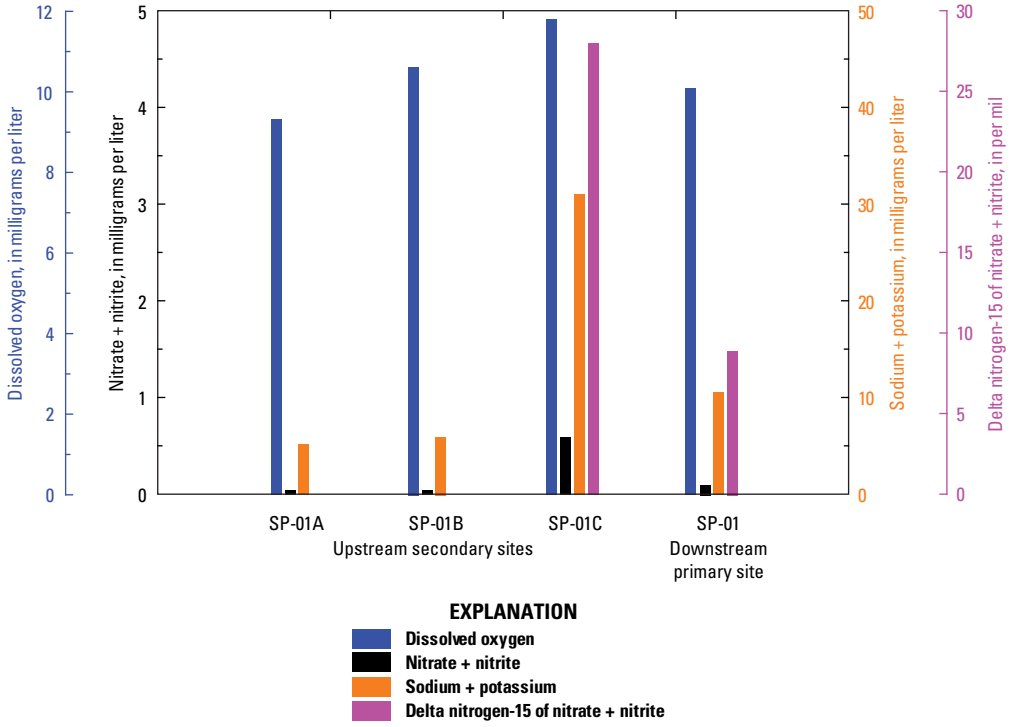

Figure A5-9. Dissolved oxygen, nitrate plus nitrite, sodium plus potassium, and delta nitrogen-15 results for April 2013 samples collected at sites SP-01, SP-01A, SP-01B, and SP-01C.

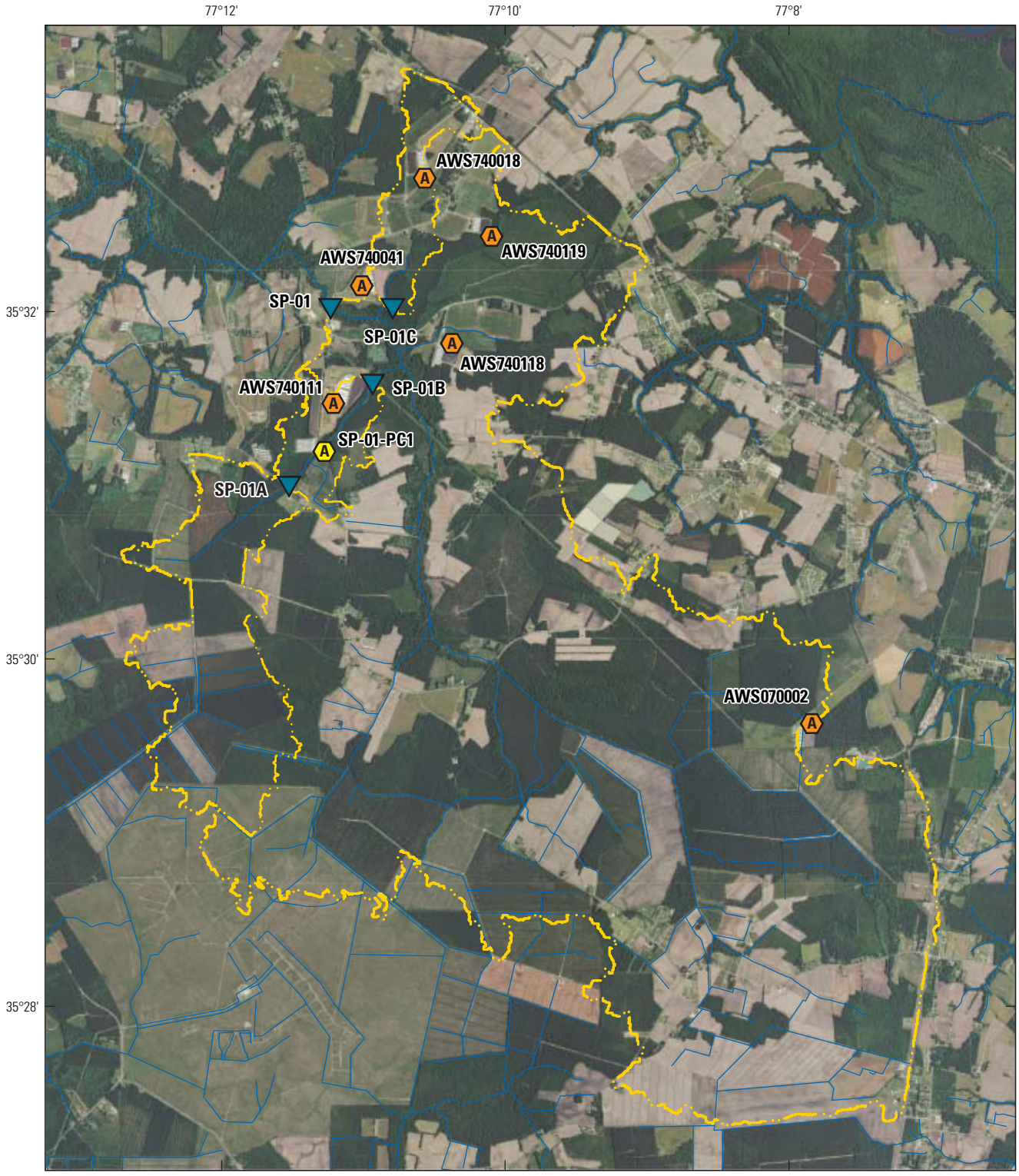

Figure A5-10. Locations of study sites SP-01, SP-01A, SP-01B, and SP-01C.

Primary site SP-04 and secondary sites SP-04A and SP-04B (figs. A5-11 and A5-12)

Primary site SP-04 contains two main tributaries and has a drainage area of 3.7 mi^2. Background site SP-04A is downstream from woodlands and agricultural fields. The results at site SP-04A for nitrate+nitrite (0.877 mg/L) and sodium+potassium (9.25 mg/L) are indicative of inputs from background agricultural fields with no CAFOs. The $\delta^{15}N$ value (12.52 ‰) at this site is similar to a manure signature but likely reflects nitrate+nitrite, derived from fertilized fields, that has been altered by denitrification. The higher nitrate+nitrite (1.86 mg/L), sodium+potassium (22.74 mg/L), and $\delta^{15}N$ (22.54 ‰) observed further downstream on this same tributary at site SP-04B, located below two swine CAFOs and a poultry CAFO, reflect a waste-manure influence. Primary site SP-04 is downstream from both tributaries, which include four active swine CAFOs and one poultry CAFO. Site SP-04 had minimal nitrate+nitrite (0.11 mg/L), but the elevated sodium+potassium (21.24 mg/L) and $\delta^{15}N$ (17.01 ‰) at this downstream location indicate an apparent waste-manure influence likely related to the swine CAFOs.

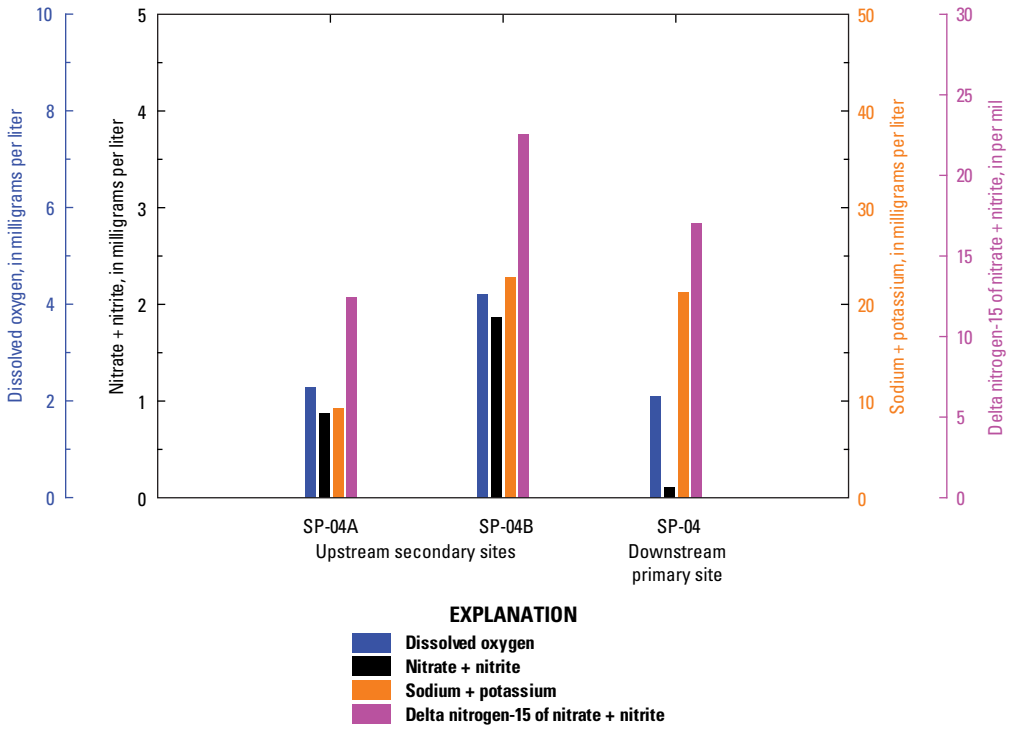

Figure A5-11. Dissolved oxygen, nitrate plus nitrite, sodium plus potassium, and delta nitrogen-15 results for April 2013 samples collected at sites SP-04, SP-04A, and SP-04B.

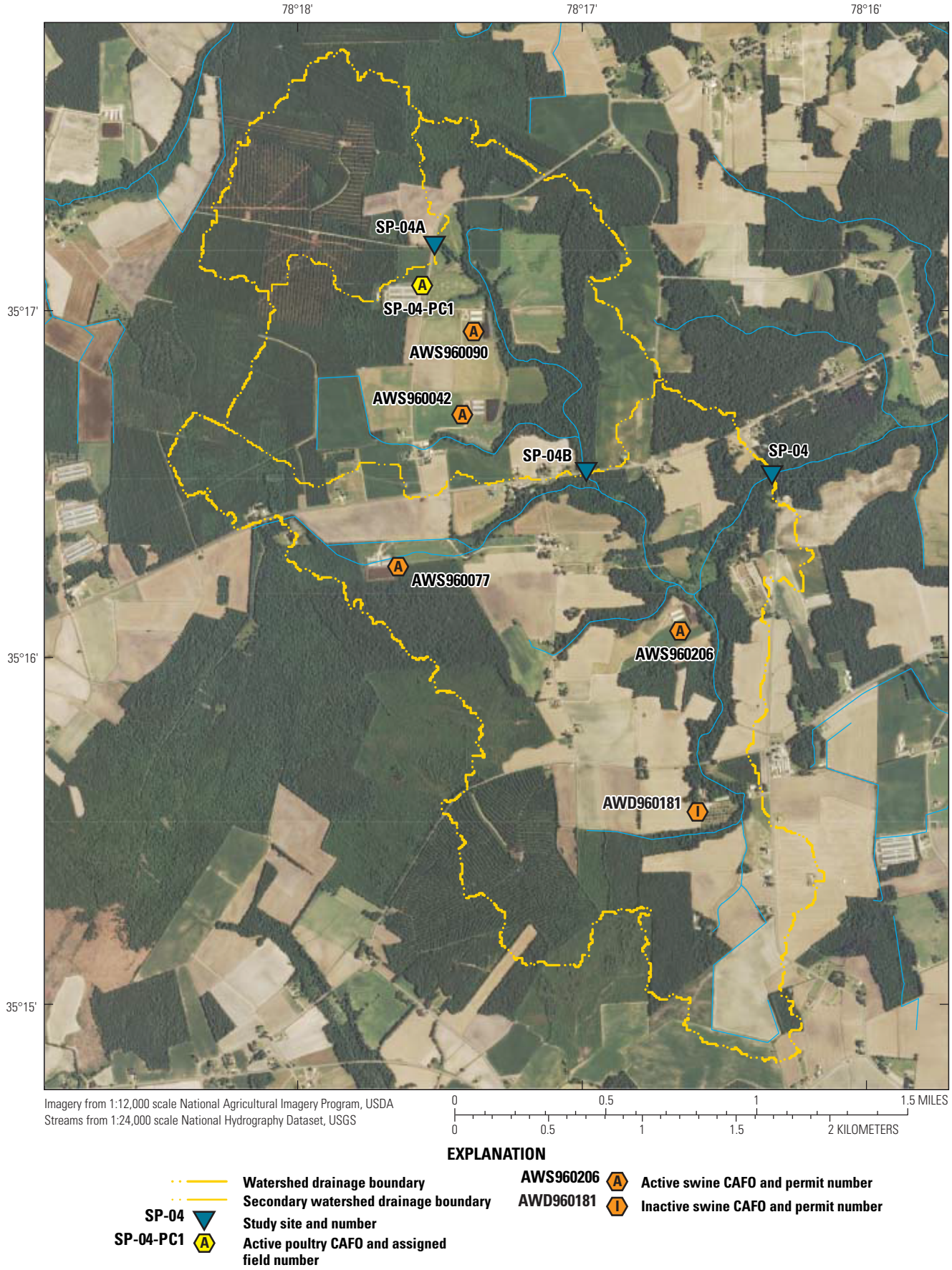

Figure A5-12. Locations of study sites SP-04, SP-04A, and SP-04B.

Primary site SP-05 and secondary sites SP-05A and SP-05B (figs. A5-13 and A5-14)

Site SP-05 is a small watershed (1.4 mi^2) with two main tributaries that predominantly drain agricultural fields with minimal riparian buffers. Primary site SP-05 is located at the confluence of the two tributaries and is immediately downstream from a poultry CAFO with two clusters of large poultry barns. Upstream from this poultry facility, sites SP-05A and SP-05B are located on each of the tributaries that receive drainage inputs from large agricultural fields. In addition, a poultry CAFO and a swine CAFO are located in the headwater area of the two tributaries upstream from sites SP-05A and SP-05B. The relatively high surface-water nitrate+nitrite concentrations observed for sites SP-05A (3.50 mg/L), SP-05B (2.62 mg/L), and SP-05 (4.13 mg/L) are comparable to those concentrations for sites with CAFO waste-manure effects. The relatively low sodium+potassium concentrations at SP-05A (12.06 mg/L), SP-05B (12.16 mg/L), and SP-05 (11.84 mg/L) and low $\delta^{15}N$ values at SP-05A (7.93 ‰), SP-05B (8.75 ‰), and SP-05 (8.00 ‰), however, do not suggest an animal-manure influence. The elevated nitrate+nitrite concentrations at these sites potentially reflect the lack of riparian buffers, which can reduce nitrate in groundwater being discharged to the streams.

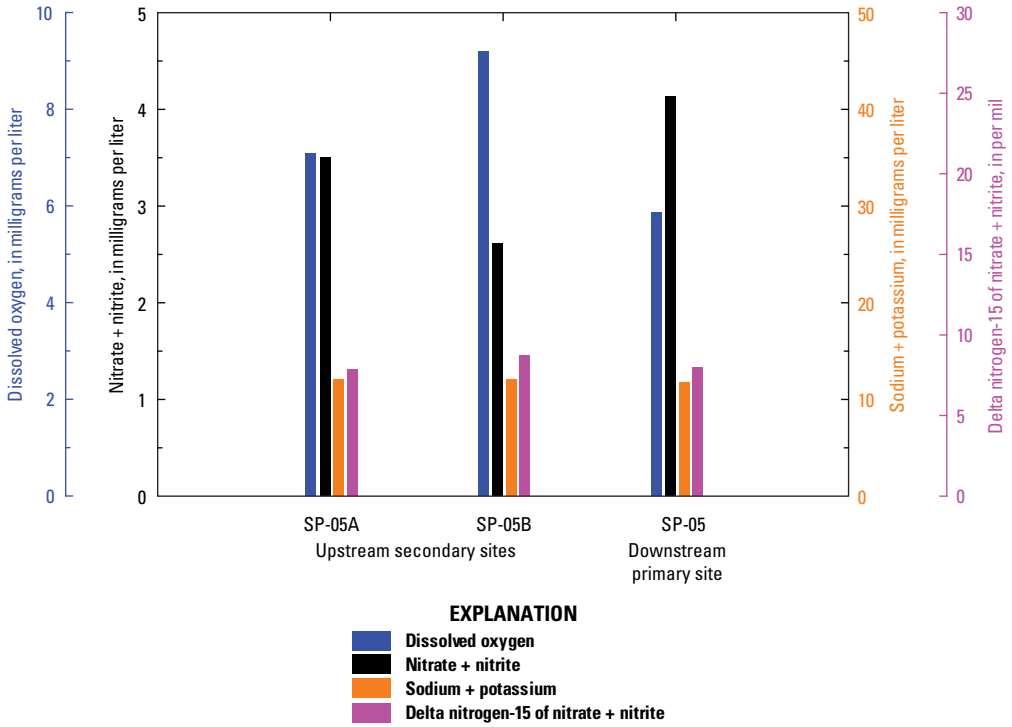

Figure A5-13. Dissolved oxygen, nitrate plus nitrite, sodium plus potassium, and delta nitrogen-15 results for April 2013 samples collected at sites SP-05, SP-05A, and SP-05B.

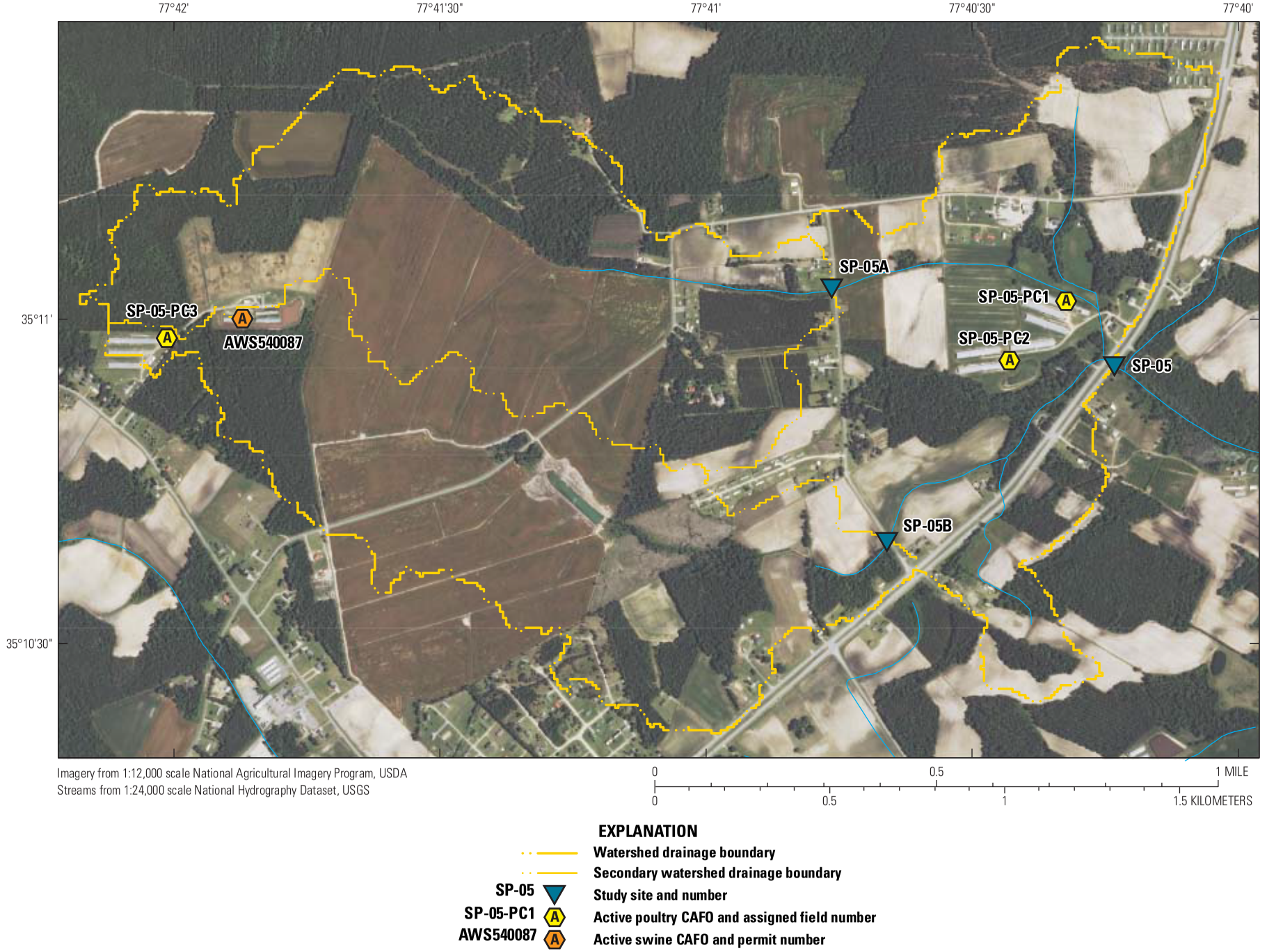

Figure A5-14. Locations of study sites SP-05, SP-05A, and SP-05B.

Primary site SP-09 and secondary site SP-09A (figs. A5-15 and A5-16)

Site SP-09 is a 7.6-mi^2 watershed dominated by agricultural fields associated with 3 permitted swine CAFOs having a total of 14 lagoons and 59 barns (appendix table A3-5). One poultry CAFO with four barns also is present in the watershed. This watershed had the highest density of acreage (187.1 acres/mi^2) available for swine manure applications and the second highest swine weight density (625 ton/mi^2) of all the study sites. Site SP-09A is located at the downstream confluence of the two major canals draining the swine manure application fields, and primary site SP-09 is about 1 mile further downstream. Swine-manure influences are evident at both SP-09A and SP-09 on the basis of the elevated nitrate+nitrite concentrations (3.20 and 1.94 mg/L, respectively), sodium+potassium concentrations (43.60 and 33.70 mg/L, respectively), and δ^{15}N values (23.02 and 23.13 ‰, respectively).

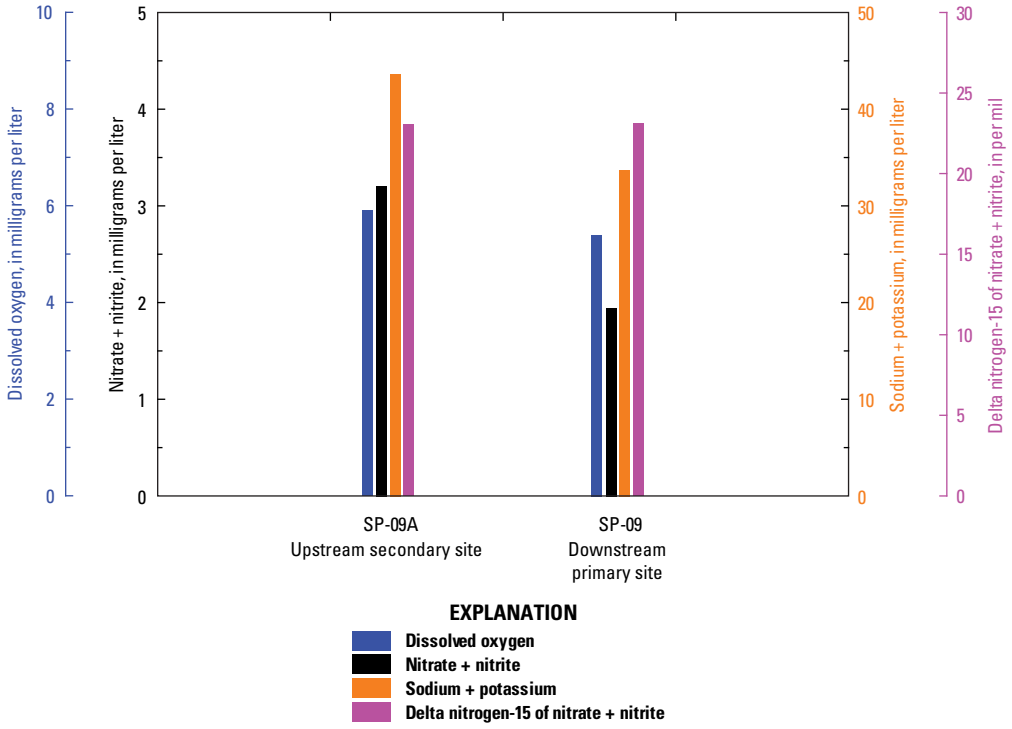

Figure A5-15. Dissolved oxygen, nitrate plus nitrite, sodium plus potassium, and delta nitrogen-15 results for April 2013 samples collected at sites SP-09 and SP-09A.

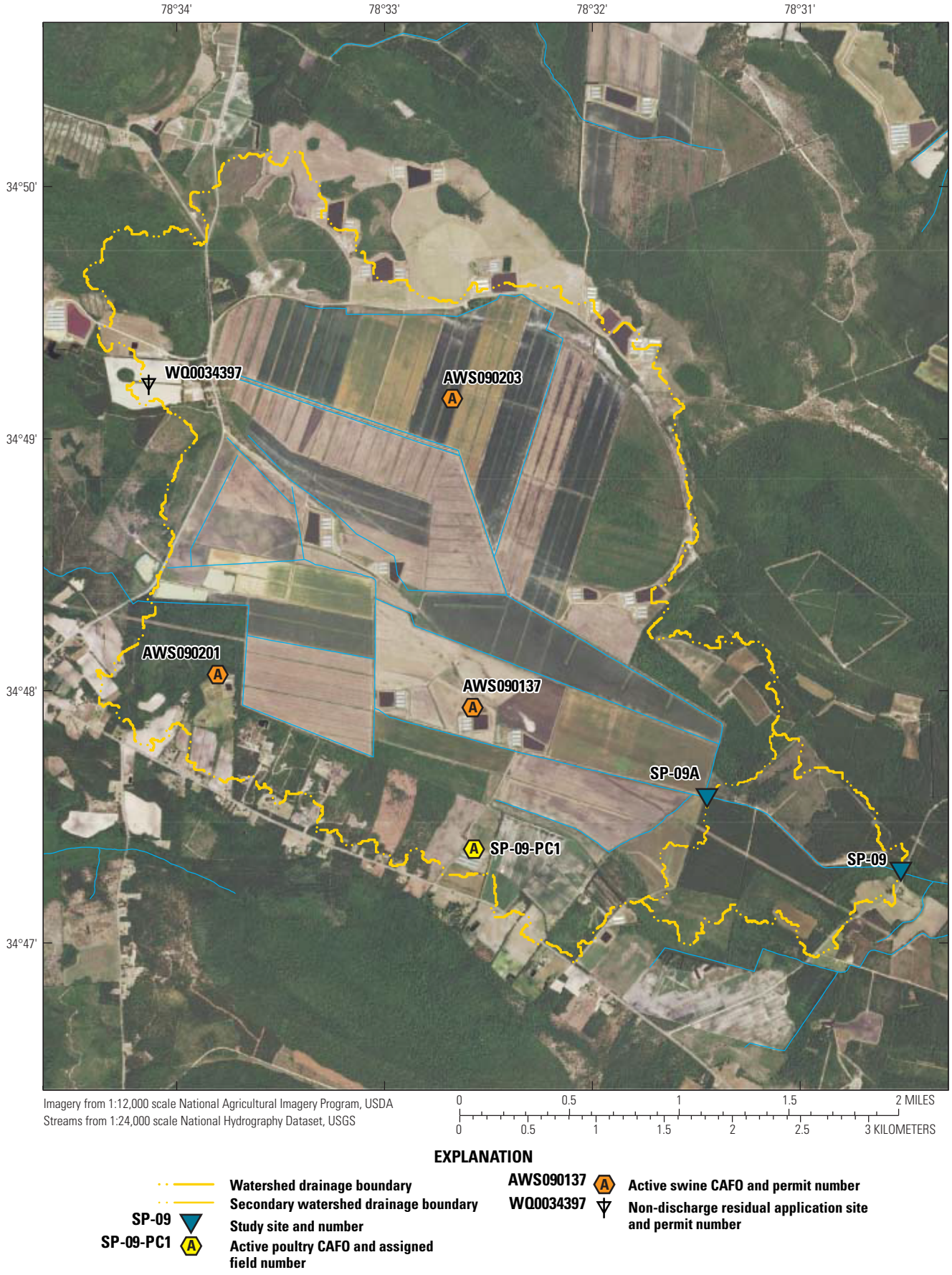

Figure A5-16. Locations of study study sites SP-09 and SP-09A.

Primary site SP-11 and secondary sites SP-11A, SP-11B, SP-11C, and SP-11D (figs. A5-17 and A5-18):

Primary watershed site SP-11, with a drainage area of 5.6 mi^2, is located just below the confluence of two main tributaries. Seven of the 9 swine CAFOs are located along the longer western tributary; two swine CAFOs and one poultry CAFO are located along the eastern tributary. The secondary sites are situated along the western tributary. Site SP-11A in the upper tributary is located below two swine CAFOs, site SP-11B is located below two additional swine CAFOs, and site SP-11D is located below two more CAFOs. Site SP-11C is on a small field drainage ditch, between two swine CAFOs and spray fields, and joins the stream between sites SP-11B and SP-11D. Several beaver ponds are located between the sites throughout the western tributary. Main tributary sites SP-11A, SP-11B, and SP-11D had nitrate+nitrite concentrations ranging from 1.01 to 1.73 mg/L. Each of these sites had elevated sodium+potassium concentrations (ranging from 31.10 to 32.60 mg/L) and $\delta^{15}N$ values (ranging from 24.21 to 28.96 ‰), indicating swine-manure influences. Field ditch site SP-11C, with a higher nitrate+nitrite concentration of 2.98 mg/L, had a more modest sodium+potassium concentration (12.66 mg/L) and $\delta^{15}N$ value (11.91 ‰), which possibly indicate a manure influence although the effect is not as pronounced as that noted for the other sites. Interestingly, downstream primary site SP-11 had minimal DO (0.3 mg/L) and no detectable nitrate+nitrite (<0.04 mg/L), reflecting enhanced instream N cycling in the lower part of this swampy watershed, yet the elevated sodium+potassium concentration of 22.80 mg/L still indicated a swine-manure influence.

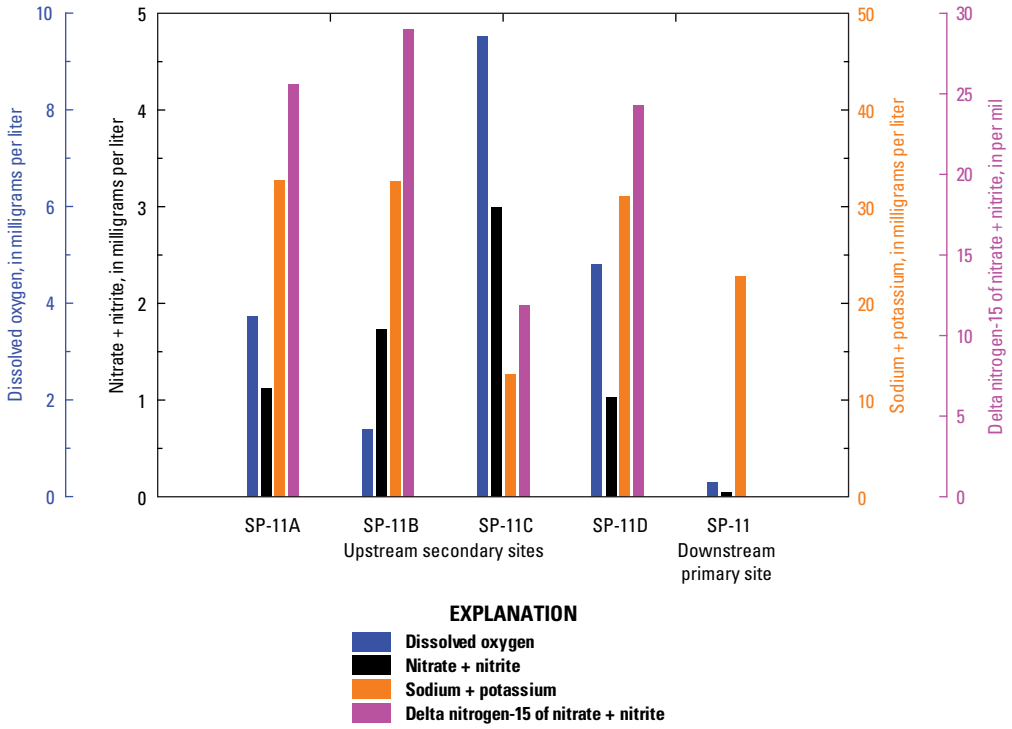

Figure A5-17. Dissolved oxygen, nitrate plus nitrite, sodium plus potassium, and delta nitrogen-15 results for April 2013 samples collected at sites SP-11, SP-11A, SP-11B, SP-11C, and SP-11D.

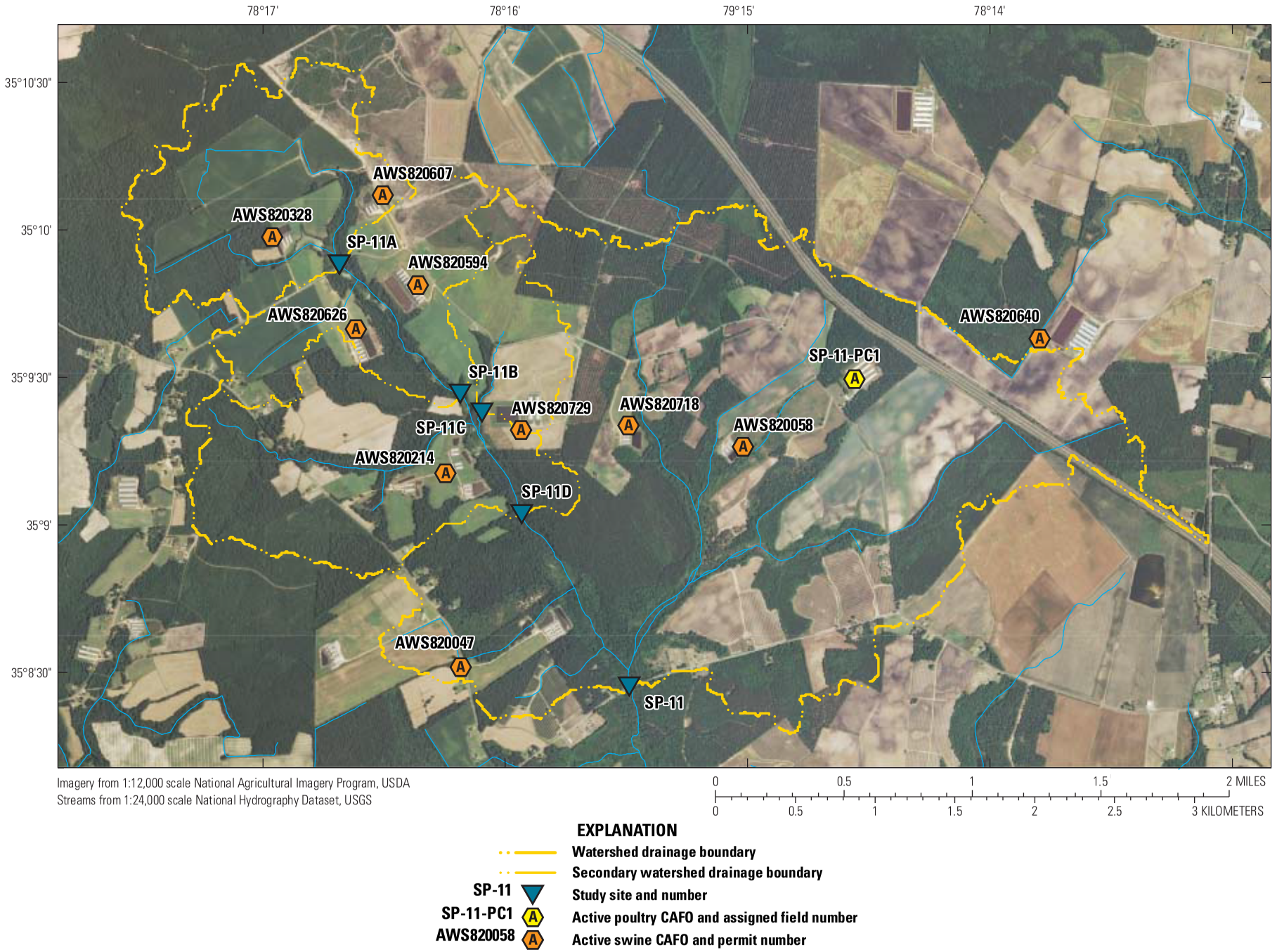

Figure A5-18. Locations of study sites SP-11, SP-11A, SP-11B, SP-11C, and SP-11D.