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EXPANSION OF THE MANAGE DATABASE WITH FOREST AND DRAINAGE STUDIES[1]

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ABSTRACT: The "Measured Annual Nutrient loads from AGricultural Environments" (MANAGE) database was published in 2006 to expand an early 1980s compilation of nutrient export (load) data from cultivated and pasture/range land at the field or farm scale. Then in 2008, MANAGE was updated with 15 additional studies, and nitrogen (N) and phosphorus (P) concentrations in runoff were added. Since then, MANAGE has undergone significant expansion adding N and P water quality along with relevant management and site characteristic data from: (1) 30 runoff studies from forested land uses, (2) 91 drainage water quality studies from drained land, and (3) 12 additional runoff studies from cultivated and pasture/range land uses. In this expansion, an application timing category was added to the existing fertilizer data categories (rate, placement, formulation) to facilitate analysis of 4R Nutrient Stewardship, which emphasizes right fertilizer source, rate, time, and place. In addition, crop yield and N and P uptake data were added, although this information was only available for 21 and 7% of studies, respectively. Inclusion of these additional data from cultivated, pasture/range, and forest land uses as well as artificially drained agricultural land should facilitate expanded spatial analyses and improved understanding of regional differences, management practice effectiveness, and impacts of land use conversions and management techniques. The current version is available at www.ars.usda.gov/spa/manage-nutrient.

(KEY TERMS: nitrogen; phosphorus; water quality; nonpoint source pollution; drainage; forest hydrology.)

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INTRODUCTION

The "Measured Annual Nutrient loads from AGricultural Environments" (MANAGE) database was published in 2006 to be a readily-accessible, easily-queried database of site characteristic and field-scale nutrient export data for agricultural land use (cultivated and pasture/range) in the United States (U.S.) (Harmel *et al.*, 2006). Runoff studies in the original version and updates must have: (1) been published in a scientific journal, (2) collected runoff nitrogen (N) and/or phosphorus (P) data at the field- or farm-spatial scale (minimum 0.009 ha) from a homogeneous agricultural land use, (3) assessed rainfall-runoff (not rainfall simulation), and (4) collected data for a minimum of one full year period. Only data from the U.S. and selected data from Canada were

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included to constrain the database scope. This original version of MANAGE drew heavily on an early 1980s compilation of nutrient export data (Beaulac, 1980; Reckhow *et al.*, 1980; Beaulac and Reckhow, 1982) and included data from 40 studies. When MANAGE was updated in 2008 (Harmel *et al.*, 2008), it included an additional 15 runoff studies and included nutrient concentration data along with nutrient loads.

Since the 2008 update, MANAGE has undergone several significant expansions (Table 1). Each of these expansions is described subsequently.

1. Studies with forest land use (30 runoff studies),
2. Drainage studies (91 drainage studies) reporting N and/or P concentrations and loads from drained land, and
3. Twelve additional agricultural studies with runoff N and/or P data from cultivated and pasture lands.

The current version can be downloaded at http://www.ars.usda.gov/spa/manage-nutrient.

Forest Land Use Studies

The addition of forest land use to the MANAGE database is a significant improvement since a third of the U.S. land area is forested (FAO, 2015). In addition, the U.S. harvests about 708,000,000 m^3 of wood annually, making it the largest producer of forest products in the world (Juslin and Hansen, 2002). Therefore, concerns have been raised about the potential impacts on water resources, particularly in terms of nutrient enrichment from forest harvesting, fertilization, prescribed and wild fire, and other management activities. MANAGE now has results from 420 site years from 30 studies from 24 U.S. locations. These studies report field- and watershed-scale nutrient concentrations and losses from a wide range of forest activities. One of the challenges in developing a research database for forestry is capturing the wide range of silvicultural activities employed. These activities have changed over the last century with technological improvements and changes in forest management objectives. Furthermore, given the wide range of natural forest types, activities commonly employed in one region are not appropriate for another. For example, cable yarding is commonly used for moving harvested trees to log landings in mountainous terrain, where rubber-tire skidders are used in more gently rolling topography. In addition, the inclusion of forestry best management practices (BMPs) has been a significant change that occurred in the past 40 years. To account for these differences, additional data categories particular to forest management were added and include timber type and silvicultural practices (i.e., harvesting, site preparation, planting, prescribed burning) (Figure 1).

There are several opportunities for MANAGE users to benefit from the forest study data. First, the inclusion of studies from different ecoregions facilitates evaluation of runoff nutrient losses at the regional and national level. MANAGE also provides an extensive dataset for evaluating forest BMPs, many of which have been shown to limit nutrient losses (Ice, 2004); however, this aspect of forest hydrology needs additional study and analysis particularly given the inherent natural variability in forest stream nutrient concentrations (Binkley *et al.*, 2004). Finally, while forests are typically associated with much lower nutrient losses than other land uses (e.g., agricultural and urbanized) (McBroom and Young, 2009), additional research is needed to determine the effects of land conversions among different land uses. Such critical nutrient loss concerns can be better addressed as forest land uses are now included in MANAGE, along with grassland and cultivated agriculture.

TABLE 1. Summary Statistics for the Original and Updated MANAGE Database Versions.

Reference	Harmel *et al.* (2006)	Harmel *et al.* (2008)	Present Work	Present Work	Present Work
Land use	Cultivated, pasture/range	Cultivated, pasture/range	Cultivated, pasture/range	Cultivated, pasture/range	Forest
Site years (no. sites × no. years)	1,103	1,677	1,980	1,279	420
Publications (studies)[1]	40	55	67	91	30
Database records	163	274	330	315[2]	107
Nutrient export data	Loads	Loads and concentrations	Loads and concentrations	Loads	Loads and concentrations
Major addition(s)	—	Additional studies plus runoff concentration data	Additional studies plus crop yield, N/P plant uptake, fertilizer timing	Studies from artificially drained agricultural lands	Studies from forest land uses

[1]In rare instances, data/information from paired publications are grouped to form one study.
[2]In the Drain Load table, individual site years were listed as separate database records, thus the number of sites (plots, fields) is presented.

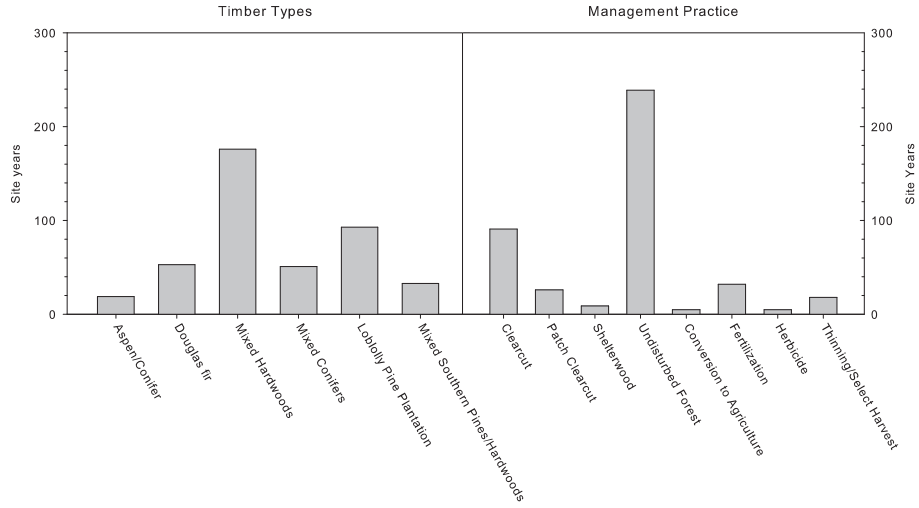

FIGURE 1. Number of Site Years of Timber Type and Silvicultural Management Practice Data for Forested Land Uses.

Drainage Studies

The addition of agricultural drainage N and P loads is a valuable complement to the existing cultivated, pasture/range, and forest data. The new MANAGE Drain Load table, which includes 1,279 site years of data from 91 studies across North America, allows investigation of drainage trends and impacts during the past 50 years (1961-2012). Studies on surface and subsurface drainage systems are included, although the latter accounted for the majority of site years (Figure 2). The most significant deviation from the existing MANAGE format is that each record in the Drain Load table represents an individual site year, whereas in the runoff tables, each record represented a site with data pooled across years. Several new data fields were needed in the database to adequately describe drainage conditions, and these include: drain type ("surface," "subsurface with inlets," or "subsurface no inlet specified"), drain spacing, and drain depth. Other fields remained consistent with the MANAGE framework to facilitate evaluation of cropping and nutrient management impacts on runoff and drainage water quality. The Drain Load table contains U.S. and Canadian data with the states/provinces of Iowa, Ontario, Illinois, and Minnesota contributing 78% of the site years. This new data compilation has already facilitated further analyses and improved understanding of the environmental impacts of artificial agricultural drainage (Christianson and Harmel, 2015a, b; Christianson *et al.*, 2016; X. Zhao et al., Changshu National Agro-Ecosystem Observation and Research Station, Nanjing, 2016, unpublished data).

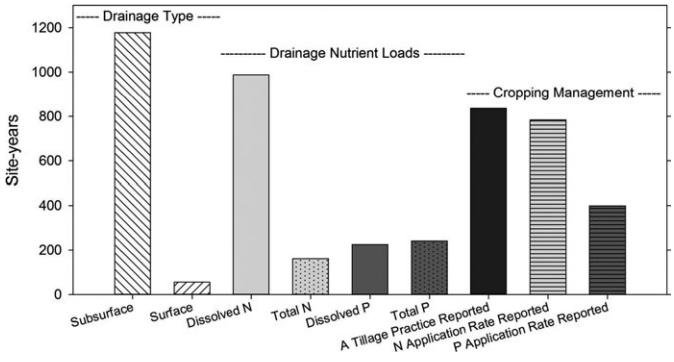

FIGURE 2. Number of Site Years for Selected Drainage-Related Data, Including Drainage Type, Nutrient Loads, and Cropping Management.

Additional Data and Studies from Agricultural Land Uses

In the recent expansion of MANAGE, 12 additional studies published from 2007 to 2014 from cultivated

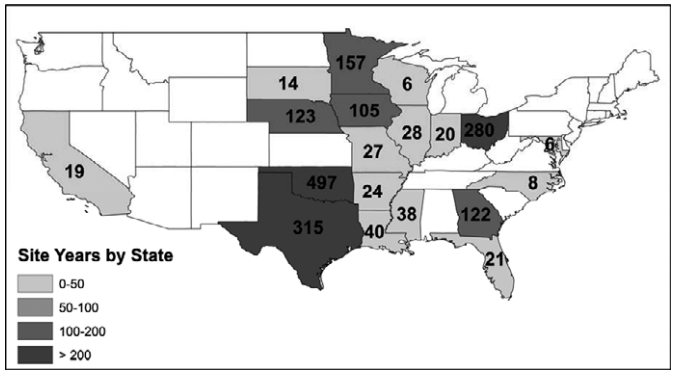

FIGURE 3. Data Availability for Runoff Data by State Presented in Site Years.

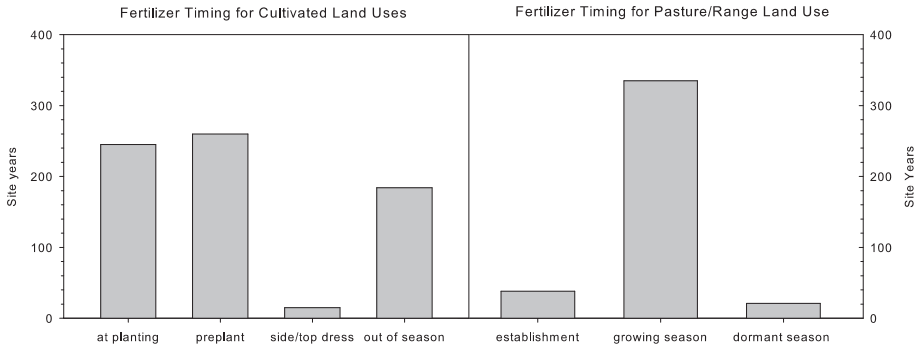

FIGURE 4. Number of Site Years of Fertilizer Timing Data for Cultivated and Grassland (pasture/range) Land Uses.

and pasture/range lands were added. These studies, which met all of the necessary criteria for inclusion, added 303 site years of runoff N and/or P data bringing the total to 1,980 site years spatially distributed as shown in Figure 3.

In addition to newly published and previously overlooked studies, this expansion also included additional data fields to facilitate analysis of 4R factors, which include right fertilizer source, rate, time, and place (IPNI, 2012), as requested by the 4R Research Fund. Fertilizer rate, placement, and formulation data were included in previous versions, but fertilizer application timing was missing. Thus, fertilizer application timing categories were added for cultivated crops ("Out of Season, >2 months before plant," "Pre-Plant, 2 months-1 week before plant," "At Planting, within 1 week of plant," and "Side/Top Dress, >1 week after plant"); for pasture ("Grass at Establishment," "Grass in Dormant Season," and "Grass in Growing Season"); and "Other." For most of the pasture/range land uses, fertilizer was most often applied during the growing season (Figure 4), which is a recommended practice for minimizing nutrient runoff. In cultivated lands, however, a substantial number of site years (184) reported "out of season (>2 months before planting)" application of fertilizer, although split application was reported for 601 site years (data not shown). In addition, crop yield (Mg/ha) and N and P uptake (kg/ha) were added, although these data were only available for 14 and 5 studies, respectively.

CONCLUSIONS

The MANAGE database (Harmel *et al.*, 2006, 2008) was designed to be a readily-accessible, easily-queried database of site characteristic and field-scale nutrient export data for agricultural land use in the U.S. It was based on the early 1980s compilation of nutrient export data by Beaulac (1980), Reckhow *et al.* (1980), and Beaulac and Reckhow (1982). The present work describes significant expansions of the database, including adding 30 forest land use studies and 91 drainage studies, as well as 12 recently published or previously overlooked cultivated and pasture/range studies. In this expansion, additional data fields were added (e.g., fertilizer application timing, crop yield, and N and P uptake). Inclusion of nutrient loss data from forest, grassland, and cultivated land uses in MANAGE should facilitate modeling analyses and improve understanding of regional differences, BMP effectiveness, and impacts of land use conversions, management techniques, and artificial drainage. Planned future expansion will include urban land use, so all major land uses can be evaluated and their influences and interactions better understood.

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