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DATA AND ANALYSIS NOTE

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USDA-ARS Riesel Watersheds, Riesel, Texas, USA: Water quality research database

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Key Points:
- Riesel Watersheds are a nested watershed network with 75 years of measured data
- Database contains discharge, erosion, land management, climatic data (1938–2012)
- Nutrient concentrations measured in storm runoff, base flow, rainfall now included

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Abstract The 75 year legacy database including discharge, sediment loss, land management, and meteorological data for the USDA-ARS Riesel Watersheds, Riesel, TX, USA has been available on the web for more than a decade (www.ars.usda.gov/spa/hydro-data) and used in numerous studies and publications; however, only recently have these data been added to the Sustaining the Earth's Watersheds, Agricultural Research Data System (STEWARDS) database (www.nrrig.mwa.ars.usda.gov/stewards/stewards.html). In addition, water quality data including dissolved inorganic N and P compounds measured from more than 1000 storm runoff events, 1300 base flow sampling events (lateral subsurface return flow or seepage flow), and 157 precipitation events through 2012 were added. The objectives of this manuscript are to present relevant background information on these data, summarize the data collection and analysis methodology, present the measured data along with cursory analyses, and convey the commitment of the USDA-ARS Riesel Watersheds to long-term data accessibility and database enhancement for water quality data and research.

1. Introduction

In recent years, the importance of long-term data has been increasingly acknowledged, and a number of long-term databases from experimental watersheds have been published [e.g., *Pierson et al*., 2001; *Bosch et al*., 2007; *Goodrich et al*., 2008; *Owens et al*., 2010; *Church et al*., 2011]. Long-term hydrology and water quality data are particularly important when coupled with climatic data to analyze the impacts of rainfall and temperature on water resources. Although private, local, and state entities need watershed-scale research results and data, few, if any, have the resources or stated responsibility to conduct long-term integrated watershed research and monitoring [*Slaughter and Richardson*, 2000]. Thus, the USDA-ARS experimental watershed network is essential for understanding hydrologic processes in the United States on local, regional, and national scales. Long-term data and corresponding analyses have been published on precipitation (1938–2001) and discharge and soil loss (1938–2002) for the Riesel Watersheds [*Harmel et al*., 2003, 2006c]; however, an intensive long-term program of water quality data collection for nutrient analyses was not initiated until 2000. This manuscript presents relevant background information along with measured data and collection methodology to highlight the continued commitment to long-term data accessibility and database enhancement at the USDA-ARS Riesel Watersheds, which is a Conservation Effects Assessment Project (CEAP) Watershed Assessment site and a Long-Term Agro-ecosystem Research (LTAR) network site.

2. Background Information

2.1. History of Applied Hydrology and Water Quality Research

The Riesel Watersheds were established near Riesel, TX, USA, in 1936–1938 as the Blacklands Experimental Watershed (Figure 1). This facility, along with the North Appalachian Experimental Watershed (Coshocton, OH) and the Central Great Plains Experimental Watershed (Hastings, NE), was designed to facilitate watershed-scale research on the impacts of agricultural land management practices on soil erosion, floods, water resources, and the agricultural economy in response to the Dust Bowl [*USDA*, 1942].

A major historical contribution of the Riesel Watersheds was the measurement of dramatic reductions in soil loss observed under conservation management with practices such as terraces, grassed waterways, contour farming, and vegetated cover in highly erodible areas [*Baird*, 1948, 1950, 1964; *Baird et al*., 1970]. These

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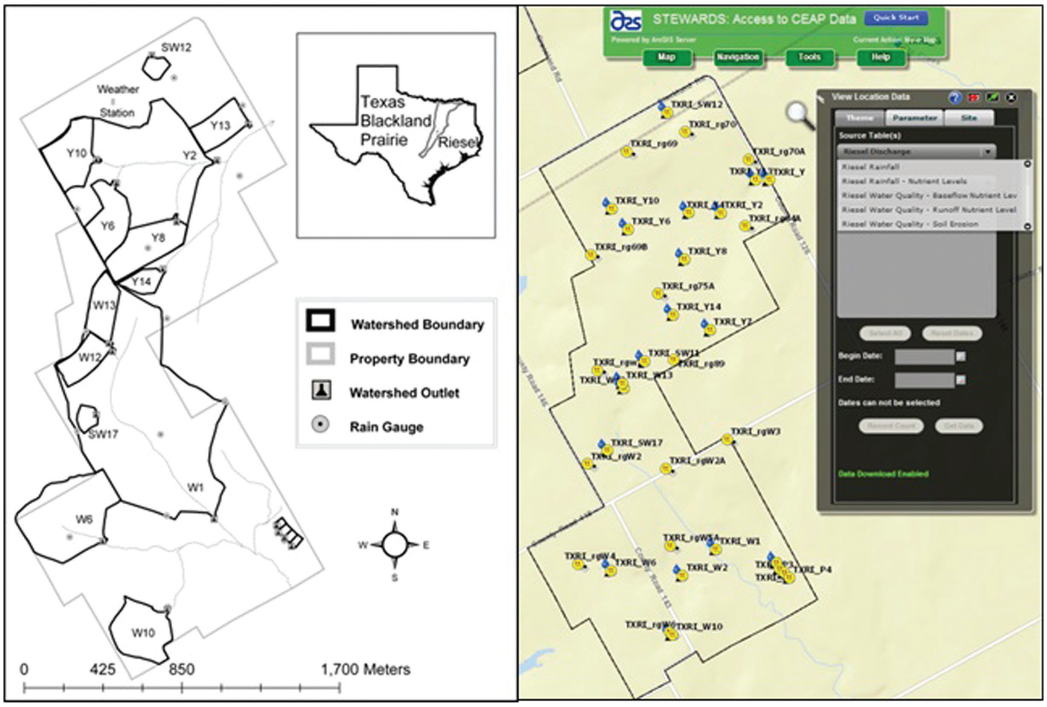

Figure 1. Active experimental watersheds and rain gauges at the USDA-ARS Riesel Watersheds.

results contributed vital information to the scientific basis of the twentieth century conservation farming revolution. Research at the Riesel Watersheds also established fundamental understanding of the agronomic and environmental effects of various agricultural practices. Improved understanding of tillage impacts on crop production and nutrient loss was developed by *Baird and Knisel* [1971], *Chichester and Richardson* [1992], and *Richardson and King* [1995]. The transport of agricultural chemicals was studied by *Swoboda et al*. [1971], *Richardson et al*. [1978], and *Bovey and Richardson* [1991] and used to justify regulatory changes and labeling of these chemicals. Similarly, the offsite transport of inorganic and organic fertilizer nutrients has been studied and has contributed to important advancements such as P Index development [e.g., *Kissel et al*., 1976; *Sharpley*, 1995; *Richardson and King*, 1995; *Harmel et al*., 2005].

Research at Riesel was also instrumental in development of the EPIC/APEX [*Williams and Sharpley*, 1989], GLEAMS [*Knisel*, 1993], and SWAT [*Arnold et al*., 1998, 2012] models, which are now applied worldwide to manage field, farm, and basin-scale water quality. Riesel data have been used to develop model routines [*Williams et al*., 1971], to calibrate and validate these models [*Arnold and Williams*, 1987], and to perform subsequent model development and evaluation [*Richardson and King*, 1995; *King et al*., 1996; *Ramanarayanan et al*., 1998; *Harmel et al*., 2000; *Green et al*., 2007].

Since its establishment, various aspects of Vertisol hydrology have been studied at the Riesel Watersheds because of its location in the Texas Blackland Prairies ecoregion [*Omernik*, 1987], which is dominated by expansive Vertisol (shrink-swell) clay soils. Unique Vertisol characteristics create considerable difficulty related to agricultural conservation practices, urban development, flood control measures, and ecological restoration. Thus, region-specific hydrologic relationships along with improved understanding of Vertisol hydrology have been established related to management impacts, temporal trends, return frequencies, water budget, drought influences, and shrink-swell processes [e.g., *Harmel et al*., 2003, 2006c; *Arnold et al*., 2005; *Allen et al*., 2005, 2011; *Amidu and Dunbar*, 2007; *Dinka et al*., 2013].

More recently, the effects of poultry litter applied as a soil amendment and nutrient source for crop and forage production have been studied at the Riesel Watersheds. This study—now the most comprehensive, long-term study of its kind in the United States—has addressed soil microbiology [*Acosta-Martínez and Harmel*, 2006], runoff water quality [*Harmel et al*., 2004, 2009, 2013, 2014; *Wagner et al*., 2012], on-farm

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economics [*Harmel et al*., 2008b], nutrient cycling [*Vadas et al*., 2007; *Harmel et al*., 2011], and natural resource modeling and assessment [*Harmel et al*., 2005; *Wang et al*., 2006; *Green et al*., 2007]. Other research at the site is evaluating: (1) the effect of agricultural conservation practices on runoff quantity and quality [*Harmel et al*., 2008a] and (2) the impacts on soil and water quality and profitability of an alternative grazing management system designed to improve soil health and sustainability.

2.2. Legacy Database

The original infrastructure at Riesel included multiple watersheds and rain gauges on property purchased by the USDA (340 ha) and on adjoining private land in the Brushy Creek watershed (1773 ha). Hydrologic, soil erosion, and climatic data have been collected continuously on selected sites since the late 1930s (Table 1), as described in detail by *Harmel et al*. [2003, 2006c, 2007, 2008a]. The Riesel Watersheds have also produced an extensive land use/land management data record dating from 1938 that provides a historical record of evolving management practices, such as tillage, planting, harvest, and cropping systems. This multifaceted database has proven extremely valuable for quantifying the impacts of changing land use/land management and climatic conditions on runoff and floods [e.g., *Baird*, 1948; *Harmel et al*., 2006c], precipitation patterns [e.g., *Harmel et al*., 2003], soil erosion [e.g., *Harmel et al*., 2006c; *Allen et al*., 2011], soil quality [e.g., *Potter et al*., 1999; *Jackson et al*., 2002; *Potter*, 2006; *Stott et al*., 2013], water quality [e.g., *Harmel et al*., 2004, 2009, 2013], and vegetation [*Derner et al*., 2011]. In addition, the only known account of soil erosion impacts of the historic 1950s drought was produced from Riesel data [*Allen et al*., 2011].

The entire legacy database and the recently added water quality data are publically available at www.ars.usda.gov/spa/hydro-data. Selected legacy data, including the water quality data, are available from the Sustaining the Earth's Watersheds, Agricultural Research Data System (STEWARDS) database at www.nrrig.mwa.ars.usda.gov/stewards/stewards.html [*Steiner et al*., 2008, 2009]. The metadata associated with measured data from the Riesel Watersheds are available in the STEWARDS database and include: site ID, date/time, units, and parameter description; field and laboratory methods; site description including latitude/longitude, site history, and instrumentation present; detailed watershed description and web link; and detailed GIS metadata. Figure 2 illustrates a portion of the metadata available in the site_descriptions and ARS_methods tables in the database tables for Riesel in STEWARDS.

2.3. Precipitation and Runoff Data Collection Methodology

Daily and subdaily precipitation and runoff data have been collected at Riesel since 1938 [*Harmel et al*., 2007]. Historically, rainfall data were collected by various types of weighing rain gauges in conjunction with chart or electronic data recorder and a standard raingauge for backup and calibration. Currently, 15 rain gauges are in operation within 340 ha (Figure 1), which makes Riesel one of the denser rain gauge networks in the world. Electronic tipping-bucket gauges were installed in the late 1990s to record rain data on 10 min intervals. A standard rain gauge at each site is used as a backup and calibration device. Each of these stations is instrumented with a Campbell Scientific datalogger as part of a radiotelemetry network.

Runoff data collection began in 1938 and continued for various periods in 40 watersheds (0.1–2372 ha). These stations were designed to capture surface runoff and as such do not directly measure subsurface flows; however, the lateral subsurface return flow (base flow) emerging upstream of these stations is quantified [*Allen et al*., 2005]. Historically, float gauges were the primary stage measurement devices. Currently, each of these structures is instrumented with a shaft encoder as the primary water level (stage) recording device and with a float gauge chart recorder and a bubbler level recorder as backup devices. From the continuous stage records, flow rates are calculated with known stage-discharge relationships.

2.4. Water Quality Data Collection Methodology

In the early years, soil erosion was the water quality issue of concern at the Riesel Watersheds; however, nutrient and chemical data were collected periodically [e.g., *Richardson et al*., 1978; *Richardson and King*, 1995]. Prior to the 1970s, on-call personnel collected storm runoff water samples by hand at watershed sites [*Knisel and Baird*, 1970] or with a flow-proportional sampler at field-scale sites. From the 1970s to 2001, storm runoff water samples were taken with Chickasha samplers [*Allen et al*., 1976] with a variable, time-weighted sampling scheme designed specifically for each watershed to adequately capture short and long duration runoff events. These automated, mechanical samplers were turned on with float-activated water level switches.

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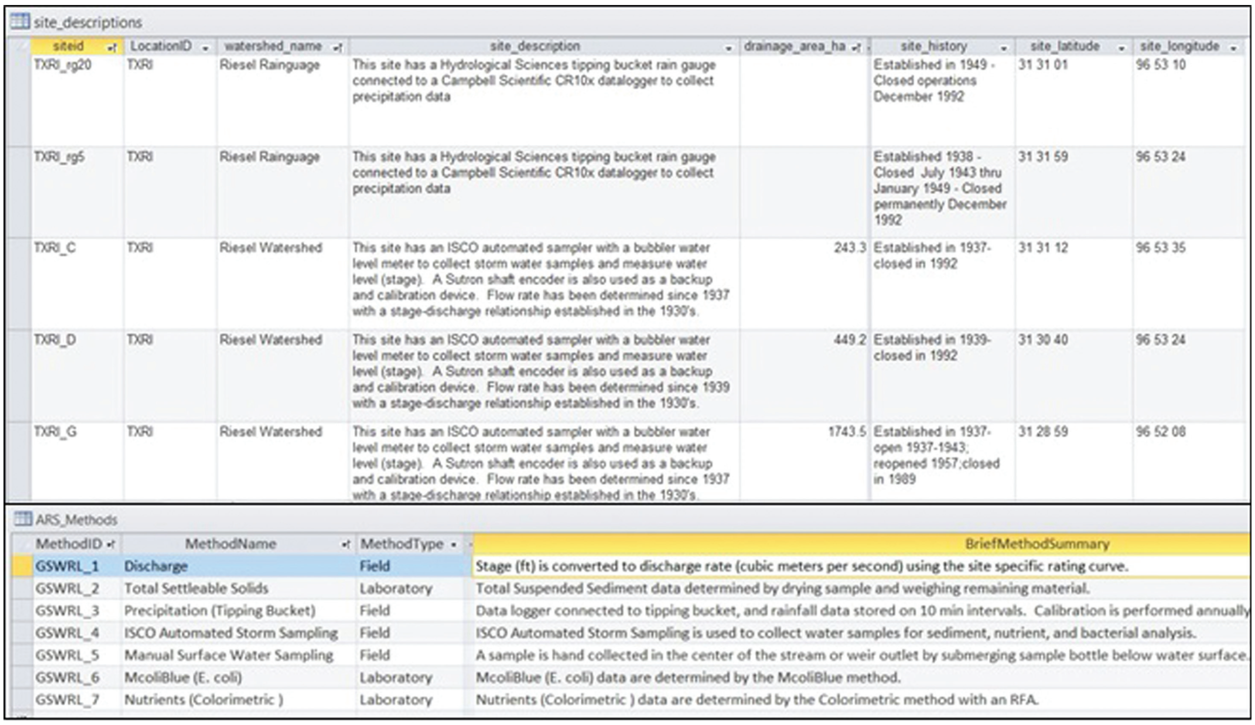
Table 1. Summary of Publically Available Legacy Data and Recently Added Water Quality Data for the USDA-ARS Riesel Watersheds Through 2012[a]

Data Type	Record	Record Length (year)	Number of Sites	Site-Years Subdaily Data	Site-Years Daily Data	Number of Sites (≥50 year)
Discharge	1938–2012	75	40	1384	1392	10
Sediment loss (erosion)	1939–2012	74	22	479	658	3
Lateral subsurface flow	2001–2012	12	1		12	0
Land management	1944–2012	69	126			10
Precipitation	1938–2012	75	57	1470	1474	13
Air temperature	1940–2012	73	1	9	73	1
Soil temperature	1997–2012	16	1	9	16	0
Relative humidity	1998–2012	15	1	9	15	0
Evaporation	1944–2012	69	1		69	1
Radiation	1990–2012	23	1	9	23	0
Data Type	**Record**	**Record Length (year)**	**# Sites**	**Sampling Events**		
NO_3+NO_2-N, NH_4-N, PO_4-P (storm runoff)	2000–2012	12	13	1056		
NO_3+NO_2-N, NH_4-N, PO_4-P (base flow)	2004–2012	9	13	1345		
NO_3+NO_2-N, NH_4-N, PO_4-P (rainfall)	2007–2012	6	1	157		

[a]Data collection continues to the current day, and the databases will be updated periodically with these data.

Electronic automated ISCO 6700 samplers (Teledyne ISCO, Inc., Lincoln, NE) were installed in 2001 and except for rare cases sampled all storm runoff events with >1.32 mm of runoff from all watersheds. These automated samplers initiate collection when activated by a bubbler flow level recorder. Once initiated these samplers collect frequent flow-interval (1.32 mm volumetric depth) samples and composite them into a single 16 L bottle, as discussed in *Harmel et al*. [2006a, 2006b]. Storm runoff and water quality data are currently collected from: (1) 10 stations at the outlets of small, single land use watersheds (1.2–8.4 ha) to measure "edge of field" processes on remnant prairie, improved pasture, and cultivated cropland, and at (2) 3 stations at the outlet of larger mixed land use watersheds (17.1–71 ha) to evaluate integrated processes (Table 2). Land use on these watersheds represents common agricultural practices in the region, including cattle production on improved pasture and rangeland, and corn, wheat, grain sorghum, and oat production



site_descriptions

siteid	LocationID	watershed_name	site_description	drainage_area_ha	site_history	site_latitude	site_longitude
TXRI_rg20	TXRI	Riesel Rainguage	This site has a Hydrological Sciences tipping bucket rain gauge connected to a Campbell Scientific CR10x datalogger to collect precipitation data		Established in 1949 - Closed operations December 1992	31 31 01	96 53 10
TXRI_rg5	TXRI	Riesel Rainguage	This site has a Hydrological Sciences tipping bucket rain gauge connected to a Campbell Scientific CR10x datalogger to collect precipitation data		Established 1938 - Closed July 1943 thru January 1949 - Closed permanently December 1992	31 31 59	96 53 24
TXRI_C	TXRI	Riesel Watershed	This site has an ISCO automated sampler with a bubbler water level meter to collect storm water samples and measure water level (stage). A Sutron shaft encoder is also used as a backup and calibration device. Flow rate has been determined since 1937 with a stage-discharge relationship established in the 1930's.	243.3	Established in 1937- closed in 1992	31 31 12	96 53 35
TXRI_D	TXRI	Riesel Watershed	This site has an ISCO automated sampler with a bubbler water level meter to collect storm water samples and measure water level (stage). A Sutron shaft encoder is also used as a backup and calibration device. Flow rate has been determined since 1939 with a stage-discharge relationship established in the 1930's.	449.2	Established in 1939- closed in 1992	31 30 40	96 53 24
TXRI_G	TXRI	Riesel Watershed	This site has an ISCO automated sampler with a bubbler water level meter to collect storm water samples and measure water level (stage). A Sutron shaft encoder is also used as a backup and calibration device. Flow rate has been determined since 1937 with a stage-discharge relationship established in the 1930's.	1743.5	Established in 1937- open 1937-1943; reopened 1957;closed in 1989	31 28 59	96 52 08

ARS_Methods

MethodID	MethodName	MethodType	BriefMethodSummary
GSWRL_1	Discharge	Field	Stage (ft) is converted to discharge rate (cubic meters per second) using the site specific rating curve.
GSWRL_2	Total Settleable Solids	Laboratory	Total Suspended Sediment data determined by drying sample and weighing remaining material.
GSWRL_3	Precipitation (Tipping Bucket)	Field	Data logger connected to tipping bucket, and rainfall data stored on 10 min intervals. Calibration is performed annually
GSWRL_4	ISCO Automated Storm Sampling	Field	ISCO Automated Storm Sampling is used to collect water samples for sediment, nutrient, and bacterial analysis.
GSWRL_5	Manual Surface Water Sampling	Field	A sample is hand collected in the center of the stream or weir outlet by submerging sample bottle below water surface.
GSWRL_6	McoliBlue (E. coli)	Laboratory	McoliBlue (E. coli) data are determined by the McoliBlue method.
GSWRL_7	Nutrients (Colorimetric)	Laboratory	Nutrients (Colorimetric) data are determined by the Colorimetric method with an RFA.

Figure 2. Selected site description and methods metadata summaries for the Riesel Watersheds.

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Table 2. Descriptive Information for Actively Monitored Watersheds at the Riesel Watersheds

Name	Area (ha)	Land Use	Name	Area (ha)	Land Use
Y6	6.6	Cultivated, commercial fertilizer	SW12	1.2	Native prairie, hayed or shredded
Y13	4.6	Cultivated, poultry litter (4.5 Mg/ha annually 2001–2012) and supplemental N	SW17	1.2	Improved pasture, grazed (2000–2010), poultry litter (6.7 Mg/ha 2011–2012)
Y10	7.5	Cultivated, poultry litter (6.7 Mg/ha annually 2001–2012) and supplemental N	W10	8.0	Improved pasture, grazed (2008–2012), poultry litter (6.7 Mg/ha 2001–2007)
W12	4.0	Cultivated, poultry litter (9.0 Mg/ha annually 2001–2012) and supplemental N	Y14	2.3	Improved pasture, poultry litter (13.4 Mg/ha 2001–2007, 6.7 Mg/ha 2011–2012)
W13	4.6	Cultivated, poultry litter (11.2 Mg/ha annually 2001–2012) and supplemental N	W6	17	Cultivated (73%), improved pasture (0%), rangeland (27%)
Y8	8.4	Cultivated, poultry litter (13.4 Mg/ha annually 2001–2012) and supplemental N	Y2	53	Cultivated (56%), improved pasture (4%), rangeland (40%)
			W1	71	Cultivated (30%), improved pasture (32%), rangeland (38%)

under a wide range of management operations. In addition, a remnant (native) tallgrass prairie watershed is maintained and sampled to provide background (reference) soil quality and water quality data.

Later, water quality sampling began for base flow (2004) and precipitation (2007). Base flow water quality samples were collected manually from all sites at the end of storm events when storm runoff samples were retrieved from the field and each following week as long as flow persisted. Nutrient concentrations in rainfall were only determined for one gauge, rgW9, and more specifically the standard gauge at the site (precipitation depth was measured for each of the 15 rain gauges). Nutrient concentrations were not determined for all precipitation events but were in general determined for events >6 mm. Precipitation depth data are reported on a daily basis (midnight-to-midnight), as this format is most useful in typical applications; however, nutrient concentrations are reported for the date of sample retrieval from the field and represent the entire precipitation event.

All water samples collected since 2000 and included in the STEWARDS database were handled and processed with methods in an approved EPA Quality Assurance Project Plan. Samples were retrieved from the field following each sampling event and were refrigerated (unfiltered at 4°C) prior to analysis for dissolved NO_3+NO_2-N, NH_4-N, and PO_4-P concentrations using colorimetric methods [*Technicon Industrial Systems*, 1973a, 1973b] with a Technicon Autoanalyzer IIC (Bran-Luebbe, Roselle, IL) or a Flow IV Rapid Flow Analyzer (O.I. Analytical, College Station, TX). Constituent concentrations are reported as event mean concentrations (EMCs) for storm events and as discrete concentrations for individual base flow samples.

Table 3. Median Measured Nutrient Concentrations in Storm Runoff Events (2000–2012), Base Flow (2004–2012), and Rainfall (2007–2012)

		Storm Runoff				Base Flow		
Watershed	n	NO_3+NO_2-N (mg/L)	NH_4-N (mg/L)	PO_4-P (mg/L)	n	NO_3+NO_2-N (mg/L)	NH_4-N (mg/L)	PO_4-P (mg/L)
Y6	76	1.090	0.050	0.155	124	2.059	0.110	0.174
Y13	109	0.970	0.070	0.360	118	0.323	0.129	0.303
Y10	99	1.410	0.090	0.490	79	0.175	0.127	0.475
W12	80	1.090	0.075	0.395	70	0.340	0.136	0.433
W13	84	1.020	0.080	0.595	63	0.795	0.138	0.809
Y8	83	1.350	0.110	0.650	60	1.391	0.130	0.415
SW12	88	0.040	0.050	0.085	62	0.352	0.085	0.095
SW17	73	0.060	0.060	0.150	51	0.228	0.106	0.178
W10	53	0.100	0.080	0.770	58	0.121	0.120	0.618
Y14	45	0.110	0.110	1.190	64	0.084	0.136	1.321
W6	78	0.560	0.115	0.160	169	0.757	0.134	0.184
Y2	94	0.965	0.110	0.345	166	0.131	0.118	0.340
W1	94	0.380	0.085	0.220	261	0.136	0.121	0.167
		Rainfall						
Rain Gauge	n	NO_3+NO_2-N (mg/L)	NH_4-N (mg/L)	PO_4-P (mg/L)				
rgW9	157	0.279	0.487	0.162				

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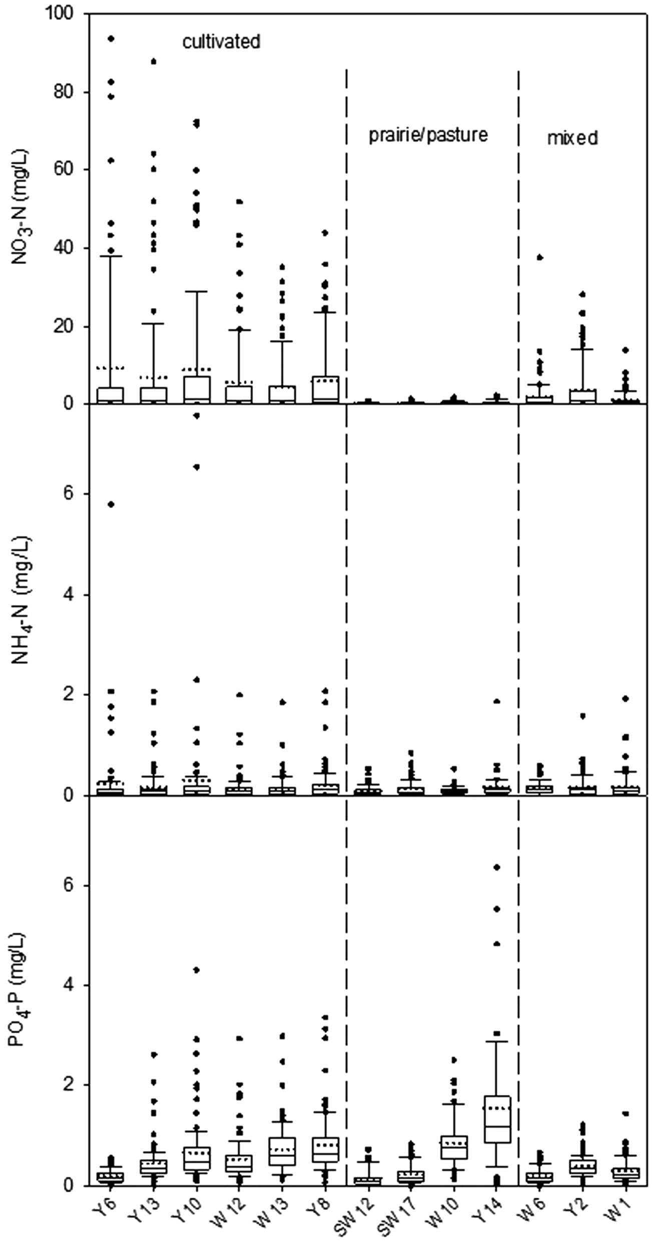

Figure 3. Event mean concentrations for cultivated, prairie/pasture, and mixed land uses. Note that within cultivated and prairie/pasture land use categories, poultry litter application rate increased from left to right.

3. Data Analyses

Summary data for nutrient concentrations measured in storm runoff events (2000–2012), base flow (2004–2012), and rainfall (2007–2012) are presented in Table 3. These data represent 1056 storm runoff events, 1345 base flow sampling events, and 157 rainfall events. Analysis of rainfall samples indicated that nutrient concentrations in rainfall at times exceeded storm runoff and base flow concentrations, especially for NH_4-N. Several cursory analyses are also presented as examples of the types of analyses possible with such long-term water quality data from a small nested watershed network.

3.1. Effects of Land Use and Fertilizer Type/Rate on Nutrient Runoff

In these example analyses, nutrient concentrations were compared for different land use types including cultivated with commercial fertilizer and/or poultry litter and supplemental N, improved pasture with grazing or litter application, native (remnant) prairie, and mixed land use. Box-and-whisker plots clearly show land use and fertilizer type/rate effects on NO_3+NO_2-N and PO_4-P concentrations but less effect on NH_4-N (Figure 3). On cultivated watersheds, the magnitude of extreme NO_3+NO_2-N concentrations decreased as poultry litter rate increased with corresponding decrease in supplemental N application, which is more susceptible to runoff than organic N in litter. However, no significant differences in median NO_3+NO_2-N concentrations were determined ($\alpha = 0.05$). Increasing litter application rates produced increasing PO_4-P concentrations (Table 3 and Figure 3), and many significant differences in median concentrations were detected between litter rate treatments with Mann-Whitney test. See *Harmel et al.* [2004, 2009] for a detailed description of the water quality impacts of poultry litter application. The pasture watersheds, with and without litter application, produced little NO_3+NO_2-N in storm runoff, and median concentrations were significantly different (lower) than for cultivated and mixed land use watersheds. In contrast, NH_4-N concentrations were similar among all land uses. Note the three extreme outlier NH_4-N concentrations measured from Y6 and Y10, the cause of which is unknown.

When the native (remnant) prairie (SW12) and the grazed improved (SW17) pasture were compared several interesting results became apparent. As shown in Table 2, SW12 received no anthropogenic macronutrient application, and SW17 was rotationally grazed and thus received deposited manure and poultry litter but only in two years.

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Although grazing and limited litter application did not seem to affect runoff NO_3+NO_2-N or NH_4-N concentrations, it did lead to statistically significant increases in PO_4-P concentrations in storm runoff and base flow. It is also interesting to note that the native prairie reference site did produce low but not negligible nutrient concentrations in storm runoff and higher concentrations yet in base flow (i.e., lateral subsurface return flow).

Based on these cursory analyses comparing nutrient concentrations in storm runoff, base flow, and rainfall, numerous possibilities for more rigorous analyses became readily apparent, including:

1. Mechanisms and magnitudes of nutrient losses through surface runoff and base flow (lateral subsurface return flow), especially as related to the debate as to the extent to which P constituents move in and through soils, especially those with high clay contents.
2. Annual nutrient contribution of rainfall in relation to crop nutrient budgets and nutrient cycling in native systems.
3. Temporal trends in nutrients losses and possible relationships with soil test P, rainfall amount and timing, grazing presence at time of rainfall/runoff, and global change.

4. Conclusions

The massive legacy 75 year database for the USDA-ARS Riesel Watersheds has for more than a decade provided valuable data on discharge, sediment loss, land management, and meteorological data (www.ars.usda.gov/spa/hydro-data). Recently, water quality data measured from more than 1000 storm runoff, 1300 base flow, and 157 precipitation sampling events through 2012 have been added to supplement the existing data. These data along with much of the legacy data and associated metadata have also been added to the STEWARDS database (www.nrrig.mwa.ars.usda.gov/stewards/stewards.html). This manuscript presents relevant background information on these data, summarizes the data collection and sample analysis methodology, and presents the measured data along with cursory analyses. The objective of this "Data and Analysis" note is to convey the commitment of the USDA-ARS Riesel Watersheds to long-term data accessibility and database enhancement to support water quality and water supply research.

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