A Tool for Estimating Best Management Practice Effectiveness in Arkansas

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Abstract. *Best management practices (BMPs) are being implemented across the United States to combat water pollution by nutrient and sediment often with little knowledge about the actual effectiveness of the BMPs. Previously, most BMP studies have focused on determining the effectiveness of a single BMP; often the knowledge acquired from these individual studies has been applicable only to the study site. However, these studies can be compiled over a wide range of site conditions and used collectively to obtain reliable estimates of BMP effectiveness. In this regard, a BMP tool was developed for use in Arkansas. The underlying database contains over 120 references and includes 163 agricultural BMPs grouped into 14 classes and 147 urban BMPs grouped into 8 classes. This tool will facilitate effectiveness-based BMP selection for agricultural and urban applications by providing BMP effectiveness estimates based on site characteristics. Because of the State's rapid urban development and heavy focus on agriculture, this tool will find use among watershed planners and local and state agencies alike. The tool can be used as a standalone application or can be linked with other applications. This tool can also be easily expanded to include data from other areas beyond Arkansas and the surrounding region or be used as a template for other BMP tools. This tool, along with a users' manual, will be available for no charge to any interested user.*

Keywords. *Best Management Practices, BMP effectiveness, BMP tool.*

Fifteen percent of streams in Arkansas do not support at least one of their designated uses (ADEQ, 2002). The Arkansas Department of Environmental Quality (ADEQ) lists agriculture as the major source of impairment impacting 1230 km (764 miles, 9.7%) of Arkansas streams; an additional 314 km (195 miles, 2.5%) are impacted by industry, municipalities, and road construction or maintenance (ADEQ, 2002). Over 5.9 million hectares (14.5 million acres, 43.5%) of Arkansas land are in agricultural production (FedStats, 2006; USDA National Agricultural Statistics Service, 2006); and 2% of Arkansas has urban land cover (Gorham, 1999).

Among other pollutants, nutrients and sediment in water bodies are the result of agriculture and urban development (ADEQ, 2002). Nutrients, such as nitrogen (N) and phosphorous (P), are required in a healthy aquatic environment; however, excessive amounts of N or P can deteriorate the health of aquatic bodies by encouraging rapid algal growt or eutrophication (USEPA, 2001). Eutrophication impairs water for recreation, navigation, fishing, and industrial purposes (Khan and Ansari, 2005); it can cause taste and odor problems, and affect human and animal health (Martin and Cooke, 1994; Mostaghimi et al., 1997; Sharpley et al., 2000; Sharpley et al., 2003). Sediments can transport nutrients, metals, pesticides, and toxic organics into water bodies when topsoil is carried away during storm events (Novotny and Olem, 1994; USEPA, 2005). Sediments degrade water quality, inhibit aquatic life, fill in culverts, lakes, and streambeds, and can make navigation difficult (Cooper and Lipe, 1992).

Best management practices (BMPs) are designed to reduce the negative environmental consequences of land use while maintaining or enhancing the productivity of the land (Heatwole et al., 1991; Kincheloe, 1994; Mostaghimi et al., 1997). Farmers can typically obtain advice on BMP selection and implementation to attain water quality improvements from the Natural Resources Conservation Service (NRCS), which catalogs over 160 agricultural BMPs and almost 150 urban BMPs (USDA-NRCS, 2006a; 2006b; 2006c). Because of the high cost involved and a significant time lag before BMP effects can be realized, it is critical that potential BMP effectiveness (defined here as the percentage by which nutrient or sediment loss is reduced) be determined before implementation. BMP effectiveness, as reported in the literature, varies considerably, making it difficult to have conclusive determinations of effectiveness for the various BMPs. Despite a plentiful number of studies to this effect, results presented have at times been conflicting. For example, based on the literature, the effectiveness of animal waste systems in reducing total phosphorus can be as low as about 25% (Mosthagimi et al., 1997) or as high as 90% (Chesapeake Bay Program, 1987). Similar observations can be made for other BMPs when the literature is examined.

Several factors, for example, site conditions, agricultural activity, BMP scale, and others, can influence BMP effectiveness. Because of the site specificity of BMPs (USEPA, 1993; Kincheloe, 1994), when considered individually, BMP effectiveness as reported in individual

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studies may only be applicable to the site where the BMP was applied. However, when results from these individual studies are compiled they represent effectiveness values over a wide range of conditions. This allows the combined data to be used to provide estimates of BMP effectiveness through analyses based on the most commonly available affecting factors (Gitau et al., 2005). Rather than establish new data, we sought to make sense out of results of past studies through accumulation and analyses of existing data and, subsequently, present these data collectively such that they can be used more effectively in BMP decision making. The objective of this study was, thus, to quantify BMP effectiveness based on studies reported in the literature, and to develop a user friendly tool which provides site-specific estimates of BMP effectiveness, with a focus on site conditions and management interventions in Arkansas. This study, thus, covers BMPs that are applicable to the primary economic activities in the state, such as poultry, rice, and cattle, among others.

Study Considerations

This study was built on the BMP tool and underlying database developed by Gitau et al. (2005). As such, both tools have many of the same specifications. Many of the original features were left intact. However, some structural changes were necessary to expand the database [which was previously focused on particulate P (PP), dissolved P (DP), and total P (TP)] to include nitrate (NO_3-N), ammonium (NH_4-N), total N (TN), and total sediment (TSed) effectiveness. In addition, the database was expanded to accommodate an urban BMP database. The data were also made more accessible by simplifying relationships between the various data elements and providing additional data display forms.

The selection of literature materials was a critical process in this study, as the literature provided the only data used. It is, therefore, integral to define the key components of the literature review. For this study, articles were selected following guidelines outlined in Gitau et al. (2005). Studies had to comprise BMP effectiveness research and pertain to nutrient or sediment reductions. The references included in the database had to include individual BMP effectiveness information. Many studies reported the reductions from two or more combined BMPs. In such instances, an assessment of individual BMP effectiveness could not be performed since results would be confounded by the cumulative effects of the multiple BMPs. Effectiveness data from such studies were, thus, excluded from the database. Similarly, effectiveness studies addressing a change in BMPs during the study period were also excluded as these would not be reflective of a change from the no-BMP case. Citations for these studies were, however, included in the database so as to be available to users interested in the associated data.

Site soils and slopes, were especially important for this database because of their influence on BMP effectiveness (Baker and Johnson, 1983, Gitau et al., 2005). For this study, soils were classified according to hydrologic soil group (HSG) as defined by the TR-55 report (USDA-NRCS, 1986). Slopes were categorized in ranges (0-3%, 3-8%, 8-15%, 15-25%, 25-50% and +50%) as in Gitau et al. (2005).

Agricultural BMPs included in the tool were defined following the National Conservation Practice Standards (USDA-NRCS, 2006a), which, at the time of this study, had a list of 163 agricultural BMPs. To facilitate statistical analyses on the data collected, BMPs were organized as shown in table 1. Agricultural BMPs were organized into 14 classes based on their mechanism of operation, these being alternative water supply, animal-waste systems, barnyard-runoff management, conservation tillage, contour-strip crop, crop rotation, drainage/irrigation systems, filter strips, nutrient management plan, riparian forest buffers, rotational grazing, stream fencing, terraces, and wetlands. These classes were further grouped into six broader categories: Barn Yard Management, Erosion Control, Filter Strips, Livestock/Manure Management, Nutrient Management, and Water Management. Filter strips could possibly fit into three different categories: erosion control, nutrient management, or barnyard runoff management. For example, barnyard runoff management practices are distinctly different from the other categories, and unlike the others, focus on the prevention of pollution from barnyards, in which case, filter strips serve as treatment for barnyard runoff. For this reason, a separate category was established for filter strips.

The urban database included eight classes (table 1) based on NRCS classifications for urban BMPs (USDA-NRCS, 2006b; 2006c). Classes included were: construction site impact reduction, source reduction, erosion control, water volume management, water quality treatment and constituent entrapment, in-stream habitat restoration, in-stream flow restoration, and stream bank protection and restoration. For urban BMPs, the NRCS defines 89 BMPs for water runoff management (USDA-NRCS, 2006b) and details 49 urban BMPs for stream protection and restoration (USDA-NRCS, 2006c). For both agricultural and urban BMPs, data showing up as outliers in the assembled datasets were not excluded from this study so as not to preclude extreme site or study conditions (Gitau et al., 2005).

This study was focused on the state of Arkansas, thus data collection efforts were first focused on studies conducted within the state. However, data available for Arkansas were insufficient for the intended analyses, thus, data were also obtained from the greater Southeastern U.S. region (Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia) and states adjacent to Arkansas (Missouri, Oklahoma, and Texas). While much of the data were from the greater southeastern region, we focused our search on data that would be relevant to site conditions and management interventions in Arkansas. The broad database, however, allows the tool to be applicable to the southeastern region, as discussed in latter sections of this article.

With the exception of state or federal government agency reports, materials that did not report study location were not included. Studies by state agencies were assumed to have been performed within that state, while federal studies were included based on the state the study was performed in. Federal studies not reporting a study location were recorded for reference purposes only.

Methods and Materials

Data Collection

Many articles were scrutinized for inclusion in the database; those that met the aforementioned selection criteria were entered into the database. Books, journal articles,

Table 1. Best Management Practice (BMP) class descriptions as used in the Arkansas database and tool.

BMP Category	BMP Class	Description
		Agricultural BMPs
Barn yard management	Barn yard runoff management	Exclusion of clean water runoff from the barnyard and disposal of the remaining barnyard runoff in a way that minimizes its pollution potential.
Erosion control	Conservation tillage	Any tillage and planting system that leaves a minimum of 30% of the soil surface covered with plant residue after the tillage or planting operation (reduced till, no till etc).
	Contour strip crop	Alternating strips of a row crop with a small grain or forage, planted on the contour or across the slope.
	Cover crops	Crops used to cover the ground to prevent erosion, especially in winter months.
	Crop rotation	A planned sequence of annual and/or perennial crops
	Terraces and diversions	A combination of ridges and channels constructed across the slope to disrupt the transport of pollutants by storing water and allowing for sediment deposition and water infiltration.
Filter strips	Filter strips	Strips of perennial grasses, planted across the slope, established adjacent to areas of high pollutant potential and managed for pollutant removal by overland flow.
Livestock/manure management	Alternative water supply	Source of water (other than streams) for livestock to reduce source of pollutants in streams by reducing the amount of time spent by animals in streams.
	Animal waste systems	Systems designed for the proper collection, transportation and storage of livestock manure and other animal waste.
	Rotational grazing	Controlled harvest of vegetation with grazing or browsing animals.
	Stream fencing	Construction of a barrier along stream corridors that exclude livestock from direct access to streams reducing the source of pollutants.
Nutrient management	Nutrient management plan	Managing the rate, timing and placement of fertilizers, manures and other nutrient sources to encourage maximum nutrient recycling and minimize nutrient runoff and leaching.
Nutrient management	Riparian forest buffers	Areas of trees, shrubs and grasses located adjacent to ponds, lakes, and streams that filter out pollutants from runoff, as well as providing shade for fish and wildlife.
	Wetland	Constructed or natural wetlands used to treat agricultural waste waters through biological processes.
Water management	Drainage systems	Systems for drainage water management, consisting of tile drains and drainage ditches.
	Irrigation water management	Systems designed to transport and distribute water for irrigation purposes.
		Urban BMPs
Urban BMPs	Construction site impact reduction	Temporary practices to lessen the impact from construction sites.
	Erosion control	Practices to control or reduce erosion from runoff water.
	In-stream flow restoration	Restoration practices that are conducted in-stream and change the pathway of a stream.
	In-stream habitat restoration	Practices to restore and/or enhance stream habitats that have been marred due to human activity.
	Source reduction	Practices to reduce the source of the pollutant.
	Stream bank protection and restoration	Practices to prevent streambank erosion or restore function to a damaged stream body.
	Water quality treatment	Treatment of polluted runoff water before it reaches streams.
	Water volume management	Practices that are designed to reduce or handle the volume of runoff water.

government documents, conference papers, web material, and other sources such as microfilms and book chapters, both published and unpublished, were used to obtain data for this study. Published studies are generally deemed as having more reliable data than do unpublished ones, thus the tendency toward including only published studies. Existing literature on accumulation and analyses of scientific data (Light and Smith, 1971; Hunter et al., 1982; Light and Pillemer, 1984; Bland, 2000), however, cautions against exclusion of unpublished materials as studies are often preferentially published based on the significance of differences obtained. Excluding unpublished materials may, thus, result in a bias. In keeping with recommendations from this literature, our database contains both published and unpublished material.

In this study, materials considered as published included journal articles, microfilm, book chapters, and government documents. The term "unpublished" referred to studies that have been or are being carried out, but for some reason, associated articles have not yet been accepted for publication. Web materials comprised material that was obtained directly from web sites and that has not been published in another form elsewhere. Web materials were also considered unpublished. Based on these definitions, this study comprised 82% (105 out of 128) published material, and 18% unpublished.

The BMP effectiveness information was derived from the articles depending on data presentation, which differed among articles. Many studies reported paired watersheds, field plots, or box plots, with effectiveness being the percent difference between a control watershed or plot and watershed or plot where a BMP was applied. Some studies used an influent/effluent approach, where effectiveness was considered as the percent change in nutrient or sediment from before the stream entered a BMP area to when it left the BMP area. Others reported the water quality values for pre- and post-BMP implementation periods; in such cases, effectiveness was calculated by taking a percent difference of an average water quality value before and after the BMP was implemented. Thus, depending on how the data were presented in the literature, BMP effectiveness values were either obtained directly or determined from the data presented.

Study and site characteristics from each article were also recorded; these were used in the determination of BMP effectiveness for site specificity. Soil and slope characteristics were not included for the urban database because urban studies did not usually report them. The scale of the study was included as a relative reference with data being grouped based upon natural breaks in the distribution of study sizes. Nine different scales were used: lab plot, field plot, farm, field, hill slope, field size watershed, small watershed, large watershed, or not applicable/not given. Study methods were grouped into eight categories: field plot, field, paired watersheds, modeling, literature review, lab study, other, or not applicable/not given. Other descriptive information, such as agricultural activity and method description, was also included in the database. All literature sources included in the database were fully cited, including a web address when available.

After all the available information had been added to the database, a thorough check was performed to ensure accuracy. Data, as input in the database, was examined against its original literature source. Discrepancies, if found, were corrected as necessary.

Database Structure

A Microsoft Access database in which to organize and manage BMP data was constructed based on the pre-existing tool's database. The original database comprised of four main tables: a primary table which housed all of the effectiveness data for nutrient and sediment reduction, and site and study characteristics, a BMP attributes table which defined individual BMPs as they were used in the database and gave the NRCS conservation code number, a references table which held a full citation of each reference used in the database, and a lookup table which contained data that were frequently used in other tables. The latter three tables were designed to support the primary table. The original database also contained a concentrations table, although its constituent data were not used in analyses.

The Arkansas database took the original tables and reconfigured them for the new data requirements. Table relationships were rearranged to improve data flow. Table structure was also expanded to accommodate N and sediment data. The new database comprises two components, one for agricultural BMPs and the other for urban BMPs. The structure of the primary table (now called Effectiveness Table), BMP Attributes, and Concentrations tables were copied to make similar tables for urban BMP data; consequently there are two Effectiveness, BMP Attributes, and Concentrations tables, one for agricultural data and one for urban data. Figure 1 shows the database tables and illustrates the linkages used in the databases.

Quantitative and qualitative NO_3-N, NH_4-N, TN, and TSed data required additional fields in the Effectiveness tables. An existing field – study location – was changed to accommodate U.S. states (rather than regions); a detailed location field was also added to give more specific information on the location of the study such as: Arkansas Delta, Tennessee River Valley, or Georgia Coastal Plain. Soils and slopes fields for the urban data were removed from the urban effectiveness table and were replaced by percent impervious area and drainage area since these are reported more frequently in and are more applicable to urban BMP studies.

The agricultural attributes table contains 192 agricultural BMPs, of which 163 are as defined by the NRCS (see the Study Considerations section). The remaining BMPs were found in the literature; with some of these BMPs having more than one method of observance. Each additional method was

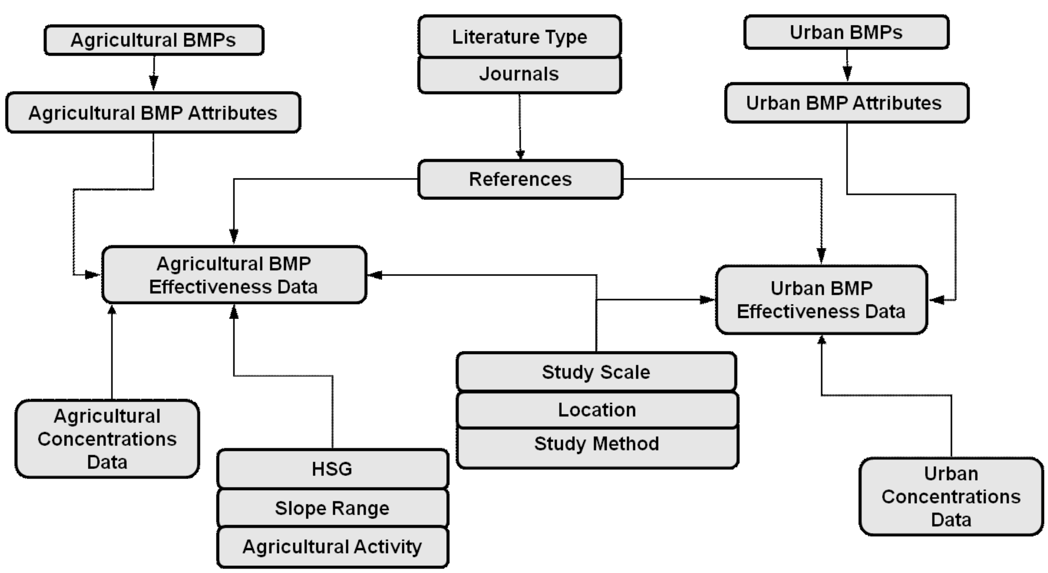

Figure 1. Schematic of table, contents and relationships in the Arkansas BMP database (HSG – Hydrologic Soil Group).

also entered into the database to facilitate searching for specific BMPs. For instance, NRCS code 329 identifies the practices of Residue Management as no-till, strip till, and direct seed. No-till, strip till, and direct seed were entered as individual BMPs in the database, but all having the NRCS code of 329. In such cases, the effectiveness was recorded for each BMP, not the NRCS code.

The effectiveness of some BMPs can be affected by their physical characteristics. It was, thus, necessary to identify these physical properties when documenting effectiveness. Such BMPs were recorded in the BMP Attributes tables multiple times for each different physical property found in the literature. For example, a vegetative filter strip (NRCS conservation practice code 393) with a filtering width of 2 m will have a different effectiveness than a vegetative filter strip of 15 m (Chaubey et al., 1995). Thereby the data for a 2-m wide vegetative filter strip would be documented as a "Vegetative Filter Strip (2 m)" and a 15-m strip as "Vegetative Filter Strip (15 m)."

In the urban database, the attributes table had a total of 147 urban BMPs coming from the definitions set by the NRCS (see the Study Considerations section) and from the literature. Additionally, definitions for each BMP were input in both BMP Attributes tables to aid database users in BMP selection.

The references table was designed as a shared table between the agricultural and urban databases. This table received only minor alterations in structure from the original references table. A field was added to distinguish between the agricultural and urban data. Another two fields, "Issue number" and "Chapter number," were included to separate them from the previous fields in which volume and Issue, and page and chapter numbers had been combined. Separating these entries simplified the process of entering and searching data. An "Electronic Address" field was also added to incorporate BMP data available online. Citations in the References table were linked to their respective data sets in the Effectiveness tables via a field called "short name." This is an abbreviation of the authors' names (e.g. Chaubey et al., 1995). This relationship is shown in figure 2; the two fields are linked as a one-to-many relationship (one entry in the references table to many entries in the effectiveness table).

In the previous database, reported concentrations data were not used in analyses after input. This database expanded the Concentrations tables to accommodate additional N and sediment data for both agricultural and urban databases and allows for display of these data through the use of searching forms.

Data from the original lookup table were divided and restructured into several, smaller lookup tables. The data in the smaller tables are directly linked to fields in the main tables. Organizing these data into smaller tables increased query processing speed and reduced data loss during querying, while ensuring referential integrity because of the improved table relationships.

BMP Tool

A BMP tool was designed to run upon the developed database. The tool provides (calculates and displays)

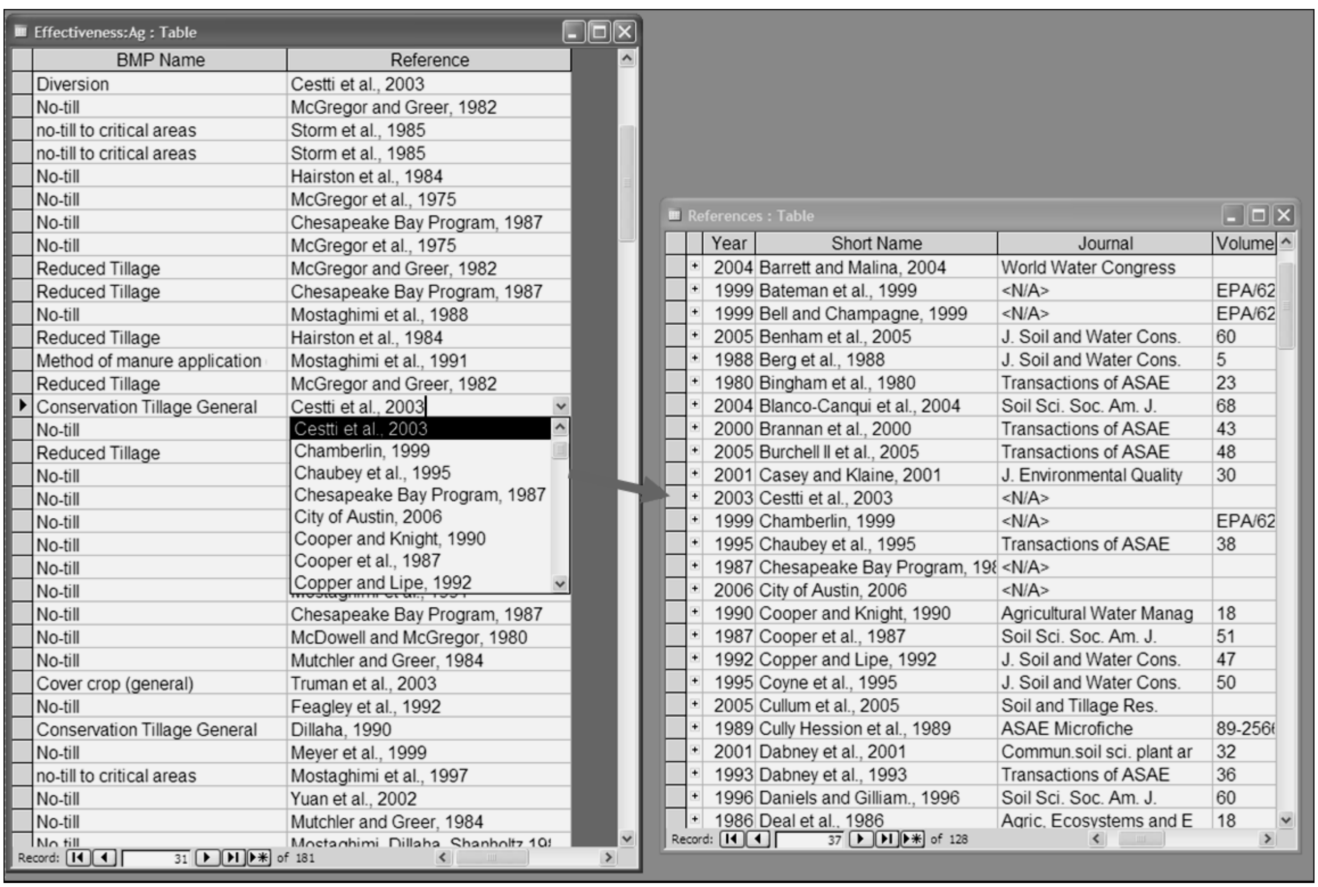

Figure 2. Relationship between the references and effectiveness tables in the database. The short name field in the References table is used as a lookup in the Effectiveness table.

estimates of BMP effectiveness in reducing nutrient and sediment losses as calculated from BMP effectiveness values in the underlying database, based on site soils and slope. The underlying database comprises different amounts of data points (entries) for each and every BMP, depending on the number of materials containing data that were available for the BMP at the time of the study. The tool uses MS Access built-in statistical functions. These are executed in real time, thus all estimates are current and reflective of existing data. As a primary function, an agricultural BMP effectiveness estimator was developed for use in determining agricultural BMP effectiveness. An urban BMP effectiveness estimator was also designed. This was similar to the agricultural BMP estimator in that it employs a user-driven lookup query. However, the urban tool was designed with only one search parameter – urban BMP class – as studies on urban BMPs did not usually report site conditions.

The tool was also designed to provide average values regardless of site characteristics and make them accessible through other tool interfaces. Additional interfaces were designed to provide estimates for individual BMPs. The tool also provides users with the option to simply display the effectiveness values for individual BMPs, as well as the associated site and study characteristics.

Several other interfaces were designed for the tool, allowing the user to update and maneuver through the underlying BMP database. For example, a function was included to allow the user to search the database by study method. Further, tagging was included to distinguish between published and unpublished materials as defined in this study. A function was also added to allow the user to search the database based on this tagging.

Results and Discussion

A BMP tool has been developed that provides BMP effectiveness estimates for site conditions and management interventions in Arkansas. The tool has two different databases, agricultural and urban, based on which it makes the BMP estimates.

Capabilities of the BMP Tool

The BMP tool developed provides site-specific effectiveness estimates for agricultural BMPs based on slope range and HSG, where corresponding effectiveness data are available in the database to allow such analyses. It also provides effectiveness estimates for urban BMPs based on BMP class. Through this tool, effectiveness estimates can be obtained for nutrient and sediment reductions. Effectiveness estimates can be viewed in predefined reports grouped by BMP class (independent of site conditions), HSG, slope, study size, or BMP category. These estimates are made using built-in statistical functions to calculate means, standard deviations, and other descriptive statistics. These functions are executed in real time, thus estimates obtained are always current and include any updates in the database tables. The tool also provides average values regardless of site characteristics (table 2). Other statistics including range, standard deviation, and the number of records, for each BMP class are also available within the generated reports.

The tool also allows users to search through the underlying data. Individual study records are displayed within searching forms (fig. 3) where the user can customize the data display without affecting the data. The BMP tool can also be used to find BMP references, as it currently holds over 120 citations. The ability to add articles and associated data to the database is a key feature of the database; this prevents the tool from becoming obsolete. User addition of new studies allows the tool to be current as new BMP knowledge is obtained.

The BMP tool can be further customized to meet user-specific needs. Also, use of the database is not restricted to Microsoft Access. Compiled data can be exported from the database into Microsoft Excel or other spreadsheets; Microsoft Access reports can be exported into Microsoft Word, as text files and html files, among others.

Results of the agricultural effectiveness estimator for the BMP category Erosion Control are shown in table 3. The results are displayed as a function of HSG and slope range. The estimator will only provide estimates for combinations of HSG and slope range that have data. When site-specific data are unavailable, the tool can also give general

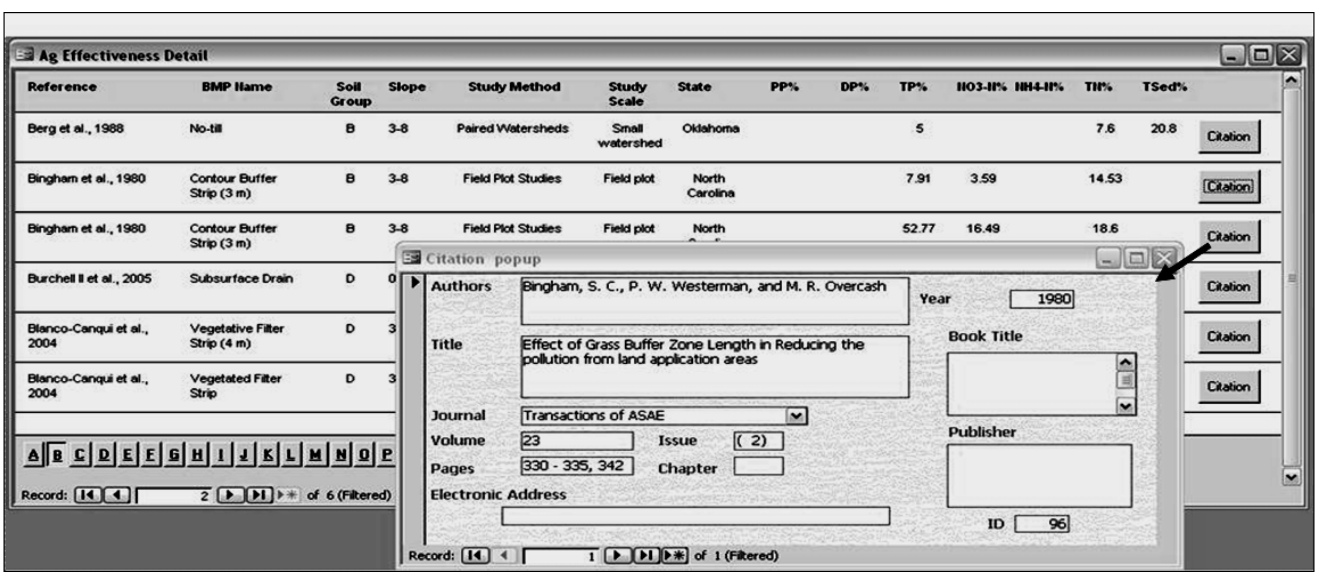

Figure 3. Screen capture from the tool displaying individual study records and its citation.

Table 2. Selected average Best Management Practice (BMP) effectiveness values contained in the BMP tool[a].

BMP Name	Pollutant Reduction (%)[b]						
	PP	DP	TP	NO_3-N	NH_4-N	TN	T Sed
Agricultural waste treatments amendments			70				
Conservation crop rotation			53			68	
Conservation tillage general			55			53	66
Constructed wetland			71				
Contour farming							43
Cover crop (general)							70
Diversion			50			27	35
Drainage water management				56			
Feed management		9	25				
Field border							34
Grassed waterway							17
Manure application by subsurface injection				68	93	58	
Mulching							77
No-till	60	24	69	37	15	59	78
No-till to critical areas			9			9	23
No-till with subsurface injection	38	92	91	84	97	95	92
Pasture and hay planting			67			66	59
Pond		80	72	82			77
Reduced tillage			44			55	55
Riparian forest buffer	63		53	59	48	47	76
Subsurface drain			4	-372[c]		-17	
Surface drainage, field ditch			-6	-518		-32	
Terraces			77			37	85
Use exclusion/stream protection			76	32		-78	83
Waste storage facility			58			52	
Waste treatment lagoon			62			43	
Watering facility			-10	41		-27	38
Wetland restoration			74	83	63	64	
Winter cover crop		37		75	37		76

[a] Blank cells indicate no data for the specified BMP and pollutant.
[b] PP - Particulate Phosphorus; DP - Dissolved Phosphorus; TP - Total Phosphorus; NO_3-N - Nitrate Nitrogen; NH_4-N - Ammonium Nitrogen; TN - Total Nitrogen; Tsed - Total Sediment.
[c] Negative values indicate increases in the pollutant.

effectiveness estimates that are independent of site characteristics. Figure 4 is a screen capture showing site-independent results for the conservation tillage class in the Erosion Control category. This is an example of tool output providing values that can be used where site-specific data are unavailable.

Because of the range of site characteristics represented, some of the data appear divergent when compared to other data within the database (table 3). Divergent data may well be indicative of extremities in site and study conditions (Gitau et al., 2005), thus, these data were not removed from the database. The tool was, however, designed to provide user access to the database and associated site and study information, thus allowing users to decide whether or not to include divergent data in their assessments.

The tool also outputs effectiveness estimates by agricultural BMP class (table 4). BMP classes are used to display the statistical parameters (average, range, standard deviation, and number of entries). From table 4, TSed, TP, and TN have the greatest number of entries in the database, respectively, 122, 83, and 76 entries. The number of entries may not match the number of references since some articles have multiple entries for the same pollutant, while other articles provide individual information for more than one BMP. With regard to BMP classes, filter strips, drainage and irrigation systems, and conservation tillage, contain the most data, possibly attributable to current interests and/or ease of implementation of the BMP on an experimental basis.

Based on data in table 4, the BMPs generally have the potential to cause reduction in all of the pollutants. As previously observed, however, some BMPs may aggravate the problem by causing increases in the loadings of certain pollutants. Within the conservation tillage BMP class, for example, increases observed in dissolved pollutants are largely associated with no-till systems for which reduction in soil disturbance results in increased soil surface concentrations of the pollutants (Romkens et al., 1973; Baker and Laflen, 1983; Dillaha, 1990). While filter strips have positive effects on sediment and sediment-attached pollutants, they have limited effects on soluble pollutants (Dillaha, 1990). Further, BMPs such as waste utilization will show pollutant reduction effects when compared, for example, to cases where fertilizers or manure were previously applied without a comprehensive nutrient management plan; they will, however, show increases when

Table 3. Agricultural effectiveness estimator results for the erosion control category as a function of hydrologic soil group (HSG) and slope[a],[b].

Erosion Control BMPs	Pollutant Reduction (%)[b]						
	PP	DP	TP	NO_3-N	NH_4-N	TN	T Sed
HSG = B, Slopes = 0-3%							
Conservation tillage							65
HSG = B, Slopes = 3-8%							
Conservation tillage	27	-42	12	36	-6	9	63
Contour strip crop			30	10		17	
Cover crops			67			66	69
HSG = C, Slopes = 0-3%							
Conservation tillage							68
HSG = C, Slopes = 3-8%							
Conservation tillage	92	-329	80	10	-14	79	79
Cover crops							74
HSG = C, Slopes = 8-15%							
Conservation tillage	79	60	81	37	57	91	87
HSG = D, Slopes = 0-3%							
Contour strip crop			26	39	32	20	19
Cover crops		37		75	37		91
HSG = D, Slopes = 3-8%							
Conservation tillage							15
Contour strip crop			26	39	32	20	19

[a] Blank cells indicate no data for the specified BMP and pollutant for the combination of HSG and slope range.
[b] PP - Particulate Phosphorus; DP - Dissolved Phosphorus; TP - Total Phosphorus; NO_3-N - Nitrate Nitrogen; NH_4-N - Ammonium Nitrogen; TN - Total Nitrogen; Tsed - Total Sediment.
[c] A negative value indicates an increase in the pollutant.

compared to a baseline in which there were no applications of any kind.

Example Application

A farm in Northeastern Arkansas with HSG-B soils and 3%-8% slopes has been determined to be contributing to sediment pollution. The farm's planners want to install BMPs to control the sediment problem, but are unsure of which BMPs would be effective for their needs. The planners use the tool to determine which BMPs would be helpful in their situation. They select the site scenarios similar to their own (HSG-B and slopes of 3%-8%) and choose the BMP category best related to their interests (in this case, erosion control). The tool then outputs the effectiveness estimates for applicable BMP classes for the specified site conditions and category. Figure 5 details how the planners run the estimator and acquire results. In this example, the tool returns results for two different BMP classes for use on this farm, conservation tillage and cover crops. Effectiveness values for individual BMPs within these classes can then be obtained through the other interfaces in the tool, as previously described.

For tool output, positive values indicate reductions in pollutant, while negative values indicate that the BMPs could potentially lead to increases in the pollutant of concern. Based on the output from the tool, BMPs in both classes can be used to reduce sediment erosion. Caution should, however, be exercised when choosing to apply conservation tillage as this practice can potentially lead to increases in dissolved phosphorus (42%) and ammonium nitrogen (6%) under the site conditions being considered. Reasons for these increases are discussed in preceding paragraphs.

The tool can be used in a similar manner for other site conditions and to evaluate BMPs in other categories. In general, BMPs with the highest effectiveness values for the pollutant of concern should be considered as the most suitable options, with other BMPs serving as alternatives. However, other factors, for example limiting climatic factors, farmer preferences, costs, and practicality of implementing the BMPs, should also be considered before selecting BMPs. As such, final selection of BMPs will call

Conservation Tillage

NRCS Code 329 Conservation Tillage General

Description *Conservation Tillage*

	PP %	DP %	TP %	NO3-N %	NH4-N %	TN %	TSed %
Avg			55.50			53.00	66.50

NRCS Code 329 No-till

Description *No-till vs. conventional tillage*

	PP %	DP %	TP %	NO3-N %	NH4-N %	TN %	TSed %
Avg	59.84	24.44	69.36	36.62	15.16	58.90	78.48

NRCS Code 329 No-till to critical areas

Description *no-till applied only on critical areas that receive annual sediment yield above*

	PP %	DP %	TP %	NO3-N %	NH4-N %	TN %	TSed %
Avg			9.40			9.30	22.83

NRCS Code 329 Reduced Tillage

Description *Limited soil disturbing activities to only those necessary to place nutrients, condition residue, and plant crops*

	PP %	DP %	TP %	NO3-N %	NH4-N %	TN %	TSed %
Avg			44.00			55.00	55.33

NRCS Code 324 Reservoir Tillage

Description *Method of creating small depressions in the soil surface to hold water that might otherwise be lost as surface runoff during irrigation or rainfall events.*

	PP %	DP %	TP %	NO3-N %	NH4-N %	TN %	TSed %
Avg							54.73

Blank Values indicate no data.

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Figure 4. Screen capture of the tool showing a report of the averaged values for conservation tillage effectiveness for the various pollutants considered. The values are calculated using data contained within the underlying database.

upon expert judgment on the part of the planners, with tool outputs serving to provide scientific information upon which decisions can be made.

Limitations of the BMP Tool

Great efforts were made to collect as much data as possible to populate the underlying database. For some BMPs, for example filter strips and conservation tillage there was a large number of articles from which data could be obtained, and from which a broad range of conditions could be represented. For other BMPs, such as animal waste storage facility and pasture and hayland planting, studies reporting BMP effectiveness were relatively fewer. For such studies, where references were few, the range of conditions represented was also narrow.

Variation in the amount of data available for each BMP brought about some challenges with regard to the ability to compare BMPs on an individual basis. With reduced tillage, for example, a sediment reduction of 92% was determined based on the one entry available. In comparison, the average sediment reduction effectiveness computed for no-till (based on 6 entries ranging from 20%-96%) was 66%, making it appear less effective than reduced tillage, contrary to common expectation. To avoid such inaccuracies, which can result due to paucity of data, collected data were grouped into classes based on operation mechanism, as previously discussed. The primary estimator was, thus, designed to provide output based on these classes, rather than on individual BMPs. Where needed, effectiveness data for individual BMPs can be obtained through other tool interfaces. These individual data should, however, not be used for comparative purposes and should be used in relation to conditions under which they were obtained, for the reasons discussed.

Climate has an impact on BMP effectiveness as do other location-specific factors (Baker and Johnson, 1983), and thus

Table 4. Statistical parameters for effectiveness data grouped by class (con't).[a]

BMP Class[b]	Pollutant[c]	Mean	Min	Max	Std	Count	Reference[d]
Alternative water supply	NH_4-N	77				1	50
	DP	75				1	50
	NO_3-N	32	12	41	16	3	27, 50
	PP	92				1	50
	TN	0.5	-27	56	48	3	27, 50
	TP	26	-10	97	62	3	27, 50
	Tsed	57	38	96	34	3	27, 50
Animal waste systems	DP	9				1	57
	TN	57	29	80	25	4	6, 8, 24, 41
	TP	61	25	90	31	7	6, 8, 20, 24, 28, 41, 57
	Tsed	60				1	6
Barn yard runoff management	TN	27	10	45	25	2	6
	TP	50	30	70	28	2	6
	Tsed	56	35	77	30	2	6, 17
Conservation tillage	NH_4-N	30	-43	93	50	6	39, 40, 49, 59, 60
	DP	-63	-329	91	186	4	38, 40, 59
	NO_3-N	37	10	68	23	6	39, 40, 49, 59, 60
	PP	69	27	93	31	4	38, 40, 49, 59
	TN	57	-3	91	35	14	2, 6, 8, 23, 30, 39.41, 49, 59, 60
	TP	61	5	97	33	13	2, 6, 8, 23, 28, 30, 38, 40, 41, 49, 60
	Tsed	69	6	99	28	48	2, 6, 8, 11, 17, 21-23, 26, 30.32, 36, 38-42, 44, 53, 59-61
Contour strip crop	TN	37	20	55	25	2	6
	TP	77	70	85	11	2	6
	Tsed	77	43	95	20	5	6, 8, 17
Cover crops	NH_4-N	37	35	41	3	3	61, 62
	DP	37	7	63	28	3	61, 62
	NO_3-N	75	4	39	18	3	61, 62
	TN	66				1	41
	TP	67				1	41
	Tsed	70	32	92	20	10	17, 33, 35, 41, 43, 46, 61, 62
Crop rotation	NH_4-N	37	35	41	3	3	62
	DP	37	7	63	28	3	62
	NO_3-N	75	74	77	1	3	62
	TN	67	66	68	2	2	8, 41
	TP	60	53	67	10	2	8, 41
	Tsed	72	32	92	22	7	17, 41, 43, 61, 62
Drainage systems	DP	80				1	9
	NO_3-N	-265	-1528	82	540	14	5, 8, 9, 14, 19, 25
	TN	-24	-47	0	15	8	14
	TP	1	-73	73	65	9	9, 14
	Tsed	77				1	9

the location in general. However, many of these factors are not reported in most studies. Further, the size of the analyzable data is such that only two factors can be included in the analyses at any one time. This study considers site slopes and soils; both are commonly reported factors and have been shown to affect BMP effectiveness (Gitau et al., 2005).

The issue of time is also important as there may be a lapse between the time BMPs are implemented and when they begin to have an effect. Further, BMP effects may start to diminish after a given time period more so as the BMP approaches its useful life. Because of the nature of the database and data collected, the tool does not currently provide time-based estimates of BMP effectiveness, rather estimates obtained using the tool are considered to represent average BMP effects over time.

The tool as it was developed allows users to update the underlying database for their purposes and as new information becomes available. While this helps keep the tool current, it is possible for results to become skewed if bad data are added or when the user is unfamiliar with the data inclusion parameters (described under study considerations). We recommend that users closely follow the guidelines in Gitau et al. (2005) and as described within this text to avoid errors due to inconsistencies between existing and added data.

Table 4 (cont'd). Statistical parameters for effectiveness data grouped by class.[a]

BMP Class[b]	Pollutant[c]	Mean	Min	Max	Std	Count	Reference[d]
Filter strips	NH_4-N	47	-35	98	35	28	4, 7, 13, 15, 16, 34, 52, 56
	DP	23	-108	89	55	21	4, 7, 13, 15, 16
	NO_3-N	22	-158	85	58	22	3, 4, 13, 15, 16, 34, 56
	PP	79	68	90	15	2	4
	TN	54	1	93	25	31	3, 4, 6, 7, 13, 15, 16, 34, 46, 52, 56
	TP	57	2	93	25	31	3, 4, 6, 7, 13, 15, 16, 46, 48, 52, 56
	Tsed	56	0	99	32	40	4, 6, 10, 13, 15-18, 33-35, 47, 56, 61
Nutrient management plan	NH_4-N	-1133	-4979	97	2173	3	39, 40
	DP	-35	-171	92	127	3	13, 40
	NO_3-N	46	0	84	39	3	39, 40
	PP	38	-57	85	57	3	13, 40
	TN	10	-102	95	74	3	39, 40
	TP	48	8	91	30	6	13, 28, 40
	Tsed	84	72	92	9	3	13, 40
Riparian forest buffers	NH_4-N	48				1	29
	NO_3-N	59				1	29
	PP	63				1	29
	TN	47	37	57	14	2	29, 45
	TP	53	50	56	4	2	17, 29
	Tsed	76	55	95	16	5	17, 45, 51
Sediment basins	DP	80				1	9
	NO_3-N	82				1	9
	TP	72				1	9
	Tsed	77				1	9
Stream fencing	NO_3-N	32				2	27
	TN	78				2	27
	TP	75				2	27
	Tsed	83	82	84	0.9	3	27, 54
Terraces and diversions	TN	38	20	55	25	2	6
	TP	78	70	85	11	2	6
	Tsed	86	80	95	7	4	6, 8, 17
Wetland	NH_4-N	63				1	58,
	NO_3-N	83				1	58
	TN	64				1	58
	TP	72	71	74	2	2	1, 58

[a] There are no data for Irrigation Water Management or Rotational Grazing.
[b] BMP - Best Management Practice;
[c] PP - Particulate Phosphorus; DP - Dissolved Phosphorus; TP - Total Phosphorus; NO_3-N - Nitrate Nitrogen; NH_4-N - Ammonium Nitrogen; TN - Total Nitrogen; Tsed - Total Sediment.
[d] References: 1 - Abtew et al., 2004; 2 - Berg et al., 1988; 3 - Bingham et al., 1980; 4 - Blanco-Canqui et al., 2004; 5 - Burchell II et al., 2005; 6 - Cestti et al., 2003; 7 - Chaubey et al., 1995; 8 - Chesapeake Bay Program, 1987; 9 - Cooper and Knight, 1990; 10 - Coyne et al., 1995; 11 - Dabney et al., 1993; 12 - Dabney et al., 2001; 13 - Daniels and Gilliam., 1996; 14 - Deal et al., 1986; 15 - Dillaha et al., 1988; 16 - Dillaha et al., 1989; 17 - Dillaha, 1990; 18 - Feagley et al., 1992; 19 - Gilliam et al., 1979; 20 - Gilliam, 1995; 21 - Hackwell et al., 1991; 22 - Hairston et al., 1984; 23 - Harmel et al., 2006; 24 - Hubbard et al., 2004; 25 - Jacobs and Gilliam, 1985; 26 - Langdale et al., 1979; 27 - Line et al., 2000; 28 - Lory, 2006; 29 - Lowrance and Sheridan, 2005; 30 - McDowell and McGregor, 1980; 31 - McGregor and Greer, 1982; 32 - McGregor et al., 1975; 33 - McGregor et al., 1999; 34 - Mendez et al., 1999; 35 - Meyer et al., 1995; 36 - Meyer et al., 1999; 37 - Mostaghimi et al., 1988a; 38 - Mostaghimi et al., 1988b; 39 - Mostaghimi et al., 1991; 40 - Mostaghimi et al., 1992; 41 - Mostaghimi et al., 1997; 42 - Mutchler and Greer, 1984; 43 - Mutchler and McDowell, 1990, 44 - Mutchler et al., 1985; 45 - Palone and Todd, 1997; 46 - Parsons et al., 2001; 47 - Renschler and Lee, 2005; 48 - Sanderson et al., 2001; 49 - Schreiber and Cullum, 1998; 50 - Sheffield et al., 1997; 51 - Sheridan et al., 1999; 52 - Srivastava et al., 1996; 53 - Storm et al., 1985; 54 - Trimble, 1994; 55 - Truman et al., 2003; 56 - Udawatta et al., 2002; 57 - VanDevender et al., undated; 58 - Vellidis et al., 2003; 59 - Yoo et al., 1986; 60 - Yoo et al., 1988; 61 - Yuan et al., 2002; 62 - Zhu et al., 1989.

Summary and Conclusion

The effectiveness of BMPs for use in Arkansas was quantified through a BMP Tool, developed in Microsoft Access. The tool is designed to be an aide in BMP selection by providing site specific estimates of BMP effectiveness, as well as averages to be used in the absence of site specific data. While the tool was focused on agricultural BMPs, it also has data for urban BMPs. Various capabilities are available in the tool, and additional features can be amended easily in either Microsoft Access or Visual Basic.

Oftentimes, BMPs are selected and implemented without sufficient scientific base as to their effectiveness. A seemingly obvious choice of BMP(s) may fail for a variety of reasons, for example incompatible site characteristics. A

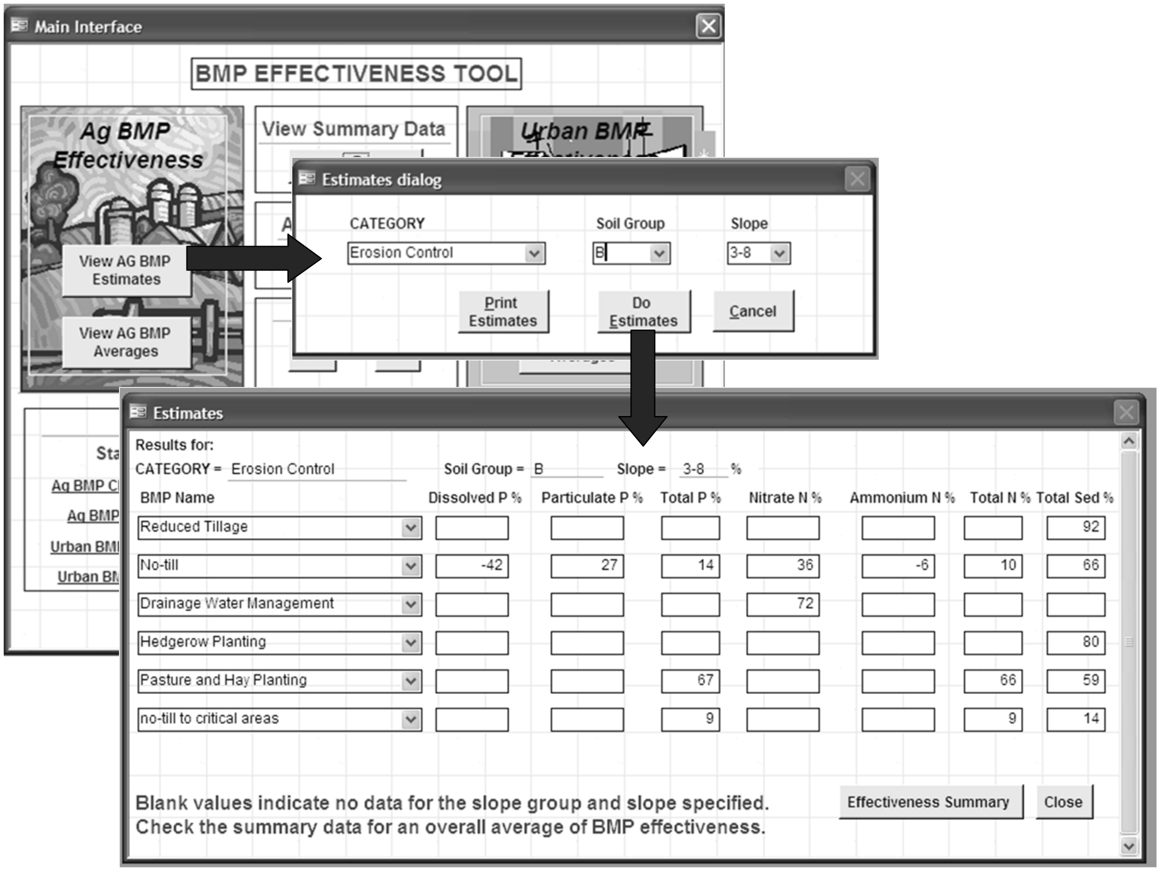

Figure 5. Agricultural effectiveness estimator, showing results of a user-driven query. Erosion control BMP category with HSG = B and slopes of 3%-8% are selected.

BMP may also be effective in controlling the losses of one pollutant while so aggravating the situation with respect to another pollutant as to make it an unacceptable choice (Gitau et al., 2005). This tool provides effectiveness values of BMPs on various pollutants as determined from a variety of scientific studies. These, in turn, provide information that can be used to guide science-based decision making as regards BMP selection. This tool will, thus, find use among watershed planners and state and local agencies alike.

This tool was developed for use in Arkansas but included a substantial amount of data from the Southeastern United States as data available for Arkansas were insufficient for the intended analyses. The tool is, thus, useable in the greater southeastern region. Because the data search was conducted considering site conditions and management interventions in Arkansas, the database may not capture or address the needs of this greater region in their entirety. The database does, however, contain additional information on location, and site and study characteristics, all of which is accessible to the user. The user can, thus, make the choice to either use the estimates as provided by the tool or the base data from their particular location. Because of its region-specific nature, tool results might not be directly applicable to areas beyond the southeastern region. The tool can, however, be easily expanded to include data from other regions or used as a template for other BMP tools.

The tool can be used as a standalone application or can be linked with other applications such as watershed models. This tool, along with a users' manual, will be available for free for any interested user. We also plan to publish the tool on the web so as to make it available to a larger group of users.

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