# Report to the Iowa Department of Natural Resources
# Nonpoint Source Needs Assessment for Iowa:
# The Cost of Improving Iowa's Water Quality

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## I. Introduction

This technical report describes the methodologies and procedures that researchers from the Center for Agricultural and Rural Development and the Department of Economics employed to estimate the costs of adopting new conservation practices and changing agricultural land use in the state of Iowa with the goal of improving water quality. In brief, economic models and data on land use and conservation practices were combined with a watershed-based hydrological model, the Soil and Water Assessment Tool (SWAT), to estimate the costs of obtaining water quality changes from the hypothetical placement of a broad-based set of conservation practices. The practices analyzed in the assessment include land set-aside, conservation tillage, contour farming, grassed waterways, terraces, and a simple nutrient reduction strategy. The net present value of the total program cost for implementing the set of identified conservation practices in a 10 year program period was estimated to range from \$ 2.414 billion to \$ 4.269 billion, depending on whether only new adopters or old and new adopters were paid and whether low or high cost estimates were used. The corresponding reductions in sediment from the baseline range from 6 to 65% across the watersheds analyzed. Nitrates reductions ranged from 6 to 20%, while total phosphorous decreases varied between 28 to 59%.

As interpreted by the 2000 EPA National Needs Assessment (USEPA 2003) the process of determining the needs of states to address nonpoint source water quality problems is equivalent to identifying the set of conservation practices that should be placed on the landscape, then estimating the costs of those practices. We follow that basic framework in this analysis. The implicit assumption concerning water quality in such a procedure is that the set of practices identified will achieve the desired water quality improvement. To explicitly assess the likely changes in water quality, we employ a water quality model, SWAT, to project the changes in nitrogen, phosphorous, and sediment loads that might be expected from the identified set of practices. Therefore, the sequence of our analysis is as follows:

1. Identify the set of practices and their location on the landscape.

In consultation with the IDNR the location of the practices was determined based on the potential environmental impact as captured by several indicators, such as proximity to a stream, an erodibility index, and slope. The set of practices chosen is broad and includes terraces, contouring, grassed waterways, conservation tillage, land set-aside, and nutrient management in the form of fertilizer reduction.

2. Estimate the costs of the complete set of practices.

In considering the costs of a practice, it is important to establish as precisely as possible the definition that we are using. We calculate both social and program costs. The IDNR is interested in the program costs that, as a government agency, it would have to incur if the program were implemented. Overall social costs are likely to be different for several reasons, as detailed below. As society as a whole would face the costs of the conservation program differently from the agency that implements it, we report both. Ideally, we wish to estimate the opportunity cost associated with the change in land use or adoption of a conservation practice. The program costs associated with that practices can then be identified. The opportunity cost of an action such as the adoption of conservation tillage or contour farming includes the direct costs of implementing the practice as well as any lost revenue associated with the undertaking the practice relative to conventional approaches, compensation necessary for any increased risk and/or any other undesirable consequences of the practice for the farmer or landowner. In short, the opportunity cost of a practice is the minimum amount of compensation necessary for the farmer or landowner to voluntarily adopt the practice. For some practices, data limitations or incomplete understanding of the agronomic consequences of a practice mean that direct costs or predictions of lost revenues are used as proxies for the complete opportunity cost. Further discussion of these issues is contained below in the section describing the costs of practices. We also discuss the program costs for the practices chosen and how the opportunity costs differ from the program costs[1].

1. Estimate the water quality benefits associated with these sets of practices.

To estimate the in-stream water quality consequences of a set of conservation practices, we have calibrated the SWAT model for each of the watersheds identified in Figure 1 to baseline levels of adoption. By running the model "after" adoption (i.e., with our hypothetical set of practices in place) we can compute the changes in water quality attributable to the set of practices.

Given that political boundaries and watershed boundaries do not perfectly correspond in Iowa, there is something of a geographic mismatch between our study regions on the cost side and on the water quality side. Figure 1 illustrates the 35 watersheds corresponding to the United States Geological Survey 8-digit Hydrologic Cataloging Units that are largely contained in the state and which are modeled in this study.

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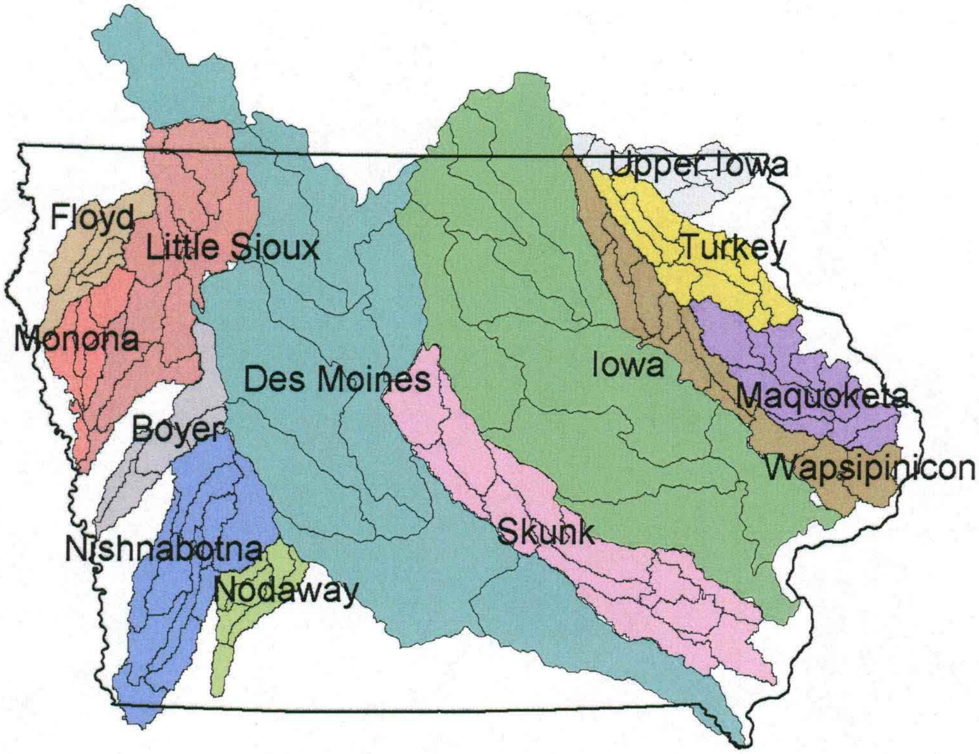
[1] Note that identifying and estimating the costs of these conservation practices is independent of the discussion of who might actually pay these costs. Whether the costs were to be imposed on landowners, borne by taxpayers, consumers, or any other groups is a political decision with significant consequences for various groups in society (farmers, taxpayers, etc), but it is an issue that can be considered independently from the computation of the costs.

**Figure 1. The study area and watershed delineations**



The watersheds correspond to 13 outlets, at which the in-stream water quality is estimated. The water quality indicators of interest are sediment, nitrogen and phosphorus. For the cost analysis we consider placing the identified set of practices all across the state and exclude the pieces of the watersheds that fall outside of the state boundaries (for example the section of the Des Moines river watershed that is in Minnesota). Thus, the costs and water quality benefits we report are not quite consummate: one represents a political boundary (the statewide costs), while the other represents a natural system boundary. Direct comparisons between the aggregate cost and water quality benefit comparisons may be misleading, although the unit costs and benefits (per acre costs and/or per outlet of the watershed measures) can still be appropriately compared.

In the remainder of this report, we describe the procedures used to complete each of these steps, with each step representing a section in the report. Summary estimates of the total costs of the studied practice set are provided in section V. There is a large number of assumptions and data issues that underpin the models and results presented here, and in the final section of the report, we summarize a number of these caveats and indicate which weaknesses in the work the researchers feel are most in need of improvement in future assessments.

## II. Identification of the set of practices and their location on the landscape.

In concert with the Iowa Department of Natural Resources, we identified conservation practices on the basis of the physical characteristics of the agricultural land. The practices analyzed include grassed waterways, terraces, strip cropping, contouring, conservation tillage, land set-aside, and nutrient management strategies. The primary data source used in the analysis is the 1997 USDA-NRCS National Resource Inventory (NRI) database (Nusser and Goebel, 1997; http://www.nrcs.usda.gov /technical/ NRI/). The NRI provides information on the natural resource characteristics of the land, cropping history, conservation practices used by producers, and other data for some 15,781 cropland and CRP physical points in Iowa. Because the data are statistically reliable for state and multi-county analysis of non-federal land), they are representative of the agricultural land in Iowa. The key unit of our analysis is an NRI point, which is treated as a producer with a farm size equal to the number of acres represented by the point.

As agreed with the IDNR, this was the sequence adopted in identifying the practices for the NRI points[2]:

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[2] Note that "Western Iowa" refers to all United States Geological Survey 8-digit Hydrologic Unit Codes (HUCs) in the Missouri basin. Unless the criteria distinguish between Western and all other areas of Iowa, the practices were applied uniformly over all basins.

**Step 1.** Retire all cropland within (<=) 100 ft. of a waterway, placing it in CRP. CRP selection can override any previous conservation practice in place in the 1997 NRI; i.e., terraces, contouring, strip cropping, and grassed waterways.

**Step 2.** Retire additional land to reach a 10% total land retirement figure statewide (i.e., Step 1 plus Step 2 plus land already in CRP in the 1997 NRI acres equals 10% of the 1997 NRI cropland + 1997 NRI CRP land). This additional land is chosen by beginning with the acreage with the highest Erosion Index (as given in the NRI), until the 10% figure is reached. Again, CRP can override previous conservation practices identified in the 1997 NRI. Points are selected until the next point's area would exceed the 10% criteria.

**Step 3.** Terraces. For the cropland remaining after Steps 1 and 2, terrace all cropland with slopes above 7% in Western Iowa and above 5% for the remainder of Iowa. This land will also be placed in no till or conservation tillage --- see step 6. This can override contouring and strip cropping in the 1997 NRI, but not grassed waterways.

**Step 4.** Contours. Implement contouring on all cropland not covered under Steps 1-3 with slopes above 4%. We do not put contours on baseline areas (1997 NRI) that were in grassed waterways, terraces, strip cropping, or existing contours.

**Step 5.** Grassed Waterways (GW). For all land not covered under Steps 1-3, and with slopes of 2% or greater (i.e., cropland with slopes from 2 to 7% in Western Iowa and 2 to 5% in the rest of Iowa), place 2% of the cropland in grassed waterways . In modeling the benefits of grassed waterways, assume only 50% of the parcel area with a grassed waterway is benefited by it. Do not override terraces, strip cropping, contours, or existing grassed waterways in the 1997 NRI.

**Step 6.** Conservation/no till. For all cropland with slopes of 2% or greater that are not retired (Steps 1-2), and not already in conservation tillage, assume 20% of each 8-digit HUC will be in no till and 80% in conservation tillage. Thus all working cropland with slopes over 2% will be in conservation or no till. Finally, note that the term conservation tillage represents tillage that leaves over 30% residue and no till is used for the tillage practices that leave over 60% residue. Within each 8-digit HUC, points are randomly selected for no till until the next point's area would exceed the 20% criteria, and the remaining are designated as conservation tillage.

**Step 7.** Nutrient Management (NM). We assume a 10% reduction in N and P fertilizer rates on all 1997 NRI corn acres for the nutrient management step.

Note that, because we can only simulate a single P factor for any given HRU in SWAT, we can simulate mulch- or no-till in combination with terraces, contouring, and grassed waterways, as currently defined in step 6 of the algorithm in part 3. However, we cannot simulate other conservation practices in combination with each other (e.g., contouring with grassed waterways), This does ignore some real world possibilities, but such combinations can not be incorporated in this present research[3].

The acreage involved in this scenario is substantial. Table 1 contains the statewide summaries of both existing and "new" (our set of identified practices) acreage. Note that since multiple practices are possible on the same land, the sum of the acreages in individual practices does not add up to the total acreage in the state[4]. The total existing acres provided are those of the NRI points that indicate the presence of a particular practice. This is likely to overestimate the acreage in which conservation practices are in place, as the NRI only indicates that the

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[3] In practice, this means that:

- when an NRI point shows both terraces and contours, we "remove" the contours and only model terraces;
- when an NRI point shows both terraces and grassed waterways, we model terraces only;
- when an NRI point shows both contours and strip cropping, we only model contours;
- when an NRI point shows both contours and grassed waterways, we only model grassed waterways.

[4] Note also that the existing CRP acres are as of 1995 since that is the most recent data contained in the 1997 NRI.

practice is present on part of the acreage represented by the NRI point and the acreage reported here represents the entire area associated with those points.

Of particular note, the identified set of practices almost triples the amount of acreage that is terraced in the state. The land retired from active production (CRP) increases by almost 50%, while the conservation till acreage is expanded by more than 60%. Nutrient management affects almost half of the acreage in the state. Note that the acreage in grassed waterways is the total cropland acreage affected by the practice. Only 2% of that acreage is actually converted into grassed waterways[5].

**Table 1. Acreage of practices.**

| | CRP | Mulch till | No till | Contour | GWs | Terraces | NM |
|---|---|---|---|---|---|---|---|
| New Acres* | 855,900 | 5,844,200 | 1,391,300 | 1,218,000 | 7,057,100 | 3,251,400 | 12,024,600 |
| Existing Acres | 1,739,400 | 8,959,800 | 5,036,500 | 5,146,900 | 2,131,600 | 1,932,100 | N/A |

*"New" acres refers to the acreage affected by the set of identified practices in our scenario. Also note that in the existing acres, it is possible to have several conservation practices on the same piece of land. Therefore, the totals will not add up.

Detailed maps of the geographical placement of the practices by watershed are provided in Appendix A. Some general observations are worth making:

1. The additional CRP acres are located more uniformly across the landscape than the existing CRP acres, which are concentrated more in the South (this presumably has to do with costs). The resulting total CRP acreage is concentrated more heavily in the South and along the Mississippi and Missouri. The more productive and flatter land of the Des Moines Lobe is less affected by this portion of the policy.

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[5] We understand that the 2% factor is arbitrary in the case of the existing acreage reported by the NRI. However, we use it for comparability purposes.

2. In contrast, our models estimate that existing conservation tillage is more widespread in the central part of the state. The additional conservation tillage acres are located quite uniformly across the landscape, therefore the resulting total acreage is relatively high everywhere, with higher peaks in central Iowa.

3. The existing contour acres are concentrated on the eastern and western watersheds flanking the rivers, but the new contour acreage is located in the watersheds adjacent to these in central Iowa.

4. Existing grassed waterways are concentrated in southeast Iowa, but new ones would go into place in northeast and north central Iowa.

5. Existing terraces are mainly located in western Iowa, while the new ones would be put in place in south central Iowa and southeastern Iowa.

## III. Estimation of the costs of the identified set of practices.

### *Social and program costs*

The differences between the social and program costs are:

1. Conservation tillage and contour program costs are limited to three years. In practice, it is likely that, for a large fraction of farmers involved in the program, the payments would represent compensation for a real loss in profits that would not disappear in 3 years. The reason is that switching to these practices would entail continued increased costs rather than one-off outlays or risk-premiums. Therefore, in calculating the social costs, we assume that the payments for these practices are annual.

2. Conservation tillage program costs are fixed at $10/acre for mulch till and $20/acre for no till. To calculate social costs we draw on the work of Kurkalova et al. (2003) for estimates of

the costs of adopting conservation tillage, as these costs reflect the real opportunity cost of shifting to conservation tillage.

3. Program costs are calculated using a ten year phase-in of the program. For consistency, the same phase-in system is used in the case in which current adopters are also paid. The social costs, on the other hand, are reported as the full annual costs. They are calculated assuming that full implementation of the program is in place.

4. The program cost for terraces is calculated assuming that the whole cost of construction is paid off in full in the first year, and the implementation is staggered in the 10 years of the program. Dave Beck at NRCS in Des Moines estimates that terraces typically have a lifespan of 25 years (Dave Beck, personal communication), therefore in calculating social costs we annualize the terraces' costs for a time horizon of 25 years, with a discount rate of 8%6. For both social and program costs we implicitly assume zero maintenance costs for years subsequent to implementation. Such costs are likely to be substantially smaller than the initial construction costs; however, this assumption may mean that we underestimate the costs of the terraces. For grassed waterways, we use a lifespan of 10 years, which is the one assumed by NRCS (USDA-NRCS, 2003c).

5. In the case of CRP, we use the methodology developed in Feng et al. (2003) to calculate the costs of land retirement7. The cost is based on the rental rate of the land, and therefore represents a true opportunity cost.

*Practices costs (per acre)*

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[6] The rate was chosen to be consistent with USDA work on conservation practices costs. See for example USDA-NRCS 2003b.

7 Our models provided us with information on the rental rate and conservation tillage opportunity cost for 13425 of the NRI points in the state. For the remaining 2355 points we use the average value calculated over the 13425 points.

A unique data source on the costs of conservation practices is not available, therefore we have developed a methodology to combine economic models with available cost data. As noted above, we draw on the procedure developed in Feng *e. al*. (2003) to estimate land retirement's costs, and on Kurkalova *et al*. (2003) for the social cost of adopting conservation tillage. This procedure results in average rental rates for the acres newly enrolled in CRP of $113.56 (S.D. 23.55). In terms of conservation tillage, using the conservation tillage model instead of the IDNR estimates results in average per acre costs of $13.52 (S.D. 14.04).

For terraces, contouring, and grassed waterways we gathered data from the Environmental Quality Incentives Program (EQIP) in Iowa to help us bracket the costs, and then used expert opinion to determine the estimates to use. This was necessary because for some practices there are few contracts in the state, and so the average cost is not necessarily meaningful. For example, for contouring there are only 26 contracts statewide. Further, the use of EQIP contract data in general has to be approached with caution since we need to extrapolate the cost of a practice for all farmers from those who have bid for and had contracts accepted. It is likely that the costs for practices to early adopters (such as those who enroll in EQIP) will be less than the equivalent costs for a typical farmer. Finally, since the EQIP data were reported from field offices and appear to have erroneous entries, we use two separate methods for estimating average costs from them. The first is our own calculation of means from the raw data, and the second is from USDA's Economic Research Service (ERS). The original source is the same, but ERS eliminated outliers to calculate averages. Table 2 provides details of the average annual costs per practice from EQIP and the cost estimates we used in agreement with the IDNR. Note that for comparability purposes the cost reported for grassed waterways is the cost per acre of cropland acreage affected by the practice rather than the cost of the actual grassed waterway acreage.

To provide cost estimates for terraces, we translated the per foot cost to a per acre cost. The first basis for the acreage conversion is based on a national report from NRCS which assumes that 435.6 feet of terrace protect 1 acre (USDA-NRCS. 2003a). The second is based on information provided to us by Eric Palas of IDALS, who told us that in parts of Iowa 5,000 feet of terraces will protect 30 acres of cropland. This would amount to 166.67 feet of terrace for 1 acre. The ERS per foot EQIP cost is $4.36, while the raw EQIP data show an average of $1.85. Therefore, the per acre installation costs of terraces range from $308.34 to $1899.22. Dave Beck at NRCS in Des Moines estimates that terraces typically have a lifespan of 25 years. Therefore, in the social cost analysis we annualize the terraces' costs for a time horizon of 25 years. This results in annualized costs of $11 in Western Iowa and $18 per acre in Eastern Iowa. As noted above, for grassed waterways we use a life span of 10 years. For consistency, we use a 8% discount rate here as well. This results in annualized costs of $1.6 to $2.4.

**Table 2. Average costs of identified conservation practices.**

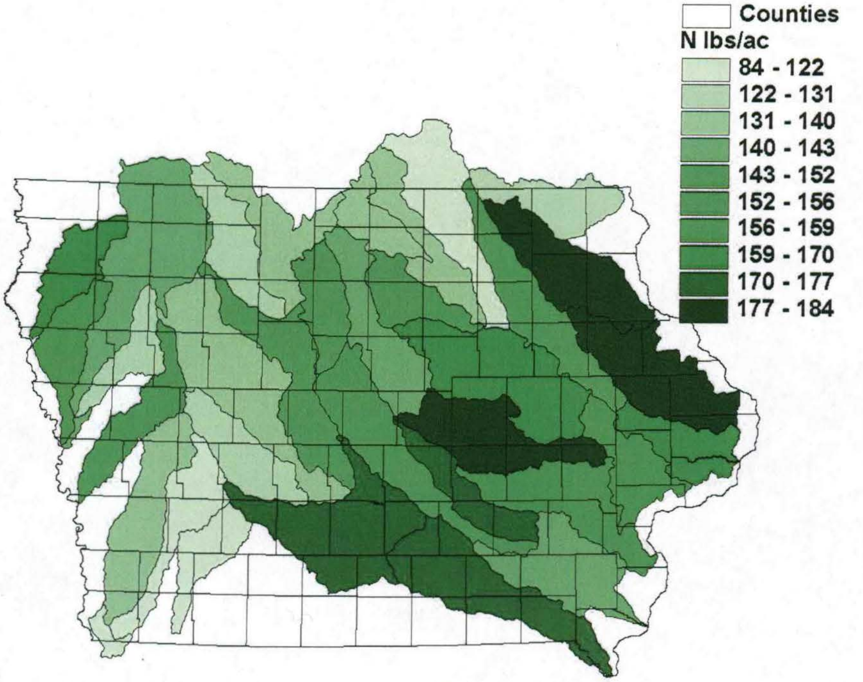
| Conservation Practice | EQIP costs (per acre) | | DNR cost estimates (per acre) | |
|---|---|---|---|---|
| | Low | High | Low | High |
| Contouring | $6.6 | $25.3 | $10 | $20 |
| Grassed Waterways (structural cost) | $3.2 | $6.9 | $20 | $30 |
| Terraces (structural cost) | $308.3 | $1899.2 | $525(Western Iowa)<br>$875(Eastern Iowa) | |

*Fertilizer rate baseline and effect of fertilizer rate reductions*

For the nutrient management costs, the baseline levels of fertilizer were estimated drawing on the IDNR's nutrient assessment. Calvin Wolter from IDNR provided us with nitrogen and phosphorus fertilizer usage for the 8-digit HUCs included in the analysis. The amount given by watershed was divided by the corn acreage for each watershed as calculated from the 2002 Land cover / Land use classification of Iowa derived from satellite imagery collected between May 2002 and May 2003 (IDNR - GS 2004). This generated a per acre fertilizer rate. Figure 2 shows the per acre nitrogen rates for the watersheds analyzed. Appendix B lists the nitrogen and phosphorus application rates by watershed for the baseline.

In the analysis, we only consider reductions in the application of nitrogen (N) and phosphorus (P) on corn. While soybeans are an important crop in the state, by far the most fertilizer application is undertaken in the production of corn, so we focus our attention there.

**Figure 2. Per acre nitrogen rate (lbs.) by watershed.**



One approach to estimating the cost of reducing N and P application in corn production[8] is through economic models based on historic data. This approach has the advantage of taking into account other potential behavioral changes by farmers that can mitigate any potential losses from fertilizer changes. For example, Ribaudo *et al.* (2001) estimate that the cost of a 10% reduction in N fertilizer for the Mississippi River Basin is about 0.22 per pound of N loss from fields (as opposed to N applied to fields) and Shaik *et al.* (2002) estimate that the cost of reducing nitrogen applications in Nebraska ranges from \$0.91 to \$2.21 per pound. Due to time and data limitations, we do not employ such an approach here; however it is useful to note that our estimates are not dramatically different from the estimates of the Shaik *et al.* study.

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[8] Note this might be different from the cost of inducing farmers to agree to reduce the application of fertilizer mainly because the later has to include extra payments when farmers believe that the reduction will have larger yield reducing effects or cause yield to be more volatile.

The method that we use in this project is straightforward; we estimate the direct profit loss due to the reduction of fertilizer. Conceptually, to do this, we need two pieces of information: the reduced cost from less fertilizer and the change in revenue due to any reduced yield. For the former, we need the amount of fertilizer actually reduced and its price. To estimate the effects on revenue, we need the price of corn and the yield impacts due to the reduction in N and P. For both corn and fertilizer, given that prices vary with market situations, only historic prices in recent years will be used.

The estimation of the yield effect is the most important and probably the most controversial/unresolved issue in costing the reduction of fertilizer application due to a number of factors. The yield effect of fertilizer application has been estimated to be almost none, positive, or negative. Some states still recommend more fertilizer for a higher yield goal, while others have discontinued the practice (Lory and Scharf, 2003). It is difficult to estimate the impacts of fertilizer application because the effects may be masked by weather, previous crops, soil condition, etc. In addition, the reduction of fertilizer may have insignificant effect in the short run; however, the long run effect may be large.

Some researchers have concluded that farmers over apply fertilizer so that some reduction in the fertilizer application will not affect crop yield (e.g., Yadav *et al.* 1997). Thus, we use zero net revenue change as one cost estimate for the reduction of the application of N and P. A zero yield effect would literally imply a positive revenue effect due to reduced fertilizer costs. However, fertilizer is quite inexpensive so we assume any cost savings are offset by small yield effects.

For phosphate, recommendations are dependent on the results of soil tests and for soils with high P content, which includes most Iowa soils. Thus, the reduction of P application is viewed as having no yield impact and we assume in turn that there is no cost associated with a 10% reduction in P.

We assume that farmers incur a one-time start-up cost of $15/acre. This is akin to the cost of initiating a nutrient management plan that would, for example, improve the efficacy of nutrient application through soil testing, so as to avoid yield effects with the lower fertilizer rates. In calculating social costs we annualize this cost assuming a life span of 5 years, because this is the assumption used by NRCS when assessing the cost of nutrient management plans. Such plans require that application rates be based on current soil tests that are not older than 5 years. (USDA-NRCS 2003b). Once again, we use a 8% discount rate.

*Total cost analysis*

The existing acreage in conservation practices is higher than the acreage that would receive payments if existing adopters were included in the program. The reason is that some of the acreage with existing conservation practices would go into CRP, and some of the acreage in contour would get terraced (and therefore receive payment only for the terrace[9]). Therefore, Table 3 reports both the existing acreage and the existing acreage that would receive payments under our policy scenario.

To calculate the net present value of the program cost we use a 8% discount rate. Table 4 shows that the proposed program analyzed here would result in considerable expense for new terraces. The second most expensive part of the scenario would be land set aside, at over $315,000,000, while the program costs for conservation tillage would be around $150,000,000. Table 5 shows how paying existing adopters also would almost double the cost of the program.

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[9] In general, if existing conservation practices are paid, the rule used is that farmers can get paid for several practices for the same piece of land, except for terrace and contour, in which case there are only terrace payments.

The lowest estimate of the net present value of the total program costs (constructed by using the lower costs estimates whenever more than one is identified) is about $2,414,000,000. The highest estimate, using the higher per acre costs and including existing adopters of conservation practices, is about $4,269,000,000.

**Table 3. Acreage of practices used in the cost calculations**

| | CRP | Mulch till | No till | Contour | GWs | Terraces | NM |
|---|---|---|---|---|---|---|---|
| New Acres | 855,900 | 5,844,200 | 1,391,300 | 1,218,000 | 7,057,100 | 3,251,400 | 12,024,600 |
| Existing Acres | 1,739,400 | 8,959,800 | 5,036,500 | 5,146,900 | 2,131,600 | 1,932,100 | N/A |
| Existing acres receiving payments | 1,739,400 | 8,759,600 | 4,919,200 | 2,092,600 | 1,981,100 | 1,721,500 | N/A |

The annualized social costs are reported in Table 6. Annualizing the costs of terraces substantially reduces their impact. Land set aside and conservation tillage payments account for the highest outlays. Watershed and county level costs are given in Appendix C.

**Table 4. Program costs by practice ($ millions)**

| | CRP costs | CT costs | contour costs (LOW) | contour costs (HIGH) | GW costs (LOW) | GW costs (HIGH) | Terraces | NM |
|---|---|---|---|---|---|---|---|---|
| New acreage | 315 | 150 | 21 | 42 | 95 | 142 | 1,712 | 121 |
| Existing acreage | 640 | 324 | 36 | 73 | 27 | 40 | 709 | 0 |
| Total acreage | 955 | 474 | 58 | 115 | 121 | 182 | 2,421 | 121 |

**Table 5. Total program costs ($ millions)**

| Cost Categories | Cost |
|---|---|
| New acreage paid only - low estimates | 2,414 |
| New acreage paid only - high estimates | 2,483 |
| Total acreage paid - low estimates | 4,151 |
| Total acreage paid - high estimates | 4,269 |

**Table 6. Annualized social costs ($ millions)**

| | CRP costs | CT costs | Contour costs (Low) | Contour costs (High) | GW costs (Low) | GW costs (High) | Terrace | NM | Total (Low) | Total (High) |
|---|---|---|---|---|---|---|---|---|---|---|
| New acreage | 96 | 97 | 12 | 24 | 11 | 17 | 53 | 33 | 303 | 321 |
| Existing acreage | 196 | 12 | 21 | 42 | 3 | 5 | 22 | 0 | 254 | 276 |
| Total acreage | 292 | 109 | 33 | 66 | 14 | 22 | 76 | 33 | 557 | 597 |

## IV. Estimation of the water quality benefits associated with the identified set of practices.

The SWAT model is used to estimate changes in water quality attributed to the new set of conservation practices. SWAT is a conceptual, physically based long-term continuous watershed scale simulation model that operates on a daily time step. The model is capable of simulating a high level of spatial detail by allowing the division of a watershed into a large number of subwatersheds. In SWAT, a watershed is divided into multiple subwatersheds, which are then further subdivided into Hydrologic Response Units (HRUs) that consist of homogeneous land use, management, and soil characteristics. Flow generation, sediment yield, and non-point-source loadings from each HRU in a subwatershed are summed, and the resulting loads are routed through channels, ponds, and/or reservoirs to the watershed outlet. Key components of SWAT include hydrology, plant growth, erosion, nutrient transport and transformation, pesticide transport and management practices. Previous applications of SWAT for flow and/or pollutant loadings have compared favorably with measured data for a variety of watershed scales (Arnold and Allen, 1996; Arnold et al., 1999; Arnold et al., 2000; Saleh et al., 2000; Santhi et al., 2001; Kirsch et al., 2002; Grizzetti et al., 2003; Chaplot et al., 2004). Further details on the SWAT components are presented in Arnold et al. (1998) and Neitsch et al. (2002).

To estimate the water quality changes, it is necessary to calibrate SWAT to existing baseline data on the watersheds and to accurately represent the current land use, land management, and weather conditions of the region, using data obtained from several sources. Modifications in land use are performed using the previously described conservation practice algorithm and discrete choice economic models that take into account price effects and natural resource conditions. A schematic of the modeling system is depicted in Figure 3, including the data flows between the economic models and SWAT.

A key data source for the system is the previously described USDA 1997 NRI database, which contains soil type, landscape features, cropping histories, conservation practices, and other data for roughly 800,000 U.S. nonfederal land "points" including 23,498 in Iowa[10]. Each point represents an area that is assumed to consist of homogeneous land use, soil, and other characteristics, which generally ranges from a few hundred to several thousand hectares in size. Crop rotations incorporated in the SWAT simulations are derived from cropping histories reported in the NRI. Other land use delineations required for the simulation, including the locations of baseline conservation practices, are also based on NRI data. The tillage implements simulated for the different levels of tillage (conventional, reduced, mulch, and no) incorporated in the analysis were obtained from the USDA 1990-95 Cropping Practices Survey (CPS) available at http://usda.mannlib.cornell.edu/ usda/ess_entry.html). Historical precipitation, maximum temperature, and minimum temperature data obtained from the Iowa Environmental

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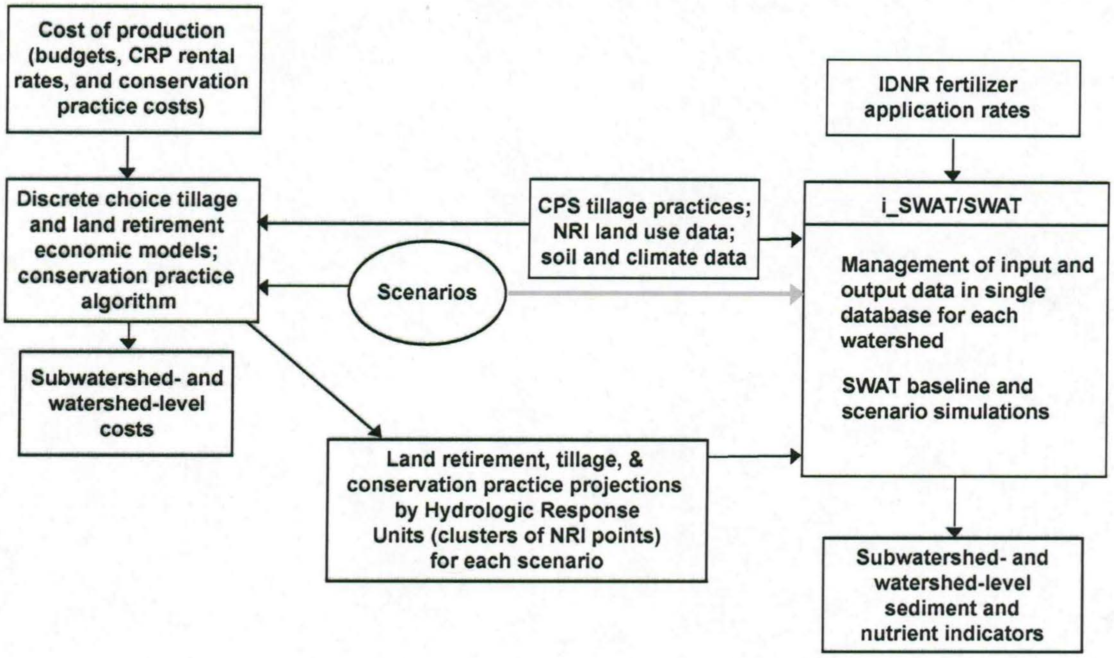
[10] These 23,498 points include the previously mentioned 15,781 cropland and CRP points.

**Figure 3. Schematic of the modeling system.**



Mesonet (http://mesonet.agron.iastate.edu/request /coop/fe. phtml) for the 18-year period (1980-99) were used for the SWAT simulations. The soil layer data required for the SWAT simulations is input from a soil database that contains soil properties consistent with those described by Baumer et al. (1994), with the additional enhancement of ID codes that allow direct linkage to NRI points.

The discrete choice tillage and land retirement economic models were used to estimate tillage and CRP costs, as a function of NRI and CPS data, production costs estimated using methods developed by AAEA (2000), and CRP land rental rates (Figure 3). The cost of the conservation practices were determined as previously discussed. The discrete choice tillage model was further used to determine which tillage level should be assigned to each NRI point for both the baseline and scenario simulations, depending on the soil and climatic characteristics for that point. The selection of which NRI points that land retirement, contouring, grassed waterways, and terraces should be assigned to, was based on the previously described conservation practices algorithm. New land use distributions predicted by the economic model are then input to SWAT by aggregating NRI points together that possess common land use, soil, and management characteristics (NRI clusters). The NRI clusters serve as Hydrologic Response Units (HRUs) in the SWAT simulations, which are further described in the HRU Development Process section. Nutrient management scenarios such as changes in fertilizer rates or timings are imposed directly on SWAT, rather than first being routed through the economic model. The SWAT executions, including the input and output data, are managed with the interactive SWAT (i_SWAT) software (Gassman et al. (2003); http://www.public.iastate.edu/ ~elvis), which is currently designed to support applications of SWAT2000 (Figure 3).

### HRU Delineation Process

Delineation of each watershed into smaller spatial units required for the SWAT simulations consists of two steps: (1) subdividing each watershed (Figure 1) into either U.S. Geological Survey (USGS) 8-digit Hydrologic Cataloging Unit (HCU) watersheds (Seaber et al., 1987) or smaller 10-digit watersheds (as described in http://www.igsb.uiowa.edu/nrgislibx/newsletters /2004-08%20GIS%20Newsletter%20 Vol%20III.pdf), and (2) creating smaller HRUs within each of the subwatersheds. Larger 8-digit subwatersheds were used for the Des Moines and Iowa River Watersheds (Figure 1), which were the two largest systems included in the analysis. The smaller 10-digit subwatersheds were used for those watersheds that consist of 1 to 3 8-digit watersheds (Figure 1), to avoid potential distortions in predicted pollutant indicators when only a small number of subwatersheds are used in a SWAT application as discussed by Jha et al. (2004).

The HRUs represent "lumped areas" of similar land use and soil types that are distributed throughout each subwatershed; however, exact spatial locations of the HRUs are not incorporated in the SWAT simulation. The HRUs required for the SWAT baseline simulations were created by aggregating NRI points together that possess common land use, soil, and management characteristics. All of the points within a given category were clustered together within each 8-digit watershed for the Des Moines and Iowa River Watershed simulations, except for the cultivated cropland. For the cultivated cropland, the NRI points were first aggregated into different crop rotation land use clusters within each 8-digit watershed, based on the NRI cropping histories. These crop rotation aggregations were then subdivided based on permutations of rotations; e.g., corn-soybean versus soybean-corn.

A more complex procedure was developed to construct the HRUs for the SWAT baseline simulations for the other 11 watersheds, because the NRI data is not spatially referenced at the 10-digit watershed level. To overcome this limitation, Iowa Soil Properties And Interpretations Database (ISPAID) soil data (http://extension.agron. iastate.edu/soils/pdfs/ISP71MAN.pdf) and 2002 IDNR land use data (IDNR-GSB, 2004) were used to help determine which HRUs should be placed in each 10-digit subwatershed. The initial step in the procedure consisted of attempting to match soil IDs shown in the ISPAID soil map for a 10-digit watershed, to soil IDs listed in the NRI for points located within the respective 8-digit watershed that the 10-digit watershed was located in. A positive match indicated that the NRI point could be located in that 10-digit watershed. If a positive match was not obtained, then the respective HRU area was initially split evenly between all the subwatersheds. The 2002 IDNR land use data was then used to determine how much the split HRU areas should be adjusted within each watershed, while maintaining the overall balance of each land area category.

The effect of conservation practices is accounted for by adjusting the "support practice (P) factor", which is one of the factors used in the original USLE equation (Wischmeier and Smith, 1978) and also in the MUSLE equation that is used in SWAT. The P factors used for contouring and terraces are based on values reported by Wischmeier and Smith (1978) as a function of slope range (Table 1). The choice of a P factor value of 0.4 for grassed waterways is based on the methodology used by Gassman et al. (2003) for simulating the impact of grassed waterways in the Mineral Creek Watershed in eastern Iowa. The effect of grassed waterways was further accounted for in SWAT by adjusting the Manning's N values for the affected HRUs.

**Table 7. Original P-factor values for contouring, strip-cropping, and terraces**

| Slope ranges | Contouring[a] | Terraces[a,b] | Grassed Waterways[c] |
|---|---|---|---|
| 1 to 2 | 0.6 | 0.12 | 0.4 |
| 3 to 5 | 0.5 | 0.1 | 0.4 |
| 6 to 8 | 0.5 | 0.1 | 0.4 |
| 9 to 12 | 0.6 | 0.12 | 0.4 |
| 13 to 16 | 0.7 | 0.14 | 0.4 |
| 17 to 20 | 0.8 | 0.16 | 0.4 |
| 21 to 25 | 0.9 | 0.18 | 0.4 |

[a] Source: Wischmeier and Smith (1978).
[b] Based on expected sediment yield for terraces with graded channels and outlets.
[c] Source: Gassman et al. (2003).

## Results

An calibration and validation exercise was performed with SWAT for the Raccoon River Watershed, to provide guidance as to how key parameters should be set for the simulation of the 13 study watersheds. Further hydrologic testing was performed for the 13 watersheds; however, the nitrate and sediment parameters that were calibrated for the Raccoon River were used for the 13 watersheds without further modification. The results of the Raccoon simulations are reported by Jha et al. (2005). This paper is also included here in Appendix D.

Tables 8 and 9 provide points of reference regarding the characteristics of each watershed and the increased amount of conservation practices by watershed for the two sets of scenario simulations, respectively. Table 10 lists the $r^2$ and model efficiency (E) statistics that were calculated for the streamflow calibration and validation phases for each watershed (further calibration results are shown in Appendix E). The total loadings for the baseline simulations are presented in Table 11 for each watershed for the five principal environmental indicators: sediment, nitrate, organic N, total N, and total P. The impacts of the scenario runs with and without the 10% reduction in fertilizer are reported in Tables 11 and 12, respectively. Figures 4 through 9 present graphical results of selected indicators for both the scenario with nutrient management (with NM) and without (without NM).

The results shown in Table 10 underscore that SWAT accurately replicated the streamflows for each watershed in both the calibration and validation periods. The monthly predictions were less accurate than the annual estimates but the majority of the $r^2$ and E values were still strong, especially in the validation period. The impacts of the initial scenario varied substantially between watersheds (Table 12). Predicted sediment decreases ranged from 6% for the Little Sioux River Watershed to 65% for the Nodaway River Watershed. Sediment reductions were greater than 30% for nine of the watersheds and 40% for seven of the watersheds. The nitrate impacts were relatively small; nitrate increases of 1 to 6% were predicted for five of the watersheds and nitrate reductions ranging from 2 to 13% were predicted the other eight watersheds, with the majority of the estimated reductions below 6%. The negative numbers likely reflect that increased nitrate leaching, followed by subsequent increases in nitrate losses via tile drains, can occur with increased levels of conservation tillage and terraces.

**Table 8. Characteristics of the 13 study watersheds.**

| # | Watershed | # of 8-digit watersheds | # of subwatersheds | Drainage Area | | Measured data from USGS station # | Key Land Uses (% of watershed) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | mi$^2$ | km$^2$ | | Cropland | Grassland (CRP and Pasture) | Forest | Urban |
| 1 | Floyd | 1 | 5 | 917 | 2,376 | 6600500 | 84 | 13 | 0 | 3 |
| 2 | Monona | 1 | 5 | 947 | 2,452 | 6602400 | 78 | 19 | 2 | 1 |
| 3 | Little Sioux | 2 | 10 | 3,553 | 9,203 | 6607500 | 86 | 13 | 1 | 0 |
| 4 | Boyer | 1 | 5 | 1,089 | 2,820 | 6609500 | 68 | 26 | 4 | 2 |
| 5 | Nishnabotna | 3 | 11 | 2,980 | 7,718 | 6810000 | 84 | 15 | 1 | 0 |
| 6 | Nodaway | 1 | 7 | 792 | 2,051 | 6817000 | 52 | 41 | 5 | 3 |
| 7 | Des Moines | 9 | 9 | 14,477 | 37,496 | 5490500 | 71 | 16 | 6 | 7 |
| 8 | Skunk | 3 | 12 | 4,342 | 11,246 | 5474000 | 69 | 25 | 5 | 1 |
| 9 | Iowa | 9 | 9 | 12,663 | 32,796 | 5465500 | 77 | 12 | 4 | 8 |
| 10 | Wapsipinicon | 2 | 11 | 2,542 | 6,582 | 5422000 | 77 | 19 | 3 | 1 |
| 11 | Maquoketa | 1 | 10 | 1,864 | 4,827 | 5418500 | 56 | 32 | 10 | 3 |
| 12 | Turkey | 1 | 9 | 1,699 | 4,400 | 5412500 | 56 | 25 | 16 | 3 |
| 13 | Upper Iowa | 1 | 7 | 992 | 2,569 | 5388250 | 51 | 26 | 19 | 3 |

**Table 9. Increase in CRP, conservation tillage, contouring, grassed waterways, and terraces by watershed.**

| # | Watershed | New CRP acres | New CT acres | New contour acres | New GW acres | New terrace acres | % increase CRP | % increase CT | % increase contour | % increase GW | % increase terraces |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Floyd | 5,600 | 170,500 | 65,400 | 197,400 | 26,700 | 200.0 | 57.7 | 149.7 | N/A | 174.5 |
| 2 | Monona | 26,100 | 111,100 | 43,000 | 47,400 | 36,400 | 100.8 | 44.3 | 70.4 | 515.2 | 136.3 |
| 3 | Little Sioux | 47,200 | 454,100 | 83,100 | 508,600 | 97,300 | 65.7 | 54.4 | 102.0 | 1457.3 | 384.6 |
| 4 | Boyer | 46,300 | 296,000 | 38,800 | # | 109,600 | 167.1 | 231.8 | 36.1 | 165.9 | 735.6 |
| 5 | Nishnabotna | 129,600 | 776,600 | 41,500 | 121,000 | 212,700 | 330.6 | 179.9 | 13.0 | 79.8 | 217.0 |
| 6 | Nodaway | 16,700 | 133,800 | 22,200 | 46,600 | 46,100 | 75.9 | 81.4 | 27.6 | 45.3 | 45.3 |
| 7 | Des Moines | 98,200 | 847,700 | 199,100 | 1,688,200 | 559,400 | 31.2 | 22.2 | 130.2 | 945.8 | 316.2 |
| 8 | Skunk | 63,200 | 569,000 | 86,600 | 447,200 | 353,100 | 31.6 | 57.9 | 118.3 | 241.2 | 288.2 |
| 9 | Iowa | 90,800 | 1,409,300 | 302,400 | 2,157,800 | 713,900 | 32.1 | 38.5 | 94.6 | 337.2 | 400.8 |
| 10 | Wapsipinicon | 29,300 | 314,900 | 56,900 | 485,400 | 111,400 | 94.2 | 38.0 | 63.9 | 298.9 | 90.3 |
| 11 | Maquoketa | 42,400 | 301,800 | 33,200 | 241,600 | 182,800 | 56.6 | 75.4 | 28.0 | 153.7 | 38.7 |
| 12 | Turkey | 38,100 | 249,000 | 27,100 | 291,900 | 192,700 | 60.9 | 65.3 | 61.6 | 1006.6 | 341.7 |
| 13 | Upper Iowa | 18,800 | 149,100 | 15,700 | 72,200 | 67,600 | 35.1 | 177.7 | 43.5 | 280.9 | 108.7 |

**Table 10. Streamflow calibration results for the 13 study watersheds.**

| # | Watershed | Statistical Evaluation | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Annual | | | | Monthly | | | |
| | | Calibration (1980-1989) | | Validation (1990-1997) | | Calibration (1980-1989) | | Validation (1990-1997) | |
| | | $R^2$ | E | $R^2$ | E | $R^2$ | E | $R^2$ | E |
| 1 | Floyd | 0.94 | 0.91 | 0.71 | 0.66 | 0.68 | 0.66 | 0.52 | 0.49 |
| 2 | Monona | 0.93 | 0.83 | 0.78 | 0.62 | 0.69 | 0.67 | 0.62 | 0.54 |
| 3 | Little Sioux | 0.94 | 0.93 | 0.88 | 0.86 | 0.71 | 0.70 | 0.75 | 0.75 |
| 4 | Boyer | 0.91 | 0.79 | 0.93 | 0.91 | 0.70 | 0.56 | 0.81 | 0.78 |
| 5 | Nishnabotna | 0.93 | 0.91 | 0.95 | 0.93 | 0.81 | 0.73 | 0.83 | 0.83 |
| 6 | Nodaway | 0.96 | 0.95 | 0.93 | 0.92 | 0.75 | 0.74 | 0.78 | 0.76 |
| 7 | Des Moines | 0.92 | 0.92 | 0.91 | 0.87 | 0.62 | 0.60 | 0.77 | 0.75 |
| 8 | Skunk | 0.96 | 0.96 | 0.99 | 0.99 | 0.63 | 0.62 | 0.81 | 0.81 |
| 9 | Iowa | 0.87 | 0.85 | 0.95 | 0.93 | 0.77 | 0.76 | 0.90 | 0.89 |
| 10 | Wapsipinicon | 0.75 | 0.74 | 0.93 | 0.90 | 0.58 | 0.56 | 0.84 | 0.84 |
| 11 | Maquoketa | 0.85 | 0.77 | 0.89 | 0.85 | 0.67 | 0.49 | 0.80 | 0.78 |
| 12 | Turkey | 0.89 | 0.86 | 0.91 | 0.85 | 0.70 | 0.64 | 0.79 | 0.75 |
| 13 | Upper Iowa | 0.95 | 0.90 | 0.81 | 0.80 | 0.66 | 0.59 | 0.79 | 0.78 |

**Table 11. Annual average baseline loadings in Metric tons (1980-1997).**

| # | Watershed | Sediment | Nitrate | Org N | Total N | Total P |
|---|---|---|---|---|---|---|
| 1 | Floyd | 244,739 | 7,315 | 1,492 | 8,807 | 492 |
| 2 | Monona | 192,448 | 4,971 | 769 | 5,740 | 333 |
| 3 | Little Sioux | 594,045 | 26,179 | 3,426 | 29,596 | 1,507 |
| 4 | Boyer | 715,817 | 5,235 | 2,227 | 7,461 | 794 |
| 5 | Nishnabotna | 3,231,484 | 15,189 | 6,604 | 21,793 | 2,788 |
| 6 | Nodaway | 507,407 | 3,316 | 1,364 | 4,680 | 530 |
| 7 | Des Moines | 2,202,076 | 38,146 | 25,680 | 63,826 | 7,217 |
| 8 | Skunk | 4,982,535 | 30,041 | 5,015 | 35,057 | 2,549 |
| 9 | Iowa | 3,433,834 | 53,855 | 54,527 | 108,383 | 8,516 |
| 10 | Wapsipinicon | 1,901,955 | 29,911 | 3,165 | 33,077 | 1,325 |
| 11 | Maquoketa | 1,274,626 | 14,766 | 3,597 | 18,362 | 1,111 |
| 12 | Turkey | 1,371,444 | 12,416 | 2,586 | 15,003 | 924 |
| 13 | Upper Iowa | 880,420 | 3,738 | 1,189 | 4,927 | 426 |

**Table 12. Percent reduction (proposed conservation practices w/o nutrient management).**

| # | Watershed | Sediment | Nitrate | Org N | Total N | Total P |
|---|---|---|---|---|---|---|
| 1 | Floyd | 30 | -1 | 54 | 9 | 51 |
| 2 | Monona | 11 | 2 | 41 | 8 | 41 |
| 3 | Little Sioux | 6 | 2 | 50 | 7 | 48 |
| 4 | Boyer | 35 | 4 | 53 | 19 | 53 |
| 5 | Nishnabotna | 43 | 13 | 53 | 25 | 51 |
| 6 | Nodaway | 45 | 6 | 46 | 17 | 45 |
| 7 | Des Moines | 10 | -5 | 40 | 14 | 37 |
| 8 | Skunk | 63 | 5 | 53 | 12 | 51 |
| 9 | Iowa | 14 | -5 | 50 | 23 | 47 |
| 10 | Wapsipinicon | 64 | 1 | 52 | 6 | 49 |
| 11 | Maquoketa | 47 | -6 | 58 | 6 | 55 |
| 12 | Turkey | 65 | -3 | 61 | 8 | 58 |
| 13 | Upper Iowa | 50 | 1 | 38 | 10 | 27 |

**Table 13. Percent reduction (proposed conservation practices with nutrient management).**

| # | Watershed | Sediment | Nitrate | Org N | Total N | Total P |
|---|---|---|---|---|---|---|
| 1 | Floyd | 30 | 13 | 54 | 20 | 52 |
| 2 | Monona | 10 | 17 | 41 | 20 | 42 |
| 3 | Little Sioux | 6 | 11 | 51 | 15 | 49 |
| 4 | Boyer | 35 | 16 | 54 | 27 | 53 |
| 5 | Nishnabotna | 43 | 20 | 53 | 30 | 52 |
| 6 | Nodaway | 45 | 11 | 47 | 22 | 45 |
| 7 | Des Moines | 10 | 6 | 41 | 20 | 37 |
| 8 | Skunk | 63 | 13 | 54 | 19 | 51 |
| 9 | Iowa | 13 | 6 | 51 | 29 | 48 |
| 10 | Wapsipinicon | 64 | 9 | 52 | 14 | 50 |
| 11 | Maquoketa | 46 | 9 | 59 | 19 | 56 |
| 12 | Turkey | 65 | 10 | 62 | 19 | 59 |
| 13 | Upper Iowa | 50 | 10 | 40 | 17 | 28 |

The estimated relative reductions for organic N and total P were much greater; the predicted loadings for these three indicators were 27 to 61% lower as compared to the baseline loadings. However, the predicted reductions in total N ranged from only 6 to 25% across the 13 watersheds, indicating that nitrate loads were the dominant component of the overall N losses.

The addition of the 10% reduction in fertilizer resulted in a clear increase in predicted reductions in nitrate losses for the second scenario run (Table 14), which ranged from 6 to 20% less than the baseline loadings for the 13 watersheds. This impact was also reflected in the losses predicted for total N. The impacts on sediment and total P were slight or negligible.

The results shown in Tables 12 and 13, and in Figures 4 through 9, reflect in part differences in initial baseline fertilizer rates and in the adoption rates of conservation practices for the scenario simulations. The size and environmental conditions of each watershed also affect the predicted outcomes. The low sediment reductions predicted for the Des Moines and Iowa River Watersheds reflect the effect of reservoirs in those two systems that trap much of the sediment upstream from the watershed outlets.

**Figure 4. Percentage reduction of sediment from the baseline by watershed (with NM)**

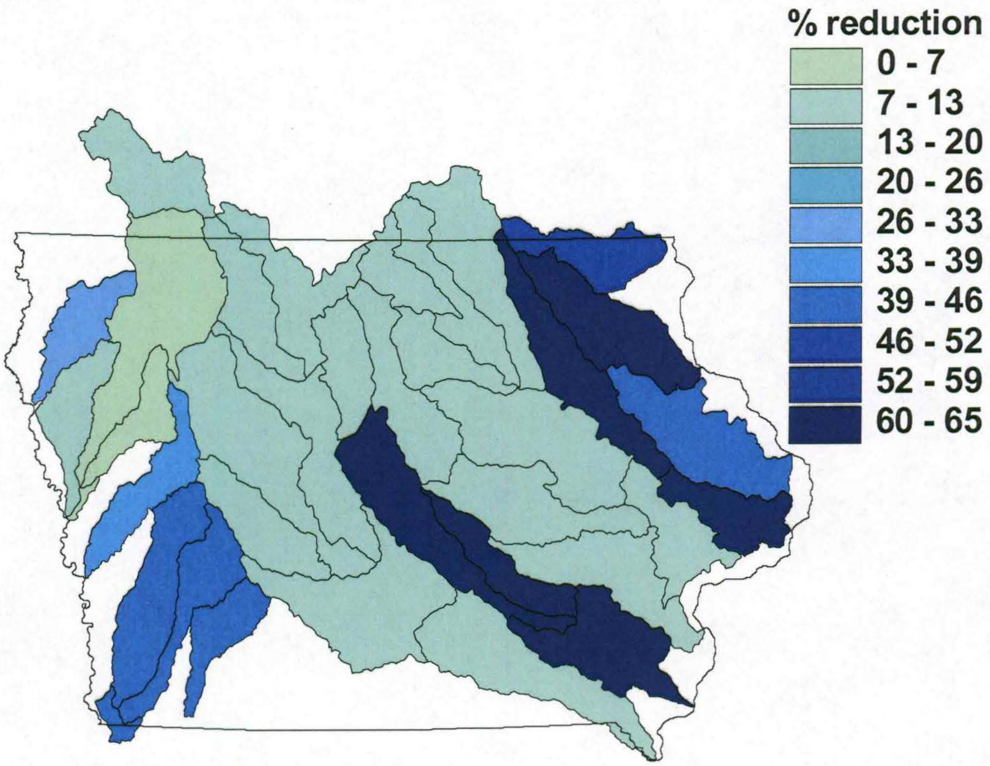


Figure 5. % reduction of Total P from the baseline by watershed (with NM)

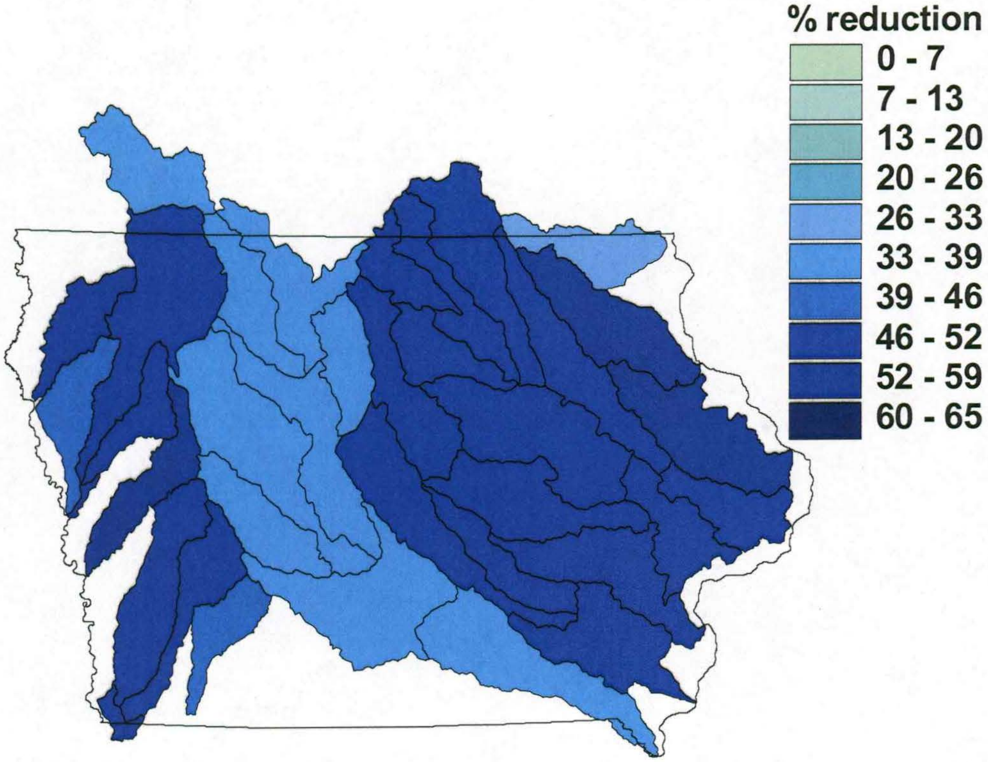


Figure 6. % reduction of Total N from the baseline by watershed (with NM)

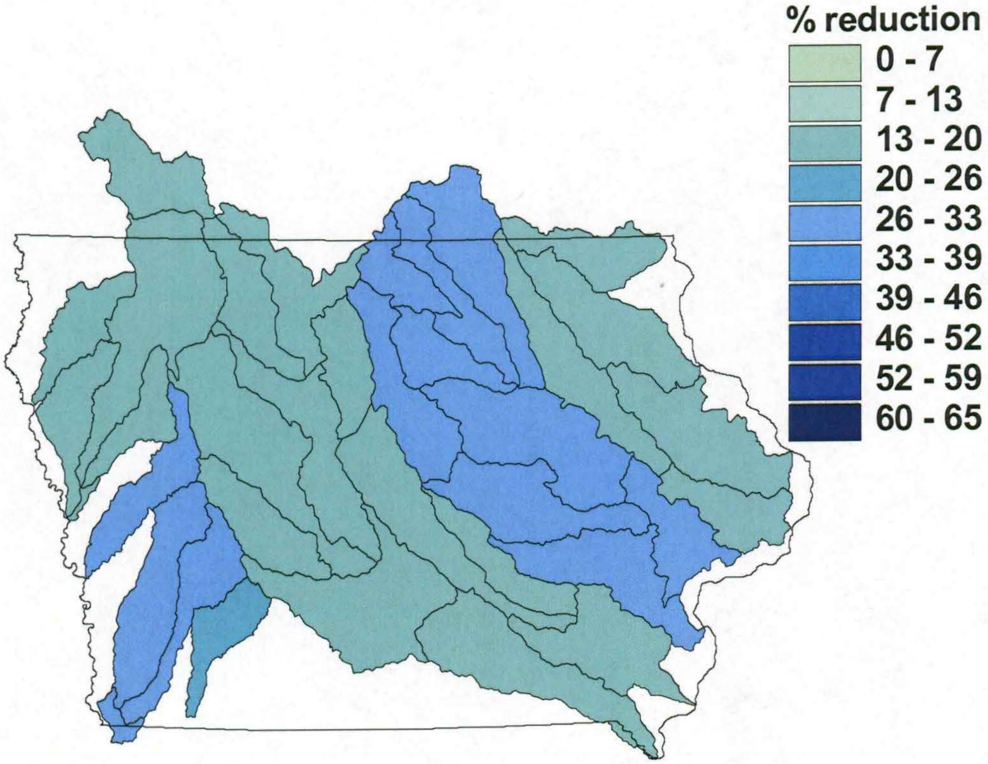


Figure 7. % reduction of Total N from the baseline by watershed (without NM)

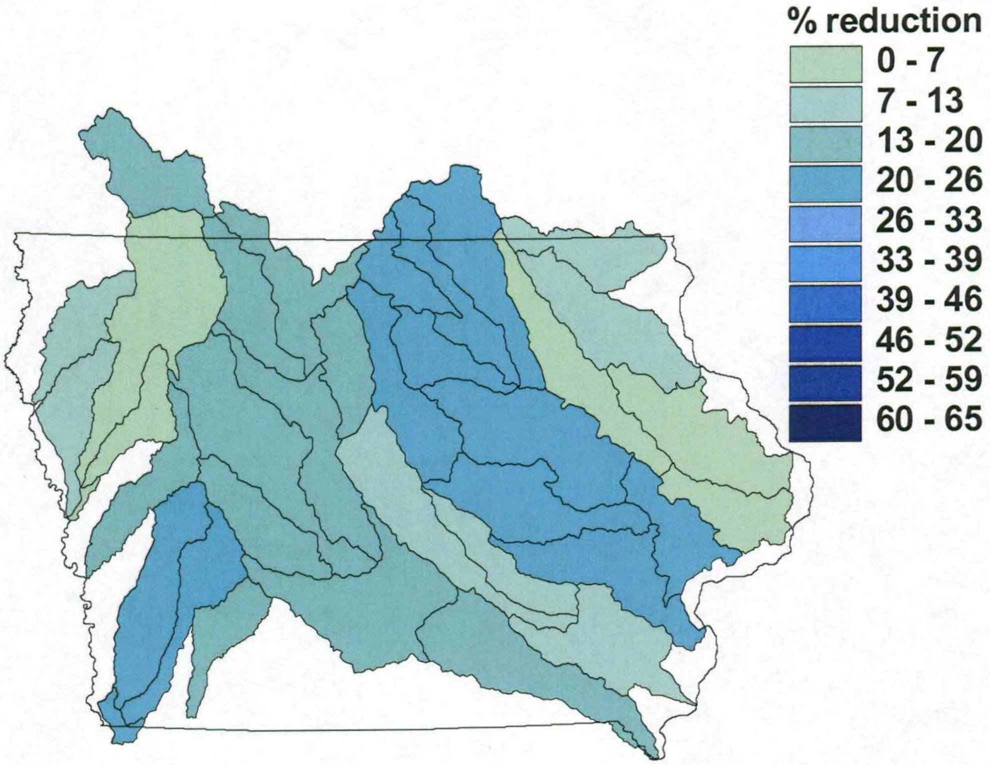


Figure 8. % reduction of Nitrates from the baseline by watershed (with NM)

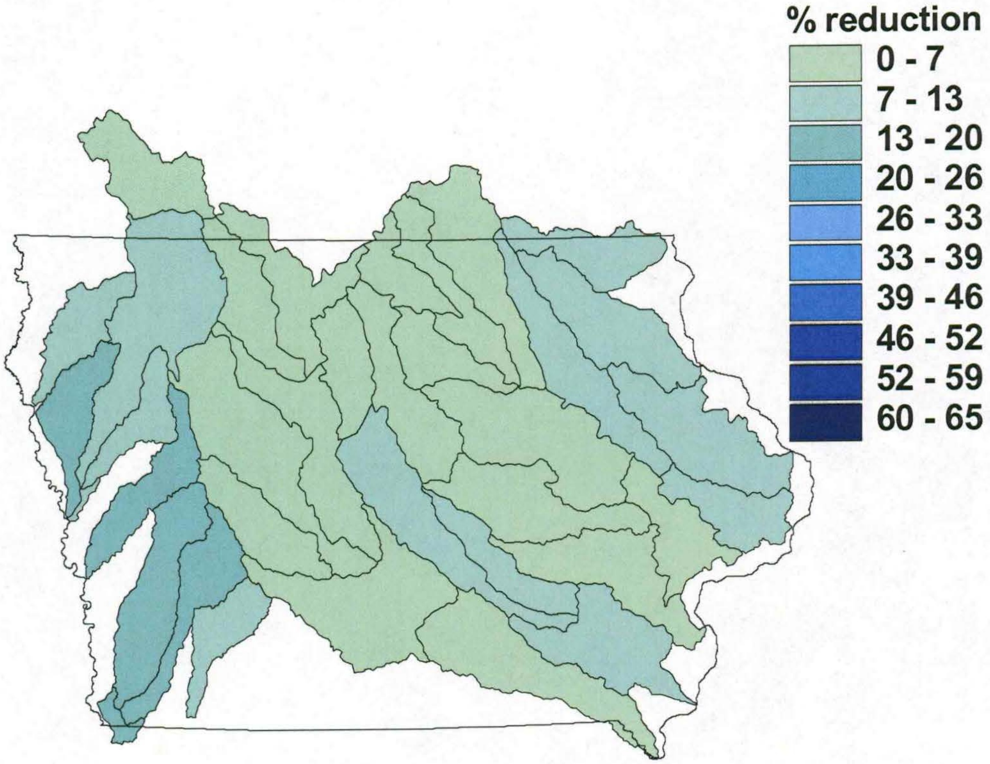
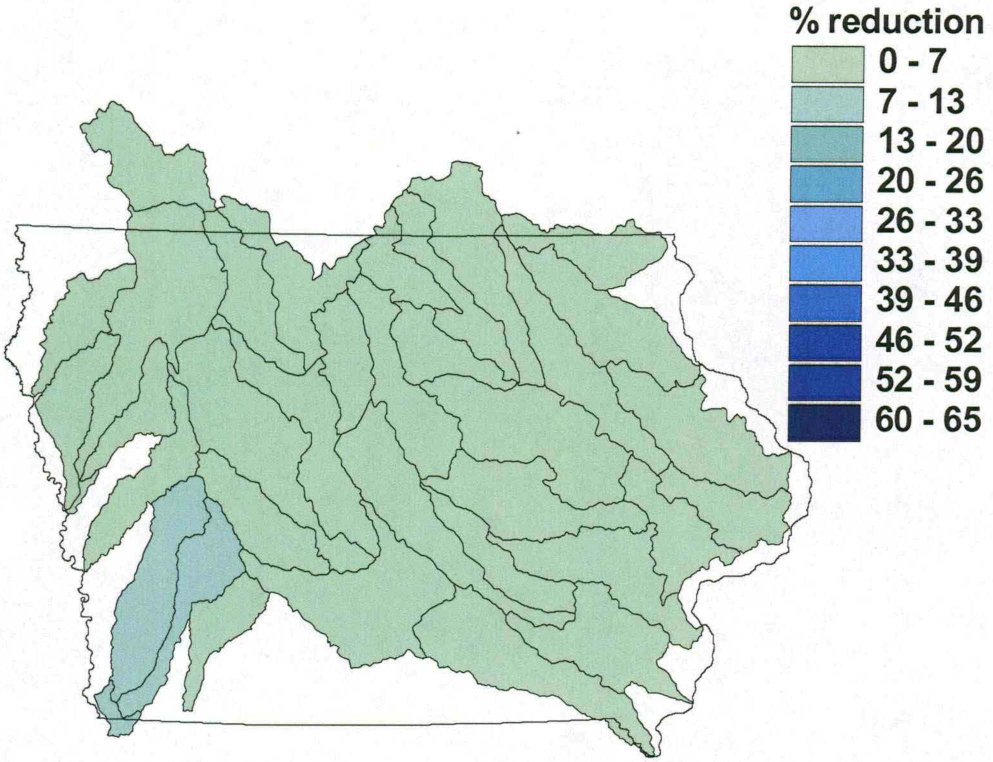


**Figure 9. % reduction of Nitrates from the baseline by watershed (without NM)**



## V. Caveats

In this section, we identify some of the most serious shortcomings and limitations of the study.

1. The hydrologic model, SWAT, does not handle conservation practices that require a fine spatial scale of analysis such as constructed wetlands or riparian buffers. Given this, we did not consider wetlands or riparian buffers as possible practices. Constructed wetlands are likely to be particularly important in controlling nitrogen runoff and therefore biases our findings towards more limited nitrate reductions. This is important when comparing the predicted sediment and nitrate reductions. Currently work is underway to add capacity to SWAT to model wetlands and buffers which can then be considered as options in future work.

2. While the costs reported in this report represent our best, current estimate of the costs of implementing the identified sets of practices, they do not necessarily meet the "need" of a particular level of water quality. Ideally, the target level of water quality would have been

identified and then the set of practices and their location that meets that water quality level at the lowest possible cost would have then been chosen and their cost computed. Instead, the estimates presented here are based on the identification of a set of practices from which we have employed the SWAT model to estimate water quality changes. Whether these water quality changes are the appropriate levels or not and whether the practices employed are the lowest cost options are major questions that are not addressed here.

3. There are no costs attributable to transaction costs associated with implementing a policy that might achieve the implementation of this scenario. Even the most efficient policy design will have some costs of implementation, enforcement, etc.

4. There are a number of limitations related to the quality and quantity of information on conservation practices and their location. For example, we only know if an NRI point is within an 8-digit HUC, but not precisely where within that HUC. Thus, the unit of analysis is quite coarse. The 1997 NRI release does not provide information on conservation tillage adoption so we have predicted adoption from a 1992 NRI estimated model calibrated to aggregate 1997 adoption data. Similarly, the NRI does not provide information on management practices such as fertilizer application and time of planting, so once again we have combined the NRI data with information from other sources.

5. A number of limitations concerning the quality of the cost data used in the analysis exist. While we found a number of potential sources of information related to the costs of conservation practices for various program participants, we were not able to find clearly relevant cost data that could reasonably be applied to the typical, currently non-adopting farmer/landowner. This issue was especially difficult for the costing of the fertilizer reduction.

6. The modeling of the reduction in fertilizer application in the SWAT simulation was overly simplistic. We assumed that there was a uniform rate of fertilizer on all corn acres within

each watershed, and a single spring application. In general, the assumption probably results in a bias toward over application of fertilizer on corn and it obviously eliminates the possibility of fall application of fertilizer by construction.

7. The results may be sensitive to the procedure described in the document concerning the aggregation of the NRI points into SWAT Hydrologic Response Units (HRUs).

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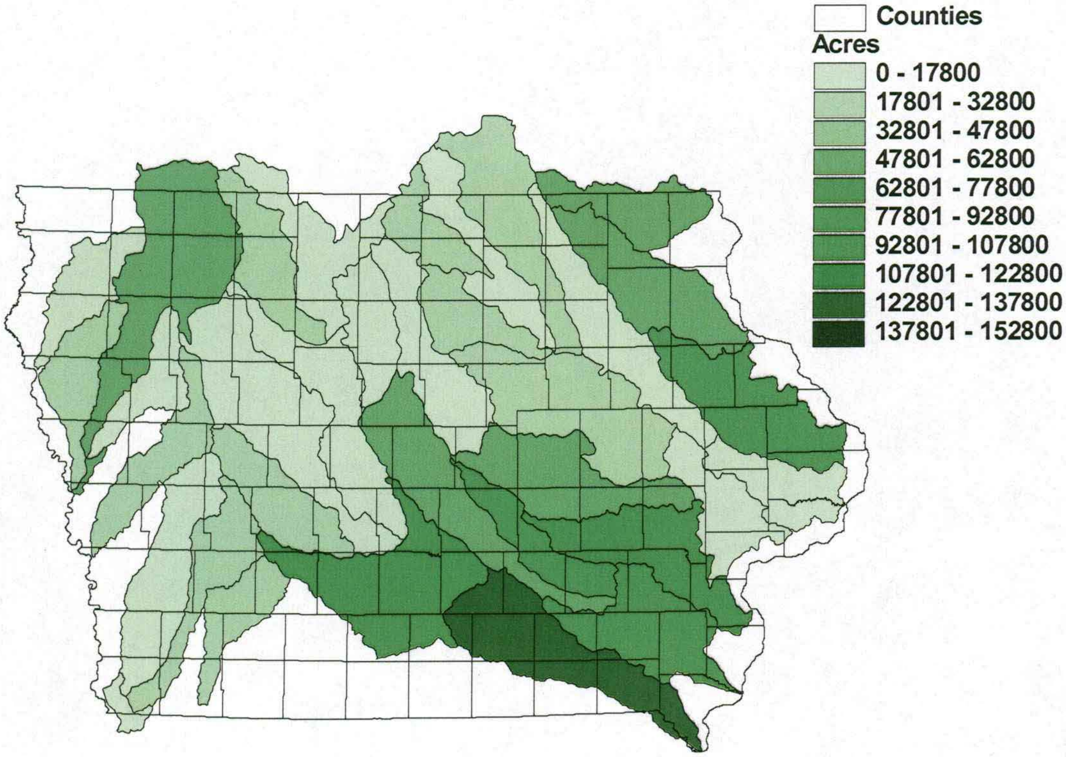
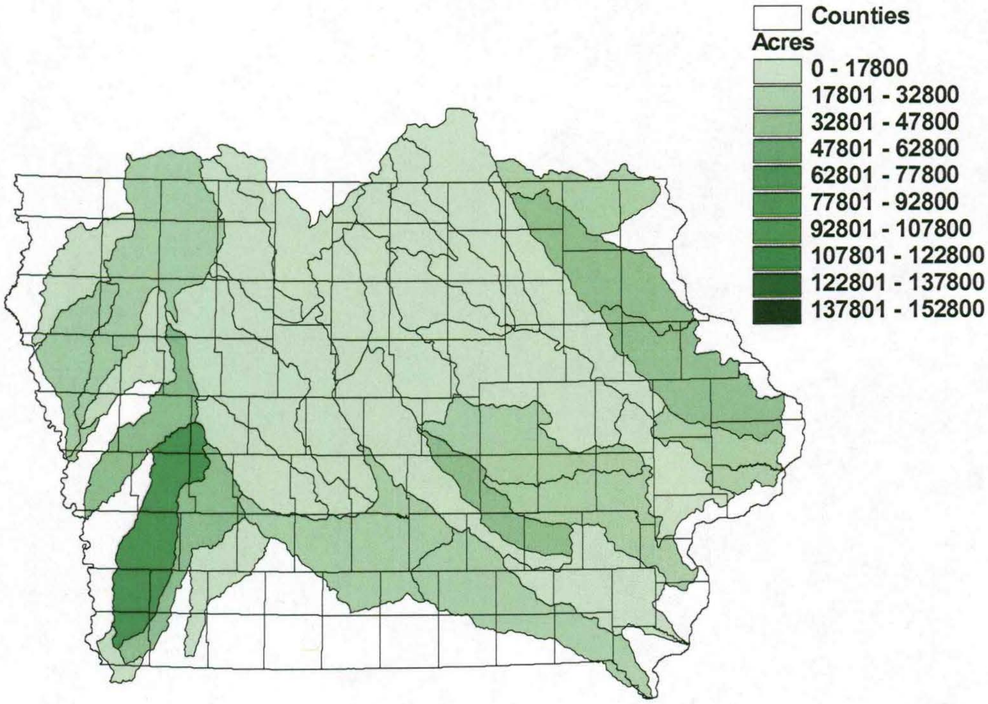
## Appendix A: Location of practices on the land by watershed

In this appendix, we summarize the placement of the identified practices within the watersheds. Existing acreage represents the baseline, from the NRI or our models. Policy scenario additional acres represent the new acreage hypothesized from the scenario, and total acreage corresponds to the sum of existing and additional acres used in the SWAT simulation. There are three maps for CRP (existing, additional, and total), conservation tillage, contour farming, terraces and grassed waterways. Note that there is only a single map for nutrient management and that we used the same legend for old, new and total acreage in each practice to allow for an easier comparison of the extent of the policy changes.

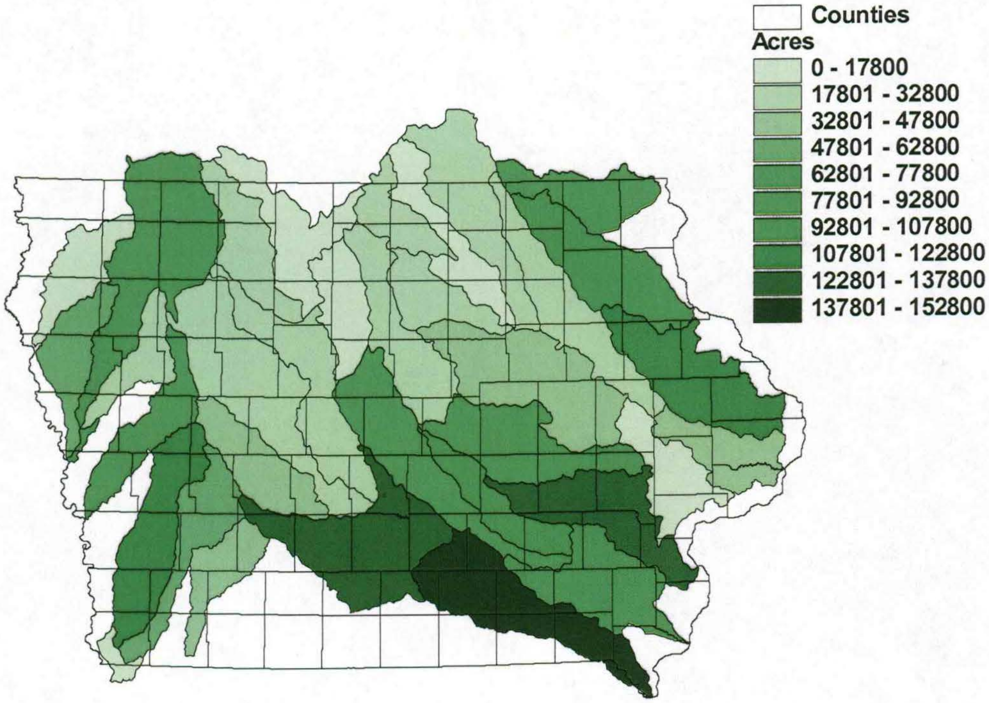
Existing CRP acres



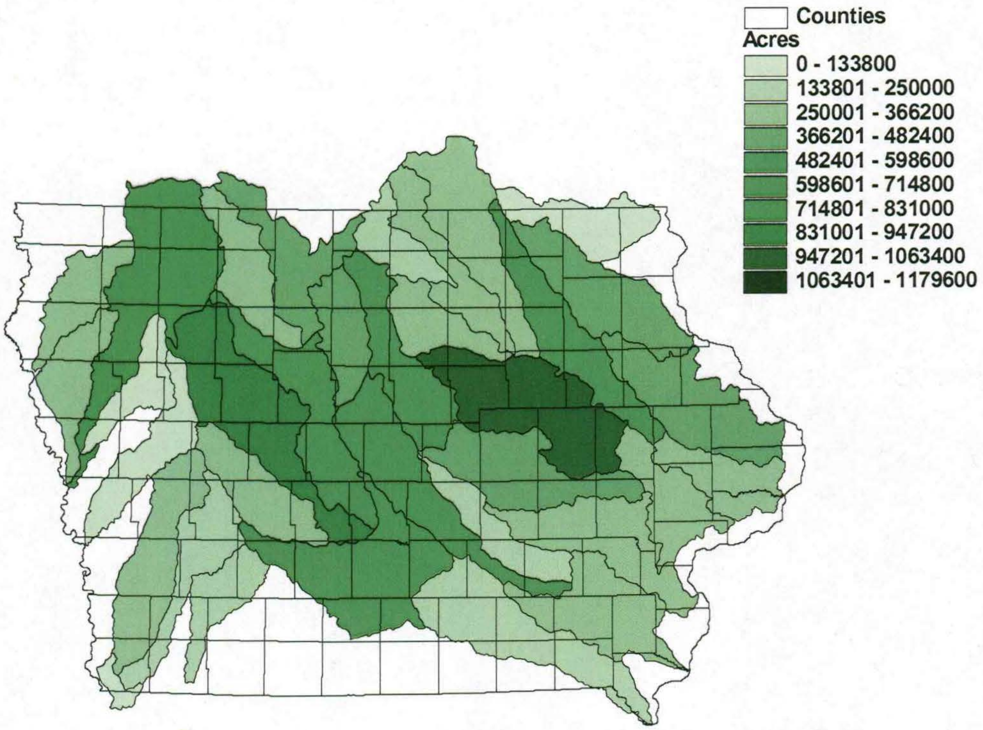
Policy scenario additional CRP acres



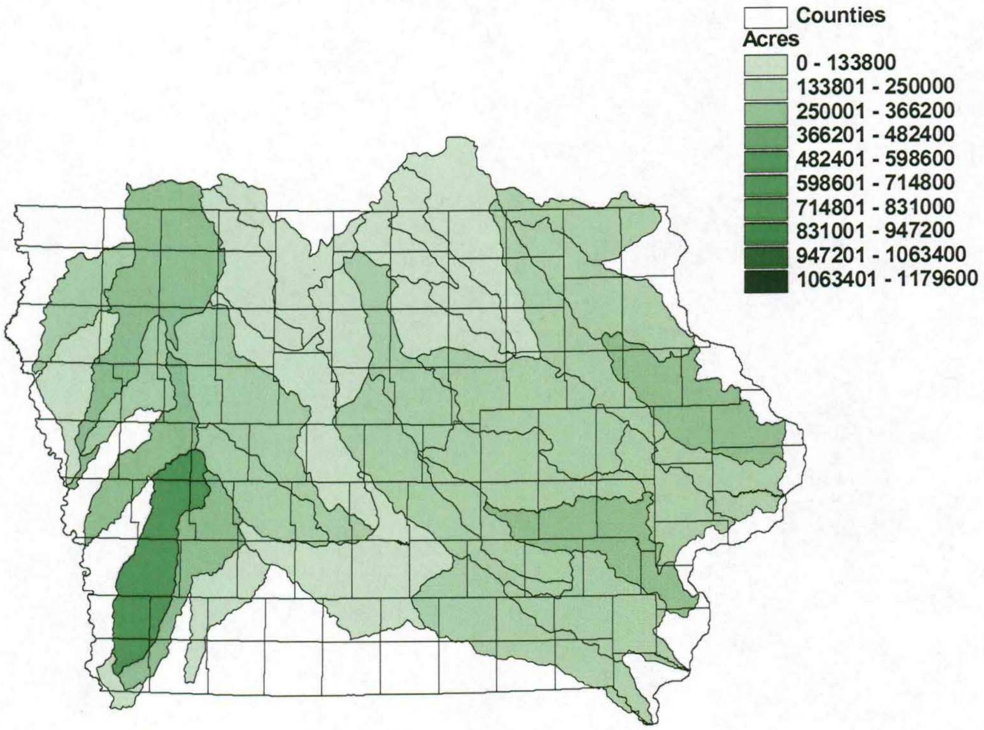
Policy scenario total CRP acres



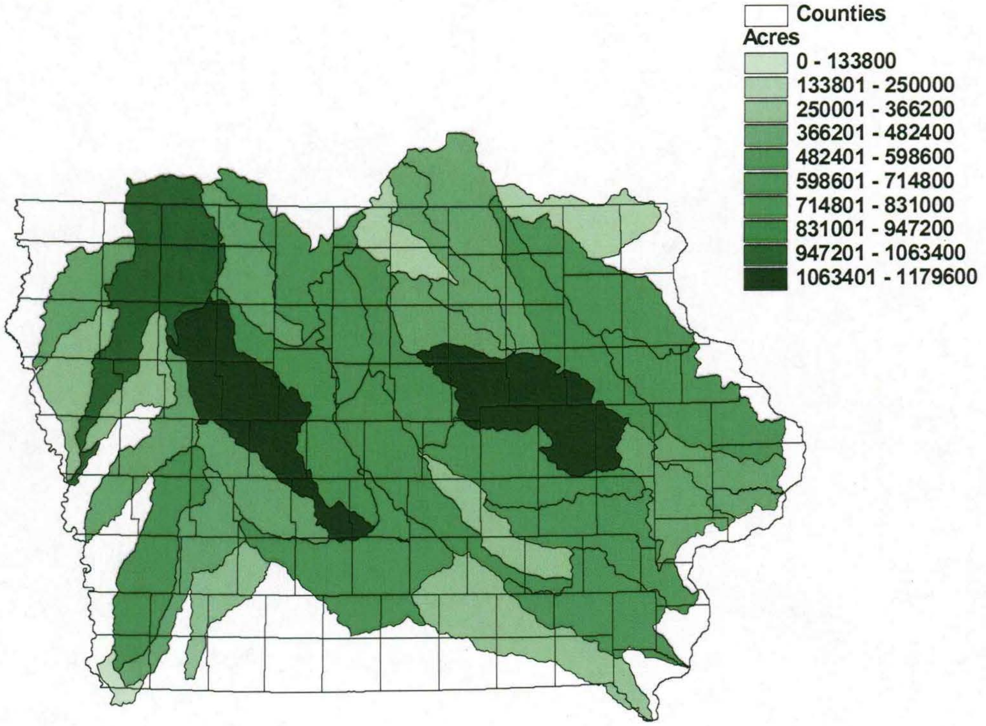
Existing conservation tillage acres



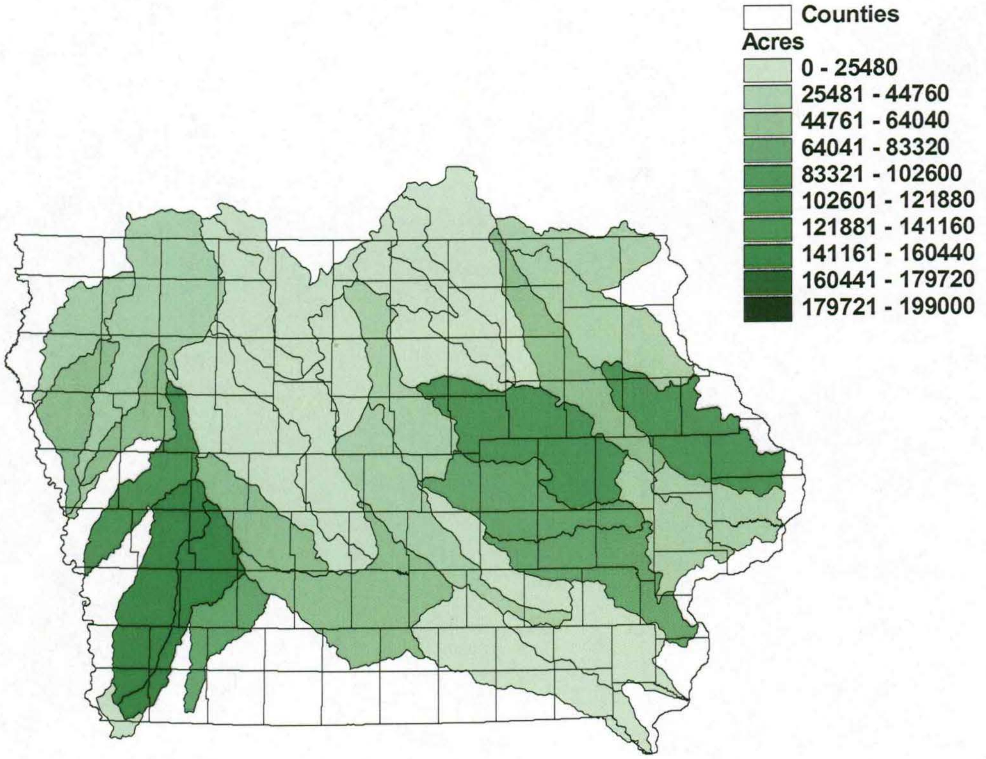
Policy scenario additional conservation tillage acres



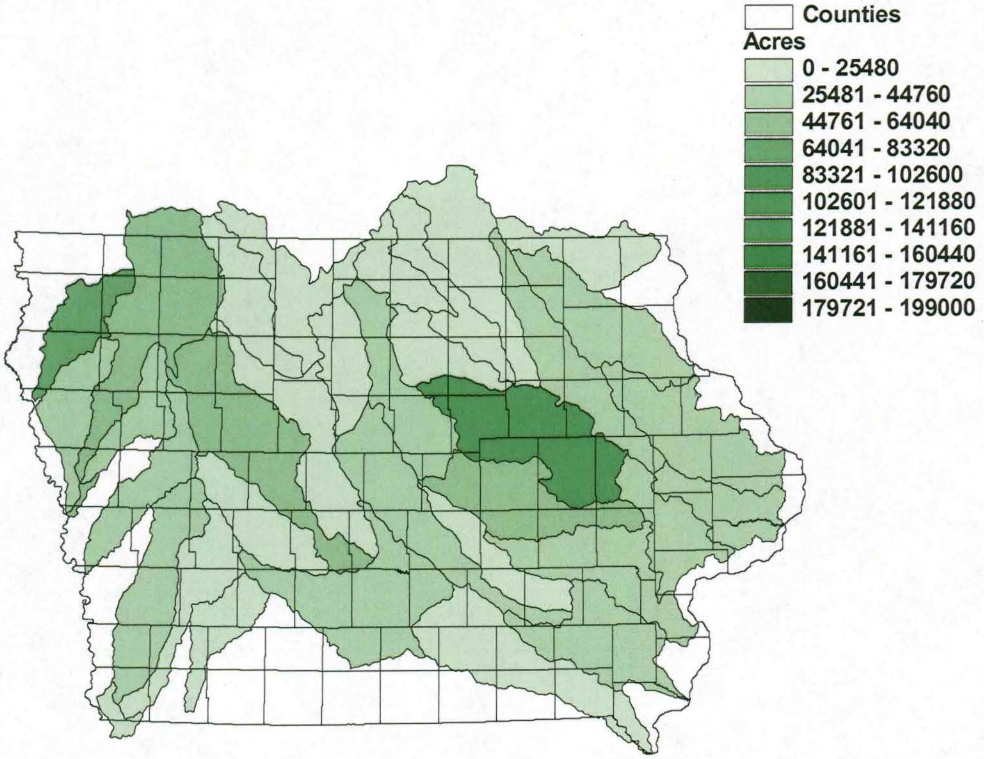
Policy scenario total conservation tillage acres



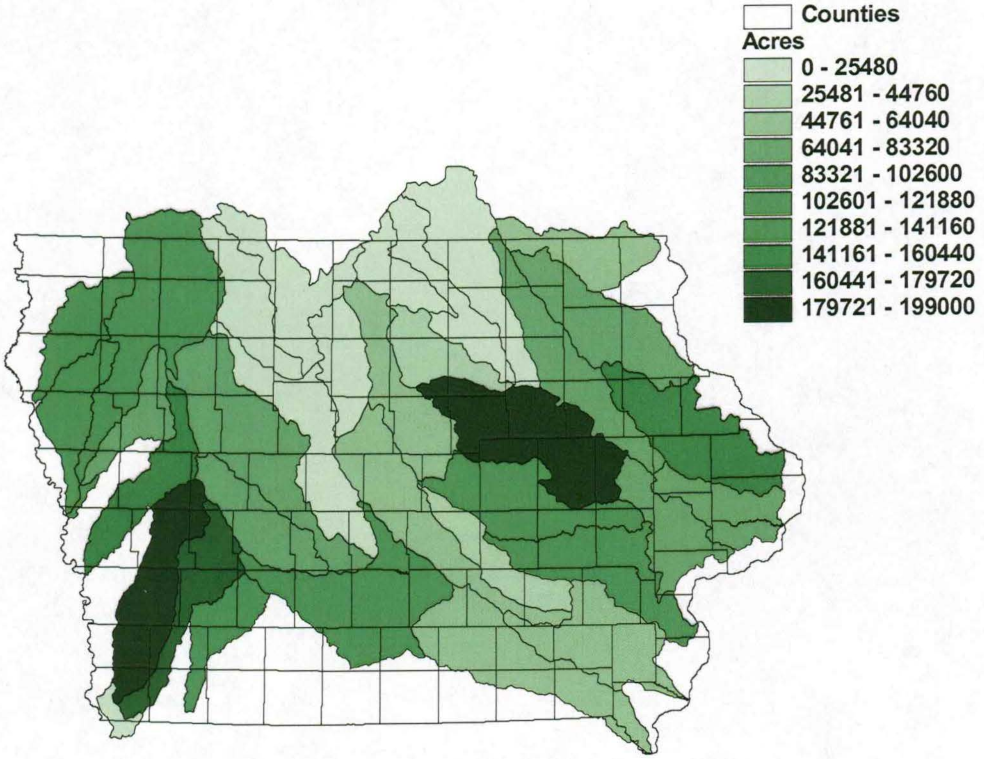
Existing contour acres



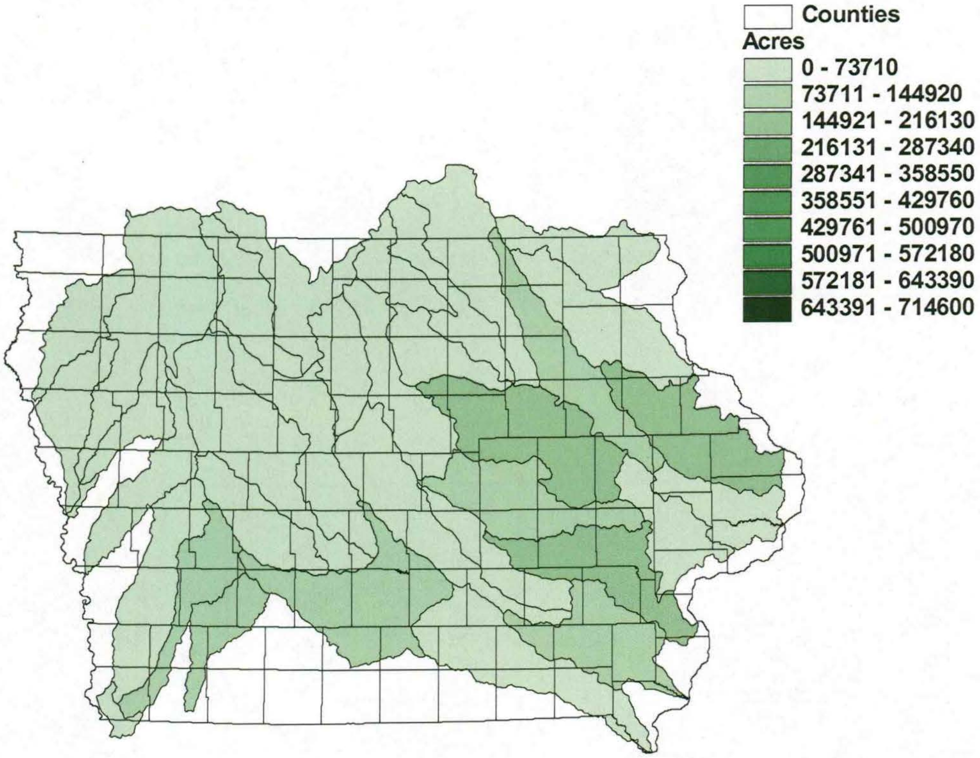
Policy scenario additional contour acres



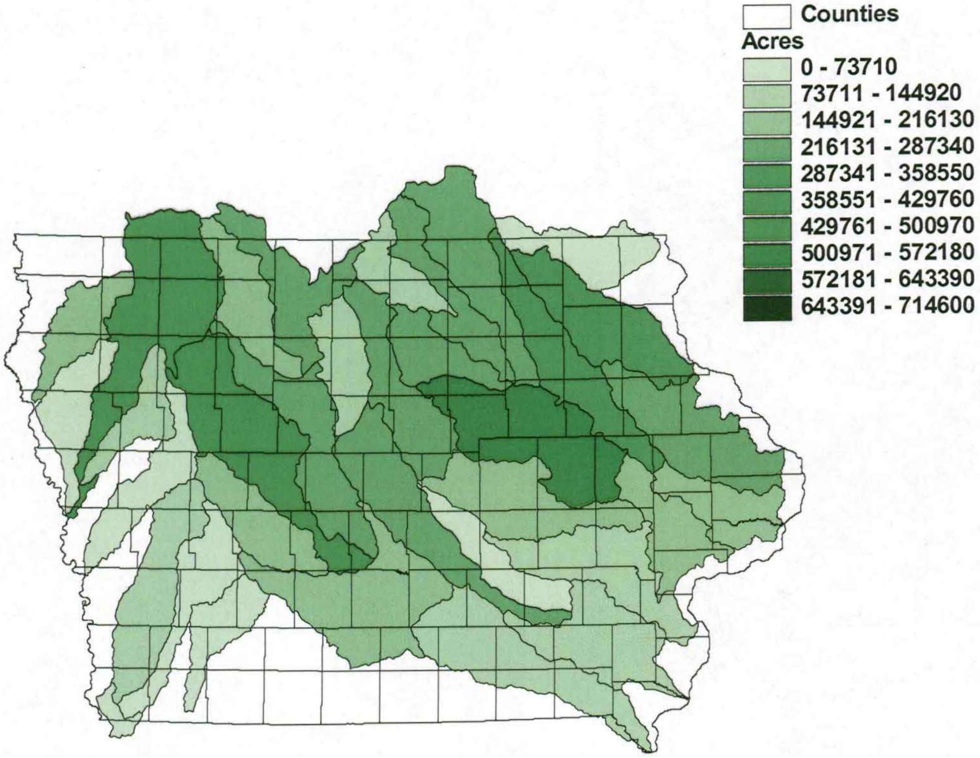
Policy scenario total contour acres



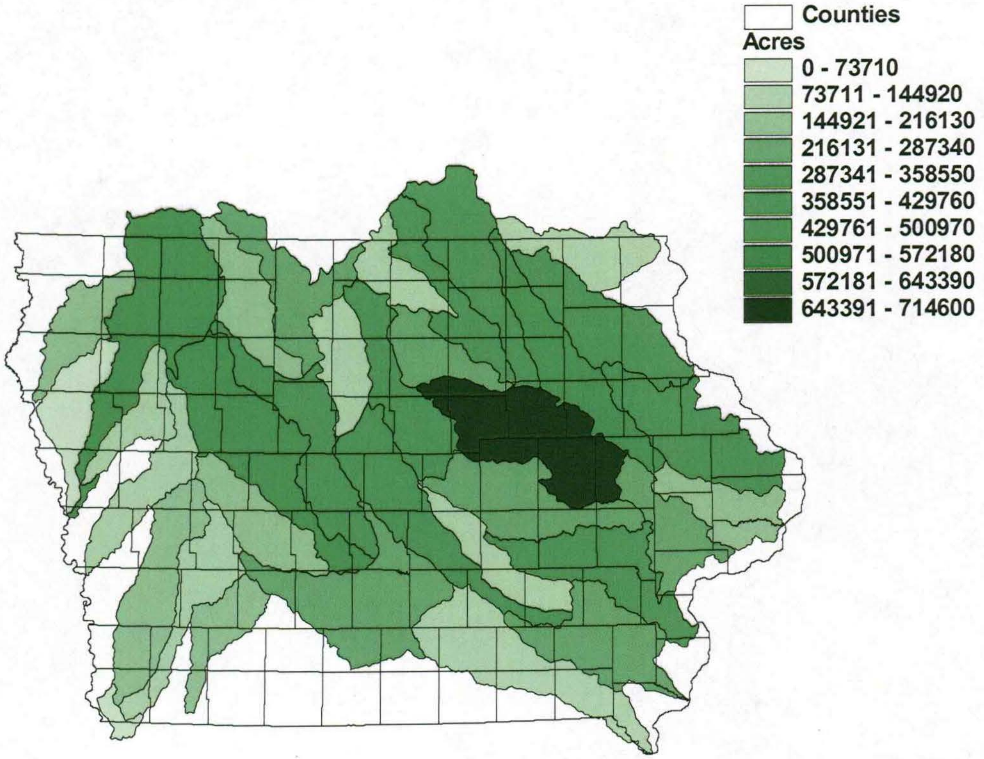
Existing grassed waterways acres



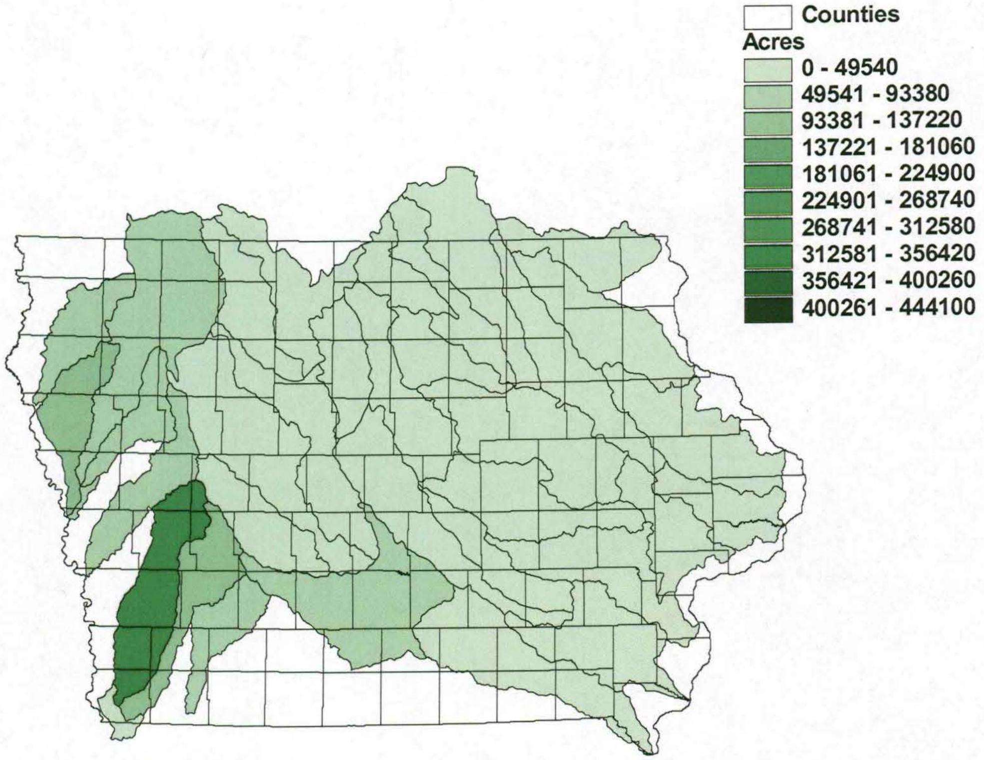
Policy scenario additional grassed waterways acres



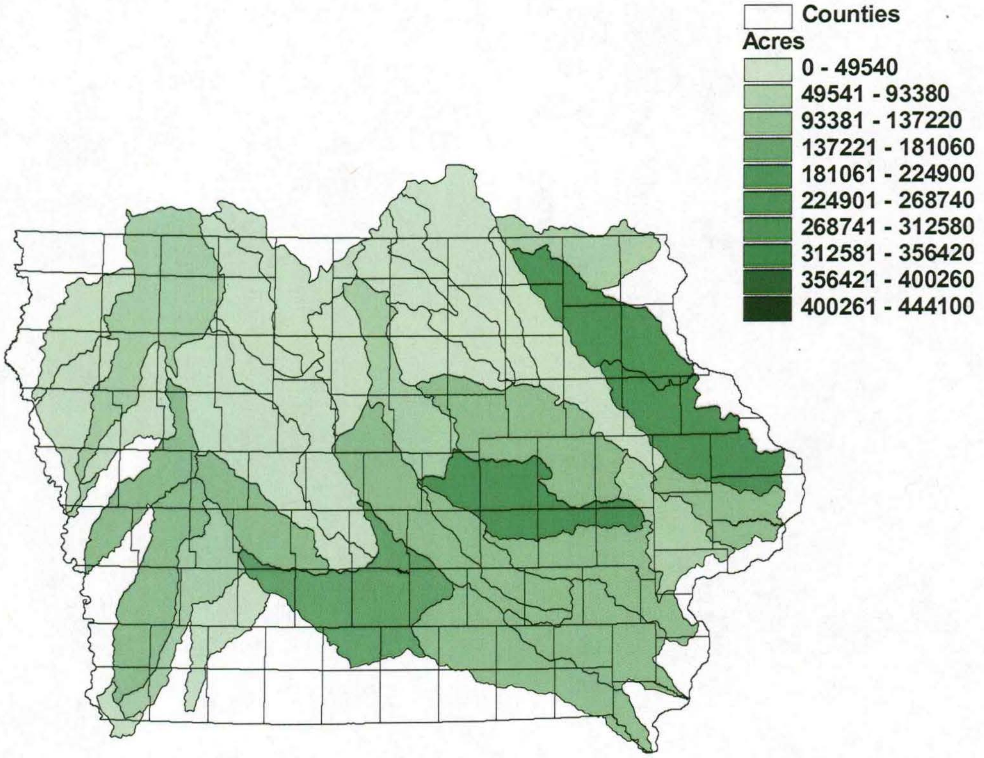
Policy scenario total grassed waterways acres



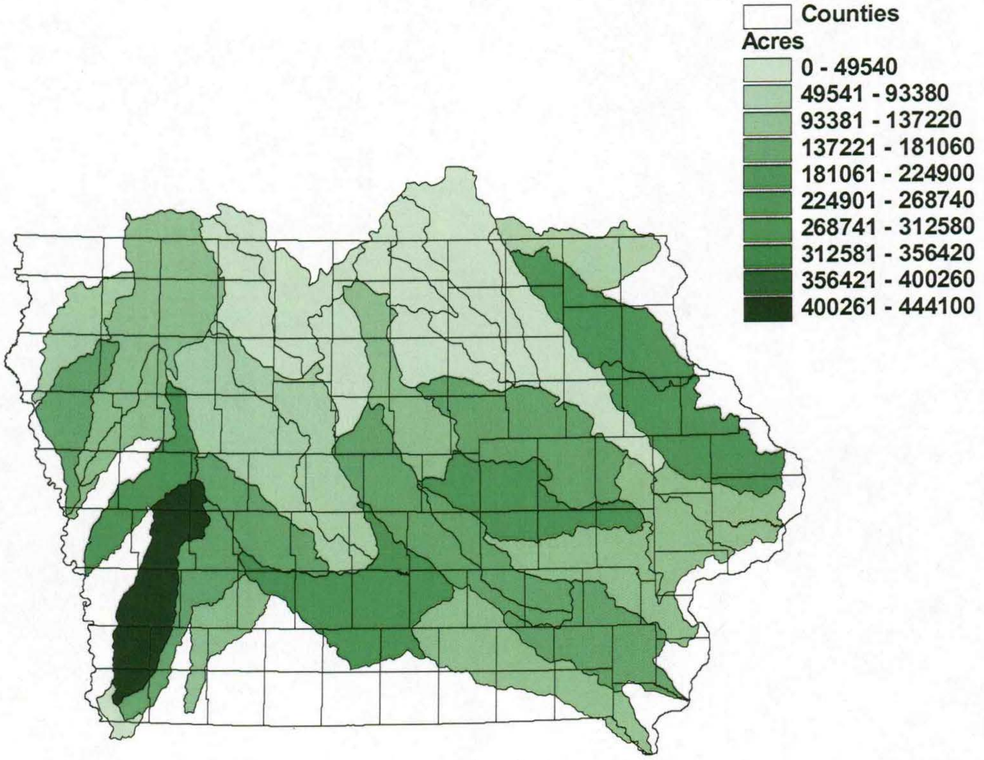
Existing terraced acres



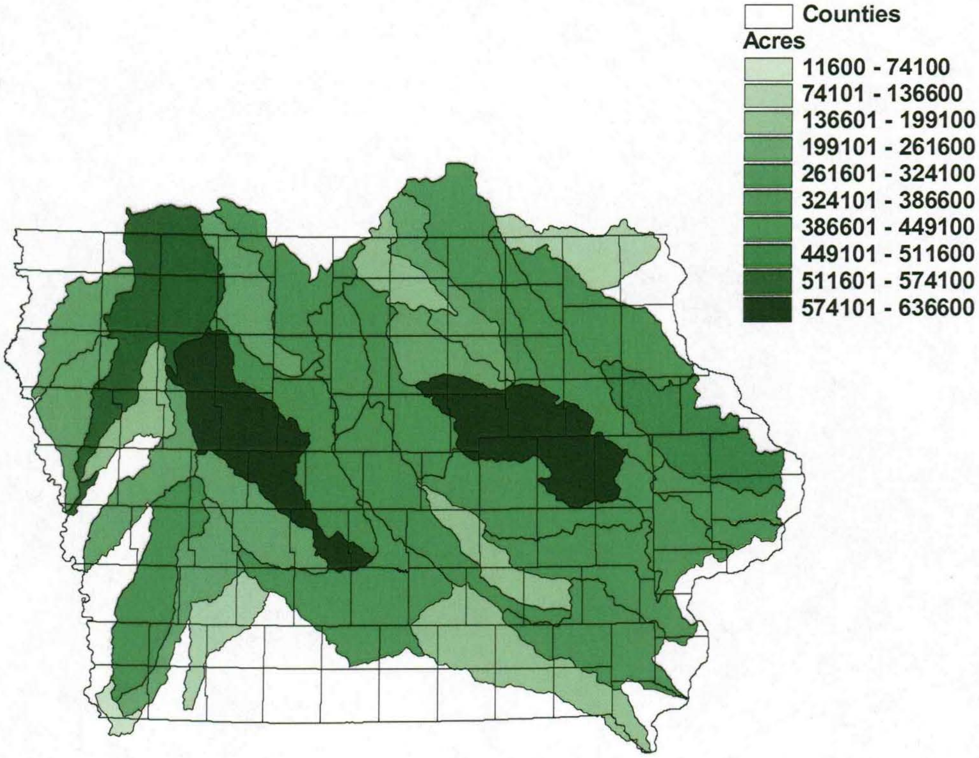
Policy scenario additional terraced acres



Policy scenario total terraced acres



Policy scenario total nutrient management acres



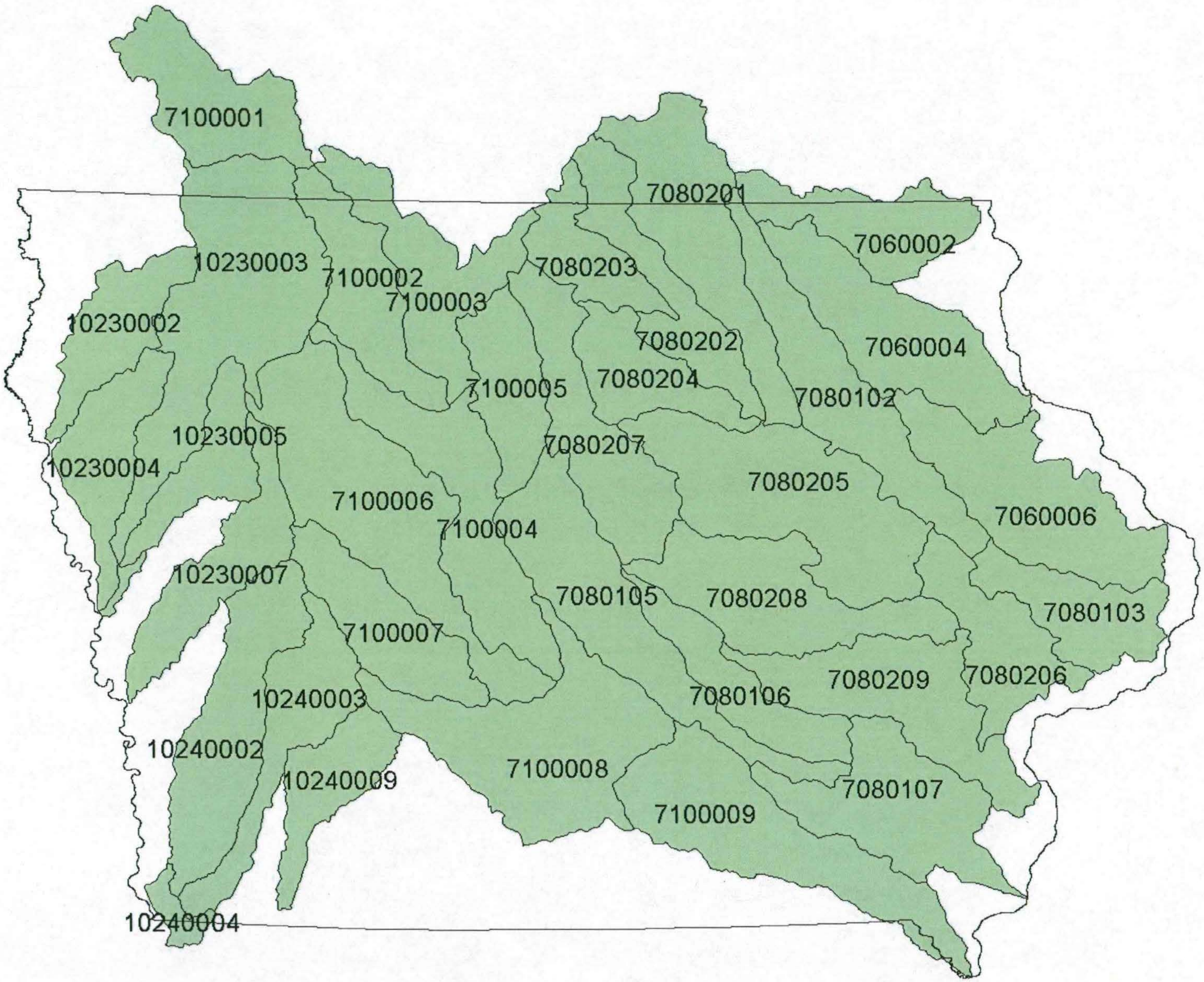
## Appendix B: Nutrient management assumptions and watershed location

Fertilizer application rates by watershed.

| HUC | N lbs/ac | N kgs/ha | P lbs/ac | P kgs/ha |
|---|---|---|---|---|
| 7060002 | 124.73 | 139.80 | 15.93 | 17.86 |
| 7060004 | 184.14 | 206.40 | 23.18 | 25.98 |
| 7060006 | 181.59 | 203.53 | 23.52 | 26.36 |
| 7080102 | 152.36 | 170.78 | 19.95 | 22.36 |
| 7080103 | 169.87 | 190.39 | 21.95 | 24.61 |
| 7080105 | 155.95 | 174.80 | 20.15 | 22.58 |
| 7080106 | 175.71 | 196.94 | 22.51 | 25.23 |
| 7080107 | 142.20 | 159.39 | 17.88 | 20.04 |
| 7080201 | 96.88 | 108.58 | 12.51 | 14.03 |
| 7080202 | 132.17 | 148.15 | 17.22 | 19.30 |
| 7080203 | 139.71 | 156.60 | 18.45 | 20.68 |
| 7080204 | 154.92 | 173.65 | 19.96 | 22.37 |
| 7080205 | 162.36 | 181.98 | 21.07 | 23.61 |
| 7080206 | 157.90 | 176.98 | 20.49 | 22.97 |
| 7080207 | 142.83 | 160.09 | 18.35 | 20.57 |
| 7080208 | 178.64 | 200.23 | 23.09 | 25.88 |
| 7080209 | 156.76 | 175.70 | 20.08 | 22.50 |
| 7100001* | 132.30 | 148.29 | 17.03 | 19.09 |
| 7100002 | 130.86 | 146.67 | 17.02 | 19.08 |
| 7100003 | 133.75 | 149.92 | 17.04 | 19.10 |
| 7100004 | 148.36 | 166.29 | 19.02 | 21.32 |
| 7100005 | 151.14 | 169.40 | 19.33 | 21.66 |
| 7100006 | 139.99 | 156.91 | 17.84 | 20.00 |
| 7100007 | 130.13 | 145.85 | 16.83 | 18.86 |
| 7100008 | 170.51 | 191.12 | 22.34 | 25.04 |
| 7100009 | 177.16 | 198.57 | 23.57 | 26.42 |
| 10230002 | 162.99 | 182.68 | 20.59 | 23.08 |
| 10230003 | 142.29 | 159.48 | 18.54 | 20.78 |
| 10230004 | 159.35 | 178.61 | 20.59 | 23.08 |
| 10230005 | 124.27 | 139.28 | 15.63 | 17.52 |
| 10230007 | 153.15 | 171.66 | 19.74 | 22.13 |
| 10240002 | 134.67 | 150.95 | 17.59 | 19.71 |
| 10240003 | 114.86 | 128.75 | 14.79 | 16.58 |
| 10240004 | 84.21 | 94.39 | 10.77 | 12.07 |
| 10240009 | 122.07 | 136.83 | 15.33 | 17.19 |

*Since 7100001 is outside the Iowa boundaries (and so we do not have information on fertilizer applications for it from IDNR), we used the average fertilizer applications for 7100002 and 7100003 for it.

USGS 8 digit HUC codes



## Appendix C: Acreage and costs of practices by watershed and by county

Acreage of practices by watershed

| HUC | CRP old acres | CRP new acres | CT old acres | CT new acres | contour old acres | contour new acres | GW old acres | GW new acres | Terraces old acres | Terraces new acres | NM new acres |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 07060002 | 53500 | 18800 | 83900 | 149100 | 36100 | 15700 | 25700 | 72200 | 15300 | 67600 | 116400 |
| 07060004 | 62600 | 38100 | 381200 | 249000 | 44000 | 27100 | 29000 | 291900 | 23500 | 192700 | 410800 |
| 07060006 | 74900 | 42400 | 400400 | 301800 | 118500 | 33200 | 157200 | 241600 | 21600 | 182800 | 468900 |
| 07080102 | 16900 | 6200 | 562500 | 167900 | 50600 | 25500 | 124700 | 334900 | 10700 | 18000 | 437000 |
| 07080103 | 14200 | 23100 | 267100 | 147000 | 38500 | 31400 | 37700 | 150500 | 1800 | 93400 | 266100 |
| 07080105 | 54900 | 16800 | 536500 | 216900 | 28200 | 32200 | 59200 | 236800 | 23300 | 129800 | 427500 |
| 07080106 | 66400 | 33300 | 163300 | 151700 | 20800 | 22600 | 33700 | 69600 | 9300 | 129000 | 196200 |
| 07080107 | 78700 | 13100 | 283200 | 200400 | 24200 | 31800 | 92500 | 140800 | 48900 | 94300 | 345000 |
| 07080201 | 21400 | 0 | 342600 | 101500 | 3300 | 7000 | 23200 | 271800 | 6600 | 9000 | 270300 |
| 07080202 | 10400 | 3800 | 302100 | 111300 | 3800 | 14300 | 20200 | 271900 | 0 | 13400 | 218900 |
| 07080203 | 26300 | 2100 | 162100 | 81100 | 0 | 15300 | 1400 | 127200 | 0 | 34500 | 177500 |
| 07080204 | 26000 | 4100 | 313000 | 111600 | 4800 | 24700 | 20300 | 223400 | 9800 | 30500 | 231600 |
| 07080205 | 19500 | 14900 | 959400 | 220200 | 105000 | 94000 | 208400 | 506200 | 26500 | 124500 | 636600 |
| 07080206 | 6300 | 7000 | 291600 | 168300 | 32300 | 37000 | 58900 | 171000 | 2800 | 93100 | 265700 |
| 07080207 | 10800 | 8900 | 561400 | 141500 | 29000 | 32700 | 46300 | 283700 | 15000 | 87100 | 432200 |
| 07080208 | 60100 | 21200 | 446600 | 198900 | 65500 | 45900 | 83600 | 166000 | 11600 | 210400 | 328600 |
| 07080209 | 102100 | 28800 | 279800 | 274900 | 76100 | 31500 | 177700 | 136600 | 20600 | 111400 | 337300 |
| 07100002 | 19000 | 2100 | 330000 | 80500 | 0 | 17300 | 5000 | 183400 | 0 | 40200 | 258100 |
| 07100003 | 12200 | 0 | 396800 | 92500 | 0 | 11200 | 0 | 218700 | 0 | 46900 | 350900 |
| 07100004 | 15400 | 15200 | 687600 | 55700 | 0 | 24900 | 23100 | 280400 | 30600 | 27800 | 414300 |
| 07100005 | 4600 | 2000 | 470800 | 20900 | 0 | 9500 | 6600 | 129200 | 0 | 15200 | 334900 |
| 07100006 | 9700 | 12200 | 904200 | 193200 | 15300 | 59100 | 4900 | 462200 | 6100 | 46600 | 576500 |
| 07100007 | 24300 | 12900 | 279400 | 151400 | 63400 | 19800 | 17200 | 148000 | 36000 | 101800 | 243400 |
| 07100008 | 103500 | 27500 | 581800 | 108300 | 50700 | 35100 | 96900 | 189500 | 74800 | 167400 | 302200 |
| 07100009 | 126500 | 26300 | 168800 | 145200 | 23500 | 22200 | 24800 | 76800 | 12900 | 113500 | 155200 |
| 10230002 | 2800 | 5600 | 295400 | 170500 | 43700 | 65400 | 0 | 197400 | 62200 | 26700 | 243900 |

|  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 10230003 | 59300 | 29400 | 718600 | 270600 | 34700 | 56400 | 13400 | 420900 | 71800 | 62400 | 535300 |
| HUC | CRP old acres | CRP new acres | CT old acres | CT new acres | contour old acres | contour new acres | GW old acres | GW new acres | Terraces old acres | Terraces new acres | NM new acres |
| 10230004 | 25900 | 26100 | 250800 | 111100 | 61100 | 43000 | 9200 | 47400 | 114100 | 36400 | 222400 |
| 10230005 | 12500 | 17800 | 116900 | 183500 | 46800 | 26700 | 21500 | 87700 | 76600 | 34900 | 156100 |
| 10230007 | 27700 | 46300 | 127700 | 296000 | 107600 | 38800 | 38700 | 64200 | 93000 | 109600 | 233900 |
| 10240002 | 15100 | 93300 | 253800 | 498300 | 158500 | 26000 | 61700 | 84900 | 319800 | 124300 | 392400 |
| 10240003 | 21300 | 36300 | 165800 | 272800 | 157900 | 11700 | 89900 | 33600 | 96200 | 84400 | 227400 |
| 10240004 | 2800 | 0 | 12100 | 5500 | 2400 | 3800 | 0 | 2500 | 1700 | 4000 | 11600 |
| 10240009 | 22000 | 16700 | 164400 | 133800 | 80500 | 22200 | 102800 | 46600 | 54100 | 46100 | 136200 |

Note: since we are showing here only the areas for the watersheds included in the SWAT runs, the total acreage is less than for the whole State.

## Acreage of practices by county

| FIPS | CRP old acres | CRP new acres | CT old acres | CT new acres | contour old acres | contour new acres | GW old acres | GW new acres | Terraces old acres | Terraces new acres | NM new acres |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 19001 | 14400 | 18600 | 117700 | 107400 | 48200 | 9700 | 84600 | 29600 | 18100 | 55900 | 95000 |
| 19003 | 26800 | 5400 | 87700 | 41000 | 23600 | 16800 | 13600 | 18600 | 20200 | 33700 | 74500 |
| 19005 | 33400 | 28300 | 20500 | 104900 | 52100 | 3200 | 65400 | 8300 | 14900 | 30000 | 71800 |
| 19007 | 24800 | 0 | 12400 | 53300 | 2700 | 10900 | 13200 | 17400 | 2700 | 11000 | 31000 |
| 19009 | 14500 | 22300 | 64000 | 119500 | 80900 | 7800 | 0 | 10000 | 27400 | 50800 | 85400 |
| 19011 | 18600 | 6700 | 224700 | 94300 | 75200 | 35000 | 38100 | 108200 | 4300 | 46800 | 163700 |
| 19013 |  | 1500 | 234500 | 25900 | 11900 | 18300 | 92900 | 86600 | 8900 | 4900 | 155200 |
| 19015 | 4100 | 7300 | 223500 | 29200 | 0 | 10700 | 7300 | 98400 | 0 | 12600 | 136100 |
| 19017 | 2500 | 0 | 179600 | 26000 | 2000 | 0 | 8000 | 61800 | 0 | 6400 | 129900 |
| 19019 | 2600 | 4500 | 192000 | 82700 | 41100 | 9100 | 79200 | 112600 | 0 | 5100 | 177400 |
| 19021 | 4000 | 1700 | 223400 | 83400 | 1400 | 25100 | 2000 | 125300 | 0 | 8800 | 158300 |
| 19023 | 19800 | 0 | 196000 | 85000 | 6100 | 20900 | 17900 | 161900 | 4500 | 15700 | 148400 |
| 19025 | 1500 | 2300 | 265400 | 29300 | 0 | 9600 | 0 | 108100 | 0 | 13700 | 142400 |
| 19027 | 600 | 6500 | 97800 | 170100 | 72600 | 18900 | 4100 | 63300 | 38800 | 56300 | 142700 |
| 19029 | 10200 | 13600 | 78900 | 146700 | 95100 | 13100 | 130700 | 30300 | 35700 | 31100 | 101600 |
| 19031 | 7100 | 5100 | 165200 | 104400 | 20400 | 18700 | 23900 | 86000 | 0 | 70600 | 147700 |
| 19033 | 10200 | 4100 | 192300 | 61900 | 0 | 12700 | 6400 | 135800 | 0 | 16700 | 155200 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 19035 | 2800 | 0 | 187800 | 74200 | 38500 | 17000 | 12800 | 100000 | 52300 | 5300 | 111800 |
| FIPS | CRP old acres | CRP new acres | CT old acres | CT new acres | contour old acres | contour new acres | GW old acres | GW new acres | Terraces old acres | Terraces new acres | NM new acres |
| 19037 | 11900 | 0 | 155400 | 68400 | 7900 | 9200 | 26800 | 143500 | 8200 | 0 | 146700 |
| 19039 | 59100 | 3200 | 41400 | 10100 | 0 | 7000 | 0 | 22100 | 0 | 13500 | 17700 |
| 19041 | 14100 | 3100 | 196200 | 52400 | 0 | 19400 | 3000 | 92800 | 1200 | 1500 | 134200 |
| 19043 | 43000 | 23200 | 160500 | 67800 | 27800 | 3800 | 5800 | 34800 | 17600 | 137100 | 163100 |
| 19045 | 25700 | 37500 | 135600 | 107100 | 17600 | 26200 | 1200 | 84600 | 0 | 77200 | 178300 |
| 19047 | 17500 | 28100 | 59400 | 249300 | 114100 | 3900 | 78000 | 6800 | 100600 | 96600 | 156000 |
| 19049 | 9000 | 1700 | 202400 | 34600 | 5400 | 8000 | 0 | 105900 | 3600 | 19100 | 112300 |
| 19051 | 44400 | 12400 | 29000 | 32100 | 1200 | 8400 | 3600 | 21100 | 0 | 16900 | 22400 |
| 19053 | 49700 | 0 | 37500 | 17600 | 3500 | 12100 | 0 | 13400 | 1000 | 8800 | 30800 |
| 19055 | 8400 | 9200 | 144700 | 104600 | 6700 | 16800 | 37300 | 134000 | 7900 | 38600 | 167800 |
| 19057 | 4300 | 0 | 79200 | 35800 | 3000 | 7300 | 4600 | 42100 | 0 | 15100 | 80700 |
| 19059 | 17800 | 0 | 119100 | 28500 | 0 | 12700 | 0 | 91500 | 0 | 6500 | 61100 |
| 19061 | 29200 | 11600 | 98700 | 83100 | 32800 | 10600 | 83600 | 17700 | 6500 | 63500 | 120400 |
| 19063 | 11300 | 0 | 121300 | 39000 | 0 | 6100 | 3300 | 81600 | 0 | 25300 | 95100 |
| 19065 | 8400 | 14700 | 236700 | 105500 | 15000 | 13100 | 14600 | 210300 | 15700 | 58500 | 204800 |
| 19067 | 14300 | 3800 | 188600 | 52800 | 0 | 5900 | 21000 | 162300 | 0 | 3100 | 123200 |
| 19069 | 3000 | 1600 | 216900 | 67700 | 3400 | 20600 | 16900 | 162700 | 7100 | 22000 | 162500 |
| 19071 | 12000 | 3300 | 74000 | 105900 | 18600 | 5400 | 1700 | 47100 | 61200 | 19000 | 121100 |
| 19073 | 2100 | 4700 | 184800 | 66900 | 0 | 18700 | 0 | 158500 | 0 | 2100 | 148200 |
| 19075 | 0 | 0 | 264300 | 31000 | 11000 | 16300 | 33100 | 168100 | 8500 | 14700 | 164000 |
| 19077 | 19600 | 9200 | 156300 | 42200 | 27300 | 7200 | 11000 | 57700 | 7900 | 61500 | 108800 |
| 19079 | 0 | 0 | 257600 | 41700 | 0 | 6500 | 10100 | 132800 | 0 | 17100 | 183200 |
| 19081 | 4800 | 6900 | 280400 | 25500 | 0 | 17900 | 0 | 98600 | 0 | 23600 | 176500 |
| 19083 | 5400 | 4500 | 204300 | 82800 | 19700 | 20600 | 40900 | 134500 | 11000 | 17500 | 184800 |
| 19085 | 13300 | 31200 | 70000 | 109000 | 50100 | 3200 | 0 | 29400 | 46100 | 38600 | 125800 |
| 19087 | 28300 | 3700 | 82400 | 44300 | 6400 | 13500 | 0 | 45900 | 3200 | 28900 | 91800 |
| 19089 | 25400 | 2100 | 159600 | 58200 | 6300 | 4900 | 2500 | 154700 | 0 | 6500 | 103600 |
| 19091 | 600 | 0 | 179100 | 17700 | 0 | 3300 | 1700 | 56500 | 0 | 3500 | 132200 |
| 19093 | 4900 | 19000 | 37100 | 175400 | 38600 | 16700 | 0 | 22200 | 107400 | 29700 | 109500 |
| 19095 | 49100 | 16900 | 70000 | 115900 | 82200 | 2500 | 140100 | 11900 | 20600 | 7800 | 111200 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 19097 | 48800 | 16600 | 42800 | 86000 | 33500 | 2500 | 44200 | 8000 | 1200 | 71500 | 82700 |
| FIPS | CRP old acres | CRP new acres | CT old acres | CT new acres | contour old acres | contour new acres | GW old acres | GW new acres | Terraces old acres | Terraces new acres | NM new acres |
| 19099 | 41000 | 5600 | 155000 | 122200 | 10400 | 19400 | 7100 | 57000 | 4400 | 134700 | 144400 |
| 19101 | 28600 | 4200 | 44000 | 58900 | 10800 | 2300 | 37900 | 20400 | 21800 | 20100 | 75100 |
| 19103 | 24200 | 5900 | 114100 | 82900 | 7100 | 15300 | 9100 | 68700 | 1000 | 55100 | 110000 |
| 19105 | 5900 | 7700 | 163100 | 57700 | 65900 | 5500 | 87500 | 57000 | 8700 | 30900 | 143600 |
| 19107 | 48900 | 20700 | 51500 | 95800 | 2400 | 13300 | 24000 | 34700 | 2400 | 57300 | 111400 |
| 19109 | 14100 | 1600 | 326400 | 81500 | 0 | 2300 | 0 | 179000 | 0 | 52200 | 289100 |
| 19111 | 14400 | 7000 | 46900 | 77800 | 9300 | 4900 | 10200 | 42200 | 4400 | 41100 | 97500 |
| 19113 | 13400 | 1700 | 210900 | 77300 | 31500 | 36000 | 74000 | 84600 | 1600 | 52500 | 144200 |
| 19115 | 20500 | 3300 | 86000 | 38300 | 6200 | 4800 | 3100 | 45500 | 1600 | 16600 | 84600 |
| 19117 | 39900 | 9800 | 40300 | 10300 | 3500 | 6500 | 17700 | 3500 | 3300 | 3600 | 14000 |
| 19119 | 1300 | 1600 | 140200 | 137300 | 75300 | 19100 | 34200 | 110500 | 20200 | 11000 | 151900 |
| 19121 | 21300 | 7100 | 164300 | 8100 | 11200 | 10900 | 21400 | 36800 | 16900 | 49500 | 67400 |
| 19123 | 33600 | 4500 | 61700 | 129800 | 24200 | 0 | 44900 | 61900 | 5100 | 58500 | 108200 |
| 19125 | 21700 | 8000 | 125200 | 35100 | 22100 | 4400 | 22500 | 20200 | 28100 | 50500 | 76400 |
| 19127 | 6900 | 4600 | 207700 | 61600 | 33300 | 13900 | 19500 | 71200 | 0 | 103800 | 127200 |
| 19129 | 4500 | 8700 | 69900 | 97600 | 11800 | 12400 | 0 | 22000 | 71100 | 26300 | 80700 |
| 19131 | 6700 | 0 | 160500 | 69000 | 0 | 1700 | 2400 | 165400 | 5000 | 3000 | 151900 |
| 19133 | 12300 | 6400 | 42600 | 79900 | 17100 | 4300 | 10400 | 18800 | 21000 | 34700 | 164700 |
| 19135 | 13600 | 1800 | 10800 | 37200 | 3600 | 5300 | 0 | 15100 | 2000 | 22000 | 20600 |
| 19137 | 10800 | 2900 | 69400 | 95700 | 41100 | 3200 | 60500 | 24500 | 58900 | 16500 | 81000 |
| 19139 | 4200 | 3700 | 87700 | 65500 | 4600 | 10200 | 1300 | 76200 | 0 | 28100 | 105300 |
| 19141 | 2000 | 5700 | 228600 | 37200 | 0 | 4100 | 2100 | 156500 | 0 | 2000 | 175000 |
| 19143 | 4000 | 8300 | 159900 | 38800 | 0 | 11300 | 0 | 84600 | 0 | 5000 | 107800 |
| 19145 | 23800 | 2100 | 167700 | 37900 | 41300 | 4900 | 0 | 23900 | 98500 | 17900 | 89600 |
| 19147 | 15700 | 16900 | 172300 | 33800 | 0 | 12300 | 0 | 98700 | 0 | 16400 | 156500 |
| 19149 | 16500 | 2900 | 218300 | 162800 | 97300 | 68100 | 0 | 50100 | 123500 | 36900 | 187100 |
| 19151 | 0 | 0 | 256500 | 30900 | 0 | 8500 | 0 | 90600 | 0 | 18900 | 158900 |
| 19153 | 5300 | 1500 | 153300 | 21300 | 2900 | 3800 | 29000 | 52200 | 31500 | 14200 | 93700 |
| 19155 | 10800 | 40600 | 149800 | 211500 | 65300 | 13300 | 0 | 30100 | 152100 | 74300 | 225700 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 19157 | 30500 | 20800 | 173000 | 52300 | 2100 | 23200 | 10700 | 37200 | 0 | 114200 | 111000 |
| FIPS | CRP old acres | CRP new acres | CT old acres | CT new acres | contour old acres | contour new acres | GW old acres | GW new acres | Terraces old acres | Terraces new acres | NM new acres |
| 19159 | 67300 | 7900 | 56900 | 45500 | 4800 | 25900 | 12500 | 27500 | 3600 | 17900 | 39900 |
| 19161 | 1500 | 5900 | 158100 | 122300 | 42500 | 28600 | 24000 | 138800 | 10900 | 16100 | 167000 |
| 19163 | 0 | 0 | 91200 | 81000 | 24600 | 9400 | 2600 | 46400 | 3000 | 55200 | 113700 |
| 19165 | 3500 | 113800 | 50500 | 136100 | 44700 | 6500 | 7200 | 32100 | 67700 | 24500 | 93700 |
| 19167 | 3800 | 1700 | 178800 | 212800 | 48800 | 46600 | 1000 | 181600 | 69400 | 10700 | 223000 |
| 19169 | 1100 | 1500 | 227600 | 41100 | 1600 | 5100 | 15800 | 105200 | 8200 | 12300 | 152200 |
| 19171 | 14800 | 9600 | 209100 | 93900 | 9000 | 13800 | 8800 | 106300 | 9300 | 111800 | 162800 |
| 19173 | 43800 | 2500 | 71000 | 98100 | 78500 | 14400 | 0 | 18300 | 5100 | 55000 | 72700 |
| 19175 | 32300 | 3400 | 90300 | 18900 | 38300 | 3600 | 46000 | 13800 | 18300 | 9000 | 40800 |
| 19177 | 37600 | 2000 | 79000 | 12600 | 0 | 5200 | 2100 | 25200 | 5500 | 20300 | 29400 |
| 19179 | 24000 | 8200 | 46300 | 42600 | 5900 | 8900 | 9300 | 21600 | 19700 | 20900 | 63900 |
| 19181 | 25200 | 1800 | 155400 | 13600 | 10700 | 13800 | 0 | 71600 | 10600 | 41000 | 76000 |
| 19183 | 30000 | 5700 | 109500 | 91600 | 5800 | 14900 | 102700 | 33600 | 13100 | 27400 | 138600 |
| 19185 | 55800 | 4000 | 16000 | 66600 | 20200 | 22500 | 4400 | 15500 | 3200 | 19500 | 37500 |
| 19187 | 4800 | 10500 | 290900 | 14800 | 0 | 12500 | 18200 | 105300 | 27100 | 2500 | 196800 |
| 19189 | 15700 | 2100 | 85000 | 72900 | 0 | 9400 | 0 | 77100 | 0 | 21600 | 126400 |
| 19191 | 39100 | 3500 | 57900 | 176100 | 25400 | 23000 | 4700 | 72900 | 15400 | 92700 | 136300 |
| 19193 | 43800 | 43200 | 177100 | 89100 | 25400 | 14200 | 7200 | 21100 | 84000 | 67500 | 154000 |
| 19195 | 9500 | 0 | 159600 | 32300 | 0 | 2500 | 0 | 111500 | 0 | 9500 | 96800 |
| 19197 | 3800 | 0 | 262300 | 29500 | 2200 | 4200 | 0 | 77300 | 0 | 27500 | 200000 |

Program costs by watershed ($,000s).

| HUC | CRP old costs | CRP new costs | CT old costs | CT new costs | Contour old costs (LOW) | Contour new costs (LOW) | GW old costs (LOW) | GW new costs (LOW) | Terraces old costs | Terraces new costs | NM new costs | Total costs - new adopters only | Total costs -new and old adopters |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 07060002 | 60,262 | 21,421 | 12,300 | 17,840 | 3,610 | 1,570 | 5,140 | 14,440 | 133,875 | 591,500 | 17,460 | 664,231 | 879,418 |
| 07060004 | 70,513 | 42,713 | 52,130 | 29,770 | 4,400 | 2,710 | 5,800 | 58,380 | 205,625 | 1,686,125 | 61,620 | 1,881,318 | 2,219,785 |
| 07060006 | 84,367 | 52,659 | 55,160 | 36,020 | 11,850 | 3,320 | 31,440 | 48,320 | 189,000 | 1,599,500 | 70,335 | 1,810,154 | 2,181,971 |

| HUC | CRP old costs | CRP new costs | CT old costs | CT new costs | Contour old costs (LOW) | Contour new costs (LOW) | GW old costs (LOW) | GW new costs (LOW) | Terraces old costs | Terraces new costs | NM new costs | Total costs - new adopters only | Total costs -new and old adopters |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 07080102 | 19,036 | 8,374 | 75,930 | 20,100 | 5,060 | 2,550 | 24,940 | 66,980 | 93,625 | 157,500 | 65,550 | 321,054 | 539,645 |
| 07080103 | 15,995 | 30,874 | 35,620 | 17,490 | 3,850 | 3,140 | 7,540 | 30,100 | 15,750 | 817,250 | 39,915 | 938,769 | 1,017,524 |
| 07080105 | 61,839 | 19,197 | 71,680 | 25,900 | 2,820 | 3,220 | 11,840 | 47,360 | 203,875 | 1,135,750 | 64,125 | 1,295,552 | 1,647,606 |
| 07080106 | 74,793 | 41,282 | 22,350 | 18,170 | 2,080 | 2,260 | 6,740 | 13,920 | 81,375 | 1,128,750 | 29,430 | 1,233,812 | 1,421,150 |
| 07080107 | 88,648 | 14,747 | 38,390 | 23,980 | 2,420 | 3,180 | 18,500 | 28,160 | 427,875 | 825,125 | 51,750 | 946,942 | 1,522,774 |
| 07080201 | 24,105 | 0 | 46,120 | 12,080 | 330 | 700 | 4,640 | 54,360 | 57,750 | 78,750 | 40,545 | 186,435 | 319,380 |
| 07080202 | 11,715 | 4,121 | 40,730 | 13,290 | 380 | 1,430 | 4,040 | 54,380 | 0 | 117,250 | 32,835 | 223,306 | 280,170 |
| 07080203 | 29,624 | 2,914 | 22,340 | 9,550 | 0 | 1,530 | 280 | 25,440 | 0 | 301,875 | 26,625 | 367,934 | 420,179 |
| 07080204 | 29,286 | 5,214 | 45,090 | 13,210 | 480 | 2,470 | 4,060 | 44,680 | 85,750 | 266,875 | 34,740 | 367,189 | 531,856 |
| 07080205 | 21,965 | 22,553 | 128,290 | 26,260 | 10,500 | 9,400 | 41,680 | 101,240 | 231,875 | 1,089,375 | 95,490 | 1,344,318 | 1,778,628 |
| 07080206 | 7,096 | 9,729 | 37,750 | 20,110 | 3,230 | 3,700 | 11,780 | 34,200 | 24,500 | 814,625 | 39,855 | 922,219 | 1,006,575 |
| 07080207 | 12,165 | 11,438 | 76,280 | 16,920 | 2,900 | 3,270 | 9,260 | 56,740 | 131,250 | 762,125 | 64,830 | 915,323 | 1,147,178 |
| 07080208 | 67,697 | 23,971 | 60,300 | 23,660 | 6,550 | 4,590 | 16,720 | 33,200 | 101,500 | 1,841,000 | 49,290 | 1,975,711 | 2,228,478 |
| 07080209 | 115,005 | 29,881 | 37,610 | 32,880 | 7,610 | 3,150 | 35,540 | 27,320 | 180,250 | 974,750 | 50,595 | 1,118,576 | 1,494,591 |
| 07100002 | 21,402 | 2,574 | 46,620 | 9,590 | 0 | 1,730 | 1,000 | 36,680 | 0 | 351,750 | 38,715 | 441,039 | 510,060 |
| 07100003 | 13,742 | 0 | 55,940 | 11,020 | 0 | 1,120 | 0 | 43,740 | 0 | 410,375 | 52,635 | 518,890 | 588,572 |
| 07100004 | 17,347 | 18,059 | 92,360 | 6,650 | 0 | 2,490 | 4,620 | 56,080 | 267,750 | 243,250 | 62,145 | 388,674 | 770,750 |
| 07100005 | 5,181 | 2,910 | 67,660 | 2,340 | 0 | 950 | 1,320 | 25,840 | 0 | 133,000 | 50,235 | 215,275 | 289,436 |
| 07100006 | 10,926 | 15,977 | 120,110 | 23,070 | 1,530 | 5,910 | 980 | 92,440 | 53,375 | 407,750 | 86,475 | 631,622 | 818,543 |
| 07100007 | 27,372 | 18,644 | 38,330 | 18,050 | 6,340 | 1,980 | 3,440 | 29,600 | 315,000 | 890,750 | 36,510 | 995,534 | 1,386,016 |
| 07100008 | 116,582 | 24,735 | 80,400 | 12,910 | 5,070 | 3,510 | 19,380 | 37,900 | 654,500 | 1,464,750 | 45,330 | 1,589,135 | 2,465,068 |
| 07100009 | 142,489 | 24,097 | 22,440 | 17,370 | 2,350 | 2,220 | 4,960 | 15,360 | 112,875 | 993,125 | 23,280 | 1,075,452 | 1,360,566 |
| 10230002 | 3,154 | 5,888 | 38,890 | 20,430 | 4,370 | 6,540 | 0 | 39,480 | 326,550 | 140,175 | 36,585 | 249,098 | 622,062 |
| 10230003 | 66,795 | 36,032 | 95,940 | 32,430 | 3,470 | 5,640 | 2,680 | 84,180 | 376,950 | 327,600 | 80,295 | 566,177 | 1,112,013 |
| 10230004 | 29,174 | 26,210 | 32,070 | 13,220 | 6,110 | 4,300 | 1,840 | 9,480 | 599,025 | 191,100 | 33,360 | 277,670 | 945,888 |
| 10230005 | 14,080 | 22,443 | 15,720 | 21,950 | 4,680 | 2,670 | 4,300 | 17,540 | 402,150 | 183,225 | 23,415 | 271,243 | 712,173 |

| HUC | CRP old costs | CRP new costs | CT old costs | CT new costs | Contour old costs (LOW) | Contour new costs (LOW) | GW old costs (LOW) | GW new costs (LOW) | Terraces old costs | Terraces new costs | NM new costs | Total costs - new adopters only | Total costs -new and old adopters |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10230007 | 31,201 | 53,934 | 17,610 | 35,290 | 10,760 | 3,880 | 7,740 | 12,840 | 488,250 | 575,400 | 35,085 | 716,429 | 1,271,990 |
| 10240002 | 17,009 | 100,766 | 35,090 | 59,570 | 15,850 | 2,600 | 12,340 | 16,980 | 1,678,950 | 652,575 | 58,860 | 891,351 | 2,650,590 |
| 10240003 | 23,992 | 38,016 | 25,160 | 32,500 | 15,790 | 1,170 | 17,980 | 6,720 | 505,050 | 443,100 | 34,110 | 555,616 | 1,143,588 |
| 10240004 | 3,154 | 0 | 1,870 | 550 | 240 | 380 | 0 | 500 | 8,925 | 21,000 | 1,740 | 24,170 | 38,359 |
| 10240009 | 24,781 | 17,672 | 22,630 | 15,960 | 8,050 | 2,220 | 20,560 | 9,320 | 284,025 | 242,025 | 20,430 | 307,627 | 667,673 |

Note: again, since we are showing here only the areas for the watersheds included in the SWAT runs, the total of the costs by practice is less than for the whole State.

Program costs by county ($,000s).

| FIPS | CRP old costs | CRP new costs | CT old costs | CT new costs | Contour old costs (LOW) | Contour new costs (LOW) | GW old costs (LOW) | GW new costs (LOW) | Terraces old costs | Terraces new costs | NM new costs | Total costs - new adopters only | Total costs - new and old adopters |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19001 | 5,302 | 5,514 | 2,759 | 2,329 | 840 | 169 | 1,135 | 397 | 8,185 | 22,910 | 956 | 32,276 | 50,497 |
| 19003 | 9,867 | 1,833 | 2,225 | 864 | 411 | 293 | 183 | 250 | 7,116 | 11,872 | 750 | 15,861 | 35,662 |
| 19005 | 12,297 | 10,169 | 493 | 2,138 | 908 | 56 | 878 | 111 | 8,748 | 17,614 | 723 | 30,810 | 54,134 |
| 19007 | 9,131 | 0 | 319 | 1,134 | 47 | 190 | 177 | 234 | 951 | 4,251 | 312 | 6,120 | 16,745 |
| 19009 | 5,339 | 8,333 | 1,735 | 2,488 | 1,409 | 136 | 0 | 134 | 9,652 | 17,896 | 860 | 29,846 | 47,981 |
| 19011 | 6,848 | 2,899 | 5,066 | 1,845 | 1,310 | 610 | 511 | 1,452 | 2,525 | 27,478 | 1,648 | 35,931 | 52,191 |
| 19013 | 847 | 913 | 5,455 | 598 | 207 | 319 | 1,247 | 1,162 | 5,225 | 2,877 | 1,562 | 7,430 | 20,411 |
| 19015 | 1,510 | 2,982 | 5,244 | 568 | 0 | 186 | 98 | 1,321 | 0 | 7,398 | 1,370 | 13,824 | 20,675 |
| 19017 | 920 | 0 | 4,214 | 551 | 35 | 0 | 107 | 829 | 0 | 3,758 | 1,307 | 6,445 | 11,722 |
| 19019 | 957 | 2,056 | 4,406 | 1,854 | 716 | 159 | 1,063 | 1,511 | 0 | 2,994 | 1,786 | 10,359 | 17,501 |
| 19021 | 1,473 | 901 | 5,359 | 1,669 | 24 | 437 | 27 | 1,682 | 0 | 4,650 | 1,593 | 10,932 | 17,815 |
| 19023 | 7,290 | 0 | 4,768 | 1,840 | 106 | 364 | 240 | 2,173 | 2,642 | 9,218 | 1,494 | 15,088 | 30,135 |
| 19025 | 552 | 1,071 | 5,944 | 713 | 0 | 167 | 0 | 1,451 | 0 | 8,044 | 1,433 | 12,878 | 19,375 |

| FIPS | CRP old costs | CRP new costs | CT old costs | CT new costs | Contour old costs (LOW) | Contour new costs (LOW) | GW old costs (LOW) | GW new costs (LOW) | Terraces old costs | Terraces new costs | NM new costs | Total costs - new adopters only | Total costs - new and old adopters |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19027 | 221 | 3,230 | 2,303 | 3,671 | 1,265 | 329 | 55 | 849 | 19,798 | 30,449 | 1,436 | 39,964 | 63,606 |
| 19029 | 3,755 | 4,538 | 2,061 | 3,096 | 1,657 | 228 | 1,754 | 407 | 12,576 | 10,956 | 1,023 | 20,247 | 42,051 |
| 19031 | 2,614 | 2,690 | 3,573 | 2,033 | 355 | 326 | 321 | 1,154 | 0 | 41,452 | 1,487 | 49,141 | 56,004 |
| 19033 | 3,755 | 1,704 | 4,444 | 1,251 | 0 | 221 | 86 | 1,822 | 0 | 9,805 | 1,562 | 16,366 | 24,652 |
| 19035 | 1,031 | 0 | 4,247 | 1,580 | 671 | 296 | 172 | 1,342 | 18,424 | 1,867 | 1,125 | 6,211 | 30,755 |
| 19037 | 4,381 | 0 | 3,754 | 1,434 | 138 | 160 | 360 | 1,926 | 4,814 | 0 | 1,477 | 4,996 | 18,444 |
| 19039 | 21,760 | 1,282 | 976 | 202 | 0 | 122 | 0 | 297 | 0 | 6,423 | 178 | 8,504 | 31,239 |
| 19041 | 5,191 | 1,084 | 4,449 | 1,030 | 0 | 338 | 40 | 1,245 | 423 | 881 | 1,351 | 5,929 | 16,032 |
| 19043 | 15,832 | 8,478 | 3,831 | 1,317 | 484 | 66 | 78 | 467 | 10,334 | 80,496 | 1,642 | 92,465 | 123,024 |
| 19045 | 9,462 | 16,024 | 3,120 | 2,204 | 307 | 456 | 16 | 1,135 | 0 | 45,327 | 1,795 | 66,941 | 79,846 |
| 19047 | 6,443 | 10,968 | 1,280 | 5,171 | 1,988 | 68 | 1,047 | 91 | 35,439 | 34,030 | 1,570 | 51,899 | 98,096 |
| 19049 | 3,314 | 444 | 4,538 | 688 | 94 | 139 | 0 | 1,421 | 2,114 | 11,214 | 1,130 | 15,037 | 25,097 |
| 19051 | 16,347 | 3,426 | 711 | 646 | 21 | 146 | 48 | 283 | 0 | 9,923 | 225 | 14,650 | 31,777 |
| 19053 | 18,299 | 0 | 939 | 350 | 61 | 211 | 0 | 180 | 352 | 3,100 | 310 | 4,151 | 23,802 |
| 19055 | 3,093 | 3,552 | 3,448 | 2,089 | 117 | 293 | 501 | 1,798 | 4,638 | 22,663 | 1,689 | 32,083 | 43,880 |
| 19057 | 1,583 | 0 | 1,765 | 773 | 52 | 127 | 62 | 565 | 0 | 8,866 | 812 | 11,144 | 14,606 |
| 19059 | 6,554 | 0 | 2,958 | 585 | 0 | 221 | 0 | 1,228 | 0 | 2,736 | 615 | 5,386 | 14,897 |
| 19061 | 10,751 | 4,428 | 2,430 | 1,702 | 571 | 185 | 1,122 | 238 | 3,816 | 37,283 | 1,212 | 45,047 | 63,738 |
| 19063 | 4,160 | 0 | 2,984 | 805 | 0 | 106 | 44 | 1,095 | 0 | 14,854 | 957 | 17,818 | 25,007 |
| 19065 | 3,093 | 5,655 | 5,366 | 2,303 | 261 | 228 | 196 | 2,822 | 9,218 | 34,347 | 2,061 | 47,417 | 65,551 |
| 19067 | 5,265 | 1,347 | 4,503 | 1,047 | 0 | 103 | 282 | 2,178 | 0 | 1,820 | 1,240 | 7,735 | 17,785 |
| 19069 | 1,105 | 618 | 5,434 | 1,476 | 59 | 359 | 227 | 2,183 | 4,169 | 12,917 | 1,636 | 19,189 | 30,182 |
| 19071 | 4,418 | 1,115 | 1,712 | 2,315 | 324 | 94 | 23 | 632 | 21,559 | 6,693 | 1,219 | 12,069 | 40,106 |
| 19073 | 773 | 2,131 | 4,449 | 1,294 | 0 | 326 | 0 | 2,127 | 0 | 1,233 | 1,492 | 8,603 | 13,825 |
| 19075 | 0 | 1,415 | 6,421 | 645 | 192 | 284 | 444 | 2,256 | 4,991 | 8,631 | 1,651 | 14,881 | 26,929 |
| 19077 | 7,216 | 3,849 | 3,935 | 864 | 476 | 125 | 148 | 774 | 4,638 | 36,109 | 1,095 | 42,817 | 59,230 |

| FIPS | CRP old costs | CRP new costs | CT old costs | CT new costs | Contour old costs (LOW) | Contour new costs (LOW) | GW old costs (LOW) | GW new costs (LOW) | Terraces old costs | Terraces new costs | NM new costs | Total costs - new adopters only | Total costs - new and old adopters |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19079 | 0 | 878 | 6,329 | 848 | 0 | 113 | 136 | 1,782 | 0 | 10,040 | 1,844 | 15,505 | 21,970 |
| 19081 | 1,767 | 3,127 | 6,833 | 582 | 0 | 312 | 0 | 1,323 | 0 | 13,856 | 1,776 | 20,976 | 29,576 |
| 19083 | 1,988 | 1,818 | 4,735 | 1,761 | 343 | 359 | 549 | 1,805 | 6,458 | 10,275 | 1,860 | 17,878 | 31,952 |
| 19085 | 4,897 | 11,028 | 1,591 | 2,312 | 873 | 56 | 0 | 395 | 16,240 | 13,598 | 1,266 | 28,654 | 52,254 |
| 19087 | 10,420 | 1,453 | 2,190 | 871 | 111 | 235 | 0 | 616 | 1,879 | 16,968 | 924 | 21,067 | 35,667 |
| 19089 | 9,352 | 841 | 3,895 | 1,214 | 110 | 85 | 34 | 2,076 | 0 | 3,816 | 1,043 | 9,076 | 22,467 |
| 19091 | 221 | 0 | 4,354 | 336 | 0 | 57 | 23 | 758 | 0 | 2,055 | 1,331 | 4,538 | 9,135 |
| 19093 | 1,804 | 7,487 | 918 | 3,681 | 672 | 291 | 0 | 298 | 37,835 | 15,042 | 1,102 | 27,902 | 69,131 |
| 19095 | 18,078 | 5,760 | 1,674 | 2,481 | 1,432 | 44 | 1,880 | 160 | 12,095 | 41,980 | 1,119 | 51,543 | 86,702 |
| 19097 | 17,967 | 6,427 | 965 | 1,854 | 584 | 44 | 593 | 107 | 705 | 0 | 832 | 9,264 | 30,078 |
| 19099 | 15,096 | 1,989 | 3,444 | 2,601 | 181 | 338 | 95 | 765 | 2,583 | 79,087 | 1,453 | 86,233 | 107,633 |
| 19101 | 10,530 | 1,625 | 1,012 | 1,267 | 188 | 40 | 509 | 274 | 12,799 | 11,801 | 756 | 15,762 | 40,801 |
| 19103 | 8,910 | 2,276 | 2,552 | 1,730 | 124 | 267 | 122 | 922 | 587 | 32,351 | 1,107 | 38,653 | 50,948 |
| 19105 | 2,172 | 3,142 | 3,996 | 1,228 | 1,148 | 96 | 1,174 | 765 | 5,108 | 18,142 | 1,445 | 24,819 | 38,418 |
| 19107 | 18,004 | 7,714 | 1,219 | 1,981 | 42 | 232 | 322 | 466 | 1,409 | 33,643 | 1,121 | 45,157 | 66,153 |
| 19109 | 5,191 | 720 | 7,960 | 1,686 | 0 | 40 | 0 | 2,402 | 0 | 30,648 | 2,910 | 38,406 | 51,558 |
| 19111 | 5,302 | 2,747 | 1,159 | 1,566 | 162 | 85 | 137 | 566 | 2,583 | 24,131 | 981 | 30,078 | 39,420 |
| 19113 | 4,934 | 662 | 4,606 | 1,589 | 549 | 627 | 993 | 1,135 | 939 | 30,824 | 1,451 | 36,290 | 48,311 |
| 19115 | 7,548 | 1,011 | 2,035 | 791 | 108 | 84 | 42 | 611 | 939 | 9,746 | 852 | 13,094 | 23,766 |
| 19117 | 14,691 | 2,539 | 946 | 211 | 61 | 113 | 238 | 47 | 1,938 | 1,691 | 141 | 4,741 | 22,614 |
| 19119 | 479 | 558 | 3,462 | 2,885 | 1,312 | 333 | 459 | 1,483 | 7,116 | 3,875 | 1,529 | 10,663 | 23,490 |
| 19121 | 7,842 | 2,121 | 3,834 | 172 | 195 | 190 | 287 | 494 | 9,923 | 27,983 | 678 | 31,639 | 53,720 |
| 19123 | 12,371 | 1,940 | 1,324 | 2,641 | 422 | 0 | 603 | 831 | 2,994 | 34,347 | 1,089 | 40,848 | 58,562 |
| 19125 | 7,990 | 2,523 | 2,942 | 793 | 385 | 77 | 302 | 271 | 16,498 | 29,650 | 769 | 34,082 | 62,200 |
| 19127 | 2,540 | 1,762 | 5,028 | 1,380 | 580 | 242 | 262 | 956 | 0 | 60,944 | 1,280 | 66,564 | 74,974 |
| 19129 | 1,657 | 3,175 | 1,827 | 2,009 | 206 | 216 | 0 | 295 | 25,047 | 9,265 | 812 | 15,772 | 44,509 |

| FIPS | CRP old costs | CRP new costs | CT old costs | CT new costs | Contour old costs (LOW) | Contour new costs (LOW) | GW old costs (LOW) | GW new costs (LOW) | Terraces old costs | Terraces new costs | NM new costs | Total costs - new adopters only | Total costs - new and old adopters |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19131 | 2,467 | 0 | 3,946 | 1,308 | 0 | 30 | 32 | 2,220 | 2,936 | 1,761 | 1,529 | 6,848 | 16,228 |
| 19133 | 4,529 | 2,027 | 1,000 | 1,512 | 298 | 75 | 140 | 252 | 7,398 | 12,224 | 1,658 | 17,748 | 31,112 |
| 19135 | 5,007 | 331 | 223 | 737 | 63 | 92 | 0 | 203 | 1,174 | 12,635 | 207 | 14,205 | 20,672 |
| 19137 | 3,976 | 820 | 1,772 | 1,953 | 716 | 56 | 812 | 329 | 20,749 | 5,813 | 815 | 9,785 | 37,811 |
| 19139 | 1,546 | 1,191 | 2,167 | 1,364 | 80 | 178 | 17 | 1,023 | 0 | 16,498 | 1,060 | 21,314 | 25,125 |
| 19141 | 736 | 0 | 4,970 | 756 | 0 | 71 | 28 | 2,100 | 0 | 705 | 1,761 | 5,394 | 11,128 |
| 19143 | 1,473 | 2,084 | 3,702 | 956 | 0 | 197 | 0 | 1,135 | 0 | 1,761 | 1,085 | 7,219 | 12,394 |
| 19145 | 8,763 | 2,754 | 3,998 | 768 | 719 | 85 | 0 | 321 | 34,700 | 6,306 | 902 | 11,136 | 59,316 |
| 19147 | 5,781 | 841 | 4,136 | 719 | 0 | 214 | 0 | 1,325 | 0 | 9,629 | 1,575 | 14,304 | 24,220 |
| 19149 | 6,075 | 6,198 | 4,904 | 3,312 | 1,695 | 1,186 | 0 | 672 | 43,506 | 12,999 | 1,883 | 26,251 | 82,431 |
| 19151 | 0 | 1,162 | 6,113 | 660 | 0 | 148 | 0 | 1,216 | 0 | 11,097 | 1,599 | 15,882 | 21,995 |
| 19153 | 1,951 | 571 | 3,820 | 423 | 51 | 66 | 389 | 701 | 18,495 | 8,337 | 943 | 11,042 | 35,748 |
| 19155 | 3,976 | 14,103 | 3,604 | 4,280 | 1,138 | 232 | 0 | 404 | 53,582 | 26,174 | 2,272 | 47,465 | 109,765 |
| 19157 | 11,230 | 8,040 | 4,144 | 984 | 37 | 404 | 144 | 499 | 0 | 67,050 | 1,117 | 78,095 | 93,650 |
| 19159 | 24,779 | 2,489 | 1,375 | 915 | 84 | 451 | 168 | 369 | 1,268 | 6,306 | 402 | 10,932 | 38,605 |
| 19161 | 552 | 2,486 | 3,786 | 2,599 | 740 | 498 | 322 | 1,863 | 4,286 | 6,541 | 1,681 | 15,667 | 25,354 |
| 19163 | 0 | 5,139 | 2,200 | 1,798 | 429 | 164 | 35 | 623 | 1,761 | 32,410 | 1,144 | 41,277 | 45,702 |
| 19165 | 1,289 | 39,470 | 1,202 | 2,843 | 779 | 113 | 97 | 431 | 23,849 | 8,631 | 943 | 52,431 | 79,646 |
| 19167 | 1,399 | 737 | 4,151 | 4,482 | 850 | 812 | 13 | 2,437 | 24,448 | 3,769 | 2,245 | 14,482 | 45,344 |
| 19169 | 405 | 629 | 5,444 | 890 | 28 | 89 | 212 | 1,412 | 4,814 | 7,222 | 1,532 | 11,774 | 22,677 |
| 19171 | 5,449 | 3,985 | 4,967 | 1,880 | 157 | 240 | 118 | 1,427 | 5,460 | 65,641 | 1,639 | 74,811 | 90,963 |
| 19173 | 16,127 | 592 | 1,702 | 2,052 | 1,368 | 251 | 0 | 246 | 1,797 | 19,375 | 732 | 23,248 | 44,241 |
| 19175 | 11,892 | 1,362 | 2,143 | 373 | 667 | 63 | 617 | 185 | 6,447 | 3,171 | 411 | 5,564 | 27,330 |
| 19177 | 13,844 | 801 | 1,995 | 280 | 0 | 91 | 28 | 338 | 3,229 | 11,919 | 296 | 13,725 | 32,821 |
| 19179 | 8,836 | 3,027 | 894 | 847 | 103 | 155 | 125 | 290 | 11,567 | 12,271 | 643 | 17,232 | 38,757 |
| 19181 | 9,278 | 455 | 3,638 | 267 | 186 | 240 | 0 | 961 | 6,224 | 24,072 | 765 | 26,760 | 46,086 |

| FIPS | CRP old costs | CRP new costs | CT old costs | CT new costs | Contour old costs (LOW) | Contour new costs (LOW) | GW old costs (LOW) | GW new costs (LOW) | Terraces old costs | Terraces new costs | NM new costs | Total costs - new adopters only | Total costs - new and old adopters |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 19183 | 11,046 | 1,920 | 2,465 | 1,944 | 101 | 260 | 1,378 | 451 | 7,691 | 16,087 | 1,395 | 22,057 | 44,739 |
| 19185 | 20,545 | 885 | 378 | 1,305 | 352 | 392 | 59 | 208 | 1,127 | 6,869 | 377 | 10,037 | 32,498 |
| 19187 | 1,767 | 4,096 | 6,813 | 303 | 0 | 218 | 244 | 1,413 | 15,911 | 1,468 | 1,981 | 9,478 | 34,214 |
| 19189 | 5,781 | 953 | 2,132 | 1,399 | 0 | 164 | 0 | 1,035 | 0 | 12,682 | 1,272 | 17,504 | 25,417 |
| 19191 | 14,396 | 1,067 | 1,449 | 3,573 | 442 | 401 | 63 | 978 | 9,042 | 54,427 | 1,372 | 61,818 | 87,211 |
| 19193 | 16,127 | 14,943 | 4,012 | 1,824 | 442 | 247 | 97 | 283 | 29,591 | 23,779 | 1,550 | 42,626 | 92,896 |
| 19195 | 3,498 | 0 | 3,742 | 760 | 0 | 44 | 0 | 1,496 | 0 | 5,578 | 974 | 8,852 | 16,091 |
| 19197 | 1,399 | 0 | 6,559 | 592 | 38 | 73 | 0 | 1,037 | 0 | 16,146 | 2,013 | 19,862 | 27,858 |

| CO NAME | FIPS code | CO NAME | FIPS code | CO NAME | FIPS code |
|---|---|---|---|---|---|
| ADAIR | 19001 | GRUNDY | 19075 | PLYMOUTH | 19149 |
| ADAMS | 19003 | GUTHRIE | 19077 | POCAHONTAS | 19151 |
| ALLAMAKEE | 19005 | HAMILTON | 19079 | POLK | 19153 |
| APPANOOSE | 19007 | HANCOCK | 19081 | POTTAWATTAMIE | 19155 |
| AUDUBON | 19009 | HARDIN | 19083 | POWESHIEK | 19157 |
| BENTON | 19011 | HARRISON | 19085 | RINGGOLD | 19159 |
| BLACK HAWK | 19013 | HENRY | 19087 | SAC | 19161 |
| BOONE | 19015 | HOWARD | 19089 | SCOTT | 19163 |
| BREMER | 19017 | HUMBOLDT | 19091 | SHELBY | 19165 |
| BUCHANAN | 19019 | IDA | 19093 | SIOUX | 19167 |
| BUENA VISTA | 19021 | IOWA | 19095 | STORY | 19169 |
| BUTLER | 19023 | JACKSON | 19097 | TAMA | 19171 |
| CALHOUN | 19025 | JASPER | 19099 | TAYLOR | 19173 |
| CARROLL | 19027 | JEFFERSON | 19101 | UNION | 19175 |
| CASS | 19029 | JOHNSON | 19103 | VAN BUREN | 19177 |
| CEDAR | 19031 | JONES | 19105 | WAPELLO | 19179 |
| CERRO GORDO | 19033 | KEOKUK | 19107 | WARREN | 19181 |
| CHEROKEE | 19035 | KOSSUTH | 19109 | WASHINGTON | 19183 |
| CHICKASAW | 19037 | LEE | 19111 | WAYNE | 19185 |
| CLARKE | 19039 | LINN | 19113 | WEBSTER | 19187 |
| CLAY | 19041 | LOUISA | 19115 | WINNEBAGO | 19189 |
| CLAYTON | 19043 | LUCAS | 19117 | WINNESHIEK | 19191 |
| CLINTON | 19045 | LYON | 19119 | WOODBURY | 19193 |
| CRAWFORD | 19047 | MADISON | 19121 | WORTH | 19195 |
| DALLAS | 19049 | MAHASKA | 19123 | WRIGHT | 19197 |
| DAVIS | 19051 | MARION | 19125 | | |
| DECATUR | 19053 | MARSHALL | 19127 | | |
| DELAWARE | 19055 | MILLS | 19129 | | |
| DES MOINES | 19057 | MITCHELL | 19131 | | |
| DICKINSON | 19059 | MONONA | 19133 | | |
| DUBUQUE | 19061 | MONROE | 19135 | | |
| EMMET | 19063 | MONTGOMERY | 19137 | | |
| FAYETTE | 19065 | MUSCATINE | 19139 | | |
| FLOYD | 19067 | OBRIEN | 19141 | | |
| FRANKLIN | 19069 | OSCEOLA | 19143 | | |
| FREMONT | 19071 | PAGE | 19145 | | |
| GREENE | 19073 | PALO ALTO | 19147 | | |

## Appendix D: Description of the calibration process and results for the Raccoon River Watershed; paper originally presented by Jha et al. (2005) that is reprinted here in a slightly modified form (note: the hydrologic calibration results for the 13 watersheds are also shown in the main body of the report or in Appendix E).

# Nonpoint Source Needs Assessment for Iowa Part I: Configuration, Calibration and Validation of SWAT

**M. Jha, P.W. Gassman, S. Secchi, and J.G. Arnold**

## ABSTRACT

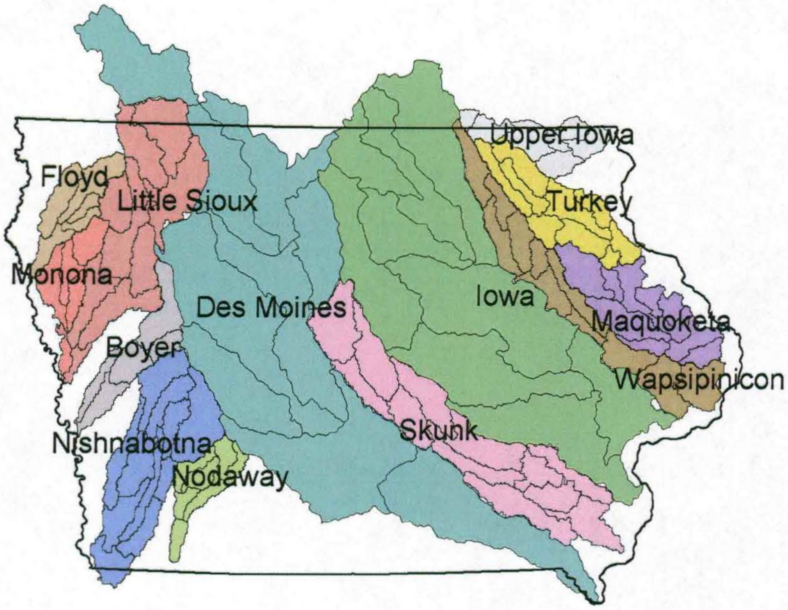
Calibration and validation of the SWAT model was performed to support an economic and environmental modeling study of mitigating cropland nonpoint source pollution losses in Iowa for the Iowa Department of Natural Resources (IDNR). SWAT was initially tested for the Raccoon River Watershed, which is a major subwatershed of the Des Moines River Watershed (one of the 13 watersheds included in the study). Simulated stream flow, sediment, and nitrate values compared favorably with measured values for the Raccoon. Stream flow $R^2$ and Nash-Suttcliffe modeling efficiency (E) values ranged between 0.77 and 0.96 for annual and monthly comparisons during the Raccoon calibration and validation periods. Strong results were also found for the simulated annual sediment loads, for which the $R^2$ and E statistics generally exceeded 0.83. The $R^2$ and E values computed for the comparison between simulated and measured annual sediment losses were greater than 0.90 in the calibration period, but the monthly statistics for the same period were only 0.45. However, all of the comparison statistics computed for the sediment loss comparisons in the validation period were between 0.83 and 0.96. The statistical evaluation for the nitrate predictions yielded a strong correlation as indicated by $R^2$ and E values of greater than 0.70 for both the annual and monthly results during the calibration and validation periods. The majority of $R^2$ and E values computed for annual comparisons between simulated and measured stream flows for the 13 study watersheds exceeded 0.85; the corresponding monthly statistics were usually greater than 0.75.

**KEYWORDS.** SWAT, modeling, calibration, validation, , sediment, nutrients, stream flow

## INTRODUCTION

The USEPA is required to perform a periodic national Clean Watersheds Needs Survey (CWNS) in response to directives that were established in the 1972 U.S. Clean Water Act (USEPA, 2000). The purpose of the survey is to identify all existing water quality or public health problems originating from point or nonpoint sources, and the corresponding mitigation costs. An integrated economic and environmental modeling system has been developed to support an Iowa Department of Natural Resources (IDNR) goal to provide more accurate cost estimates of reducing nonpoint source pollution in Iowa for the 2004 CNWS. A key component of the system is the Soil and Water Assessment Tool (SWAT) watershed model (Arnold et al., 1998; Neitsch et al. 2002), which was used to assess the impact of adopting increased levels of conservation practices on sediment and nutrient losses for 13 major watersheds in Iowa (Figure 1). The

**Figure 1. Watersheds and subwatershed delineations included in study.**



procedures and costs of adopting the conservation practices are discussed in Secchi et al. (2005) while the overall economic and environmental results of the analysis are reported in Gassman et al. (2005). The objective of this study is to present in-depth SWAT calibration and validation results for the Raccoon River Watershed and also for the Des Moines River Watershed. The calibrated parameters were then used for the 13 study watersheds. Stream flow calibration results for those watersheds are also briefly discussed, as well as the baseline sediment, nitrate, total nitrogen (N), and total phosphorus (P) loads that were estimated for each of the watersheds.

## WATERSHED DESCRIPTIONS

The SWAT simulations were configured for 13 major watersheds in Iowa that range in size from 792 km$^2$ to 14,477 km$^2$ and together cover 87% of the state (Figure 1). The key characteristics of each watershed are given in Table 1. The watersheds consist of one to nine U.S. Geological Survey (USGS) 8-digit Hydrologic Cataloging Unit (HCU) watersheds, which are defined by Seaber et al. (1987). The 8-digit watershed boundaries were used to delineate the subwatersheds for the two largest watersheds; more refined subwatershed delineations were used for the other 10 smaller watersheds as discussed in the Simulation Methodology Section. The dominant land uses across the 13 watersheds are cropland and grassland. Forest is also a relatively major land use for the Maquoketa, Turkey, and Upper Iowa watersheds that are located primarily in northeast Iowa.

## SWAT MODEL

The SWAT model is a conceptual, physically based long-term continuous watershed scale simulation model that operates on a daily time step. The model is capable of simulating a high level of spatial detail by allowing the division of a watershed into a large number of subwatersheds. In SWAT, a watershed is divided into multiple subwatersheds, which are then

**Table 1. Characteristics of the 13 study watersheds.**

| ID | Watershed | # of 8-digit watersheds | # of sub-watersheds | Drainage area ($km^2$) | USGS monitoring station #[a] | Major land use (%) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Cropland | Grassland[b] | Forest | Urban |
| 1 | Floyd | 1 | 5 | 2,376 | 6600500 | 84 | 13 | 0 | 3 |
| 2 | Monona | 1 | 5 | 2,452 | 6602400 | 78 | 19 | 2 | 1 |
| 3 | Little Sioux | 2 | 10 | 9,203 | 6607500 | 86 | 13 | 1 | 0 |
| 4 | Boyer | 1 | 5 | 2,820 | 6609500 | 68 | 26 | 4 | 2 |
| 5 | Nishnabotna | 3 | 11 | 7,718 | 6810000 | 84 | 15 | 1 | 0 |
| 6 | Nodaway | 1 | 7 | 2,051 | 6817000 | 52 | 41 | 5 | 3 |
| 7 | Des Moines | 9 | 9 | 37,496 | 5490500 | 71 | 16 | 6 | 7 |
| 8 | Skunk | 3 | 12 | 11,246 | 5474000 | 69 | 25 | 5 | 1 |
| 9 | Iowa | 9 | 9 | 32,796 | 5465500 | 77 | 12 | 4 | 8 |
| 10 | Wapsipinicon | 2 | 11 | 6,582 | 5422000 | 77 | 19 | 3 | 1 |
| 11 | Maquoketa | 1 | 10 | 4,827 | 5418500 | 56 | 32 | 10 | 3 |
| 12 | Turkey | 1 | 9 | 4,400 | 5412500 | 56 | 25 | 16 | 3 |
| 13 | Upper Iowa | 1 | 7 | 2,569 | 5388250 | 51 | 26 | 19 | 3 |

[a] These U.S. Geological Survey monitoring stations are the sources of measured stream flow data used to calibrate SWAT (see Calibration and Validation Section).

[b] Grassland includes both Conservation Reserve Program (CRP) and pasture areas.

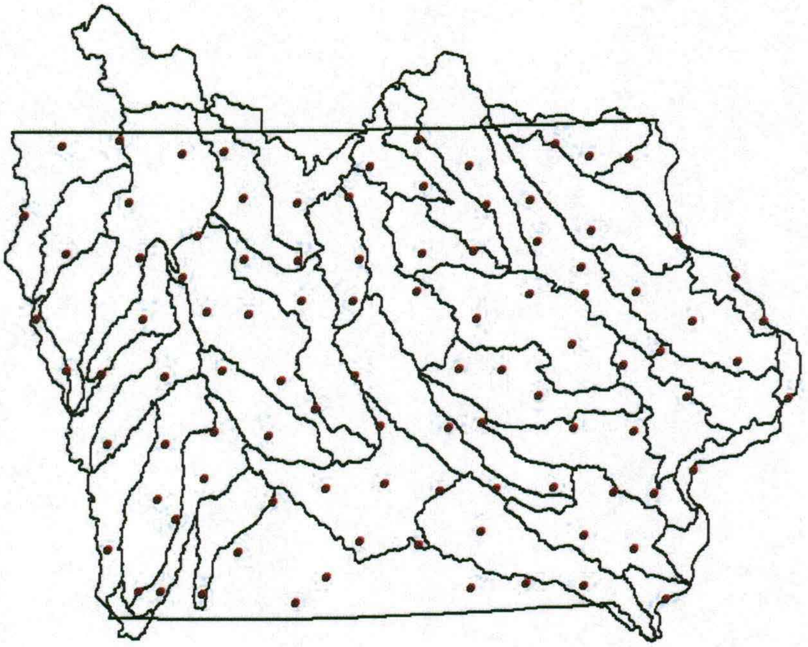
further subdivided into Hydrologic Response Units (HRUs) that consist of homogeneous land use, management, and soil characteristics. Flow generation, sediment yield, and non-point-source loadings from each HRU in a subwatershed are summed, and the resulting loads are routed through channels, ponds, and/or reservoirs to the watershed outlet. Key components of SWAT include hydrology, plant growth, erosion, nutrient transport and transformation, pesticide transport and management practices. (Arnold and Allen, 1996; Arnold et al., 1999; Arnold et al., 2000; Saleh et al., 2000; Santhi et al., 2001; Kirsch et al., 2002; Grizzetti et al., 2003; Chaplot et al., 2004). Further details on the SWAT components are presented in Arnold et al. (1998) and Neitsch et al. (2002).

## Simulation Methodology

The USDA 1997 National Resources Inventory (NRI) database (Nusser and Goebel, 1997; http://www.nrcs.usda.gov/technical/NRI/) is a key data source that was used to perform the SWAT simulations for the 13 watersheds. The NRI contains soil type, landscape features, cropping histories, conservation practices, and other data for roughly 800,000 U.S. nonfederal land "points" including 34,120 in Iowa (14,472 of which are cropland points). Each point represents an area that is assumed to consist of homogeneous land use, soil, and other characteristics, which generally ranges from a few hundred to several thousand hectares in size, and are spatially referenced at the State, Major Land Resource Area (MLRA), county, and 8-digit watershed levels. Crop rotations incorporated in the SWAT simulations are derived from cropping histories reported in the NRI. Other land use delineations required for the simulation, including the locations of baseline conservation practices, are also based on NRI data. The tillage implements simulated for the different levels of tillage (conventional, reduced, mulch, and no) incorporated in the analysis were obtained from the USDA 1990-95 Cropping Practices Survey (CPS), which is accessible at http://usda.mannlib.cornell.edu/usda/ess_entry.html). Historical precipitation, maximum temperature, and minimum temperature data obtained from the Iowa

Environmental Mesonet (http://mesonet.agron.iastate.edu/request/coop/fe. phtml) for the 18-year period (1980-99) were used for the SWAT simulations; the location of the weather stations is shown in Figure 2. The soil layer data required for the SWAT simulations is input from a soil database that contains soil properties consistent with those described by Baumer et al. (1994), with the additional enhancement of ID codes that allow direct linkage to NRI points.

**Figure 2. Weather stations used in the SWAT simulations for the 13 Iowa watersheds (Source: Iowa Environmental Mesonet).**



Delineation of each watershed into smaller spatial units required for the SWAT simulations consists of two steps: (1) subdividing each watershed (Figure 1) into either 8-digit or smaller 10-digit watersheds (IDNR-IGS, 2004a), and (2) creating smaller HRUs within each of the subwatersheds. Larger 8-digit subwatersheds were used for the Des Moines and Iowa River Watersheds (Figure 1), which were the two largest systems included in the analysis. The HRUs represent "lumped areas" of similar land use and soil types that are distributed throughout each subwatershed; however, exact spatial locations of the HRUs are not incorporated in the SWAT simulation. The HRUs required for the SWAT baseline simulations were created by aggregating NRI points together that possess common land use, soil, and management characteristics. All of the points within a given category were clustered together within each 8-digit watershed for the Des Moines and Iowa River Watershed simulations, except for the cultivated cropland. For the cultivated cropland, the NRI points were first aggregated into different crop rotation land use clusters within each 8-digit watershed, based on the NRI cropping histories. These crop rotation aggregations were then subdivided based on permutations of rotations; e.g., corn-soybean versus soybean-corn.

The smaller 10-digit subwatersheds were used for those watersheds that consist of 1 to 3 8-digit watersheds (Figure 1), to avoid potential distortions in predicted pollutant indicators when only a small number of subwatersheds are used in a SWAT application as discussed by Jha et al. (2004). A more complex procedure was developed to construct the HRUs for the SWAT baseline simulations for the other 11 watersheds, because the NRI data is not spatially referenced at the 10-digit watershed level. To overcome this limitation, Iowa Soil Properties and Interpretations Database (ISPAID) soil data (http://extension.agron. iastate.edu/soils/pdfs/ISP71MAN.pdf) and IDNR land use data available for 2002 (IDNR-IGS, 2004b) were used to help determine which HRUs should be placed in each 10-digit subwatershed. The initial step in the procedure consisted of attempting to match soil IDs shown in the ISPAID soil map for a 10-digit watershed, to soil IDs listed in the NRI for points located within the respective 8-digit watershed that the 10-digit watershed was located in. A positive match indicated that the NRI point could be located in that 10-digit watershed. The 2002 IDNR land use data was then used to help further verify which 10-digit watershed an NRI point was most likely to be located in, based on whether the land use was cropland, CRP, forest, urban, and so forth. The remaining NRI points were assigned arbitrarily to the 10-digit subwatersheds to ensure that the total land area was accounted for.

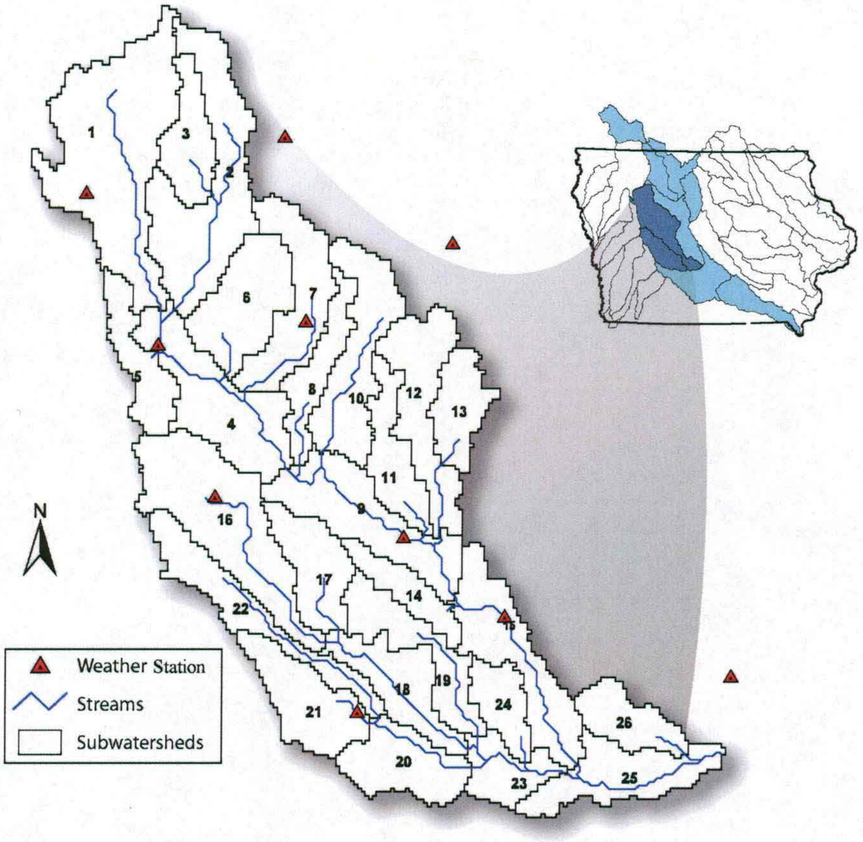
An in-depth calibration and validation exercise was performed for the Raccoon River Watershed, which is a major subwatershed of the Des Moines River Watershed (Figure 3). The Raccoon River Watershed was chosen for the intensive calibration and validation phase because of the reliable stream flow, sediment, and nitrate data that is available for the watershed (Lutz, 2004). A total of 26 10-digit subwatersheds were delineated for the Raccoon River simulations. The process of determining which subwatersheds the HRUs should be placed in was similar to the procedures described above for the watersheds that were subdivided with the 10-digit subwatersheds.

## RESULTS AND DISCUSSION

To perform the Raccoon River Watershed calibration, baseflow was initially separated from surface flow for the measured daily streamflow data at Van Meter, Iowa (near the outlet of the watershed) using an automated digital filter technique (Arnold and Allen, 1999). The technique estimated the baseflow to be about 65% of the streamflow. Model hydrologic parameters were adjusted from their initial estimates within acceptable ranges to achieve the desired proportion of surface runoff to baseflow. Reducing the curve numbers (CNs) by 8% and the available soil water capacity (SOL_AWC) values by 0.04 mm resulted in a proportion of 60% baseflow and 40% surface runoff on an annual basis. SWAT model calibration was then carried out to match the simulated flow with the measured flow at Van Meter. The calibration (1981-1989) yielded a strong correlation in annual streamflow as indicated by an $R^2$ of 0.96 and a modeling efficiency (E) value of 0.95. The calibration time-series comparison (Figure 4) also reveals a good correspondence, with resulting $R^2$ and E values of 0.78 and 0.77, respectively. SWAT also performed very well during the validation period (1990-2000) as indicated by annual $R^2$ and E values of 0.93 and 0.87, respectively, and corresponding monthly values of 0.86 and 0.82.

Model calibration of sediment yield was performed for channel degradation and deposition. Parameters such as the linear (SPCON) and exponent (SPEXP) components of the sediment equation and channel cover factor were adjusted to match simulated sediment yield with the

**Figure 3. Location of the Raccoon River Watershed within the Des Moines River Watershed, and delineation of the subwatersheds and location of the weather stations and streams for the SWAT simulation.**



measured sediment loads at Van Meter, which were extrapolated from single monthly sediment samples. The calibration process yielded $R^2$ and E values of 0.90 and 0.88 for the annual results, and 0.46 and 0.44 for the monthly results, respectively. Similarly, the validation process resulted in $R^2$ and E values of 0.96 and 0.83 for the annual comparison and 0.91 and 0.90 for the monthly comparison, respectively. Overall, the model tracked the monthly sediment yields very well (Figure 5).

Model calibration was also performed for the nitrate loadings at Van Meter. Again, the measured data are extrapolated from single monthly samples. Calibration parameters including the nitrogen percolation coefficient were varied within their acceptable ranges, but the model was not found to be very sensitive to these adjustments. Basically, for the nitrate calibration, the ratio of the surface runoff and baseflow was varied to produce a good match between the simulated and measured values of streamflow and nitrate (Figure 6). The statistical evaluation yielded a strong correlation as indicated by $R^2$ and E values of greater than 0.70 for both the annual and monthly results during the calibration and validation periods.

The calibrated sediment and nitrate parameters for the Raccoon River simulation were then used for the SWAT simulations performed for the 13 study watersheds, due to a lack of available measured data. Stream flows were calibrated for all 13 watersheds for the period 1981-89, and

Figure 4. Simulated versus measured monthly stream flows at Van Meter, Iowa for the Raccoon River Watershed.

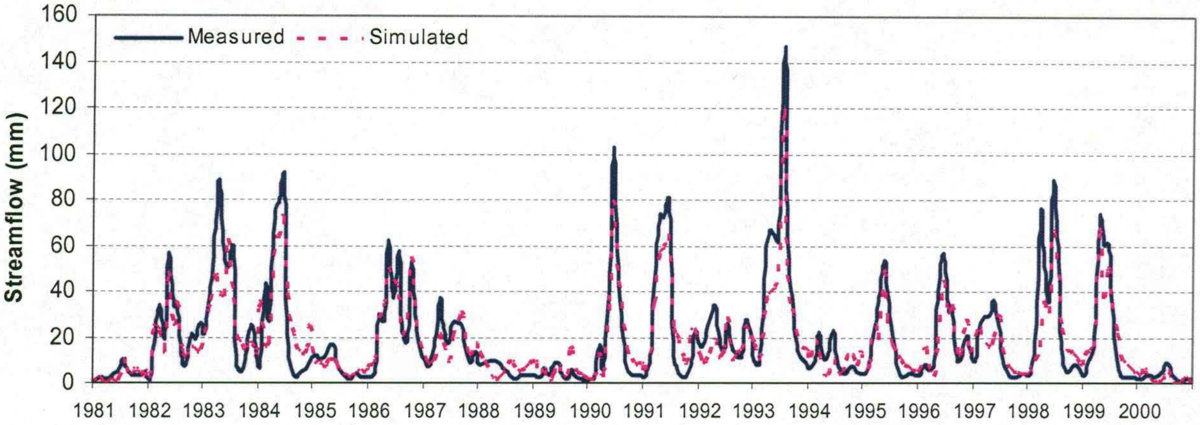


Figure 5. Simulated versus measured monthly sediment loads at Van Meter, Iowa for the Raccoon River Watershed.

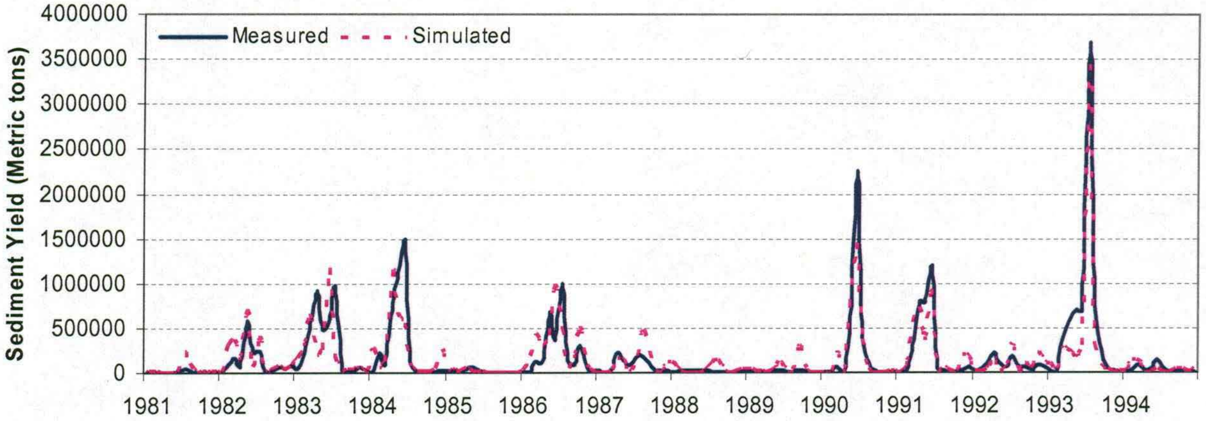
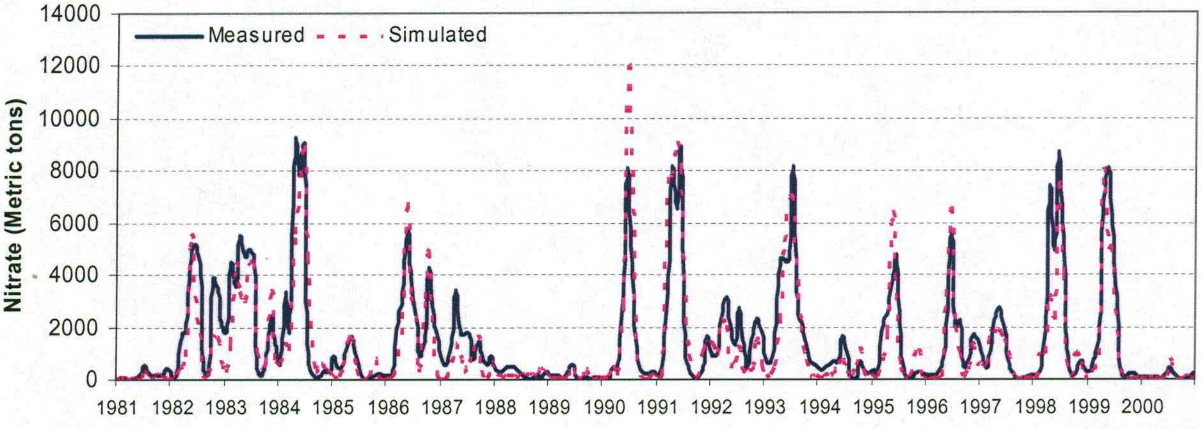


Figure 6. Simulated versus measured monthly nitrate loads at Van Meter, Iowa for the Raccoon River Watershed.



subsequent validation was performed for 1990-97. Table 2 lists the $R^2$ and E statistics that were calculated for the streamflow calibration and validation phases for all 13 watersheds; example monthly stream flow time series comparisons are shown in Figures 7 and 8 for the Des Moines and Iowa River Watersheds, respectively. The majority of the annual $R^2$ and E values calculated for the annual calibration and validation periods exceeded 0.85 (Table 2). The monthly predictions were less accurate than the annual estimates but the majority of the $r^2$ and E values were still strong, especially in the validation period in which most of the computed statistics were greater than 0.75. The results shown in Table 2 underscore that SWAT accurately replicated the stream flows for each watershed in both the calibration and validation periods.

**Table 2. Streamflow calibration results for the 13 study watersheds.**

| ID | Watershed | Annual Statistics | | | | Monthly Statistics | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Calibration (1980-1989) | | Validation (1990-1997) | | Calibration (1980-1989) | | Validation (1990-1997) | |
| | | $R^2$ | E | $R^2$ | E | $R^2$ | E | $R^2$ | E |
| 1 | Floyd | 0.94 | 0.91 | 0.71 | 0.68 | 0.68 | 0.66 | 0.52 | 0.49 |
| 2 | Monona | 0.93 | 0.82 | 0.78 | 0.65 | 0.7 | 0.68 | 0.63 | 0.54 |
| 3 | Little Sioux | 0.93 | 0.93 | 0.82 | 0.81 | 0.67 | 0.67 | 0.72 | 0.71 |
| 4 | Boyer | 0.91 | 0.79 | 0.93 | 0.92 | 0.71 | 0.56 | 0.81 | 0.78 |
| 5 | Nishnabotna | 0.9 | 0.89 | 0.95 | 0.95 | 0.8 | 0.7 | 0.81 | 0.81 |
| 6 | Nodaway | 0.96 | 0.95 | 0.93 | 0.93 | 0.75 | 0.74 | 0.78 | 0.77 |
| 7 | Des Moines | 0.92 | 0.92 | 0.91 | 0.88 | 0.62 | 0.61 | 0.77 | 0.75 |
| 8 | Skunk | 0.96 | 0.95 | 0.98 | 0.98 | 0.64 | 0.64 | 0.83 | 0.83 |
| 9 | Iowa | 0.87 | 0.86 | 0.95 | 0.93 | 0.77 | 0.76 | 0.9 | 0.89 |
| 10 | Wapsipinicon | 0.77 | 0.74 | 0.92 | 0.9 | 0.62 | 0.6 | 0.83 | 0.83 |
| 11 | Maquoketa | 0.85 | 0.77 | 0.9 | 0.86 | 0.67 | 0.49 | 0.8 | 0.78 |
| 12 | Turkey | 0.89 | 0.85 | 0.91 | 0.85 | 0.7 | 0.63 | 0.79 | 0.75 |
| 13 | Upper Iowa | 0.95 | 0.91 | 0.81 | 0.8 | 0.66 | 0.59 | 0.79 | 0.78 |

**Figure 7. Simulated versus measured monthly stream flows during the calibration and validation periods for Des Moines River Watershed at Keosaqua/St Francis.**

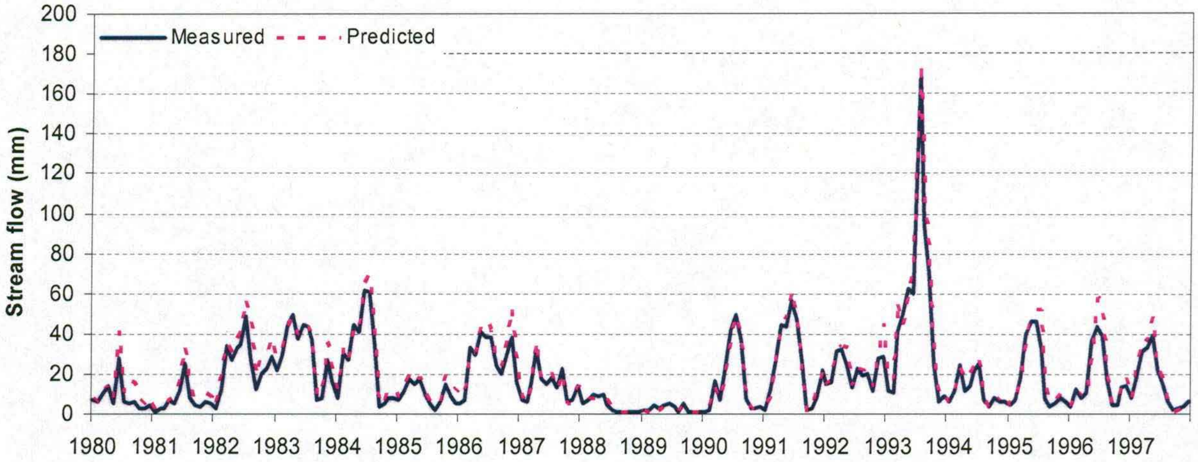
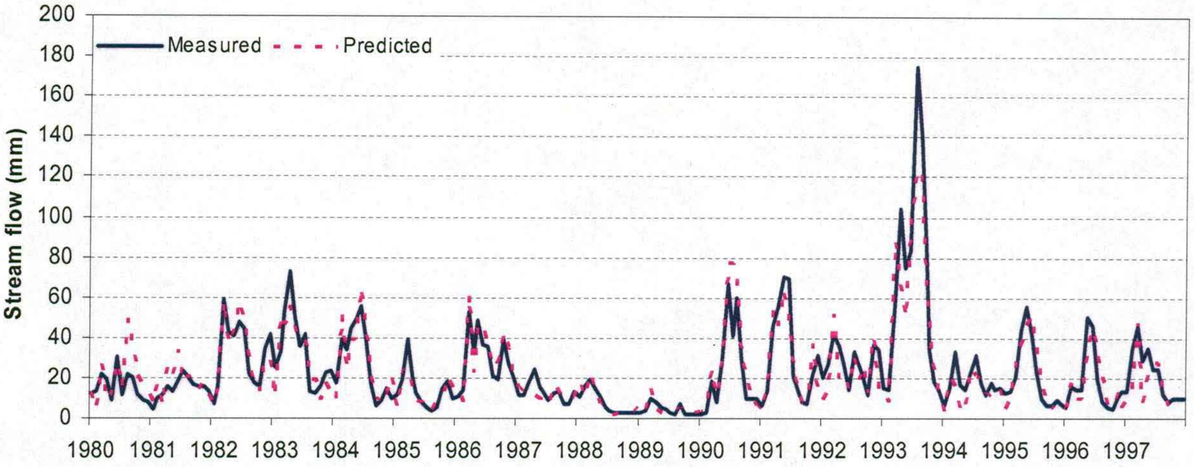


**Figure 8. Simulated versus measured monthly stream flows during the calibration and validation periods for Iowa River Watershed at Wapello.**



The total average annual loadings for the baseline simulations are presented in Table 3 for each watershed outlet for four environmental indicators: sediment, nitrate, total N, and total P. The total stream flows and pollutant loadings varied greatly between the 13 watersheds, reflecting differences in size, land use, and soil and climate conditions. The Des Moines and Iowa River Watershed results were also affected by reservoirs that trap large amounts of sediment and some sediment-bound nutrients.

**Table 3. Annual average baseline loadings in metric tons for 1980-1997.**

| | Watershed | Sediment | Nitrate | Total N | Total P |
|---|---|---|---|---|---|
| 1 | Floyd | 241,423 | 7,125 | 8,406 | 405 |
| 2 | Monona | 198,589 | 4,847 | 5,605 | 327 |
| 3 | Little Sioux | 632,456 | 23,851 | 28,569 | 2,067 |
| 4 | Boyer | 777,245 | 4,947 | 6,991 | 709 |
| 5 | Nishnabotna | 1,968,399 | 8,257 | 10,656 | 1,001 |
| 6 | Nodaway | 520,045 | 3,312 | 4,656 | 518 |
| 7 | Des Moines | 2,174,303 | 38,252 | 63,349 | 7,075 |
| 8 | Skunk | 3,800,345 | 28,122 | 32,087 | 2,021 |
| 9 | Iowa | 3,423,237 | 54,050 | 103,738 | 7,786 |
| 10 | Wapsipinicon | 2,238,966 | 27,533 | 31,484 | 1,571 |
| 11 | Maquoketa | 1,218,739 | 14,781 | 17,746 | 919 |
| 12 | Turkey | 1,297,814 | 12,436 | 14,842 | 850 |
| 13 | Upper Iowa | 730,155 | 3,675 | 4,683 | 379 |

## CONCLUSION

The calibration and validation results reported for the Raccoon River Watershed indicate that SWAT can effectively replicate streamflow, and associated sediment, and nitrate losses, for large Iowa river watersheds. The additional streamflow calibration and validation results for the Des Moines River Watershed and 11 other watersheds further confirm that SWAT can replicate Iowa river system conditions. These results provide the foundation for the environmental results that are reported in Gassman et al. (2005) for two different scenarios of adopting conservation practices and a fertilizer reduction strategy. Additional calibration and validation work is needed for applying SWAT in Iowa, especially with regards to phosphorus predictions

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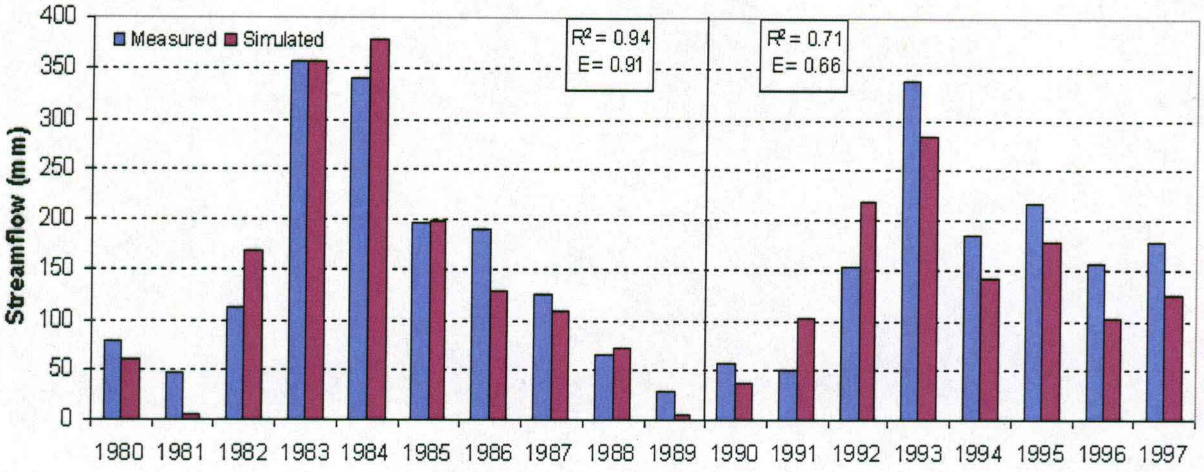
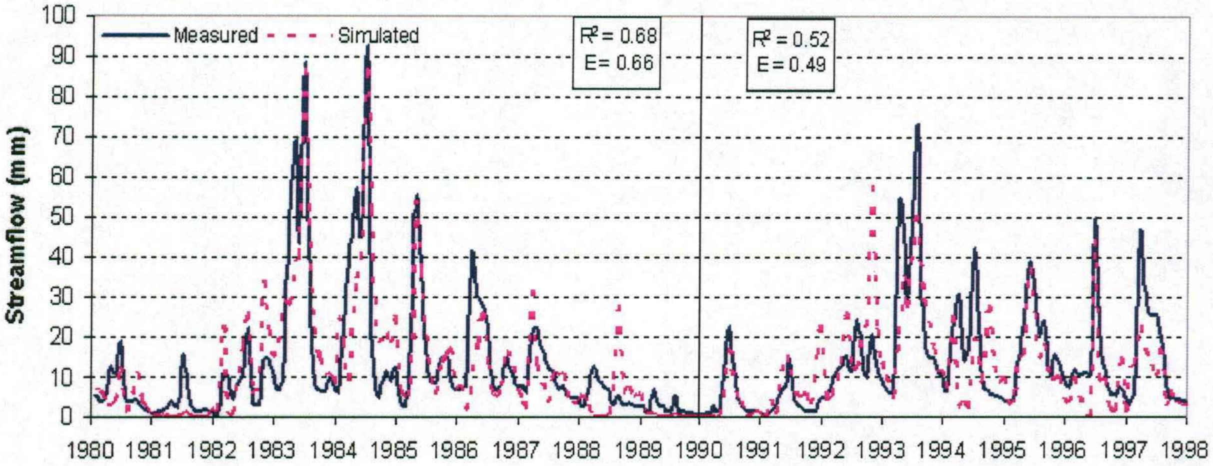
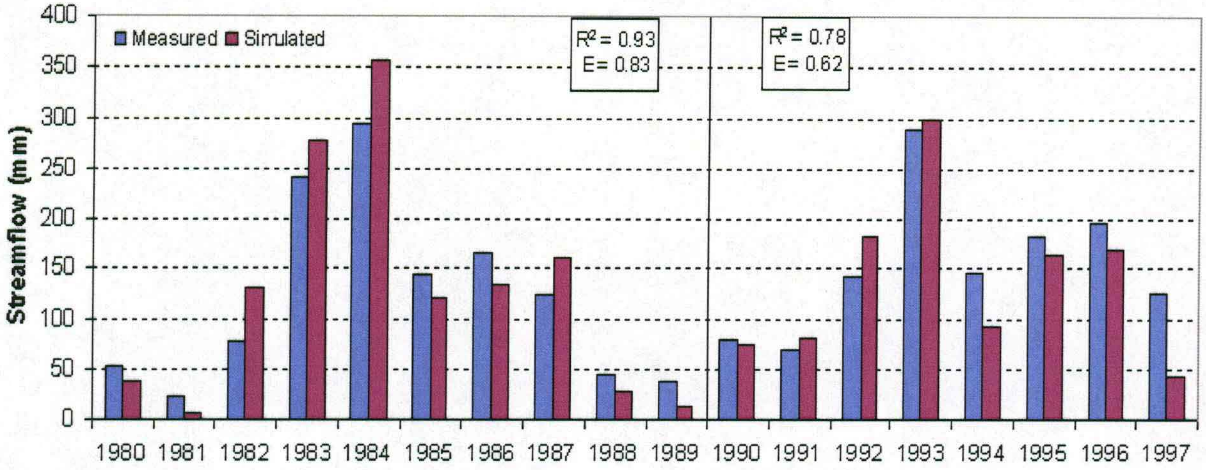
## Appendix E: Hydrologic calibration (1980-89) and validation (1990-97) results for all 13 watersheds.

### 1. Floyd

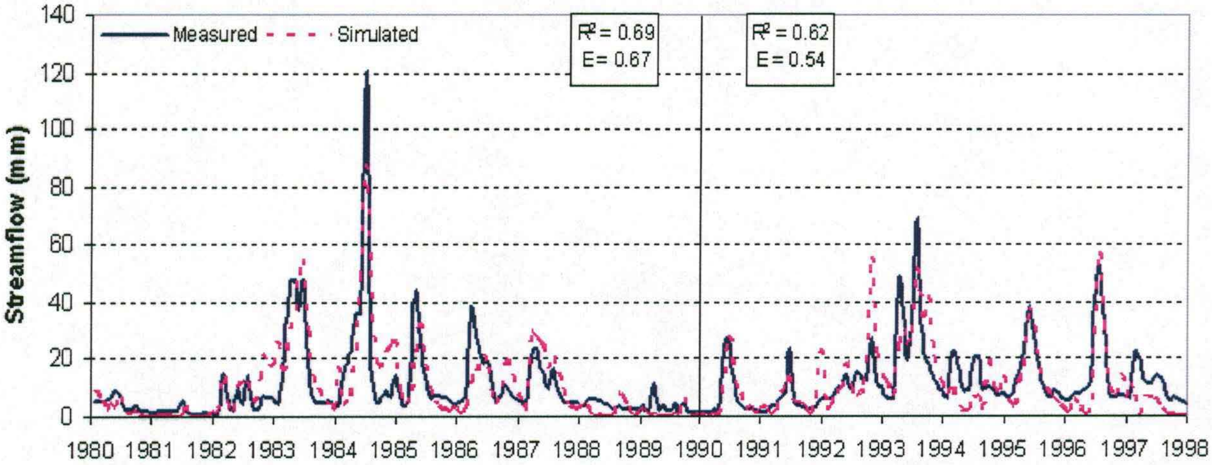




2. Monona

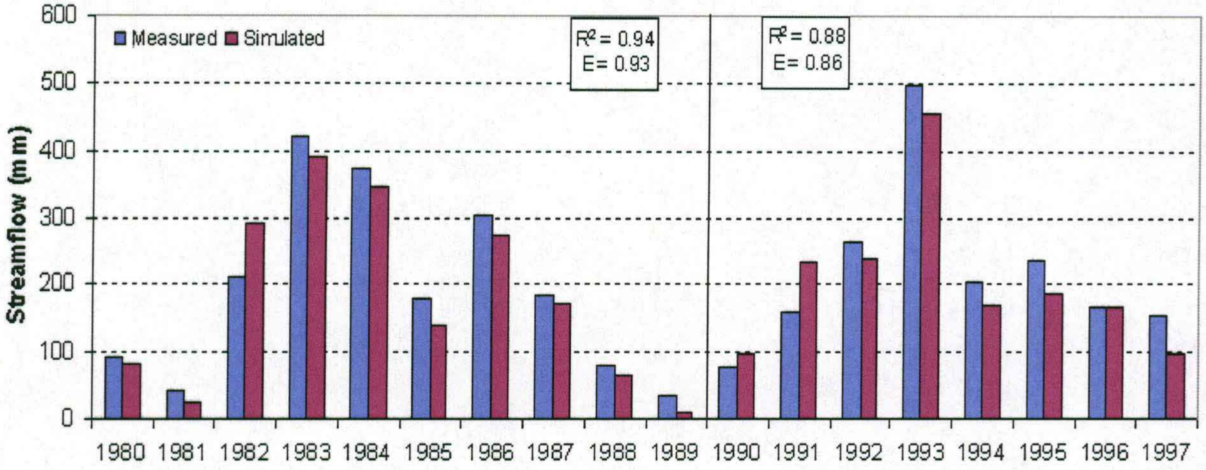


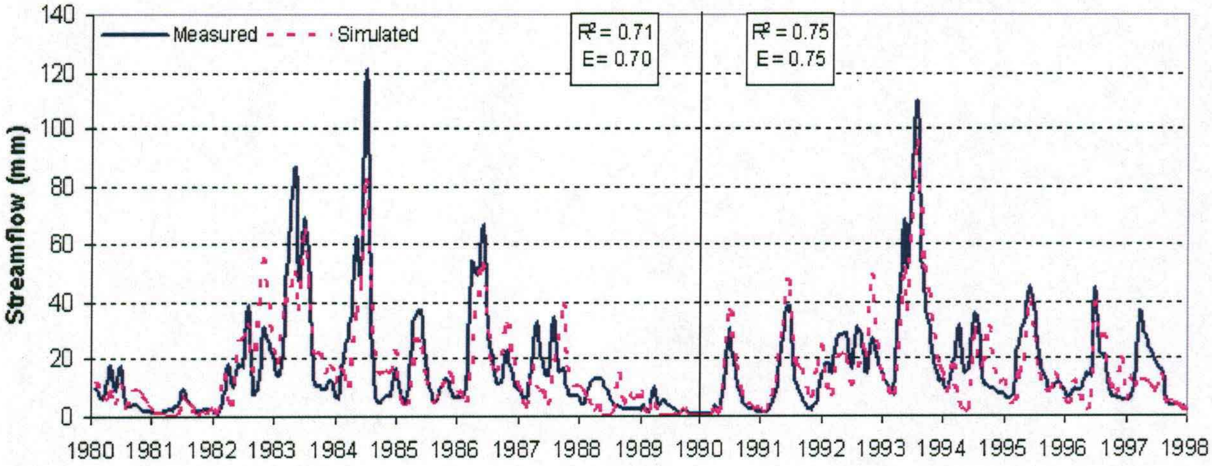
400
350
300
250
200
150
100
50
0
Streamflow (mm)
Measured
Simulated
$R^2$ = 0.93
E= 0.83
$R^2$ = 0.78
E= 0.62
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997



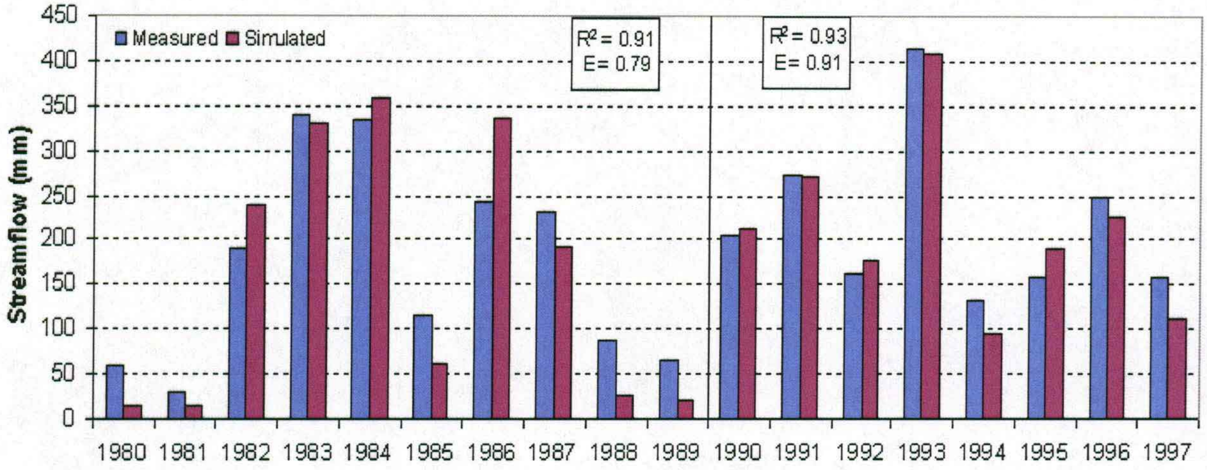
140
120
100
80
60
40
20
0
Streamflow (mm)
Measured
Simulated
$R^2$ = 0.69
E= 0.67
$R^2$ = 0.62
E= 0.54
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998

3. Little Sioux

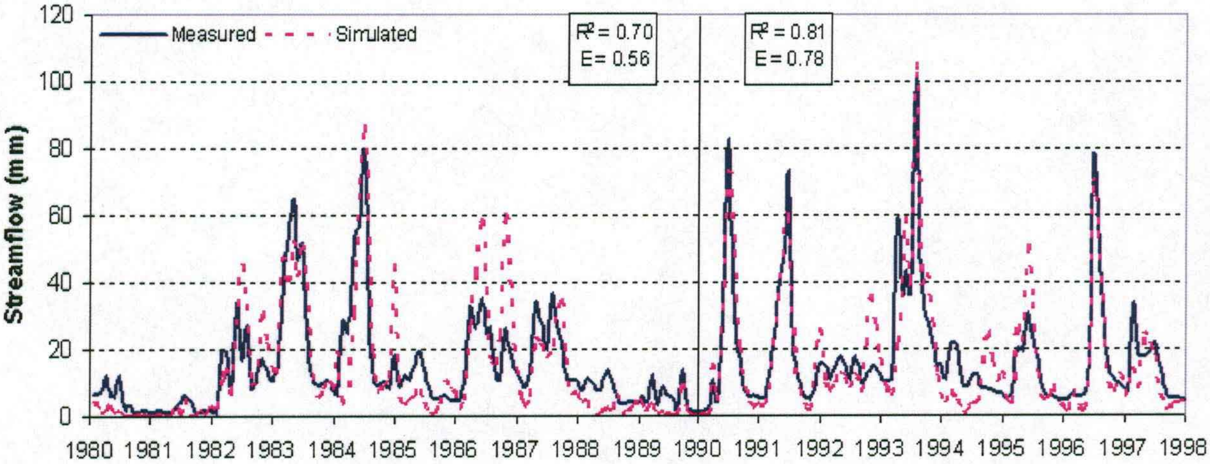




4. Boyer

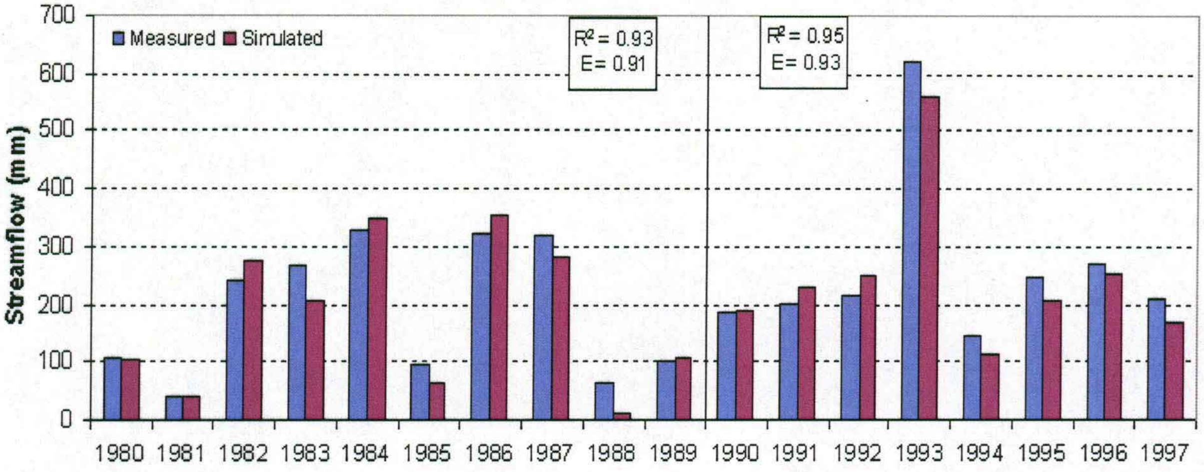


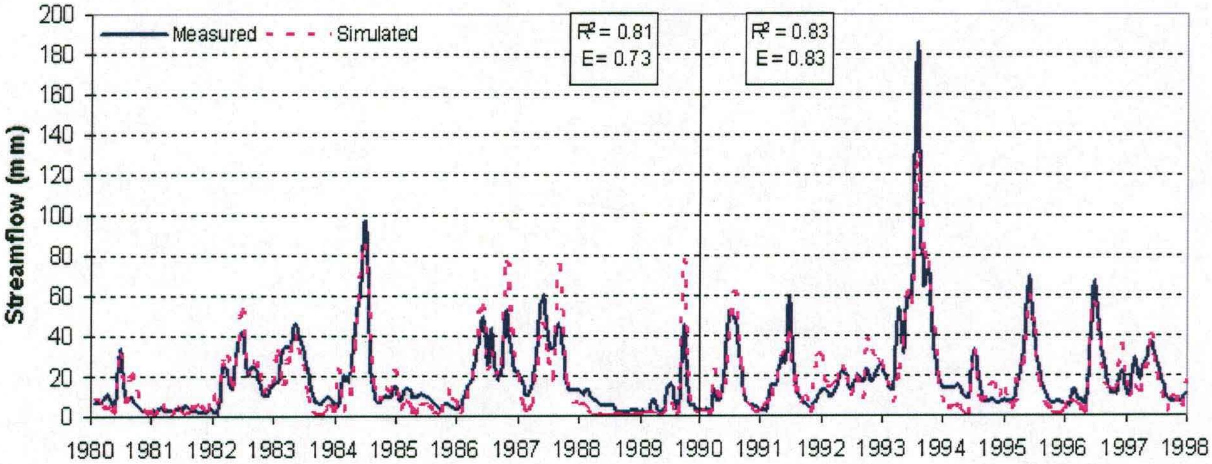
Measured
Simulated
R² = 0.91
E= 0.79
R² = 0.93
E= 0.91
Streamflow (mm)
450
400
350
300
250
200
150
100
50
0
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997



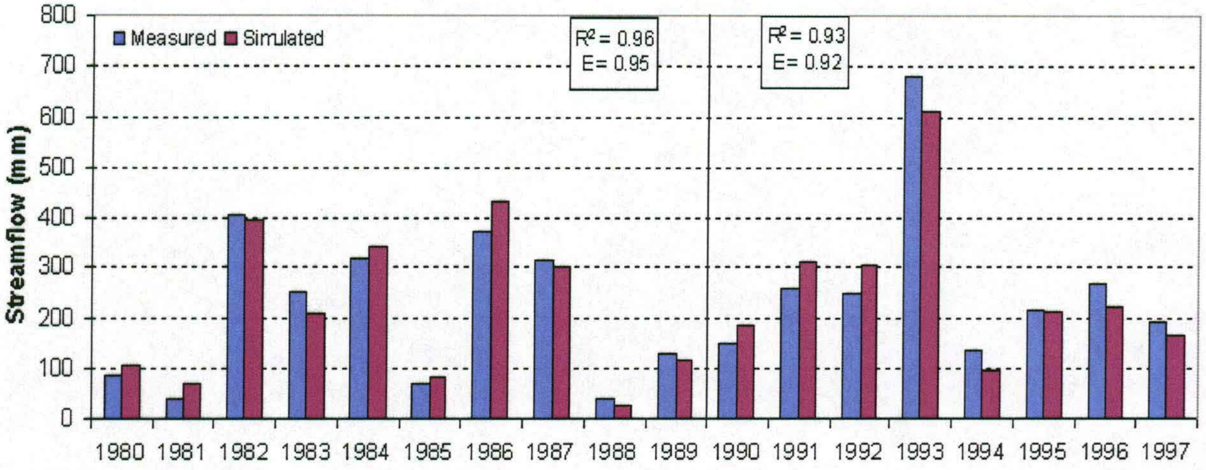
Measured
Simulated
R² = 0.70
E= 0.56
R² = 0.81
E= 0.78
Streamflow (mm)
120
100
80
60
40
20
0
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998

5. Nishnabotna

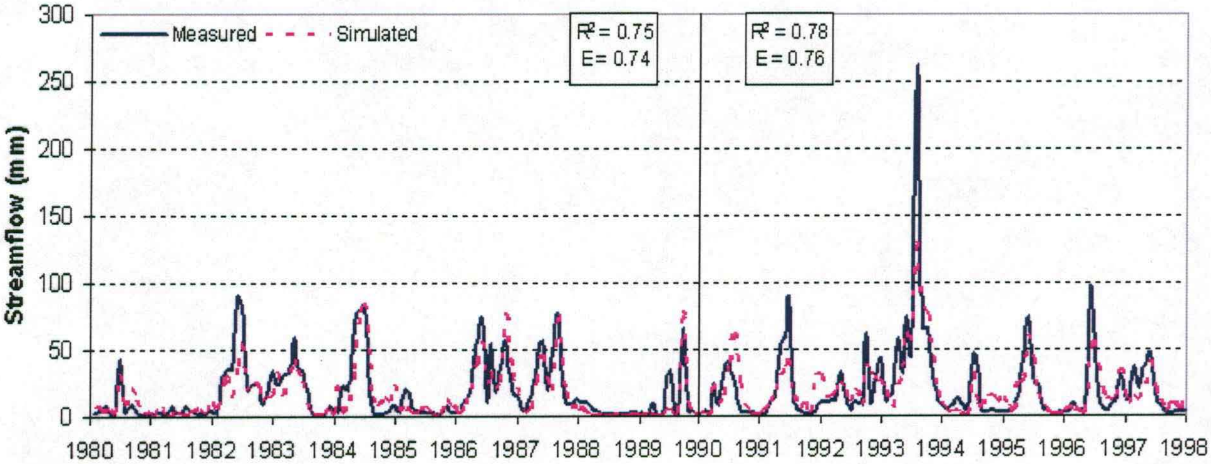




6. Nodaway

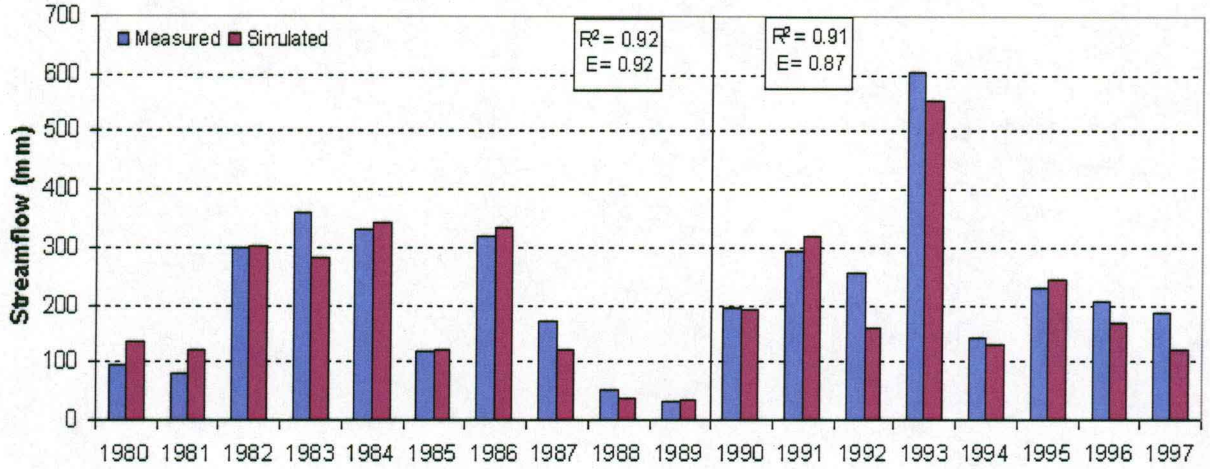


800
700
600
500
400
300
200
100
0
Streamflow (mm)
Measured
Simulated
R² = 0.96
E= 0.95
R² = 0.93
E= 0.92
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997

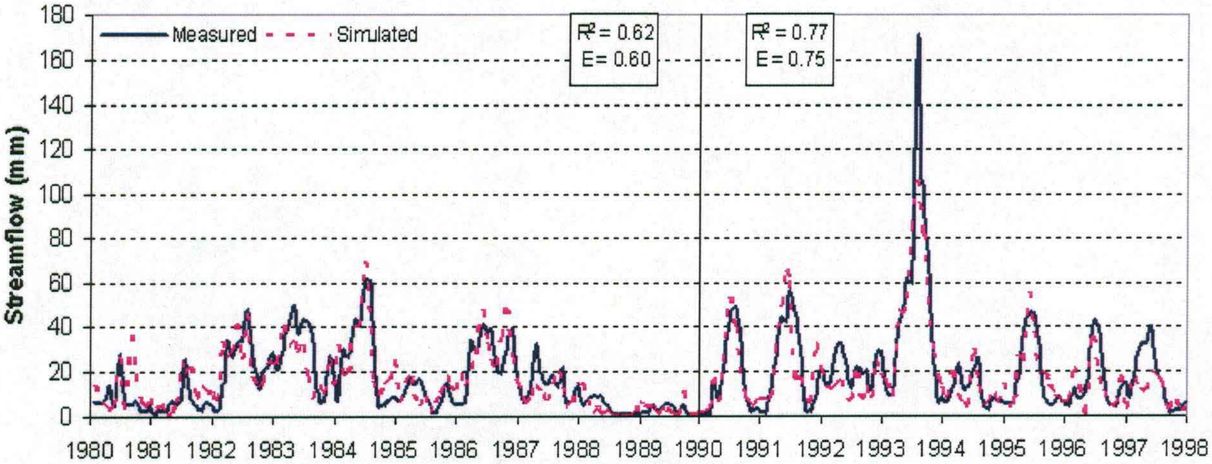


300
250
200
150
100
50
0
Streamflow (mm)
Measured
Simulated
R² = 0.75
E= 0.74
R² = 0.78
E= 0.76
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998

7. Des Moines

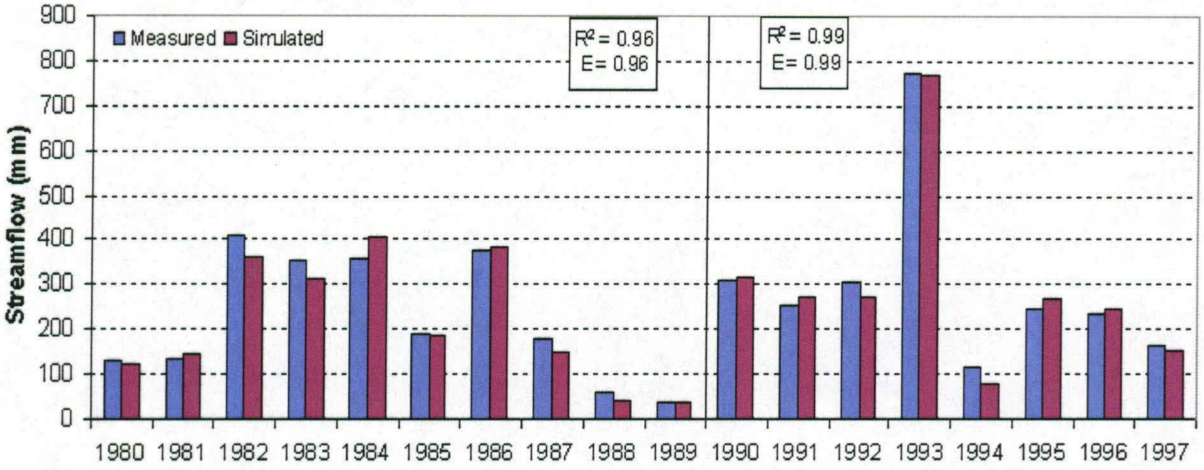


Measured
Simulated
R² = 0.92
E= 0.92
R² = 0.91
E= 0.87
Streamflow (mm)
0
100
200
300
400
500
600
700
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997

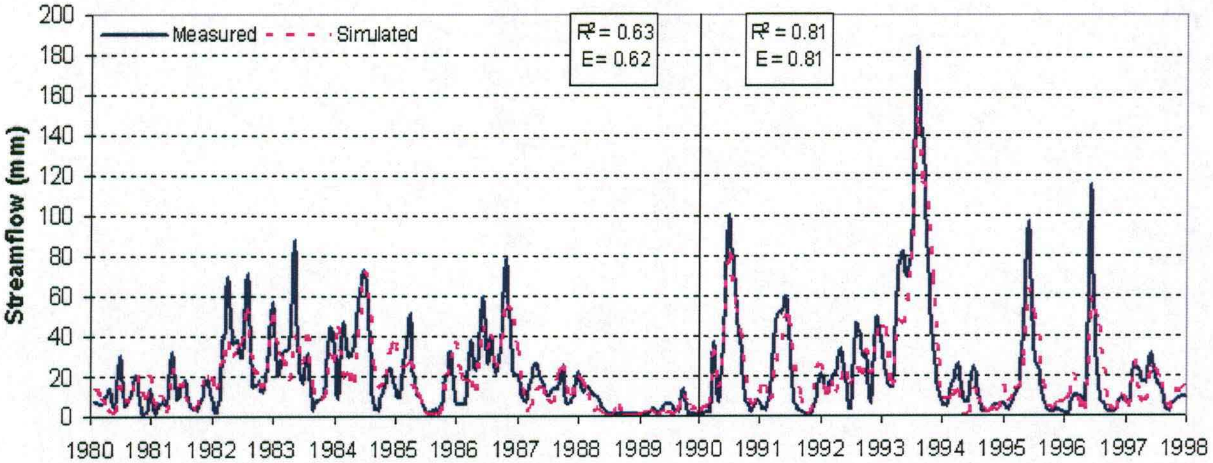


Measured
Simulated
R² = 0.62
E= 0.60
R² = 0.77
E= 0.75
Streamflow (mm)
0
20
40
60
80
100
120
140
160
180
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998

8. Skunk



Measured
Simulated
R² = 0.96
E= 0.96
R² = 0.99
E= 0.99
Streamflow (mm)
900
800
700
600
500
400
300
200
100
0
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997



Measured
Simulated
R² = 0.63
E= 0.62
R² = 0.81
E= 0.81
Streamflow (mm)
200
180
160
140
120
100
80
60
40
20
0
1980
1981
1982
1983
1984
1985
1986
1987
1988
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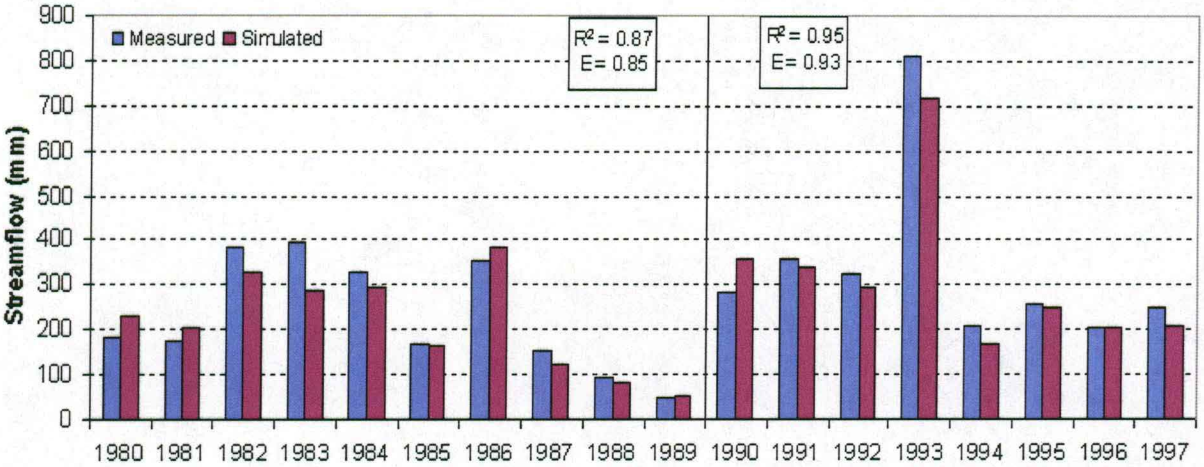
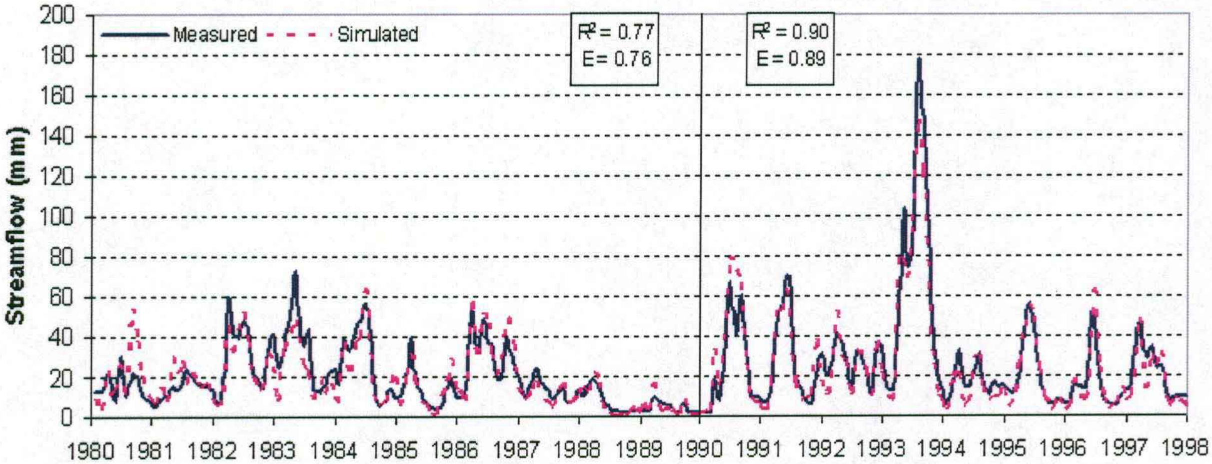
1990
1991
1992
1993
1994
1995
1996
1997
1998

<u>9. Iowa</u>

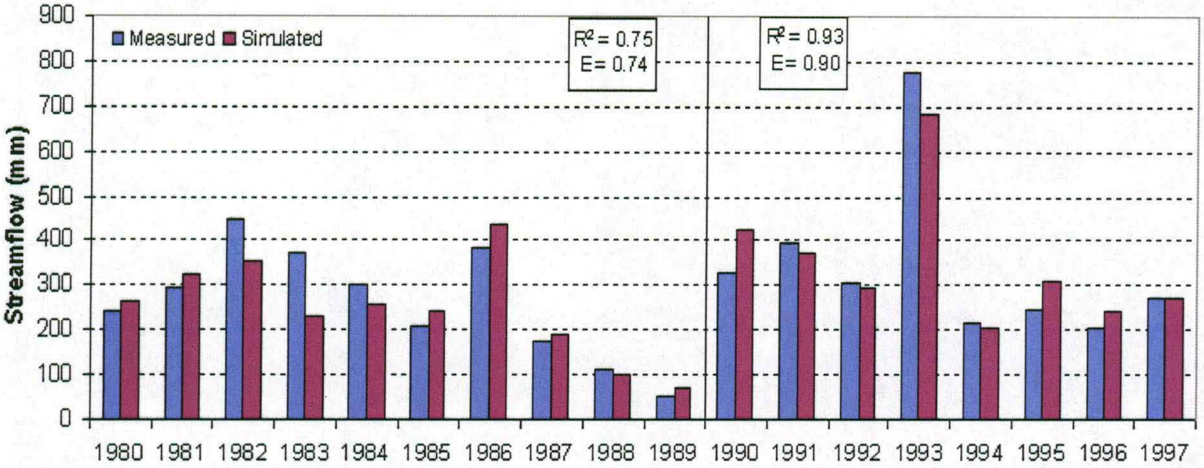


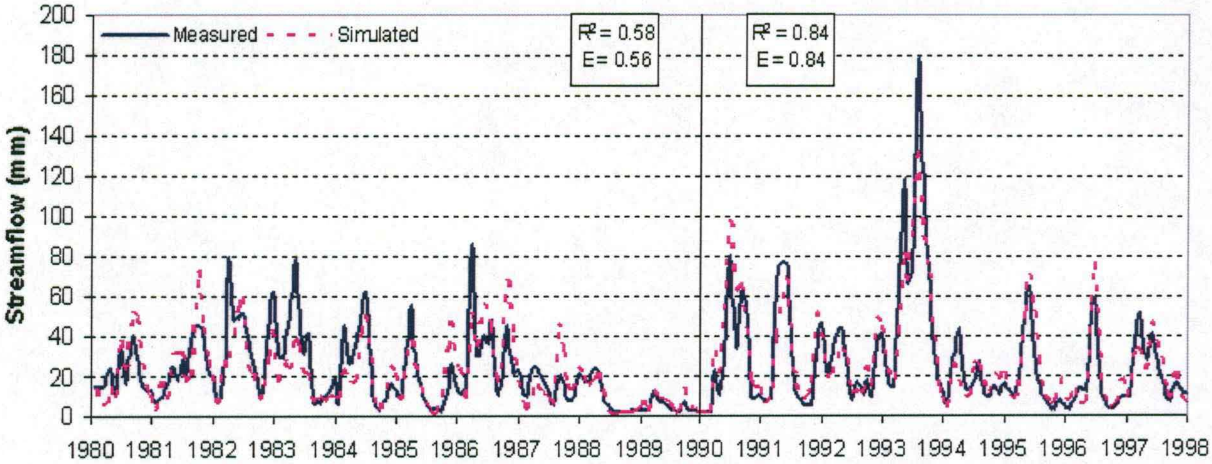
Measured
Simulated
R² = 0.87
E= 0.85
R² = 0.95
E= 0.93
Streamflow (mm)
900
800
700
600
500
400
300
200
100
0
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997



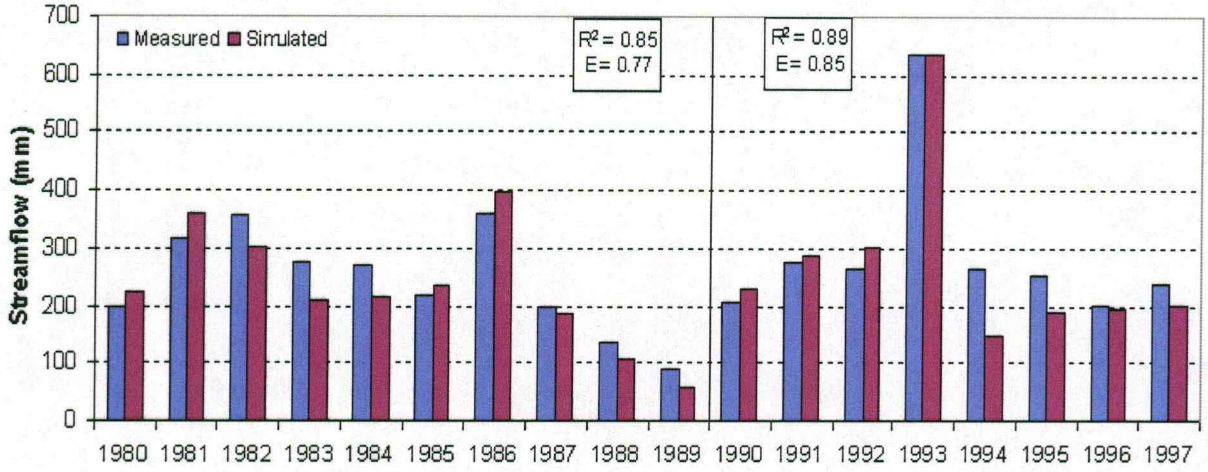
Measured
Simulated
R² = 0.77
E= 0.76
R² = 0.90
E= 0.89
Streamflow (mm)
200
180
160
140
120
100
80
60
40
20
0
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998

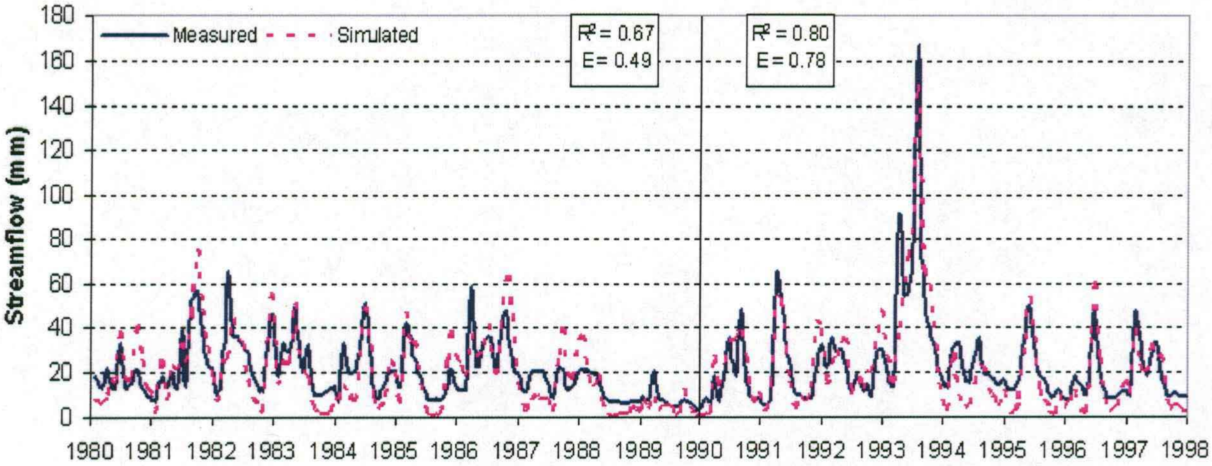
10. Wapsipinicon



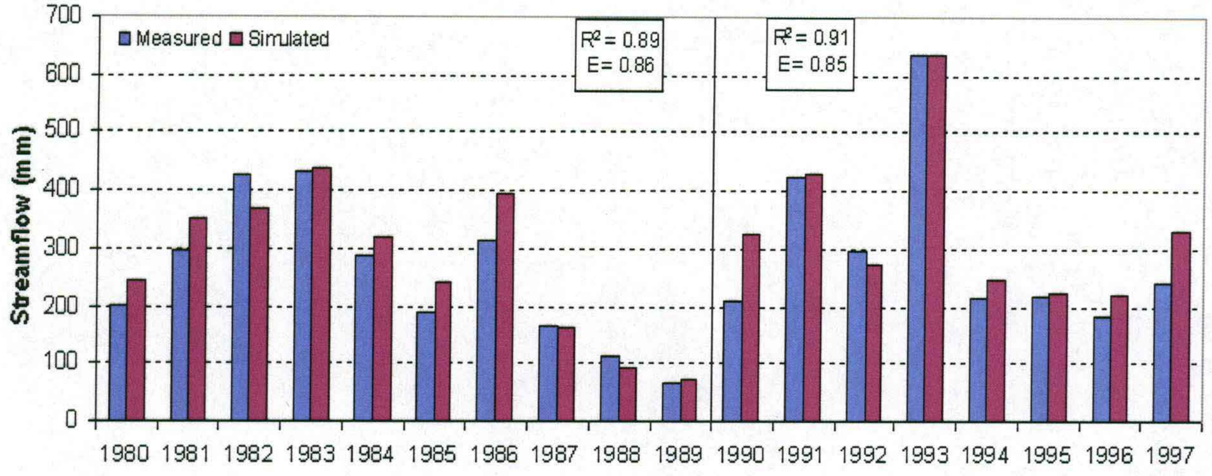


11. Maquoketa

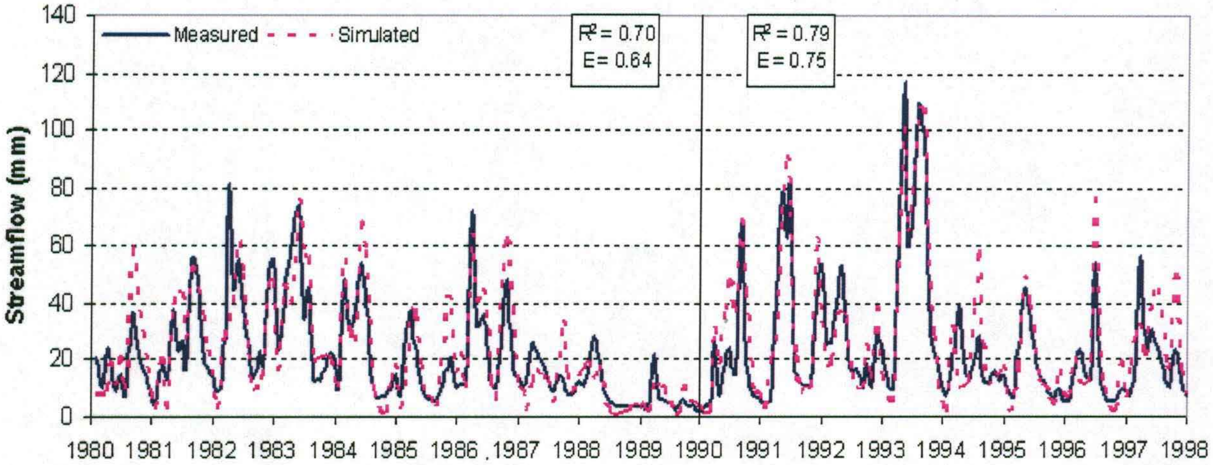




## 12. Turkey



Measured
Simulated
R² = 0.89
E= 0.86
R² = 0.91
E= 0.85
Streamflow (mm)
700
600
500
400
300
200
100
0
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997



Measured
Simulated
R² = 0.70
E= 0.64
R² = 0.79
E= 0.75
Streamflow (mm)
140
120
100
80
60
40
20
0
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998

13. Upper Iowa