Modeling Nutrient Loads and Management Operations in the North Bosque Watershed

Prepared as a
Conservation Effects Assessment Project (CEAP)
Special Emphasis Watershed Study

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EXECUTIVE SUMMARY

The Conservation Effects Assessment Project (CEAP) is a multi-agency effort to quantify the environmental benefits of conservation practices sponsored by U.S. Department of Agriculture (USDA) conservation programs. One component of this project focused on assessment studies that include ARS Benchmark, Special Emphasis, and Competitive Grants Watersheds. The watershed studies provide a framework for evaluating and improving performance of national assessment models. The North Bosque Watershed is considered a Special Emphasis Watershed. It was selected to address the specific resources concern for manure management for dairy operations.

The purpose of this Special Emphasis Study was to simulate nutrient and sediment loadings in the North Bosque Watershed using the Agricultural Policy Environmental eXtender (APEX) model (Williams and Izaurralde, 2006). APEX was calibrated and validated. The calibrated model was used for scenario analyses. Twenty scenarios were modeled: Scenario 1 represents the current conditions in the watershed; Scenarios 2 - 6 represent various dairy manure application rates simulating different stages of nutrient management. Scenarios 7-8 represent the natural condition of the landscape without reservoirs, livestock or cropland. Scenarios 9-10 represents the condition of the watershed if the reservoir structures were not present on the landscape.: Scenarios 11-12 represents the conversion of additional cropland to improved conservation practices and the conversion of pastures to improved pasture grasses. Scenarios 14-20 repeat the crop and manure management practices with the addition of 6 new reservoirs into the watershed landscape.

APEX was calibrated/validated to measured monthly stream flow, sediment yield, phosphorous and nitrogen loading at the Hico monitoring station (1993-1998), Texas. Time series plots and statistical measures were used for model performance evaluation.

The validated model was applied to evaluate the effects of various conservation practices on three levels: farm level (15,000); sub-basin level (12 Digit HUAs); and watershed level (North Bosque). The analysis was performed for the 40-year period from 1965 to 2004. The major conservation practices simulated were nutrient management, manure transfer, reservoirs, modified buffer, reduced tillage practices, and pasture and hayland planting.

Nutrient management at the farm level had a wide range of results because of the great diversity of scenario design. Changing the speed of water channelization as runoff leaves the field, the placement of the manure on the field, and the removal of the manure for composting reduced the amount of nutrients leaving the waste application areas. At the mouth of the North Bosque the watershed level phosphorus loadings for various scenarios range from decreases of 29% (when multiple practices were applied to the watershed) to increases of 21% (when reservoirs were removed from the watershed). For the entire Bosque at the exits into Lake Waco total phosphorus was reduced by 15% in the first case and was increased by 15% when the reservoirs were removed. Nitrogen loadings at this North Bosque watershed exit range from decreases of 30% to increases of 23%.

Phosphorus, nitrogen and sediment levels leaving the farm were decreased in all application areas where conservation buffers or pasture planting are applied. However, for almost all scenarios, the sediment loads at both the mouth of the North Bosque and the total Bosque had only slight changes. Conversely, the nutrients carried by these sentiments had much greater variation. This is partly due to the fact that the model accounts for manure erosion as a separate activity. However, the nutrients in the manure are aggregated into the sediment for reporting purposes. Even when the watershed statistics showed small changes the small sub-basin reported wide variations in nutrients leaving the fields. Field level phosphorus reductions ranged from less than 1% to over 50% for manure application areas. Nitrogen reductions ranged from less than 1% to over 30% for these areas. Farm level sediment reductions ranged from less than 1% to over 70% for waste application areas.

At the watershed level, as more conservation practices were applied, scenarios showed progressive improvement of watershed health. Starting with modest improvements of around 5% for distributing the water across the fields while leaving all manure on the waste application fields, watershed health on the North Bosque improved by about 12% when 50% of the manure was removed from the watershed. The larger improvements came when six new reservoirs were added. These reservoir locations were chosen to provide buffering of unprotected sub-watersheds that contained dairies in the upper reaches from the mainstreams as water flowed into Lake Waco. The addition of these reservoirs reduced both phosphorus and nitrogen loads leaving the North Bosque by around 29%. This translated to around 15% improvement in water quality entering Lake Waco.

The exercise of dividing the watershed into very small sub-basins for modeling purposes (in this study 15,000 watersheds averaging about 26 ha per sub-area) provided a clear demonstration of the ability of targeting a small percentage of the total land area to make a significant improvement in watershed health and nutrient loadings into large lakes such as Lake Waco. The majority of the practices of this study targeted the waste application fields near the dairies in the northern part of the watershed. These areas accounted for less than 14% of the total land area drained by the Bosque River.

The most significant implications of this study's can be given in three summary statements. First, any conservation practice that causes divergence of the runoff water over the landscape slowing the channelization of the water will improve the quality of the water eventually reaching the stream. The APEX model can quantify these improvements when the sub-basins are small enough to represent fields and the sub-basins are divided into the upper and lower landscape positions for model simulations. Second, the removal or hauloff of a portion of manure from the basin does have a significant impact on the nutrient loads reaching the streams in the watershed. The magnitude, of course, will very with the size of the area dedicated for the purpose of manure application. Third, the careful placement of a small number of new reservoirs in a watershed that protect previously unprotected regions of the watershed that contribute nutrient loadings to the stream can significantly improve the water quality in downstream water supplies.

Given these results, the modeled conservation practices have been effective in reducing nonpoint source pollution at all levels. Considering that the modeled management and structural practices were limited to relatively small portions of the total watershed, there exists good potential for further nutrient and sediment reductions in the North Bosque and. and Total Bosque watersheds through continued conservation planning and application.

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LIST OF ABBREVIATIONS

APEX	Agricultural Policy Environmental EXtender-Model used in this Study
DWMA	Distributed Water and Manure Applied to all Waste Application Areas
DWMU	Distributed Water and Manure Applied to Upper Landscape Areas only
HUA	Hydrologic Unit Area
ICIPG	Improved Cropland Conservation and Improved Pasture Grasses
MNUL=0	All of the Manure produced applied to the Waste Application Fields
MNUL=1	50% of Manure produced Hauled off of watershed
N	Nitrogen
NAT	Native Resource Conditions
NO3	Mineral Nitrogen in Water
NORE	No Protective Reservoirs
NRC	New Reservoir Construction
NRCS	Natural Resources Conservation Service
NSE	Nash-Sutcliffe Efficiency
NWS	National Weather Service
P	Phosphorous
PL566	Public Law – 566
QP	Mineral Phosphorous in Water
R^2	Coefficient of Determination
SCS	Soil Conservation Service
SSURGO	Soil Survey Geographic
TCEQ	Texas Commission on Environmental Quality
TIAER	Texas Institute for Applied Environmental Research
TNRCC	All of the Existing Reservoirs- PL566 (NRCS) and other Reservoirs
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
WAF	Waste Application Fields
YON	Organic Phosphorous in Sediment
YOP	Organic Phosphorous in Sediment
Yt	Sediment Yield in kg/ha

INTRODUCTION

The North Bosque encompasses 3153 km^2, originating in Erath County and flowing southeast through Bosque and McLennan Counties where it is impounded to create Lake Waco. The watershed also covers parts of Coryell, Hamilton, and Somervell Counties (Figure 1). The watershed is predominately rural. Major land use/land cover was native pastures/range and improved pasture, with only 4.3 % crop, 1 % urban. Dairies and milk sheds covers about 0.2 %. In the early 2000s the study area had the largest concentration of dairy animals in the state of Texas. An economic study of Erath county (the most dairy intensive of the 6 counties in the watershed) estimated the single county alone accounts for 27% of all milk production in the state of Texas. The dairy industry provides 1980 jobs directly and supports another 932 non-dairy jobs. This accounts for 31% of the county's employment. Milk sales for the year 2000 in the county were estimated at $200 million. However, the watershed drains into Lake Waco. The lake provides 75 % of the water supply for the City of Waco, Texas. In 2000 the North Bosque River was listed as an impaired water body in the *Texas Water Quality Inventory* for concerns of elevated levels of bacteria, chlorophyll a, and nutrients entering the segment from tributary watersheds. Upper North Bosque was also placed on the 303(d) list for elevated levels of sediment, nitrogen (N), phosphorus (P), chloride, sulfate, and chlorophyll a. These impairments have mainly been associated with the dairy industry in the northern part of the watershed.

Since 1997 the watershed has received $4.55 million to fund EQIP. EQIP practices implemented and/or approved for the watershed include: nutrient management, waste storage facilities, waste utilization, brush management, manure hauloff, pasture planting, range planting, and prescribed grazing. In addition to the EQIP funds, $1.7 million of 319 funds and $4 million Lake Waco/ Bosque River Watershed Initiative –USDA funds have been provided.

This study was done assuming that the watershed has 61 permitted dairies with 39,825 confined dairy cows. In the late 1990s and early 2000s the estimated numbers were substantially higher with numbers in the 60,000's. However these numbers have declined substantially in recent years. The purpose of the study is to provide quantitative estimates of the short and long term impacts that USDA programs (particularly the EQIP program) have on the phosphorous loading levels flowing from the North Bosque watershed into Lake Waco.

The goals are to:

A. Make these quantitative estimates of both onsite and offsite environmental benefits and costs expressed as loadings and concentrations of P, N, and sediments under three time periods and analytical assumptions:
    1) current conditions (installed practices),
    2) past and likely future conditions,

3) possible future conditions (alternative mixes of practices) that would reduce loading levels to Lake Waco.

B. Study two types of impacts:

   1) short term impacts will analyze the timing, location and suites of EQIP practices that trap, filter, and otherwise mitigate the phosphorus loads and concentrations downstream and into the lake.

   2) long term impacts will analyze the impacts of increased organic matter and the self-mitigating timing and impacts of manure on soil health in the watershed thereby changing the ability of the watershed resources to influence the P loads into the lake.

The study specifically address the impacts of EQIP practices with special focus on waste management and proposed Comprehensive Nutrient Management Plans (CNMP) from dairy manure as it affects P loading into Lake Waco. The study area encompasses the Entire Bosque above Lake Waco but concentrates on the North Bosque—the area where most of the dairies are located and the specific area mandated by this study. The larger area of the entire Bosque is included to provide a comprehensive picture of the role the North Bosque plays in the entire Bosque Watershed.

Objective

Watershed Objective: To reduce the phosphorous loading levels flowing from the North Bosque watershed into Lake Waco

Study Objective: To analyze the impact of the EQIP program by evaluating the timing, location and suites of practices that trap, filter, or otherwise mitigate phosphorus loads down stream into Lake Waco.

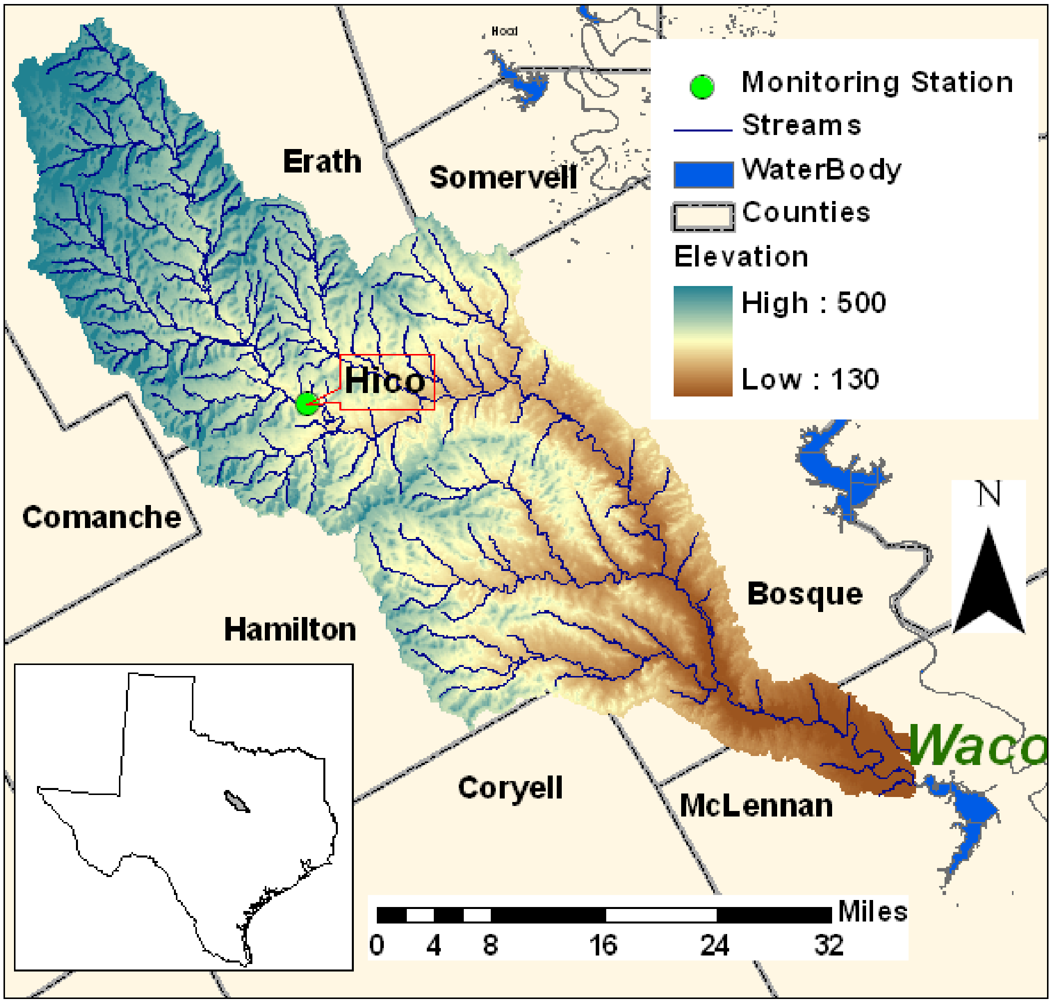

Figure 1. Location of the North Bosque watershed in Texas

METHODOLOGY

Overview of APEX

The APEX model is a comprehensive terrestrial ecosystem model developed for use in whole farms or watersheds. It is an outcome of extensive physical/ environmental/ hydrologic model development conducted over the past four decades by the United States Department of Agriculture-Agriculture Research Service (USDA-ARS) and the Texas A&M System's Texas AgriLife Research (formerly, Texas Agricultural Experiment Station) located in Temple, Texas. The model simulates the hydrological, biological, chemical, and meteorological processes of complex farming systems involving multiple crops, soil types, field delineations, and structural and agronomic conservation practices across the landscape (Figure 2). The APEX model, and its predecessor, the Environmental Policy Integrated Climate (EPIC) model (Williams, 1995), have had a long history of use in simulation of agricultural and environmental processes, as well as in agricultural technology and government policy (Gassman *et al.*, 2005; Gassman *et al.*, 2010). APEX extended the EPIC model's ability by allowing the user to simulate several related sub-areas instead of a single area, while routing water, sediment, nutrients, and pesticides from sub-area to sub-area across complex landscapes and channel systems to the watershed outlet. With this capability, APEX allows assessment of various conservation practice systems including terraces, grass waterways, strip cropping, buffer strips, feed yards, animal waste lagoons, and water retention structures.

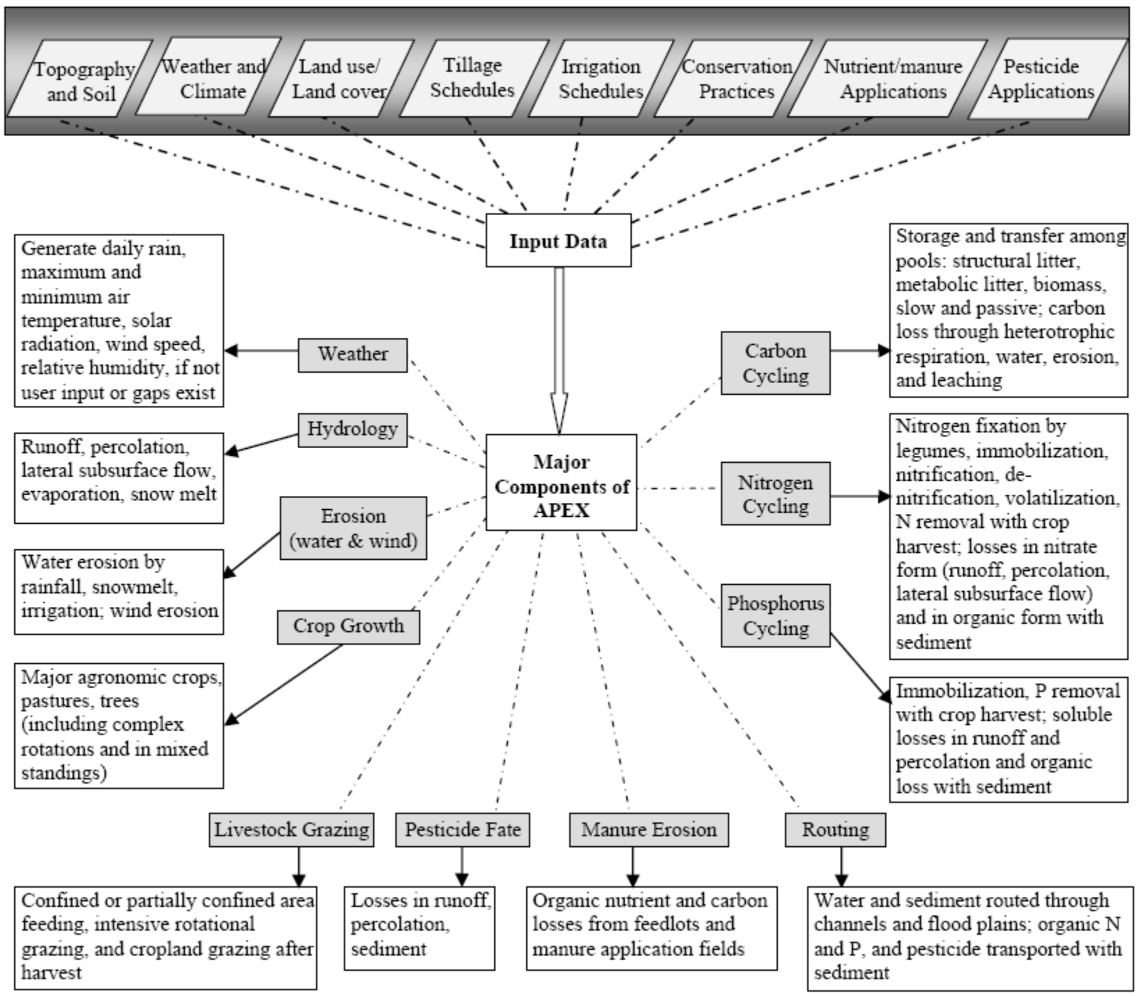

Figure 2. Major processes simulated in the APEX model (Wang et al., 2010)

The APEX model operates on a continuous basis using a daily time-step. The major components simulated on an individual sub-area include weather, hydrology, soil erosion, nutrients (nitrogen, phosphorus, carbon), pesticide fate, crop growth, soil temperature, tillage, plant environment control (drainage, irrigation, liming), and economics. These functions are adopted from the EPIC model (Williams, 1995). The routing mechanisms in APEX can route water, sediment, nutrients, and pesticides across landscapes through channels, floodplains, and reservoirs to the watershed outlet. The APEX groundwater component partitions flow between deep percolation and return flow. APEX also has a grazing component which provides flexibility to simulate a confined or partially confined area feeding, intensive rotational grazing, cropland grazing after harvest, etc. For a complete description of the APEX model see Williams and Izaurralde (2006).

During the course of this study the code of the APEX model was modified to incorporate additional capabilities needed by this study. The version of the APEX model used is Version 0806. This is the version that was modified to support 64-bit processing. This larger computing capacity was required in order to handle the 15,000+ sub-watershed's needed by the model analysis.

Shell-WinAPEX

The WinAPEX interface (Magre et al., 2006) was used to manage the databases and model runs. This interface uses Visual Basic and a Microsoft Access database to manage both the input and the output data. The data inputs were loaded into an Access database that allowed for rapid editing. The various tables in this database contain all of the needed data to create the individual files required by the apex model. WinAPEX has built-in algorithms that extract the data from the Access database and formats the properties into the respective files needed by APEX. This database management capability was needed in order to build the large number of scenarios used in the analyses as individual sub-areas may require unique tuning to represent the actual landscape conditions as accurately as possible.

Watershed Description and Model Inputs

The entire Bosque study area has 430,024 Ha (963,683 acres) of which 75% (322,700 Ha or 797,392 acres) falls in the North Bosque. The study assumed the following percentage of land use for the Full Bosque Watershed. The numbers were calculated using the GIS maps and the land use information described below. The land use was constituted of 63.5 % native pastures/Range, 14.2 % improved pasture (assumed to be improved Bermuda grass) 10.4 % misquote / cedar mix, 6.4 % deciduous trees (including wetlands), 4.3 % cropland 1 % Urban and .2 % Dairies and milk sheds. This study was done assuming that the watershed has 61 permitted dairy with 39,825 confined dairy cows. In the late 1990s and early 2000s the estimated numbers were substantially higher with numbers in the 60,000's. However, these numbers have declined substantially in recent years.

Data

There are a large number of data tables that must be filled in the access database in order to execute a model analysis. There are two primary types: 1) information that is fairly universal and for which default data is generally provided with the model and model documentation. This includes such information as the general parameters file (a myriad of coefficients internal to the model that are adjusted only with a thorough understanding of the model functionality in what the coefficients represent in the equations included in the model algorithms), crop parameter files, equipment parameter files, fertilize parameter files, irrigation parameter files; and conversion coefficients tables. 2)These tables include information specific to the study area such as soils, weather, land use, sequencing of crop activities and rotations, sub-area information (area, slope, soil type, channel routing / channel dimensions), animal kinds and numbers, location, farm/ownership information, reservoir information, manure lagoon information, and scenario parameter information. Let us address a few of the more important attributes listed as type 2 information. It is important to note at this stage that the APEX Model allows only one soil, one land use, and one management practice in each of the sub-basins.

Land Use/ Land Cover

A new land use/land cover inventory was taken. Unsupervised classification was used to stratify 2002 satellite data (6 bands –TM) into 25 categories. From this stratification, points were chosen in locations where large areas classified into one of the 25 categories. Below is an example of the original unsupervised 25 class separations that was used to assign land use to each watershed,

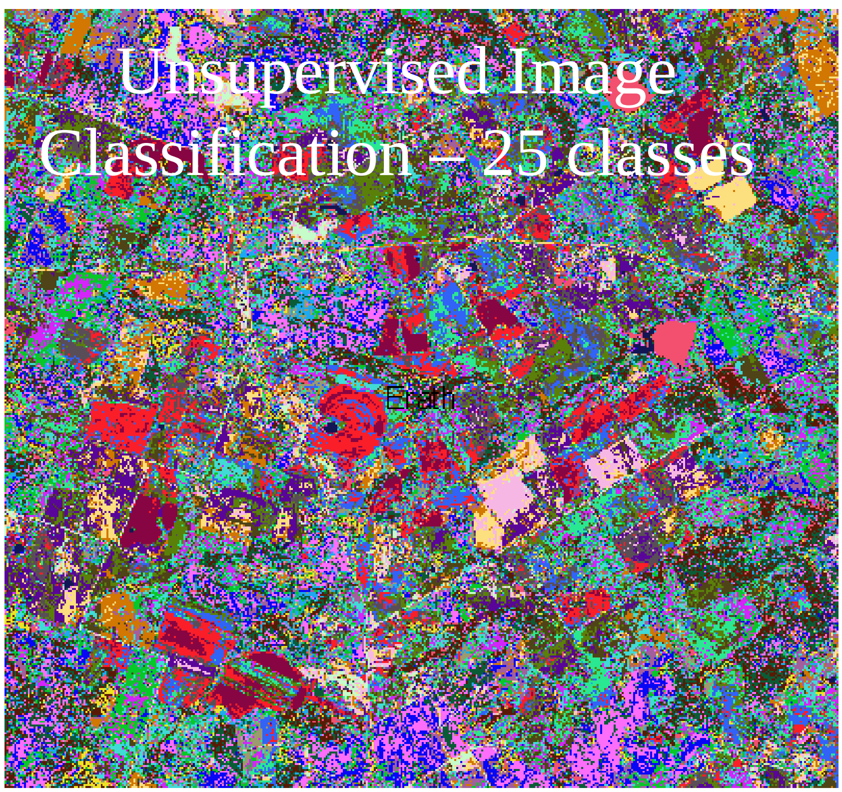

Figure 3. Classification of 2002 Satellite Image

These areas were screened to identify 12 points for each of the 25 categories. These locations were chosen to allow access for field verification (e.g. within a few hundred yards of a road, etc.) In the final set of 300 points a total of 260 points were reached and classified by ground observation.

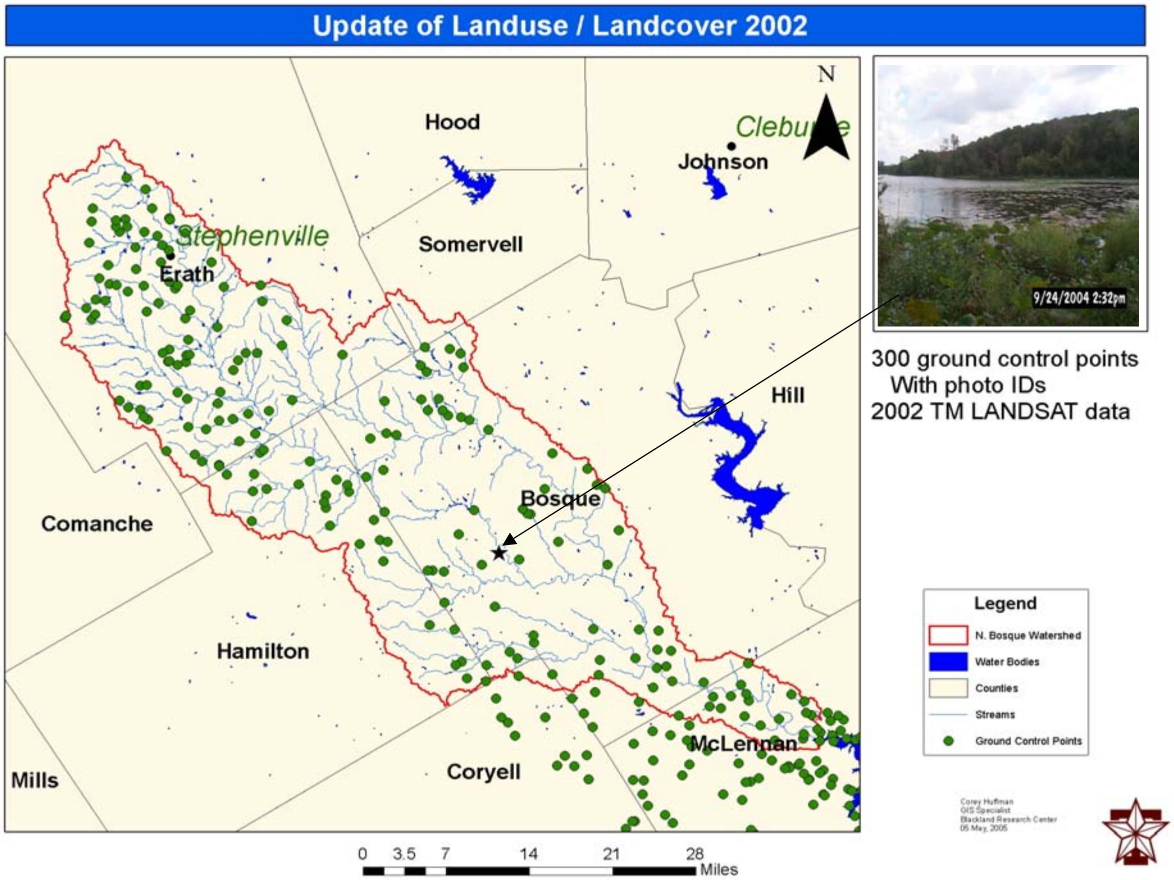

Figure 4. Ground Control Points

These points were used to classify the entire watershed for land use/land cover as of 2002. Each of these 25 classes was assigned to one of the 11 classes shown in the graph below. This land use land/cover information was loaded into a GIS database and was used to assign a specific land use (one of 11 classes) to each of the 15,000 watersheds. This was done in an effort to get the model simulations to reflect current conditions on the ground as closely as possible.

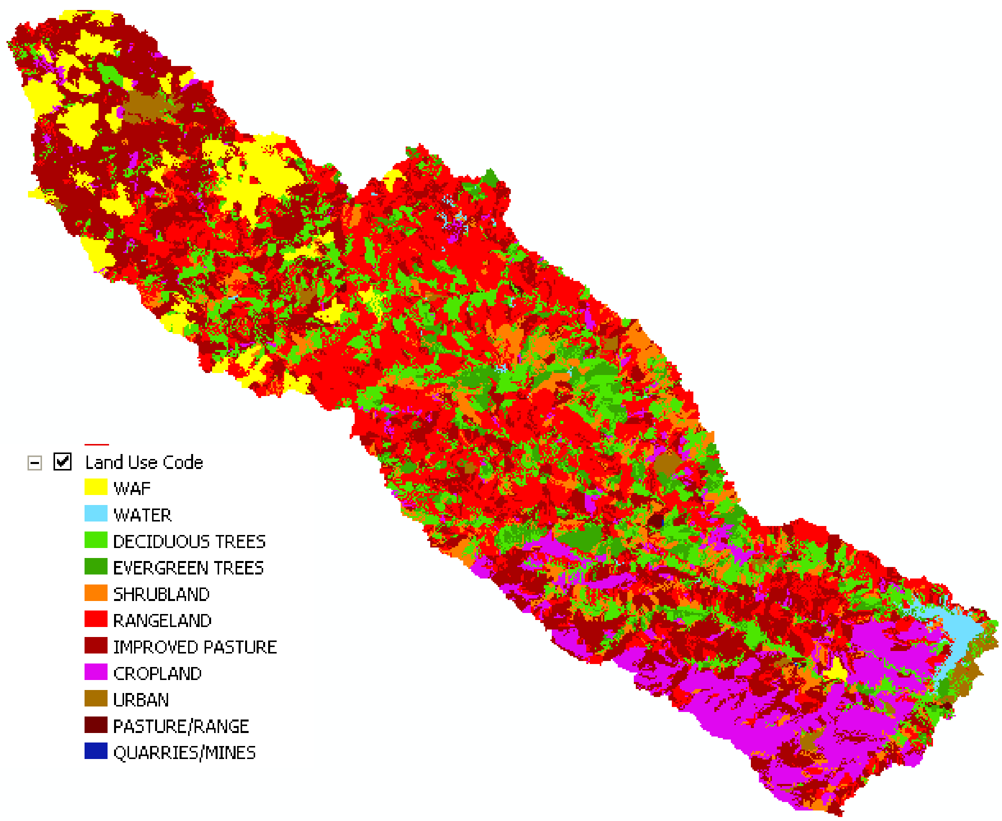

Figure 5. 2002 land-use/land cover

Dairy Locations and Cow Numbers

This study was done assuming that the watershed has 61 permitted dairies with 39,825 confined dairy cows. In the late 1990s and early 2000s the estimated numbers were substantially higher with numbers in the 60,000's. However these numbers have declined substantially in recent years. Some estimates indicate the numbers may be around 40,000. However, as the database shows specific dairy locations and cow numbers for each dairy we used a percentage of the permitted cow numbers to distribute the cows among the individual dairies. This was done to avoid a misrepresentation of the actual cow numbers and management of the individual dairy herds. No effort was made to actually quantify the number of cows in each of the individual dairies --as these numbers will vary by season and by years depending upon many external factors that cannot be verified. The locations of the dairies as used in the model are shown below.

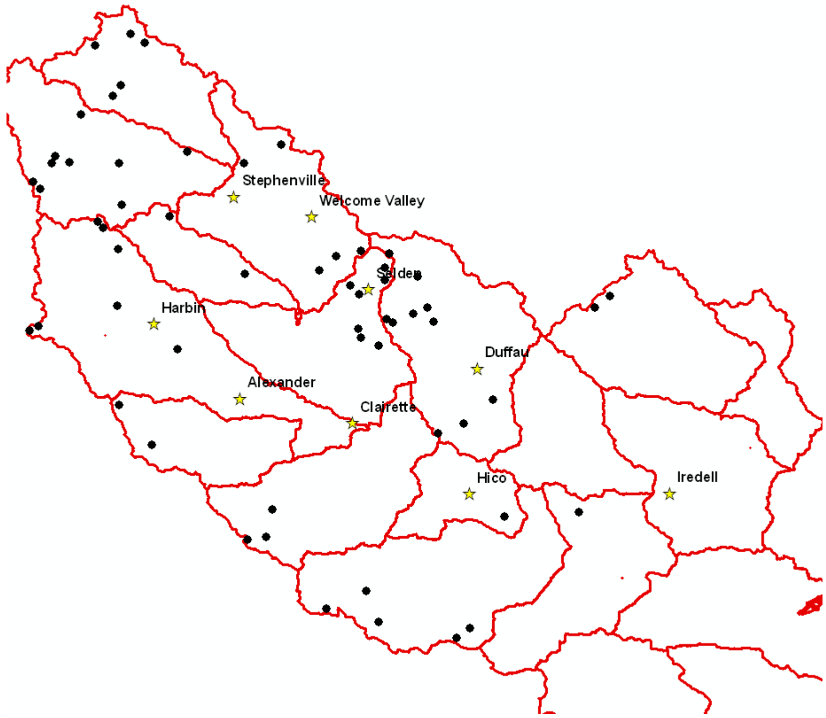

Figure 6. Dairies Locations in North Bosque

Waste Application Fields

Waste application fields identified in the TIAER and TCEQ database were used to locate the waste application fields into the sub-watersheds. As we did not have an accurate

Figure 7. Fields Identified as Waste Application Areas

accounting of which waste application fields were used by which dairies, the fields were assigned to the nearest dairy. As we will describe later, this assumption likely caused some misrepresentation of the actual conditions as a few dairies did not have enough waste application areas assigned to support the cow numbers recorded for the dairy.

When this problem was identified during the analysis phase no effort was made to rectify these specific assignments as the issue was addressed by changing scenario assumptions. Unless we had specific information to assign land use otherwise, all waste application fields were assumed to have coastal Bermuda grass as the land cover.
The image shows examples of what we have classified as potential Waste Application Fields (shown in Yellow) using the 2004 NAPA one-meter images.

Soils Data

NRCS SSURGO soils data was used to identify the soils in each of the sub-basins. Below is a representation area showing the comparison of the SSurgo Soils data with the sub-area boundaries.

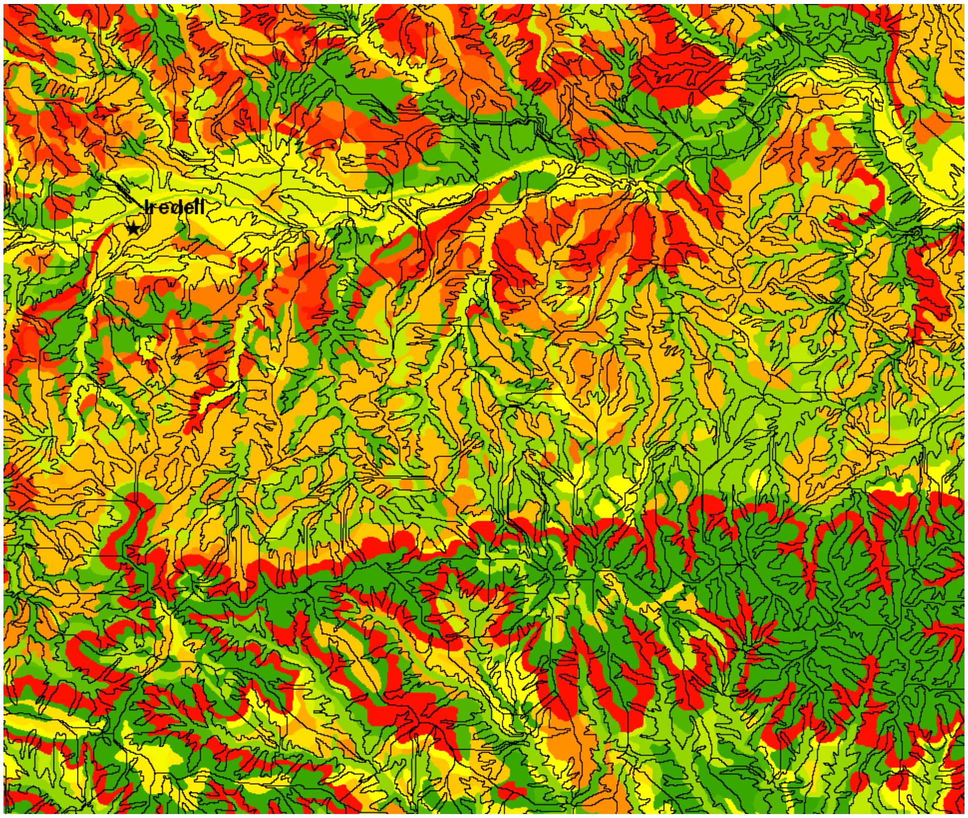

Figure 8. SSURGO Soils Shown in Color- Sub-areas Shown in Black Line

The APEX model requires a substantial list of soil attributes in order to execute the analyses. The values of these attributes for each of the individual sub-basins are extracted from the SSURGO database by identifying the specific soil series assigned to that sub-basin using a GIS overlay of the sub-basins boundaries with the NRCS SSURGO soils map. Once the soil series names are identified, the soils attributes are extracted from the Access database as the model runs files are being built.

Weather

Daily Weather Data was obtained from the historical weather records of NOAA's National Weather Service. Considering the need of the analyses, ten stations were chosen that had both temperature and precipitation records from 1965-2004. These stations were:
Waco Regional Airport-TX9419, Waco Dam-TX9417, Mc Gregor- TX5757, Gatesville - TX3485, Whitney Dam-TX9715, Hamilton-TX3884,Hico-TX4137, Dublin-TX2598,Stephenville 7 W-TX8625,and Stephenville 1 N-TX8623.

Wind Stations included McGregor, Eastland, Goldthwaite, and Hillsboro.

Figure 9. Weather stations

From this weather information, both the daily files from 1965 to 2004 and the weather generator files produced from the statistical processing of this data were entered into the database.

Topography

Topography was defined by a 10 meter Digital Elevation Model (DEM) from TNRIS (Texas Natural Resource and Information Systems) and processed to develop the detailed watershed data. The DEM was used to calculate sub-area parameters such as slope, slope length, and to define the stream network. The resulting stream network was used to define the layout and number of sub-areas. Characteristics of the stream network, such as channel slope, length, and width, were all derived from the DEM.

Reservoirs

There are two primary types of reservoirs found in the study area. First are those constructed by the NRCS as flood prevention reservoirs. Most of these reservoirs were constructed in the 1950s and 60s. The Bosque watershed has 41 such reservoirs located in the entire basin above Lake Waco. The second type of reservoirs is private, water supply reservoirs, and those built by other organizations. We identified 34 of these reservoirs to be included in the study.

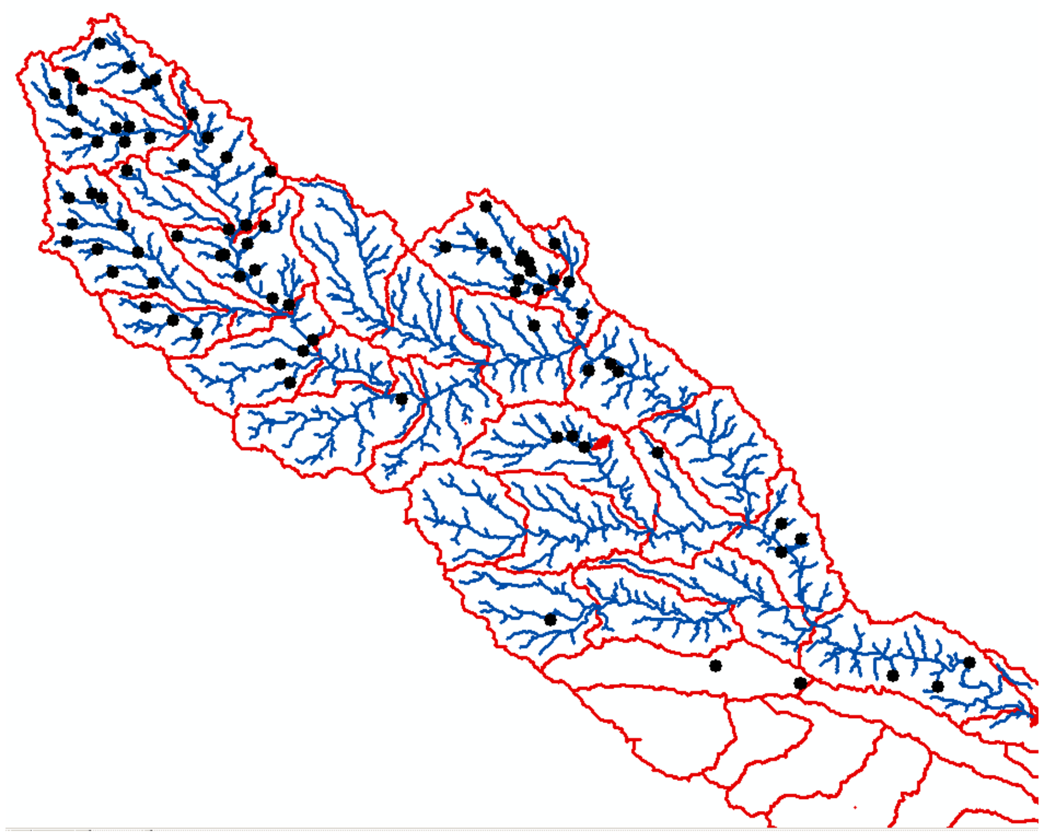

Figure 10. Reservoir Locations Both NRCS and other Reservoirs

Sub-area Delineation

The philosophy of the study design was to divide the Bosque basin into small enough sub units so as to let one sub-basin represent one field or pasture. After some experimentation and generation of sub-basins using GIS tools and viewing these with the land use and NAIP data, a decision was made to try to divide the basin into somewhere around 15,000 sub-watersheds.

The area contains ten 12-digit sub-areas from Hico to the northwest end of the Bosque watershed (the area that contained most of the dairies), twenty seven 12 Digit areas in the North Bosque and thirty eight total 12 digit basins in the entire Bosque.

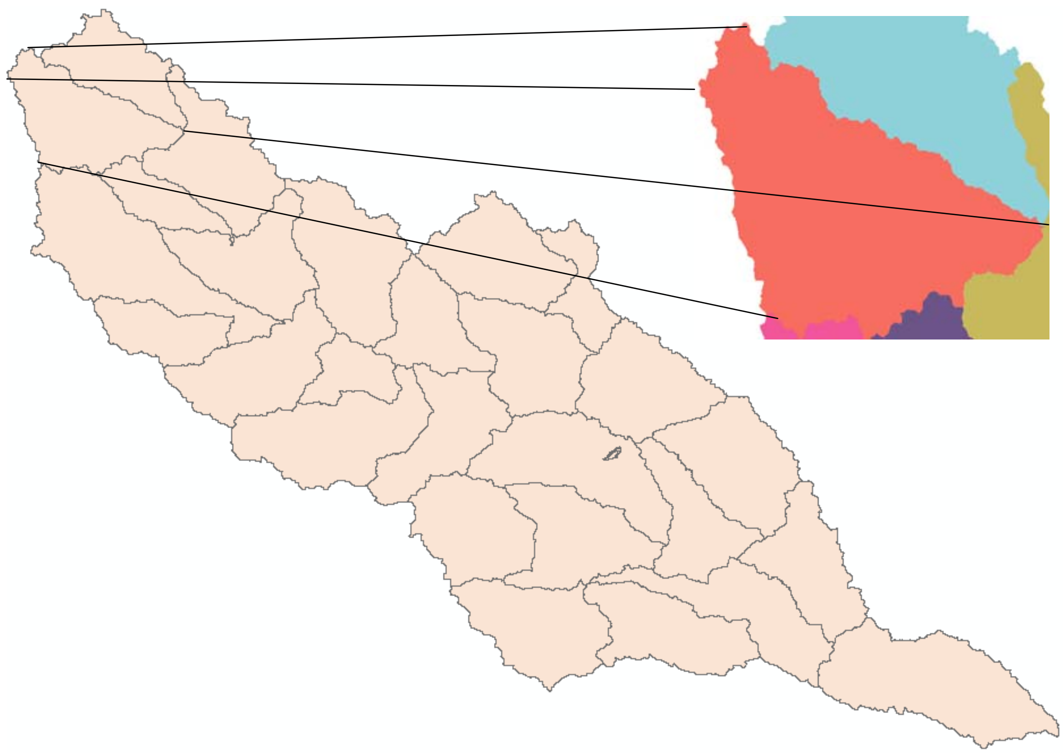

Figure 11. Twenty Seven 12 Digit HUAs in North Bosque

When a 12 digit HUA is sub-divided again it will have an average of about 600 sub-basins of about 46 ha in size. This procedure is described below in the derived data section. Looking at one of these 12 Digit sub-areas. Figure XX show how a 12 digit basin looks when it is further divided into these much smaller sub-watershed. The sub division of the thirty nine 12 digit HUA's result in 7544 sub-areas.

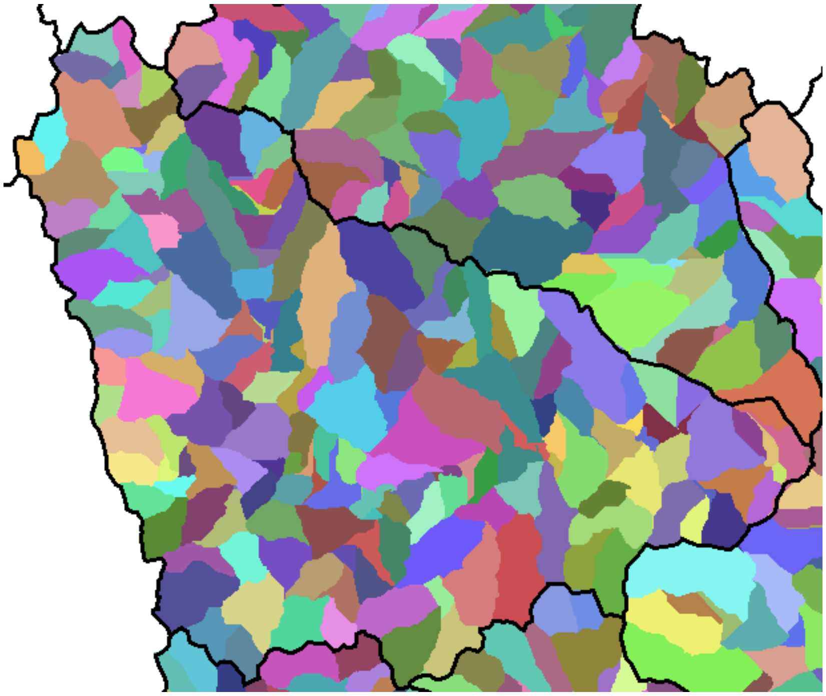

Figure 12. Sub Division of Twelve Digit HUA

Landscape Position

The original delineation of 7,544 sub-basins was again divided into upper and lower landscape positions to make a total of 15,088 sub-basins. This separates the lower position areas in the landscape to allow alternative treatment as we considered alternative BMPs and EQIP practices. The separation of the landscape into two positions was accomplished using a GIS algorithm that performed several functions: 1) The algorithm calculated the position of each 10 meter cell by assigning a percentage distance between the stream line and the ridge line of each of the 7,544 sub-basins. 2) It then calculated the change in slope for each of the cells. 3). The next step was to identify the cells that had the most rapid change in slope found in the lower 40% of the sub-basin. 4) The final step was to allow the algorithm to assign the cells below the maximum slope change as lower landscape positions. The cells above that line were assigned to the upper landscape position. The average sub-area after the division into 15,088 is about 26 ha in size.

The rules set required that all upper landscape positions flow into or through a lower landscape position before entering the stream channel. The lower landscape position was assumed to have a drainage channel receiving water from the immediately adjacent upper landscape position. In many cases water entering the top of the sub-basin from areas above flow into this lower position sub-basin (i.e. the stream channel) and completely through the sub-basin.

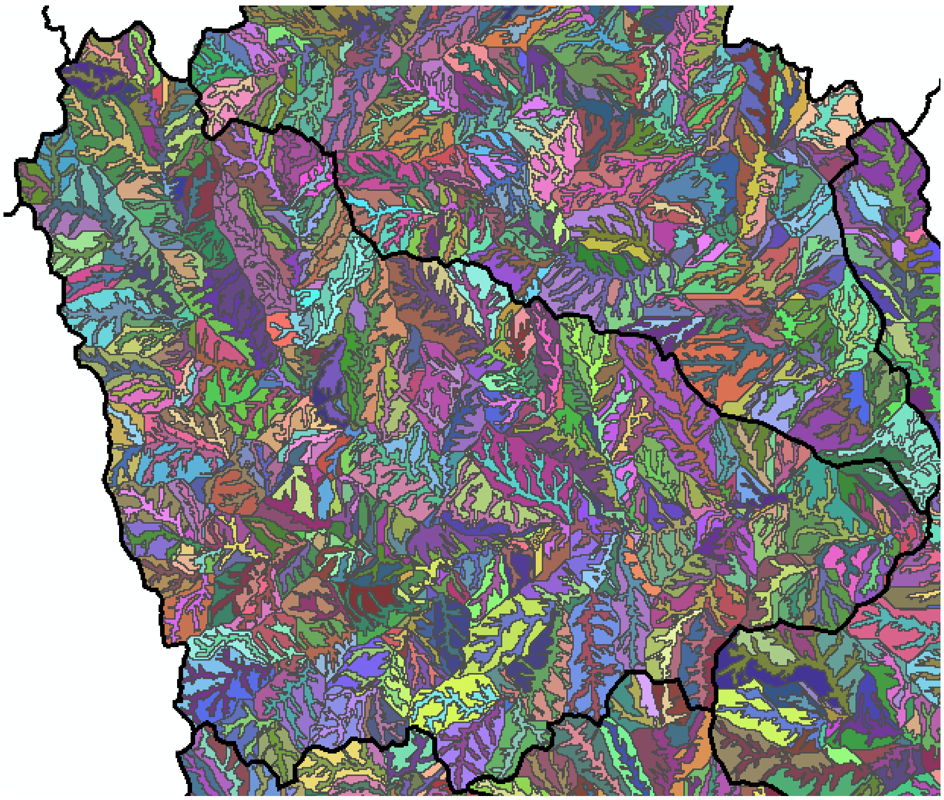

Figure 13. Creation of Upper and Lower Landscape Positions

It is interesting to note in this GIS graphic, there is strong but not unexpected characteristic of dairy placement in the landscape. The next graphic shows the landscape placement of 2 dairies in close proximity to each other (the green dots). Note they are located in the upper slope position. In fact all milking sheds and loafing sheds, with few exceptions, are located on or very near the ridge tops of each of the watersheds. The ridge tops are the driest and best drain areas in the watershed and therefore are prime locations for the concentrated dairy operations. This characteristic did not create undue concern during the analyses as the routing of the individual sub-basins generally converged into a common sub-basin before leaving the 12 digit accounting sub-areas. The next graphic shows a close-up view of a dairy placement within the landscape.

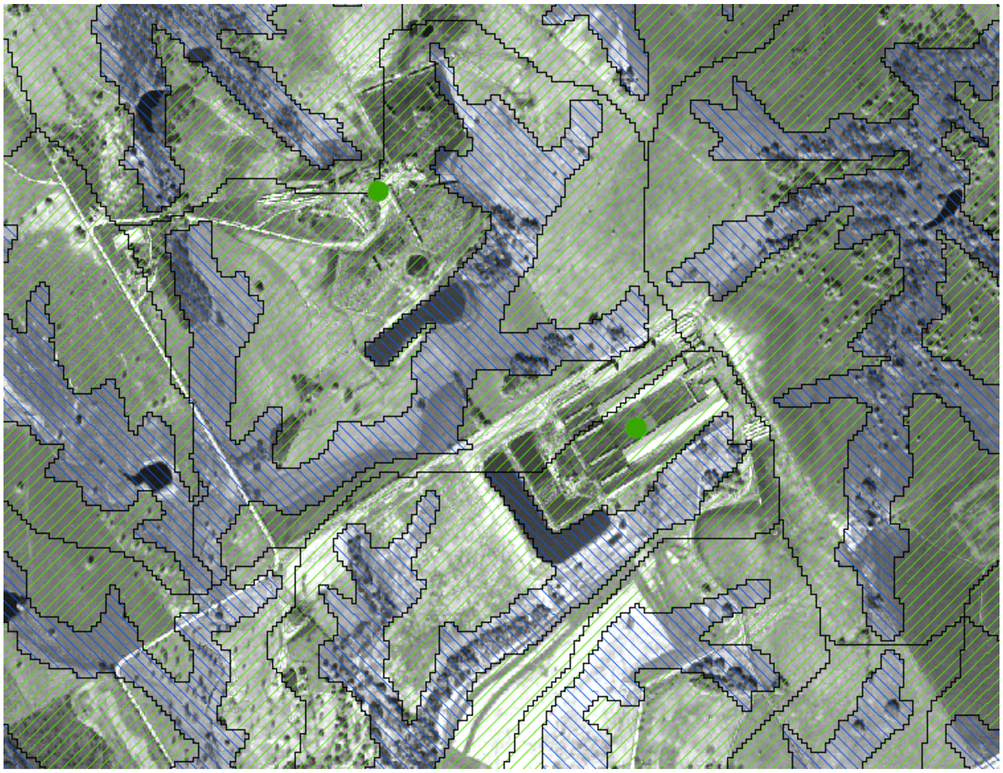

Figure 14. Sub –Watershed with Dairy showing landscape positions

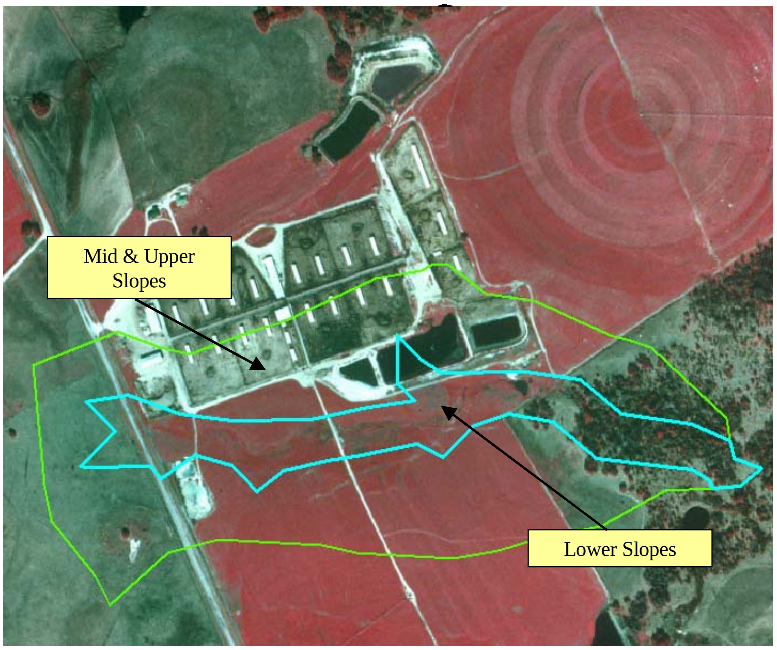

Figure 15. Close Up View of Sub–Watershed with Dairy showing landscape positions

However, there are a few exceptions when drainage boundaries can become very important. Below is approximately the same scene. The black line is the watershed boundary between the Bosque and Leon Watersheds. Note this one scene shows four dairies that are located on the crest of the two watersheds and drain into both the Bosque and Leon Watersheds.

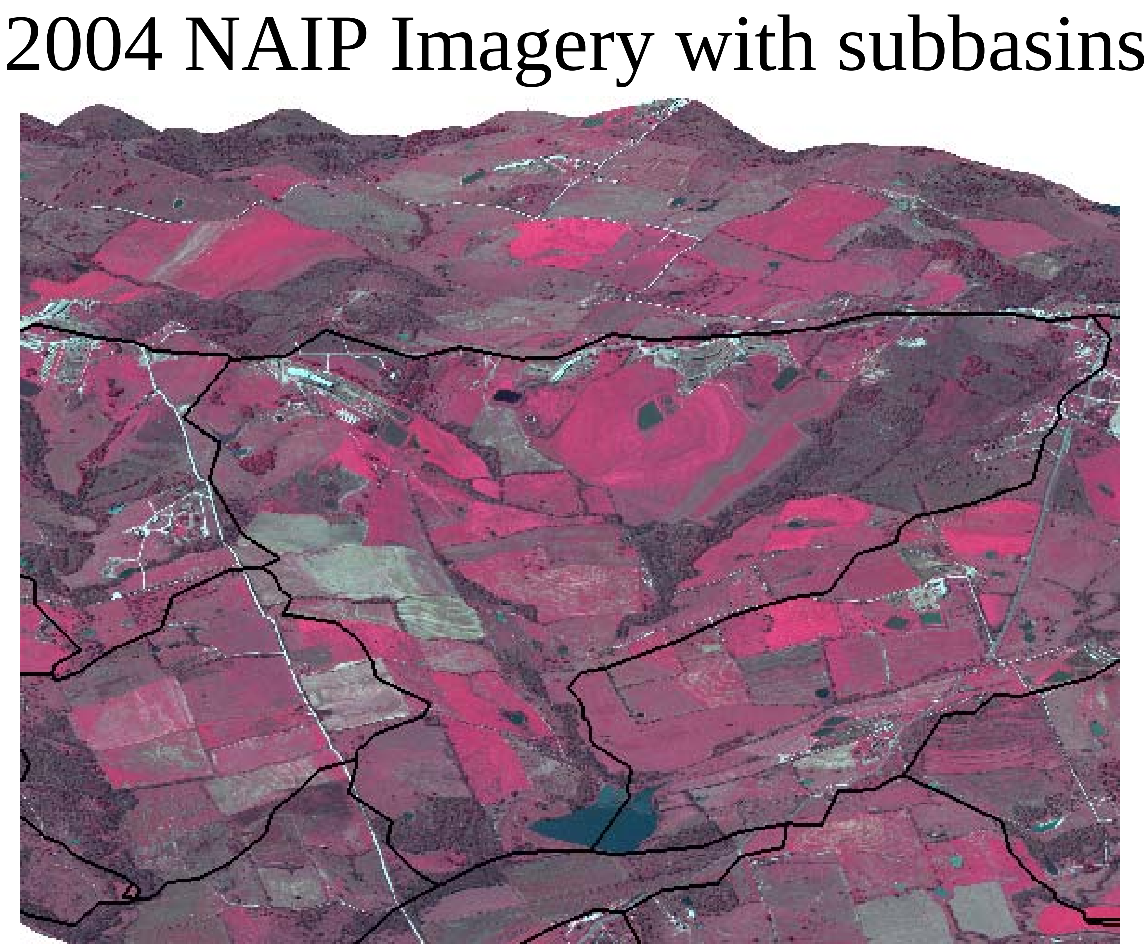

Figure 16. Watershed boundary between the Bosque and Leon Watersheds

GIS Derived Sub-watershed Data

Part of the rationale for creating so many small watersheds in the study was to allow the analysis to address actual watershed characteristics as close as possible. As part of this effort. GIS tools were used to calculate estimates of the actual landscape characteristics as opposed to using the more generic landscape characteristics previously used in other studies.

Slope

The slope was calculated as a simple average of all of the slope positions in the sub-basin.

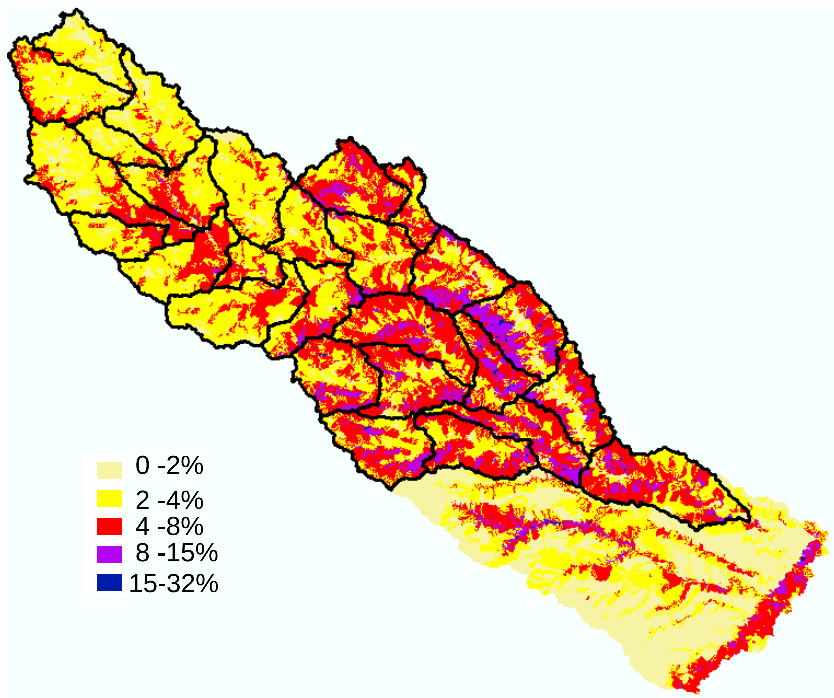

Figure 17. Average Percent Slop for Each Sub-basin

It is useful to note that much of the land with a higher slopes occur through the central and lower portion of the North Bosque. This observation provides insight into the interpretation of results in later sections of the report.

Slope Length

The slope length in the upper landscape position was calculated as the distance from the top of the ridge to the inflection point (the point where the change in slope toggled from a positive to negative number). The slope length of the lower landscape position was calculated as the average width of the watershed divided by two. This was the same as assuming the channel divided the watershed in the middle. The average width of the watershed was calculated by taking the area of the watershed and dividing by lower position watershed length (below).

Channel lengths

The channel lengths of the lower landscape position was calculated as the longest distance observed between the top of the watershed area and the channel outlet of the watershed times a correction factor of 1.1 to allow for some meander. The channel length for the upper position sub-area was calculated as the average distance between the ridge and the stream times the percentage of the upland area of the total area (upland position + lowland position).

Channel percent slope

The channel percent slope was calculated by taking the channel lengths above and dividing by the change in elevation between the highest and lowest points in the sub-basin.

Drainage pathways

Drainage pathways were calculated using the elevation layer and the standard stream delineation algorithms in the ArcGIS toolbox.

EQIP Practices

EQIP practices from NRCS records were obtained from the Texas State office. These contracts were only available as county summaries as there are extensive regulations pertaining to disclosure of individual records. As the model runs on such a fine scale, and since farmer practices are a moving target, the decision was made to randomly locate the EQIP practices on appropriate land use areas and make no attempt to match these specific practices to the specific location in which they were actually applied. Since the Bosque basin included only 4.3% cropland, another decision was made to not attempt a detailed analysis of cropland ICIPG practices. The EQIP practices for cropland are thus identified in a single scenario listed below. These include composites cropland practices where modeling and data modifications could be made that would reflect the BMPs identified as acceptable EQIP practices on cropland. However, non-cropland EQIP practices such as brush clearing, improve pastures, manure management, water management, reservoir management, landform modifications, manure haul off, and lagoon management are all addressed in the scenarios. For clarification and to prevent the perception that scenario practices included all EQIP or no EQIP practices, we will tag scenario practices that incorporate selected cropland and pasture management modifications as “Improved Cropland and Improved Pasture Grasses” (ICIPG). As we will see later, the impact of these sets of practices have considerably different environmental impact and must be addressed separately.

Management systems for field crop

Cropping systems were chosen that represented crops and management practices in the area. Since cropland constitutes such a small part of the total land area, and since the study does not focus on cropping systems, a simple mix of primary crops was chosen. Three crops (corn, sorghum and wheat) were placed into three rotations for the study. These rotations were 1) continuous corn, 2) corn sorghum and 3) wheat sorghum. Traditionally for model analyses are divided into three tillages-- conventional till, reduced till, and no till. For this study, however, only two tillage levels were established.

Both would be considered reduced tillage. We modified cropland tillage practices to reflect two levels of management that we called EQIP management and Non-EQIP management.

Management systems for non-cropland

The land use areas defined as range pastures and woodland areas were set up with two alternative management systems. These management systems were identified as EQIP management and Non-EQIP management. For the most part, the difference between the two management systems was differentiated by changes in plant community /plant mixes and by the percentage cover of scrubs like Mesquite bushes and cedar trees.

Management operations and rotations

The management assigned to the various scenario runs is chosen from 13 management operation files. In general these operation files are assigned to the various land-use cover categories. The operations are often changed for different scenarios for a given land-use category. The permanent cover management includes Coastal Bermuda grass, Buffalo grass, deciduous trees, Big Bluestem grass, Side Oats Grama grass, perennial legumes, mesquite trees, Little Bluestem, and cedar trees. Crops incorporated into the simulation were various combinations of winter wheat, sorghum, and corn. The dairy dry lots and lagoons were assigned operation and no vegetation was grown on these areas. More specifically the details of the operations are given below. All operations were considered dryland with the exception of the irrigation used to apply the wet manure on the waste application fields.

Coastal Bermuda was used for all waste application areas. This constituted the planning of the coastal Bermuda and harvesting of hay from the waste application area four times a year. No additional fertilizer was applied beyond the application of manure waste.

The dairy and feedlot areas were identified as fallow areas and the feedlot and loafing shed areas were scraped every 30 days of manure. This manure was then applied to the waste application fields as either dry or wet manure. If sufficient waste application areas were not available for the manure produced from the dairy, the manure was stockpiled and was reported as surplus manure at the end of the simulation.

The pasture and range areas identified from the land cover classifications were assigned various combinations of grasses and shrubs. These included:

A land cover that included Mesquite trees, Little Bluestem grass, and side oats grama grass. The grasses on this land cover were harvested three times a year to simulate livestock grazing. No commercial fertilizer was added to these areas. The Mesquite trees were considered legumes and supplied some nitrogen to the land cover.

And pasture rotation comprised of Big Bluestem, Side Oats Grama grass, and perennial legumes. As in the rotation above this operation assumed harvest three times a year to simulate livestock grazing. The perennial legumes provided the nitrogen for this rotation. No manure or commercial fertilizer was added to this rotation.

One rotation was created for very poor quality rangeland that included only Mesquite trees. There was no harvesting of biomass from these areas.

A second rotation for very poor quality rangeland's was created that contained only cedar trees. There was no harvesting of biomass from these areas.

Heavy woodlands were simulated by a cover of deciduous trees. No harvesting of biomass was removed from these areas.

Improved pasture was simulated using two rotations: Coastal Bermuda grass as was used with waste application fields; however, in this rotation commercial fertilizer was used rather than manure to provide nutrients.

The second rotation used Buffalo grass rather than Coastal Bermuda but otherwise was treated the same as the Bermuda rotation above.

There were three rotations used for croplands.

The first was a rotation of winter wheat and grain sorghum. The winter wheat was planted in September and harvested in May. The grain sorghum was planted the following March and was harvested in July followed by the replanting of wheat in September. The automatic fertilizer option was used to provide the nutrients for this rotation.

The second cropping rotation was a corn grains are sorghum rotation. In the first year corn was planted in March and harvested in July. In the second year grain sorghum was planted in March and harvested in July. As above, automatic fertilizer option was used to provide the nutrients in this rotation.

The third cropping rotation was a rotation of continuous corn this crop was planted in March and harvested in July with an automatic fertilizer operation applying the needed nutrients.

The use of the automatic fertilizer option is described elsewhere in this report. This option is used to remove the impact of management of nitrogen application on rotations resulting from various soil types, previous crops, and moisture conditions.
The model does not have an option to manage phosphorous application.

Scenarios

The scenarios constructed for the analysis were designed into several groups of related scenarios. In all cases, alternative scenarios are referenced to a baseline or current conditions scenario in order to place the information in proper perspective to our best estimate of current conditions. In order to minimize the confusion of scenario analysis and to facilitate the understanding of the different scenarios, scenarios were divided into two primary categories. The first is what we refer to as the "Primary Alternative Scenarios" that include important scenarios we feel should be addressed as a cohesive group of alternative scenarios encompassing the primary focus of the project. The second group, we refer to as "Special Alternative Scenarios". This includes several groups of related scenarios that address the specific impacts of special conservation practices. These include a comparison of current conditions to past conditions, a look at the potential impact of new reservoirs when added at critical locations to the watershed, and a special analysis of the impact of reservoirs on the watershed and vise versa.

Baseline/Current Conditions/

Baseline conditions were identified that we feel reflect the conditions as of the late 1990s since this was the time period for which calibration data was available. Simulations were conducted for the 40 year period 1965 through 2004. The model code is not designed to incorporate changing management conditions as the simulation progresses. We had to choose a set of conditions that would be static for the simulation. Also the data used for the calibration time period reflected changing management conditions. Therefore, it becomes difficult in the calibration process to simulate the appropriate conditions. For this reason we chose a shorter time period for which the calibration data was available (Jan 1993-July 1998) as the baseline time period for calibration. In addition we defined the baseline as follows:

1) All reservoirs in the area are active and functional.
2) Current cropping practices included ICIPG Practices on 50 % of cropland and pasture fields and 50% were non-ICIPG practices.
3) Runoff water was allowed to channelize before leaving the field (not distributed). All landscape positions were treated alike. (Water was not distributed between upper and lower landscapes. Manure was applied to the entire Waste Application Field (WAF).)
4) All manure produced in the watershed was applied onto the waste application fields in the watershed (i.e. no manure hauloff).
5) All dairy lagoons were protected to allow no overflow.
6) Cow Numbers were set at approximately 40,000 Dairy Cows.

Calibration and Validation of Baseline Conditions

Calibration is the process by which a model is adjusted to make its predictions agree with observed data. Validation is similar to calibration except the model is not modified. Validation tests the model with observed data that is not used in the calibration. Validation improves the reliability of the model predictions.

The monthly record of stream flow, sediment yield, mineral N, mineral P, organic N and organic P available at the Hico monitoring station were used to calibrate and validate the

APEX model. About half of the observed data (July, 1995 - July, 1998, 3 years) were chosen for calibration because this period includes the biggest and smallest rainfall events. The remaining data (January, 1993 - June, 1995) were used for validation. The model options chosen for this study were the NRCS curve number (CN) method for runoff estimation, variable daily CN soil moisture index method to estimate daily CN, modified rational equation to calculate peak flow, the Hargreaves method to calculate potential evapotranspiration, a variation of the modified Universal Soil Loss Equation—the MUST equation (Williams, 1995) to calculate erosion/sedimentation, and the GLEAMS enrichment ratio method (Leonard et al., 1987) for P transport and transformation.

The parameters adjusted for flow calibration include curve number index coefficient (PARM42), groundwater storage threshold (PARM40), return flow ratio (RFPO). The parameters adjusted for sediment yield include RUSLE c factor coefficients (PARM46 and PARM47), sediment routing exponent (PARM18) and sediment routing coefficient (PARM19). The calibration of N and P losses were conducted by adjusting soluble P runoff coefficient (PARM8), sediment routing coefficient (PARM9), Biological mixing efficiency (PARM29), denitrification soil water threshold (PARM35), P upward movement (PARM59). These parameters were described in Table 1. The values within the parenthesis denote the actual calibrated values. Statistical measures including mean, standard deviation, R^2, Nash–Sutcliffe efficiency (NSE) (Nash and Sutcliffe, 1970), percent bias (PBIAS), and ratio of the root mean square error to the standard deviation of observed data (RSR) were used to evaluate the model performance based on criteria suggested by Moriasi et al. (2007).

Table 1. Model parameters and ranges used for calibration and final calibrated values.

Component	Parameter	Description	Range	Calibrated value
Flow	PARM42	Curve number index coefficient	0.5 – 2.5	1.0
	PARM40	Groundwater storage threshold	0.001 – 1.0	0.1
	RFPO	Return flow / (return flow + deep percolation)	0.05 – 0.95	0.5
Erosion/ Sedimentation	PARM46	RUSLE c factor coefficient in exponential residue function in residue factor	0.5 – 1.5	0.62
	PARM47	RUSLE c factor coefficient in exponential crop height function in biomass factor	0.01 – 3.0	1.0
	PARM18	Sediment routing exponent, exponent of water velocity function for estimating potential sediment concentration	1.0 – 1.5	1.0
	PARM19	Sediment routing coefficient for potential sediment concentration when flow velocity = 1.0 (m/s)	0.005 – 0.05	0.007
Nutrients	PARM8	Soluble P runoff coefficient	10 – 20	10.0
	PARM14	Nitrate leaching ratio, (0.1_1), nitrate concentration in surface runoff to nitrate concentration in percolate.	0.05 – 1.0	0.05
	PARM29	Biological mixing efficiency	0.1 – 0.5	0.2
	PARM35	Denitrification soil_water threshold, fraction of field capacity soil water storage to trigger denitrification	0.9 – 1.1	1.1
	PARM59	P upward movement by evaporation coefficient	1– 20	10

RESULTS and DISCUSSIONS

Model Calibration and Validation

The simulated monthly stream flow, sediment yield, and nutrient losses compared well with observed values for the calibration period, as evidenced by the values of NSE (0.69-0.85), R^2 (0.70-0.92), PBIAS (-18% - 8%), and RSR (0.39-0.56) in Table 2. Based on the statistical criteria (established based on values of NSE, RSR, and PBIAS) for evaluating water quality model performance proposed by Moriasi et al. (2007), the model performance is good for monthly flow, sediment and nutrient losses during the calibration period (July 1995 – July 1998). During the validation period (January 1993 – June 1995) the model performance was good for monthly flow, mineral P, and Total P, for which NSE values ranged from 0.74 to 0.78 and RSR values from 0.49 to 0.56 and satisfactory for monthly sediment, organic P, and Total N, for which NSE values ranged from 0.54 to 0.62 and RSR values from 0.68 to 0.70. However, the model performance was unsatisfactory for organic N and mineral N losses during the validation period. This could partly be attributed to the uncertainty in model input data as described above and the uncertainties associated with measured water quality data. Nutrient loads were relatively lower during the validation period than in the calibration period. With recognized uncertainty in measured data (Harmel et al., 2006; Harmel and Smith, 2007), low loads might contribute to the relatively weaker comparison during the validation period because low loads may be hard to be detected therefore with higher uncertainty. Harmel et al. (2006) indicates that model results within 10 to 31% of the measured values are within the average uncertainty range of water quality data measured with a typical quality assurance/quality control effort. Moriasi et al. (2007) also proposed that the values of PBIAS (percent error or bias) for simulated average monthly N or P within ±25% to ±40% of observed values are acceptable. The PBIAS values in this study were within ±20%, except for mineral P (28.6%) and organic N (-21.7%) (table 2).

Table 2. Summary statistics of monthly calibration and validation results for flow (m^3/sec), sediment (Mg/ha), and nutrient (kg/ha) at Hico monitoring station

		Observed		Simulated		NSE	R^2	PBIAS (%)	RSR[‡]
		Mean	Std	Mean	Std				
Calibration	Flow	5.07	6.05	5.10	7.28	0.85	0.92	0.7	0.39
	Sediment	0.05	0.12	0.06	0.08	0.81	0.84	8.0	0.42
(July, 1995 - July, 1998)	Mineral P	0.03	0.05	0.03	0.04	0.69	0.70	-13.6	0.56
	Orgnic P	0.04	0.07	0.04	0.05	0.77	0.79	-5.1	0.47
N=36	Mineral N	0.10	0.12	0.10	0.13	0.70	0.73	5.5	0.55
	Orgnic N	0.24	0.36	0.20	0.26	0.77	0.83	-18.1	0.49
	Total P	0.08	0.12	0.07	0.09	0.77	0.79	-8.8	0.47
	Total N	0.34	0.47	0.30	0.38	0.79	0.82	-11.2	0.46
Validation	Flow	3.54	4.17	3.54	4.20	0.74	0.76	0.0	0.54
	Sediment	0.04	0.07	0.04	0.05	0.62	0.64	-10.6	0.70
(January, 1993 – June, 1995)	Mineral P	0.02	0.03	0.02	0.04	0.78	0.84	28.6	0.49
	Orgnic P	0.03	0.04	0.04	0.04	0.61	0.62	5.1	0.70
	Mineral N	0.08	0.09	0.09	0.11	0.17	0.52	8.3	0.94
N=31	Orgnic N	0.20	0.28	0.16	0.21	0.46	0.48	-21.7	0.73
	Total P	0.05	0.07	0.06	0.08	0.74	0.76	13.4	0.56
	Total N	0.28	0.35	0.24	0.30	0.54	0.57	-13.2	0.68

[‡]RSR: Ratio of the root mean square error to the standard deviation of observed data.

Simulated monthly flow, sediment yield, Total N and Total P at the Hico monitoring station followed, in general, the patterns of observed values during both the calibration and the validation periods (figures 5-8). Total N and Total P losses were clearly under-estimated in April 1993 and February 1997. However, APEX over-estimated the Total N and Total P losses in September 1993 and August 1996 (figures 7 and 8). One possible reason for the discrepancies between the observed and simulated monthly nutrient losses could be that the actual number of cows in each of the individual dairies as well as seasonal or annual changes to their counts were unknown. The actual waste application field for each of the individual dairies was also unknown. Further calibration by adjusting the number of cows or seasonal changes in each dairy or adjusting the assignment of waste application fields for each dairy may improve the results. Figure 9 shows the Total P loss from each sub-area in the study watershed. The high Total P losses were from the waste application fields, especially where the waste application areas were inadequate to support the waste application from nearby dairies. The cow numbers assigned to the nearby dairies may be smaller than that currently used in the simulation.

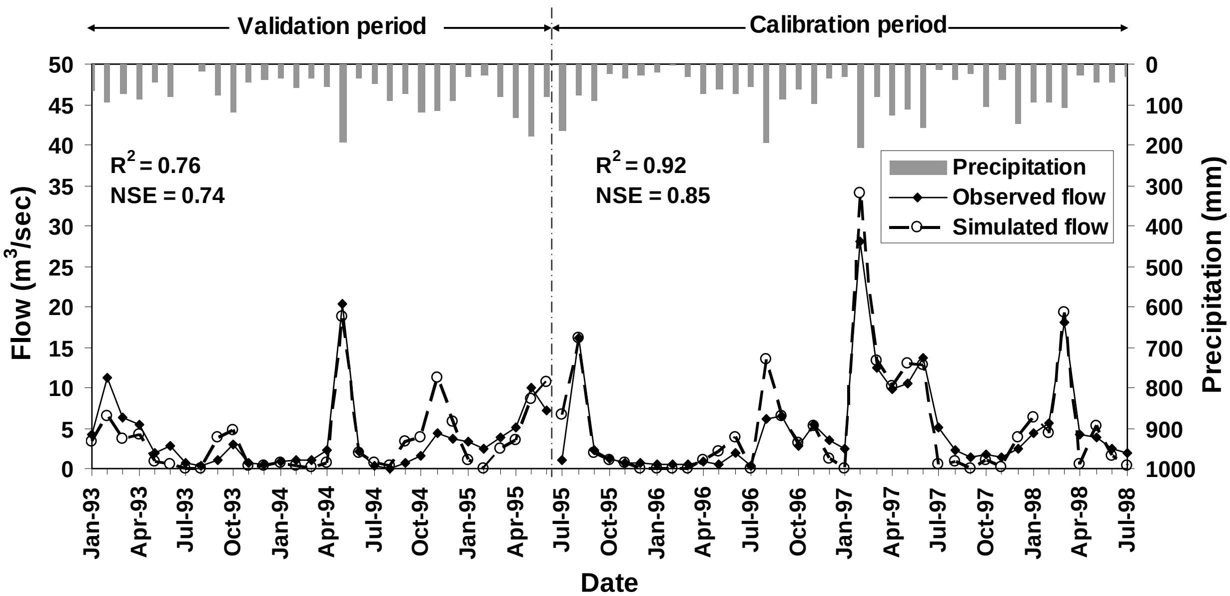

Figure 18. Observed and simulated flow for the calibration and the validation periods at the Hico monitoring station

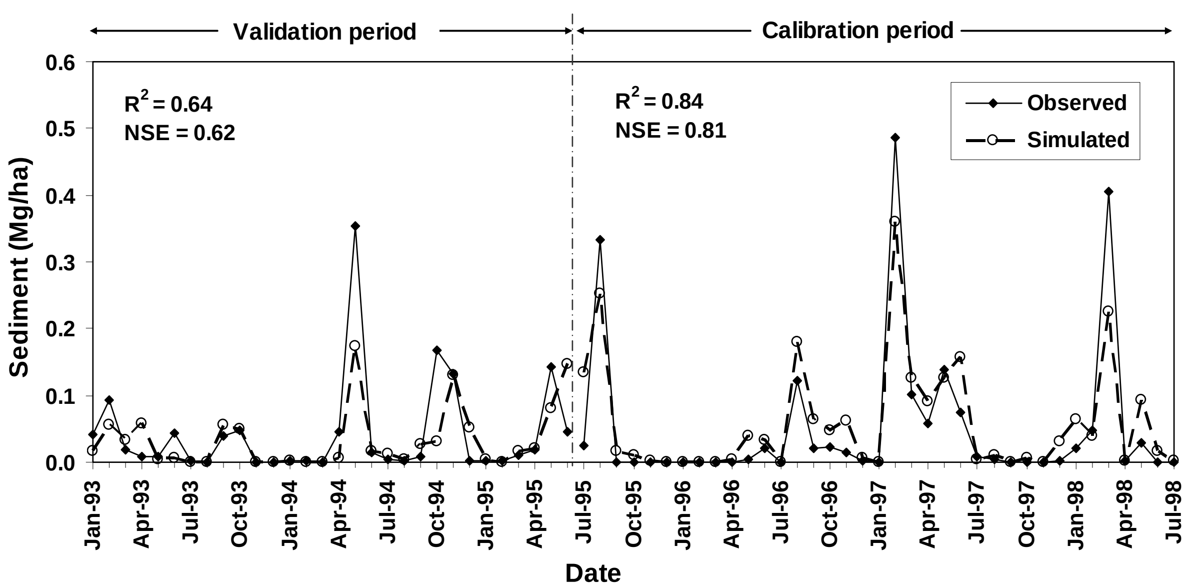

Figure 19. Observed and simulated sediment yield for the calibration and the validation periods at the Hico monitoring station

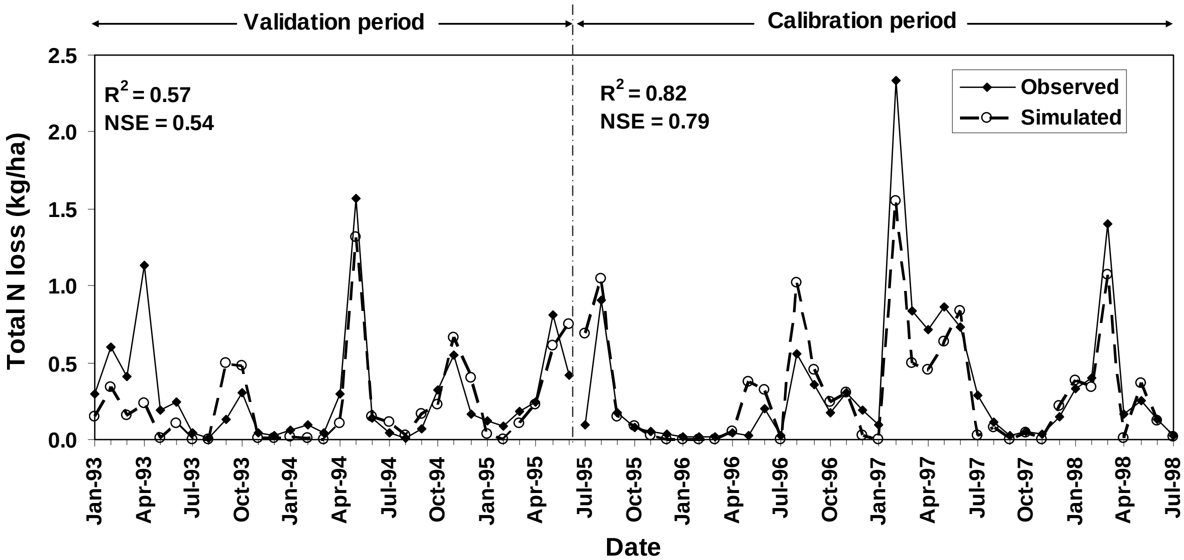

Figure 20. Observed and simulated Total N loss for the calibration and the validation periods at the Hico monitoring station

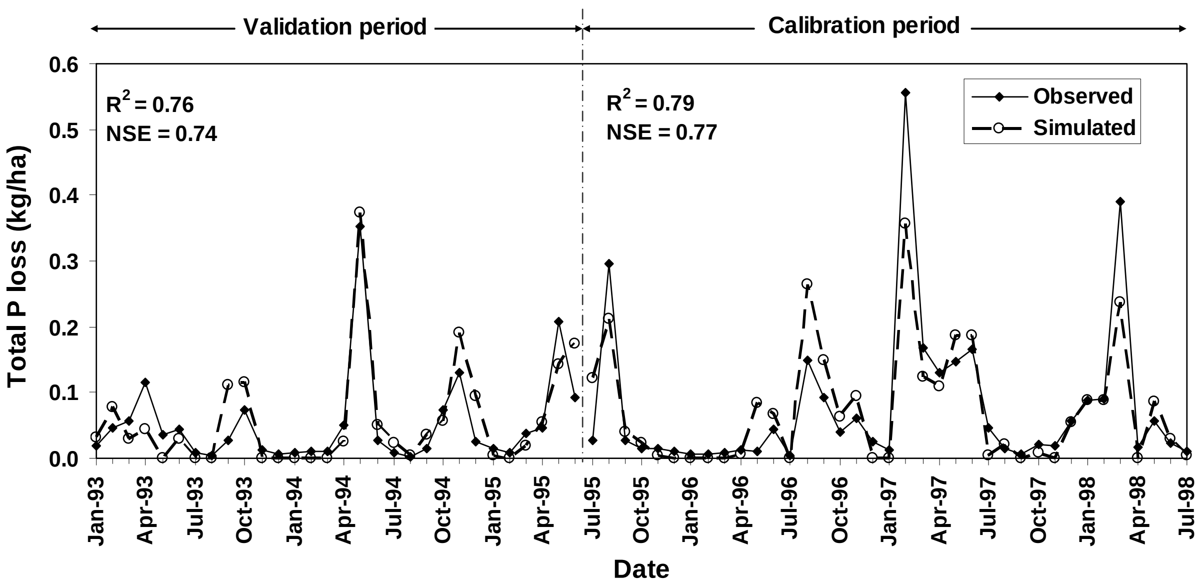

Figure 21. Observed and simulated Total P loss for the calibration and the validation periods at the Hico monitoring station

Scenario Analysis

Baseline/Current Conditions

a. All reservoirs in the area are active and functional (74 total).
b. Current cropping practices included ICIPG Practices on 50 % of cropland and pasture fields and 50% were non-ICIPG practices.
c. Runoff water was allowed to channelize before leaving the field (not distributed). All landscape positions were treated alike. Water was not distributed between upper and lower landscapes. Manure applied to entire Waste Application Field (WAF).
d. All manure produced in the watershed was applied onto the waste application fields in the watershed (i.e. no manure hauloff).
e. All dairy lagoons were protected to allow no overflow.
f. Cow numbers were set at approximately 40,000 Dairy Cows.

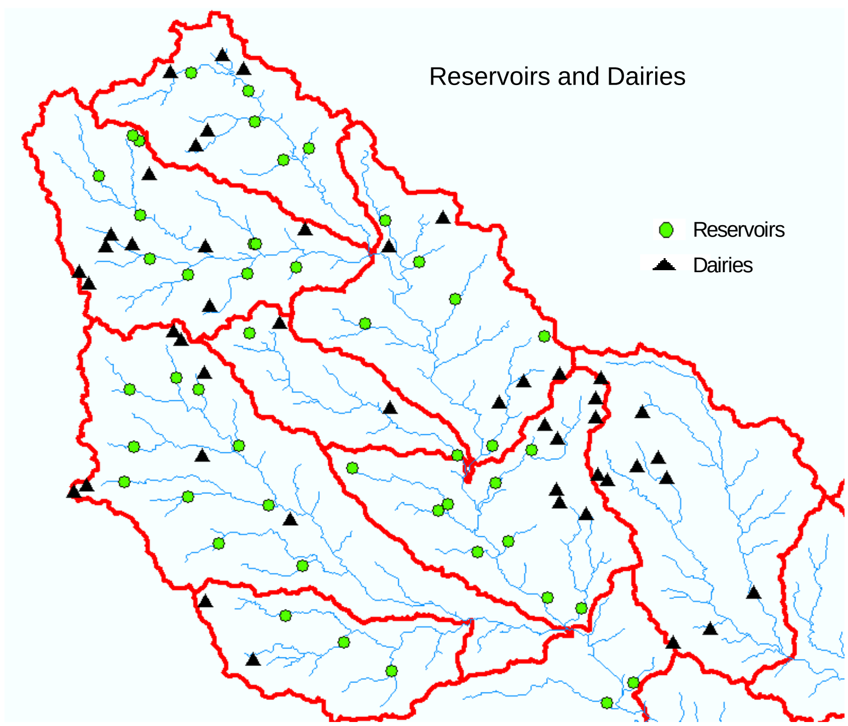

Figure 22. Reservoirs and Dairies

While reporting the results of the studies it is often useful to observe an enlarged view of the most active part of the watershed. The above view of the extreme north end of the watershed will often be shown as an overlay with other information. This view is useful while trying to understand the impacts of the reservoirs and the dairies on the small sub-areas near and below these structures. In addition, the points identifying the reservoirs and dairies will be used as overlays throughout the results section.

The summary information for the average values of the North Bosque will be reported in two types of tables. The first type of tables (as shown in Table 3) reports the different attributes in kilograms per hectare per year. These values are one representation of what is commonly referred to as the “load values” in a stream or the loading values coming from a specific area. One should note these loading values are on an average annual basis per hectare. Frequently when setting standards, loads are referenced in total loads delivered to a point such as a reservoir or mouth of a river per time period. Although runoff and water yield are reported in the table, the nutrient attributes are independent of the volume of water used to deliver these loads to the reporting point. Load values are considered important for long-term water quality and issues like reservoir health.

The second type of table (as shown in Table 4) reports attributes in parts per million (ppm). This represents a concentration of the element in the water. This reporting unit is per volume of water in the stream as opposed to per hectare in the previous ‘Load” table. However, concentrations reported in ppm have implicit units as they are calculated using average annual loads and average annual stream flows for the period of simulation (in this case 40 years). As compared with load values, concentration values for shorter time steps such as daily or weekly are more important when addressing toxic levels in the streams. The model can be set to report these values. However for this study and these simulations only monthly values are reported for each of the scenarios (as is demonstrated in the validation section above). This information is maintained in the raw database but the reporting of this level of detailed information is beyond the scope of this results section of the report.

Scenario	Runoff-mm/yr	Water Yield mm/yr	Erosion t/ha	YON kg/ha	YOP kg/ha	NO3 kg/ha	QP kg/ha	Total N kg/ha	Total P kg/ha
Baseline	80.8	117.6	2.37	4.45	0.89	1.19	0.23	5.63	1.12

Table 3. Baseline in kg/ha

Scenario	YON ppm	YOP ppm	NO3 ppm	QP ppm	Total N ppm	Total P ppm
Baseline	3.776	0.754	1.007	0.199	4.783	0.954

Table 4. Baseline in Parts Per Million

The series of graphics shown below give a detailed look at the North Bosque watershed. These graphics identify each of the 15,000 sub-basins processed by the study. They are shown here for the basic simulation that was executed to represent the baseline conditions from which all other scenarios are compared. These graphics are taken from the same baseline simulation used in the validation section above where historical data was compared to simulated values at the Hico location.

This series of graphics reports loads and concentrations in the water as the stream leaves each of the individual 15,000 sub-areas. Please understand this is not the amount of nutrients produced in that sub-area but the sum total of all of the land areas contributing to the stream flow and nutrients going through that individual sub-area. In other words it quantifies the quality of the water leaving the sub-area but does not identify the sources of contaminants in the water.

We will start the view of the graphics by looking at two of the most important attributes for water quality --that of the phosphorus dissolved in the water (QP) and the nitrogen dissolved in the water (NO3). The first two graphics are expressed in parts per million (ppm). This will give us a visual of what we will call the baseline conditions of the mid-1990s. Some guidelines identify .1 ppm as a threshold when dissolved P the in the water can potentially start to cause health problems in vulnerable groups of the human and animal populations. One will note that sizable portions of the small sub-basins in the watershed are above this threshold value. The table 4 above shows that this value is .199 for the P concentration (QP) in the water as the flow exits the North Bosque.

The threshold value for the nitrogen in the water (NO3) is considered to be about 10 ppm. The graphic shows that most of the area in the North Bosque falls below this threshold value. Even the small areas with concentrations above this threshold are quickly diluted in the streams to concentrations below 10 ppm.

The next series of graphics reports N and P values in kilograms per hectare. These graphics are presented in pairs. One graphic displays the detail of the small sub-basins (15,000). (The graphic below that quantifies the summary information for each of the 12 digit areas (27 in number).) By viewing these graphics together one can gain a better understanding of the baseline conditions. In both graphics the color codes and categories remain the same. Both graphics labeled “small sub-basins” and “flow accumulation” report attribute values for all areas that drain from above into the basin. The graphics labeled individual HUAs report the statistics for the areas inside that individual 12 digit HUA. These statistics are obtained by subtracting out all of the areas flowing into that specific HUA.

Even though the graphic reporting dissolved phosphorus in ppm shows numerous problem areas in the watershed, the first of this series displaying dissolved phosphorus in kilograms per hectare shows most of the areas are releasing less than 1 kg of P per hectare into the stream network.

The graphic displaying the mineral N in the water shows that most of the area produces less than 3 kg per hectare of mineral nitrogen. Only a very few sub-areas report more than 6 kg per hectare.

When we look at the organic phosphorus trapped in the settlement leaving a sub-basin we observe these values are noticeably higher than the phosphorus levels in the water. However, one would also notice that, even in this baseline scenario, the sub-basins showing higher levels of organic P are more numerous in the middle to the lower portion of the watershed. These areas are outside the concentration of the dairies. There are, however, a few “hotspots” in the northern areas where there are concentrations of dairies in small areas. These areas will be addressed as the scenario analysis proceeds.

The graphic showing the organic N gives a good example of how nutrients are concentrated in the stream. In some cases the load levels return to a lower level as the stream flows through the watershed, as can be observed in the upper portion where the very high levels of sediment nitrogen return to low levels when water from additional sub-basins are added to the primary stream. However, the more frequent situation occurs as the sediment loads increase with accumulating flows as the primary streams flow through the watershed. This is represented by the increasing number of dominant red streamlines in the lower parts of the basin.

When both sources of phosphorus are added together to provide an estimate of total phosphorus we observe the watershed maps chance to show a more random scatter of sub-basins with higher levels of phosphorus. The zoom view of the upper part of the watershed as the reservoirs, stream lines and dairies identified in the zoom view shows a higher levels of total phosphorus occurring near the concentrations of dairies. These higher levels of nutrients are not coming from the dairies themselves, as the lagoons on the dairies are not permitted to have overflows, but from the waste application fields where the manure from the dairies is being applied. Remember in this baseline scenario all manure produced by the dairy animals must be applied to waste application fields in the watershed.

One will observe a similar pattern when looking at the graphics for total nitrogen. Here again sub-basins with high levels of total nitrogen are somewhat randomly distributed across the watershed. One observation worth noting in the zoom graphic of total nitrogen is the impact individual reservoirs have on the delivery of total nitrogen downstream. This may be observed by looking at the change in the color of the streamline below the reservoirs. In the majority of cases the streams reflect improved water quality as the reservoir traps the sediment coming into the reservoir.

Below these nitrogen and phosphorus graphics two more attributes are reported. One pair of graphics reports the water yield by 12 digit HUAs. This water yield includes both the runoff and the return flow for the area. The second set of graphics reports the sediment delivery or sediment loads in the stream by HUAs. In both cases the top graphic reports the individual HUAs value while the bottom graphic reports the accumulated values for all areas above the point where the stream exits that HUA.

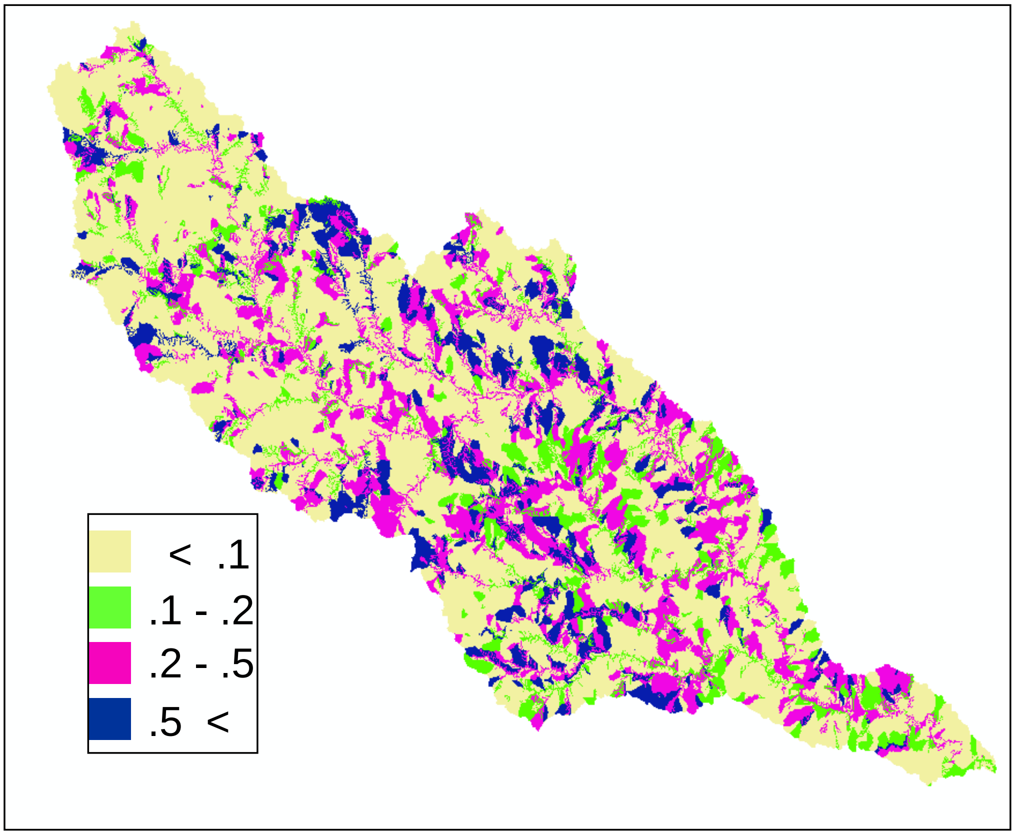

Figure 23. Baseline Mineral P in Water in ppm

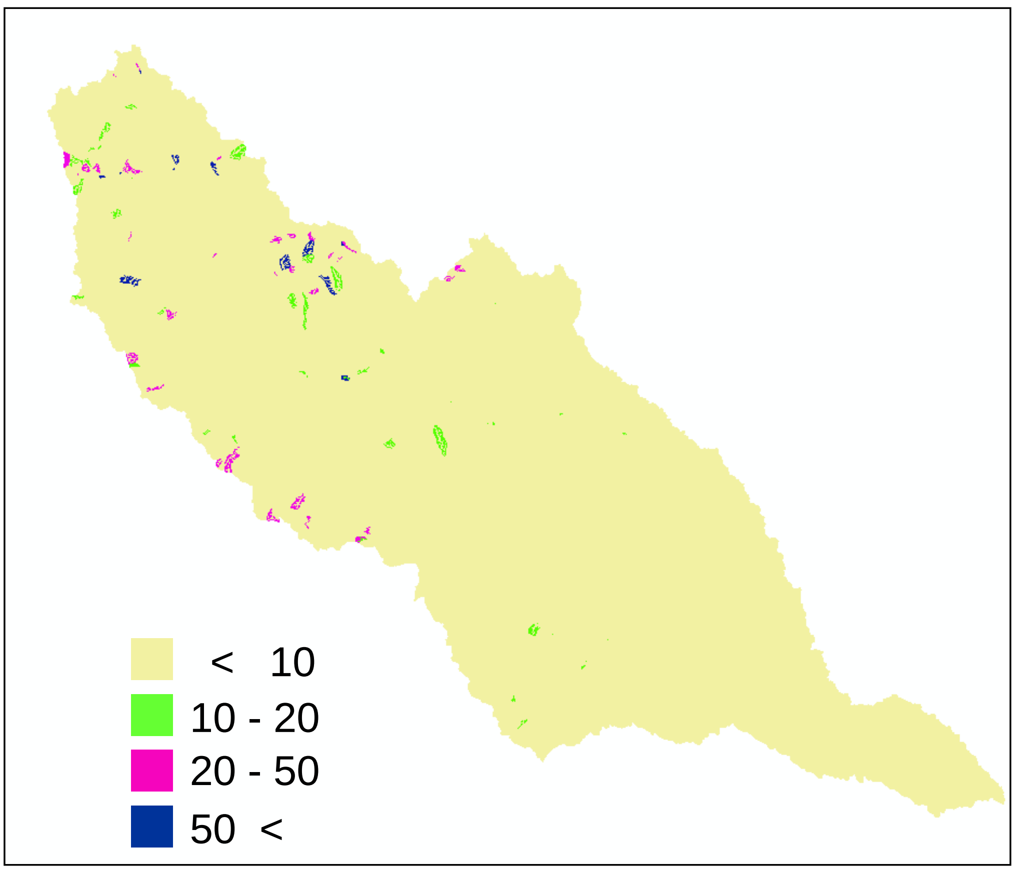

Figure 24. Baseline Mineral N in Water ppm

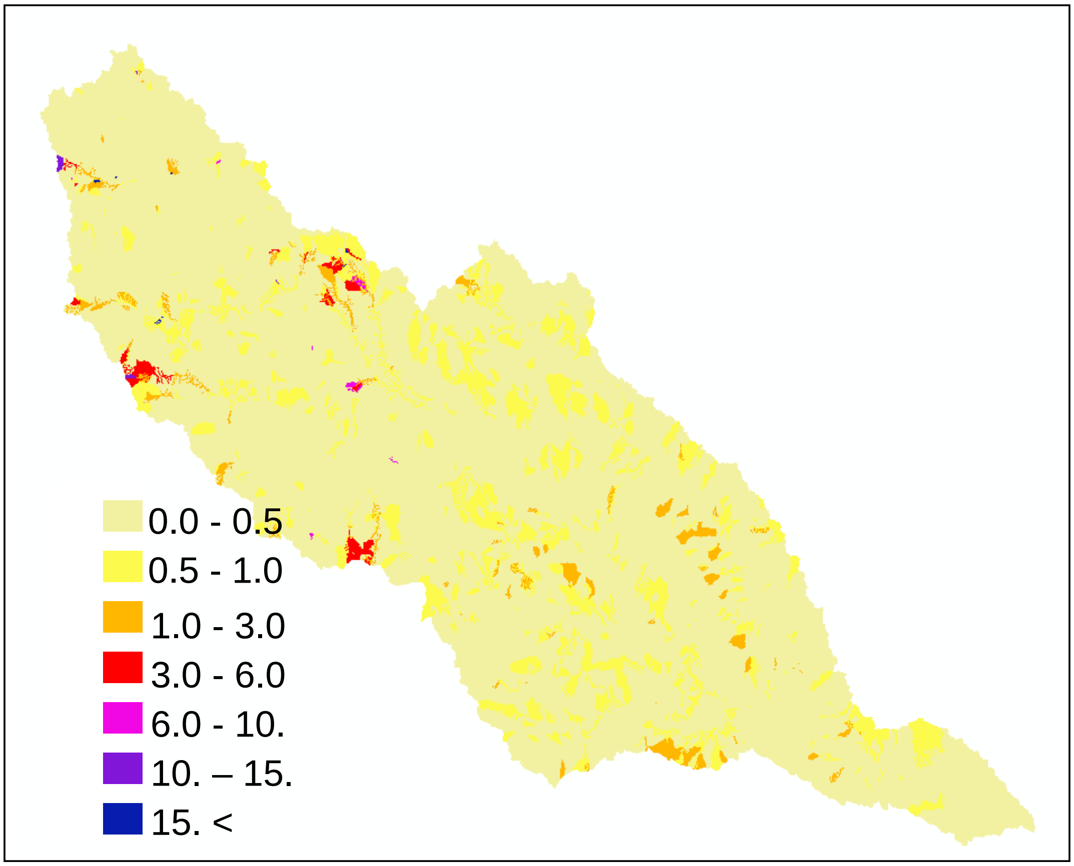

Figure 25. Baseline Mineral P in Water Flow Accumulation kg/ha-Small Sub-basins

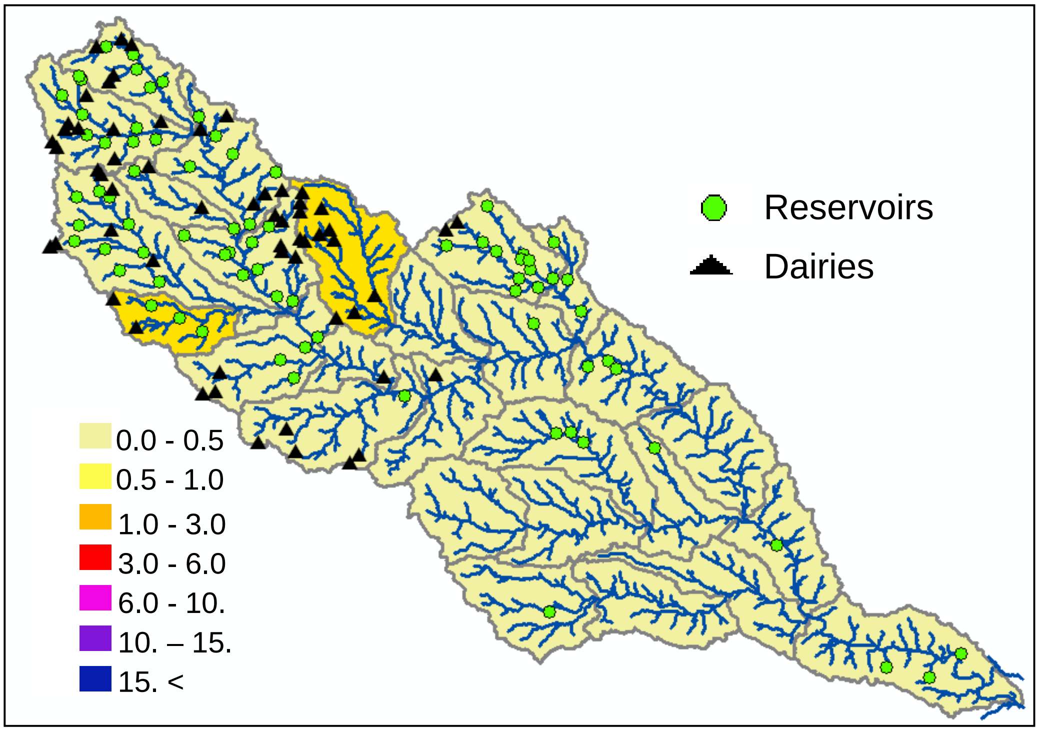

Figure 26. Baseline Mineral P in Water Flow Accumulation in kg/ha 12 Digit HUA

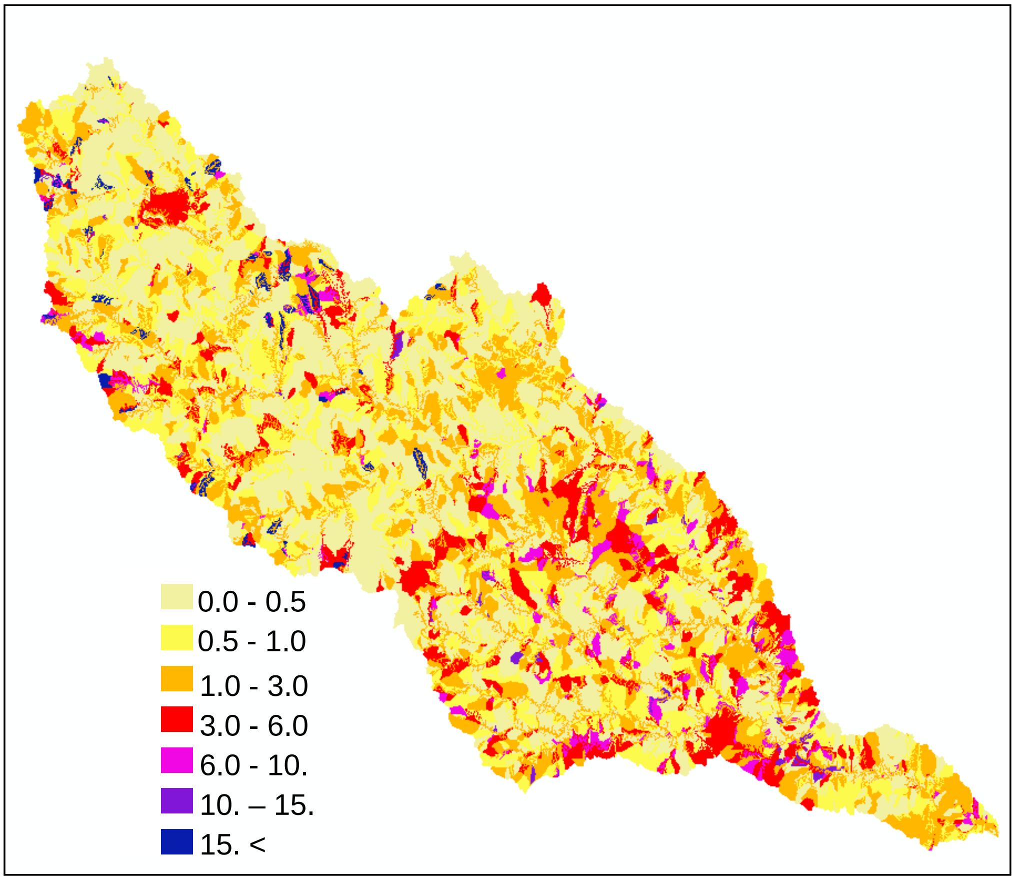

Figure 27. Baseline Mineral N in Water Flow Accumulation in kg/ha –-Small Sub-basins

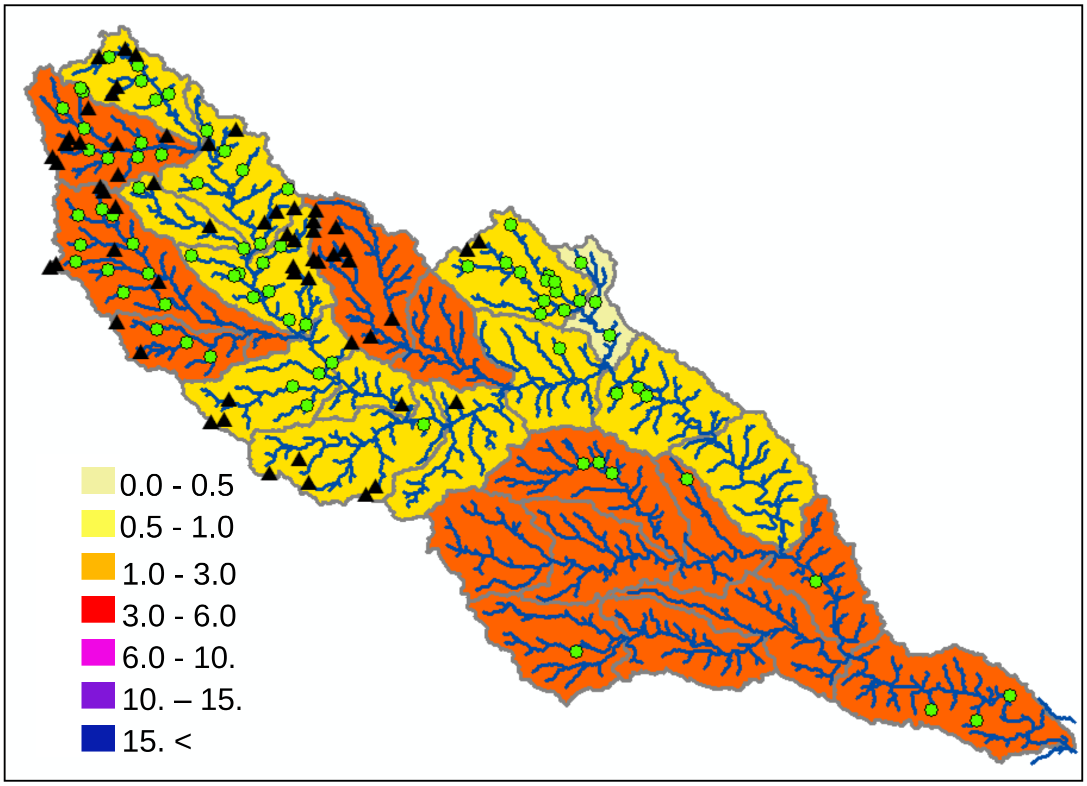

Figure 28. Baseline Mineral N in Water Flow Accumulation in kg/ha –12 Digit HUA

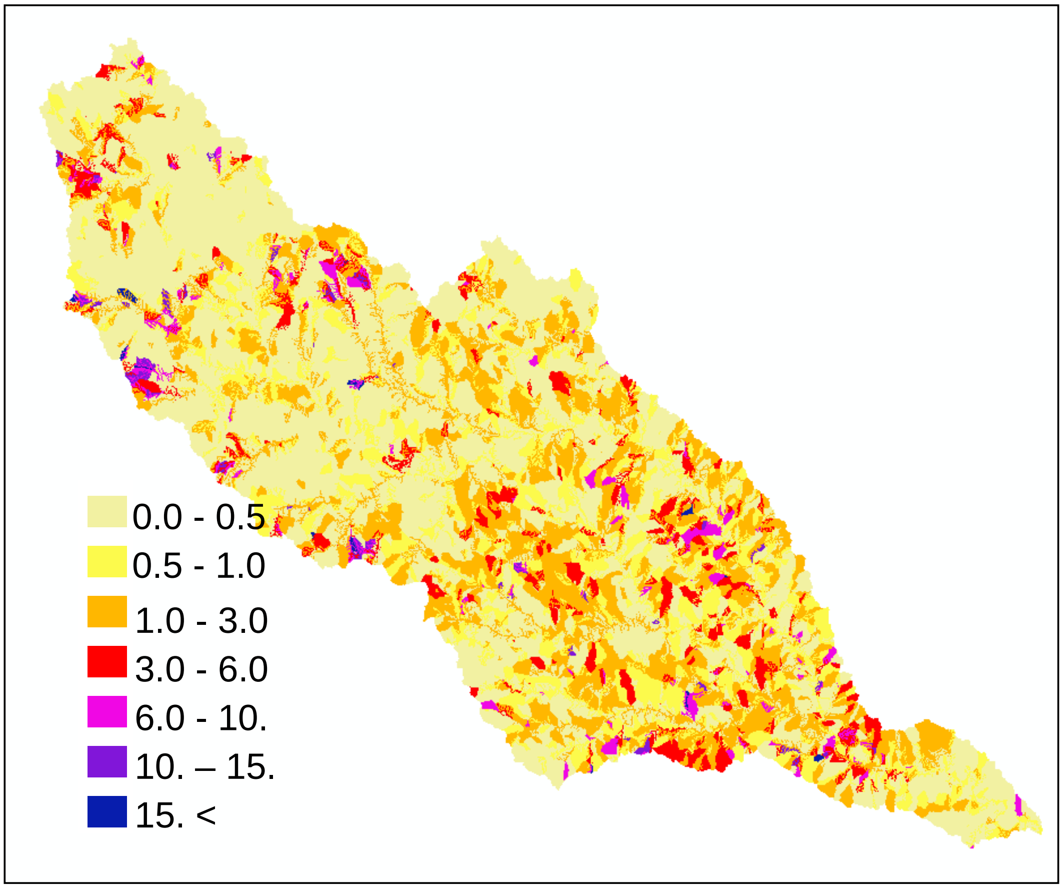

Figure 29. Baseline Organic P in Sediment flow accumulation in kg/ha Small Sub-basins

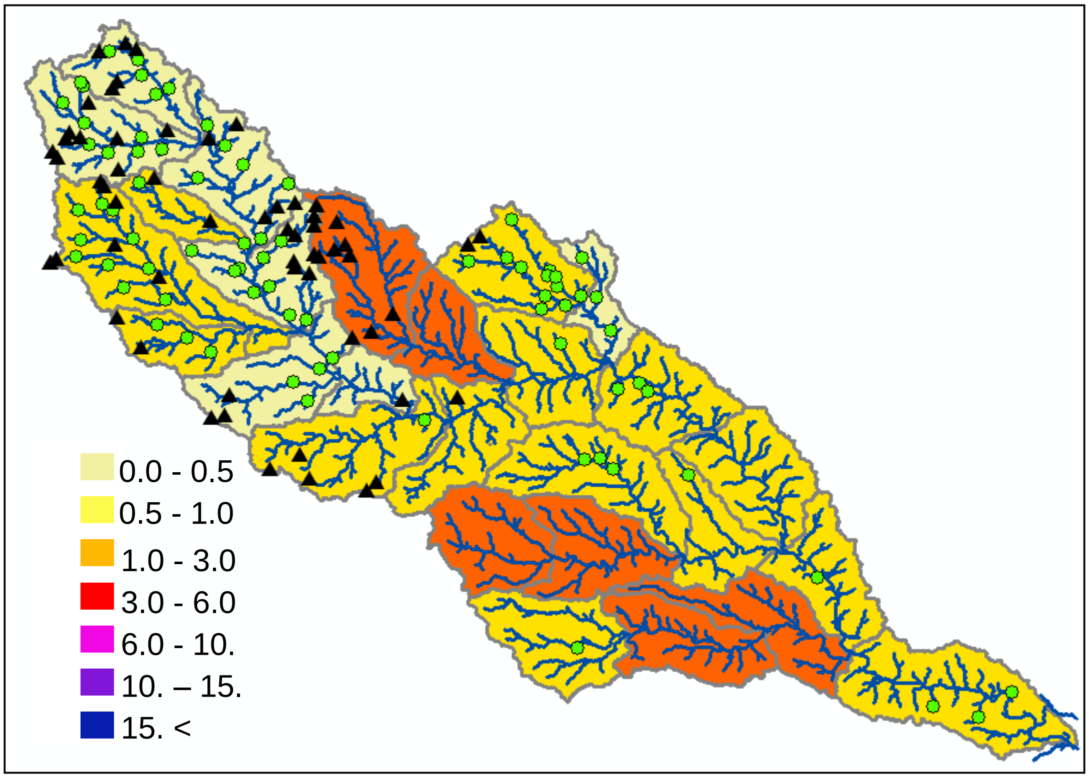

Figure 30. Baseline Organic P in Sediment flow accumulation in kg/ha 12 Digit HUA

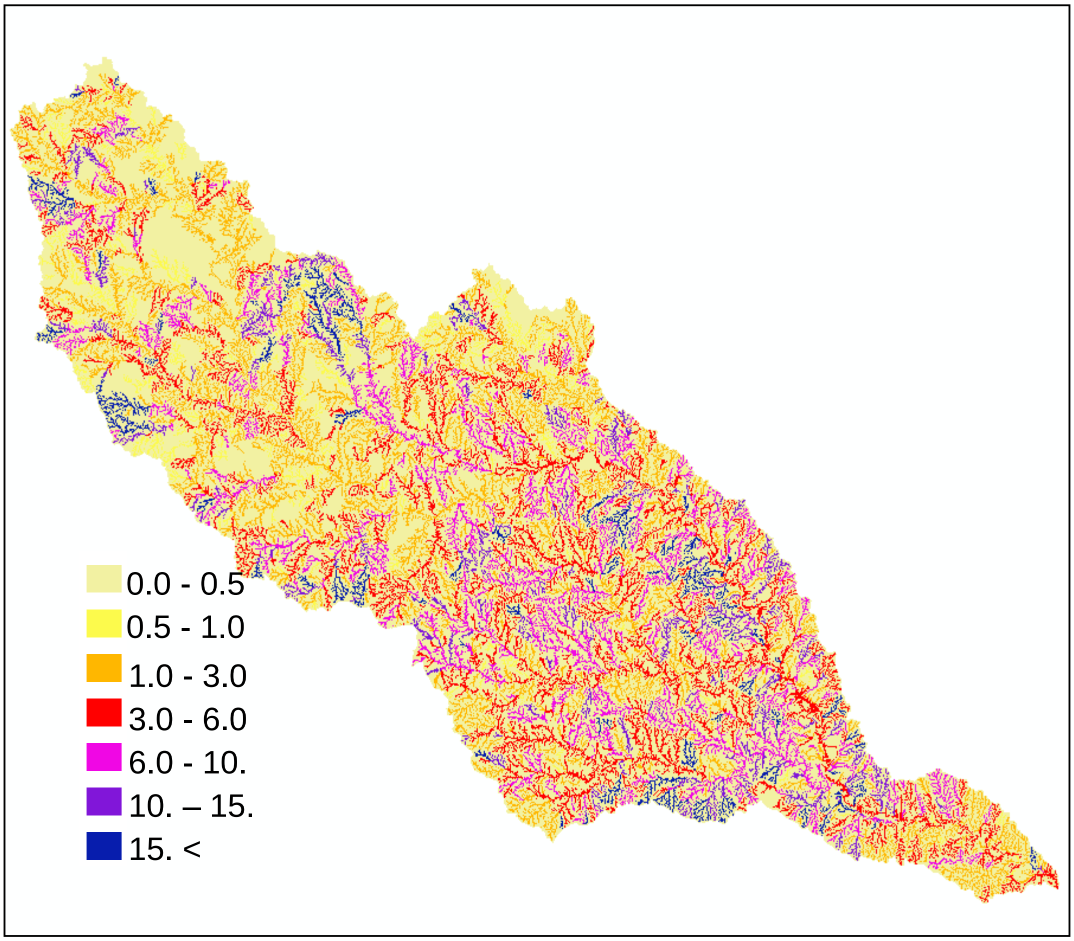

Figure 31. Baseline Organic N in Sediment kg/ha Flow Accumulation Small Sub-basins

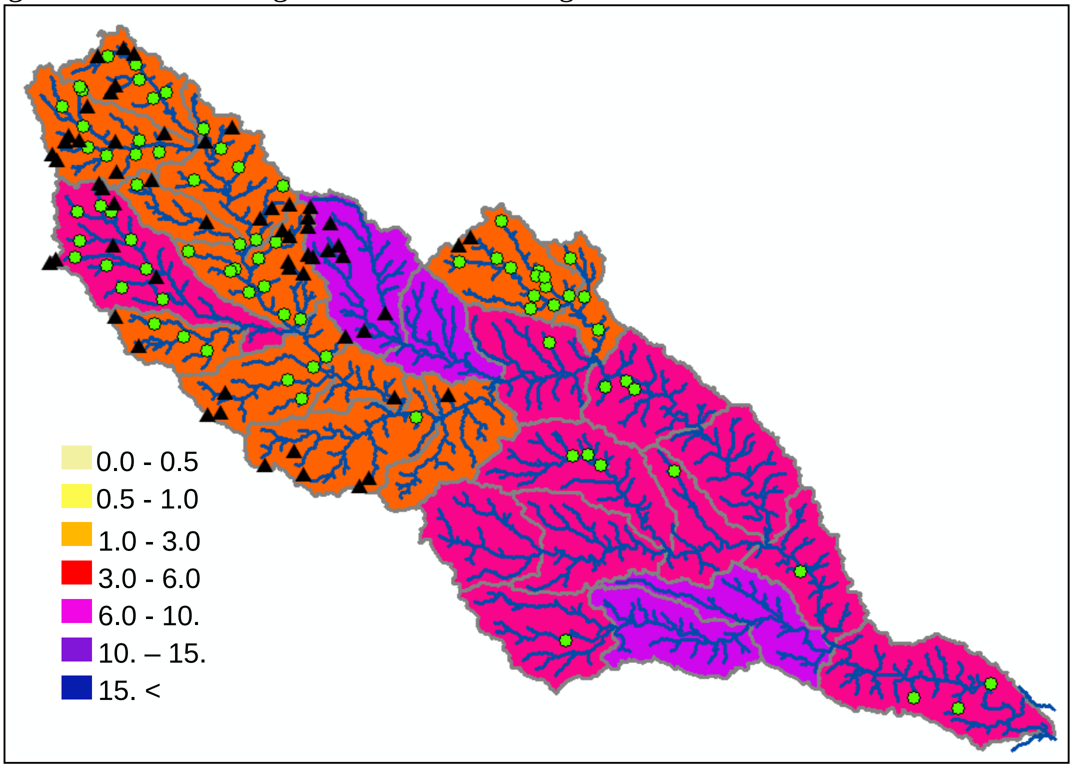

Figure 32. Baseline Organic N in Sediment kg/ha Flow Accumulation 12 Digit HUA

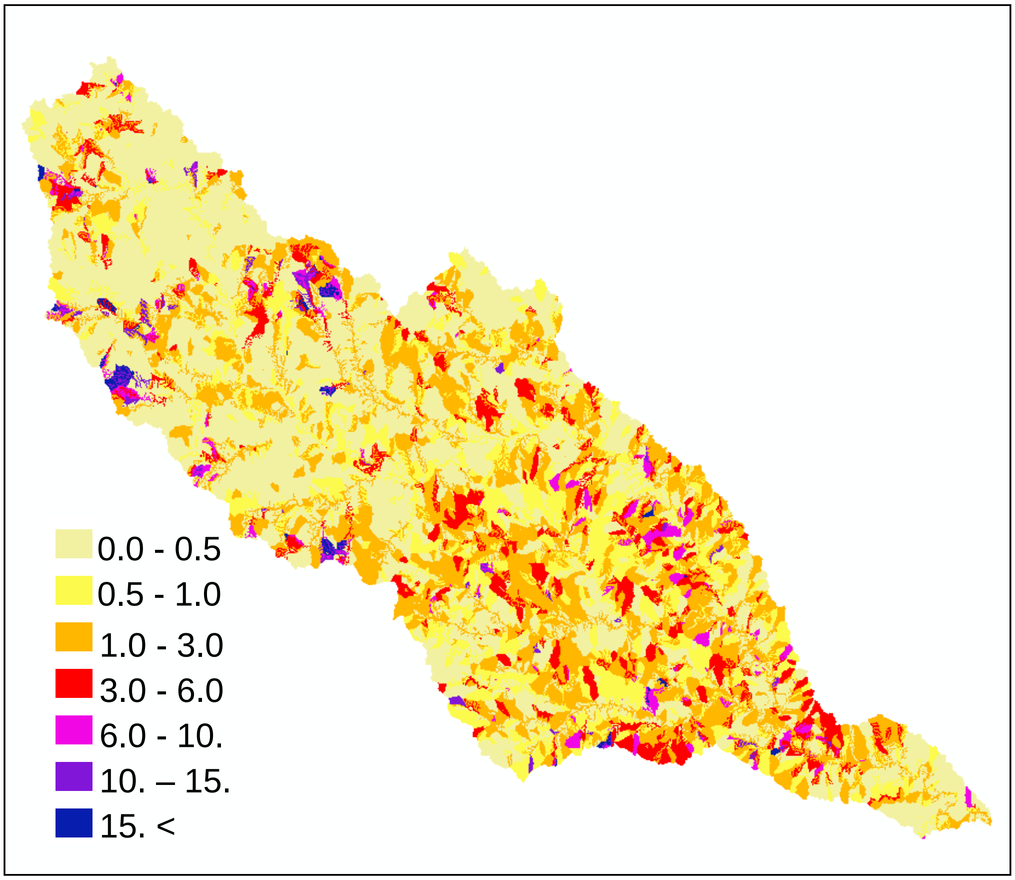

Figure 33. Baseline Total P Kg/ha

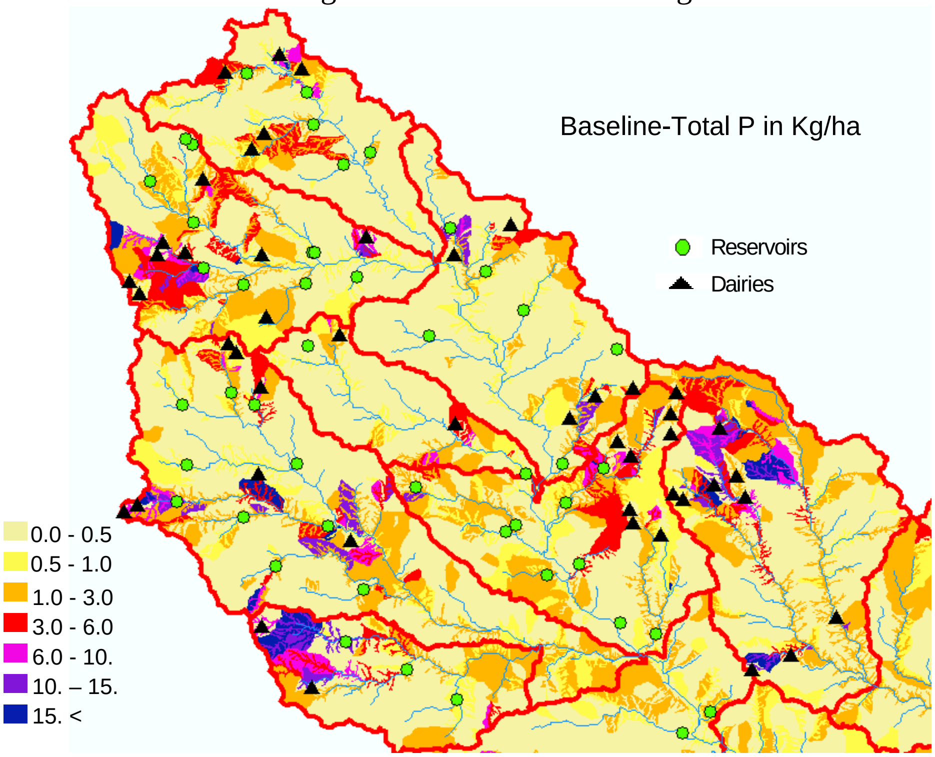

Figure 34. Baseline – Total P in Kg/ha with Reservoirs and Dairies

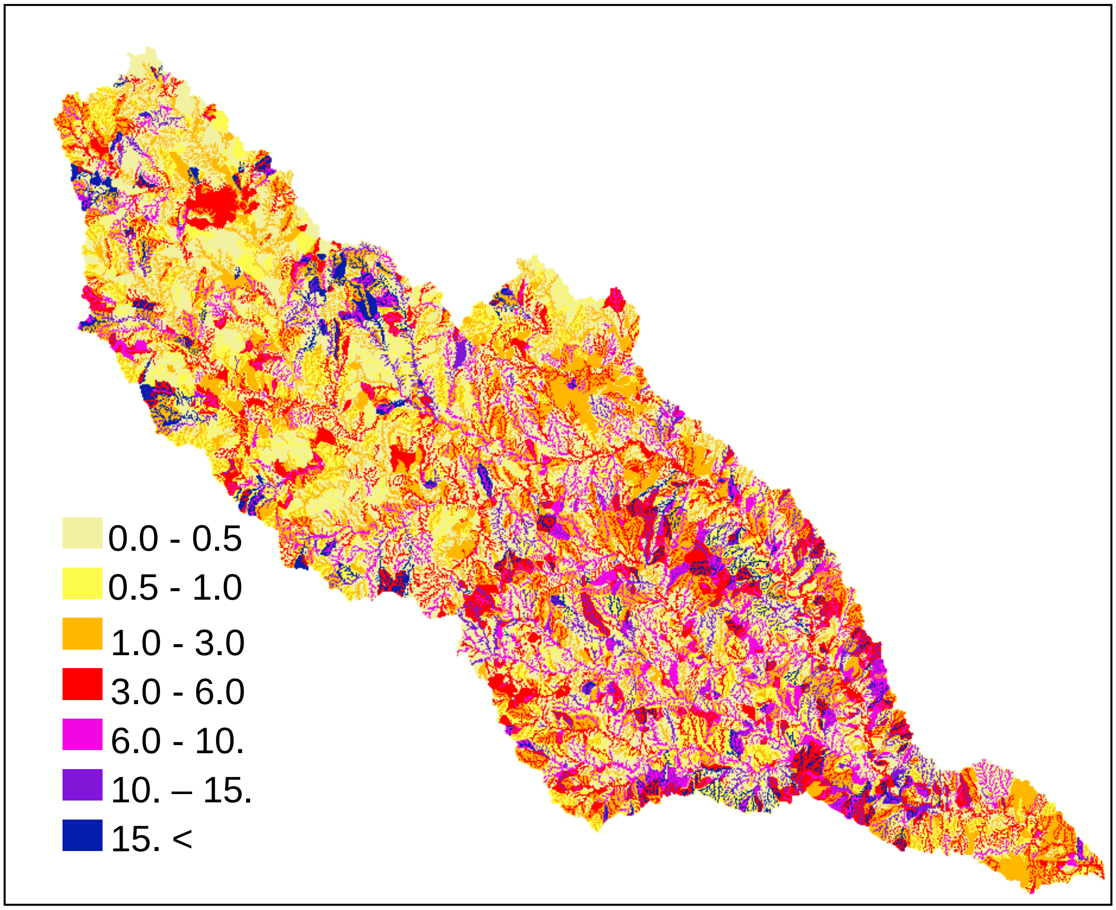

Figure 35. Baseline Total N Kg/ha

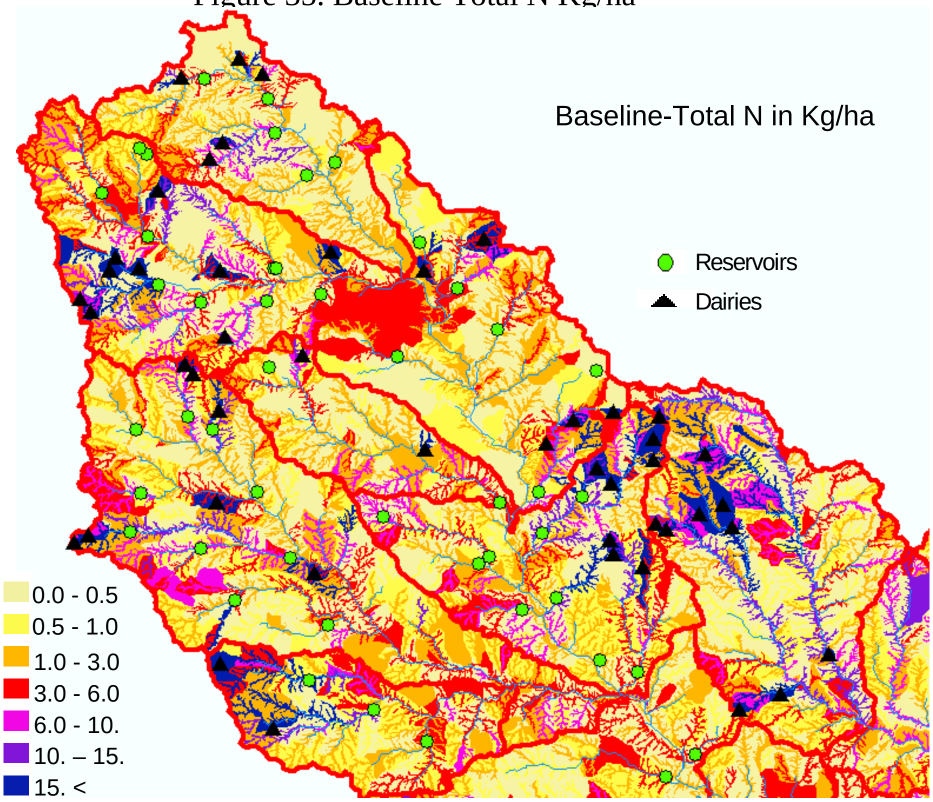

Figure 36. Baseline – Total N in Kg/ha Reservoirs and Dairies

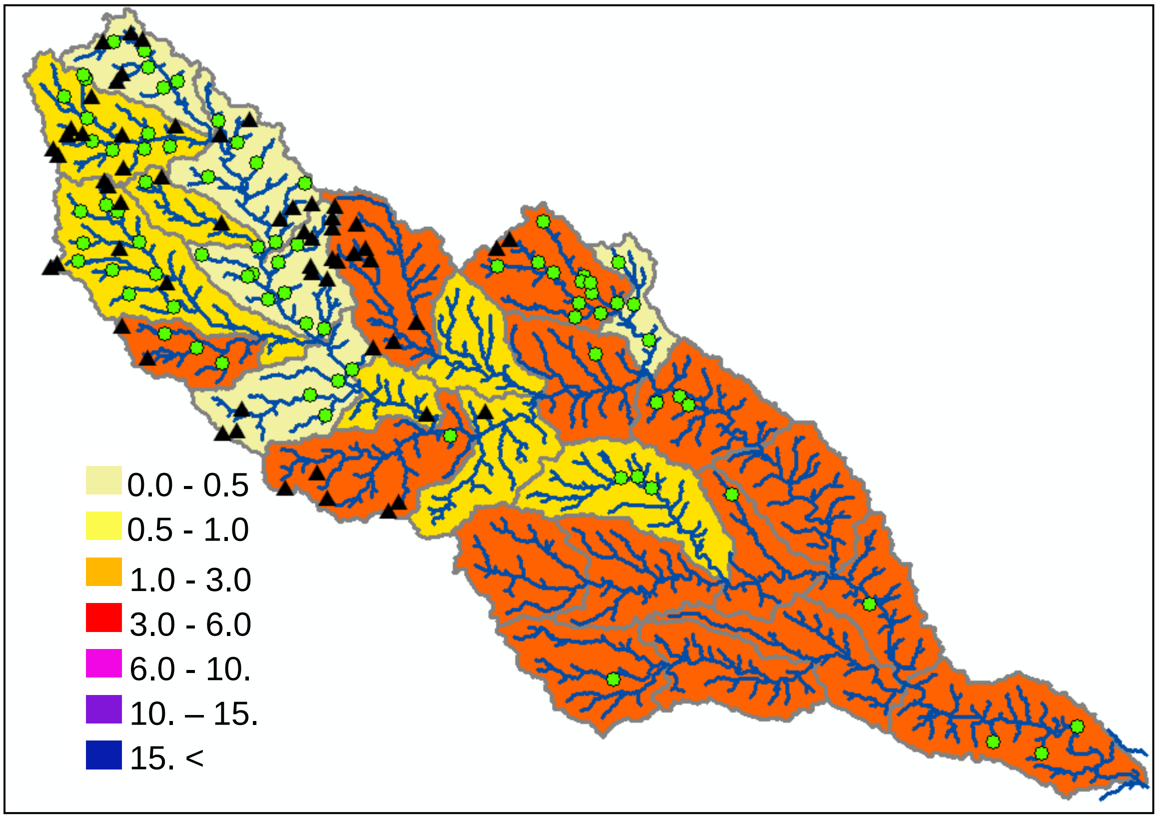

Figure 37. Baseline Total P - Individual HUA in kg/ha 12 Digit HUA

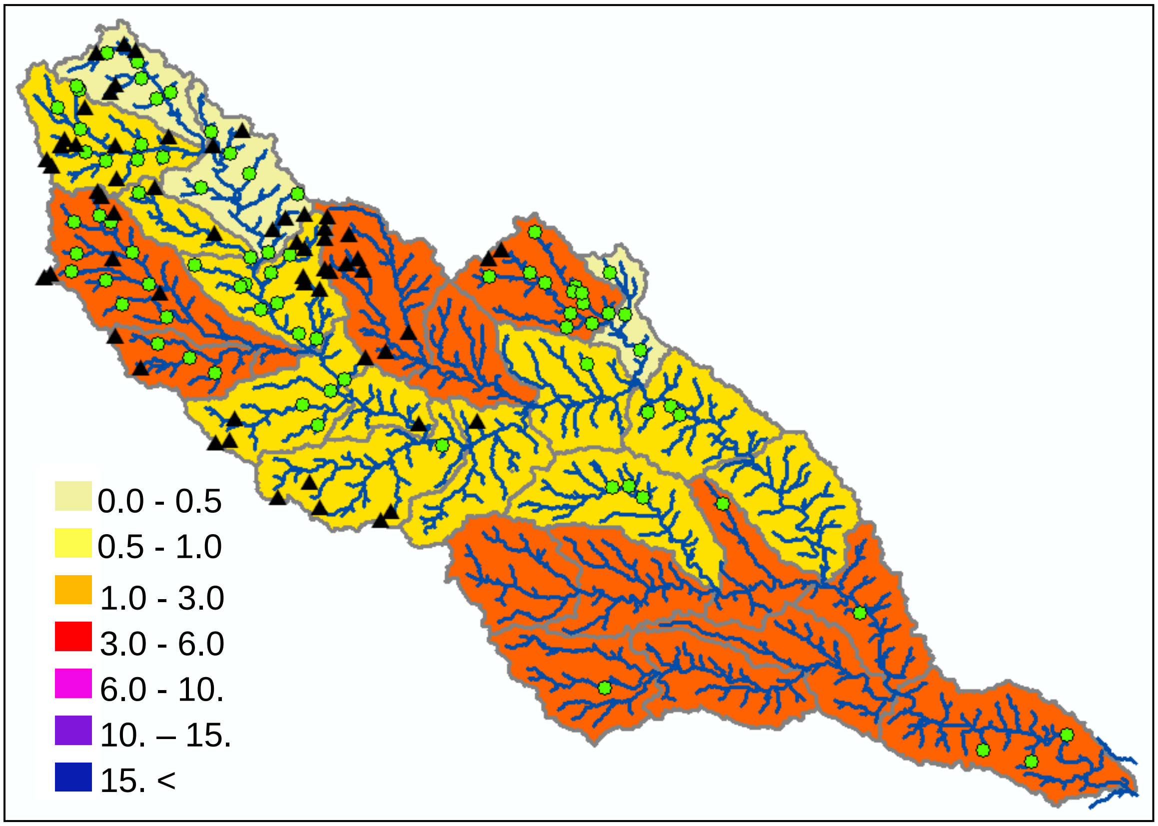

Figure 38. Baseline Total P Flow Accumulation in kg/ha 12 Digit HUA

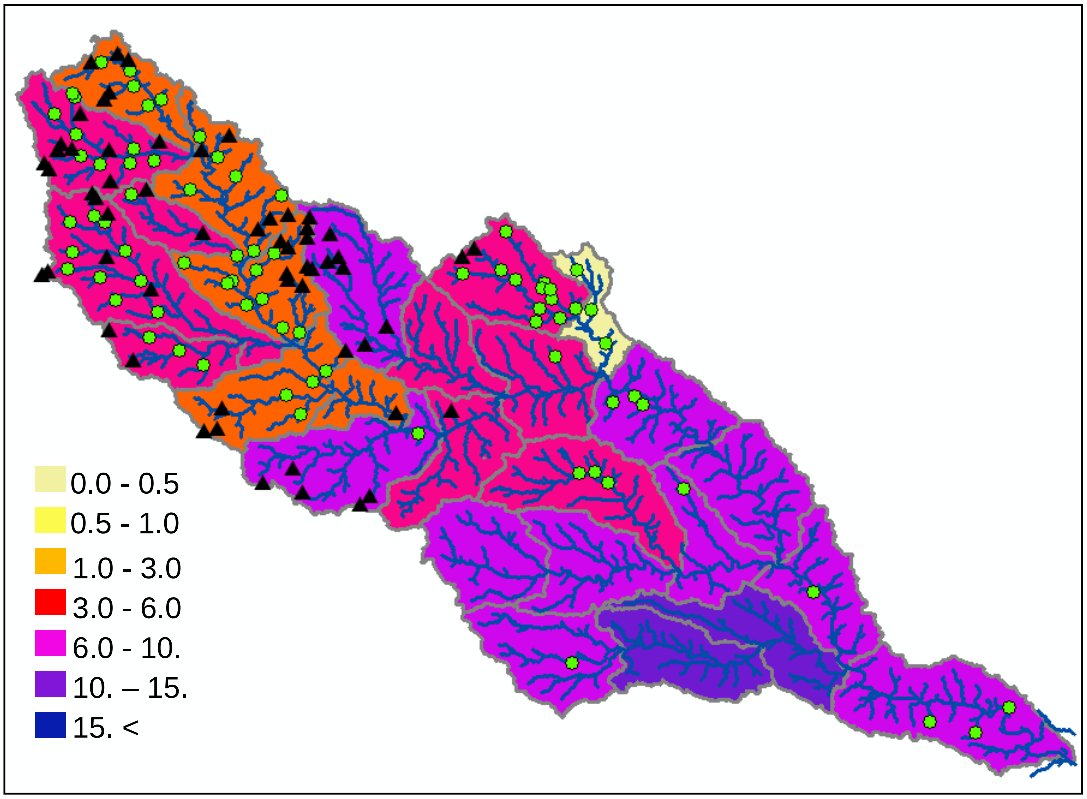

Figure 39. Baseline-Total N Individual HUA in kg/ha by 12 Digit HUA

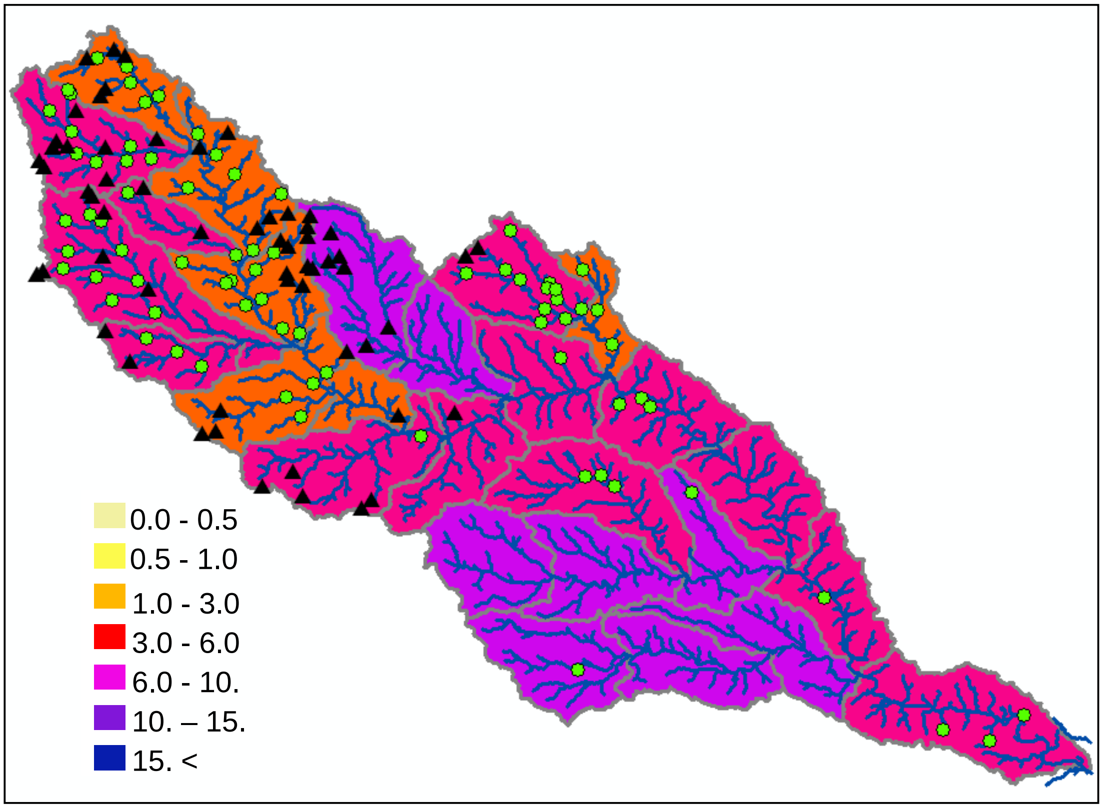

Figure 40. Baseline Total N Flow Accumulation 12 Digit HUA

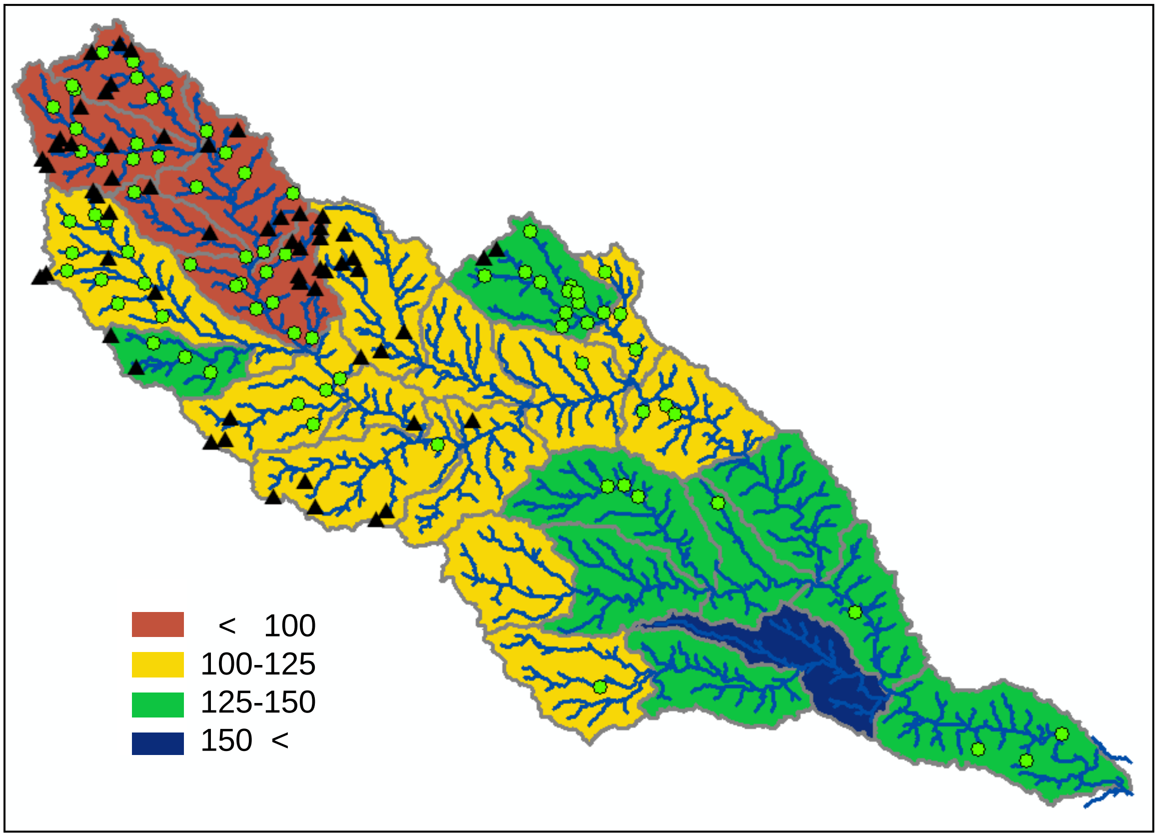

Figure 41. Baseline Water Yield in mm

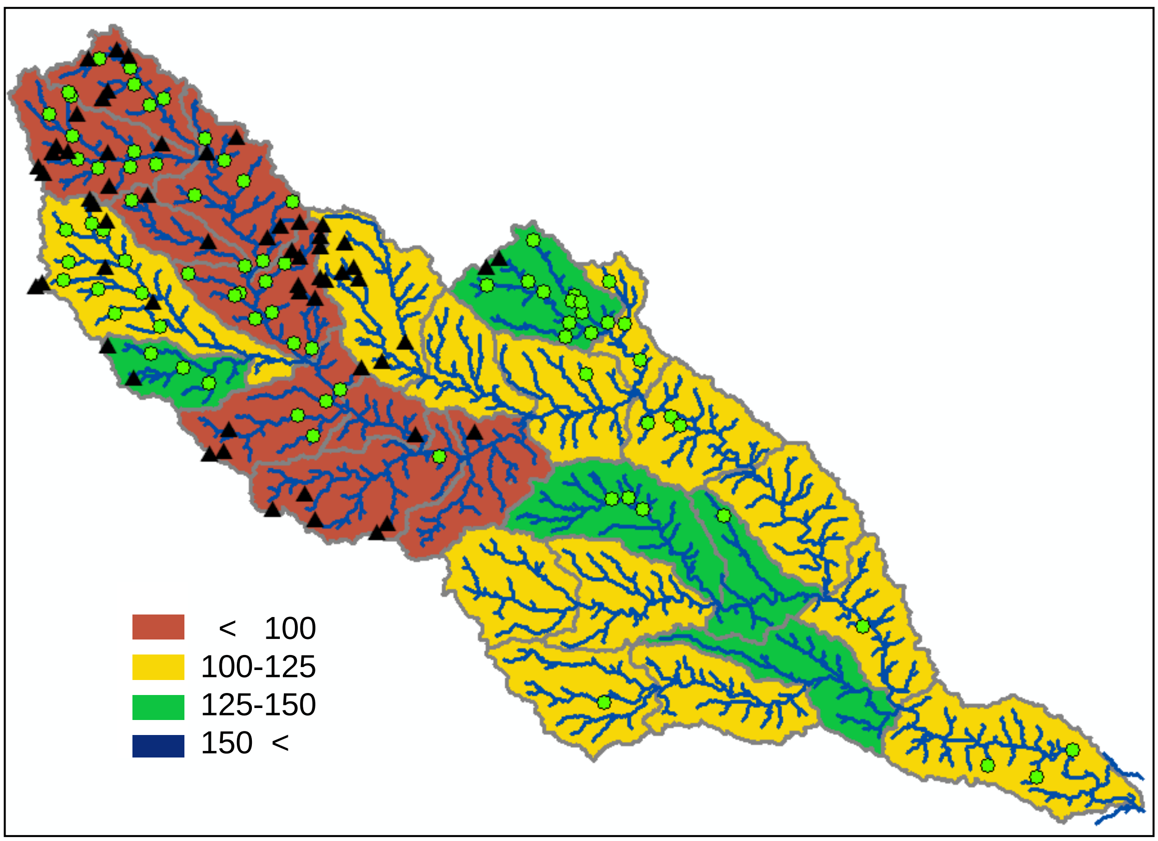

Figure 42. Baseline Water Yield Flow Accumulation in mm

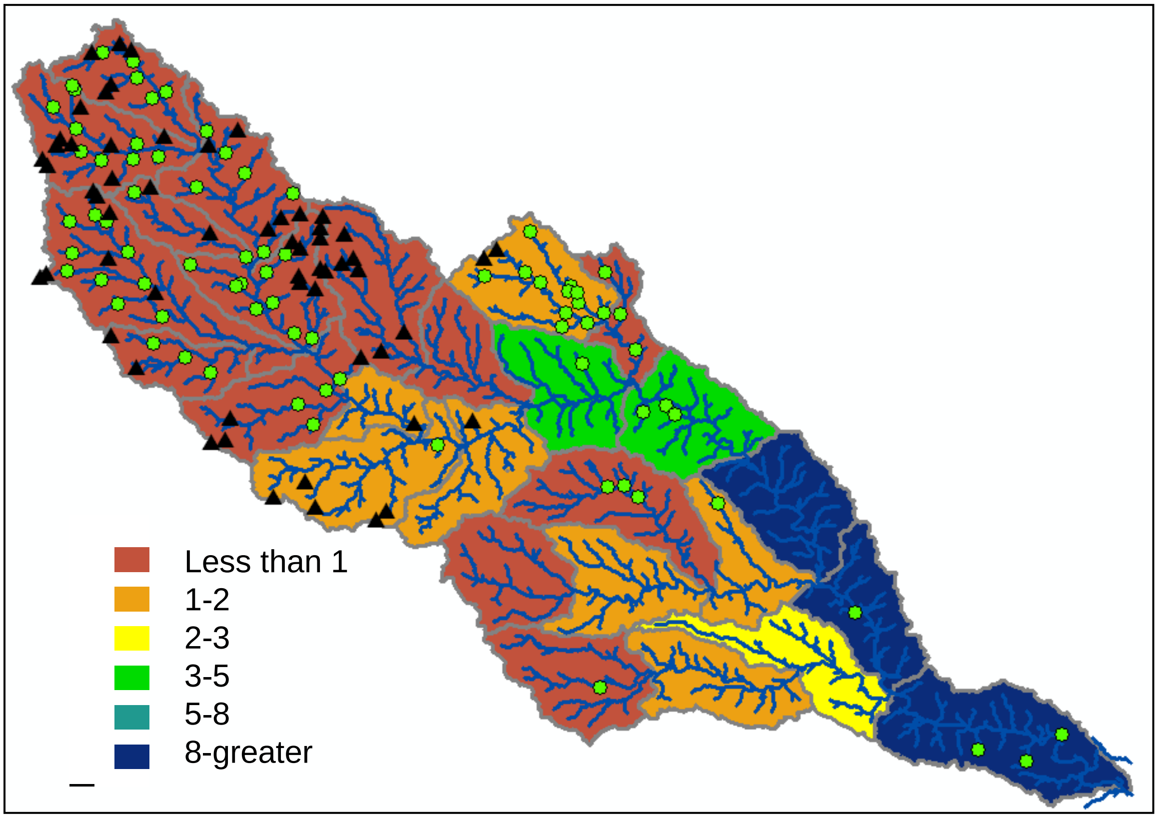

Figure 43. Baseline Sediment Yield in Tons/ha 12 Digit HUA

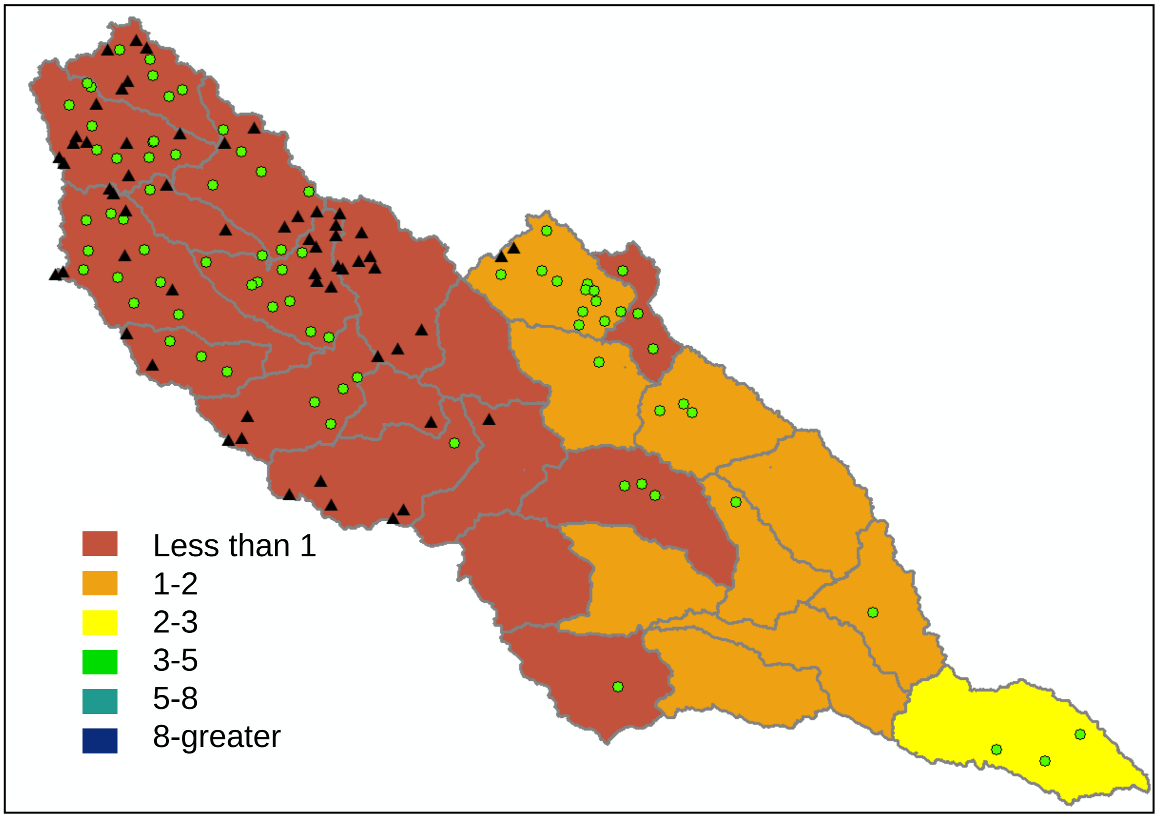

Figure 44. Baseline Accumulated Sediment Yield in Tons/ha

Primary Alternative Scenarios MNUL=0

1. All reservoirs in the area are active and functional (74 total). (TNRCC)
2. Current cropping practices included ICIPG Practices on 50 % of cropland and pasture fields and 50% were non-ICIPG practices.
3. All manure produced in the watershed was applied onto the waste application fields in the watershed (i.e. no manure hauloff).(MNUL=0)
4. All dairy lagoons were protected to allow no overflow.
5. Cow Numbers were set at approximately 40,000 Dairy Cows.

6. Distributed Water Management & Manure Application to all WAF (DWMA)
7. Distributed Water Management and Lower Landscape Management –Manure Application fields on Upper only (DWMU)

As we start to address the different groupings of scenarios, the results will be reported by the twenty seven - 12 digit HUAs in the North Bosque. This simplification and aggregation into these larger units increases the ability to visualize the results of each scenario and the comparison between scenarios. (It also facilitates comparison with other reports for the Bosque watershed where previous studies, for the most part, reported the information by 12 digit units.)

The graphics used for the scenarios differ from those displayed for the baseline. The scenario graphics and table will be reported as percentage deviations from the baseline as opposed to the baseline that was reported in parts per million and kilograms per hectare. These graphics, as well as most of the graphics to follow, are presented in a series of 8 screens. These 8 graphics will be displayed in pairs. These graphics will start with the reporting of the percentage change from the baseline of total N and total P. On respective pages the percentage change of total N and P will be reported for each individual 12-digit basins. The bottom graph on that page will show the flow accumulation of the change in total N or P at the point where the stream leaves that 12 digit area. After these total values are reported the remaining four graphs will show each of the component parts of N and P (in the water and in the sediment).

In each group of scenarios we will choose a representative scenario for that section for which we will show the graphics. For example in this section we will show “Distributed Water Management & Manure Application to all (waste application fields) WAF (DWMA)”. The table as shown below will report the summary information for the North Bosque for all scenarios in that grouping.

The first grouping has two scenarios. One of the reasons for separating the land positions into the upper and lower landscape categories was to allow management practices to be fine tuned on the waste application fields. In these two scenarios only the configuration of the landscape of the waste application fields and the position of the manure applied to the WAF are varied. Both of these scenarios, in contrast to the baseline, change the configuration of the runoff of the waters leaving the field. Under these scenarios the channel length and channel depth associated with each of the fields (sub-basins) are changed to prevent water from concentrating into a channel before leaving the sub-basins. This is true of both the upper and lower landscape positions. Under the baseline scenario the water from each sub-basin concentrates into a channel before running into the sub-basin below. This means that any water coming from that sub-basin is routed through the basin below and on into the major stream networks. Because of the extremely small size and large number of sub-basins (15,000 as opposed to a few hundred in earlier studies), the water is channelized on the landscape much quicker than when larger sub-basins are used. Preventing the water from channelized and distributing the water evenly across the landscape in the adjoining lower sub-basin creates a filtering action that we anticipated would likely reduce sediment and therefore nutrients entering the stream. This technique is somewhat like unto creating filter strips that are often placed between a field and stream channels. In this configuration the entire field becomes a filter strip. While configuring the studies we considered using filter strips (as the model allows the use of filter strips), however, we decided the relatively narrow width of filter strips at the bottom of the basin would likely reach sedimentation capacity in far less than 40 years and would not represent the true nature of what was happening on the landscape. When the water is distributed across the sub-basin and the manure is applied to the entire WAF the scenario is identified as DWMA (Distributed Water with Manure on All).

The second manure management technique was to address the feasibility and the impact of applying manure only to the sub-basins located in the upper landscape position. One will remember in the original design all basins were divided into two parts identified as upper and lower landscape positions. Under this manure application technique all the manure assigned to the waste application field would be applied only in the upper landscape position. This means that the application rate might very well be twice the rate as compared to when manure was applied to the entire waste application field. The thought was as the manure is applied only to the surface, because the waste application fields are Bermuda grass and do not allow manure incorporation into the soil, the eroding manure carried by the runoff water would be trapped in the adjoining part of the waste application field defined as the lower landscape position. We hypothesized this technique might reduce nutrient loads reaching the stream even more than when the entire field was used. When manure is applied only to the upper position the scenario is identified as DWMU (distributed water with manure on upper landscape only).

The results of the simulation runs as shown below (and subsequent scenarios) identified very little difference between the two techniques. The introduction of the water spreading technique that delays the water from concentrating into the channel proved to be the most effective technique. This practice mask any benefits resulting from the placement of the manure. For most of the sub-areas very small improvements were gained by applying manure to the upper position only. We attribute this result to two conditions. First, the distribution of the water did in fact behave as a very large buffer strip. This prevented the manure from eroding with the water as the water moved off the landscape. This occurred in both the upper and lower landscape positions as manure was applied to both positions. Secondly, since very little manure left the upper landscape position there was not a sufficient amount of nutrients to fully provide the nutrient requirements of the Bermuda grass in the lower landscape position. As a result grass production and, therefore, the cover provided by the grass was substantially reduced in many of the sub-basins located in the lower landscape position. In some basins even soil erosion increased carrying with it the nutrients attached to the sediments. We see from the table below representing the entire North Bosque there was a substantial decline in the nutrients attached to the sediment. (It should be noted the model erodes manure in a separate activity and subroutine when manure is placed on the surface of the soil as is the case here. The nutrient content of the manure is included in the nutrient content of the sediment reported by the model.) However, there appears to be an increase in the nutrients dissolved in the water with the net result of slight improvements in the total percentage changes in nutrients.

The management practices introduced in these scenarios improve the watershed health by about 4-5%. Even though this improvement is not large it is still significant given the fact that only a small percentage of the watershed is classified as waste application areas, and these scenarios addressed only management practices on waste application areas. The other significant observation is the fact that all manure was applied to these waste application areas and remained in the watershed. As will be shown in the next scenario this limited the effectiveness of these management practices.

Scenario	Runoff Percent Change	Water Yield Percent Change	Erosion Percent Change	YON Percent Change	YOP Percent Change	NO3 Percent Change	QP Percent Change	Total N Percent Change	Total P Percent Change
DWMA-TNRCC-0	-0.05	0.085	1.19	-8.36	-8.44	9.25	13.02	-4.66	-3.96
DWMU-TNRCC-0	0	0	1.14	-8.36	-8.44	9.3	12.96	-4.64	-3.97

Scenario	YON ppm	YOP ppm	NO3 ppm	QP ppm	Total N ppm	Total P ppm
DWMA-TNRCC-0	3.457	0.69	1.099	0.225	4.557	0.915
DWMU-TNRCC-0	3.46	0.691	1.101	0.225	4.561	0.916

Table 5. Primary Alternative Scenarios MNUL=0

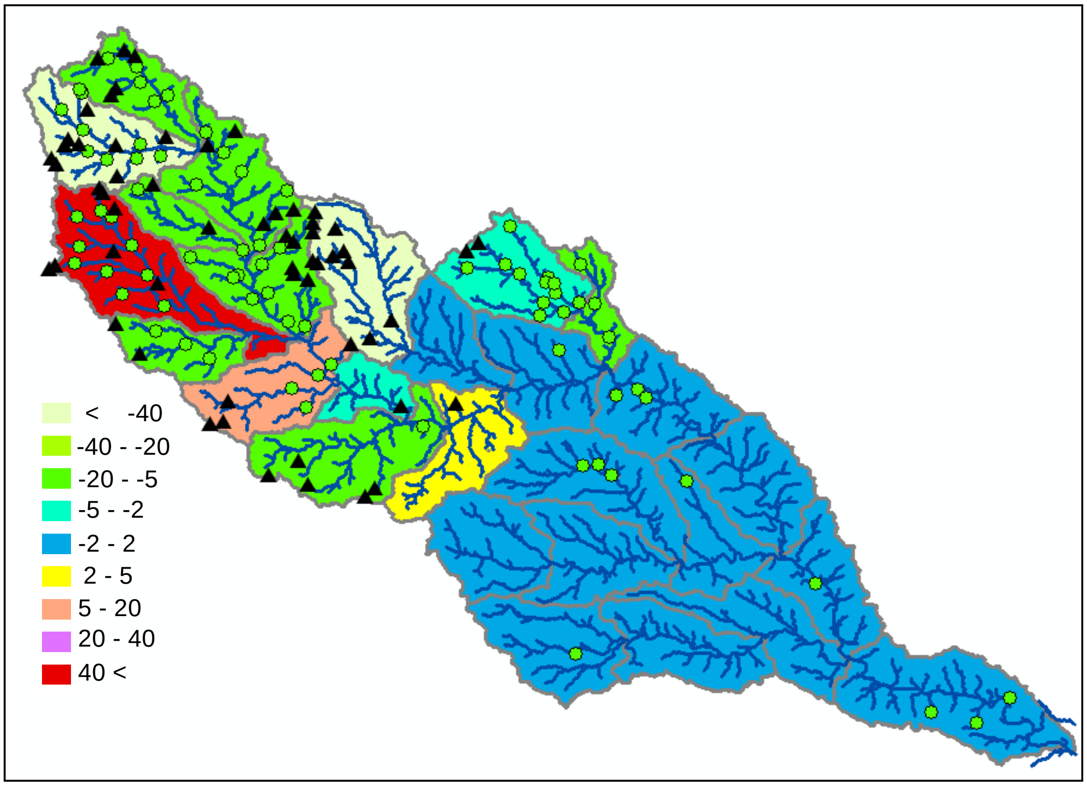

Figure 45a. % Change Total N DWMA-Existing Reservoirs All Manure-Applied

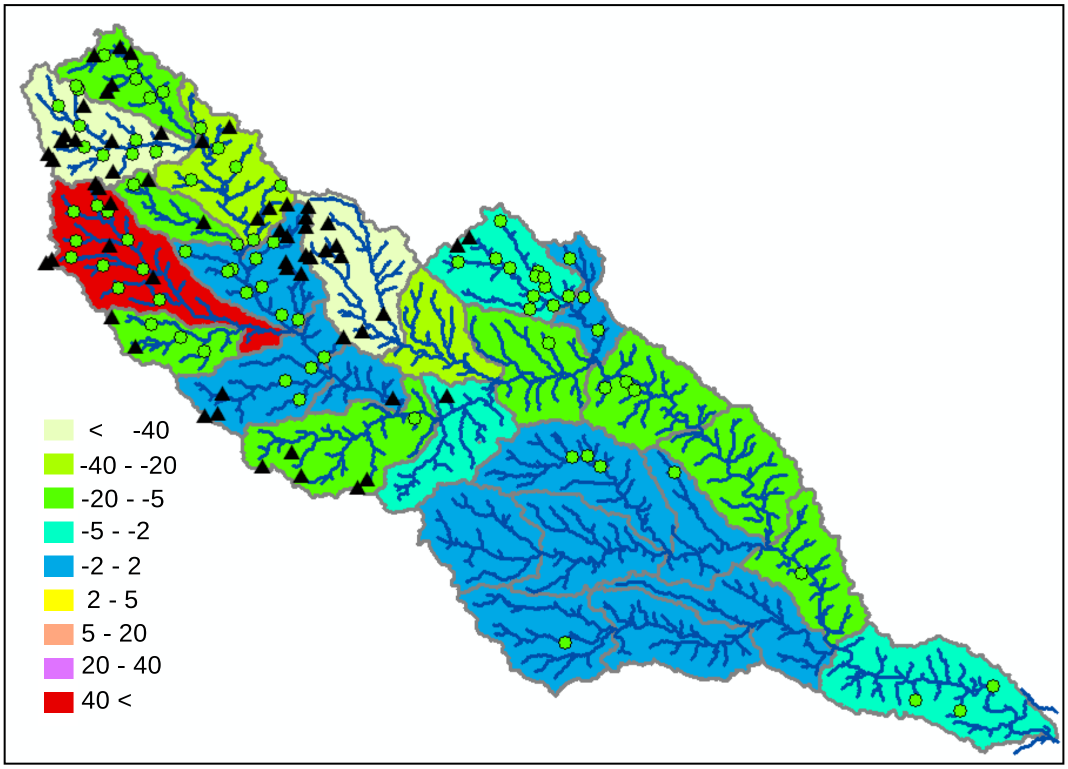

Figure 45b. % Change Total N Flow Accumulation DWMA-Existing Reservoirs All Manure-Applied

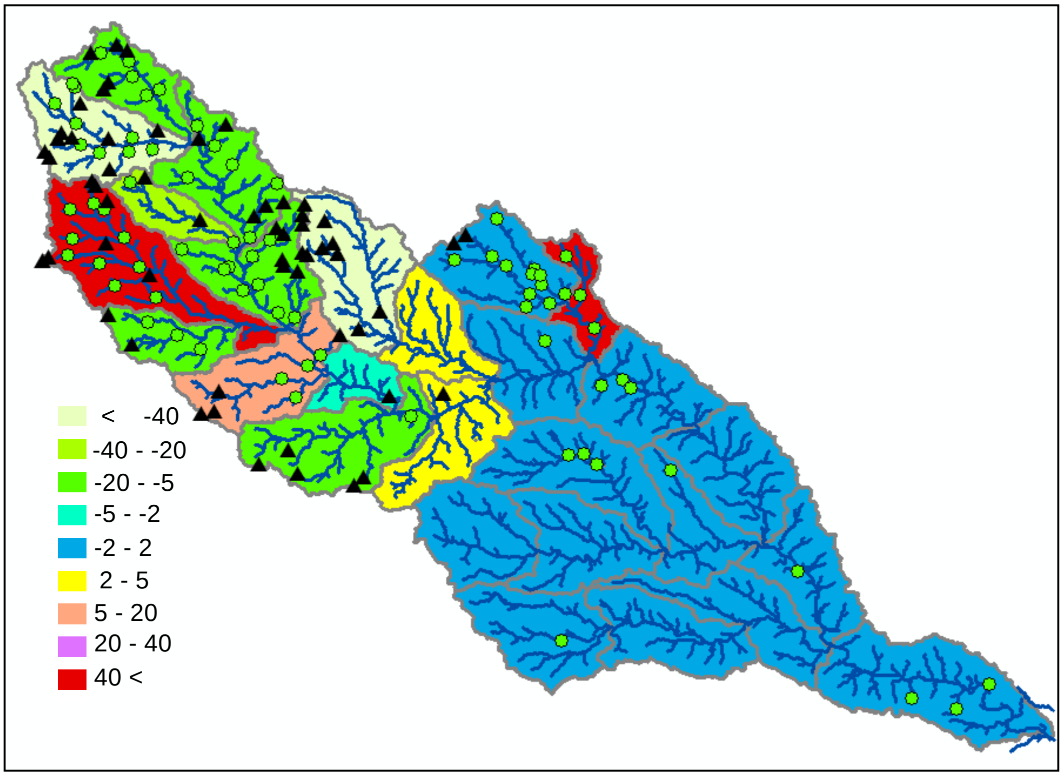

Figure 45c . % Change Total P DWMA-Existing Reservoirs All Manure-Applied

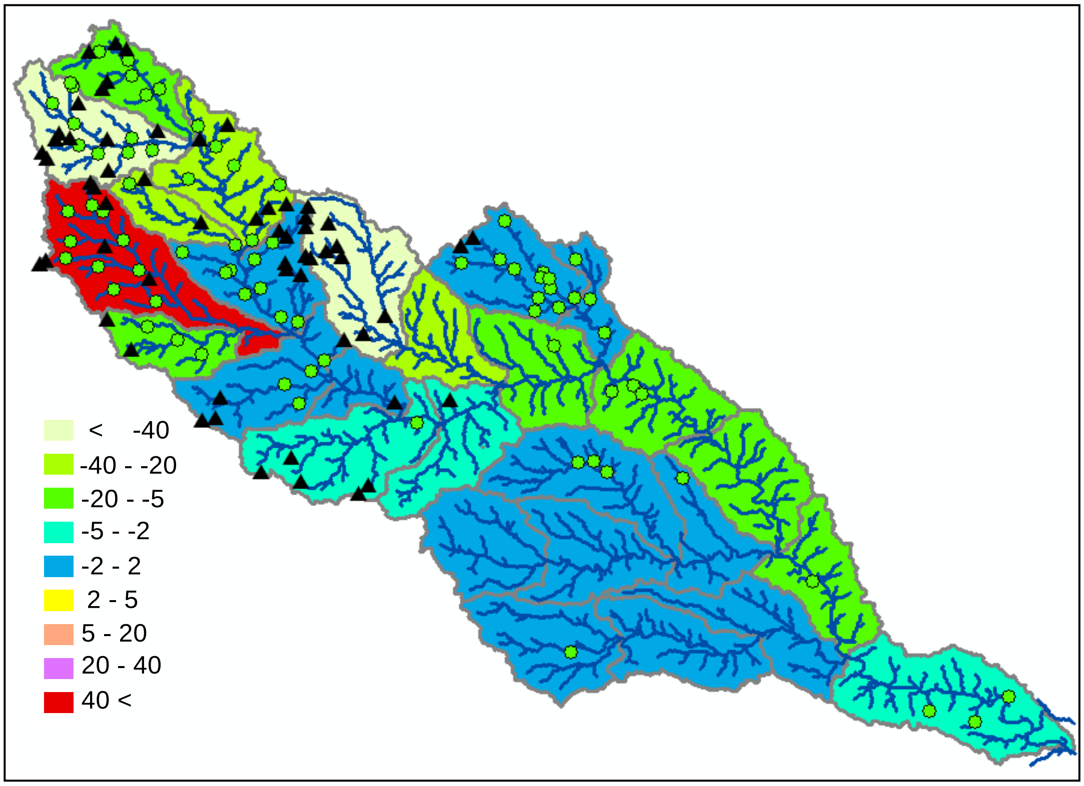

Figure 45d . % Change Total P Flow Accumulation DWMA-Existing Reservoirs All Manure-Applied

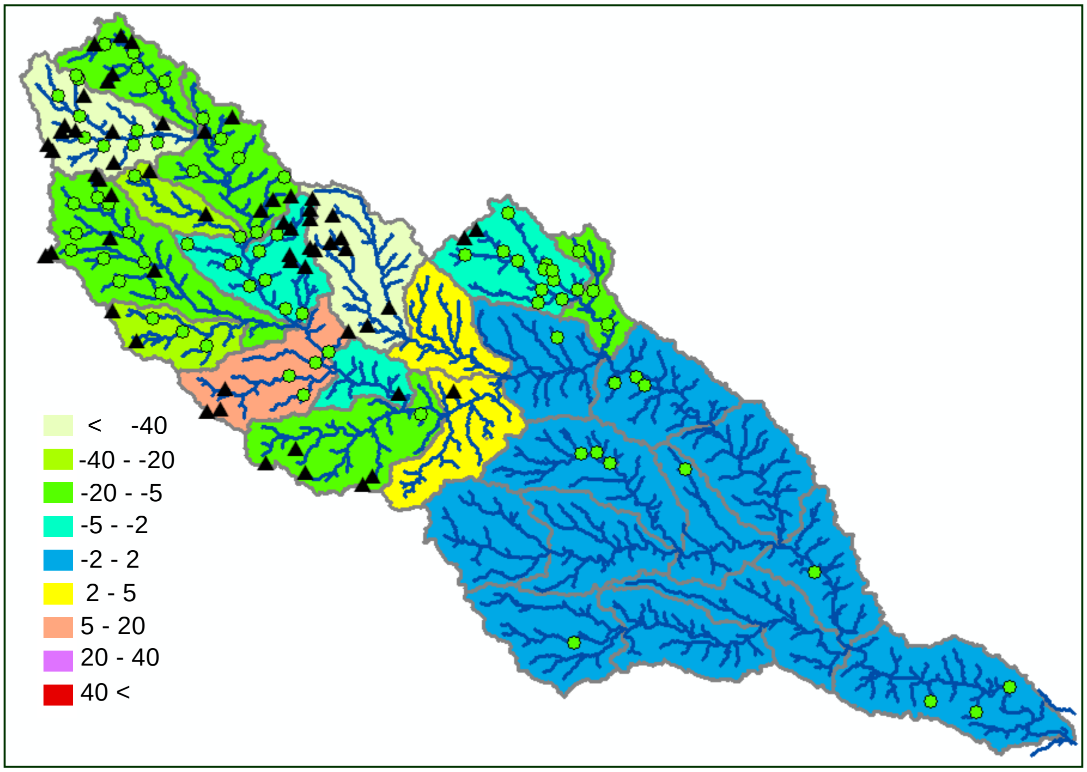

Figure 45e . % Change Organic N in Sediment DWMA-Existing Reservoirs All Manure-Applied

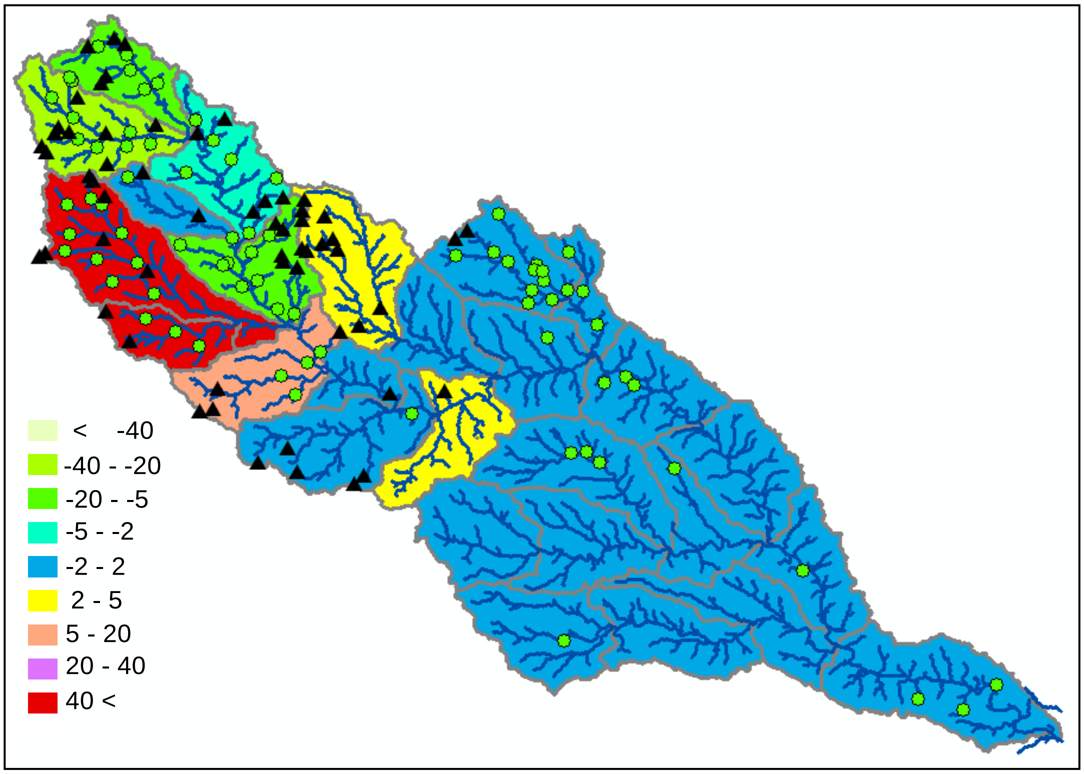

Figure 45f . % Change Mineral N in Water DWMA-Existing Reservoirs All Manure-Applied

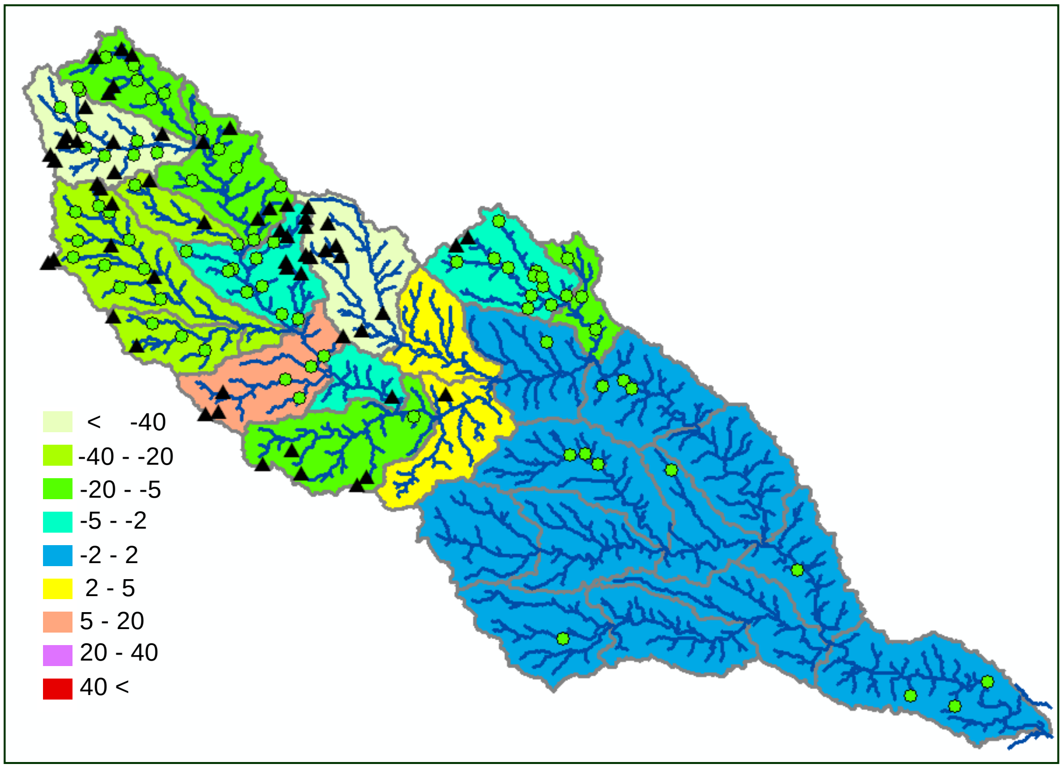

Figure 45g. % Change Organic P in Sediment DWMA-Existing Reservoirs All Manure-Applied

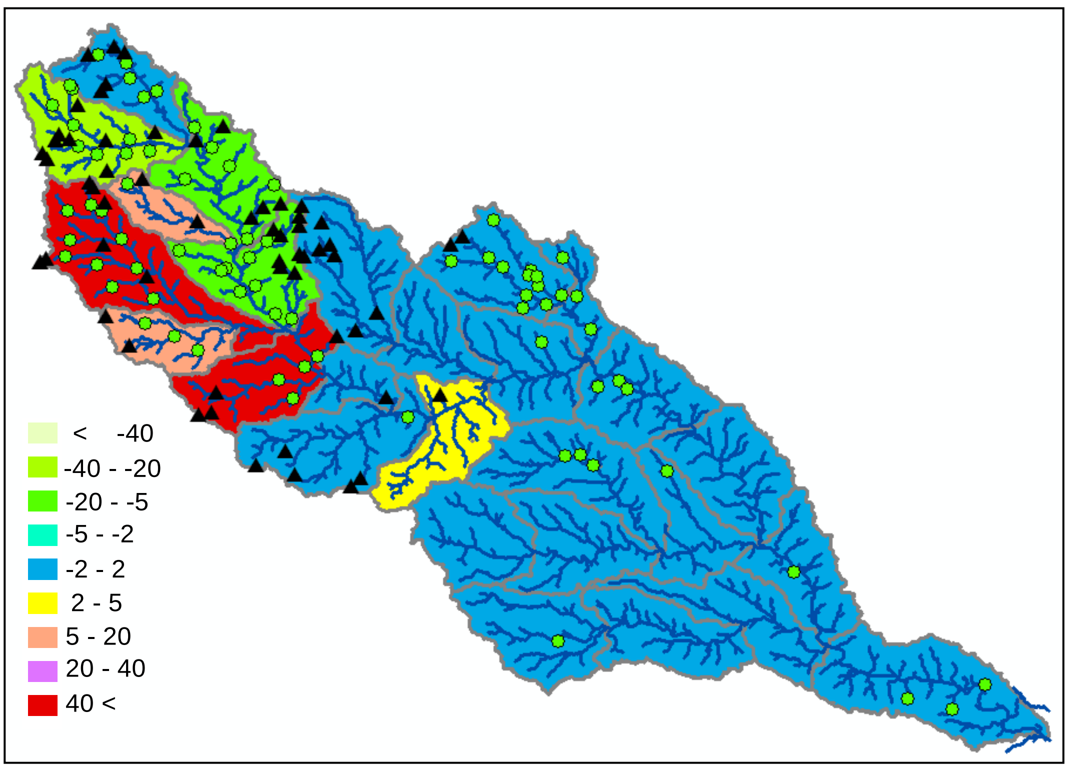

Figure 45h. % Change Mineral P in Water DWMA-Existing Reservoirs All Manure-Applied

Primary Alternative Scenarios MNUL=1

1) All reservoirs in the area are active and functional (74 total). (TNRCC)
2) Current cropping practices included ICIPG Practices on 50 % of cropland and pasture fields and 50% were non-ICIPG practices.
3) Approximately 50% of the manure produced in the watershed was applied onto the waste application fields in the watershed**.** P was controlled to not exceed 200ppm in the surface layer. The remainder of the manure was hauled off to locations outside the watershed.(MNUL=1)
4) All dairy lagoons were protected to allow no overflow.
5) Cow Numbers were set at approximately 40,000 Dairy Cows.
6) Distributed Water Management & Manure Application to all WAF (DWMA)
7) Distributed Water Management and Lower Landscape Management –Manure Application fields on Upper only (DWMU)

This series of three primary alternative scenarios is identical to the series above with one exception. Rather than all of the manure being applied as above these scenarios assume approximately 50% of the manure is hauled out of the watershed. This is not an extreme assumption in that beginning in the late 1990s and early 2000s composting of manure was introduced into the watershed. As of the date of this report, approximately 50% of the manure is in fact composted and removed from the watershed.

The 50% of the manure removed is not made by arbitrary decision. (An algorithm in the model looks at the phosphorus content in the surface soil layer and controls when manure is applied so that this surface layer does not exceed 200 ppm of phosphorus.) In the original baseline run waste application fields were identified using the land use / land cover information and these application fields were assigned to a nearby dairy. As a result it was possible for some dairies to be assigned more application fields than needed while other dairies had a shortage of areas where manure could be applied. Efforts were made to rectify the more glaring errors resulting from this assignment procedure; however, there was still a wide variation of the availability of WAFs areas to any individual dairy. In this series of scenarios this problem was substantially mitigated. Under these assumptions a much larger percentage of the manure produced by one dairy may be delivered for composting when compared to neighboring dairies. Also the manure loads applied per hectare on the waste application fields all share the same maximum loading. This does not mean the same quantities of manure are applied. The application rates may vary by soil, grass production, rates of water infiltration, erosion, and other factors that affect the phosphorus residual levels.

The table below shows that the comparison of the 50% manure removal to the baseline scenario reduces the total phosphorus loading by 5.2%. Note, however, that when the distributed water management is also applied to the land management there is a substantial improvement in the overall watershed health (more than 12%). This is partially attributed to the fact that the manure application algorithm manages the individual fields. The troublesome fields that were likely forced to accept more manure than the ecosystem could manage were allowed manure hauloff giving substantial reductions in total manure applied to them and therefore resulted in more than proportionate reduction in manure and nutrient losses outside the sub-basin.

Occasionally the % change graphics for individual 12 digit HUAs report substantial increases for nutrient yields that seem to be out of character with the scenario. An example appears below shown in red in figure 46e. For the most part these are areas with extremely low baseline nutrient yield values when observed in kilograms per hectare. When these numbers are very near zero, small changes result in large percentage changes resulting in what appears to be large deviations from the norm and surrounding areas. Therefore those portions of the graphics can be discounted as not being representative of the true conditions. There are a few exceptions where a few small sub-areas influence the 12 digit average, as was the case in the previous scenario group where MNUL=0. For the most part issues with these small sub-areas are quickly mitigated in this set (MNUL=1) and subsequent sets of analysis.

Scenario	Runoff Percent Change	Water Yield Percent Change	Erosion Percent Change	YON Percent Change	YOP Percent Change	NO3 Percent Change	QP Percent Change	Total N Percent Change	Total P Percent Change
BASE TNRCC-1	-0.062	0	0.03	-2.79	-2.61	-6.38	-15.09	-3.54	-5.22
DWMA TNRCC-1	-0.087	0.085	1.18	-10.29	-10.55	-7.05	-20.11	-9.61	-12.55
DWMU TNRCC-1	-0.099	0.085	1.18	-10.29	-10.59	-7.02	-20.13	-9.6	-12.59

Scenario	YON ppm	YOP ppm	NO3 ppm	QP ppm	Total N ppm	Total P ppm
Base-TNRCC-1	3.671	0.735	0.943	0.169	4.614	0.904
DWMA-TNRCC-1	3.385	0.674	0.935	0.159	4.32	0.833
DWMU-TNRCC-1	3.385	0.674	0.936	0.159	4.32	0.833

Table 6. Primary Alternative Scenarios MNUL=1

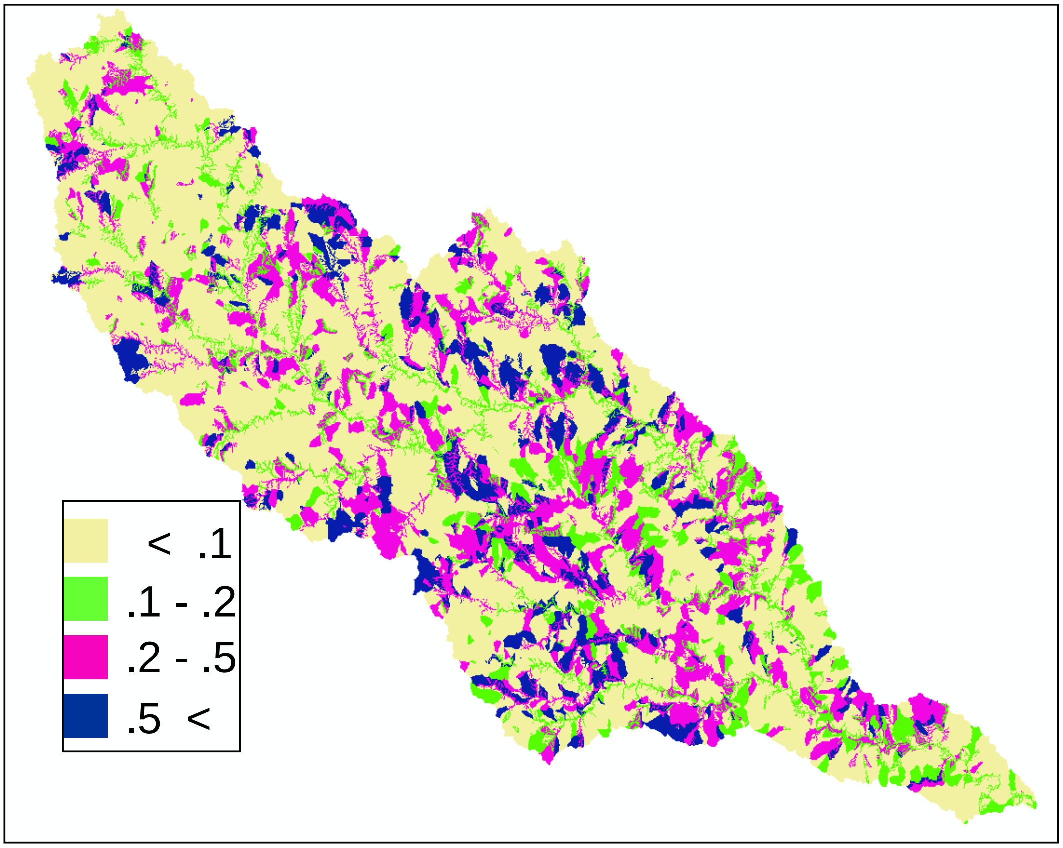

Figure 46a Mineral P in Water in ppm DWMA Existing Reservoirs Hauloff

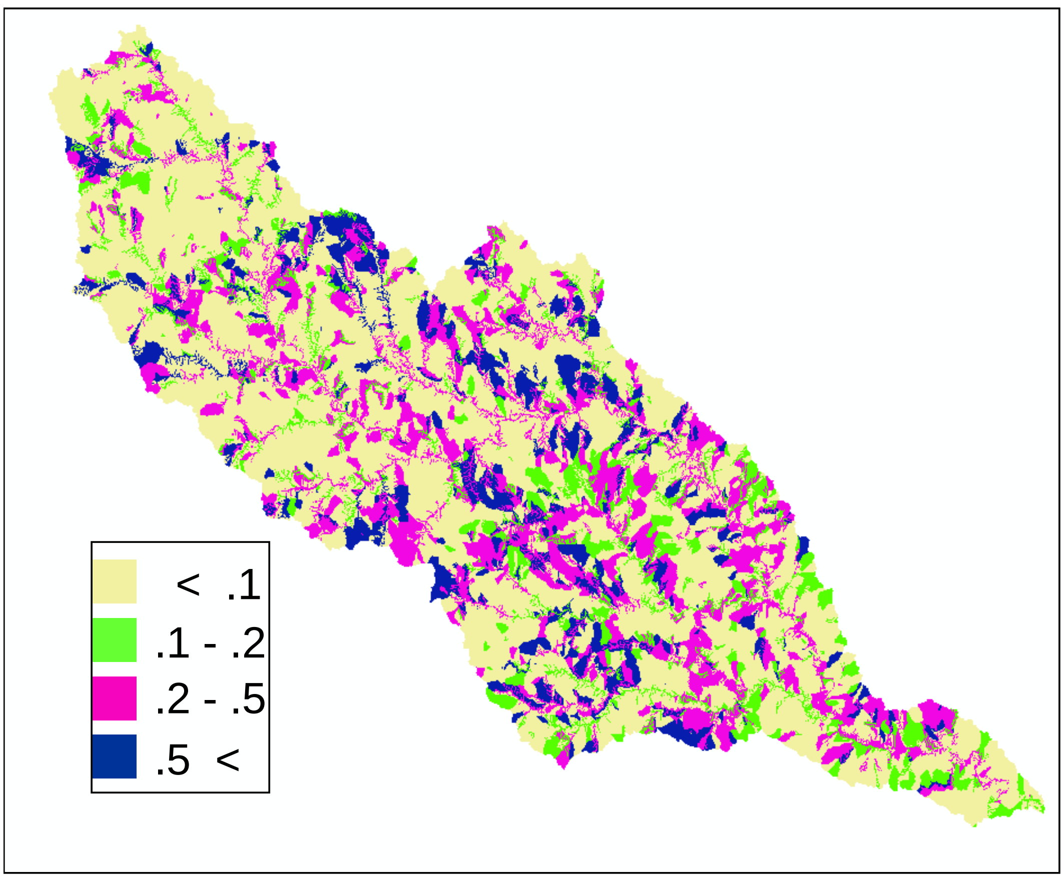

Figure 46b Baseline Mineral P in water in ppm

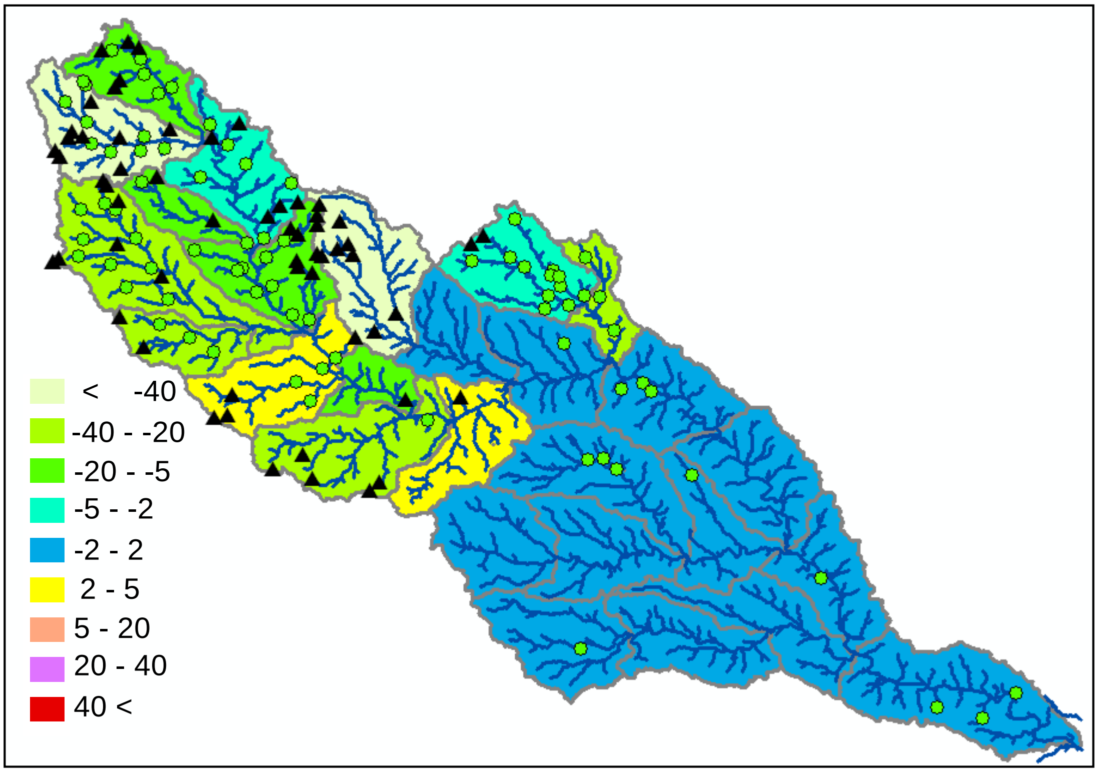

Figure 46c. % Change Total N DWMA-Existing Reservoirs -Hauloff

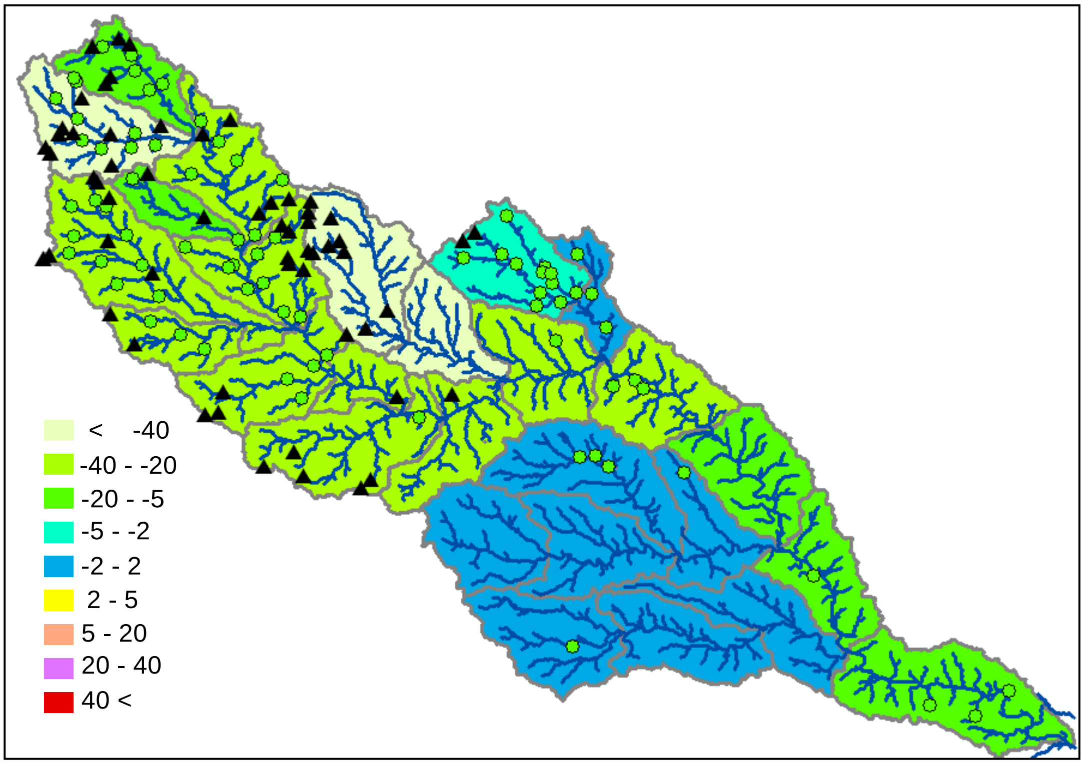

Figure 46d. % Change Total N Flow Accumulation DWMA-Existing Reservoirs – Hauloff

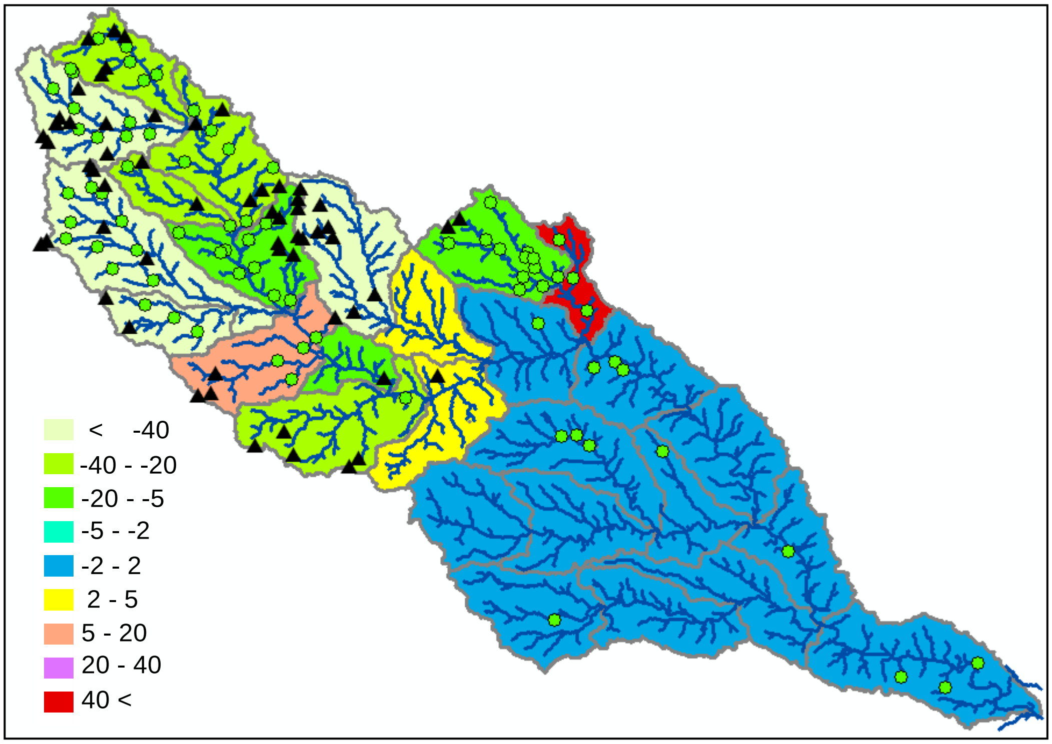

Figure 46e. % Change Total P DWMA- Existing Reservoirs –Hauloff

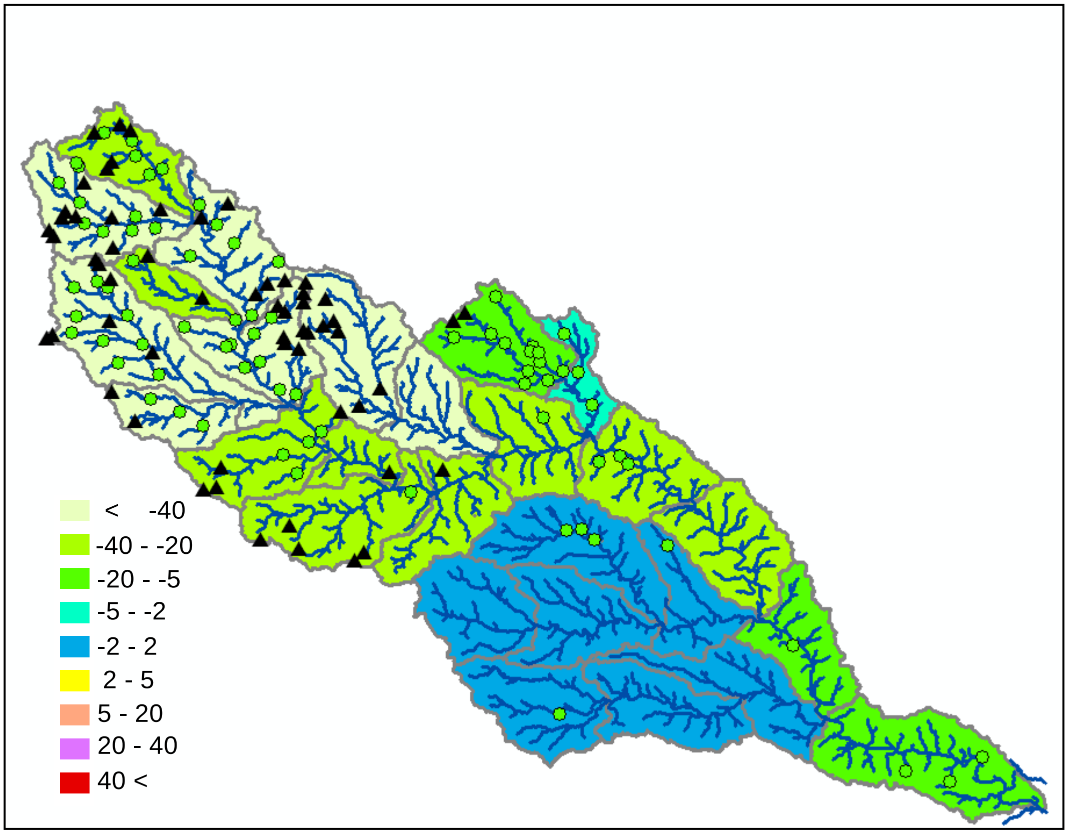

Figure 46f. % Change Total P Flow Accumulation DWMA- Existing Reservoirs – Hauloff

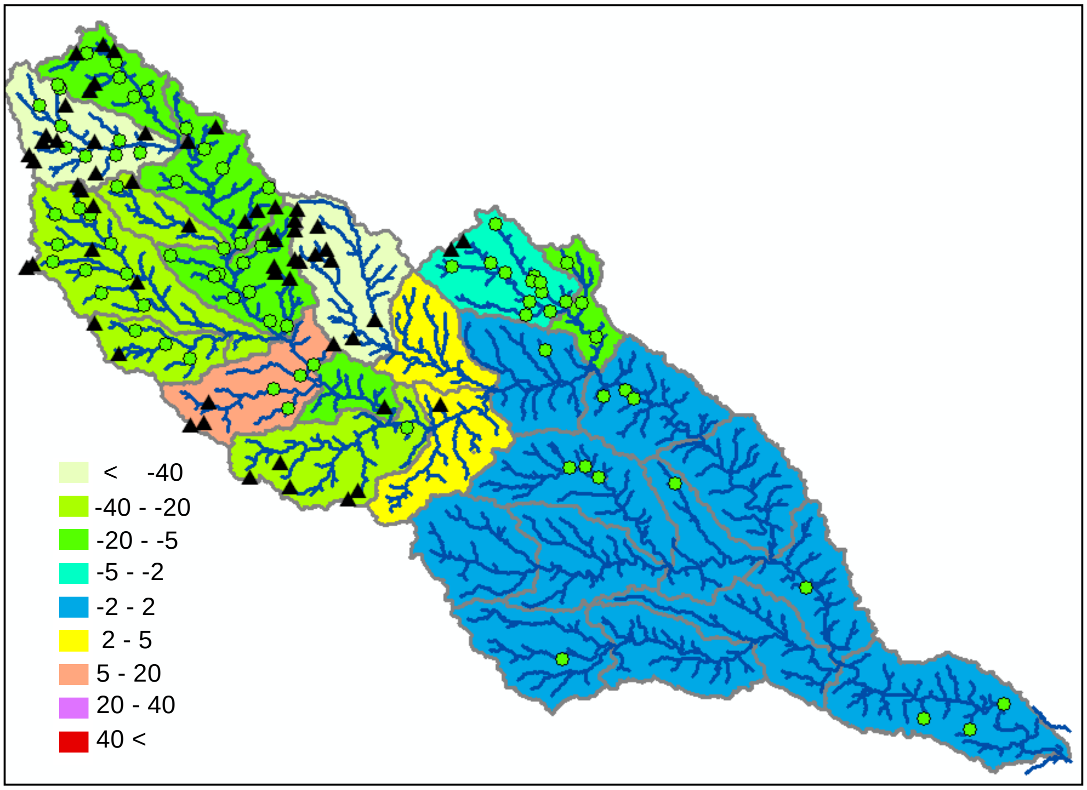

Figure 46g. % Change Organic N in Sediment DWMA- Existing Reservoirs -Hauloff

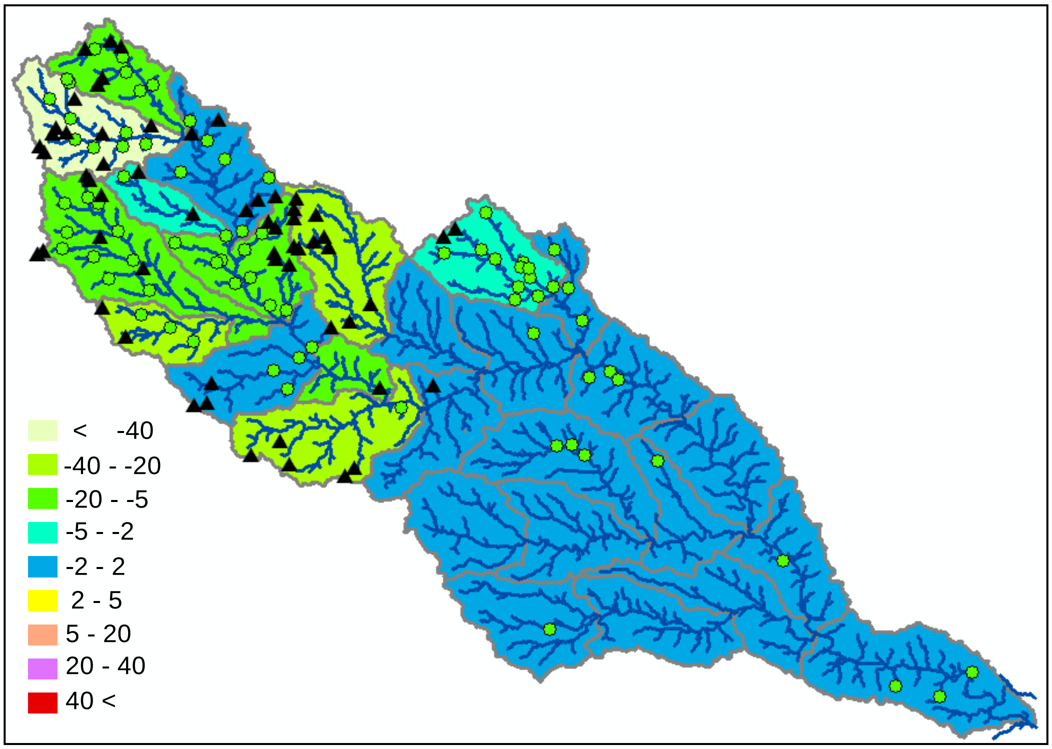

Figure 46h. % Change Mineral N in Water DWMA- Existing Reservoirs –Hauloff

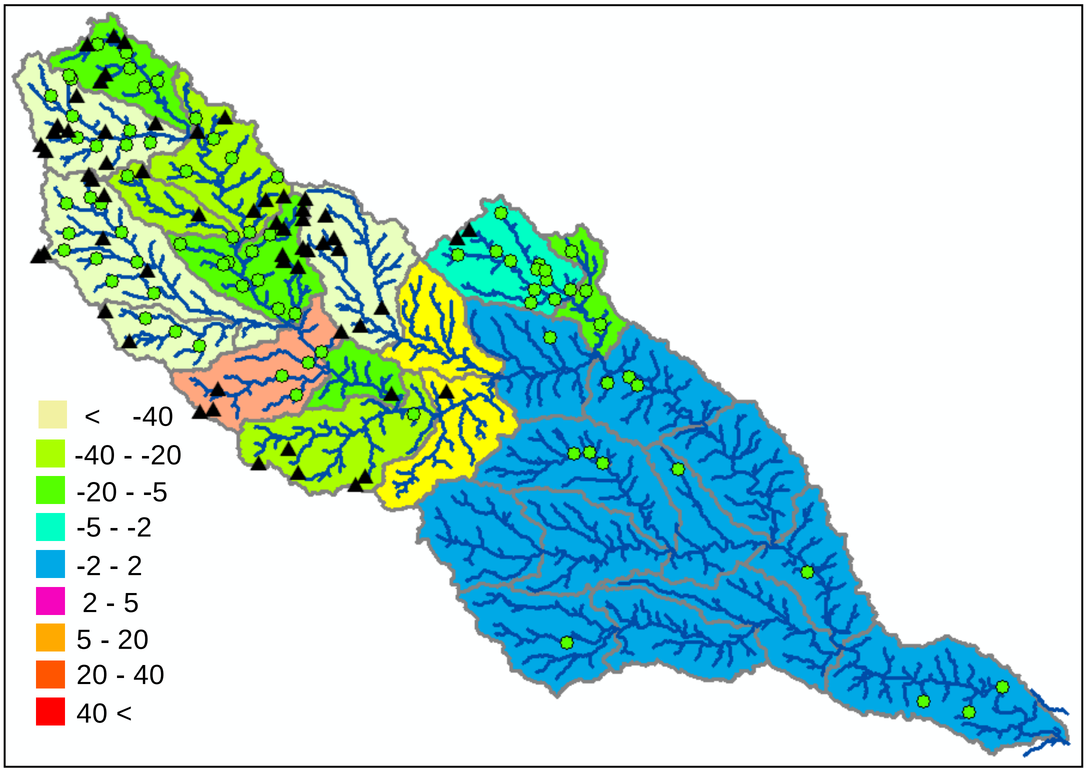

Figure 46i. % Change Organic P in Sediment DWMA- Existing Reservoirs -Hauloff

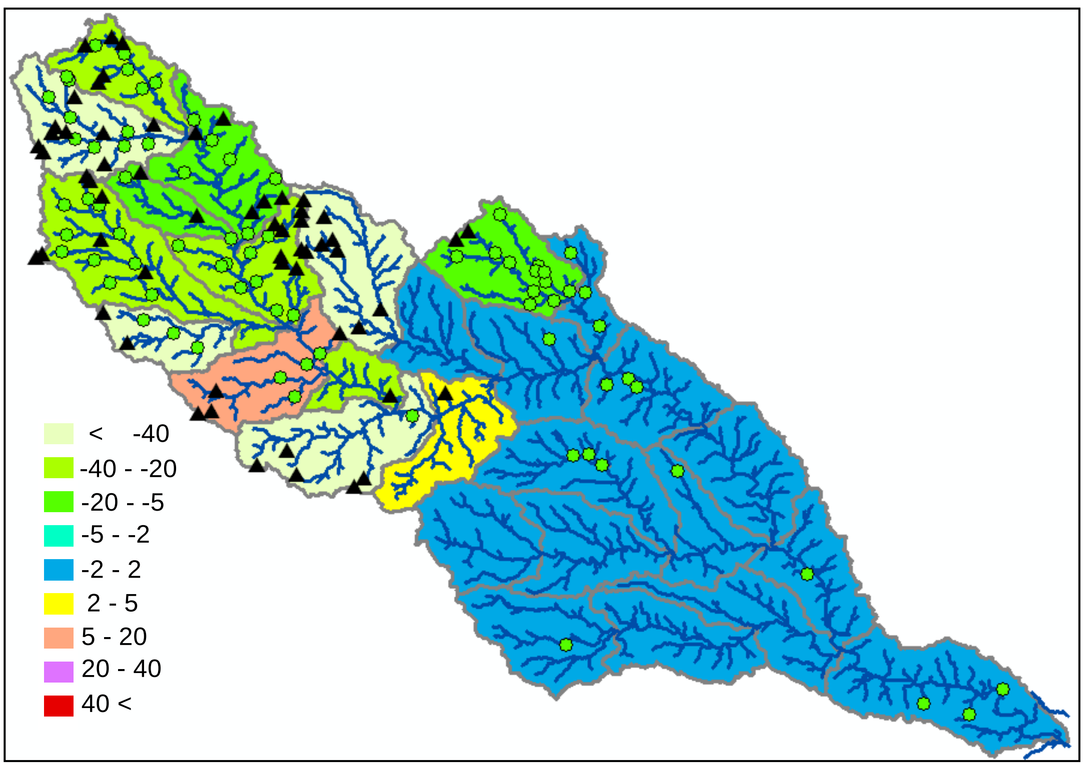

Figure 46j. % Change Mineral P in Water DWMA- Existing Reservoirs –Hauloff

Special Scenario Comparisons

Current vs Past

Native Resource Conditions/with Crop Land-- No Dairies, no improved pasture, no Reservoirs (NAT1)

Native Resource Conditions/No Crop Land-- No Dairies, no improved pasture, no Reservoirs (NAT2)

This group of two scenarios is designed to show what the watershed would look like if all modern agriculture were removed from the area. This is done in two parts: First, all dairy animals are removed from the watershed; but the cropland remains intact under current conditions. The second scenario removes cropland in addition to the dairy animals and replaces that cropland and all improved pastures with native grasses. In addition these scenarios assume there are no man-made reservoirs in the watershed.

This set of scenarios provides one additional insight into the study and analytical procedures. It gives an indication to the overall sensitivity of the model and methodology to the extreme conditions that could be applied to the landscape.

Scenario	Runoff Percent Change	Water Yield Percent Change	Erosion Percent Change	YON Percent Change	YOP Percent Change	NO3 Percent Change	QP Percent Change	Total N Percent Change	Total P Percent Change
NAT1	6.51	0.426	1.09	-1.72	-6.55	-13.13	-15.38	-4.12	-8.4
NAT2	6.646	-0.596	-4.97	-8.58	-18	-23.67	-15.94	-11.75	-17.57
Scenario	YON ppm	YOP ppm	NO3 ppm	QP ppm	Total N ppm	Total P ppm			
NAT1	3.696	0.702	0.871	0.168	4.567	0.87			
NAT2	3.473	0.622	0.773	0.169	4.246	0.791			

Table 7. Special Scenarios- Native Condition

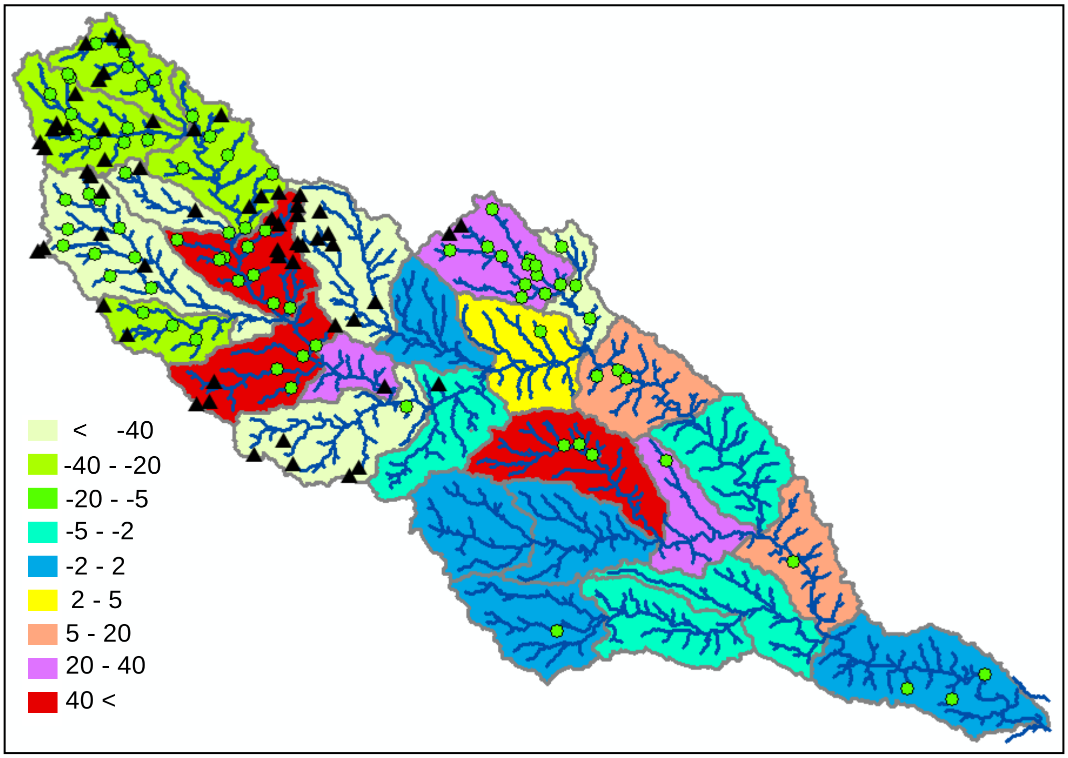

Figure 47a. % Change Total N Native Conditions-No Dairy with Cropland

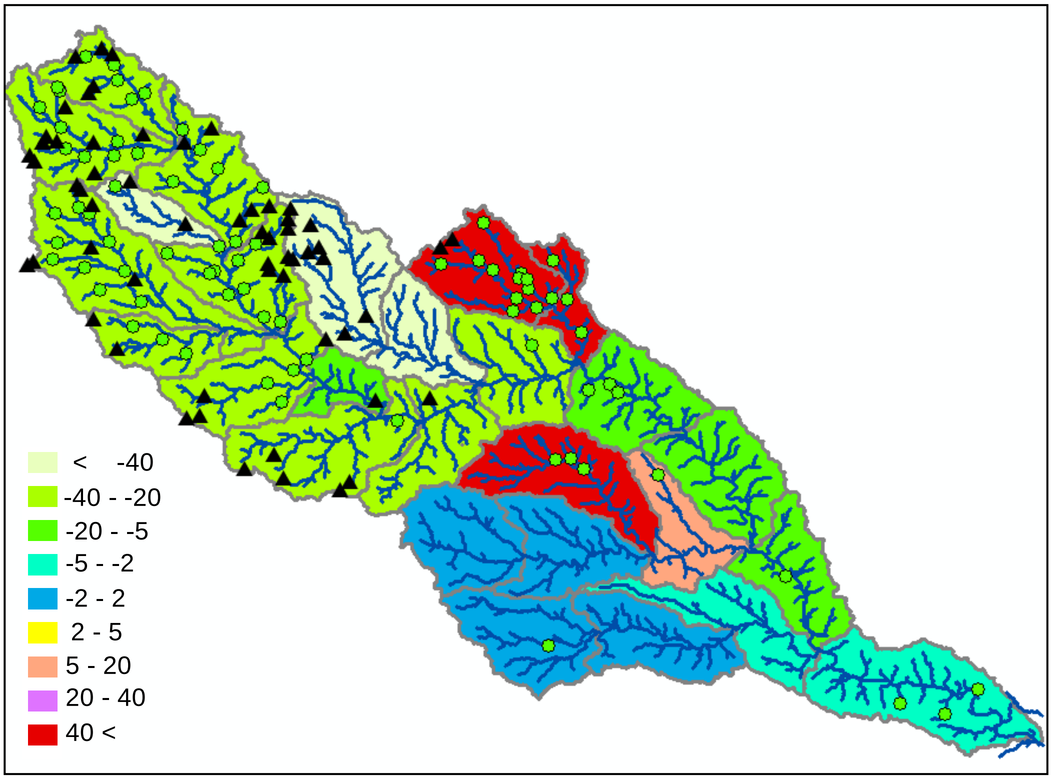

Figure 47b. % Change Total N Flow Accumulation Native Conditions-No Dairy with Cropland

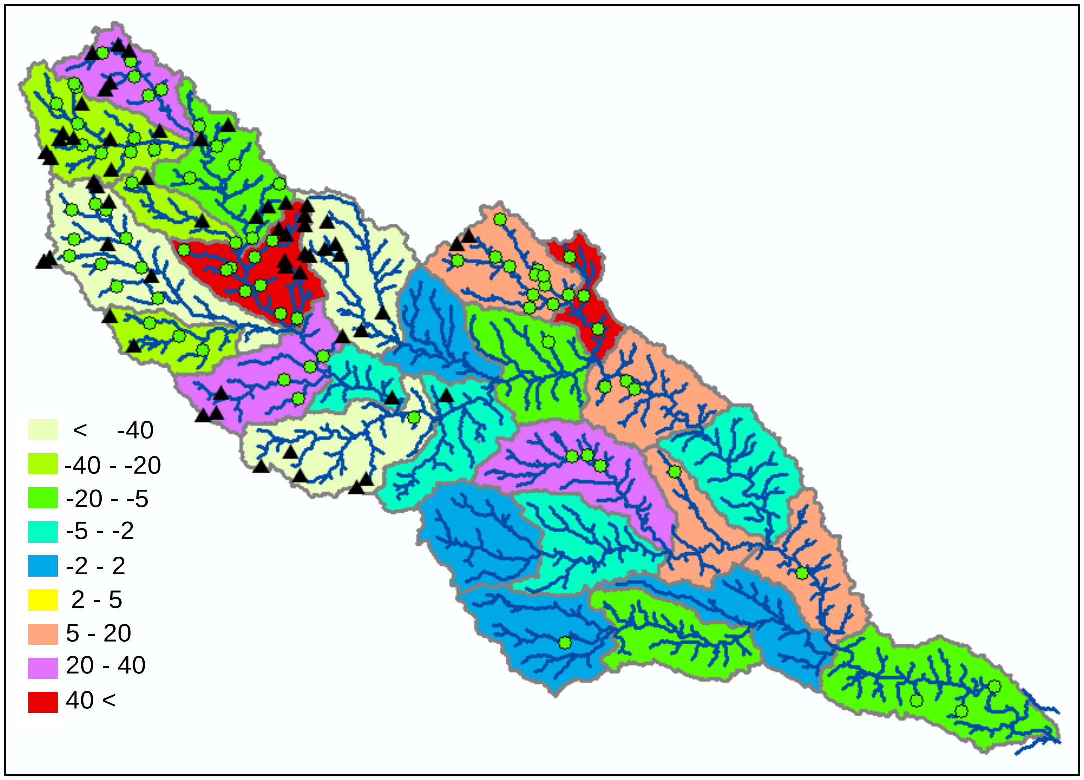

Figure 47c. % Change Total P Native Conditions-No Dairy with Cropland

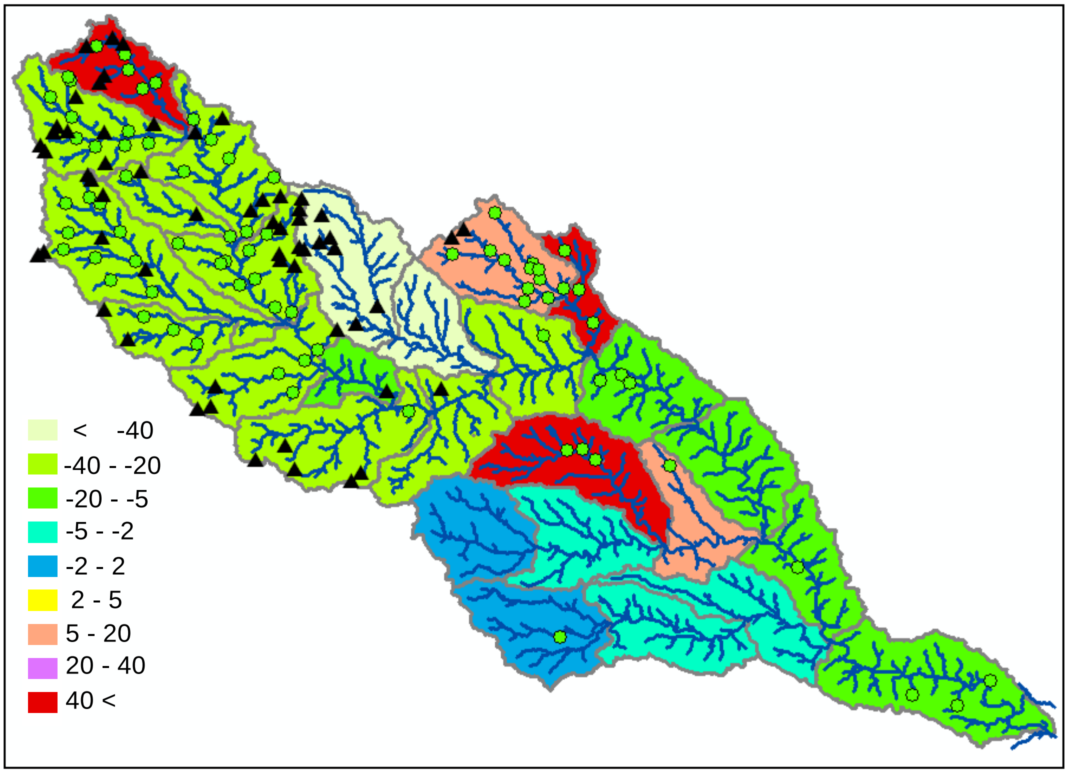

Figure 47d . % Change Total P Flow Accumulation Native Conditions-No Dairy with Cropland

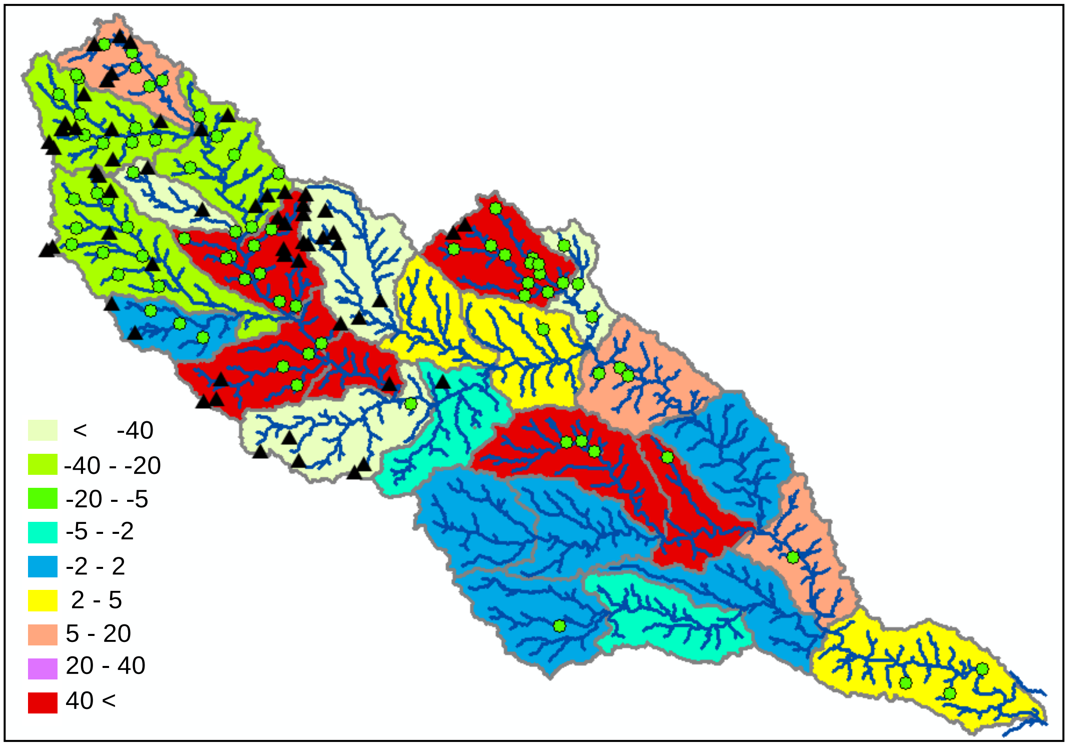

Figure 47e. % Change Organic N in Sediment Native Conditions-No Dairy with Cropland

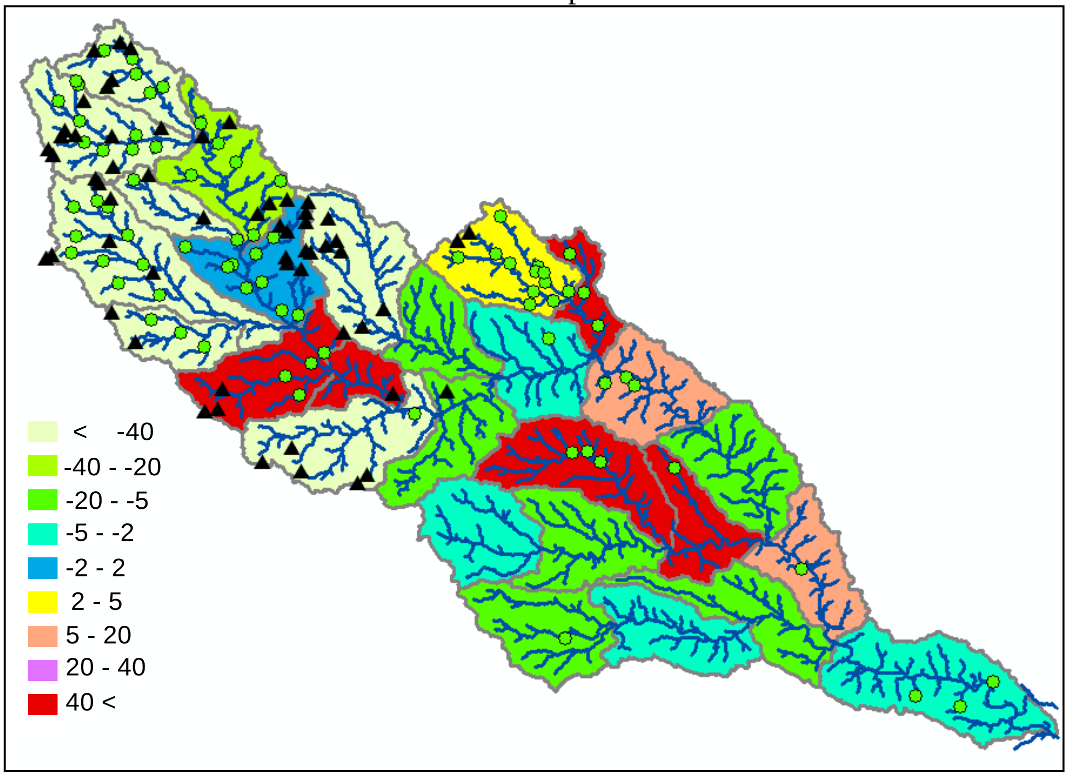

Figure 47f. % Change Mineral N in Water Native Conditions-No Dairy with Cropland

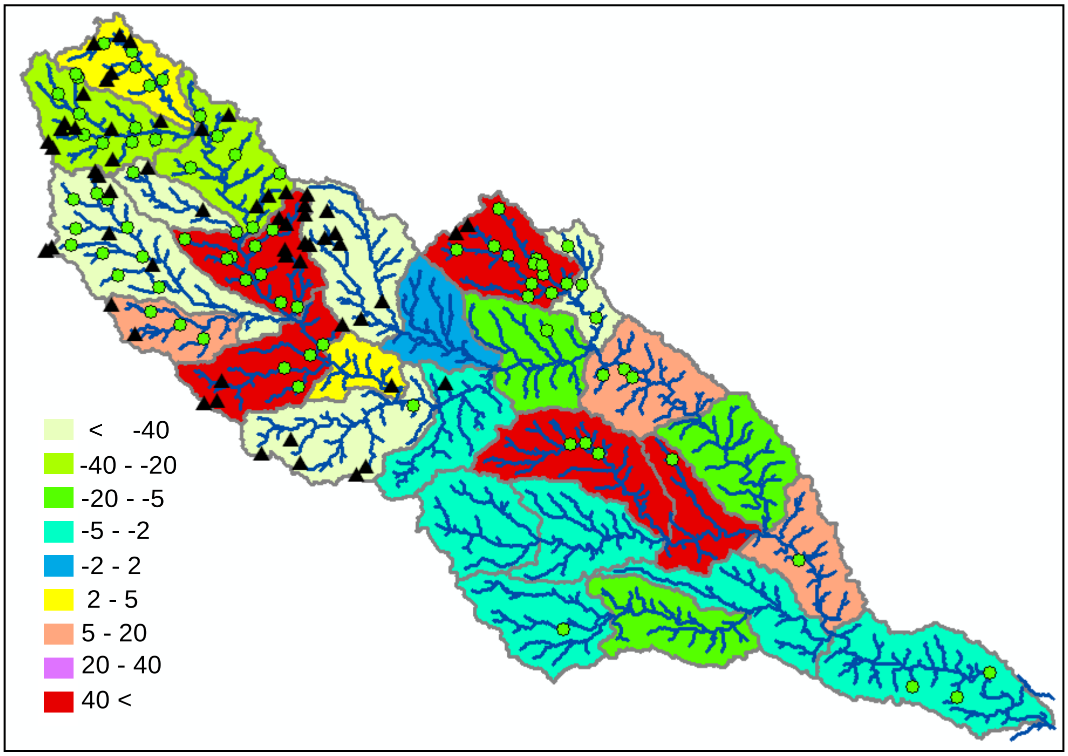

Figure 47g. % Change Organic P in Sediment Native Conditions-No Dairy with Cropland

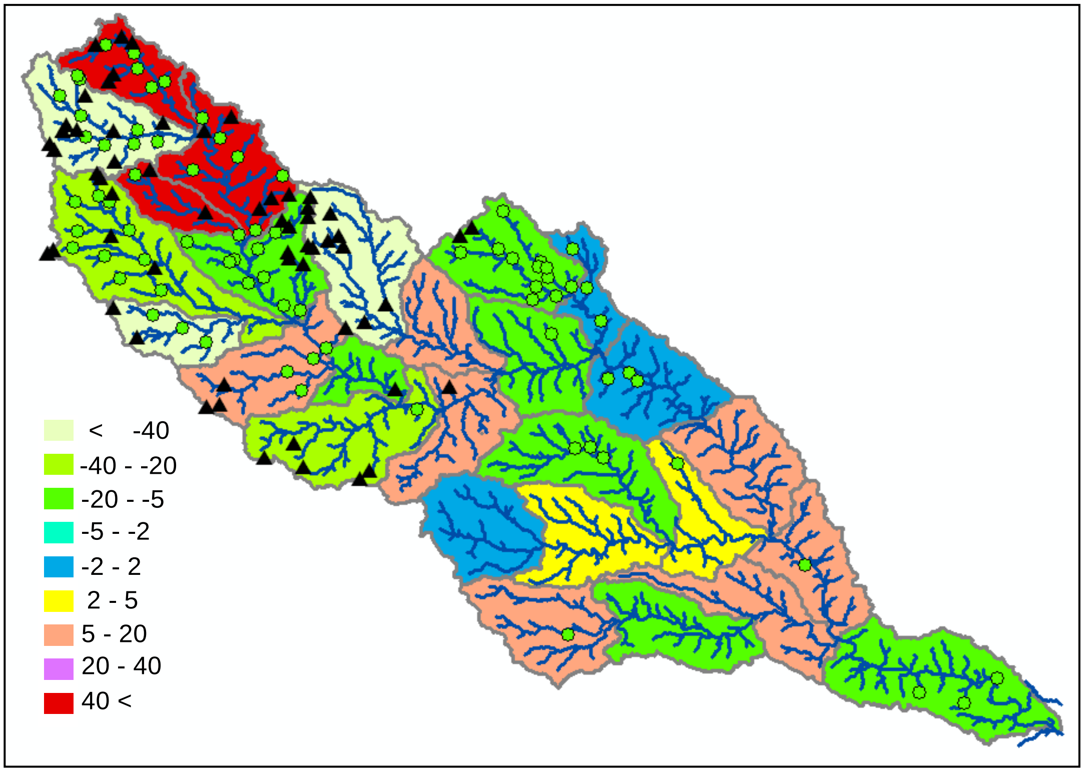

Figure 47h. % Change Mineral P in Water Native Conditions-No Dairy with Cropland

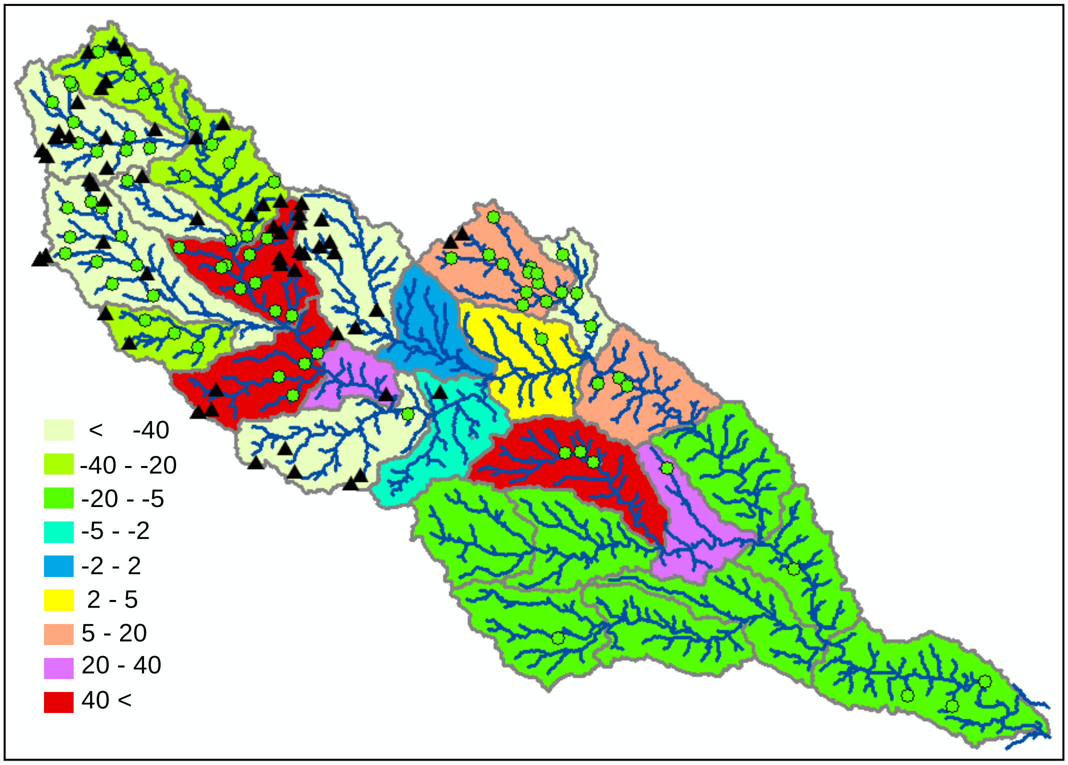

Figure 48a. % Change Total N Native Conditions-No Dairy No Cropland

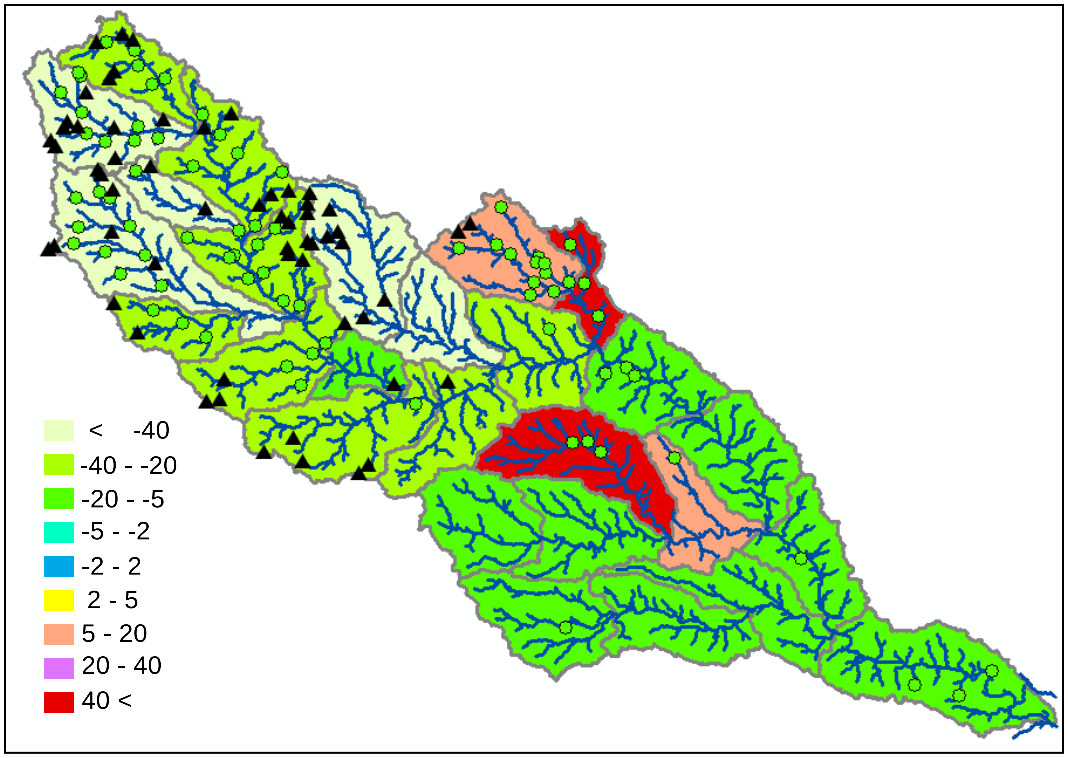

Figure 48b. % Change Total N Flow Accumulation Native Conditions-No Dairy No Cropland

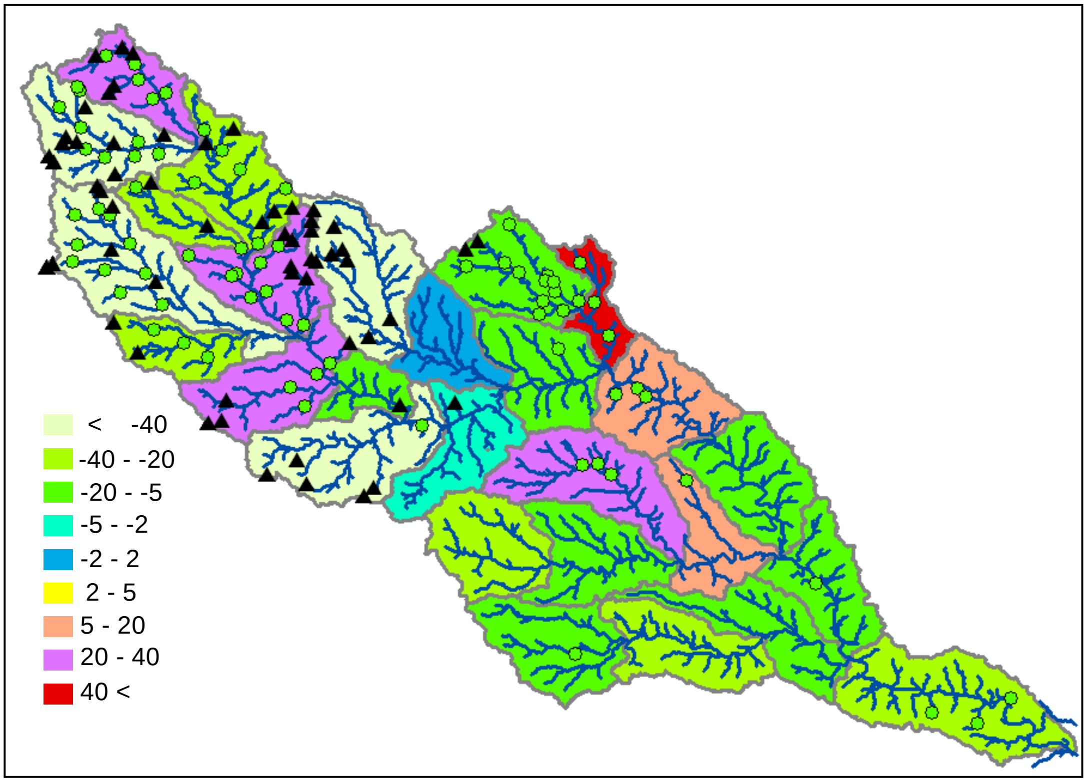

Figure 48c. % Change Total P Native Conditions-No Dairy No Cropland

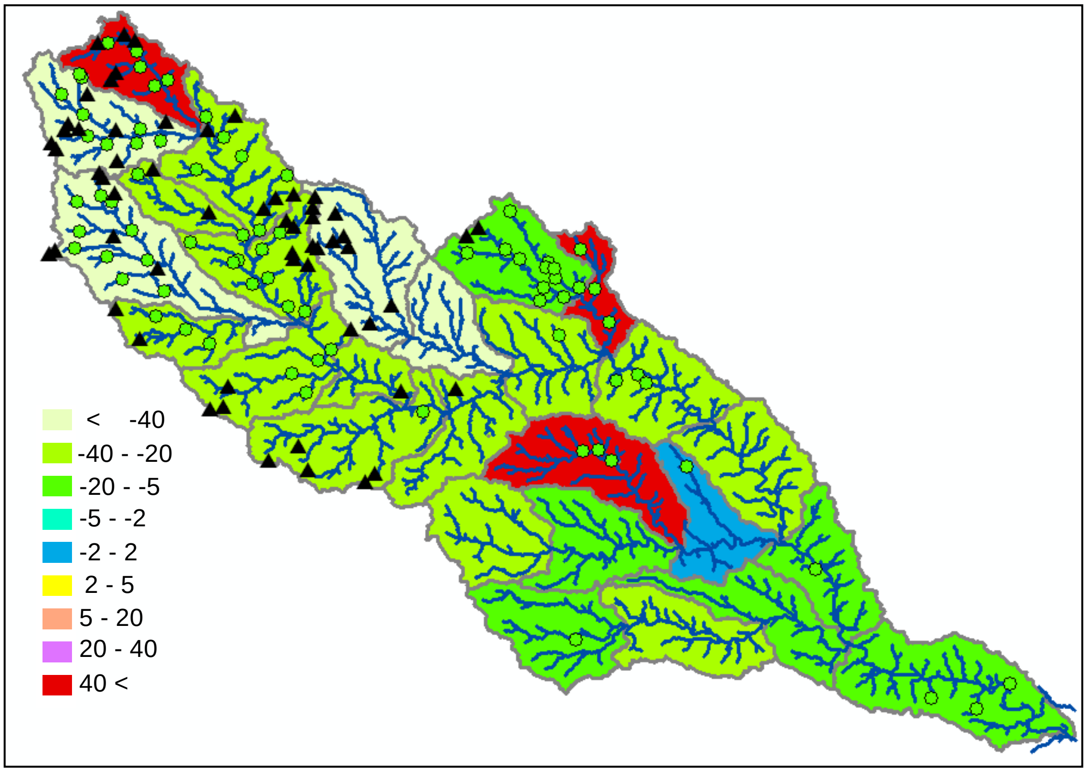

Figure 48d. % Change Total P Flow Accumulation Native Conditions-No Dairy No Cropland

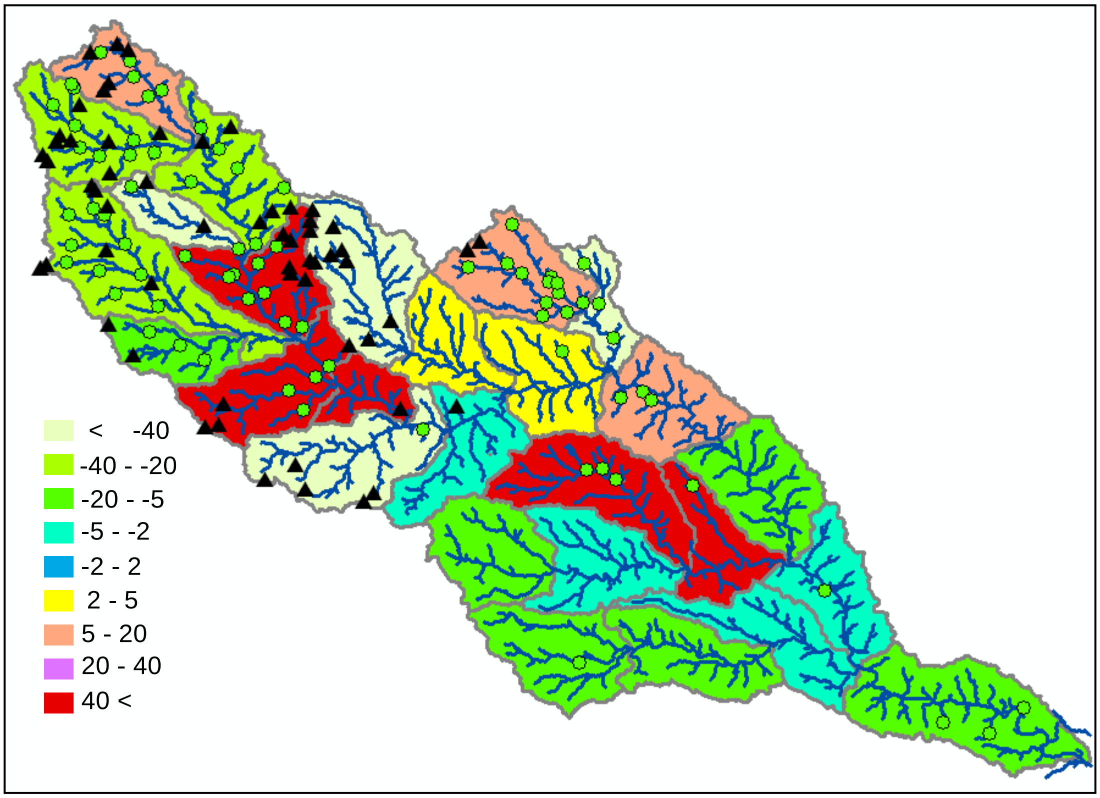

Figure 48e. % Change Organic N in Sediment Native Conditions-No Dairy No Cropland

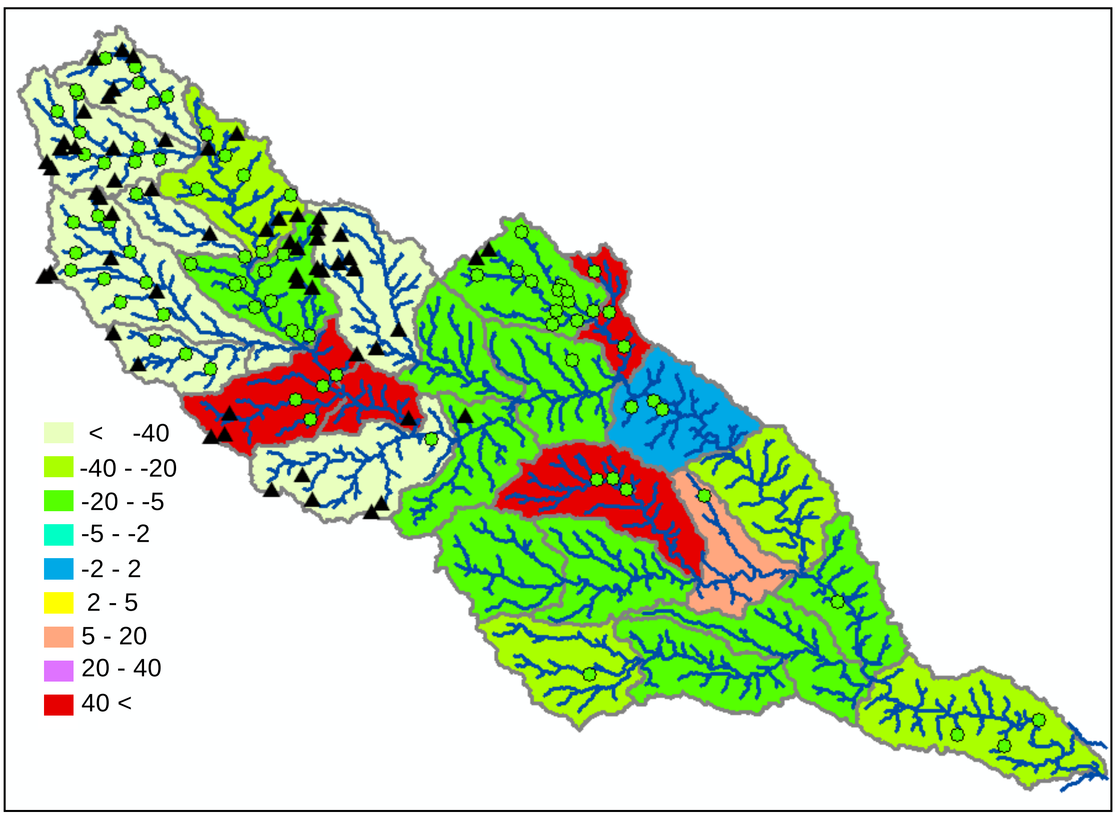

Figure 48f. % Change Mineral N in Water Native Conditions-No Dairy No Cropland

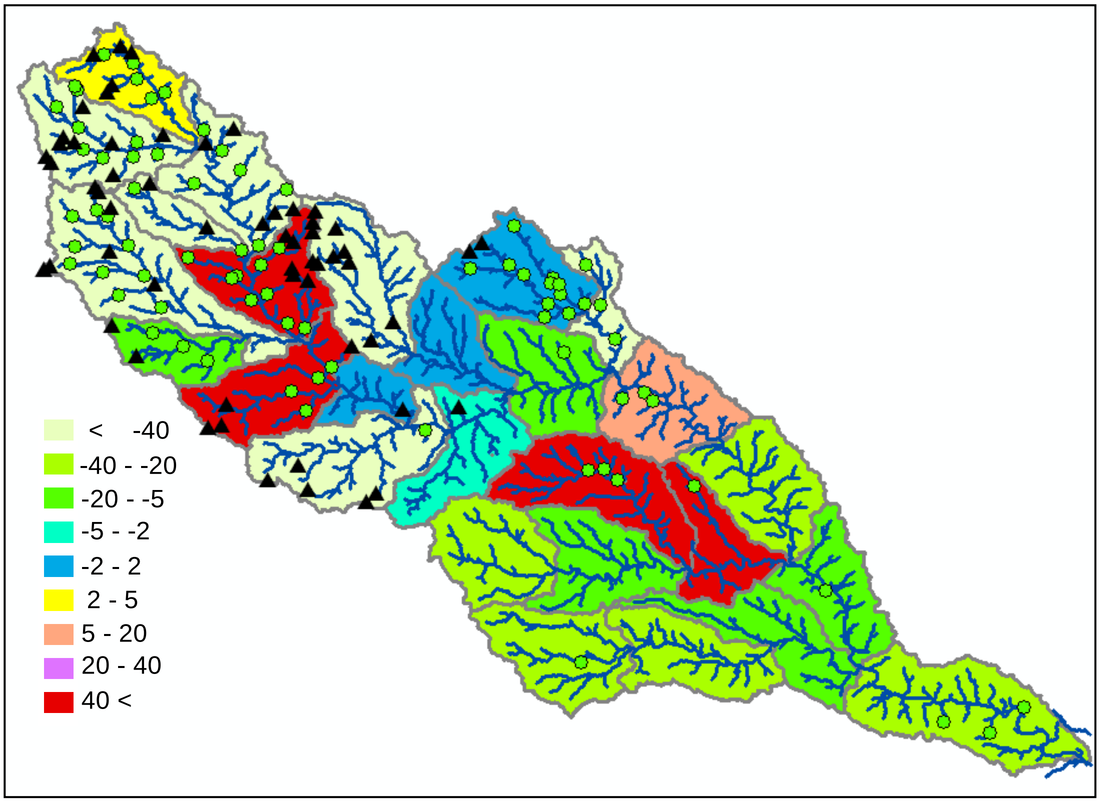

Figure 48g. % Change Organic P in Sediment Native Conditions-No Dairy No Cropland

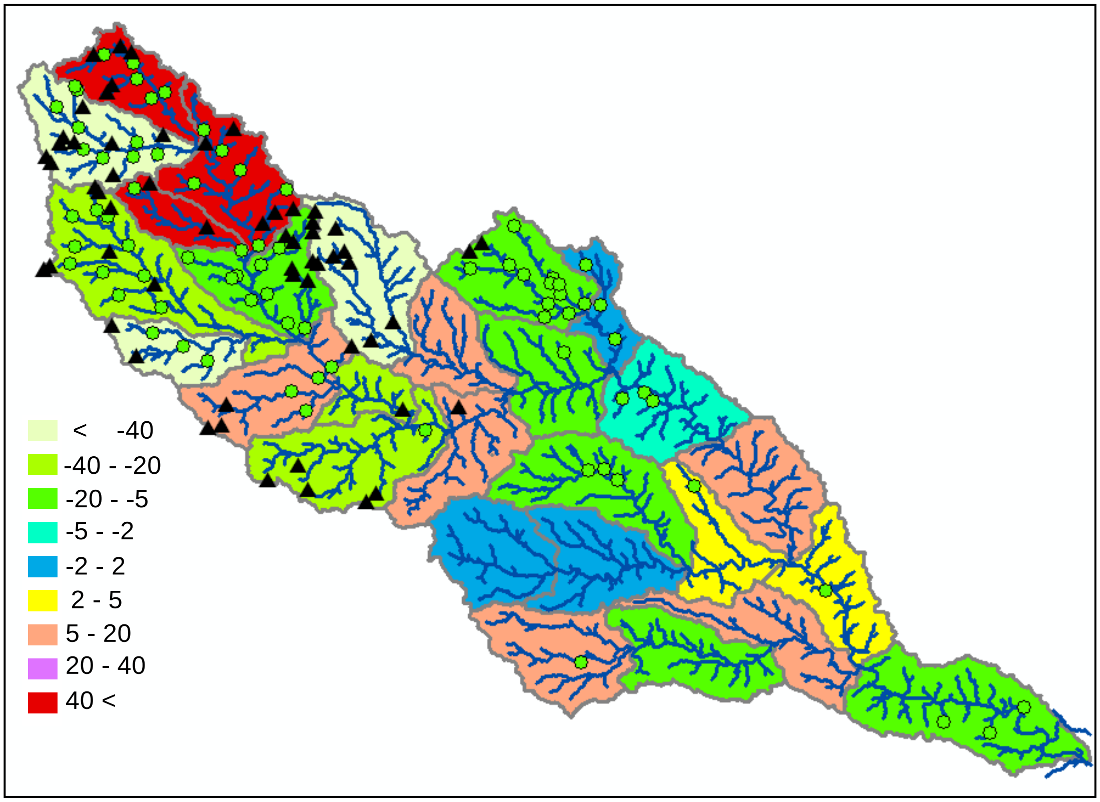

Figure 48h. % Change Mineral P in Water Native Conditions-No Dairy No Cropland

No Protective Reservoirs –

1) All 74 reservoirs in the watershed are removed (NORE).
2) Current cropping practices included ICIPG Practices on 50 % of cropland and pasture fields and 50% were non-ICIPG practices.
3) All dairy lagoons were protected to allow no overflow.
4) Cow Numbers were set at approximately 40,000 Dairy Cows.
5) All manure produced in the watershed was applied onto the waste application fields in the watershed (i.e. no manure hauloff).(MNUL=0)
6) Approximately 50% of the manure produced in the watershed was applied onto the waste application fields in the watershed. The remainder of the manure was hauled off to locations outside the watershed.(MNUL=1)

These two scenarios show the impact on the area if the water basin had no man-made reservoirs. The reservoirs removed included the PL566 (NRCS) structures and other private and public reservoirs. These 74 structures protect 27% of the land area in the study.

In general the scenarios show a significant increase in N and P loading if the reservoirs were not in place. Note that under these scenarios the dairy and cropping activities remain as above. An inspection of the graphics below shows that the changes did in fact occur in the areas where the reservoirs were removed.

Scenario	Runoff Percent Change	Water Yield Percent Change	Erosion Percent Change	YON Percent Change	YOP Percent Change	NO3 Percent Change	QP Percent Change	Total N Percent Change	Total P Percent Change
NORE-0	3.645	2.726	3.95	26.23	26.98	11.98	-0.49	23.23	21.23
NORE-1	3.534	2.811	4.01	19.16	18.32	3.99	-20.28	15.96	10.25

Scenario	YON ppm	YOP ppm	NO3 ppm	QP ppm	Total N ppm	Total P ppm
NORE- 0	4.64	0.933	1.098	0.193	5.738	1.126
NORE- 1	4.376	0.868	1.019	0.155	5.395	1.023

Table 8. Special Scenarios- No Reservoirs with and without Hauloff

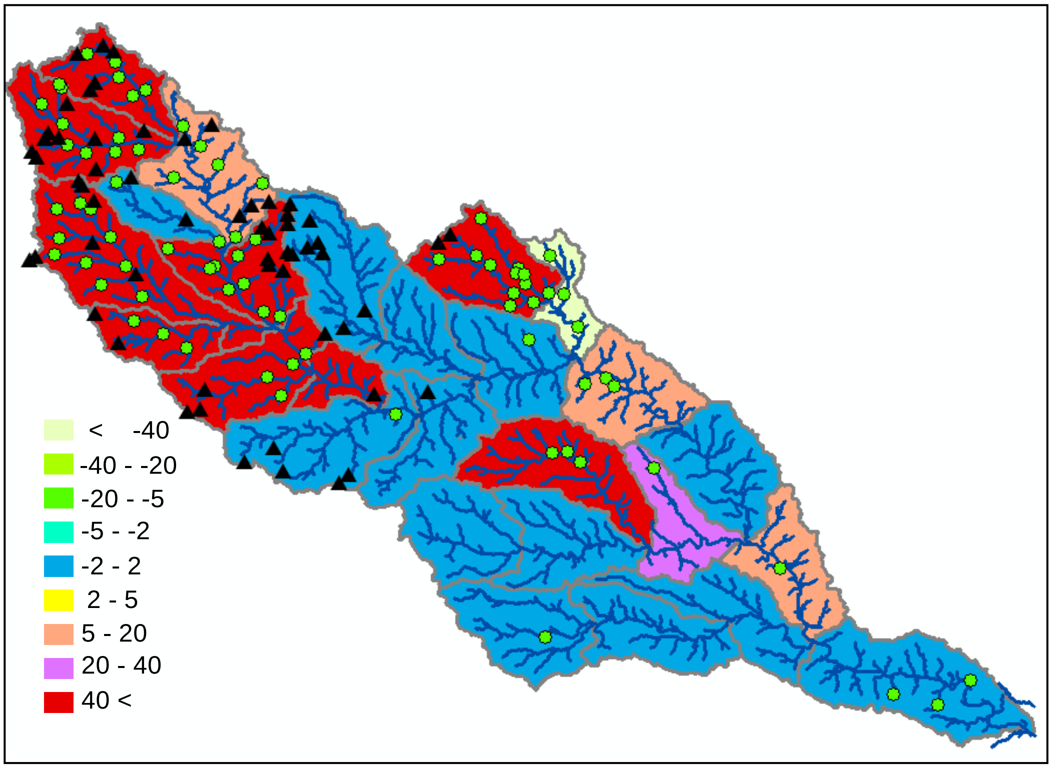

Figure 49a. % Change Total N No Reservoirs All Manure Applied

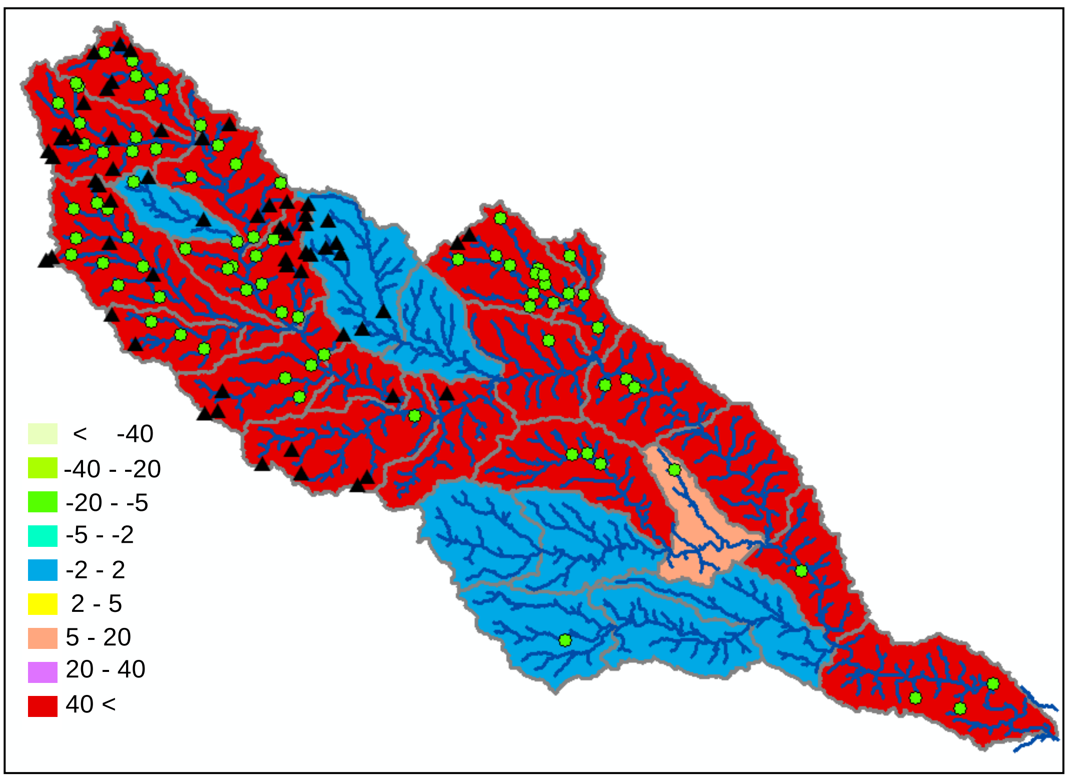

Figure 49b. % Change Total N Flow Accumulation No Reservoirs All Manure Applied

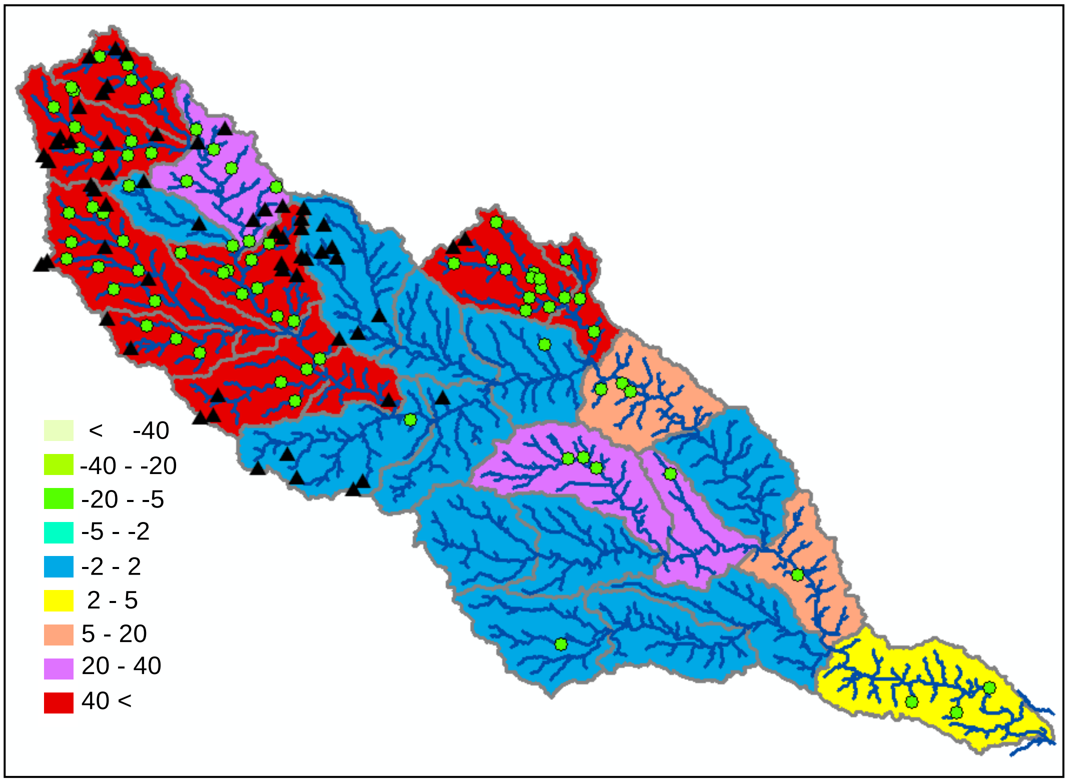

Figure 49c. % Change Total P No Reservoirs All Manure Applied

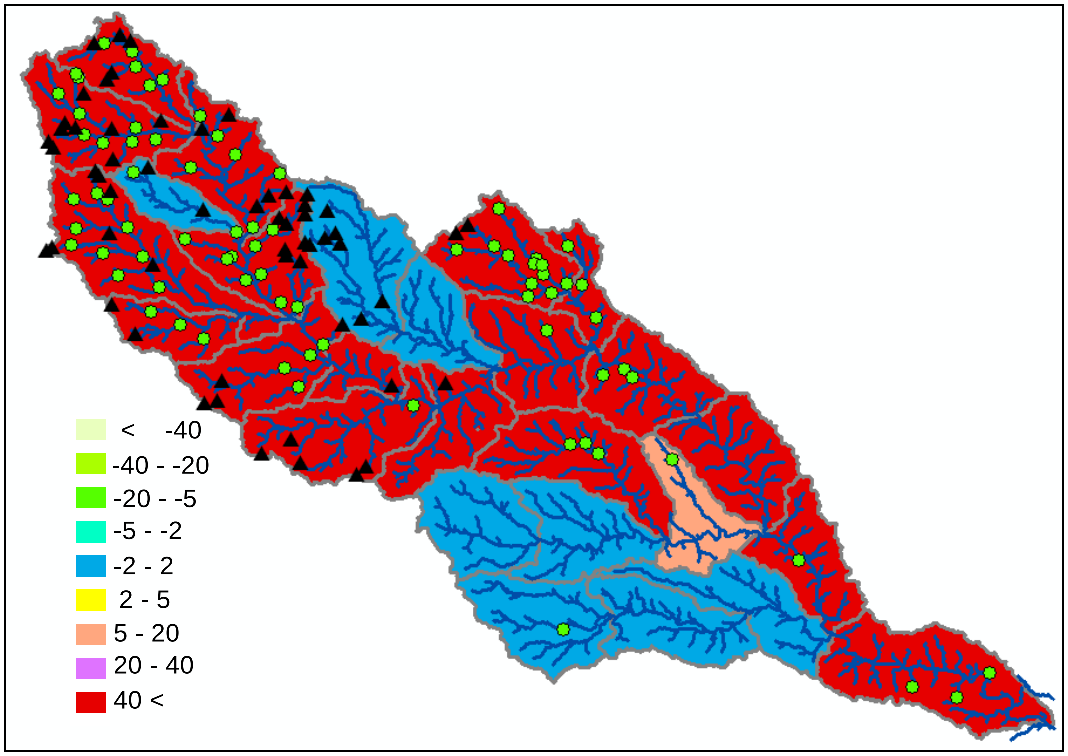

Figure 49d. % Change Total P Flow Accumulation No Reservoirs All Manure Applied

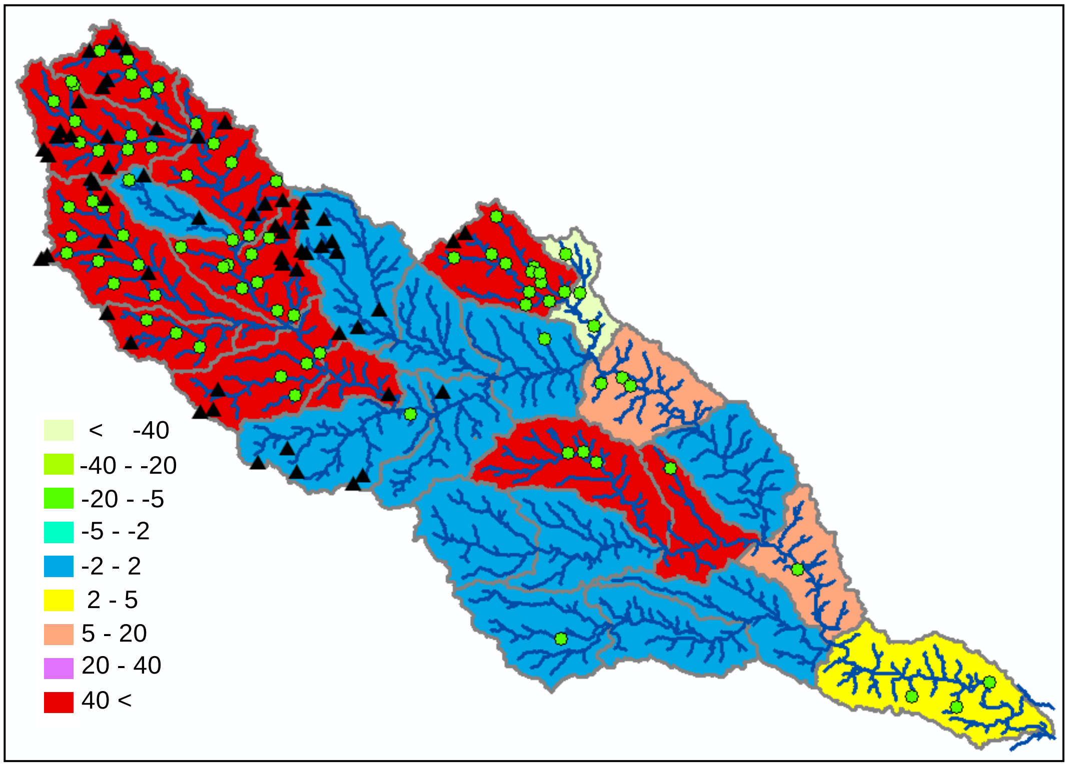

Figure 49e. % Change Organic N in Sediment No Reservoirs All Manure Applied

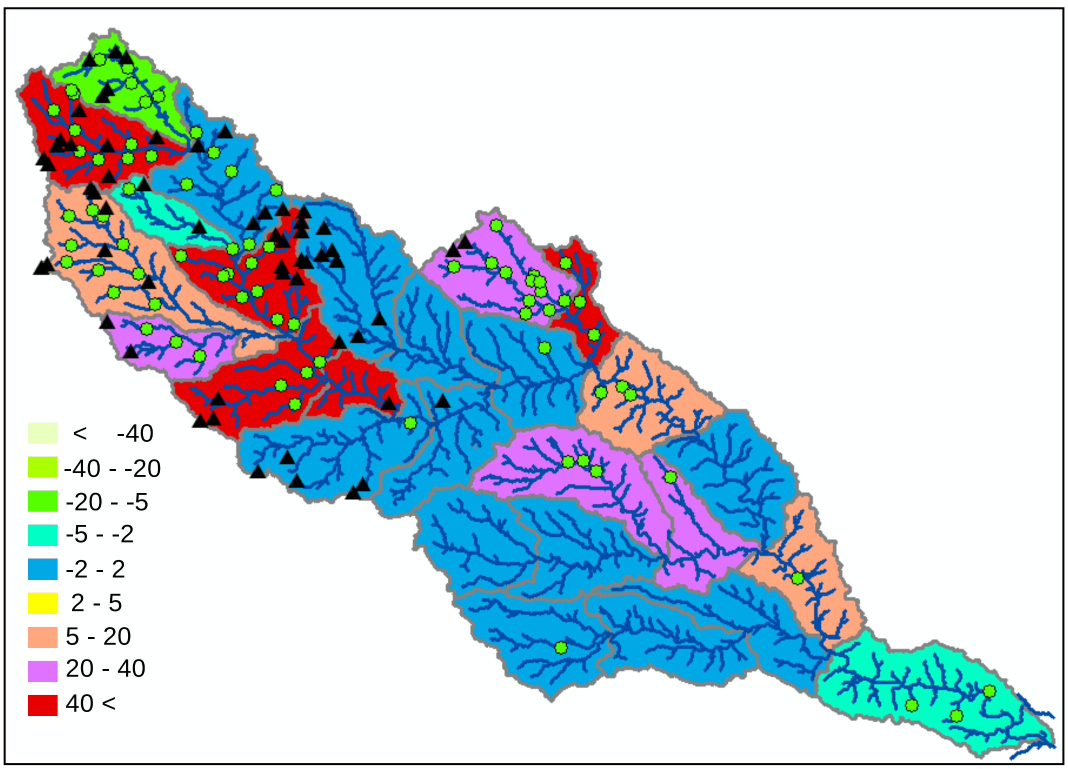

Figure 49f. % Change Mineral N in Water No Reservoirs All Manure Applied

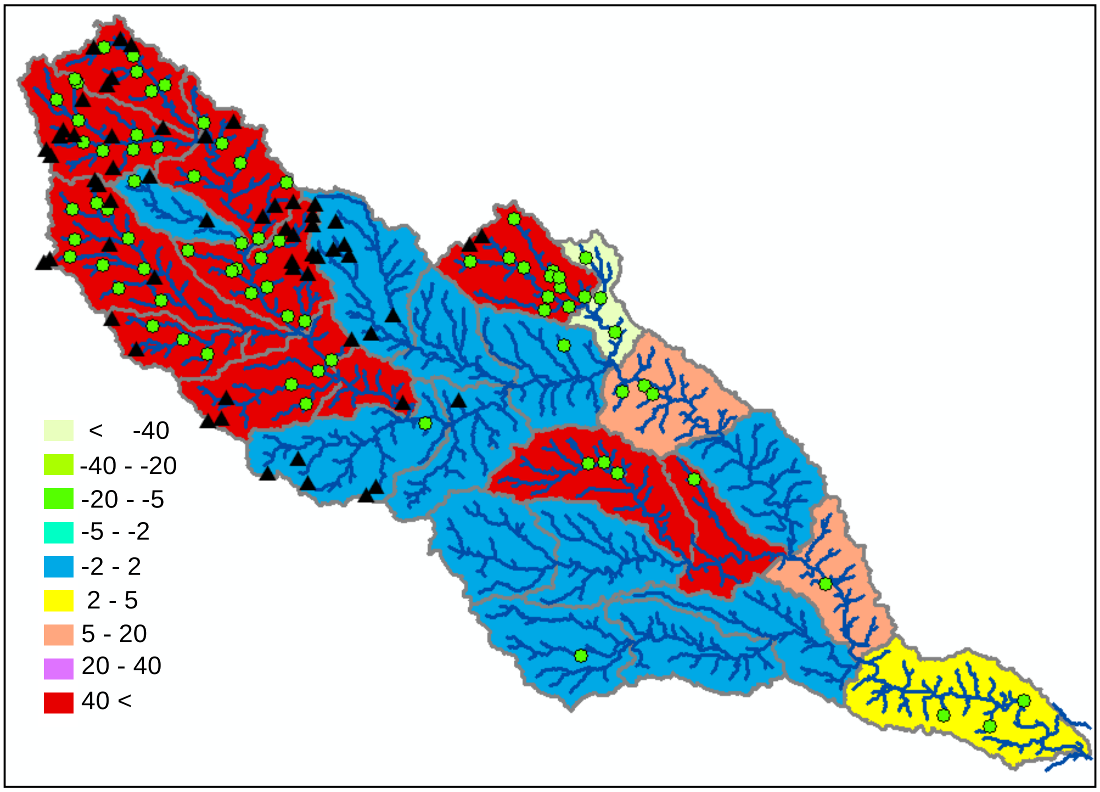

Figure 49g. % Change Organic P in Sediment No Reservoirs All Manure Applied

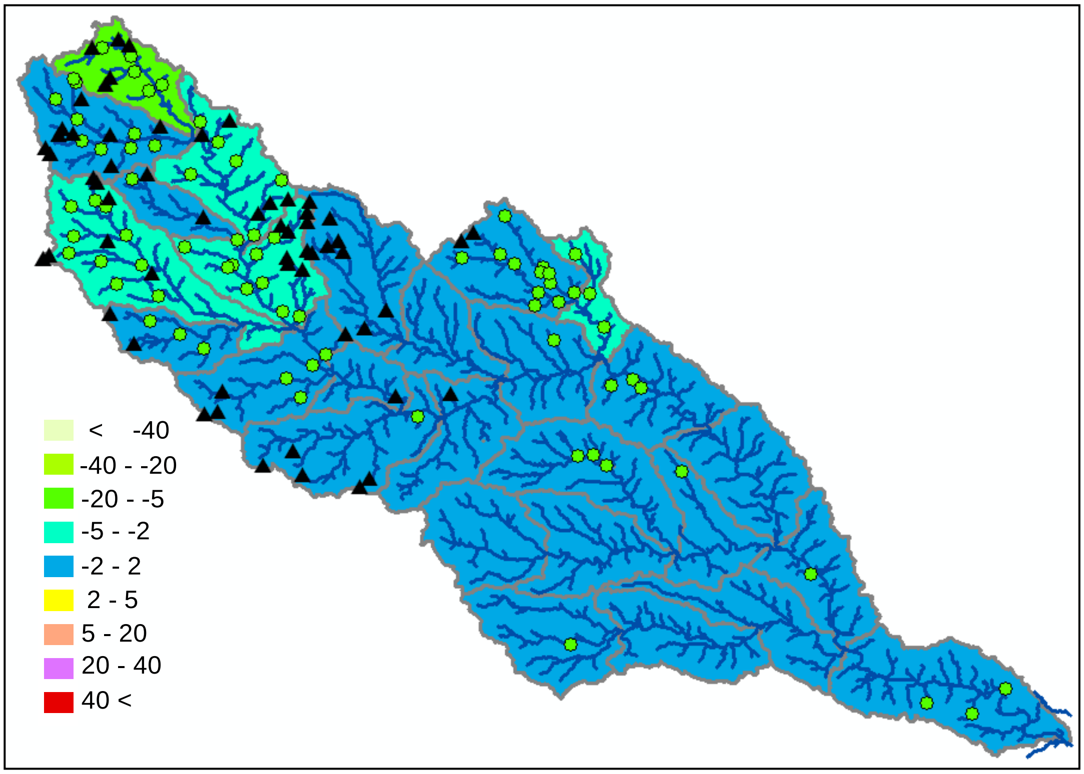

Figure 49h. % Change Mineral P in Water No Reservoirs All Manure Applied

Current vs. Alternative Future Practices

Analysis adding 6 new pre-selected reservoirs with 4 basic scenarios repeated.

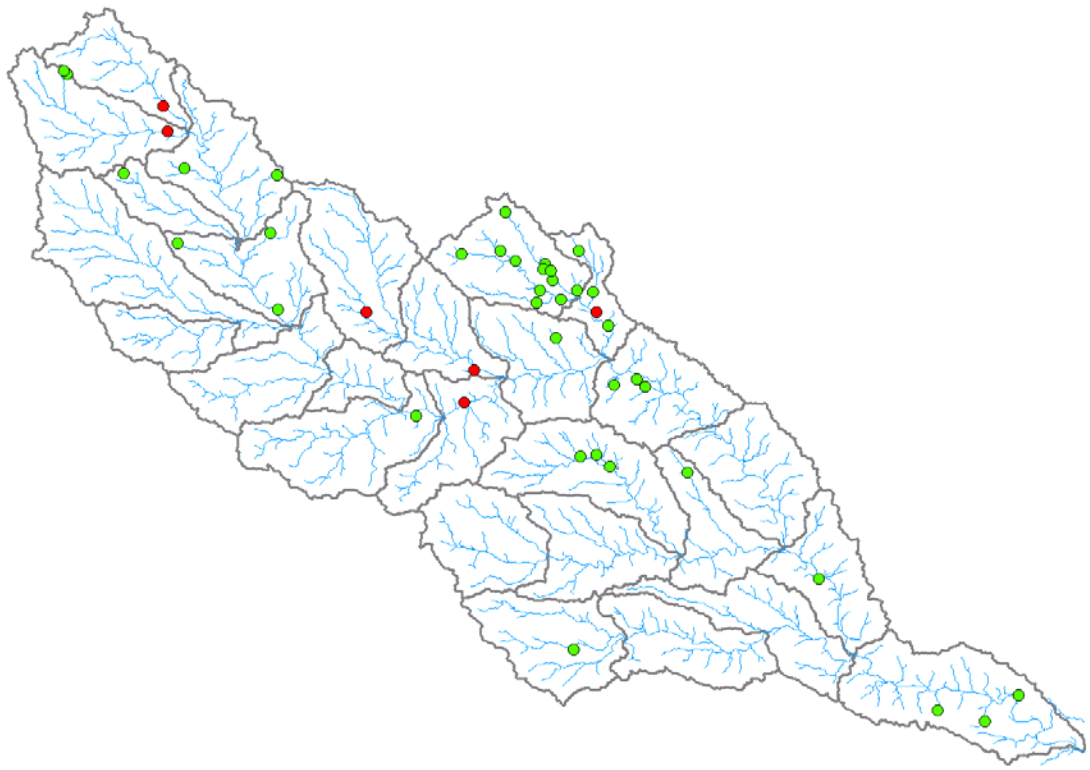

Figure 50. New Reservoir Locations

In the next two sets of scenarios six new reservoirs are added to the study (shown in red above). The previous sets of assumptions are then rerun with the addition of the six new locations. These additional reservoirs are carefully chosen to protect areas of the watershed that do not have a reservoir located between dairies in the upper portion of the watershed and Lake Waco. These six reservoirs are different from the existing reservoirs in that they are placed on the mainstream of the drainage system at their location. As mentioned earlier, the other reservoirs are placed off stream from the main drainage network. This substantially increased the portion of the total watershed protected by reservoirs. This protected area increased from the previous 27% to 69% of the area.

Scenario Conditions:

1) All previous reservoirs in the area are active and six new reservoirs (80 total) are added (NRC).
2) Current cropping practices included ICIPG Practices on 50 % of cropland and pasture fields and 50% were non-ICIPG practices.
3) All manure produced in the watershed was applied onto the waste application fields in the watershed (i.e. no manure hauloff). (MNUL=0)
4) All dairy lagoons were protected to allow no overflow.
5) Cow Numbers were set at approximately 40,000 Dairy Cows.
6) Runoff water was allowed to channelize before leaving the field (not distributed). All landscape positions were treated alike. Water is not distributed between upper and lower landscapes. Manure is applied to entire Waste Application Field (BASE)
7) Distributed Water Management & Manure Application to all WAF (DWMA)
8) Distributed Water Management and Lower Landscape Management –Manure Application fields on Upper only (DWMU)

Scenario	Runoff Percent Change	Water Yield Percent Change	Erosion Percent Change	YON Percent Change	YOP Percent Change	NO3 Percent Change	QP Percent Change	Total N Percent Change	Total P Percent Change
BASE-NRC-0	-1.947	-1.278	0.31	-30.9	-29.98	-17.82	-6.47	-28.15	-25.06
DWMA-NRC-0	-1.984	-1.278	-3.16	-31.24	-30.27	-17.93	-6.17	-28.44	-25.23
DWMU-NRC-0	-1.86	-1.363	-3.22	-31.36	-30.55	-10.83	5.66	-27.04	-22.98

Scenario	YON ppm	YOP ppm	NO3 ppm	QP ppm	Total N ppm	Total P ppm
BASE-NRC- 0	2.643	0.535	0.838	0.189	3.481	0.724
DWMA-NRC- 0	2.63	0.533	0.837	0.19	3.467	0.722
DWMU-NRC-0	2.628	0.531	0.91	0.214	3.538	0.745

Table 9. Special Scenarios- New Reservoirs All Manure Applied

This set of scenarios show a substantial improvement in watershed health when the six reservoirs are added. The baseline scenario reduces total phosphorus by 25%. Even the distributed water scenarios when all manure is applied go from less than 5% to more than

25% improvement. Even when these scenarios are compared to the previous scenarios that employ hauloff nutrient reductions still go from 12% to over 25%. Notice in the table above, with all the manure applied, as is the case with these three scenarios, there is very little effect due to the water distribution and placement of the manure. The new reservoirs seem to do an effective job of trapping the nutrients flowing through the reservoir regardless of the land treatment applied above the reservoir. As can be seen in the graphics that follow, the areas below the new reservoirs do, in fact, account for the major improvement in water quality.

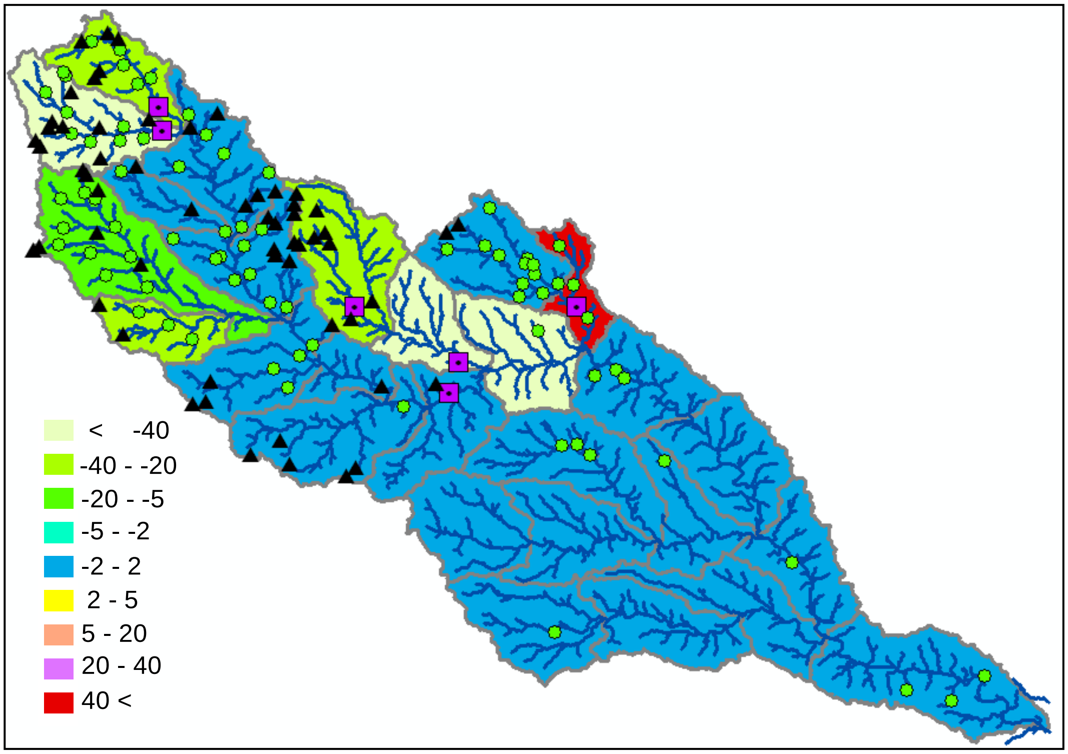

Figure 51a. % Change Total N BASE-Added Reservoirs All Manure Applied

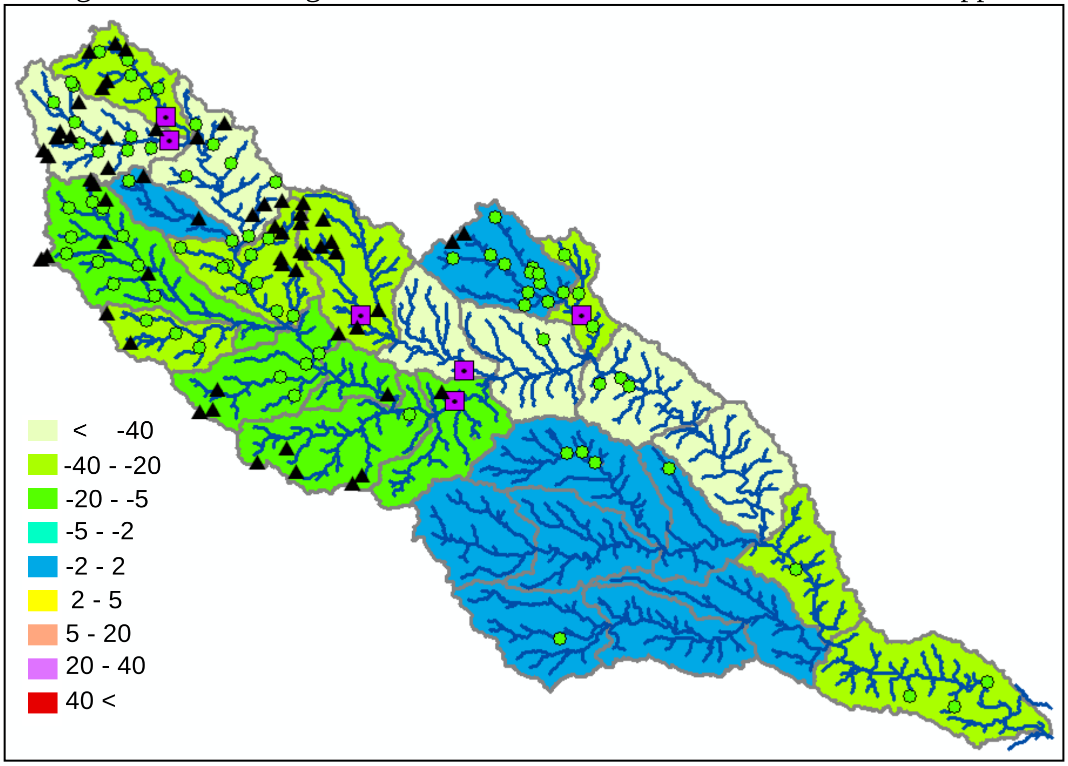

Figure 51b. % Change Total N Flow Accumulation BASE-Added Reservoirs All Manure Applied

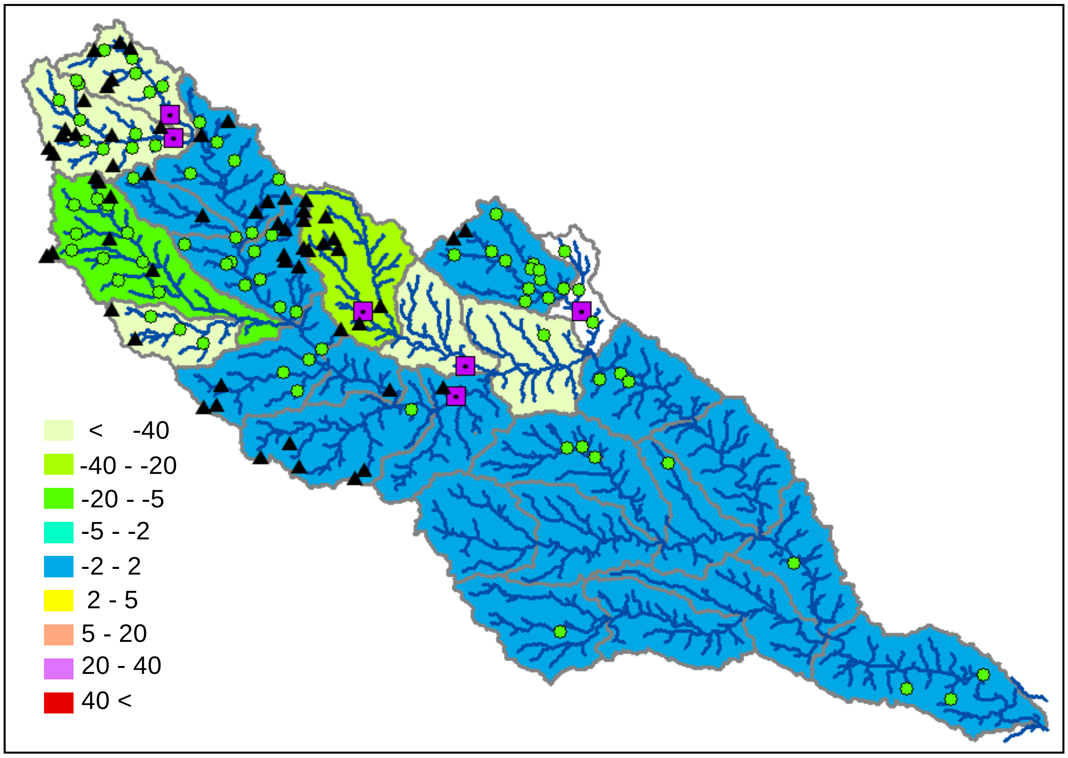

Figure 51c. % Change Total P BASE-Added Reservoirs All Manure Applied

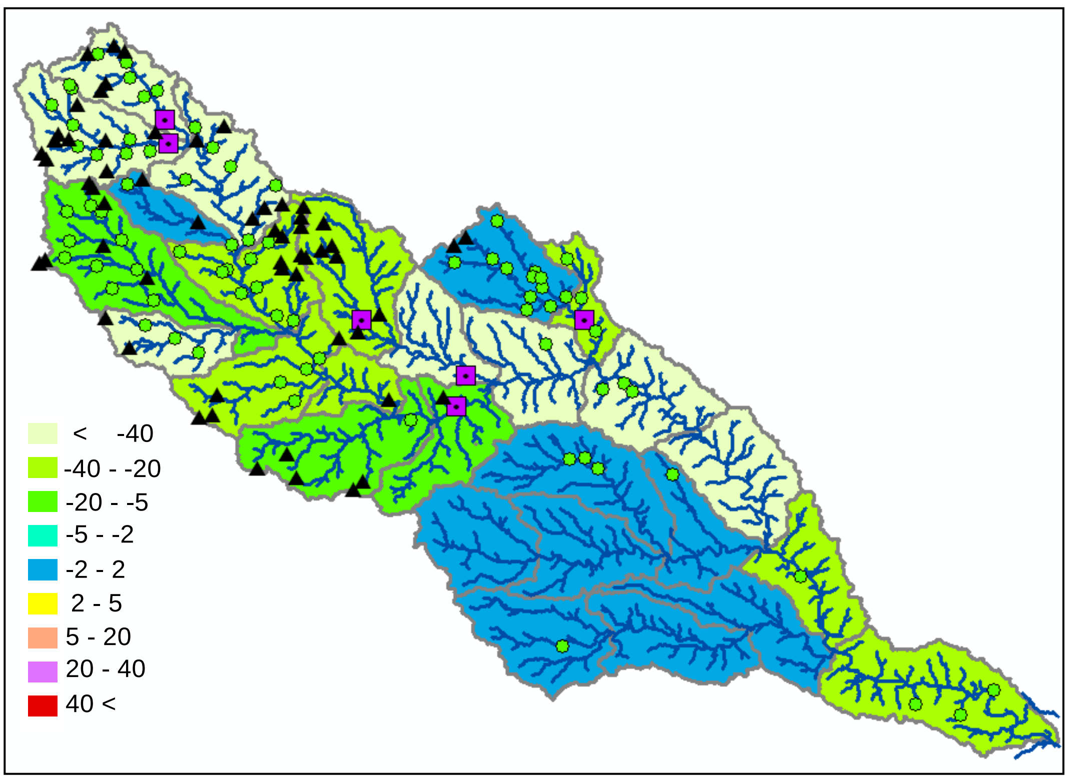

Figure 51d. % Change Total P Flow Accumulation BASE-Added Reservoirs All Manure Applied

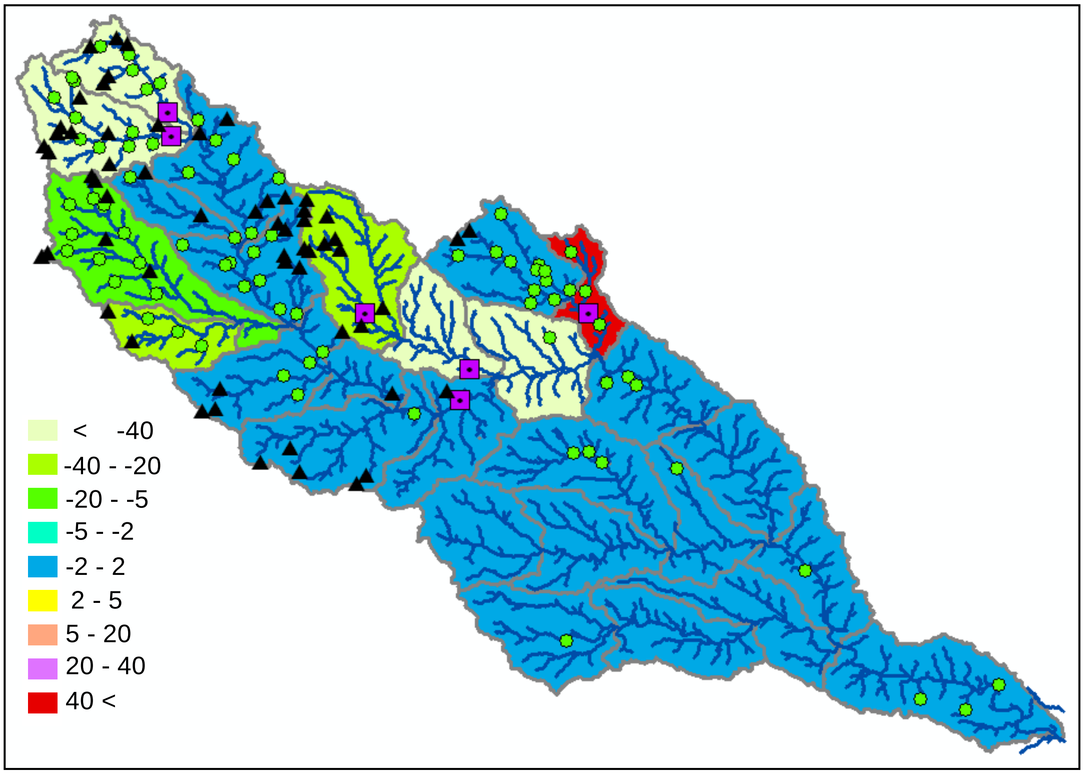

Figure 51e. % Change Organic N in Sediment BASE-Added Reservoirs All Manure Applied

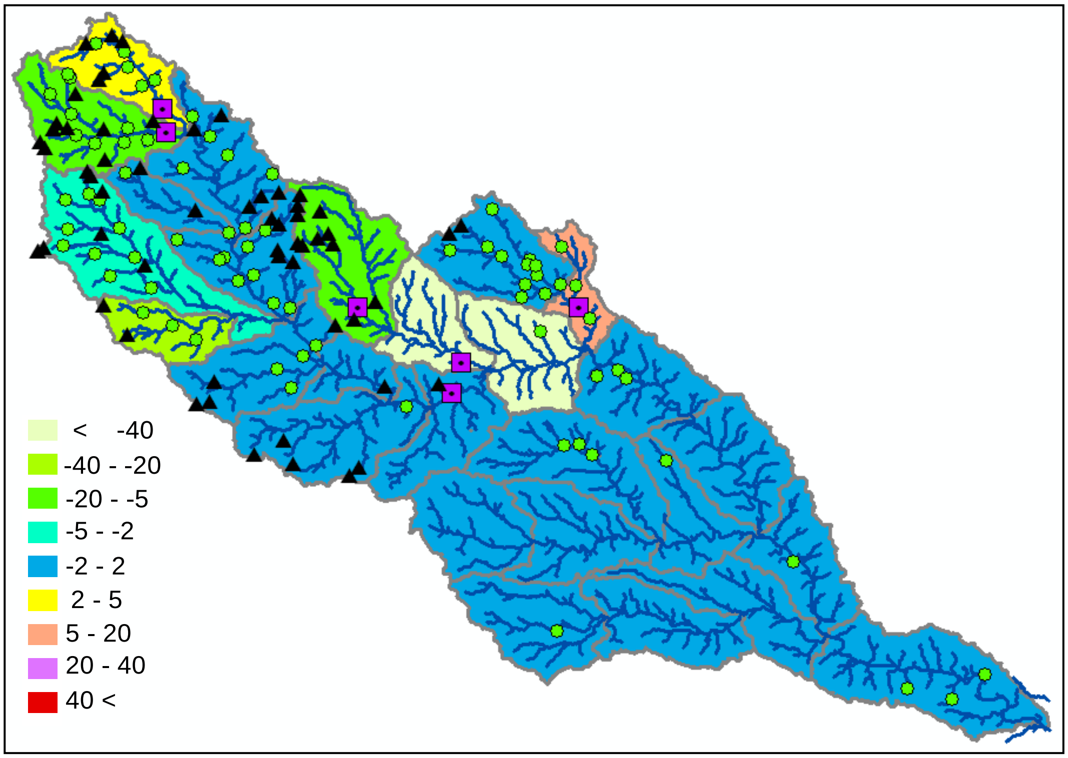

Figure 51f. % Change Mineral N in Water BASE-Added Reservoirs All Manure Applied

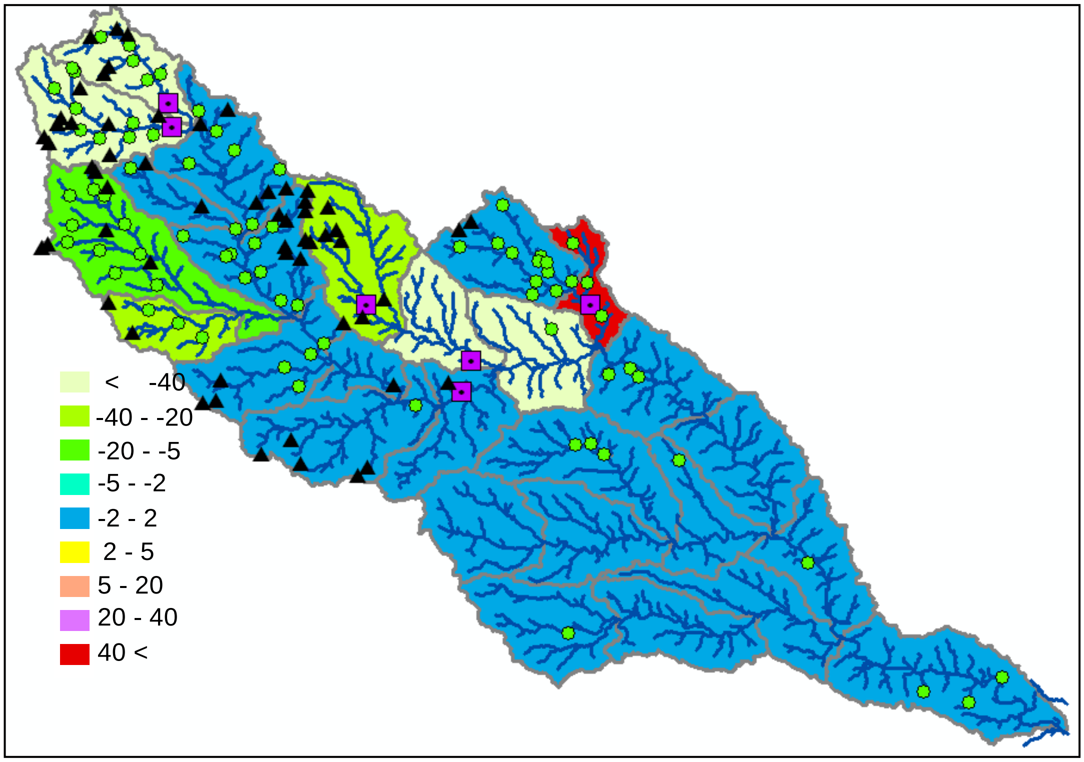

Figure 51g. % Change Organic P in Sediment BASE-Added Reservoirs All Manure Applied

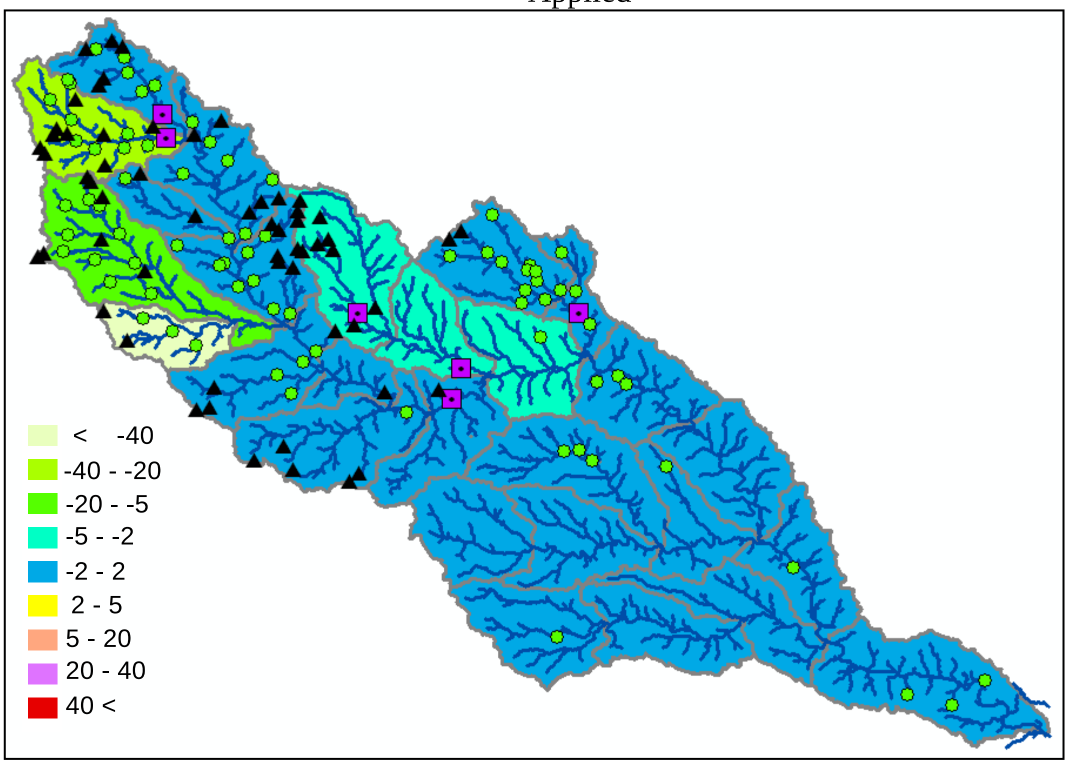

Figure 51h. % Change Mineral P in Water BASE-Added Reservoirs All Manure Applied

Primary Alternative Scenarios MNUL = 1 with new reservoirs

1) All previous reservoirs in the area are active and six new reservoirs (80 total) are added (NRC).
2) Current cropping practices included ICIPG Practices on 50 % of cropland and pasture fields and 50% were non-ICIPG practices.
3) Approximately 50% of the manure produced in the watershed was applied onto the waste application fields in the watershed. The remainder of the manure was hauled off to locations outside the watershed.(MNUL=1)
4) All dairy lagoons were protected to allow no overflow.
5) Cow Numbers were set at approximately 40,000 Dairy Cows.
6) Runoff water was allowed to channelize before leaving the field (not distributed). All landscape positions were treated alike. Water is not distributed between upper and lower landscapes. Manure applied to entire Waste Application Field (BASE)
7) Distributed Water Management & Manure Application is assigned to all WAF (DWMA)
8) Distributed Water Management and Lower Landscape Management with Manure applied on Upper landscapes only (DWMU)

Scenario	Runoff Percent Change	Water Yield Percent Change	Erosion Percent Change	YON Percent Change	YOP Percent Change	NO3 Percent Change	QP Percent Change	Total N Percent Change	Total P Percent Change
BASE-NRC-1	-2.095	-1.193	0.38	-31.32	-30.38	-22.97	-21.47	-29.56	-28.51
DWMA-NRC-1	-2.083	-1.193	-3.14	-31.44	-30.48	-22.97	-21.46	-29.66	-28.6
DWMU-NRC-1	-2.095	-1.193	-3.12	-31.61	-30.77	-23.4	-22.83	-29.88	-29.11

Scenario	YON ppm	YOP ppm	NO3 ppm	QP ppm	Total N ppm	Total P ppm
BASE-NRC- 1	2.625	0.532	0.785	0.159	3.41	0.69
DWMA-NRC- 1	2.62	0.531	0.785	0.159	3.405	0.689
DWMU-NRC- 1	2.614	0.529	0.781	0.156	3.394	0.684

Table 10. Special Scenarios- New Reservoirs with Manure Hauloff

This set of three scenarios shows a slight improvement in the watershed health when 50% of the manure is hauled off. However, this improvement is from 25% when all the manure is applied (previous set) to 28% when half of the manure is applied. The impact of manure removal is much less when the new reservoirs are in place.

The two graphics below showing the detailed sub-watersheds provide an interesting comparison of the scenarios above. The first graph shows the upper part of the basins with the new reservoirs in place and with all of the manure produced applied to the waste application fields. The second graphic shows the identical scenario with the exception that half of the manure is removed. At first glance the graphics look almost identical; however, on close inspection one will notice the change in the color of the streamlines in some areas. When all of these changes are aggregated throughout the basins a substantial change in the mineral P is recorded. In the first case where all manure is applied the addition of the reservoirs reduces the mineral P by 6.5% from the baseline. When half the manure is not applied to the land the loads of mineral P in the water are reduced by 21.5%. These two graphics provide an excellent example of the overall impact on the watershed when a relatively small number of fields are targeted for changes in nutrient management.

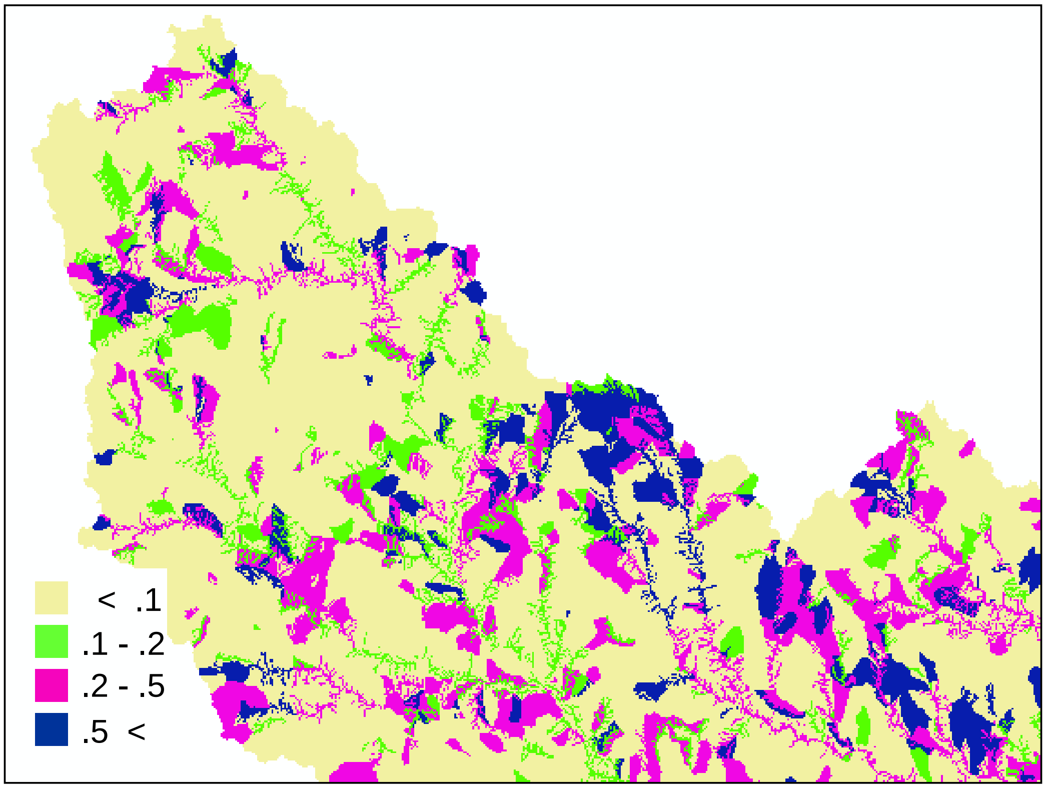

Figure 52. Added Reservoirs All Manure Applied – Mineral P in Water in ppm

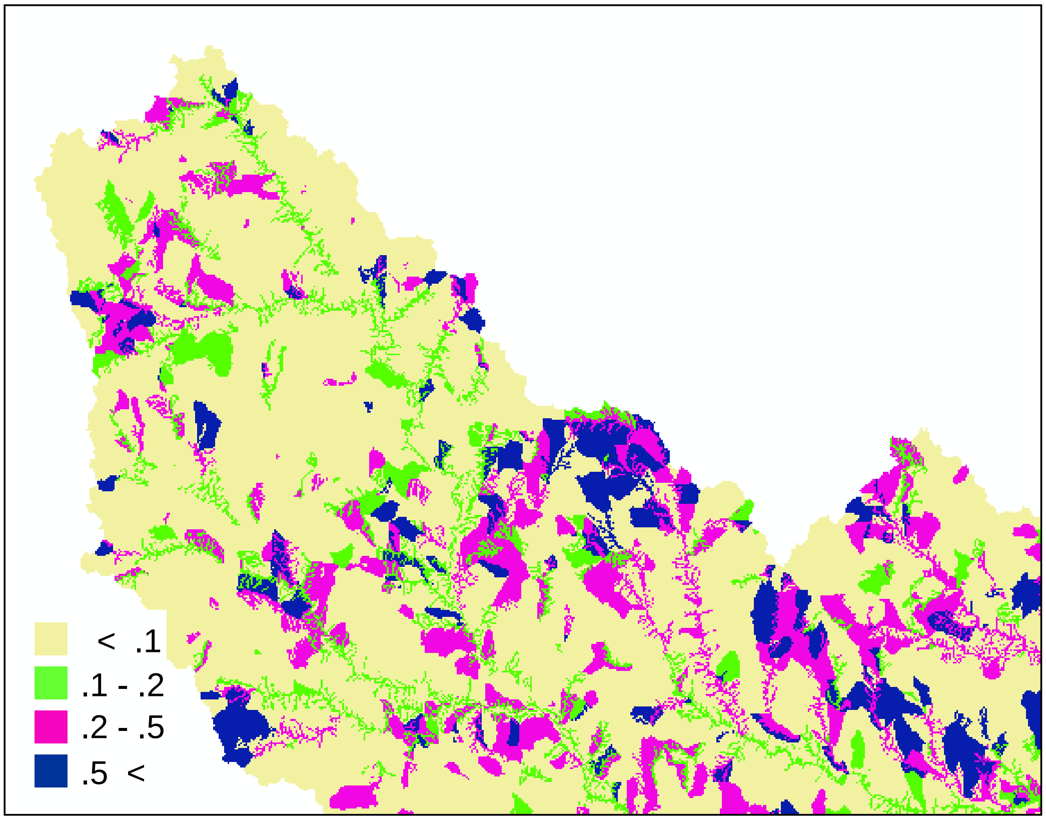

Figure 53. Added Reservoirs -Hauloff – Mineral P in Water in ppm

Below is an extensive set of graphics depicting the scenario that represents the most complete set of practices for improving the overall health of the watershed (DWMA-NRC-1). This includes the addition of the new reservoirs, the removal of half of the manure, the distributions of the water to prevent channelization before leaving the field, and the application of manure to all parts of the waste application fields. As reported earlier the application of the manure to the lower portion only did not provide any identifiable improvements. Graphics report the small watershed and 12 digit flow accumulation. At the mouth of the North Bosque watershed, this scenario reported an improvement in the organic P of 30.5%, of mineral P of 21.5%, of total P of 28.6%, and of total N of 29.7%. As reported before an inspection of a small watershed graphics reveals isolated areas where it appears the watershed showed percentage increases in the reported attributes. These sub-watersheds may merit a closer inspection to identify what caused this increase. However, as before, inspection of some of the sub-watersheds revealed that, in fact, the values for the baseline run, when reported in kilograms per hectare, were extremely small. The scenario run had slightly larger numbers with the net result of a large percentage increase. In other words these sub-basins are reflecting rounding errors or a divide by zero phenomena.

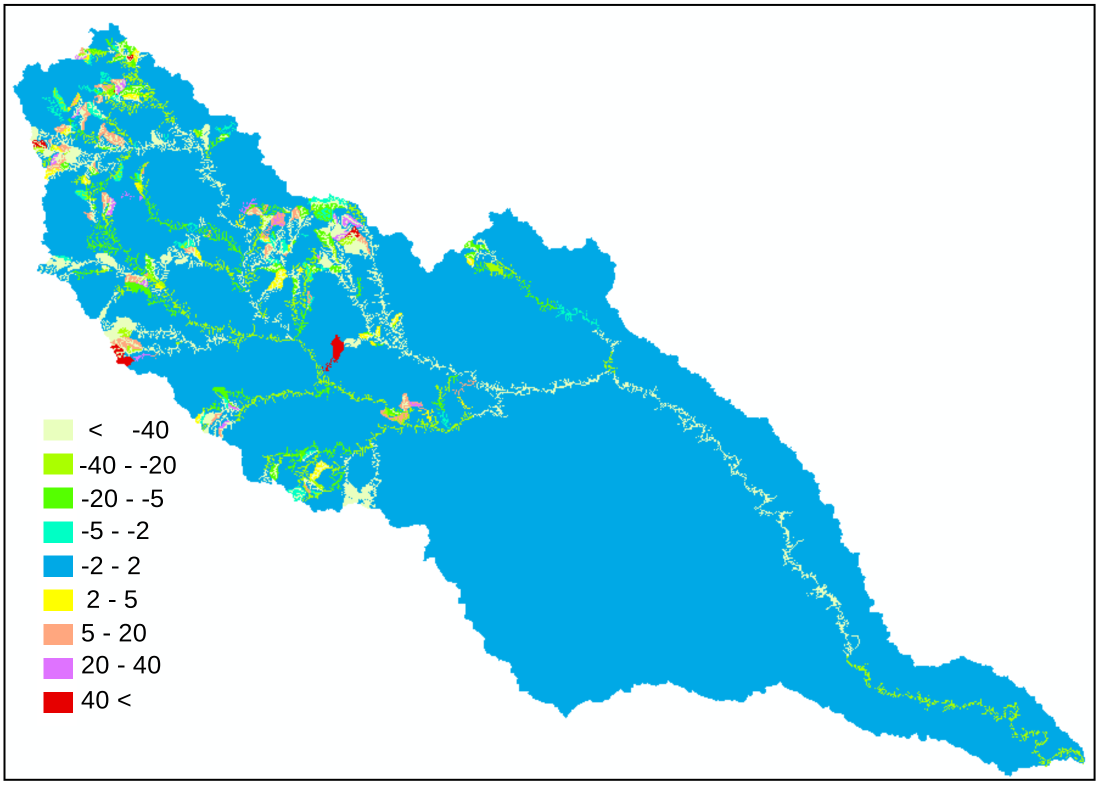

Figure 54a. % Change Total N DWMA-Added Reservoirs-Hauloff- Flow Accumulation-Small Watersheds

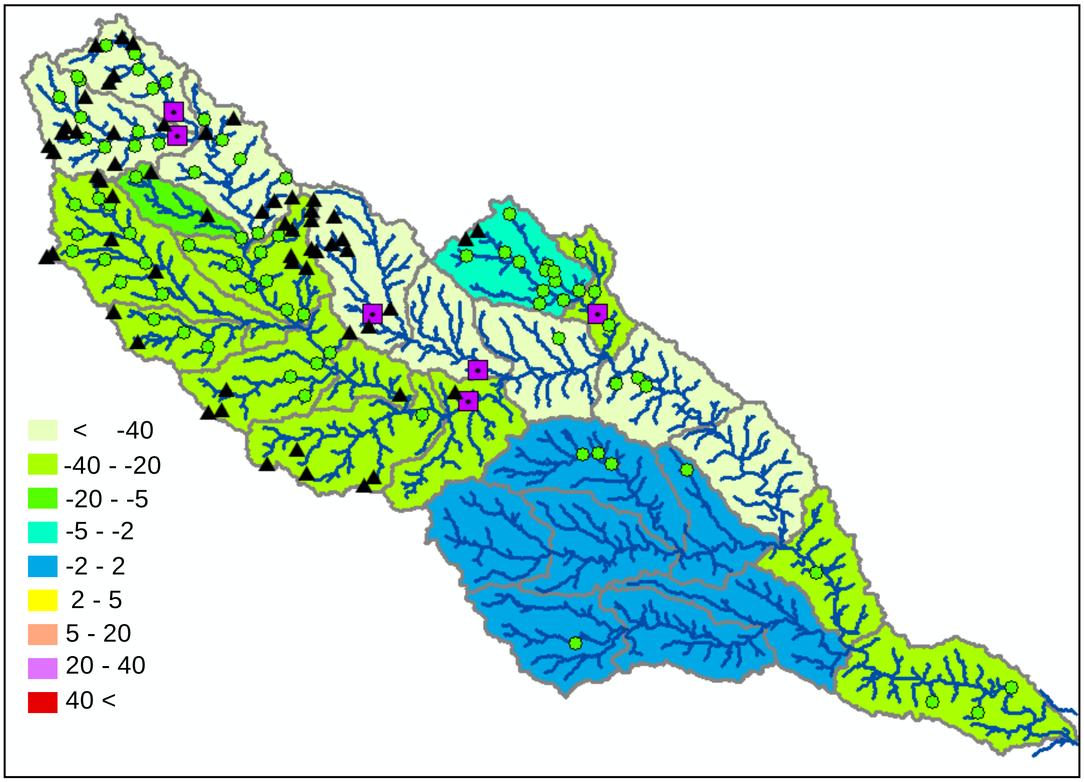

Figure 54b. % Change Total N Flow Accumulation DWMA-Added Reservoirs-Hauloff-12 Digit HUA

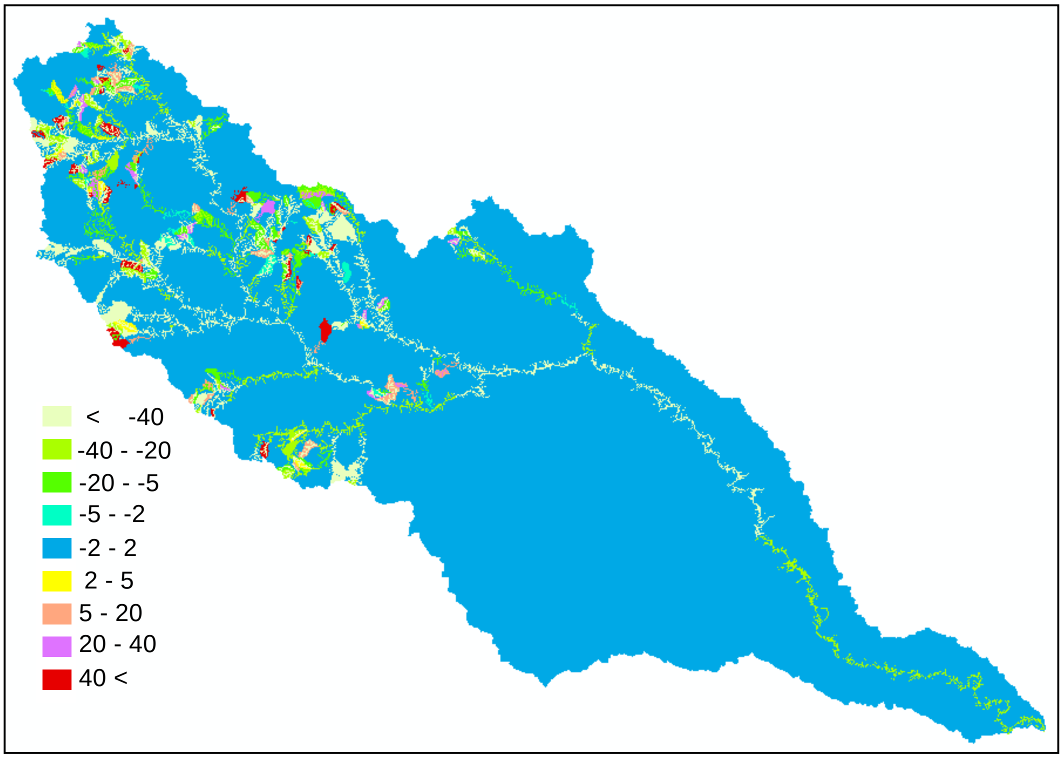

Figure 54c. % Change Total P DWMA-Added Reservoirs-Hauloff Flow Accumulation-Small Watersheds

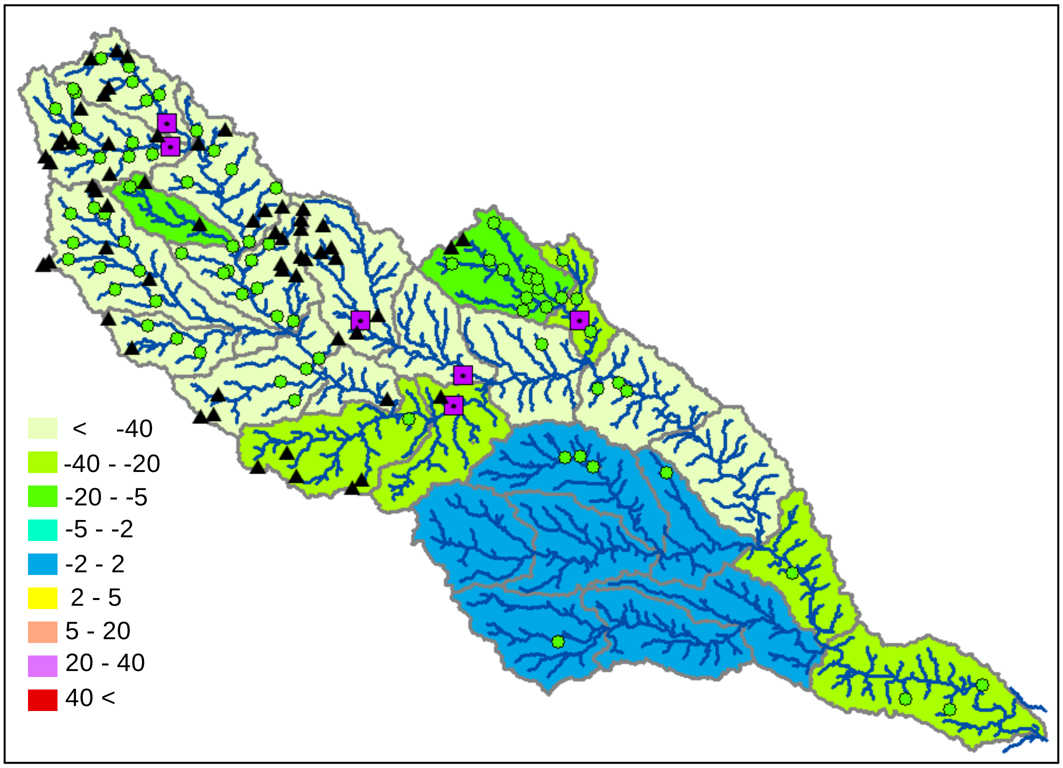

Figure 54d. % Change Total P Flow Accumulation DWMA-Added Reservoirs-Hauloff-12 Digit HUA

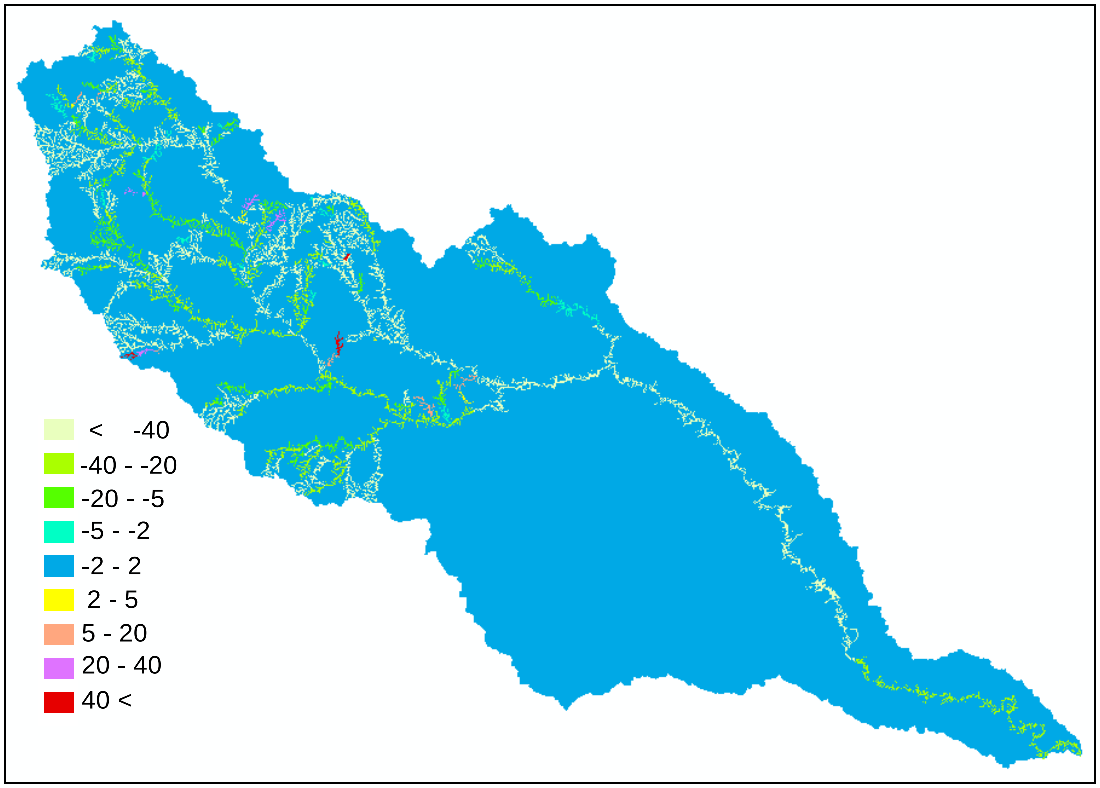

Figure 54e. % Change Organic N in Sediment DWMA-Added Reservoirs-Hauloff Flow Accumulation-Small Watersheds

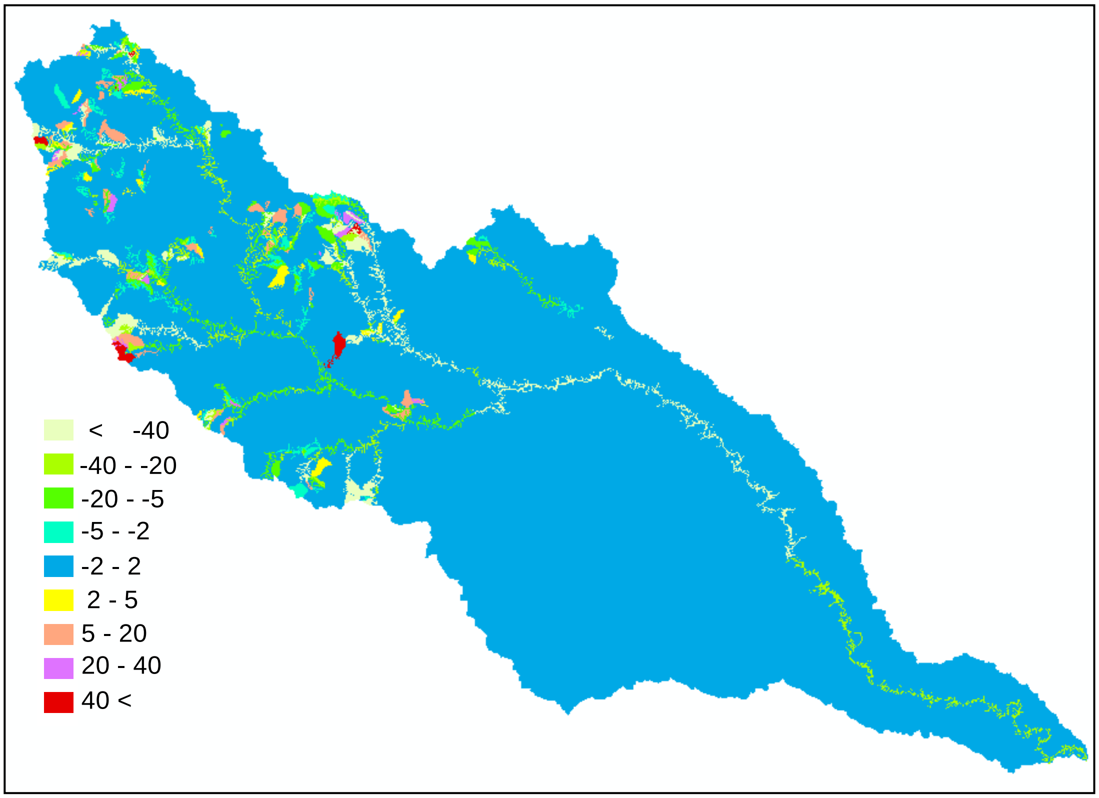

Figure 54f. % Change Mineral N in Water DWMA-Added Reservoirs-Hauloff- Flow Accumulation-Small Watersheds

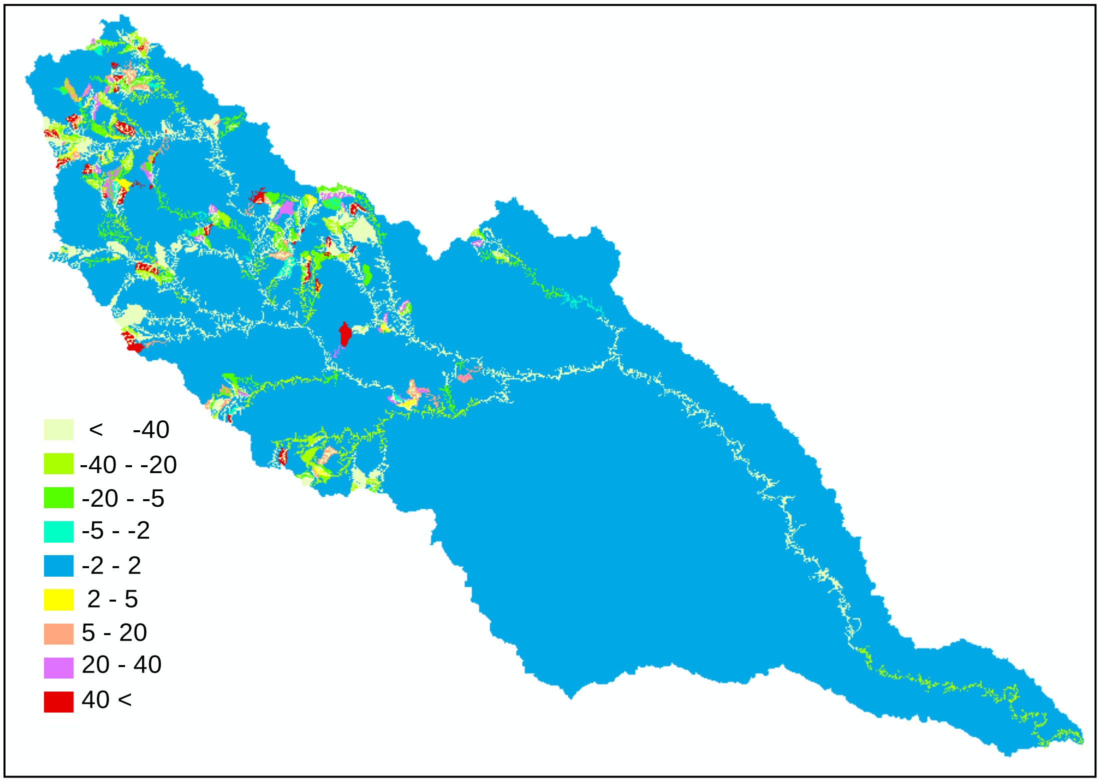

Figure 54g. % Change Organic P in Sediment DWMA-Added Reservoirs-Hauloff Flow Accumulation-Small Watersheds

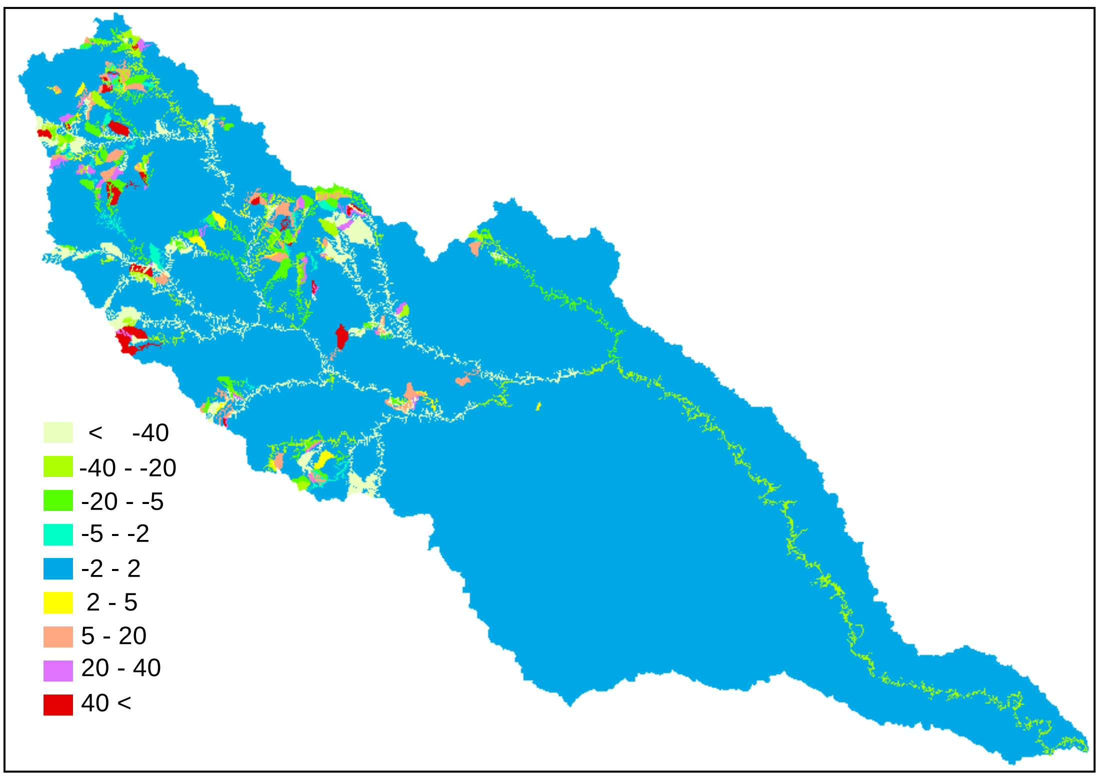

Figure 54h. % Change Mineral P in Water DWMA-Added Reservoirs-Hauloff Flow Accumulation-Small Watersheds

Improved Conservation on Cropland and Improved Pastures Grasses (ICIPG)

1) ICIPG Practices on 100 % of cropland and pasture fields.
2) All reservoirs in the area are active and functional (74 total). (TNRCC)
3) All previous reservoirs in the area are active and six new reservoirs (80 total) are added (NRC).
4) All manure produced in the watershed was applied onto the waste application fields in the watershed (i.e. no manure hauloff).(MNUL=0)
5) Approximately 50% of the manure produced in the watershed was applied onto the waste application fields in the watershed. The remainder of the manure was hauled off to locations outside the watershed.(MNUL=1)
6) All dairy lagoons were protected to allow no overflow.
7) Cow Numbers were set at approximately 40,000 Dairy Cows.
8) Distributed Water Management & Manure Application is assigned to all WAF (DWMA)

Scenario	Runoff Percent Change	Water Yield Percent Change	Erosion Percent Change	YON Percent Change	YOP Percent Change	NO3 Percent Change	QP Percent Change	Total N Percent Change	Total P Percent Change
ICIPG-TNRCC-0	7.762	0.511	2.69	15.15	9.95	-19.3	34.76	7.9	15.14
ICIPG-TNRCC-1	7.626	0.596	2.73	11.58	6.4	-35.78	2.03	1.61	5.49
ICIPG-NRC-0	5.79	-0.852	2.04	-19.94	-22.08	-44.04	15.65	-25.02	-14.18
ICIPG-NRC-1	5.666	-0.767	2.09	-20.37	-22.43	-49.18	0.58	-26.44	-17.62

Scenario	YON ppm	YOP ppm	NO3 ppm	QP ppm	Total N ppm	Total P ppm
ICIPG-TNRCC-0	4.326	0.825	0.809	0.267	5.135	1.093
ICIPG-TNRCC-1	4.188	0.798	0.643	0.202	4.831	1
ICIPG-NRC- 0	3.049	0.593	0.568	0.233	3.617	0.826
ICIPG-NRC- 1	3.03	0.59	0.516	0.202	3.546	0.792

Table 11. Reduced Tillage and Improved Pasture Grasses (ICIPG)

The three scenarios that follow address impacts of improved conservation and improved pasture grasses As is indicated earlier, cropland constituted less than 5% of the land area in the study. As a result cropland practices were not considered a major portion of the study and were not addressed in great detail. However, these three scenarios do report some of the more interesting findings of this part of the study. In the baseline conservation practices identified and used in this scenario were applied to 50% of the cropland and improved pastures. In these three scenarios this percentage was increased 100%.several characteristics are worth noting about these ICIPG scenarios. As was mentioned earlier most of the cropland occurs in the lower portion of the watershed. The higher slopes are found in the central and lower portion of the watershed. The graphic shown below may be somewhat misleading unless they are compared to the previous graphics as they show the percentage change from the baseline. That means that these scenarios include the other practices that have been added (the distributed water practice and the manure hauloff practice). Two of the scenarios also include the new reservoirs. For the most part the changes in the tillage practices manage the nitrogen budget in the respective fields. This is reflected by the fact there was improvement in nitrogen amounts leaving the fields only in the mineral nitrogen going from and improvement of 23% to a 49%. However, one should note that the mineral nitrogen only constitutes 14% of the total nitrogen leaving the watershed. Therefore total nitrogen did not improve from the previous scenarios (see tables above).

Even though the table above reporting the outflows from the North Bosque reflects only moderate changes in output from these scenarios when compared to earlier scenarios, closer inspections reflect significant changes in the middle and lower parts of the watershed. As noted these are the areas where management changes were made for the ICIPG scenarios. The upper end of the watershed where the dairies and reservoirs are located continued to show improvements in watershed health. The middle and the lower portions of the watersheds showed higher levels of phosphorus problems. This may be due to the reduced tillage and less incorporation of the applied phosphorus into the soil.

There are many questions left unanswered associated with the ICIPG scenarios. The interactions created in the scenarios must be left for consideration in later studies.

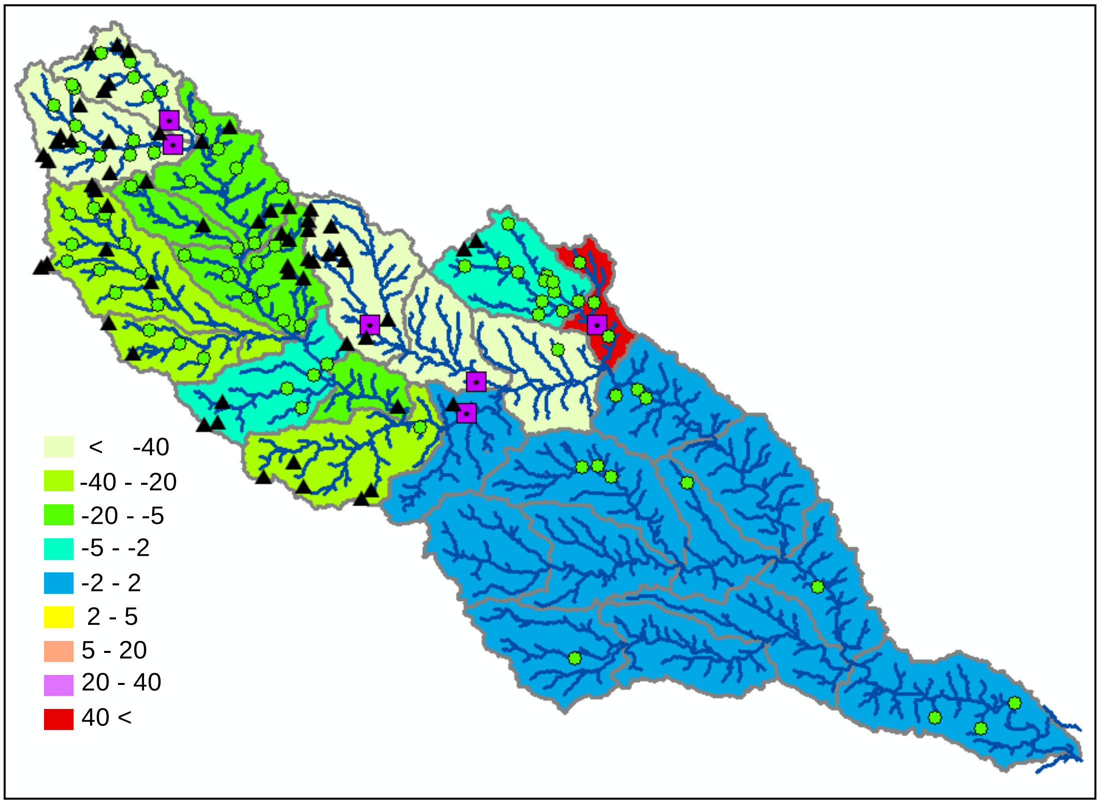

Figure 55a. % Change Total N ICIPG-Added Reservoirs-Hauloff

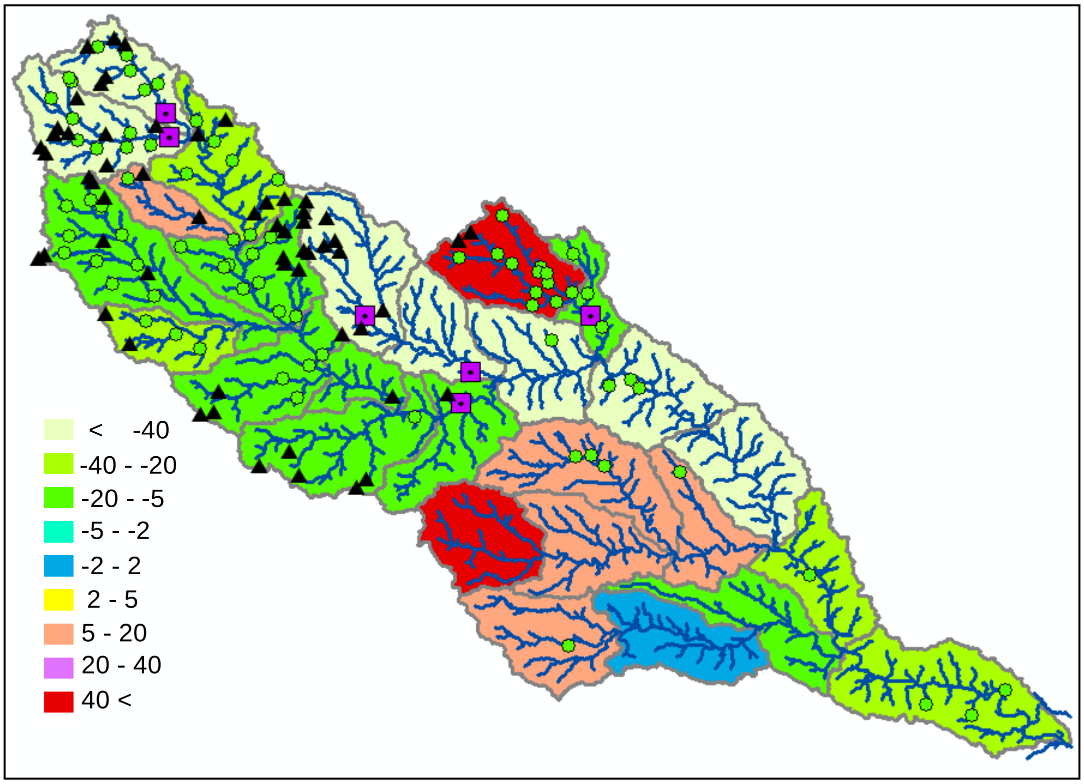

Figure 55b. % Change Total N Flow Accumulation ICIPG-Added Reservoirs-Hauloff

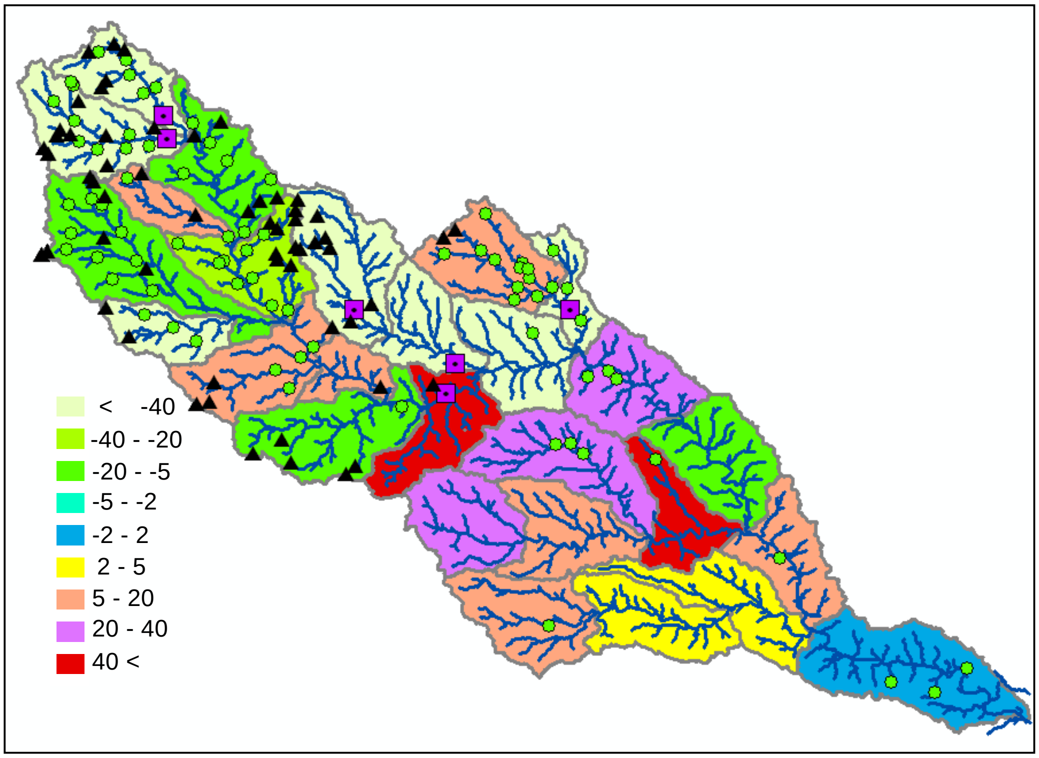

Figure 55c. % Change Total P ICIPG-Added Reservoirs-Hauloff

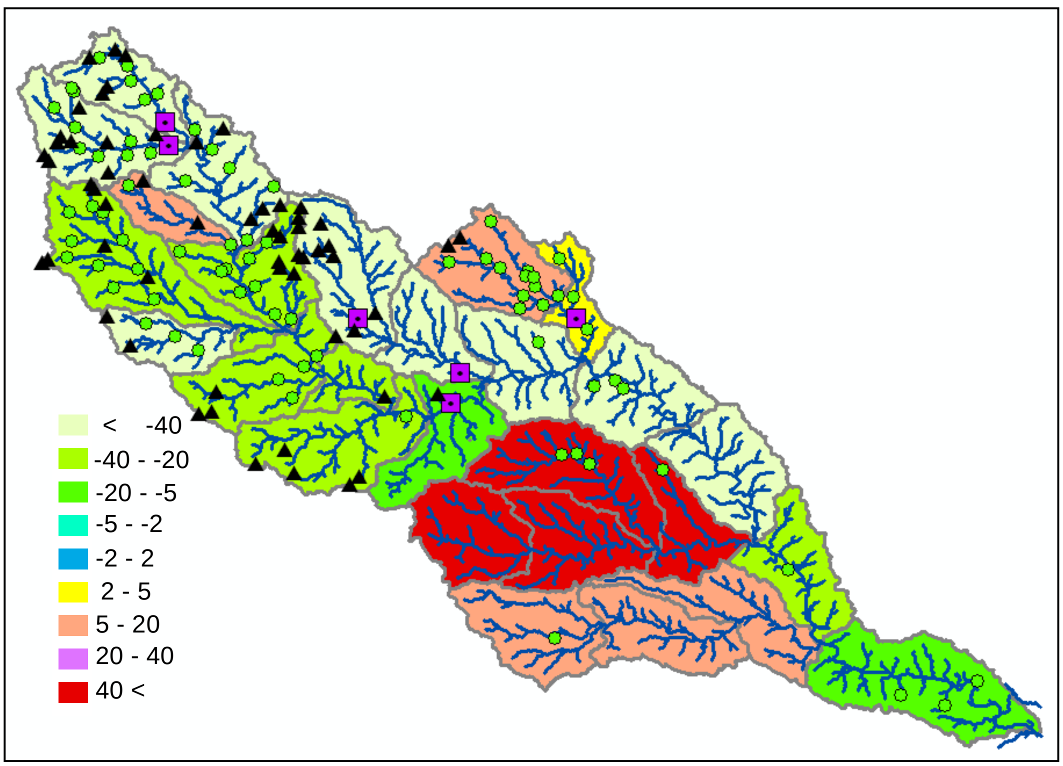

Figure 55d. % Change Total P Flow Accumulation ICIPG-Added Reservoirs-Hauloff

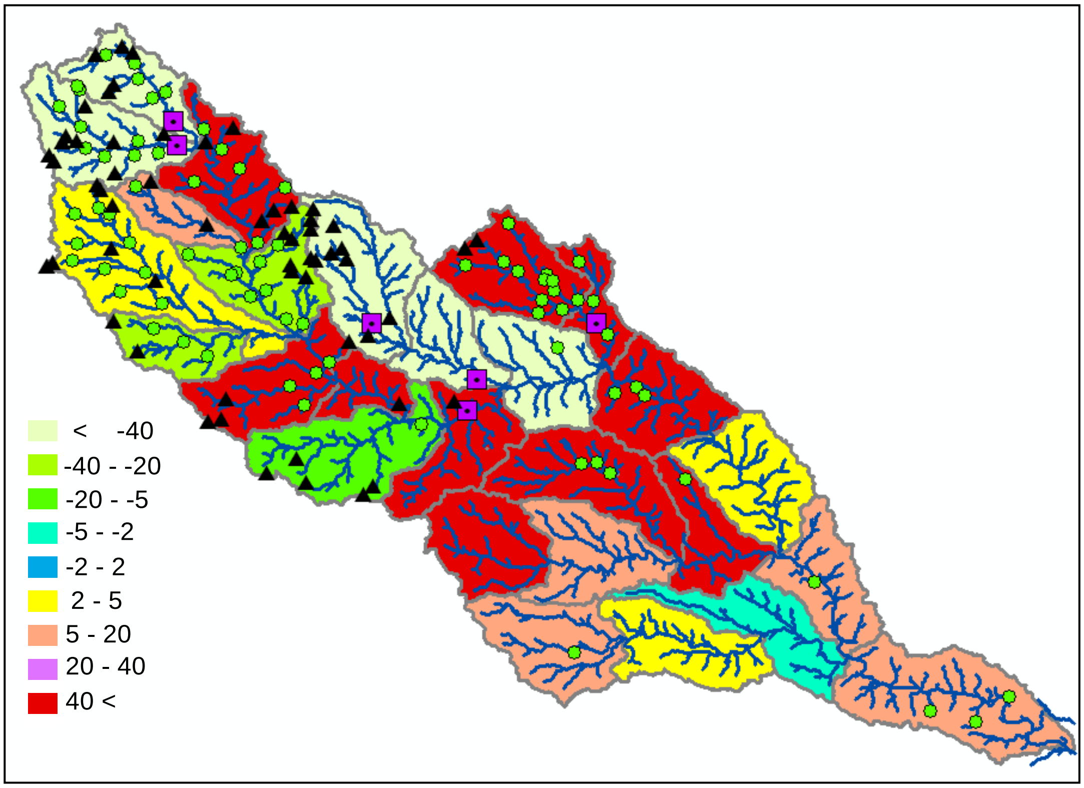

Figure 55e. % Change Organic N in Sediment ICIPG-Added Reservoirs-Hauloff

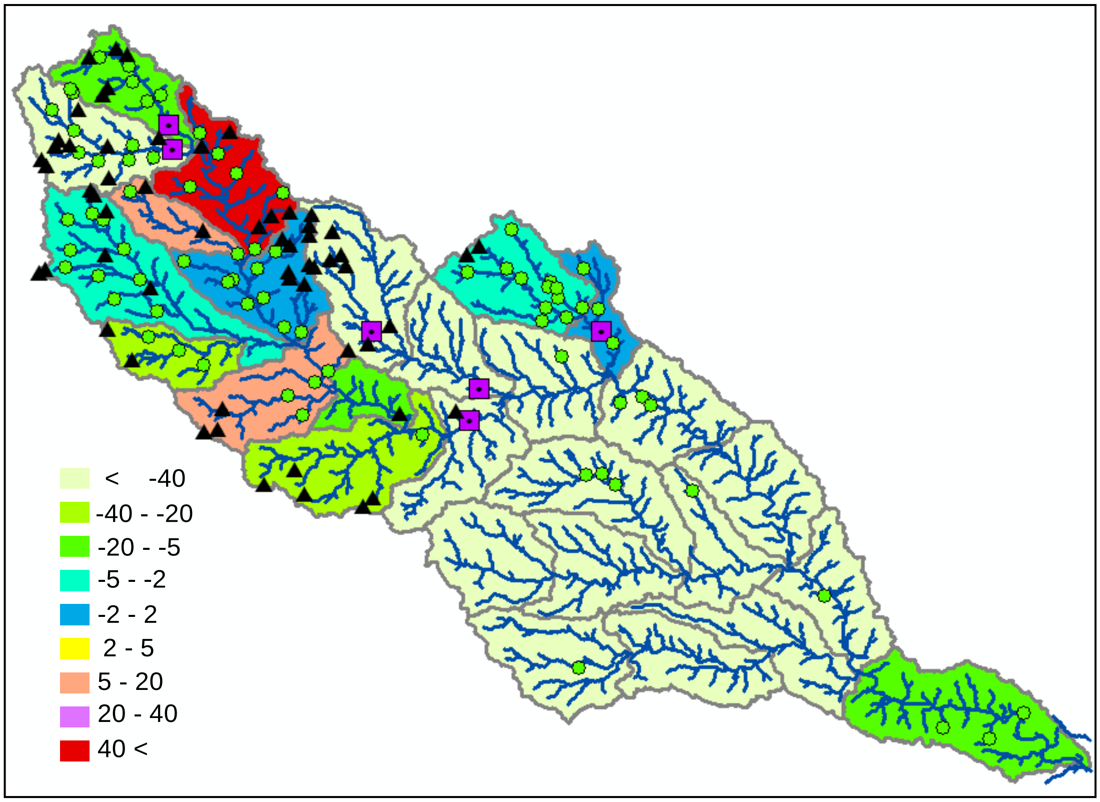

Figure 55f. % Change Mineral N in Water ICIPG-Added Reservoirs-Hauloff

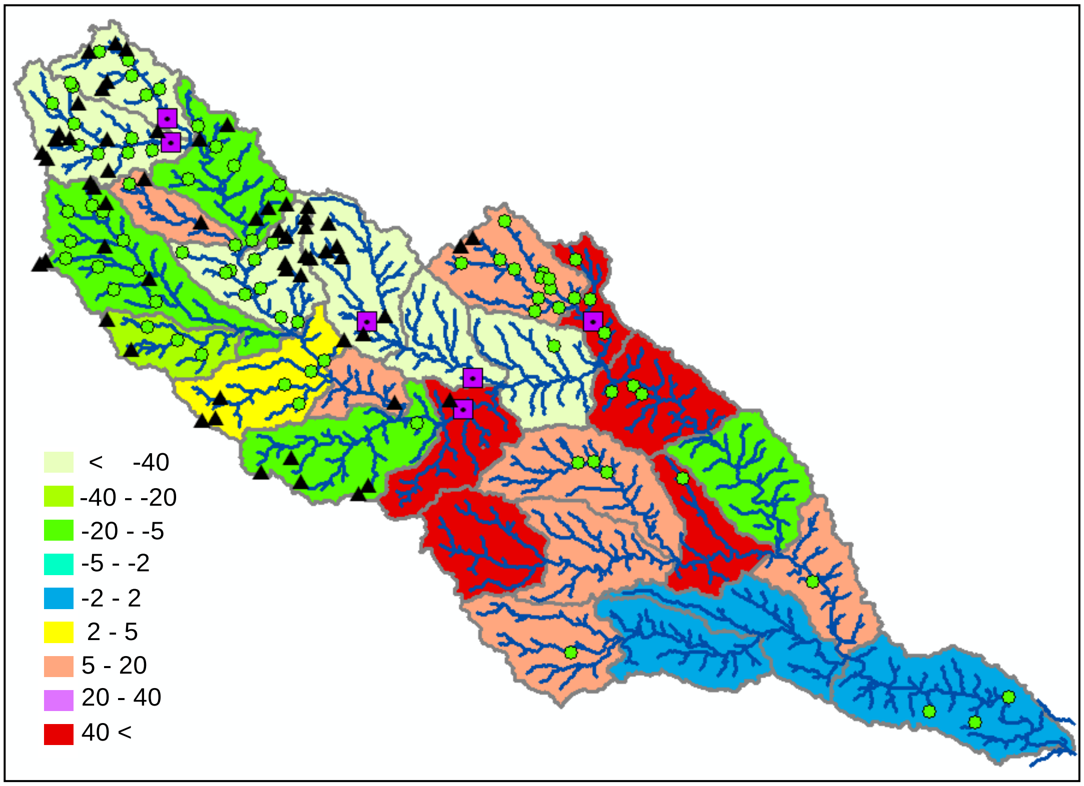

Figure 55g. % Change Organic P in Sediment ICIPG-Added Reservoirs-Hauloff

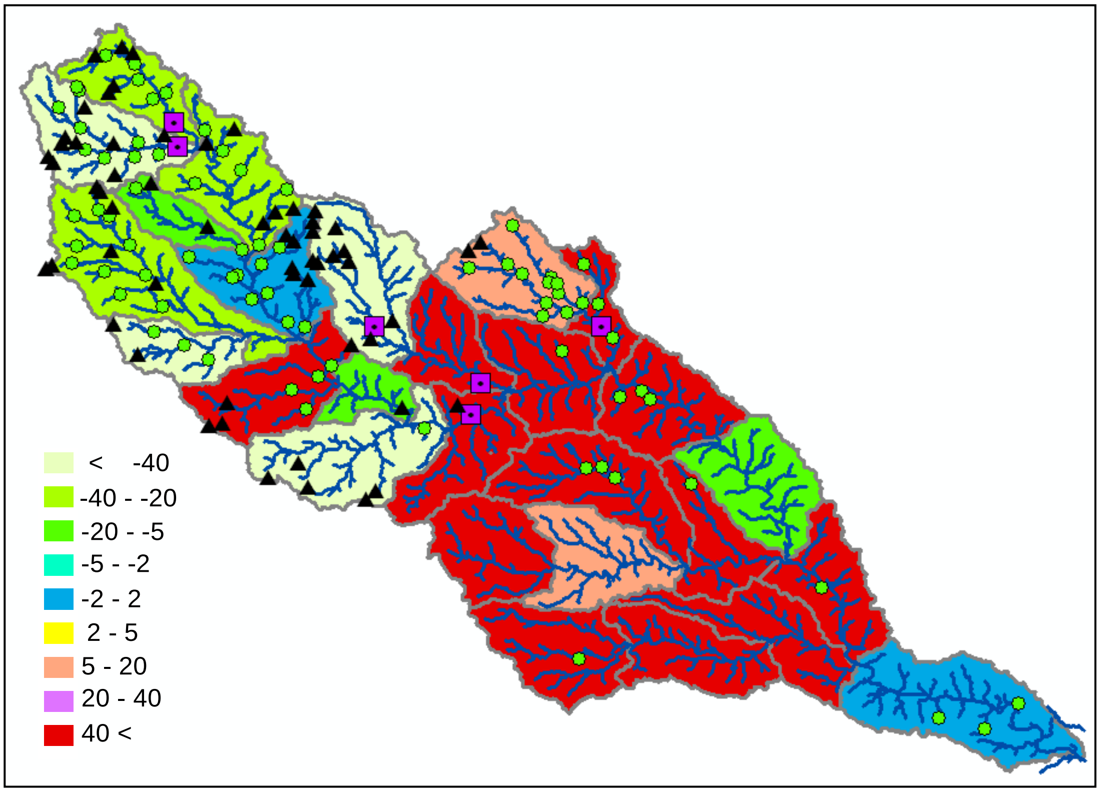

Figure 55h. % Change Mineral P in Water ICIPG-Added Reservoirs-Hauloff

North Bosque Watershed vs Entire Bosque Watershed to Lake Waco

The following table provides a summary of all of the scenarios conducted in the study. For each of the scenarios the table compares the North Bosque to the entire Bosque for each of the attributes listed. The table has been sorted in ascending order to rank the scenario by the percentage improvement in total phosphors for the North Bosque watershed.

	All Bosque	North Bosque	All Bosque	North Bosque	All Bosque	North Bosque	All Bosque	North Bosque	All Bosque	North Bosque	All Bosque	North Bosque	All Bosque	North Bosque
Scenario	Yt_ PCT	Yt_ PCT	YON kg_PCT	YON kg_PCT	YOP kg_PCT	YOP kg_PCT	NO3 kg_PCT	NO3 kg_PCT	QP kg_PCT	QP kg_PCT	Total N kg_PCT	Total N kg_PCT	Total P kg_PCT	Total P kg_PCT
DWMU-NRC-1	-2.1	-3.1	-17.6	-31.6	-14.7	-30.8	-11.2	-23.4	-16.1	-22.8	-16.1	-29.9	-14.9	-29.1
DWMA-NRC-1	-2.1	-3.1	-17.5	-31.4	-14.6	-30.5	-11.0	-23.0	-15.2	-21.5	-16.0	-29.7	-14.7	-28.6
BASE-NRC-1	1.4	0.4	-17.4	-31.3	-14.4	-30.4	-11.0	-23.0	-15.2	-21.5	-15.9	-29.6	-14.6	-28.5
DWMA-NRC-0	-2.1	-3.2	-17.4	-31.2	-14.4	-30.3	-8.6	-17.9	-4.3	-6.2	-15.3	-28.4	-12.9	-25.2
BASE-NRC-0	1.3	0.3	-17.1	-30.9	-14.2	-30.0	-8.6	-17.8	-4.6	-6.5	-15.1	-28.1	-12.8	-25.1
DWMU-NRC-0	-2.1	-3.2	-17.5	-31.4	-14.6	-30.6	-5.2	-10.8	4.1	5.7	-14.6	-27.0	-11.8	-23.0
ICIPG-NRC-1	3.0	2.1	-2.9	-20.4	-5.9	-22.4	-30.7	-49.2	0.7	0.6	-9.4	-26.4	-4.9	-17.6
NAT2	-8.8	-5.0	-27.7	-8.6	-44.6	-18.0	-48.2	-23.7	-7.7	-15.9	-32.5	-11.8	-39.0	-17.6
ICIPG-NRC-0	3.0	2.0	-2.7	-19.9	-5.7	-22.1	-28.2	-44.0	11.3	15.7	-8.7	-25.0	-3.1	-14.2
DWMU-TNRCC-1	-2.3	1.2	-5.8	-10.3	-5.1	-10.6	-3.4	-7.0	-14.2	-20.1	-5.2	-9.6	-6.5	-12.6
DWMA-TNRCC-1	-2.3	1.2	-5.8	-10.3	-5.1	-10.6	-3.4	-7.0	-14.2	-20.1	-5.2	-9.6	-6.5	-12.6
NAT1	2.0	1.1	3.1	-1.7	2.2	-6.5	-5.6	-13.1	-3.9	-15.4	1.0	-4.1	1.3	-8.4
BASE-TNRCC-1	0.0	0.0	-1.6	-2.8	-1.2	-2.6	-3.1	-6.4	-10.7	-15.1	-1.9	-3.5	-2.6	-5.2
DWMU-TNRCC-0	-2.4	1.1	-4.7	-8.4	-4.1	-8.4	4.5	9.3	9.2	13.0	-2.6	-4.6	-2.1	-4.0
DWMA-TNRCC-0	-2.3	1.2	-4.7	-8.4	-4.1	-8.4	4.5	9.2	9.2	13.0	-2.6	-4.7	-2.1	-4.0
ICIPG-TNRCC-1	1.8	2.7	14.8	11.6	7.8	6.4	-24.3	-35.8	1.6	2.0	5.6	1.6	6.9	5.5
NORE-1	3.8	4.0	14.6	19.2	13.8	18.3	5.3	4.0	-14.2	-20.3	12.4	16.0	9.6	10.2
ICIPG-TNRCC-0	1.7	2.7	16.8	15.2	9.5	9.9	-16.3	-19.3	24.9	34.8	9.0	7.9	11.8	15.1
NORE-0	3.8	4.0	18.6	26.2	17.9	27.0	9.1	12.0	-0.2	-0.5	16.4	23.2	15.2	21.2

Table 12. All Scenarios Ranked by Percentage Change in Total P for the North Bosque

The next series of graphs will provide some insight to the above table. These maps display attribute information for the entire Bosque. Notice the much higher load levels for both N and P in the middle and South Bosque as shown in the lower portion of the graphic. As pointed out earlier, these areas have a much higher concentration of cropland activity. Since the study was concentrating on the North Bosque, only a cursory effort was made to validate this observation. Also the crop rotations placed on the croplands were limited in number and simplified in management practices. The accuracy of the information, the questions raised, and the implications of the graphics will have to be addressed by further analyses and later studies. However, the comparison of these graphics with the above table point out the importance of understanding the contributions of each of the large sub-watersheds (North, Middle, and South Bosque) to the nutrient loads delivered into Lake Waco.

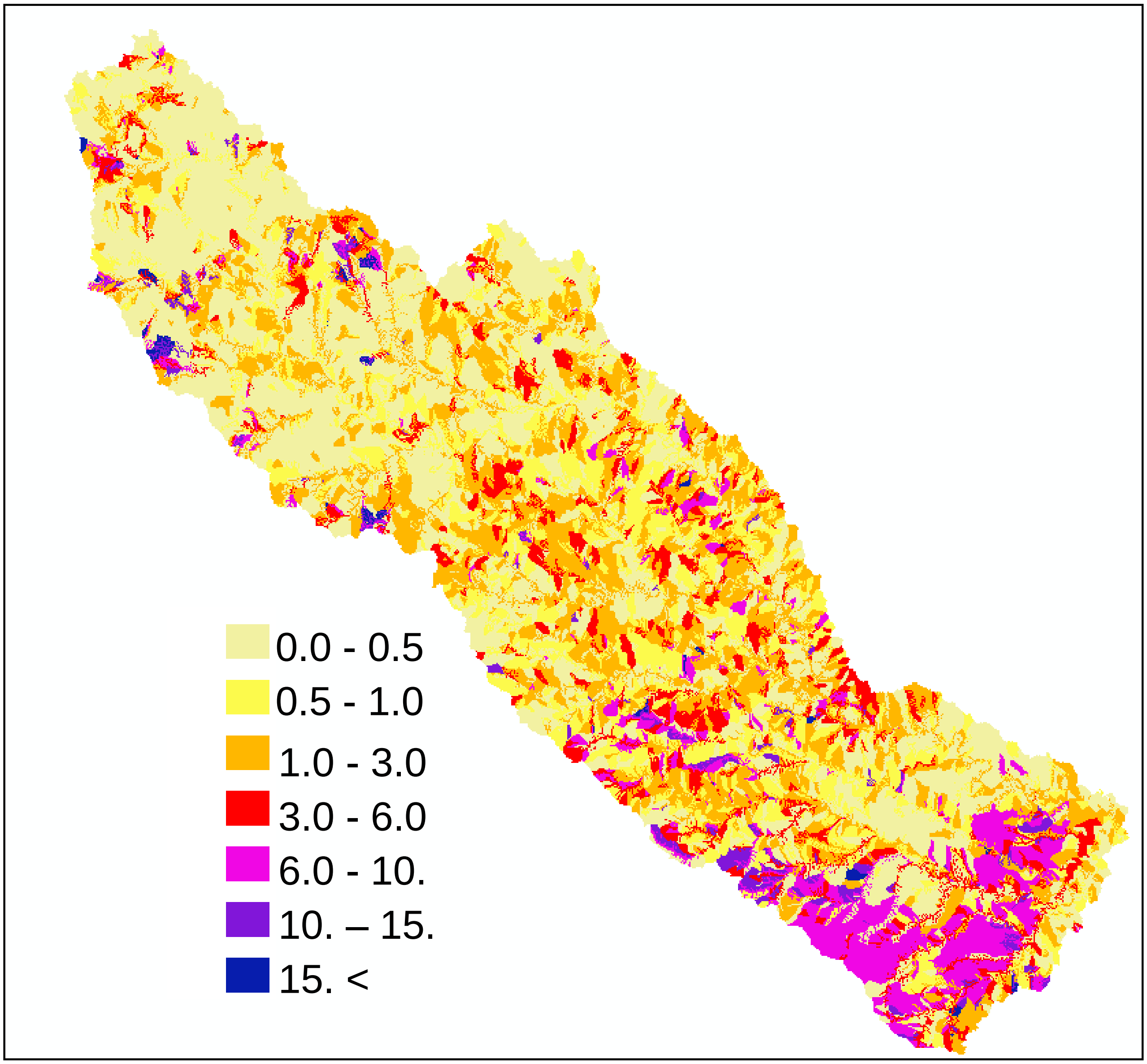

Figure 56. Baseline Total P in kg per ha

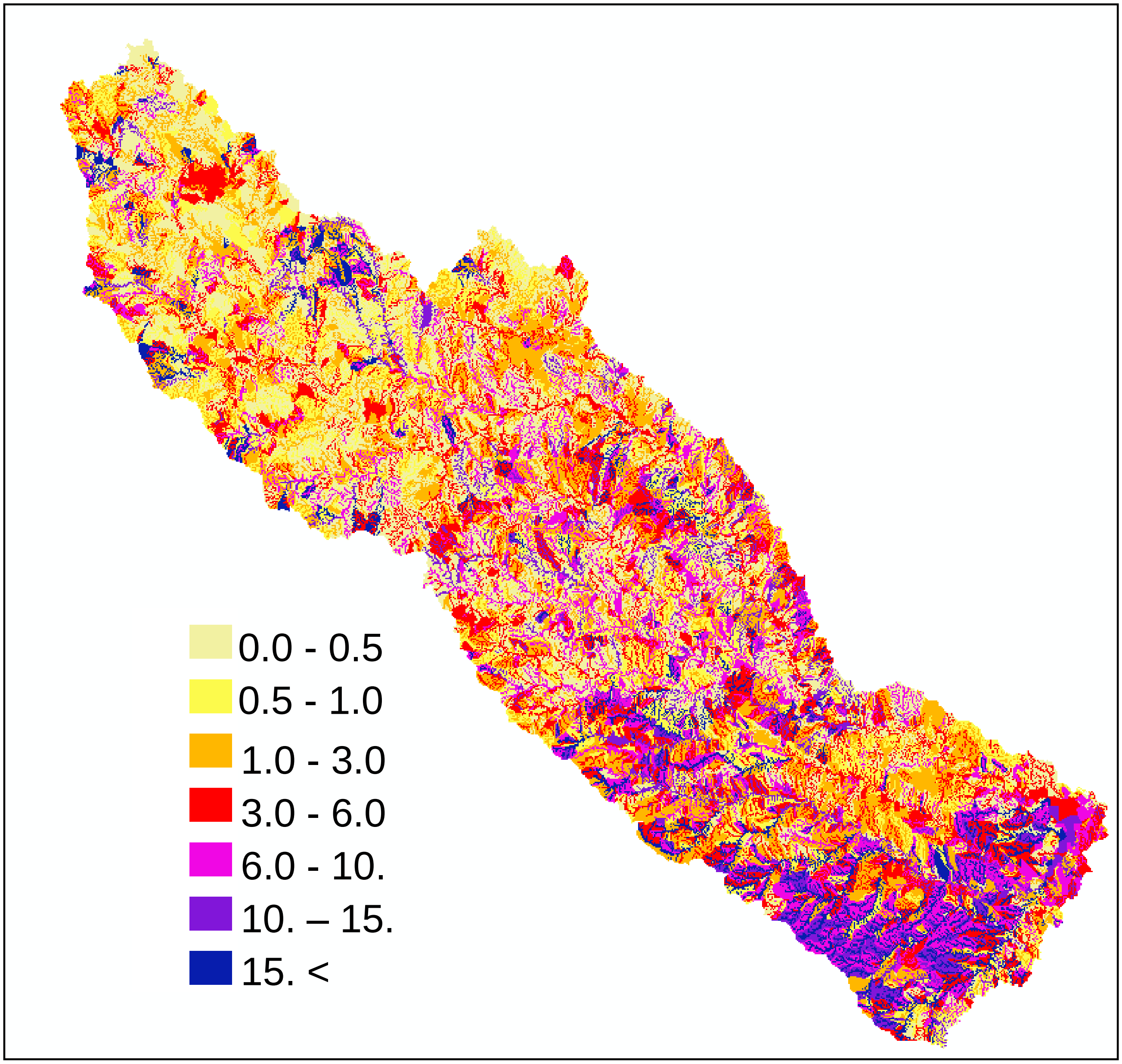

Figure 57. Baseline Total N in kg per ha

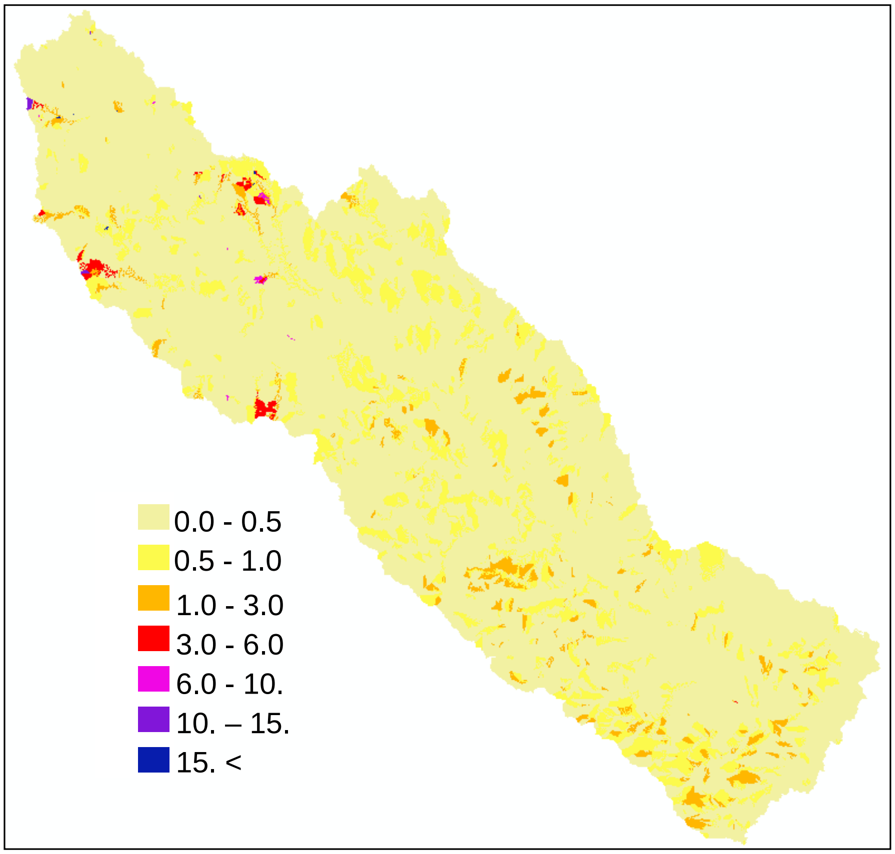

Figure 58. Baseline Mineral P in Water kg per ha

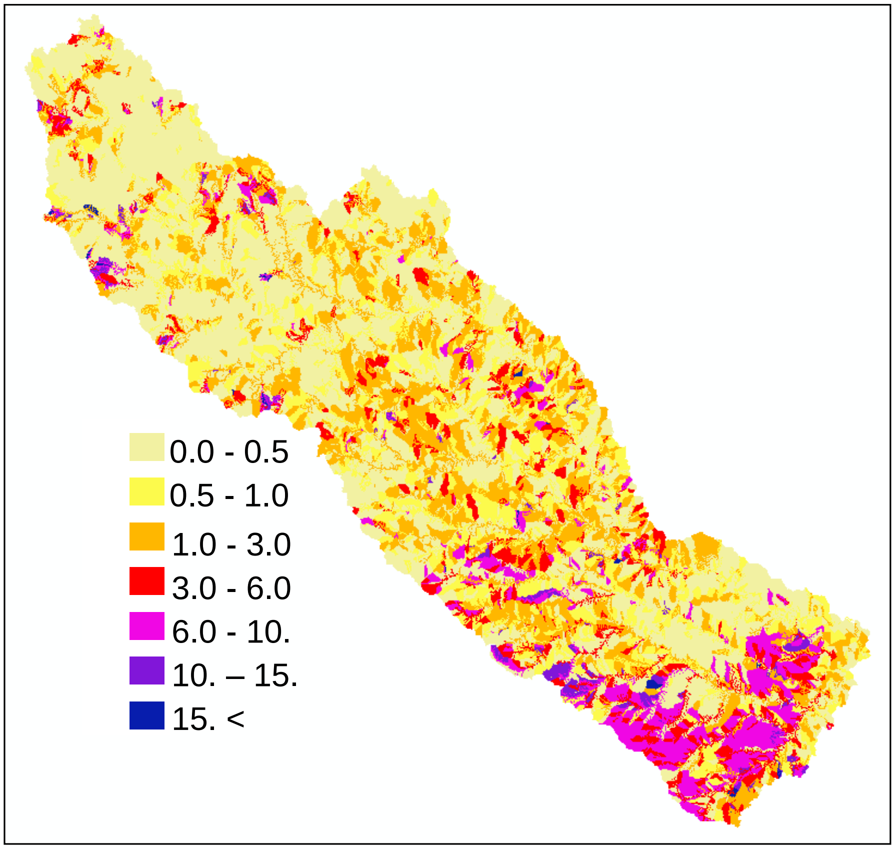

Figure 59. Baseline Organic P in Sediment in kg per ha

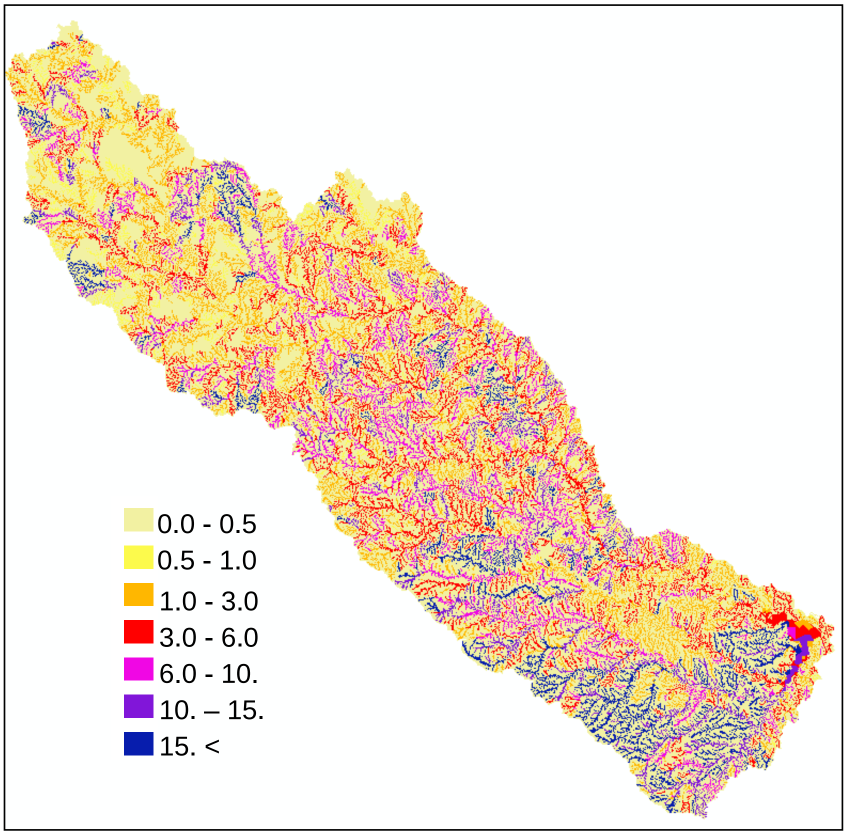

Figure 60. Baseline Organic N in Sediment in kg per ha

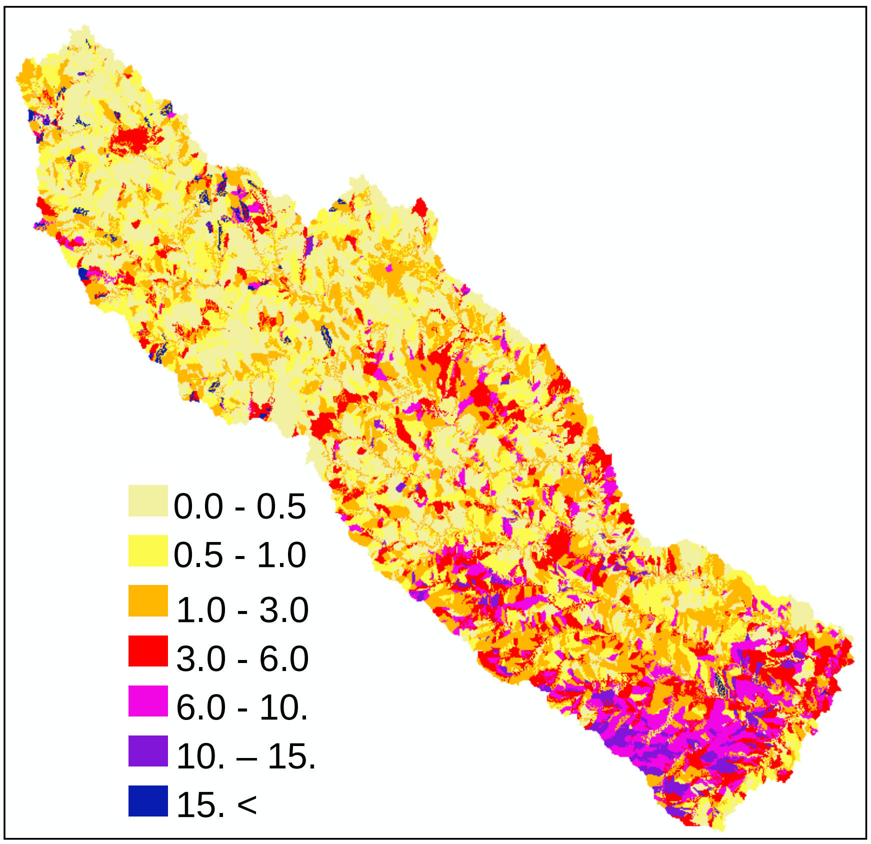

Figure 61. Baseline Mineral N in Water in kg per ha

Reservoir Impacts

Not only was the simulation of the impact of reservoirs important to the quantification of N, P, and sedimentation with and without the reservoirs presents, but it is also important as the reservoirs have a useful life and are filling with sediment. Understanding what happens to the watershed when the reservoirs are no longer functional is important to understand the future conditions of the watershed. The following tables describe the simulated current condition of the reservoirs and estimate the dam life under the baseline scenario. The conservation practices implemented and used on the land areas above each of the reservoirs have a significant impact on the overall life of the reservoirs and the ability of the reservoirs to mitigate future water quality flowing into Lake Waco

Results from the Analysis of Reservoir Structures

The introduction of the reservoirs into the area resulted in the following impacts reported here for the entire Bosque down to Lake Waco.

These 74 reservoirs protected only 27% of the watershed area. This is because these type reservoirs are traditionally built on small tributary streams off of the main channel of the river system. Even so they have a significant impact on the health of the entire basen.

Nitrogen attached to the sediment in the stream was reduced by 16% from 7 kg/ha to 5.9 kg/ha.
Phosphorus attached to the sediment in the stream was reduced by 13% from 1.6 kg/ha to 1.4 kg/ha.
Sediment delivery was reduced by only 5% from 2.0 mt/ha to 1.9 mt/ha
Soluble Nitrogen leaving the watershed was 2.0 kg/ha and dropped to 1.8 kg/ha.
Soluble Phosphorus was not changed from .24 kg/ha.

This analysis shows a reduction in N and P as a result of the construction of all impoundments. It is interesting to note the sediment delivery was reduced less than N and P. Possibilities include stream bank sediments being picked up as the basin waters are cleaned by the structures because of energy requirements of the flowing waters. A second explanation is suggested by observing the detailed output as the months with higher sediment delivery were during the non-growing season months and N and P loads were lower.

When the six new reservoirs were added to the watershed these new reservoirs were placed on the mainstream channel at the locations identified for the reservoir. This substantially increased the portion of the total watershed protected by reservoirs. This protected area increased from the previous 27% to 69% of the area.

Nitrogen attached to the sediment in the stream was reduced by 30% from 7 kg/ha to 4.9 kg/ha.

Phosphorus attached to the sediment in the stream was reduced by 25% from 1.6 kg/ha to 1.2 kg/ha.
Average Sediment delivery was not changed from the scenario without the six reservoirs remaining at only 5% from 2.0 mt/ha to 1.9 mt/ha.
Soluble Nitrogen leaving the watershed previously at 2.0 kg/ha dropped to 1.6 kg/ha.
Soluble Phosphorus changed only slightly from .24 kg/ha. to .23 kg/ha.

The graphics below report the predicted sedimentation for the NRCS reservoirs. These reservoirs have the most accurate information as to the time of construction and capacities of the reservoirs. Most were constructed in the 1960s. The model predicts these reservoirs have 50% or more of the principal spillway capacity still remaining after 40 years. The model also predicted that the reservoirs trapped approximately 60- 80% of the sediments coming into the reservoirs. These estimates and calculations are consistent with much of the literature dealing with reservoir and reservoir sedimentation.

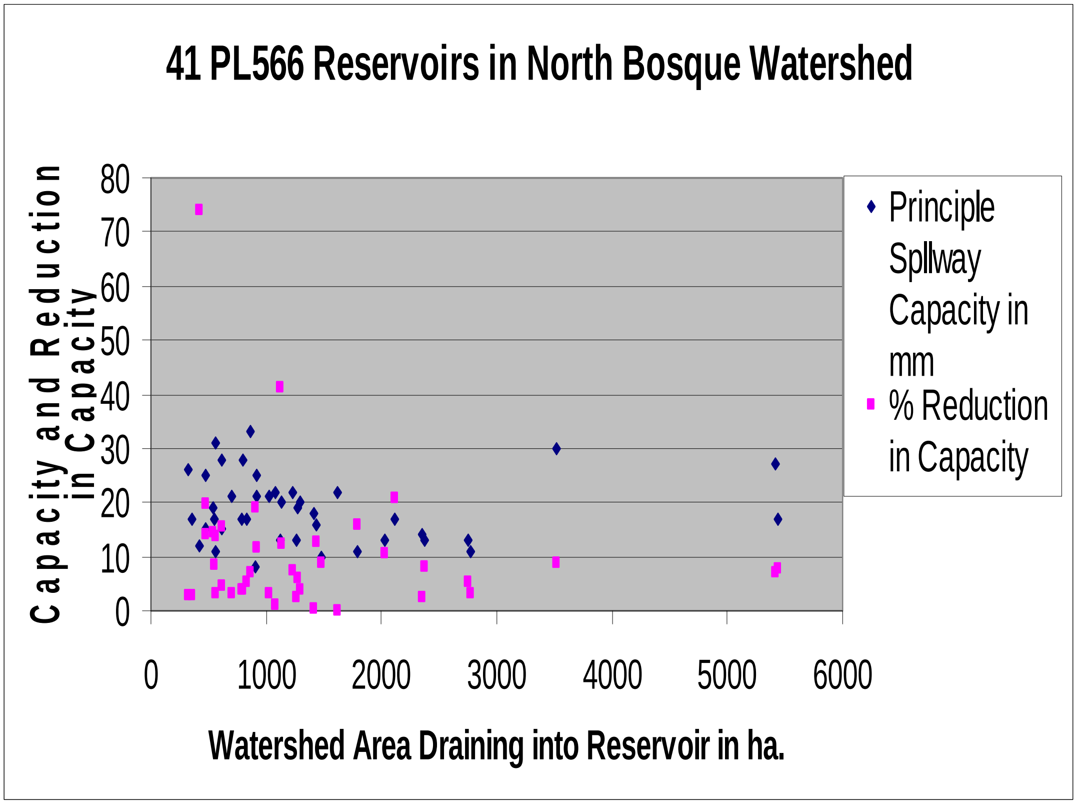

Figure 62. Watershed Area Draining into Reservoir in ha

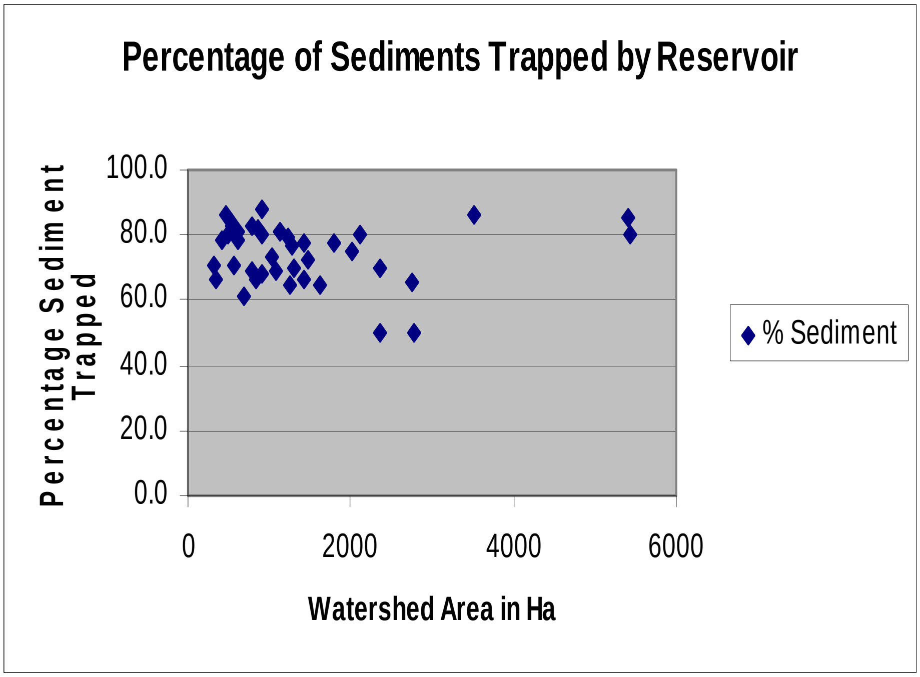

Figure 63. Sediment Trapped in NRCS Reservoirs

SUMMARY AND CONCLUSIONS

The objective of this study was to provide quantitative estimates of current and alternative practices (both onsite and offsite) of environmental benefits and costs for the North Bosque watershed with special emphasis placed on the manure management in the dairy areas of the watershed. This environmental accounting was to be expressed as loadings and concentrations of P, N, and sediments under three time periods and analytical assumptions: 1) current conditions (installed practices), 2) past and likely future conditions, 3) possible future conditions (alternative mixes of practices) that would reduce loading levels into Lake Waco.

The study area encompassed the Entire Bosque watershed above Lake Waco but concentrated on the North Bosque—the area where most of the dairies are located and the specific area mandated by this study. The larger area of the entire Bosque was reported in a special section to provide a comprehensive picture of the role the North Bosque plays in the entire Bosque Watershed.

The philosophy of the study design was to divide the Bosque basin into small enough sub units so as to let one sub-basin represent one field or pasture. After some experimentation a decision was made to try to divide the basin into somewhere around 15,000 sub-basins. Each of these basins was assigned to either an upper or a lower landscape position thereby allowing different management to be applied depending upon its position relative to the drainage net network.

There were two primary research tools used in constructing the analysis -- the Apex model and a GIS interface to manage the myriad of input and output data.

The APEX model is a comprehensive terrestrial ecosystem model developed for use in whole farms and watersheds analyses. It is a product of extensive physical/ environmental / hydrologic model development conducted over the past four decades by the United States Department of Agriculture-Agriculture Research Service (USDA-ARS) and the Texas A&M System's Texas AgriLife Research (formerly, Texas Agricultural Experiment Station) located in Temple, Texas. The model simulates the hydrological, biological, chemical, and meteorological processes of complex farming systems involving multiple crops, soil types, field delineations, and structural and agronomic conservation practices across the landscape

During the course of this study the code of the APEX model was modified to incorporate additional capabilities needed by this study. The version of the APEX model used is Version 0806. This is the version that was modified to support 64-bit processing. This larger computing capacity was required in order to handle the 15,000+ sub-watershed's needed by the model analysis for the Bosque watershed. This was the first study design to model a watershed exceeding 400,000 ha at a field scale level of approximately 26 ha per sub-area..

As the model runs on such a fine scale, and since farmer practices are a moving target, the decision was made to randomly locate the EQIP practices on appropriate land use areas and make no attempt to match these specific practices to the specific location in which they were actually applied.

Summary Statements on the North Bosque Watershed

This study was done assuming that the watershed has 61 permitted dairies with 39,825 confined dairy cows.

Twenty scenarios were modeled. Scenario 1 represents the current conditions in the watershed; Scenarios 2 - 6 represent various dairy manure application rates simulating different stages of nutrient management. Scenarios 7-8 represent the natural condition of the landscape without reservoirs, livestock or cropland. Scenarios 9-10 represents the condition of the watershed if the reservoir structures were not present on the landscape.: Scenarios 11-12 represents the conversion of additional cropland to improved conservation practices and the conversion of pastures to improved pasture grasses. Scenarios 14-20 repeat the crop and manure management practices with the addition of 6 new reservoirs into the watershed landscape.

Baseline conditions were identified that reflected the conditions as of the late 1990s since this was the time period for which calibration data was available. Simulations were conducted for the 40 year period 1965 through 2004. The model code is not designed to incorporate changing management conditions as the simulation progresses. We had to choose a set of conditions that would be static for the simulation. Also the data used for the calibration time period reflected changing management conditions. Therefore, it becomes difficult in the calibration process to simulate the appropriate conditions. For this reason we chose a shorter time period for which the calibration data was available (Jan 1993-July 1998) as the baseline time period for calibration.

The model was calibrated to stream flow information at Hico, Texas. This location was chosen because Hico had the most complete set of stream flow information available thereby providing the best location for calibration and validation. In addition, Hico is located very near the middle of the Bosque watershed but below the major dairy areas found in the region. The model was calibrated such that the simulated monthly stream flow, sediment yield, and nutrient losses compared well with observed values for the location. It should be noted that the calibration of the APEX model differs from the calibration of many other models. For the APEX model only the primary parameters are adjusted. These are single numbers for each of the coefficients. Each coefficient applies to the entire basin. There is no provision for “fine-tuning” the individual sub-areas.

The scenario that represented the most complete set of practices for improving the overall health of the watershed was identified as DWMA-NRC-1. This includes the addition of the new reservoirs, the removal of half of the manure, the distributions of the water to prevent channelization before leaving the field, and the application of manure to all parts of the waste application fields. As was reported the application of the manure to the lower portion only did not provide any identifiable improvements. At the mouth of the North Bosque watershed, this scenario reported an improvement in the organic P of 30.5%, of mineral P of 21.5%, of total P of 28.6%, and of total N of 29.7%.

The exercise of dividing the watershed into very small sub-basins for modeling purposes (in this study 15,000 watersheds averaging about 26 ha per sub-area) provided a clear demonstration of the ability of targeting a small percentage of the total land area to make a significant improvement in watershed health and nutrient loadings into large lakes such as Lake Waco. The majority of the practices of this study targeted the waste application fields near the dairies in the northern part of the watershed. These areas accounted for less than 14% of the total land area drained by the Bosque River.

The most significant implications of this study can be given in three summary statements. First, any conservation practice that causes divergence of the runoff water over the landscape slowing the channelization of the water will improve the quality of the water eventually reaching the stream. The APEX model can quantify these improvements when the sub-basins are small enough to represent fields and the sub-basins are divided into the upper and lower landscape positions for model simulations. Second, the removal or hauloff of a portion of manure from the basin does have a significant impact on the nutrient loads reaching the streams in the watershed. The magnitude, of course, will very with the size of the area dedicated for the purpose of manure application. Third, the careful placement of a small number of new reservoirs in a watershed that protect previously unprotected regions of the watershed that contribute nutrient loadings to the stream can significantly improve the water quality in downstream water supplies.

Lessons learned about Modeling Methodology

There are several lessons worth noting as a result of this study. The creation of a very large number of sub-watersheds each representing a field highlights several issues. Firstly, the effort to model the actual landscape information requires a specific assignment of soils, land-use, management, etc. for large watersheds, as was studied here, is an extremely difficult task specifically for the assignment of management practices. In addition, since the model identifies the individual fields, issues pertaining to individual farms and farm practices arise. General studies of this nature cannot (restricted by law-disclosure issues) and should not presume to accurately describe the practices applied to individual fields. Therefore, studies of this nature must be designed to address practices that are appropriate for individual fields but not presume that these practices are, in fact, found on that field.

Secondly, the above being said, the methodology does not preclude the fact that the model is capable of addressing environmental impacts when the true conditions about the field are in fact known. The database in the model is set up in such a way that the data could be easily modified to address specific issues on specific areas for the purpose of developing specific practices for an individual farmer or area. NRCS field persons, therefore, could use it as a planning tool to quantify the on-site and off-site impacts of potential conservation designs.

Thirdly, although it may be difficult to set up a modeling database using the methodology and structure of this study, once the analytical tool is in place it can be used in the time efficient and cost effective program to address many questions associated with the environmental issues and watershed health of a watershed the size of the Bosque River. In other words, the useful life of the analytical tool is much longer than for many traditional research studies.

Fourthly, the tool can be used to screen locations and evaluate the impact of structures such as reservoirs on the watershed. This is a cost-effective way to quickly address many alternatives as to the placement, size, and number of reservoirs being considered for mitigation of stream quality and quantity. As was done in this study, the reservoirs size and capacity can be back calculated to reflect the catchment areas above the proposed placement location.

Recommendations

There are several recommendations we would wish to submit as a result of this study.

Firstly, we recommended NRCS continue to develop new and creative conservation practices that will disperse the water and slow runoff water concentration. These should be in the form of modified buffer technology but with the object of increasing the land area used for the buffering activity to include large areas of the lower landscape position. As these practices are developed they should be implemented and tested on appropriate waste application areas.

Secondly, we recommend for the North Bosque that the current practice of composting and hauling manure from the watershed be continued and encouraged. The continued use of this practice provides a significant contribution toward the reduction of nutrient loads flowing from the watershed.

Thirdly, we recommend that the action agencies like in NRCS, Corps of Engineers, and other agencies seriously consider the feasibility of constructing additional reservoirs for the purpose of protecting Lake Waco from previously unprotected areas contributing runoff and nutrient loads into the watershed. We feel this may be a cost-effective practice that could substantially improve the water quality in Lake Waco.

Fourthly, we recognize the time, effort, and public funds dedicated to the development of this analytical tool are substantial. We recommend that this tool, including the databases used in these analyses, remain active and available to others wishing to do further studies and evaluate additional conservation practices appropriate for the Bosque River Watershed.

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