

Chapter 15

A Tiered Approach to Nitrogen Management: A USDA Perspective

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USDA NRCS FIELD-LEVEL PLANNING

The USDA Natural Resources Conservation Service (NRCS) is a federal agency that employs over 10,000 staff members to provide technical assistance to landowners in managing their natural resources of soil, water, air, plants, and animals. The USDA NRCS has a technical presence in nearly every county in the US. NRCS employees and their conservation partners from state and local agencies and non-

governmental organizations provide one-on-one conservation advice to landowners concerning their management of private lands. As a part of this technical assistance, NRCS offers advice and planning assistance for utilization of nutrients on the land, including efficient use of nitrogen.

Nutrient Management Conservation Practice Standard

Nutrient management is defined as the managing of the rate, timing, form, and method of nutrient application to ensure adequate soil fertility for plant production and to minimize the potential for environmental degradation, particularly water quality impairment (Delgado and Lemunyon, 2006). Nutrient management includes the implementation of management techniques that permit efficient crop production while protecting natural resource quality. Nutrients are considered any element or compound essential for plant growth, derived from various sources, and planned for application, particularly the major elements nitrogen, phosphorus, and potassium.

Nutrient sources can be any material that contains essential plant nutrients, such as fertilizers, animal manures, biosolids, and irrigation water. NRCS has developed a National Conservation Practice Standard for nutrient management (Code 590, <ftp://ftp-fc.sc.egov.usda.gov/NHQ/practice-standards/standards/590.pdf>). Coupled with the NRCS Nutrient Management Policy (<http://www.nrcs.usda.gov/technical/ECS/nutrient/gm-190.html>), each state across the U.S. has a state-specific conservation practice standard for nutrient management (Code 590). These state-specific conservation practice standards address the local issues and conditions found in different regions of the country and reflect the state-specific land-grant university information. The NRCS website for Nutrient Management (Code 590) for each state can be found at <http://www.nrcs.usda.gov/technical/efotg/index.html>. In each step of nutrient management planning, NRCS planners, landowners, and land users must balance the tasks of meeting the nutrient requirements of the crop with limiting the impact on the environment.

NRCS does not develop fertilizer recommendations (commonly referred to as “fert recs”) for the application of nutrients, but instead relies on the individual state land-grant universities to make recommendations on nutrient application rates for individual crops. The land-grant universities have a history of field research on nutrient utilization for most major crops grown in their states. NRCS also does not dictate any material sampling (soil, plant, manures, fertilizers, or water) and analytical testing procedures other than what is acceptable to the land-grant university. NRCS specifies that nutrient planning shall be based on current soil test and tissue test results (results less than five years old) developed in accordance with the land-grant university guidelines, or industry practice if recognized by the land-grant university. NRCS’s roles in nutrient management are as follows:

- Evaluating environmental risk associated with nutrient recommendations for soil fertility and plant production
- Developing appropriate mitigation alternatives to minimize environmental risks related to the management of nutrients
- Assisting clients in the development and implementation of an integrated nutrient management component of their overall conservation plan

Nutrient Management Plans

Nutrient management plans are documents on record that indicate how nutrients will be managed for plant production. These plans are prepared with the assistance of the planner for use by the producer or landowner. Plans are developed in compliance with all applicable federal, state, and local regulations. Nutrient management plans are developed in accordance with the technical requirements of the NRCS Field Office Technical Guide (FOTG) using land-grant university guidelines, the above mentioned agency policy requirements, and guidance found in the NRCS *National Agronomy Manual* (NAM Part 503; <http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17894.wba>). Nutrient management plans may stand alone or be an element of a comprehensive nutrient management plan (CNMP), which includes aspects of the livestock operation. The established guidelines of a CNMP can be found at <http://www.nrcs.usda.gov/technical/afo/>.

Nutrient management plans contain the following components:

- Aerial site photograph(s) or site map(s), and a soil survey map of the site
- Location of designated sensitive areas or resources and any associated nutrient management restriction
- Current and/or planned plant production sequence or crop rotation
- Results of soil, water, manure and/or organic by-product sample analyses
- Results of plant tissue analyses (when used for nutrient management)
- Realistic yield goals for the crops to be grown during the planned period
- Complete nutrient budget for nitrogen, phosphorus, and potassium for the crop rotation or sequence
- Listing and quantification of all sources of nutrients used to supply crop and soil nutrition
- Field-specific recommendations on nutrient application rates, timing, form, and method of application and incorporation
- Guidance for implementation, operation, maintenance, and recordkeeping

NRCS offers nutrient management planning assistance and works directly with landowners and land users to conserve nitrogen resources in the soil. This cooperative planning process includes the following components:

- Determining nitrogen needs of the crops to be grown based on growing conditions and realistic estimates of crop yields, or economic opportunity of return
- Predicting the nutrients available from the landscape through soil, water, manure, and plant analysis
- Developing a nutrient budget to determine the nutrients available and determining the amount that meets the nutrient requirements of the crop
- Determining sensitive resource areas where erroneous application of nutrients could impact the environmental condition
- Developing a plan for the proper rate, timing, form, and method of nutrient application
- Developing and providing the methodology for being able to adapt the management criteria of nutrients based on post-harvest, pre-plant, or in-field monitoring and analyses

EXAMPLE OF A TIER ONE APPROACH

Nutrient Management as Part of Conservation Planning

Traditionally, nutrient management has been seen as a standby or temporary source of nutrient supply, yet conservation can lower nutrient demand without reducing yields. Conservation can save practitioners money and even has the potential to increase economic returns. Implementing conservation practices often improves the efficiency of nutrient use. More biomass and/or grain can be harvested for the same nutrient input. Lowering the nutrient demand can also reduce the likelihood that these practices will impact the environment. Another benefit of nutrient conservation is that it results in fewer products or materials that need to be stored, transported, and distributed over the agricultural landscape. This increased efficiency leads to savings in time and energy, in addition to the aforementioned economic returns.

NRCS field staff and consultants need a simplified, robust $\text{NO}_3\text{-N}$ leaching assessment tool that can quickly estimate the vulnerability of agricultural fields to nitrogen losses that could contaminate off-site surface and ground water. The complexity of the nitrogen cycle, with the many potential sources and sinks for N, makes reliable calculation of amounts of N in real-time conditions almost impossible without the use of computer simulation models and reliable soil and climate databases.

Within the conservation planning process, the NRCS staff develops a working relationship with the landowner to supply the appropriate natural resources information that is pertinent to inventory and assess the agricultural operation. This resource information will contain local

and regional data that describe the situation on the land. However, as specific as the data may be, they may not be able to give the specific quantitative amounts of nutrient available to perform certain conservation planning processes. This information on field-by-field management must be captured in real-time so adaptive measures can be taken.

A Tiered Approach to Conservation Planning

A tiered approach to conservation planning has been proposed by Shaffer and Delgado (2002). A Tier One tool like the Phosphorus Index (Lemunyon and Gilbert, 1993) or a leaching index or nitrogen index would allow for the use of readily available local inputs from the producer's field. Williams and Kissel (1991) developed an index to calculate water movement through the soil based on amount of yearly rainfall, soil percolation, and rainfall during the non-growing period of the year. This calculation, called the Leaching Index (LI), actually estimates the leaching of water down the soil profile.

The idea of developing a nitrogen risk assessment tool is not new; in fact, it has been discussed for several years within the scientific community (Shaffer and Delgado, 2002). NRCS field personnel have been asking for an easy-to-use, field-level tool that would evaluate the potential risk of nitrogen losses at a particular site. The Nitrogen Index Tier One Tool concept would perform additional functions beyond the existing Williams and Kissel (1991) Leaching Index, which only assesses the potential movement of water through the soil profile.

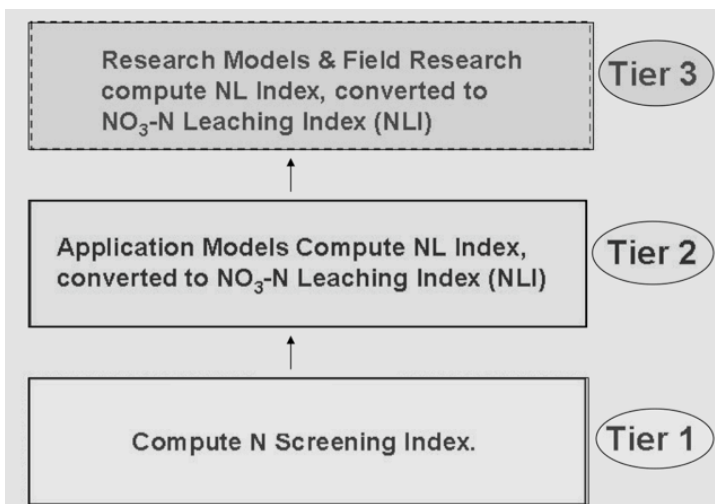


Figure 1. A tiered approach to nitrogen management (from Shaffer and Delgado, 2002).

The information needed for a Tier One risk assessment tool should be readily available, field-scale information that can be gathered during a farm visit. By using simple data, generalizations can be made and simple risk assessments can be performed in a few minutes (Shaffer and Delgado, 2002, Figure 1). Previous work has attempted to account for various soil and climate influences on nitrogen movement in the landscape. Shaffer and Delgado (2002) discussed the advantages and disadvantages of the Leaching Index (LI) and other available indexes. None of the available indexes had the flexibility and capabilities that the new quantitative/qualitative index developed by Delgado et al. (2006a, 2008a), included.

The Nitrogen Index

The Delgado et al. (2006a, 2008a) Nitrogen Index can account for landowner management practices conducted at the site, as well as off-site factors. Use of cover crops, rotations with deep-rooted crops, denitrification traps, and other best management practices used by the producer can be accounted for in the Nitrogen Index when assessing the risk of nitrogen losses (Delgado et al. 2006a, 2008a). The resulting index score will be reduced (indicating lower risk) if the conservation practices recommended by NRCS, state agencies, and universities, along with any other established effective practices, are applied. The Nitrogen Index is flexible in that it can also be applied to different states, regions, and/or countries (Delgado et al., 2006, 2008a; De Paz et al., 2009; Figueroa et al., 2009a, 2009b).

The Nitrogen Index (Delgado et al., 2006a, 2008a) is a parallel to the Phosphorus Index (PI) as a relative risk assessment tool that would provide field guidance for determining the potential movement of nitrogen in the landscape. The Delgado et al. (2006a, 2008a) Nitrogen Index can consistently and systematically make assessments over various landscapes and cropping systems. This relative assessment provides an index number (not load or concentration) where higher scores indicate a greater risk for N movement.

Nitrogen Index loss pathways include surface transport of nitrogen via runoff and erosion, atmospheric losses due to denitrification and ammonia volatilization, and nitrate leaching losses. Each one of the loss pathways is assessed separately. The score of the separate assessments can be used to determine the severity of natural resource concerns and to develop mitigation strategies for conservation practices and management techniques. Individual movement risk category scores rated as “high” would provide categorical targets for further review or mitigation.

Site characteristics include soil factors, hydrology factors, climate factors, N management factor, sink factors, and crop management (conservation practices). For details on each of these site characteristics, review Shaffer and Delgado (2002) and Delgado et al. (2006a, 2008a). Site characteristics would be readily available at the field level, shared by the

producer, or contained in existing databases. Users of this tool would be NRCS field office staff, conservation partners, private technical service providers, other natural resource personnel, both national and international (Delgado et al., 2006a; De Paz et al., 2009; Figueroa et al., 2009a, 2009b).

NRCS has collaborated with the USDA Agricultural Research Service and land-grant university partners on the development of a conceptual framework for the N Index. This process continues and NRCS stands willing to review new or current prototypes to continue the development of future versions of Tier One Tools that incorporate the most recent advances in science. A new web-based version of the Nitrogen Index is in development that will facilitate and extend the applicability of the Index. If needed, a process model (Tier Two or Tier Three tool) capable of quantifying all of the movement categories could be applied following the N Index (Shaffer and Delgado 2002) for critical areas that require more precise evaluation.

EXAMPLE OF A TIER TWO APPROACH

Shaffer and Delgado (2002) described a Tier Two approach for conservation planning as one that involves a more precise tool, such as a simulation model that considers daily time step intervals in its evaluations, but the overall Tier Two approach with somewhat generic inputs is still much simpler than a Tier Three approach that applies a scientific research model on an individual site. NRCS is one of the many users of the NLEAP computer simulation model, a Tier Two tool. The NRCS provides technical assistance along with soil and water conservation and natural resources management to private landowners throughout the nation. Using the NLEAP model, NRCS technical staff can provide information to assess the impact of implementing soil and water conservation practices on the loss of nitrogen from the farming system (Shaffer et al., 2006; Delgado et al., 2006a).

NLEAP allows the conservation planner to look at specific pathways for nitrogen loss with the producer, such as ammonia volatilization or nitrate leaching losses below the root zone within a specific farming system, and assesses the benefits of implementing conservation practices and best management strategies to control those specific losses. At the national level, the model can be used to develop appropriate management scenarios that fit different geographic regions of the country. For watershed level planning, the NLEAP model will allow the producers in the watershed or basin to target the most vulnerable areas by applying conservation practices and best management strategies to lessen the risk of nitrogen movement. And, for the producer, the model can help fine tune specific rates, timing, forms, and methods of nitrogen applications at the field scale to reduce losses to the environment while maintaining desired crop production.

The latest version of this model, NLEAP-GIS 4.2, is an effective and user-friendly tool with the potential to be used at a national and international level (Shaffer et al., 2010; Delgado et al., 2010). USDA NRCS technical staff has been using Nitrogen Losses and Environmental Assessment Package (NLEAP) since the NLEAP DOS version was published in the early 1990s. Recently, NRCS has cooperated in testing and using the more advanced version of the NLEAP-GIS for several different applications to accomplish the following:

- Assess the effects of management scenarios on N dynamics and losses (Shaffer et al., 2006; Delgado et al., 2006b).
- Develop and conduct national workshops to train technical personnel in nitrogen management techniques and procedures that protect water quality.
- Develop and implement the concept of a national nitrogen trading tool (Delgado et al., 2008a).
- Apply the concept of a tiered approach, as described by Shaffer and Delgado (2002).

This tiered approach, which has been used by the NRCS, starts with a Tier One N index for a quick analysis. In cases where N management practices need a more detailed assessment, a Tier Two model such as NLEAP (Shaffer and Delgado, 2001, 2002) is used.

Nutrient planners from the NRCS have cooperated in the implementation of several national training meetings and workshops where they have trained USDA and international nutrient planners in the use of NLEAP and the N Index (Shaffer et al., 2006; Delgado et al., 2006b). These trainings (with continuing education units) have been offered at national meetings of professional societies such as the Soil and Water Conservation Society (2006) and the Soil Science Society of America (2006).

NLEAP APPLICATIONS

The USDA NRCS has worked on several projects using NLEAP. The following case studies are examples.

Case Study I. Using NLEAP for Conservation Planning: A Case Study in Goshen County, Wyoming, North Platte River Watershed (2001)

The area of Goshen County, located along the North Platte River, has a history of irrigation water shortages and high levels of nitrates in the ground water. The historic diversion rates of the canals in the project area have been insufficient to meet the water demands of irrigated crops. Nitrogen in the ground water has been a problem in Goshen County for many years. The towns of Lingle, Ft. Laramie, and Torrington receive their drinking water from an alluvial aquifer. These towns have had begun testing wells for nitrate-nitrogen concentrations because some

have exceeded the maximum contaminate level (MCL) of 10 mg L⁻¹ nitrate-N set by the United States Environmental Protection Agency in the 1972 Clean Water Act (<http://www.epa.gov/watertrain/cwa/>). The common alluvial aquifer may affect the groundwater quality in these North Platte River Valley towns.

Nitrates can leach rapidly through the predominant soils in the watershed (Dunday, Dwyer, and Haverson soils). These soils have permeability rates greater than 6.2 inches per hour. NRCS has assigned a leaching potential of "high" to these soils by results of the Leaching Index. The Wyoming Water Research Center (WWRC) conducted a study to determine ground water vulnerability in Goshen County. The WWRC study indicated that the North Platte River alluvial deposits found within the watershed are highly vulnerable to leaching.

The NLEAP model was used by NRCS staff in Wyoming to analyze the nitrate leaching potential of the soils in the watershed. The analysis was based on the crops in rotation with the greatest nitrogen requirements (corn and sugar beets). A database for the corn and sugar beet rotation was developed as a test data source to generate simulation results for the watershed. This database was developed for a period of 7 years. Database parameters include crops; type of tillage system (conventional plow); all tillage operations from seedbed preparation to harvest; irrigation type (flood, sprinkler); amount of irrigation water applied at each irrigation; fertilizer type, rate, and method of application; dates of each operation including irrigation; residue amounts after harvest; and percent ground cover after each tillage operation.

For this case study, a rotation of corn and sugar beets was used on the sandy soils under a conventional spring plow tillage system. The same tillage operations for seedbed preparation, cultivation of the crop and harvesting were entered into the database. NLEAP simulated flood and sprinkler irrigation, which changed the amount of irrigation water applied. Different fertilizer management practices such as a single application at planting, split applications during the growing season, and sprinkler application (fertigation) were evaluated.

The NLEAP simulated values are presented in Figure 2. The advantages of using sprinkler irrigation and split application are shown by model results with significant reduction of nitrate leaching. Converting to a sprinkler system is advantageous for reducing nitrate leaching from 246 to 121 lb NO₃-N acre⁻¹. If the N fertilizer application is split, the nitrate leaching is reduced to 110 lb NO₃-N acre⁻¹. Due to higher N use efficiencies and lower nitrate leaching, there is potential to cut back the N fertilizer rate without reducing yields. These studies by NRCS in Wyoming are in agreement with other studies by Wylie et al. (1994, 1995) using NLEAP, and by Delgado and Bausch (2005) for northeastern Colorado. The NLEAP program helped NRCS Wyoming in their conservation efforts by using a Tier Two tool to assess the effect of management plans and conservation practices on the risk of nitrogen losses to the environment at a site-specific location within the watershed.

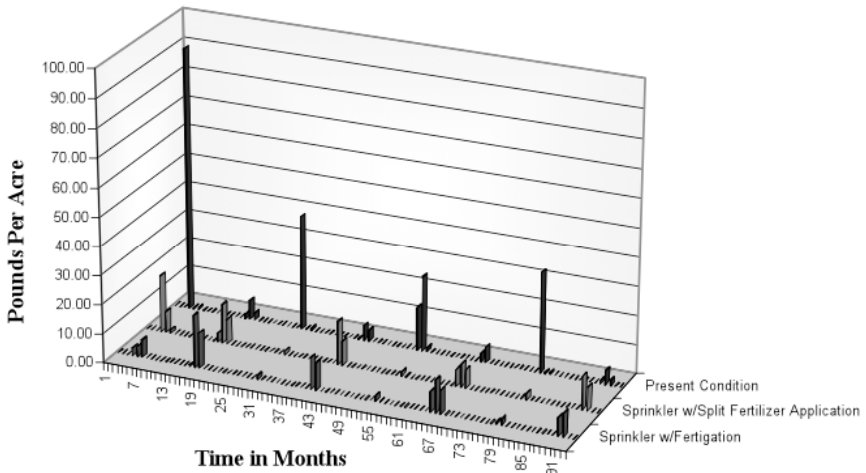


Figure 2. An NLEAP evaluation of the effect of conservation practices on a corn sugar beet-potato rotation in Wyoming’s North Platte River watershed. The USDA NRCS and Agricultural Research Service cooperation found that higher nitrate leaching was observed for the present furrow irrigation conditions. Implementation of center pivot irrigation or center pivot irrigation with split nitrogen applications (fertigation) will contribute to lower nitrate leaching losses.

Case Study II. Applications of the New NLEAP-GIS Model

The NLEAP-GIS model is being applied in efforts to solve N management issues in the ongoing cooperation with the NRCS National Water Management Center and Arkansas State University. The new NLEAP-GIS model is being used to assess the effect of management practices in the Mississippi River Delta of East Arkansas. Field data have been collected over the last three years on cropping systems in the study area. Sample data include crop type, type of tillage systems, planting and harvesting dates, types of irrigation and dates/amounts of application, nutrient application rate, type and method, crop yields, residue amounts after harvest, and percent ground cover at planting. Workshops have been conducted with the new NLEAP-GIS model in cooperation with NRCS at the Arkansas State University to test and validate the model (Figure 3). These workshops and preliminary data show that improving best management practices that reduce N inputs can reduce nitrate leaching in the East Arkansas Delta. Additionally, rotations with soybeans that account for N cycling from the soybean crop residue will also help to minimize leaching in these irrigated fields and improve nitrogen use efficiency (Figure 4). Improving conservation planning across these fields could reduce environmental N losses.



Figure 3. An NLEAP-GIS workshop conducted in cooperation with the NRCS National Water Management Center, Arkansas State University and USDA Agricultural Research Service.

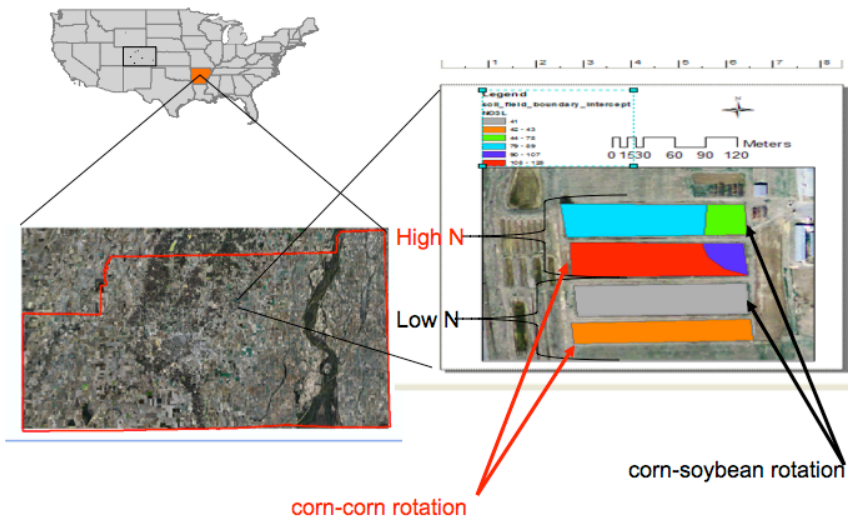


Figure 4. An NLEAP-GIS evaluation of the effect of conservation practices in the Arkansas Delta. The NRCS National Water Management Center, Arkansas State University, and USDA Agricultural Research Service cooperation found that higher nitrate leaching was observed for excessive nitrogen fertilizer applications. Introduction of a leguminous crop in the corn-soybean rotation helps to minimize nitrate leaching in this region when nitrogen credits are also given for the leguminous crop residue.

NEW OPPORTUNITIES

Market-based conservation, including water quality trading, promises to be another opportunity for the use of computer simulation models. The NLEAP-GIS model is being used to assess the potential for conservation practices to be used in nitrogen credit trading. NRCS supports the use of these new concepts that are applied to the Nitrogen Trading Tool and their potential applications for natural resource assessment and conservation planning (Delgado et al., 2008b; 2010; Gross et al., 2008). The conceptualization, design, interpretation, and results/reporting framework related to a Nitrogen Trading Tool (NTT) concept was jointly developed by USDA Agricultural Research Service and NRCS (Delgado et al., 2008b, 2010; Gross et al., 2008). This framework can be used to assess and reduce losses of reactive N to the environment. The framework uses a pair of model simulation runs to calculate the benefits of a new management practice against a given baseline scenario over a long-term period (24 years), in order to estimate environmental benefits over time.

NRCS applied this original concept and prototype developed with NLEAP to the Agricultural Policy Environmental Extender (APEX), which simulates the day-to-day farming activities, wind and water erosion, loss or gain of soil organic carbon, and edge-of-field losses of soil, nutrients (N & P), and pesticides. APEX, a Tier Three tool, can assess a wider range of conservation practices (such as buffer strips, fencing, and wetlands) (Figure 5). NRCS has extensive experience using APEX in the Conservation Effects Assessment Program (CEAP), a multi-agency effort to quantify the environmental benefits of conservation practices used by private landowners in selected conservation programs (<http://www.nrcs.usda.gov/technical/nri/ceap/>).

Through USDA's Conservation Innovation Grant (CIG) funding, Texas Institute for Applied Environmental Research (TIAER) staff developed APEX-NTT as an augmentation of NLEAP-NTT that could only estimate nitrogen credits. APEX-NTT provides farmers, government officials, and other users with a fast and efficient method of estimating nitrogen and phosphorus credits for water quality trading, as well as other water quality, water quantity, and farm production impacts associated with conservation practices (Saleh et al., 2010). The information obtained from the tool will allow farmers to determine the most cost-effective practice alternatives for their individual operations and provide them with rigorous, science-based environmental options in a water quality credit trading program.

The new APEX NTT prototype is currently being expanded for application across the USA. The NLEAP-GIS Nitrogen Trading Tool, which provided the proof of the concept and validated the basic framework, still provides a rigorous reference for comparison to the APEX NTT and other future nutrient trading tools that may become available.

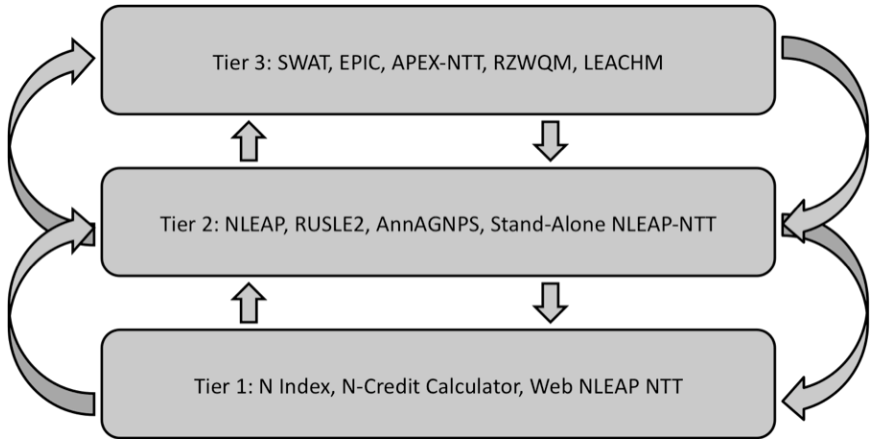


Figure 5. Tiered approach to using tools for nitrogen management. USDA Natural Resources Conservation Service tiered approach to technology tool development concept schematic.

CONCLUSION

Computer simulation models are very useful tools for the following:

- Assessing the potential for farm management practices to impact natural resources
- Quantifying the potential for conservation practices to prevent or mitigate those impacts
- Targeting conservation practice application to the most vulnerable acres in order to prevent nutrient losses to the environment

The NRCS continues to use computer simulation models such as NLEAP-GIS, APEX, and NTT technologies to help assess and protect natural resources for a healthier environment.

Tier One risk analysis tools such as the Nitrogen Index are being developed as field-based or first level tools that can consistently and systematically assess nitrogen status across various landscapes and cropping systems. Continued development and use of Tier One technology tools, coupled with the scientific underpinnings of computer simulation models such as NLEAP and APEX for verification, will be instrumental to applying sound nutrient management strategies with NRCS conservation planning technical assistance and conservation programs.

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