Employing Best Management Practices to Reduce Agricultural Water Pollution: Economics, Regulatory Institutions, and Policy Concerns

by

Terence J. Centner, Jack E. Houston,
Clemens Fuchs, & Jürgen Zeddies

Originally published in DRAKE LAW REVIEW
45 DRAKE L. REV. 125 (1997)

EMPLOYING BEST MANAGEMENT PRACTICES TO REDUCE AGRICULTURAL WATER POLLUTION: ECONOMICS, REGULATORY INSTITUTIONS, AND POLICY CONCERNS

*Terence J. Centner**
*Jack E. Houston***
*Clemens Fuchs****
*Jürgen Zeddies*****

TABLE OF CONTENTS

I. INTRODUCTION

Nonpoint source water pollution generated by agricultural production is under increasing scrutiny and is considered a major environmental issue in

* Professor, University of Georgia. B.S., 1973, Cornell University; J.D., 1976, S.U.N.Y. at Buffalo; LL.M., 1982, University of Arkansas-Fayetteville.

** Associate Professor, University of Georgia. A.B., 1967, University of Washington; Ph.D., 1984, Washington State University.

*** Lecturer, Machhochschule Neubrandenburg, Germany. M.S., 1983; Ph.D., 1988, Universität Hohenheim, Germany.

**** Professor, Universität Hohenheim. M.S., 1966; Ph.D., 1969, Universität Goettingen, Germany.

the United States[1] and the European Union.[2] The pollution of water by agriculture may be categorized into three major groupings: erosion, nutrients, and pesticides. Although these groupings are distinct and may present different problems, each pollution issue contributes to the public's concern of water quality. A set of measures receiving considerable attention in the United States is "best management practices" (BMPs). Various definitions of BMPs exist, but all generally refer to practices determined to be the most effective practical means for preventing or reducing the amount of pollution generated by nonpoint sources to a level compatible with quality goals.[3] In theory, BMPs minimize water pollution through the application of ecologically sound conservation principles.

The first form of agricultural pollution in the United States to receive widespread attention was soil erosion. The Soil Conservation Service, created through federal legislation in 1935,[4] and subsequent soil conservation legislation, evolved to address erosion problems. Next, due to the discovery of pesticides in the groundwater in numerous locations in the United States,[5] considerable research was conducted to reduce pesticide use in the production of commodities.[6] Ongoing integrated pesticide management efforts are helping agricultural producers reduce their use of pesticides, and other scientific achievements are facilitating eradication programs, such as the

---

1. *See, e.g.*, George R. Hallberg, *From Hoes to Herbicides: Agriculture and Groundwater Quality*, 41 J. SOIL & WATER CONSERVATION 357, 357 (1986); Charles W. Abdalla et al., *Valuing Environmental Quality Changes Using Averting Expenditures: An Application to Groundwater Contamination*, 68 LAND ECON. 163, 163 (1992); SANDRA S. BATIE ET AL., NATIONAL GOVERNORS' ASS'N, MANAGING AGRICULTURAL CONTAMINATION OF GROUNDWATER: STATE STRATEGIES (1989).

2. *See, e.g.*, CENTER FOR INT'L FOOD & AGRIC. POLICY, FOOD, AGRICULTURE AND THE ENVIRONMENT 2 (1995); ICI Fertilizers-London Economics, *Assessing the Effectiveness and Impact of Policies Proposed for the Control of Nitrate in Water* (April 1990).

3. The Environmental Protection Agency defines a BMP as:

> [m]ethods, measures or practices selected by an agency to meet its nonpoint source control needs. BMPs include but are not limited to structural and nonstructural controls and operation and maintenance procedures. BMPs can be applied before, during and after pollution-producing activities to reduce or eliminate the introduction of pollutants into receiving waters.

40 C.F.R. § 130.2(m) (1996). States may also define BMPs in their legislation. *See, e.g.*, NEB. REV. STAT. § 46-657 (1993).

4. Act of Apr. 27, 1935, ch. 85, §§ 1-4, 49 Stat. 163-64 (1935) (codified as amended at 16 U.S.C. § 590a-d (1994)).

5. *See generally* AGRICULTURAL CHEMICALS IN GROUND WATER: SUMMARY MINUTES FROM THE 1987 PESTICIDE STRATEGY WORKSHOP (EPA Oct. 1987); AGRICULTURAL CHEMICALS IN GROUND WATER: PROPOSED PESTICIDE STRATEGY (EPA Dec. 1987); GROUNDWATER QUALITY: STATE ACTIVITIES TO GUARD AGAINST CONTAMINANTS (GAO/PEMD-88-5 Feb. 1988); Elizabeth G. Nielson & Linda K. Lee, *The Magnitude and Costs of Groundwater Contamination from Agriculture Chemicals*, AGRIC. ECON. REP. 576 (U.S. Dep't Agric. 1987).

6. *See generally* AGRICULTURE AND WATER QUALITY: INTERNATIONAL PERSPECTIVES (John B. Braden & Stephen B. Lovejoy eds., 1990); GARY W. JACKSON ET AL., FARMSTEAD ASSESSMENTS—A MEANS TO MANAGE FARM SOURCES OF GROUNDWATER CONTAMINATION (Office of Technology Assessment, May 1989); Lawrence Ng, *A DRASTIC Approach to Controlling Groundwater Pollution*, 98 YALE L.J. 773 (1989).

eradication of the bowl weevil in some U.S. states.[7] These and other biotechnological engineering efforts may be expected to reduce pesticide usage substantially in the future. More recently, pollution by nutrients, especially nitrogen[8] and phosphorus,[9] have caused concern.

This article addresses research in the United States and Germany concerning the use of BMPs, with an emphasis on nitrate pollution. The first two sections identify the legal institutions of the United States and Germany directly relating to BMPs. In the third section, BMPs prescribed for use in the state of Georgia are described and related to ongoing national research funded by the U.S. Department of Agriculture. The fourth section summarizes a pilot research project conducted in Georgia to reduce nitrate pollution. Reductions in irrigation and nitrogen fertilizer significantly reduce farmers' net revenues. Such voluntary measures are unlikely to be adopted without some type of subsidy. A more ambitious research study in Baden-Württemberg, Germany, showed that low compensatory payments to reduce nitrogen fertilization levels can reduce nitrate pollution. These research projects suggest that economics may preclude voluntary adoption of BMPs to reduce nitrate pollution.

II. U.S. LEGAL INSTITUTIONS

This section notes the major legal institutions in the United States that provide laws, regulations, and recommendations for the use of BMPs to reduce pollution. Further, a few other provisions addressing nonpoint source water pollution are identified.

A. *Section 319 of the Clean Water Act*

Section 319 of the Clean Water Act delineates federal requirements for nonpoint source management programs to attain or maintain applicable water quality standards for navigable waters.[10] Prior to possible amendments to this section in 1995, reports by each state were to identify significant nonpoint sources of pollution denigrating applicable water quality standards.[11] States were to develop a process for identifying BMPs and measures to control nonpoint sources of pollution, and to identify state and local programs for

---

7. *See* GA. COMP. R. & REGS. r. 40-24-1 to -9 (1994).

8. *See, e.g.*, James Stephen Carpenter, *Farm Chemicals, Soil Erosion, and Sustainable Agriculture*, 13 STAN. ENVTL. L.J. 190, 202-03 (1994); Susan A. Schneider, *The Regulation of Agricultural Practices to Protect Groundwater Quality: The Nebraska Model for Controlling Nitrate Contamination*, 10 VA. ENVTL. L.J. 1, 2-3 (1990).

9. *See, e.g.*, Andrew N. Sharpley et al., *Nitrogen and Phosphorus Fate from Long-Term Poultry Litter Applications to Oklahoma Soils*, 57 SOIL SCI. SOC'Y AM. J. 1131 (1993); Peter Passell, *A Free-Enterprise Plan for an Everglades Cleanup*, N.Y. TIMES, May 1, 1992, at B18; Nelson Antosh, *Texas Farmers Lured by a Bird*, HOUSTON CHRON., Apr. 2, 1995, at E1.

10. *See* 33 U.S.C. § 1329 (1994). For a description of the section 319 program, see Linda A. Malone, *The Necessary Interrelationship Between Land Use and Preservation of Groundwater Resources*, 9 UCLA J. ENVTL. LAW & POL'Y 1, 67-70 (1990).

11. *See* 33 U.S.C. § 1329(a)(1) (1994).

controlling pollution emanating from nonpoint sources.[12] Although the federal government appropriated funds for projects to control nonpoint source pollution,[13] federal legislation did not mandate the use of BMPs in the Clean Water Act.

Pursuant to section 319 directives, states adopted nonpoint source management plans. For example, Georgia adopted its plan in December 1989 and designated the Georgia Soil and Water Conservation Commission as the administering agency for the management of agricultural nonpoint sources of pollution.[14] The Commission conducted a statewide program to encourage the voluntary adoption of BMPs and reported its findings with a list of BMPs.[15] A subsequent publication in 1994 updated the findings and recommended persons involved in agricultural activities use the suggested BMPs.[16] Additional state legislation delineates further information on BMPs.[17]

The proposed U.S. House of Representatives Bill No. 961 may substantially alter section 319 by eliminating the term "best management practices."[18] Under this proposal, state programs identify management practices and measures to be undertaken to reduce pollutant loadings, and identify programs to manage nonpoint sources to the degree necessary to provide for reasonable progress. If reference to BMPs in section 319 is eliminated, individual states could amend their laws and regulations to move away from established BMPs. Although it is not clear whether states will rush to dismantle the voluntary regulations in force, the expected result is less consistency in water pollution responses among states.

B. *Other U.S. Provisions*

Other U.S. provisions affect the use of various management practices to reduce agricultural pollution. Regulations of the Clean Water Act classify concentrated animal feeding operations as point sources of pollution;[19] these operations are governed by other provisions.[20] The Federal Insecticide, Fun-

---

12. *Id.*; *see* Albert P. Barker & Richard B. Burleigh, *Agricultural Chemicals and Groundwater Protection: Navigating the Complex Web of Regulatory Controls*, 30 IDAHO L. REV. 443, 469 (1993-94); Robert D. Fentress, Comment, *Nonpoint Source Pollution, Groundwater, and the 1987 Water Quality Act: Section 208 Revisited?*, 19 ENVTL. L. 807, 817-23 (1989).

13. *See* 33 U.S.C. § 1288(j)(1) (1994).

14. ENVIRONMENTAL PROTECTION DIV., GA. DEP'T. NATURAL RESOURCES, GEORGIA NONPOINT SOURCE MANAGEMENT PLAN 24 (Dec. 1989).

15. *Id.* at 24-25.

16. GEORGIA SOIL & WATER CONSERVATION COMM'N, AGRICULTURAL BEST MANAGEMENT PRACTICES FOR PROTECTING WATER QUALITY IN GEORGIA (Sept. 1994).

17. GA. CODE ANN. § 12-2-8 (1994); GA. COMP. R. & REGS. r. 391-3-16-.01 to .05 (1992).

18. H.R. 961, 104th Cong., 1st Sess. (1995).

19. 33 U.S.C. § 1362(14) (1994); *see also* 40 C.F.R. 122.1(b)(2)(i), 122.23 (1996).

20. *See* Martha L. Noble & J.W. Looney, *The Emerging Legal Framework for Animal Agricultural Waste Management in Arkansas*, 47 ARK. L. REV. 159, 168-70 (1994).

gicide, and Rodenticide Act (FIFRA)[21] governs pesticides, and various regulations impact the use of pesticides that pollute water.[22] Pursuant to FIFRA, the Environmental Protection Agency (EPA) proposed regulating certain individual pesticides under approved State Management Plans.[23] Such plans provide an apparatus to respond to threats of pollution by specific pesticides in localized areas. The Safe Drinking Water Act[24] established maximum contaminant levels for various contaminants, and required states to develop wellhead protection programs.[25] The Coastal Zone Management Act of 1972[26] directed coastal states to submit a program with management measures for nonpoint source pollution to serve as an update and expansion of the section 319 program.[27] Management measures under the Act differed from best management practices and are intended to include only economically achievable measures.[28]

State tort law may also be used to address groundwater pollution problems. New regulations concerning liability for pesticide pollution were adopted in some states.[29] The thrust of this legislation is: If agricultural producers have not done anything wrong in the use of registered pesticides for agricultural production, then providers should not be liable for damages when the pesticides enter groundwater and cause pollution.[30]

III. LEGAL INSTITUTIONS FOR GERMANY

A. *European Union Nitrate Directive*

In 1991, the European Council Directive 91/676 was adopted, which concerned the protection of waters against pollution caused by nitrates from agricultural sources.[31] This Directive specifically addresses the pollution problem created from intensive livestock production and the excessive use of fertilizers.[32] Member states of the European Union were required to establish action programs for designated vulnerable zones susceptible to pollution. The action programs were to consist of mandatory measures as listed in

---

21. 7 U.S.C. §§ 136-136y (1994).
22. 40 C.F.R. § 131 (1996).
23. 60 Fed. Reg. 23,928, 23,843 (1995).
24. 42 U.S.C. §§ 300f to 300j-26 (1994).
25. *Id.* §§ 300g-1, 300h-7.
26. 16 U.S.C. §§ 1451-1464 (1994).
27. *Id.* § 1455b(a), (b).
28. *Id.* § 1455b(g)(5).
29. *See, e.g.*, GA. CODE ANN. § 2-7-170 (1990); IDAHO CODE § 39-127 (1993); IOWA CODE § 455E.6 (1995); VT. STAT. ANN. tit. 10, § 1410(c) & (d) (Supp. 1995).
30. Terence J. Centner, *Groundwater Quality Regulation: Implications for Agricultural Operations*, 12 HAMLINE L. REV. 589, 590 (1989); Terence J. Centner & Michael E. Wetzstein, *Agricultural Pesticide Contamination of Groundwater: Developing a "Right-to-Spray Law" for Blameless Contamination*, 14 J. AGRIC. TAX'N & LAW 38, 40 (1992); Mark J. Hanson, *Minnesota's Groundwater Protection Initiative*, 10 HAMLINE J. PUB. L. & POL'Y 275, 293 (1989).
31. *See generally* Council Directive 91/976, 1991 O.J. (L 375) 1.
32. *Id.*

Annex III.[33] Although these measures are not labeled BMPs, they constitute similar measures.

Fertilizer Application. The action programs shall delineate the prohibition of types of fertilizer application during certain periods.[34] The limitation of fertilizer application shall take into account the characteristics of the vulnerable zone and good agricultural practices.

Manure Storage. The action programs shall consider the storage capacity for animal manure during periods when land application in the vulnerable zone is prohibited.[35]

Limitations on Fertilizer Application. The addition of nitrogen in fertilizer may be precluded by an action program due to the soil conditions, climatic conditions, and land use and agricultural practices.[36]

B. *German Provisions*

Several German laws and regulations relate to agricultural pollution. The *Trinkwasserverordnung* decree for drinking water is based on EU guidelines and has regulations for pathogen agents and water chemistry.[37] The *Bundesnaturschutzgesetz* is the federal law for environmental protection and uses the term "proper agricultural production."[38] This means a sustainable agriculture which avoids negative external effects and therefore avoids water pollution. The goal of the law is to support water resource conservation. The term proper agricultural production is also used in the "water balance law," the *Wasserhaushaltsgesetz (WHG)*.[39] The water balance law is the controlling law of the federal government, which must be enforced by state regulations.[40] Also, the *Pflanzenschutzgesetz* governs the use of agricultural chemicals.[41]

In general, it is not necessary to have permission to use water for agricultural production. The most powerful instrument to protect groundwater resources is the designation of special water protection areas by the state.[42] For these protected areas, certain uses and activities can be prohibited. If current agricultural production is restricted, then the economic disadvantages

---

33. *Id.* at Annex III.
34. *Id.*
35. *Id.*
36. *Id.*
37. Verordnung über Trinkwasser und über Wasser für Lebensmittelbetriebe, (Trinkwasserverordnung-TrinkwV), BGBl. I, p. 2612-19 (1990).
38. Gesetz über Naturschutz und Landschaftspflege (Bundesnaturschutzgesetz-BNatSchG), BGBl. I p. 889-905 (1987).
39. Gesetz zur Ordnung des Wasserhaushalts (Wasserhaushaltsgesetz-WHG), BGBl. I, p. 1529-44 (1986), *amended by* Zweites Gesetz zur Änderung des Gerätesicherheitsgesetzes, BGBl. I p. 1564, 1571 (1992), [hereinafter WHG].
40. *See generally* Zweites Gesetz zur Änderung des Gerätesicherheitsgesetzes, BGBl. p. 1564 (1992).
41. Gesetz zum Schutz der Kulturpflanzen (Pflanzenschutzgesetz - PflSchG), BGBl. I, p. 1505-23 (1986).
42. WHG, *supra* note 39, at 1534.

must be compensated.[43] The compensation payments can be financed by a consumer fee or by water supply companies. In the state of Baden-Württemberg, for example, a consumer compensation regulation was introduced in 1988, and is known as SchALVO.[44] This regulation is within the purview of the *WHG* and is determined by the water law of Baden-Württemberg.[45] The compensation payments are paid as a lump sum or as an individual estimate of income loss.[46] In paragraph 9 of SchALVO, the minimum lump sum for agricultural lands in water protected areas is 310 Deutsche Marks per hectare.[47]

The conditions for agricultural production in water protected areas are based on proper production techniques and other limitations.[48] Proper production techniques entail the suitable use of the area according to its natural features through practices such as varied broad rotations, cover crops, soil conservation practices, nitrogen fertilization according to the nitrogen uptake of the plants, and the use of pesticides under principles of an integrated plant protection plan. Additional limitations required to justify the compensation payments include the reduction of nitrogen fertilization by twenty percent, the confined use of manure application, cover crops, and use of selected pesticides.[49]

For nearly twenty-five percent of the fields in the water protected areas, the amount of nitrate in the soil is controlled in the fall.[50] If more than forty-five kilograms of nitrate-nitrogen is present in the top ninety centimeters of soil, it is presumed that the guidelines are not met.[51] These regulations serve a similar objective as BMPs in the United States. Further regulations on soil protection and water protection are prescribed in the *Bodenschutzgesetz* of Baden-Württemberg.[52]

IV. BEST MANAGEMENT PRACTICES

Under section 319 of the Clean Water Act, research has led to the identification of BMPs to reduce water pollution from agricultural and other land-disturbing activities. Given the diverse qualities of various agricultural and land-disturbing activities, BMPs vary for different activities. Moreover,

---

43. *Id.* at 1571.

44. SchALVO, Verordnung des Ministeriums für Umwelt über Schutzbestimmungen in Wasser- und Quellenschutzgebieten und die Gewährung von Ausgleichsleistungen, Landesregierung Gesetzblatt für Baden-Württemberg, 742 (1987), *amended by* Verordnung, Landesregierung Gesetzblatt für Baden-Württemberg, 338 (1993) [hereinafter SchALVO].

45. Wassergesetz von Baden-Württemberg, Landesregierung Gesetzblatt für Baden-Württemberg, 269 (1988).

46. SchALVO, *supra* note 44, ¶ 8, at 744.

47. *Id.*

48. *Id.* App.1.

49. *Id.* App.2.

50. *Id.* App.3.

51. *Id.* ¶ 12 & App.3.

52. *See* Gesetz zum Schutz des Bodens von Baden-Württemberg (Bodenschutzgesetz), Landesregierung Gesetzblatt für Baden-Württemberg, 8336 (1991).

current research continues to disclose new and improved practices that might assist in the reduction of pollution. The Georgia Soil and Water Conservation Commission reviewed sixteen different agricultural BMPs which are prescribed for protecting water quality in Georgia: contour farming and terracing, conservation tillage, stripcropping, filter strips, grassed waterways, cover crops, pasture management, streamside vegetative buffers, stream and waterbody protection, critical area planting, nutrient management, irrigation water management, agricultural waste management systems, composting, pest management, and crop rotation.[53]

The practices are listed under the primary pollution problem that each addresses: erosion, nutrients, and pesticides.[54] Many BMPs, however, have secondary application to one or more other sources of pollution. Ongoing research on specific BMPs from summaries of current research projects funded by the U.S. Department of Agriculture are also noted.[55]

A. *Erosion*

A majority of the BMPs primarily address soil erosion, although many BMPs may be beneficial in reducing nutrient and pesticide pollution.

Contour Farming and Terracing. Perhaps the most celebrated erosion control practice is contour farming, which is farming across the slope on or near the level, as opposed to up and down the slope. Contour farming is most suitable on uniformly sloping fields. As a BMP, contour farming is joined with terracing. Terraces are earthen embankments constructed on the contour or across a slope to intercept runoff. Terraces are expensive to construct and cannot be used on sandy, stony, or shallow soils.[56]

Conservation Tillage. Conservation tillage, including no-till, has gained acceptance as a major agricultural practice to reduce soil erosion.[57] Generally, conservation tillage is defined as a method for planting that leaves at least thirty-percent of the soil surface covered with crop residue.[58] Conservation tillage is also used to conserve moisture. Adoption of this practice is often accompanied by an increase in the use of herbicides.

Stripcropping. Stripcropping involves the planting of a strip of a sod or close-growing crop with an alternate strip of a row crop.[59] Through this

---

53. GEORGIA SOIL AND WATER CONSERVATION COMM'N, *supra* note 16.

54. *Id.* at 202-03. An alternative classification would be to look at structural, cultural, and management BMPs. *See* Terry J. Logan, *Agricultural Best Management Practices and Groundwater Protection*, 45 J. SOIL & WATER CONSERVATION 201, 202 (1990).

55. The projects are funded through the United States Department of Agriculture. COOPERATIVE STATE RESEARCH, EDUC. & EXTENSION SERVICE, U.S. DEP'T AGRIC., RESEARCH & EDUC. FOR THE 21ST CENTURY (1995), *available at* gopher://gopher.reeusda.gov:70/77/Feds/usda.info/nri/nri-cgp/.index/index.

56. GEORGIA SOIL & WATER CONSERVATION COMM'N, *supra* note 16, at 4.

57. Conservation tillage may increase nutrient and pesticide loss to groundwater.

58. GEORGIA SOIL & WATER CONSERVATION COMM'N, *supra* note 16, at 1.

59. Stripcropping may be especially useful with contour farming. SOIL CONSERVATION SERVICE, U.S. DEP'T OF AGRIC., CONSERVATION CHOICES—YOUR GUIDE TO 30 CONSERVATION AND ENVIRONMENTAL FARMING PRACTICES (1994) [hereinafter CONSERVATION CHOICES].

practice, erosion may be reduced, and the use of rotating crops on the strips may reduce the amount of pesticides needed.[60]

Filter Strips. In areas where a sheet flow of water may be expected,[61] filter strips of grass may be used to remove sediment or other pollutants from the runoff.[62] Strips are often at least twenty-five feet in width, and grading is usually needed to create a broad area for the uniform flow of water.[63] Current research seeks to determine whether grass buffer strips may cleanse wastes applied via overland flow.[64]

Grassed Waterways. Grassed waterways are permanent drainage ways of perennial grasses to protect soils from erosion by concentrated water flows. Careful maintenance is required to ascertain whether strips and waterways are functioning. These areas should not be used for roads, and if livestock are allowed to graze, they must be limited to periods when soil moisture is low to preclude compaction, bogging, or the destruction of the vegetation.[65]

Cover Crops. Cover crops of grasses, legumes, or small grains, are planted to protect or improve the soil.[66] The benefits often involve a vegetative cover to preclude soil erosion in the absence of the main crop and the incorporation of their residues into the soil.[67]

Pasture Management. Pasture management may involve the selection of plant species, stocking rates, nutrient application, control of weeds, and grazing management.[68] Due to erosion and pollution caused by livestock, appropriate planning and implementation of stream and waterbody protection policies may be important in protecting and enhancing the quality of water. This may include the exclusion of livestock from streams or other bodies of water, as well as preventive measures to keep pesticides, fertilizers, animal manures, and other pollutants out of water. For some areas, seed may be drilled or cast to augment existing pastures.[69]

Streamside Vegetative Buffers. The use of trees, woody shrubs, and other vegetation adjacent to and upgradient from streams and water bodies provides a natural filter for sediment and organic material and their attached nutrients, pesticides, and other pollutants.[70]

Stream and Waterbody Protection. Practices and preventive measures to deter pollutants and sediment from entering streams and water bodies form

---

60. GEORGIA SOIL & WATER CONSERVATION COMM'N, *supra* note 16, at 5.

61. Sheet flow is a shallow and uniform flow of water over a broad surface.

62. Filter strips also may include shrubs and trees.

63. GEORGIA SOIL & WATER CONSERVATION COMM'N, *supra* note 16, at 6.

64. R.K. HUBBARD ET AL., USING GRASS-RIPARIAN ZONE BUFFERS TO TREAT ANIMAL WASTE APPLIED BY OVERLAND FLOW, THE UNIVERSITY OF GEORGIA, *available at* gopher://gopher.reeusda.gov:70/77/Feds/usda-info/nri/nri-cgp/.index/index.

65. GEORGIA SOIL & WATER CONSERVATION COMM'N, *supra* note 16, at 8-9.

66. In Germany, cover crops may be called intercrops.

67. Cover crops may be especially important after a low-residue producing crop, such as soybeans or corn cut for silage. CONSERVATION CHOICES, *supra* note 59.

68. GEORGIA SOIL & WATER CONSERVATION COMM'N, *supra* note 16, at 18-19.

69. CONSERVATION CHOICES, *supra* note 59.

70. Current research includes: R.K. HUBBARD ET AL., *supra* note 64.

the BMP of stream and waterbody protection. Such practices involve structural measures, such as fencing cattle out of streams, the construction of culverts, the development of sediment basins, the creation of alternative water sources for livestock, and agro-forestry practices to reduce nutrient mobility.[71] Filter strips, grassed waterways, and streamside vegetative buffers are also BMPs that protect waterbodies.

Critical Area Planting. For areas that are unusually steep, or cannot be stabilized by ordinary conservation practices, special vegetation may need to be planted.[72] Critical area planting refers to this planting, and careful efforts to establish the vegetation may be required.[73]

B. *Nutrient Pollution*

Nutrient Management. Phosphorus and nitrogen are the two nutrients that are most often associated with agricultural nutrient pollution.[74] Research concerning amounts, sources, forms, placement, and timing of nutrient applications enables agricultural producers to engage in application management to control nutrient pollution. Current research seeks to learn more about nitrogen[75] and the phosphorus cycle.[76] Producers continue to adopt technology to facilitate nutrient management and thereby reduce the excess phosphorus and nitrogen that enter surface water and groundwater.

Irrigation Water Management. Nutrient pollution may also be reduced due to the adoption of a BMP involving irrigation water management. By controlling the rate, timing, and amount of irrigation water, producers are able

---

71. For a current research project, see J.J. MCDONNELL ET AL., A SPATIAL/TEMPORAL INVESTIGATION OF THE HYDROLOGY AND BIOGEOCHEMISTRY OF NITROGEN TRANSPORT WITHIN A FORESTED HILLSLOPE/WETLAND/LAKE ECOTONE, STATE UNIVERSITY OF NEW YORK, SYRACUSE, *available at* gopher://gopher.reeusda.gov:70/77/Feds/usda-info/nri/nri-cgp/.index/index.

72. Vegetation may consist of grass, legumes, trees, or shrubs. CONSERVATION CHOICES, *supra* note 59.

73. GEORGIA SOIL & WATER CONSERVATION COMM'N, *supra* note 16, at 27.

74. *See supra* notes 8-9 and accompanying text.

75. Five USDA projects look at nitrogen: J.H. CHERNEY ET AL., DEVELOPMENT OF DAIRY MANURE MANAGEMENT STRATEGIES TO MINIMIZE WATER POLLUTION, CORNELL UNIVERSITY, *available at* gopher://gopher.reeusda.gov:70/77/Feds/usda-info/nri/nri-cgp/.index/index; R.H. FOX & D.D. FRITTON, NITRATE LEACHING FROM CORN AS AFFECTED BY NITROGEN FERTILIZER RATE, TILLAGE, AND LYSIMETER DESIGN, PENNSYLVANIA STATE UNIVERSITY, *available at* gopher://gopher.reeusda.gov:70/77/Feds/usda-info/nri/nri-cgp/.index/index; G.L. MALZER ET AL., OPTIMIZING ENVIRONMENTAL CONDITIONS WITH SOIL-SPECIFIC N RATE MANAGEMENT, UNIVERSITY OF MINNESOTA, *available at* gopher://gopher.reeusda.gov:70/77/Feds/usda-info/nri/nri-cgp/.index/index; C.A. ROTZ ET AL., MANAGEMENT STRATEGIES FOR BALANCING NITROGEN FLOWS ON THE DAIRY FARM, U.S.D.A. AGRIC. RES. SERV., *available at* gopher://gopher.reeusda.gov:70/77/Feds/usda-info/nri/nri-cgp/.index/index; ZOHRAB SAMANI, DENITRIFICATION AS A MEANS TO REMEDIATE GROUNDWATER CONTAMINATED WITH DAIRY WASTE, NEW MEXICO STATE UNIVERSITY, *available at* gopher://gopher.reeusda.gov:70/77/Feds/usda-info/nri/nri-cgp/.index/index.

76. P.A. HELMKE & W.F. BLEAM, SOLUBILIZATION OF ORGANICALLY BOUND SOIL PHOSPHORUS BY METAL COMPLEXING AGENTS, UNIVERSITY OF WISCONSIN, *available at* gopher://gopher.reeusda.gov:70/77/Feds/usda-info/nri/nri-cgp/.index/index.

to reduce the leaching of nutrients.[77] Technology, such as check valves and antisyphon devices, needs to be used to prevent well pollution when fertigation[78] or chemigation[79] is used.

Agricultural Waste Management Systems. Facilities and procedures used to temporarily store manure and other waste products for timely application to agricultural land comprise the BMP of agricultural waste management systems.[80] Liquid manure stored in lagoons and slurry manure in waste storage structures are major components of agricultural waste management systems. Further consideration of facility design, procedures, and application of agricultural wastes is also part of this BMP.[81]

Composting. Livestock facilities with organic wastes, such as animal manures and dead poultry, may need to adopt a composting process. The process may stabilize the organic matter, reduce odors, preserve nutrients, and prepare the matter for handling or spreading. Composting allows wastes to be utilized on-farm as a soil amendment and a nutrient source of nitrogen, with land application at an appropriate time.[82]

C. *Pesticide Pollution*

Pest Management. Some of the most celebrated developments in BMPs are integrated pest management (IPM) programs. Through practices and strategies, such as the use of field scouting and data collection and analysis, pesticides are only applied at critical times of need. This BMP lessens the quantities of pesticides used. Research on farm management systems and IPM information may lead to a substantial reduction in the pollution from pesticides. Practices involving chemical mixing sites and rinse pads may also form pest management BMPs which are important in reducing pesticide contamination.

Crop Rotation. Through a planned sequence of changing the crop grown on a particular field, producers are able to control some pests, diseases, and weeds without the use of pesticides.[83] Rotation may also create different types of residues and better soil quality.[84]

---

77. GEORGIA SOIL & WATER CONSERVATION COMM'N, *supra* note 16, at 16. Current research includes: J.G. BENJAMIN ET AL., MINIMIZING CHEMICAL LEACHING BY ALTERNATE FURROW IRRIGATION AND FERTILIZER BANDS, U.S.D.A. AGRIC. RES. SERV., *available at* gopher://gopher.reeusda.gov:70/77/Feds/usda-info/nri/nri-cgp/.index/index.

78. Fertigation is the application of fertilizer with irrigation.

79. Chemigation is the application of pesticides or chemicals with irrigation.

80. GEORGIA SOIL & WATER CONSERVATION COMM'N, *supra* note 16, at 203.

81. Because manure storage must be sufficient for at least a six month period, in Georgia, for example, it is suggested that manure be spread twice a year. CONSERVATION CHOICES, *supra* note 59.

82. GEORGIA SOIL & WATER CONSERVATION COMM'N, *supra* note 16, at 29-30.

83. GEORGIA SOIL & WATER CONSERVATION COMM'N, *supra* note 16.

84. For example, a legume may enhance soil nitrogen for a subsequent crop. Current research includes: C. FRANCIS & G. HELMERS, BIOLOGICAL AND ECONOMIC CONSEQUENCES OF FLEXIBLE CROP ROTATIONS, UNIVERSITY OF NEBRASKA, *available at* gopher://gopher.reeusda.gov:70/77/Feds/usda-info/nri/nri-cgp/.index/index.

V. VOLUNTARY ADOPTION OF BMPS IN THE UNITED STATES

A research project in Georgia developed an analytical model to assess potentially polluting agricultural practices. The Gum Creek Watershed (GCW) was identified as a stream likely to be threatened by agricultural nonpoint source pollution, and was selected as a water quality demonstration project. The GCW, located in the Coastal Plain of Georgia, has warm and humid weather and fertile soil, factors which enhance intensive agricultural production of diverse crops, including peanuts, cotton, corn (maize), pecans, pasture, and melons. Several sub-watersheds have more than fifty-percent of their surface area planted with crops that have high fertilizer and pesticide requirements, and soils with high or intermediate pesticide and nutrient leaching pollution potential.

The GCW project sought to reduce potential nonpoint source pollution by inducing farmers to voluntarily adopt BMPs within a federal cost-sharing pilot program.[85] An economic study evaluated the potential for voluntary adoption of BMP alternatives through adoption assessment, biophysical simulation, and mathematical programming under uncertain weather and market conditions.[86] Farmers' willingness to cost share was used to estimate expectations of net returns and associated water and soil pollution based upon government cost share scenarios. Using information gathered from individual farmer surveys,[87] a representative farm type in the watershed was modeled. Economic modeling assumed maximization of farmers' expected net returns to the land when agricultural source pollution is restricted to allowable levels under current production technology. The restriction of pollution levels, or abatement from current practices, would be compensated partially by government lump sum subsidies to farmers.

A. *The Modeling Framework*

Three locally-validated biophysical simulators were linked to obtain crop yields and pollution output. PEANUTGRO version 1.02, a process-oriented peanut crop growth model, was used to simulate and predict peanut crop development, water and nitrogen balance, and final peanut yield.[88] CERES-Maize version 2.10 simulated the growth and yield of corn, which was produced in rotation with peanuts.[89] GLEAMS version 2.0 simulated the

85. *See generally* GEORGIA COOPERATIVE EXTENSION SERVICE, THE UNIVERSITY OF GEORGIA, USDA DEMONSTRATION PROJECT ANNUAL REPORT: GUM CREEK WATER QUALITY PROJECT (1992).

86. Henglun Sun, Economic Analysis of Water Quality Management in the Gum Creek Watershed Cost Sharing Program (1994) (unpublished Ph.D. dissertation, University of Georgia).

87. *See generally* UNIVERSITY OF GEORGIA COLLEGE OF AGRIC. & ENVTL. SCIENCES, DEP'T OF AGRIC. & APPLIED ECONOMICS, CROP ENTERPRISE COST ANALYSIS (1992).

88. *See generally* K.J. BOOTE ET AL., PEANUT CROP GROWTH SIMULATION MODEL: USER'S GUIDE (1989).

89. J. RITCHIE ET AL., A USER'S GUIDE TO CERES MAIZE - V2.10 (2d ed., Mich. State Univ., IFDC & IBSNAT, 1992).

physical movement of agricultural chemicals within and through the plant root zone. It generated the chemical pollution and soil erosion output levels, given crop growth parameters, agricultural management systems, and other physical data.[90]

Crop yields were simulated over seventeen years of local weather data, and farmers' net returns were calculated using corresponding market-year price data. To examine voluntary participation incentives, the GCW survey included willingness to accept payment questions in order to enumerate farmers' adoption probabilities for four government cost share rates. Net returns and potential pollution effects were combined with the farmers' probable adoption of cost-sharing to generate annual expectations of net returns and potential emission levels.

B. *Simulations of Nitrogen and Irrigation Application Alternatives*

The crop and nitrogen runoff/leaching simulations considered site specific characteristics of the watershed. Supplemental irrigation in the simulations was triggered each time in the growing season when water content in the soil[91] was detected to drop to specified percentages. Nitrogen was assumed to be applied twice in the corn cropping season. The GLEAMS simulator generated the expected nitrogen runoff, nitrogen leaching, and soil losses as pollution output parameters from the relevant input and output parameters of thirty management scenarios with regard to five supplemental irrigation levels and six nitrogen application levels.

Supplemental irrigation was shown to increase farmers' average expected net returns, while resultant soil losses would remain essentially constant. Nitrogen runoff would increase up to five percent, but nitrogen leaching could increase by as much as fourteen percent. If the resultant effects were less than or equal to GCW area targets set for nonpoint pollution by the EPA, the profitability of this supplemental irrigation option is substantial. Nitrogen leaching actually declines slightly at the low supplemental irrigation rates before increasing at higher, more profitable irrigation rates. Without irrigation, nitrogen leaching could be reduced more than eighteen percent if no nitrogen fertilizer is applied. Given the current cropping mix, agricultural sources of potential water quality degradation or enhancement could thus be altered only within a rather limited range of responses.

C. *Economic Responses to Cost Sharing Incentives*

The incentive program for the GCW was assumed to be a lump-sum sharing of the farmers' reduction of net returns (opportunity costs) by adopting the new BMP rather than the current management practice. The expectations of the area-wide, representative GCW net returns, soil losses, nitrogen losses by runoff, and nitrogen losses by leaching had both voluntary adoption and nonadoption possibilities. Mathematical programming

---

90. W.G. KNISEL ET AL., GLEAMS VERSION 2.0 PART III: USER MANUAL (1992).

91. The water content was measured at 50 centimeters in depth.

techniques were used to optimize management practices and cost shares. Pollution control targets, which would comprise a generally acknowledged environmental criteria set, did not exist for comparison with the simulated soil and nitrogen pollution outputs. Soil losses and nitrogen emission levels were restricted to levels less than or equal to the pollution levels corresponding to a management alternative with 122.7 kilograms per hectare of nitrogen and a fifty percent water availability trigger.

Pollution abatement and corresponding cost share programs were then modeled over a range of management alternatives. GAMS/MINOS was used to solve the optimizing problem.[92] The optimal baseline solution closely approximated the management alternative derived by simulation results. Simulations and mathematical programming results indicated that irrigation and nitrogen fertilizer applications do not alter water quality in the GCW as much as generally anticipated. Under limited government payments, either pollution abatement through reduction of irrigation or nitrogen fertilizer applications, farmers may experience a significant reduction in net revenues. Without threats of other regulatory means, more farmers may opt out of a voluntary program. Further abatement of nitrogen leaching should consider other cropping management alternatives or emphasize nonagricultural sources. Optimization results at varying cost share subsidies showed that nitrogen leaching could be expected to be reduced by up to ten percent from baseline results in the scenarios tested. Soil losses and nitrogen runoff were quite inflexible with respect to abatement potential.

VI. INCOME EFFECTS OF BMPS IN GERMANY

A research project in Baden-Württemberg disclosed tradeoffs between the use of BMPs to reduce water pollution and farmers' income. An ecological-economic model was used for simulation and optimization of agricultural production strategies for decreasing the erosion and high nitrate content. The soil simulation model CREAMS was used to determine the ecological impact of management practices on the environment.[93] An economic model was employed to maximize the profit function. Two crop rotations were selected: (1) sugar beets—winter wheat—corn—winter wheat; and (2) sugar beets—winter wheat—winter barley. The ecological-economic model was selected to show how to fertilize each crop over a time horizon of twenty years and how to split the fertilizer over the growing season.

---

92. ANTHONY BROOKE ET AL., GAMS: A USER'S GUIDE, RELEASE 2.25 (1988); BRUCE A. MURTAGH & MICHEAL A. SAUNDERS, MINOS 5.1 USER'S GUIDE TECHNICAL REPORT SOL 83-20R (1987).

93. CREAMS is the acronym for a Field Scale Model for "Chemicals, Runoff and Erosion from Agricultural Management Systems." U.S. DEP'T OF AGRIC., CREAMS: A FIELD SCALE MODEL FOR CHEMICALS, RUNOFF, AND EROSION FROM AGRICULTURAL MANAGEMENT SYSTEMS CONSERVATION RESEARCH REP. (1980).

A. *Ecological Model*

The empirical simulation model, CREAMS, was used to estimate the soil erosion and the nutrient balance in agricultural fields.[94] The factors examined were the integrative medium of inputs, turnover, and outputs. Inputs for the model consisted of climatic data, land use, cultural practices, fertilization, and pesticide usage. Outputs of nutrients and pesticides occurred through evapotranspiration, surface runoff, soil erosion, and leaching. Three integrated submodels of the CREAMS model estimated the water cycle, soil erosion, and dynamics of nutrient levels and pesticide residues. The nutrient-pesticide submodel required the application of the water and erosion submodels.

In the nutrient submodel, a simplified nitrogen balance was estimated, with the balance consisting of nitrogen inputs and outputs. Inputs of nitrogen resulted from precipitation, fertilization, and mineralization. Nitrogen outputs occurred through plant uptake, soil erosion, surface runoff, denitrification, and leaching.

B. *Economic Model*

The goal of the economic model was to maximize profit over a given time and space subject to implicit and explicit constraints. The calculation of profit was based on the results of the ecological model and on further economic parameters obtained from field records. Data from the ecological model included nitrogen uptake, mineralized nitrogen in the fall, nitrogen leaching, and the nitrogen concentration in water seeping through the ground. Field data consisted of inputs, prices, costs, and sugar beet quotas. The model used nitrogen fertilization as the only input variable in this calculation, although further calculations could include other input variables, such as pesticide applications.

The desired output was nitrogen uptake, as uptake determined yields and avoided excessive nitrogen mineralization in the fall. A governmental premium of 310 Deutsche Marks per hectare is lost if mineralized nitrogen exceeds forty-five kilograms per hectare in the fall. An optimizing algorithm, COMPLEX,[95] as further developed by Manetsch,[96] was used to maximize the function.[97] The economic model initially chose the nitrogen fertilization level, which was the input variable for CREAMS. The desired output was the uptake of nitrogen, since mineralized nitrogen in the fall was undesired. The calculations of nitrogen uptake and mineralized nitrogen in the fall provided the inputs for the economic model. For an adequate ecological situation,

---

94. *Id.*

95. M.J. BOX, *A New Method of Constrained Optimization and a Comparison with Other Methods*, 8 COMPUTER J. 42, 43-44 (1965).

96. T.J. MANETSCH, TOWARDS EFFICIENT GLOBAL OPTIMIZATION IN LARGE DYNAMIC SYSTEMS—THE ADAPTIVE COMPLEX METHOD (Mich. State Univ., Feb. 1989).

97. After determining an appropriate starting point, the method generated $k - 1$ additional feasible points by random sampling in the feasible region.

excessive nitrogen leaching or excessive mineralized nitrogen in November resulted in a penalty.

In the intensively cultivated loess hillslope countrysides of the Kraichgau, extensive soil erosion and nitrogen losses may create problems for surface and groundwater. Excessive soil erosion is most likely to occur from May until June. Minimal soil coverage during this time leads to higher soil erosion. In the first rotation,[98] soil erosion was reduced. The average soil erosion was thirty tons per hectare per year with sugar beets, twenty-three tons per hectare per year with corn, and nine tons per hectare per year with winter wheat. In conventional cultivation, soil erosion exceeded the tolerable values. Under conservation systems, soil erosion was reduced through one or more practices, including track loosening in corn,[99] grass strips in the middle of slopes, or a diversion ditch for runoff water. Therefore, these management practices provided minor protection against excessive soil erosion. A no-till practice or the planting of an intercrop of mustard[100] after sugar beets or corn were shown to be the most effective system.

For the second crop rotation of sugar beets—winter wheat—and winter barley, soil erosion tended to be determined by single events. Higher soil erosion took place in years with sugar beets. The same rotation with an intercrop of mustard after winter barley reduced soil erosion to about one ton per hectare per year.

When compensatory payments for ecological constraints were available, the model showed less nitrogen fertilizer being needed to achieve a maximum income for a producer. The model also showed significant amounts of nitrogen remaining in the soil after plantings of winter wheat or winter barley. The use of an intercrop was able to reduce nitrogen in autumn significantly. Therefore, the model used an intercrop of mustard after winter wheat during the first rotation and after winter barley during the second rotation.

The analysis showed that use of a considerable amount of nitrogen fertilizer in spring increased yields and profits without substantial ecological impacts including excessive mineralized nitrogen, nitrogen leaching, and erosion. The model, however, showed that low compensatory payments to reduce nitrogen fertilization levels could provide significant ecological benefits.

VII. SUMMARY

Depending on institutional constraints and economics, BMPs may be implemented by agricultural producers to reduce nonpoint source agricultural pollution. An interdisciplinary approach is necessary to develop accurate measurements of pollutants, to develop models identifying and monitoring negative pollution effects, and to consider various strategies maximizing net returns to producers within the constraints of targeted water quality standards. Research projects from Georgia and Baden-Württemberg employed models

---

98. This is a rotation of sugar beets—winter wheat—corn—winter wheat.

99. Track loosening is equipment behind tractor tires to break up and loosen the soil.

100. The mustard intercrop, sinapis alba, is established in the fall and then killed by the cold winter leaving debris over the soil.

evaluating institutional constraints of payments to reduce nitrogen usage, penalties for excessive leaching, or financial incentives for meeting minimum mineralized nitrogen levels. By modeling net returns, the models identified preferred economic strategies for producers.

The Gum Creek Watershed study developed an economic framework to analyze farmers' voluntary adoption of water quality management alternatives within a government cost share project. Supplemental irrigation management appeared to offer opportunities to increase farmers' expected net revenues with little impact on soil and nitrogen runoff. Economically optimal irrigation and nitrogen fertilizer applications, however, did not alter the water quality as much as generally anticipated. The costs of agricultural pollution abatement by reducing irrigation and nitrogen fertilizer application rates were very high and increased at the margin. Further abatement of nitrogen leaching, therefore, may consider other management alternatives, such as changing or restricting the cropland for peanuts in the rotation. Under limited government payments, pollution abatement significantly reduced farmers' net revenues, suggesting that it is unlikely producers will voluntarily adopt measures to reduce pesticide or nitrogen pollution.

The CREAMS model used by the project in Baden-Württemberg analyzed soil erosion and fertilization for the development of optimal nitrogen fertilization strategies. The model's results showed considerable potential for reducing agricultural pollution. Specifically, intercropping was shown to substantially reduce soil erosion and nitrate leaching. Under the climatic conditions of Baden-Württemberg, optimal timing and reduced fertilization allows increased profits because of compensation payments provided by the government.

This research demonstrates that BMPs can reduce agricultural nonpoint pollution, but pollution reduction may be costly to producers. Thus, reduced pollution will likely require some type of government intervention. One method is to prescribe BMPs or proscribe practices and activities which create excessive pollution through regulatory institutions. Another method is to establish pollution thresholds with penalties for exceeding the threshold or incentives to meet the threshold. In the European Union, there is a willingness to reduce nitrogen pollution through compensatory payments. In the United States, the reduction of agricultural pollution generally remains voluntary. Perhaps as more information is made available from research projects, such as those reported in this article, more appropriate strategies may be developed to reduce pollution while preserving producer incomes.