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Environmental and Economic Benefit Analysis of Proposed Revisions to the National Pollutant Discharge Elimination System Regulation and the Effluent Guidelines for Concentrated Animal Feeding Operations

ENVIRONMENTAL AND ECONOMIC BENEFIT ANALYSIS OF THE PROPOSED REVISIONS TO THE NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM REGULATION AND THE EFFLUENT GUIDELINES FOR CONCENTRATED ANIMAL FEEDING OPERATIONS

U.S. Environmental Protection Agency
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INTRODUCTION AND SUMMARY — CHAPTER 1

The U.S. Environmental Protection Agency (EPA) is revising and updating the two primary regulations that ensure that manure, wastewater, and other process waters generated by concentrated animal feeding operations (CAFOs) do not impair water quality. EPA's proposed regulatory changes affect the existing National Pollutant Discharge Elimination System (NPDES) provisions that define and establish permit requirements for CAFOs, and the existing effluent limitations guidelines (ELGs) for feedlots, which establish the technology-based effluent discharge standard that is applied to specified CAFOs. Both of these existing regulations were originally promulgated in the 1970s. EPA is revising the regulations to address changes that have occurred in the animal industry sectors over the last 25 years, to clarify and improve implementation of CAFO requirements, and to improve the environmental protection achieved under these rules.

This report addresses the environmental and economic benefits of several alternative regulatory scenarios, including two scenarios that EPA is proposing. It examines in detail four environmental quality improvements that would result from the regulatory changes: improvements in the suitability of freshwater resources for fishing and swimming; reduced incidence of fish kills; improved commercial shellfishing; and reduced contamination of private wells. Because these are not the only beneficial impacts of the regulatory scenarios considered by EPA — and because, in general, EPA takes a conservative approach to quantifying the benefits analyzed — the Agency believes that this report presents a lower-bound estimate of the beneficial impacts of the proposed scenarios.

This chapter first defines and describes animal feeding operations and CAFOs, then briefly summarizes the environmental problems and industry changes associated with animal feeding operations that EPA is addressing with its proposed regulations. Finally, the chapter outlines the regulatory changes and alternatives that EPA is considering, and provides a summary of the methods and results of the more detailed benefits analyses presented in the remaining chapters.

1.1 DEFINITION OF CAFOS

The term CAFO is a regulatory designation that describes certain animal feeding operations (AFOs). AFOs are defined by federal regulation as lots or facilities where animals "have been, are, or will be stabled or confined and fed or maintained for a total of 45 days or more in any 12 month period and crops, vegetation forage growth, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility" (40 CFR 122.23(b)(1)). AFOs congregate animals on a small land area where feed must be brought to the animals. Winter feeding of animals on pasture or rangeland is not normally considered an AFO.

Current EPA regulations employ a three-tier structure to identify AFOs that are subject to regulation as CAFOs. Tier 1 facilities include any animal feeding operation where more than 1,000 "animal units" (AUs) are confined; such facilities are by definition CAFOs unless discharges from the operation occur only as the result of a 25-year, 24-hour (or more severe) storm event.[1] Tier 2 facilities include AFOs that confine 301 to 1000 AUs; these facilities are defined as CAFOs if:

- Pollutants are discharged into navigable waters through a manmade ditch, flushing system, or other similar man-made device; or

- Pollutants are discharged directly into waters that originate outside of and pass over, across, or through the facility or come into direct contact with the confined animals.

The regulatory definition of a CAFO does not extend to operations with 300 or fewer AUs (i.e., Tier 3 facilities). Under certain circumstances, however (e.g., a facility causing significant surface water impairment), a permitting authority may designate such facilities as CAFOs.

Current CAFO regulations address only those facilities with wet-manure management systems; this eliminates most poultry operations from regulation under the Clean Water Act because they use dry manure management systems. In addition, the current definition of CAFO includes only swine over 55 pounds and mature dairy cattle, assuming that immature swine and heifers would be raised in the same operations as adults. As a result, the regulatory definition does not address the "stand-alone" immature swine or heifer operations that have proliferated in the last two decades.

USDA reports that there were 1.2 million livestock and poultry operations in the United States in 1997. This number includes all operations that raise beef or dairy cattle, hogs, chickens (broilers or layers), and turkeys, and includes both confinement and non-confinement (i.e., grazing

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[1] Animal units are defined in EPA's current regulations at 40 CFR 122 and vary by animal type. An AU is considered equivalent to one beef cow.

and rangefed) production.[2] Of these, EPA estimates that there are about 376,000 AFOs that raise or house animals in confinement, as defined by the existing regulations. For many of the animal sectors, it is not possible to estimate from available data what proportion of the total livestock operations have feedlots (i.e., confinement) and what proportion are grazing operations only. For analytical purposes, EPA has therefore assumed that all dairy, hog, and poultry operations are AFOs. Exhibit 1-1 summarizes the estimated total number of AFOs of all sizes in each of the four major livestock categories, based on 1997 data. EPA estimates that only a subset of these AFOs will be regulated as CAFOs.

Exhibit 1-1

NUMBER OF ANIMAL FEEDING OPERATIONS
(based on 1997 data)

Sector	Total AFOs
Beef operations, including both cattle and veal operations.	106,930
Dairy operations, including both milk and heifer operations.	118,130
Hog operations, including both "farrow to finish" and "grower to finish" operations.	117,860
Poultry operations, including broilers, layers (both wet and dry operations) and turkeys.	123,750
Sum Total	466,670
Total AFOs[1]	**375,740**

Source: EPA estimates derived from published USDA/NASS data, including 1997 Census of Agriculture. For more information, see *Technical Development Document of Proposed Effluent Limitations Guidelines for Animal Feeding Operations*.

[1] "Total AFOs" eliminates double counting of operations with mixed animal types. Based on survey level Census data, operations with mixed animal types account for roughly 20 percent of total AFOs.

1.2 CURRENT ISSUES RELATED TO CAFOS

AFOs (including CAFOs) produce and manage large amounts of animal waste, most in the form of manure. USDA estimates that 291 billion pounds (132 million metric tons) of "as excreted" manure were generated in 1997 from major livestock and poultry operations. Despite the existing ELG and NPDES regulations that define CAFOs and regulate their discharges, the management of animal wastes at AFOs has continued to be associated with environmental problems, including large spills of manure, fish kills, and outbreaks of *Pfiesteria*. In addition, industry changes in recent years may contribute to and exacerbate the problems caused by releases of manure from AFOs. EPA is revising the existing regulations with the following goals:

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[2] EPA's proposed regulatory changes do not address certain types of animal confinement operations, such as farms that raise sheep, lambs, goats, horses, and other miscellaneous animal species, as well as nontraditional animals, such as bison and various exotic species.

- To address reports of continued discharge and runoff of manure and nutrients from livestock and poultry farms;
- To update the existing regulations to reflect structural changes in these industries over the last few decades; and
- To improve the effectiveness of the CAFO regulation.

Below we summarize the potential environmental impacts of manure releases from AFOs, and outline the recent industry changes that may exacerbate these impacts.

1.2.1 Potential Environmental Impacts of CAFOs

Manure management practices at AFOs can include storage in piles or in open waste lagoons, followed by land application to agricultural fields as fertilizer. While some discharges from regulated CAFOs are governed as point sources, unregulated releases of manure from waste piles or lagoons and overapplication of manure to agricultural lands can affect nearby surface and groundwater. National and local studies have confirmed the presence of manure pollutants in surface waters. Once contaminants from manure have reached surface waters they can cause a variety of ecological and human health problems, including water quality impairments, ecological impacts, and human health effects from recreational exposure or from contaminated drinking water.

1.2.1.1 Water Quality Impairments

EPA's 1998 *National Water Quality Inventory*, prepared under Section 305(b) of the Clean Water Act, identifies agriculture (including irrigated and non-irrigated crop production, rangeland, feedlots, pastureland, and animal holding areas) as the leading contributor to identified water quality impairments in the nation's rivers and lakes, and the fifth leading contributor to identified water quality impairments in the nation's estuaries. The report also identifies the key pollutants and stressors that impair the nation's waters. Among the most problematic pollutants are several - including pathogens, nutrients, and oxygen depleting substances - that are associated commonly, although not exclusively, with animal waste.[3]

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[3] The *National Water Quality Inventory 1998 Report to Congress* notes that 28 states and tribes reported impairment by agricultural subcategory. Specifically, these states and tribes reported that animal feeding operations degraded 16 percent of impaired river miles; range and pasture grazing degraded 11 and 6 percent of impaired river miles, respectively; and irrigated and non-irrigated crop production degraded 18 and 27 percent of impaired river miles, respectively.

1.2.1.2 Ecological Impacts

The most dramatic ecological impacts associated with manure pollutants in surface waters are massive fish kills. Incomplete records indicate that every year dozens of fish kills associated with AFOs result in the deaths of hundreds of thousands of fish. In addition, manure pollutants such as nutrients and suspended solids can seriously disrupt aquatic systems by over-enriching water (in the case of nutrients) or by increasing turbidity (in the case of solids). Excess nutrients cause fast-growing algae blooms that reduce the penetration of sunlight in the water column, and reduce the amount of available oxygen in the water, reducing fish and shellfish habitat and affecting fish and invertebrates. Manure pollutants can also encourage the growth of toxic organisms, including *Pfiesteria,* which has also been associated with fish kills and fish disease events. Reduction in biodiversity due to animal feeding operations has also been documented; for example, a study of three Indiana stream systems found fewer fish and more limited diversity of fish species downstream of CAFOs than were found downstream of study reference sites.

1.2.1.3 Human Health Effects

Manure contains over 100 human pathogens; contact with some of these pathogens during recreational activities in surface water can result in infections of the skin, eye, ear, nose, and throat. Eutrophication due to excess nutrients can also promote blooms of a variety of organisms that are toxic to humans either through ingestion or contact. This includes the estuarine dinoflagellate *Pfiesteria piscicida.* While *Pfiesteria* is primarily associated with fish kills and fish disease events, the organism has also been linked with human health impacts through dermal exposure. Finally, even with no visible signs of algae blooms, shellfish such as oysters, clams and mussels can carry toxins produced by some types of algae in their tissue. These can affect people who eat contaminated shellfish.

Contaminants from manure, including nitrogen, algae, and pathogens, can also affect human health through drinking water sources and can result in increased drinking water treatment costs. For example, nitrogen in manure can be transported to drinking water as nitrates, which are associated with human health risks. EPA has identified nitrate as the most widespread agricultural contaminant in drinking water wells. Algae blooms triggered by nutrient pollution can affect drinking water by clogging treatment plant intakes, producing objectionable tastes and odors, and reacting with the chlorine used to disinfect drinking water to produce harmful chlorinated byproducts (e.g., trihalomethanes).

1.2.2 <u>Recent Industry Trends</u>

Since EPA promulgated the existing ELG and NPDES regulations governing CAFOs in the 1970s, a number of trends in the livestock and poultry industries have influenced the nature of pollution from AFOs and the potential for contamination of surface and groundwater. These trends include a combination of industry growth and concentration of animals on fewer, larger farms; location of farms closer to population centers; and advances in farm production practices and waste management techniques. The changes in the industry have limited the effectiveness of the current regulations that define and govern releases from CAFOs.

1.2.2.1 Increased Production and Industry Concentration

U.S. livestock and poultry production has risen sharply since the 1970s, resulting in an increase in the amount of manure and wastewater generated annually. The Census of Agriculture reports 1997 turkey sales of 299 million birds, compared to 141 million sold in 1978. Sales of broilers increased to 6.4 billion in 1997 from 2.5 billion in 1974.[4] Red meat production also rose during the 1974-1997 period; the number of hogs and pigs sold in 1997 totaled 142.6 million, compared to 79.9 million in 1974.

As production has increased, the U.S. livestock and poultry sectors have also consolidated animal production into a smaller number of larger-scale, highly specialized operations that concentrate more animals (and manure) in a single location. At the same time, significant gains in production efficiency have increased per-animal yields and the rate of turnover of animals between farm and market. These large AFOs can present considerable environmental risks, because they often do not have an adequate land base for manure disposal through land application. As a result, large facilities must incur the risks associated with storing significant volumes of manure, or must attempt to maximize the application of manure to the limited land they have available. By comparison, smaller AFOs manage fewer animals and tend to concentrate less manure nutrients at a single location. These operations are more likely to have sufficient cropland and fertilizer needs to land apply manure nutrients generated at a livestock or poultry business.

1.2.2.2 Location of Animal Operations Closer to Consumer Markets

Since the 1970s, the combined forces of population growth and re-location of operations closer to consumer markets and processing sectors have resulted in more AFOs located near densely populated areas. Surface waters in these areas face additional stresses from urban runoff and other point sources. The proximity of large AFOs to human populations thus increases the potential for human health impacts and ecological damage if manure and wastewater at AFOs is improperly discharged.

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[4] This more than two-fold increase in the number of broilers raised annually signals the need to review the existing CAFO regulations, which effectively do not cover broiler operations since virtually no such operations use wet manure management systems.

1.2.2.3 Advances in Agriculture Production Practices to Manage and Dispose Manure

Continued research by USDA, state agencies and universities has led to advances in technologies and management practices that minimize the potential environmental degradation attributable to discharge and runoff of manure and wastewater. Today, there are many more practicable options to properly collect, store, treat, transport, and utilize manure and wastewater than there were in the 1970s, when the existing regulations were instituted. As a result, current regulations do not reflect the full range of management practices and technologies that may be implemented to achieve greater protection of the environment (e.g., by more effectively treating certain constituents present in animal manure or by converting manure into a more marketable form). In addition, during the time since promulgation of the existing regulation, certain practices have proven to be relatively less protective of the environment. There is documented evidence that lagoons may leak if not properly maintained, and evidence of overapplication of manure and nutrient saturation of soils in some parts of the country.

1.3 PROPOSED CHANGES TO CAFO REGULATIONS

In response to persistent reports of environmental problems, and to changes in the industries and technologies associated with AFOs, EPA is proposing changes to both the NPDES regulations for CAFOs and the ELG regulations for feedlots. Proposed changes to the NPDES regulations for CAFOs affect which animal feeding operations are defined as CAFOs and are therefore subject to the NPDES permit program. Changes to the ELG regulations for feedlots affect which technology-based requirements will apply to CAFOs.

EPA's analysis of the benefits of revised regulations considers four alternatives for the NPDES definition of a CAFO (described as Scenarios 1, 2/3, 4a, and 4b), combined with two alternative ELG regulations (Options 1 and 2), yielding a total of eight regulatory scenarios. EPA is co-proposing two of these scenarios. The first incorporates NPDES scenario 2/3 and ELG Option 2; this scenario would preserve the current three-tier structure for identifying facilities that are CAFOs (though with revised conditions for identifying CAFOs within the tiers), and would revise the ELG to establish a phosphorus-based manure application limit. The second proposed scenario incorporates NPDES scenario 4a and ELG Option 2; this scenario would replace the current three-tier structure with a two-tier structure, and would also incorporate a phosphorus-based ELG. Specific proposed changes are described in more detail below, and are summarized in Exhibit 1-2.

1.3.1 <u>Changes to NPDES Regulations</u>

EPA considered four regulatory scenarios that reflect changes to the current approach to determining which facilities are CAFOs that are subject to NPDES requirements. Scenario 1 would retain the existing three-tier structure for identifying CAFOs (described in section 1.1). Scenario 2/3 would also retain the current three-tier structure, but would revise the conditions within the tiers for determining which facilities are CAFOs. Scenario 4a would replace the current three-tier structure with a two-tier structure that would alter the definition of a CAFO to include all AFOs with 500 or more AUs; operations with fewer than 500 AUs would be regulated at the discretion of the permitting authority (similar to the current Tier 3 facilities). Finally, Scenario 4b would change to a two-tier structure similar to that in Scenario 4a, but would define as a CAFO any operation with 300 or more animal units.[5]

As noted above, EPA has chosen to co-propose NPDES Scenario 2/3 and NPDES Scenario 4a. In doing so, the Agency is soliciting comments on regulatory approaches that, on a national basis, yield similar environmental benefits, but offer different administrative benefits and have differing impacts on regulated industry sectors. Specifically:

- Scenario 2/3 would apply a three-tier structure combined with a risk-based approach to identify which AFOs pose a potential to discharge. This scenario would automatically define all operations over 1,000 AUs as CAFOs. AFOs with between 300 and 1,000 AUs would be required to *either* apply for an NPDES permit *or* certify to the permitting authority that they do not meet any of the conditions that define a CAFO. An advantage of this approach is that it would offer states flexibility in developing requirements and programs that could reduce the number of facilities needing NPDES permits. A potential disadvantage, however, is the complexity associated with administering this approach, as well as the cost associated with extending the certification/application requirement to facilities as small as 300 AUs.

- In contrast to Scenario 2/3, the two-tier structure of Scenario 4a would define all operations with at least 500 AUs as CAFOs. As such, all facilities with at least 500 AUs would be required to obtain and comply with an NPDES permit; operations with fewer than 500 AUs would be subject to permitting only if designated by the permitting authority as a significant contributor of pollution. An advantage of this approach is that it simplifies the structure of the regulations and supports EPA's goal of clarifying their scope. In addition, operations with at least 300 but fewer than 500 AUs would not automatically incur permitting or certification costs; however, the potential benefits associated with a more flexible, risk-based approach to permitting operations with between 500 and 1,000 AUs would be foregone.

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[5] Each of the regulatory scenarios analyzed also reflects several proposed structural changes that would revise the CAFO definition and permit requirements under the NPDES permit program. For example, EPA is proposing to include dry poultry and stand-alone immature swine and heifer operations as AFOs; this change would increase the number of facilities that meet the definition of a CAFO and must obtain an NPDES permit. In addition, EPA is proposing several clarifications designed to assure that all facilities meeting the CAFO definition obtain an NPDES permit. Similarly, EPA is proposing changes to the ELGs for feedlots that would clarify the development of technical standards for manure storage and land application operations. These changes from the current baseline are reflected in all of the regulatory scenarios.

Exhibit 1-2

REGULATORY SCENARIOS CONSIDERED IN THE BENEFITS ANALYSIS

Regulatory Scenario	NPDES Revisions	ELG Revisions
Baseline	CAFOs include any AFO with over 1,000 AUs, as well as AFOs with fewer AUs that meet certain requirements.	Manure application not regulated
Option 1-Scenario 1	Baseline scenario plus dry poultry and immature swine and heifer operations.	Nitrogen-based manure application
Option 1-Scenario 2/3	New NPDES conditions for identifying CAFOs among AFOs with 300 - 1000 AUs, plus dry poultry and immature swine and heifer operations.	Nitrogen-based manure application
Option 1-Scenario 4a	CAFOs include all AFOs with 500 or more AUs, plus dry poultry, immature swine and heifer operations.	Nitrogen-based manure application
Option 1-Scenario 4b	CAFOs include all AFOs with 300 or more AUs, plus dry poultry, immature swine and heifer operations.	Nitrogen-based manure application
Option 2-Scenario 1	Baseline scenario plus dry poultry and immature swine and heifer operations.	Phosphorus-based manure application
Option 2-Scenario 2/3*	New NPDES conditions for identifying CAFOs among AFOs with 300 - 1000 AUs, plus dry poultry and immature swine and heifer operations.	Phosphorus-based manure application
Option 2-Scenario 4a*	CAFOs include all AFOs with 500 or more AUs, plus dry poultry, immature swine and heifer operations.	Phosphorus-based manure application
Option 2-Scenario 4b	CAFOs include all AFOs with 300 or more AUs, plus dry poultry, immature swine and heifer operations.	Phosphorus-based manure application

* Proposed scenarios.

1.3.2 Changes to ELGs

EPA's proposed changes to the effluent limitation guidelines would include a technical standard for nutrient-based land application of manure. The Agency is considering two regulatory options. Option 1 would limit manure application to a nitrogen-based agronomic application rate (i.e., manure application could not exceed the soil and crop demand for the nitrogen within the manure). Option 2 would limit manure application to a phosphorus-based agronomic application rate (i.e., manure application could not exceed the soil and crop demand for the phosphorus within the manure).

EPA's proposed regulatory scenarios both reflect the phosphorus standard. Because manure is phosphorus rich, nitrogen-based manure application is likely to result in application of phosphorus in excess of crop requirements. Although excess phosphorus does not usually harm crops and is often adsorbed by soils, the capacity of soil to adsorb phosphorus will vary by soil type. Recent observations indicate that soils can and do become saturated with phosphorus. When saturation occurs, continued application of phosphorus in excess of what can be used by the crop and soil will result in phosphorus leaving the field with storm water via leaching or runoff; eutrophication of surface waters can result.

1.3.3 Number of Regulated Operations

EPA has estimated the likely number of AFOs that would be regulated under the revised definition of CAFO in each of the four NPDES scenarios (i.e., Scenarios 1, 2/3, 4a, and 4b). EPA analyzed data from the USDA's 1997 Census of Agriculture to identify AFOs and CAFOs. EPA first determined the number of operations that raise animals under confinement by using available data on the total number of livestock and poultry facilities. Next, EPA determined the number of CAFOs based on the number of facilities that discharge or have the potential to discharge to U.S. waters and which meet a minimum size threshold (i.e., number of animals) as defined by the regulatory options. Exhibit 1-3 shows the number of CAFOs estimated for each scenario.

1.4 ANALYTIC METHODS AND RESULTS

To determine the economic benefits of the regulatory scenarios, EPA performed four separate analyses of expected changes in environmental quality that would likely result from reduced AFO pollution. These include:

- **Improvements in Water Quality and Suitability for Recreational Activities:** this analysis estimates the economic value of improvements in inland surface water quality that would increase opportunities for recreational fishing and swimming;

- **Reduced Incidence of Fish Kills:** this analysis estimates the economic value of a potential reduction in the number of fish kills caused by AFO-related waste;

- **Improved Commercial Shellfishing:** this analysis characterizes the impact of pollution from AFOs on access to commercial shellfish growing waters, and values the potential increase in commercial shellfish harvests that may result from improved control of that pollution; and

Exhibit 1-3

ESTIMATED NUMBER OF CAFOS UNDER ALTERNATIVE REGULATORY SCENARIOS*

Production Sector	Currently Regulated	NPDES Scenario 1	NPDES Scenario 2/3	NPDES Scenario 4a	NPDES Scenario 4b
Beef	2,220	2,290	2,720	3,080	4,080
Dairy	3,150	3,560	5,430	3,760	7,140
Heifers	620	590	830	800	1,050
Veal	20	20	70	90	210
Swine	5,260	5,630	7,520	8,550	14,370
Layers	470	870	1,420	1,640	2,050
Broilers	620	4,320	13,830	9,780	14,140
Turkeys	50	420	1,680	1,280	2,100
Total	**12,410**	**17,700**	**33,500**	**28,980**	**45,140**

* AFOs with more than one animal type are counted more than once; numbers have been rounded to nearest ten.

- **Reduced Contamination of Private Wells:** this analysis examines the impact of the revised regulations on groundwater quality, and values predicted improvements in the quality of aquifers that supply private wells.

Exhibit 1-4 summarizes the results of these four studies for each of the regulatory scenarios. It is important to note that these results are not intended to represent the total value of all benefits associated with a reduction in AFO pollutants; they include only the subset of benefits that is addressed by EPA's analyses. Moreover, EPA's analyses generally take a conservative approach to quantifying benefits; therefore, the results are likely to reflect conservative estimates of the specific benefits that EPA has examined.

1.5 ORGANIZATION OF REPORT

The remainder of this report presents EPA's analysis of the benefits expected under each of the regulatory scenarios considered. Specifically:

- Chapter 2 provides a detailed description of the potential impacts of AFOs on environmental quality and human health;

Exhibit 1-4

ESTIMATED ANNUALIZED BENEFITS OF CHANGES IN REGULATION OF CAFOS (1999 dollars, millions)

Regulatory Scenario	Recreational and Non-use Benefits	Reduced Fish Kills	Improved Shellfishing	Reduced Private Well Pollution	Total
Option 1- Scenario 1	$4.9	$0.1 - $0.2	$0.1 - $1.8	$33.3 - $49.0	$38.4 - $55.9
Option 1- Scenario 2/3	$6.3	$0.1 - $0.3	$0.2 - $2.4	$33.3 - $49.1	$39.9 - $58.0
Option 1- Scenario 4a	$5.5	$0.1 - $0.3	$0.2 - $2.2	$35.5 - $52.2	$41.2 - $60.2
Option 1- Scenario 4b	$7.2	$0.1 - $0.3	$0.2 - $2.6	$35.5 - $52.2	$43.0 - $62.3
Option 2- Scenario 1	$87.6	$0.2 - $0.3	$0.2 - $2.1	$35.4 - $52.1	$123.3 - $142.1
Option 2- Scenario 2/3*	$127.1	$0.2 - $0.4	$0.2 - $2.7	$35.4 - $52.1	$163.0 - $182.3
Option 2- Scenario 4a*	$108.5	$0.2 - $0.4	$0.2 - $2.4	$36.6 - $53.9	$145.5 - $165.1
Option 2- Scenario 4b	$145.0	$0.2 - $0.4	$0.2 - $3.0	$36.6 - $53.9	$182.1 - $202.2

* Proposed scenarios.

- Chapter 3 describes the range of benefits that would result from decreased AFO loadings, and outlines EPA's general approach to quantifying and valuing the subset of benefits analyzed;

- Chapter 4 assesses the value of changes in surface water quality that would result from a reduction in AFO loadings, focusing on changes in the quality of freshwater resources that would improve their suitability for fishing and swimming;

- Chapter 5 assesses the value of reducing the incidence of fish kills attributable to pollution from AFOs;

- Chapter 6 assesses the value of improved commercial shellfishing resulting from decreased AFO loadings;

- Chapter 7 assesses the value of reduced contamination of private wells associated with reductions in the pollution of groundwater by AFOs; and

- Chapter 8 provides the summary and conclusions of the benefits analysis.

1.6 REFERENCES

USDA/USEPA (U.S. Department of Agriculture and U.S. Environmental Protection Agency). 1999. *Unified National Strategy for Animal Feeding Operations*, Section 4.2. Available on EPA's web site at: http://www.epa.gov/owm/finafost.htm#1.0.

POTENTIAL IMPACTS OF AFOS ON ENVIRONMENTAL QUALITY AND HUMAN HEALTH

CHAPTER 2

Animal manure, the primary cause of pollution related to AFOs, contains a variety of pollutants that can cause environmental degradation, particularly when released to surface waters in large quantities.[6] Documented releases from AFOs have been associated with a number of adverse human health and ecological impacts, including fish kills, disease outbreaks, and degradation of water quality and aquatic life.

EPA's 1998 *National Water Quality Inventory*, prepared under Section 305(b) of the Clean Water Act, presents recent information on impaired water bodies nationwide. The *Inventory* identifies agriculture (including irrigated and non-irrigated crop production, range grazing, pasture grazing, and animal feeding operations) as the leading contributor to identified water quality impairments in the nation's rivers and lakes, and the fifth leading contributor to identified water quality impairments in the nation's estuaries. The report also identifies the key pollutants and stressors that impair the nation's waters. Among the most problematic pollutants are several - including pathogens, nutrients, and oxygen depleting substances - that are associated commonly, although not exclusively, with animal waste (USEPA, 2000).[7]

The animal waste management practices and pollutant transport pathways that can lead to contamination of surface waters are well known. Animal wastes at AFOs are typically managed by land application and/or storage in waste piles or lagoons. Land application and storage of manure are centuries-old farming practices. In small or low-density farming operations these methods pose

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[6] This document uses the term manure to refer to both "solid" manure and urine, since these wastes are typically managed together. Additional animal wastes associated with AFOs (e.g., hair, feathers, bedding material and carcasses) are identified separately in the discussion.

[7] The *National Water Quality Inventory 1998 Report to Congress* notes that 28 states and tribes reported impairment by agricultural subcategory. Specifically, these states and tribes reported that animal feeding operations degraded 16 percent of impaired river miles; range and pasture grazing degraded 11 and 6 percent of impaired river miles, respectively; and irrigated and non-irrigated crop production degraded 18 and 27 percent of impaired river miles, respectively.

minimal pollution potential. AFOs, however, manage large amounts of manure in a concentrated area. Under these circumstances, the following waste management failures pose an increased potential for pollution:

- **Over-application of manure:** While land application of manure can provide valuable nutrients to soil and crops, the capacity of soil and crops to absorb nutrients over any given period is limited. Excess manure applied to cropland can damage crops and soil, and is more likely to run off into surface waters or be released to air through volatilization or erosion (for example, through spray application)..

- **Runoff from uncovered manure piles:** Manure piles are frequently used for temporary storage of animal wastes. Precipitation may wash pollutants from uncovered manure piles into nearby surface waters.

- **Lagoon failures:** AFOs frequently store large quantities of manure in lagoons prior to land application or other disposal. While lagoons are designed to prevent the release of wastes into the environment, they are subject to various types of failure, including spills due to overfilling; washouts in floods; liner failures; failures of dikes, pipes, or other above-ground structures; and accidental and intentional operator-related releases.

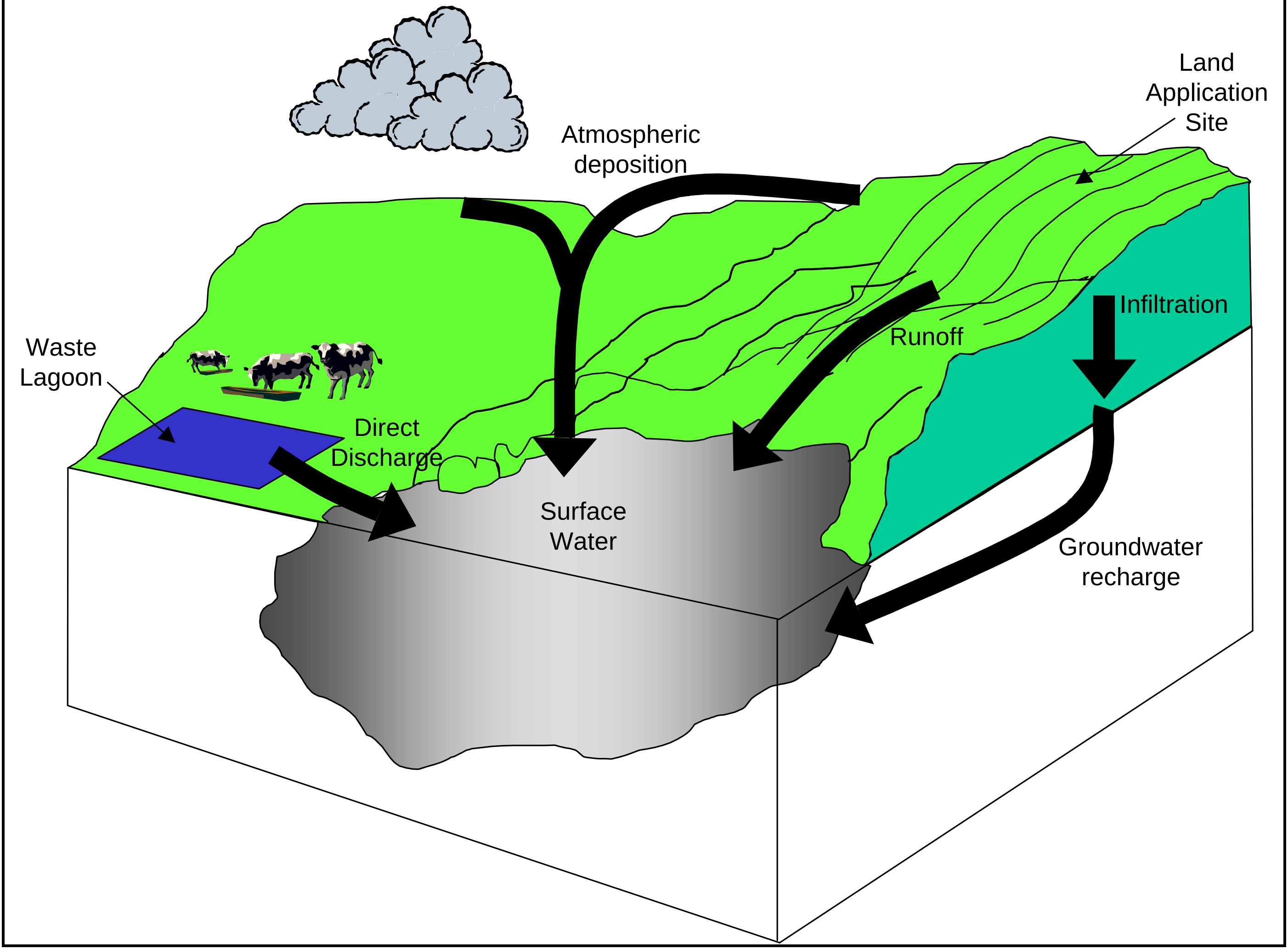
This chapter briefly describes the pathways, pollutants, and environmental and human health effects associated with releases from AFOs. More detailed information is available in *Environmental Assessment of the Proposed Effluent Limitation Guidelines for Concentrated Animal Feeding Operations* (available in Section 8.1 of the Record).

2.1 PATHWAYS FOR THE RELEASE OF POLLUTANTS FROM AFOS

Pollutants in animal wastes can reach surface waters by several pathways, including overland discharge, migration through groundwater, and atmospheric deposition. The most common pathway is overland discharge, which includes surface runoff (i.e., land-applied or piled manure that is washed into surface waters by rain), soil erosion, and acute events such as spills or impoundment failures. Contamination can also occur when pollutants leach through soil into groundwater and then to surface water through groundwater recharge. In addition, airborne pollutants created by volatilization or by spray-application of manure to land can contaminate surface water through atmospheric deposition. Exhibit 2-1 illustrates the various pathways by which AFO releases can affect surface waters and groundwater. The following discussion describes these pathways in greater detail.

Exhibit 2-1

PATHWAYS FOR AFO-RELATED POLLUTANTS



2.1.1 Overland Discharge

Contamination from manure often reaches surface water though overland discharge; that is, by flowing directly into surface waters from land application sites or lagoons. There are three distinct types of overland discharge: surface runoff, soil erosion, and direct discharge of manure to surface water during acute events. For example, a single flood event might include lagoon "washouts," soil erosion and surface runoff. This section describes the various types of overland discharge in more detail.

2.1.1.1 Surface Runoff

Surface runoff occurs whenever rainfall or snowmelt is not absorbed by soil and flows overland to surface waters.[8] Runoff from land application sites or manure piles can transport pollutants to surface waters, especially if rainfall occurs soon after application, if manure is over-applied, or if it is misapplied.[9] The potential for runoff of animal wastes varies considerably with climate, soil conditions, and management practices. For example, manure applied to saturated or frozen soils is more likely to runoff the soil surface (ODNR, 1997). Other factors that promote runoff to surface waters are steep land slope, high rainfall, low soil porosity or permeability, and close proximity to surface waters.

Surface runoff is a particularly significant transport mechanism for water soluble pollutants, including nitrogen compounds. However, runoff can also carry solids. Runoff of manure pollutants has been identified as a factor in a number of documented impacts from AFOs, including hog, cattle, and chicken operations. For example, in 1994, multiple runoff problems were cited for a hog operation in Minnesota, and in 1996 runoff from manure spread on land was identified at hog and chicken operations in Ohio. In 1996 and 1997, runoff problems were identified for several cattle operations in numerous counties in Minnesota (CWAA, 1998; ODNR, 1997).

2.1.1.2 Soil Erosion

In addition to simple surface runoff, pollutants from animal wastes can enter surface water through erosion, in which the soil surface itself is worn away by the action of water or wind. Soil erosion often occurs in conjunction with surface runoff as part of rainfall events, but it represents a transport mechanism for additional pollutants that are strongly sorbed (i.e., chemically bound) to

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[8] Surface discharges can also result from direct contact between confined animals and surface waters. Certain animals, particularly cattle, will wade into the surface waters to drink, and will often urinate and defecate there as well. This practice is now restricted for CAFOs, but may still occur at other types of AFOs.

[9] Experiments show that for all animal wastes, application rates have a significant effect on runoff concentrations of pollutants. See Daniel *et al.*, 1995.

soils. The most important of these pollutants is phosphorus. Because of its tendency to sorb to soils, many agricultural phosphorus control measures focus on soil erosion control. However, soils do not have infinite adsorption capacity for phosphorus or other pollutants, and dissolved pollutants (including phosphates) can still enter waterways through runoff even if soil erosion is controlled (NRC, 1993).

In spite of control efforts, soil erosion remains a serious challenge for agriculture. For example, in 1997 the USDA Natural Resources Conservation Service (NRCS) reviewed the connection between manure production, soil erosion, and water quality in a watershed in South Carolina. NRCS calculated that soil erosion from the 13,000 acres of cropland in the watershed ranged from 9.6 to 41.5 tons per acre per year. The report further found that manure and erosion-related pollutants such as bacteria, nutrients, and sediment are the primary contaminants affecting streams and ponds in the watershed (USEPA, 1997).

Catastrophic Release of Manure:
New River, North Carolina, 1995

On June 21, 1995, a breach in the dike of a 30 million gallon hog waste lagoon discharged over 25 million gallons of waste into tributaries of the New River in Onslow County, North Carolina.

Within a week of the event, North Carolina state officials estimated that roughly 2,600 fish were destroyed, though monitoring indicated that oxygen levels had recovered in the river within a week of the event. JoAnne Burkholder, a North Carolina State University marine scientist, noted that the initial waste deluge probably smothered many fish. Others were killed more slowly by declining oxygen levels and the toxic effects of ammonia and bacteria in the water.

Two days after the spill scientists sampling in some of the affected areas found ammonia levels of about 20 times the lethal limit for most fish.

Though oxygen levels recovered rapidly, Burkholder noted that it could take years for the upper New ecosystem to fully recover and support the range of fish, clams and other creatures that existed before the spill. In addition to immediate problems, longer term problems caused by the breach would include rains churning up settled pollution and potential algae blooms.

State environmental officials also confirmed that high levels of fecal coliform bacteria were detected in the river, and Onslow County healthy officials posted warnings in public recreation areas to prevent people from swimming. According to local newspaper reports, in some places fecal coliform levels were 10,000 times the state standard for swimming.

Sources: *Warrick and Stith,1995b; Warrick 1995b, 1995c, 1995d.*

2.1.1.3 Acute Events

In addition to surface runoff and erosion, acute events such as spills, floods, or other lagoon or application failures can affect surface waters. Unlike runoff and erosion, which generally affect land-applied wastes, acute events frequently affect waste management lagoons. Spills can result from mechanical malfunctions (e.g., pump failures, manure irrigation gun malfunctions, and failures in pipes or retaining walls), overfilling, or washouts during flood events. There are even indications that some operators discharge wastes into surface waters deliberately in order to reduce the volume of waste in overfull lagoons (CWAA, 1998). Acute events frequently result in large waste discharges and are often associated with immediate ecological effects such as fish kills. Furthermore, In addition to immediate fish kills, large releases can be linked with eutrophication, sedimentation, and the growth of pathogens. All of these impacts can also cause acute mortality in fish and other aquatic species.

2.1.2 Leaching to Groundwater

Pollutants from animal waste can migrate to groundwater and subsequently contaminate surface waters through the process of "groundwater recharge," in which hydrological connections between aquifers and surface waters allow transfer of water (and pollutants). Groundwater contamination itself can result from leaching of land-applied pollutants into the soil, or from leaking lagoons. Although most lagoons are lined with clay or are designed to be "self-sealed" by manure solids that prevent infiltration of pollutants into groundwater, these methods are not always effective. For example, a survey of hog and poultry lagoons in the Carolinas found that the contents of nearly two-thirds of the 36 lagoons sampled had leaked into the groundwater (Meadows, 1995). Similarly, clay-lined lagoons can crack or break as they age, and are susceptible to burrowing worms. In a three-year study of clay-lined swine lagoons on the Delmarva Peninsula, researchers found that leachate from lagoons located in well-drained loamy sand adversely affected groundwater quality (Ritter *et al.*, 1990).

Surface water contamination from groundwater is most likely to occur in areas with high soil permeability and shallow water tables, and is most likely to involve water soluble contaminants such as nitrogen (Smith *et al.*, 1997). Overall, the potential for contamination by this pathway may be considerable. For example, in the Chesapeake Bay watershed, the USGS estimates that about half of the nitrogen loads from all sources to non-tidal streams and rivers originates from groundwater (ASCE, 1998). In addition, about 40 percent of the average annual stream flow in the United States results from groundwater recharge (USEPA, 1993).

2.1.3 Discharges to the Air and Subsequent Deposition

Discharges to the air from AFOs include both volatile pollutants (e.g., ammonia and various by-products of manure decomposition) and particulate matter such as dried manure, feed, hair, and feathers. The degree of volatilization of pollutants from manure depends on environmental conditions and the manure management system employed. For example, spray application of manure increases the potential for volatilization, as does the practice of spreading manure on the land without incorporating it into the soil. Volatilization is also affected by climate and soil conditions, (e.g., soil acidity and moisture content), and is reduced by the presence of growing plants (Follett, 1995).

Particulate matter from manure forms an organic dust made up of dried manure, feed, and epithelial cells. These airborne particles can contain adsorbed gases, endotoxin (the toxic protoplasm liberated when a microorganism dies and disintegrates), and possibly steroids from animal waste. According to information presented to the Centers for Disease Control, at least 50 percent of the dust emissions from swine operations are believed to be respirable and may therefore be associated with inhalation-related human health effects (Thu, 1998).[10]

In addition to creating the potential for air-related health effects, both volatilized pollutants and particulate matter can contaminate nearby surface waters through atmospheric deposition. Volatilization of the ammonia in urine, in particular, has been linked with atmospheric deposition of nitrogen (Lander *et al.,* 1998). While it is not clear what percentage of total deposition of pollutants can be linked to AFOs, EPA's 1998 *National Water Quality Inventory* indicates that atmospheric deposition from all sources is the third greatest cause of water quality impairment for estuaries, and the fifth greatest cause of water quality impairment for lakes, reservoirs and ponds.

2.2 POTENTIAL ECOLOGICAL HAZARDS POSED BY AFO POLLUTANTS

The primary pollutants associated with animal waste are nutrients (particularly nitrogen and phosphorus), organic matter, solids, pathogens, and odorous/volatile compounds. Animal waste is also a source of salts and trace elements and, to a lesser extent, antibiotics, pesticides, and hormones. The concentration of particular pollutants in manure varies with animal species, the size, maturity, and health of the individual animal, and the composition (e.g., protein content) of animal feed.[11] The range of pollutants associated with manure is evident in a 1991 U.S. Fish and Wildlife Service (USFWS) report on suspected impacts from cattle feedlots on Tierra Blanca Creek in the Texas Panhandle. The impacts the USFWS reported included elevated concentrations of ammonia, coliform bacteria, chloride, nitrogen, and volatile suspended solids, as well as reduced concentrations of dissolved oxygen. In addition, USFWS found elevated concentrations of the feed additives copper and zinc in creek sediment (USFWS, 1991).

The ecological impacts of animal waste releases to surface water can range from minor, temporary fluctuations in water quality (e.g., associated with limited surface runoff) to chronic degradation of ecosystems (e.g., associated with consistently poor management practices such as over-application), to dramatic impacts such as extensive fish or wildlife kills (e.g., associated with acute events such as spills or toxic algae blooms). In some cases, individual pollutants associated with animal waste are the clear and direct cause of observable ecological effects. In other cases,

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[10] "Respirable" generally refers to particles less than 10 microns in diameter, or PM10; these particles are responsible for the majority of human health effects related to air pollution because they are small enough to travel through the nasal passage and into the lungs.

[11] For more detailed discussion of the pollutants associated with animal waste, see Phillips *et al.,* 1992.

ecological effects such as declines in aquatic populations are the result of complex systemic changes that are linked directly or indirectly to pollution from AFOs.

Exhibit 2-2 lists the key pollutants associated with AFO waste, and notes their potential impacts. The remainder of this section describes in more detail the relationship between AFO pollutants and observed ecological effects. Section 2.3 focuses on the specific impacts of AFO pollutants on human health.

Exhibit 2-2

KEY POLLUTANTS IN ANIMAL WASTE

Pollutant	**Description of Pollutant Forms in Animal Waste**	**Pathways**	**Potential Impacts**
Nutrients			
Nitrogen	Exists in fresh manure in organic (e.g., ammonia in urea) and inorganic forms (e.g., ammonium and nitrate). Microbes transform organic nitrogen to inorganic forms that are absorbed by plants.	< Overland discharge < Leachate into groundwater < Atmospheric deposition as ammonia	< Eutrophication < Animal, human health effects
Phosphorus	Exists in both organic (water soluble) and inorganic forms. As manure ages, phosphorus mineralizes to inorganic phosphate compounds that are absorbed by plants.	< Overland discharge < Leachate into groundwater (water soluble forms)	< Eutrophication
Potassium	Most potassium in manure is in an inorganic form available for absorption by plants; it can also be stored in soil for future uptake.	< Overland discharge < Leachate into groundwater	< Eutrophication < Increased salinity
Organic Compounds	Carbon-based compounds in manure that are decomposed by surface water micro-organisms. Creates biochemical oxygen demand, or BOD, because decomposition consumes dissolved oxygen in the water.	< Overland discharge	< Depletion of dissolved oxygen < Reduction in aquatic life
Solids	Includes manure itself and other elements (e.g., feed, bedding, hair, feathers, and corpses).	< Overland discharge < Atmospheric deposition	< Turbidity < Siltation
Pathogens	Includes range of disease-causing organisms, including bacteria, viruses, protozoa, fungi, and algae. Some pathogens are found in manure, others grow in surface water due to increased nutrients and organic matter.	< Overland discharge < Growth in waters with high nutrient, organic materials < Algal by-products	< Animal, human health effects
Salts	Includes soluble salts containing cations sodium and potassium (from undigested feed), calcium and magnesium; and anions chloride, sulfate, bicarbonate, carbonate, and nitrate.	< Overland discharge < Leachate into groundwater	< Reduction in aquatic life < Human health effects
Trace Elements	Includes feed additives arsenic, copper, selenium, zinc, cadmium; and trace metals molybdenum, nickel, lead, iron, manganese, aluminum, and boron (pesticide ingredients).	< Overland discharge	< Toxicity at high levels

Exhibit 2-2

KEY POLLUTANTS IN ANIMAL WASTE

Pollutant	Description of Pollutant Forms in Animal Waste	Pathways	Potential Impacts
Odorous, Volatile Compounds	Includes carbon dioxide, methane, hydrogen sulfide, and ammonia gases generated during decomposition of waste.	< Inhalation < Atmospheric deposition of ammonia	< Human health effects < Eutrophication
Other Pollutants	Includes pesticides, antibiotics, and hormones used in feeding operations.	< Overland discharge	< *Impacts unknown*

2.2.1 Nutrients and Eutrophication

EPA's 1998 *National Water Quality Inventory* indicates that nutrients from all sources comprise the leading stressor in impaired lakes, ponds, and reservoirs, and are among the most frequent stressors in impaired rivers, streams, and estuaries. Nutrients are naturally occurring elements that are necessary for plant growth. However, when excess nutrients enter surface waters they can stimulate overgrowth of algae and bacteria, changing ecosystems in a process called "eutrophication." In addition, nutrients (nitrogen, in particular) in high concentrations can be toxic to animals and humans.

The two nutrients of most concern related to AFOs are nitrogen and phosphorus.[12] Each of these elements exists in several forms in the environment, and is involved in several phases of uptake and digestion by animals and plants. This section briefly describes the processes by which nitrogen and phosphorus enter aquatic ecosystems, then discusses the process and impacts of eutrophication.

2.2.1.1 Nitrogen and Nitrogen Compounds

Nitrogen, an element essential to plant growth, moves through the environment in a series of chemical reactions known as the nitrogen cycle. Nitrogen in manure exists in both organic forms (e.g., urea) and inorganic forms (e.g., ammonium and nitrate) (NCAES, 1982). In fresh manure, 60 to 90 percent of total nitrogen is present in the organic form. Inorganic nitrogen can enter the environment by volatilizing in the form of ammonia, or through soil or water microbe processes that transform organic nitrogen to an inorganic form that can be used by plants (i.e., as fertilizer). Both ammonia and ammonium are toxic to aquatic life, and ammonia in particular reduces the dissolved oxygen in surface waters that is necessary for aquatic animals. Nitrites pose additional risks to

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[12] Potassium contributes to the salinity of animal manure, which may in turn contribute salinity to surface water polluted by manure. Actual or anticipated levels of potassium in surface water and groundwater, however, are unlikely to pose hazards to human health or aquatic life. For more information see Wetzel, 1983.

aquatic life: if sediments are enriched with nutrients, nitrite concentrations in the water may be raised enough to cause nitrite poisoning or "brown blood disease" in fish (USDA, 1992).

A 1975 study found that up to 50 percent or more of the nitrogen in fresh manure may be in ammonia form or converted to ammonia relatively quickly once manure is excreted (Vanderholm, 1975). Ammonia is highly volatile, and ammonia losses from animal feeding operations can be considerable. In North Carolina, animal agriculture is responsible for over 90 percent of all ammonia emissions; ammonia composes more than 40 percent of the total estimated nitrogen emissions from all sources. Once airborne, these volatile pollutants may be deposited onto nearby streams, rivers, and lakes. Data from Sampson County, North Carolina show that "ammonia rain" has increased as the hog industry has grown, with ammonia levels in rain more than doubling between 1985 and 1995 (Aneja *et al.*, 1998).

National Study of Nitrogen Sources to Watersheds

In 1994, the USGS analyzed potential nitrogen sources to 107 watersheds, including manure (from both confined and unconfined animals), fertilizers, point sources, and atmospheric deposition. While the study found that proportions of nitrogen originating from various sources differ according to climate, hydrologic conditions, land use, population, and physical geography, results for selected watersheds for the 1987 base year showed that in some instances, nitrogen from manure represents a large portion of the total nitrogen added to the watershed. For example, in nine study watersheds more than 25 percent of nitrogen originates from manure.

Source: *Puckett, 1994.*

Ammonia is highly toxic to aquatic life and is a leading cause of fish kills. In a May 1997 incident in Wabasha County, Minnesota, ammonia in a dairy cattle manure discharge killed 16,500 minnows and white suckers (CWAA, 1998). In addition, ammonia and other pollutants in manure exert a direct biochemical oxygen demand (BOD) on the receiving water. As ammonia is oxidized, dissolved oxygen is consumed. Moderate depressions of dissolved oxygen are associated with reduced species diversity, while more severe depressions can produce fish kills (USFWS, 1991).

2.2.1.2 Phosphorus

Like nitrogen, phosphorus is necessary for the growth of plants, but is damaging in excess amounts. Phosphorus exists in solid and dissolved phases, in both organic and inorganic forms. Over 70 percent of the phosphorus in animal manure is in the organic form (USDA, 1992). As manure ages, phosphorus mineralizes to inorganic phosphate compounds which are available to plants. Organic phosphorus compounds are generally water soluble and may leach through soil to groundwater or runoff into surface waters. In contrast, inorganic phosphorus tends to adhere to soils and is less likely to leach into groundwater, though it can reach surface waters through erosion or over-application. A report by the Agricultural Research Service noted that phosphorus bound to eroded sediment particles makes up 60 to 90 percent of phosphorus transported in surface runoff from cultivated land (USDA/ARS, 1999). Animal wastes typically have lower nitrogen: phosphorus ratios than crop requirements. The application of manure at a nitrogen-based agronomic rate can therefore result in application of phosphorus at several times the agronomic rate. Soil test data in the United States confirm that many soils in areas dominated by animal-based agriculture exhibit excessive levels of phosphorus (Sims, 1995).

Available Nitrogen and Phosphorus
1998 U.S. Department of Agriculture Study

In 1998, the USDA studied the amount of manure nitrogen and phosphorus produced by confined animals relative to crop uptake potential. USDA evaluated the quantity of nutrients available from recoverable livestock manure relative to crop growth requirements, by county, based on data from the 1992 Census of Agriculture. The analyses did not consider manure from grazing animals in pasture. When calculating available nutrients, USDA also corrected for unrecoverable manure, nutrient losses that occur during storage and treatment, and losses to the environment that can occur through runoff, erosion, leaching to groundwater, and volatilization (especially for nitrogen in the form of ammonia). Considering typical management systems, USDA estimates that average manure nitrogen losses range from 31 to 50 percent for poultry, 60 to 70 percent for cattle (including the beef and dairy categories), and 75 percent for swine. The typical phosphorus loss is 15 percent.

USDA's study examined the potential for available manure nitrogen and phosphorus generated to meet or exceed plant uptake in each of the 3,141 mainland counties, considering harvested non-legume cropland and hayland. Based on the analysis of 1992 conditions, available manure nitrogen exceeds crop system needs in 266 counties, and available manure phosphorus exceeds crop system needs in 485 counties. The relative excess of phosphorus compared to nitrogen is expected because manure is typically nitrogen-deficient relative to crop needs. Therefore, when manure is applied to meet a crop's nitrogen requirement, phosphorus is typically over-applied with respect to crop requirements (Sims, 1995).

These analyses do not evaluate environmental transport of applied manure nutrients. Therefore, an excess of nutrients does not necessarily indicate that a water quality problem exists; likewise, a lack of excess nutrients does not imply the absence of water quality problems. Nevertheless, the analyses provide a general indicator of excess nutrients on a broad basis.

Source: *Lander et al., 1998.*

2.2.1.3 Eutrophication

Eutrophication is a process in which excess phosphorus or nitrogen over-enriches water bodies and disrupts aquatic ecosystems. Excess nutrients cause overgrowth of plants, including fast-growing algae "blooms." Eutrophication can affect the population diversity, abundance, and biomass of phytoplankton and zooplankton, and can increase the mortality rates of aquatic species (USEPA, 1991). Even when algae are not themselves directly harmful to aquatic life, floating algal mats can reduce the penetration of sunlight in the water column and limit growth of seagrass beds and other submerged vegetation. Reduction in submerged aquatic vegetation adversely affects both fish and shellfish populations, and is the leading cause of biological decline in Chesapeake Bay (Carpenter *et al.*, 1998). The 1998 *National Water Quality Inventory* indicates that excess algal growth alone is the seventh leading stressor in lakes, ponds, and reservoirs.

Increased algal growth can also raise the pH of water bodies as algae consume dissolved carbon dioxide to support photosynthesis. This elevated pH can harm the gills of aquatic organisms. The pH may then drop rapidly at night, when algal photosynthesis stops. In extreme cases, such pH fluctuations can severely stress aquatic species. In addition, excess nitrogen can contribute to water quality decline by increasing the acidity of surface waters (USEPA, 1995, 1991).

Damage from eutrophication increases when algae blooms die and are digested by bacteria in a decomposition process that depletes the level of oxygen in the water. Dissolved oxygen is necessary for the survival of aquatic life in a healthy ecosystem, and depressed levels of dissolved oxygen can cause widespread morbidity and mortality among aquatic species. Algal decay and night-time respiration can lower the dissolved oxygen content of a water body to levels insufficient to support fish and invertebrates. Severe reductions in dissolved oxygen can result in dramatic fish kills (Carpenter *et al*., 1998).

In addition to reducing plant diversity and dissolved oxygen, eutrophication can encourage the growth of toxic microorganisms such as cyanobacteria (a toxic algae) and the dinoflagellate *Pfiesteria piscicida*. These organisms can be toxic to both wildlife and humans. Researchers have documented stimulation of *Pfiesteria* growth by swine effluent spills, and have shown that the organism's growth can be highly stimulated by both inorganic and organic nitrogen and phosphorus enrichment (NCSU, 1998).

2.2.2 Pathogens

Pathogens are organisms that cause disease in humans and other species; they include certain species of bacteria, viruses, protozoa, fungi, and algae. Animal waste itself contains hundreds of species of microorganisms, including bacteria, viruses, protozoa, and parasites (USDA, 1998; Jackson *et al.*, 1987; Boyd, 1990). Pathogens may be transmitted directly from manure to surface water, and pathogens already in surface water may increase in number due to loadings of animal manure nutrients and organic matter. Of particular concern are certain pathogens associated with algae blooms. EPA's 1998 *National Water Quality Inventory* focuses on bacterial pathogens and notes that they are the leading stressors in impaired estuaries and the second most prevalent stressors in impaired rivers and streams.

Over 150 pathogens in livestock manure are associated with risks to humans; these include the bacteria *Escheria coli* and *Salmonella* species. and the protozoa *Cryptosporidium parvum* and *Giardia* species. A recent study by the USDA revealed that about half the cattle at the nation's feedlots carry *E. coli* (NAS, 2000). The pathogens *C. parvum*, *Giardia*, and *E. coli* are able to survive and remain infectious in the environment for long periods of time (Stehman, 2000). In addition, some bacteria in livestock waste cause avian botulism and avian cholera, which have in the past killed tens of thousands of migratory waterfowl annually (USEPA, 1993).

Eutrophication is associated with blooms of a variety of organisms that can be toxic to fish. This includes the estuarine dinoflagellate *Pfiesteria piscicida*, which is believed to be the primary cause of many major fish kills and fish disease events in North Carolina estuaries and coastal areas, as well as in Maryland and Virginia tributaries to the Chesapeake Bay (NCSU, 1998; USEPA, 1993). In 1997, hog operations were linked to a *Pfiesteria piscicida* outbreak in North Carolina rivers in which 450,000 fish died (U.S. Senate, 1997). That same year, poultry operation wastes caused *Pfiesteria* outbreaks that killed tens of thousands of fish in Maryland waters, including the Pokomoke River, King's Creek, and Chesapeake Bay (Shields, 1997; Shields and Meyer, 1997; New York Times, 1997).

1995 Algae Blooms and Pfiesteria Outbreaks: Neuse River, North Carolina

Algae blooms and pfiesteria outbreaks on the Neuse River in North Carolina during the summer and fall of 1995 were the identified causes of three major fish kills and the suspected causes of several incidents of human illness.

Heavy rains in June of 1995 caused overflows of wastewater treatment plants and hog lagoons in the watershed. Within weeks, large mats of algae and aquatic weeds were reported near the town of New Bern on the Trent River, a tributary of the Neuse. By July, historically low levels of dissolved oxygen were recorded in a stretch of the Neuse downstream from New Bern, coinciding with the deaths of over 100,000 fish. A second fish kill in August on another Neuse tributary numbered in the thousands.

In September and October a third major fish kill occurred along a 35-mile stretch of the Neuse River itself; the dead fish were covered with sores, and the cause of the outbreak was determined to be the dinoflagellate pfiesteria. After multiple reports of similar welts and sores on the bodies of those who went swimming or fishing in contaminated areas, state officials declared a health warning for the area, urging people not to swim, boat, or fish in the affected area. In addition, the area was closed to commercial fishing for two weeks.

Source: *Leavenworth, 1995a, 1995b.*

The generation of toxins associated with eutrophication can also threaten other species. In freshwater, cyanobacterial toxins have caused many incidents of poisoning of wild and domestic animals that have consumed contaminated waters (Health Canada Environmental Health Program, 1998; Carpenter *et al.*, 1998). In coastal waters, visible algae blooms known as red or brown tides have caused significant mortality in marine mammals. Even when algae blooms are not visible, shellfish such as oysters, clams and mussels can carry the toxins from certain algae in their tissue. Shellfish are filter feeders, and pass large volumes of water over their gills to obtain nutrients. As a result, they can concentrate a broad range of microorganisms in their tissues, and provide a pathway for pathogen transmission from surface water to higher trophic organisms (Chai *et al.*, 1994). Information is becoming available to assess the health effects of contaminated shellfish on wildlife receptors. In 1998, the death of over 400 California sea lions was linked to ingestion of mussels contaminated by a bloom of toxic algae (Scholin *et al.*, 2000). Previous incidents associated the deaths of manatees and whales with toxic and harmful algae blooms (Anderson, 1998).

In August 1997, the National Oceanic and Atmospheric Administration (NOAA) released *The 1995 National Shellfish Register of Classified Growing Waters*. The register characterizes the status of 4,230 shellfish-growing water areas in 21 coastal states, reflecting an assessment of nearly 25 million acres of estuarine and non-estuarine waters. NOAA found that 3,404 shellfish areas had some level of impairment. Of these, 110 (3 percent) were impaired to varying degrees by feedlots, and 280 (8 percent) were impaired by "other agriculture," which could include land where manure is applied (NOAA, 1997).

2.2.3 Organic Compounds and Biochemical Oxygen Demand (BOD)

Livestock manures contain many carbon-based, biodegradable compounds. Once these compounds reach surface water, they are decomposed by aquatic bacteria and other microorganisms. During this process dissolved oxygen is consumed, which in turn reduces the amount of oxygen available for aquatic animals. EPA's 1998 *National Water Quality Inventory* indicates that oxygen-depleting substances are the second leading stressor in estuaries. They are also the fourth leading stressor both in impaired rivers and streams and in impaired lakes, ponds, and reservoirs.

Carbon compounds and associated biochemical oxygen demand (BOD) can deplete oxygen and affect the health of aquatic ecosystems in the absence of any other pollutants (e.g., due to decaying vegetation).[13] When carbon compounds enter aquatic ecosystems in conjunction with nutrients (which is generally the case in manure-related pollution), the impacts of BOD are compounded by eutrophication and the presence and growth of pathogens. The result is often a rapid decrease in biodiversity. A study of three Indiana stream systems documents such a reduction in biodiversity due to AFOs (Hoosier Environmental Council, 1997). The study found that waters

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[13] Biochemical oxygen demand (BOD) is an indirect measure of the concentration of biodegradable substances present in an aqueous solution. Anaerobic lagoon effluent from AFOs typically contains BOD values 10 to 200 times higher than treated domestic sewage. See NCAES, 1982; USDA, 1992; USDA/NRCS,1992/1996.

downstream of animal feedlots (mainly hog and dairy operations) contained fewer fish and a limited number of species of fish in comparison with reference sites. It also found excessive algal growth, altered oxygen content, and increased levels of ammonia, turbidity, pH, and total dissolved solids.

2.2.4 Solids and Siltation

Solids from animal manure include the manure itself and any other elements that have been mixed with it, such as spilled feed, bedding, hair, feathers, and corpses. Smaller solids with less weight remain in the water column as "suspended solids" while heavier solids sink to the bottom of receiving waters in the gradual process of "siltation."

Solids entering surface water can degrade aquatic ecosystems to the point of non-viability. Suspended particles can reduce the depth to which sunlight can penetrate, decreasing photosynthetic activity and the resulting oxygen production by plants and phytoplankton. The increased turbidity also limits the growth of aquatic plants, which serve as critical habitat for fish, crabs, shellfish, and other aquatic organisms upon which these animals feed. In addition, suspended particles can clog fish gills, reduce visibility for sight feeders, and disrupt migration by interfering with fish's ability to navigate using chemical signals (Goldman and Horne, 1983; Abt, 1993). EPA's 1998 *National Water Quality Inventory* indicates that suspended solids from all sources are the fifth leading stressor in lakes, ponds, and reservoirs.

A major source of siltation is erosion from agricultural lands, including AFOs, cropland, and grazing lands (USEPA, 1992b). Silt can contain heavier manure particles as well as the soil particles carried by erosion. Such sediment can smother fish eggs and otherwise interrupt the reproduction of aquatic species (Boyd, 1990). It can also alter or destroy habitat for benthic organisms. Solids can also degrade drinking water sources, thereby increasing treatment costs. The 1998 *National Water Quality Inventory* indicates that siltation from all sources (including agriculture and non-agriculture) is the leading stressor in impaired rivers and the third greatest stressor in impaired lakes, ponds, and reservoirs.

Arkansas Water Quality Inventory Report:
Agricultural Activities and Turbidity

Arkansas' 1996 Water Quality Inventory Report *discussed a sub-watershed in northwestern Arkansas. Land uses in that area, primarily poultry production and pasture management, are major sources of nutrients and chronic high turbidity, and water in the area only partially supports aquatic life.*

Source: *USEPA, 1993.*

2.2.5 Salts and Trace Elements

Animal manure contains a number of salts and trace elements such as metals. While these contaminants do not directly alter or interfere with ecosystem processes such as oxygen availability, they are toxic in high concentrations, both to animals and plants. For example, bottom feeding birds may be susceptible to metal toxicity because they are attracted to shallow feedlot wastewater ponds and waters adjacent to feedlots. In addition, metals can remain in aquatic ecosystems for long periods of time because of adsorption to suspended or bed sediments or uptake by aquatic biota.

The salinity of animal manure is due to the presence of dissolved mineral salts. In particular, significant concentrations of soluble salts containing sodium and potassium remain from undigested feed that passes unabsorbed through animals.[14] Salinity tends to increase as the volume of manure decreases during decomposition, and can have an adverse effect on aquatic life and drinking water supplies (Gresham *et al.*, 1990). Repeated application of manure can lead to increased soil salinity in the root zone and on top of the soil, where it can damage crops; to reduce salinity farmers apply excess water, and salts are washed into surface waters in runoff. In fresh waters, increasing salinity can disrupt the balance of the ecosystem, making it difficult for resident species of plants and animals to remain. For example, laboratory experiments have linked increased salinity with inhibited growth and slowed molting in mallard ducklings (USFWS, 1992).

Trace elements in manure can include arsenic, copper, selenium, zinc, cadmium, molybdenum, nickel, lead, iron, manganese, aluminum, and boron. Of these, arsenic, copper, selenium, and zinc are often added to animal feed as growth stimulants or biocides (Sims, 1995). Trace metals may also end up in manure through use of pesticides that are applied to livestock to suppress houseflies and other pests (USDA/ARS, 1998).

A recent Iowa investigation of chemical and microbial contamination near large scale swine operations demonstrated the presence of trace elements not only in manure lagoons used to store swine waste before it is land applied, but also in drainage ditches, agricultural drainage wells, tile line inlets and outlets, and an adjacent river (CDCP, 1998). Similarly, USFWS has reported on suspected impacts from a large number of cattle feedlots on Tierra Blanca Creek, upstream of the Buffalo Lake National Wildlife Refuge in the Texas Panhandle. USFWS found elevated concentrations of the feed additives copper and zinc in the creek sediment (USFWS, 1991).

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[14] See Boyd, 1990 and NCAES, 1982. Other major cations contributing to manure salinity are calcium and magnesium; the major anions are chloride, sulfate, bicarbonate, carbonate, and nitrate. See NRC, 1993.

2.2.6 Odorous/Volatile Compounds

Sources of volatile compounds and odor from AFOs include animal confinement buildings, manure piles, waste lagoons, and land application sites, where decomposition of animal wastes by microorganisms produces gases. The four main gases generated are carbon dioxide, methane, hydrogen sulfide, and ammonia. Aerobic conditions yield mainly carbon dioxide, while anaerobic conditions that dominate in typical, unaerated animal waste lagoons generate both methane and carbon dioxide. Anaerobic conditions are also associated with the generation of hydrogen sulfide and about 40 other odorous compounds, including volatile fatty acids, phenols, mercaptans, aromatics, sulfides, and various esters, carbonyls, and amines (USDA, 1992; Bouzaher *et al*, 1993).

Volatile compounds affect aquatic ecosystems through atmospheric deposition; ammonia (discussed in Section 2.2.1.1) is the most important AFO-related volatile because it is itself toxic and also contributes to eutrophication as a source of nitrogen. Other compounds are less clearly associated with broad ecological impacts, but may have localized impacts.

2.2.7 Other Pollutants and Ecosystem Imbalances

In addition to the pollutants discussed above, pesticides, antibiotics, and hormones used in animal feeding operations may exist in animal wastes and may be present in increased levels in the environment (USDA/ARS, 1998). These compounds may pose risks such as chronic aquatic toxicity (from pesticides) and reproductive impairment (from hormones). While there is limited information on the quantities of these compounds that reach surface waters from AFOs, some research suggests that manure-related runoff may be a significant source of these contaminants.

- **Pesticides:** Pesticides are used to suppress houseflies and other livestock pests. There is little information on the rate at which pesticides in manure enter surface water, but a 1999 literature review by the University of Minnesota notes a 1994 study that links quantities of cyromazine (used to control flies in poultry litter) in runoff to the rate of manure application and rainfall intensity. The review also identifies a 1995 study finding that roughly one percent of all applied pesticides enter surface water. The impacts of these compounds on aquatic ecosystems are unclear, but there is some concern that pesticides may contribute to endocrine disruption (Mulla, 1999).

- **Hormones:** Animal operations use a variety of hormones such as steroids (e.g., estrogen, progesterone, testosterone) and proteins (e.g., prolactin, growth hormone) to improve animal health and productivity. Studies have identified hormones in animal manures. Naturally high hormone concentrations in birds contribute to higher hormone levels in poultry manure, including measurable amounts of estrogen and testosterone. When present in high concentrations, hormones in the environment are linked to reduced fertility, mutations, and the death of fish. There is evidence that fish in some streams are experiencing endocrine disruption (Shore et al., 1995; Mulla, 1999).[15]

- **Antibiotics** The majority of livestock (roughly 60 to 80 percent) receive antibiotics during their productive life span. Some of these agents are used only therapeutically (e.g., to treat illness), but in both the swine and poultry industries, most antibiotics are administered as feed additives to promote growth or to improve feed conversion efficiency. Essentially all of an antibiotic administered is eventually excreted, either unchanged or in metabolite form (Tetra Tech, 2000). Little information is available regarding the concentrations of antibiotics in animal wastes, or on the fate and transport of antibiotics in the environment. However, the key concern related to antibiotics in animal manure is the potential emergence of antibiotic-resistant pathogens in surface and drinking water. As antibiotics use has increased, more strains of antibiotic resistant pathogens are emerging (Mulla, 1999).

Finally, manure pollutants of all types can affect terrestrial as well as aquatic ecosystems. Over-application of manure, in particular, can have terrestrial effects. High oxygen depletion rates due to microbial activity have been reported in manure-amended agricultural soils. In addition, elevated microbial populations can affect crop growth by competing with plant roots for soil oxygen and nutrients. Trace elements (e.g., feed additives such as arsenic, copper, and selenium) and salts in animal manure can accumulate in soil and become toxic to plants (USDA, 1992 and USFWS, 1991).

2.3 HUMAN HEALTH IMPACTS RELATED TO AFO POLLUTANTS

Human health impacts from manure-related contaminants are primarily associated with drinking contaminated water, contact with contaminated water, and consuming contaminated shellfish. The most common causes of health effects are ingestion of nitrates in drinking water, ingestion of water containing pathogens from manure, and contact with or ingestion of harmful algae or toxic algal by-products. The ingestion of elevated concentrations of trace elements (e.g., arsenic, copper, selenium, and zinc) may also affect human health, and certain gases associated with AFOs may pose inhalation risks for nearby residents.

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[15] The presence of estrogen and estrogen-like compounds in surface water has been the focus of recent research. While their ultimate fate in the environment is unknown, studies indicate that no common soil or fecal bacteria can metabolize estrogen (Shore et al., 1995). Estradiol, an estrogen hormone, was found in runoff from a field receiving poultry litter at concentrations up to 3.5 micrograms per litre (ug/L). Fish exposed to 0.25 ug/L of estradiol can undergo gender changes, and exposures at levels above 10 ug/L can be fatal (Mulla, 1999).

While some recorded human health effects stem from contamination of public drinking water supplies and ingestion of shellfish, more frequently health effects are caused by contamination of private wells, or recreational ingestion or contact. Public water supplies are generally protected by monitoring and treatment, though contaminants and algae blooms may increase treatment costs and affect system operation. Ingestion of contaminated shellfish is reduced by monitoring and closure of shellfish beds in response to excessive levels of contaminants.

2.3.1 Health Impacts Associated with Nitrates

Nitrogen in manure is easily transformed into nitrate form, which can be transported to drinking water sources (e.g., through leaching to groundwater) and presents a range of health risks. EPA found that nitrate is the most widespread agricultural contaminant in drinking water wells, and estimates that 4.5 million people served by wells are exposed to elevated nitrate levels (USEPA, 1990). Elevated nitrate levels can cause nitrate poisoning, particularly in infants (this is known as methemoglobinemia or "blue baby syndrome"), in which potentially fatal oxygen starvation gives a "blue" appearance to the skin. In addition to blue baby syndrome, low blood oxygen due to methemoglobinemia has also been linked to birth defects, miscarriages, and poor health in humans and animals.[16]

Reported cases of methemoglobinemia are most often associated with wells that were privately dug and that may have been badly positioned in relation to the disposal of human and animal excreta (Addiscott *et al.*, 1991). Reported cases of methemoglobinemia are rare, though the incidence of actual cases may be greater than the number reported. Studies in South Dakota and Nebraska have indicated that most cases of methemoglobinemia are not reported. Under-reporting may result from the fact that methemoglobinemia can be difficult to detect in infants because its symptoms are similar to other conditions. In addition, doctors are not always required to report it (Michel, 1996; Meyer, 1994).

In 1995, several private wells in North Carolina were found to be contaminated with nitrates at levels 10 times higher than the health standard; this contamination was linked with a nearby hog operation (Warrick 1995c, 1995d). In 1982, nitrate levels greater that 10 milligrams per liter were found in 32 percent of the wells in Sussex County, Delaware; these levels were associated with local poultry operations (Chapman, 1996). In southeastern Delaware and the Eastern Shore of Maryland, where poultry production is prominent, over 20 percent of wells were found to have nitrate levels

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[16] See USEPA, 1991. In addition, studies in Australia found an increased risk of congenital malformations with consumption of high-nitrate groundwater. Nitrate- and nitrite-containing compounds also have the ability to cause hypotension or circulatory collapse. Nitrate metabolites such as N-nitroso compounds (especially nitrosamines) have been linked to severe human health effects such as gastric cancer. See Bruning-Fann and Kaneene, 1993.

exceeding EPA's maximum contaminant level (MCL) (Ritter *et al.*, 1989). Nitrate is not removed by conventional drinking water treatment processes. Its removal requires additional, relatively expensive treatment units.

2.3.2 Health Impacts Associated with Algal Blooms

Eutrophication can affect human health by encouraging the formation of algal blooms. Some algae release toxins as they die and may affect human health through dermal contact or through consumption of contaminated water or shellfish. In marine ecosystems, algal blooms such as red tides form toxic byproducts that can affect human health through recreational contact or consumption of contaminated shellfish (Thomann and Muller, 1987). In freshwater, blooms of cyanobacteria (blue-green algae) may pose a serious health hazard to those who consume the water. When cyanobacterial blooms die or are ingested, they release water-soluble compounds that are toxic to the nervous system and liver (Carpenter *et al.*, 1998).

Non-toxic algae blooms triggered by nutrient pollution can also affect drinking water by clogging treatment plant intakes and by producing objectionable tastes and odors. In addition, increased algae in drinking water sources can increase production of harmful chlorinated byproducts (e.g., trihalomethanes) by reacting with chlorine used to disinfect drinking water.

Impacts of Manure Pollutants on Water Treatment Costs

Public water providers may incur considerable expenses associated with removing manure-related contaminants and algae from public water supplies. For example:

- *In California’s Chino Basin, it could cost over $1 million per year to remove the nitrates from drinking water due to loadings from local dairies.*

- *In Wisconsin, the City of Oshkosh has spent an extra $30,000 per year on copper sulfate to kill the algae in the water it draws from Lake Winnebago. The thick mats of algae in the lake have been attributed to excess nutrients from manure, commercial fertilizers, and soil.*

- *In Tulsa, Oklahoma, excessive algal growth in Lake Eucha is associated with poultry farming. The city spends $100,000 per year to address taste and odor problems in the drinking water .*

Sources: *For more details on these examples, see USEPA, 1993; Behm, 1989; Lassek, 1998; and Lassek, 1997.*

2.3.3 Health Impacts Associated with Pathogens

Over 150 pathogens in livestock manure are associated with risks to humans (Juranek, 1991; CAST, 1992). Although human contact can occur through contaminated drinking water, adequate treatment of public water supplies generally prevents exposure. Most exposure occurs through incidental ingestion during recreation in contaminated waters or through ingestion of contaminated shellfish (Stelma and McCabe, 1992). Relatively few microbial agents are responsible for the majority of human disease outbreaks from water-based exposure routes. Intestinal infections are the most common type of waterborne infection, but contact recreation with pathogens can also result in infections of the skin, eye, ear, nose, and throat (Juranek, 1995; and Stehman, 2000). In 1989, ear and skin infections and intestinal illnesses were reported in swimmers as a result of discharges from a dairy operation in Wisconsin (Behm, 1989).

A study for the period 1989 to 1996 revealed that Cryptosporidium parvum (a pathogen associated with cows) was one of the leading causes of infectious water-borne disease outbreaks in which an agent was identified. C. parvum can produce gastrointestinal illnesses such as cryptosporidiosis, with symptoms that include severe diarrhea (Stehman, 2000). While otherwise healthy people typically recover quickly from illnesses such as cryptosporidiosis, these diseases can be fatal in certain subpopulations, including children, the elderly, people with HIV infection, chemotherapy patients, and those taking medications that suppress the immune system.[17] In Milwaukee, Wisconsin in 1993, C. parvum contamination of a public water supply caused more than 100 deaths and an estimated 403,000 illnesses. The source was not identified, but speculated sources include runoff from cow manure application sites (Casman, 1996). More recently, a May, 2000 outbreak of *Escherichia coli* O157:H7 in Walkerton, Ontario resulted in at least seven deaths and 1,000 cases of intestinal problems; public health officials theorize that flood waters washed manure contaminated with E. coli into the town's drinking water well (Brooke, 2000).

Algae blooms are associated with a variety of organisms that are toxic to humans, including the algae associated with "red tide" and a number dinoflagellates. One pathogen of particular concern is the estuarine dinoflagellate Pfiesteria piscicida. While Pfiesteria is primarily associated with fish kills and fish disease events, the organism has also been linked with human health impacts through dermal or inhalation exposure. Researchers working with dilute toxic cultures of Pfiesteria have exhibited symptoms such as skin sores, severe headaches, blurred vision, nausea/vomiting, sustained difficulty breathing, kidney and liver dysfunction, acute short-term memory loss, and severe cognitive impairment. In addition, people with heavy environmental exposure have exhibited symptoms as well. In a 1998 study, such environmental exposure was definitively linked with cognitive impairment, and less consistently linked with physical symptoms (NCSU, 1998; Morris et al., 1998).

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[17] By the year 2010, about 20% of the human population (especially infants, the elderly, and those with compromised immune systems) will be classified as particularly vulnerable to the health effects of pathogens (Mulla, 1999).

While many soil types prevent most pathogens from reaching aquifers, groundwater in areas of sandy soils, limestone formations, or sinkholes is more vulnerable to contamination. Private wells, in particular, are prone to contamination because they tend to be shallower than public wells and therefore more susceptible to contaminants leaching from the surface.[18] While the general extent of groundwater contamination from AFOs is unknown, there are incidents that indicate a connection between livestock waste and contaminated well water. For example, in cow pasture areas of Door County, Wisconsin, where a thin topsoil layer is underlain by fractured limestone bedrock, groundwater wells have commonly been shut down due to high bacteria levels (Behm, 1989).

2.3.4 Health Impacts Associated with Trace Elements and Salts

Trace elements in manure include feed additives such as zinc, arsenic, copper, and selenium. While these are necessary nutrients, they are toxic at elevated concentrations, and tend to persist in the environment and to bioconcentrate in plant and animal tissues. Trace elements are associated with a variety of illnesses. For example, over exposure to selenium can cause liver dysfunction and loss of hair and nails, while ingestion of too much zinc can produce changes in copper and iron balances, particularly copper deficiency anemia (IRIS, 2000).

Total concentrations of trace elements in animal manures have been reported as comparable to those in some municipal sludges, with typical values well below the maximum concentrations that EPA allows in land-applied sewage sludge (Sims, 1995). Based on this information, trace elements in agronomically applied manures should pose little risk to human health and the environment. However, repeated application of manures above agronomic rates could result in exceedances of the cumulative metal loading rates that EPA considers safe, potentially affecting human health and the environment. There is some evidence that this is happening. For example, in 1995, zinc and copper were found building to potentially harmful levels on the fields of a North Carolina hog farm (Warrick and Stith, 1995b).

Salts in manure can also affect the salinity of drinking water. Increased salts in drinking water can in turn increase blood pressure in salt-sensitive individuals, increasing the risk of stroke and heart attack (Anderson, 1998; Boyd, 1990).

2.3.5 Other Health Impacts

Potential health effects associated with other contaminants in manure include inhalation-related risks associated with volatile organic chemicals and odors, and the effects of hormones, antibiotics, and pesticides that are found in animal feed.

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[18] In a 1997 survey of drinking water standard violations in six states over a four-year period, the U.S. General Accounting Office reported that bacterial standard violations occurred in up to 6 percent of community water systems each year and in up to 42 percent of private wells. See USGAO, 1997.

Volatile Compounds

In 1996, the Minnesota Department of Health found levels of hydrogen sulfide gas at residences near AFOs that were high enough to cause symptoms such as headaches, nausea, vomiting, eye irritation, respiratory problems (including shallow breathing and coughing), achy joints, dizziness, fatigue, sore throats, swollen glands, tightness in the chest, irritability, insomnia, and blackouts (Hoosier Environmental Council, 1997). In an Iowa study, neighbors within two miles of a 4,000-sow swine facility reported more physical and mental health symptoms than a control group (Thu, 1998). These symptoms included chronic bronchitis, hyperactive airways, mucus membrane irritation, headache, nausea, tension, anger, fatigue, and confusion. Odor is itself a significant concern because of its documented effect on moods, such as increased tension, depression, and fatigue (Schiffman *et al.*, 1995). Heavy odors are the most common complaint from neighbors of swine operations (Agricultural Animal Waste Task Force, 1996).

Pesticides

Various ingredients in pesticides have been linked to a variety of human health effects, such as systemic toxicity and endocrine disruption (see below). However, information linking pesticide levels in surface and drinking water to human exposure and to animal manure is currently limited. It is therefore unclear what health risks are posed by pesticide concentrations in AFO wastes.

Hormones and Endocrine Disruption

Hormones in the environment can act as endocrine disruptors, altering hormone pathways that regulate reproductive processes in both human and animal populations. Estrogen hormones have been implicated in the drastic reduction in sperm counts among European and North American men (Sharpe and Skakkebaek, 1993) and widespread reproductive disorders in a variety of wildlife (Colburn et al., 1993). A number of agricultural chemicals have also been demonstrated to cause endocrine disruption as well, including pesticides (Shore et al, 1995). The effects of these chemicals on the environment and their impacts on human health through environmental exposures are not completely understood, but they are currently being studied for evidence that they cause neurobiological, developmental, reproductive, and carcinogenic effects (Tetra Tech, 2000). No studies exist on the human health impact of hormones from manure watersheds.

Antibiotics and Antibiotic Resistance

While antibiotics themselves are not generally associated with human health impacts, antibiotic resistance poses a significant health threat. In April 2000, the New England Journal of Medicine published an article that discussed the case of a 12-year old boy infected with a strain of Salmonella that was resistant to no fewer than 13 antimicrobial agents (Fey, 2000). The cause of the child’s illness is believed to be exposure to the cattle on his family’s Nebraska ranch. The Centers for Disease Control, the Food and Drug Administration, and the National Institutes of Health issued a draft action plan in June, 2000, to address the increase in antibiotic resistant diseases (CDCP, 2000). The plan is intended to combat antimicrobial resistance through surveys, prevention and control activities, research, and product development. Some actions are already underway.

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CONCEPTUAL FRAMEWORK AND OVERVIEW OF METHODS CHAPTER 3

Pollutants associated with AFOs can have a range of harmful impacts on water quality, on aquatic and shoreline ecosystems, and on the range of uses (or services) that water resources provide. While some pollutants pose a direct threat to human health (e.g., pathogens that prevent drinking or contact with contaminated water), AFO-related pollutants can also contribute to the decline of recreational and commercial activities, injury to species that live in or depend on contaminated waters (e.g., aquatic shorebirds), and even a reduction in the intrinsic "existence" value that people place on a pristine or well-protected ecosystem.

The benefits of a regulation that reduces AFO pollution are reflected by identifiable changes in environmental quality that result from the regulation, and by the related improvements in the range of potential uses of the resource. The value of the regulation is then measured according to the value that people place on the changes in these potential uses. EPA characterizes these changes by considering the use and non-use benefits that water resources provide under baseline conditions, and contrasting these benefits with the enhanced benefits realized under each of the regulatory scenarios.

This chapter describes the general approach that EPA uses to value environmental quality improvements associated with reduced AFO pollution. The first section describes the types of environmental improvements and benefits to humans that would likely result from changes in water quality due to the regulation of CAFOs. The chapter then identifies the key environmental changes and benefits that are the focus of the evaluation of EPA's proposed regulations, and describes EPA's approaches to measuring and valuing the selected benefits. The broad methods outlined in this chapter form the basis of the specific benefits analyses described in Chapters 4 through 7.

3.1 POSSIBLE ENVIRONMENTAL IMPROVEMENTS AND RESULTING BENEFITS

Groundwater and surface water resources (including rivers, lakes, estuaries, and oceans) provide a range of benefits to humans and other species that reflect the actual and potential "uses" that they support. Potential uses can include active consumption or diversion of water for industry, agriculture, or drinking water, and can also include a range of active and passive "in-place" uses such as swimming, fishing, and aesthetic enjoyment.

Water resources also provide intrinsic (or non-use) benefits that reflect the importance of protecting environmental quality regardless of any specific use that humans may enjoy or intend. Intrinsic benefits include "existence value," i.e., the sense of well-being that people derive from the existence of pristine water resources, even when they do not expect to see or use these resources.[19] The protection of resources for future generations (intergenerational equity) or for non-human species (ecological benefits) are other key intrinsic benefits.

Degradation of a water resource may restrict its use or the intrinsic benefits it provides, and therefore reduce its value. Conversely, improvement in environmental quality provides benefits associated with an increase in the range of potential uses and intrinsic benefits that a resource can support. Exhibit 3-1 provides a summary of the potential benefits associated with an improvement in the quality of aquatic resources.

Exhibit 3-1

POTENTIAL BENEFITS OF WATER QUALITY IMPROVEMENTS

	Use Benefits
In-Stream	• Commercial fisheries, shell fisheries, and aquaculture; navigation • Recreation (fishing, boating, swimming, etc.) • Subsistence fishing • Human health risk reductions
Near Stream	• Water-enhanced non-contact recreation (picnicking, photography, jogging, camping, etc.) • Nonconsumptive use (e.g., wildlife observation)
Option Value	• Premium for uncertain future demand • Premium for uncertain future supply
Diversionary	• Industry/commercial (process and cooling waters) • Agriculture/irrigation • Municipal/private drinking water (treatment cost savings and/or human health risk reductions)
Aesthetic	• Residing, working, traveling and/or owning property near water, etc.
	Intrinsic (Non-Use) Benefits
Bequest	• Intergenerational equity
Existence	• Stewardship/preservation • Vicarious consumption
Ecological	• Reduced mortality/morbidity for aquatic and other species • Improved reproductive success for aquatic and other species • Increased diversity of aquatic and other species • Improved habitat, etc.

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[19] A common example of intrinsic value is the broad public support for the preservation of National Parks, even by people who do not expect to visit them.

AFO pollutants have impacts on a broad range of water resource services. Pollution by nutrients, for example, can reduce the value of both groundwater and surface water as a drinking water source, and algae in eutrophied surface water can reduce recreational and aesthetic uses (due to foul odor and appearance), as well as clog municipal and industrial intakes. Acute nitrogen loadings and decaying algae cause fish kills, which affect commercial and recreational fishing, and indicate injury to natural resources; some of these injuries may require restoration in order to achieve full recovery of the ecosystem. Both chronic and acute nutrient loadings can reduce aquatic populations and the shoreline species that depend on them; this affects both opportunities to view wildlife and ecological "existence" values. Finally, nutrient-related red tide and *Pfiesteria* events can restrict access to shellfish and beaches, affecting shellfishing and recreational opportunities.

Other AFO pollutants have similar impacts or can cause additional effects (e.g., turbidity from solids, human health effects from pathogens). In addition, any pollutant that reduces the quality of an environmental resource may adversely affect intrinsic values, such as bequest values (i.e., preserving environmental quality for future generations). While the beneficial impacts of improved control of any one pollutant can be difficult to isolate, AFO-related pollution generally involves a broad range of impacts that, taken together, affect to some degree most of the potential uses and intrinsic benefits of water resources.

3.2 SPECIFIC BENEFITS ANALYZED

The benefits of water quality improvements are a function of the specific pollutants reduced, the water resources affected, and the improvements in the potential uses of these resources. The key challenge of a benefits calculation is to establish a clear link between the implementation of a regulation, the reduction of a pollutant, the resulting improvement in environmental quality, and the value of that improvement.

While AFO-related pollutants can affect most potential uses of surface and groundwater, EPA has identified a set of environmental quality changes that meet three criteria: 1) they represent identifiable and measurable changes in water quality; 2) they can be linked with the proposed CAFO regulations; and 3) together, they represent a broad range of potential human uses and benefits and are likely to capture important environmental changes that result from the rule. Specifically, EPA implements four analyses:

- **Improvements in Water Quality and Suitability for Recreational Activities:** this analysis addresses increased opportunities for recreational fishing and swimming, as well as the potential increase in non-use values associated with improvements in inland surface water quality;

- **Reduced Incidence of Fish Kills:** this analysis assesses the value of reducing the incidence of fish kills attributable to pollution from AFOs;

- **Improved Commercial Shell Fishing:** this analysis characterizes the impact of pollution from AFOs on access to commercial shellfish growing waters, and values the potential increase in commercial shellfish harvests that may result from improved control of that pollution; and

- **Reduced Contamination of Private Wells:** this analysis values the impact of the revised regulations in reducing the concentration of nitrates in water drawn from private wells.

EPA's analysis does not attempt to comprehensively identify and value all potential environmental changes associated with proposed revisions to the CAFO regulations. For example, the analysis of the suitability of water resources for recreational use excludes the Great Lakes, as well as all estuarine or marine waters. In addition, the analysis examines only a limited set of potential improvements in water quality; it does not attempt to value the improvement of non-boatable waters to boatable condition, nor does it attempt to value improvements in the quality of water resources that are already suitable for swimming. Furthermore, the analysis does not value the potential impact of improvements in water quality on near-stream activities, such as birdwatching or camping, nor does it consider non-water related benefits, such as potential reductions in odor from waste management areas. EPA also does not evaluate potential impacts on certain diversionary uses (e.g., improvements in the quality of reservoirs and other sources of public water supplies, and the associated reduction in the cost of treating water to remove AFO-related pollutants).

While changes in water quality resulting from CAFO regulations may have real impacts on these types of uses, and may even be associated with significant benefits, several factors make it difficult to measure the specific impacts of the regulation and identify related changes in value. For example, analysis of potential changes in estuarine or marine water quality nationwide is currently beyond the capabilities of the water quality model employed in this study. In addition, while EPA's proposed CAFO regulations will contribute to improvements in environmental quality beyond surface waters, it is difficult to establish clear relationships between regulation of AFOs and certain environmental quality changes, such as reductions in odor or improvements in the health of shorebirds. Although these benefits are not specifically addressed by the analysis, they likely represent additional benefits of the regulation.

3.3 PREDICTING CHANGE IN ENVIRONMENTAL QUALITY AND RESULTING BENEFICIAL USE

To calculate the benefits associated with a proposed regulations, an analysis must explore the difference between present conditions (i.e., the baseline scenario) and the likely future conditions that would result from the regulation. The baseline scenario is typically assessed using the best and most recently collected data that characterize existing environmental quality. Because likely future conditions are theoretical, the characterization of environmental quality for each of the regulatory scenarios must be evaluated through environmental modeling or other approaches designed to simulate possible future conditions. The difference in environmental quality between the present and future conditions thus represents the marginal environmental quality gains or human benefits that would be produced under each scenario.

EPA's analysis of the proposed CAFO regulations examines the difference between the baseline and each of the regulatory scenarios for each of the four benefits categories identified above. Ideally, the baseline scenarios would be constant across benefit categories and analyses; however, data limitations forced EPA to define baseline conditions based on the most up to date record of existing conditions for each analysis. For instance, the analysis of increased commercial shellfish supply benefits relies upon 1995 data on shellfish bed closures to define baseline conditions, whereas the analysis of fish kill events relies upon data collected between 1980 and 1999. Detailed information on the time frame used to define baseline scenarios for each of the selected environmental benefit categories is provided for each of the analyses addressed in Chapters 4 through 7.

For each of the benefit categories analyzed, post-regulatory conditions are assessed using modeling approaches most applicable to the specific analysis. For each of the selected benefit categories, EPA models post-regulatory conditions as follows:

- **Improvements in Water Quality and Suitability for Recreational Activities:** EPA relies on a national water quality model to predict changes in the ambient concentration of pollutants attributable to changes in pollutant loadings from CAFOs. Under each regulatory scenario, the model determines whether estimated changes in pollutant concentrations would improve the suitability of water resources for recreational uses such as fishing and swimming.

- **Reduced Incidence of Fish Kills:** Through modeling of nitrogen and phosphorus loading reductions, the analysis estimates changes in the frequency of fish kill events under each regulatory scenario.

- **Improved Commercial Shell Fishing:** EPA employs data on the impact of agricultural pollution on commercial shellfish harvesting, combined with modeled estimates of the change in pathogen loadings from CAFOs, to estimate the potential increase in annual shellfish harvests under each regulatory scenario.

- **Reduced Contamination of Private Wells:** EPA employs data from the U.S. Geological Survey (USGS), EPA, and the Bureau of Census to model the relationship between nitrate concentrations in private domestic wells and sources of nitrogen to aquifers. EPA uses this model, combined with estimates of the change in nitrogen loadings under alternate regulatory scenarios, to predict changes in well nitrate concentrations nationally.

3.4 VALUING BENEFITS

The final step of the benefits analyses is to estimate the economic value of the modeled physical changes in environmental quality. This section provides a brief overview of economic valuation concepts and discusses the valuation approach applied in the studies performed for the proposed CAFO rule.

3.4.1 Overview of Economic Valuation

Economists define benefits by focusing on measures of individual satisfaction or well-being, referred to as measures of welfare or utility. A fundamental assumption in economic theory is that individuals can maintain the same level of utility while trading-off different "bundles" of goods, services, and money. The tradeoffs individuals make reveal information about the value they place on these goods and services.

The willingness to trade-off compensation for goods or services can be measured by an individuals' willingness to pay. While these measures can be expressed in terms of goods, services, or money, economists generally express willingness to pay in monetary terms. In the case of an environmental policy, willingness to pay represents the amount of money an individual would give up to receive an improvement (or avoid a decrement) in environmental quality.[20]

The use of willingness to pay to measure benefits is closely related to the concept of consumer surplus. Resource economists generally rely on consumer surplus as a measure of overall economic welfare for benefits to individuals. The concept of consumer surplus is based on the principle that some consumers benefit at current prices because they are able to purchase goods (or services) at a price that is less than their total willingness to pay for the good. For example, if a consumer is willing to pay $4 for an additional gallon of clean drinking water that costs the consumer only $1.50, then the marginal consumer surplus is $2.50.

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[20] Economists also sometimes consider a similar concept of "willingness to accept compensation"; i.e., the amount of monetary compensation that would make the individual indifferent between having an environmental improvement and foregoing the improvement.

3.4.2 Primary Approaches for Measuring Benefits

Economists generally define the economic benefits provided by a natural resource as the sum of individuals' willingness to pay for the goods and services the resource provides, net of any costs associated with enjoying these services.[21] In some cases (e.g., commercial fishing), natural resource products are traded in the marketplace, and willingness to pay information can be directly obtained from demand for these commodities. In other cases, when natural resource goods or services are not traded in the market, economists use a variety of analytic techniques to value them, or to estimate the economic benefits of improvements in environmental quality.[22] These non-market methods, which are grounded in the theory of consumer choice, utility maximization, and welfare economics, attempt to determine individuals' willingness to pay for natural resource services directly, through survey research, or indirectly, through the examination of behavior in related markets. Descriptions of market and non-market methods for analyzing benefits follow below.

- **Market Methods:** To measure the economic value of environmental improvements, market methods rely upon the direct link between the quality or stock of an environmental good or service and the supply or demand for that market commodity. Market methods can be used, for example, to characterize the effect of an increase in commercial fish and shellfish harvests on market prices. In turn, these market changes affect the welfare of consumers and producers in quantifiable ways.

- **Revealed Preference:** Revealed preference approaches are premised on the assumption that the value of natural resource services to users of those services can be inferred by indirect economic measures. For example, willingness to pay for recreational beach services can be estimated by observing how the number of visits individuals make to a beach varies with the cost of traveling to the beach. Similarly, property values can be influenced by proximity to an environmental amenity or disamenity; econometric analysis can estimate the nature and magnitude of such effects, providing a basis for valuing natural resource services.

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[21] In the case of goods and services traded in the marketplace, net benefits also include producer surplus: the excess of producer revenues over costs. For simplicity, we leave aside for now any discussion of producer surplus in assessing the benefits associated with enjoyment of natural resource services.

[22] These same techniques can be applied to estimate the economic damages attributable to a decline in environmental quality.

- **Stated Preference:** Stated preference models involve the direct elicitation of economic values from individuals through the use of carefully designed and administered surveys. Contingent valuation techniques are the most widely used stated preference approach, and rely on surveys designed to derive people's willingness to pay for an amenity (e.g., improved water quality) described in the study. This method can be used to estimate both use and non-use values.

- **Averted Cost:** Changes in environmental quality can impose additional costs on the users of an affected resource. For example, contamination of drinking water supplies might lead homeowners to purchase in-home water filters. A potential proxy measure of the benefits of preventing pollution of the resource is the averted cost of these expenditures.

3.4.3 Valuation of CAFO Regulatory Benefits Based on Previous Studies

Because of their high resource demands, the use of primary approaches is beyond the scope of this analysis. Instead, the analysis draws on previous studies that evaluated similar water quality benefits issues. This approach—typically referred to as "benefits transfer"—involves the application of values, functions, or data from existing studies to estimate the benefits of the resource changes currently being considered, and is commonly used in analyzing the benefits of proposed environmental regulations. The primary research material and analytic approach used for the valuation of each benefit category are summarized below; more detailed descriptions of the methods applied are provided in subsequent chapters of this report.

- **Improvements in Water Quality and Suitability for Recreational Activities:** To determine how people value improvements in the suitability of water resources for recreational activities (e.g., fishing, swimming), the analysis relies on the results of a contingent valuation survey conducted by Carson and Mitchell (1993). Based on this study, economic benefits are determined from people's willingness to pay for achievement of water quality levels that restore affected waters to fishable or swimmable conditions.

- **Reduced Incidence of Fish Kills:** The valuation of benefits from the reduced incidence of fish kills is based on fish replacement costs, as reflected in an American Fisheries Society (1990) report. Because this value represents only a portion of the economic damages associated with fish kills, it likely provides a conservative estimate of the benefits of reducing the frequency of such events.

- **Improved Commercial Shell Fishing:** To value the economic benefit of increased shellfish harvests, the analysis relies on available literature that models consumers' demand for shellfish. Based on the demand equations from these primary sources, EPA determines the increase in consumer surplus that would result from increased harvests.

- **Reduced Contamination of Private Wells:** The analysis surveys the literature concerning the values people place on avoiding or reducing nitrate contamination in private domestic wells. Based on this review, it develops estimates of people's willingness-to-pay to reduce nitrate concentrations to certain levels, and applies these estimates to value predicted changes in the quality of water that supplies private wells.

3.4.4 Aggregating Benefits

The final step in determining the benefits of the proposed CAFO regulatory scenarios is aggregation of the benefits calculated for each of the benefit categories. To avoid over-estimation, this requires consideration of the extent to which underlying analyses may double-count certain benefits. For this analysis, however, the benefits that each of the underlying studies explore are relatively distinct. As a result, the potential for double-counting appears to be small.

Another consideration in aggregating benefits is ensuring that all values are reported on a comparable basis, taking into account the effects of inflation on real dollar values. For purposes of this analysis, all values are reported in 1999 dollars. The price indices employed in converting source data to 1999 dollars vary, depending on which index is most appropriate. Further information on these adjustments is provided in the detailed discussion of each analysis.

The detailed analyses presented in Chapters 4 through 7 report benefits on an annual basis. To determine the present value of these benefits, EPA employs three alternative discount rates: a 7 percent real discount rate, which is representative of the real rate of return on private investments and consistent with the rate mandated by the Office of Management and Budget for analysis of proposed regulations; a 3 percent real discount rate, which is representative of the social rate of time preference for consumption of goods and services, and consistent with the rate recommended by many economists for analysis of environmental benefits; and a 5 percent real discount rate, which represents the mid-point of the 3 and 7 percent range.

In calculating the present value of benefits at the time new regulations are implemented, EPA assumes an infinite time frame; i.e., as long as the regulations remain in effect, the associated benefits will be enjoyed in perpetuity. EPA further assumes that its estimates of beneficial impacts on surface water resources will be fully realized in the year immediately following implementation of the revised regulations. This assumption reflects EPA's judgment that reductions in the loadings of pollutants from CAFOs will quickly yield improvements in surface water quality. With respect to reduced contamination of private wells, however, EPA assumes that several years will pass before the full benefits of the regulation are realized. To permit consistent comparison of these benefits to the annual benefits estimated for surface water resources, EPA presents the benefits of reduced contamination of private wells on an annualized basis, as well as on a present value basis. The calculation of an annualized value for this benefits category indicates the constant flow of benefits over time that would generate the same present value as the anticipated, uneven, flow of benefits.

Additional information on the calculation of present values and the aggregation of benefits is presented in Chapter 8.

3.5 SUMMARY

Exhibit 3-2 summarizes EPA's approach to measuring and valuing the anticipated benefits of the revised CAFO regulations. Additional information on the methods employed is provided in the detailed discussion of each analysis that follows.

Exhibit 3-2

SUMMARY OF APPROACH TO ESTIMATING REGULATORY BENEFITS

Benefit Category	Human Use	Measurement Approach	Valuation Approach
Improvements in Water Quality and Suitability for Recreational Activities	Recreational fishing, swimming, and non-use benefits associated with surface water resources.	Model potential changes in water quality based on estimated changes in loadings of CAFO-related pollutants.	Stated preference approach assessing willingness-to-pay for water quality that supports recreation.
Reduced Incidence of Fish Kills	Recreational fishing, near-stream use and non-use benefits.	Estimate changes in the frequency of fish kill events based on estimated reductions in nutrient loadings.	Avoided damages based on fish replacement costs.
Improved Commercial Shellfishing	Commercial shellfishing.	Estimate increased access to shellfish growing waters and resulting increase in annual shellfish harvests, based on modeled changes in fecal coliform concentrations.	Market estimate of increased consumer surplus.
Reduced Contamination of Private Wells	Drinking water.	Model potential changes in private domestic well water quality based on estimated changes in loadings of CAFO-related pollutants.	Stated preference approach assessing willingness-to-pay to reduce the concentration of nitrates in water drawn from private domestic wells.

3.6 REFERENCES

AFS. 1990. American Fisheries Society Socioeconomics Section, *A Handbook of Monetary Values of Fishes and Fish-Kill Counting Guidelines*, Draft, July 1990.

Carson, Richard T. and Robert Cameron Mitchell. 1993. "The Value of Clean Water: The Public's Willingness to Pay for Boatable, Fishable, and Swimmable Water Quality." *Water Resources Research*, Vol. 29, No. 7.

MODELING OF IMPROVEMENTS IN SURFACE WATER QUALITY AND BENEFITS OF ACHIEVING RECREATIONAL USE LEVELS

CHAPTER 4

4.1 INTRODUCTION AND OVERVIEW

A major component of EPA's CAFO benefits analysis is an assessment of how water quality in freshwater rivers and lakes would be influenced by reduced CAFO pollution, accompanied by an evaluation of the economic value of these changes to society. EPA has developed a comprehensive analysis of these benefits using the methodology summarized in Exhibit 4-1. As shown, key components of the analysis include:

- Development of model facilities that typify conditions across different production sectors, facility sizes, and geographic regions;

- Modeling of "edge-of-field" pollutant releases that take into account manure management practices, manure constituents, and physical conditions (e.g., soil characteristics);

- Calculation of the number of AFOs in the various production sectors/size categories to allow extrapolation of the model facility loadings estimates;

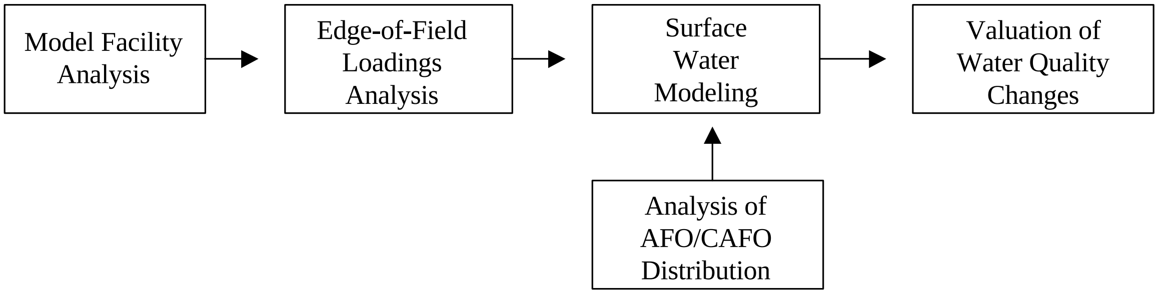
- Modeling of the change in surface water pollutant concentrations as determined by changes in loadings; and

- Valuation of the water quality changes through a benefits transfer analysis focused primarily on the public's willingness to pay for improved water conditions necessary to support recreation.

EPA implements this set of analyses for baseline conditions as well as the various regulatory scenarios under consideration to allow estimation of overall water quality benefits. The following sections summarize the five analytic components and the resulting estimates.

Exhibit 4-1

OVERVIEW OF RECREATIONAL BENEFITS ANALYSIS

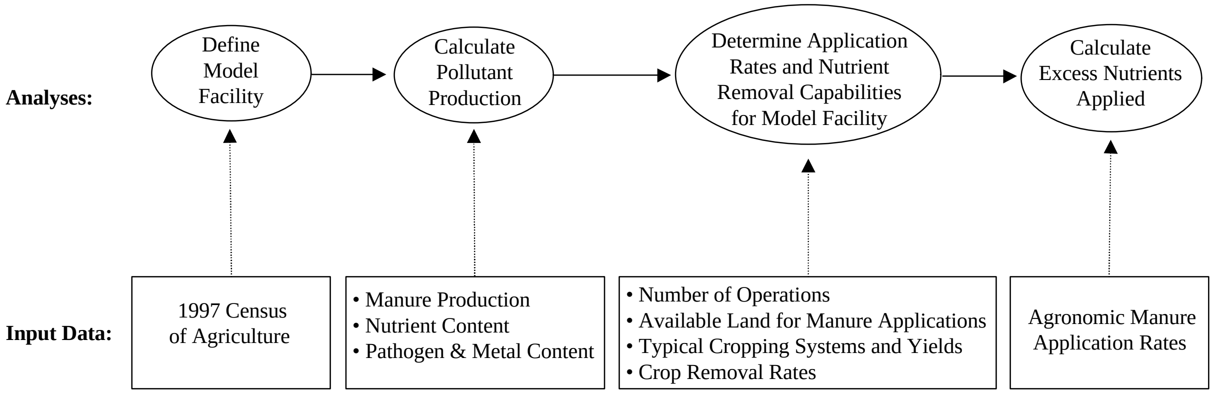


4.2 MODEL FACILITY ANALYSIS

Assessing the impacts of CAFO regulatory scenarios requires that EPA recognize the diversity of animal feeding operations across the country. Exhibit 4-2 provides an overview of the analysis used to define model facilities and their associated pollution potential.[23] For detailed information regarding the development of model facilities, see Chapters 4 and 11 of the *Technical Development Document of Proposed Effluent Limitations Guidelines for Animal Feeding Operations* (EPA, 2000a), hereafter referred to as the "TDD".

Exhibit 4-2

MODEL FACILITY ANALYSIS



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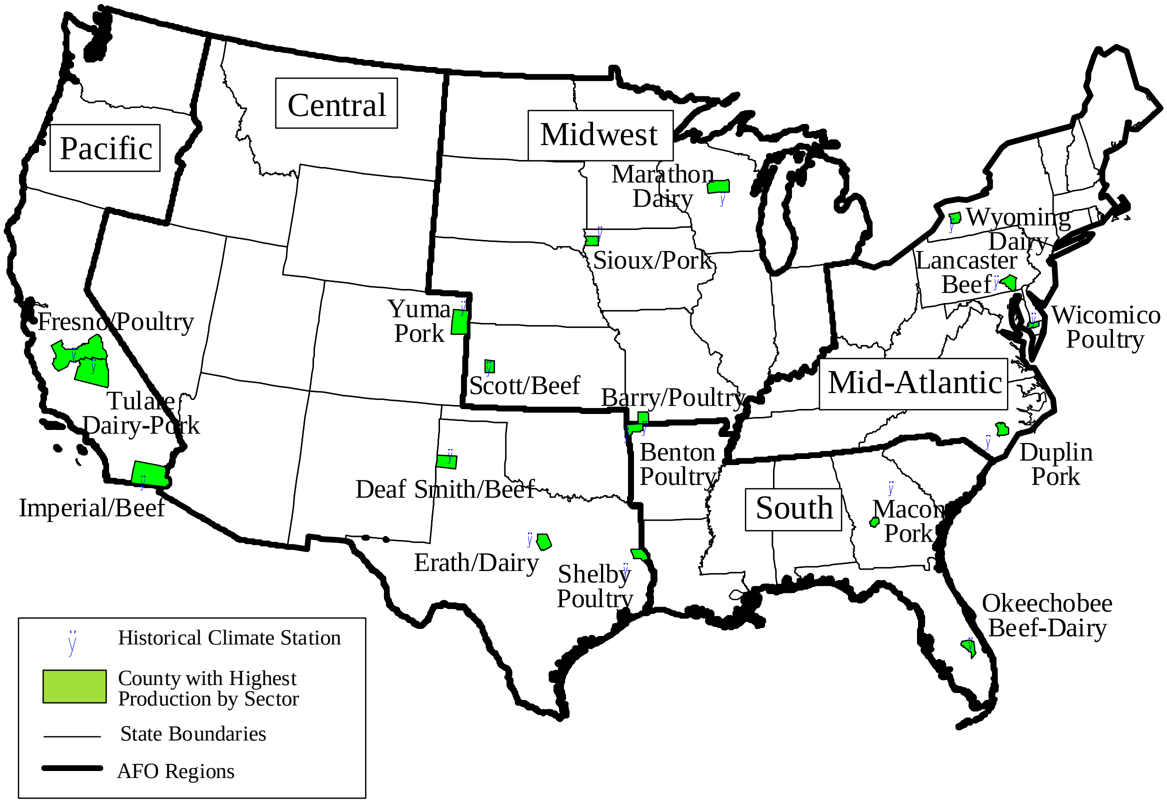
[23] Note that for this analysis, the term agriculture facility, facility, or operation includes the feedlot and the land application area under the control of the feedlot operator.

First, EPA disaggregates the universe of AFOs according to a suite of characteristics directly affecting manure generation, manure management, and pollutant loadings. AFOs are grouped into five geographic regions, as shown in Exhibit 4-3. To establish geographic regions, EPA developed algorithms to estimate the number of facilities by size (number of animals), using a combination of inventory and sales data. NASS applied the algorithms to 1997 Census of Agriculture data to generate the output by which EPA estimated facility counts. Due to disclosure criteria established by NASS to protect respondent-level census data, the regions were aggregated into broader production regions.

Exhibit 4-3

GEOGRAPHIC REGIONS FOR GROUPING AFOS



Within each geographic region, EPA defines model facilities by production sector, subsector, and size (number of animals). Based on these various dimensions, an example of a model facility would be a large beef facility with more than 8,000 head in the Midwest region. Exhibit 4-4 summarizes the key dimensions on which model facilities are defined. In all, EPA considered 200 different model facilities. The key model facilities are those that reflect the majority of production, resulting in approximately 76 different model facilities used for further analysis.

Exhibit 4-4

SUMMARY OF MODEL FACILITY DIMENSIONS

Production Sector	Facility Size	Regions
Beef, cattle Beef, veal Dairy, milk Dairy, heifers Swine, farrow-finish Swine, grower-finish Layer, wet manure system Layer, dry manure system Broiler Turkey	>1,000 Animal Units 500-1,000 Animal Units 300-500 Animal Units	Pacific Central Midwest South Mid-Atlantic

To guide the selection of modeling parameters related to fields and soils, EPA must identify a specific location for each model facility in a given geographic region. For these purposes, the analysis assumes that the model facility is located in the highest animal-production county of the region's highest production state for a given animal type.

EPA calculates manure production and the associated production of pollutants for each model facility using a process developed by Lander, et al. (1998), and refined by Kellogg, et al. (2000). The number of animals per operation is converted to USDA animal units[24] using conversion factors standardized to a 1,000-pound beef cow. EPA multiplies the number of animal units per model facility by the manure production per animal unit to determine total manure production. Manure production is adjusted to reflect the fraction that is recoverable, i.e., the portion of manure that is collected, stored, or otherwise managed so as to be available for land application. Finally, EPA calculates total generation of nutrients based on the typical nitrogen and phosphorus concentrations per unit of recoverable manure for each animal type, e.g., pounds of nitrogen per ton of manure from finishing pigs in the swine sector.[25]

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[24] The USDA animal unit is based on average liveweight of the animal, and is markedly different from the animal unit definition in EPA's regulations at 40 CFR 122 and 412.

[25] Metal production (zinc, copper, cadmium, nickel, lead) is calculated in terms of pounds of metals excreted per animal unit, while pathogen production (fecal coliform and fecal streptococcus) is calculated in terms of colonies per animal unit.

Next, EPA defines land application practices for each model facility and the capacity for soil and crop removal of nutrients applied to the land. This analysis entails several steps. The analysis first considers the total nitrogen and phosphorus generated in manure at the model facility. EPA divides these figures by the average total acreage available for land application of manure for an operation in the given region, size class, and production sector; this average acreage is drawn from a recent NRCS study (Kellogg et al., 2000).

EPA then considers the likely cropping systems at the model facilities and relates the quantity of nutrients applied annually to cropland and pastureland nutrient requirements. For example, typical cropping systems for the Mid-Atlantic AFO Region are corn, soybean, and wheat in two-year rotation. The ratio of nutrients applied to crop nutrient requirements provides a measure of the excess nutrients applied in the manure.[26] This in turn forms the foundation for loadings analyses of regulatory scenarios that call for adherence to agronomic rates of nutrient application. To characterize land application practices, the analysis considers three categories of facilities:

- Category 1 facilities include CAFOs with sufficient crop- or pastureland on-site to apply the manure they generate at agronomic rates. The analysis assumes that these facilities apply all manure on-site (i.e., no manure is shipped off-site) under both baseline and post-regulatory conditions.

- Category 2 facilities include those with insufficient crop- or pastureland on-site to apply the manure they generate at agronomic rates. For the baseline scenario, the analysis assumes that these facilities apply all the manure they generate on-site, regardless of the degree to which agronomic application rates are exceeded. For the post-regulatory scenarios, the analysis assumes that on-site manure application is limited to the agronomic rate, and that the remaining manure is shipped off-site for application to crop- or pastureland at agronomic rates. EPA's model captures the pollutant loadings associated with both on-site and off-site application of the manure generated by Category 2 facilities.[27] (The sole exception to this approach occurs in modeling loadings from Category 2 broiler operations. The baseline analysis caps on-site application of this manure at five times the agronomic rate; any excess manure is assumed to be shipped off-site. The analysis of post-regulatory conditions assumes that Category 2 broiler facilities apply manure

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[26] EPA assumes that 30 percent of the animal waste's nitrogen content volatilizes during and shortly after land application. The analysis also assumes that facilities use no fertilizers other than manure.

[27] For consistency, pollutant loadings from the off-site cropland to which these facilities are assumed to ship manure are also captured in the baseline analysis. The modeling of baseline conditions assumes the application of commercial fertilizer to this land.

on-site only up to the agronomic rate, beyond which the excess is shipped off-site. In both cases, the manure shipped off-site is not captured in the loadings modeling.)

- Category 3 facilities include CAFOs without cropland. EPA assumes that these facilities transfer all manure off-site for use or disposal. The pollutant loadings associated with this manure are not captured in modeling either baseline or post-regulatory conditions.

4.3 EDGE-OF-FIELD LOADINGS ANALYSIS

The second major component of the water quality analysis is estimation of pollutant loadings leaving the model facility, i.e., edge-of-field loadings. EPA estimates the loadings associated with: (1) application of manure; (2) lagoons and other storage structures; and (3) feedlots. The sections below review the methods applied for each of these analyses.

4.3.1 Loadings from Manure Application

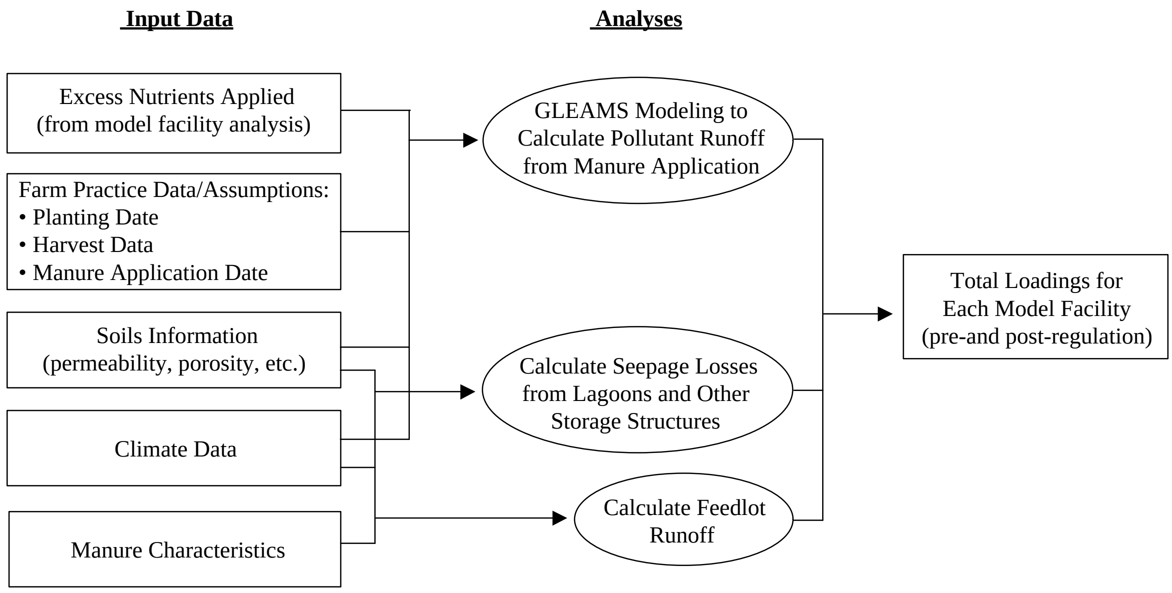
EPA's loadings analysis first examines loadings from manure application to cropland and pastureland. The analysis combines information on manure generation and land application practices (see above) with data on the timing of application, hydrological conditions, geological conditions, and weather patterns (see Exhibit 4-5). EPA integrates these data using the Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) model. This field-scale model simulates hydrologic transport, erosion, and biochemical processes such as chemical transformation and plant uptake. The model uses information on soil characteristics and climate, along with nutrient production data, to model losses of nutrients in surface runoff, sediment, and groundwater leachate. Loadings are modeled for the pre- and post-regulatory scenarios to estimate changes in loadings attributable to the proposed standards.

The data used in the GLEAMS model runs include the following:

C **Soils Data**: GLEAMS uses data from the State Soil Geographic (STATSGO) data base maintained by USDA's Natural Resources Conservation Service. Key soil parameters drawn or estimated from the data base include permeability, soil porosity, baseline organic matter content, percent clay, and percent silt. EPA employs data on these parameters, in combination with data on other factors (see below), to characterize soil erosion, surface runoff, and groundwater leaching at model facilities.

Exhibit 4-5

EDGE-OF-FIELD LOADINGS ANALYSIS FOR MODEL FACILITIES



- **Climate Data**: EPA prepared climate data using CLIGEN, a synthetic climate generator commonly used in conjunction with a variety of agricultural runoff models. CLIGEN simulates weather patterns based on 25 or more years of precipitation and temperature data.

- **Crop Planting and Harvest Dates**: EPA developed assumptions for crop planting and harvesting using USDA reports and determined likely manure application dates for model facilities based on contacts with USDA Extension Agents in relevant locations. The application dates are a function of the crops grown. Some single-cycle crops (e.g., corn) allow only one application per year, while other crops (e.g., alfalfa) allow multiple applications.

4.3.2 Loadings from Lagoons and Other Storage Structures

Lagoons and other manure storage structures at animal feedlots are also potential pollution sources, posing risks primarily through seepage to groundwater and subsequent discharge to surface water. For the purposes of this analysis, EPA assumes that all lagoons and other storage structures leak. Storage structure seepage estimates were obtained from Ham and DeSutter (1999), who measured nitrogen that leaked from three established swine-waste lagoons in Kansas. From these results, it was assumed that 2,000 pounds per acre per year leaked from manure storage structures lined with silt loam soils. EPA scales seepage estimates for clay and sandy soils from these estimates as described in the TDD.

For most storage structures, EPA models transport of pollution through groundwater and estimates the associated attenuation of pollutants. However, conditions in some cases (as defined by Sobecki and Clipper, 1999) suggest that leaks from lagoons or other storage structures may seep directly to surface water, i.e., hydrologic conditions are such that pollutant concentrations are not attenuated by dilution in groundwater. This might occur, for example, in the presence of sandy soils or karst-like terrain. To characterize the potential for leaks from lagoons or other storage structures to seep directly to surface water, EPA evaluated soil and hydrological conditions in each AFO region. Based on this evaluation, EPA determined the percentage of the region's area in which the potential for direct contamination of surface water is high. EPA's analysis assumes that this percentage of storage leaks in each region would result in direct contamination of surface water.

4.3.3 Loadings from Feedlots

Another pollution source that EPA analyzes is runoff from feedlots. These loadings can be particularly significant in the beef sector because the animals are typically housed in open lots.

To estimate feedlot runoff loadings, EPA first calculates the volume of runoff from the feedlot at the model facility. The annual depth of runoff from the feedlot is calculated for each of the five AFO regions using average precipitation from the National Climatic Data Center. The volume of runoff is calculated using this depth of runoff and the estimated area of the dry lot and feedlot handling areas for each model facility.[28]

To characterize the loadings of pollutants in feedlot runoff, EPA assumes a solids content of 1.5 percent. The composition of these solids is estimated based on the characteristics of dry manure, which varies across production sectors. Annual loadings of specific pollutants are then determined, based on the estimated composition of solids, the assumed percentage of solids in feedlot runoff, and the estimated annual volume of runoff from the feedlot.

4.3.4 Model Loadings Under Regulatory Scenarios

EPA applies the data and methods described above to analyze loadings associated with baseline conditions and each of the various regulatory scenarios. Under all of the options, the analysis assumes that regulated facilities modify current activities to comply with feedlot best

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[28] EPA assumes that only surface runoff occurs from the feedlot.

management practices, mortality handling requirements, nutrient management planning/ recordkeeping, and elimination of manure application within 100 feet of surface water. Factors that vary among regulatory scenarios that may impact loadings include:

- reduction of manure application to agronomic nitrogen rates; and
- reduction of manure application to agronomic phosphorous rates.

4.4 ANALYSIS OF AFO/CAFO DISTRIBUTION

To develop a national estimate of baseline pollutant loadings from AFOs, as well as estimates of the change in loadings under alternate regulatory scenarios, EPA must determine the number of operations that would be governed by the proposed regulations, i.e., the number of facilities considered to be AFOs and the number of AFOs considered to be CAFOs, and therefore subject to the proposed rule. These operations represent the universe to which model facility results are extrapolated.

The sections below discuss EPA's approach and the resulting characterization of the population of AFOs and CAFOs. More detailed information on the procedure used by EPA to estimate the number of operations that may be subject to the proposed regulations can be found in the TDD (USEPA, 2000a).

4.4.1 Approach

EPA estimates the number of operations that may be affected by alternative requirements using a two-step procedure. First, EPA determines the number of operations that raise animals under confinement by using available data on the total number of livestock and poultry facilities (see below). Next, the number of CAFOs is determined based on operations that are *defined* as CAFOs and smaller operations that are *designated* as CAFOs based on site-specific conditions, as determined by the permitting authority. For purposes of this discussion, the affected CAFO population includes those facilities that discharge or have the potential to discharge to U.S. waters. This definition does not include those smaller operations that are not defined or designated as CAFOs.

The USDA Census of Agriculture is a complete accounting of United States agricultural production and is the only source of uniform, comprehensive agricultural data for every county in the nation. The Census is conducted every five years by USDA's National Agricultural Statistics Service (NASS).[29] The Census is implemented through a mail questionnaire that is sent to a list of known U.S. agriculture operations from which $1,000 or more of agricultural products were produced and sold or normally would have been sold during the census year.

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[29] In prior years, the Census was conducted by the Department of Commerce's Bureau of the Census.

Aggregated 1997 Census data are readily available from USDA. In general, the published compendium provides summary inventory and sales data for the nation and for states. The Census database itself, however, contains respondent-level information that can be aggregated into more precise agriculture facility size groupings. The requested data summaries used for EPA's analysis were compiled with the assistance of staff at USDA's NASS, who performed special tabulations of the data to obtain information on the characteristics of facilities at specific size thresholds for each sector. All data provided to EPA were aggregated to ensure the confidentiality of an individual operation. EPA supplemented the available data with information from other sources, including other USDA data sets and industry publications. The following discussion briefly notes the nature of key gaps in the Census data and EPA's approach to addressing them.

- All USDA data are reported across all animal agriculture operations and do not distinguish between confinement and nonconfinement production types (e.g., pasture or rangeland animals). However, only operations that raise animals under confinement (as defined under 40 CFR 122 Appendix B) would be subject to the proposed regulations. For analytical purposes, EPA has assumed that all animals at larger dairy and poultry operations are grown under confinement, which may overstate EPA's estimate of the number of operations subject to the regulation. For the beef and hog sectors, the USDA has limited data on the number of operations that are feedlot operations only. NASS Statistical Bulletin Number 953, *Cattle: Final Estimates 1994-1998*, was used to estimate the number of beef feedlots with more than 1,000 head; 1997 Census data on "Cattle fattened on grains and concentrates (sold)" are used to distinguish confinement from non-confinement operations with less than 1,000 head (USDA/NASS, 1999a; USDA/NASS, 1999b). Available information from USDA and industry feedback was used to adjust the total number of hog operations to exclude those that are pasture operations (USDA/Animal and Plant Health Inspection Service, 1995; NPPC, 1997).[30]

- Available Census data on the number of animal facilities by inventory size distribution do not always correspond with the facility size definitions examined by EPA. Where data were not available in the desired size ranges, EPA interpolated estimates from available data by assuming that, for a given size group, the largest 40 percent of the facilities account for 60 percent of the animal inventory.

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[30] Available information from USDA indicates that few large hog operations are non-confinement facilities (USDA/APHIS, 1995); therefore EPA assumes that all hog operations with more than 2,500 swine are AFOs.

- USDA data are also not available for the number of poultry operations with wet manure management systems. EPA estimated these figures using available data from USDA and supplemental information from industry experts and agricultural extension agency personnel.

- Information on the number of animal facilities that raise more than a single animal type is also not available. EPA algorithms written for use with the 1992 Census data included an estimate of CAFOs that maintained more than one animal type. The analysis revealed that, for facilities with more than 1000 animal units, 21 percent raise more than one animal type; for facilities with less than 1000 animal units, about 25 percent raise more than one animal type. To the extent that combinations of animal types are located at facilities, facility counts may be overstated.

- Finally, USDA Census data report the number and size of livestock and poultry facilities as of year-end (December 31) and may not adequately reflect seasonal fluctuations in beef, dairy, and layer inventory, or the year-to-year fluctuations in number of animals sold. EPA algorithms reflect average herd sizes at larger confinement facilities over the year. The outputs are based on both reported inventory and sales, adjusted by expected turnovers. This approach is consistent with that developed by USDA to estimate potential manure nutrient loadings from animal agriculture (Lander, et al., 1998; Kellogg, et al., 2000).

4.4.2 Estimated Number of AFOs and CAFOs

Based on the USDA data sources described above, there were 1.2 million livestock and poultry facilities in the United States in 1997. This number includes all operations in the beef, dairy, pork, broiler, layer, and turkey production sectors, and includes both confinement and non-confinement (grazing and range fed) production.

Of all these operations, EPA estimates that there are about 376,000 AFOs that raise or house animals in confinement, as defined by the existing regulations. Exhibit 4-6 summarizes the number of AFOs by production sector and facility size.

Exhibit 4-6

TOTAL NUMBER OF AFOs BY PRODUCTION SECTOR AND FACILITY SIZE

Production Sector	Total AFOs	>1000 AU[1]	300 AU-1000 AU	<300 AU
Beef: cattle	106,080	2,080	2,000	102,000
Beef: veal	850	10	200	640
Dairy: milk	116,880	1,450	5,690	109,740
Dairy: heifers	1,250	400	750	100
Hogs: FF[2]	64,240	2,420	9,240	52,580
Hogs: GF[2]	53,620	1,670	3,250	48,700
Broilers	34,860	3,940	10,200	20,720
Layers: wet[3]	3,110	360	800	1,950
Layers: dry[3]	72,060	360	1,330	70,370
Turkeys	13,720	370	1,730	11,620
Sum Total	466,670	13,060	35,190	418,420
Total AFOs[4]	**375,740**	**12,850**	**28,150**	**334,740**

Source: Values presented in the table are EPA estimates, derived from published USDA/NASS data, including 1997 Census of Agriculture. For more information, see *Technical Development Document of Proposed Effluent Limitations Guidelines for Animal Feeding Operations*.

[1] As defined by the existing regulation, one animal unit (AU) is equivalent to one slaughter or feeder cattle; 0.7 mature dairy cattle; 2.5 hogs (over 55 pounds); 0.5 horses; 10 sheep or lambs; 55 turkeys; 100 laying hens or broilers (with continuous overflow watering); 30 laying hens or broilers (with liquid manure system); or 5 ducks.

[2] FF = farrow-finish (includes breeder and nursery pigs); GF=grower-finish. Data from USDA's NAHMS indicate that roughly 40 percent of hog farms are grower-finish and 60 percent are farrowing operations.

[3] The "Layers: wet" category covers operations with liquid manure systems. Such AFOs are currently defined as CAFOs for operations with 30,000 birds (1,000 AUs). No layer operations use continuous watering systems. "Layers: dry" are defined at 1,000 AUs for operations with 100,000 birds.

[4] "Total AFOs" eliminates double counting of operations with mixed animal types. Operations with mixed animal types account for roughly 20 percent of total AFOs.

Exhibit 4-7 summarizes the total number of CAFOs defined or designated under each of the regulatory scenarios. Under the proposed scenarios, between about 29,000 and 33,500 AFOs will be defined or designated as CAFOs, and are therefore subject to the proposed rule.[31]

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[31] This number is likely the upper bound estimate of the total number of operations that will be subject to the proposed revisions.

Exhibit 4-7

TOTAL NUMBER OF CAFOs BY REGULATORY SCENARIO

Regulatory Scenario	Total CAFOs
Option 1-Scenario 1	17,700
Option 1-Scenario 2/3	33,500
Option 1-Scenario 4a	28,980
Option 1-Scenario 4b	45,140
Option 2-Scenario 1	17,700
Option 2-Scenario 2/3*	33,500
Option 2-Scenario 4a*	28,980
Option 2-Scenario 4b	45,140

Source: Values presented in the table are EPA estimates, derived from published USDA/NASS data, including 1997 Census of Agriculture. For more information, see *Technical Development Document of Proposed Effluent Limitations Guidelines for Animal Feeding Operations*.
* Proposed scenarios.

4.4.3 Geographic Placement of Facilities

Finally, AFOs and CAFOs by region are placed into counties (and eventually watersheds) using the published county level Census data. Where county level data was not presented, the facilities in the undisclosed counties were imputed from state- and region-level data.

4.5 SURFACE WATER MODELING

EPA develops estimates of changes in surface water quality by building on the analysis of edge-of-field pollutant loadings for model facilities and the analysis of the distribution of AFOs and CAFOs. These data are integrated into the National Water Pollution Control Assessment Model (NWPCAM), a national-scale model designed to translate pollutant loadings into water quality changes and associated economic benefits to support policy-level regulatory decisionmaking.

NWPCAM covers virtually all inland waters in the U.S., allowing EPA to examine how changes in loadings under various regulatory scenarios would influence key water quality parameters.[32] The model incorporates routines that simulate overland transport of pollutants, discharge of pollutants to nearby surface waters, discharges to surface water from other (non-AFO/CAFO) sources, and the fate and transport of pollutants in the interconnected network of surface waters. Specifically, the modeling involves the following steps:

- Developing the network of rivers and streams that serves as the geographic foundation for the modeling;
- Distributing AFO/CAFOs and associated facility-level edge-of-field loadings to agricultural lands within a defined watershed or county;
- Simulating transport of nutrients/pollutants and subsequent discharge to nearby waterbodies;
- Delivering nutrient/pollutant loadings from point sources (e.g., municipal wastewater treatment plants, industrial facilities) and non-point sources (e.g., non-AFO/CAFO agricultural run-off, municipal run-off) to waterbodies; and
- Simulating dilution, transport, and kinetics of the nutrients/pollutants loaded to the waterbody as the nutrients/pollutants are transported along the waterbody.

Exhibit 4-8 summarizes these steps and the primary data used in the analysis. The sections below discuss the modeling in more detail and provide an overview of the estimated changes in pollutant loadings under the various regulatory scenarios.[33]

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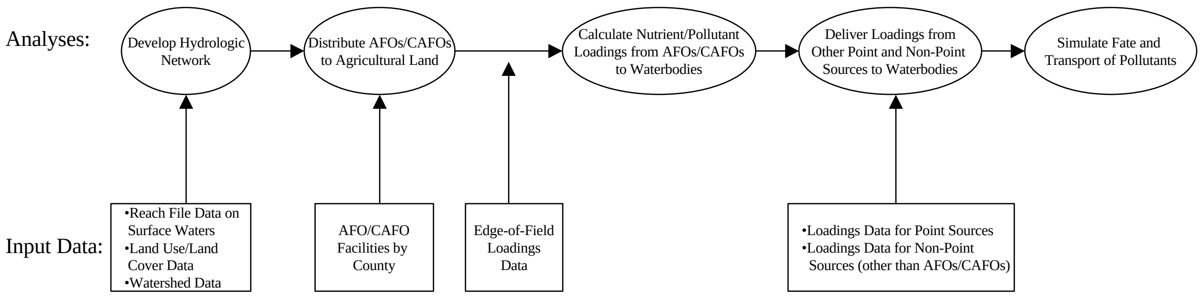
[32] NWPCAM does not address water quality benefits in bays, estuarine waters, or the Great Lakes.

[33] Both the water quality modeling and the economic benefits analysis are presented in greater detail in *Estimation of National Surface Water Quality Benefits of Regulating Concentrated Animal Feeding Operations (CAFOs) Using the National Water Pollution Control Assessment Model (NWPCAM)* (USEPA, 2000b). This report is provided under separate cover as Attachment A.

Exhibit 4-8

WATER QUALITY MODELING ANALYSIS



4.5.1 Defining the Hydrologic Network

In the initial step of the analysis, EPA prepares the hydrological network of rivers and streams that serves as the geographic backdrop to the modeling. The hydrological network is developed from EPA's Reach Files, a series of hydrologic databases describing the inland surface waters of the U.S. Each "reach" in the database represents a segment of a river or stream; these segments are linked together to characterize complete systems of rivers and streams. EPA's Reach File 3 (RF3) forms the geographic foundation for NWPCAM, allowing the model to simulate the flow of water and pollutants from a point of origin to major rivers, and ultimately to ocean discharge.[34]

Once the hydrologic network is established, EPA uses a geographic information system (GIS) approach to overlay information on land-cover, characterizing land across the U.S. at a square-kilometer degree of resolution. From these data, EPA can identify areas classified as "agricultural" land. Each land section, or "cell", is associated with a river reach in the hydrologic network.

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[34] RF3 includes numerous small tributaries and headwaters. To simplify the modeling, EPA focuses on loadings to a subset of larger rivers and streams (referred to as "RF3 Lite"). Unless otherwise noted, the water quality and economic modeling results reported below reflect changes in loadings to the RF3 Lite subset of RF3.

4.5.2 Distributing AFOs and CAFOs to Agricultural Land

Once the hydrologic network is established, NWPCAM integrates data on the location of AFOs and CAFOs to spatially orient the facilities relative to surface waters. This analytic step links directly to the analyses discussed above wherein EPA determined the numbers of AFOs and CAFOs by county and, through analysis of model facilities, estimated the edge-of-field loadings associated with each facility. Here, AFOs/CAFOs and their associated edge-of-field loadings are randomly distributed to agricultural land in the appropriate county. By placing each facility in a land use cell, the facility can be linked to a river reach in the hydrologic network.[35]

4.5.3 Calculating AFO/CAFO-Related Loadings to Waterbodies

Once facility pollutant loadings are linked to a geographic area and river reach, these loadings are delivered from the agriculture cells to the river reaches using a routine to simulate an overland transport process. Overland travel times and associated nutrient decay are based on flow in a natural ditch or channel, as may typically be found on agricultural lands. A unit runoff ($ft^3/sec/km^2$) is derived for each watershed based on data compiled by the U.S. Geological Survey. The unit runoff therefore represents runoff from each agricultural cell within the watershed and can be used to derive time-of-travel estimates necessary to route pollutants from the facility to a river reach. NWPCAM also calculates nutrient/pollutant decay associated with overland transport. Total loadings to any given river reach are the total loadings discharged from all land-use cells draining to the reach (as well as discharges from upstream river reaches).

4.5.4 Loadings from Other Sources

In addition to loadings from AFOs/CAFOs, NWPCAM integrates data on loadings from other pollutant sources. This complete inventory of loadings is needed to assess the cumulative changes in water quality (i.e., the attainment of beneficial use levels) in surface waters. Specifically, the model integrates data on discharges from municipal and industrial point sources as well as loadings from (non-AFO) non-point sources. These loadings are constant across regulatory scenarios. To model nutrient loads for non-point sources, EPA uses SPARROW (*SPA*tially *R*eferenced *R*egression *O*n *W*atershed attributes) (Smith, et al., 1997), a statistical modeling approach for estimating major nutrient source loadings at a detailed geographic scale based on watershed characteristics.[36]

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[35] EPA did not model facilities below 300 animal units. Discharges from these small operations were included in the agriculture nonpoint source component.

[36] Non-point source data for fecal coliform, fecal streptococci, and sediments were not available at the national level; therefore, only nutrients are covered in the analysis of non-AFO non-point sources.

4.5.5 Fate and Transport Modeling

Once all loadings to surface waters have been estimated, NWPCAM routes pollutants through the hydrologic network from upstream to downstream reaches. The model simulates pollutant decay during this routing process. The resulting pollutant concentrations are then compared to beneficial use criteria to determine how potential recreational uses would change with improved water quality (see below).

4.5.6 Estimated Changes in Loadings

Exhibit 4-9a summarizes the NWPCAM estimates of baseline loadings from AFOs and CAFOs and shows loadings under the various regulatory scenarios. Similarly, Exhibit 4-9b presents the resulting removals under each of the regulatory scenarios. As shown, reduction of nutrient and pollutant loadings is greater under the phosphorus-based standards (Option 2), particularly under Option 2-Scenario 4b. Significant reductions are also realized under the proposed scenarios; for example, nitrogen loadings are reduced from 67 million kilograms per year in the baseline to between 37 and 38 million kilograms per year.

Exhibits 4-10a and 4-10b present additional modeling results for metals. As shown, significant reductions in loadings of metals could be realized under the regulatory scenarios. However, these results differ from those presented above for several reasons. First, the estimates reflect changes in loadings to the larger set of RF3 rivers and streams as opposed to the smaller set of RF3 Lite rivers and streams. Second, EPA does not model metals independently; instead, overland transport of metals is assumed to be similar to the overland transport of phosphorus, with the assumption that metals adhere to soil in a manner similar to phosphorus. For these reasons, the metals loading reductions cannot be compared directly to the reported reductions for nutrients and other pollutants. The metals reductions are reported here for descriptive purposes and do not play a role in the calculation of economic benefits (see below).

4.6 VALUATION OF WATER QUALITY CHANGES

To value predicted reductions in the pollution of rivers and streams by CAFOs, NWPCAM applies estimates of Americans' willingness to pay for improvements in water quality. This approach first entails relating changes in water quality parameters - e.g., concentrations of chlorophyll " - to the ability of a body of water to support fishing or swimming. Once the potential improvement in the ability of modeled rivers and streams to support these uses is determined, the analysis relies upon estimates of willingness to pay for such improvements obtained from the results of a contingent valuation survey developed by Richard Carson and Robert Mitchell. This survey, which is national in scope, characterizes households' annual willingness to pay to improve freshwater resources from baseline conditions to fishable or swimmable quality.

Exhibit 4-9a

ESTIMATED ANNUAL AFO/CAFO NUTRIENT/POLLUTANT LOADINGS UNDER BASELINE AND REGULATORY SCENARIOS

Regulatory Scenario	Nitrogen (million kg)	Phosphorus (million kg)	Fecal Coliforms (billion colonies)	Fecal Streptococci (billion colonies)	Sediments (billion kg)
Baseline Conditions	67	76	50	117	118
Option 1-Scenario 1	53	41	24	80	118
Option 1-Scenario 2/3	52	31	19	72	118
Option 1-Scenario 4a	53	34	21	73	118
Option 1-Scenario 4b	50	28	15	70	118
Option 2-Scenario 1	43	34	21	67	92
Option 2-Scenario 2/3*	37	22	15	57	83
Option 2-Scenario 4a*	38	24	18	59	84
Option 2-Scenario 4b	34	17	12	52	80

Source: *Estimation of National Surface Water Quality Benefits of Regulating Concentrated Animal Feeding Operations (CAFOs) Using the National Water Pollution Control Assessment Model (NWPCAM)*, prepared for U.S. EPA Office of Wastewater Management, prepared by Research Triangle Institute, August 2000.

* Proposed scenarios.

Exhibit 4-9b

ESTIMATED ANNUAL REMOVALS UNDER REGULATORY SCENARIOS

Regulatory Scenario	Nitrogen (million kg)	Phosphorus (million kg)	Fecal Coliforms (billion colonies)	Fecal Streptococci (billion colonies)	Sediments (billion kg)
Option 1-Scenario 1	14	35	26	37	0
Option 1-Scenario 2/3	15	45	31	45	0
Option 1-Scenario 4a	14	42	29	44	0
Option 1-Scenario 4b	17	48	35	47	0
Option 2-Scenario 1	24	42	29	50	26
Option 2-Scenario 2/3*	30	54	35	60	35
Option 2-Scenario 4a*	29	52	32	58	34
Option 2-Scenario 4b	33	59	38	65	38

Source: *Estimation of National Surface Water Quality Benefits of Regulating Concentrated Animal Feeding Operations (CAFOs) Using the National Water Pollution Control Assessment Model (NWPCAM)*, prepared for U.S. EPA Office of Wastewater Management, prepared by Research Triangle Institute, August 2000.

* Proposed scenarios.

Exhibit 4-10a

ESTIMATED ANNUAL AFO/CAFO METALS LOADINGS UNDER BASELINE AND REGULATORY SCENARIOS*

Regulatory Scenario	Zinc (million kg)	Copper (thousand kg)	Cadmium (thousand kg)	Nickel (thousand kg)	Lead (thousand kg)
Baseline Conditions	27	1,495	42	572	1,143
Option 1-Scenario 1	17	949	19	353	748
Option 1-Scenario 2/3	12	727	9	277	570
Option 1-Scenario 4a	13	796	11	306	613
Option 1-Scenario 4b	12	677	8	251	545
Option 2-Scenario 1	14	796	16	286	634
Option 2-Scenario 2/3**	9	516	5	192	405
Option 2-Scenario 4a**	10	600	7	226	457
Option 2-Scenario 4b	8	444	3	154	366

Source: *National AFO/CAFO Metals Edge-of-Field Loadings and Reductions from Agricultural Landuse Cells to RF3 Reaches for AFO/CAFO Rulemaking Scenarios*, table prepared for EPA by Research Triangle Institute, August 2000.

* Metals loadings are estimated based on modeling of the overland transport of phosphorus. These estimates do not play a role in the subsequent modeling of economic benefits.

** Proposed scenarios.

Exhibit 4-10b

ESTIMATED ANNUAL METALS REMOVALS UNDER REGULATORY SCENARIOS*

Regulatory Scenario	Zinc (million kg)	Copper (thousand kg)	Cadmium (thousand kg)	Nickel (thousand kg)	Lead (thousand kg)
Option 1-Scenario 1	10	546	23	219	395
Option 1-Scenario 2/3	15	768	33	295	573
Option 1-Scenario 4a	14	699	31	266	530
Option 1-Scenario 4b	15	818	34	321	598
Option 2-Scenario 1	13	699	26	286	509
Option 2-Scenario 2/3**	18	979	37	380	738
Option 2-Scenario 4a**	17	895	35	346	686
Option 2-Scenario 4b	19	1,051	39	418	777

Source: *National AFO/CAFO Metals Edge-of-Field Loadings and Reductions from Agricultural Landuse Cells to RF3 Reaches for AFO/CAFO Rulemaking Scenarios*, table prepared for EPA by Research Triangle Institute, August 2000.

* Metals loadings are estimated based on modeling of the overland transport of phosphorus. These estimates do not play a role in the subsequent modeling of economic benefits.

** Proposed scenarios.

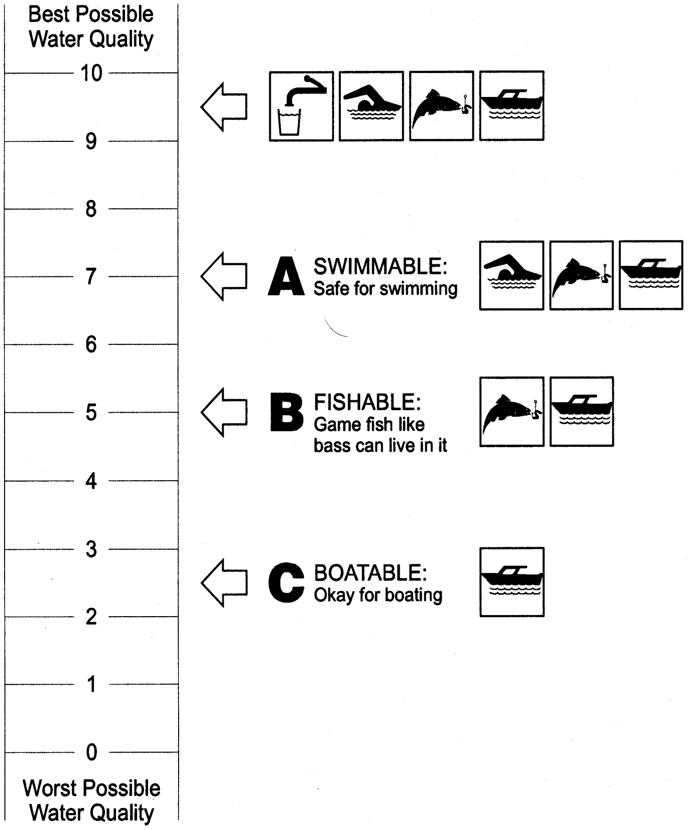
The discussion that follows summarizes the valuation approach. It begins by explaining the process by which EPA relates the results of the surface water modeling effort to the ability of a body of water to support a particular use. It then describes Carson and Mitchell's contingent valuation study and its use in analyzing the economic benefits of alternate CAFO regulations.

4.6.1 Support of Designated Uses

EPA's approach to relating surface water conditions to the ability of a body of water to support a particular designated use is based on a water quality index - often referred to as a water quality "ladder" - that Resources for the Future initially developed to support Carson and Mitchell's contingent valuation survey. As Exhibit 4-11 shows, the ladder uses a scale that ranges from 0 to 10, with 0 representing the worst possible water quality and 10 representing the best possible quality. The low end of the scale represents water quality so poor that it supports no plant or animal life, and human contact with it would be unsafe; the high end of the scale represents water safe enough to drink. Between these extremes, the ladder depicts levels of water quality sufficient to support boating, fishing, or swimming.

Exhibit 4-11

WATER QUALITY LADDER



Each step of the water quality ladder is defined by measures of the following parameters:

- dissolved oxygen content;
- biological oxygen demand;
- suspended sediment concentrations;

C pathogen counts; and

C chlorophyll " concentrations.

In order for a body of water to be considered boatable, fishable or swimmable, it must satisfy the minimum conditions consistent with that use for all modeled parameters. With the exception of chlorophyll ", these minimum conditions are the same for all areas. The maximum chlorophyll " concentration considered consistent with a particular use varies across four geographic regions, which EPA defined specifically for this analysis. This approach takes into account the impact of regional variation in factors like climate on the relationship between chlorophyll " concentrations and the trophic state of a lake or reservoir.

Based on the framework described above, NWPCAM classifies each segment of each modeled river or stream as swimmable, fishable, boatable, or non-supportive of any of these uses. For each scenario analyzed, the model calculates the total stream-miles that support each designated use.

4.6.2 Application of CV Study

The contingent valuation survey upon which this analysis relies examined households' willingness to pay to maintain or achieve specified levels of water quality in freshwater lakes, rivers and streams throughout the United States (Carson and Mitchell, 1993).[37] The survey was conducted in 1983 via in-person interviews at 61 sampling points nationwide, and employed a national probability sample based on the 1980 Census. Respondents were presented with the water quality ladder depicted in Exhibit 4-11 and asked to state how much they would be willing to pay to maintain or achieve various levels of water quality throughout the country. In eliciting responses, the survey used a payment card showing the amounts average households were then currently paying in taxes or higher prices for certain publicly provided goods (e.g., national defense); respondents were then asked their willingness to pay for a given water quality change. The survey respondents were told that improvements in water quality would be paid for in higher product prices and higher taxes.

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[37] The scope of the survey excluded the Great Lakes.

Exhibit 4-12 presents the results of the survey, adjusted to account for inflation and changes in real income between 1983 and 1999.[38] These values represent "best estimates" of mean annual household willingness to pay (WTP) for the specified water quality improvement.

Exhibit 4-12

INDIVIDUAL HOUSEHOLD WILLINGNESS TO PAY FOR WATER QUALITY IMPROVEMENTS (1999 $)

Water Quality Improvement	Total WTP	Incremental WTP
Swimmable: WTP to raise all sub-swimmable water quality to swimmable	$634	$205
Fishable: WTP to raise all sub-fishable water quality to fishable	$429	$184
Boatable: WTP to maintain boatable water quality	$245	$245

Source: Carson and Mitchell, 1993. The values originally reported have been adjusted to account for inflation and changes in real income between 1983 and 1999.

Applying the willingness to pay estimates presented above to analyze the benefits of alternate CAFO regulations requires consideration of how households' willingness to pay for water quality improvements is likely to vary with the extent and location of the resources affected. All else equal, people are likely to value an action that improves water quality along a ten-mile stretch of river more highly than they would value an action that improves only a one-mile stretch. Similarly, people are likely to place greater value on improving the quality of water resources that are nearer to them. This is simply because less time and expense is typically required to reach nearer resources; as a result, these resources generally provide lower cost and more frequent opportunities for recreation and enjoyment. This assumption is supported by the results of the Carson and Mitchell survey, which asked respondents to apportion their willingness to pay values between improving the quality of local waters - where local waters were defined as those in each respondent's own state - and improving the quality of non-local waters (i.e., those located out-of-state). On average, respondents allocated two-thirds of their values to achieving water quality goals in-state, and one-third to achieving those goals in the remainder of the nation.

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[38] EPA employed the Consumer Price Index to adjust 1983 values to 1999 values. In addition, the adjustment to 1999 values takes into account the increase in real per capita disposable income over the period of interest. The adjustment for changes in real income is consistent with the survey's results, which found that respondents' willingness to pay for water quality improvements increased in almost direct proportion to household income.

To reflect the considerations noted above, the analysis of the benefits of alternate CAFO regulations examines water quality improvements on a state-by-state basis and separately calculates the benefits of in-state and out-of-state improvements, assuming that households will allocate two-thirds of their willingness to pay values to the improvement of in-state waters. In addition, the analysis takes into account the extent of each scenario's estimated impacts (i.e., the number of stream-miles that improve from non-supportive or boatable to fishable, or from non-supportive, boatable or fishable to swimmable) by scaling household willingness to pay for a given improvement in the quality of the nation's waters by the proportion of total stream-miles in-state or out-of-state that are projected to make the improvement. For purposes of these calculations, the analysis relies on estimates of the 1999 population and the average number of individuals per household (2.62) as reported in the Statistical Abstract of the United States. Appendix 4-A provides a detailed summary of the calculations employed.

It is important to note that the valuation process described above does not address a number of potential improvements in water quality. For example, the analysis assigns no economic value to improvements in the quality of waters already classified as swimmable under the baseline scenario; the Carson and Mitchell contingent valuation survey did not examine this area, and thus provides no basis for valuing such changes. In addition, the analysis does not value the improvement of non-boatable waters to boatable condition. Although the survey asked respondents how much they would be willing to pay to avoid a drop in water quality to non-boatable conditions, the definition of non-boatable water quality - "water containing raw sewage, with strong odors, floating garbage and pathogens that would cause illness through human contact" - was so extreme that the resulting willingness to pay values may be overstated. Consequently, EPA has chosen not to employ Carson and Mitchell's estimates of willingness to pay to maintain boatable water quality in this analysis. EPA is reassessing the boatable level in the water quality ladder to be more consistent with the language of the Carson and Mitchell study. Overall, the Agency believes that the benefits calculated here are conservative because they reflect only swimming and fishing improvements, not boating improvements or improvements in the quality of waters already considered swimmable.

4.6.3 Estimated Benefits

Exhibit 4-13 presents NWPCAM's estimates of the annual economic benefits associated with each regulatory scenario. As the table indicates, the estimates range from approximately $5 million per year under Option 1-Scenario 1 to $145 million per year under Option 2-Scenario 4b. EPA estimates that the annual benefits of the proposed scenarios range from approximately $108.5 million per year to $127.1 million per year. Roughly 80 percent of these benefits are derived from improving previously non-fishable waters to fishable status. The remaining benefits are attributed to improving a smaller number of stream miles to swimmable condition.

Exhibit 4-13

ANNUAL ECONOMIC BENEFIT OF ESTIMATED IMPROVEMENTS IN SURFACE WATER QUALITY (1999 $, millions)

Regulatory Scenario	Waters Improved to Fishable	Waters Improved to Swimmable	Total Benefits
Option 1-Scenario 1	$2.8	$2.1	$4.9
Option 1-Scenario 2/3	$3.2	$3.1	$6.3
Option 1-Scenario 4a	$3.1	$2.4	$5.5
Option 1-Scenario 4b	$3.8	$3.4	$7.2
Option 2-Scenario 1	$71.0	$16.7	$87.6
Option 2-Scenario 2/3*	$102.4	$24.7	$127.1
Option 2-Scenario 4a*	$84.0	$24.5	$108.5
Option 2-Scenario 4b	$115.5	$29.5	$145.0

* Proposed scenarios.

4.7 REFERENCES

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Appendix 4-A

NWPCAM CALCULATION OF THE ECONOMIC BENEFITS OF IMPROVED SURFACE WATER QUALITY

Definitions

N = national benefits of estimated improvements in water quality
S_j = total benefits of estimated improvements in water quality for residents of state "j"
$B_{(l, j)}$ = benefits of in-state improvements in water quality for residents of state "j"
$B_{(n, j)}$ = benefits of out-of-state improvements in water quality for residents of state "j"
M_j = total stream-miles in state "j"
M_n = total stream-miles outside state "j"
$M_{(x, j)}$ = stream-miles in state "j" that achieve water quality improvement "x"
$M_{(x, n)}$ = stream-miles outside state "j" that achieve water quality improvement "x"
H_j = total households in state "j"
WTP_x = average household willingness to pay for water quality improvement "x"

Calculations

$$N = \sum_{J} S_j$$

$$S_j = B_{(l, j)} + B_{(n, j)}$$

$$B_{(l, j)} = \sum_{X} (M_{(x, j)} / M_j)(H_j)(WTP_x)(2/3)$$

$$B_{(n, j)} = \sum_{X} (M_{(x, n)} / M_n)(H_j)(WTP_x)(1/3)$$

REDUCED INCIDENCE OF FISH KILLS CHAPTER 5

5.1 INTRODUCTION

Episodic fish kills resulting from manure runoff, spills, and other discharges from AFOs remain a serious problem in the United States. As described in Chapter 2, large releases of nutrients, pathogens, and solids from AFOs can cause sudden, extensive kill events.[39] In less dramatic cases, nutrients contained in runoff from AFOs can trigger increases in algae growth—often called algae blooms—that reduce concentrations of dissolved oxygen in water and can eventually cause fish to die.[40]

In addition to killing and harming fish directly, pollution from AFOs can affect other aquatic organisms that in turn harm fish. In particular, the Eastern Shore of the United States has been plagued with problems related to *Pfiesteria*, a dinoflagellate algae that, under certain circumstances, can transform into a toxin that attacks fish, breaking down their skin tissue and leaving lesions or large, gaping holes that often result in death. The transformation of *Pfiesteria* to its toxic form is believed to be the result of high levels of nutrients in water. Fish kills related to *Pfiesteria* in North Carolina's Neuse River have been blamed on waste spills and runoff from the state's booming hog industry.

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[39] For example, in 1998, the release of manure into the West Branch of Wisconsin's Pecatonica River resulted in a complete kill of smallmouth bass, catfish, forage fish, and all but the hardiest insects in a 13-mile reach.

[40] For example, in 1996, the gradual runoff of manure into Atkins Lake, a shallow lake in Arkansas, resulted in a heavy algae bloom that depleted the lake of oxygen, killing many fish.

This chapter examines the damages attributable to AFO-related fish kills and estimates the economic benefits that revised CAFO standards would provide in reducing such incidents. As explained below, the analysis employs state data on historical fish kill events, combined with predicted reductions in the frequency of such events under alternate regulatory scenarios, to estimate the decrease that would occur in the number of fish killed annually in AFO-induced incidents. It then employs data on average fish replacement costs to develop a conservative estimate of the economic benefits associated with the predicted reduction in fish kill incidents.

5.2 ANALYTIC APPROACH

5.2.1 Data Sources and Limitations

Data on fish kill incidents are limited, with no consistent collection and reporting requirements and no national repository of fish kill data. States are not required to report fish kills to EPA. As a result, EPA does not maintain a comprehensive database detailing the frequency or severity of fish kill events.

Despite the lack of EPA reporting requirements, many states do record information on fish kills. For purposes of this analysis, EPA has compiled a database of fish kill events in 19 states. This database incorporates a range of information on each incident. Exhibit 5-1 lists the 19 states included in the database, the years for which data from each state were obtained, and the average number of fish kill events reported by each state annually.[41]

As Exhibit 5-1 indicates, the data upon which this analysis relies are not comprehensive. The fish kill database excludes 31 states, including several, such as Oklahoma, that host a relatively large number of AFOs. The period of time for which data were obtained also varies from state to state; the information collected from some states, such as Missouri, covers nearly two decades, while that collected from others, such as West Virginia, covers only a few years. In addition, even in the states and years for which data were collected, it is likely that some fish kill events remain unreported, particularly if they occurred in remote areas.[42] These data gaps introduce considerable uncertainty into the analysis.

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[41] EPA's database incorporates records on fish kills obtained from the Natural Resources Defense Council (NRDC) and the Izaak Walton League (IWL).

[42] For instance, in 1995 the Raleigh *News & Observer* reported a 1991 manure spill incident in the North Carolina town of Magnolia that neither the town nor the responsible farm reported to state water quality officials.

Exhibit 5-1

FISH KILL EVENT DATA OBTAINED BY EPA

State	**Years for which Data were Obtained**	**Average Annual Number of Recorded Events**
Arkansas	1995-1999	8.6
Illinois	1987-1999	14.0
Indiana	1994-1999	27.2
Iowa	1981-1998	26.3
Kansas	1990-1999	15.7
Kentucky	1995-1998	15.5
Minnesota	1981-1991	23.9
Mississippi	1990-1998	18.6
Missouri	1980-1999	125.3
Montana	1994-1998	1.8
Nebraska	1991-1998	22.1
New Mexico	1995-1998	4.8
New York	1984-1996	18.0
North Carolina	1994-1998	41.2
Ohio	1995-1998	20.3
South Carolina	1995-1998	5.5
Texas	1990-1998	114.7
West Virginia	1995-1997	6.0
Wisconsin	1988-1998	6.4
	Total	**515.9**

In addition to the data gaps cited above, the analysis is limited by inconsistencies in the information collected in state fish kill reports. Some states appear to have established consistent guidelines for investigating a kill, which often include reporting the number of stream miles or lake acres affected, estimating the number of fish killed, describing the exact location of the kill, identifying the source of the pollutants suspected to have caused the kill, and obtaining water quality samples for testing. Other states appear to gather information on an ad hoc basis. In addition, the data present a number of anomalies or other limitations. For example, 25 percent of the records included in EPA's database give no estimate of the number of fish killed or provide only a qualitative description of the incident's magnitude. Another 13 percent of the records indicate that the number of fish killed in the event was zero.[43] In addition, most reports do not indicate the type(s) of fish killed.

Despite the apparent limitations of these data, they are useful for purposes of this analysis. EPA's database is the most comprehensive source of information on fish kill events currently available, and in most instances characterizes the source of the pollutants that caused individual fish kill events. Thus, EPA can apply these data to characterize a baseline of kill events potentially attributable to pollution from AFOs.

5.2.2 Predicted Change in Fish Kills Under Alternate CAFO Regulations

To estimate the potential benefits of alternate CAFO regulations in reducing fish kill incidents, EPA's analysis must first assess the current — or baseline — number of AFO-related fish kills. It must then determine the impact of alternate regulatory scenarios in reducing these incidents. EPA's approach to this analysis is described below.

5.2.2.1 Baseline Scenario

The EPA database records fish kill events attributable to a wide range of sources and causes, the classification of which varies from state to state. Exhibit 5-2 lists the sources and causes that are potentially associated with AFOs, and indicates EPA's assessment of the strength of the association; i.e., whether the Agency considers the link to AFOs to be definite or possible. Based on this assessment of sources and causes, EPA reviewed the data on each reported event, identifying fish kills positively or possibly attributable to pollution from AFOs. Exhibit 5-3 presents the results of this evaluation. As the exhibit indicates, EPA's database lists 589 fish kill events that are positively or possibly attributable to pollution from AFOs. These incidents killed a reported total of approximately 4.2 million fish. Based on these data, EPA estimates that in the states evaluated, incidents positively attributable to pollution from AFOs kill an average of 351

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[43] This may be due to a variety of circumstances. In some cases, the report may accurately indicate an event in which contamination occurred (such as a manure spill or municipal waste release) but no fish were killed. In other cases, a record may indicate zero fish killed simply because investigators were unable to develop a count (e.g., because the number killed was too great to count, or because the investigation was conducted too late to determine the number killed).

thousand fish per year. In addition, incidents possibly attributable to pollution from AFOs kill, on average, another 40 thousand fish annually. In total, the database indicates that in the 19 states analyzed, pollution from AFOs may kill an average of 391 thousand fish each year.[44]

Exhibit 5-2

SOURCES AND CAUSES OF FISH KILL EVENTS POTENTIALLY RELATED TO ANIMAL FEEDING OPERATIONS

Source	Relation to AFOs	Cause	Relation to AFOs
animal feeding/waste operations	Definite	ammonia toxicity	Definite
agriculture	Possible	lagoon breaks	Definite
agriculture point source	Possible	manure	Definite
algae related	Possible	nutrients	Definite
		algae blooms	Possible
		dissolved oxygen	Possible
		employee error	Possible
		equipment failures	Possible
		fertilizer	Possible
		nonpoint source runoff	Possible
		spills	Possible
		weather	Possible

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[44] EPA estimates the average number of fish killed annually in the 19 states of record by dividing the total number of fish killed in each state by the number of years for which data from the state are reported. EPA then sums the state averages to obtain the annual average for all 19 states.

Exhibit 5-3

NUMBER OF FISH KILL EVENTS POTENTIALLY RELATED TO ANIMAL FEEDING OPERATIONS

Cause	Number of Occurrences for Each Source					
	Animal Feeding and Waste Operations	**Agriculture**	**Agriculture Point Source**	**Algae-Related**	**Unknown Source**	**Total**
Ammonia Toxicity	**8**	**6**	**3**	-	-	17
Ammonia Toxicity/ Dissolved Oxygen	**96**	**3**	**4**	-	-	103
Dissolved Oxygen	-	26	1	33	-	60
Employee Error/Manure	**3**	**2**	-	-	-	5
Equipment Failure	-	1	-	-	-	1
Equipment Failure/Manure	-	**3**	-	-	-	3
Equipment Failure/Fertilizer	-	1	-	-	-	1
Fertilizer	-	24	-	-	-	24
Lagoon Breaks	**5**	-	-	-	-	5
Manure	**74**	**158**	**1**	-	**110**	343
Manure/Dissolved Oxygen	-	-	**2**	-	-	2
Manure/Weather	-	**1**	-	-	-	1
Algal Toxins/Algal Oxygen Deficiency	-	6	-	1	-	7
Nonpoint Source Runoff	**1**	5	-	-	-	6
Nutrient	-	**1**	-	-	-	1
Spills	**3**	-	1	-	-	4
Weather	-	-	3	-	-	3
Other / Unknown	**1**	2	-	-	-	3
Total:	191	239	15	34	110	589

Note: Numbers in bold indicate fish kill events considered to be definitely induced by AFOs.

5.2.2.2 Regulatory Scenarios

Due to time and resource constraints, EPA has not conducted a detailed analysis of the impact of alternate CAFO standards on the frequency or severity of fish kill events. It is likely, however, that the implementation of new regulations would have a number of beneficial effects. For example, because more AFOs would be subject to regulation as CAFOs, the number of fish kill incidents caused by lagoon breaks and similar catastrophic events would likely diminish. In addition, the improvements in manure management practices required under the new regulations would likely reduce the chronic discharge of nutrients to the nation's waters, and thus reduce the number of fish killed as a result of severe eutrophication.

In lieu of more detailed modeling, EPA has attempted to develop a reasonable estimate of the impact of alternate CAFO standards on fish kills. The analysis begins with EPA's estimate of the number of fish killed annually by releases from AFOs.[45] EPA multiplies this figure by the anticipated percentage reduction in nutrient loadings from the animal feeding operations modeled by NWPCAM (see Chapter 4). The resulting value, for each regulatory scenario, represents an estimate of the reduction in the number of fish killed annually by releases from AFOs.

Because the relationship between nutrient loadings and fish kill events is complex, this approach provides only a rough approximation of the beneficial impacts of alternate regulations. To reflect the underlying uncertainty, the analysis employs two different scaling factors:

- the percentage reduction in phosphorus loadings; and
- the percentage reduction in nitrogen loadings.

Exhibit 5-4 summarizes the estimated percentage reduction in nitrogen and phosphorus loadings under each regulatory scenario. The values reported are those estimated by NWPCAM for the full RF3 set of rivers and streams. The analysis uses these values, rather than those reported for the RF3 Lite subset, in order to reflect changes in loadings to small as well as large rivers and streams.[46]

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[45] For purposes of this analysis, EPA considers all fish kill events identified as definitely or possibly attributable to AFOs.

[46] Chapter 4 provides additional detail on the RF3 and RF3 Lite datasets.

Exhibit 5-4

REGULATORY SCENARIO SCALING FACTORS

Regulatory Scenario	Percent Nitrogen Reduction	Percent Phosphorus Reduction
Option 1/Scenario 1	18.10	45.53
Option 1/Scenario 2/3	23.02	59.79
Option 1/Scenario 4a	21.82	56.51
Option 1/Scenario 4b	25.66	63.00
Option 2/Scenario 1	34.55	55.22
Option 2/Scenario 2/3*	43.00	72.06
Option 2/Scenario 4a*	41.48	68.81
Option 2/Scenario 4b	47.24	77.40
* Proposed scenarios		

Based on the methods described above, EPA estimates the anticipated reduction in fish kills under each of the regulatory scenarios. Exhibit 5-5 presents the results. As the exhibit shows, EPA estimates that under the proposed scenarios, the reduction in fish killed annually would range from 162 thousand to 282 thousand.

Exhibit 5-5

ESTIMATED REDUCTION IN THE NUMBER OF FISH KILLED ANNUALLY DUE TO RELEASE OF POLLUTANTS FROM AFOs (thousands)

	Scaling Factor	
Regulatory Scenario	Nitrogen Reduction	Phosphorus Reduction
Option 1/Scenario 1	71	178
Option 1/Scenario 2/3	90	234
Option 1/Scenario 4a	85	221
Option 1/Scenario 4b	100	247
Option 2/Scenario 1	135	216
Option 2/Scenario 2/3*	168	282
Option 2/Scenario 4a*	162	269
Option 2/Scenario 4b	185	303
*Proposed scenarios		

5.2.3 Valuation of Predicted Reduction in Fish Kills

The economic damages that stem from natural resource injuries like fish kills include the costs of restoring the resource to its prior state, any interim lost use values (e.g., the economic value of lost fishing days from the time the damage occurs until fish stocks are restored), and any interim lost non-use values. Unfortunately, estimating these values for a large number of heterogeneous fish kill events nationwide is infeasible without a significant investment of analytic resources. Determining full habitat restoration costs requires a case-by-case assessment of the nature of the injury and the restoration options available, while estimating interim lost non-use values requires the use of stated preference techniques to explore people's willingness to pay to avoid temporary depletions of fish stocks and associated damage to fish habitat. The economics literature does provide estimates of potential lost use values— e.g., willingness to pay for another day of fishing or willingness to pay for an additional fish caught—that could, theoretically, be applied to the analysis using a benefits transfer approach. This assessment, however, would need to make general assumptions about a number of highly variable site-specific factors, such as the duration of the reduction in fish stocks, the effect of this reduction on recreational fishing activity in the affected areas, and the availability and characteristics of alternative fishing areas. Thus, an evaluation of interim lost use values would be subject to considerable uncertainty.

Because of the difficulties cited above, this analysis takes a simplified approach, estimating the economic benefits of reducing the frequency of fish kills based on one component of resource restoration costs: the replacement cost of the fish. Specifically, the analysis employs replacement cost estimates presented in a report developed by the American Fisheries Society (AFS, 1990). These replacement values incorporate the cost of raising fish at a hatchery, transporting them, and placing them in the water. As such, they provide a conservative estimate of the economic benefits of reducing the incidence of fish kills.[47]

The American Fisheries Society report provides replacement cost estimates for a variety of fish species and size categories. Unfortunately, the available data on fish kills do not always indicate the species of fish affected, and generally do not report mortality by size of fish. In light of these limitations, EPA applies a general fish replacement cost estimate, derived by selecting species known to have been killed in incidents related to AFOs and averaging reported replacement costs for these species across all size classes. The resulting average replacement cost employed in the analysis equals $1.31 per fish ($1999).[48] To value the benefits of each regulatory scenario, the analysis simply multiplies this average replacement cost by the corresponding estimated reduction in the number of fish killed each year.[49]

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[47] The analysis employs fish replacement costs as a proxy measure for valuing anticipated reductions in fish kill incidents. The approach does not presume that all fish killed would necessarily be restocked.

[48] To adjust replacement costs to 1999 dollars, EPA applies the Gross Domestic Product deflator.

[49] To bound the potential uncertainty associated with fish replacement costs, the analysis also develops benefits estimates based on the averages of the minimum and maximum replacement costs reported for each species. Appendix 5-A presents the results of this analysis.

5.3 RESULTS

Exhibit 5-6 presents estimates of the annual benefits attributable to the reduced incidence of fish kills under each of the regulatory scenarios. As the exhibit indicates, these benefits range from $93 thousand to $397 thousand, depending upon the regulatory option considered and the scaling factor employed. Annual benefits under the proposed scenarios are estimated to range from $213 thousand to $369 thousand.

Exhibit 5-6

ESTIMATED ANNUAL BENEFITS ATTRIBUTED TO REDUCTION IN FISH KILLS ($1999, thousands)

	Scaling Factor	
Regulatory Scenario	**Nitrogen Reduction**	**Phosphorus Reduction**
Option 1/Scenario 1	$93	$233
Option 1/Scenario 2/3	$118	$306
Option 1/Scenario 4a	$112	$290
Option 1/Scenario 4b	$132	$323
Option 2/Scenario 1	$177	$283
Option 2/Scenario 2/3*	$220	$369
Option 2/Scenario 4a*	$213	$353
Option 2/Scenario 4b	$242	$397

*Proposed scenarios

5.4 LIMITATIONS AND CAVEATS

EPA's analysis of the benefits of alternate CAFO regulations in reducing fish kills is subject to numerous data gaps and uncertainties. In the face of these uncertainties, the analysis employs a number of simplifying assumptions. The major limitations of the analysis are summarized below.

- The scope of the analysis is limited to 19 states. The data available from these states may not include all fish kill events, and the data on reported incidents often fail to include estimates of the number of fish killed. Therefore, EPA's baseline estimate is likely to understate the number of fish kill events and the total number of fish killed nationwide each year in incidents related to pollution from AFOs.

- EPA has not undertaken a detailed analysis of the impact of alternate regulatory scenarios on the incidence of fish kills. In lieu of a detailed analysis, EPA assumes that fish kills attributable to releases of pollution from AFOs will be reduced in proportion to estimated reductions in loadings of nutrients from AFOs. The direction and magnitude of bias associated with these assumptions is unknown.

- To value estimated reductions in fish kill incidents, the analysis applies an estimate of average fish replacement costs. Because this proxy measure ignores other aspects of the economic damages associated with fish kills (i.e., habitat restoration costs, interim lost use values, and interim lost non-use values), it likely understates the economic benefit of reducing fish kill incidents.

5.5 REFERENCES

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Appendix 5-A

CALCULATION OF ANNUAL BENEFITS USING MINIMUM AND MAXIMUM FISH REPLACEMENT VALUES

Replacement values for a fish species can vary significantly depending on the size class of the fish. This appendix presents the results of the benefits assessment using averages of the minimum and maximum replacement values reported for each fish species. The average minimum and maximum replacement costs equal $0.28 and $2.37 ($1999), respectively. Exhibit 5A-1 presents annual benefit estimates based upon the minimum fish replacement cost; annual benefits for the proposed scenarios in this case range between $45 and $79 thousand. Exhibit 5A-2 presents annual benefit estimates based on the maximum replacement cost; in this case, annual benefits under the proposed scenarios range from $385 to $668 thousand.

Exhibit 5A-1

**ESTIMATED ANNUAL BENEFITS
ATTRIBUTED TO REDUCTION IN FISH KILLS:
MINIMUM REPLACEMENT COST
($1999, thousands)**

	Scaling Factor	
Regulatory Scenario	**Nitrogen Reduction**	**Phosphorus Reduction**
Option 1/Scenario 1	$20	$50
Option 1/Scenario 2/3	$25	$66
Option 1/Scenario 4a	$24	$62
Option 1/Scenario 4b	$28	$69
Option 2/Scenario 1	$38	$60
Option 2/Scenario 2/3*	$47	$79
Option 2/Scenario 4a*	$45	$75
Option 2/Scenario 4b	$52	$85

*Proposed scenarios

Exhibit 5A-2

ESTIMATED ANNUAL BENEFITS ATTRIBUTED TO REDUCTION IN FISH KILLS: MAXIMUM REPLACEMENT COST ($1999, thousands)

	Scaling Factor	
Regulatory Scenario	**Nitrogen Reduction**	**Phosphorus Reduction**
Option 1/Scenario 1	$168	$422
Option 1/Scenario 2/3	$213	$554
Option 1/Scenario 4a	$202	$524
Option 1/Scenario 4b	$238	$584
Option 2/Scenario 1	$320	$512
Option 2/Scenario 2/3*	$399	$668
Option 2/Scenario 4a*	$385	$638
Option 2/Scenario 4b	$438	$718

*Proposed scenarios

IMPROVED COMMERCIAL SHELLFISHING CHAPTER 6

6.1 INTRODUCTION

The National Oceanic and Atmospheric Administration (NOAA) has identified pathogen contamination of U.S. coastal waters as a leading cause of government restrictions on commercial shellfish harvesting. Among the sources of pollution that contribute to such contamination are animal feeding operations (AFOs) and runoff from agricultural lands. This chapter estimates the impact of pollution from AFOs on commercial access to shellfish growing waters, the resulting impact on commercial shellfish harvests, and the potential increase in harvests that would result under alternate approaches to regulating the discharge of pollutants from CAFOs. It then uses available estimates of consumer demand for shellfish to calculate the economic benefits associated with the predicted increase in commercial shellfish harvests under each regulatory scenario.

6.2 ANALYTIC APPROACH

6.2.1 Data on Shellfish Harvest Restrictions Attributed to AFOs

EPA's analysis of the impact of pollution from AFOs on shellfish harvests is based on information from *The 1995 National Shellfish Register of Classified Growing Waters* (NOAA, 1997) and related databases. NOAA produces the Register, which is published every five years, in cooperation with the nation's shellfish-producing states, federal agencies such as the U.S. Food and Drug Administration (FDA), and the Interstate Shellfish Sanitation Conference (ISSC). Its purpose is to summarize the status of shellfish-growing waters under the National Shellfish Sanitation Program (NSSP), which ISSC administers. The NSSP establishes comprehensive guidelines to regulate the commercial harvesting, processing, and shipment of shellfish. These guidelines include the measurement of fecal coliform concentrations as an indicator of pollution in shellfish-growing waters. Based in large part upon these measurements, shellfish-growing areas are designated as approved, conditionally approved, restricted, conditionally restricted, prohibited, or unclassified, and subjected to appropriate harvest and processing standards. Exhibit 6-1 describes these standards for each designation.

Exhibit 6-1

NSSP STANDARDS FOR CLASSIFIED SHELLFISH GROWING WATERS

Classification	Description	Standard[1]
Approved Waters	Growing waters from which shellfish may be harvested for direct marketing.	MPN may not exceed 14 per 100 ml, and not more than 10 percent of the samples may exceed an MPN of 43 per 100 ml for a 5-tube decimal dilution test.
Conditionally Approved Waters	Growing waters meeting the approved classification standards under predictable conditions. These waters are open to harvest when water quality standards are met. At all other times these waters are closed.	
Restricted Waters	Growing waters from which shellfish may be harvested only if they are relayed or depurated before direct marketing.[2]	MPN may not exceed 88 per 100 ml, and not more than 10 percent of the samples may exceed an MPN of 260 per 100 ml for a 5-tube decimal dilution test.
Conditionally Restricted Waters	Growing waters that do not meet the criteria for restricted waters if subjected to intermittent microbiological pollution, but may be harvested if shellfish are subjected to a suitable purification process.	
Prohibited Waters	Growing waters from which shellfish may not be harvested for marketing under any conditions.	NA
Unclassified Waters	Growing waters that are part of a state's shellfish program but are inactive (i.e., there is no harvesting) and unmonitored.	NA

Source: National Oceanic and Atmospheric Administration, *The 1995 National Shellfish Register of Classified Growing Waters*, obtained from: http://seaserver.nos.noaa.gov/projects/95register/, 11 June 2000.

Notes:

[1] MPN = fecal coliform most probable number (median or geometric mean).

[2] The process of relaying shellfish refers to the transfer of shellfish from restricted waters to approved waters for natural biological cleansing using the ambient environment as a treatment system, usually for a minimum of 14 days before harvest. Depuration is the process of removing impurities by placing the contaminated shellfish in clean water for a period of time.

The 1995 Shellfish Register provides information on 21.4 million acres of estuarine and non-estuarine commercial shellfish-growing waters as of January 1, 1995. A companion CD contains a GIS-based database of the location of all 4,320 shellfish growing areas in 21 coastal states, the acreage of each growing area, and the species harvested.[50] These species are classified into 13 categories of clams, four categories of oysters, six categories of mussels, and two categories of scallops. In most cases, each category represents a unique species (e.g., Blue Mussel (*Mytilus edulis*)), but in some instances a category may include two or more species (e.g., Other Mussels (*Mytilus galloprovincialis* and *Mytilus edulis*)). The types of species harvested vary geographically, with large differences between the East and West Coasts.

In addition to the data described above, the shellfish database notes for each growing area any harvest limitations imposed and the known or possible source(s) of pollutants causing any impairment. The list of pollutant sources includes both "Animal Feedlots" and "Agriculture Runoff." Sources of impairment are further classified as actual or potential contributors. If a source is listed as an actual contributor, its significance as a cause of impairment is rated as high, medium, or low. Exhibit 6-2 shows the acreage of shellfish-growing waters that are potentially or known to be impaired by pollution from AFOs and/or agricultural runoff. As the exhibit indicates, AFOs and/or agricultural runoff are known or potential contributors to the impairment of more than 1.6 million acres of shellfish-growing waters.

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[50] The Shellfish Register includes data for the following states: Alabama, California, Connecticut, Delaware, Florida, Georgia, Louisiana, Massachusetts, Maryland, Maine, Mississippi, North Carolina, New Hampshire, New Jersey, New York, Oregon, Rhode Island, South Carolina, Texas, Virginia, and Washington.

Exhibit 6-2

SHELLFISH HARVEST LIMITATIONS BY REGION

Region	Approved Acres	Harvest-Limited Acres	Harvest-Limited Acres with Impacts from AFOs and/or Agricultural Runoff
North Atlantic (MA, ME, NH)	2,920,575	714,191	33,626
Middle Atlantic (CT, DE, MD, NJ, NY, RI, VA)	4,969,680	973,715	100,284
South Atlantic (FL, GA, NC, SC)	3,505,729	1,751,844	660,679
Gulf of Mexico (AL, LA, MS, TX)	3,238,431	3,067,730	718,828
Pacific (CA, OR, WA)	206,574	214,494	96,296
Total	14,840,989	6,721,975	1,609,713

Discrepancies between reported totals and sum of regional totals are due to rounding.
Source: U.S. National Oceanic and Atmospheric Administration, *The 1995 National Shellfish Register of Classified Growing Waters*, U.S. Department of Commerce, Silver Spring, MD, August 1997.

6.2.2 Estimated Impact on Shellfish Harvests

As a causal factor in the imposition of government restrictions or prohibitions on shellfish harvesting, pollution from AFOs likely serves to reduce shellfish landings below levels that would otherwise be realized. To evaluate the potential beneficial effects of new CAFO regulations, EPA's analysis begins by estimating the adverse impacts currently attributable to pollution from AFOs. The approach to this analysis involves the following steps.

- Step 1: characterize current, or baseline, annual shellfish landings.
- Step 2: estimate the area of shellfish-growing waters from which current landings are harvested.
- Step 3: calculate the average annual per-acre yield of shellfish from harvested waters.
- Step 4: estimate the area of shellfish-growing waters that are currently unharvested as a result of pollution from AFOs.

- Step 5: estimate the foregone harvest, i.e., the potential annual harvest of shellfish from waters that are currently unharvested as a result of pollution from AFOs.

Each of these steps is described in greater detail below.

6.2.2.1 Baseline Annual Shellfish Landings

To characterize the baseline quantity (Q_0) of shellfish harvested in each coastal state, the analysis relies on data collected by NOAA's National Marine Fisheries Service (NMFS), which reports commercial fishing harvests by state, year, and species (NMFS, 2000). NMFS maintains complete commercial harvest data on various species of clams, mussels, oysters and scallops for each state. The data consist of total pounds harvested and total ex-vessel revenues for harvested species. The data are provided as state-wide totals only and do not disaggregate harvest quantities between shellfish growing areas within each state. For the purpose of this analysis, EPA obtained shellfish harvest data by species and state for the five most recent years available: 1994 through 1998. The analysis employs the mean of the reported annual values for each species and state to characterize shellfish harvests under baseline conditions.[51]

6.2.2.2 Estimated Acreage of Harvested Waters

The available data do not indicate the distribution of shellfish landings from waters that the 1995 Shellfish Register identifies as approved, conditionally approved, restricted, or conditionally restricted. For purposes of this analysis, EPA assumes that baseline landings are harvested primarily from approved or conditionally approved waters. Thus, in a given state (j), the area of shellfish growing waters assumed to be harvested is determined by the following calculation:

$$\text{Acres Harvested}_{(j)} = \text{Acres Approved}_{(j)} + \text{Acres Conditionally Approved}_{(j)}$$

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[51] The calculation of the mean ignores years for which harvest data for a particular species are unavailable. If landings in these years were actually zero, this approach will overstate average annual landings.

6.2.2.3 Average Annual Yield of Harvested Waters

To calculate the average annual yield (Y) of harvested waters for a given species (n) in a given state (j), the analysis simply divides the annual baseline harvest (Q_0) for that species and state by the acres assumed to be harvested:

$$Y_{(n,j)} = Q_{0(n,j)}/\text{Acres Harvested}_{(j)}$$

This calculation provides an estimate of the pounds of shellfish landed per year from harvested waters.

6.2.2.4 Characterization of Waters that are Unharvested due to Pollution from AFOs

The next step in the analysis is to estimate the area of shellfish-growing waters that are currently unharvested due, at least in part, to pollution from AFOs. Consistent with the approach outlined thus far, EPA assumes that waters classified in the 1995 Shellfish Register as restricted, conditionally restricted, or prohibited are essentially unharvested. Thus, in a given state (j), the area of shellfish growing waters assumed to be unharvested is determined by the following calculation:

$$\text{Acres Unharvested}_{(j)} = \text{Acres Restricted}_{(j)} + \text{Acres Conditionally Restricted}_{(j)} + \text{Acres Prohibited}_{(j)}$$

This calculation, however, includes all impaired waters. To identify areas impaired, in whole or in part, by pollution from AFOs, EPA's analysis considers two cases. Under Case 1, EPA evaluates only those shellfish-growing waters for which AFOs are specifically identified as a contributing source of impairment. Under Case 2, EPA expands the analysis to include shellfish-growing waters that the Register identifies as impaired, in whole or in part, by AFOs and/or agricultural runoff. The inclusion of Case 2 is justified by the classification of shellfish-growing waters on the basis of fecal coliform levels. To the extent that agricultural runoff causes elevated fecal coliform counts, animal manure, potentially from AFOs, is the likely contributing factor.[52]

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[52] In addition, NOAA staff who maintain the Register suggest that difficulty in pinpointing the source of pollution often results in classifying impacts from AFOs under the more general heading of "Agriculture Runoff." Personal communication with Jamison Higgins, NOAA, April 12, 1999.

6.2.2.5 Estimated Impact of Pollution from AFOs on Commercial Shellfish Landings

To characterize the impact of pollution from AFOs on commercial shellfish landings, it is first necessary to estimate the potential yield of impaired shellfish growing areas. For purposes of this analysis, EPA assumes that the average annual yield from harvested waters, as calculated above, is representative of the potential annual yield from impaired waters. Thus, the foregone harvest (Q_F) from an area of any size for a given species (n) in a given state (j) is calculated as follows:

$$Q_{F(n,j)} = Y_{(n,j)} \text{ x Acres Unharvested}_{(j)}$$

It would be inappropriate, however, to assume that pollution from AFOs accounts for the entire foregone harvest. The Shellfish Register identifies AFOs and/or agricultural runoff as a source of impairment for only a subset of impaired growing waters. Moreover, even in situations where AFOs and/or agricultural runoff contribute to impairment, they are not necessarily the sole source of impairment. Under these circumstances, it is difficult to characterize the marginal impact of pollution from AFOs and/or agricultural runoff on annual shellfish harvests.

To address this concern, EPA relies on the Shellfish Register's characterization of the significance of pollution from AFOs and/or agricultural runoff as a source of impairment. As noted above, the Register indicates whether a source is an actual or potential contributor to impairment, and when identified as an actual contributor notes the overall importance of the source (i.e., high, medium, or low). EPA uses this information to characterize the marginal impact of pollution from AFOs and/or agricultural runoff on shellfish harvests. It does so by subjectively assigning a weighting factor that varies with the contribution of AFOs and/or agricultural runoff to impairment of a given shellfish growing area; Exhibit 6-3 summarizes the weighting factors employed. EPA then applies these weighting factors to estimates of the foregone harvest (Q_F) from each shellfish-growing area to estimate the marginal impact of pollution from AFOs and/or agricultural runoff on annual shellfish harvests. Mathematically, the harvest of a given species that EPA estimates as lost due to pollution from AFOs and/or agricultural runoff (Q_A) in an impaired area is simply the product of the foregone harvest of the species from the area (Q_F) and the appropriate weighting factor(W):

$$Q_A = Q_F \text{ x } W$$

Summing Q_A across all impaired shellfish growing areas in a given state provides EPA's estimate of the marginal impact of pollution from AFOs and/or agricultural runoff on annual commercial harvests of each shellfish species.

Exhibit 6-3

WEIGHTING FACTORS EMPLOYED TO CHARACTERIZE THE IMPACT OF AFOs AND AGRICULTURAL RUNOFF ON HARVESTS FROM IMPAIRED SHELLFISH-GROWING WATERS

Significance of Source	Weighting Factor
Not a contributor	.00
Potential contributor	.25
Actual contributor (low)	.50
Actual contributor (medium)	.75
Actual contributor (high)	1.0

6.2.3 Estimated Impact of Alternate Regulations on Commercial Shellfish Harvests

The next step in EPA's analysis is to estimate the impact of alternate CAFO regulatory scenarios on commercial shellfish harvests. To do so, EPA employs information obtained from the surface water quality modeling effort described in Chapter 4. The modeling exercise does not extend to estuaries or near-coastal waters, where most commercial shellfish-growing areas are located; however, it does consider the impact of each regulatory scenario on fecal coliform counts associated with pollution from AFOs. Since classification of shellfish-growing areas is based in part on measurement of fecal coliform counts, the estimated impact of alternate regulatory scenarios on this measure of water quality in upstream areas provides a reasonable proxy for characterizing potential changes downstream.

EPA's approach to estimating the beneficial impacts of new CAFO regulations on commercial shellfish harvests assumes that the adverse impact of pollution from AFOs will be reduced in proportion to modeled reductions in fecal coliform pollution attributable to AFOs. The details of this approach are described below.

- First, EPA assigns each coastal state included in the shellfish analysis to one of the 18 hydroregions that EPA's water quality model evaluates. In all but one case, the entire coastline of each state falls within a single hydroregion. The sole exception, Virginia, was assigned to the hydroregion that encompasses the majority of its coastline.

- Next, for each hydroregion/state, EPA calculates the percentage reduction in fecal coliform counts predicted under each regulatory scenario.[53]

- Third, EPA multiplies its estimates of the percentage reduction in fecal coliform counts attributable to AFOs by its previously developed estimates of the impact of pollution from AFOs and/or agricultural runoff on shellfish harvests (Q_A). This calculation was performed separately for each species and state. The result, Q_R, represents the incremental increase in harvest associated with each regulatory alternative.

Adding Q_R to baseline harvests (Q_0) yields an estimate of annual shellfish harvests following implementation of revised CAFO regulations (Q_1). This calculation is performed for each state and species. Thus:

$$Q_{1(n,j)} = Q_{0(n,j)} + Q_{R(n,j)}$$

6.2.4 Valuation of Predicted Change in Shellfish Harvests

The appropriate measure of the economic benefits of an increase in commercial shellfish harvests is the welfare gain (i.e., the change in producer and consumer surplus) associated with the increased harvest. For purposes of this analysis, EPA focuses solely on changes in consumer surplus.[54] This focus is necessary because the information required to evaluate any changes in producer surplus that might result from an increase in shellfish harvests (i.e., a long-run supply curve for each species harvested) is difficult to obtain. In addition, the shellfish harvesting industry is to a significant extent characterized by regulated harvest levels and unregulated harvester effort (i.e., open access fisheries).[55] Generally accepted natural resource economics theory suggests that, in open access fisheries, overcapitalization leads to zero producer surplus. Thus, although shellfish harvesting is not entirely open access, any producer surplus in the industry is likely to be small, and any changes in producer surplus brought about by new CAFO regulations is likely to be minor.

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[53] Regional estimates of changes in fecal coliform counts are only available for NPDES Scenarios 1, 2/3, and 4b. For purposes of characterizing changes in fecal coliform counts under NPDES Scenario 4a, EPA employs the estimated percentage reduction nationwide.

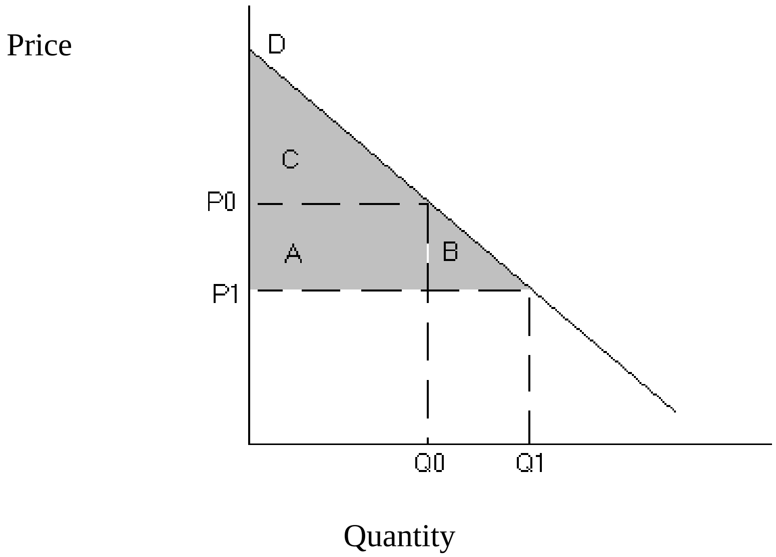
[54] As discussed in Chapter 3, the concept of consumer surplus is based on the principle that some consumers benefit at current prices because they are able to purchase a good at a price that is less than the amount they are willing to pay.

[55] Anecdotal evidence suggests that some shellfishing areas are leased by municipalities to individual enterprises with sole rights to harvest the area. In these cases, the limits on competition could lead to positive producer surplus. The extent of this practice, however, is unclear.

To calculate the change in consumer surplus associated with an increase in commercial shellfish harvests, the analysis makes use of information on consumer demand. Exhibit 6-4 illustrates a simple demand curve. The demand curve is the downward sloping solid line labeled D, and the initial quantity sold is the dashed, vertical line at Q_0. The intersection of these two lines gives the price at which quantity Q_0 is sold. This price is marked as P_0 and represented by the dashed horizontal line. The consumer surplus for quantity Q_0 is the area below the demand curve and above the horizontal line at P_0. That is, the consumer surplus for Q_0 is the area labeled "C" in Exhibit 6-4.

Exhibit 6-4

CONSUMER DEMAND AND CONSUMER SURPLUS



The measurement of the benefits of revised CAFO regulations relies on the assumption that a decrease in the contamination of shellfish-growing waters would increase commercial access to shellfish beds, and thus increase the quantity of shellfish supplied to consumers (i.e., an increase from Q_0 to Q_1). This in turn would result in a lower market price for shellfish (i.e., P_1). The benefit to consumers can be determined based on the old and new prices and quantities. Before the change, the area labeled "C" in Exhibit 6-4 measures consumer surplus. After the change, consumer surplus is measured by the area of A+B+C. Thus, the difference in consumer surplus between these scenarios (i.e., Area A + Area B) is the additional consumer surplus attributable to the proposed rule and the appropriate economic measure of benefits to consumers.

6.2.4.1 Characterization of Consumer Demand for Shellfish

Analysis of the changes in consumer surplus that might result from an increase in shellfish harvests requires an understanding of the effect of an increased harvest on market prices. To gather the necessary information, EPA reviewed the economics literature. This review identified a number of relevant studies: Lipton and Strand (1992), which estimates a demand equation for surf clams and ocean quahogs on the East Coast; Wessells et al. (1995), which estimates a demand equation for U.S. harvested mussels in Montreal; Cheng and Capps, Jr. (1988), which estimates demand equations for oysters and total shellfish in the U.S.; and Capps, Jr. and Lambregts (1991), which estimates demand equations for scallops and oysters in Houston, Texas. Exhibit 6-5 lists the demand elasticities obtained from each of these studies.[56] These demand elasticities provide the means to determine the consumer benefits associated with changes in shellfish harvests.

Exhibit 6-5

SHELLFISH DEMAND ELASTICITIES

Citation	Species	Elasticity
Cheng and Capps	oysters	-1.132
Cheng and Capps	total shellfish	-0.885
Capps and Lambregts	oysters	not significant
Capps and Lambregts	scallops	-1.84
Wessells et al.	mussels	-1.98
Lipton and Strand	surf clams	-2
Lipton and Strand	ocean quahogs	-0.87

6.2.4.2 Determining the Change in Consumer Surplus Associated with Increased Harvests

EPA's analysis of the benefits of an increase in shellfish harvests begins by estimating prices and quantities (i.e., P_0 and Q_0) under baseline conditions, as well as the quantity of shellfish EPA estimates would be harvested following the implementation of new CAFO regulations (Q_1). Consistent with the analysis of shellfish harvests described above, Q_0 for each state and species is based on NMFS data, and specified as the mean annual harvest for the years 1994 through 1998. P_0 is calculated by dividing the total reported revenues from 1994 through 1998 for each species and state, adjusted to 1999 dollars, by the total quantity harvested.[57] Q_1 is determined as described above,

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[56] The price elasticity of demand represents the percentage change in demand for a good brought about by a one percent change in its price; thus, a price elasticity of -2 implies that a one percent increase in price will result in a two percent decrease in demand.

[57] EPA adjusts reported revenues to 1999 dollars using the Consumer Price Index. For purposes of calculating P_0, EPA considers only those years for which harvest and revenue data are available.

adding to Q_0 the increase in shellfish harvests estimated to occur under each regulatory scenario (Q_R). EPA determined the value of these factors for each broad category of shellfish for which NMFS data are available: scallops, oysters, mussels, and clams. When the data allow, EPA developed separate values for quahogs, surf clams, and other clams. This approach enables the analysis to take advantage, whenever possible, of the demand equations identified for the quahog and surf clam subcategories.[58]

Once P_0, Q_0, and Q_1 are estimated, the appropriate price elasticities of demand are applied to determine the new price (P_1) associated with an increase in shellfish harvests. For purposes of this analysis, the percentage change in price is determined by dividing the percentage increase in the quantity of shellfish supplied in each case by the appropriate price elasticity. This percentage change is then applied to the initial price (P_0) to calculate the new price (P_1) for each species harvested.[59]

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[58] The analysis employs the Wessells et al. demand elasticity for mussels and the Capps and Lambregts demand elasticity for scallops for all states in which these species are harvested. When disaggregated data on surf clam or quahog harvests are available, the analysis relies on the demand elasticities for these species developed by Lipton and Strand; in all other instances, demand for clams is analyzed using the total shellfish price elasticity estimated by Cheng and Capps. For oysters, the analysis relies upon the demand elasticity estimated by Cheng and Capps; this value was selected because it was based on evaluation of a broader market than that considered by Capps and Lambregts.

[59] Mathematically, the price elasticity of demand (Θ) is calculated as:

$$\Theta = MQ/MP$$

where:

$$MQ = (Q_1 - Q_0)/Q_0$$
$$MP = (P_1 - P_0)/P_0$$

therefore:

$$MP = MQ/\Theta$$
$$P_1 = (Q_1 - Q_0)(P_0)/[(\Theta)(Q_0)] + P_0$$

EPA employs the estimated values for P_0, P_1, Q_0 and Q_1 to measure the increase in consumer surplus associated with the projected increase in shellfish harvested and resulting reduction in market price under each regulatory scenario. This calculation is conducted for every state and species category. The estimated annual benefit under each regulatory scenario is simply the sum of the estimated increase in consumer surplus across states and species.[60]

6.3 RESULTS

Exhibit 6-6 summarizes the estimated economic benefits associated with increased shellfish harvests under each regulatory scenario evaluated. The exhibit presents two cases: Case 1, which considers beneficial impacts on shellfish growing waters that the Shellfish Register specifically identifies as impaired by pollution from AFOs; and Case 2, which expands the analysis to consider beneficial impacts on shellfish growing waters identified as impaired by pollution from AFOs and/or agricultural runoff. As the exhibit indicates, EPA's estimates of annual benefits under Case 2 are more than an order of magnitude greater than under Case 1; this range reflects the significant increase in the number and area of shellfish growing waters considered to be impaired by AFOs when runoff from agricultural land, as opposed to pollution specifically attributed to AFOs, is included in the analysis. For the proposed scenarios, the estimate of annual benefits ranges from approximately $195 thousand under Case 1 to $2.7 million under Case 2. Within each case, the range of annual benefits across regulatory scenarios is relatively small: from $146 thousand to $245 thousand under Case 1, and from $1.8 million to $3.0 million under Case 2. In both cases, Option 1/Scenario 1 provides the lowest benefits, while Option 2/Scenario 4b provides the highest.

Exhibit 6-6

ESTIMATED ANNUAL BENEFITS OF INCREASED COMMERCIAL SHELLFISH HARVESTS (1999 $, thousands)

Regulatory Scenario	Case 1: AFOs	Case 2: AFOs and Agricultural Runoff
Option 1/Scenario 1	$146	$1,816
Option 1/Scenario 2/3	$198	$2,357
Option 1/Scenario 4a	$178	$2,204
Option 1/Scenario 4b	$221	$2,564
Option 2/Scenario 1	$165	$2,141
Option 2/Scenario 2/3*	$219	$2,717
Option 2/Scenario 4a*	$195	$2,417
Option 2/Scenario 4b	$245	$2,960

* Proposed scenarios

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[60] The calculation of increased consumer surplus is based on a simple geometric approximation of the change in areas under the demand curve, rather than formal integration using calculus. As a result, the estimated increase in consumer surplus may be slightly overstated.

6.4 LIMITATIONS AND CAVEATS

The analysis set forth above is subject to a number of uncertainties and relies upon several simplifying assumptions. These factors may lead to a potential under- or over-estimation of the benefits of decreasing AFO-related contamination of commercial shellfish growing waters. The most significant of these limitations are described below.

- The analysis assumes that a reduction in pollution from AFOs will result in an increase in commercial shellfish harvests. While this assumption appears reasonable in light of the extent to which AFOs contribute to current restrictions or prohibitions on shellfish harvesting, the actual impact of these restrictions or prohibitions on annual shellfish landings is unknown.

- To estimate the potential impact of pollution on annual shellfish landings, the analysis calculates an average annual yield (pounds per acre) for shellfish growing waters. The calculation of this figure assumes that current harvests are obtained from waters classified as approved or conditionally approved. To the extent that this approach over- or understates the increase in annual yields that might be realized from waters currently subject to harvest restrictions or prohibitions, the analysis may either over- or understate the impact of pollution on annual shellfish landings.

- The actual contribution of AFOs to the impairment of shellfish growing waters is unclear. In light of ambiguities in the data and uncertainties associated with the impact of pollution from other sources, the analysis considers two cases and employs subjectively developed weighting factors to characterize the impact of pollution from AFOs on shellfish harvests. The degree of judgment required in the analysis and the broad range of results across the cases analyzed suggests considerable uncertainty concerning the impact of pollution from AFOs.

- Similarly, in characterizing the impact of alternate regulatory scenarios, the analysis assumes that the adverse impact of pollution from AFOs (i.e., the foregone harvest) will be reduced in proportion to modeled reductions in fecal coliform pollution. While this approach may provide a reasonable approximation of the relative impacts of alternate CAFO regulations, it is less reliable than detailed modeling of pathogen concentrations in shellfish-growing areas. The nature and magnitude of any bias introduced by reliance on this approach is unclear.

- The analysis relies on estimates of the price elasticity of demand for shellfish that are not necessarily representative of current conditions or of conditions nationwide. The nature and magnitude of any bias introduced by reliance on these estimates, however, is unclear.

6.5 REFERENCES

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REDUCED CONTAMINATION OF PRIVATE WELLS CHAPTER 7

7.1 INTRODUCTION

CAFOs can contaminate aquifers and thus impose health risks and welfare losses on those who rely on groundwater for drinking water or other uses. Of particular concern are nitrogen and other animal waste-related contaminants (which come from manure and liquid wastes) that leach through soils and ultimately reach groundwater. Nitrogen loadings convert to elevated nitrate concentrations at household and community system wells, and elevated nitrate levels in turn pose a risk to human health.

The federal health-based National Primary Drinking Water Standard for nitrate is 10 mg/L. This Maximum Contaminant Level (MCL) applies to all Community Water Supply systems, but not to households that rely on private wells. As a result, households served by private wells are at risk to exposure to nitrate concentrations above 10 mg/L, which EPA considers unsafe for sensitive subpopulations (e.g., infants). Nitrate above concentrations of 10 mg/L can cause methemoglobinemia ("blue baby syndrome") in bottle-fed infants (National Research Council, 1997), which causes a blue-gray skin color, irritableness or lethargy, and potentially long-term developmental or neurological effects. Generally, once nitrate intake levels are reduced, symptoms abate. If the condition is untreated, however, methemoglobinemia can be fatal.[61]

The most recent U.S. Census data show that approximately 13.5 million households located in counties with AFOs are served by domestic wells. A number of sources provide information on the percentage of such wells with nitrate concentrations in excess of 10 mg/L. As indicated in Exhibit 7-1, the values reported vary widely, depending on the location studied, local hydrology, and other factors. According to the nationwide USGS Retrospective Database, however, the concentration of nitrate in 9.5 percent of domestic wells in the U.S. exceeds the 10 mg/L threshold. Thus, EPA estimates that approximately 1.3 million households in counties with AFOs are served by domestic wells with nitrate concentrations above 10 mg/L.

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[61] No other health impacts are consistently attributed to elevated nitrate concentrations in drinking water. As discussed in Chapter 2, however, other health effects are suspected.

Exhibit 7-1

PERCENTAGE OF WELLS EXCEEDING THE MCL FOR NITRATE

Study	Location	Type of Well	Percent Exceeding 10 mg/L
CDC, 1998	Illinois, Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, South Dakota, Wisconsin	Domestic	13.4%
Agriculture Canada, 1991 (as cited by Giraldez and Fox, 1995)	Ontario	Domestic farm	13%
Kross et al., 1993	Iowa	Rural	18%
Retrospective Database (USGS)	National	Domestic	9.5%
Richards et al., 1996	Indiana, Kentucky, Ohio, West Virginia	Rural	3.4%
Spalding and Exner, 1993	Iowa, Kansas, Nebraska, North Carolina, Ohio, Texas	Rural	20%, 20%, 20%, 3.2%, 2.7%, 8.2%, respectively
Swistock et al., 1993	Pennsylvania	Private	9%
U.S. EPA, 1990	National	Rural domestic	2.4%
USGS, 1985	Upper Conestoga River Basin	Rural	40+%
USGS, 1998	Nemaha Natural Resources District, Nebraska	Rural	10%
Vitosh, 1985 (cited in Walker and Hoehn, 1990)	Southern Michigan	Rural	34%

EPA's proposed revisions to the NPDES regulation and effluent guidelines would affect the number and type of facilities subject to regulation as CAFOs, and would also introduce new requirements governing the land application of manure. As a result, EPA anticipates that its regulatory proposal will reduce nitrate levels in household wells. In light of clear empirical evidence from the economics literature that households are willing to pay to reduce nitrate concentrations in their water supplies -- especially to reduce concentrations below the MCL — the anticipated improvement in the quality of water drawn from private domestic wells represents a clear economic benefit. This chapter estimates these benefits for each of the eight regulatory scenarios evaluated.

7.2 ANALYTIC APPROACH

Exhibit 7-2 provides an overview of EPA's approach to estimating the benefits of well nitrate reductions. As the exhibit indicates, the analysis begins by developing a statistical model of the relationship between nitrate concentrations in private domestic wells and a number of variables found to affect nitrate levels, including nitrogen loadings from AFOs. It then applies this model, in combination with the projected change in nitrogen loadings from CAFOs under each regulatory scenario, to characterize the distribution of expected changes in well nitrate concentrations. Next, the analysis applies this distribution to the number of households served by private domestic wells to calculate (1) the increase in the number of households served by wells with nitrate concentrations that are below the MCL and (2) the marginal change in nitrate concentrations for households currently served by wells with nitrate concentrations below the MCL. Finally, the analysis employs estimates of households' values for reducing well nitrate concentrations to develop a profile of the economic benefits of anticipated improvements in well water quality. Additional detail on EPA's analytic approach is provided below.

7.2.1 Relationship Between Well Nitrate Concentrations and Nitrogen Loadings

EPA's approach begins with the use of regression analysis to develop a model characterizing the empirical relationship between well nitrate concentrations and a number of variables that may affect nitrate levels, including nitrogen loadings from AFOs. The variables included in the model are based on a review of hydrogeological studies that have observed statistical relationships between groundwater nitrate concentrations and various other hydrogeological and land use factors. The following discussion describes the variables included in EPA's model and the sources of data for each variable. It also notes potentially significant variables that the model does not include. Appendix 7-A and Appendix 7-B provide additional detail on the model's development.

7.2.1.1 Included Variables and Data Sources

Although the groundwater monitoring and modeling studies that EPA reviewed covered different geographic areas and focused on varying nitrate sources (e.g., septic systems, agricultural fertilizers, animal feedlots), they often found similar variables to be significant. In particular, nitrogen application or loadings rates, whether from animal wastes, private septic systems, or agricultural fertilizers, were the most consistent and significant factor affecting well nitrate levels (e.g., Burrow, 1998; CDC, 1998).[62] EPA's model includes variables characterizing nitrogen loadings from each of these sources:

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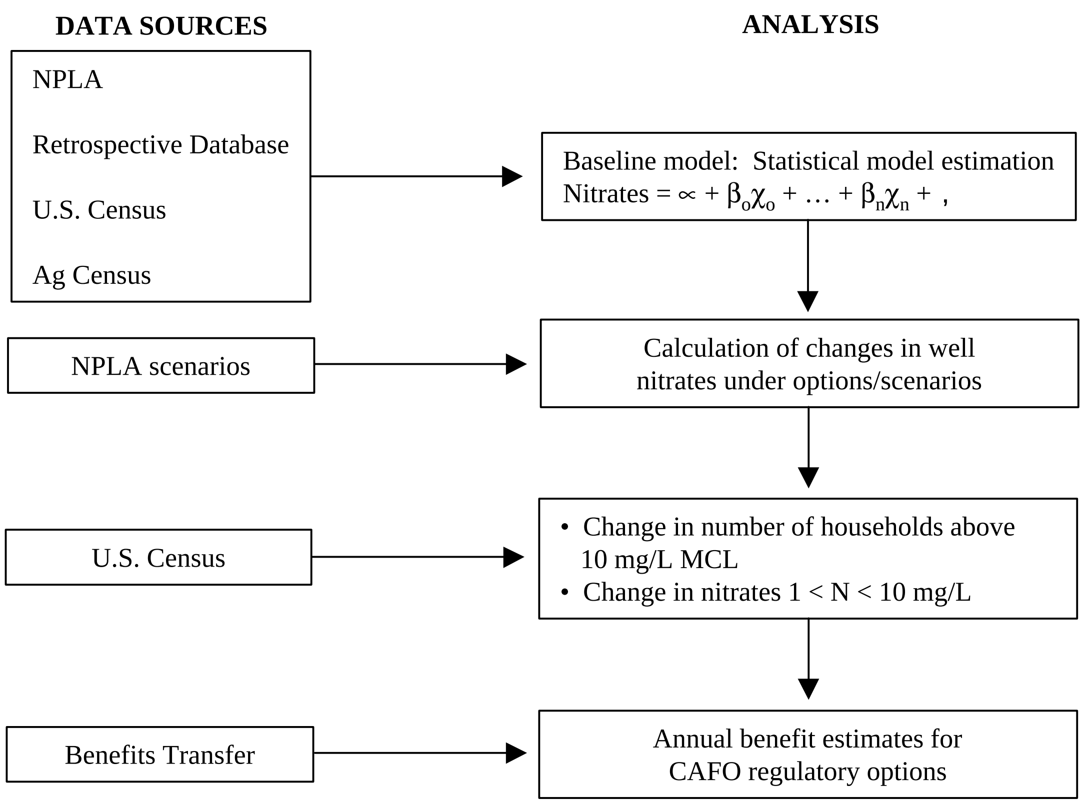
[62] Citations provided here and in Section 7.2.1.2 are suggestive of the literature on these issues. A more comprehensive review of the literature is provided in Attachment B.

Exhibit 7-2

OVERVIEW OF ANALYTIC APPROACH



- *AFOs* — Studies that addressed the effect of animal manure production on groundwater nitrate concentrations found a positive correlation between these variables (e.g., Ritter and Chirnside, 1990; Division of Water Quality, Groundwater Section, 1998). EPA's model therefore includes a variable that characterizes nitrogen loadings from AFOs. EPA obtained data on these loadings, aggregated at the county level, from the National Pollutants Loadings Analysis (Tetra Tech, 2000).

- *Septic Systems* — Several studies found that the proximity of septic systems to wells is a small, but significant, contributing factor to elevated nitrate concentrations (e.g., Carleton, 1996; Richards et al., 1996). As a proxy measure for loadings from septic systems, EPA's model includes a variable characterizing the use of private septic systems in each county. Information on septic system use was drawn from the 1990 U.S. Census.

- *Other Sources* — Several studies found that the type of crop cultivated in the vicinity of wells significantly influences well nitrate levels, reflecting variation in the crops' nutrient and water needs and suggesting that agricultural fertilizers are a significant source of nitrogen to groundwater (e.g., Swistock et al., 1993; Lichtenberg and Shapiro, 1997). EPA obtained data on nitrogen loadings associated with agricultural fertilizers and other sources (e.g., atmospheric deposition) from the USGS Retrospective Database (1996).

In addition to variables characterizing nitrogen loadings, EPA's model includes the following variables describing well, soil, and land use characteristics found to significantly influence well nitrate concentrations:

- *Well Depth* -- Several studies found well depth to be a significant variable, inversely correlated with well nitrate concentrations, regardless of nitrate source (e.g., Detroy, 1988; Ham et al., 1998).

- *Soil Group:* A number of studies identified at least one hydrogeological characteristic, such as aquifer composition and soil type, as a significant factor affecting well nitrate concentrations (e.g., Lichtenberg and Shapiro, 1997; Lindsey, 1997).

- *Land Use:* Agricultural land use in the vicinity of wells was found to be associated with higher groundwater nitrate in several studies (e.g., Mueller et al., 1995; Carleton, 1996).

For purposes of model development, EPA obtained data on these variables from the USGS Retrospective Database.

7.2.1.2 Omitted Variables

Because of incomplete or unreliable national data, EPA's model does not include all of the potentially significant variables the literature identifies. For example, several studies cite well construction and age as significant variables with respect to well nitrate concentrations (e.g., Spalding and Exner, 1993; Swistock et al., 1993). In general, older wells are more vulnerable to nitrate contamination because their casings are more likely to be cracked, allowing surface contaminants to enter the well. Different construction materials and methods also affect how easily nitrate or other pollutants can reach groundwater via direct contamination at the wellhead. Data on this variable, however, are often unreliable because they are generally obtained by surveying well owners and relying on their subjective assessment of when and how a well was constructed; no reliable, nationally comprehensive data on well construction are available.

Several studies also found the distance from a pollutant source to the well to be significantly correlated with well nitrate concentrations (e.g., Swistock et al., 1993; Division of Water Quality, Groundwater Section, 1998). Although spatial data for well locations are available, data on the location of animal feedlots, cropland, and septic systems are not; therefore, the model excludes this variable.

7.2.2 Modeling of Well Nitrate Concentrations Under Alternate Regulatory Scenarios

To estimate the impact of selected variables on well nitrate concentrations, EPA compiled a database of 2,928 records. Each record provides information characterizing a different well, including the observed well nitrate concentration; well depth, soil, and land use information; data on baseline nitrogen loadings from AFOs; and data characterizing nitrogen loadings from septic systems, agricultural fertilizer, and other sources. EPA developed its regression model on the basis of this database.

After estimating the regression model using baseline loading information, EPA estimated expected values for well nitrate concentrations, both for the baseline and for each of the eight alternative regulatory scenarios. The calculation of expected values under each scenario employed data on AFO nitrogen loadings obtained from the National Pollutants Loadings Analysis (Tetra Tech, 2000); these loadings vary across the regulatory scenarios, reflecting different manure application rates, manure management practices, and other factors.[63] To examine the impact of alternate regulatory scenarios on well nitrate concentrations, the AFO loadings variable is the only independent variable that changes value; the values for all other variables are held constant. Exhibit 7-3 summarizes the expected percentage changes in well nitrate concentrations under each scenario.[64]

Exhibit 7-3

PERCENT REDUCTION IN PROJECTED NITRATE CONCENTRATIONS

	Projected Nitrate Concentration (mg/L)	
Regulatory Scenario	**Mean Percent Reduction**	**Median Percent Reduction**
Option 1 — Scenario 1	3.0	0.8
Option 1 — Scenario 2/3	3.2	0.8
Option 1 — Scenario 4a	3.7	0.8
Option 1 — Scenario 4b	3.7	0.8
Option 2 — Scenario 1	3.5	0.8
Option 2 — Scenario 2/3*	3.7	0.8
Option 2 — Scenario 4a*	4.3	0.9
Option 2 — Scenario 4b	4.3	0.9

*Proposed scenarios

7.2.3 Discrete Changes from above the MCL to below the MCL

As noted above, the most recent U.S. Census data show that approximately 13.5 million households located in counties with AFOs are served by domestic wells. The USGS Retrospective Database indicates that the concentration of nitrate in 9.47 percent of U.S. domestic wells exceeds 10 mg/L. Thus, under the baseline scenario, EPA estimates that approximately 1.3 million households in counties with AFOs are served by domestic wells with nitrate concentrations above 10 mg/L.

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[63] For additional information on the development of pollutant loadings estimates under alternate regulatory scenarios, see Chapter 4.

[64] Testing of EPA's model indicates that it underestimates well nitrate concentrations (see Attachment B). As a result, comparing predicted values under alternate regulatory scenarios to observed baseline values would bias the analysis. To avoid this bias, EPA compares the well nitrate concentrations the model predicts under each regulatory scenario to the values it predicts under baseline conditions. The benefits assessment is based on the resulting projected percentage changes in expected well nitrate concentrations.

To estimate the impact of alternative CAFO standards on the number of wells that would exceed the nitrate MCL, EPA applied the mean percentage reduction in nitrate concentrations predicted under each regulatory scenario to the nitrate concentration values that the USGS Retrospective Database reports. Based on the resulting values, EPA calculated the percentage reduction in the number of wells with nitrate concentrations exceeding 10 mg/L. As shown in Exhibit 7-4, it then applied these values to EPA's baseline estimate of the number of households in counties with AFOs that are served by domestic wells with nitrate concentrations above 10 mg/L. Based on this analysis, EPA estimates that the regulatory scenarios evaluated would bring between 152,000 and 166,000 households under the 10 mg/L nitrate threshold.

Exhibit 7-4

EXPECTED REDUCTIONS IN NUMBER OF HOUSEHOLDS WITH WELL NITRATE CONCENTRATIONS ABOVE 10 mg/L

Regulatory Scenario	Percentage of Wells above MCL at Baseline Expected to Achieve MCL under Option/Scenario	Reduction in Number of Households above the MCL
Option 1 — Scenario 1	11.9%	152,204
Option 1 — Scenario 2/3	11.9%	152,204
Option 1 — Scenario 4a	12.6%	161,384
Option 1 — Scenario 4b	12.6%	161,384
Option 2 — Scenario 1	12.6%	161,384
Option 2 — Scenario 2/3*	12.6%	161,384
Option 2 — Scenario 4a*	13.0%	165,974
Option 2 — Scenario 4b	13.0%	165,974

* Proposed scenarios

7.2.4 Incremental Changes below the MCL

Households currently served by wells with nitrate concentrations below the 10 mg/L level may also benefit from marginal reductions in nitrate concentrations. For purposes of this analysis, EPA assumes that such incremental benefits would be realized only for wells with baseline nitrate concentrations between 1 and 10 mg/L; presumably, an individual would not benefit if nitrate concentrations were reduced to below background levels, which for purposes of this analysis are assumed to be 1 mg/L.[65] Exhibit 7-5 shows, for each regulatory scenario, EPA's estimate of the

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[65] EPA's analysis also ignores marginal reductions in nitrate concentrations for wells that would remain above the MCL. The Agency's review of the economics literature failed to identify studies that would provide an adequate basis for valuing such changes.

mean and median reduction in nitrate concentrations for wells with baseline values between 1 and 10 mg/L. The exhibit also indicates for these wells the aggregate expected reduction in nitrate levels, expressed in mg/L.[66] EPA estimates that approximately 600,000 households would benefit from these marginal reductions.

Exhibit 7-5

MEAN AND MEDIAN REDUCTIONS IN NITRATE CONCENTRATIONS FOR WELLS WITH CONCENTRATIONS BETWEEN 1 AND 10 mg/L AT BASELINE

Regulatory Scenario	Mean Nitrate Reduction (mg/L)	Median Nitrate Reduction (mg/L)	Total Expected National Nitrate Reduction (mg/L)
Option 1 — Scenario 1	0.16	0.12	961,741
Option 1 — Scenario 2/3	0.16	0.12	1,007,611
Option 1 — Scenario 4a	0.19	0.15	1,186,423
Option 1 — Scenario 4b	0.19	0.15	1,186,423
Option 2 — Scenario 1	0.18	0.14	1,103,166
Option 2 — Scenario 2/3*	0.19	0.15	1,159,907
Option 1 — Scenario 4a*	0.22	0.18	1,374,990
Option 2 — Scenario 4b	0.22	0.18	1,374,990

* Proposed scenarios

7.2.5 Valuation of Predicted Reductions in Well Nitrate Concentrations

EPA's analysis relies upon a benefits transfer approach to value predicted reductions in well nitrate concentrations. EPA used three general steps to identify and apply values for benefits transfer:

(1) A literature search to identify potentially applicable primary studies.

(2) Evaluation of the validity and reliability of the studies identified. Primary evaluation criteria included:

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[66] The information reported in Exhibit 7-5 pertains only to wells with baseline nitrate concentrations below the MCL. Information for wells with baseline nitrate concentrations above the MCL is not included, since the benefits associated with reducing nitrate concentrations in these wells to below the MCL are potentially captured in valuing the achievement of safe nitrate concentrations.

- the relevance (applicability) of the commodity being valued in the original studies to the policy options being considered for CAFOs; and

- the robustness (quality) of the original study, evaluated on multiple criteria such as sample size, response rates, significance of findings in statistical analysis, etc.

(3) Selection and adjustment of values for application to CAFO impacts.

Appendix 7-C provides detailed information on EPA's literature search and the criteria applied to evaluate and select the studies employed in the benefits assessment.

Through its review and evaluation of the relevant literature, EPA selected three studies to provide the primary values used for the benefit transfer:

- A study by Poe and Bishop (1992), which the analysis employs to value changes in well nitrate concentrations from above the MCL to below the MCL.

- A study by Crutchfield et al. (1997), which EPA employs to value marginal changes in nitrate concentrations below the MCL.

- A study by De Zoysa (1995), which EPA employs to value marginal changes in nitrate concentrations below the MCL.

The discussion below briefly summarizes these studies. Additional information is provided in Exhibit 7-6.

Exhibit 7-6

SUMMARY INFORMATION ON STUDIES USED FOR BENEFITS TRANSFER

Study Reference	Poe and Bishop	Crutchfield et al.	De Zoysa
Year of Analysis	1992	1997	1995
Place	Portage County, WI	IN, Central NE, PA, WA	Maumee River Basin, northwest Ohio
Household Water Supply/ Groundwater Use	100% on private wells	IN 73%; NE 31%; PA 47%; WA 26% non-municipal	Not specified
Groundwater Baseline Scenarios	An increase in the number of wells in Portage County with nitrate contamination	None given	Typical N concentrations range from 0.5-3 mg/L, although some are much higher
Change in Groundwater Scenario	Groundwater protection program to keep nitrate levels below EPA standards	If tap water has 50% greater N levels than EPA's MCL, how much to reduce to min. safety standards; how much to eliminate	Reduce levels to 0.5-1 mg/L
Source of Contaminants	Agricultural activities	Not specified	Agricultural fertilizer
Types of Values Estimated	Option price (use value)	Total value	Total value
Duration of Payment Vehicle	Annually, for as long as respondent lives in the county	Monthly, in perpetuity	One time
Mean HH WTP in 1999 Dollars	$412.00 (25% reduction in nitrates to safe level) $484.00 (households with 100% probability of future contamination)	$21.72 to reduce from 10 mg/L to 0 mg/L ($2.17 per mg/L)	$59.33 (lower bound mean) $1.78 per mg/L (using 3% discount rate)

7.2.5.1 Poe and Bishop (1992)

Poe and Bishop (1992, 1999) and Poe (1993) report on the results of a contingent valuation study conducted in rural Portage County, Wisconsin, to estimate the conditional incremental benefits of reducing nitrate levels in household wells. The area has had extensive nitrate problems, and previous research suggested that 18 percent of private wells in the area exceeded the MCL. The survey comprised two stages. In the first stage, individuals were asked to submit water samples from their tap and to complete an initial questionnaire. In the second stage, individuals were provided with their nitrate test results, general information about nitrates, and a graphical depiction of their exposure levels relative to both natural levels and the MCL; they then were asked to respond to contingent valuation questions (*ex post*).

The respondents' willingness-to-pay values varied, as expected, in accordance with the results of their wells' nitrate tests and other information provided to them. Poe (1993) reports that households' whose wells were considered certain at some point in the future to exceed the nitrate MCL would be willing to pay, on average, \$484 per year for a program to keep all wells in Portage County at or below the MCL. Poe and Bishop (1999) expand on the results of the survey by developing a non-linear valuation function that characterizes how household willingness to pay for a 25 percent reduction in well nitrate concentrations varies with the initial extent of nitrate contamination. Their analysis shows that household willingness to pay for such a program increases as baseline well nitrate concentrations increase from 2 mg/L to 14.5 mg/L, then declines to zero at a baseline concentration of approximately 22.5 mg/L. Based on their valuation function, Poe and Bishop estimate that households would be willing to pay an average of \$412 per year for a 25 percent reduction from a baseline nitrate contamination level of 14.5 mg/L. Since such a change would reduce nitrate concentrations to very near the MCL, EPA considers it representative of household willingness to pay to reduce such concentrations to safe levels. Taking the mid-point of the \$484 and \$412 values reported by Poe (1993) and Poe and Bishop (1999), respectively, EPA estimates that households whose wells exceed the nitrate MCL would be willing to pay \$448 per year to reduce nitrate concentrations to safe levels.

The reliability of these results appears to be reasonably high because the contingent valuation (CV) instrument was developed and implemented with careful attention to detail and established CV research protocol. A potential limitation is that the study is based on a relatively small sample size (480 households); however, good response rates were obtained from this sample (approximately 80 percent for the first stage and 64 percent for the *ex post* stage). The Poe and Bishop study is the only study EPA reviewed that elicited such informed *ex post* values. These value statements may be considered more reliable than others because respondents knew more about the condition of their own water supply and thus were able to make better informed decisions. Moreover, in comparison to the other studies evaluated, the value estimates from this study seemed to represent a conservative lower bound on households' values for reducing nitrates to the MCL.

7.2.5.2 Crutchfield et al. (1997)

Crutchfield et al. (1997) evaluated the potential benefits of reducing or eliminating nitrates in drinking water by estimating average willingness to pay for safer drinking water. They surveyed 800 people in rural and non-rural areas in four regions of the United States (Indiana, Nebraska, Pennsylvania, Washington), using the contingent valuation method (CVM) and posing questions in a dichotomous choice format. Respondents were specifically asked what their willingness to pay would be to have the nitrate levels in their drinking water (a) reduced to “safe levels,” and (b) completely eliminated. Respondents were told that this would be accomplished using a filter installed at their tap, and the cost would be included in their monthly water bill. Respondents were also asked questions regarding sociodemographic characteristics such as income, age, education, and whether they currently use treated or bottled water. Across all regions, the resulting willingness to pay, per household, to reduce nitrates to safe levels ranged from \$45.42 per month to \$60.76 per month, with a mean of $52.89. The willingness to pay to completely remove nitrates from drinking water ranged from $48.26 per month to $65.11 per month, with a mean of $54.50. The study found two variables to be significantly related to a respondent's willingness to pay: "years lived in ZIP code," which was positively correlated with willingness to pay, and "age of respondent," which was negatively correlated.

7.2.5.3 De Zoysa (1995)

De Zoysa (1995) applied the contingent valuation method to evaluate the benefits of a number of programs to enhance environmental quality in Ohio's Maumee River basin, including a program to stabilize and reduce groundwater nitrate levels. The study solicited willingness-to-pay values from residents of both rural and urban areas in the river basin, as well as residents of one out-of-basin urban area. A portion of respondents were asked whether they would pay different amounts, via a one-time special tax, to reduce nitrate contamination from fertilizer applied to fields. Under the hypothetical scenarios, nitrate concentrations would be reduced from the current range of 0.5-3.0 mg/L to a range of 0.5-1.0 mg/L. Individuals were also asked questions regarding sociodemographic characteristics, preferences for priorities for public spending, and how they used the resource in question. Based on the lower bound of the mean values reported, the study found an average one-time household willingness to pay of $52.78 for a 1 mg/L reduction in groundwater nitrate concentrations. The study also found that income, the level of priority placed on groundwater protection, and interest in increasing government spending on education, healthcare, and vocational training all were positively and significantly correlated with willingness to pay to improve groundwater quality.

7.2.5.4 Adjustments to the Values

EPA employs the results of the Crutchfield et al. and De Zoysa reports to estimate annual household willingness to pay to reduce well nitrate concentrations when those concentrations are already below the nitrate MCL. EPA derives the appropriate value from Crutchfield by comparing the reported monthly willingness-to-pay values for reducing nitrate concentrations from above the MCL to the MCL and from above the MCL to zero. The difference between these values is $1.61 per month. For a change between the MCL of 10 mg/L and 0 mg/L, this represents a per mg/L monthly willingness to pay of $0.16, or $1.92 annually (1997$). To derive a comparable annual value from De Zoysa, EPA annualizes the willingness to pay value obtained from that study (an average one-time household willingness to pay of $52.78 for a 1 mg/L reduction in groundwater nitrate concentrations) at an annual discount rate of 3 percent. This calculation yields an estimated annual household willingness to pay for a 1 mg/L reduction in nitrate concentrations of $1.58

(1995$). EPA applied the Consumer Price Index (CPI) to convert these values to 1999 dollars.[67] The Agency then applied the midpoint of the two values, $1.97 per mg/L per household per year, to value changes in well nitrate concentrations between 10 mg/L and 1 mg/L. Reductions in well nitrate concentrations below 1 mg/L are not valued, since EPA assumes a natural nitrate background level of 1 mg/L.

As noted above, EPA relies on the findings of Poe and Bishop to estimate that households whose wells exceed the nitrate MCL would be willing to pay $448 per year to reduce nitrate concentrations to safe levels. These values are expressed as willingness to pay per year as long as the individual lives in the county, and thus can be directly translated to the policy scenarios.

Exhibit 7-7 summarizes the point value estimates used for benefits transfer.

Exhibit 7-7

WILLINGNESS-TO-PAY VALUES APPLIED TO BENEFITS TRANSFER

Study	Value	1999$
Poe and Bishop	Annual WTP	$448.00
Average of Crutchfield et al. and De Zoysa	Annual WTP per mg/L between 10 mg/L and 1 mg/L.	$1.97

7.2.5.5 Timing of Benefits

It is unlikely that changes in CAFO regulations would immediately result in the changes in well nitrate concentrations that EPA's statistical model predicts. While hydrogeological conditions and other factors may vary significantly from case to case, considerable time may pass before most wells reach the steady state nitrate concentrations the model forecasts. Therefore, it is necessary to develop a time profile of the anticipated benefits of revised CAFO standards.

EPA estimates that approximately 75 percent of affected wells would realize the full benefits of reduced nitrogen loadings within 20 years (Hall, 1996). Assuming that the number of wells achieving new steady state conditions increases linearly over time, this translates to approximately 3.7 percent of wells achieving new steady state conditions each year. At this rate, all affected wells would achieve new steady state conditions in approximately 27 years. For purposes of characterizing the benefits of reduced contamination of private wells, EPA's analysis adopts these assumptions.

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[67] CPI-U Series ID CUUR0000SA0, not seasonally adjusted, U.S. city average, all items.

7.3 RESULTS

Exhibit 7-8 illustrates the time profile of benefits for EPA's proposed revisions to the CAFO standards. As the exhibit shows, annual benefits increase from approximately \$3 million per year in the first year following implementation to between \$70 million and \$80 million annually in the twenty-seventh and subsequent years. The profile of benefits over time for all regulatory scenarios is similar, but in each case reaches a different steady-state level. Exhibit 7-9 summarizes the estimated annual benefits, once steady state conditions are achieved, for each of the regulatory scenarios evaluated. As the exhibit indicates, these benefits range from a low of approximately \$70 million per year, the estimate arrived at for Option 1-Scenario 1, to a high of approximately \$77 million per year, the estimate developed for both Option 2-Scenario 4a and Option 2 Scenario 4b.

7.4 LIMITATIONS AND CAVEATS

Omissions, biases, and uncertainties are inherent in any analysis relying on several different data sources, particularly those that were not developed specifically for that analysis. Exhibit 7-10 summarizes key omissions, uncertainties, and potential biases for this analysis.

Exhibit 7-8

ANNUAL BENEFITS OF REDUCING PRIVATE WELL CONTAMINATION

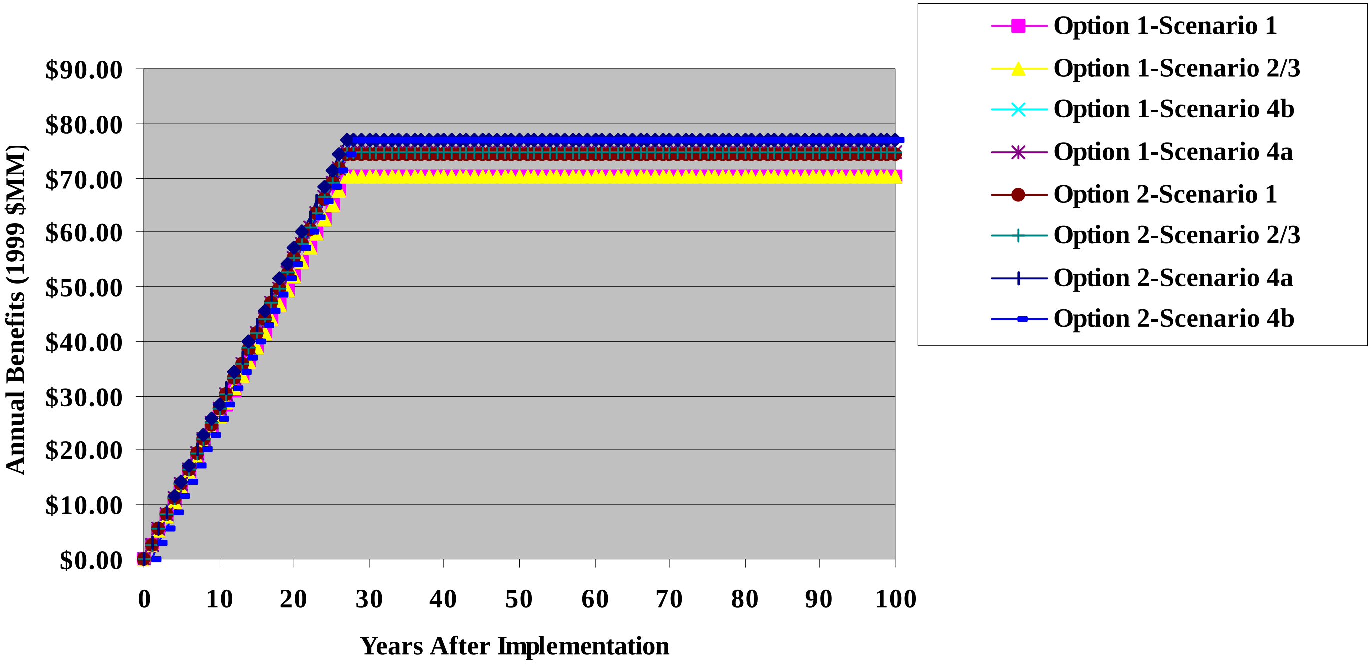

Exhibit 7-9

ESTIMATED ANNUAL BENEFITS OF REDUCED CONTAMINATION OF PRIVATE WELLS UNDER STEADY STATE CONDITIONS

($1999, millions)

Regulatory Scenario	Annual Benefits
Option 1-Scenario 1	$70.08
Option 1-Scenario 2/3	$70.17
Option 1-Scenario 4a	$74.64
Option 1-Scenario 4b	$74.64
Option 2-Scenario 1	$74.47
Option 2-Scenario 2/3*	$74.59
Option 2-Scenario 4a*	$77.07
Option 2-Scenario 4b	$77.07

* Proposed scenarios

Exhibit 7-10

OMISSIONS, BIASES, AND UNCERTAINTIES IN THE NITRATE LOADINGS ANALYSIS

Variable	Likely Impact on Net Benefit	Comment
Well, land, and nitrate data		
Geographic coverage	Unknown	Data availability limited the well samples used in the statistical modeling to those from 138 counties nationwide.
Well location selection	Positive	Wells sampled in the USGS Retrospective database may or may not be random. Samples may be focused on areas with problems with nitrate.
Year of sample	Unknown	Samples taken over 23 years. Land use and other factors influencing nitrate concentrations in the vicinity of the well may have changed over time.
Nitrate loadings from AFOs with 0-300AU	Positive	Data for the smallest AFOs were not included in this analysis because they will not be affected by the proposed regulations. This may subsequently underestimate total loadings, resulting in an overestimate of the impact of nitrogen loadings on well nitrate concentrations.
Percent of wells above 10 mg/L	Unknown	Based on the USGS Retrospective database, EPA assumes that 9.74 percent of wells currently exceed the MCL. If the true national percent is lower (higher), EPA's analysis overstates (understates) benefits.
Sampling methods	Unknown	Data set compiled from data collected by independent state programs, whose individual methods for measuring nitrate may differ.
Model Variables		
Well construction and age	Unknown	No reliable data available nationally.
Spatial data	Unknown	No national data available on the distance from well to pollutant source.
Benefit Calculations		
Per household value for reducing well nitrates to the MCL	Negative	The Poe and Bishop values generally appear to be a lower bound estimate of households' WTP for reducing nitrates to the MCL.
Years until wells achieve steady state.	Negative	The analysis assumes a linear path over 27 years until reduced nitrogen loadings would result in most wells achieving reduced nitrate concentrations. A large portion of wells (especially shallower wells) may achieve this on a much faster time path.
Values for marginal reductions below the MCL	Positive	If most of the benefits from reductions in nitrate concentrations below the MCL are related to a threshold effect or removing all human induced nitrates, then the assumption that benefits increase linearly with reductions in nitrate concentrations from 10 mg/L to 1 mg/L will overstate the benefits of marginal reductions.
Baseline characterization	Negative	Baseline well concentrations are based on observed levels that are in some cases more than 20 years old. These reflect AFO loadings from past decades that likely understate current loadings and, hence, underestimate anticipated well concentrations absent regulations.
Exclusion of values for reduced nitrate concentrations in wells that would remain above the MCL after the implementation of new regulations	Negative	Reductions in nitrate concentrations in wells that would remain above the MCL after the implementation of new regulations are not valued. The Agency's review of the economics literature failed to identify studies that would provide an adequate basis for valuing such changes.
Exclusion of values for marginal reductions in nitrate concentrations below the MCL, for wells with nitrate concentrations above the MCL at baseline and below the MCL after implementation of new regulations	Negative	The benefits of marginal changes in nitrate concentrations between 10 mg/L to 1 mg/L for wells with nitrate levels above the MCL at baseline and below the MCL after implementation of new regulations are not calculated. These benefits are potentially captured in valuing the achievement of safe nitrate concentrations.

7.5 REFERENCES

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Appendix 7-A

MODEL VARIABLES

EPA's statistical analysis of the relationship between nitrogen loadings and well nitrate concentrations is based on the following linear model:

$$\text{Nitrate (mg/L)} = \text{ß}_0 + \text{ß}_1 \text{ Ag Dummy} + \text{ß}_2 \text{ Soil Group} + \text{ß}_3 \text{ Well Depth}$$

$$+ \text{ß}_4 \text{ Septic Ratio} + \text{ß}_5 \text{ Alt N Source} + \text{ß}_6 \text{ Loadings Ratio} + ,_{i,}$$

where nitrate concentration (mg/L) is the dependent variable.

The variables used to explain nitrate concentrations in well water (i.e., the model's independent variables) can be classified into two groups: well and land characteristics, and nitrogen inputs. Definitions of these variables are provided below. Unless otherwise noted, EPA obtained the data used in developing the model from the USGS Retrospective Database.

Well and Land Characteristics

Ag Dummy: This variable describes the predominant land use at the well's location (1 for agricultural land; 0 otherwise). Other land uses identified in the database include woods, range, urban, and other.

Soil Group: The soil group variable is an index that integrates several factors — including runoff potential, permeability, depth to water table, depth to an impervious layer, water capacity, and shrink-swell potential — to characterize hydrological conditions in the vicinity of the well. Possible values range from a minimum of 1 to a maximum of 4.

Well Depth: The well depths reported in the USGS database range from 1 foot to 5,310 feet. For observations used in the regression analysis, the maximum well depth is 1,996 feet.

Nitrogen Inputs

AFO Loadings Ratios and Scenarios: The AFO loadings ratio is a unique value for each county. It is calculated by dividing estimated leached nitrate loadings for the county (pounds per year) by the county's total area (acres). The analysis employs baseline loadings data to estimate the coefficients for the independent variables. It applies these coefficients, combined with loadings data representative of post-regulatory conditions, to estimate changes in well nitrate concentrations under each regulatory scenario.

Septic Ratio: The septic ratio is a proxy measure of potential nitrogen loadings from septic systems. The analysis develops a unique value for each county. This value is calculated by dividing the number of housing units in the county that use septic systems by the county's total area (acres). EPA obtained data on septic system use from the 1990 U.S. Census.

Alternate N Source: Alternate nitrogen sources include fertilizer and atmospheric deposition. Values for this variable are reported in pounds per acre per year.

Summary Statistics

Exhibit 7A-1 reports summary statistics on the variables used in the analysis.

Exhibit 7A-1

SUMMARY STATISTICS

Variable	N	Mean	Standard Deviation	Minimum	Maximum
Nitrate Concentrations	2928	3.585	6.552	0.050	84.300
Ag Dummy	2928	0.775	0.418	0.000	1.000
Soil Group	2928	2.418	0.658	1.000	4.000
Well Depth	2928	169.191	133.468	1.000	1,996.000
Septic Ratio	2928	0.029	0.028	0.000	0.151
Alternate N Source	2928	28.890	18.981	0.869	99.631
Loadings Ratio (Baseline Scenario)	2928	6.626	14.022	0.003	63.354

Appendix 7-B

THE GAMMA MODEL

The analysis uses a gamma model to fit the right skew of observed values for well nitrate concentrations as well as the nonnegative constraint on the dependent variable. Visual inspection of the nitrate concentration distribution suggests a gamma distribution with density function:

$$f(y) = \frac{\theta^{\alpha}}{\Gamma(\alpha)} \exp(-\theta y)\, y^{\alpha-1} \cdot$$

Let For this distribution, the expected value of y_i is

$$+ (y_i) = "/2_i = " \text{ exp } (\$P_i)$$

The use of the gamma distribution instead of the more commonly employed exponential distribution is appropriate because " is assumed to equal 1 in the exponential distribution, but was estimated to be significantly different than 1 in EPA's empirical work. The gamma distribution also offers the advantages of making the density function more flexible and giving more curvature to the distribution. The likelihood function is:

$$\log L\left(y_i \middle| x_i ; a , b\right) = \sum_i \left[a \log q_i - \log \Gamma(a) - q_i y_i + (a - 1)\log(y_i)\right]$$

Exhibit 7B-1 provides statistical results from the gamma model. All coefficients are of the expected sign and significant at the 1 percent level. In particular, the coefficient for the Loadings Ratio variable is positive, as expected, indicating that an increase in nitrogen loadings leads to increased well nitrate concentrations.

Exhibit 7B-1

GAMMA REGRESSION RESULTS

Variable	Parameter Estimate	Standard Error	Asymptotic T-Statistic	Significance
Intercept	1.492	0.151	9.891	0.000
Ag Dummy	0.691	0.066	10.452	0.000
Soil Group	-0.335	0.043	-7.725	0.000
Well Depth*	-0.106	0.015	-7.178	0.000
Septic Ratio	2.623	1.102	2.380	0.009
Alt N Source*	20.258	1.628	12.444	0.000
Loadings Ratio	0.010	0.002	5.037	0.000
Alpha	0.498	0.011	46.368	0.000
Mean log-likelihood = -1.854				
N = 2,928				
*The raw data were scaled by a factor of 100 for Well Depth and 1,000 for Alt N Source in order for the GAUSS program to converge to a solution.				

Appendix 7-C

LITERATURE SEARCH AND EVALUATION

Literature Search

The objective of EPA's literature search was to identify prior studies that had developed or elicited values for changes in groundwater quality, focusing in particular on values for reduced nitrates. The search drew in part upon two databases: the Colorado Association of Research Libraries (CARL), which includes the holdings of several university libraries in Colorado and the West; and the Environmental Valuation Resource Inventory (EVRI), a database compiled by Environment Canada that includes empirical studies on the economic value of environmental benefits and human health effects. In addition, EPA solicited suggestions for studies pertaining to groundwater valuation and nitrate contamination through the ResEcon listserver, which reaches a network of approximately 700 academics, professionals, and other individuals with interests in natural resource and environmental economics. Through this extensive search and additional review of selected bibliographies, EPA identified 11 potentially relevant studies. Since most households' values for reducing nitrates in private domestic wells are primarily nonmarket values, most of the identified studies involve stated preference value elicitation (e.g., contingent valuation).

Evaluating Studies for Benefits Transfer

The economics literature suggests several criteria in evaluating primary studies for undertaking benefits transfer. Desvousges et al. (1992) develop five criteria to guide the selection of studies for application to a surface water quality issue: that the studies to be transferred (1) be based on adequate data, sound economic method, and correct empirical technique (i.e., "pass scientific muster"); (2) evaluate a change in water quality similar to that expected at the policy site; (3) contain regression results that describe willingness to pay as a function of socioeconomic characteristics; (4) have a study site that is similar to the policy site (in terms of site characteristics and populations); and (5) have a study site with a similar market as the policy site. NOAA condenses the five Desvousges criteria into three considerations: (1) comparability of the users and of the resources and/or services being valued and the changes resulting from the discharge of concern; (2) comparability of the change in quality or quantity of resources and/or services; and (3) the quality of the studies being used for transfer [59 FR 1183]. In a general sense, items (2), (4), and (5) of Desvousges et al. and items (1) and (2) of NOAA are concerned with the *applicability* of an original study to a policy site. Items (1) and (3) of Desvousges et al. and item (3) of NOAA are concerned with the *quality* of the original study.

To assess original studies for use in valuing estimated changes in well nitrate levels under alternate CAFO regulations, EPA evaluated the *applicability* and the *quality* of the original studies on several criteria. To the extent feasible, EPA obtained or derived information from each of the reports or papers for 28 categories of information used to characterize the studies. Because applicability to CAFOs and quality of the value estimates are distinct concepts, EPA evaluated these characteristics of the studies separately. Overall, the goal of the rating process was to identify studies that elicited high-quality value estimates (reliable and valid) and which were most applicable to the benefits assessment. There were three steps in the rating process:

1. identify study characteristics upon which to judge applicability and quality;
2. assign scores to the studies based on these characteristics;
3. assign weights to these scores for aggregating scores into unidimensional measures of applicability and quality.

Criteria for Ranking based on Applicability

Applicability refers to the relationship between values elicited in the primary groundwater valuation studies and benefit estimates necessary for application to the analysis of alternate CAFO regulations. EPA's criteria for evaluation of applicability included comparison of the following characteristics of studies with likely CAFO situations:

- location (urban, rural, etc.);
- water supply/groundwater use (percentage on wells);
- type of contaminants (scenario involved nitrate contamination of groundwater);
- source of contaminants (scenario involved conditions similar to those relevant for CAFOs);
- value estimates are for the correct theoretical construct (e.g., total willingness to pay for reducing groundwater contamination from nitrates).

Criteria for Ranking based on Quality

Analysis of study quality was based on evaluation of the validity and reliability of the value estimates derived in the primary groundwater valuation research. Most of the 11 identified studies involved stated preference elicitation using survey methods. Based on professional experience as to what constitutes a valid and reliable stated preference valuation study, EPA identified characteristics of these studies that indicate reliability and validity. Criteria for evaluation of study quality included:

- whether the study was published or peer reviewed;

- whether the survey implementation met professional standards;

- how many respondents there were and what the response rate was;

- whether and how the groundwater baseline was characterized and what change was presented in the groundwater scenario;

- whether the credibility of scenario change was assessed;

- what valuation methodology was used and whether it was appropriate for eliciting the intended value measures;

- the type and duration of payment vehicle;

- whether appropriate empirical estimation was undertaken;

- whether expected explanatory variables were found to be significant.

INTEGRATION OF RESULTS CHAPTER 8

8.1 INTRODUCTION

This chapter summarizes EPA's estimates of the benefits associated with potential revisions to the NPDES provisions and Effluent Limitation Guidelines (ELGs) pertaining to CAFOs. It first describes the Agency's approach to aggregating the results of the studies described in Chapters 4 through 7. It then describes EPA's approach to discounting future benefits and presents the aggregated benefits of each regulatory scenario analyzed, both in a single present value and as an annualized benefits stream. Finally, the chapter discusses the key limitations of the analysis and the implications of these limitations in characterizing the benefits of revised CAFO standards.

8.2 INTEGRATION OF ANALYTIC RESULTS

To develop an integrated assessment of the benefits of each alternative regulatory scenario, EPA simply adds the results of the analyses presented in Chapters 4 through 7. To the extent that these analyses address similar benefits, this approach may lead to double-counting and overestimation of benefits. In this case, however, EPA has determined that the potential for double-counting is small. The analyses that generate the largest benefits estimates — the NWPCAM analysis of the benefits of improved surface water quality, the evaluation of potential improvements in commercial shell fishing opportunities, and the assessment of potential reductions in the contamination of private wells — examine different water resources and different uses of those resources.[68] Thus, the benefits estimated in these analyses are clearly additive. The only possible source of double-counting, therefore, lies in integrating the results of the NWPCAM analysis with EPA's evaluation of the benefits attributable to reducing the frequency and magnitude of fish kills.

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[68] The NWPCAM analysis addresses changes in the quality of lakes, rivers, and streams above the head of tide, and considers recreational swimming, fishing, and non-use values. The assessment of potential improvements in shell fishing opportunities focuses on marine and estuarine waters and the commercial use of shellfish resources. The assessment of potential reductions in the contamination of private wells considers the use of groundwater as a source of domestic water supplies.

The extent to which the NWPCAM analysis and the fish kills analysis may double-count benefits is unclear, but unlikely to be significant. Both analyses address changes in the quality of rivers, lakes, and streams.[69] In addition, at least some of the benefits of reducing the incidence of fish kills likely stem from the associated improvement in recreational fishing opportunities, a beneficial use which the NWPCAM analysis considers. Thus, some double-counting is possible. The NWPCAM analysis, however, is based upon modeling of surface water quality under steady state conditions; the analysis is not likely to capture all of the impacts of revised CAFO standards on circumstances (e.g., the overflow of a lagoon under severe storm conditions) that may lead to fish kills. In addition, the approach employed in valuing the reduced incidence of fish kills explicitly excludes lost use values, such as those associated with recreational fishing. These considerations suggest that at least some, if not all, of the benefits estimated in the fish kills analysis are incremental to those estimated in the NWPCAM analysis.

From a practical standpoint, the implications of any double-counting between the NWPCAM analysis and the fish kills analysis are minimal. At most, the estimated annual benefits of reducing the incidence of fish kills amount to no more than approximately 5 percent of the annual benefits estimated in the NWPCAM analysis; this is the case for Option 1-Scenario 4a. Under EPA's proposed regulatory scenarios, the estimated annual benefits of reducing the incidence of fish kills equal less than 0.4 percent of the annual benefits estimated in the NWPCAM analysis. Thus, EPA has concluded that its approach to integrating the findings of the underlying analyses does not result in any significant degree of double-counting.

8.3 PRESENT VALUE OF BENEFITS

The results of the analyses in Chapters 4 through 7 are expressed as annual benefits streams. To calculate the present value of these benefits at the time new regulations are implemented, EPA employs three alternative real discount rates: three, five, and seven percent. The seven percent discount rate represents the real rate of return on private investments and is consistent with the rate mandated by the Office of Management Budget for analysis of proposed regulations. The three percent discount rate reflects the social rate of time preference for consumption of goods and services, and is consistent with the rate recommended by many economists for analysis of environmental benefits. The five percent discount rate represents the mid-point of the three to seven percent range.

In calculating the present value of benefits, EPA assumes an infinite time frame; i.e., as long as the regulations remain in effect the associated benefits will be enjoyed in perpetuity. As a practical matter, this approach is equivalent to assuming that the regulations will remain in effect for several generations, since the present value of benefits beyond this point approaches zero; however,

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[69] The data upon which the fish kills analysis is based include fish kill incidents below the head of tide. The NWPCAM analysis extends only to freshwater resources.

it avoids the need to arbitrarily specify a period of time over which the regulations are assumed to remain in effect, and allows EPA to represent fully the present value of the benefits estimated. For purposes of illustrating the sensitivity of EPA's results to this assumption, Appendix 8-A illustrates the impact of alternative time frames on present value estimates developed for one of EPA's proposed regulatory scenarios. Appendix 8-B provides additional detail on the calculation of present values.

Exhibits 8-1 through 8-4 present the results of the present value calculations for each of the benefit categories addressed in Chapters 4 through 7. As shown, the estimated benefits for alternative regulatory scenarios vary significantly, with scenarios that employ Option 2 (which would establish a phosphorus-based manure application limit) generally providing higher benefits than scenarios employing Option 1 (a nitrogen-based manure application limit). In all cases, Option 2-Scenario 4b yields the highest benefits, while Option 1-Scenario 1 yields the lowest. Within benefits categories, benefits are lowest using the seven percent discount rate and highest using the three percent discount rate, reflecting the impact of alternative discounting assumptions on the present value of future benefits.

Exhibit 8-1

PRESENT VALUE OF ESTIMATED BENEFITS:
ACHIEVING RECREATIONAL USE LEVELS
(1999 dollars, millions)

	Discount Rates		
Regulatory Scenario	**3 Percent**	**5 Percent**	**7 Percent**
Option 1-Scenario 1	$163.3	$98.0	$70.0
Option 1-Scenario 2/3	$210.0	$126.0	$90.0
Option 1-Scenario 4a	$183.3	$110.0	$78.6
Option 1-Scenario 4b	$240.0	$144.0	$102.9
Option 2-Scenario 1	$2,920.0	$1,752.0	$1,251.4
Option 2-Scenario 2/3*	$4,236.7	$2,542.0	$1,815.7
Option 2-Scenario 4a*	$3,616.7	$2,170.0	$1,550.0
Option 2-Scenario 4b	$4,833.3	$2,900.0	$2,071.4

* Proposed scenarios

Exhibit 8-5 presents, on a present value basis, EPA's aggregated estimate of the benefits of alternative revisions to the CAFO standards. As the exhibit shows, the present value of benefits under EPA's proposed regulatory scenarios ranges from approximately $2.1 billion dollars (assuming a discount rate of seven percent and employing the low-end of the estimated range of benefits for Option 2-Scenario 4a) to $6.1 billion dollars (assuming a discount rate of three percent and employing the high-end of the estimated range of benefits for Option 2-Scenario 2/3).

Exhibit 8-2

**PRESENT VALUE OF ESTIMATED BENEFITS:
REDUCED INCIDENCE OF FISH KILLS
(1999 dollars, millions)**

Regulatory Scenario	Discount Rates		
	3 Percent	**5 Percent**	**7 Percent**
Option 1-Scenario 1	$3.1 - $7.8	$1.9 - $4.7	$1.3 - $3.3
Option 1-Scenario 2/3	$3.9 - $10.2	$2.4 - $6.1	$1.7 - $4.4
Option 1-Scenario 4a	$3.7 - $9.7	$2.2 -$5.8	$1.6 - $4.1
Option 1-Scenario 4b	$4.4 - $10.8	$2.6 - $6.5	$1.9 - $4.6
Option 2-Scenario 1	$5.9 - $9.4	$3.5 -$5.7	$2.5 - $4.0
Option 2-Scenario 2/3*	$7.3 - $12.3	$4.4 - $7.4	$3.1 - $5.3
Option 2-Scenario 4a*	$7.1 - $11.8	$4.3 - $7.1	$3.0 - $5.0
Option 2-Scenario 4b	$8.1 - $13.2	$4.8 - $7.9	$3.5 - $5.7

* Proposed scenarios

Exhibit 8-3

PRESENT VALUE OF ESTIMATED BENEFITS: IMPROVED COMMERCIAL SHELL FISHING
(1999 dollars, millions)

Regulatory Scenario	Discount Rates		
	3 Percent	5 Percent	7 Percent
Option 1-Scenario 1	$4.9 - $60.5	$2.9 - $36.3	$2.1 - $25.9
Option 1-Scenario 2/3	$6.6 - $78.6	$4.0 - $47.1	$2.8 - $33.7
Option 1-Scenario 4a	$5.9 - $73.5	$3.6 - $44.1	$2.5 - $31.5
Option 1-Scenario 4b	$7.4 - $85.5	$4.4 - $51.3	$3.2 - $36.6
Option 2-Scenario 1	$5.5 - $71.4	$3.3 - $42.8	$2.4 - $30.6
Option 2-Scenario 2/3*	$7.3 - $90.6	$4.4 - $54.3	$3.1 - $38.8
Option 2-Scenario 4a*	$6.5 - $80.6	$3.9 - $48.3	$2.8 - $34.5
Option 2-Scenario 4b	$8.2 - $98.7	$4.9 - $59.2	$3.5 - $42.3

* Proposed scenarios

Exhibit 8-4

PRESENT VALUE OF ESTIMATED BENEFITS: REDUCED CONTAMINATION OF PRIVATE WELLS
(1999 dollars, millions)

Regulatory Scenario	Discount Rates		
	3 Percent	5 Percent	7 Percent
Option 1-Scenario 1	$1,633.2	$798.2	$475.6
Option 1-Scenario 2/3	$1,635.3	$799.2	$476.2
Option 1-Scenario 4a	$1,739.4	$850.0	$506.5
Option 1-Scenario 4b	$1,739.4	$850.0	$506.5
Option 2-Scenario 1	$1,735.6	$848.2	$505.4
Option 2-Scenario 2/3*	$1,738.2	$849.5	$506.1
Option 2-Scenario 4a*	$1,796.0	$877.7	$523.0
Option 2-Scenario 4b	$1,796.0	$877.7	$523.0

* Proposed scenarios

Exhibit 8-5

PRESENT VALUE OF AGGREGATED BENEFITS
(1999 dollars, millions)

Regulatory Scenario	Discount Rates		
	3 Percent	5 Percent	7 Percent
Option 1-Scenario 1	$1,804.5 - $1,864.9	$900.9 - $937.1	$549.0 - $574.9
Option 1-Scenario 2/3	$1,855.9 - $1,934.1	$931.5 - $978.5	$570.7 - $604.2
Option 1-Scenario 4a	$1,932.4 - $2,005.9	$965.8 - $1,009.9	$589.2 - $620.7
Option 1-Scenario 4b	$1,991.2 - $2,075.6	$1,001.1 - $1,051.8	$614.4 - $650.6
Option 2-Scenario 1	$4,667.0 - $4,736.4	$2,607.0 - $2,648.7	$1,761.7 - $1,791.4
Option 2-Scenario 2/3*	$5,989.5 - $6,077.7	$3,400.2 - $3,453.2	$2,328.1 - $2,365.9
Option 2-Scenario 4a*	$5,426.2 - $5,505.0	$3,055.9 - $3,103.1	$2,078.8 - $2,112.5
Option 2-Scenario 4b	$6,645.5 - $6,741.2	$3,787.4 - $3,844.8	$2,601.4 - $2,642.4

* Proposed scenarios

8.4 ANNUALIZED BENEFITS ESTIMATES

In addition to calculating the present value of estimated benefits, EPA has developed an estimate of the annualized benefits attributable to each of the regulatory scenarios analyzed; these annualized values reflect the constant flow of benefits over time that would generate the associated present value. Appendix 8-C provides additional detail on the calculation of annualized benefits.

EPA assumes that benefits related to surface water quality improvements will begin immediately after the revised regulations are implemented (i.e., because loadings will immediately decrease), and that these benefits will be constant from year-to-year. As a result, the annualized benefits in these categories (improved surface water quality, reduced fish kills, and improved shellfishing) are equivalent to the annual benefits estimated in Chapters 4 through 6, regardless of the discount rate employed. In the case of private well contamination, however, EPA assumes an uneven annual stream of benefits. As a result, EPA's estimates of the annualized benefits of reduced private well contamination depend upon the discount rate employed.

Exhibit 8-6 summarizes the range of annualized benefits for each benefit category under each of the regulatory scenarios analyzed. Note that the range of benefits associated with reduced contamination of private wells reflects the variation in discount rates employed in developing the annualized benefits estimate (three to seven percent). In contrast, the range of values presented for reduced fish kill and shellfishing benefits is based solely on uncertainty in the underlying analyses.

There is considerable variation in the range of benefits across regulatory scenarios, as well as some variation within scenarios with respect to the relative magnitude of surface water and groundwater benefits. In particular, under scenarios that employ Option 1, the annualized benefits of reduced private well contamination exceed those associated with other benefits categories. In contrast, under scenarios that employ Option 2, the recreational and non-use benefits associated with improved surface water quality account for the greatest share of benefits.

Exhibit 8-6

ESTIMATED ANNUALIZED BENEFITS OF REVISED CAFO REGULATIONS
(1999 dollars, millions)

Regulatory Scenario	Recreational and Non-use Benefits	Reduced Fish Kills	Improved Shellfishing	Reduced Private Well Contamination
Option 1- Scenario 1	$4.9	$0.1 - $0.2	$0.1 - $1.8	$33.3 - $49.0
Option 1- Scenario 2/3	$6.3	$0.1 - $0.3	$0.2 - $2.4	$33.3 - $49.1
Option 1- Scenario 4a	$5.5	$0.1 - $0.3	$0.2 - $2.2	$35.5 - $52.2
Option 1- Scenario 4b	$7.2	$0.1 - $0.3	$0.2 - $2.6	$35.5 - $52.2
Option 2- Scenario 1	$87.6	$0.2 - $0.3	$0.2 - $2.1	$35.4 - $52.1
Option 2- Scenario 2/3*	$127.1	$0.2 - $0.4	$0.2 - $2.7	$35.4 - $52.1
Option 2-Scenario 4a*	$108.5	$0.2 - $0.4	$0.2 - $2.4	$36.6 - $53.9
Option 2- Scenario 4b	$145.0	$0.2 - $0.4	$0.2 - $3.0	$36.6 - $53.9

* Proposed scenarios

Exhibit 8-7 presents EPA's aggregated estimate of annualized benefits for each of the regulatory scenarios analyzed. Under the proposed regulatory scenarios, annualized benefits range from $146 million (Option 2-Scenario 4a, assuming a seven percent discount rate) to $182 million (Option 2-Scenario 2/3, assuming a three percent discount rate). Again, note that variation in discount rates affects only the annualized benefits associated with reduced contamination of private wells; other annualized benefits remain constant regardless of discount rates.

Exhibit 8-7

SUMMARY OF ANNUALIZED BENEFITS
(1999 dollars, millions)

	Discount Rates					
	3 Percent		**5 Percent**		**7 Percent**	
Regulatory Scenario	**Low**	**High**	**Low**	**High**	**Low**	**High**
Option 1-Scenario 1	$54.1	$55.9	$45.0	$46.9	$38.4	$40.2
Option 1-Scenario 2/3	$55.7	$58.0	$46.6	$48.9	$39.9	$42.3
Option 1-Scenario 4a	$58.0	$60.2	$48.3	$50.5	$41.2	$43.4
Option 1-Scenario 4b	$59.7	$62.3	$50.1	$52.6	$43.0	$45.5
Option 2-Scenario 1	$140.0	$142.1	$130.4	$132.4	$123.3	$125.4
Option 2-Scenario 2/3*	$179.7	$182.3	$170.0	$172.7	$163.0	$165.6
Option 2-Scenario 4a*	$162.8	$165.1	$152.8	$155.2	$145.5	$147.9
Option 2-Scenario 4b	$199.4	$202.2	$189.4	$192.2	$182.1	$185.0

* Proposed scenarios

8.5 LIMITATIONS OF THE ANALYSIS AND IMPLICATIONS FOR CHARACTERIZING BENEFITS

The results presented above are based on the four separate analyses presented in Chapters 4 through 7, and are subject to the specific uncertainties and limitations that are discussed in detail in each of these chapters. Beyond these limitations, however, it is important to note that EPA's analysis does not attempt to comprehensively identify and value all potential environmental changes associated with proposed revisions to the CAFO regulations. Instead, the Agency focuses on specific identifiable and measurable benefits. The impacts of the regulatory proposal likely include additional benefits not addressed in these analyses, such as reductions in the cost of treating public water supplies; improved recreational opportunities in the Great Lakes, estuaries, and other near-coastal waters; improvement in the condition of non-boatable waters to boatable condition; improvements in the quality of water resources that are already suitable for swimming; improvements in commercial fishing; improvements in near-stream activities; and non-water related benefits, such as potential reductions in odor from waste management areas. In light of these limitations, EPA believes that the benefits quantified in this report represent a conservative estimate of the total benefits of revised CAFO standards.

Appendix 8-A

IMPACT OF ALTERNATIVE TIME FRAMES ON PRESENT VALUE AND ANNUALIZED BENEFITS ESTIMATES

Exhibit 8A-1

PRESENT VALUE OF BENEFITS: OPTION 2-SCENARIO 4a
(1999 dollars, millions)

	Discount Rate					
	3 Percent		5 Percent		7 Percent	
Time Period	Low	High	Low	High	Low	High
25 years	$2,466.8	$2,508.0	$1,958.3	$1,991.6	$1,589.8	$1,617.3
50 years	$4,012.2	$4,073.0	$2,731.5	$2,774.6	$1,988.6	$2,021.2
75 years	$4,750.9	$4,821.0	$2,960.1	$3,006.1	$2,062.2	$2,095.7
100 years	$5,103.7	$5,178.3	$3,027.6	$3,074.5	$2,075.7	$2,109.4
Infinite	$5,426.2	$5,505.0	$3,055.9	$3,103.1	$2,078.8	$2,112.5

Exhibit 8A-2

ANNUALIZED BENEFITS: OPTION 2-SCENARIO 4a
(1999 dollars, millions)

	Discount Rate					
	3 Percent		5 Percent		7 Percent	
Time Period	Low	High	Low	High	Low	High
25 years	$141.7	$144.0	$138.9	$141.3	$136.4	$138.8
50 years	$155.9	$158.3	$149.6	$152.0	$144.1	$146.5
75 years	$160.0	$162.3	$151.9	$154.3	$145.3	$147.6
100 years	$161.5	$163.9	$152.5	$154.9	$145.5	$147.8
Infinite	$162.8	$165.1	$152.8	$155.2	$145.5	$147.9

Appendix 8-B

CALCULATION OF PRESENT VALUES

The present value (*PV*) of a benefit (*B*) to be received *t* years from now is determined by the following equation:

$$PV = B_t / (1 + r)^t$$

where *r* represents the annual discount rate. Thus, the present value of an annual stream of benefits from Year 1 through Year *n* is calculated as follows:

$$PV = \sum_{t=1}^{n} B_t / (1 + r)^t$$

When B_t is constant — i.e., when benefits (*B)* each year are the same — and *n* approaches infinity, the equation above can be simplified to:

$$PV = B / r$$

EPA employs the above equation to calculate present values for all categories of benefits that are assumed to remain constant from Year 1 onward; i.e., for all categories except reduced contamination of private wells. In the latter case, benefits are assumed to increase in a linear fashion until Year 27, and then to remain constant. Thus, the value in Year 27 (V_{27}) of the constant, infinite stream of benefits (*B*) expected to accrue from that year forward is calculated as:

$$V_{27} = B / r$$

In calculating the present value of reduced contamination of private wells, EPA sets the value of B_{27} equal to that of V_{27}. The present value of benefits is then determined using the following equation:

$$PV = \sum_{t=1}^{27} B_t / (1 + r)^t$$

Appendix 8-C

CALCULATION OF ANNUALIZED BENEFITS

The constant annual benefit A that, over a period of n years, equals the estimated present value (PV) of benefits is determined by the following equation:

$$A = \mathrm{PV}(r) / (1-[1 / (1 + r)^{n}])$$

where r represents the annual discount rate. As n approaches infinity, this equation simplifies to:

$$A = PV(r)$$

EPA uses the equation above to calculate the annualized benefits reported in this analysis.