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EXECUTIVE SUMMARY

America's groundwater is fifty times as plentiful as water in its rivers and lakes. Groundwater is increasingly utilized as a source of water today and is a source of drinking water for approximately one-half the nation's population. Groundwater also provides about 40 percent of the nation's irrigation requirements and about 80 percent of rural water needs, both in the home and for livestock.

Few doubt that contamination of groundwater is a growing problem. The impact of agricultural activities on groundwater quality and quantity is an issue of major national importance. Proper management of agricultural systems to maintain acceptable groundwater quality is increasing in importance. Research efforts need to be focused on physical, chemical and biological processes that influence groundwater quality.

This proposal presents a comprehensive research and extension plan to sustain agricultural productivity and protect groundwater resources for rural areas. The goal is provision of an adequate quantity of acceptable quality groundwater. Current research in groundwater within State Agricultural Experiment Stations and within federal and other agencies is inadequate to meet existing needs for research and extension.

There is an immediate need for increased research on source and prevention, fate, remedial (corrective), and impact and institutional issues. Example research programs to address these major issues are given.

Technology transfer through Cooperative Extension is proposed to transmit benefits of research investments to the public. Issues of training and numbers of personnel are key constraints to Extension's programming in groundwater quality.

Funding for fundamental research and extension programs in groundwater quality must be added to existing limited resources. USDA funding of $55 million per year for research grants, fellowships, equipment and facilities grants, and extension grants is proposed to accomplish the goal of clean groundwater.
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CHAPTER 1
INTRODUCTION

The nation's groundwaters are being adversely affected by man's activities including intrusion into groundwater of agricultural chemicals applied to soil and crops. Even with concerted monitoring, the extent of groundwater contamination will not be adequately assessed in the near future, nor will be the relative impact of agricultural and other sources of chemicals. In addition, institutional arrangements for groundwater allocation and protection are in their infancy. Substantial efforts must be organized to ensure the future of our groundwater supplies.

Our dependence upon groundwater is substantial. Approximately 86 percent of the total water resource in the contiguous United States is found in underground aquifers. Groundwater supplies about 24 percent of the nation's freshwater, and its use is increasing about 4 percent annually. Of the total water withdrawn, 68 percent is used for irrigated agriculture. Half the U.S. population depends upon wells for drinking water, with 95 percent of rural households depending solely upon groundwater. Of additional importance, about 30 percent of the nation's streamflow is supplied by groundwater seepage.

Contamination or depletion of groundwater is a crucial concern throughout the nation. Contamination may persist for many years because groundwater moves very slowly and biologically or chemically active zones that can degrade contaminants are scarce. Thus, prevention is a critical public objective because contamination is so irreversible.

Advances in analytical chemistry now allow detection of chemicals in groundwater at very low concentrations. Because the toxicological effects of many of these chemicals have not been clearly established, public concern is understandably great. Thus, demands have been made for more regulation of agricultural, industrial and municipal activities that introduce chemicals to groundwater. Federal, state and local programs have been affected, but it is uncertain whether
they are even moving in the best direction. This increased regulation can add economic burdens, revocation of chemical registration and substantial changes in land use. Few non-regulatory measures have been attempted. Whether these actions will protect our groundwater from further damage will not be clear until we better understand the physical, chemical and biological complexities of the soil filter that overlies our groundwater and until we systematically review institutional responses to these problems.

Society has a tremendous stake in preventing groundwater contamination. Chemicals are indispensable in modern agriculture, but some can impair the use of groundwater for crop or animal production, or for domestic water supply. Other sources of groundwater contamination are not from agriculture, as in many urban areas or in locations that have been used for waste disposal. The relative importance of these various sources of contamination needs examination. Public concerns arising from isolated contamination events may eventually cause severe (and possibly unjustified) constraints on use of a wide range of chemicals. In the interest of maintaining high agricultural productivity, it is essential to develop procedures to prevent groundwater contamination rather than reacting to contamination after it occurs.

The specific practice that causes groundwater contamination varies by geographical region. Typical groundwater contaminants are inorganic salts, pesticides, nitrates, seawater, gasoline, or organic wastes. The nature and intensity of the physical, chemical and biological processes that affect the fate of these chemicals vary by region. The social, economic and political implications of contaminated or insufficient groundwater also vary according to locale. Yet, across all these differences, there is clear commonality in the ultimate goal of researchers, extension educators, community managers, regulators and society as a whole: clean water. Specifically, the goal is the provision of an adequate quantity of groundwater of acceptable quality in the presence of sustained agricultural, industrial and municipal activities.
Over the last decade many studies have focused on agricultural chemicals due to the clearly identified expertise residing within the agricultural departments and agricultural experiment stations of land-grant universities. A substantial amount of this research has been collaborative with federal and other research organizations. This experience provides a running start for further cooperative research and extension efforts. As a first step, attention may be concentrated on agricultural chemicals and agricultural practices to develop a broad scale research and education effort. Yet, we must not ignore other non-agricultural sources of chemicals, as these will certainly be of considerable importance in many rural and urban areas. We must be ready to apply our knowledge of chemical movement in soil and groundwater wherever the problem arises.

A workshop was held in Syracuse, New York in March 1985 to address groundwater quality. Representatives from agricultural experiment stations and various federal agencies were invited. A list of attendees is given in Appendix A. A committee was selected to write a first draft, which was circulated widely for comment on the proposed research and extension program.

This proposal outlines a comprehensive agenda for research and extension activities to provide clean groundwater. Because of the agricultural experience of the existing research and extension infrastructure and the historical leadership displayed by the United States Department of Agriculture (USDA) and land-grant universities, the primary focus is on agricultural chemicals and those likely to be found in rural settings. Recognizing the broader implications of all chemicals introduced to the environment that potentially may move to groundwater, the proposal is organized with the anticipation that other federal and state agencies will become funding contributors on those issues that fall within the mandated responsibilities of each agency.

Because current federal and state funding for research and extension is limited, increased financial resources must be committed to providing clean groundwater. The following research and extension plan is intended to:
1. Provide an overview of groundwater contamination problems, research and extension needs, and anticipated state, federal and academic interactions necessary to address those needs and solve the problems;

2. Establish a conceptual frame within which agencies or legislative bodies may develop more specific programs to evoke the financial resources necessary to galvanize the collective, cooperative, interdisciplinary studies necessary to meet our groundwater quality goals; and

3. Propose an information dissemination strategy to meet needs of the agricultural system and those of the public for clean water.
CHAPTER 2

PROBLEM STATEMENT

Actions to protect groundwater fall into broad areas of prevention and treatment. Research and extension cut across both issues. We have divided groundwater quality issues into five broad categories: (1) Source, (2) Fate, (3) Remedial, (4) Impact and (5) Institutional.

1. **SOURCE**: relates to the methods of introduction of chemicals into the environment, to the forms of chemicals introduced or to design of changes to reduce risk (occurrence and significance) of contamination.

2. **FATE**: relates to the persistence, mobility, transformation and degradation of chemicals in the soil or groundwater system and includes measuring and monitoring protocols.

3. **REMEDIAL**: relates to the treatment of contaminated soil and water to improve their quality.

4. **IMPACT**: relates to the toxicological, economic, social, legal and political consequences and legal liability of groundwater contamination.

5. **INSTITUTIONAL**: relates to risk management at various levels of organized activity - farm, household, voluntary and governmental organizations at local, state and federal levels.

The primary groundwater concerns in all regions are source issues because the method of introduction, form of introduced chemical and alternatives to avoid exposure are the principal variables as regional, agricultural or industrial practices change. In fact, the very diversity of groundwater issues makes them particularly difficult to resolve. The physical, biological and institutional context differs significantly from place to place.

A number of key sources are common to all regions:

- agricultural pesticides and fertilizer
- leaking of underground fuel storage tanks
• industrial solvents
• land disposal of agricultural, municipal and industrial wastes
• landfills
• septic tank drainage
• hazardous waste sites

Important sources which are more regionally specific are:
• salinity and naturally occurring salts (selenium, cadmium, copper and boron) from irrigated soils
• seawater intrusion
• animal feedlots
• mining
• solvents and heavy metals from intensive industrial activity
• military waste disposal
• movement of contaminants through Karst limestone formations

These sources are associated with agricultural, industrial and municipal activities. In all cases physical, chemical and biological processes interact to determine the fate of a chemical and its possible presence in groundwater. These processes probably are common to all regions, but their magnitude and intensity may vary according to differences in soils, climate and topography within each geographical location. Site-specific factors such as the physical and chemical properties of the aquifer and soil, rainfall, temperature, microbiological activity and geologic weathering produce unique local conditions that determine the fate of a particular chemical. Our lack of understanding of processes in the field hinders our ability to design chemical management programs, measuring or monitoring efforts and regulatory registration protocols that will insure an adequate supply of acceptable quality groundwater. However, recognition of the commonality of basic fate processes in the presence of diverse sources and forms of chemicals establishes a framework within which
coordinated and comprehensive research can be designed and accomplished.

A number of chemicals have been detected in groundwater in the past and more will surely be found in the future. Twenty-nine states have identified nonpoint source pollution of groundwater as a major concern, citing agricultural pesticides and septic tank seepage as primary sources. Specifically, sampling of wells in New York, Wisconsin and California has identified pesticide contamination. Out of 8,000 wells in eastern Suffolk, Long Island, 13 percent of the private wells, 7 percent of the community water supply wells and 8 percent of non-community wells contained Aldicarb concentrations over 7 ppb. Sampling of wells in California has documented toxic chemicals such as DBCP, and a survey in Wisconsin found 22 percent of the public water supplies contained measurable pesticides.

Even if the source of contamination is removed, contaminated groundwater is not readily decontaminated because of long travel times through many of these systems. Therefore, it is necessary to address remedial (corrective) measures and the impacts of contamination upon society to provide a basis for preventative action. Currently, we lack adequate knowledge to define these issues. Specific research objectives must be accomplished before we can recommend effective remedial measures and sound evaluation of societal impacts. These issues are quite similar across regional boundary, and there are needs for educational programs, remedial methods, cost/benefit analyses, toxicological studies and designs of social/political institutions that will most effectively meet the ultimate goal of clean groundwater. Not the least of the needs is an information base to allow decision-makers to determine what "acceptable" means.

Existing research and extension programs cannot solve the problems identified here. The financial resources committed to the problem by state and federal agencies are inadequate and the programs are not sufficiently comprehensive.

The available funds do not adequately address fundamental processes or develop continuing programs. In addition, most resources have been expended in short term studies that are of
immediate and usually local importance. Most importantly, these do not deepen our understanding of generalized natural processes or develop broadly applicable methodologies for treatment of impact issues or institutional arrangements for prevention or remediation. Further progress by researchers and extension personnel is limited by a need to study fundamentals of heterogeneous soils and to rethink basic assumptions. As a result, many current management and regulatory efforts are drawing upon outdated and incompatible scientific information. Toxicological studies, environmental fate predictions, economic analyses, institutional designs and remedial treatment measures all suffer because of unreliable data produced by discontinuous, inadequate and undependable funding sources. Meanwhile, new chemicals are continually being used, analytical detection capabilities are improving and the public is daily made more aware of the groundwater contamination problem.

The research, teaching and extension functions located within the land-grant university system are increasingly being asked to address problems associated with groundwater contamination. Effective extension and educational efforts can only be accomplished from an improved base of research information on the issues of source and prevention, fate, remediation, impact and institutions.
CHAPTER 3

GOALS AND BENEFITS OF A NATIONAL PROGRAM

The General National goal is to provide an adequate quantity of groundwater of acceptable quality in the presence of sustained agricultural, industrial and municipal activities.

Specific local goals will be identified within each geographical region under the terms of the funds obligated to particular research projects. These projects will evolve from the source and prevention issues identified in each region, and will focus upon the unique source, fate, remedial, impact, or institutional issues that evolve from them. Attainment of specific local goals will contribute, each in their own way, to the national goal. In this way, local research efforts that address these issues will be accomplished within a national program that generates the necessary large increments of funding needed for this research. It is anticipated that the source of funding may be from a consortium of agencies, each seeking to resolve particular issues within the domain of that agency. A principal source of funding is the USDA.

Expected benefits include the following:

1. Development of a better understanding of the interacting physical, chemical and biological processes that determine the environmental consequences of imposed perturbations.
2. Minimization of groundwater contamination resulting from chemicals introduced into the environment by human activities.
4. Development of profitable, integrated, alternative agricultural management schemes, such as integrated pest management, with less dependence upon potentially hazardous chemicals for maximum productivity.
5. In those cases where chemicals are found in groundwater, better prediction of the extent and duration of contamination and development of better remedial measures.
6. Better understanding of the public health implications of chemical contamination of
groundwater.

7. Development of economic analyses useful in evaluating alternatives of water treatment, source management, aquifer protection and management techniques.

8. Provide better guidance to social and political institutions that must respond to issues related to groundwater contamination and greater ability to place those implications in the context of benefits accruing from the original use or disposal practice.

UNIQUE CONTRIBUTIONS OF THIS PROGRAM

The research and extension activities of the land-grant university system have been in place for over a century. These institutions have enabled American agriculture to achieve unparalleled productivity. The expertise that exists within this system is not exceeded in any other agency or institution in the world, particularly for issues related to soil, water, agricultural chemicals and supporting institutional arrangements.

This expertise is poised for application to problems associated with groundwater contamination. Existing research and extension programs, when supplemented, expanded and focused by input of additional federal and state resources can apply substantial experience and insight to solution of these problems. Knowledge embodied in the State Agricultural Experiment Stations (SAES) and Cooperative Extension will provide the most favorable environment for rapid translation of new concepts into practice. The land-grant universities, in addition to research, provide education for a majority of agricultural scientists in the United States and many developing countries.

Cooperative Extension provides the technology transfer component of the land-grant system to ensure that new knowledge reaches users as quickly as possible. In addition, the system of Cooperative Extension provides an important feedback mechanism which brings new and important field problems to the attention of the researchers. Knowledge and expertise of public policy researchers and extension educators in the land-grant system can be joined to develop
important public policy education approaches.
CHAPTER 4

CURRENT RESEARCH IN GROUNDWATER

1. Within State Agricultural Experiment Stations

Planning of a research program in groundwater quantity and quality requires an understanding of the current level of effort. Therefore, this chapter provides a summary of the current research efforts in groundwater and related subjects within the State Agricultural Experiment Stations (SAES) and within other federal agencies (USEPA, USGS, ARS, USDOE, etc.). Information is provided from the USDA Current Research Information System (CRIS) for research conducted by the State Agricultural Experiment Stations. Table 1 indicates that the SAES (FY 83) have a relatively small commitment to groundwater quality research. The commitment of faculty scientists to groundwater quality projects totals only 88 SY's, which represents about 1.5 percent of the total SAES commitment of approximately 6600 SY's to all agricultural research. However, data in Table 1 indicate that SAES research on groundwater quality is broad in scope with work on many aspects of groundwater quality within constraints of existing limited resources. These researchers form a solid base from which a significant initiative in groundwater quality and quantity can be launched.

Considering the high degree of our national dependence on groundwater and intensified concern for acceptable quality groundwater, a new initiative is needed. While America seems to be making progress in cleaning up its lakes and streams, groundwater pollution is a new concern in 35 states according to a recent water quality assessment inventory made by USEPA. Funds supporting SAES research in groundwater quality are given by sources in Table 1. Funds from the Cooperative State Research Service (CSRS) include all funds distributed by CSRS, including formula funds under the Hatch Act. The category of other federal funds includes sources such as USEPA, USDOE, USGS, TVA, US Army, US Navy, etc.
TABLE 1. State Agricultural Experiment Stations' Commitments to Groundwater and Related Water Resources Research (FY '83)

<table>
<thead>
<tr>
<th>Area</th>
<th>Funding Sources</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CSRS**</td>
<td>Other Federal</td>
<td>State</td>
<td>Other Non-Federal</td>
<td>Total</td>
</tr>
<tr>
<td>Groundwater</td>
<td>3.1</td>
<td>$68,437</td>
<td>$33,841</td>
<td>$140,331</td>
<td>$5,622</td>
</tr>
<tr>
<td>Using Water of Impaired Quality</td>
<td>5.9</td>
<td>105,905</td>
<td>152,390</td>
<td>377,386</td>
<td>81,675</td>
</tr>
<tr>
<td>Groundwater Mgmt.</td>
<td>3.0</td>
<td>64,679</td>
<td>142,408</td>
<td>293,421</td>
<td>62,397</td>
</tr>
<tr>
<td>Watershed Protect.</td>
<td>9.1</td>
<td>117,333</td>
<td>520,966</td>
<td>657,297</td>
<td>201,413</td>
</tr>
<tr>
<td>Water Quality Mgmt. Protection</td>
<td>0.3</td>
<td>10,751</td>
<td>9,446</td>
<td>38,206</td>
<td>4,971</td>
</tr>
<tr>
<td>Water Quality Control</td>
<td>11.9</td>
<td>129,773</td>
<td>267,684</td>
<td>560,965</td>
<td>457,187</td>
</tr>
<tr>
<td>Pollutant Identification</td>
<td>3.8</td>
<td>63,897</td>
<td>441,929</td>
<td>346,865</td>
<td>121,281</td>
</tr>
<tr>
<td>Pollutant Source &amp; Fate</td>
<td>15.6</td>
<td>368,897</td>
<td>691,653</td>
<td>1,015,064</td>
<td>393,168</td>
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<tr>
<td>Water in Soils</td>
<td>28.0</td>
<td>674,931</td>
<td>309,641</td>
<td>2,014,945</td>
<td>481,162</td>
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<tr>
<td>Chemical Processes</td>
<td>3.1</td>
<td>55,095</td>
<td>44,397</td>
<td>204,958</td>
<td>41,917</td>
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<tr>
<td>Total</td>
<td>88.1</td>
<td>$1,756,093</td>
<td>$2,677,095</td>
<td>$5,955,576</td>
<td>$1,959,632</td>
</tr>
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</table>

*Scientist year(s)  
**Cooperative State Research Service
The funding data indicate that groundwater quality research requires a significant financial investment. The support level from Table 1 is $140,300 per SAES scientist. Figures in Table 2 demonstrate the ability of the SAES scientists to attract both private and federal extramural funds, as well as support from state sources. Private sector support (other non-federal sources) of 16 percent is well above the national average of 3-4 percent support provided by the private sector for university research in general. Funds from the CSRS represent 14 percent of the total support, and other federal funds represent 22 percent.

TABLE 2. GROUNDWATER QUALITY RESEARCH IN THE STATE AGRICULTURAL EXPERIMENT STATIONS BY SOURCES OF FUNDING (FY'83)

<table>
<thead>
<tr>
<th>SOURCE</th>
<th>AMOUNT</th>
<th>PERCENT</th>
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<tr>
<td>STATE</td>
<td>$ 5,955,576</td>
<td>48</td>
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<tr>
<td>FEDERAL</td>
<td>4,433,188</td>
<td>36</td>
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<tr>
<td>OTHER NON FEDERAL</td>
<td>1,959,632</td>
<td>16</td>
</tr>
<tr>
<td>TOTAL . . . . .</td>
<td>$12,348,396</td>
<td>100</td>
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</table>

As noted earlier, specific groundwater quality and quantity problems could be explored on a regional basis. Table 3 has been developed from CRIS information to illustrate the SY’s and dollars from the three sources - state, federal, and private - for groundwater research. From Table 3, it is seen that past research (FY'83) in groundwater has been concentrated in the Western and Southern regions. Needs of the North Central and Northeastern regions have been identified by respective regional research committees for dramatic increases in research, as well.

Research in the related area of pesticides, identified by CRIS, is given in Table 4. A substantial effort in SY's and financial support is devoted within SAES (FY'83) in this area. Major research efforts are coded as Fundamental Biology, Improved Means of Non-Pesticide Control and
Improved Pesticide Use Patterns. Clearly, scientists working in these areas can make very important contributions to research on groundwater quality.
TABLE 3. Groundwater and Related Water Resources Research in State Agricultural Experiment Stations by Region (FY'83)

<table>
<thead>
<tr>
<th>Regions</th>
<th>SY'S*</th>
<th>CSRS**</th>
<th>Federal</th>
<th>State</th>
<th>Non-Federal</th>
<th>Total</th>
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<tr>
<td>Northeast Region</td>
<td>9.3</td>
<td>$296,062</td>
<td>$844,582</td>
<td>$393,656</td>
<td>$168,921</td>
<td>$1,703,221</td>
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<tr>
<td>SOUTHERN REGION</td>
<td>31.6</td>
<td>$760,882</td>
<td>$896,832</td>
<td>$2,501,420</td>
<td>$628,948</td>
<td>$4,788,082</td>
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<td>NORTH CENTRAL</td>
<td>13.2</td>
<td>$283,672</td>
<td>$279,731</td>
<td>$950,495</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>SD, WI)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WESTERN REGION</td>
<td>34.0</td>
<td>$415,477</td>
<td>$655,950</td>
<td>$2,110,005</td>
<td>$866,851</td>
<td>$4,048,283</td>
</tr>
<tr>
<td>(AK, AZ, CA, CO, GU,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HI, ID, MT, NV, NM,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OR, UT, WA, WY)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td>88.1</td>
<td>$1,756,093</td>
<td>$2,677,095</td>
<td>$5,955,576</td>
<td>$1,959,632</td>
<td>$12,348,396</td>
</tr>
</tbody>
</table>

* Scientist year(s)  
** Cooperative State Research Service
### TABLE 4. State Agricultural Experiment Stations' Research in Pesticides

<table>
<thead>
<tr>
<th>Area</th>
<th>SYS</th>
<th>CSRS</th>
<th>Other Federal</th>
<th>State</th>
<th>Other Non-Federal</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fund Biology</td>
<td>308.0</td>
<td>$7,201,847</td>
<td>$4,579,556</td>
<td>$22,697,037</td>
<td>$5,146,454</td>
<td>$39,624,893</td>
</tr>
<tr>
<td>Improved Means of Non Pest. Control</td>
<td>208.5</td>
<td>5,248,475</td>
<td>2,373,939</td>
<td>16,740,695</td>
<td>3,853,569</td>
<td>28,216,678</td>
</tr>
<tr>
<td>Improve Pest. Use Patterns</td>
<td>133.8</td>
<td>2,818,355</td>
<td>1,163,843</td>
<td>10,843,577</td>
<td>3,601,304</td>
<td>18,427,080</td>
</tr>
<tr>
<td>Toxicology, Pathology, Metabolism, Fate of Pest.</td>
<td>31.8</td>
<td>1,154,410</td>
<td>1,019,929</td>
<td>1,981,531</td>
<td>481,891</td>
<td>4,637,760</td>
</tr>
<tr>
<td>Economics of Pest Control</td>
<td>18.4</td>
<td>716,750</td>
<td>333,734</td>
<td>1,295,947</td>
<td>383,051</td>
<td>2,729,483</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>700.6</td>
<td>$17,139,837</td>
<td>$9,471,001</td>
<td>$53,558,787</td>
<td>$13,466,268</td>
<td>$93,635,894</td>
</tr>
</tbody>
</table>
2. Within Federal and Other Agencies

Groundwater is the source of 50 percent of the drinking water in the United States and is used in large quantities for irrigation and industrial purposes. Although no federal laws and few state laws have groundwater contamination as their major focus, there are many federal and state statutes which aim to control or mitigate groundwater contamination. The legal framework for federal efforts to protect groundwater is a group of statutes aimed primarily at other environmental problems that focus indirectly on groundwater. Because of this lack of focus and the diversity of sources for groundwater contamination, numerous federal and state agencies are involved in groundwater quality and quantity research. Agencies which support groundwater research internally, externally or both are as follows:

Environmental Protection Agency

Groundwater research programs in the Environmental Protection Agency (EPA) are the responsibility of the Office of Research and Development (ORD). Funds to support this program come from the Safe Drinking Water Act (SDWA) of 1974 and the Resource Conservation and Recovery Act (RCRA) of 1976. Two internal research committees advise the ORD regarding groundwater research needs: (i) Hazardous Waste Research Committee and (ii) Water Research Committee. The ORD conducts its programs in fourteen laboratories and several field stations. In addition to designing a research program to satisfy multiple client needs, ORD works with other federal agencies concerned with groundwater problems. A Memorandum of Understanding between EPA and the US Geological Survey (USGS) was established in August 1981 providing an umbrella for formal coordination of the two agencies' programs. The EPA also conducts joint research projects with several other agencies including the US Air Force, the US Department of Energy and the National Research Council.
EPA laboratories with major responsibilities in the area of groundwater quality are the Environmental Monitoring Systems Laboratory-Las Vegas, Nevada, the Robert S. Kerr Environmental Research Laboratory-Ada, Oklahoma, and the Hazardous Waste Engineering Research Laboratory in Cincinnati, Ohio. Resources dedicated to research underway in these laboratories are as follows:

<table>
<thead>
<tr>
<th>Research Areas</th>
<th>Total Dollars (in 1000's)</th>
<th>Scientist-Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitoring</td>
<td>$ 1,763.0</td>
<td>9.4</td>
</tr>
<tr>
<td>Prediction</td>
<td>6,307.1</td>
<td>31.0</td>
</tr>
<tr>
<td>Aquifer Cleanup or Restoration</td>
<td>853.6</td>
<td>6.7</td>
</tr>
<tr>
<td>Hazardous Waste Engineering</td>
<td>9,272.0</td>
<td>46.2</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$18,195.7</strong></td>
<td><strong>93.3</strong></td>
</tr>
</tbody>
</table>

The Environmental Monitoring Systems Laboratory (EMSL) conducts groundwater monitoring research to support the underground injection control regulations of the Safe Drinking Water Act and the Groundwater Protection Regulation of the Resource Conservation and Recovery Act. Spin-off from these programs has established geophysical technical support to assist the Comprehensive Environmental Response, Compensation and Liability Act (Superfund) in hazardous waste site investigations. This research also offers techniques to detect leaks from underground fuel storage tanks. The program includes research in three primary areas:

- groundwater monitoring and sampling methods in both unsaturated and saturated zones
- application of surface and downhole geophysics to subsurface characterization
• data interpretation and analysis.

Quality assurance is addressed in all areas.

The Robert S. Kerr Environmental Research Laboratory (RSKERL) is responsible for conducting investigations to provide technical information upon which EPA can base its response to those groundwater issues which are addressed in a number of environmental laws.

Management considerations include the ability to identify, evaluate and control potential sources of groundwater contamination in order to assess the risk and impacts associated with emergency spill situations and other contamination events and to take remedial action in the restoration of groundwater quality. Research at RSKERL in hydrologic processes is directed toward three areas: (i) expanding understanding of the physics of fluid flow through porous media, (ii) developing methodology for evaluating the degree of heterogeneity (spatial variability) of both physical and chemical processes in the subsurface and (iii) advancing mathematical techniques for forecasting spatial and temporal distribution of chemicals in subsurface soils, as well as fluid fluxes in the subsurface environment.

The Hazardous Waste Engineering Research Laboratory (HWERL) has two program areas that support research and development of hazardous waste source control. The first program is in support of the Resource Conservation and Recovery Act (RCRA) and is concerned with disposal of hazardous waste in landfills, surface impoundments and other geological storage facilities. The second program is in support of the Superfund and is concerned with development of technology for cleanup of uncontrolled hazardous waste sites.

In addition to in-house programs conducted in the above three laboratories, EPA also provides extramural support for research programs outside the agency. Among these is the National Center for Groundwater Research, operated by a consortium including the University of Oklahoma, Oklahoma State University and Rice University. In addition to the National Center, numerous grants and contracts support research in other universities.
The report on the review of EPA's groundwater research program by the Groundwater Research Review Committee, Science Advisory Board, USEPA, states, "Even statutes of such enormous importance as RCRA and Superfund, however, have little in their legislative histories to suggest that groundwater protection was a principal focus, or that there was an adequate database available on which to make legislative decisions. Unlike surface water or air pollution problems, EPA knows relatively little about groundwater. Given the emphasis implied in the list of laws above, it should be clear that there is a critical need for adequate research into all aspects of groundwater if the Agency is to fulfill its many responsibilities... It is not surprising that within the Federal government little progress has been made to date to pull together the fragmented and disparate programs pertaining to groundwater. Even within EPA itself, which holds the predominant responsibility, efforts to coordinate the management of numerous groundwater-related programs are just beginning."

The recently organized Office of Groundwater Protection has been established to coordinate efforts in the EPA and to support programs at the state level. An initial effort of this office has been to commission a series of symposia on state and local needs. Many faculty from land-grant universities have been involved and results are being included in faculty programming.

US Geological Survey

Groundwater activities in the US Geological Survey (USGS) are multidisciplinary in nature and are related to every program element of the Water Resources Division. Groundwater activities involve geology, hydraulics, water chemistry, hydrology, biology, geochemistry and groundwater/surface water interactions. In FY 1984, the total amount of funding available to the Water Resources Division was approximately $225 million, including appropriated funds, reimbursable funds, and matching funds from the States. Of this amount, approximately $90 million was expended for the collection of groundwater data and for conducting groundwater
investigations. USGS basic and applied research is intended to improve the understanding of the hydrological, geological, geochemical and microbiological processes that control the movement, both alteration and fate of toxic substances in groundwater. Approximately $8.5 million supports both in-house and extramural research.

The USGS is assigned the administration of the national program for water resources research under the Water Resources Research Act of 1964 as amended. The state institutes formed under this program at land-grant universities are focusing on groundwater contamination problems and would be cooperators in the program proposed here.

USDA/Agricultural Research Service

The current water quality research commitment in USDA’s Agricultural Research Service (ARS) exceeds $6 million. However, about ninety percent is devoted to development of techniques for assessing and enhancing quality of surface water. The current ARS programs on groundwater quality are in four major categories: (i) nutrients, (ii) pesticides, (iii) salinity, and (iv) modeling. Recent progress in groundwater quality is based on advances in agricultural chemical technology, hydrology and soil water chemistry in eight areas: (i) efficiency of use, (ii) integrated pest management, (iii) improved chemical disposal practices, (iv) environmental modeling, (v) soil chemistry, (vi) salinity, (vii) nutrients and (viii) process models. The ARS plan includes an estimated increase of 25 SY's at a cost of $5 million annually, which is an increase in groundwater quality research from 10 percent in 1983 to 25 percent of total funding for water quality research.

US Department of Energy

The US Department of Energy (DOE) is conducting a major groundwater research program. It is spending approximately $20 million per year on source control, $20 million per year on aquifer cleanup and $10 million per year on monitoring. Objectives of the program are to provide a base of fundamental scientific information so that geochemical, hydrological and
biophysical mechanisms that contribute to the transport and long-term fate of energy-related contaminants in natural systems can be understood and described. Areas of emphasis include the understanding of geochemical processes and transport of energy-related organic compounds and mixtures in the subsurface environment. A new ten-year program to develop a "new generation" prediction model is proposed but unfunded. The program involves the application of supercomputers, laboratory/university consortia and controlled field-scale experiments. This program proposal has been reviewed by the Groundwater Committee of the National Research Council whose recommendations are under consideration by DOE.

US Air Force

The major thrust of this program is to develop methods for predicting the impact of various Air Force activities including the fate of solvents, waste disposal and accidental spills which may result in groundwater contamination. Delineation of the extent and impacts of dioxin contamination resulting primarily from use, storage and disposal of agent orange is also a major thrust. Procedures for restoration of groundwater quality are being investigated. Topics under investigation include sorption and degradation of trichloroethylene (TCE), aromatic hydrocarbons and other chlorinated compounds in subsurface environments, assessment of heavy metal mobility in soils at several Air Force bases, incineration of dioxin-contaminated soils, feasibility of applied genetic engineering techniques to achieve dioxin biodegradation and evaluation of methods to enhance in situ biodegradation of TCE and other organic compounds in contaminated soils and groundwater.

US Army

The objectives of this program are to develop cost-effective pollution control monitoring systems, to provide environmental and health effects data on army-unique pollutants, and to promote efficient management of environmental quality programs through development of management systems and information data bases. Areas receiving emphasis include: (i) treatment
methods for groundwater and soil contamination, (ii) environmental early warning systems, (iii) landfill leachate control methods, (iv) hazardous waste management techniques, (v) advanced technology for contaminant control/cleanup and (vi) alluvial intrusion. The Corps of Engineers - Civil Works Programs - are involved in water management and are potential cooperators in institutional studies.

Tennessee Valley Authority

The objective of this program is to provide the information and tools needed for assessing the significance of potential pollutant sources, preventing contamination and isolating sources of contamination. Ongoing activities include assessment of problems associated with groundwater quality and the disposal of power plant wastes, development and demonstration of methods for disposal or utilization of fly ash, flue gas desulfurization/sludge, coal cleaning waste and fluidized bed combustion waste, and development of a comprehensive data base and management method for land application of wastewater treatment sludge.

Electric Power Research Institute

The Electric Power Research Institute (EPRI) initiated the Solid Waste Environmental Studies (SWES) program to develop data and methods for predicting the fate of constituents in solid waste at utility disposal sites. The ultimate goal of the SWES project is to improve (develop) and validate geohydrochemical models for predicting the release, transport, transformation and environmental fate of chemicals associated with utility solid waste. The goals of the SWES project include both near-term and long-term objectives.
SUMMARY

In addition to the above programs there are research programs underway in state agencies and private universities. These programs are funded by federal, state, and private organizations or companies. In many cases, these programs are working cooperatively with the above agencies as well as independently. It is obvious from the above that a broad spectrum of groundwater research is currently underway in the United States and is addressing, to some degree, major issues surrounding the potential for groundwater contamination and cleanup of groundwater. In general, the quality of this research is excellent. However, the quantity of groundwater research, although significant, is not sufficient to develop the knowledge required for insuring an adequate quantity of acceptable quality groundwater in the presence of sustained agricultural, industrial and municipal activities.

One area which does not appear to be receiving adequate attention is transfer of this technology into the users community, whether that be state or private. Another area which is not receiving appropriate attention is economic analysis of treatment, source management and aquifer protection. Information about cost effectiveness of these actions is necessary if private or public entities are to respond rationally to groundwater contamination issues.
A summary of the research areas or topics being studied in federal agencies is provided in the following table:

<table>
<thead>
<tr>
<th>AGENCY</th>
<th>SOURCE CONTROL</th>
<th>PREDICTION</th>
<th>MONITORING</th>
<th>CLEANUP</th>
<th>INSTITUTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>US DEPT. OF AGRICULTURE (ARS)</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>US ARMY</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>US AIR FORCE</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>US DEPT OF ENERGY</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>US GEOLOGICAL SURVEY</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>ENVIRON. PROTECTION AGENCY (EPA)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TENNESSEE VALLEY AUTHORITY (TVA)</td>
<td>X</td>
<td>X</td>
<td></td>
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</tr>
</tbody>
</table>
CHAPTER 5

RESEARCH NEEDS

There is an immediate need for increased research on issues of: source and prevention, fate, remedial and impact (economic, policies and institutional). Specific examples follow.

1. Source and Prevention Issues

A. Source Identification, Characterization and Prevention

Sources of groundwater contamination can be classified as diffuse, such as large agricultural fields, and point, such as urban or industrial effluents or toxic waste disposal sites. Currently, many point sources are well-documented by EPA and a continuing program of remedial or preventive activity is underway for those that have been identified. Diffuse sources of contamination are most often agricultural, although a number of waste disposal sites can be included in this category. Further information is required on:

(i) The quantities of specific chemicals being introduced to the environment as a result of routine agricultural practices,

(ii) The extent of existing soil and groundwater contamination from prior chemical usage,

(iii) Identification of groundwater recharge areas and quantification of recharge rates,

(iv) Configuration and hydraulic characteristics of aquifers and establishment of groundwater flow regimes,

(v) Balancing of management activities between sources of potential contamination on the basis of minimizing risk with available public resources, and

(vi) Design factors for risk management.
B. Source Management

Proper management of chemicals and the land to which they are applied can minimize the potential for groundwater contamination. Much attention has been given to issues in the agricultural community through identification of Best Management Practices (BMP) for agricultural systems and the development of Integrated Pest Management (IPM) programs that seek to reduce chemical usage. Organizational arrangements to support BMP and IPM are in early stages of their evolution. A number of potentially useful results has been produced, but much remains to be done. Further research is required on:

(i) Profitable alternative agronomic practices that produce maximum pest control or plant response from a minimal quantity of applied chemicals. Specifically:

a. improved application efficiency
   - precision placement and calibration systems
   - chemigation principles and practices
   - less reliance on systems that require soil application

b. accurate determination of chemical application timing and rates
   - more accurate determination of required chemical rates
   - pest population identification
   - improved irrigation scheduling and application to minimize chemical leaching
   - application rates based upon soil and climatic factors and equipment constraints

c. identification of integrated pest management practices that make more judicious use of chemicals
   - scouting (or monitoring) programs to determine when pest
infestations are severe enough to require pesticide control
  • breeding of insect-resistant crop varieties
  • crop, chemical and tillage rotations that provide pest control with maximum efficiency of a minimal quantity of chemical
  • biological pest control
d. water management techniques to reduce leaching
  • irrigation scheduling to reduce water movement below the root zone without salt buildup
  • recycling of agricultural chemicals in groundwater used for irrigation, e.g. nitrate recycling
e. Regulatory, fiscal incentives and local organizations to manage risk

(ii) Registration protocols that identify environmental circumstances (soil and climatological) that could potentially result in the migration to groundwater of an otherwise safely used agricultural chemical. Specifically:
  a. realistic screening tests for pesticide fate under field conditions
    • laboratory studies that can be reliably extrapolated to the field
    • standardized field study protocols
    • consideration of regional differences in mediating factors affecting pesticide fate
  b. use of label restrictions to prevent chemical usage in uniquely hazardous environmental circumstances
  c. applicator training, regulation and organizational alternatives

(iii) Environmentally sound criteria to guide the synthesis of new agricultural chemicals. Specific improvements will include:
  a. nitrification inhibitors to minimize nitrate available for leaching
b. controlled release formulations

c. drift and leaching control additives to inhibit groundwater transport

d. increased specificity, activity or selectivity of active ingredients

e. chemicals effective at extremely low application rates

f. less toxic chemicals, yet rapidly degraded, or non-mobile in soil

(iv) Public management options including alternative uses for those lands identified as principal groundwater recharge zones, so that chemical application to those lands can be minimized.

a. zoning restrictions and other land use approaches

b. economic consequences (See 4, "Impact Issues")

c. policies and laws to impact the implementation of wiser site application usage and control

(v) Improved pesticide storage, handling and disposal practices, including:

a. safe storage facilities

b. packaging that is resistant to leakage from normal handling

c. control measures for localized, concentrated spills

d. incineration methods for disposal

e. tank rinsate capture and disposal

(vi) Point source management

a. improved handling of animal wastes including environmentally-oriented land application programs and on-site storage

b. topsoil cycling with aid of barnyard manure, "clean" sewage sludge, etc.

c. development of biological treatment plants on a farm scale

(vii) Prediction of storm events that can concentrate chemicals or speed "wash out"
2. Fate issues

A. Chemodynamics

All chemicals introduced into the soil/groundwater systems are subject to physical, chemical and biological processes that act in concert to determine the chemical's fate. Prediction of the extent and duration of groundwater contamination depends upon an adequate understanding of these dynamic processes. Although previous work has identified the general character of these processes, there is currently a lack of adequate understanding of them under most field conditions and with respect to many of the new organic chemicals being introduced into the environment. Basic research is needed in the following areas:

(i) Chemical and biological degradation processes

a. development of strains of micro-organisms with the ability to degrade selectively certain organic chemicals
b. effects of transient chemical presence and varying concentrations upon the ability of soil microorganisms to degrade applied chemicals
c. characterization of the role of subsurface organic and inorganic compounds in chemical and biochemical degradation within aquifers
d. investigation of the role of subsurface microorganisms in chemical degradation
e. development of aseptic sampling devices and improved experimental methods to supplement traditional approaches in degradation studies
f. influence of pesticide formulation upon susceptibility to degradation
g. determination of the kinetics of both chemical and biological processes as functions of environmental and chemical factors such as $O_2$ concentration, pH, temperature and chemical molecular structure
h. effect of spatial and temporal variability in degradation processes upon chemical concentrations in soil and groundwater

i. in situ study of microbiological degradation processes below the active crop root zone

j. development of in situ persistence estimates

(ii) Mobility and leaching processes

a. measurement of sorption as a function of soil type, chemical molecular structure, pH, concentration and organic matter and bioconcentration by the microbial population

b. identification of sorption relationships in multiple sorbate systems

c. kinetics of salt dissolution and precipitation during leaching

d. influence of pesticide formulation upon sorption and leaching

e. influence of soil structure and aggregation upon water and chemical movement directly to deeper soil depths through macropores or preferred pathways

f. effect of spatial variation in soil sorption or leaching processes upon chemical movement to groundwater

g. effect of soil layering on unstable wetting fronts and subsequent movement of chemicals in preferred paths (fingers) to groundwater

h. kinetics of solute adsorption during leaching

i. influence of suspended or dissolved adsorbants (dissolved organic matter, suspended clay) on transport of adsorbing chemical

j. effect of Karst topography

(iii) Volatilization and plant uptake processes

a. quantification of volatilized losses of applied chemicals
b. evaluation of foliar and surface applications for potential volatile losses

B. Measuring and Monitoring Protocols

Substantial efforts are underway to ascertain the extent of groundwater contamination or the potential for soil-borne materials to migrate to groundwater. Many of these efforts utilize limited numbers of samples in both space and time as the criteria upon which rather far-reaching decisions are made. Given the large temporal and spatial variability of the soil/groundwater system, this is recognized to be an intellectually naive but currently pragmatic approach.

Research is needed to develop:

(i) Improved methods for assessing seasonal and spatial variability of salts and chemicals in soil and groundwater
   a. redesigned spatial sampling patterns
   b. statistical methods that consider the spatial array of sampling points
   c. estimates of residence times within the system

(ii) Innovative statistical methods for interpreting sparse data such as limited numbers of sampling events

(iii) Improved analytical methods that make possible analysis of greater numbers of samples at reduced cost per sample

(iv) Improved methods of extrapolating from point measurements to larger areas such as fields or watersheds

C. Predictive Models of Water and Chemical Fate

Simulation models of the behavior of chemicals in the soil/groundwater system are becoming valuable tools in assessing the fate of groundwater or soil contaminants. These models can be useful on three levels. The research community can use them in their most mechanistic form to test the understanding of basic physical, chemical and
biological processes operating in the system. On a second level, simplified forms of these models can be used by community managers or regulatory personnel to predict in broad terms the environmental fate of a chemical introduced into the system and to determine those geographic regions and cropping systems where use of a specific chemical poses a potentially serious threat to groundwater. These models are thereby useful in a prospective manner by regulators and managers in the administration of preventative measures. On a third level, educators and extension personnel can use the simple models to promote better public understanding of the complex issues involved in chemical management and maintenance of groundwater quality. Models to serve all three purposes currently exist, but much development and testing work remains specifically to produce:

(i) Appropriate methods to consider the effects of spatially variable processes in the models including the possible development of stochastic models

(ii) Transferable and generalized models of groundwater flow regimes, particularly for macropore, fractured and Karst topography

(iii) Computer graphics capabilities and enhanced visual display for those models used for educational purposes

(iv) Experimental protocols that provide reliable data for testing and validation of models

(v) Methods of extrapolating from point simulations to larger areas

(vi) Reliable transit equations

(vii) Field data to verify models

3. Remedial (Corrective) Issues

Once a chemical or contaminant has entered the soil or reached the groundwater there are few existing technologies that can be used to remove the chemical from the system, thus
the above emphasis on prevention. An exception is the relatively localized contamination in buried waste-disposal sites. In most cases, we can only wait for the chemical to be degraded, diluted or purged within the system by the slow recharge processes. Given our limited access to the soil/groundwater system, we need to develop economical remedial procedures that will allow decontamination of groundwater at those few points of access.

Advances from research in biotechnology offer impressive new methods to attack groundwater pollution in the future. Bacteria to help speed the breakdown of pesticides are being "genetically engineered." Recombinant DNA techniques show promise to develop organisms which can quickly degrade pesticides and other pollutants. Research is needed on:

A. Water Treatment Methods

(i) Identification and introduction of microorganisms specifically adapted or genetically engineered for degradation of contaminating organic molecules in soil/groundwater systems such as water supply wells

(ii) Development of processes to stimulate indigenous microorganisms to degrade organic pollutants in zones near water supply wells

(iii) Development of water treatment devices that are useful on an individual household basis or at point of use

(iv) Development of community water treatment systems useful in rural areas that cannot meet the capital investment requirements needed for large-scale treatment

4. Impact (Economic, Policies) and Institutional Issues

Our present awareness of groundwater contamination is due in large measure to the demonstrated presence of chemicals in public and private water supplies. This contamination has toxicological, economic, political and social consequences, many of which are new to our experience. Further, the complex economic and policy setting in which
contamination occurs is poorly understood. A number of issues needs to be addressed:

A. Toxicological Consequences

(i) Risk assessment
   a. prediction or quantification of exposure to contaminated water and the impact on the food chain
   b. identification of toxicological implications of ingesting contaminated water for humans and animals

(ii) Development of laboratory protocols that accurately evaluate chemical effects upon humans

B. Economic, Social and Political Consequences

(i) Analysis of economic and other incentives that influence individual or business behavior in ways that lead to groundwater contamination

(ii) Economic evaluation of the potential human health risk and property impacts of groundwater contamination, particularly from agriculture

(iii) Appraisal of the economic and social consequences of alternative policies and institutional strategies for the control of groundwater contamination
   a. preventive strategies at the source
   b. community versus point-of-use treatment options
   c. treatment versus new water source development
   d. distributional consequences of management or control options - (who benefits, who pays?) Emphasis on type of farm, farmer vs. taxpayer, income category, etc.
CHAPTER 6

COMMUNICATING THE INFORMATION

All groundwater programs, whether for research, demonstration, implementation or public management, must have a solid basis in facts. Immense amounts of data and information exist and must be utilized during the research and implementation phases. In recent years some of the information support mechanisms have not kept pace with the increasing knowledge essential to improved groundwater management. These information systems must be examined and made an integral part of the research process.

The most critical step in the communications process is to put refined and tested information, technologies and activities into operation in America's rural communities. Technology transfer has been defined as "the sum of those activities leading to the adaptation, adoption or demonstration of new technology where the audio, visual and written media provide a partial vehicle for accomplishing the transfer." Technology transfer must be employed to gain the benefits of research investments on source and prevention, fate, remedial, impact and institutional issues related to groundwater contamination. Only in this way can increased understanding have an impact upon daily decision-making at local, state and federal levels.

1. Transferring the Technology

Successful technology transfer programs on issues related to groundwater contamination need to be integrated with existing rural and urban environmental and community programs. This can be accomplished efficiently through close cooperation between State Cooperative Extension, State Water Quality managers, USGS, Water Resources Research Institutes, Soil Conservation Service personnel and researchers within land-grant and other institutions. Substantial experience with technology transfer on other issues exists in these institutions and this expertise will be employed.

Recent advances in computerized information retrieval and transfer systems,
electronic mail and computerization of many county extension offices provide an established framework that can be utilized in the transfer of research advances on issues related to groundwater contamination. This framework will insure rapid, efficient transfer of information as it is developed, and with respect to local issues that demand immediate attention.

The challenges presented by the problems associated with groundwater contamination will require the development of new capabilities within Cooperative Extension and other local agencies. A national assessment by the Cooperative Extension System has pointed out the high-need topics of education on health effects of contaminated water, sources of contamination and movement into groundwater and best management practices to prevent groundwater contamination.

Because these have not been traditional extension topics, new linkages to other institutions, delivery methods and new staff resources will be needed. Nevertheless, Cooperative Extension has begun to address these issues. Some examples are:

- On Long Island, New York, Cooperative Extension has participated in addressing the problems of aldicarb contamination and procedures to minimize adverse impacts.
- In Texas, Cooperative Extension programs have helped cotton farmers to reduce irrigation amounts by 50 percent and have assisted homeowners in reducing water use.
- Nebraska Cooperative Extension programs helped to save an estimated 1.5 million acre feet of water through irrigation scheduling in 1983.
- In Arizona, Cooperative Extension has assisted farmers with programs to install and maintain state mandated water meters on irrigation wells.
2. **Information Transfer Issues**

A. The diverse audiences that require information on groundwater issues must be identified and distinguished as technology transfer programs are developed. Model extension programs need to be developed for target audiences:

(i) Regulatory agencies  
(ii) Community managers  
(iii) Agriculturalists  
(iv) Governmental officials  
(v) Health officials  
(vi) Planning boards  
(vii) Chemical industry  
(viii) General public

B. Nationally coordinated, regionally focused efforts must be undertaken to develop educational materials on the topic of groundwater and chemicals. These materials:

(i) Must recognize specific regional aspects of groundwater contamination and the need for regional experts  
(ii) Must target each of the audiences identified above and adapt the content appropriately  
(iii) Might consist of such specific topics as:  
    a. nitrates in drinking water  
    b. pesticides in drinking water  
    c. pesticide movement and degradation in soil  
    d. toxicology of water pollutants  
    e. fertilizer movement in soil  
    f. basic concepts of water movement in soil
g. basic concepts of soil biology and chemistry
h. effects of contemporary agricultural practices upon the environment
i. safe use and application of agricultural chemicals
j. alternative agricultural practices analyzed on basis of both technical and economic aspects
k. irrigating water management (e.g. irrigation scheduling and nutrient recycling)

C. Extensive and coordinated use must be made of computer technology in the development of information and technology transfer programs. Computerized approaches can be taken in:
   (i) Data base management
   (ii) Information exchange (networking) between agencies, universities and extension offices
   (iii) Educational programs

D. Identification of research needs to agricultural experiment station scientists.

3. Personnel Issues

A. New positions need to be created within research and extension that will focus on groundwater quality in urban and rural environments and that will consider new clientele related to agricultural, industrial and domestic sources of contamination.
   (i) As new people are hired, attention should be given to their educational backgrounds in the sciences related to groundwater quality. Redirection of existing personnel is not the long run answer, given their general lack of training in pertinent subject matter.
   (ii) Groundwater specialists must develop close ties with such researchers as soil scientists, hydrologists, engineers, toxicologists, geologists and
statisticians if groundwater programs are to be effective. This is due to the interdisciplinary nature of groundwater problems. Some of this expertise may exist outside the traditional land-grant system.

B. To handle immediate problems, existing extension personnel must be trained in groundwater issues to the greatest feasible degree and utilized for technology transfer in the interim period until more personnel are hired with specialization in groundwater.
CHAPTER 7

NATURE OF THE PROGRAM

Exemplary research and extension programs are presented that address the selected research and extension needs outlined previously. These are intended as examples only and should not be interpreted as comprehensive or exclusive of any project that is relevant to described research needs.

Many research and extension needs clearly have a regional commonality. Substantial opportunity thereby exists for multi-state, multi-agency research and extension efforts. Properly organized and coordinated, these efforts can address local groundwater issues in a manner that can provide fundamental information on natural processes that will be transferable to a variety of intra-regional situations. This leads us to suggest that any programs evolving from this proposal (perhaps in the forms outlined below) be identified as multi-state and multi-agency in design. In this way, experimental designs, objectives and interpretation of results can be accomplished with consideration for the broad application of any information gained.

Example projects include:

1. Methods for Predicting the Soil and Groundwater Fate of Toxic Substances

   A. Objective:

      To evolve a comprehensive prediction model for forecasting the environmental fate of chemicals released at and near the land surface.

   B. Approach:

      A prediction model will be developed which integrates laboratory, field and watershed scale research so that the environmental fate of agricultural chemicals, solvents and petroleum constituents may be predicted. Particular emphasis will be given to establishing how detailed experiments of soil under laboratory conditions relate to the highly variable conditions found in the field.
Representative soil conditions ranging from coarse textured sandy soils to fine textured clays will be considered in terms of the key processes which govern the fate of chemicals in soil and water. These processes include: adsorption-desorption phenomena, persistence and transport in the aqueous and vapor phases and transformations by chemical and biological mechanisms. This will identify how these processes can be methodologically related to the major soil conditions such as soil composition, pH, water content and the soil fauna and flora.

Techniques will be developed for predicting the average behavior of economically important contaminants and fertilizers in the field and within the watershed. Methods will be established for estimating the probability distribution of concentrations of contaminants so that the significance of extreme conditions in the soil-water system can be assessed.

2. Relationships between Efficiency and Fate

A. Objective:

To determine how chemical and physical properties of agricultural chemicals determine their biological efficacy and their fate in the environment, and to transmit this information to the agricultural community.

B. Approach:

A study will be made of agricultural chemicals to identify their chemical and physical properties that determine their efficiency for crop production and which determine their fate under the representative soil and water condition evaluated in project area 1. In some cases a chemical may have properties which are desirable for pest control but contribute to persistence and mobility in the soil.
More effective chemicals tend to have higher acute mammalian toxicity and greater persistence. Factors which govern the persistence and mobility will be investigated using the methodological base established in project area 1. Predictive techniques will be developed and applied so that pesticides can be screened in terms of their efficacy and environmental fate. This will provide a more precise evaluation procedure for pesticide management and use. The degree to which the needs of crop production, especially minor crops, may be balanced with the need to protect water resources will be explicitly determined. Effective ways of balancing the needs of crop production and water protection will be formulated in conjunction with a corresponding extension program for agriculturalists.

3. **Selective Pesticides**
   
   A. **Objective:**

   To establish procedures for developing effective, but selective pesticides.

   B. **Approach:**

   An explicit aim of the investigations will be to ascertain how pesticides can be formulated to balance their efficacy for pest control with the need to have the lowest acute or chronic mammalian toxicity. This investigation will seek to establish procedures by which pesticides can be formulated so that efficacy against target pests is increased and toxicity to non-target organisms are decreased.

4. **Crop Production Practices**

   A. **Objective:**

   To develop and test new chemical and non-chemical crop production practices that can be substituted by growers to reduce or replace the usage of pesticides with undesirable impacts on groundwater, and to develop educational programs for growers based on these alternative methods and investigate institutions and
incentives to facilitate adoption.

B. Approach:

There is a critical need to develop and implement a much larger number of effective low-cost techniques for pest control, especially where there is interaction between groundwater quality and agricultural practices. Farmers need to escape from the high technology trap of being compelled to rely on a decreasing number of pesticides. This need is especially critical for producers of crops where the availability of effective pesticides is steadily diminishing.

Farmers need an economical array of pest control tactics that can be economically deployed with flexibility and ease when changes in weather and pest populations occur. This investigation will evaluate and identify effective pest control techniques which include chemicals specific to the target pests, cultural manipulation, traps, biological controls and the use of different plant varieties in relation to soil and groundwater properties. Explicit consideration will be given to the need to balance costs objectively, effects on crop yields and consequences for the soil and water environment. It is expected that these techniques will use computerized data bases and use personal computers as management aids in identifying and applying pest control programs.

Subsidies and regulations, information and technical assistance and organizational changes including liability will be explored. These and similar factors are important in the adoption of lower risk practices and in the design of risk management programs.

5. Risk Assessment and Information Transfer

A. Objective:

To make risk assessment information available to communities,
agriculturalists and individuals dependent on groundwater.

B. Approach:

Toxicology is fundamental to groundwater or drinking water risk assessment. The real concerns regarding chemicals in groundwater are establishing whether low levels of contamination found in groundwater are of concern to the health of individuals. For many chemicals found in groundwater we have much toxicological information. Theories of risk assessment will be developed and applied to guide programs of information transfer.

A model program for research, training and extension in environmental toxicology as impacted by pesticides will be established. The need and feasibility of establishing "Toxicology Information Centers" will be explored. The possibility of linking these Centers through a Toxicological Information Network (EXTOXNET) will be pursued. It is believed that this program will provide critical support in meeting the rapidly increasing demand for toxicological information.

6. Groundwater Flow Regimes

A. Objective:

To develop a research base on groundwater flow regimes including the temporal and spatial impact of chemicals on the groundwater system.

B. Approach:

This program will screen and evaluate the risks to groundwater posed by representative classes of pesticides when used in the recharge areas which supply drinking-water wells. The capacity of the soil system to assimilate and decompose pesticides will be assessed relative to permissible loading rates to groundwater. Loading rates and criteria for pesticides under representative soil, weather and cropping conditions will be developed using the toxicological data
developed in problem area 5. A combined research and extension program will be developed to provide information on five primary management questions:

(i) How to determine what prevention strategies should be chosen to optimize risk management?

(ii) When contamination occurs, how can its direction and extent be best determined so that appropriate remedial responses can be instituted?

(iii) How can the contamination be traced back to its source in space and time, so that the source can be properly identified and subsequently managed?

(iv) How can the recharge area of wells be delineated so that potential problems of pesticide contamination can be identified within the catchment area and prevented through the adoption of permissible loading criteria?

(v) How can irrigation be scheduled to minimize leaching of agricultural chemicals, yet avoid salt buildup in soils?

Corresponding documentation and informational materials will be developed and made available so that rural households and communities may adopt management measures to protect their wells.

7. Water Testing and Treatment: An Extension Program

A. Objective:

To develop an educational program on testing and treatment methods for groundwater contamination. To develop educational programs for public and private decision-makers on policy choices and their implications as well as the private and social costs of both contamination and abatement.
B. Approach:

Rural households that depend entirely on groundwater for their drinking water are facing the risks of contamination from pesticides, pathogenic micro-organisms, nitrates and other synthetic chemicals. As a result, the rural public now seeks the following information:

(i) Identification of contaminants in their water
(ii) Description of the identified contaminants
(iii) Identification of treatment options
(iv) Identification of prevention options
(v) Specification of costs of each option
(vi) Programs for public decision-makers at local and state levels on consequences of policy options

Accordingly, an extension program will be developed which specifies appropriate and cost-effective methods for testing drinking water which may contain contaminants. Treatment methods for removing the contaminants from public and private domestic wells will be evaluated in terms of their efficacy, costs and ease of use. Options will include: reverse osmosis, aeration, carbon filters and ion exchange resins. Guidelines for evaluation and selection of the water treatment options will be formulated and informational materials developed and made available for extension programs.

8. Economic and Social Impact Data

A. Objective:

To define, assess and evaluate the benefits and costs to the farmer and society of alternative strategies to prevent or control agricultural contamination of groundwater.
B. Approach:

The design and implementation of efficient groundwater contamination prevention in policies and strategies requires a greater understanding of the magnitude and economic roots of the problem, agriculture's contribution to that problem relative to other sources, specific practices that contribute to or help prevent contamination and the costs associated with contamination and its control.

A research program will be developed which assesses the magnitude and extent of the impacts of agricultural practices on groundwater contamination. The economic and social benefits of reducing health risks and other impacts of agricultural and other contamination of groundwater will be sought. Current data collection efforts on agricultural groundwater contaminants will be assessed in order to determine additional needs.

The effectiveness and economic implications of various management practices or institutional mechanisms that could be adopted to control or prevent agricultural pollution of groundwater will be studied.

9. Micro-economic Effects of Contamination

A. Objective:

To evaluate the economic effects on farm businesses of "new or safer" chemicals and crop production practices and to provide educational information for farmers.

B. Approach:

Changes in types of agricultural chemicals, application rates for agricultural chemicals and crop production practices will affect the profit situations of farmers and the input and output mix decisions which they make. An investigation will be made of how farmers will respond to additional operating constraints directed toward
groundwater pollution control consistent with their management goals, including risk management. Tillage or management options involving significant reduction in chemical use will be included. Cost and return budgets will be developed for the chemical application rates and crop production practices considered; and appropriate programming techniques will be employed as necessary to evaluate the firm level economic effects.

10. Macro-economic Effects of Contamination and Control

A. Objective:

To estimate the effects on local, regional and national economies of new agricultural chemicals, application rates and crop production practices which have acceptably minimal impacts on groundwater and to provide educational information for public affairs education concerned with agricultural pollution of groundwater.

B. Approach:

If farmers, either voluntarily or under institutional duress, change to new agricultural chemicals or adjust application rates and production practices, local economies and the national agricultural economy will be affected. Changes in farm economic situations will subsequently impact local economies. Regional economic models will be used to estimate aggregate impacts. Various price models will be used to estimate likely changes in commodity prices. Price implications are far ranging and will be examined relative to such diverse variables as land use, food cost and international trade.
CHAPTER 8

FUNDING

Funding for the groundwater quality program must be in addition to research and extension funds already provided to the USDA and federal agencies for related research programs. The primary purpose is to provide a fundamental research and extension program to ensure an adequate quantity of acceptable quality groundwater in the presence of sustained agricultural, industrial and municipal activities. Initial annual funding of at least $55 million should be provided to this program to meet critical needs.

Four major categories of grants are proposed to accomplish the goals of the program. These are research grants, fellowships, equipment, and extension grants:

1. **Research Grants**
   A. Research grants to individual scientists
   B. Multi-disciplinary research grants
   C. Young Investigator Research Grants

   It is essential that research grants be of a sufficient magnitude and duration to ensure that significant objectives can be accomplished. It is proposed that each grant should fund a significant research effort of individual scientists or groups of scientists. An amount of approximately $150,000/year/grant for at least 5 years is needed. For multi-disciplinary grants, an amount of at least $250,000/year and a term of at least 5 years is required. These grant amounts will include indirect costs. Experience with NIH Extramural Research Programs, NSF Research Programs, USDA Competitive Grants Programs, and data from State Agricultural Experiment Station Directors suggest these minimum levels of funding in order that scientists can enhance and maintain an effective research program.

   Multi-disciplinary research must be encouraged because the necessary research
goals in groundwater quality require the involvement of many disciplines for optimum progress. Close ties must be developed among researchers such as soil scientists, economists, sociologists, hydrologists, engineers, toxicologists, geologists and statisticians if a groundwater quality program is to be effective.

Existing programs of Competitive Grants, Special Grants or "earmarked" Hatch funding are potential mechanisms for supporting these research grants through the USDA. The Special Grants Program is favored because it retains the quality assurance of the competitive grants process and can incorporate regionally important issues. The present process for funding Integrated Pest Management which is administered by the Regional Associations of Agricultural Experiment Station Directors and CSRS serves as a model.

It is important to attract and support young investigators in groundwater quality research. This program should be analogous to the NSF Presidential Young Investigator Award Program. Faculty members within the first three years of their initial University appointment would be eligible for Young Investigator Awards in the groundwater quality program. The concept of a matching component from industry should be encouraged to enhance the level of support for the Young Investigators. It is proposed that the research grants must include some funds for essential equipment. Inadequate funding for equipment is a major hinderance to quality research in this program area.

2. Fellowships

A major effort should be established for increasing the number of young scientists educated in a groundwater quality program. Predoctoral fellowships with a term of up to 3 years and a renewable additional year are proposed to train the necessary young scientists. The incorporation of graduate students in the research grants will provide a very important opportunity for students to participate fully
3. Equipment and Facilities Grants

Groundwater quality research requires sophisticated instrumentation, facilities and computing equipment which are lacking in many laboratories. To meet needs for major equipment, facilities, computing and instrumentation, a grants program should be established to provide adequate funds to carry out strong research programs. It is proposed that the development of modern facilities and instrumentation and computing for the groundwater quality program be developed on a basis of matching funds. Matching funds might include a sharing between the university and the federal government, as well as between university, federal government and industry. The groundwater quality research program would be enhanced by strong university/government/industry relationships. Each of the partners has a very important stake in groundwater quality research.

4. Extension Grants

A unique feature of this proposal is the joint relationship between research and extension, including research on educational needs. Transfer of technology utilizing the well-established system of Cooperative Extension is crucial to the success of the program of groundwater quality research. The technology transfer program can be accomplished through close cooperation between Cooperative Extension personnel and researchers within land-grant and other institutions. Innovative and creative educational programs will be supported on the basis of proposals similar to research grants.

5. Program Support Level

Tables 5 and 6 illustrate critical areas and support level for the research and extension program in groundwater quality. An annual-based budget of $55 million will provide a significant contribution to this important research and extension
program. Because of our great dependence upon groundwater, it is essential that research and extension capabilities be supported in order to ensure adequate quantity of acceptable quality groundwater in the future.
Table 5. Grants Program for Research and Extension in Groundwater Quality

<table>
<thead>
<tr>
<th>Type of Grant</th>
<th>Support Level</th>
<th>Millions of Dollars</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RESEARCH</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Individual Research Grants</td>
<td></td>
<td>15.0</td>
</tr>
<tr>
<td>Provision for 80 grants at $150,000/year/grant (average including indirect costs) and to include $3 million for equipment essential for individual research grants. It is anticipated each grant award would be for 5 years.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multidisciplinary Research Grants</td>
<td></td>
<td>13.0</td>
</tr>
<tr>
<td>Provision for 42 grants at $250,000/year/grant (average including indirect costs) and to include $2.5 million for equipment and instrumentation. A regional approach would be encouraged.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Young Investigator Incentive Awards</td>
<td></td>
<td>1.5</td>
</tr>
<tr>
<td>Provision to fund 20 awards at $75,000/year. Support is intended to supplement salaries, provide essential equipment and to serve as a major impetus in starting a research program.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>FELLOWSHIPS</strong></td>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td>Provision for 60 pre-doctoral fellowships at $16,667/year/fellowship. The award would be for 3 years and would include provisions for tuition, fees, and research support.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>EQUIPMENT AND FACILITIES GRANTS</strong></td>
<td></td>
<td>12.0</td>
</tr>
<tr>
<td>Grants for facilities, specialized equipment, computing equipment, and instrumentation for research in groundwater quality. A matching program with the University/government/industry is proposed.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>EXTENSION GRANTS</strong></td>
<td></td>
<td>12.5</td>
</tr>
<tr>
<td>Innovative and creative grants to develop educational programs on testing, treatment, technology transfer, etc. will be supported. This would provide for 50 grants at $250,000/year/grant.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TOTAL .......... 55.0
Table 6. Support of Research/Extension Program Areas in Groundwater Quality

<table>
<thead>
<tr>
<th>Program Area</th>
<th>Support Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>RESEARCH</td>
<td>42.5</td>
</tr>
<tr>
<td>Source and Prevention</td>
<td>16.0</td>
</tr>
<tr>
<td>(Models, Processes and Methods for Identifying Sources and Prevention Practices)</td>
<td></td>
</tr>
<tr>
<td>Fate</td>
<td>14.0</td>
</tr>
<tr>
<td>(Models and Processes of Transport, Degradation and Fate)</td>
<td></td>
</tr>
<tr>
<td>Remedial (Corrective)</td>
<td>6.5</td>
</tr>
<tr>
<td>(Develop Treatment Technologies)</td>
<td></td>
</tr>
<tr>
<td>Impact and Institutional</td>
<td>6.0</td>
</tr>
<tr>
<td>(Toxicological, Economical, Social, Political and Institutional Consequences)</td>
<td></td>
</tr>
<tr>
<td>EXTENSION</td>
<td>12.5</td>
</tr>
<tr>
<td>Programs to make risk assessment information available to communities, development of toxicological guidelines for pesticides, cost-effective ways of technology transfer, water testing, water treatment, etc.</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>55.0</td>
</tr>
</tbody>
</table>
APPENDIX A

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GROUNDWATER QUALITY WORKSHOP

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