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# State of the Art of Technology for Rural Water System Development

R. T. Alguire
*University of Arkansas, Fayetteville*

Joe F. Nix
*University of Arkansas, Fayetteville*

H. C. MacDonald
*University of Arkansas, Fayetteville*

Robert E. Babcock
*University of Arkansas, Fayetteville*

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**UNIVERSITY OF ARKANSAS** · Fayetteville, Arkansas 72701

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R. T. Alguire
Joe F. Nix
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Robert E. Babcock

Arkansas Water Resources Research Center
University of Arkansas
Fayetteville, Arkansas
72701

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R. T. Alguire
Joe F. Nix
H. C. MacDonald
Robert E. Babcock

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Washington, D.C. 20036

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# INTRODUCTION

The objective of this study was to review the current state of the art in rural water system technology. This was to be accomplished by a literature review of the Water Resources Scientific Information Center (WRSIC), National Technical Information Service (NTIS), and Smithsonian Science Information Exchange (SSIE). This literature search was to be augmented by interviews with consulting engineers, operating system managers and industrial literature. Both groundwater and surface water technology was to be reviewed. The technology was then to be grouped into four classes: (1) current technology, (2) technology which has been developed, but not currently being used, (3) technology under development which looks promising, and (4) research needed. After the searches were conducted, it became feasible to combine group (2) and (3) into one group entitled technology under development but not fully utilized.

The literature searches began with the WRSIC File. A review of the descriptors applicable to this area was sent by phone to the SWRIC Center in Raleigh, N. C. Out of the several hundred thousand abstracts on file, we received 212 abstracts that pertain to rural water systems. A review of these abstracts reveals that most fall into three main categories. Over two-thirds of these abstracts are plans or ex post facto studies of successful systems of rural or suburban water, other non technical and/or unrelated topics, or waste water oriented. These were deleted since their abstracts showed no useable technology. The second category were design, operation and maintenance, and institutional organization manuals. The third category was planning and feasibility technology reports.

The next area of literature search was SSIE to identify current research applicable to rural areas. This search revealed that a limited amount of research was being directed specifically to rural water systems. The structure of the descriptors and the breakout of the rural water system technology prevents a complete analysis of all technologies within the scope of this project. Since rural water had been adapting technologies for its use for years, it is very likely that research is being done that may be applicable to rural systems without being described as its purpose.

A logic structure was devised in both SSIE and NTIS which looked at each technological aspect (such as treatment, distribution, planning, etc.). Each of these cagegories produced large numbers of abstracts in the file. These were statistically sampled with negative results. Each file of abstracts were then searched for rural and/or small community classifications with negative results in SSIE. The technology that was identified in SSIE was, socio-economic in nature or large studies on the quality of life in rural areas and their needs.

The NTIS failed to reveal any other technology other than that previously described or standard texts on the subjects listed. A review of other literature revealed several other technologies that are available for use (Wood, 1974; Rice, 1974). One is a distribution system model for network design and the other is an ex post facto evaluation of a rural system. This review does not include the standard text books on water engineering since they are primarily for major systems. They do have references to smaller systems, but they are primarily used for teaching and reference material for practicing engineers.

# GROUNDWATER

## INTRODUCTION

Groundwater composes 97 percent of the world's fresh water supply; only 3 percent is surface water. In recent years groundwater supplied about one-fifth of all water used in the United States. This ratio of groundwater to total water use varies widely from one region to another, with the greatest groundwater use being in the central and western states. Arkansas in 1970 for example, obtained 77 percent of rural water supplies from groundwater, while the nearby states of Louisiana, New Mexico, Oklahoma and Texas averaged 70 percent. These figures relate to all rural water used including that for livestock, but if we confine our usage to only rural domestic, the figure for groundwater approaches an amazing 98 percent of the total water consumption (Scalt et al. 1973).

Although groundwater is not an unlimited resource, with proper geologic engineering and management studies a dependable and relatively economical supply can be developed in many rural areas, where often the first inclination is to develop a surface source of water.

Not only is groundwater often less costly than surface water, but it is frequently more desirable. It is often more easily available and can be found at great distances from streams, lakes, and reservoirs, thus allowing some flexibility in locating the point of use. It also has the advantage of having a fairly constant temperature and chemical quality.

The first step in planning is to appraise the specific water requirements. It is necessary to know, for example, which chemicals can be tolerated in the water and in what quantities. The amount of water to be used per day and the peak daily usage must be known, along with anticipated increases due to future expansion. It is then necessary to consider water supply sources which will meet the proposed requirements. The basic criteria to be considered are quantity, quality, and cost of water.

Usually, the quantity of water available from a given source is the most basic consideration. In this regard, future possibilities must not be neglected: competing water users or droughts, among other factors, may severely limit the quantity of water available in the future.

The quality of water can also be an important aspect in many cases. For example, if the supply is to be obtained from a river, it is helpful to know the anticipated seasonal changes in the quality, as well as the quantity, of the water. Comparative costs must be considered when more than one source of water is available. It may then be necessary to determine which of the various sources available will provide the most reliable, most suitable supply of water at the least cost.

## GROUNDWATER SUPPLY INVESTIGATIONS

After the water supply requirements have been evaluated and the feasibility of development of a groundwater source is indicated, a careful investigation should be made by an experienced groundwater hydrologist. An orderly approach is essential in investigating a groundwater supply, since an improper approach can result in failure to select the optimum locations for production wells and, ultimately, inefficient design. Such errors may cause either an overly optimistic or pessimistic evaluation of the water supply potential.

The table below illustrates the various phases in groundwater investigations and the different stages for their undertaking:

## Table I

## PHASES OF GROUNDWATER SUPPLY INVESTIGATIONS

| | |
|---|---|
| Reconnaissance<br>Survey<br>Exploration | Phase I |
| Testing<br>Development | Phase II |
| Design and Installation<br>Management - Maintenance - Rehabilitation | Phase III |

## Phase I - Reconnaissance, Survey and Exploration

(Current Technology)

The appraisal of the groundwater potential in an area requires an understanding of the nature and occurrence of water-bearing formations in the form of geologic and hydrologic data. Usually, a large amount of information can be collected in a very short time, since there often is existing information such as logs of nearby water wells. These logs can provide general data regarding the thickness, depth, and type of aquifers in the area. The collected data can indicate a range of possible well yields and the required depth and diameter of the wells. In some cases, the permeability of aquifers can be estimated on the basis of the preliminary data.

Information regarding the quality of groundwater is usually available from state or local departments of health or from municipal water agencies. The recharge of aquifers can be estimated by studying the relationship between surface water and groundwater, the local geology, and the infiltration characteristics of the surface soils.

Finally, state or local laws or ordinances affecting groundwater must also be checked. In some states, permits are required to drill water wells and to pump large quantities of water from aquifers.

Comprehensive treatment of methods and techniques of groundwater investigation havebeen developed by the United Nations Economic Commission for Asia and the Far East (UNESCO, 1967). In particular the UNESCO report concentrates on procedures for field investigations.

(Technology under Development but Not Fully Utilized)

Remote sensing techniques have been quite widely used for groundwater reconnaissance and exploration. The first comprehensive symposium on the practical application of earth resources survey data with general application to groundwater exploration was provided by the NASA Earth Resources Survey Symposium (NASA, 1975).

In chronological order, the development of remote sensing of groundwater starts with aerial photography and advances to satellite data interpretation. Mollard (1970) summarized the state-of-the-art usage of black and white photographic data as an aid to the identification of previously unknown sources of groundwater. Hine (1970) provided fracture trace mapping as a tool for groundwater exploration. Sonderegger (1970) used color and color IR photography for fracture trace mapping in Alabama and for the location of high yield wells. Abdel - Hady and Karbs (1971) have shown the application for thermal IR imagery for remote sensing and surveying the depth to the water table. A survey or remote sensing techniques from the first Earth Resources Technology Satellite was provided by Deutsch (1974).

(Research Needed)

Remote sensing applications for groundwater investigations have recently been summarized by Moore and Deutsch (1975). Satellite imagery and specifically remote sensing technology offers an opportunity to apply new technique in groundwater reconnaissance, survey and exploration. Potential exists for locating new aquifers, study aquifer recharge and discharge, estimate groundwater pumpage for irrigation, predict aquifer management problems, and to monitor pollution. Work needs to continue in this area to develop remote sensing to its full potential as a tool for groundwater exploration.

Research in exploration techniques in the subsurface and out in space has received considerable emphasis. Borehole geophysics has become more and more sophisticated in attempts to extract greater quantities and more accurate information from increasingly costly drill holes. In addition, researchers continue to study the use of surface geophysics techniques, such as earth resistivity, to map groundwater reservoirs and thus eliminate some of the expensive test drilling. A cross section of such studies included those by Brown (1971), Cartwright and Sherman (1972), Frohlich (1973), Hackbarth (1971), Huber and Adams (1971), Keys and MacCary (1971, 1973), MacCary (1971), Merkel (1972), Merkel and Kaminski (1972), and Norris (1972).

The geophysical or ground exploration technique for groundwater exploration have been summarized by Zohdy et al. (1974). The application of surface geophysics to groundwater investigations covers electrical, seismic, gravity, and magnetic methods. In chronological order, recent specific applications follow. Merkel and Lavin (1972) evaluate geophysical techniques for evaluating groundwater pollution problems in Pennsylvania. Geoelectrical techniques were used by Frohlich (1973, 1974) to locate aquifers in glacial deposits in Missouri. An update and successful application of electrical resistivity methods was provided by Minning (1973). The importance of geophysical mapping in groundwater studies was recently defined by Adams et al. (1975).

## Phase II - Testing and Development

(Current Technology)

An exploration boring program may be needed to identify the characteristics of the aquifers and to obtain preliminary well design data. The borings should be supervised by a qualified groundwater hydrologist and should preferably be drilled by the water well contractor who will subsequently install the wells.

To provide information regarding the nature and occurrence of water-bearing formations, samples of the strata penetrated by the borings are collected and analyzed. Water samples obtained by pumping from aquifers are analyzed to evaluate groundwater quality. The data obtained are used to refine the earlier estimates of groundwater adequacy and to select favorable locations for test and production wells.

After the exploration program has been completed, one or more test wells can be designed and installed at locations selected on the basis of data obtained from the test borings.

To measure the hydraulic characteristics of the well and the aquifer, two types of pumping tests are conducted. In the step drawdown test, a well is pumped at various rates, and the water level drawdown is measured to evaluate the efficiency of the well. This provides information useful in the final design of production wells. Next, a constant pumping rate test measures the hydrologic coefficients of the aquifer. These coefficients are used to evaluate the aquifer's ability to store and transmit water.

The combined results of these pumping tests control the design of wells, the selection of pumping equipment, and the rate of pumping best suited to the well. The pumping tests also serve in selecting the optimum spacing of the water wells so that pumping from one well does not adversely lower the water level in another well. The pumping test data can be used in certain computer programs for evaluating the long-term adequacy of the groundwater supply and the effects of pumping.

A basic manual intended to serve as instructions and guidance to field personnel engaged in the construction operation and maintenance of small diameter, relatively shallow wells, used primarily for individual or small community water supplies has been provided by Gibson and Singer (1971).

(Technology Under Development but Not Fully Utilized)

In most cases, the pumping test of a well is made simply to "see what she'll do." What is not recognized by most drillers is that an accurate test of a water well in advance of pump purchase will more than pay for itself in savings that can be made in the selection of the proper pump and in the reduction in energy - power costs. More importantly properly planned and carefully conducted tests reveal important facts about the groundwater aquifer, information that cannot be determined reliably by any other means.

Johnson (1966) provides a summary of testing techniques for wells and Bredehoeft (1965) has recognized the need for using available technology for improving testing techniques.

Groundwater hydraulics has received attention with major compilations of theory presented by Johnson (1972), Lohman (1972), Schicht (1972), and Stallman (1971). Advanced theoretical analyses were completed by Bostock (1971), Moench (1971), Nawrocki (1971), and Papadopulos (1973). Lohman et al. (1972b) prepared a glossary providing redefinition of many groundwater terms.

The time required to develop a well depends on the characteristics of the aquifer. Development work is essential to properly complete a water well. It produces the following results:

1. Cleans out drilling mud--natural or added--from the formation.
2. Increases porosity and permeability of the aquifer in the well vicinity by removing the fines adjacent to the screen.

3. Reduces sand inflow and maintenance costs.

Time spent in well development is never wasted.

(Research Needed)

Bredehoeft (1976) has indicated that quantitative groundwater aquifer models have been developed and solved that are more complex and comprehensive than our ability to describe the system parameters. Research is needed to develop new testing methods and procedures for accurately determining parameter identification. This is particularly true in evaluating the environmental impacts of using groundwater source supplies in which chemical reaction rates, dispersion, and local concentrations are deemed important.

## Phase III Design and Installation, Management, Maintenance, and Rehabilitation

(Current Technology)

Production wells are designed according to the pumping test results and formation characteristics. The cost of proper design, high-quality materials, correct installation, and development is repaid many times over because of the resulting lower costs of long-term pumping. Close attention to drilling techniques, methods of setting well screens, and developing the wells can make the difference between a mediocre well and an excellent well. Each production well should be test pumped upon completion.

Records of water level changes and quantities of water pumped from each well should be maintained so that maintenance and rehabilitation of wells (Phase IV) can be performed, if required at some future date.

Basic design and installation information on wells, pumping systems, and rural groundwater system accessories are summarized in Johnson (1966) and more recently by Gibb (1973) and Romano (1975). Types of wells, construction, development and costs are described.

Peters (1972) has shown that groundwater management demands an understanding of the geologic history and structure of the basin, and of its water carrying and water storage characteristics. It demands an understanding of the hydrologic regime under average and extreme conditions of water supply and the effects of artificial recharge upon that regime. Groundwater management demands sufficiently detailed data and methods to support saline water barriers, artificial recharge, and protection from pollution.

Together, geologic and hydrologic data contribute to the development of a mathematical model of the basin. When verified, a quantity model will predict water levels under various plans of groundwater management. Bredehoeft (1976) has presented an excellent summary of groundwater hydrology models developed over the last 40 years.

(Technology under Development but Not Fully Utilized)

1) Aquifer Evaluation - Even if a single water well proves initially that the aquifer it taps can supply current water demands, there is a definite need to investigate the aquifer's capability of supplying water on a long-term basis. This is an important element of good water supply management planning.

Fortunately, the adequacy of a groundwater supply can be realistically appraised in a relatively short time. Unlike a stream, whose dependability to supply water must be evaulated on the basis of long years of continuously recorded flow measurements, a water supply from an aquifer can be quantitatively evaluated in little more than the length of time required to perform the necessary exploration and testing programs.

The drilling of several exploration borings is needed to map the aquifer: to define its thickness, composition, extent, boundaries, and the quality of water it contains. At one or more favorable sites, wells are drilled and completed to test the aquifer. The wells are then pumped at a constant rate while water levels in the aquifer are measured in nearby observation wells. Data recorded during these tests are used to compute the aquifer's coefficients of transmissibility and storage. These parameters are needed to properly evaluate the aquifer.

2) Data Collection - It is important that the collection of data on a groundwater supply be continued long after the exploration and testing programs have been completed. After the wells have been placed into production, records of water levels and pumpage volumes should be maintained; and chemical analyses of the groundwater should be made periodically. Future records of water levels and pumpages will be useful in verifying or re-evaluating the original estimates of long-term groundwater adequacy. Chemical analysis data serve to check on contamination that may be occurring so that preventive measures can be taken to alleviate any deterioration in the water quality. Hickey (1972) has summarized some of the important considerations in the process of designing a groundwater data collection program. Winter (1972) suggested that the design of a water information or basic data systems should be flexible enough to provide information and data for a broad range of interests from national to local.

3) Modeling - The digital computer has gradually supplanted the analog technique for many groundwater modeling needs. Applications and advances in modeling theory have been discussed by numerous authors

(Bredehoeft, 1976; Domenico, 1972; Dominick and Roberts, 1971; Maddock, 1972, 1973; Prickett and Lonnquist, 1971, 1973; Tanaka et al., 1974; Taylor, 1971; Taylor and Luckey, 1972; Thomas, 1973; Trescott, 1973; Weber and Hassan, 1972; Weeks et al., 1974; Verge, 1972).

Modeling studies related to improving aquifer characteristics via parameter and systems identification techniques for a better prediction of water head drawdowns; and management policies in conjunction with surface waters include the following specific studies (Hem and Steele, 1975):

> Pinder (1973) used the Galerkin method of approximation in conjunction with the finite element method of analysis to simulate the movement of groundwater contaminants.
>
> Bredehoeft and Pinder (1973) coupled the mass transport equation and the equation of motion and solved it numerically for a saturated isothermal groundwater system in which there are no chemical reactions.
>
> Maddock (1973, 1974a) combined groundwater simulation modeling, mathematical programming, and decision theory to plan and manage a groundwater system, subject to variation in pumping costs, transmissivity coefficient, and others. The approach is based on the development and use of an algebraic technological function that is shown to exist for an aquifer whose flow to wells can be remodeled by Boussinesq's equation.

4) Pollution Susceptibility - Groundwater pollution is a problem that is related to waste disposal, either liquid or solid, deep or shallow. As urban wastes increase to monumental proportions, acceptable areas for solid waste disposal areas become more and more scarce, and the chances for groundwater pollution from land fill operations more

serious (Cherry and Brown, 1973; Hughes, 1972; Hughes et al., 1971; Seitz et al., 1972). The quantities of sewage effluent from treatment plants of urban areas and industrial complexes are also increasing at a high rate and creating problems of disposal in light of environmental regulations limiting disposal in streams. One potential solution receiving considerable attention is spraying or spreading the waste water on farming or forested areas (Bailey and Malatino, 1972; Bernhart, 1973).

Growing governmental management of waste disposal, pollution prevention, and water quality maintenance emphasizes the need for formal and systematic groundwater monitoring and data collection. The design and planning of groundwater data programs were the subject for a symposium sponsored by the American Geophysical Union (Dutcher, 1972; Gilliland, 1972; Hanson, 1972; Hickey, 1972; Johnson, 1972 Luckey, 1972). The Ohio River Valley Water Sanitation Commission (ORSANCO Advisory Committee on Underground Injection of Wastewaters, 1973) published recommendations for regulatory actions, administrative procedures, and geological and technological evaluations relating to underground injection of wastewaters in the Ohio Valley region.

Along with the burgeoning urban growth and industrial development and national and state programs to protect and manage the quality of the water resources of the nation has come a greater interest in the quality of groundwater, geochemical processes, and the fate of wastes introduced to groundwater systems. Engberg (1973) studied selenium in the groundwaters of Nebraska, and Hassan (1974) reflected on the activities of nature and man on the water quality cycle. Detailed theoretical studies were reported by Hufen et al. (1972, 1974). The large expansion in feedlots for fattening cattle and the increasingly heavier use of high-nitrogen fertilizers on crops offer potential for contamination of groundwater supplies. Examples have been reported by Miller (1971) and Olson et al. (1973). Lehmann (1975) has provided an excellent groundwater pollution bibliography with abstracts.

Waste disposal and artificial recharge have received growing interest and concern from groundwater researchers. In 1971 the American Association of Petroleum Geologists (AAPG) and U.S. Geological Survey sponsored a highly important symposium, Underground Waste Management and Environmental Implications, from which 36 papers were published as AAPG memoir 18. McKelvey (1972) in the lead paper introduced the important concept of underground space as a valuable natural resource. In 1973 the U.S. Geological Survey and American Association of Petroleum Geologists joined with the International Association of Hydrological Sciences in sponsoring an important international symposium, Underground Waste Management and Artificial Recharge. Those organizations published two proceedings volumes containing 46 papers on the state of the art, regional history, concepts, laboratory and field studies, and operational case histories for the management of waste products and artificial recharge in deep underground space in the United States and a number of foreign countries (Braunstein, 1974). Researchers of waste disposal have studied such items as effects of disposal on occurrence of earthquakes (Raleigh, 1972), geochemical effects from liquid wastes injected in limestone formations (Goolsby, 1971, 1972), delineation of areas for disposal of waste water (Bond et al., 1972), and construction of waste injection wells (Foster and Goolsby, 1972). Other aspects of liquid waste disposal were presented by Handy et al. (1973), Kaufman (1973), and the U.S. Army Corps of Engineers (1972). An excellent bibliography on subsurface waste disposal was prepared by Rima et al. (1971). Some additional important references, selected from among many, Keys and Brown (1974), Leenheer et al. (1974), and Wood (1974).

(Research Needed)

There is a need for additional research into the mechanisms involved in coupled groundwater and surface water contaminant movement. This applies to both artificial and natural recharge processes. Some work has been done in this area. Research in artificial recharge has included laboratory studies of factors affecting recharge (Signor, 1973; Nightingale and Bianchi, 1973) as well as field studies and applications (Baier and Wesner, 1971; Griffis, 1972; Ripley and Saleem, 1973). An extensive review of artificial recharge developments was presented in a state of the art paper by Brown and Signor (1973). It includes references to other significant papers.

One important area of research has been the conjunctive use of groundwater and surface water. Collins (1972) reported on surface water-groundwater interaction on Long Island, New York; Denielson and Quazi (1972) discussed stream depletion by wells in the South Platte River basin of Colorado; and Freeze (1972a, b) investigated base flow contributions to channel flow. Still other contributors to better understanding of this important subject include Ham (1971), Maddock (1974), Moench et al. (1974), and Taylor and Luckey (1974).

For the future, advances must be made in our knowledge of geochemistry and quality of groundwater. Studies related to groundwater pollution, deep waste disposal, and solid waste or land fill operations undoubtedly will increase greatly. Better automatic data processing and storage techniques will be mandatory as requirements for nationwide groundwater monitoring networks create large volumes of new data.

Increasing attention to predictive groundwater management and protection has brought about a growing need for quantitative data and understanding. Data related to aquifer storage and yield, artificial and natural recharge and discharge, evapotranspiration, boundary conditions controlling development and effects of development, hydrology of urban and urbanizing areas are but a few of a multitude of data parameters required for predictive management of the groundwater of the nation.

However, the greatest need for research falls in the area of institutional regulations, procedures, and policies. Many states collect and maintain excellent records on groundwater information while in other states groundwater data is virtually non-existent. Unfortunately, in some cases a state with poor records is adjoining to a state with good records with the aquifer underneath both states. The usefulness of the good records is severely limited because of the inadequate data in one state. It is not so much a matter of how to collect good groundwater data. The research need is in the area of how to bring about instututional changes that will result in coordinated and compatible data sets.

## SURFACE WATER

### Impoundments

Historically, ground water has been the principal source of domestic water in rural areas where adequately producing aquifers are present. This source of domestic water was found to be desirable on an individual home basis since the need for a distribution system was eliminated and since, in most instances, no treatment was required. Disadvantages of the use of individualized groundwater systems are that both the quantity of water and in some cases, the quality of water which could be obtained was highly variable. The demand for a more consistent, high quality water supply in rural areas has caused alternate sources of water to be considered.

In rural areas where aquifers furnish high quality water on a consistent basis, the use of groundwater may still be the most practical alternative. However, as population density of rural areas increase, the practicality of a water distribution and/or treatment facility increases (Fast, et al., 1975). The usefulness of groundwater systems which exhibit quality problems can be extended by treatment. However, even in areas where high quality groundwater is currently available, the possibility of pollution and/or depletion of the aquifer cannot be eliminated. On an individual home basis, the use of groundwater may be in conflict with the method of sewage disposal used.

In areas where rainfall is adequate, the possibility of surface storage becomes an obvious alternative. Clearly, the feasibility of the use of surface water storage is highly regionalized with such factors as topography, climate, and land-use patterns all playing an important role in determining feasibility. The purpose of this discussion is to describe some of the potential problems associated with the use of surface water storage; and also to describe the technology which is in existence and that which is needed to cope with these problems. Although much of the literature reviewed dealt with the use of impoundments for urban and small community water systems, the problems encountered in using impoundments in rural water systems would be similar.

## The Nature of Impoundment Problems

In many areas, particularly in the southeastern United States, relatively large impoundments have been created by such agencies as the Corps of Engineers and the Tennessee Valley Authority. In most cases, these impoundments can furnish high quality water and where the location permits, should be considered as a source of water for rural water systems. Since the use of these larger reservoirs and impoundments have been studied in great detail and are presently being used extensively for urban domestic and industrial water, the following discussion will be limited to small reservoirs on the scale that might prove functional as a source of water for a rural water system.

In some portions of the United States, the Soil Conservation Service (Department of Agriculture) develops small impoundments primarily for flood protection and, where the need arises, for domestic water supply. The authorization for this program is through Public Law 566. (Watershed Protection and Flood Prevention Act of 1954). The multiple use aspect of these impoundments has a significant effect on the economics of their use in water supply systems.

When water is impounded by damming of a flowing stream or by damming of an intermittent drainage, certain physical, chemical, and biological changes can take place (Symons, et al., 1967). Some of these alterations may render the resulting body of water less desirable as a domestic water supply.

One obvious problem associated with impoundments is that of siltation. Should the silt load of the feeding stream be significantly high, the silt trapping nature of an impoundment would result in a limited life for the reservoir (Roehl, et al, 1973). With changing land-use patterns, it is often difficult to predict loading of silt into a reservoir.

Another problem associated with impounded water and natural lakes alike is that of nutrient enrichment and subsequent development of nuisance aquatic vegetation. In addition to the fact that nuisance vegetation can cause secondary water quality degredation (discussed below), it can cause clogging of water supplies and result in severe taste and odor problems. Such problems have been numerous in the natural lakes in the northcentral portion of the United States (Hutchinson, G. E., 1957).

The fact that high quality water is present in a stream feeding an impoundment does not insure that high quality water will be present in the reservoir. Classically, standing bodies of water undergo thermal stratification, assuming that the depth is sufficient. The development of a warm layer of water on the surface of the lake prevents oxygenation of the water in the deeper portion of the impoundment. During this period when the deeper portion of the lake is cut off from its oxygen supply, bacterial action causes a depletion of dissolved oxygen (Symons, et al., 1967). At very low dissolved oxygen concentrations the water develops an anaerobic regime. Under this oxygen depleted condition, various chemical species commonly found in soils become reduced and migrate throughout the oxygen depleted zone of the impoundment. Among chemical species which characterize this type of water are iron, manganese, and hydrogen sulfide.

The reduced species such as iron, manganese, and hydrogen sulfide, are undesirable constituents of any water supply system. If they are not removed, these species can cause severe taste and odor problems as well as cause costly depositions in pipes and machinery (U.S. Department HEW, 1967). The removal of these undesirable components from water supply systems is often expensive and of varying effectiveness (Ingols and Craft, 1974).

The extent to which reduced species are found in an impoundment may vary considerably. In areas where the feed water system is low in organic materials, the probability of the development of an anaerobic zone becomes less likely. Often, the problem is worsened by the presence of nuisance aquatic vegetation. Such vegetation can cause a physical blocking of the aeration process and render the entire impoundment anoxic or simply results in the addition of cycling organic matter to the aquatic system. The latter usually results in accelerated oxygen consumption in the deeper portions of the impoundment.

Two additional factors which affect the extent of the development of reduced species in impounded water are climatic conditions and soil types. For example, a relatively shallow impoundment may not undergo thermal stratification to the extent of a deeper impoundment. This does not mean that an anoxic zone will not develop. If climatic conditions do not result in enough mixing action and if the soil and water contain adequate organic materials, an oxygen depleted zone may develop in a body of water with little or no thermal stratification (Burk and Nix, 1969).

It is obvious that these processes can result in water quality degradation of varying percentages of the impoundment. Due to the wide spread nature of this type of water quality degradation, it would appear that the alleviation of this problem is of primary concern in the utilization of impoundments as a source of water for rural water systems.

## Examples of Water Quality Problems in Impoundments

Dunst, et al., (1974) have reviewed lake rehabilitation techniques and experiences throughout the world. Within this compilation are numerous examples of water quality problems which have developed in lakes and reservoirs which were used as domestic and industrial water supplies.

Specifically, McCollough, (1974) has described the extent of water quality degradation in Prompton Lake, Pennsylvania. In this instance, the nuisance algae developed and low dissolved oxygen was observed throughout the impoundment (3,400 acre feet of storage).

Harper, (1975) describes the development of low quality water resulting from oxygen depletion in Lake Wohlford which is the principal water supply for Escondido, California. Although the area served by this impoundment is not rural, the description of the system and the problems of taste and odor is an excellent example of the type of conditions which can result with an accumulation of reduced species.

A vivid example of how water quality degradation within impoundments can result in extensive problems when used as a domestic water supply is presented by Rapoza, (1971) for Greenville Reservoir, New Hampshire. This reservoir was a part of a Soil Conservation Service flood control project and through an agreement with the town of Greenville and the State Water Quality Board, 2 million gallons per day were assigned as water supply. At a usage level of 85,000 gallons per day, the water was treated by flocculation, settling, filtration, and chlorination. Even following these conventional treatment steps, extensive damage was encountered as the water was used in the homes of Greenville. Clearly, little concern was given to the possibility of water quality degradation prior to the planning and construction of the impoundment.

The extent of migration of reduced species in six Soil Conservation Service flood water retarding impoundments located in westcentral Arkansas has been described by Burk and Nix, (1969). During the period from June through September, these impoundments were found to contain high concentrations of manganese often extending to within five feet of the surface. Following periods of heavy rain, the low quality water was flushed from the reservoir but reestablishment of the prior anoxic conditions was observed to occur within two to three weeks. One of the reservoirs studied is used as water supply for the town of Waldron, Arkansas.

The water quality regime of another Soil Conservation Service reservoir has been documented by Moore, (1973). The multi-purpose reservoir located in northwest Arkansas serves as water supply for the town of Prairie Grove, Arkansas. Again, substantial water quality degradation was observed throughout the impoundment during the summer months.

One cannot review the observations of these investigators without realizing that water quality problems develop in impounded water and that without corrective measures, cause the value of the impoundments as domestic water supply to be questionable.

## Current Technology

The control of sediment loading of impoundments involves engineering review early in the planning stages of a reservoir. In some cases, it may be possible to reduce sediment loading to an acceptable level simply by properly locating the water control structure (Burt and Gentry, 1974; Hawkins, 1972). In most impounded water, the extent of sediment loading is closely related to land-use within the watershed of the impoundment. The protection of the watershed against activities which would result in the production of large quantities of sediment offers the most practical solution to the problem of sediment problems (Roehl and Holeman, 1973). In areas where high sediment loads are normal, and cannot be controlled by the elimination of certain land-use practices, design of the impoundment to provide for sediment accumulation may be feasible.

Small to moderate quantities of suspended sediment in domestic or industrial water supplies can be removed with existing technology. Flocculation, followed by settling and filtration has historically furnished water adequately free of suspended load.

It is generally considered that the best method of controlling excessive nutrient input into lakes and reservoirs is by controlling the source of the nutrient. Often the source of such nutrients is associated with some type of sewage disposal. Treatment at the point of origin is the method of choice but particularly in rural areas, this is not always practical. Even properly operating septic systems may cause the introduction of substantial quantities of nutrients through groundwater (Lee, 1973). Certain agricultural activities are also sources of nutrients. Runoff from fertilized lands or from grazing environment may produce water which, when impounded, will support excessive aquatic vegetation (Biggar and Corey, 1969). At the present time, control of nutrient input from agricultural activities is best accomplished by locating impoundments in drainages with relatively low density agricultural activities. The practices of fertilization of grazing land in the immediate vicinity of small impoundments should be regarded as a danger to the usability of the impoundment for water supply.

### Current Technology

Chemical treatment to reduce aquatic vegetation has been used in domestic water supply impoundments (Muchmore, 1974), but such treatments involve a waiting period to allow chemicals to dissipate prior to utilization within a water system. Such treatments generally give only temporary relief.

As discussed earlier, water quality degradation within impounded water can be produced by the development of an anoxic zone within the body of water. Such conditions may be caused by the presence of excessive aquatic vegetation, thermal stratification, or simply quiescent water standing in an unmixed condition (Burk and Nix, 1969). Present technology offers two methods for dealing with the problem of relatively high concentrations of reduced species such as iron, manganese, and hydrogen sulfide. First, direct aeration of the body of water through several engineering schemes has proven successful in reducing the presence of these undesirable components (Irwin, et al., 1966). Secondly, reduced species can be removed by several treatment techniques after the water has been removed from the impoundment. (Anderson, et al., 1973).

Management of reservoirs for improvement of water quality by selective withdrawal has been reported by Monkmeyer, et al., (1974). Under certain flow regimes, it is possible for the poorer quality water to be discharged downstream by release from the lower portion of the impoundment. For this scheme to be totally effective, the rate of release must be enough to prevent reestablishment of conditions which initially produced the water quality degradation. Where reasonable quantities of water are available for throughflow, the selective withdrawal technique has a great deal to offer. It should be pointed out that stratification and subsequent water quality degradation usually occurs in the summer and fall, both periods of the year when water for throughflow may be scarce. Of the six reservoirs studied by Burk and Nix (1969), only one had significant discharge during the summer period except immediately following storm events.

Direct treatment of the impoundment has met with considerable success (Irwin, et al., 1966). One method involves the pumping of the deeper water containing reduced species to the surface of the impoundment where it becomes oxygenated, causing the oxidation and precipitation of components such as iron and manganese. A second approach is the introduction of air directly into the zone of the impoundment which contains undesirable components.

Rapoza, (1971) has described a system where water was pumped from the deeper portion of the reservoir to the surface where oxygenation occurred. This case documents substantial water quality improvement followed a sustained period of pumping. Irwin, et al., (1966), have discussed the implementation of impoundment destratification through the use of a water pumping system. These authors report significant improvements in water quality and further observe that the blue-green algae bloom which had occurred during the fall prior to mechanical treatment did nor occur following destratification in the four impoundments tested.

Destratification techniques have been improved by aeration of the deep water of reservoirs. The direct introduction of air into the deep water causes a vertical transport and mixing of the reservoir. The water receives aeration from the introduced air as well as mixing after reaching the surface of the impoundment. Harper (1975) has described the use of such a system and has reported improvement of water quality on the same order as that reported using the direct pumping of water. Both of these methods essentially destroy any stratification producing a water column which is homogeneous. Continued pumping or aeration is necessary to maintain good water quality.

### Technology Under Development but Not Fully Utilized

Fast, et al., (1975) have described a system which allows the aeration of deep reservoir water without the disruption of thermal stratification. Aeration is accomplished by introducing air at the bottom of a large cylindrical column extending into the affected portion of the reservoir. The aerated water column moves upward where it encounters horizontal diversion tubes at an elevation below the thermocline. The aerated water was ejected from the device in a horizontal direction below the thermocline with essentially no disruption of the surface water.

This practice resulted in improvement of water quality of the deeper water. An indirect advantage of this treatment is that the oxygenated cold water is capable of supporting a cold water fishery.

The removal of iron and manganese within a treatment facility has been discussed by many authors. Furgason and Day, Part I, Part II, (1975) present an excellent review of the state of technology for removing those components from water. Methods available for removal of iron and manganese include ion exchange, sequestering, chemical oxidation followed by filtration. Ion exchange has proven to be costly and has the additional disadvantage of resulting in sodium enrichment of the water.

Sequestering involves the treatment of water containing iron and manganese with a chemical, usually a polyphosphate, which chelates with the metal ions and decreases their impact. Although sequestering has obvious economic benefits, the results are not always satisfactory. The phosphate additive has been observed to increase bacterial activity and result in the deposition of material within the treatment and distribution system. Investigators also report that this method does not produce as significant a decrease on the effect of manganese as it was on iron.

Chemical oxidation of iron and manganese is the most used method for iron and manganese treatment. (Ferguson, Part I, Part II, 1975) The water is usually aerated which results in partial oxidation followed by the addition of a more powerful oxidant to further reduce the concentration of these metals. Chlorine has been used successfully as the oxidant. The method of filtering the insoluble iron and manganese compounds is highly variable. Gravity filtration, pressure filtration, and filtering through greensand (sand containing manganese dioxide) have been used. Pressure filtration and greensand filtration have been reported to be more economical. Jarr, et al., (1974) have obtained a patent on an iron removal filter.

In a recent work, Furgason and Day (1975) have used ozone as a chemical oxidant in an iron and manganese removal process. Their results indicate that the insoluble material resulting from ozone treatment of water containing iron and manganese is easier filtered than that from the more conventional methods. The time needed for reaction of the reduced metals, with the ozone is very short, resulting in concentrations of iron and manganese well below those recommended for portable water supplies. The economics of the ozone treatment process also serves as a disinfectant process and the bi-product is water, thus eliminating taste problems associated with excessive chlorination. Such treatment also reduces the possibility of the generator of chlorinated compounds within the water system.

## Research Needed

Additional information is needed on the relationship between surface runoff water quality and various land-use practices, especially those which have the capability of producing elevated sediment and nutrient loads. This information would allow planners and developers of rural water storage systems to attempt to exclude or at least minimize the effect of these activities on a downstream water supply impoundment.

The processes which are responsible for oxygen depletion and associated decrease in water quality in reservoirs is related to such factors as concentration of organic material in the runoff water, soil types, nutrient loading, climate, etc., it would seem proper to develop modeling approaches which might be useful in predicting reservoir water quality prior to the construction of an impoundment. Although quantitative modeling of such systems would be extremely involved, some simplified criteria might be identified which would give an indication of a particular site that would be expected to develop an anoxic zone during stratification. Factors such as vegetation and upper soil removal prior to impoundment should be evaluated. Nielson (1967) has made some preliminary attempts at predicting stored water quality.

Existing modes for the management of the water quality of impoundments through techniques such as selective withdrawal should be expanded.

The compatability or non-compatability of the multiple use concept of reservoirs should be explored. Since the multiple use concept may play an important part in possible funding of reservoirs used for rural water system, information on conflicts between these various uses should be explored. Considerable controversy has arisen in some states regarding the use of water supply reservoirs for recreational purposes.

Ozone treatment has a great deal to offer in the area of water disinfection as well as iron and manganese removal. Additional research on the use of ozone in water treatment should be encouraged. Although ozone treatment may have applications in municipal and urban treatment facilities, it has several factors which make it particularly attractive for smaller rural water systems. These techniques would also be applicable in the treatment of ground water systems containing iron and manganese.

Possibly the most important need of all is the development of intermediate-size equipment and facilities to be used in rural water systems. Special attention should be given to providing treatment equipment and distribution equipment of a size required to furnish a small rural water system rather than attemption to make use of larger equipment designed for municipal use (Foster, 1974; Campbell & Lehr, 1975).

Rivers and Streams

Technology relating to the use of rivers and streams for rural water supplies has very few areas that are not common to surface water impoundments because, of course, the rivers and streams provide the input to the impoundment. However, of course, in some cases the river or stream provides the water supply directly. River and stream water quality can be readily broken into two major regimes. The first of these regimes represents the river at low flow in which the river water quality is essentially that of the groundwater feeding it with the exception of cases of direct access to the river by livestock or unless point source discharges exist in the region being studied. In this regime few technical problems exist that are not common to either impoundments or groundwater sources.

The second major regime represents the river during storm event or runoff period in which diffuse or non-point pollution invade the river or stream. Unfortunately almost all river and stream water quality and flow gauging has taken place at low flow with little regard for runoff data. Sherwani and Moreau, (1975) have presented an excellent discussion concerning the work that has been done in this area. Unfortunately little if any of this work is being utilized except in a few isolated cases.

Technology Under Development but Not Fully Utilized

Pollutant concentrations and mass flows vary widely during a storm event and of course the pollutants are related to the land use, order of stream, and physiographic soils (Nix, et al., 1974; Robbins, et al., 1971; Sherwani and Moreau, 1975).

Among the factors which contribute to water quality alteration of rivers or streams during periods of high runoff are 1) direct contribution of constituents by rain, 2) interaction of runoff water with the natural geological and forest environment, 3) interaction of runoff water with disturbed land, 4) leaching of materials from agricultural areas, 5) direct introduction from man made sources (urban runoff, etc.). Some work has been done in developing field estimates on non-point source loads and related runoff coefficients for storm events of different frequency and magnitudes on selected rural and urban watersheds (Bryan, 1970; Colston, 1974; EPA, 1973). In some cases mathematical models have been developed to predict urban runoff. (EPA, 1971; ASCE, 1974). Storm impact monitoring must be carefully planned to be of value. The records should be long term, at least one year's duration, from which reliable estimates of frequency distribution of impacts and the seasonal effects can be constructed. Mobile monitoring is advantageous because the sag point shifts with storm intensity. Parametric coverage should include bacteria, organic carbon, suspended solids, nitrogen, phosphorus and total [illegible] phosphate. Grab samples should be taken for the determination of BOD$_5$, long-term, and nitrogen-inhibited BOD to gain insight into the kinetics of decomposition of substances being transported into critical segments. The sampling interval should be set so as to define the rising and falling limit of the hydrograph (Sherwani and Moreau, 1975).

The second level of analysis requires the development of mass balances (water budgets) for the constituents sampled. This requires rainfall and surface flow measurements to be taken simultaneously with water quality sampling.

## Research Needed

The direct and substantial interaction between land use and water quality is obvious but methods and procedures for quantifying this interaction are inadequate. Considerable research is needed in order to anticipate the consequences to water quality brought about by land use changes. What is urgently needed is research and development of water quality monitoring programs where specific considerations are given to the hydrograph. The consideration of storm runoff is essential for determining critical conditions (MacDonald, et al., 1976) of rivers and streams.

# REASONS TECHNOLOGY IS NOT FULLY UTILIZED

## Interviews with Professional and Operating Groups - Institutional Shortcomings

The general lack of pure technological research of recent origin created a major concern among the principals of this investigation. There were not large expectations in this area since SSIE builds its list of terms and synonyms from the descriptors in current use and "water treatment" was not on the list. General discussions among individual professionals had precipitated many needs for technological improvements, but these items failed to surface in the literary research.

This statement does not mean that nothing is being done in research on rural water systems, but that it is fragmented and directed at general parameters--such as socio-economic evaluations of planned or existing systems, case studies of operating systems, formulation of existing technology to the rural problems and exploration, quality analysis, and inventory of existing sources. These are all worth while research programs and have value, when examined by research personnel. Their direct value in their present form for groups that implement rural water systems on a generally local areal scheme was doubtful.

These considerations were used to formulate the general questionnaire followed during the interviews. The questionnaire was not sophisticated by design. It was used only as a guide in directing the trend of the interview. All people concerned were actively involved in rural water systems and therefore had a working knowledge of the procedures and problems of implementing a system.

The questions were:

1) In the institutional side of implementing a rural water system, what are the problems and needed changes for development of the system?

2) What is the basic level of technology used do design a system of this nature and how was it acquired?

3) Do you use some of the current technology such as:

   1. Computerized network wodels
   2. Computerized demand models
   3. Population and development forecasting techniques
   4. Engineering and Design Guides for rural water systems.

   and if not, why?

4) What do you perceive as the needs for technological innovation to make rural water systems more economically feasible.

The response to the first question was unanimous in that the institutional framework which must be satisfied to secure financing, approval, and operation is formidable to say the least. As one operator stated, "It seems to be a supreme test as to see how bad you want a water system." The fragmentation of the financial arrangements was a major portion of their concern. Since a FHmA loan can not be joined, by interpretation, with other loans the project breaks down into two categories, the loan and the grants.

The primary loaning agency is the FHmA, which has its own criteria for acceptability of a project for this loan. The additional financing is then made up from grants from several other agencies. HUD grants require a formulation around economic disadvantage, EDA formulation is on economic potential for industrialization, etc. Each agency also requires certain conditions and previous studies to have been accomplished. These requirements make each system a special case in itself as far as securing adequate financing.

This is followed by the approval and review side of the institutional format. A preliminary design and economic feasibility has to be done, usually without financial support, before an approval of the public health groups, which vary greatly from state to state in organizational framework and acceptable standards, and regional planning organizations.

The successful completion of these steps must preceed the acquisition of funds and construction. There was a consensus that this process could be greatly simplified and standardized, since its success was highly dependent on the experience and capability of the group completing this phase. One engineer went so far as to state that, "The success or failure of a rural water system is solely dependent on the consulting engineering group used." This statement was unsolicited and generally proves to be correct.

A consultant that has researched all the requirements and agressively pursues their fulfullment to maximize the design and financial arrangements of a system, constructs and puts into operation a far better water supply system. The groups that tend to fight the institutional framework seem to, as one individual so aptly put it, "shoe-string" the system together, which is then confronted with a future of never ending problems.

Another concern in the institutional framework was FHmA requirements Each system must stand on its own and must prove economically feasible with signed users. This precludes long term planning and allows a general expansion potential of a maximum of 100%. This does not consider existing or future potential users in the system beyond 100% of the signed users.

Therefore, an approved system then can act as a barrier on two separate fronts. If the system is successful, it can reach capacity rapidly and additional expansion would have to be put in on top of the other one. Also, if the system is adjoined to a major urban system with an excess of high quality water in which it decides to purchase, the main trunk cannot be sized to provide this source potential on the far side of this new system. It therefore becomes a barrier for other systems, since they cannot tie on; they must secure right-of-way and lay a major trunk through the other system or look for other sources and treatments with higher associated costs.

Comprehensive planning and deferred loans could provide for economical staged expansion from large sources. The economics of this type of expansion would greatly improve the feasibility and reliability of water supplies from major sources such as Beaver Lake in Arkansas.

The question on the current technology being used was answered the same by all groups. The technology is standard and is readily available to accomplish the design of the system. Very little dynamic innovation is warranted since economics and the approval constraints lock this technological utilization into the tried and proven category of development.

The economics of these rural water systems are marginal or limited in the early stages of development and could not easily survive maintenance or operation problems. Therefore, there is no incentive to try technology that does not have a history of reliable operation and acceptability. This is compounded by the fact that acceptance by the approving and review agencies must be verified before inclusion into the system, and there is not a framework for validating new pieces of equipment or technology.

This same philosophy carries over into the constructing of the system. The engineer stated that his contractors must be fully licensed, bonded and have an established record of good practice. It was further stated that no man is going to drill his first well on one of my jobs. There is nothing wrong with this philosophy, in fact most, including this principal, find that this is good practice and sound engineering. It does, however, preclude innovative techniques in construction unless firmly established in the industry. Again, the motivation and framework for developing, testing and validating new technology is lacking.

The third question, as to whether new technology, which is available, has been identified and why it was not used, brought the same response from all groups. New technology, although some were familiar with its existance, if not its text, was unwarranted in the current practice of developing rural water systems. The procedure for putting in the system is set, and requires no additional technology within the institutional framework as it currently is formulated.

The systems are economically fixed by this framework. FHmA will loan so much per bona fide user and this is augmented by certain grant funds. This total dollar value then becomes the economic constraint. The approval process and proven techniques then formulate the other constraint. The best system is then fitted into these constraints and the geographic area using established procedures of engineering. The system is rarely large enough or done with enough frequency to utilize computer techniques effectively.

The final question about needed technological research was answered with a generally negative response. In fact, all those interviewed came up with no recommendations for technological research other than those already discussed in the institutional framework. This was not surprising, since they were not using new existing technology. Further discussion concluded that any research that improves the economics of source acquisition and network construction cost would greatly enhance the economic viability of rural system development. Those interviewed made no specific suggestions.

The interviewing of those that operated the systems added very little to the technological review other than a need to improve operating and maintenance characteristics of the systems. When asked for specific reccomendations, they brought forth problems that were actually design and construction problems. The interview always broke over into two general categories--1) Those that praised the engineering group that implemented their system and were generally maintenance free, and 2) Those that spoke despairingly of the engineering group and had heavy maintenance cost and a wide variety of operating problems.

This reinforced the statement made that the engineering group employed is generally responsible for the success or failure of the system. This is obviously not absolute, but does establish the basic framework for success or failure.

Two systems in the same area and built by the same organization have two entirely different characteristics of operation. One is operating smoothly and the other is having serious problems. This was traced back to the two groups that operate the systems. One group did a good job and the other did not.

No cistern system or small systems that operated from a small reservoir was located for interview. All systems of this size in the area of [illegible] either bought water or used groundwater as a source. Water from other sources requires heavy treatment while deep groundwater is of such quality as to only need residual chlorination.

## Consumer Complacency

One of the obvious reasons technology is not being fully utilized is the complacency of the consumer. The consumer simply does not demand it because he is convinced that he has "the best water around." Whitsell and Hutchinson, (1973) found this to be true. Also, they found that regardless of how dangerous the supply looked or how distasteful the water, the consumer rarely complained. The consumer judges the adequacy of his supply on the basis of two criteria: whether there was enough to supply his needs, and whether it tastes all right. Since the consumer that is forced to depend on a sole source will soon become accustomed to the taste, the only real reason for him to prefer a better system turns out to be a water shortage (Whitsell and Hutchinson, 1973). Public agencies are usually drastically under staffed and operate on the principle that the "squeaky wheel gets the oil." Therefore, unless the consumer demands modern technology be used, it is rarely utilized. Public awareness and information dissemination programs could help in this area.

## CONCLUSIONS

The thing that we seem to lose sight of in recent times is that to set standards without supporting the technological advances needed to achieve them is not the most advantageous strategy to pursue. It is admirable and idealistic to realize one day that we have failed to provide or protect some aspect of our system and then to pass laws to say we have to meet these standards by such a date. Although hearings are held, testimony is given and considerations are made, the incremental benefits are exceeded greatly by incremental costs, but they are passed any way.

In rural water, this was accomplished by the Safe Drinking Water Act. The cost of meeting these standards for all rural areas, which serves 20% of the population may cost as much as the systems for the other 80%. We are taking neglected systems of low quality and moving them up to very high standards. This may well be desired for health reasons, but in some cases where economics cannot support such systems, would not an improvement be better than no water or severely contaminated water?

The major point of this discussion is that under the institutional framework in which these systems are constructed, there is a set scale of economics that preclude development freedom or innovative advancements. This is why the technology which would have major impact on the feasibility these systems are lacking. There is not, nor is it likely to be developed under current procedures, the driving force necessary to encourage, test and validate new technology.

There is new technology needed. A better drilling system to drill and set wells in the 2500 foot range, pipe in the 6-inch to 3-inch size that can be plowed into ground safely, which was specifically designed for this purpose, and telimentry and plant design for consolidation of O & M functions are all necessary and worthwhile research functions. An institutional process whereby comprehensive planning and financing systems that can be added to by stages to improve the scale of economics are desperately needed.

This research has shown that an institutional framework of county or regional water authorities may be advisable. This would make integrated systems of large enough scale to finance properly and to provide for growth and expansion. The systems we are building today will be inadequate later, but what is far worse, they will not have the capability to be readily expandable. The continued development of rural areas will provide the problem for years to come if we do not restructure our system to meet it comprehensively.

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