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"Engineering Economics of Rural Water Systems:
A New American Approach"

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M.D. CAMPBELL AND W.A. HUNTAbstract

A review of engineering principles is presented as applied in the United States by the National Demonstration Water Project and Commission on Rural Water to its field projects. Emphasis is placed on the economic analysis of the various engineering alternatives of surface and ground water utilization in rural areas. Effectiveness of centralized management and organization is stressed. The preference of various American governmental agencies for central water systems is based on the concept of central management, which implicitly promotes reliable service over many years. However, central management need not be tied to central water systems in the physical sense. The multiple well or "cluster-well concept" is introduced and explored within an economic analysis of system alternatives for specific project areas. The role of local conditions as they affect the ultimate configuration of the system's design is defined in quantitative and qualitative terms.

2. A RURAL PROBLEM

Millions of Americans, especially in remote economically-depressed regions do not have safe drinking water facilities, e.g. "Appalachia", rural minority centers, etc. This is the conclusion which emerges when existing facilities are surveyed and judged against a reasonable standard of adequacy. Documenting this assertion requires not only that existing water facilities be surveyed, but also that a concept of adequacy be developed which can be used as a standard in judging these facilities.

2.1 The Meaning of "Adequate Facilities".

Since drinking water is necessary for life, everyone has some method for obtaining water. The term "facility", however, implies some man-made device for accomplishing this properly. In other words, drinking directly from a stream is a method, whereas a well is a facility. Determining the adequacy of existing facilities requires that the concept of quality be added to that of quantity. It would be grossly misleading, for example, to list a well as an existing water facility if the water were contaminated.

Considerations of cost and convenience also arise. If a family transports pure water from a distant source at great expense, is this an adequate water facility? Unhappily, while most people are willing to concede the need for safe water, they are less willing to accept "low cost" and "convenience" as minimum standards, at least for the purpose of establishing a public responsibility.

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There is no reason why this attitude should prevail. Cost and convenience to citizens, as well as public safety, are factors in most public policies, and they can be applied to rural water as well. A minimum standard of "adequate facilities" would seem to be a satisfactory supply of potable water delivered to the home.

2.2. The Inadequacy of Existing Facilities.

Judged by even this minimum standard, present water facilities are inadequate in rural America. Consider the following facts from the studies which have been done:

(A) Some 75 per cent of the population in the United States is served by public water systems (that is, community facilities serving many households), but a recent U.S. Public Health Service survey of selected systems found that 41 per cent failed to meet PHS Drinking Water Standards. Only 50 per cent of the systems serving fewer than 500 people met even the minimum standards. (8)

(B) A 1969 study by the U.S. Farmers Home Administration (FmHA) identified over 30,000 communities with populations below 5,500 which needed assistance in either building a water system for the first time or improving an inadequate one. The study did not cover communities considered by FmHA to be unsuitable for central systems. (14)

(C) Individual water supplies can also be considered "adequate facilities" if properly constructed and maintained. However, surveys which have been done of individual water supplies suggest that they are worse than community supplies, primarily due to a wide occurrence of initially substandard facilities, e.g. "dug" wells, spring-fed supplies, etc. Recent regional field studies in three southern states found a substantial majority of the individual supplies actually sampled contaminated, in some cases as high as 90 per cent. Further, the areas sampled were generally located in economically-depressed regions and relate more toward the conditions in those areas than to other rural regions; however, since nearly one-quarter of the American population, most of them in rural areas, relies on individual water supplies, an estimated 20 to 30 million Americans in rural areas could be drinking unsafe water.

These and other data lead to one conclusion: existing water facilities in the United States are inadequate, and it is rural America which is hardest hit. The known inadequacies of water facilities in rural areas suggests that the national system for delivering these services is performing at less than peak efficiency. This is due partly to weaknesses in the present system itself and partly to the nature of rural life itself. (11)

Pollution and geography are the key factors which have produced the rural problem. It is well known that most of the American streams are now generally polluted by human and industrial wastes, and acceptable

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ground water aquifers which are the major source of water in rural areas have also been adversely affected. The result is that an ample and convenient supply of water can only be obtained by drilling, pumping, treating, piping and storing.

The population density in the United States also becomes a factor. Persons who live in densely-populated urban areas, large or small, can be served efficiently and economically by a central water source and treatment facility. However, the scattered rural population, especially those living outside any incorporated municipality, cannot usually be reached by central water systems. They must rely instead on individual systems.

This rural situation means that even many persons with moderate incomes cannot receive satisfactory water service. The fact that many rural residents have low incomes, however, further complicates the problem. Affluent residents can afford wells. This does not, however, guarantee adequate facilities since there is usually no supervisory body to provide regular maintenance and inspection to prevent malfunction, contamination and pollution. Low-income persons are often left with even worse facilities or no facilities at all. They cannot pay the cost of constructing and maintaining an adequate water system. They are thus faced with a dilemma: either move to the city or endure poor water service.

3. WEAKNESSES IN THE AMERICAN NATIONAL DELIVERY SYSTEM

While the American national delivery system for rural water has reached many rural residents in the past, the increased pollution of water supplies, the need for more complex and expensive facilities, and the general shift of human and financial resources away from rural areas have made this system progressively less satisfactory in recent years. The major weaknesses in the present system are:

3.1 Policy and Priority.

There is no coherent and adequately supported national commitment to the provision of basic sanitation services, both water and wastewater, for rural residents or to assistance for areas most in need.

3.2 Financing.

Subsidized and non-subsidized financing is not available in many rural areas to residents who need it most.

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The limited availability of public and private developers prevents many rural residents from assembling and managing the resources required to provide sanitation services.

3.4. User Support.

Users, who generally want adequate domestic sanitation services are not aware of the steps involved in obtaining and sustaining this service and the role which they must play in this endeavor.

3.5. Technology.

Design and construction of facilities is not sufficiently directed at meeting technical problems in rural areas, although most common problems can be overcome at a reasonable cost with existing technology.

3.6. Operation and Maintenance.

Inadequate attention to operation and maintenance has often meant that services which have been established could not be maintained over the loan period. (13)

The development of a national commitment to good water facilities involves both the question of general responsibility for action, via public sector or private sector, and the question of proper governmental level for any public action deemed necessary.

4. THE RESPONSIBILITY FOR ACTION.

There are several possible options when the responsibility for attacking social problems is being assigned. The entire problem may be left in the hands of private, profit-making groups without any participation by the public sector of the economy. At the other end of the scale, the public sector may assume all of the responsibility to the point of constructing, owning, operating and maintaining necessary facilities itself. Or there can be a partnership involving both public and private interests.

The private sector does play a major role in water in the United States, especially in the development of ground water technology, etc. In addition, about 15% of all water companies are private, profit-making concerns. They serve approximately fifteen million people, mostly in rural areas.

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A major drawback to the private sector approach, however, is that profit-making interests have not been able to extend service to all rural residents in the past and may not be able to do so in the future. The primary reason for this is financial. Since most of the rural population now lacking adequate facilities lives in scattered communities and isolated areas where the cost of providing service is high, a central distribution or collection system can only be extended at prices low-income families cannot afford, nor can such families bear the financial burden of having segments of the private sector, such as water well contractors, construct individual facilities.

The presence of a public, municipal water system rather than profit-making companies does not automatically solve the problem. Like private companies, if municipal or other governmental water systems extend service into rural areas, the cost of such service is usually too high for many low income families.

What seems to be required in the United States is some form of public subsidy for the construction and operation of facilities. This kind of public assistance is now so common that it is no longer considered a public subsidy. Certainly schools and roads for all citizens would have been impossible without governmental intervention. Rather than give a direct subsidy to those who could not afford to buy services themselves, government assumed the responsibility for developing public facilities available to all, regardless of income.

Although the problem has been handled somewhat differently, the health of the American population has also long been regarded as a matter of public concern. Not only has communicable disease been attacked by public efforts, but environmental health, including water and sanitation, has been controlled as well (17). Local governments in one way or another, regulate the vast majority of the American water systems. State governments, through health departments and planning bodies, provide research, regulation, and sometimes financing. The federal government, long involved with research in water and sanitation through such agencies as the U.S. Public Health Service, the U.S. Office of Water Resources Research, the U.S. Geological Survey and the U.S. Environmental Protection Agency, has been an important source of funding or significant technical assistance for water and wastewater projects.

A striking indication that American policy-makers at the federal level have accepted the importance of an adequate water supply as a factor in community development is provided by activities of the U.S. Agency for International Development. Between the early 1940's and 1968, the United States contributed close to one billion dollars to the development

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of water supply systems in foreign countries. (9) Within the United States, however, there has been no public effort of a scope and cohesiveness to match the effort which has been made abroad.

Americans have traditionally been inclined to rely on private initiative as much as possible and turn to government, especially for funds, only when private methods are inadequate. Although the private sector will continue to have an important role to play in water system development, it is likely that it cannot do the job alone.

5. WEAKNESSES IN FUNDING POLICY.

Low-income families, as defined by the U.S. Office of Economic Opportunity guidelines, cannot pay water bills or meet loan payments much in excess of U.S. \$7.00 per month. This rate is difficult to reach without benefit of public subsidy.

Although the Farmers Home Administration (FmHA) financing has undeniably been important in advancing the quantity and quality of rural water facilities, it is not unfair to note that funds have not usually been made available to those who need them most, low-income residents. The agency's eligibility requirements under individual loan programs (502 and 504) have been a difficult hurdle for the rural poor. They sometimes lacked clear title to their property or could not meet loan payments when the life of the loan was a short ten years. Properly concerned with the fiscal health of its operations, FmHA has avoided the riskier loans, thus channeling funds for water facilities to those in the best position to afford their own without assistance.

Even more importantly, perhaps, grant and loan funds for community systems have by and large been extended only to "central" systems with one water source and treatment facility, mostly on the grounds that efficiency and continuity of operation are best assured by such systems. Rural communities or clusters of houses not meeting FmHA criteria for central systems have thus been excluded.

Even where eligibility standards have not been a problem, a persistent shortage of grant funds has limited the agency's ability to respond to low-income residents. This shortage has worsened into an outright stoppage of grant funds. Loan funds are presumably in plentiful supply but this does not solve the problem.

6. POLICY FOR THE FUTURE.

Whether funds are provided for water projects through a federal agency or through states, there are certain basic features which are

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incorporated in any funding program. Most basic of all is the need for public subsidies--grant funds. If low-income citizens are forced to rely on their own meager resources entirely, it will be a long time before they have adequate facilities. Money will not solve all the problems of developing water systems, of course, but the other program efforts are irrelevant if grant funds for construction are not available.

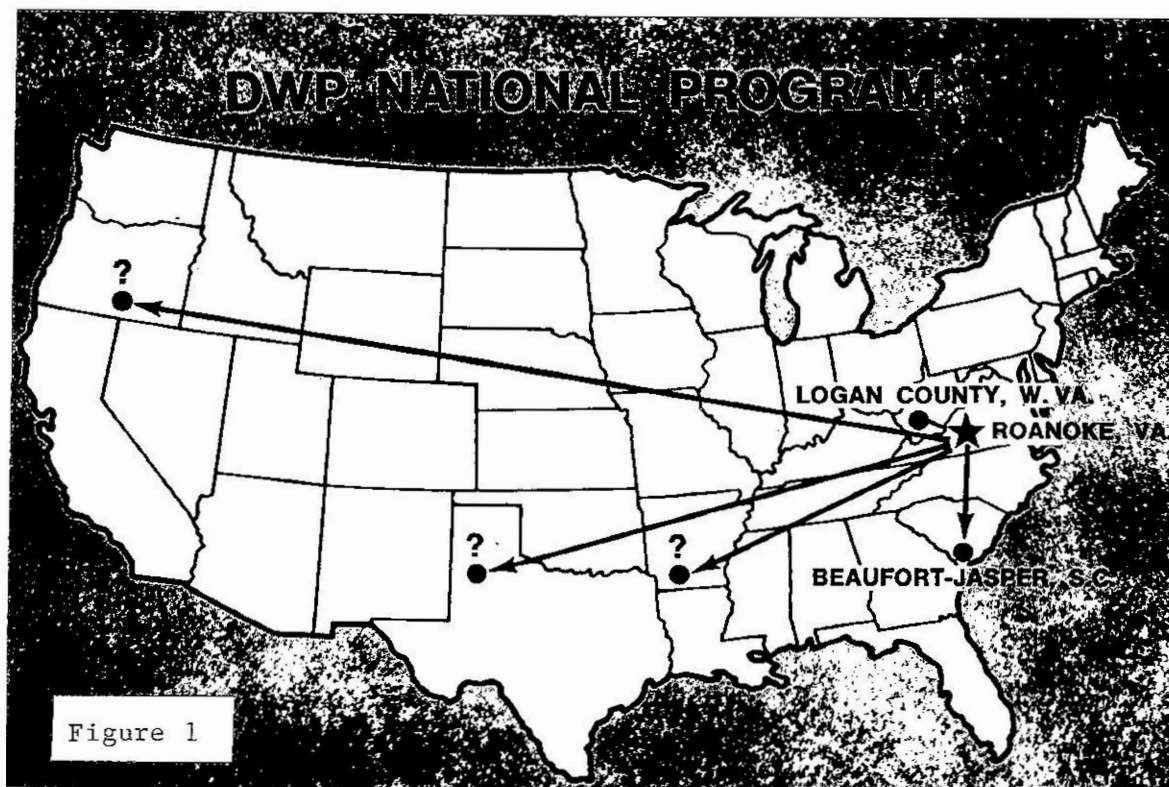
Public assistance to those who need help and are willing to help themselves hardly needs a justification; it has been traditional in American society, nor should there be any misunderstanding about the extent to which low-income residents help themselves. Under the previous FmHA water association plan, where systems were financed by a combination of 50 per cent grant and 50 per cent loan funds, users in the end would pay about 79 per cent of the total cost of the system (initial capital plus operating expenses) or 62 per cent of the present value of the total system cost.

An additional criterion which a new policy should meet is the softening of eligibility requirements for assistance so that low-income households can qualify. Since there will always be some rural people who are so isolated that they will be excluded from any central system, their needs will have to be met on an individual basis. Lower interest rates and longer repayment periods would alleviate much of this problem.

In any case, future funding agencies should be less restrictive about the kinds of water systems they will finance. The difficulties involved in reaching low-income rural residents by traditional central systems have led in recent years to attempts to devising a new approach based on the experience of rural electric cooperatives in bringing electricity to rural homes. (15) This approach also makes possible the kind of effort which is broadly endorsed in the American ethic--a combined public-private effort.

The public-private approach is being tested in various parts of the United States by National Demonstration Water Project (NDWP) and the Commission on Rural Water (CRW) (Figure 1). Beginning in the late 1960's as a single project in Virginia, NDWP has now developed a number of model projects in other states, all designed to demonstrate the effectiveness of using local organizations to solve the problems involved in getting water and sanitation facilities for rural residents.

The original NDWP project sprang from the efforts of low-income residents in a five-county area around Roanoke, Virginia, to obtain adequate water supplies. (2) With funding from the U.S. Office of Economic Opportunity, NDWP established a series of water companies, separately incorporated,



and trained residents to operate the companies as nonprofit associations. After a considerable struggle, the necessary approvals were obtained and financing was secured from the Farmers Home Administration for the construction of facilities. Several companies are now in full operation and others are in various stages of development. Water is now being supplied to residents who never before had an adequate water supply.

With the Roanoke experiment a success, NDWP is testing this model in various areas with different problems. A project now underway in Logan, West Virginia, includes wastewater facilities as well as water. Figures 2 and 3 are typical of the West Virginia Project area. Another model project in Beaufort-Jasper counties of South Carolina is attempting to work out a cooperative arrangement with a local municipality in one area and a water system which includes fire protection in another. Other development efforts sponsored by NDWP are now underway in Lee County, Arkansas, and in New Mexico. NDWP is also working on developing a field demonstration project at the national level in conjunction with the National Rural Electric Cooperative Association. (12)

The NDWP program is a strong combination of public and private effort. Developmental work has been funded by the U.S. Office of Economic Opportunity. Money for construction of water facilities has in the past depended largely on the U.S. Department of Agriculture's Farmers Home Administration and now grants for the construction of wastewater systems are sought from the U.S. Environmental Protection Agency. Development activities themselves, including the research and technical assistance associated with these activities, have been under-

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taken by private social and technical research organizations representing the ground water industry and various community organizations, and numerous government agencies at all levels having an interest in improving rural water and waste disposal facilities. A national clearinghouse for rural water information has also been established. As a result of the activities undertaken by this group of public and private organizations, NDWP is attempting to develop a method of rural water development which can be effective in all parts of the United States.

The precise choice of implementing organization--the funding agency itself, another governmental agency, a public-private organization such as NDWP--is not the crucial issue; any of the three or a combination of the three might be successful. What is important is that the present lack of an organization within the United States to implement a program of rural water development is a serious weakness in the present national delivery system.

7. THE NDWP APPROACH.

To meet this weakness in the American national delivery, NDWP adopted certain concepts in the development of its field projects. (4,7,12) The term water "system", for example, normally implies centralized operation in the tapping of a water source; treatment of water (if necessary) and the distribution of water, but it need not mean centralized physical facilities. The centrality of a water system may lie in (A) its water source and treatment configurations, (B) its type of management, or (C) both.

A water system may have central management, one water source, and one treatment facility for all households included in the system (See Figure 4). This is probably what the term "system" means to most people; it suggests perhaps an incorporated town in which a city water authority supervises the water facilities for all households and commercial establishments within the city limits. It might also describe an unincorporated area, perhaps part of a county, in which similar centralized services are provided by a privately-owned, profit-making company.

There has been a general feeling in the United States that only a central water source or a central treatment facility could provide satisfactory service and quality. (1) This preference for central systems is based on the fact that such systems have had central management which has been a crucial factor in the production of reliable service and quality. However, central management need not be tied to central systems in the physical sense. Another type of system, recognized during the early phases of the NDWP effort as feasible and perhaps necessary in rural areas, employs central management but a number of water

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CENTRAL WELL SYSTEM

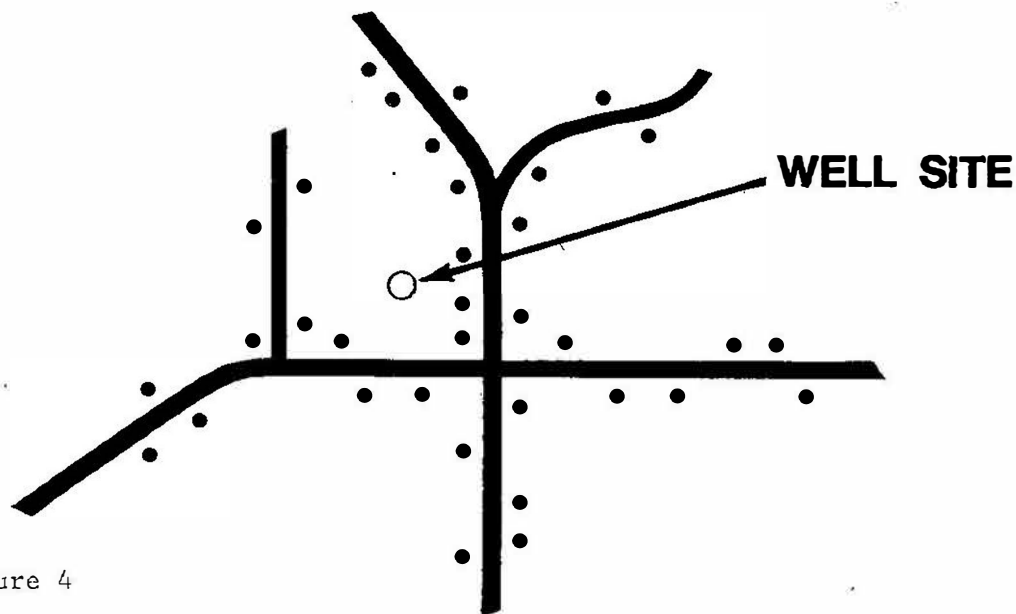


Figure 4

systems. A number of low capacity wells and small treatment plants could serve a varying number of people--one house, several houses, several dozen houses--all as part of the "system" in the sense of management. (See Figure 5) With central management, therefore, the actual configuration of the facilities need only meet realistic engineering criteria which is based on a detailed economic analysis of system alternatives for the specific project.

7.1. Local Conditions.

The design of water systems for any community with essentially rural, low-income residents must consider the ultimate cost to the user. In NDWP experience, the local conditions and their respective impact on the specific project area play a critical role in assessing the ultimate configuration of the system's design. The local conditions or field parameters fall into three broad categories:

(A) Geographic (topography, population density, surface reservoir proximity, suitability, etc.)

(B) Hydrologic (surface water quality and availability, ground water quality and availability, etc.)

(C) Political (state and federal regulatory agency attitude, etc.)

CLUSTER WELL SYSTEM

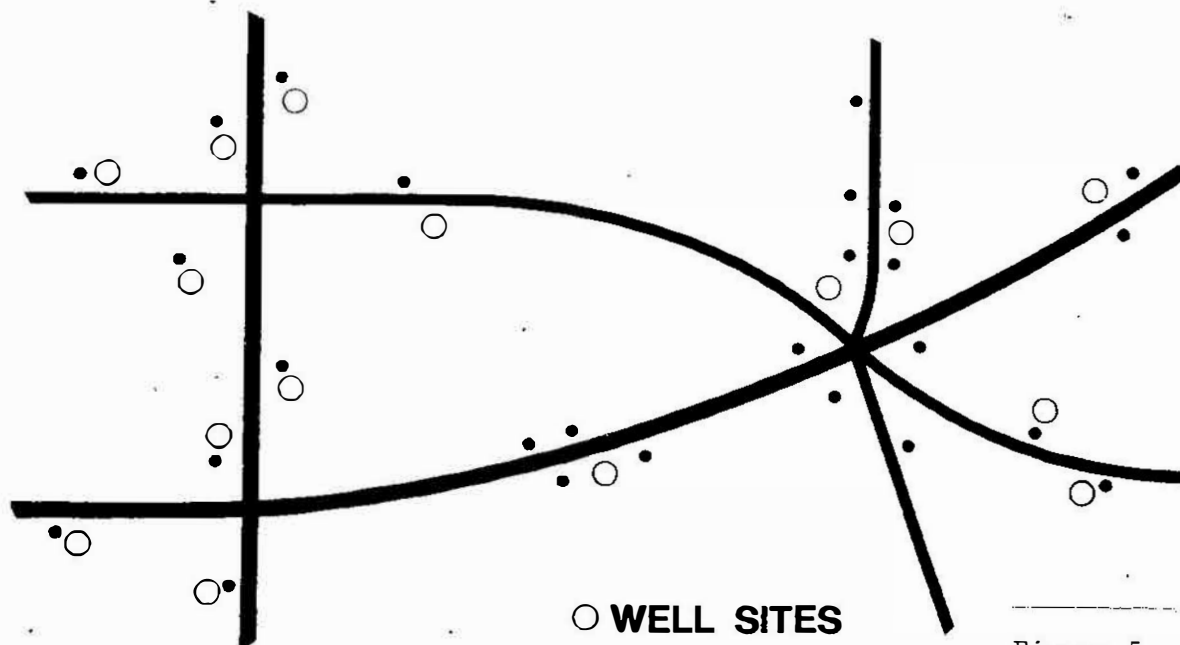


Figure 5

Each one of the above are interrelated to one degree or another in any one project. Early in the preliminary design, NDWP project personnel define the "field parameters". In one NDWP project area, for example, the economic impact of certain geographic factors were significant to project design since frequent bedrock exposure and a clustered population density in isolated areas were common features. Bedrock exposures combined with isolated clusters of homes are factors which place design emphasis on reducing the extent of distribution line construction between each isolated group of homes as much as possible. In other project areas the geographic factor has far less impact, such as in areas of low relief having unconsolidated sediments at the surface, thereby inherently requiring less capital for distribution line construction.

The hydrologic parameter is the second factor which is carefully delineated before a particular water system type can be selected. Local water availability and quality are reviewed with respect to either a surface water or ground water source. Since a ground water source is usually, although not exclusively, favored on economic grounds, its quality becomes a significant factor. (3,4,10)

If, for example, previous test drilling and production analyses of the ground water in the project area indicate that significant treatment will be required to remove iron, manganese, etc. from the water before it can be offered to the potential customer, the economic impact of this factor may put the use of available surface water sources in a favorable economic position. In the same manner, if the cost of construction of a small surface water reservoir with its attendant treatment plant is greater than a well system drawing from the ground water reservoir,

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the balance would be in favor of the latter.

In designing NDWP projects, concern for the system over a long-term period, say over 40 years, is one of the guiding philosophies. As explored previously, proper management is another guiding philosophy. To design on this basis, however, requires a slight departure from previous practices. Detailed data on water quality and availability is imperative to proper design and is normally unavailable. Many projects are unfortunately designed on the basis of gross data which can lead to early failure, malfunction or severe loss of efficiency. NDWP projects recognize the need for the detailed evaluation of local conditions and allocate development funds for defining such parameters.

The third field parameter which affects the design of the system is the political factor. This factor is not as easily defined quantitatively as the first two, but can be assessed qualitatively. For example, in NDWP experience, problems have arisen when a specific design is presented to the regulatory agency(s) for approval. One state agency historically prohibits PVC pipe; another may require specific well sizes; most states apparently require system design based on a per capita usage of 100 gpd, an unrealistically high figure even for many affluent suburban homes and one which places an unduly high cost burden on the rural community. In practice over the past decade, PVC pipe has proven its value and well diameter an increment less than that stipulated could be acceptable on standard engineering grounds. A strong tendency exists for regulatory agencies to favor systems which are over-designed and economically unsuited to the project's local conditions. This tendency most likely stems from the agencies' concern for the system's longevity and operational simplicity. The regulatory institution therefore must be considered early in the system's design. System costs, of course, are affected, especially if preference is expressed by an agency for one type of water supply system over another. One example of this is the common preference for a central high capacity well system, a preference which is based more on operational control considerations than on engineering grounds. On an economic basis (including due consideration for operation and maintenance) a number of decentralized installations of lower capacity may often be the superior design.

7.2 Local Parameter Translation.

Having briefly explored the approach to assessing the degree of impact of the local conditions on the ultimate design of the system, the next stage of the NDWP evaluation begins. This consists of translating the relative impact of the conditions into the system's design. There are four generally accepted system types or alternatives for obtaining a community water supply in rural areas: (See Figure 6)

Figure 6

SYSTEM ALTERNATIVES

- A. TAP & TREAT RAW SURFACE WATER**
e.g., small surface reservoir, river, etc.
- B. PURCHASE OF TREATED SURFACE OR GROUND WATER**
e.g., extension of existing water lines, etc.
- C. CONSTRUCTION OF A SINGLE HIGH-CAPACITY WELL SYSTEM**
e.g., one well, central treatment plant, extensive distribution system.
- D. CONSTRUCTION OF MULTIPLE OR "CLUSTER" WELL SYSTEM**
e.g., more than one well, additional treatment plants, less extensive distribution systems.

NDWP field affiliate projects have so far employed all but alternative A, their choices being dictated by the analysis outlined below. According to the NDWP approach, each of the system types are reviewed with respect to their possible use in the project area. Given the local parameters, an economic comparison of the systems total cost is made. (See Figure 7) To assist in this comparison, Figure 7 shows the equations which have been developed. Each factor on the right side of the equations can be evaluated in terms of the effect of every significant local parameter on total systems cost over project life (i.e. the term of the loan). Furthermore, comparisons of equivalent factors, i.e. maintenance costs for a central well system and a multiple well system, can be made and their relative impact on total cost assessed.

When the total system costs among the four alternatives are compared, the local parameters dictate which system is selected. This selection is based on economically-sound engineering which insures the lowest possible monthly per-user rate and therefore efficient use of funds. Although the examples given are for water systems, the same approach is taken with wastewater systems design. (6)

7.3. Central-Well Systems Versus Cluster-Well Systems.

NDWP-sponsored rural water projects usually include some variation of

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a well system and hence the need existed to develop an approach which would more accurately compare the total costs of a central well system with a multiple well system. Construction of a single high-capacity or central well system for a rural community is a method which has many advantages. The single water source and treatment facility makes possible economies of scale, and central management of the water system promotes efficiency and continuity in system operation, particularly if the central management is a governmental body. As mentioned previously, federal agencies with authority to finance rural water projects have shown a decided preference for this type of central system. The principal drawback to this approach is that many rural residents cannot be reached from a central water source, or extensions thereof, except at a price they cannot pay. If individual households and small communities are scattered over a large area, as they often are in rural regions, residents who cannot afford individual wells face a choice between expensive water from a distant source or no water of acceptable quality at all.

The limitation of the traditional central well system approach to water system development have led NDWP to the development of the "cluster well" alternative. Several wells of medium to low capacity are constructed, each serving a small cluster of homes, but the multiple system

Figure 7

TOTAL SYSTEM COST COMPARISONS

$$S_R = P_W + T_{CR} + D_{CR} + O_{CR} + M_{CR} = \text{RAW SURFACE WATER SYSTEM}$$

$$S_T = P_P + D_{CE} + M_{CE} = \text{PURCHASED WATER SYSTEM}$$

$$S_C = W_{CC} + T_{CC} + D_{CC} + O_{CC} + M_{CC} = \text{HIGH CAPACITY WELL SYSTEM}$$

$$S_M = \sum_{i=1}^n W_{MC_i} + T_{MC_i} + D_{MC_i} + O_{CM_i} + M_{CM_i} = \text{MEDIUM-LOW CAPACITY WELL SYSTEMS}$$

where :

$$S_R, S_T, S_C, S_M = \text{TOTAL COST OF SYSTEM OVER PROJECT LIFE}$$

$$P_W = \text{PUMPING PLANT CONSTRUCTION COST}$$

$$P_P = \text{PURCHASED WATER COST ESTIMATION OVER PROJECT LIFE}$$

$$T_{CR}, T_{CC}, T_{CM} = \text{TREATMENT PLANT CONSTRUCTION COST}$$

$$D_{CE}, D_{CR}, D_{CC}, D_{CM} = \text{DISTRIBUTION SYSTEM CONSTRUCTION COST}$$

$$W_{CC}, W_{CM} = \text{WELL SYSTEM (S) CONSTRUCTION COST}$$

$$O_{CR}, O_{CC}, O_{CM} = \text{SYSTEM (S) OPERATION COST OVER PROJECT LIFE}$$

$$M_{CE}, M_{CR}, M_{CC}, M_{CM} = \text{SYSTEM (S) MAINTENANCE COST OVER PROJECT LIFE}$$

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of wells and low capacity treatment plants is centrally managed. In this way, the objectives of both low construction cost and efficient operation may be achieved. Although the "cluster well" alternative is not always applicable since one or more of the local field parameters may preclude its employment, this alternative does find widespread application in the United States and elsewhere.

A key consideration in comparing the design economics of the central well system and the cluster-well system is the distance between homes to be served. There is a point beyond which it becomes more economical to construct a second well than to lay pipe to connect a distant house to an existing well. Figure 8 shows another equation which has been developed by NDWP as a criterion for comparing costs:

Figure 8

CENTRAL WELL SYSTEM vs. CLUSTER WELL SYSTEM

$$\frac{S_C}{S_M} = C_R$$

$$\text{or : } \frac{W_{CC} + T_{CC} + D_{CC} + O_{CC} + M_{CC}}{\sum_{i=1}^n W_{CM_i} + T_{CM_i} + D_{CM_i} + O_{CM_i} + M_{CM_i}} = C_R$$

where : C_R = TOTAL SYSTEM COST RATIO

S_C = TOTAL SYSTEM COST OF HIGH CAPACITY
OR CENTRAL WELL SYSTEM

S_M = TOTAL SYSTEM COST OF MEDIUM LOW
CAPACITY OR MULTIPLE WELL SYSTEM

CENTRAL WELL EXTENSIONS

$$P_C > W_{CM} + T_{CM} + D_{CM} + O_{CM} + M_{CM}$$

where : P_C = TOTAL INTERCONNECTING DISTRIBUTION
COST (IN PLACE)

When the effects of the local field parameters have been translated into estimated dollars in terms of their effect on construction, operation and maintenance costs, estimated cost components are entered into

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the respective expressions and the equations solved for total systems cost, e.g., S_C for the central system, S_M for a multiple well system. Ideally, if the Total System Cost Ratio is unity (one) or less, the central well system would be the superior design for the particular project area, etc.

7.4. Central Well Extensions.

As is often the case, one well system is constructed to serve a cluster of homes and then additional wells are added according to the economics of laying additional pipe to outlying customers.

In the lower part of Figure 8, a useful relationship is shown which has been developed to assess the feasibility of constructing facilities which are some distance from an existing system. Again, a key consideration in comparing the economics of extending existing systems and a potential, separate system is the distance between homes. There is a point beyond which it becomes economical to construct a second system than to lay pipe to connect distant houses to an existing system. If the following is valid, then one or more outlying wells are justified:

$$P_C > (W_{CM} + T_{CM} + D_{CM} + O_{CM} + M_{CM})$$

$$\text{Or: } P_C > S_M$$

Where: P_C = Total Interconnecting Distribution Cost (In Place),
plus costs related to increased production of
existing system.

Therefore, if P_C is less than S_M , an extension of the existing system is merited. If P_C is greater than S_M , a "cluster" system would be merited.

An example of this comprehensive design approach can be found in the NDWP supported project in Arkansas. Two regions within the project area have specific local conditions which affect system's design. In one region, the project will obtain water from a newly-constructed extension of an existing line and another will obtain water via a multiple or cluster well system. This is typical of adjusting the system design to the local parameters. A similar variety of approaches are being taken in NDWP's South Carolina project.

7.5. Operation and Maintenance.

The pipe-laying cost is not the only critical factor. The effect of

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operation and maintenance (O & M) must also be carefully estimated, but this is a most difficult task since the basic data are generally unavailable to the consulting engineer. O & M is usually referred to as an "undefinable variable." Although it is true that O & M costs are difficult to calculate, they can be approximated with far greater accuracy than presently attempted by many consulting engineers who often resort to convenient, but often inappropriate, "rules of thumb." * Estimating operation and maintenance costs begins in the design stages of the system's development. Proper system design and materials selection appropriate to the local geographic, hydrologic and geologic conditions, are of critical importance in maintaining the proper balance between initial construction costs and future maintenance expenses. (5)

Local field parameters dictate the scope of operation and maintenance required for the system. In one area, for example, well incrustation and/or corrosion may be a problem, in another it may not be. The water supply may or may not require an iron treatment plant, which will effect operation and maintenance costs accordingly. Some systems even require additional treatment to remove other dissolved minerals. As treatment needs increase, and with them, both initial construction costs and the attendant operation and maintenance costs, the suitability of treatment plant consolidation also increases, dictated solely by the local field parameter of water quality.

8. NDWP FOCUS ON OPERATION AND MAINTENANCE.

No matter how well and how inexpensively water systems are constructed, the rural problem cannot be solved unless these facilities are adequately operated and maintained. Probably the biggest mistake made in financing water development in the United States and foreign countries was the failure to take this into account. After facilities were constructed, the developers simply went away, leaving the residents to shift for themselves. Without any real local maintenance capability, the systems deteriorated, wells failed, treatment plants malfunctioned, distribution lines broke, etc. The lesson was not that development will not work in rural areas but that development must include a strong awareness of operation and maintenance.

* The NWWA Research Facility, in cooperation with S.N. Goldstein, is presently preparing under NDWP sponsorship a guide for the operation and maintenance of rural water and wastewater systems. This guide should be available for public dissemination by September, 1974.

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However rural water systems are administered in the United States in the future--by municipalities, public service districts, or nonprofit corporations--the administering authority must have enough funds and expertise to keep the system running effectively and efficiently. Wells and treatment plants must be inspected and repaired, meters read, bills collected, records kept, and loan payments made. A public subsidy for a water system would be wasted unless funds are included to accomplish a realistic operation and maintenance program.

In particular, maintenance capability must be built into any user-owned and user-operated facility. This capability goes beyond system's design to the broad question of management. The officers of a rural utility service company must be able to carry out all its functions, from seeing that wells operate at peak efficiency, that they do not become contaminated, to making sure that taxes are paid. These tasks will not be easy where users' incomes are low and where reliable public services have not been a part of the heritage of the area. The problem can be tackled either by training the members of each individual water company to perform the necessary work or by developing a separate service company to manage operations for all companies in a project area. Many water well contractors in the United States are getting involved with this type of approach to insure proper operation and maintenance of rural water systems.

At the present time, however, maintenance provisions for rural water systems in the United States are not generally equal to the task. There is inadequate inspection of community water systems, and individual facilities are rarely checked at all. System designers usually underestimate the maintenance requirements during the life of a loan made for the construction of facilities. Reports and other devices for evaluating the performance of water systems are spotty. It is not surprising that small, rural water companies have obtained a reputation for performing badly.

No attempt has been made here to discuss all the technical problems and developments that relate to water systems. It is clear, in any case, that the major weaknesses in the American delivery system for rural areas are not solely technical in nature. Indeed, there are no technical problems which cannot be solved with the proper political, economic, and financial backing. The major needs--commitments and funding--can only be served in the state and federal political arena. System development, centralized management, economically-sound engineering, and strong operation and maintenance are all features which the National Demonstration Water Project and the Commission on Rural Water are attempting to implement in its field projects. As the present NDWP projects age, their performance will test the effectiveness of the NDWP approach.

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